Strategic Study
Workshop Series

Algorithm Development for Security Applications

May 2011 Workshop
Final Report

Awareness and Localization of Explosives-Related Threats
A Department of Homeland Security Center of Excellence
Northeastern University

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1. Executive Summary

A workshop focusing on fusing orthogonal technologies for detecting explosives for aviation applications was held at Northeastern University in Boston on May 3-4, 2011. This workshop was the fifth in a series dealing with algorithm development for security applications. The pattern with the series has been to deal broadly with a new topic in the odd-numbered workshops in order to scope out the topic. The even-number workshops are then used to address a focused application related to the topic. The present workshop followed this pattern by broadly addressing the topic of fusion, which is also known as sensor fusion or data fusion.

The topic of fusion was chosen for the workshop in order to support the Department of Homeland Security's (DHS[1]) objective of improving the performance of existing technologies, where performance is defined as increased probability of detection, decreased probability of false alarms, lower threat mass and increased number of types of explosives. There is evidence that existing technologies will eventually be unable to satisfy DHS's requirements for improved performance unless they are fused with other technologies.

Much of the discussion at the workshop dealt with defining the terms *fusing*, *orthogonal* and *technology*. Multiple definitions exist for each of the terms. Additional discussions dealt with improved performance of new and emerging technologies when deployed as stand-alone systems and when fused. The discussion of improved performance was primarily addressed how to increase the probability of detection and reduce the probability of false alarms. Additional discussions dealt with operational issues such of cost of ownership, concept of operations and risk-based screening.

The key findings and recommendations from the workshop are as follows.

Finding: DHS is not well educated in fusion and its terminology.

Recommendation: DHS should define terms used by fusion experts in R&D and other fields.

Finding: DHS has experience with fusing systems and some of these have failed.

[1] A table of acronyms used in this report can be found in Section 14.

Recommendation: Need to learn why these systems failed.

Recommendation: Need to focus on a particular problem and try to solve it to set precedence.

Recommendation: Need to establish performance metrics to be able to judge effectiveness of individual sensor systems and compare improvements due to fusing two or more systems.

Recommendation: Address how technologies are designed and chosen so that, when fused, the resulting fused system has better performance than existing technologies.

Finding: Risk-based fusion was discussed, but was not part of the workshop.

Recommendation: This topic needs to be a focus and discussed.

2. Disclaimers

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Northeastern University nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation or favoring by the United States government or Northeastern University. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Northeastern University, and shall not be used for advertising or product endorsement purposes.

This document summarizes a workshop at which a number of people participated and some made presentations. The views in this summary are those of the organizing committee and do not necessarily reflect the views of all the participants. All errors and omissions are the sole responsibility of the organizing committee.

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

3. Introduction

The Explosive Division (EXD) of US Department of Homeland Security (DHS) Science & Technology Directorate (S&T), in coordination with the Transportation Security Administration (TSA), has identified requirements for future explosive detection scanners that include a larger number of threat categories, lower false alarm rates and lower total operating costs. One tactic that DHS is pursuing is to create an environment in which the capabilities and capacities of the established vendors can be augmented by third-party algorithm development. A third-party developer in this context refers to academia, National Labs and companies other than the incumbent vendors. DHS is particularly interested in adopting the model that has been used very successfully by the medical imaging industry, in which university researchers and small commercial companies develop algorithms[2] that are eventually deployed in commercial medical imaging equipment.

One tactic that DHS is using to stimulate academic and industrial third-party algorithm development is to sponsor workshops addressing the research opportunities that may enable the development of next-generation algorithms for homeland security applications. The series of workshops are entitled "Workshops for Algorithm Development for Security Applications (ADSA)." An overview of the first four ADSA workshops can be found in Section 9. The workshops were convened by Professor Michael B. Silevitch (NEU) as part of the DHS Center of Excellence (COE) for Awareness and Localization of Explosives-Related Threats (ALERT[3]).

The fifth workshop in the ADSA series was held on May 3-4, 2011, at NEU. The workshop focused on fusing technologies for aviation security applications. This focus was chosen for the following reasons, which were articulated by the participants at the first four ADSA workshops:

- A single technology may not exist to meet all the DHS's future detection requirements
- There are hardware, algorithmic and operational issues when technologies are fused

The technologies that were discussed as candidates for fusion to existing technologies are as follows:

[2] When we speak of an algorithm, we are talking about the mathematical steps. The actual implementation is the software usually in a general purpose computer.

[3] ALERT in this work plan refers to the COE at NEU.

- X-ray diffraction (XRD), along with diffraction enhanced and index of refraction imaging
- Quadrupole resonance (QR)
- Raman scattering spectroscopy
- Explosive trace detection (ETD) and sampling schemes
- Terahertz (THZ) imaging and spectroscopy

The emphasis was on fusing technologies to CT-based explosive detection systems (EDS). However, fusing to other modalities such as AIT was also covered.

The hardware, algorithmic and operational issues related to fusing technologies that were addressed are:

- Fusing images and automated threat detection (ATR) results
- Prospective operation of modalities
- Communication of control information, images and ATR results
- DHS testing of fused systems
- Concept of operations for fused systems
- Interfaces and standards

The workshop was led by Professor Silevitch, Dr. Harry Martz (Lawrence Livermore National Laboratory) and Dr. Carl Crawford (Csuptwo).

The purpose of this document is to report the findings and recommendations from the workshop. The findings and recommendations include a list of open questions and challenges that must be explored, dissected, defined, understood and reduced to practice. A key finding of the workshop is that a systems approach must be brought to bear on future designs of fused systems.

We conclude this section with a quotation, from one of workshop participants, which summarizes the workshop.

> "I believe that most people came away with a sense that fusion is much more difficult to do than one's initial perceptions."

4. Findings and Recommendations[4]

4.1 Semantics

Findings

The words *fusion, orthogonal* and *technologies*, *sensor* and *data*, were not well defined for those working on fusion for DHS. This led to confusion about the objectives of the workshop.

Presently deployed equipment consists of sources and detectors of energy, reconstruction algorithms[5], ATR and workstations. It was unclear if combining a detector employing a given reconstruction algorithm with a second reconstruction algorithm should be considered to be fusion.

Recommendations

1. The following points should apply to the term "technology".
    a. A technology is any source of data that is used to support a detection decision
    b. Technologies include imaging devices such as CT, transmission x-ray, millimeter-wave (MMW) and x-ray back-scatter (XBS).
    c. Technologies include non-imaging devices such as explosive trace detection (ETD) and QR.
    d. Technologies include devices that assist the operation of another technology. For example, a device that lists the types of clothing worn by a passenger may be useful for an advanced imaging device (AIT) device.
    e. Technologies include devices that assess risk such as video analytics and passenger selectee systems.

[4] The following points should be considered when reading this section. This section was created by reviewing the minutes, questionnaires, presentations and other notes. The editors are not in complete agreement on all the points. Some of the points may be conjecture instead of fact.

[5] Reconstruction may consist of only data processing for some technologies such as ETD.

   f. Technologies include humans (transportation security officers, TSO) such as ones used to assess risk and perform on-screen resolution (OSR).
   g. A technology that automates OSR (i.e., replaces a TSO) is a technology.
   h. The definition of technology includes, if applicable, a source, detector and reconstruction algorithm.
   i. ATR and workstations should be included as technologies. Technologies include the following types:
      i. Existing, emerging or future devices
      ii. Devices that can pass acceptance testing on their own
      iii. Devices that have to be fused with other devices in order to pass acceptance tests
2. The following point should apply to the term "sensor".
   a. A sensor is a type of technology.
3. The following points should apply to the term "data".
   a. Data are the results that are produced by a technology.
   b. Data includes, but not limited to, the following:
      i. Images
      ii. Spectra
      iii. Analog and binary ATR results
      iv. Features
      v. Human observations
      vi. Level of risk
      vii. Statistical distribution information
      viii. Results from intelligence operations
4. The following points should apply to the term "orthogonal".
   a. The term orthogonal means that entirely different aspects of a given threat are considered when two or more technologies are fused, such as CT and ETD. However, one has to avoid the situation when the different aspects of a threat are correlated. However, when two or more orthogonal technologies are fused, performance is improved.
   b. Orthogonal cannot mean that the same information is re-used to add certainty to a decision.

c. Orthogonal technologies may be devices that are operated differently based on information supplied to them as changes in operating parameters or prtocols. The following are examples of this statement.
    i. X-ray devices operating at different kVs.
    ii. Imaging devices operating at different resolutions or signal to noise ratios.
    iii. Protocols set to detect certain types of explosives or certain configurations of explosives.
    iv. Protocols set based on risk.

5. The following points should apply to the term “fusion”.
    a. Fusion means that multiple technologies are deployed to meet detection requirements. The types of deployment are described in the following points.
    b. Fused technologies can be fused just through co-location, which is also denoted layering. This means that no physical or electrical connections exist between the technologies with the exception of perhaps a human reviewing the decisions from each device. This situation means that the technologies are considered to be stand-alone devices. This definition for fusion is usually excluded when other people define the term. However, the definition is useful when one considers that a human can fuse the results of the co-located technologies.
    c. The data created by multiple technologies can be combined, for example in a workstation, to create a decision about the presence of an explosive.
    d. The output of one technology can be used to control the operation of another technology.
    e. New reconstruction algorithms should not be considered to be fusion. This topic is discussed by other programs that were initiated at the previous ADSA workshops.
    f. Fusion accommodates the following situations.
        i. A potential threat may be evaluated in series or in parallel. Logic is applied to determine how threats are evaluated by other technologies.

ii. Divested objects may be sent to different technologies, as in the case of the check-point today.
iii. Different technologies detect different explosives or configurations of explosives.

g. A fused system is also a technology.
h. There has to be a limit or boundary for the size of scope of a fused system. It would be difficult to discuss fusion if the complete airport is considered to be one fused system.

4.2 Need for Fusion

Findings

DHS has future needs for improved detection of explosives. This improvement is defined as decreased probability of false alarm (PFA), increased number of types of explosives and decreased minimum threat mass. As the number of threats increases and the minimum mass decreases, the area under the receiver operator curve (ROC) cannot increase. In particular, it may be difficult to achieve the required levels for PFA. Although new emerging technologies may eventually meet future detection requirements, currently fielded and proposed technologies are insufficient. Hence there is a need for another method to meet detection requirements. Fusion of existing technologies and emerging technologies is seen as a way to meet future detection requirements.

Fusion is already used today. Examples include multiple stand-alone devices at the check-point, and secondary inspection with ETD and manual inspection.

Recommendations

1. Fusion should be considered as an option to meet future detection requirements.
2. All of the existing technologies (e.g., CT, ETD, TRX, XRD, QR, MMW, AIT, etc.) may be fused.
3. Emerging technologies include: ion trap mobility spectrometry (ITMS), quantum cascade laser (QCL), mass spectrometry, THZ, spectral CT, k-edge imaging and differential phase contrast x-ray CT.
4. Fusion can be applied for check-baggage inspection, at the check-point, for cargo inspection, for stand-off detection and for other applications.

4.3 Prospective Design

Findings

It is also known that some technologies, when fused, do not lead to improved detection performance. In fact, there is evidence that degraded performance may be obtained. It is not well-established why prior attempts at fusion (e.g., CT-XRD) failed.

Presently deployed equipment may not be amenable for fusion for the following reasons:

1. Some technologies are inherently stand-alone and need to be enhanced to be connected to a network.
2. There is no standard deployed format or network protocols for:
    a. Sharing data created by a technology.
    b. Controlling the operation or protocol of a technology.
3. There is no common language (ontology) for DHS applications to combine the results of multiple technologies.
4. In current systems, the results of ATR are binary when reported outside of a technology.
5. Also in current systems, features used by ATR are not available for fusion when reported outside of a technology.

The strengths and weaknesses of existing technologies are generally not available to third-party researchers because of the following reasons:

1. Information is classified.
2. Information is proprietary to the equipment vendors.
3. Information is proprietary to government testing agencies such as the TSL.
4. The information was not adequately collected.

Recommendations

1. Common data formats and networking protocols should be developed and required on all equipment in order to share data. The existing standards initiative, DICOS, should be supported, because it meets these requirements and also has the backing of vendors.
2. Common protocols should be developed to control the operation or protocol of equipment.

3. Common language should be developed describe the results of technologies so that they can be fused. This common language has been denoted as an ontology.
4. ATRs should be modified as follows:
    a. An analog decision (versus the binary red/green light decision that is mandated by the TSA for technologies that use ATR) should be reported. The decision may be per explosive category or configuration.
    b. Measurements of features should be reported by technologies along with ATR results. The ontology described above should be designed to accommodate these measurements.
5. Hold classified sessions with stakeholders to achieve the following goals:
    a. Discuss the strengths and weaknesses of existing and emerging technologies.
    b. Discuss how requirements for new technologies can be put into the public domain and also respect the rights of the equipment vendors. This will allow the participation of third parties who do not have security clearances.
    c. Separate meetings may be required with the following groups.
        i. Vendors
        ii. DHS, TSA
        iii. Third parties
    d. Review previous attempts to fuse systems to detect explosives.
6. Software should be created to simulate the features generated by existing and future equipment. The software could obviate the issues with proprietary and classified information.

4.4 Operational

Findings

The present DHS and TSA procedures for funding, testing, deploying, operating and maintaining systems are geared towards non-fused systems. However, if multiple stand-alone systems are considered to be fused, then an exception to the procurement strategy for the technology deployed at the check-point, such as TRX, shoe screeners, AIT, liquid-bottle scanners, and Behavioral Detection Officers (BDO) must be considered.

People in the Department of Defense (DoD) space are experienced in the design and deployment of fused systems.

Recommendations

1. DHS and TSA funding should be provided for developing the following technologies.
    a. Technologies that provide features that are not currently available, assuming that the new features will lead to better performance. The new technologies are not required to pass acceptance tests as stand-alone systems.
    b. Simulators of technologies.
    c. Languages for sharing ATR results and features. Feature extraction algorithms for a given technology, versus complete ATRs.
    d. Acceptance criteria for technologies that could be fused versus criteria for technologies that can pass acceptance tests as stand-alone systems.
2. Testing, such as EDS certification testing, should be modified so that systems can be tested individually, even if they cannot pass the acceptance tests as a stand-alone system. A method should be developed to fuse the results of these tests with technologies that do not pass the acceptance tests so that the performance of a fused system could be assessed for compliance with the test for a complete system.
3. Put in processes to procure, deploy, operate and maintain fused systems.
4. Emphasize paper studies showing that technologies, if deployed, would lead to better detection performance. Do not fund projects where systems are fused and then tested without *a priori* evidence that increased performance would be obtained.
5. The following additional requirements should be studied in the context of fusion.
    a. Concept of operations

    b. Cost
    c. Footprint/size constraints
    d. Operator training
    e. Throughput
6. Investigate the role that TSA's common communication protocol (Security Technology Integrated Program, STIP) has for fusion.
7. Involve the national laboratories to help set requirements and to review technologies.
8. Convene a joint task force (JTF) to study fusion. Members of the JTF should be from the incumbent vendors, academia, DHS, TSA, National Labs and small businesses.
9. Draw upon the experiences with fused systems in DoD applications by doing the following.
    a. Reading the DoD literature
    b. Contacting people working on fusion for DoD.

4.5 Workshop Logistics

Findings

The present workshop was a good attempt to discuss fusion. As with other odd-numbered ADSA workshops, the discussion of the topic was at a high level. The strengths and weaknesses of most of the technologies were not disclosed.

The discussion of risk-based-screening was considered to be out of scope for the workshop. However, some discussions still took place about this topic and more discussions are required at future workshops.

A large body of literature on fusion exists on other fields, such as for DoD applications. The National Academy of Sciences (NAS) wrote an excellent report on fusion as applied to aviation security.

Recommendations

1. The next workshop, ADSA06, should address the following topics:
    a. Focus on one application, such as AIT including XBS and MMW.
    b. Address the system engineering aspects of fusion including providing evidence that technologies when fused will lead to improved detection performance.

   c. Discuss risk based screening
   d. Discuss what went right and wrong with previous fusion attempts in aviation security, medical imaging and defense (DoD), and non-destructive examination (NDE).
   e. Presenters should have minimal bias. People from the national labs are good candidates.
   f. Review the findings and recommendations from this workshop.
   g. Improve the meeting format to facilitate more discussion.
   h. Review the literature on fusion, especially the NAS report.
   i. Ask participants to research topics before the workshop.
   j. Review presentations in advance of the workshop to assure that are consistent with the objectives of the workshop.
2. Conduct a tutorial at which technologies can be explained in detail.
   a. The tutorial may be conducted over the internet to reduce expenses
   b. The overview presentation (see Section 16) given by Tim White, PNNL, could be used as the basis of the tutorial.
3. Conduct a classified meeting to discuss what can be disseminated into the public domain.

5. Acknowledgements

The planning committee would like to thank the following people and organizations for their involvement in the workshop.

- DHS S&T for funding ALERT and sponsoring the workshop.
- Doug Bauer, DHS, and George Zarur, DHS & TSA (retired), for their vision to involve third parties in the development of technologies for security applications.
- Suriyun Whitehead, DHS, for coordinating the participation of DHS and TSA.
- Northeastern University for hosting the workshop.
- Mariah Nobrega for handling logistics before and during the workshop.
- Brian Loughlin, Mariah Nobrega and Rachel Parkin for providing audio-visual assistance.
- Doug Bauer, Homer Pien, Harry Martz, Suriyun Whitehead, Matthew Merzbacher, Laura Parker, David Castanon and Carey Rappaport for reviewing this report.
- Rachel Parkin and Mariah Nobrega for editing this report.
- Brian Loughlin and Rachel Parkin for taking the minutes during the workshop.
- Brian Loughlin for transcribing the questionnaires.
- David Atkinson for providing Lifesavers for all the participants.

The workshop would not have been a success without the participants and the speakers. The technical content of this report is due mostly to them. We extend our heartfelt thanks to them for their contributions.

6. Workshop Planning and Support

The planning committee for the workshop consists of the following people:

Michael Silevitch, Northeastern University
John Beaty, Northeastern University
Harry Martz, Lawrence Livermore National Laboratory
Carl Crawford, Csuptwo, LLC

The workshop was moderated by:

David Atkinson, Pacific Northwest National Lab
Carl Crawford, Csuptwo, LLC
Harry Martz, Lawrence Livermore National Laboratory

The final report was assembled and edited by:

Carl Crawford, Csuptwo, LLC
Rachel Parkin, Northeastern University
Mariah Nobrega, Northeastern University
Harry Martz, Lawrence Livermore National Laboratory

Logistics for the workshop were handled by:

Rachel Parkin, Northeastern University
Mariah Nobrega, Northeastern University

The SSI review was handled by:

Horst Wittmann, Northeastern University

7. Appendix: Notes

This section contains miscellaneous notes about the workshop itself and the final report.

1. This report will be distributed as a hardcopy, via the Internet and a CD, subject to approval from DHS.
2. The timing in the agenda was only loosely followed because of the amount of discussion that took place during the presentations and to allow for additional times for participants to network.
3. Some of the questionnaires were transcribed from handwritten versions. Errors in these questionnaires are due to the editors of this report and not due to the authors of the questionnaires.
4. Some of the presenters edited (mainly redacted information) after the workshop.

8. Appendix: Agenda

May 3, 2011			
240 Egan Research Center (Raytheon Room)			
Time	**Topic**	**Speaker**	**Affiliation**
8:00 AM	Registration/Continental breakfast		
9:00 AM	Call to order	Carl Crawford	Csuptwo
9:05 AM	*Welcoming remarks*		
	ALERT	Michael Silevitch	Northeastern University / ALERT
	Department of Homeland Security	Doug Bauer	Dept of Homeland Security
	Logistics	Mariah Nobrega	Northeastern University / ALERT
9:20 AM	*Background and Context*		
	DHS perspective	Eric Houser	Dept of Homeland Security
	Introduction and workshop objectives	Carl Crawford	Csuptwo
	Explosives review	John Reynolds	Lawrence Livermore Nat’l Lab
	Existing technology overview - strengths and weaknesses	Harry Martz	Lawrence Livermore Nat’l Lab
10:55 AM	Break		
11:15 AM	*Orthogonal Technologies (I)*	David Atkinson (moderator)	Pacific Northwest Nat’l Lab
	X-ray diffraction (XRD)	Geoffrey Harding	Morpho Detection
	Quadrupole resonance (QR)	Alejandro Bussandri	Morpho Detection
	Explosive trace detection (ETD)	Dennis Barket	FLIR
12:30 PM	Lunch		
1:20 PM	*Orthogonal Technologies (II)*	David Atkinson (moderator)	Pacific Northwest Nat’l Lab
	Explosive trace detection (ETD)	Herschel Rabitz	Princeton
	Terahertz imaging and spectroscopy (THZ)	Peter Siegel	California Institute of Technology
	Differential phase contrast x-ray CT	Guang-Hong Chen	University of Wisconsin, Madison

2:35 PM	*Fusion in medical imaging*		
	Image fusion for improved diagnostics	Robert Nishikawa	University of Chicago
	Image fusion for improved diagnostics	Homer Pien	Massachusetts General Hospital
	Classifier fusion	Meindert Niemeijer	University of Iowa
	Operator/classifier fusion	Jeremy Wolfe	Harvard Medical School
4:15 PM	Break		
4:35 PM	National Academy of Sciences study on fusion	Donald Brown	University of Virginia
4:55 PM	Reception sponsored by Csuptwo (440 Egan)		
5:55 PM	*Dinner and speakers*		
	AIT ground truth project	Homer Pien	Massachusetts General Hospital
	CT iterative reconstruction	Charles Bouman	Purdue University
	Emerging explosive detection technologies	George Zarur	DHS/TSA (retired)
7:55 PM	End Day 1		
May 4, 2011			
240 Egan Research Center (Raytheon Room)			
7:30 AM	Continental breakfast		
8:00 AM	Day 2 objectives	Carl Crawford	Csuptwo
8:05 AM	Raman Spectroscopy	Tim Johnson	Pacific Northwest Nat'l Lab
8:30 AM	*Mathematics of fusing systems*		
	Ontology for connecting classifiers	Sondre Skatter	Morpho Detection
	Mathematics	Nat Beagley, Ken Jarman	Pacific Northwest Nat'l Lab
	Feature identification from compressive measurement	Larry Carin	Duke
	Reject rate analysis of cascaded systems	David Perticone	L-3 Communications
9:55 AM	Break		
10:15 AM	*Enabling technologies*		
	Integrated check point	Ritesh Patel	SPAWAR Systems Center Pacific

	DICOS	Doug Bauer, Suriyun Whitehead	Dept of Homeland Security
	Certification and qualification testing	Carl Crawford	Csuptwo
11:25 AM	*Third party industry experiences*	Harry Martz	Lawrence Livermore Nat'l Lab
	Telesecurity Sciences	Doug Boyd	Telesecurity Sciences
	Optosecurity	Luc Perron	Optosecurity
	Photon counting and CZT	Derek Bale	Endicott Interconnect
12:40 PM	Lunch		
1:40 PM	*Synthesis*		
	Review, next steps and discussion	Harry Martz	Lawrence Livermore Nat'l Lab
	Around the room	All participants	
2:50 PM	*Closing remarks*		
	Department of Homeland Security	Doug Bauer	Dept of Homeland Security
	ALERT	Michael Silevitch	Northeastern University
3:00 PM	Adjourn	Carl Crawford	Csuptwo

9. Appendix: Previous Workshops

9.1 ADSA 01

The first ADSA workshop, ADSA01, took place on April 23-24, 2009. The focus of the workshop was the development of new algorithms for detecting explosives at an integrated checkpoint. Industry/practioner, government and national lab participants were: Analogic, GE Security, Guardian Technologies, American Science and Engineering, L-3 Communications, Rapiscan, Reveal Imaging, Siemens Corporate Research, Smiths Detection, Department of Homeland Security, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Pacific Northwest National Laboratory and the Transportation Security Administration.

The report can be accessed at:
https://myfiles.neu.edu/m.nobrega/Strategic_Studies_Reports/ADSA01_final_report.pdf

9.2 ADSA 02

The second ADSA workshop, ADSA02, was held on October 7-8, 2009. Industry/practitioner, government and national lab participants were: Optosecurity, Reveal Imaging, Telesecurity Sciences, L-3 Communications, Optosecurity, Surescan, Analogic, GE Security, Mercury Computers, Guardian Technologies, Siemens Corporate Research. Department of Homeland Security, Lawrence Livermore National Laboratory, Massachusetts General Hospital, Transportation Safety Administration and Pacific Northwest National Laboratory.

The report can be accessed at:
https://myfiles.neu.edu/m.nobrega/Strategic_Studies_Reports/ADSA02_final_report.pdf

9.3 ADSA 03

This is a workshop on advanced algorithm development for Advanced Imaging Technology (AIT), the DHS standard name for Whole Body Imaging (WBI) Technology. The primary objective of the workshop is to find ways to involve third parties in the development of both near-term and revolutionary improvements to existing AIT equipment. Algorithms developed by the third parties would be designed to augment the capabilities and capacities of the existing vendors of AIT equipment.

The report can be accessed at:
https://myfiles.neu.edu/m.nobrega/Strategic_Studies_Reports/ADSA03_final_report.pdf

9.4 ADSA 04

A fourth ADSA workshop was held at NU on October 5-6, 2010, under the direction of Professor Michael Silevitch, Harry Martz (LLNL) and Carl Crawford (DHS S&T). The purpose of the fourth workshop was to discuss how third parties could participate in the development of reconstruction algorithms for explosive detection equipment based on CT scanning.

The report can be accessed at:
https://myfiles.neu.edu/m.nobrega/Strategic_Studies_Reports/ADSA04_final_report.pdf

10. Appendix: List of Participants

Greger Andersson
Smiths Detection

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Endicott Interconnect

Michael Barrientos
Department of Homeland Security

Dennis Barket
FLIR

Doug Bauer
Department of Homeland Security

William Baukus
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FLIR

Doug Pearl
Insight Consulting

Luc Perron
Optosecurity

David Perticone
L-3 Communications

Jon Petruccelli
Massachusetts Institute of Technology

Homer Pien
Massachusetts General Hospital

Herschel Rabitz
Princeton University

Visvanathan Ramesh
Siemens Corporate Research

Carey Rappaport
Northeastern University

Erick Rekstad
Department of Homeland Security

John Reynolds
Lawrence Livermore Nat'l Lab

Martin Richard
Consultant

Markus Schiefele
American Science and Engineering, Inc.

Jon Schoonover
Los Alamos Nat'l Lab

Jean-Pierre Schott
Lawrence Livermore Nat'l Lab

Anthony Serino
Raytheon Company

Robert Sheftel
Department of Homeland Security

Emil Sidky
University of Chicago

Peter Siegel
California Institute of Technology

Michael Silevitch
Northeastern University

Sergey Simanovsky
Analogic Corporation

Sondre Skatter
Morpho Detection

Stephen Skrzypkowiak
TSA

Paul Southam
University of East Anglia

Frank Sprenger
XinRay Systems LLC

Helmut Strecker
Morpho Detection

Dan Strellis
Rapiscan Systems

Simon Streltsov
LongShortWay

Greg Struba
Department of Homeland Security

Zachary Sun
Boston University

Ashit Talukder
California Institute of Technology

Ling Tang
Rapiscan Labs

Lei Tian
MIT

Luis Tirado
Northeastern University

Brian Tracey
Tufts University

Simon Warfield
Children's Hospital

Jeff Waters
U.S. Navy

Whitney Weller
L-3 Communications

Dana Wheeler
Radio Physics Solutions

Suriyun Whitehead
Department of Homeland Security

David Wiley
Stratovan Corporation

Kathryn Williams
Northeastern University

Lerry Wilson
Intelliscience

Mario Wilson
Department of Homeland Security

Horst Wittmann
Northeastern University

Jeremy Wolfe
Harvard Medical School

Martin Woolf
Raytheon Company

Zhengrong Ying
Zomographic LLC

George Zarur
Department of Homeland Security

Otto Zhou
University of North Carolina at
Chapel Hill

11. Appendix: Participant Biographies

	 David Atkinson	 Kumar Babu	 Claus Bahlmann
Derek Bale	 Michael Barrientos	 Dennis Barket	 Doug Bauer
William Baukus	 Nathaniel Beagley	 John Beaty	 Richard Bijjani

 Carl Bosch	 Charles Bouman	 Douglas Boyd	 Dave Brady
 Donald Brown	 Emel Bulat	 John Bush	 Alejandro Bussandri
Gunnar Carlsson	 David Castañón	Guang-Hong Chen	 Charles Choi
 Carl Crawford	 Christopher	Synho Do	Ruth Doherty

Bryan Donaldson	Alicia Elsetinow	 Xin Feng	Eric Galler
 Tom Gamble	 Yakup Genc	 Steve Godbout	 Jens Gregor
 Bernard Harris	Martin Hartick	 Timothy Harvey	Bert Hesselink
 Alex Hudson	Ken Jarman	Alexis Johnson	Tim Johnson

 W. Clem Karl	 Kevin Kelly	Don Kim	Ronald Krauss
Justin Lee	David Lieblich	Mike Litchfield	 David Martinez
 Harry Martz	Angela Matos	 Eric Miller	 Rick Moore
 Meindert Niemeijer	 Robert Nishikawa	 Se Baek Oh	Boris Oreper

Jody O'Sullivan	 Xiaochuan Pan	 Laura Parker	Ritesh Patel
Garth Patterson	Doug Pearl	 Luc Perron	 David Perticone
Jon Petruccelli	 Homer Pien	Herschel Rabitz	 Visvanathan Ramesh
 Carey Rappaport	 Erick Rekstad	John Reynolds	 Martin Richard

			
Markus Schiefele	Jon Schoonover	Jean-Pierre Schott	Anthony Serino
			
Robert Sheftel	Emil Sidky	Peter Siegel	Michael Silevitch
			
Sergey Simanovsky	Sondre Skatter	Steve Skrzypkowiak	Frank Sprenger
			
Helmut Strecker	Dan Strellis	Simon Streltsov	Greg Struba

 Ling Tang	 Lei Tian	Brian Tracey	Simon Warfield
Jeff Waters	 Whitney Weller	 Suriyun Whitehead	 David Wiley
Lerry Wilson	Mario Wilson	 Horst Wittmann	 Jeremy Wolfe
Martin Woolf	Zhengrong Ying	George Zarur	

Greger Andersson
Smiths Detection

David Atkinson
Pacific Northwest National Laboratory

David Atkinson is a senior research scientist at the Pacific Northwest National Laboratory and provides overall leadership for PNNL's capabilities explosives detection. He also has related roles in serving as a subject matter expert in advising government clients and end users, influencing national priorities, and multi-disciplinary program building. Dr. Atkinson holds a Ph.D. in analytical chemistry from Washington State University, where he designed advanced chemical detection systems. He has worked in trace chemical detector development and deployment in the DOE National Laboratory complex over the last 19 years, with a specific emphasis on explosives detection. He has participated in all aspects of R&D on explosives detection, from performing fundamental research (and publishing the results), to doing testing/evaluation, to deploying equipment in the field and training end users. Dr. Atkinson has spent much of his career working to enhance explosives detection, and this application dominates his presentations at international meetings. He has done many years of work for the Federal Aviation Administration (FAA) and the Department of Homeland Security (DHS) on applying detection instrumentation to aviation security (airport explosives detection), and is funded by DHS to provide technical guidance on explosive detection equipment.

Kumar Babu
Attending in personal capacity

Mr. Babu has held many senior and key positions including those of Principal Systems Engineer at both Rapiscan and Analogic Corporation, Director of Engineering at L-3 Communications – Security and Detection Systems and that of Senior Member Technical Staff, in the Advanced Technology division of Texas Instruments Defense Systems (now Raytheon). In all he has, over twenty five years of experience in project and department management, systems design, hardware and software engineering and algorithm development. He has a Master's degree in Electrical Engineering from the Polytechnic Institute of Brooklyn, and a Bachelor's degree in Electrical Engineering from Bangalore University.

Claus Bahlmann
Siemens Corporate Research

Claus Bahlmann is a project manager at Siemens Corporate Research (SCR) in Princeton, NJ USA. His research interests include pattern recognition, computer vision, and machine learning. He has applied these techniques in various application domains, including real-time and forensic image and video analysis for safety and security, as well as medical. Before joining SCR in 2004, he was a research associate for the University of Freiburg, Germany. While at the University, he received his doctoral degree with the highest of honors for work conducted in discovering new types of generative and discriminative classification of online handwriting recognition. In 2002, his work "On-line Handwriting Recognition with Support Vector Machines - A Kernel Approach" was awarded Best Paper at the IWFHR 2002 conference. In 2005, his Ph.D. thesis "Advanced Sequence Classification Techniques Applied to Online Handwriting Recognition" earned the Wolfgang-Gentner-Nachwuchsförderpreis award from the University of Freiburg. Dr. Bahlmann received a Bachelor and Masters of Sciences in computer science from the University of Bielefeld, Germany.

Derek Bale
Endicott Interconnect

Dennis Barket
FLIR Systems

Dr. Barket co-founded Griffin Analytical in November of 2001 with aspirations to bring lab-quality analysis to field applications. He has led the analytical instrumentation company from its inception through its merger into ICx Technologies, Inc. and subsequent acquisition of ICx by FLIR Systems. Since its beginning in 2001, Griffin has been awarded numerous contracts from the United States Department of Defense and other Federal agencies. In 2006, Griffin achieved national recognition by winning the TIBBETTS Award for excellence in Small Business and Innovation Research (SBIR). Griffin is currently focused on delivering monitoring and chemical detection equipment to the Department of Defense and Department of Homeland Security with an emphasis on fieldable mass spectrometry. Dr. Barket obtained his Ph.D. in Analytical Chemistry from Purdue University where his graduate work was funded by a NASA Graduate Research Fellowship Award. His Ph.D. research in the area of applied mass spectrometry focused on environmental chemistry. Dr. Barket earned his undergraduate degree at Indiana University with a double major in Biology and Chemistry.

Michael Barrientos
Department of Homeland Security

Michael Barrientos has been with the Transportation Security Laboratory since 1995 as an engineer. Initially Mr. Barrientos was assigned to work with the Test and Evaluation Group and was involved with such projects as the certification of the first Explosives Detection System for Checked Baggage. While working he received his Master of Science from Embry-Riddle Aeronautical University (where he received his bachelors degree in aircraft engineering in Human Factors), then was reassigned to work with Human Factors Branch where he played a key role in the development of Threat Image Projection Technology and research on Advanced Display Systems. Mr. Barrientos is now working for Ted Grant under the Personnel Inspection Branch as the Program Manager for the Integrated Checkpoint Program Manager and oversees projects for checkpoint as well as Human Factors while pursuing his doctoral degree in Systems Engineering at Stevens Institute of Technology.

Douglas C. Bauer
Department of Homeland Security

Dr. Douglas Bauer is the Explosives Division Program Executive for Basic Research with management responsibility for multiple programs in basic and applied research, homemade explosives (HME) characterization, detection and damage assessment, development of the next generation EDS x-ray technologies, and counter IED basic research in prevention, detection, response and mitigation. Dr. Bauer also has management responsibility for two new university-based Centers of Excellence addressing explosive threats in transportation through fundamental research. Dr. Bauer holds engineering degrees from Cornell and Carnegie Mellon Universities (where he received his PhD), a law degree from Georgetown University Law Center, and a theology degree from Virginia Theological Seminary. He served in the U.S. Navy as a line officer aboard surface ships, including service in DESERT STORM, and is now retired as a naval Captain.

William Baukus
Consultant

Nathaniel Beagley
Pacific Northwest National Laboratory

Nathaniel Beagley is in the Computational Mathematics group at Pacific Northwest National Laboratory. He has a background in applied mathematics and many years of experience working in decision theory, machine learning, and algorithm development for the analysis of large data sets. Particular research interests include improving operational decisions through better interpretation of sensor data ("sensor to decisions") and how to improve sensor efficiency and accuracy through intelligent data capture, data organization, and analysis algorithms. He has applied his work to a wide variety of application areas including explosives detection, bio-pathogen detection, and satellite remote sensing data.

John Beaty
Northeastern University

Mr. John Beaty is the Industrial Liaison and Director of Technology Development for Awareness and Localization of Explosives Related Threats (ALERT). He is also the Director of Technology Development for the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems. Mr. Beaty has extensive experience managing research and development for the scientific instrument, semiconductor, and government contract industries. John spent 30 years with three companies, Thermo Electron Corporation, Schlumberger Test and Transactions, and FEI Company developing a wide variety of instruments and tools, using diverse technologies. In most instances, John procured development resources from a variety of sources: government, industry, industry consortia, and venture capital.

Richard Bijjani
Reveal Imaging Technologies

Dr. Richard Bijjani, Chief Technology Officer at Reveal, has been in the security business for over 12 years. In 1990 he managed R&D during the development of a dynamic signature verification product at Kumahira Inc. In 1994 Dr. Bijjani joined InVision Technologies as head of the Algorithm and Machine Vision group. He oversaw the algorithm development effort that led to the successful certification by the FAA of multiple EDS systems. Dr. Bijjani joined Vivid Technologies in 1997 where he led the design and development of the additional EDS systems. Dr. Bijjani has a Ph.D. in Electrical Engineering from Rensselaer Polytechnic Institute.

Carl Bosch
Surescan

Mr. Carl Bosch is the Director of Systems Engineering for the x1000 technology. He provides leadership for all system design, application and algorithms for explosive detection. He has 30 years experience leading the product development activities for complex systems in aerospace and medical device industry. Mr. Bosch earned his B.S. in Electrical Engineering at Lehigh University in 1977 and his M.S. in Systems Engineering at the University of Pennsylvania in 1980. Prior to joining SureScan, Mr. Bosch led multi-disciplinary product development teams in the design of intraoperative surgical gamma detection probes and pulse wave Doppler ultrasound blood flow measurement devices as the Vice President, R&D, for Neoprobe Corporation. Prior to joining Neoprobe, Mr. Bosch led the product development activities for the Nuclear Medicine and Positron Emission Tomography (PET) diagnostic imaging modalities for GE Medical Systems. Prior to his experience in the medical device industry, Mr. Bosch held a series of technical and managerial positions with responsibility for the design of attitude control, command and data systems for spacecraft and related ground systems with various divisions of GE Aerospace.

Charles Bouman
Purdue University

Dr. Charles A. Bouman is the Michael J. and Katherine R. Birck Professor of Electrical and Computer Engineering at Purdue University where he also holds a courtesy appointment in the School of Biomedical Engineering and serves has a co-director of Purdue's Magnetic Resonance Imaging Facility. He received his B.S.E.E. degree from the University of Pennsylvania, M.S. degree from the University of California at Berkeley, and Ph.D. from Princeton University in 1989. Professor Bouman's research focuses on inverse problems, stochastic modeling, and their application in a wide variety of imaging problems including tomographic reconstruction and image processing and rendering. Prof. Bouman is the Editor-in-Chief of the IEEE Transactions on Image Processing and a member of the IEEE Signal Processing Society's Board of Governors. He also is a Fellow of the IEEE, AIMBE, IS&T, and SPIE and has served Vice President of Publications for the IS&T Society.

Douglas Boyd
Telesecurity Sciences

Dr. Douglas Boyd has contributed to the fields of imaging technology, accelerator and beam physics, superconducting systems, nuclear physics, and medical physics. Following his graduate studies in nuclear physics at Rutgers, Dr. Boyd continued his research at Bell Labs under a post-doctoral fellowship program. He then moved to Stanford University and was the project leader for the world's first pion radiotherapy facility. As part of this program he was one of the early developers of fan-beam, Xenon-detector CT scanners. In 1976 Dr. Boyd joined the faculty in at UCSF with the intent to establish a laboratory to develop the next generation of no-motion CT scanners, with emphasis on cardiac imaging. This led to the foundation of

Prior of Imatron, Inc., which since 1982 became the leader in development of electron beam Cardiac CT Scanners (EBCT).

Dr. Boyd's team also pioneered in a number of related imaging developments, including the research leading to the first successful explosive detection scanners for airports, for which he was awarded the prestigious Safe Skies award in 1992. Prior to TSS, Dr. Boyd served as a founding director of InVision Technologies, Inc, a company that since 1990 pioneered in the development of modern CT explosive detection systems that are installed at most major airports in the world today. In 2006, realizing that EDS technology had not yet reached its full potential, Dr. Boyd established TeleSecurity Sciences with the objective to automate the threat resolution process.

David Brady
Duke University

David Brady is the Michael Fitzpatrick Professor of Photonics at Duke University and principal investigator for the Duke Imaging and Spectroscopy Program. Brady has developed numerous computational and compressive imaging systems, including coded aperture snapshot spectral imagers, reference structure tomography, compressive holography and multiscale optical systems. Brady is a fellow of IEEE, SPIE and OSA.

Donald Brown
University of Virginia

Donald Brown is William Stansfield Calcott Professor of Engineering and Applied Science and Director of the Applied Predictive Technology Laboratory at the University of Virginia. He is a fellow of IEEE and recipient of the IEEE Joseph Wohl Career Achievement Award for his work in systems engineering and data fusion. He is also the recipient of the IEEE Norbert Wiener Award for Outstanding Research in the areas of systems engineering, data fusion, and information analysis. He received the IEEE Intelligence and Security Informatics Award for outstanding research achievements information for security, law enforcement, and intelligence. The Governor of Virginia presented him with the Governor's Technology Award for his achievements in providing the technology to enable rapid crime analysis by local law enforcement agencies. Dr. Brown is the inventor of the Staff Toolkit for Rapid Incident Prediction (STRIPE). This system has been deployed in both Iraq and Afghanistan to aid the U.S. and coalition partners in predicting and understanding the patterns of insurgent attacks. The system is now a key element of the Distributed Common Ground Station – Army (DCGS-A).

Emel Bulat
Northeastern University

Emel Bulat is the Corporate and Government Partnership Liaison for ALERT, the DHS COE for Explosives Detection, Mitigation and Response, at Northeastern University, as well as the Center for Subsurface Sensing and Imaging Systems (CenSSIS, a National Science Foundation Engineering Research Center), and the Puerto Rico Testsite for Exploring Contamination Threats (PROTECT, a National Institute of Environmental Health Sciences P42 Program). Ms. Bulat previously worked in the defense, telecommunications and semiconductor industries where she received numerous awards including the IR100 Award. She has served on several NSF and DARPA panels and was an invited guest lecturer for the United Nations. She holds a BS and MS in Chemistry as well as an MBA, has 10 US patents, and has co-authored 15 technical and 2 business peer-reviewed journal papers.

John Bush
Battelle

John Bush is a Senior Research Engineer at Battelle. He is the senior systems engineer – and technical leader for Battelle's Manhattan II Algorithm Standards initiative. This work has directly contributed to the present NEMA DICOS standards work. Current DHS S&T Tasking is to develop DICOS Testing Tools to evaluate the recently published DICOS Standard and assess OEM systems for DICOS compliancy. The initial tools, associated usage methodology and technical manuals were completed 31 January 2011. Currently, two modalities with applications and one work-station application are presently incorporated within the DICOS Data Standard. These are X-ray CT for Checked Baggage (encompassing scanning, autonomous image analysis, and partial OSARP analysis), DX for Carry-on Bags (encompassing scanning, Phantom Threat Insertion or TIP, and TSO analysis), and Work Station Threat Detection Reporting. John has supported a large number of DHS / TSA / TSL related projects since returning to Battelle in 2004. The project work has centered on air cargo, checked baggage, check point and aircraft hardening. Numerous economic assessments were completed. He was the technical lead on a project titled, Containerized Research Platform – that directly contributed to the present MH2 work. He has earned BS Aerospace Engineering, MS Mechanical Engineering, and MS Operations Management degrees; and is a registered professional engineering within the State of Ohio.

Alejandro Bussandri
Morpho Detection

Alejandro was born and raised in Cordoba, Argentina. He received his Ph.D. in physics at FaMAF, the mathematics, physics and astronomy division of the Universidad Nacional de Cordoba. His doctoral studies focused on the use of Nuclear Quadrupole Resonance (NQR) to probe structural and dynamical disorder in molecular alloys. After graduating in 1999, he joined the group of Prof. Hans van Willigen at UMASS Boston to work on NMR/EPR methodology in photo stimulated electron transfer process. Alejandro joined Quantum Magnetics in 2002 as a Research Scientist working on the development of novel magnetic resonance (MR) applications. He has worked on a number of projects designed to demonstrate the applicability of MR techniques to process control, nondestructive evaluation (NDE), and security applications. He led the NQR sensor characterization in the Navy-funded Advanced Mine Detector (AMD) and ShoeScanner. Alejandro is currently the PI for the development of a handheld NQR wand for detection and identification of plastic explosives and metal threats concealed on a person’s body & under clothing.

Larry Carin
Duke University

Gunnar Carlsson
Ayasdi, Inc.

David Castañón
Boston University

Prof. David Castañón received his B.S. degree in Electrical Engineering from Tulane University in 1971, and his Ph.D. degree in Applied Mathematics from the Massachusetts Institute of Technology in 1976. From 1976 to 1981, he was a research associate with the Laboratory for Information and Decision Systems at the Massachusetts Institute of Technology in Cambridge, MA. From 1982-1990, he was Chief Scientist at Alphatech, Inc. in Burlington, MA. He joined the Department of Electrical and Computer Engineering at Boston University, Boston, MA in 1990, where is currently professor and served as department Chair in 2007. Prof. Castañón is Associate Director of the National Science Foundation Center for Subsurface Sensing and Imaging, co-Director of Boston University's Center for Information and Systems Engineering and a member of the Air Force's Scientific Advisory Board. He is also a member of the IEEE Control System Society's Board of Governors, and has served as President of the IEEE

Control Systems in 2008. His research interests include stochastic control, optimization, detection and inverse problems with applications to defense, medical diagnosis and homeland security.

Guang-Hong Chen
University of Wisconsin – Madison

Charles Choi
General Dynamics AIS

Dr. Charles Choi is a Lead Systems Engineer at General Dynamics Advanced Information Systems (GDAIS). He has served as a lead engineer on several programs developing advanced sensor systems from defense to homeland security to medical imaging, ranging from R&D to prototype development to fielded operational systems. Dr. Choi's specific expertise is in system engineering and signal and image processing for multiple sensor systems. He has led several projects for the U.S. Navy, Defense Threat Reduction Agency and serves as the GDAIS representative on the NEMA Digital Imaging and Communications in Security (DICOS) standards committee. Dr. Choi is also supporting multiple business development initiatives and projects including undersea technologies and homeland security. He has a BSE from Duke University and MS, MSE and PhD from the University of Michigan.

Carl Crawford
Csuptwo, LLC

Dr. Carl Crawford is president of Csuptwo, LLC, a technology development and consulting company in the fields of medical imaging and Homeland Security. He has been a technical innovator in the fields of medical and industrial imaging for more than 25 years. Dr. Crawford was the Technical Vice President of Corporate Imaging Systems at Analogic Corporation, Peabody, Massachusetts, where he led the application of signal and image processing techniques for medical and security scanners. He developed the reconstruction and explosive detection algorithms for the Examiner 6000, a computerized tomographic (CT) scanner deployed in airports worldwide. He was also employed at General Electric Medical Systems, Milwaukee, Wisconsin, where he invented the enabling technology for helical (spiral) scanning for medical CT scanners, and at Elscint, where he developed technology for cardiac CT scanners. He also has developed technology for magnetic resonance imaging (MRI), single photon emission tomography (SPECT), positron emission tomography (PET), ultrasound imaging (U/S), and dual energy imaging and automated threat detection algorithms based on computer aided detection (CAD). Dr. Crawford has a doctorate in electrical engineering from Purdue University, is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) and an associate editor of IEEE Transactions on Medical Imaging.

Christopher Crowley
Morpho Detection

Dr. Christopher W. Crowley is currently a Principal Scientist with Morpho Detection Inc., at the Magnetics Center of Excellence in San Diego, CA. Dr. Crowley obtained a Ph.D. in Electrical Engineering in 1988 from McGill University. He has over 20 years of experience in the fields of nuclear magnetic resonance, nuclear quadrupole resonance and advanced magnetic sensing. He has worked in the fields of both medical imaging systems and security systems. Dr. Crowley's current research interests include the development of advanced security technologies for screening personnel.

Synho Do
Massachusetts General Hospital

Ruth Doherty
Department of Homeland Security

Bryan Donaldson
Intelliscience

Alicia Elsetinow
TSA

Xin Feng
Marquette University

Dr. Xin Feng is an Associate Professor in the Department of Electrical and Computer Engineering at Marquette University in Milwaukee, Wisconsin. He obtained his D.Sc. Degree in Systems Science and Mathematics from Washington University - St. Louis. Dr. Feng has more than twenty years of research experience in the areas of Pattern Recognition, Machine Learning, Data Mining, Algorithms Development, and Optimization. He has directed 20+ Ph.D. students and 50+ M.S. students, and has published 100+ referred articles and obtained more than one million dollars in research funding from NSF, NASA and other federal agencies. He also has collaborated extensively in the industrial setting with several industrial patents in the areas of intelligent control and automation, engine temperature control, signal and image processing. Dr. Feng is a senior member of IEEE, past Chairman of IEEE Computer Society-Milwaukee Chapter, and has organized several IEEE conferences and symposiums in data mining, machine learning, intelligent control systems, and artificial neural networks.

Eric Galler
Global Security

Tom Gamble
Surescan

Dr. Gamble received his B.S. from the University of Michigan, Ann Arbor, in 1968 and his Ph.D. from the University of California, Berkeley, in 1978, both in Physics. Dr. Gamble is the primary inventor of the x1000 technology. He spent over 20 years at ENSCO corporation before joining SureScan in 2007, where he is currently Chief Scientist. Dr. Gamble has 35 years experience in physics research, signal processing, system design, and algorithm development in a wide range of applications. These include superconducting magnetometer design, exploration geophysics, communication and radar Elint, physiologic and hemokinetic monitoring, site security, acoustic and seismic target identification, non-parametric pattern recognition, X-ray tomography and machine vision. He holds several patents and has numerous publications, including one selected as the best in Geophysics in 1980.

Yakup Genc
Siemens Corporate Research

Yakup Genc is a Senior Program Manager with the Imaging and Visualization Department at Siemens Corporate Research in Princeton, USA. His responsibilities include developing technology and research strategy in the areas of 3D vision and augmented reality, acquiring and executing projects and supervising staff. He currently leads a team of five research scientists and engineers in the areas of model-based computer vision, augmented reality, object detection and tracking, object recognition, and computer graphics and visualization with a particular interest in transferring the theoretical advancements into industrial and security applications. Dr. Genc received his PhD in Computer Science from the University of Illinois at Urbana-Champaign. Right after graduation, he joined Siemens Corporate Research as a research scientist in September 1999. Besides developing real-world computer vision systems for industrial applications, he has been actively involved in academic research and participated in the program committees of various conferences and workshops (e.g., CVPR, ECCV, ICCV, ISMAR, etc.), reviewing papers for journals (e.g., IEEE PAMI, IJCV, etc.) and by publishing in conferences, workshops and journals. Dr. Genc has more than 25 peer-reviewed papers in computer vision and related fields. He also has 7 US and international patents awarded. Dr. Genc is a member of IEEE Computer Society.

Steve Godbout
Optosecurity

Mr. Godbout is the Director of Technology Engineering at Optosecurity. He is responsible for Optosecurity's algorithm development and scientific research team. Following Optosecurity's CTO lead, his role is also to lay out the architectural road map to Optosecurity's scientific innovations.After completing his Ph. D in Astrophysics, Mr. Godbout was awarded a government grant for Industrial Post-Doctoral research. With this grant in hand, he joined the ranks of the world's leader in white light 3D digitizing hardware, InSpeck. Inc. As a scientific developer for InSpeck, he acquired enviable experience in 3D acquisition, modeling and editing. This experience carried over to a short period as a game developer at Ubisoft in Québec City

Mr. Godbout joined the ranks of Optosecurity's software team in January 2007 as a scientific developer and soon moved to the Liquids Detection R&D team where his experience in physics played a pivotal role over the different incarnations of Optosecurity's liquid detection software. Mr. Godbout's work and passion for scientific challenges helped him quickly climb the ranks at Optoscecurity as he was promoted in 2009 to Senior Technology Architect and then to head the entire team as Director of Technology Engineering.

Jens Gregor
University of Tennessee

Dr. Jens Gregor received a PhD in Electrical Engineering from Aalborg University, Denmark in 1991. He then joined the Department of Computer Science at the University of Tennessee, Knoxville. Following a recent merger, he currently holds the rank of Professor in the Department of Electrical Engineering and Computer Science. His research spans the fields of pattern recognition, image reconstruction and large scale computing. This work has been published in a combined total of more than 65 book-chapters, journal articles and conference papers. He has developed and implemented statistical and algebraic imaging algorithms for medical and preclinical applications as well as waste management and non-destructive testing applications. Over the years, he has served as a consultant to local industry and Oak Ridge National Laboratory.

Geoffrey Harding
Morpho Detection

Bernard Harris
Raytheon

Mr. Harris has over forty years of experience in radiation physics related activities. He has been with Raytheon for over fourteen years and is currently engaged in programs that evaluate the potential capabilities of various candidate spectroscopic methods for cargo container inspection based on gamma ray, x-ray and neutron interactions with container enclosed contraband. This includes seeking concealed explosives, narcotics and nuclear materials. Prior to joining Raytheon he was employed as a research physicist at the Harvard –Smithsonian Center for Astrophysics, Charles Stark Draper Laboratories, Cabot Corporation, and American Science and Engineering Inc. His areas of expertise include radiation transport modeling and devising unique nuclear instrumentation for non-destructive quantitative spectroscopic analysis.

Dan Harrison
General Electric Global Research Center

Martin Hartick
Smiths Heimann

Martin Hartick studied Physics at Technical University Darmstadt (core area: Nuclear Solid State Physics). After having completed his PhD thesis in 1993 he joined Heimann Systems GmbH in 1994 and was responsible for the development of an automated luggage scanner for the detection of explosives in check in luggage using diffraction technology. In 2001 he took over the position of managing the group of Physics Technologies within the R&D department at Heimann Systems GmbH. He is responsible for the evaluation of new technologies which might be useful for the detection of threats. He has been the project leader for different R&D projects for the detection of threats in luggage and body scanners using X-ray and mm-wave technology. In 2002 Heimann Systems was bought by Smiths Detection and became Smiths Heimann.

Timothy Harvey
Department of Homeland Security (Support Contractor)

Tim is a Booz Allen Hamilton consultant providing support for the Explosives Division (EXD) of the DHS Science and Technology Directorate. He provides emerging technology strategy planning along with programmatic and systems engineering support across EXD programs. Prior to Booz Allen, Mr. Harvey was the principal co-founder of two high-technology startup companies; one DARPA funded and one venture capital funded. In previous work at Raytheon/E-Systems, Mr. Harvey was responsible for reconnaissance, intercept system development that employed sophisticated, multi-aperture signal processing for signal intercept in a cluttered environment. Tim has developed over 15 products with expertise ranging from R-F/analog subsystems, software radios, digital signal processing, holographic data storage, protein genetic engineering, enterprise data storage and LAN/WAN network systems. Tim received his B.S. & M.S. EE from Virginia Tech.

Bert Hesselink
Stanford University

Eric Houser
Department of Homeland Security

Dr. Eric Houser is the Acting Director of the Explosives Division of the Department of Homeland Security, Science and Technology Directorate. He holds a Ph.D. in Inorganic Chemistry from the University of Illinois. He joined the DHS, Transportation Security Laboratory in 2005 and transferred to DHS, S&T, Explosives Division in 2008. Previous to joining DHS he was a research staff member at the Naval Research Laboratory in the field of advanced materials and chemical sensors. His research interests include the development of trace and bulk detection systems, advanced imaging technology, novel sensing approaches and materials science.

Alex Hudson
Rapiscan Systems

Currently VP of Global Engineering for Rapiscan Systems Inc. Previously Technical Project Manager on the RTT project for Rapiscan Laboratories Inc. Prior to Rapiscan, Dr. Hudson worked as an R&D Manager in Advanced Development at Varian Inc. Before this he worked as the Supervisor of the Advanced Systems Design Group with Quantum Magnetics (a subsidiary of InVision Technologies, now a part of GE Security). Dr. Hudson has nine years of high tech product development experience, with 5 in the field of aviation security, developing technologies and sensors for various applications based on quadrupole resonance (QR), magnetic resonance (MR), computed tomography (CT) and data fusion. At Varian, Inc. his role was to lead a research group, developing cutting-edge cryogenic RF antenna products and to manage a portfolio of R&D projects created to deliver competitive new magnetic resonance spectroscopy systems. While at Quantum Magnetics, Dr. Hudson was Principle Investigator of a multi-million dollar Quadrupole Resonance (QR) explosive detection grant funded by the Transportation Security Laboratory. As part of this work, he developed a safe test material for QR explosive detection machines, in collaboration with LLNL, which is now commercially available from XM Products. Dr. Hudson holds a BS in Physics from Bristol University, UK and a PhD from Nottingham University, UK in Magnetic Resonance Imaging.

Ken Jarman
Pacific Northwest National Laboratory

Alexis Johnson
Ayasdi, Inc.

Tim Johnson
Pacific Northwest National Laboratory

W. Clem Karl
Boston University

William Clem Karl received the Ph.D. degree in Electrical Engineering and Computer Science in 1991 from the Massachusetts Institute of Technology, Cambridge, where he also received the S.M., E.E., and S.B. degrees. He held the position of Staff Research Scientist with the Brown-Harvard-M.I.T. Center for Intelligent Control Systems and the M.I.T. Laboratory for Information and Decision Systems from 1992 to 1994. He joined the faculty of Boston University in 1995, where he is currently Professor of Electrical and Computer Engineering and Biomedical Engineering. He has served as an Associate Editor of the IEEE Transactions on Image Processing as well as in various organizational capacities, including session organizer and chair for the Asilomar Conference on Signals, Systems and Computers special session on Inverse Problems in Imaging, session organizer and chair for the Conference in Information Sciences and Systems special session on Medical Imaging, and as part of the organizing committee for the First SIAM Conference on the Life Sciences. He is currently the general chair of the 2009 IEEE International Symposium on Biomedical Imaging. He is a member of the IEEE Image, Video, and Multidimensional Signal Processing and Biomedical Image and Signal Processing Technical Committees, or which he is the vice-chair. Dr. Karl's research interests are in the areas statistical signal and image processing, estimation, detection, and medical signal and image processing.

Kevin Kelly
Rice University

Don Kim
TSA

Ronald Krauss
Department of Homeland Security

Dr. Krauss has been working at the W.J. Hughes Technical Center in Atlantic City, NJ for 19 years as a staff scientist in the Transportation Security Laboratory (TSL), in the area of physics-based methods for explosives and weapons detection. He is currently a Technology Lead for Bulk Explosives/Weapons Detection Research and Development. The laboratory was first created under the Federal Aviation Administration, then transitioned to the Transportation Security Administration, and now reports to the DHS Science and Technology Directorate. In addition to contributing subject matter expertise to various R&D projects and product testing, Dr. Krauss manages the bulk detection and simulant laboratories at the TSL. Originally from Long Island, NY, Dr. Krauss received a B.S. in Physics from Rensselaer Polytechnic Institute in 1983, and a Ph.D. in Experimental Nuclear Physics from Texas A&M University in 1991. His doctoral research was performed at the Alternating Gradient Synchrotron at Brookhaven National Laboratory from 1987-1991. Working with the Medium Energy Physics group on K+ meson total cross section measurements in order to probe the effects of the nuclear environment on nucleon structure, Dr. Krauss concentrated on data collection and analysis.

Justin Lee
Massachusetts Institute of Technology

David Lieblich
Analogic Corporation

Mike Litchfield
Reveal Imaging Technology

Mike Litchfield is Chief Scientist at Reveal Imaging Technologies. He is responsible for guiding the development and implementation of novel X-ray CT imaging instruments that have enabled successful applications of advanced, TSL Certified, Automated Explosive Detection algorithms running on relatively low cost, low maintenance, reduced size Explosive Detection Systems deployed extensively throughout the USA and worldwide. Mr. Litchfield received his BSEE / MSEE from Worcester Polytechnic Institute and has 27 years of experience researching, developing and engineering scientific instruments for the Semiconductor Fabrication, Medical Imaging and Automated Explosives Detection Industries. Instruments developed range from purely scientific endeavors such as the control and drive electronics for a Front End Oscillator of a 64 Beam Fusion Laser Device and a Terawatt Table-top Pulsed Laser X-ray Lithography System to more practical commercial applications such as a low cost, hand-held, medical Ultra-sound 3D Imaging system and precision analog and high speed digital Automated Test Equipment.

David Martinez
Clickview

Dr. Martinez is the CEO and Founder of CLICKVIEW Corporation, a pioneer in the commercial development of Structured Reporting products for Clinical Radiology. Using industry standard HL7 and DICOM interface protocols, CLICKVIEW Structured Reports capture and integrate biometric data from imaging modalities, RIS, HIS, and PACs systems to automate and streamline the production of Radiologist's interpretive reports. The imaging data, patient demographics and Radiologist's interpretations are structured in a template system to produce clinical reports which include pre-formatted text, and may include tables, computations, charts, drawings and images.

Harry Martz, Jr.
Lawrence Livermore National Laboratory

Dr. Harry E. Martz, Jr. is the Director for the Center for Nondestructive Characterization (CNDC) and lead of the Measurement Technologies focus area in the Science and Technology Department at the Lawrence Livermore National Laboratory (LLNL). He is responsible for leading the research and development efforts of different nondestructive measurement science and technology methods including but not limited to X- and gamma-ray digital radiography and computed tomography (CT), visual and infrared imaging, ultrasonics, micropower impulse radar imaging, and signal and image processing. This research and development includes the design and construction of instruments, and preprocessing, image reconstruction, analysis and visualization algorithms. Harry received a B.S. degree in chemistry from Siena College, Loudonville, NY, in 1979. In 1983, he received a masters degree and in 1986 a Ph.D. degree both in nuclear/inorganic chemistry and physics from Florida State University, Tallahassee, FL. After receiving his Ph.D. in 1986, he became a full-time employee at LLNL. From 1986 to 1988 he was engaged in X-ray and proton radiography and CT techniques for material characterization, and gamma-ray gauge studies for Treaty Verification applications. From 1988 to 1990 he was the computed tomography project leader and in 1991 he became the CT project manager in the NDE Section. In 1994 Harry became the NDE Thrust Area/Research Leader and became the Director of the Center for Nondestructive Characterization in 1999. In 2006 he became the lead of the Measurement Technologies focus area. Dr. Martz received a 2000 R&D 100 award in the area of Waste Inspection Tomography using Nondestructive Assay. He received the LLNL 1998 Director's Performance Award for Active and Passive Computed Tomography. He was given the Federal Laboratory Consortium for Technology Transfer 1990 Award of Merit. Dr. Martz is a member of Alpha Chi Sigma and Sigma Pi Sigma—the National Physics Honor Society.

Angela Matos
Department of Homeland Security

Eric Miller
Tufts University

Eric L. Miller received the S.B. in 1990, the S.M. in 1992, and the Ph.D. degree in 1994 all in Electrical Engineering and Computer Science at the Massachusetts Institute of Technology, Cambridge, MA. He is currently a professor in the Department of Electrical and Computer Engineering at Tufts University and hold an adjunct position as Professor of Computer Science at Tufts. Dr. Miller's research interests include physics-based tomographic image formation and object characterization, inverse problems in general and inverse scattering in particular, regularization, statistical signal and imaging processing, and computational physical modeling. This work has been carried out in the context of applications including medical imaging, nondestructive evaluation, environmental monitoring and remediation, landmine and unexploded ordnance remediation, and automatic target detection and classification. Dr. Miller is a member of Tau Beta Pi, Phi Beta Kappa and Eta Kappa Nu. He received the CAREER Award from the National Science Foundation in 1996 and the Outstanding Research Award from the College of Engineering at Northeastern University in 2002. He is currently serving as an Associate editor for the IEEE Transactions on Geoscience and Remote Sensing and was in the same position at the IEEE Transactions on Image Processing from 1998-2002. Dr. Miller was the co-general chair of the 2008 IEEE International Geoscience and Remote Sensing Symposium held in Boston, MA.

Rick Moore
Massachusetts General Hospital

Rick Moore, joined Massachusetts General Hospital (MGH) in 1974, initially working on radiopharmaceutical development, including the positron imaging of 18-F-FDG. In 1982 he embarked on developing radiology workstations for the hospital. Starting in 1984, he created patient-outcome tracking systems to measure clinical performance and then took on the leadership of the Breast Imaging Research laboratory at MGH with Dr. Daniel Kopans. Over the period of 21 years, they built a robust research program, co-developing many imaging and non-imaging diagnostic and screening systems including Digital Breast Tomosynthesis (3D mammography), clinical Patient Reporting Systems, the Ambulatory Cardiac Function monitor, the Ambulatory Renal Monitor, ultra-performing, GPU-based MLEM parallel reconstructors and the design and clinical evaluation cycles for other instruments. Rick collaborates on design, development and analysis of devices and methods that employ biomarkers and morphology to detect, characterize and predict disease. He consults on data acquisition, database management, transmission presentation and interpretation of medical content. This includes managing collaboration sites, project coordination, technologist and physician training and supervision. Rick has co-authored more than 42 peer-reviewed papers, co-holds 8 patents, and lives with parrots.

Meindert Neimeijer
University of Iowa

Meindert Niemeijer, PhD. currently works as a research scientist at the University of Iowa where he is responsible for parts of the University of Iowa image analysis of the eye research program. He obtained his PhD degree in 2006 from Utrecht University in the Netherlands. He has been actively involved in the retinal image analysis field for the last 9 years. His main research interests are in retinal imaging and image analysis, applied pattern recognition, information fusion and the application of imaging combined with datamining on large image databases. He has developed an automated screening system for diabetic retinopathy and tested this system on more than 35,000 patient exams. He recently accepted a position at IDx LLC, a start-up company developing a commercial version of an automated screening system for eye diseases.

Robert Nishikawa
University of Chicago

Robert M. Nishikawa received his B.Sc. in physics in 1981 and his M.Sc. and Ph.D. in Medical Biophysics in 1984 and 1990, respectively, all from the University of Toronto. He is currently an Associate Professor in the Department of Radiology and the Committee on Medical Physics at the University of Chicago. He is director of the Carl J. Vyborny Translational Laboratory for Breast Imaging Research. He is also a fellow of the American Association of Physicists in Medicine (AAPM). Robert M. Nishikawa's principal areas of research have three intertwining themes. The first is the development of computer-aided diagnosis (CAD) techniques for x-ray imaging of the breast, in particular for digital breast tomosynthesis, full-field digital mammography (FFDM), and breast CT. The second is the image quality assessment and evaluation of imaging technologies, specifically, the clinical effectiveness of CAD. The evaluations include Monte Carlo modeling of using computer-aided detection in screening mammography, observer studies to understand how effectively radiologists can use computers as aids when interpreting mammograms, and clinical studies to directly measure the effectiveness of CAD. The third is the investigation of the performance of new breast x-ray imaging systems. These studies include the evaluation of new clinical systems, such as phase contrast mammography, advanced computed radiography detectors, and the optimization of digital breast tomosynthesis.

Se Baek Oh
Massachusetts Institute of Technology

Se Baek Oh received the B.S. and M.S. degrees in mechanical engineering from the Korea Advanced Institute of Science and Technology (KAIST) Daejeon, Korea, in 1999 and 2001, respectively, and the Ph. D. degree in mechanical engineering from the Massachusetts Institute of Technology (MIT), Cambridge, MA, in 2009. He is currently Postdoctoral Associate of Mechanical Engineering at MIT and working on optical information processing and diffractive optics engineering for multidimensional imaging and light synthesis. Current research interests include shift variant optics, partially coherent imaging, phase retrieval with partially coherent light, multiplexed microscopy via volume holograms, Wigner analysis and phase space optics, depth variant PSF design, and wave-effect rendering for computer graphics.

Boris Oreper
L-3 Communications

Jody O'Sullivan
Washington University

Xiaochuan Pan
University of Chicago

Dr. Xiaochuan Pan is a Professor with tenure in the Department of Radiology, Department of Radiation and Cellular Oncology, the College, the Committee on Medical Physics, and the Cancer Research Center at The University of Chicago. His research interest centers on imaging science and its biomedical applications. Dr. Pan has authored and co-authored more than 300 journal and proceeding papers and is a Fellow of AIMBE, IEEE, OSA, and SPIE. He has served, and is serving, as a charter member of study sections and/or grant reviewer for NIH, NSF, National Science Foundation of China, Natural Sciences and Engineering Research Council of Canada, and other funding agencies and foundations. He is an Associate Editor for a number of journals in the field, including IEEE Transaction on Medical Imaging, IEEE Transactions on Biomedical Engineering, Medical Physics, and Journal of Cardiovascular CT. Dr. Pan has served, and is serving, as a conference-program chair, theme chair, session chair, and technical or scientific committee member for international conferences, including conferences of IEEE Biomedical Engineering, IEEE Medical Imaging, Radiological Society of North America (RSNA), and American Association of Physicists in Medicine (AAPM).

Laura Parker
Department of Homeland Security

Laura Parker is in the Explosives Division of the Science and Technology Directorate at the Department of Homeland Security (DHS). She works on the Basic Research Program within the Explosives Division to identify critical and enabling science and technology (S&T) to improve S&T customer capabilities to prevent, detect, respond, and mitigate explosives threats. She is also working with the DHS-sponsored university-based Center of Excellence that addresses explosive threats through fundamental research that is co-lead by Northeastern University and University of Rhode Island.Prior to her present position at DHS, Dr. Parker worked as a contractor providing technical and programmatic support of chemical and biological defense and explosives programs for various Department of Defense (DoD) offices. Dr. Parker has also worked in several DoD laboratories in the field of energetic materials. She obtained her Ph.D. from the Pennsylvania State University in chemistry.

Ritesh Patel
SPAWAR/Navy

Garth Patterson
FLIR

Doug Pearl
Insight Consulting

Doug Pearl has extensive experience in the biomedical industry and in the commercial applications of medical diagnostics. He has written on the problem of False Positives in the screening of low risk (low prevalence) populations. He has provided strategy and marketing advice to a variety of biomedical clients, including Fortune 500, public biotechnology and development stage start-up companies. He has extensive experience working with clinicians, scientists and customers to determine key drivers of success in the marketplace, and parallel experience working with senior management, marketing, and R&D to transform this information into relevant actions. Prior to launching Insight Consulting, Doug Pearl was Vice President, Business Development for Matritech, Inc., a public biotechnology company in Cambridge, MA. Prior to Matritech, he was a consultant at Bain & Company in Boston. Mr. Pearl has a Masters in Management from the Yale School of Management and an undergraduate degree, summa cum laude, from Princeton. He has also worked as a Research Associate at the Harvard School of Public Health.

Luc Perron
Optosecurity

Mr. Perron is the Vice-President of Product Management at Optosecurity He is a directly responsible for Optosecurity's product roadmap and leads several of the Company's new technology deployments and field trials. He is also responsible for Quality Assurance and Field Support. Mr. Perron started his career as an Aerospace Engineer in the Canadian Armed Forces and retired with the rank of Major after 20 years of service. During his military career, he occupied several management positions related to the field of software engineering or imaging, including the direction of a Digital Image Processing laboratory for the Military Intelligence in Ottawa and the direction of the Canadian Forces Imaging Test and Evaluation Laboratory also in Ottawa. In his last military assignment, he was responsible for all software development on board the CP-140 Aurora Maritime Patrol and anti-submarine aircraft. He later became an associate director for DMR Consulting, a Division of Fujitsu, where he lead several high profile IT projects in content management such as the backlog conversion operation for the Quebec Land Titles project. He was often called upon to contribute as an imaging expert in projects outside of Canada for other Fujitsu consulting offices around the world. He was awarded the title of Master of Information Technology by the Association for Information and Image Management (AIIM) in 1999.

David Perticone
L-3 Communications

Dr. David Perticone holds the position of Engineering Fellow at L-3 Communications Security and Detection systems in Woburn, MA. He is an internationally recognized expert in the field of contraband detection, and in seventeen years of experience has developed automated detection algorithms or detection systems for five different classes of materials. His work on dual-energy x-ray systems set the industry performance standard for the platform, and led to some of the world's most widely deployed screening solutions. Since 2004 he has been Principal Investigator or Chief Scientist on three state-of-the-art, first of kind, detection systems utilizing MeV scale neutrons and photons. Two of these systems were jointly developed with the Massachusetts Institute of Technology, where he has been a research affiliate since 2005. His initial career was in elementary particle physics, where he worked for Stanford University (SLAC), Cornell University, and the University of Minnesota. These efforts led to over 140 published articles. Despite spending significant efforts on algorithm development, machine learning, and computer modeling, he thinks of himself as an applied physicist. His degrees are all in physics, with a B.S. from Rensselaer Polytechnic Institute and an M.S and Ph.D. from Cornell University.

Jon Petruccelli
Massachusetts Institute of Technology

Homer Pien
Massachusetts General Hospital

Homer Pien, Ph. D., is Director of the Laboratory for Medical Imaging and Computations in the Department of Radiology, Massachusetts General Hospital, and Assistant Professor, Harvard Medical School.

Herschel Rabitz
Princeton University

Visvanathan Ramesh
Siemens Corporate Research

Dr. Visvanathan Ramesh heads the Real-time Vision and Modeling Department at Siemens Corporate Research Inc. in Princeton, NJ, where he is responsible for directing research & development in industrial vision, wireless and signal processing and multimedia systems with applications in security, safety and automation. In this capacity, he supervises a global and international team with an average of 35 people located in Princeton, Munich and Bangalore. His team has developed and deployed high-performance real-world products and solutions for video surveillance, vision based driver assistance systems, and 3D vision systems for automation and control. He has numerous publications spanning over 17 years which have focused on statistical modeling for computer vision with emphasis on systematic engineering and performance characterization of vision systems. His other research interests include artificial intelligence, biomedical engineering, and intelligent systems. Dr. Ramesh has served on numerous conference and workshop organization committees. Dr. Ramesh, who earned his Ph.D. in Electrical Engineering from the University of Washington where he defended his dissertation on "Performance Characterization of Image Understanding Algorithms" in December 1994. He also was a co-author of an award winning paper on real-time tracking at the IEEE Computer Vision and Pattern Recognition Conference, 2000.

Carey Rappaport
Northeastern University

Carey is Deputy Director for Awareness and Localization of Explosives Related Threats (ALERT). He is also Associate Director of the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems. He has been a professor at Northeastern University since 1987. He received dual SBs, SM, and Eng from MIT in 1982 and the Ph.D. from MIT in 1987. Professor Rappaport was the Principal Investigator of a $5M ARO-sponsored Multidisciplinary University Research Initiative in humanitarian demining, the lead researcher supporting Alion Science and Technology, Inc's. $130M Omnibus Task Order with US Army Night Vision and the Electronic Sensors Directorate, as well as the Principal Investigator for a $4.9M Dept. of Homeland Security Advanced Spectrographic Radiation Portal Monitor for special radioactive materials.

Erick Rekstad
Department of Homeland Security

Erick Rekstad received his Bachelors Degree in Computer Engineering from Virginia Polytechnic Institute (Virginia Tech). He was an Examiner for the United State Patent and Trademark Office for over 5 years in the area of video based security and video compression algorithms. This included algorithms in the field of behavior recognition, object tracking and improved video compression algorithms. Currently, he is the lead Engineer on the Advanced Imaging Technology (AIT) and Advanced Technology (AT) programs for TSA's Office of Security Technology (OST). This includes the development of performance requirements and interpretation of those requirements in order to support the qualification and potential deployment of equipment. He also develops engineering documents to support the acquisition process (Concept of Operations, Operational Requirement Documents, and Procurement Specifications).

John Reynolds
Lawrence Livermore National Laboratory

Martin Richard
Consultant

Mr. Martin Richard is a mathematical-physicist from University of Montreal Canada and Ecole Polytechnique of Montreal. Mr. Richard has instructed in postgraduate curriculum as well as working in many R&D efforts across the world over the past 20 years. Specialist of machine learning, computer simulation and imagery, he has been intensively involved in governments, military, private and public organizations. Mr.Richard is currently doing international consulting as a defense scientist and security expert.

Markus Schiefele
American Science and Engineering, Inc

Dr. Schifele received his Masters (equivalent) in Physics, PhD in Physics and Bachelor (equivalent) in Mathematics from the University of Ulm, Germany. He moved to the US in 2005, and his area of expertise is algorithm development, especially image processing, and software engineering.

Jon Schoonover
Los Alamos National Laboratory

Jean-Pierre Schott
Lawrence Livermore National Laboratory

Dr. Jean-Pierre Schott is the Senior R&D Technical Consultant and lead architect for medical devices, special effects and security industries at Lawrence Livermore National Laboratory. Dr. Schott has over 20 years of experience in bombs and weapons detection, medical devices, computer vision, computer graphics, digital imaging and signal processing. As Senior

Director of imaging technology at Analogic, Dr. Schott managed CT reconstruction, image quality, explosive and weapons detection algorithm and software groups. He prepared and presented reconstruction, image quality and detection designs for the PDR and the CDR phases of three lines of security scanners (checked and checkpoint luggage.) Previously, Dr Schott was Director of Advanced Development at Medispectra, managing directors, managers, engineers, scientists and consultants of the algorithm, image processing, database and software groups. He also architected the overall classification and image processing algorithms and led the cross-functional team, including external counsel, which produced 9 patent applications covering the intellectual property of the key technology. Dr. Schott has also served as Director of Engineering at Synapix, managing the entire engineering department, including 2D and 3D graphics groups, QA, documentation, UI and computational geometry.

Anthony Serino
Raytheon

Robert Sheftel
Department of Homeland Security

Emil Sidky
University of Chicago

Dr. Emil Sidky received his undergraduate degrees in Physics, Mathematics and Astronomy-Physics from the University of Wisconsin - Madison in 1987. He then earned his Ph.D. in Physics at the University of Chicago in 1993. From Fall 1993 to Spring 2001, Dr. Sidky has taken post-doctoral positions at the University of Copenhagen, Denmark, University of Bielefeld, Germany, and Kansas State University, producing over 20 publications in the area of atomic physics. Nine years ago, Dr. Sidky returned to the University of Chicago as a NIH post-doctoral fellow in the Department of Radiology and has published over 25 articles in the field of medical imaging.

Peter Siegel
California Institute of Technology

Peter H. Siegel received his BA in Astronomy from Colgate University in 1976, an MS in Physics and a PhD in Electrical Engineering from Columbia University, in 1978 and 1983 respectively. He served as an NRC Fellow at the Goddard Institute for Space Studies in NY and then as a staff member in the Electronics Development Lab at the National Radio Astronomy Observatory, Charlottesville, VA. He moved to the Jet Propulsion Laboratory, Pasadena, CA to work on submillimeter wave sensors for NASA space astrophysics and Earth remote sensing applications in 1987. At JPL Dr. Siegel has been involved in four space flight missions and more than 75 research and development programs. He founded and has led for more than 20 years a large technical team of 20+ members, SWAT - Submillimeter Wave Advanced Technology, focused on NASA applications of terahertz technology. In 2001 Dr. Siegel joined the staff at the California Institute of Technology, where he holds appointments as Member of Professional staff in Biology and Faculty Associate in Electrical Engineering. At Caltech he has been expanding terahertz applications into biology and medicine. Dr. Siegel is an active member of the IEEE THz community and has served as vice-chair and chair of MTT-4, THz Technology, as an IEEE distinguished lecturer and continuing member of the speaker's bureau, as organizer and chair of seven special THz sessions at sequential IMS meetings, as a long term member of the TPC and special guest editor for MTT and JIMT. He is also chair of the International Organizing Committee and founding chair of the International Society of Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), the oldest and largest organization devoted to THz research and applications. Most recently he took on the task of founding Editor-in-Chief of a new IEEE Journal: Transactions on Terahertz Science and Technology, whose Inaugural Issue is slated for September 2011. Dr. Siegel's interests cover all areas of THz technology, techniques and applications.

Michael Silevitch
Northeastern University

Professor Michael B. Silevitch received the BSEE, MSEE, and PhD degrees from Northeastern in 1965, 1966, and 1971, respectively. He joined the faculty of Northeastern in 1972, and was appointed to the Robert D. Black Endowed Chair in Engineering at Northeastern in 2003. A College of Engineering distinguished professor with dual appointments in Electrical and Computer Engineering as well as Civil and Environmental Engineering, Silevitch is co-director of Awareness and Localization of Explosives-Related Threats (ALERT), a Department of Homeland Security Center of Excellence; director of the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS), a National Science Foundation Engineering Research Center; and research translation leader of the Puerto Rico Testsite to Explore Contamination Threats (PROTECT) program, funded through the National Institute of Environmental Health Sciences. Previously, he directed the Center for Electromagnetics Research (a National Science Foundation Industry–University Center), the Center for the Enhancement of Science and Mathematics Education (CESAME), and the Gordon Engineering Leadership Program, a graduate program that provides an innovative model for training engineering leaders. He is an elected Fellow of the IEEE for leadership in advanced subsurface sensing and imaging techniques.

Sergey Simanovsky
Analogic Corporation

Dr. Simanovsky is Principal Imaging Engineer leading a team of engineers responsible for the development of automatic explosives detection algorithms used on several EDS systems that have been successfully certified by TSA. He also worked on CT image reconstruction algorithms and beamline integration for a multi-slice EDS system and a single-slice low cost medical CT scanner. Dr. Simanovsky has a Ph.D. in Physics from Worcester Polytechnic Institute.

Sondre Skatter
Morpho Detection

Sondre Skatter, Ph.D., Manager Systems Engineering at Morpho Detection, received the Diploma degree in physics from the Norwegian University of Science and Technology and a Ph.D. from the Norwegian University of Life Sciences. Sondre joined InVision in 1998 to start the adaptation of the CTX technology to the wood industry (WoodVision). Sondre later developed and tuned the data fusion system for the QRCT project, which was a TSA funded program to integrate CTX technology with Quadrupole Resonance explosive detection. After the YXLON acquisition he lead the data fusion efforts in the Phoenix XRD program, integrating the CTX 9000 with the YXLON 3500. He later took on the role as technical lead and program manager for the same project.

Stephen Skrzypkowiak
Transportation Security Administration

Stephen Skrzypkowiak earned his PhD degree in electrical engineering from the University of South Florida (USF). He has also held teaching and research positions at USF. Steve is a consultant to the DHS, TSA and TSL and has been since 2002. He currently supports these agencies in the technical review of various detection systems, revision of the explosive certification standard and the development of various detection and procurement specifications. He provides technical support for various TSL research projects. He is the TSA consultant Point of Contact to the DICOS committee in the working groups of Digital Radiography (DR), Computed Tomography (CT), Threat Detection (TD) and Technical committees. He was a DHS consultant as a technical support member to the IEEE P Draft Standard for Evaluating the Image Quality of X-ray Computed Tomography (CT) Security-Screening

Systems. He developed the Computed Tomography Image Quality (CTIQ) hardware and software to measure the image quality of Explosive Detection Systems for the Transportation Security Laboratory (TSL). As Director of Engineering, Steve led the L-3 communication team from the development of the 3DX6000 through TSA certification and fielding before becoming Director of Advance Systems Engineering. He is a Florida Professional Engineer and member of the IEEE, SPIE and NSPE.

Frank Sprenger
XinRay Systems

Dr. Frank Sprenger is the Director of Research and Development at XinRay Systems. He has extensive experience in the development of X-ray technology for medical and security applications. Before joining Xinray Systems he worked as a project manager at the innovation department of Siemens AG Vacuum Technology Division on high power rotating envelope X-ray tubes and field emission electron sources. Prior to that, Dr. Sprenger worked at the Max-Planck-Institute for Nuclear Physics in Heidelberg, Germany on ultra-cold electron beams. Dr. Sprenger received his Ph.D in Physics from the University of Heidelberg, Germany in 2003.

Helmut Strecker
Morpho Detection

Dr. Helmut Strecker, Manager Research & Development at Morpho Detection Germany GmbH, received a Diploma degree in physics in 1976 and a Ph.D. in computer science in 1990. From 1980 to 1999 he was scientist at the Philips Research Laboratories in Hamburg working on new x-ray analysis methods for industrial and security applications. He was responsible for the development of an automatic explosives detection system based on coherent x-ray scatter / X-Ray Diffraction (XRD) at Philips starting in 1993, resulting in an XRD based product line at YXLON / GE Security and finally Morpho Detection (MDI). Morpho Detection's XRD systems have become a standard for Level 3 screening at German airports and are used in a System-of-Systems (SoS) configuration in conbination with CTX systems at Level 1 in other countries. He is currently responsible for the development of "next-generation" XRD systems within MDI. He was the Principal Investigator on the TSA Grant Project "Improvements of Explosives Detection Based on Coherent X-Ray Scatter (CXRS)" performed between 1999 and 2003. He was also in charge of the activities, which led to the successful certifications of XRD systems by the US Transportation Security Administration in 2004 (XES 3000) and ECAC in 2009 (XRD 3500, "Standard 3").

Dan Strellis
Rapiscan Systems

Dr. Dan Strellis is the Director of R&D Technical Programs at Rapiscan Laboratories, the research arm of Rapiscan Systems. Rapiscan Systems is a major supplier of security screening systems throughout the world with over 70,000 units deployed. He oversees the current Government-funded R&D projects for the company in an effort to develop new techniques and capabilities for the Rapiscan Systems products. He received his B.S. and M.S. in Nuclear Engineering from the University of Illinois and his Ph.D. in Nuclear Engineering from University of California, Berkeley.

Simon Streltsov
LongShortWay

Greg Struba
Department of Homeland Security

Gregory is a Booz Allen Hamilton consultant who provides SETA support to the Explosives Division of the DHS Science and Technology Directorate. Greg's efforts have been focused on the Manhattan II Next Generation Program, the Homemade Explosives (HME) Program, and Basic Research Programs. Specific projects include Whole Body Imaging, Novel Threat Data Collection, and Safety Standardization. Greg Struba received his Bachelors degree in Mechanical Engineering from Rochester Institute of Technology, Rochester NY, and his Masters degree in Engineering and Technology Management from The George Washington University in Washington DC. Prior to joining Booz Allen Hamilton (December 2008), Greg Struba worked for Lockheed Martin Corporation for 5 years as a systems engineer in support of the Intelligence Community.

Ashit Talukder
California Institute of Technology

Ling Tang
Rapiscan Labs

Dr. Ling Tang is a senior algorithm development manager of Rapiscan Laboratories, Inc. He is an experienced algorithm scientist and a software architect with extensive hands-on skills in object-oriented analysis, design, and component-based development. Dr. Tang has an excellent track record of project leadership and on-time milestone delivery for multiple projects in a wide set of application domains including X-ray Imaging Systems, Explosive Detection, Pattern Recognition, and Storage Network Management.

Lei Tian
Massachusetts Institute of Technology

Lei Tian is currently a graduate student working with 3D Optical System Group, in the department of Mechanical Engineering at Massachusetts Institute of Technology. His research is focused on digital holography applied to multi-phase flow visualization, non-interferometric phase imaging and phase space optics.

Brian Tracey
Tufts University

Simon Warfield
Children's Hospital

Dr. Warfield is Associate Professor of Radiology at Harvard Medical School, Director of Radiology Research and Director of the Computational Radiology Laboratory (CRL) in the Department of Radiology at Children's Hospital. Dr. Warfield has served as the Principal Investigator of research grants funded by the National Institutes of Health and the National Science Foundation. He is an editor of Medical Image Analysis and an Associate Editor for IEEE Transactions on Medical Imaging. Dr. Warfield founded the CRL in 2001 with the mission of improving our understanding of the structure and function of the brain and other organs of the human body, in order to improve our capacity to diagnose and treat disease. Dr. Warfield's research interests in the field of medical image computing have focused on the development of innovative algorithms to address the requirements of clinical care and translational research in medicine. This has included the development of novel algorithms for image segmentation and image registration, especially suited to quantitative assessment of early brain development utilizing advanced brain atlasing and pattern recognition approaches. The CRL develops and distributes open source software for pediatric image analysis.

Jeff Waters
U.S. Navy

Whitney Weller
L-3 Communications

Whitney Weller has studied operations and implementation of advanced imaging technologies with a focus on automatic target recognition. Prior to joining L-3 he served as Director of Millimeter Wave Standoff Detection systems at QinetiQ North America. Whit has experience with advanced sensor platforms, sensor fusion and sensor networks. He has a background which includes work for Bell Labs on dense wave division multiplex systems. Whit holds a Bachelors Degree in Electrical and Computer Engineering from the University of Massachusetts and is a member of ANSI HSSP, NDIA and IEEE Sensor Society.

Dana Wheeler
Radio Physics Solutions

Mr. Wheeler was previously the CTO of HXI (formerly Terabeam-HXI) mm-wave operation since July 2002. Prior to Terabeam, he served as Chief Operating Officer for Harmonix Corporation. Over 30 years of experience in the mm-wave field with numerous technical articles published, he has successfully managed the commercial development and product launch of many mm-wave high data-rate communications systems and military autonomous landing systems. Has also held senior management positions at Sanders, a Lockheed Martin Co. (now BAE Systems), M/A-COM and Millitech Corp. Holds a B.S. in Electrical Engineering Technology from University of Massachusetts.

Suriyun Whitehead
Department of Homeland Security (Support Contractor)

Suriyun is a Booz Allen Hamilton consultant who provides SETA support to the Explosives division of the DHS Science and Technology Directorate. He is focused on the Manhattan II Next Generation EDS, Whole Body Imaging, and Basic Research Programs into enabling technologies, common standards and detection requirements. Suriyun received his Masters degree in Computer Systems Engineering from the University of Bristol, in the United Kingdom. Over the past 10 years, Suriyun has been involved in the design and development of large scale systems of systems, advanced security and sensing systems, enterprise data management, data fusion, and related airport security programs.

David Wiley
Stratovan

David Wiley earned his B.S., M.S., and Ph.D. in Computer Science at the University of California, Davis. For over ten years, he performed research at the UC Davis Institute for Data Analysis and Visualization (IDAV) holding various roles from undergraduate researcher to post doctoral researcher. He has published over 20 peer-reviewed publications in journals, conferences proceedings, and books. He has over twenty years of software development experience and has created numerous commercial software applications. He formed Stratovan Corporation in 2005 as a spin-out company from IDAV to address the software needs of the medical imaging industry. He currently leads Stratovan in becoming the leading supplier of next-generation interactive imaging software to the medical device and diagnostics markets worldwide.

Lerry Wilson
Intelliscience

Mario Wilson
Department of Homeland Security

Horst Wittmann
Northeastern University

Dr. Horst Wittmann is the Research Evaluation Advisory Panel Leader for Awareness and Localization of Explosives Related Threats (ALERT). He is also Senior Research Development Officer in the Office of the Provost of Northeastern University. In 2001 he retired from the federal Senior Executive Service as Associate Director of the Sensors Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH, and from his position as Lead US Representative at the NATO Research and Technology Board, Sensors and Electronics Technology Panel. Dr. Wittmann's field of scientific specialization is solid-state physics; he received the B.S in 1959 and the Ph.D. in 1964. He is a fellow of the IEEE and AAAS.

Jeremy Wolfe
Harvard Medical School

Jeremy Wolfe graduated summa cum laude from Princeton in 1977 with a degree in Psychology and went on to obtain his PhD in 1981 from MIT, studying with Richard Held. His PhD thesis was entitled "On Binocular Single Vision". Wolfe remained at MIT until 1991. During that period, he published papers on binocular rivalry, visual aftereffects, and accommodation. In the late 1980s, the focus of the lab shifted to visual attention. Since that time, he has published numerous articles on visual search and visual attention. In 1991, Wolfe moved to Brigham and Women's Hospital and Harvard Medical School where he is Professor of Ophthalmology. The lab is currently funded by the US National Institutes of Health and Department of Homeland Security. Wolfe teaches Psychology courses at MIT & Harvard. Jeremy Wolfe is Past-President of the Eastern Psychological Association, President-elect of Division 3 of the American Psychological Association, and editor of the journal "Attention, Perception and Psychophysics". He won the Baker Memorial Prize for teaching at MIT in 1989. He is a fellow of the AAAS, the American Psychological Assocation (Div. 3 & 6), the American Psychological Society, and a member of the Society for Experimental Psychologists. He lives in Newton, Mass.

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12. Appendix: Questionnaire

ADSA05 attendees were asked to fill out a questionnaire providing feedback on the workshop. The questions are listed below; the answers appear in the next section, grouped by question.

1. Should fused systems be considered?
2. What analytical basis or metric should be used to decide which technologies to fuse for what effect?
3. What technologies could be fused and for what application?
4. What are the technological enablers?
5. What examples are there for fused technologies that worked and didn't work? (The examples can be for aviation security and other applications such as Defense.)
6. What information needs to be made available so that people can do research and c
7. ompanies develop and deploy technologies?
8. What are the boundary conditions or rules should be put in place to use fused systems?
9. What changes need to be made by the TSA to allow fused systems to be deployed?
10. What should the agenda be for going forward for the research/development requirements necessary to proceed with technology fusion as related to security applications?
11. What did you like about this workshop?
12. What would you like to see changed for future workshops?
13. What topics would you like to see addressed in future workshops?
14. What other comments do you have?

13. Appendix: Questionnaire Responses

13.1 Questionnaire A-1

1. The workshop never narrowed down what "fused" means. Given the possible definitions of:

a) Providing a means for multiple units to be combined in order to provide a combination of systems to screen items.
b) Integrate different technologies into a single system to provide multiple means of detecting threats.
c) Providing an improved interface for an operator in order to allow the operator to make a better judgment call.

In general yes, we need to continually strive to perform a higher level of detection with lower false alarm rate. This needs to be done while maintaining a high throughput. These three elements basically necessitate the need for equipment to work together in order to make the screening a more efficient process.

We should be building to a single device that integrates multiple technologies. The stepping stone to this builds the fusion:

a) We first need the ability to interface different devices to perform screening in tiers (i.e. if one system alarms how we send that information to a second device to provide a better educated decision at the second level).
b) We add logic to the process to allow a combined result based on input from multiple devices.
c) Finally we build a single device using multiple technologies to take advantage of each technology's pros and compensate for their weaknesses.

2. The metric should be overall Pd, Pfa, and processing time (where processing time includes a measure of ease of use).

3. We want to be able to fuse any available technology to improve screening. The point is to determine the benefits and weaknesses of each technology and determine an optimal combination to provide a means to screen passengers and items efficiently and effectively. If we can get the system to perform the layers of detection for us then we won't need to rely

on a secondary screening process. That is, anything that is spit out by the system as a threat will be at the level that requires a BAO to resolve or is clearly a weapon. Examples may be:

AIT+ETD+WTMD

AT+ETD

4. DICOS should enable a foundation for some common communications protocol. The key is having a standard interface means where no matter the technology or device it can transmit and receive relevant information to make a determination. This may be difficult given that different technologies produce different outputs and we want to avoid just relying on a system's "green" light/"red" light decision and actually make a final determination using more detailed information.

5. This goes back to what is fusion. One could argue the ability to enable an operator interface with a CT and perform a high throughput is an example that worked. I would say this process was only formed in an effort to produce a throughput that is acceptable. Procedurally this was deemed an acceptable method based on risk. What we need is a fusing of technology that provides an equivalent level of detection as an open bag search with the throughput levels near that of not performing any screening at all.

6. To achieve the final state, TSA would need to provide a long term plan of action in order to define what is needed. In the short term, researchers and vendors need to fully list out the pros and cons of each technology and begin to determine how technologies can be combined to meet the current detection requirements. This will then help to drive what information needs to be shared in order to fuse the technologies.

7. The final fused system needs to meet the Pd, Pfa, and throughput needs while minimizing the footprint.

8. The TSA needs to better define requirements that are not technology specific. The general acquisition process needs to be reviewed in order to determine how best to promote fused systems.

9. As indicated above, the first step for researchers and vendors is to fully list out the pros and cons of all known technologies and then begin to determine what information could be shared in order to produce a higher level of detection by compensating for certain weaknesses while taking advantage of strengths.

10. Some of the beginning steps were taken to define the pros and cons of technologies and the discussion on past/current attempts to integrate devices was interesting.

11. Clearly define the purpose. It was sort of joked about in the beginning that we didn't know what "fused" means. Unfortunately, it was never clarified or broken out into stages. A whole workshop could be spent on just this effort.

12. a) A technology specific workshop with the deliverable of defining the pros and cons of each technology and a list of possible outputs and inputs.

b) An effort to clearly define what fused means to this effort.

13. Blank

13.2 Questionnaire B-2

1. Yes, I believe that combining systems together will help to enhance the detection and reduce the Fpos.

Fusing systems will also in many cases be instrumental to improve the resilience of the solution (made of many sub-systems) in the sense that the weakness(es) of one system may be compensated by the presence of others.

Fusing systems successfully and efficiently will require a good level of knowledge of each sub-system in order to find the best to bride combination and possibly best permutation of them. This will be an important technical task as well that should not be neglected.

Fusing represents from my point of view a big challenge due to the fact that hardware manufacturers as well as software third parties (such as Guardian Technologies) will need to work together with more transparency, without jeopardizing their own market place. So far, I unfortunately did not observe such transparency nor real and honest interest from the hardware makers to work this way. Smaller third parties often need to reveal much more sensitive technological information about their product than what the manufacturers do.

According to my understanding, experiences and information that came from TSA to me, U. S. authorities like TSA are not going to be the "technology integrator." That is said, the so far lack of success between the manufacturer and software third party together announce the huge importance of it is going to become the biggest issue of "fused systems." Fusing systems limitations is not a technical one but a political/methodology one. Political matters we need to live with it. However, some level of control over this "fusing" project can be provided by defining and enforcing a strict methodology…but under whose responsibility?

2. I still been to refine my thoughts about it but I would say at first that each problem may have its own need and the best solution to solve its issues should be tailored to it. Path for success can't be drawn like that.

I am promoting the following approach:

By the authorities:

Formulation of the problem

Set the operational objectives, CONOPS, and constraints,…

Like someone suggested at the end of the workshop: make “workshop” with many parties to tackle a specific problem, draw the great lines of what the solution may look like.

By the authorities: Select a JTF (Joint Task Force) made of manufacturer software third parties and possibly more people, put them together in a room, shut the door and open it when the team gets to something that can solve the issue from the scientific-technical point of view.

This simple naïve approach should at least be tried before being killed…Once the JTF is done, authorities can decide whether to call a BAA or do anything else according to their own internal processes, policies, and NEED.

I have been personally involved in such similar processes over the last 20 years and it works well most of the time. Those parties who are not part of the solution are the cause of the problem and they must be excluded the next time. This way, those who are not collaborative need to think about it twice. This is how the Canadian, U.S. and U.K. peers agencies work together.

3. Each system has its own strengths and weaknesses. This depends on what it is needed to detect and under what circumstances (shield, clutter, artful concealment, type of container, type of threat, topology of threat-bag, and so on…).

Like I express in the first answer, I strongly believe that this is no golden rule(S) to answer adequately this question here. Each and every specific case should be thought of separately when it comes time to decide what is the BEST TO BRIDE technologies-algorithms to tackle one of the specific issues.

I have one comment here and this corresponds to one of my observations:

Multi-view systems like TRX for detection threat in carry-on luggage are system that would bring a marginal improvement in the Threat detection. However, their principal asset is to help reducing the Fpos caused by SHIELD alarms.

4. I think that there is no technology enabler for the moment. Things are technologically entirely realizable.

I would phrase this question this way: *What are the fusion disablers?* Please refer to my long answer of the question number 1 above. The most important disabler is the willingness of real transparence. But this could be compensated to some extent by the imposition of working protocol; methodology if you will.

5. I personally made a system myself as a proof of concept that achieved a 95+% detection of breast cancer with less than 2% Fpos. This was a system that used X-ray mammograms in conjunction with physician historical notes (digitalized), plus the epidemiologic data (when available), blood test data, family history, and more. This system worked just fine; to look back at that time is like science fiction to medical people.

Another example, I made consulting for NSA a while ago with the Canadian liaison office of CSIS (Canadian Security and Intelligence Service) to analyze several sources of information (images, text, faxes, emails, quantitative, and qualitative data, sounds) …all this simultaneously. More than 10 PB (10,000TerBytes) of new data every day. Great discoveries were made out of that…It worked just fine.

Lot of DoD and DND (Department of National Defense) in Canada use this now, and for more than a decade already. I am making this great fusion concept a real one for 15 years and more now.

IMPORTANT:

We talked about fusion of data. People can often think more about fusion of images from many sensors. Or better, the fusion of raw data from multiple sensors for imagery. But I think we should open this just even more. Fusion should encompass, by definition, all sources of data, no matter the modalities in place. As an example, Customs or Border Services can share information with Foreign Offices with airports, airliners, security agencies, law enforcement entities; airport authorities are using their mm-waves at airport portals, in addition to their luggage scanners, their blood pressure/temperature sensors…and more. A part of this is implemented in Mexico and Paris already. I met STAC in Paris years ago to make such a system to them. We may think about fusing all the separate assessments of each sub-system into one meta-model, or rather use one big meta-model that makes its own assessments (disregarding the sub-systems "eigen-detection" capability first.

6. This is the question that is forever asked. The fact of the matter is (from my stand point) that some agencies such as TSA are more concerned about how to:

Build a simulacrum of security for people and politicians.

Make their lives easier to the detriment of real solutions.

That is said, if they were interested in improving the security, they would:

Do something similar to what I've suggested in my answer #2 (ref JTF).

Listen to those little players who want to show their innovative solutions.

Be able to think out of the box.

Stop waiting for the benediction of the manufacturer lobby to consider something.

What information: Answer-> Tell the companies (not only the hardware manufacturers) what the problems are and provide images when available, or to facilitate their collection.

7. (1)Ensure the evaluation of the entire solution independent from one's own interest.

(2) Please refer to last paragraph of my answer to Question Number 1 above. Put in place methodology.

(3) Set first the criterion of acceptance of the developed system. So far, being on the side of the software third party, it has been a long race toward unceasing moving targets. Many examples of this with TSA/TSL.

(4) Fund the R&D to allow smaller innovative and promising parties in this. Financial limitations limit and exhaust smaller players.

Authorities must put in place some boundaries to prevent big players (more often the hardware manufacturers) to act in such a way that during the fusion project the smaller party is put in an uncomfortable and dangerous position so the next time the small boy is no longer in the picture! You may say that the big ones will be affected too if fusion fails, but my answer to this is that the big one is going to be affected this time only but will survive and be there the next time (which will not be the case for the small companies).

8. I don't know from a technical standpoint how to answer this question without repeating many things I've said before.

9. I believe that the use of JTF as stated in Answer 1 is fundamental. To make this possible, it is required for the authorities to have a pool of company and resources that can be invited to participate in such discussions.

The sensitivity of the topic requires cleared people, trusted companies, and cleared facilities. Investigation for this purpose is required. This is an important overhead job that can be undertaken immediately. Time to clear an individual should not be a common reason or an excuse to exclude someone or an entity from being part of the solution. I believe that for many projects such as for TSA related stuff, there is no great issue to refuse someone from another friendly country like the UK or Canada to be cleared up to a TS project. Let me tell you something real hear: There were Canadian people at the workshop that have NATO Cosmic (more than 3 levels on top of TS clearance) that could go alone within the Fort Meade NSA's wall, without being escorted, and that can simply not attend an unclassified meeting at TSA's facilities in Atlantic City. What if those individuals represent key aspects of the solution? This is a show-stopper for many good value and safe people.

10. This is a great forum to meet with people that share the same interests, concerns and also expertise. It is easier to take the phone and call someone you already met to informally talk about something you are thinking about- just to share ideas. This is the type of context that allows people to realize they're not alone thinking about something, because not all is said in literature and publications.

Moreover, the formula of the workshop us just great to me. Not too short or long; it is just long enough. Having meals while working would increase efficiency and a certain dynamic that allows meeting even more people.

11. I don't see anything to change in this successful event.

12. I am very interested in data fusion and I think we should try to reserve a 2 hour block to talk about it at least for the ADSA6 workshop. This is an emerging subject; funny to say that I am making this for 15 years already…☺ Discussing data fusion for a couple of hours will allow trends to be seen and how this topic is maturating in peoples' minds. We observed this week that when trying to define what fusion is, there were many interpretations of it. This means, or at least suggests, that we revisit this issue later.

13. I think Michael Silevitch mentioned something interesting at the end of the workshop. He suggested creating and publishing a kind of journal similar to what already exists in the medical domain.

I agree; this is a very good idea and I would agree to involve myself and participate actively in this in the way it would be the most useful.

13.3 Questionnaire C-3

1. As long as there is no "silver bullet," multiple modalities should be used, and only by fusing can they be optimally implemented.

2. Orthogonality is important. The detection features of candidate technologies should be mapped on an objective set of sales in "feature space" to ensure the best coverage over possible scenarios.

3. - mm-wave

-XRB

-NQR

-Trace detection (IR, Raman, ODD)

4. Blank

5. In mine detection, electromagnetic induction and IR thermography failed to improve detection/false alarms over GRP alone.

6. Good models for physical interactions with realistic targets are the biggest deficiency. Models guide reconstruction, and may provide the basis for "front end" fusion of multiple modalities.

7. Keep work fundamental, involving basic research, and avoiding SSI/classification as much as possible. Avoid proprietary system implementation. Define the problem statement very carefully.

8. Change its mindset to consider and investigate prototype rather than certified or production-version systems.

9. Step back to examine data earlier in the sensing /processing chain. Fusion is most effective at the raw data level.

10. Blank

11. Lock the agenda better, so tight scheduling can be accomplished. Meeting scheduled during lunch were messed up when the lunch time changed.

12. Reconstruction/modeling

13. -Marketing is still too prevalent
-Stick to technical material
-Vet talks for new faces to ensure relevance

13.4 Questionnaire D-4

1. Yes

2. I think standard Pfa/Pd is good starting point-no special insights.

3. Still a little unclear to me. I am interested in what can be fused with X-ray backscatter but it’s not totally clear what the best candidates are.

4. Blank

5. Not sure.

6. Images of common threats taken with multiple modalities.

7. -smooth ‘failure modes’> i.e. revert to individual performance if systems fail.

8. Probably change to spec. and testing

9. Blank

10. 1) I’m new to area, so it gave a good overview

    2) Met people working on X-ray backscatter who I hadn’t previously met.

11. I really like the suggestion of small working groups. Figuring out data and participation will of course be tricky

12. Blank

13. Very hopeful!

13.5 Questionnaire E-5

1. Yes. There seems to be good evidence that fusion can improve decision performance-so it should be studied with a thorough systems engineering approach.

2. Metric should ultimately be cost/benefit. A good example is the fusion of PET/CT that only became viable after PET alone became economically viable (reimbursement) that only resulted after many years of demonstrated benefits in the "true positive" patient population. This is complicated for security since there is a much smaller (>zero) true positive patient population. So the cost-benefit in security needs to be on the economic value of lower FAR.

3. XRD seems most promising for checked baggage technology for detection (actually clearing) potential threats. However risk data is probably the most likely data to reduce alarms without high cost of implementation technology. Analogy in medical is patient history screening that determines whether to even scan a patient.

4. -Open data architecture for access to other feature data (esp. from risk models).

-Ongoing development of orthogonal inspection technology (XRD, spectroscopy, etc.)

5. Medical has many (PET/CT, CT or MR with/without contrast)

Israel demonstrates fusion of passenger risk assessment with baggage screening procedures

6. 1) Information on the economic model for FAR reduction.

2) Continuous flow of stream of commerce data on false alarm features.

3) Framework for feature sharing of checkpoint and checked bagged detection systems to integrate all passenger data.

7. IP protection

8. Access to data from deployed system to build better decision algorithms from current and fused data sources

9. Develop and prioritize a data model for improving decision algorithms in threat detection (and FA clearing) applications. Prioritization needs to be based on cost/benefit.

10. Several good talks on adjacent applications and perspectives.

11. More input from TSA/TSL with concrete examples of ways it intends to help facilitate or enable change. For fusion (for example) is risk data as an input "off limits?" For deployment of new technology, what is the cost model TSA is willing to consider?

12. Improved characterization in Pd and FAR. Discussion of sample sizes for development certification and ongoing improvement of Pd and FAR. Strong case can be obtained from medical applications where huge volume of patient scans is used to continually improve detection and economic performance (and false positive reduction).

13. Excellent location and support staff. Other topic for future workshop could be on-screen resolution. –esp. what can be done to evaluate and improve the ROC for OSR for a given system, fused systems, or system of systems.

13.6 Questionnaire F-6

1. Yes, at a system level discussion.

2. Deployed systems, advanced concepts. Consider performance, cost, size, GUI.

3. BX, TX, THz, mmw, IR, spectroscopy, etc.

4. Funding, need, support requirement

5. Blank

6. Blank

7. Blank

8. Blank

9. Issue man small contracts, approximately $100,000, for investigation of fusion options.

10. Open, informal nature

11. More systems/requirements discussion.

12. Case studies of various technologies and how the information they provide could be fused.

13. Overall good job.

13.7 Questionnaire G-7

1. Yes. This is a necessity and where screening will be going in the future.

2. Proven (not theoretical) increase in Pd or drop in Pfa. Peer reviewed for efficacy.

3. AIT and trace for checkpoint.

CT and diffraction or CT and trace for baggage.

AIT and optical spectroscopy for checkpoint high energy x-ray and neutrons cargo.

4. Robust algorithms with ground truth basis

Systems engineering of integrating hardware

5. Mm-wave and video

Infrared imaging and video (optical imaging)

6. Raw image data output (unprocessed)

7. Completely characterized performance, including a variety of typical background and conditions.

Extensive OT&E

8. More efficient technology pilot programs.

Clearer requirements!

Less political processes and selection

9. Contests (similar to Netflix challenge)

Bakeoffs of technologies

10. Broad view of fusing technologies (chem/physics/algorithms)

11. No rock band playing outside the venue during talks

12. Chemical based detection (though it is not all image based)

Data intensive computing aspects of security.

13. Good job

13.8 Questionnaire H-8

1. Yes.

2. Must consider all practical and technical parameters including: cost-speed, spatial resolution, measured features, explosive types those features apply to, specificity and sensitivity of those features for those explosive types, etc. Operational scenario has to be considered. Tiered inspection seems most practical. X-ray CT still seems most appropriate for Level 1 inspection. Discussions of scenarios for checkpoints and checked baggage need to be separate.

3. X-ray, CT, and x-ray diffraction for checked bags.

4. Blank

5. Blank

6. All parameters discussed in Question 2 plus correlations and uncertainty of all features. Optimal fusion of high-dimensional sensors will require collection of very large simultaneous data sets.

7. Any system of systems will have to be certified only as a combined system. It is hard to image how that could be feasible commercially unless all subsystems are owned by the same company or a commercial collaboration.

8. Blank

9. Blank

10. Discussions of the state of the art for various probe technologies.

11. Blank

12. More of (10)

13. Discussion of probability computations is largely irrelevant in the abstract. For high dimensional measurements the question of independence is extremely complex.

13.9 Questionnaire I-9

1. Yes, but systems are like overlapping puzzle pieces, so how they are joined/fused depends heavily on individual characteristics.

2. Whether or not systems can be co-located (i.e. 3D CT data with similar 3D data) within those groups the physical characteristics elicited by each system must be considered. Orthogonal systems produce different characteristic data and can potentially provide significant value when combined.

3. All available, starting with one technology, you then must supplement its weaknesses.

4. Blank

5. Medical at large. 3D examples include PET/CT and MRI/CT. However, significant value is being achieved also including patient records, such as lab test results, pathology reports, doctors' notes, etc. There are enormous efforts underway in medicine to "fuse" all of this information totgether to better treat patients. There have been significant hurdles and there continue to be significant hurdles, such that this process proceeds very slowly.

6. Common data formats to begin with. These must address calibration and protocol differences among manufacturers.

7. It is difficult to devise a "general purpose" system, or rather, ecosystem of security devices. I recommend a series of "fixed" configurations of security devices so that algorithms can count on certain input data. Without known configurations/ecosystems of security devices, an algorithm must adapt to what inputs it may (or may not have) i.e. different checkpoints may or may not have certain security devices.

8. Once common file formats are vetted, they should require adoption by vendors, possibly a requirement for certification.

9. Focus on interoperability, common file formats and threat descriptors. Then an integrating system can be constructed, sensitive to individual manufacturer differences, that can "fuse" or interpret the aggregate information.

10. Openness and discussions.

11. Blank

12. Blank

13. Blank

13.10 Questionnaire J-10

1. Considered yes! But carefully as one takeaway from this workshop was that the fusion needs to happen in a smart way. A lot of thought must be taken into the a priori knowledge of the system's performance.

2. I would say that the obvious ones should be used: performance, time for screening, cost footprint.

3. Trans. X-ray with trace ← baggage screening

Backscatter x-ray with trace ← personnel screening

X-ray, neutron, trace ← cargo screening

THz, IR ← people tracking, personnel screening

4. -Improved x-ray detectors and electronics, smaller MS, Raman systems, compact neutron sources, compact x-ray sources, light-weight x-ray sources, faster electronics.

5. IR, UV, and visual imaging fusion for Defense ISR

6. Input from TSA and other end-users on what is doable for fusion at the checkpoint.

7. Improved performance, improved usability

8. Testing at TSL needs to be monitored and changed to accommodate multiple systems being tested together at the same time.

9. More input on what has worked in the fields. Examples from all possible overlap area would be helpful

10. Interactive environment of the talks

11. Timeline should be more strictly enforced; some speakers didn't not abide by rules. Limit the offensive behavior by attendees (e.g. G. Zarur comments were out of line).

Limit vendor grandstanding, marketing.

12. Lessons learned from vendors and third parties on what has worked and what has not worked.

13. Overall, this was a nice workshop and I hope to attend future areas.

13.11 Questionnaire K-11

1. Yes.

2. Study on combined performance versus isolated performance based on/for critical examples

3. CT, XRD (X-ray diffraction) for HBS-EDS (Explosive detection scanner that passes TSL's CERT)

4. Fieldable single systems.

5. Initial CT-XRD work showed significant FA reduction and even detection improvements (but less pronounced).

6. Combined threat and non-threat DC's

7. "Generic "data interfaces.

8. Blank

9. Follow-on workshops focusing on special areas of interest

Definition of possible data fusion schemes

10. Meeting experts from different areas, different technologies

Presentations were good

11. Preparations was very good in general, but the speakers were not all prepared to address "data fusion"

12. Blank

13. Blank

13.12 Questionnaire L-12

1. Absolutely, but must be done intelligently and must account for continually fluctuating government requirements and emerging threats.

2. There are conflicting requirements. If the data (metrics) for a particular fusion scenario are compelling enough, then the user (TSA) may be willing to invest in infrastructure changes. The bottom line is that a fusion concept that has critical vulnerabilities or cannot be practically implemented is doomed to obscurity or failure. So metrics include Pd, Pfa, unit-cost, installation cost, footprint, throughput, etc.

3. Baggage: X-ray imaging XRD (X-ray diffraction)

Personnel: mmw (Millimeter wave), metal detector, X-ray backscatter and something that gives material identification (maybe the fusion would help with that). Plus THz (Terahertz)/HIS

Cargo: neutron imaging, photon imaging

Trace sampling must be automated and must be application-proven

4. CT (issues with relatively poor material identification)

XRD (has issues with engineering to get higher throughput, amorphous materials)

NQR (has issues with sample temperature, serial pulsing for multiple substances, amorphous material detection, shielding, frequency shifting with temperature, very low signal strength)

Millimeter wave imaging: (relatively poor image quality, no material identification)

X-ray backscatter imaging: (good IQ but need 3D capability, has poor material identification)

Phase contrast imaging (may be too difficult for higher energy but may be useful for imaging the edges in backscatter imaging)

5. (Morpho) NQR +CT did not really work well

(Rapiscan +QR Sciences) NQR + X-ray projection and metal shield detector-did not work well

(Smiths, Rapiscan) XRD+CT mysteriously did not perform well despite expectations

Neutron+photo (CSIRO) not really effective

(L-3) XRD+CT limited application of XRD, never tested

6. If the community chooses a set of materials that are not explosives, not simulants, not related to explosives, maybe research can be done easier by avoiding SSI or classified work. I would call them surrogates but some use that word for simulants. This could facilitate information transfer including images, raw data, techniques, etc. But sharing is always going to be limited by the motivation of profit, patents, and prestige.

7. This is dependent on the application and the user. Place emphasis on physical fusion, aka data integration as a prerequisite for sensor fusion on an information-theoretic level.

8. First a useful fused system needs to be demonstrated and tested. TSA can only do so much. They don't own the real estate at airports and cost is a huge impediment because of the huge number of airports and cargo screening applications. Also, other government agencies, such as CBP, can benefit from sensor fusion.

9. Focus, focus, focus on one or two most promising fusion opportunities. Get sensors optimized for fusion. Demonstrate a working prototype that has been constrained by BA (e.g. footprint constraint). If successful, proceed with full scale development.

10. Reasonable balance of subject matter. The forum, in and of itself, is a good thing.

11. Agenda was too packed, not enough time for focused discussion and technical presentation. Objectives may not have been met.

Not enough representation of failed fusion attempts (I'm not aware of successful ones). Why did they fail? Or are they just in suspended animation?

12. -more focused meetings on limited subjects i.e. limit the scope and dig deeper -palletized/containerized/sea-going cargo-huge problem.

13. Blank

13.13 Questionnaire M-13

1. Yes
2. To get better Pd/Pfa ratio.
3. Infrared and mmw for body scanning.
4. Blank
5. Infra-red and mmw work for body scanner.
6. Scanned images including raw data.
7. Blank
8. More options:
    a. Pat down
    b. Body scanner
    c. Beta-testing products
9. Provide more research results for discussion.
10. Diversity, so many vendors.
11. Keep this way, it is very successful.
12. Imaging processing technology.
13. Mini career fair for students looking for co-op or intern positions.

13.14 Questionnaire N-14

1. Yes.

2. Requirement gap

3. Checkpoint

4. Clear framework that protects IP

5. QRCT → Worked from technical point of view

CTXRD → Worked from technical point of view

6. Data!!

7. Blank

8. Not require combination of systems to be subjected to certification

9. Case studies, real problems, multiple vendors

10. Discussions on fusion nomenclature, fusion architectures

11. Emphasis on risk metric

Integration of sensors with intelligence

12. Blank

13. Blank

13.15 Questionnaire O-15

1. Yes. Mostly orthogonal operating and overall area under the curve.

2. Cover the threats.

3. Targeted transmission x-ray, backscatter x-ray, NQR, trace.

4. Funding for performance.

Funding for change in performance

5. PET-CT works.

Transmission X-ray and X-ray scatter spectra.

Weight and CT

6. Real datasets

Mathematical phantoms

7. Risk agnostic

Must exceed simple "superposition"

8. Smart acquisition

DICOS or "no sale"

9. Demonstrate performance with real prototypes, real targets, real clutter (challenges)

10. Frank give and take

Free association

High energy interactions

Industry, academic, and government (multicultural)

11. Increase the times of the schedule until 10pm.

Breakout groups report back for whole group.

Include TSO's

12. Gloves off threat characterization

Direct exploration of value of profiling

13. Carl and Michael should be rewarded.

TSA inclusion is key (reward them).

Add TSO's

Add analysts

13.16 P-16 Questionnaire

1. Yes.

2. Start with measuring confusion matrix and/or per-subcategory performance. These should be done by an independent entity.

3. AIT-WTMD-QR shoe scanner as a fused portal.

4. DICOS

5. Blank

6. Weakness areas of existing technology

7. Stand-alone fall-back mode

8. Separate component testing, where none of the components pass the overall test.

9. Development funding, testing, and procurement of systems for future fusion. Explicit requirements for such systems.

10. Well organized

11. 1) Greater consistency of presentation length-some were rushing through the second half of their slides.

2) Have a classified session where more data could be presented.

12. Blank

13. Blank

13.17 Questionnaire Q-17

1. Definitely yes. Fused system seems to be the most promising approach to improve the ROC curve by combing merits of multiple systems.

2. 1) All candidate systems must be evaluated and thus ranked by which is the dominating device (e.g. CT scanners followed by THz…) before they are blindly fused. Also the fusion of features is the most important. The most effective way to provide better solutions to the grand challenges.

3. 1) Dual-energy x-rays along with the others

2) Classification/detection algorithms with larger set of features.

3) State of the art algorithms such as neural nets, etc.

4. -Academia provides the backbone of research

-Industry enables the application/transfers

-The government should provide guidance and more funding!! (which is lacking now)

5. Blank

6. Datasets that provide added features so the new algorithms can be tested and compared.

7. The total energy of multiple sources acted on humans.

8. Blank

9. Provide funded contests on fusion algorithms.

10. It is by far the best ADSA workshop.

-The presenters are the top researchers in the field.

-More opportunities are provided by interfacing/interactions.

-More technology content.

11. -Organized SIG groups in the interfacing sessions (one hour per day).

-Communication channels be setup in a more organized way instead of meeting someone randomly in the table/in the hallway. The SIG group would be serving that purpose.

12. -Intelligent technologies in ATR.

-Survey presentations which will provide systematic information in specific fields.

-Knowledge-based system?

13. Carl and the ALERT staff/faculty did a wonderful job! Thank you very much!

13.18 Questionnaire R-18

1.

Yes. But it should be clear that fused systems don't always improve systems. That became clear during the workshop.

2.

You need to collect data and do measurements.

3.

Blank.

4.

Blank.

5.

TSA/TSL should know this. I was aware of CT/NQR and CT/XRD. I don't think these worked out well.

6.

Real data with clean and bomb bags.

7.

Blank.

8.

Blank.

9.

Make funding available to collect and develop fused systems without a commitment to build a deployed system subject to a spec.

10.

Lots of talented people and most of the talks were good.

11.

Should have social/networking component. Many meetings use "open mike" where anyone gets one minute to address the group on any topic they like.

12.

Blank

13.

Good job and thanks for the invite.

13.19 Questionnaire S-19

1. Yes. Both image fusion and data fusion are essential. A systems approach to fusion on multiple levels would be ideal.

2. 1) Pd/Pfa

2) Work flow/speed/system cost

3. 1) XDi and CT (already in play)

2) Vis IR imaging to complement AIT and achieve autonomous AIT

3) Trace and AIT

4. Compressive sampling/linear dimensionality reduction is enabling for data fusion. Image fusion is well advanced.

Feature detection from compressed features could guide image definition and fusion.

5. IR/SWIR/Vis image fusion is working in distributed area sensing

Weapon sights, etc.

Multimodal classifiers for landmines/UXO

Medical diagnosis uses fused classifiers

6. Sufficient information is available

7. Systems should be interactive/tunable to enable hum/machine analysts to drill down in data

8. Blank

9. Fusion requires collaboration across a broad community from math/processing to hardware. No single institution has the full range of accessary skills.

10. Technical strength of presentations was high.

11. A more interactive format based on breakouts and challenges might produce more progress.

12. A workshop on technology roadmap development and transition strategies (also teaming and program structure) would be useful.

13. Blank

13.20 Questionnaire T-20

1. Yes.

2. Companies will only consider what is required by the government.

3. Blank

4. Government equipment

5. Blank

6. Government test plans and actionable results during testing rather than just pass/fail. If one fails without feedback there is no path forward.

7. Blank.

8. It is 100% driven by their requirement.

9. Either focus technology area so discussion is easy or don't focus discussions on technologies many haven't seen before.

10. Quality of attendees.

I also enjoyed the medical perspective.

11. Narrow scope of technology or don't force discussion.

12. Direct discussion with TSA about what they can do to make testing more successful.

13. Blank.

13.21 Questionnaire U-21

1. Yes, as there seems to be a definite statistical benefit if done correctly. However, if poorly implemented can lead to worse results.

2. Being able to quantify risk and analyze technologies for their ability to mitigate risk seems to be the desired approach since what's important is the amount of risk, not Pd/Pf.

3. Technologies presented so far seems to benefit best as a system of systems, such as having a QR wand follow an ATI scan.

4. Algorithms to fuse decision boundaries such as boosting algorithms to fuse features to have a joint classification.

5. PETCT with fusing of PET with CT where CT provides the motion estimate to deblur the PET.

6. Common datasets to work with (such as the Sandia set) common standards to facilitate technology communication (DICOS for example). Some IP will need to be shared so that parties can better develop the bridging between technologies.

7. Complexity bounds-too many systems may make a system too complex and cause performance to suffer.

Size/power-More systems increase size footprint and power usage.

8. More openness to work with multiple parties to collectively understand the constraints and limitations of a final fused system.

9. Discussions on deeper level of fusion methodology. This one was heavily on a high level fusion; we could go deeper with the next one.

10. Broad overview of various works out there in attempting to fuse various types of data.

11. Blank

12. Feature level integration technique of different modalities.

13. Blank.

13.22 Questionnaire V-22

1. Definitely

2. Detection always needs to consider Pd and Pfa rates. Best solutions normally involve multiple detection methods and as long as the detection methods are complementary (ideally orthogonal), it will always be beneficial to fuse the data. However, fusion is also more costly, so it does not make sense to fuse unless there is a net gain in Pd or Pfa rate required.

3. Practically unlimited but it's also useful to fuse technology with user input and database information.

4. -Connectivity and standard data format (ex: DICOS)

-Data registration (common referencing)

5. Good: Fighter pilot Heads up Display

Poor: Current checkpoint screening equipment with secondary screening station that simply repeat the image display without providing additional information to the TSO

6. Access to comprehensive set of operational data.

7. Need some sort of weighting factor to determine the reliability of each of the individual systems.

8. Need to provide a framework to facilitate system integration and/or data fusion.

Need some clear objectives with opportunities to finance development of new solutions.

9. 1) Define requirements

2) Provide research and development opportunities.

3) Organize laboratory and field trials

10. -Networking opportunities

11. -Need more practical examples/sample test cases and feedback from operations

12. -cargo screening

-remote operations

-process automation

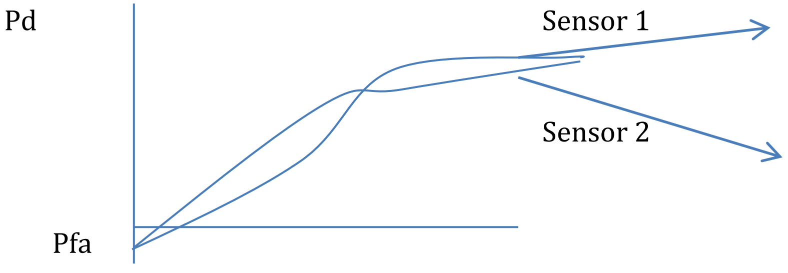
13.

Blank

13.23 Questionnaire W-23

1. Absolutely, but characterization of individual sensor systems with associated decision/classification algorithms, must be a prerequisite for fusing them. "Coordinated" data collection (all sensors observing same scenarios) is crucial for understanding correlation between sensor system output (features, labels, etc.)

2. ROC curves, area under ROC curves, (although this can be misleading, e.g. confusion matrices).



Look to comparison metrics used by similar applications (medical-not just imaging, military, etc.

Cost should be included-or at least placeholders for cost-both cost of implementation and operations and costs of missed or false alarms.

Bayes (or traditional) risk metrics.

3. Don't forget to include "metadata" and human "sensing" in fusion with instruments, where possible and useful.

4. DATA, intelligently collected to characterize each system individually and their combination simultaneously (or at least on the same set of objects/scenes)

MODELING, to supplement data where unavailable (in simplest form) just modeling likelihoods of sensor outputs.

DICOS and common language (ontology) to streamline real-time sharing of relevant information between systems components (proposed or real).

5. Blank

6. DATA. See # 4. Carefully designed training and test data (see medical examples in ANODE09 and ROC09), informed as to useful content requirements by algorithm developers. Fusion and information sharing/accessibility approaches planned or anticipated or to be facilitated by TSA.

From Vendors: Provide feature/“evidence”/score data and confidence where possible-e.g. during TSA certification tests.

7. Recommend DHS develop a “fusion assessment” program for algorithm developers-blind tests, standard assessment training and testing data. See NA-22 Sim., Algorithm and Modeling program where such assessment is just beginning.

For actual implementation certification and testing, some way of verifying performance across range of environmental, other operational settings.

8. Keep going with DICOS, integrate ontology concepts put forth by S. Skatter (these need further development and expansion), and recommendations by Carl Crawford for requirements for vendors during certification testing. I could repeat these here, but agree with exactly Carl’s recommendations so simply reference them here.

9. Based on current state of the art, I would focus on “hardening” DICOS first. Then implement Carl’s recommendations for TSA data requirements on tested vendors. (If these aren’t in place, there’s no need to develop better fusion algorithms). Simultaneously, develop an algorithm/fusion framework assessment as described in #7. Then begin funding fusion projects, required to discuss how they’ll eventually match up to TSA requirements and be subject to assessment program.

10. -Very nice facilitating of discussion.

-Really appreciated not allowing instrument physics folks to spend too much time on just the physics.

-Like having food at workshop (also facilitates discussion).

-Advance reading material very helpful.

11. Blank

12. Do more on fusion explicitly. Have Don Brown get up and say again, "Why are we still so far from actual fusion for explosives detection?"

13. Blank

13.24 Questionnaire X-24

1. Yes, but that doesn't automatically mean they should be used.

2. Compatibility of data descriptors and algorithms can be developed to fuse the data.

Independence of measurement techniques.

Improvement in Pd, Pfa by fusion.

3. Blank

4. Availability of datasets for validation/verification of algorithms. Datasets should be based on actual threat materials or simulants that have been demonstrated to replicate all the relevant features of threat materials.

5. Don't know

6. This may be difficult due to PI concerns and SSI information.

7. There should always be a final decision by a human, not automatic reliance of a computer based-decision.

Fused systems must respect privacy and intellectual property.

8. New acquisition needs to be linked to improved capability, not a knee-jerk reaction to a specific incident.

9. 1) Define what constitutes success

2.) Analyses of alternatives for commercial off-the-shelf software and systems.

3) Identify places where most benefit is possible.

4) Solicit proposals to address these areas.

10. Ability to ask questions during presentations.

Wide cross-section of talents and areas of expertise.

Nice balance between science and technology development/maturation.

11. More time for discussion-perhaps panels on a few select topics.

Tell people to turn off their phones or put them on vibrate-it distracting!

Classified session would be good.

How about a sort of red-teaming approach to see what might be done to avoid our systems?

12. Role of simulant selection in evaluation of algorithms.

How to incorporate intelligence in evaluation of threat. Risk-based approach.

13. Very good organization for the meeting. Congratulations to the ALERT Team.

13.25 Questionnaire Y-25

1. The answer to this question depends on many factors. My outlook being that of industry, I know how hard it can be to sell anything to airports/governments even for increased security let alone multiple systems for only one purpose. Fused systems can and should be considered as i believe they can help solve but the business case will be a tough one.

2. Fused systems absolutely have to complement themselves. One system's shortcomings have to be addressed by the secondary or tertiary system. I think that a multiple system per security concern scenario will economically only be considered by airports and governments if they drive the false alarms to sub 5%.

3. For LAGS application, any type of spectroscopy could be fused to regular X-Ray scanners. For explosives concealed on the body, QR technologies such as the wand presented in this workshop should definitely be combined to mm-wave AIT. Standoff THz could also be fused with the previous two.

4. Good cooperation between makers of fused systems, be it hardware-software or software-software. Information has to flow sufficiently so that strengths and shortcomings of all systems are known. NDAs can help by IP protection has to come down quite a bit.

5. Other than the research projects presented here, I know of no examples of fused systems

6. Common and freely shared dataset as seen by all different sensors involved. Common result sharing data structure or language. Precise specifications of strengths and shortcomings of all involved systems.

7. I cannot think of anything better than the combined sum of individual systemic rules...

8. Better and easier access to common data sets made between sensors. The TSA can be an enabler by helping to create substantial datasets but if these data sets are not easily available (non-classified) to vendors, third party companies, researchers and academia, then progress will be very slow and enterprises will not be made to work towards fusion.

9. Maybe the creation of system (sensor) information exchange so that the research/development community can start evaluating the best candidate systems for fusion. Then, some common and substantial datasets needs to be made readily available.

10. Venue, quality of speakers, organization in general, food was excellent

11. Hotel close to venue, better hotel/further away from ambulance sirens ;)

12. I would like to see/learn more about Material Identification Using Nonionizing Radiation Sensors

13. Thank you for the invitation. It is always a great learning experience to participate in these workshops.

Data fusion being a somewhat new concept to me, armed with my still yet limited industry experience, I was assuming one paradigm of real world application of data fusion for the first full day and a half of this workshop. Then came Mr. Crawford's talk and that whole paradigm shifted on me. I feel I should comment here on my reflections about this:

Collaborative fusion: Two or more makers (vendors, third parties) of security sensors/algorithms realize that their endeavors would strongly benefit from fusion of their data or results. From there, an honest collaboration must take place so that all sides of the union can benefit from one another's strength by having another system cover their own weaknesses. This scenario seems easily achieved, at least for the development side of the endeavor. However, when the time comes to commercialize a multi-sensor/algorithm system, the price and/or footprint and/or con ops and its effects on passenger delays will make the fused system a hard, if not impossible, sell.

Imposed fusion: A national regulator imposes requirements for its dream system and somehow tries to find the right combination of systems to fuse to satisfy the stated requirements. I must admit i had not envisioned such a scenario and am still struggling to see how such a scenario might work. To start, it does not seem like vendors would be very open about sharing their own weaknesses. Then, I am not certain that an independent lab would be the most efficient at identifying what systems should be fused and what fusion method should be used. The only advantage I can see to this is that airports could potentially be forced to adopt such a system whatever the cost is.

Since discussion is the goal of these workshops, why limit ourselves to a couple of days each time? It seems to me that good discussions could go on for a while if an online forum, opened only to the workshop participants were to be made available. Just a thought.

13.26 Questionnaire Z-26

1. Yes.

2. For an automated system: P(d), p(FA) of individual sensors. Overlap / independence of the detections, false alarms. Consolidated P(D) P(FA) performance. For human in the loop – more varied metrics. Speed of resolution, staff needs, frequency of rejected bags to search, full system detection performance.

3. HBS - XRD and CT, XRD and multi-view, Trace and CT, CT and level 2 operator assist

Checkpoint- XRD and multiview

4. Either one company needs to have access to all of the technologies to be fused, or multiple vendors of the sensors have to agree to fuse them. The best performing data fusion will happen when the specific sensors' data processing can be modified to optimize the fusion. Fusing at the data level output from the sensors may work for some combinations, but is unlikely to realize the best performing system in all cases. This is however a good starting point and permits the most number of teams to participate.

5. QR-CT – did not work very well. The CT product was already certified, so there was little incentive to deploy. Mis-classification in CT leads to some sub-optimal data combinations which reduced over-all performance. CT algorithm used as-is, rather than being 'opened up' and modified to use QR data. RF interference between CT and QR sensors (makes tight integration in same box difficult). Requirement to stop belt for QR leads to a throughput issue. (CONOPS for individual sensors are mismatched)

QR-line scan – combination of QR and x-ray checkpoint sensors. Average success. Human in the loop, with no algorithm implemented on the line scan. Opportunities for further improvement by using line scan automation. Combination was a loose integration (in-line machines). Too large for regular use. Could be tightly integrated (with considerable investment – but the market may not support this investment) New false alarm mechanisms that are orthogonal in the sensors increase combined FA rate. Detection improved – but not across all threat types. Is the additional detection worth the cost/footprint etc.?

Shoe scanner – Vapor trace, QR and metal detection. Promising data-fusion. The sensors complement each other by covering a broad range of threats, with little overlap in detection for each sensor. Makes data fusion easier – as all data needs to be used. Little arbitration needed between results. Sensors have similar scan times and are all compatible with the same CONOPS (passenger stands still for 10s in machine, all sensors work during this time window, many in parallel making efficient use of the scan time)

XRD-CT. Loose integration. Quite successful – although it is a very expensive system with low throughput from the XRD sensor. The data fusion is on the object level (CT finds objects of interest, XRD resolves them). However, the two boxes are separate, so the objects need to be re-discovered with a line scan sensor. Works OK. Significant improvements could be realized if the XRD was parellized (presentation given during symposium). This would enable co-location of the XRD and CT sensors, and would result in a very low false alarm rate setup – which could be further improved with the addition of dual energy to the CT sensor.

6. Data, sensor performance, vulnerabilities, lower-level un-processed data. Detection and False alarm sets.

7. Depends on application. E.g. some want improved detection, others want reduced false alarm. Some applications require both.

8. The EDS 'bar' needs to become a sliding performance scale, to incentivize higher performance. The TSA need to put their money into the game and actually purchase more expensive sensor combinations – that perform better, based on life time costs, not upfront capital costs.

9. Funding at a significantly higher level. Technology demonstrators in the field. Consortium teams.

10. Blank

11. More technology, physics of the sensors.

12. Emerging technologies. Standoff trace, alternative bulk detection methods, liquid classification, bag clutter reduction methods, etc.

13. Blank

13.27 Questionnaire AA-1

1. Yes. However, the operating elements of DHS (e.g. TSA, C&BP, and SS; a.k.a. the system users) must somewhat explicitly define their requirements. Otherwise, the fused systems topic is too broad. From an ADSA perspective, direct links to algorithms should always be obvious. Hence, the data fusion topic should not stray far from this.

Fused Systems should only consciously be linked with topics like 'Threat Anticipation;' and in all cases should be consistent with prevailing and near prevailing legal statues.

I see three generations of fused systems corresponding our meeting; 1. Present era needs, Needs five years from today, and Anticipated needs 10 years from today. I see open architecture interoperability as always being in play. However, the fused definition evolves.

With respect to algorithms, once the hardware / communication systems are installed DHS / TSA (and other DHS operational based elements) will always want to be able to quickly upgrade with new third party algorithms, and suites of algorithms. Incidentally, TSA's Don Kim noted TSA wants its NUI systems to operate multiple algorithms. The needs of today are (in my view) primarily NII device / system centered.

2. Performance; starting with PD and PFA. The said Cost and Speed (Throughput) are also performance factors. We also need to remove the 'noise' from the PFA declarations. System Time-outs should not contribute to PFA. That said the % of checked bags that are successfully autonomously cleared needs to be progressively getting higher.

The notion of using successive autonomous algorithms should not be discounted. The computing environment to facilitate adaptive inspection needs to exist. I do not know if this is a "Now" or a '5 Year' need.

Bench mark evaluation contrasting fielded medical CT systems with security CT systems appears valid. Yes, the application is very different. That said, as George Zarur loves to roar, is the Security Application seeing the 'best' that CT has to offer? (He thinks not; and I suspect he is correct.)

3. X-ray anything. To be clear, work in the other clearly established non X-ray modalities is OK provided there is a vetted CONOPS by the user. DHS S&T Secretary O'Toole clearly is communicating the need to be prudent; the need is now. From George Zarur to two nationally prominent Battelle SMEs I KNOW, the sustained finding over the decades is to maximize X-ray in all its

forms; e.g. DR, Backscatter, XRD< CT, Dual Energy CT, etc. This is not multi-modal; but it is multi-something!

4. My opinion is:

1. Focused standards, DICOS, and the other IHE embraced best practices
2. Fast Computing
3. Generic Workstations (DICOM Supplement 118 Compliant)
4. Broader research bases; larger vendor base

The above not withstanding – as they are important, the greatest technological enabler comes from DHS Leadership; declaration that devices, algorithms, workstations, reports will be DICOM / DICOS compliant. Period.

A technical approach needs to be grounded to something; e.g. DICOM / DICOS. Given this, let the research begin, continue.

For example: While I understand the merit of OptoSecurity's NII system, the fact their system is TIF based renders the accomplishments to a form of 'technical babble.' Why is this system being installed within the TSIF? Showcasing a DICOS based version of this system within the TSIF would be a different matter.

5. I would assert that fusion has been around for a long time (decades). Successive generations of system designers keep raising the 'performance bar' that defines the capability we today label as fusion. This is costly; and herein is the rub. Traditionally, DHS (and its predecessor elements) have not wanted to – or could not, afford to develop their own unique systems; their own fused products. The words COTS adaptation has been an illusion; and a harmful barrier to progress.

Historically, aerospace engineering has been the 'Toy Department' of engineering. For much of my career, performance has trumped cost; and working with new and emerging technologies has always been stimulating. This is especially true of defense aerospace. That said the 'Defense Anything' sector has historically been synonymous with aerospace, NASA, etc. Such development has also been very expensive – even as it has been a cauldron for innovation.

Good fusion is often so subtle as to be difficult to readily detect. As one example, the medical infomatics presenters always cite Yahoo or Amazon. In these applications, the software system of systems adapts to individual user peculiar preferences. Another example: [I know a] Navy test pilot. I know that a navy fighter can land on a pitching deck of a carrier – at night; hands free. That said pilots only utilize this feature during specified training. Any 'fire and forget' missile.

6.

- User requirements (CONOPS and more) and timelines
- Standards and preferred engineering practices
- Market characterization
- Economic details
- Life Cycle information
- A published, official – this is it, economic acquisition model consistent with purchasing open architecture products.

7.

- Design for achieving interoperability
- Insist on canonical adherence to standards and defined engineering best practices.
- Establish a common lexicon
- Establish definition of the most used terms
- Communicate (educate upon) the legal environment that will exist; i.e. are new laws required; can they be expected to occur?

8.

- Become a much more knowledgeable owner / operator of these systems.
- Substantially less reliance upon purely functional sections.
- Greater internal 'hands-on' expertise with the details of the systems
- Establish the standards and engineering work practices
- Establishment of an ongoing R&DT&E, OT&E product development agendas across the TRL systems life cycle.
- Acquisition Reform; including fairness to the vending base and an insistence on system compliance to specified requirements.

9.

- DICOS / DICOM (Supplement 118) generic workstations
- DICOS / DICOM based workstation operating system facilitating multiple DICOS based algorithms
- DICOS DICOM compliant algorithms provide ever increasing performance
- Fast Computing
- Enhanced, fieldable sensing for CBIS, Integrated Check Point and Air Cargo

10.

- Academic
- Nice assembly of SMEs and middle management leaders.
- Freedom to think

11.

- Establishment of common topics, problem statements, etc. focused upon a reduced to practice aspect detection algorithms. In my mind, these problem statements (with accompanying data) can be previewed and distributed at one ADSA workshop – with the intent to present best-offered responses at the next workshop. This should enhance, stimulate the academic content.
- Example 1: Evolving a Fast Computing Platform. Again, provide all of the needed input data. The challenge is to report on a 100% derived computing platform that can execute the provided Test Problem.

Example 2: Fast Computing competition. Create a DICOS complaint CT dataset. The challenge is to complete and present a DICOS compliant algorithm-based solution on a workstation. Report the time.

Example 3: Dataset Compression / Decompression competition.

- Training, orientation; topics might include (though attendees could be continuously asked for new topics):

DICOS, DICOS relationship to DICOM, DICOM

12. I propose that the next ADSA workshop be devoted to defining, explaining, and better mutual understanding of the two (now) well established application worlds; Security Non-Intrusive Inspection (NII) and Medical Imaging. These two paradigms are not close to being equal. The workshop should stick to the engineering and science of sensing, algorithms, presentation.

It is essential that the security researchers gain a fair understanding that innovation and creativity (ludicrous as it may seem to so state) are not restricted within the medical imaging paradigm; and it is important that medical researchers appreciate the technical challenges posed within the security application.

GE Healthcare and Siemens, key university researchers, NEMA DICOM, key IHE technical co-chairs should present and be available to address Q&A.

13. In some ways, this workshop felt somewhat off target. Presentations and discussion topics should never stray too far from 'Algorithm Detection' for security applications.

Creating advanced detection algorithms is a challenging topic; from more granular sensing, more reliable sensing, advanced algorithms, fast computing, to maximizing the human / displayed information interface (TSO staff are not radiologists; TSO's typically have seconds not sizeable fractions of an hour).

The most recent DHS S&T budgeting realignment speaks to a need to address the present era systems, laws of the land, etc. (Within the US, we are not at liberty to do what other countries (apparently) can do. ADSA is not a US Policy conference. I'm sure there are other venues for making the case.)

Taking Don Kim's challenge of having NII imaging systems routinely operating multiple algorithms; let alone ever improving algorithms. I see this statement as being the beacon of light for the ADSA case. This is where we want to get to.

Physics and math are always neat. However, for many of the attendees, literacy with the physics and mathematical equations is expected. So why dwell on it? Presentation of the math and science should minimize background and (unintended) self-aggrandizement. That said, efficiently showing the science and mathematics germane to the presentation should be provided. The point here is that each chart and each set of minutes consumed while presenting in front of this very distinguished assembly should be cherished.

Commercial plugs should be very discrete to non-existent.

I found the OptoSecurity presentation both interesting and frustrating. If the view is to support DICOS / DICOM, then why hype a TIF based solution? Why bring a TIF based solution to the TSIF? A better topic would be effort required to bring the OptoSecurity software system to DICOS compliancy. That observed I did find the present capability impressive.

Is the ADSA Workshop to be about project reviews?

13.28 Questionnaire BB-2

1. YES, when multimodality is used, it will increase the specificity of the detection while maintain or increase the sensitivity of the detection.

2. For a given explosive detection, the statistical analysis should be rigorously conducted to guarantee the PD rate; this is the key of the security check.

3. X-ray CT should be fused with other available detection methods, but X-ray CT must be the foundational modality, other modalities provide a fine tuning or complementary information.

4. New contrast mechanisms such as XRD or Phase contrast mechanism, together with novel dual energy CT image reconstruction algorithms are the key enabling technologies. Sooner or later, x-ray tube and detector will become the bottleneck for further improvement if image quality to warrant accurate image segmentation. Thus, more attention should be paid to new x-ray tube technology and photon counting detectors.

5. Blank

6. Ideally, three tiers are needed to enable the Department of Homeland Security to obtain the most sensitive and most innovative technology for national security:

Tier #1: Innovative ideas should be funded to conduct researches in laboratory which have great potential for national security, but not tightly bound to national security. In this tier, there is no need to provide them sensitive information at all. You just need to encourage the brightest researchers to create new ideas and methods.

Tier #2: By examining the funded basic science research, DHS evaluates all these funded research to determine which are those new technologies should be further explored to translate into a working prototype system for national security applications. For these identified technologies, DHS can further provide some limited testing data sets to evaluate whether the identified technologies will truly work for national security purpose. If no, the examined research topic should be terminated. If yes, the proper clearance should be sponsored for appropriate researchers to further conduct the investigation, perhaps, national laboratories such as Sandia will have to get involved in this stage. This further investigation will prepare the DHS to pick up the best technologies.

Tier #3: After the DHS picked up the best technologies, companies can go ahead to negotiate license with the inventors of technologies for further commercialization. Bottom line, the DHS should bravely step forward to create a funding mechanism to encourage the researchers to create a large pool of potential technology candidates for DHS to pick up. The DHS should not wait for the vendor to come to the DHS to sale whatever they generated, not matter good or bad.

7. Need to make sure 1+1 is truly larger than 2. The bottom line is that the positive detection rate should be improved and false positive rate should also be lowered to save the cost on human interventions.

8. DICOS standardization must be forced by the DHS over the vendors to enable TSA has something standardized and easy to work with.

9. DHS should recruit a group of experts to generate DICOS standard, not to allow vendors to negotiate forever for a common protocol. In this aspect, DHS has a unique role. This is different from the DICOM used in medical imaging where the national enforcement does not work.

10. Open discussion should be encouraged and the timing management is great for this workshop.

11. Obviously, questions were often raised from a few federal employees who have the first hand internal data about what is going on in explosive detection. However, this group of question raisers was not able to raise good questions for new technologies presented or when slightly deeper science was involved. You can see this fact from the number of questions and relevance of question for each presentation. This is not a complaint; it is the nature of diversity of the educational background from the participants. It is also my impression that this group of people knows more chemistry than physics and other topics. I would encourage some good tutorial lectures from university professors to help a bit.

12. I think all important topics have been covered from the previous workshop. The key thing for the organizers to think about perhaps is how to categorize the topics into several focused task groups, such as image reconstruction task group, image segmentation task group, ROC and statistical analysis task group, DICOS task group, new technology development task group etc. to discuss each topic in depth.

13. Overall, I consider this workshop as an outstanding one with great success in time management. Personally, I found it is quite helpful for me to learn a great deal on explosive detection and help me think about how to orient my research activities from medical application toward national security applications.

13.29 Questionnaire CC-3

Overview

I found the workshop extremely interesting from the point of view of policy, strategy and technology. Unfortunately, I am not knowledgeable in the technologies discussed at the workshop, and thus feel I am not qualified to speak directly to the questions presented regarding the technical aspects and feasibility of integration of these technologies.

If I may, however, I would like to contribute some observations from someone in the medical software industry, and 'outside' of the explosives detection industry. I do fear, however, that much of what follows is obvious, but none-the-less I think it might be helpful.

Please feel free to contact me for any questions.

The Question of Context

My sense is that the balance of presentations was tilted toward the attractive attributes of a variety of detection technologies and less toward an overview systems approach considering scope, objectives, priorities, time lines, problems, deficiencies, and strategies for evaluating competing priorities and objectives. Indeed, while several speakers did raise these issues I did not get a sense which technologies were really the most relevant to the specific tasks and objectives of highest importance to Homeland Security and TSA. It may very well be that such priorities, i.e., vulnerabilities, are 'sensitive' and can only partially be known to attendees in a public venue.

For example: To meet a specific operational objective, four priorities might be: 1) Integrating Detector A and Detector B to improve ROC characteristics; 2) Optimizing decision support algorithms; 3) Networking freestanding detector systems on a terminal, airport, regional or national basis; 4) Developing a knowledge base documenting successful strategies and failures. Each will require substantial investment of time, funding and human resources.

How do we decide how and when and in what order each priority objective should be developed and deployed? I suspect that such matters have been considered, perhaps in great specificity behind classified doors, but some general overview would have been helpful to help place the technologies in context. Alternately, it may be that such policy decisions and strategies are in the development stage and the workshop was meant to bring fresh ideas to the table.

EDIS: Déjà vu-"The EMR From 50,000 Feet"

I think that many of the issues discussed at the conference regarding the synergistic use of technology, data management, and information in the development of a national/international Explosives Detection Information System (EDIS) are, at a high level, strikingly similar to those encountered in the evolution of Electronic Medical Record (EMR) systems.

If I may, I would like to share some observations which may be helpful in developing the system under consideration.

1. The EMR is not a single "Thing". Rather it has evolved into a synergistic network array of components which communicate and interoperate over an underlying operating system (OS) to exchange patient information through the use of industry standard protocols: HL7 (for general text and data), and DICOM (for digital radiographic images).

2. In my opinion, the three key functional objectives of the EMR are:

    a. Efficiently aggregate and integrate heterogeneous data from a vast array of sources in the medical domain such as:

        i. "Soft" information: Clinical observations, judgments, interpretations, consultations;
        ii. Raw, parsed and structured data: Labs, biometrics, medications, EKG, vital signs, etc.;
        iii. Image data: CT scans, Pet scans, Ultrasound, MRI scans, Plain Radiographs, Cine.

    b. Streamline the Healthcare Provider's (Physician, Nurse, Assistant, Clerk, etc.) workflow by displaying and communicating *patient care decision support data* simply, efficiently and with the minimum of 'noise' (non-relevant data).

    c. Create a "Knowledge Database" by structuring the data and information from 2.a (above) as data elements rather than analog (strings) elements for ease of data mining. The vast majority (75-80% ?) of the data model can determined ahead of time to facilitate development and data mining.

        i. In conventional software development the data mining capability is added to the database after it is deployed. This is expensive and time consuming.
        ii. As I commented during one of the discussions designing the database with a maximum capability for data mining from

the start will greatly facilitate the extraction of useful data after deployment.

3. The enabling concepts and technologies, in my opinion, of a successful EMR are:

4. IT: The adoption of evolving communications protocols: HL7/DICOM functioning over a network infrastructure. Clearly DICOS is a major advance for TSA but if it is similar to DICOM it may have limited interoperability with non-imaging systems, i.e. it is not a system network OS, and has no inherent database capability beyond a basic flat file structure-not a 4GL database.

5. COMPONENTS: A strategy of changing "Best of Breed" EMR components: CT Scanners, Lab Components, even entire specialty software packages-Pharmacy, Surgery, Billing, etc. This means the EMR components are not "hardwired" (fused) but because of the standard communications protocols, they can be swapped (think 'Hot Swap' of a disk drive from a server) out as the technology, science, medicine, disease, and functional objectives evolve and escalate in complexity. From the software world, any 'custom, hardwired, fused, etc.' module is a nightmare to migrate to a new release of its host system. I suspect a 'hardwired/fused' custom explosives detector system would create the same type of problems as the overall system evolves.

6. WORKFLOW PROCESS: Understanding, facilitating and seamlessly integrating the EMR into the user workflow process to maximize the utility of its information in the patient care setting while enhancing the user experience.

    i. Venture capitalists have lost hundreds of millions (billions?) of dollars investing in EMR companies over the past 30 years because the systems did not fit into the clinical workflow. For example Kaiser Permanente paid IBM about $450,000,000 to develop and EMR and after 10 years terminated the contract because the clinical staff found it did not fit into their workflow and refused to use it.
    ii. Early developers failed to understand that simply electronically aggregating data and information was a necessary but insufficient condition for successful adoption of the EMR.
    iii. The federal government is investing on the order of $40B dollars to fund a national EMR network, yet there is evidence that resistance by providers (funding aside) is in part due to the

perception that an EMR makes their workflow less efficient. That is, the EMR workflow does not fit into the user's workflow to save time and effort. In fact, today, less than 10% of the hospitals in the country have functional EMRs that quality for "Meaningful Use" certification by the federal government.

iv. Radiology is, to a large part because of DICOM, a department with enterprise imaging capabilities, and has evolved much more rapidly than other departments.

v. From personal experience designing an EMR Radiology specialty application, it is a much more subtle and difficult task that it appears. EMR systems that have failed have often been focused on the engineering aspects of the project and have paid insufficient attention to the user interface and user experience to maximize utilization of the information.

4. Software Specifications, Feature Creep, Iterative Reality Testing: A straight line is not always the shortest distance between two points.

a. Specification Changes: Software engineers hate specification changes and will be resistant to most changes, but their expectations should be set *at contract* time that the process will by necessity be iterative.

b. "Feature Creep" aka "The Budget Killer". Also hated by software engineers, but necessary as the policy team in conjunction with the Project Manager learn more and more about the development tasks (Detailed specifications not-with-standing they are only the start). Feature Creep needs to be managed by balancing what is a 'must have' feature (new science, new threat, new budget, etc.) against a 'wish list, nice to have' feature. Budget reserves should be set aside for 'must have' additional features.

c. Iterative Reality Testing. This is an informal process we use in-house throughout the development cycle that checks to verify that the development is in fact tracking our reality, ground based objectives before we program ourselves into the wrong direction or into an unforeseen expensive 'corner' from which we have to backtrack. Often enough following the 'straight line' of the priori specifications may not track the functional objectives of the project as initially conceived and course/specifications need to be changed in unexpected places and directions. Budget and time flexibility should be built into the development program for such mid-stream corrections.

14. Appendix: Acronyms

Term	Definition
2D	Two-dimensional
3D	Three-dimensional
AAPM	American Association of Physicists in Medicine
ADSA	Algorithm Development for Security Applications (name of workshops at ALERT)
ADSA01	First ADSA workshop held in April 2009 on the check-point application
ADSA02	Second ADSA workshop held in October 2009 on the grand challenge for CT segmentation
ADSA03	Third ADSA workshop held in April 2010 on AIT
ADSA04	Fourth ADSA workshop held in October 2010 on advanced reconstruction algorithms for CT-based scanners.
ADSA05	Fifth ADSA workshop held in May 2011 on fusing orthogonal technologies
ADSA06	Sixth ADSA workshop to be held in November 2011 on the development of fused explosive detection equipment with specific application to advanced imaging technology
AIT	Advanced imaging technology. Technology for find objects of interest on passengers. WBI is a deprecated synonym.
ALERT	Awareness and Localization of Explosives-Related Threats, A Department of Homeland Security Center of Excellence at NEU
ART	Algebraic reconstruction technique
ASIR	Adaptive statistical image reconstruction
ASTM	American Society for Testing and Materials
AT	Advanced technology
ATD	Automated threat detection
ATR	Automated threat resolution; a synonym of ATD.
BAA	Broad agency announcement
BDO	Behavioral Detection Officer (a type of TSO)
BHS	Baggage handling system
BIR	Baggage inspection room
BLS	Bottle Liquids Scanners
BPSS	Boarding Pass Scanning Systems
CAD	Computer aided or assisted detection
Cambria	TSA procurement program for next-generation check-point

Term	Definition
	scanners
CAPPS	Computer Assisted Passenger Prescreening System
CAT	Credential Authentication Technology
Gordon-CENSSIS	Center for Subsurface Sensing and Imaging Systems, a National Science Foundation Engineering Research Center at NEU
CERT	Certification testing at the TSL
CIA	Central Intelligence Agency
COE	Center of excellence, a DHS designation
CONOP	Concept of operations
COP	Concept of Operation
CPI	Cast & Prosthesis Imagers
CPU	Central processing unit (a general purpose computer)
CRT	Certification readiness testing
CS	Compressed or compressive sensing
CT	Computed tomography
DAS	Data acquisition system
DHS	Department of Homeland Security
DHS S&T	DHS Science & Technology division
DICOM	Digital Imaging and Communications in Medicine; http://medical.nema.org
DICOS	Digital Imaging and Communications in Security. NEMA standard for image format for security; NEMA IIC Industrial Imaging and Communications Technical Committee.
DoD	Department of Defense
DR	Digital radiology
EDS	Explosive detection scanner that passes TSL's CERT.
ETD	Explosive trace detection
EXD	Explosive detection directorate of DHS
FA	False alarm
FAA	Federal Aviation Administration
FAT	Factory acceptance testing
FBI	Federal Bureau of Intelligence
FBP	Filtered back-projection
FDA	Food and Drug Administration
FOUO	For official use only
FOV	Field of view
GC	Grand challenge
GPU	Graphical processing unit

Term	Definition
HME	Homemade explosive
HVPS	High voltage power supply
IED	Improvised explosive device
IEEE	Institute of electrical and electronic engineers
IGT	Image guided therapy
IHE	Integrating the Healthcare Enterprise
IMS	Ion mobility spectrometry
INL	Idaho National Laboratory
IQ	Image quality
IRT	Iterative reconstruction technique
JTF	Joint task force
LAC	Linear Attenuation Coefficient
LLNL	Lawrence Livermore National Laboratory
Manhattan II	TSA procurement program for next-generation EDS. This term has been supplanted with the term Checked Baggage Inspection System (CBIS)
MBIR	Model based iterative reconstruction
MC	Monte Carlo [modeling]
MMW	Millimeter wave
MRI	Magnetic resonance imaging
MV	Multiple view
NDA	Non-disclosure agreement
NDE	Non-destructive evaluation
NEMA	National Electrical Manufacturers Association
NEU	Northeastern University
NII	Non-invasive inspection
NIST	National Institute of Standards and Technology
NQR	Nuclear Quadrupole Resonance
OOI	Object of interest
OSARP	On screen alarm resolution protocol/process
OSR	On screen resolution
OUO	Official use only
PD	Probability of detection
PET	Positron emission tomography
PFA	Probability of false alarm
PPV	Positive predictive value
QR	Quadruple resonance
RFI	Request for information

Term	**Definition**
ROC	Receiver operator characteristic
ROI	Return on investment or region of interest
RSNA	Radiology Society of North America
SAT	Site acceptance testing
SBIR	Small business innovation research
Sensitivity	Probability of true positive
SIRT	Simultaneous iterative *reconstruction* technique
SOC	Stream of commerce
SOP	Standard operating procedure
Specificity	1 – probability of false positive
SPECT	Single photon emission computed tomography
SPIE	International society for optics and photonics
SR	Statistical reconstruction
SSI	Sensitive security information
STIP	Security Technology Integrated Program
TBD	To be determined
THZ	Tera-Hertz imaging
TIP	Threat image projection
TQ	Threat quantity; minimum mass required for detection. Value(s) is classified.
TRX	TIP-ready x-ray line scanners
TSA	Transportation Security Administration
TSL	Transportation Security Lab, Atlantic City, NJ
TSO	Transportation security officer; scanner operator
WBI	Whole body imaging; a deprecated term for AIT
XBS	X-ray back scatter
XRD	X-ray diffraction
XDI	X-ray diffraction imaging
Z	Atomic number
Zeff	Effective atomic number

15. Appendix: Minutes

15.1 Day 1: May 3, 2011

CC: Good morning. I want to put some ground rules in place. This is a workshop, not a conference. The agenda is not exhaustive; it is filled with discussions. The speakers have been instructed that they will be interrupted. Conversations are expected. This applies to all people in the room including those in academia, government, and industry. For those with clearance this is all in the public domain; it is not for secure information/SSI. Some of this material is repeated from previous workshops. This is done to bring people up to speed. Patience is required as this is an odd number workshop. We find that odd numbers are more difficult than the even numbers. This one deals with fusion, fusing orthogonal technologies. When I put this workshop together I thought I understood what these three words meant. The job today is to define these words. Rule #1: It's all open discussions-are there any questions?

CC: The moderator's job is to make sure the speakers stick to the topic. If they don't, we will come to the speaker and ask them to make changes on the fly. This isn't formal; it's my job to make sure discussions happen.

MBS: Good morning, I am Michael Silevitch, the host for this meeting. We in the academic community need to be connected to the user community and the customer inside DHS. These workshops are useful to break down barriers that exist. What I've been told by the workshop participants is that we are building a community of stakeholders to tackle this problem of terrorist threats. We need to keep focusing these workshops on topics of discussion. My view of fusion is Sensor A communicating what it sees to Sensor B in the environment and Sensor B can use this information for what it needs. This is fusion.

I want to welcome everyone to the workshop. Take off your ties, interact, and give us your passionate ideas. One thought on what we are missing is a seminal journal. I don't see the emergence of a peer-reviewed journal in security technologies. One question is if this journal is needed? Do we need one? Should we create one? This would be a vehicle for our community to help it evolve. I will leave you with this thought and I'd like to introduce Doug Bauer.

DB: Good morning. I'm in the Explosives Division of the Science Directorate at DHS. One of the calls we've had from our Undersecretary is to see if there are applications in tangential areas that could be brought into our field.

ALERT is important because it focuses on what we are doing today. As we bring in information from principally the medical area into our area, ALERT is well-positioned because of the relationships it had developed even prior to the creation of ALERT. One of these is the Gordon Leadership Program. I want to thank you for being here. We have to find multiple ways to grow not just by partnerships, but by professional development. Thanks for participating and being a part of it.

Presentation-Eric Houser

EH: I am here to talk about our vision for programs and activities as they involve the COE which we hope will expand technology transfer with industry. DHS (TSA, Secret Service, etc.) is going to be asked for equipment on a scale we haven't done before. To raise the bar we are going to need to do sensor fusion. What is the future role of the COEs despite facing massive budget cuts in the near future? Despite these cuts we are going to be massively increasing the funding of COEs. The reason for this is because the philosophy of the COEs is focused on the transition of technologies to industry. Industry and the government are more on the problem side. To solve these problems requires funding primarily from the government. The funding will go to the COEs as a major recipient of this funding. I am here to tell you that despite being squeezed on the funding we are going to increase our funding.

What we've done in the past is put out a request for proposals and then sent the money out the door. Going forward we are going to be much more collaborative. The new approach (for TSA) is going to be similar to DARPA's approach (a more collaborative approach). The COEs will play a key role in this effort. This group will help define the future of technology for S&T. There is going to be a twelve to eighteen months effort and I hope the COE will be a part of this. First we will define the art of the possible, through forums like this workshop, and if it is decided we can build something, then we are going to fund it. What this means is there is a new paradigm. This means we have to accelerate the speed at which we operate and to do this requires new ways of doing it. I want to proclaim to you the importance of the COE in this process. Thank you.

CC: Formal introduction and workshop objectives: we need to secure all ports and detect for explosives, weapons, drugs, etc. The focus of this workshop is explosives. My images are from the web. All presenters, please be sure not to use secure/secret images. You can go on the internet and find out how to build explosives pretty easily. We need to get better at detecting these materials. We need to have better detection performance. I stress that when you use the word detection you must also consider the false alarm rate. DHS tactics include augment technologies through third party vendors.

Progress with Tactics (slide)

SW: We went out and funded Sandia to collect data.

CC: In some cases it seemed simple but it is not.

GZ: There is a process to make these images available to third parties as much as possible. If there is value to these images it is for third parties to add value rather than have a closed system.

CC: Everything in this presentation is open for discussion. (Disclaimer)

Threat Detector-Standalone (slide)

CC: This is basically the detector model out there. There is no requirement for identification of the type of threat.

SW: This isn't true for trace detectors.

SW: Last item on slide, external control based on risk---no.

??: This isn't true anymore.

CC: What is out there today? There are a large number of acronyms in this field. Please interrupt if you don't know what an acronym is.

Technologies Deployed (slide)

Bob ?? : Can you explain risk-based?

CC: Is the threat higher with one passenger than another type? For this workshop, how risk is measured is out of scope. In the course of the discussion, if the device can be changed based on risk then that is acceptable.

Receiver Operator Characteristic (slide)

CC: At some point here the government says you have a detector the arrow can't go up, the ROC can only go down and eventually we will fail; we can't do any better. This is the scary part, you either have to invent a new technology or fuse sensors. This is what we are discussing.

???: You are saying we are operating at a point where there is no slack.

HM: There is some slack but not a lot. Right now if they are operating at the requirement and barely passing. The government would have to change the requirement. The false alarm rate might have to be raised.

GZ: You want to operate at the best PD possible.

CC: I think the point is these are set at the policy level by TSA and these aren't up for discussion.

HM: You are saying that there is an optimum level which the government might not set policy, this is what you are saying?

???: Yes.

Possible Technologies to Fuse to Deployed Technologies (slide)

CC: What are the technologies that can be deployed? This isn't an exhaustive list only some will be discussed today.

"Fused" Systems for Checked Bag (slide)

CC: At the check point today there is a stand-alone device with a human and if it doesn't pass it goes onto a hand search with no other sensors. Question, is this a fused system?

SW: There is some loose coupling going on.

Bill Baukus: I would argue it isn't a fused system but rather a tiered system.

HM: How would you define tiered?

BB: They are working in parallel.

HM: I am curious.

David Wiley: In medical a simple fused sensor is a PET CT. If you think of multiple PET CTs this is the other end of the spectrum.

CC: So the decision we made is not to define fusion but rather to admit all of these types of fusion and figure out how to do a better job increasing the area under ROC.

Don Brown: This simple type of fusion sensor can work well. The question is how to fuse them to increase their performance. This is a quick, fast way to do it well in many events.

Krauss (DHS): I do believe it is important to fuse metal detectors and ????????? From an efficiency standpoint this is important. I hope it is not a focus on increasing the ROC curve alone.

Other Examples (slide)

And Fusion-Correlation (slide)

Technologies Definitions (slide)

CC: Intelligence is out of the scope for this workshop.

Orthogonal Definition (slide)

CC: If I could drop this word for the material for this workshop I would. If I'm looking at trace versus metal detector it or things might be totally different. The questionnaire is a key deliverable, please fill it out. Please let the presenter get through the second slide without interruption.

Jody O'Sullivan: The out of scope of the human part – if it's a suicide bomber, as in bomb embedded in person, the measurements of that person become critical. The technologies which measure changes in aspect of individual – temperature, pulse (human) – are straightforward to measure remotely.

CC: Agreed, but they're out of scope for here, concentrating on explosives detection.

Harry Martz: This could be a topic for a future workshop.

DA: George mentioned that the goal should be to push PD as high as possible, but there are cost, space, and time constraints that really limit that. Three times the screening costs is not worth it. One of the goals with fusion should be to use current time/space constraints. There's a lot of value in that. Have to think about these constraints in context of ROC curve.

DB: I'm glad we have a lot of people here from TSA. So that begs a deeper question – should we have fusion, what is the capability that we are moving toward and searching? Better detection against larger number of threats, obviously, but I welcome other additions, even if in the written answers are in the questionnaires, because your needs determine our focus. As medicine is being driven by physicians, it's setting the trajectory for the systems that we are trying to put in place. Please lay out your expectations over the horizon so that we're doing something that aligns with what your needs are.

XF: Fusion is sensor, not algorithm fusion right?

CC: Both are permitted.

XF: Adding more hoops will not be acceptable… but adding features is different.

CC: We don't want to limit the scope in that sense.

??: There's a lot to be gained from a tiered system where you don't say yes or no, you consider the whole spectrum.

EH: We would rather not test like that but if we have to I think we will.

Doug Boyd: In my talk I'm going to talk about mental fusion versus algorithm fusion. Mental fusion = radiologist drawing conclusions from a bunch of different devices. Patient normal/sick? Bag normal/threat? The operator has to be considered, what the human does with mental fusion can be converted to algorithm fusion by weighting the different modalities depending on the different PDs and PFAs of each site.

RP: It becomes important to get cooperation. Collaboration is key, especially in the fast-paced, noisy checkpoint environment.

CC: I think the conversation we're having now is that fusion means different things to different people.

John Reynolds

JR: This will be a brief review on explosives. I designed a talk that was around detection, focused on the things that I believe you need to know about explosives that will impact how you view them and view detection.

(Shows talk slides)

JR: For detection, density is really important. Performance Factors related to detection issues (slide)

PS: For damage from a person, can you give an example of the typical sizes that you would expect to be really serious problems versus not as serious?

JR: It depends on the explosive and how it's being handled, but a few grams would probably hurt somebody. Our safety limit with a new material is starting off with a gram or less of a mixture. When we know something is very dangerous, like TATP, we won't use because we know even in a few milligrams it'll go off.

PS: The question was about detection point of view. If you're a suicide bomber, how much do you need?

JR: The target isn't the bomb, but what it's going after. Highly variable, but don't want to talk about quantities in an open forum. That said, if you look at suicide bomber vests, they're very heavy, have a lot on them, and you can imagine there's a lot in there. They tend to be very efficient.

Bert Hesselink: How do you define explosives from other materials? (Didn't hear) Can you tell me on the basis of what you know, are there any characteristics?

JR: Differential scanning calorimety? (??) Sample it, pull it out and you can tell it's an energetic material. When you do just a spectroscopic characterization of it, if it's a homemade mixture, it may not show you the characteristic that you want to have. The only way that I know that you can do a true assessment of whether it will detonate is to make it, build it, and try it. You can do thermal testing, to see if it produces an exothermic when it heats up…

I will be here through the entire conference and will be happy to talk to anyone about things like this.

<u>Harry Martz</u>

CC: Tim White can't be here, so harry is going to present his presentation.

HM: We want to talk about technologies that are currently deployed, emerging, and their availability for fusion, plus others. These technologies go around from problem to problem and they all have limitations. There's room for improvement.

CC: What's your definition of a limitation?

HM: (gives lots of examples)

CC: Do X-rays detect explosives.

HM: That's a trick question. Yes. It detects the x-ray attenuation coefficient. If there are a lot of densities, a lot of things that have similar densities, those are false alarms. There's not a molecular signature so… as we add more materials, those technology limitations are becoming critical. How do we overcome that? It takes time to get technologies in the field. There are a lot of technologies that can be used.

(Shows summary slide)

Divided into things used for people and for baggage/cargo.

As you can see, if there was a silver bullet, why do we have so many technologies? Because it's a difficult problem. People have looked at fusing technologies with some success, but no major successes. Is there something we're missing ? Is there something that we can do today?

CC: You should do an example.

HM: OK, X-Ray Backscatter. (Shows slide) You'll have an X-ray source and when the source hits the body, you get these various interactions of x-ray with body, you get transmissions, scattering, and then you map that and try to make sense of what you're seeing. It's the contrast of the scattered/non-scattered index to the BMI.

TG: Are you measuring absorption in that scheme?

HM: Both. Metal, typically you don't get a lot of backscatter. Fatty tissue backscatters a lot. Muscle backscatters less. Let me point out that now they have backscatters on both sides, which allows them to couple backscatter and transmission.

MS: Are you using the same source for these? In my sense, that's one of the few ways of detecting stuff that you ingest, in body cavities.

HM: Yes, and that's why they're going to that. It also increases throughput.

Marcus Schiefele: Unfortunately, the dose in backscatter is so low that the transmission signal is too low to be of much use to get an image.

HM: So there's not enough information to show body cavities.

MS: Yes.

CC: A comment – some of the details of the strengths and weaknesses can't be discussed because of classification issues. Can this technology be strengthened by fusing it?

HM: We've done some preliminary analysis of the data. If you can use from prior data, if you go in and know the body mass index (BMI) and map it out, you can start to do this in an algorithm plotting a human. Depending on BMI, materials on one person will be dark and on another person will be bright. You have attenuation in, and out, and that complicates things. This could help improve our information. Will it be enough? That's what we're here to figure out.

MBS: What if the threat is in pieces? E.G. parts of an explosive that can be assembled. How can we effectively begin to at least conceptualize a CONOPS around that?

HM: John brought this up and we haven't talked about this a lot. There are requirements from the government on what we need to detect. So it depends on amounts, two components, A+B. In a carry-on you may have to look for precursors, not just the two pieces put together. Hair dye, for example… a certain percentage of this would be of concern. What would be nice in a data fusion thing, is if bags come in, below the threat mass, but you get several, you look at the properties of that material, you say, something's up, maybe they're trying to sneak in small amounts and put that together.

??: Video analytics too.

MBS: It's really human biometrics, or that risk.

JPSchott: It's also about connecting the person to the luggage, there's no checking between what they have in their carry-on and checked luggage.

GZ: Also, for certain objects, the detection is extremely small. For most objects it is fairly significant, the question is, do you do that with a human operator or an automated process?

MBS: The discussion of CONOPS and strategy is where we really need good discussions between TSA and the community. Otherwise we'll conceptualize these things but who knows if this will be effective.

Alex Hudson: There's a range for optimization in automated algorithms. The body type variants we see are huge, and this is an area that is wide open for research, since it's quite a tricky problem that's worth some initial collaboration.

HM: Please make comments on this we would like to have a nice summary for presentation.

Presenter-Geoffrey Harding (Morpho Detection-Xray Diffraction)

GH: I am here to talk to you about an extension of x-ray diffraction, x-ray diffraction imaging. Technology wise we are most advanced with our checkpoint imaging. There is a slight confusion about x-ray diffraction imaging.

Summary/Conclusions (slide)

GH: XCI=X-ray Diffraction Imaging. Morpho Detection is generating a 3rd gen. XDI checkpoint?

??: Is it a silver bullet?

GH: That is out of scope. I would leave it up to the wisdom of the collective group.

False Alarms and the Density Feature (slide)

GH: I took this slide from Harry Martz. The idea is I should increase the number of threat classes. You make it very difficult to find a threat density. It causes a higher false alarm rate. This slide discusses why false alarms arise. This illustrates the additional cost this brings.

Every Screener Yields Imprecise Features (slide)

GH: As you increase the number of threat classes the false alarm/detection probability goes up and the rate goes down. A way to fight this is to use either one sensor with multi features or multiple sensors.

Physics Principle Underlying XDI (slide)

Data Correction (slide)

GH: There are some things you need to adjust for.

DA: Can we push into the fusion of this data?

GH: We need to push on so we can discuss this.

CRD Profiles Crystalline Explosives (slide)

GH: This is a homemade explosive.

MBS: What if it isn't crystal structure?

GH: This is a really interesting question but I have to push on.

Accelerating Bag Throughput (slide)

GH: We have 3 generations here of XRD, the idea is the time to scan can be reduced with multiple beams.

3rd Generation XDI: Check Point Screener (slide)

Projection of X-ray Beams on XZ Plane

DA: We want to get into how we use this. Carl said not to use the word orthogonal. You are obviously trying to put this together….

(Lost)

?? (Female) How does that profile change when you change liquids?

GH: Hydrogen peroxide is a very small molecule…They hydrocarbons are dominated by a carbon-carbon bond.

Wiley: Are you capturing volumetric data?

GH: We slice the luggage into the slice of sugar cubes and take measurements.

DA: How do the voxel sizes compare?

Wiley: They should be the same. It provides enormous value? Do you capture a spectrum?

GH: Yes. That is very valuable.

JW: In terms of fusing this with other images, what is your output? A visual signal? How do I as the user look at this?

Wiley: It's complicated?

GH: There are peaks you can look at this.

JW: But as a user I can't look at a peak for each sugar cube. How does the signal get used?

GH: There is some signal reduction. There are other people here you can talk to.

DA: We are going to move on to the next talk.

Presenter-Alessandro Bussandri

Quadrupole Resonance

AB: This is not a silver bullet we know that. What we are working on is a handheld QR wand which can find an explosive up to 5 inches deep in less than 5 seconds. The application is for security check points including threats under clothing and inside body cavities. For instance you can fuse AIT with QR. The conclusion for this work is QR can be integrated into the checkpoint.

MBS: How sensitive is this?

AB: ??????????

HM: In the past you tried to fuse QR with CT.

ELM: 10 years ago QR was touted as the next big thing but there were concerns about interference with AM.

AB: We combined active and passive RFI pacification.

??(beard/glasses/striped shirt): (Answers HM's question) The basic limitation is it can only see a certain subset of explosives. The question becomes,, "Is it worth the money to add another sensor?"

CR: Is it temperature dependent?

AB: Plus or minus five degree is not a problem.

ELM: Is it stationary?

AB: Yes but motion is not a problem. You have to hold the wand still for 5 seconds.

MBS: This can penetrate inside the body and look into cavities. There aren't too many modalities that allow this. In terms of AIT fusion this could be the important orthogonal technologies.

SW: How localized is it? Can it be integrated?

AB: The size of the area that you are sensing depends on the coil. The bigger the coil will enlarge the area you scan.

MBS: How long?

AB: 5 seconds.

SW: Would you say this is targeted to one or two threats or is it more broad-based? If this is for an airport screening, how do you take this interesting phenomenon and exploit it in the airport environment? Do you build a scanner?

AB: We know we can't build a corral in the checkpoint. We are looking into building a RFI scanner and capture ???????????? Then subtract ?????????????????

DA: The value of adding this depends if it adds capability. If this does something CT doesn't do well then it makes sense.

AB: Optional integration with trace.

RM: Does it detect metal?

AB: Yes.

?? How strong is the field?

Ruth: If there is metal the system will alarm? Does this mean any zipper or similar item?

AB: No, it has to be a larger amount of metal.

DA: What does the alarm look like?

AB: Red light/green light.

John B.: There seems to be some things that will confuse it such as metals. This application would work with drugs? Are the confusants predominantly nitrates? This is a spectroscopic technique. The only thing you have to do is tune your frequency to a different substance such as TNT.

MBS: What is the quadrupole you are resonating with?

AB: ???????????????

AB: How could quadrupole improve security checkpoints? It could be used as an AIT-guided anomaly resolution tool. We are working on combining active and passive RFI. How could QR be configured to AIT? First AIT whole body can clear most of the body. AIT concealments=approximate body temp.

Dennis Barket (FLIR)

DB: My conclusion is mass spec. Can replace ____________________ the class of detectors I am talking about are trace detectors. Low vapor pressure targets.

We come from an analytical instrumentation background, mainly chem bio for DoD applications.

What you're doing fundamentally in one sense is weighing the molecules with mass spectrometry. (Presents: What is Mass Spectrometry slide) The takeaway from this slide I'd like you to see is the vacuum environment needed. What's nice about MS is you can get qualitative/quantitative information in the same scan.

DA: So what is the resolution? Because the histogram is misleading. From this type of instrument.

DB: It's going to depend on the type of mass spectrometer.

DA: In the Griffins specifically.

DB: In the hundreds.

DA: The peaks are a lot sharper than what we saw from some of the other techniques. You can see there's a lot more information in the mass spectrum than in some of the absorption spectrums.

Why Use Mass Spectrometry? (Slide) GCMS or LCMS you can get orders of magnitude increase on your selectivity. Some people say the problem with MS is that it sees everything, so you have to use front-end techniques to separate everything out, reduce noise and isolate.

DA: How would you propose implementing this in a checkpoint? Is this a direct replacement for IMS or would it integrate?

DB: It could integrate… Challenges (slide)

DA: Are any of these insurmountable in the short-term? I think looking at some of these challenges practically (~5 years) is of value.

DB: In checkpoint applications, we're certainly months and years – not five years – away. We need to think about training and ease of use.

SW: So that makes your tool more effective as a stand-alone advice, but how do you fuse this data andintegrate it into another system?

CC: Can you explain the problem space you're talking about?

DB: You're ionizing the sample and putting it into the form the mass spec can look into.

DB: Can you use the ??? To look at that piece of baggage without having (??) in the middle? Can we get away from swipes, get into different surface sampling techniques? My position is yes.

DA: Do we really fix the swipe (?) problem or just shift it into a different paradigm with an operator dependence we can't get rid of?

DB: We're going to have to use the swipes for this generation. It will be complimentary to a technique, but it takes us down the road away from them. They get a bad rap and are costly, things like that, but the fact is they work okay.

DB: Back to Suriyun's question. What we do now in the chem.-bio world and other applications is the tiered approach, where you have a trigger/detect/confirmation. So we have mass spectrometers for the 2nd and 3rd tier, and we use different methods for the first tier. So that's where you get into a little bit of fusion in the chem.-bio world.

JRey: Some of the oxidizing materials are highly corrosive to some of these techniques and you can't really ionize. How would you handle that?

DB: There is no separation here; there is no DC or LC in a way. If it can be thermalized, it can be used here. If it can be pulled right off the surface…

JRey: I'm thinking in terms of some of the peroxide mixtures, I think that's very problematic for inspection with mass spectrometers on their own.

DA: You can see it but it's hard because it's low mass, it's in the background…

DB: There are tricks that we're working on

JRey: With ionizing gas or something like that.

DA: Back to SW's question again, how do you envision this integrating? After all this is why we're here today. Is it just a tiered approach, or part of an AIT system?

DB: I do think it's possible in an AIT system. The issue is going to be the thing with throughput, some of the time issues that you have. If you have 15 minutes, GCMS can do wonderful things. But you've got 20 seconds.

SW: But if you were trying to integrate it into some sort of portal, are you taking a sample or classifying the whole person as a threat?

DB: Depends on the sample. You've got to figure out clever ways to get oxidizers into the sniffer system.

JRey: Certain salts don't get into the system. Does the desiccation do that?

DB: There's a spray. One extra step.

DA: But you're making a TSA agent handle liquids, which makes them uncomfortable.

SW: We're trying to figure out a way to cover the whole space. So if we're trying to fuse them, it sounds like we're still not there yet.

GP: The Desi and Dart (?) are not a thermal process. We can expand beyond those that cannot be thermalized. There is the possibility with our integrated software already available to communicate…

GZ: ???

DB: Right now the community is sorting through those to find out which techniques provide the optimized coverage. I ran through the challenges and I think Griffin has answered a lot of challenges specifically for these sorts of applications. That's right where the state of the art is now and I think there's a long way we can go from that.

CC: We'll reconvene at 1:20.

Orthogonal Technologies (II)

Herschel Rabitz

HR: These are non-linear techniques with many many solutions, some of which are more robust than others. The theory behind this is that in principle these reagents (?) exist. The problem is, how do we find them? We're physicists, we need to borrow from engineering.

(Technical explanation of quantum control landscapes)

The issue is, can we find photonic reagents through this adaptive feedback process.

DA: So with these listed silver bullet items, what are the drawbacks going forward, realizing it's not completely mature yet?

HR: It's expensive, it's not robust at this point, and there are large engineering issues.

DA: Define expensive. CTs are expensive (1.2M)

HR: We're cheaper than that. $500K. But we're not one to work with the engineering issues. There are some physical technology issues.

MBS: Is the visible regime sacrosanct, or can you move it to the infrared or even the terahertz? Have you thought through the range?

HR: It certainly isn't sacrosanct – one of the messages I want to get across is to think broadly about this. The energy is related to the bandwidth, which is enormous. It's not limited, that's a very important point.

??: Is this a non-penetrating surface phenomenon?

HR: Certainly with visible radiation. Don't get me wrong about the plasma. That's something we've latched on through convenience, but the issue is not whether one does or does not use plasma. Don't read it because I pushed the radar side of this, that's just where we started.

JB: So creating a photonic reagent, how do you tailor or tie into the natural vibrational/rotational frequencies of the molecule? How do you create an existing reagent to set up natural vibrations for that molecule? How do you arrive at that?

HR: It isn't necessarily vibrations, (???) is involved as well. There's an analogy between orientation and having multiple chemicals involved this way. The principle for discriminating between two molecules is very similar. The pulses that are optimally identified to do the excitation work with all the (??) completely orthogonal to the molecule. It is analogous of MNR, and to be generous to those people, they thought about those things as well.

Peter Siegel

THZ Radar for Standoff Imaging Applications

I'm going to try to represent the THZ area for you. You don't get a lot of discrimination with terahertz. The way we use terahertz is with radar; that makes all the difference and it is what we are going to talk about today. What you are looking at is a system we are working on at JPL. Our subject is wearing a pipe bomb vest as you can clearly see with and without a shirt. Two years ago you could not have seen this. You can chirp and ???????? At a much higher rate than previously. We are in the frequency range between 300-3000GHz. Components are both purchased from industry and produced in-house. Passive THz Imaging is the first thing people try to do. This image was done 10 years ago and took about half an hour to produce. Here you can see the colder image underneath the shirt. The contrast is really poor; there are systems that do this today but they don't do a good job in my opinion. Radar has been used for many years doing discriminatory imaging. This shows you the power of the approach. Here is a mannequin picture scanned from bottom to the top using reconstruction by the chirp.

DA: A question I have is the images don't look much different from mm images.

PS: We are working at 25 meters.

DA: Oh. So the spatial resolution is much better.

PS: It's just the aperture is much bigger. In our case one meter aperture gives you 1 cm resolution at 25 meters.

CR: This is multimonostatic?

PS: Yes. For us the whole challenge is not getting the image. We were targeting 1 cm at 25 meters. The goal is getting image acquisition fast enough.

JB: I am really interested in the source.

PS: We make our own based on amplifiers and multipliers.

JB: Are they available?

PS: We don't make them at JPL but there are companies around the world that will make them but it depends on the criteria you need. Our record is 2.7 Terahertz but it is not cheap to do this.

DA: You said it is not that different from mm wave so you probably wouldn't want to use them together.

PS: Fusion comes not from mm and sub-mm but rather from infrared and THz. I think this technology, while not quite ready for the market, has a lot of possibilities in this area. We are looking for funding.

Presenter: Guang-Hong Chen

GHC:

Presenter: Robert Nishikawa

RN: My conclusion is improved performance can be obtained through multi-modality image analysis. The clinical questions we are addressing have to do with breast cancer – is the lesion malignant or benign? Same fundamental problem; is the suspicious object in the image a threat? CAD – Computer-aided Diagnosis… is the equivalent of ATR (Automated Threat Recognition).

DM: Are these mammographers or general radiologists?

RN: All mammographers. There are two aspects. Either they're not able to do it well, or we are not presenting the data to them optimally.

JW: So the radiologists are only doing diagnostics and not detection?

RN: Right.

JBush: One of the things that have been dramatically coming across here is how important the application is. That said, they also have the FDA… that's a whole different situation than what we have in security. It gets down to diagnosing human situations, so we really have to look at the application.

RN: That's very true.

DA: One of the scary things about this is that the computer has no medical knowledge. It's just going on ground truth. Why can't we outsource image interpretation?

Homer Pien

HP: I am going to go through a whole bunch of examples. There is no substance to my talk but some generalizations that I want to point you to. For our purposes, we do not ask the generic question, "Does this patient have a disease?" This is what we're asking the automated systems to do. So knowing the amount of contrast we put in, we can now start to model, get perfusion parameters, etc. This is also under the assumption that there is an increase in vasculature & corresponding blood flow for cancer cells.

With MRI, what we're primarily sensing is water molecules. We can actually tell the direction of movement of water molecules. Then what you end up getting is, if you picture a garden hose, most of the molecules are going to be traversing along the length of the hose. So we form a 3-D topography picture. As this thing rotates, you're going to see a hole. That's where the tumor was. Through this technique, we're able to see the result of the neuronal regeneration as a result of shrinking tumors.

The point is by combining 5, 6, or 7 different channels of data, we get a much better idea of how this treatment is working for this patient.

PET Imaging: You try to inject positron emitters into the body. So this is a positron emitting fluorine. We then inject this into the body – anything in the body that sucks up glucose is going to take that molecule in, like cancers, which are hyper-metabolic. We can then scan for the emitters.

Summary (slide)

In essence, TSA doesn't have the luxury that we do in terms of long imaging times personalized to condition of the patient. We don't use the same imaging and sensor fusion techniques for every patient, "personalized medicine/imaging." So, to what degree can we act similarly on the security domain? Maybe there are various triggers that say, you should be scanned with x-ray backscatter and maybe not.

Lastly, the community of people working on medical imaging is huge. Not just because the science is compelling, but because all the advances have taken place with open, peer-reviewed literature. The cream floats to the top and best practices are defined that way. I don't know how well that translates to the security area. However, in the medical area there are still numerous safeguards/privacy guards in place.

GZ: What source (??)

HP: Less energy, you're going to get fewer signals. We were using a simple, seamless, orthogonal CT.

GZ: We don't know the linear attenuation of the object in the bag. But we do know the linear attenuation of explosive. Will that help?

HP: My gut says yes. So we can do a gut testing explosive.

GZ: But we do that when we do the classification.

HP: In some form, yes, you're absolutely right.

<u>Meindert Niemeijer</u>

CC: I couldn't distribute MN's paper because of copyright issues, but it's well worth reading.

MN: My main work is in screening for eye disease. I think there are many parallels in trying to automate this screening, but today's talk will be on the more general idea of combining computer-aided detection systems.

So some algorithms don't seem to work very well, but in combination they yield a lot of information. It's unlikely that a single system will be the best for any particular class. It's likely that many of these medical conclusions could be adapted for the security domain.

To give you a bit of an idea about how performance increases for the individual systems, the sold lines represent individual systems. The best combined system is this dash line. The performance difference between the best single and combined system are statistically significant.

DB: Do you have an opinion, if we ran the following test, if we ran an iterative test and a ________ test, what do you think would be the best, single or cumulative test.

MN: It is easy to try a whole bunch of them. The sum rule is the safe choice.

Mark W.: Did you look at the difference between types 1 and type 2 classifiers?

MN: No, we didn't. We treated them as a black box and didn't analyze the output. We could have boosted the results even better.

Presenter: Jeremy Wolfe

JW: If true fusion is sensor A informs sensor B then I am only going to remind you that sensor Z is the human observer. How can the user make use of the results; a human has to use the sensor results until you can automate the whole process. Today's talk is one math problem, an old joke, and the uses of an analog CAD. Suppose you have a decent DAC system. If you false alarm 10% of the time, this is similar to current systems you see. If you use this for screening mammography or baggage. Disease prevalence is .003%. In 1000 case yields you get 3 positives and 110 false marks. People don't respond well to low prevalence signals. Even if you have a nice CAD system, if it is being applied in a system where what you are looking for is rare, the human will often miss it. You could move the CAD criterion. 1000 case yields equals 10 false marks. PPV .17 but you are missing 40% of the targets. Summary, the math and the human search engine are working against you. Observers found about 80% of the mark without CAD and almost 100% with CAD. The problem is the targets not marked are missed more frequently. The use of analog CAD combines with peoples' visual sense to give valuable added information. It is another signal which can be fused. Concludes remarks by restating three main points.

Presenter: Donald Brown

DB: There are five recommendations in the report but I will give you a couple. The bottom line is you have to do the systems approach. I will go through the overview of the report. Bear in mind, this study is four years old. Transportation security needs included hijackings and terrorist threats. There are multiple points of vulnerability including planes being shot at from outside of the airports. Shortcomings of existing systems include number of EDs, the stand alone nature of detection systems, access-control are stand alone systems, and the vulnerability to coordinated attacks.

MBS: I don't understand why coordinated attacks make the system more vulnerable. I don't really understand how fusion would help this.

DB: I will get to this point towards the end of my talk. We had to define terms including data sharing, data integration, data fusion, decision-data fusion, and parametric-data fusion. I am going to argue the last is very close to what was discussed in the medical talks today.

Three reasons for data fusion include improve detection accuracy while decreasing false alarms, reduce footprint at airports, and reduce labor costs.

Steps in data fusion include data preparation (putting it into a form that will enable fusion), data association (linking, correlating, or aggregating data in time, space, or other relevant dimensions), and estimation of prediction(current or future state assessment). Decision vs. parametric data fusion. Gives example of fusion approaches.

Current efforts at the DoD-automatic target recognition, joint surveillance and target attack radar system, airborne warning and control system, all source analysis system, horizontal fusion, advanced research solutions. Current efforts in private industry and transportation security infrastructure for data fusion, data integration, data fusion (SUB-DAX Fusion)

Opportunities for data fusion-systems engineering for data fusion. If you had to look at the reasons why the DoD fusion efforts failed it boils down to bad systems engineering. Baggage screening, pre-screening of passengers, etc.

15.2 Day 2: May 4, 2011

MBS: I have the pleasure to introduce David Luzzi, our Dean of Engineering. He would like to say a few words.

DL: I would like to welcome you to NU. We seek to be a true partner to the government and security on several levels throughout the college. I welcome you to the college and hope you have a tremendous conference and workshop. Just let us know anything you need we will do our best to get it done. Thanks to the staff.

<u>Carl Crawford – Day 2 Objectives</u>

CC: Is there a need for a tutorial on the technologies alone?

TG: Given the physics presentations…

(1/2 of audience raises hands to indicate interest)

CC: ADSA06 will be Nov 8-9.

ADSA06 (slide)

<u>Tim Johnson</u>

TJ: I am a spectroscopist, a physical chemist. I don't really have a dog in this fight – I think Raman spectroscopy is potent but I don't think it's the be-all-and end-all.

I will tell you honestly, Raman can't do everything. (Shows Standoff Raman pros & cons slide)

Raman has achieved to a great degree the smaller, quicker, faster, cheaper achievement and standoff detection has been realized. One other con – it can't analyze metals, because metals have no vibrational spectra. However, it's not just that it can do one type of chemical – it can do all of them.

CC: Is it too sensitive?

TJ: They're all just chemicals, and each chemical has a unique spectra.

DB: What if it's in an aluminum can?

TJ: Practically, no, the power of the laser required would make it logistically impractical.

DB: Opaque plastic?

TJ: Depends on how thick, which plastic, essentially the transmissivity of the plastic to this particular wavelength. Con to remote standoff sensing – the lasers are very powerful and you don't want to be anywhere near them. THz has really come of age but struggles remotely.

MBS: THz doesn't have the specificity, I think, that Raman has.

TJ: THz does well with crystalline materials, not so well I think with amorphous materials.

(Long technical explanation of standoff detection laws)

Accurate wavelength calibration is a concern for both manufacturers and practitioners of the art. The takeaway message is, you need to calibrate the relative intensity response.

So Raman. Not the be all and end all. (Reiterates cons) But for chemical detection of liquids and solids it does very very well and standoff has been proven.

TJ: I need to put as a caveat that chemical detection does depend a little bit on the strength of the Raman signal.

??: Can you comment on the utility of the cars (??)

TJ: There has been some talk about this. The beauty of (??) that is very exciting for me is that it is in sync with the outgoing laser beams (didn't catch). This is a very exciting technology.

Bill Baukus: Can you talk a little bit about the quantity of the material you can see?

TJ: micrograms down to nanograms easily, given a powerful laser. Of course, there are mechanical issues – keeping optics aligned – and it's a little easier in the lab than the real world. We really only need about a milligram to get great reference material.

Mathematics of fusing systems

Sondre Skatter

SS: Conclusions (slide) Need a shared quantitative framework to make detection systems interoperable, a common mathematical language.

(Technical explanation)

The goal is a data fusion framework. (Slide)

CC: So you're missing a circle here, which is that you have to make money, which is probably bigger than anything else.

SS: Right, but we can make money and do this.

Ontology (slide) as applicable to connecting classifiers

(Technical explanation)

SS: So there's a difference between someone examining the available evidence and concluding that two sides are equally correct/incorrect, or not making a decision due to lack of evidence – even though they result in the same effect (inaction, indecision).

(Algorithm explanation about Bayesian adaptation)

MBS: How do you come up with the probability of the bombs?

SS: That is what this slide is (Computing the likelihoods P (X|Ei) ADSA06 (slide)-slide shows two examples.

Martin Woolf: You have to be careful picking your priors otherwise you are going to bias it.

SS: I agree with you.

Don B.: The next step is to look at phase risk, have you done that?

SS: No. Basically you measure the risk and whether you alarm or not is based on the overall risk.

DB: If you don't measure the risk though you will have a problem.

SS: Here we model a histogram and compute the probability. Serial Update of the Risk Values ADSA06 (slide) I know I am running out of time. One more slide and I'm done.

DAC: One of the assumptions that it seems you have is you have conditional dependence, what happens if you don't find it?

Presenters: Ken Jarman and Nat Beagley

KJ: I am going to talk about the "gotchas" and some case studies. Conclusions, probabilistic integrations provides a versatile functional sensors doesn't always help on method that outputs an intuitive likelihood of threat. Integrating nominally orthogonal sensors doesn't help. A lot of our work is in the area of national security. One thing we didn't mention is PNNL is in eastern Washington State. Probabilistic Sensor Data Integration what we get from characterization studies is probable output. We characterize a probability distribution of whether or not there is a threat. These rules take us from a likelihood of a threat for what we have to what we don't have.

CC: How do you go from the sensor?

KH: I think of the sensor as the whole package which includes the human.

CC: And this leads to a decision.

KJ: It could be a binary yes/no. If we have coordinated data allows you get rid of the conditional dependence. If you don't have enough data you can incorporate modeled data. This is particularly useful in a design system. Downside is the Bayesian requires some choice of prior threat probability which is challenging for extremely rare events. Another downside is conditional independence assumptions.

Case Study: Large Event Spectator Screening ADSA06 (slide)

This is to illustrate one of the ideas here. We looked at training data for a large event. Seasonal nuisance factor was introduced we had to adjust our data for this. Here is the ROC curve for the three sensors. These are coordinated sensors and we could use conditional dependence. Looking at the overall error probability, lower is better. You can see that sensor 3 is insensitive to the environmental but sensors 12 and are very sensitive. This suggests that how you integrate depends on seasonality and you might have to throw out some of the sensors. You have to tune the system.

NB: Case Study: Fusion of Classifiers Detection of Tularemia ADSA06 (slide)

This case looks at introduction of a lethal virus and looked at it from 4 sensors. I will go over this quickly as it's been gone over by prior discussion. (Goes very quickly, tough to keep up). These are very different data types so we had to use different algorithm types. We modeled each individual sensor and came up the probability for each class. I won't get it; no specifics now. This is a MatLab program I wrote. You have 4 instruments looking at this threat. You can see the results of adding and subtracting the sensors and the results range from 80% down to 44%. What is happening when you break down the data is

CC: Did you know they were non-orthogonal a priori?

NB: No.

??: Could the priors been wrong?

Patel: Are they averages for one sensor?

NB: The % is the weighted average for the samples; it does't break it down by class.

DAC: I guess sensor fusion doesn't work at this level. You don't have independence at this level.

NB: True. The whole point is you need to be careful and not assume because you put two sensors together that you get a better result.

Strelstov: The system is built to get a result….I think this is what you want to look at when you go back.

NB: I am not going to argue with you. The other point I wanted to make with this data if you look at these three sensors together you get a better result. When you incorporate the fourth sensor in an integrated way you do improve the system even though you the fourth sensor doesn't seem to be useful.

SS: This is what happened with the Netlfix $1 million algorithm contest.

MBS: What is coming through to me is the design of the system a priori is that data is orthogonal is needed, if you don't have this understanding, this is what we should go into here.

NB: That is what this slide is about (Algorithm and Data Considerations ADSA06 (slide) and The Data Reality: ADSA06 (slide)

Presenter: Larry Carin

LC: Good morning, I am going to discuss Compressive analysis. My conclusion s as shown on this slide is that low-dimensional signal representations can and may be sued to mitigate the curse of dimensionality. Outline ADSA06 (slide)

We will show compressive sensor modalities at Duke U.. Dictionary learning and decompressive inference. David Brady is leading a DARPA program which the goal is to build a 50 Gigapixel camera. This picture is from a 2.4 gigaipixel camera. We are also working on coded aperture Raman imaging. To give you a sense of what can be done, this is a compressive measurement of a hyperspectral image. When you do the inversion properly this is what you can do (slide with no title but with 23 images). These are state of the art results. Moving on to analysis. We have been working with United Technologies Research Center (UTRC). We have just delivered to them a GPU implementation of 32 frames in less than a second. This is .5% of what a conventional camera can do. OTC is interested in fire suppression imaging from a distance. We are doing CS conversion in real time. They are going to put this into a real camera. What I am going to talk about now is what we do on the math side. We have been looking at a lot of things but first to give you a sense of what we can do is you can exploit a low dimensional structure. In the first image 80% of the RGB pixels are missing so we can recover them. How do we do this? We break the image down into an 8x8bloock.

Collaborative Filtering ADSA06 (slide)

Collaboratively we can uncover the underlying dictionary so we can recover the image. It is similar to the Netflix problem. Though it is massively under-sampled we can recover the image.

Hyperspectral Data-2% Observed at Random (slide) This shows you the recovery we are able to do.

??: Is your dictionary still to be built?

LC: Yes. There is a tradeoff if you make the patches too big you get spectral smearing. For those of you who know HSI data, that is not the point. One of the first things when working with NGA is though the pictures are nice what matters is material characterization. Mapping (slide). Here we measure 100% on left and 20% on right. We can get the same material characterization while collecting a massively reduced amount of data.

Non-Gaussian Noise (slide)

Foreground, Background & Tracking (slide)

LC: This is a scene at an intersection in Atlanta. This is our extracted background and foreground. You can see that we can extract the weak outliers pretty effectively. This is a truck moving slowly. The algorithm incorrectly thinks it is part of the background.

The heart of our work is dictionary learning. What we are working on is geometric wavelets. What we do is take a dataset and do a multi-scale data decomposition. What we show here is a course defined representation of the digit 1. This is a data agnostic approach. Last thing I am going to discuss is POMDP. We are asking how do we collect the data in the first place. We do this with the POMDP. Partially Observed Markov Decision Process (slide). This model is work we did that is about 6 years old on landmine detection.

Summary/Conclusions (slide)-reviews this slide that he started presentation with.

Marcus Schiefele: Does your under-sampled image have to be under-imaged?

LC: There is nothing random about the sampling itself. Once it is designed, it is fixed. It is proven to be optimally random. Compressive sampling is in a way rather old. What the CS community has done is do what engineers did ad hoc in the 1940s.

SW: In terms of these scanning machines a lot is done before the operator sees the image, do you have to go straight to the raw data?

LC: We are data guys, we will take what you give us. Typically decisions are taken early on that affect the process down the stream. You have to make compromises you don't want to make. With CS you can reduce the compromises and hopefully make better inferences.

Presenter: David Perticone

Summary: Two detection systems are cascaded when both are required to alarm to reject an object. The outline is a brief discussion of probability and example studies of ??????????

Cascaded System Architecture (slide)

Illustration with 100 Bag Set (slide)

White boxes are goo and white is a miss. The last box is where the sets are combined. What is the worst case? None of the misses overlap on the same bag.

Maximum Detection for two P=0/.9 systems. If the systems are perfectly correlated. As a reminder we make the CTs and also AT which have a higher performance than human. We are trying to move our expertise into cargo.

Break

Enabling Technologies

Michael Barrientos and Ritesh Patel

MB: We are trying to create the ability for better throughput and better utilization of the workforce. We have been able to enhance and integrate technologies into a common display format. Our current goals are to refine the system – we currently have a working project that can actually go out to the airports. With that, Ritesh Patel [will continue speaking.]

RP: Our main expertise is in systems engineering and integration. We've been working on this integrated checkpoint project for a year and think that the System Engineering Approach is the key to an integrated solutions. We are focused on building "systems of systems" and remembering that the checkpoint is a decision process with a human factor. As you fuse data, complexity increases.

CC: What is a TSO?

RP: Transportation security officer; the people in the airports. ICP Logic and Relevance (slide)

Now you tag a particular bag, allowing access to it in several areas, essentially sharing information, if they need to collaborate they can do that over the system as opposed to interacting with the passenger. So all of this data needs to be integrated within the checkpoint context, whether for a TSO or for an automated system.

Once we had our prototype built, we engaged in several validation sessions. We had TSOs participate, use the system and give us feedback. With that we were able to make some changes and incorporate their feedback into the system.

ICP Demo Layout (slide)

A key difference is that we have a divesture station. Most passengers don't divest properly, which creates problems later on in the cycle. So once a passenger enters, that information is correlated into the system. The key is to keep the passenger moving and not stop them if they fail at any one of these points. The information is recorded and all of that info is then sent to the innovative display. So at the end all the information is provided to the TSO in a cumulative fashion to allow them to make the decision, this passenger passed/failed. I it's a fail, they will be passed on to a secondary operator to allow them to have more information about the results and analyze their further decisions.

The integrated display is what the TSO would see. (Integrated display slide)

??: How are you associating the bags with the person?

RP: Through a bar code. What happens is that each ticket has a unique code that will allow for "tagging" of the carryon items to a specific person. We went to the bar codes because they were the easiest solution at the time. There are several ways you can do this.

??: What about divested items?

RP: They will be put into a bin and each bin will have a pre-marked bar code. There are also systems like the AT (?) where X-rays that can be integrated into the bar code. They're not now, but they can be. The advantage you get in throughput is that if the first passenger has a failure, the second passenger is stuck. In this model you can divert a passenger.

So now the secondary operator does not have to consult with the first operator. They can see all the information that the first operator has. In conclusion, we are working at TSL integration cycle right now and there is an opportunity to explore and incorporate some of the algorithms you are working on into our prototypes.

ZY: What's your projected increase in throughput?

RP: We have an incomplete model, based on initial data it looks like a 20-25% increase in throughput.

MBS: Is that a marginal increase, a solid increase?

RP: I think with new ATRs that would automatically identify threats, which that number would increase significantly.

ZY: So what's the increased cost associated with the increased throughput?

RP: I don't see that there's any major cost increase. We are not training remote personnel, we can better utilize the workforce or even reduce it with remote screening. So there might be some increases based on changes you have to make to the system, but that's happening already.

RN: One of the problems in the medical field is misidentification of data. I don't know how it happens but images get mislabeled, and you will need to work with that.

RP: We thought the easiest thing was to look at the bar code on their ticket. Of course one person could give their ticket to someone else, but that's where photo ID comes in.

RN: I'm not saying you need to come up with a solution, but you need to think about it, because it will happen.

CC: What if I forget a drink in my bag?

RP: In the current model, I'm stuck behind you, I lose two minutes or whatever. In this system, you're shunted to the side and I proceed.

CC: Can this work practically in terms of tracking all these people?

RP: Currently, for scanning, if there is a threat on your body you are patted down, wanded, etc. But if it's in your bag, the procedure is that you need to remove it and rescan it.

CC: But the whole concept of operations doesn't necessarily get fixed by putting it on the display.

RP: It depends on how big the queue gets. Thus far our model is limited and we can effectively maintain up to 3 passengers in the secondary queue.

JW: I think you raise a lot of good questions Carl, some of which are already addressed. Ultimately, we believe by modularizing and standardizing these processes it will allow us more flexibility and autonomy to deal with these situations.

<u>Suriyun Whitehead</u>

SW: I work at S&T and I'm presenting DICOS on behalf of program manager Doug Bauer. DICOS is Digital Imaging and Communications in Security. We've talked a lot about fusion integration and it's going to take some time to work our way through it, but in order to do it we need to figure out how to get the data from point A to point B. We think developing standards the way they do in the medical industry is a good idea. This is about a standard way of doing things. It's all about information sharing and it helps system integration.

This is one of the mechanisms that can be tapped in to help with TSA initiatives. To date we've had version one released of the standard, and it covers checked baggage and hand luggage x-ray, specifically CT and DR related modalities for apps.

Now the checkpoint is limited in square footage which limits what's being accomplished. Each of these systems speaks its own language. We've got multiple operators/stations and it's all tiered. There are a lot of things we already have like video etc that we want to integrate to get unified view. Need to do more of hooking up systems to get into one place. So it's a common language. As air travel is set to increase, we need to do a better job of leveraging the resources that we have. With respect to leveraging DICOS, there are a couple different initiatives (slide).

Everyone is at this conference to see how they can contribute to this space. We're looking to tap into that, whether it's connecting directly with a vendor or plugging models into our system. So you may need to select specific algorithms to apply, slow down a machine. You need some sort of interface to apply to do that. DICOS Interfaces (slide). So we want standard formats for these things so we don't have to re-translate it for each vendor, etc. This is a process of continuing improvement. So instead of visual representation, perhaps algorithms work in a different signal space. We tried to follow the medical model of where DICOM is today with images and ATD results.

Status (slide) I should mention DICOS is really focused on the application layer. It sits on top of all the other DICOM transmission pieces. It doesn't mean it has to be like that, but it needed to be that way to get off the ground really quickly. We're developing DICOS v2 , developing AIT related now. They're on about 12-18 month cycles for release of the center. Summary (slide) released a slide of DICOS testing tools for testing and it is available from NEMA committee or from us. John Bush over there, Battelle developed those tools to do that so you can pick his brain.

HP: DICOM has a communication structure with a not insubstantial. You talked about a scenario with different TSOs at different airports potentially sharing bandwidth. How do you balance the increased overhead of packaging information, bytes, real-time communication channel with this? There are embedded files that have to be parsed, etc; adding 3-4 seconds becomes significant.

CC: I don't think you're right and I don't think we should talk about it here.

PSiegel: Coming from a space background, I am unnerved by push toward larger integration with less autonomy, knowing how unreliable computers/networks. What happens when something goes wrong in some part of the network and everyone in the entire queue is stopped dead?

??: Absolutely there has to be a backup solution, you just can't have the whole network go down.

GZ: That's why we still have the TSOs at the checkpoint. Computer doesn't work, TSO takes over. We are not doing operations on people based on the image on the scanner. The backup is still human beings. I don't see this as being a critical point of failure.

PSiegel: Do the TSOs really have that authority now?

GZ: Of course!

JB: The important thing about all this, is you have to have a credible backup, no matter what you do. Those credible backup procedures and systems will be identified. There's also a blip – it can't be too good. So the organization has incentive to keep the primary system working.

SW: And yes, it's not the silver bullet. It's one approach to try to explore how to do things a little differently. We have a lot of analysis on this, because TSA is constrained by the size of the checkpoint and air travel is set to increase massively. I'm not laying out a perfect CONOPS, I'm saying these tools are to be leveraged as we work on a CONOPS. This is about making options available to our customer, who is trying to find ways to screen efficiently and effectively.

LPerron: Can you expand a little bit on the DICOM testing standard in phase 2?

SW: #1, NEMA is taking inputs from anybody if anyone would like to test it. There are offered testing tools at Battelle.

LP: They're more for individual components of the big picture.

SW: They're also testing different transmission scenarios. We want to make sure it's robust and fits the networks that are out there. We don't want to require huge new systems just to get started.

DB: Maybe the sequence of the last two presentations have led to a loss of emphasis on what we're tryinging to do here with DICOS. I don't want people to lose focus on the fact that when we started down the DICOS development path, our purpose wasn't to pursue integration, it was to pursue participation and increased innovation with increased ID of threats and fewer false alarms. That's a different value, integration, than what motivated us in the first place. We can't be blind to efficiency gains and lifecycles cost but it is not the main motivation with what we are trying to do with DICOS.

SW: What I said was that TSA plans to adopt risk-based screening methods that will tailor it to individuals with suspicious behaviors.

DB: On a bag by bag case?

SW: I don't think they mentioned how.

DB: The administrator made that comment because he said why is each person subjected to equal screening? A six year old girl for example? The administrator was reacting to this question; this is the context.

Presenter: Carl Crawford

System Requirements and Testing

CC: Essentially I wanted to discuss the environment in which equipment is procured and how this affects fusion. The bottom line is the environment is really set up for fusing.

Detection Requirements (slide)

Other Requirements (slide)

CC: There is networking to support remote viewing stations. There are no requirements for confidence level of a threat. Testing is all done in Atlantic City at the test facility. There is no place to test sub systems for fusion.

TSA Deployment (slide)

TSA acquisition is based on multiple stand alone technologies such as shoe scanners, What has to change going forward to support fusion? Networking has to be enabled. We have to be able to control the system, change the priority. For ATR we have to be able to adjust the confidence level. You might even have to classify the type of threat.

TSA Changes (slide)

Procurement has to become fusion centric. Fusion in the field would have to happen.

Testing (slide)

TSL might have to start testing components separately. You would record strength and weaknesses then compare.

HM: It all depends what the requirements are.

CC: You can't test all fused permutations.

Possible Issues (slide)

You will have to put multiple vendors at the same site. That is it. Any questions?

?? From TSA: In your No Requirements For slide, you mentioned about not having a requirement for a knob. There is no requirement for knob per se but there is a requirement for multiple algorithms. I just wanted to mention.

Presenter: Doug Boyd

DB: All of my images are sourced from the internet. I am constrained by what I can discuss. We are developing algorithms for TSA. This includes NII (non-invasive inspection). It also includes a common workstation which connects to all types of airport imaging equipment, the DICOS network, ATR, and fusion (both mental or algorithmic). My conclusions are ATR can become competitive with human observers.

History of TSS (slide)

MBS: Who are your customers overseas?

DB: The first was Israel, the second was Great Britain, and the third was France. China and Europe would be our biggest customers I would say.

ATR Methods (slide)

There are three steps, reconstruction, dual-energy, segmentation and classification. Before you can include this you have to have many views. For 2, 3, and 4 views we use discrete reconstruction. This works incredibly well. In the medical world there is a common workstation called the PACS.

HM: Have you thought about/merged the techs? What would your comments be on that?

DB: The answer is no, we have not fused them. Our common workstation does bring all the data into a common box and what we've talked about could apply to those images in this box.

MBS: In this difficult funding environment, how is this affecting your company as a small 3rd party vendor?

DB: When you're awarded a large contract, you have to ramp up to that contract – space, staff – when the contract is then canceled you have to divest. So that always causes a certain amount of destruction.

XF: Are your colors based on classification or?

DB: That was ad hoc.. None of the above.

<u>Luc Perron</u>

LP: The security world is very reactive and we haven't done any business so far in the US… we're a Canada-based company. (Optosecurity). Started operations in 2005 and given challenge by transport Canada to detect guns in X-Ray images.

We don't necessarily want to replace TSOs or screeners, we want to provide a system for them. So what we are providing is a decision support system. From out challenge we have the world's largest x-ray library of handguns. Now the x-ray itself is not necessarily helping us very much because of geometric distortions, meaning that the location of the gun in the bag makes it look completely different. Now scanning on different scanners the result can look completely different depending on the speed of the scanner belt or the sampling. So you have to go a little deeper than that.

So we decided we really needed to work with the raw data. There was no DICOS so we created our own format. Now in order for us to work with multiple vendors we have to be as open as possible. When we capture the data, we capture it on memory there, and then when we store it it's a TIF. What this means is the same raw data coming from 4 different manufacturers look exactly the same. Of course not all X-ray machines have the same specs, but they work from the same theory. Hence, it works with a normalizing formula.

So when we do automated detection, we need to put things in context – especially for the liquids. It's very easy to distinguish between organic and metallic, but trying to distinguish between a safe and unsafe liquid is a little more complicated. So we need to measure density. But liquid I s never by itself – it is in a container. So we need to figure out what the bottle is made out of, its volume, its density… and we need to do all this within a second or two. We convert an X-Ray image into a full 3-D model. A single view machine can even be supported through this.

So eVelocity is our project. Solution Overview (slide)

So with our web-based remote monitoring, we can show images that are coming in live. This is not R&D, these are images coming in live, already deployed in an airport in Europe. Lessons Learned (slide): What we need is predictability and reliability, and we've proven we're able to do that. For DHS/TSA – US acquisition rules do not encourage innovation, because it is defined for large corporate companies. If you are outside the box, there is no room for you. You need to do something about it, especially if you want to do fusion.

Dan Harrison: The bags you're scanning real-time, is this supposed to be accomplished in an airport?

LP: Yes.

DH: Can I have them?

LP: Yes… for a price.

CC: How do you get these images?

LP: The images we scan in a lab are ours… that is what I showed you. The images from the airport are… the airport's.

HM: Does the airport allow these to be shared?

LP: Yes, with approval. Most airports agree – we're helping them, so they let us use the images.

(Certification question)

LP: When we certified our machine there were three different certifications on 3 different platforms. We are built in on 2 and an add-on on 1. On the last (Smiths) it's the combination of the 2 that got certified. They never helped but they never put in any stumbling blocks either.

RD: You said in order to have efficient ATB, you require predictability. Predictability of what?

LP: The way we run it, we are simulating different scenarios. For example, we need to understand what we're producing as an output. We need to know what hydrogen peroxide looks like to recognize it. So far we have been pretty good at predicting, so we're running thousands of text cases, automatically, over and over again.

(Brief argument about who was first to collect liquid data)

There are standards about image quality, it's a qualitative assessment. The raw data is exactly the same. Of course for viewing, the colors are a little different, but…

??: Is there a daily check of the system?

LP: The X-ray is the same, on the (???) version it's up to the vendor to do that. It's just on the algorithm side that we need to do some validation.

<u>Derek Bale</u>

CC: We're jumping to photon counting because it is bringing potential additional features in medical imaging. We want to find out if it is applicable to security.

DB: This technology is beginning to realize its potential. Conclusions (slide)

Presenter: Harry Martz

Review, Next Step, and Discussion (slide)

HM: One of the takeaways is it is not clear what fusion means and what to fuse.

MBS: It really comes down to, "Would it make sense to create a fusion experiment and then collaborate on the results of that experiment?" Specifically because we helped to create it. Some of them have been algorithms, con ops, and others. Maybe TSA can help launch such an experiment and then we could iterate it.

HM: Comments on that?

??: If you think about con ops it could talk about where we want to be in 5 and 10 years. Getting back to MBS' idea, you're exactly right, we can say, "Where are we in relation to where we want to be?" Where I think you end up is thresholds and then we can get to a common lexicon and all the other stuff.

HW: In the military, they make a distinction between sensor fusion and data fusion. So it makes the problem easier, I suggest split it between the two.

HM: So you are saying divide it between sensor fusion and data fusion?

HW: Yes.

DAC: About 18 years ago, the JDL hierarchy was created. In many ways we are at the lower level of the hierarchy.

HM: So you are saying apply this to TSA's problem.

DB: I was on the panel that created this. Some people suggested that this hierarchy was too overarching. There was actually a fifth level. It may be time to revisit it and bring it back in. There has been some discussion in DoD as to how much this helped or hurt.

HM:

DB: The problem was it tended to pigeon hole too much. It tended to cause people who were creating solutions to segment and the people who would use it don't want it segmented. They don't want piece meal solutions.

CC: Were they driving to solve a level or a specific problem?

DB: Level-that was part of the problem.

DAC: When we talk about cube fusion, we talked about things at a much broader level like trace or QR. How do you bring this together within architecture?

HM: Don, can we ask what you think of this? It is very important to get your feedback.

TSA rep.: A couple of thoughts. I talked with someone about whether TSA wants fusion. As the smaller steps are taken we need to figure out how these fit into the larger steps. As far as the comment as TSA needs to figure out what they want, I totally agree. We need to discuss more with more people from the community like here.

HM: Next slide-Takeaways Continued (slide)

Emerging technologies could be deployed with deployed technologies, other emerging technologies, and humans. For technologies discussed in the security and medical areas, there was too much focus on strengths, not enough on weaknesses, and both are needed to enable ideas on fusion. Comments?

MBS: If you are going to discuss this you have to focus on the physics. You can drown in the details but at the same time you can lose site of the details.

HM: We didn't lose sight of them discussing the strengths. At one meeting about CT a participant said at the end of it that we talked as if CT doesn't work.

RK: Two projects with regards to humans. One system delivered to TSA is a pilot study on ATRs and how it affects the screeners (didn't get second project).

Martinez: I wonder if you want to do a study as to how the workflow will affect the screeners. I work in the medical area and ....

TSA Employee: The way TSA deals with it is we try and recognize it and deal with it as an issue. We make a record of what we observe. It is certainly not exhaustive approach.

Martinez: I'm talking about ROC curves.

HM: You are talking about a new assessment area. Are we getting feedback from the operators and figuring out what would make their job easier.

Yellow sweater: It is important to recognize both medical and security are trying to get better. They are very different but at the same time there are solutions we can try to adapt.

HM: I was looking at it not directly but indirectly. How did things not work?

Yellow Sweater(John???): Medical has been working with CT since 1972 and they didn't standardize until 1994. 22 years. They are kind of our big brother.

Robert N.: I agree with John. I understand what you are saying about strengths and weaknesses but I don't understand yours and you don't understand mine. This forum isn't the right place to do this. We need to sit down with our counterpart and figure this out.

HM: If this is important enough to the government they need to start this.

CC: WE agree and realize it is very important. There needs to be mentorships. Eric Houser mentioned it yesterday. I agree this isn't the forum.

Purple shirt: Do we think enough about how the adversary thinks about the system?

HM: Probably outside the scope of this meeting but it has been discussed.

DAC: I think the question raised is deeper. Are you probing the systems for weaknesses? The systems were made with a certain time in past with certain threat in mind. Most systems are designed with current weaknesses in mind. This is the driver in many ways. What isn't working well can't be found by requirements but by current failures.

CC: The current technologies work fine. We want it to work better.

JB: I want to argue the current systems don't work well; not in terms of technologies but because they are too slow and are too expensive to work.

TSA Employee: We can rewrite the BAA to be more descriptive to make people more aware of what TSA is looking for.

HP: We could do a Red Team of smart people of how to attack system but this meeting is not open to everyone so we can provide this feedback to TSA without disclosing weaknesses of system.

CC: The answer is it can be done.

Patel: I think Homer's point is excellent. We may be able to come up with several scenarios the terrorists might come up with but we wouldn't think of everyone thing terrorists might do. There needs to be a way to incorporate the intelligence stream into this process.

CC: I will be defensive about not stressing weaknesses. It's tough to have vendors come and discuss these.

HM: I know but this is important.

Takeaways Continued (slide)

Mathematics of fusing systems. There are different places where information can be fused, and methods used to fuse information. It is complex math to human fusion. It is possible to degrade performance by fusing systems. There is no prescription for doing it right. Third part experiences. Applying their ATR algorithms to incumbent vendors.

DAC: One of the constraints I saw was we didn't have enough data. Part of this is that we still have stovepipe systems. We didn't have the same data observed by two or more different systems. In the absence of joint testing we have to make certain assumptions. This prevents us from fully understanding where we are. This is just the nature of where we are. We need joint data in multiple dimensions that will allow us to mine the data.

HM: As Michael said, we could set up an experiment where we decide what data we are looking for and decide what we want to do it.

JW: Any time you make an assumption – it's a systems design problem in trying to verify that what you are trying to apply will generate positive result. Otherwise, performance degraded.

??: Some of this jointly distributed data is probably very easy to get if you sit down and decide what you need, say, I want to compare this and this and this with these factors. It's just a little bit of common sense.

HM: I would agree, say, if you said "this is what we need" we can probably figure out how to get them without dealing with a classification issue.

DM: At what do you want to build in that knowledge base capability while you're developing these systems? When do you start planning for that?

TR: I think these are great points that they're making here regarding getting degraded, common sense… on some levels, this is systems engineering. That's what you have to do to solve this problem. Get the model right by taking this from the beginning, lay it out, top down. But it isn't cookbook engineering; say laid it out, you'll get it right every time. It's not quick, it takes some work. The good news is, if you do it right, it'll last.

MBS: I think that one thing that was out of scope – and maybe it shouldn't be out of scope next time – is the human element, like this idea of profiling, or the risk element. It's probably as amorphous as fusion itself, but by not covering it, we leave ourselves a space that should be covered. Maybe next workshop.

HM: Would it be useful to put out a straw man systems engineering of what that is and whether it should be included or not?

JBush: The point in fact is, it starts with the user. The user is the driver, not some theoretical abstract.

TG: Right off, we're talking about two main points, checkpoint and checked baggage. Solving one of those problems doesn't solve another.

JBeaty: So you're going to start considering the human factor associated with measurement. I don't think we've really spent any time looking at that and seeing where we can take it.

Wrap-up

Doug Bauer: We really tried in creating the basis for this particular workshop to undertake "reconnaissance work". There's a lot of interesting stuff going on here and we don't quite know what it is, whether it's in reconstruction, new ways we can think about computer assisted diagnosis, etc. But I think what the comments have said as we unfortunately found ourselves pressed into time, we got ourselves more and more into a mode of presentations, not dialogue, despite the fact that when Carl sent out the invitation, he specifically said we want fewer presentations, more dialogue. I want to come back to that we have to define the problem that you're trying to solve very carefully. You have to test and make sure that you've still got the problem statement right and that it hasn't varied from when you first got into it. If we take again from medicine the distinction that's made between screening and diagnosis. Then you dig deep. Not wide, but deep.

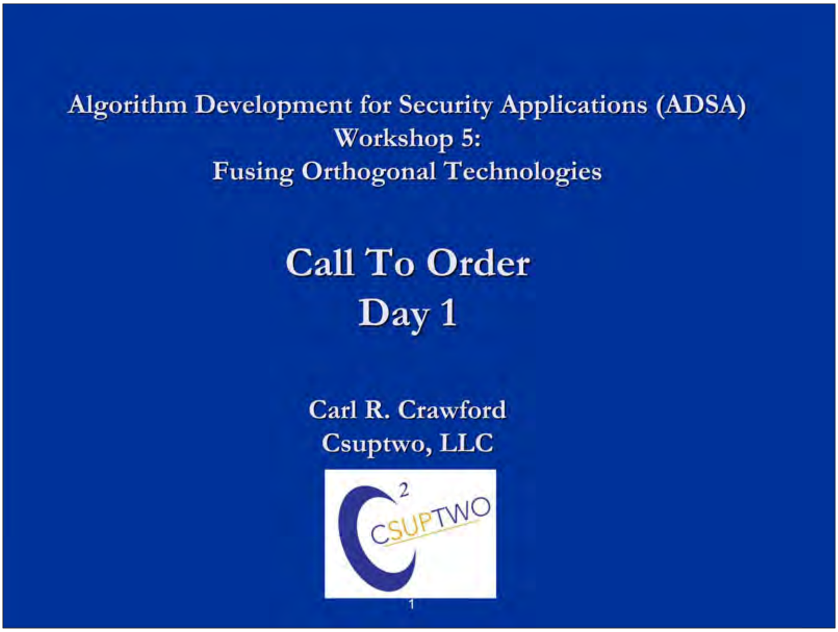
Example – checkpoint. Ask how to combine x-ray backscatter with quadrupole resonance. Define the problem and then ask, fusion means what here? At what level? How you do that means you bring a group that can dig much deeper than we've had permission and capability to dig here. I think until we get to that level, in some safe spot where people can be frank and candid about strengths/weaknesses – which were not symmetrically revealed here. My recommendation is we need to think carefully about whether we want more workshops or very specific clinical sessions where we look at very specific pathologies. We need to figure out for that in detail. We need to do that in a way that protects the nation's secrets, but we can't hide behind the nation's secrets as an excuse for inaction.

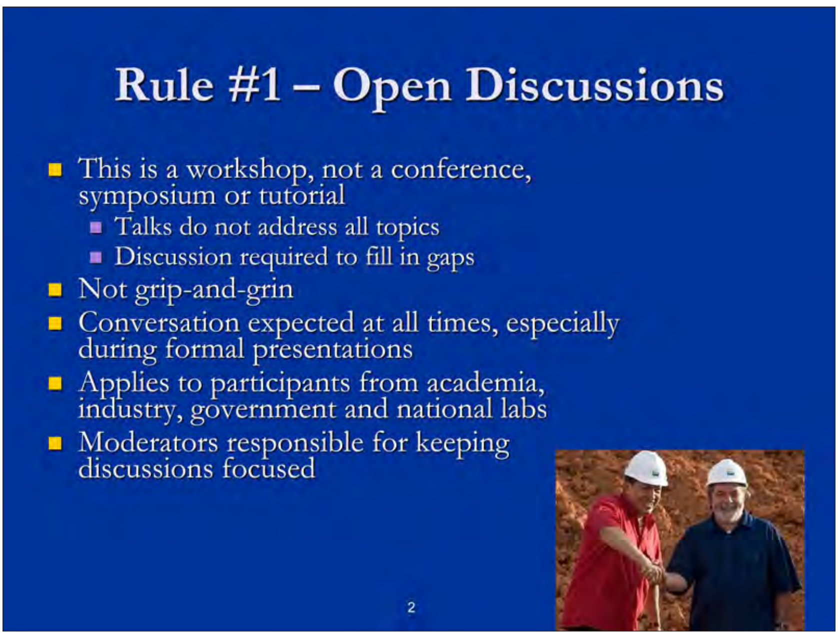
MBS: I want to echo the fact that we need to compare apples/apples and oranges/oranges. I think having clinical discussions is a very interesting and potentially productive way of proceeding, and then workshops that can discuss the conclusions drawn by these clinical discussion groups. I want to thank Carl and Harry for putting together this workshop. It was a lot of effort to bring all these groups together to try and grapple with one of the most elusive problems we're dealing with – can you make it so the whole is greater than the sum of the parts? And the answer is, sometimes you can, and sometimes you can't. I want to thank my staff for helping to orchestrate this meeting and I look forward to the integration phase and then the next steps.

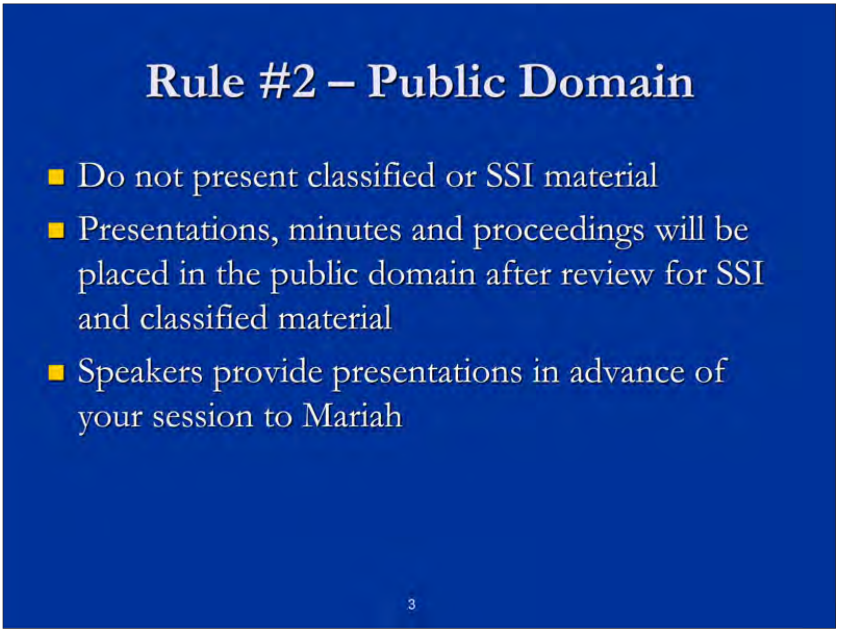
16. Appendix: Presentations

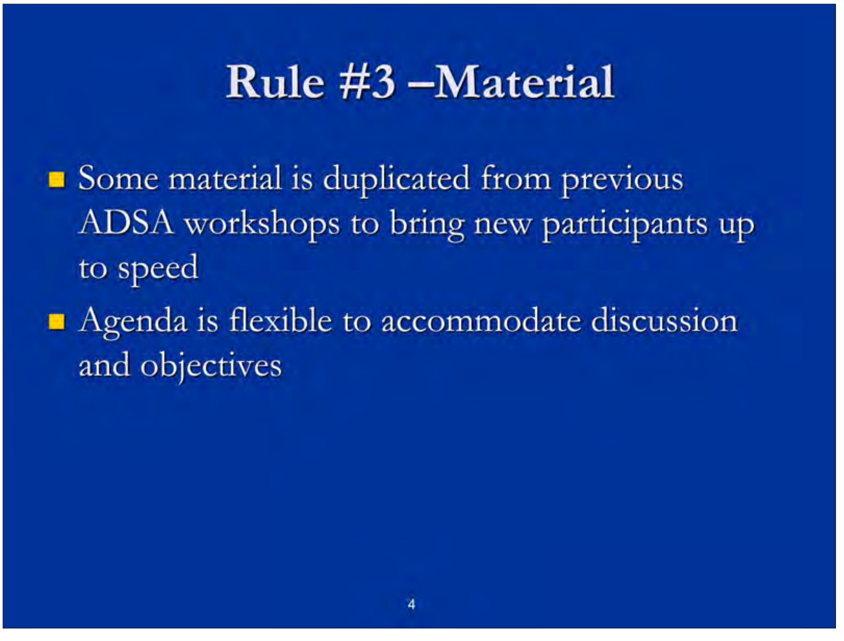
This section contains the slides presented by speakers at the ADSA04 workshop. The slides appear in the order that talks were given as shown on the ADSA05 agenda. Some of the presentation slides have been redacted to ensure their suitability for public distribution.

16.1 Carl Crawford: Call to Order






Rule #2 – Public Domain
Do not present classified or SSI material
Presentations, minutes and proceedings will be placed in the public domain after review for SSI and classified material
Speakers provide presentations in advance of your session to Mariah
3


Rule #3 –Material
Some material is duplicated from previous ADSA workshops to bring new participants up to speed
Agenda is flexible to accommodate discussion and objectives
4

Rule #4: Patience

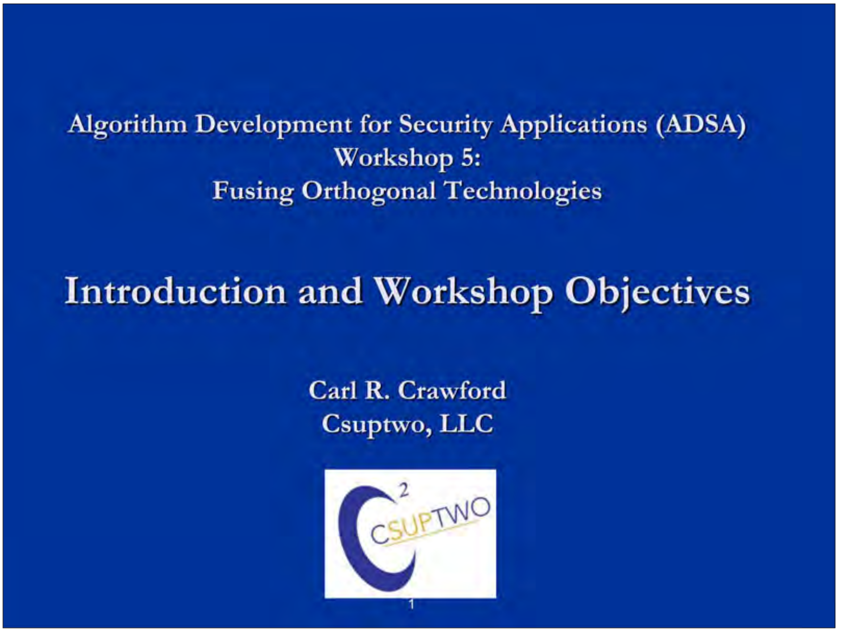
- Odd-numbered ADSA workshops are for new topics
  - Even-numbered for focused topics
- Workshop tasks:
  - Define
    - Fusing
    - Orthogonal
    - Technologies
  - Techniques
    - What and how to fuse?
    - How to efficacy?

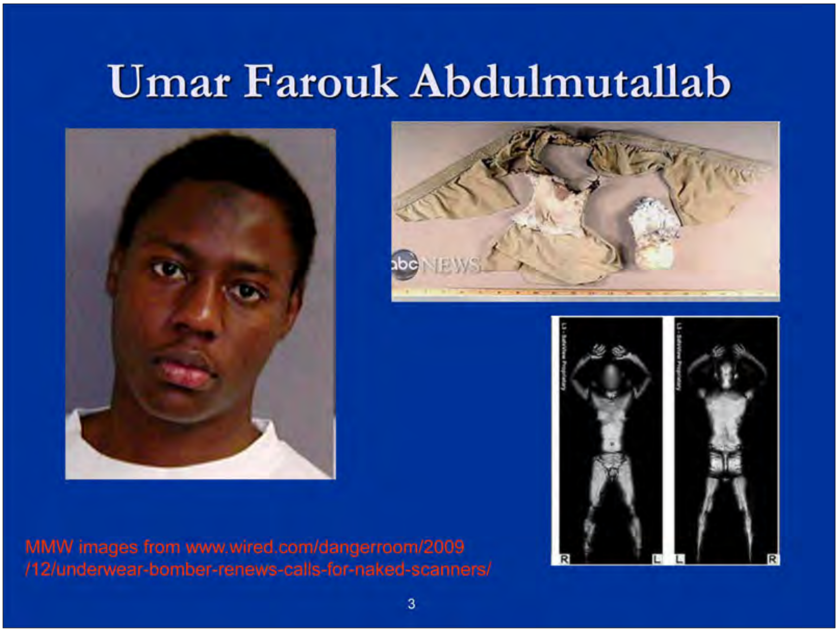
5

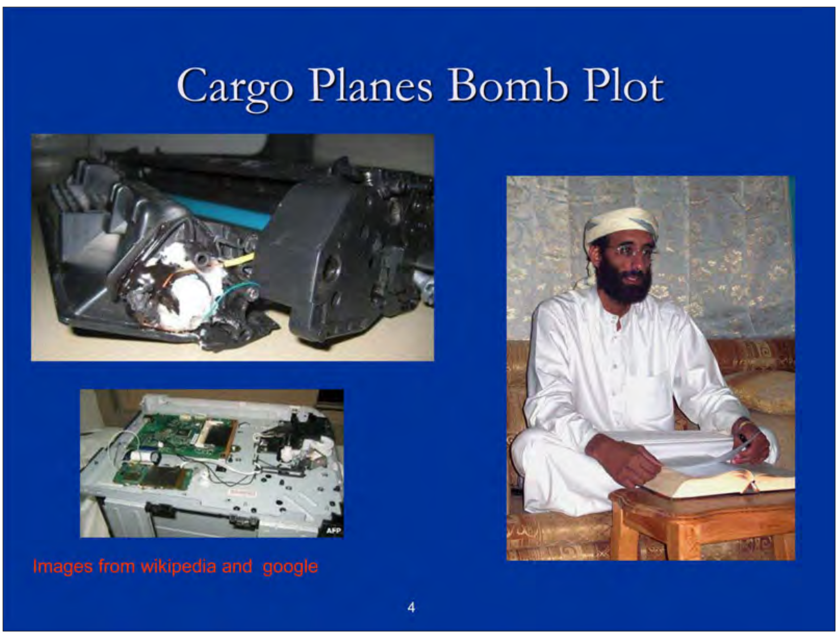
6


Rule # 1: Open Discussions
Let's Practice!
Questions?
Comments?
Remarks?
7

16.2 Carl Crawford: Introduction and Workshop Objectives




Umar Farouk Abdulmutallab
abc NEWS
R
L
L
R
MMW images from www.wired.com/dangerroom/2009
/12/underwear-bomber-renews-calls-for-naked-scanners/
3


Cargo Planes Bomb Plot
AFP
Images from wikipedia and google
4

Problem

- Terrorists still trying to take down airplanes
  - Huge economic impact
- Terrorists are making home-made explosives (HME)
- Need better detection performance
  - More types of explosives
  - Lower masses
  - Increased probability of detection (PD)
  - Decreased probability of false alarm (PFA)

6

DHS Tactics

- *Augment* abilities of system vendors with 3rd party involvement
- 3rd parties
  - Academia
  - Industry other than system vendors
- Create centers of excellence (COE) at universities
- Hold workshops to educate 3rd parties and discuss issues with involvement of 3rd parties

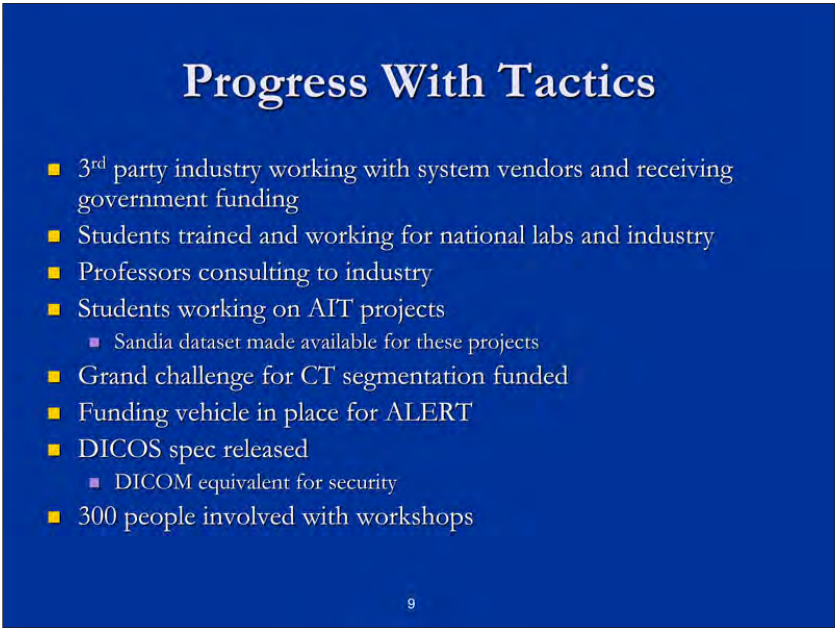
7

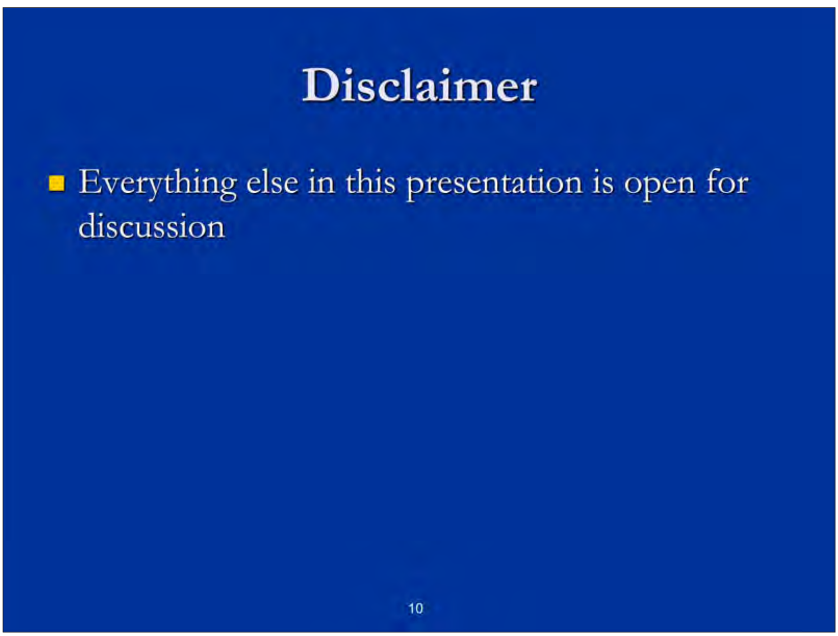
Augmenting System Vendors

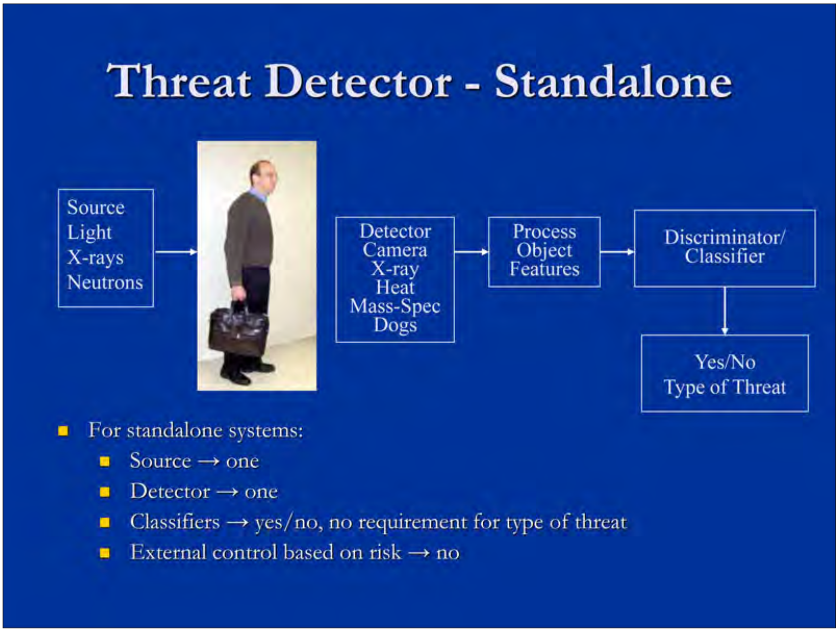
- SAIC/Reveal
- L-3 Communication
- Analogic
- Morpho Detection (formerly GE Security and InVision)
- AS+E
- SureScan
- Rapiscan
- Smiths Detection

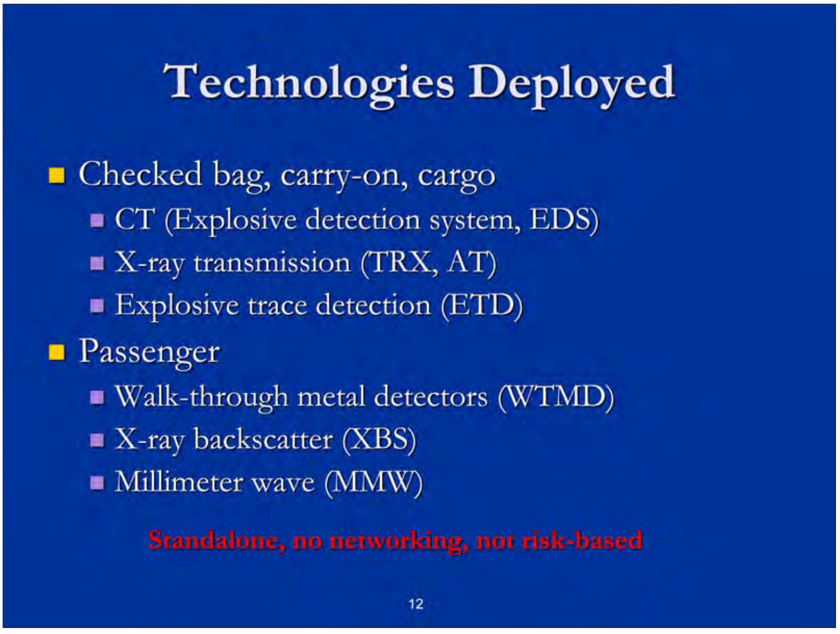
Excellent equipment developed by very smart people.
Material supplied by most of these vendors.

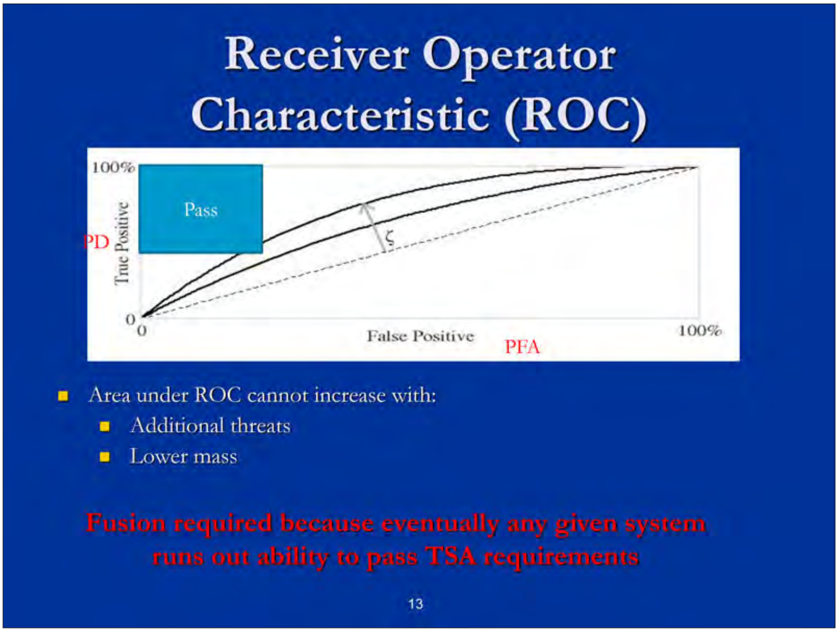
8

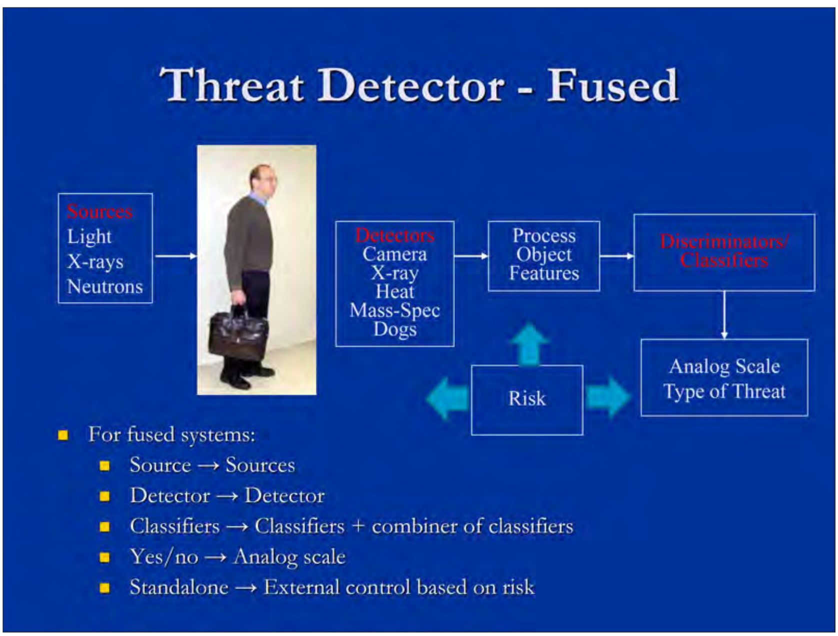

Progress With Tactics
3rd party industry working with system vendors and receiving government funding
Students trained and working for national labs and industry
Professors consulting to industry
Students working on AIT projects
Sandia dataset made available for these projects
Grand challenge for CT segmentation funded
Funding vehicle in place for ALERT
DICOS spec released
DICOM equivalent for security
300 people involved with workshops
9


Disclaimer
Everything else in this presentation is open for discussion
10


Threat Detector - Standalone
Source
Light
X-rays
Neutrons
Detector
Camera
X-ray
Heat
Mass-Spec
Dogs
Process
Object
Features
Discriminator/
Classifier
Yes/No
Type of Threat
For standalone systems:
Source → one
Detector → one
Classifiers → yes/no, no requirement for type of threat
External control based on risk → no


Technologies Deployed
Checked bag, carry-on, cargo
CT (Explosive detection system, EDS)
X-ray transmission (TRX, AT)
Explosive trace detection (ETD)
Passenger
Walk-through metal detectors (WTMD)
X-ray backscatter (XBS)
Millimeter wave (MMW)
Standalone, no networking, not risk-based
12


Receiver Operator Characteristic (ROC)
100%
Pass
PD
True Positive
ς
0
0
False Positive
PFA
100%
Area under ROC cannot increase with:
Additional threats
Lower mass
Fusion required because eventually any given system runs out ability to pass TSA requirements
13

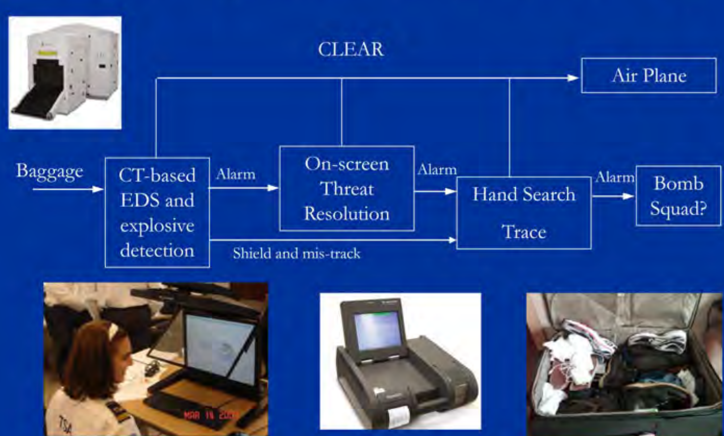

Threat Detector - Fused
Sources
Light
X-rays
Neutrons
Detectors
Camera
X-ray
Heat
Mass-Spec
Dogs
Process
Object
Features
Discriminators/
Classifiers
Analog Scale
Type of Threat
Risk
For fused systems:
Source → Sources
Detector → Detector
Classifiers → Classifiers + combiner of classifiers
Yes/no → Analog scale
Standalone → External control based on risk

Possible Technologies to Fuse to Deployed Technologies

- X-ray diffraction (XRD)
- Diffraction enhanced or index of refraction imaging
- Quadrupole resonance (QR)
- Raman scatter
- Improved explosive trace detection (ETD) and sampling schemes
- Terahertz imaging and spectroscopy (THZ)
- Magnetic resonance imaging/spectroscopy (MRI/MRS)
- Humans

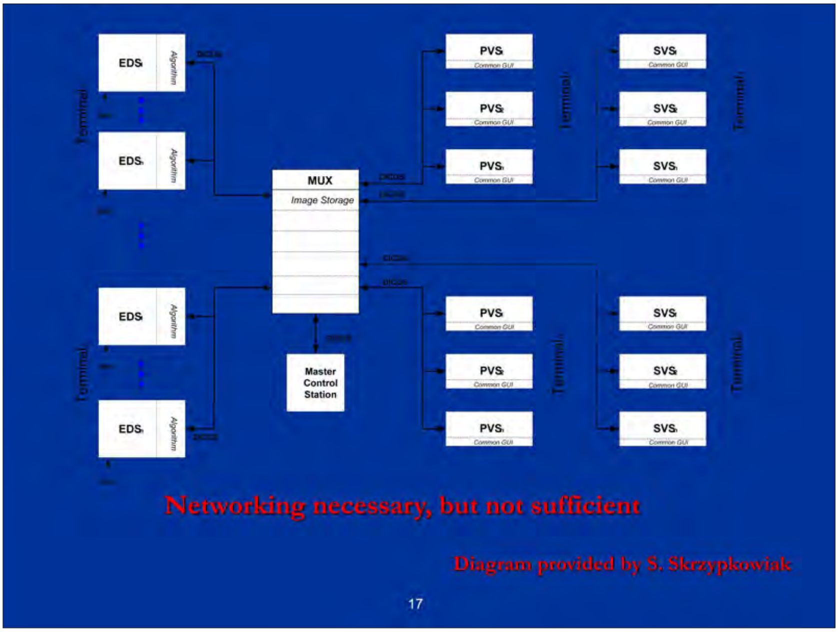
15

"Fused" Systems for Checked Bag



Images from the internet and previous presentations

16


EDS
Algorithm
Terminal
MUX
Image Storage
Master Control Station
PVS
Common GUI
SVS
Networking necessary, but not sufficient
Diagram provided by S. Skrzypkowiak
17


"Fused" Systems - Checkpoint
Behavioral Detection Officer
All images from the internet
18

Other Examples

- Security
  - CT/XRD
  - CT/QR
  - Shoe screeners + WTMD
  - Puffers (walk-through) + WTMD
- Medical
  - Picture archive communication systems (PACS) + scanner
  - SPECT/CT
  - PET/CT
  - PET/MRI

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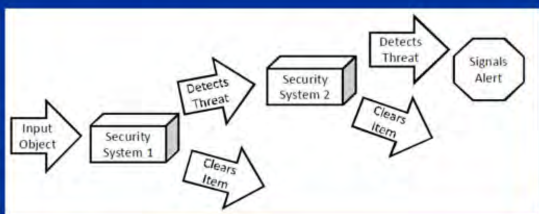
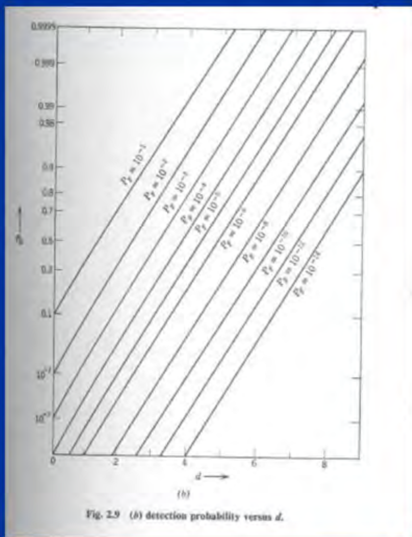
AND Fusion - Correlation



PD↓
PFA↓

Figures from NAS fusion report.

20



- •Scale is logarithmic
- •Expensive to increase PD when PD is above 90%
- •Complicated when systems are correlated
- •Non-diagonal confusion matrix

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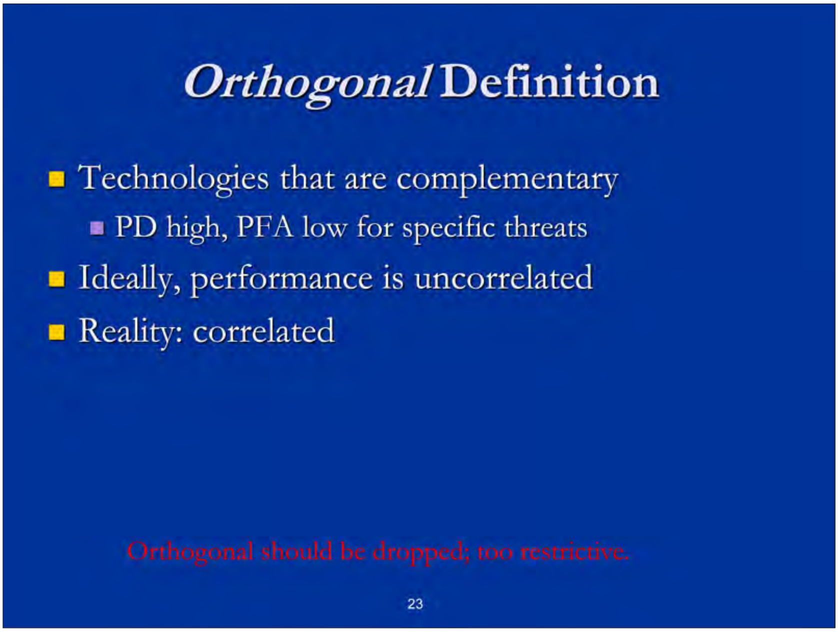
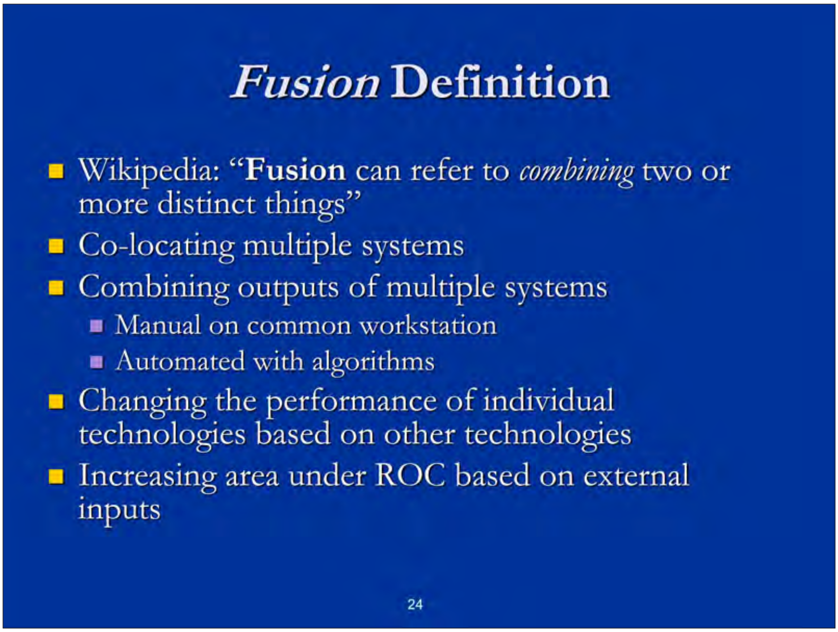
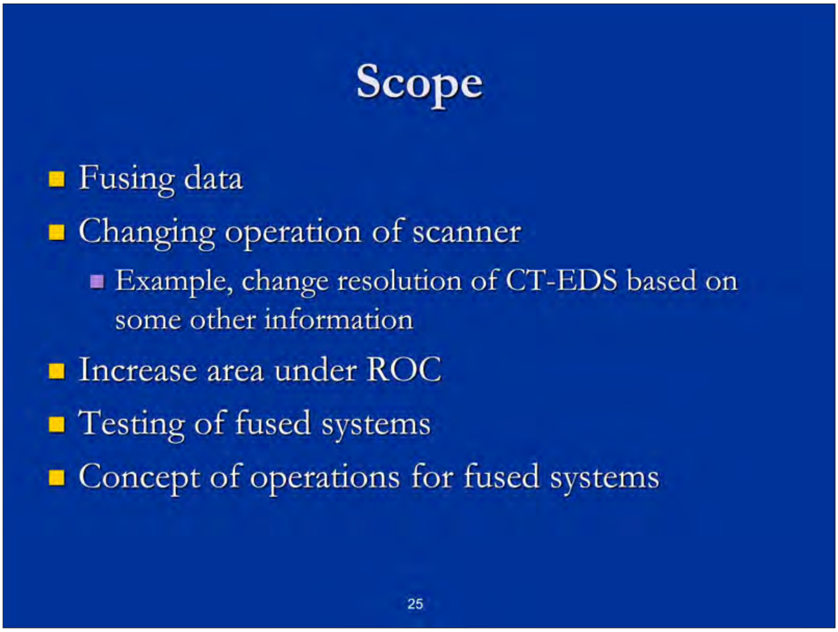
Technologies Definitions

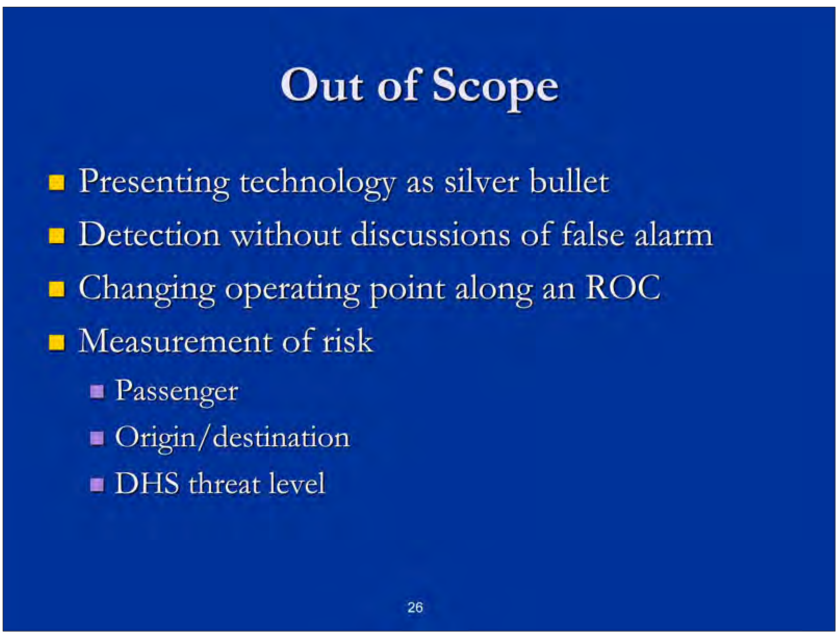
- Imaging
  - CT, x-ray transmission, XBS, MMW, video
- Spectral
  - QR, XRD, ETD, Raman, THZ
- Human
- Intelligence (out of scope)
  - Risk: world, person, specific threats
  - Observation

22


Orthogonal Definition
Technologies that are complementary
PD high, PFA low for specific threats
Ideally, performance is uncorrelated
Reality: correlated
Orthogonal should be dropped; too restrictive.
23


Fusion Definition
Wikipedia: "**Fusion** can refer to *combining* two or more distinct things"
Co-locating multiple systems
Combining outputs of multiple systems
Manual on common workstation
Automated with algorithms
Changing the performance of individual technologies based on other technologies
Increasing area under ROC based on external inputs
24


Scope
Fusing data
Changing operation of scanner
Example, change resolution of CT-EDS based on some other information
Increase area under ROC
Testing of fused systems
Concept of operations for fused systems
25


Out of Scope
Presenting technology as silver bullet
Detection without discussions of false alarm
Changing operating point along an ROC
Measurement of risk
Passenger
Origin/destination
DHS threat level
26

Questionnaire

- Request for everyone to answer questions preferably during the workshop
- Hand in at end of workshop or email
- Typed or handwritten acceptable
- Name is optional

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Questions

- Should fused systems be considered?
- What analytical basis or metric should be used to decide which technologies to fuse for what effect?
- What technologies could be fused and for what application?
- What are the technological enablers?
- What examples are there for fused technologies that worked and didn't work? (The examples can be for aviation security and other applications such as Defense.)
- What information needs to be made available so that people can do research and companies develop and deploy technologies?
- What are the boundary conditions or rules should be put in place to use fused systems?
- What changes need to be made by the TSA to allow fused systems to be deployed?
- What should the agenda be for going forward for the research/development requirements necessary to proceed with technology fusion as related to security applications?

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Barriers for 3rd Parties

- Access to data and scanners
  - Proprietary and classification issues
  - Non classified material may lead to classified material
- Classified requirement specifications
- Publications may be blocked
- Short time frame
  - DHS is reactionary
- DHS/TSA is not NIF, NSF, DOD
  - Difficult to spend money

DHS is trying to remove these barriers.
Working with industry is easiest path.

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Presenters - Content

- Connect material to security
- 2nd slide must be summary and conclusions
- Discuss strengths and weaknesses
- Concentrate on fusing technologies
  - No need to sell technology for complete solution

30

Presenters - Logistics

- Adhere to time limits set in agenda
  - Timer in use
- No questions in first ~10 minutes
- Discussion required during presentation
- Delete duplicated material on the fly
- Leave presentation on laptop or USB stick

31

Corrections from Previous Workshops

- Multiple session moderators
  - Harry Martz, LLNL
  - David Atkinson, PNNL
  - Carl Crawford, Csuptwo
- Non-working lunches and breaks
- Scheduled break and lunches

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Participant Identification

- Biographies and pictures distributed in lieu of formal introductions
- Please identify yourself and institution first time you speak or ask questions
- Minutes will be taken, but edited for final report

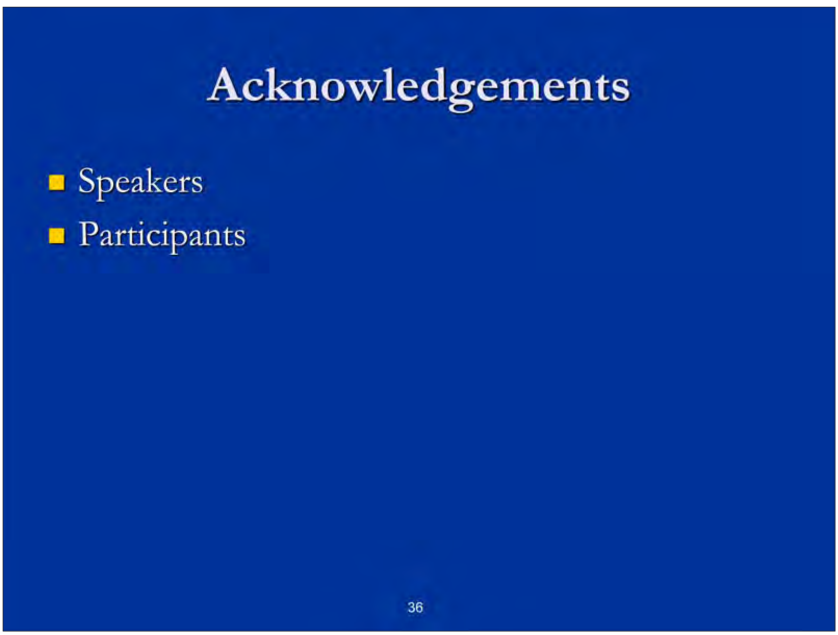
33

Deliverables

- Written report to DHS addressing goals set forth on previous slides
  - Released to public
- Report written based on
  - Presentations
  - Discussion
  - Questionnaires
  - Minutes

34


Acknowledgements
Northeastern University (NEU)
Awareness and Localization of Explosives-Related Threats (ALERT) Center of Excellence
Department of Homeland Security (DHS)
Lawrence Livermore National Laboratory (LLNL)
U.S. Department of Homeland Security
Northeastern University
Lux Veritas Virtus
Boston, Massachusetts
Lawrence Livermore National Laboratory
Awareness and Localization of Explosives-Related Threats
ALERT
35


Acknowledgements
Speakers
Participants
36

Logistics

- Mariah Nóbrega
- Rachel Harger
- Brian Loughlin

Let them know if you need support during or after workshop.

37

Final Remarks

- "Terrorism causes a loss of life and a loss of quality of life," Lisa Dolev, Qylur
- Need improved technology
- Thank you for participating

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16.3 John Reynolds: Explosives Review

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Explosives Review

John G. Reynolds

Energetic Materials Center, the Forensic Science Center
And the Center for Nondestructive Characterization

ADSA05, Northeastern University, Boston, MA, May 3, 2011

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551
This work performed under the auspices of the U.S. Department of Energy by
Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

LLNL-PRES-481290

Definitions

- Explosion—is a rapid increase in volume and release of energy in an extreme manner, creating a shock wave
- Detonation—a cooperative, supersonic chemical reaction (oxidation)
- Deflagration—burning (typically faster than a wood fire)
- Combustion—oxidation process that occurs after a detonation
- Afterburn—post event (usually detonation) oxidation of gases
- Detection—includes trace and bulk
- Critical Diameter—minimum thickness of an explosive needed for detonation
- TMD—theoretical maximum density, intrinsic density of the material without voids
- Texture—surface or volume features leading to inhomogeneity on a regional level

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Reynolds 8.12.2010

2

London Tube Bombs 2005 and 2007

- Hydrogen peroxide/fuel mixtures
  - Component #1 H_2O_2
    - Purchased from beauty shop
    - Concentrated by distillation on stove top
  - Component #2 Flour
    - Purchased at the store
    - No further purification needed
  - Ease of making the material
    - Put A in a bowl
    - Put B in the same bowl
    - Stir
    - Makes a material that can be molded for the 1st 24 hours

Metropolitan police demonstration

Reference: metro.co.uk (2008)

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London Heathrow Airport 2007

- Hydrogen peroxide/fuel mixtures
  - Component #1 H_2O_2
    - must be concentrated to work in this situation (concentrated H_2O_2 can be purchased or made)
    - formulas come from patent literature of the 1950s
  - Component #2 Fuel
    - Any carbohydrate, alcohol, carbon source will work
    - Flour, cumin seed, and sugar are popular in open terrorist literature
  - Ease of making the material
    - Put A in a bowl
    - Put B in the same bowl
    - Stir

Intended Targets

Reference: bbc.co.uk (2009)

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Flight NW 253 2009

December 25, 2009, Umal Farouk Abdulmutallab attempted to blow up NW flight upon landing in Detroit using an improvised PETN device

Igniter

Detonator

Main charge

Reference: Wikipedia and www.mlive/com

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5

Printer Cartridge Bombs 2010

October 29, 2010, PETN filled printer cartridges being shipped from the middle east were timed to blow up over US

Reference: BBC/do/uk, The Telegraph

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6

Classification of Explosives

Criteria	Class	Characteristics	Examples
Rates of Explosions	Low	Burn Rapidly	Black powder and nitrocellulose
	High	Detonates	Dynamite, TNT, RDX, PETN
Sensitivity to shock, friction and heat	Primary	Very sensitive	$Pb(N_3)_2$, Hg fulminate
	Secondary	Sort of insensitive	Dynamite, TNT, RDX, PETN
	Blasting Agents	Very insensitive	ANFO
Chemical Composition	Nitro	NO_2-C	TNT
	Nitrate ester	NO_2-O-C	Nitroglycerine
	Nitramines	NO_2-N-C	RDX
	Non-nitrogen based	variable	TATP

From Field Detection Technologies for Explosives, Y. Sin, ILM Pub. 2010

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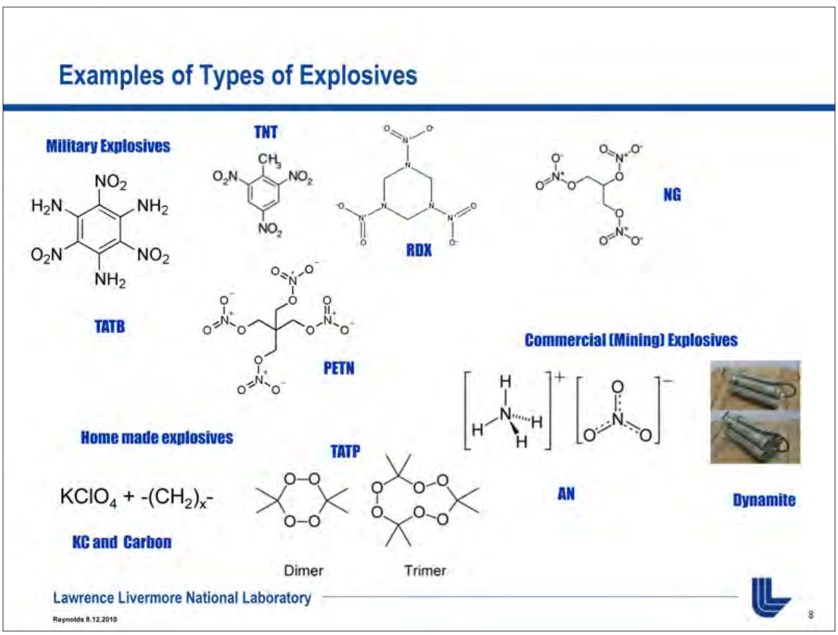
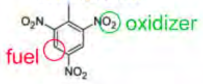


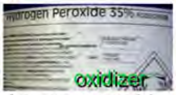
Explosion is an oxidation

Ideal explosives



TNT

Non-ideal explosive

fuel  + 

Mining - sugar & hydrogen peroxide

- Each explosive:
  - Contains a different amount of available chemical energy
  - Releases a different fraction of this energy in detonation
  - Releases the detonation energy at a different rate
  - Produces different products at different temperatures that may combust with ambient air
- The challenge is to determine all these factors, apply them to structures, and determine the minimal amount that will cause the undesirable effect ← **This sets your detection limit**

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Detonation detected by plate deformation

Detonator

Sensors

Plate

Burn

No Dent

Detonation

Dent & Holes

- The presence of a definitive dent is used as a definitive result for a detonation (above sonic pressure wave)
- The absence of a dent is not a detonation but a deflagration or burn or dud (subsonic pressure wave)
- Information can be gained by the measured depth of the dent (impulse pressure, Energy)

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Thermochemical Evaluations of Selected Explosives

Explosive	Density	Mechanical Energy of Detonation (kJ/g)	Detonation velocity at infinite radius (mm/us)	Heat of Combustion (kJ/g)
C-4 (RDX and Binder)	1.60	5.1	7.7	11.8
TNT (pressed)	1.62	4.2	7.0	14.5
Dynamite	1.10	2.4	4.5	2.4
AN + fuel oil (RHXD)	1.32	3.0	6.8	3.4
TATP	0.42	3.9	3.8	25
PETN	0.80	5.52	4.7	
PETN	1.20	5.71	6.4	
PETN	1.78	5.93	8.6	

Higher detonation energy, stronger impulse is expected

Detonation velocity is dependent on density

Higher heat of combustion more likely hood of after burning

Military explosives are generally carbon rich

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Performance Factors related to detection issues

- **Density affects detonation energy output and detonability**
  - **Most military materials are 90+ % of TMD**
  - **Most liquid materials are 100% of TMD**
  - **Solid-solids mixtures (unless mechanically pressed) are 50 to 80% of TMD (even when hand packed)**
  - **Solid-liquid mixtures are around the density of the solid**
  - **Gels and goos vary in performance because the density is constantly changing due ever changing composition**
- **Shape and form affect performance because the explosive power can be directed**
  - **Spherical directs energy in all directions**
  - **Sheet explosive directs the energy in two directions**
  - **Explosively formed projectiles direct the energy in one direction**

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Varied properties of Explosives

- Texture
  - Single component—powders, pressed, liquids and viscous liquids
  - Liquid-liquid (miscible or non miscible, viscous layers)
  - Solid-liquid (slurries, foams, wet powders)
  - Solid-solid (powders of all different packing, packing of powders to different densities)
- Reactivity—a reactive chemical mixed with something that can react
  - Thermal instability causes changes in temperature
  - Reaction causes bubbling and phase changes
  - Hygroscopic dissolution causing mixing
  - Surface reactivity non-homogenous density throughout the solid
  - Interact with containers (compatibility)

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Detecting explosives

- For military explosives, generally the carbon to nitrogen ratio is somewhat usable for nitrate based explosives—few non explosives compounds fall into this range
- For improvised explosives, this is generally not the case
  - Some are not nitrate based
  - Many are mixtures of materials commonly found in commerce
  - Many are binary mixtures where the components alone do not identify as explosive (could be brought to site separately)
  - Endless combinations of oxidizers and fuels
  - In solid-solid and some solid-liquid cases, the detection property can depend upon the density. However, the density can be quite variable.

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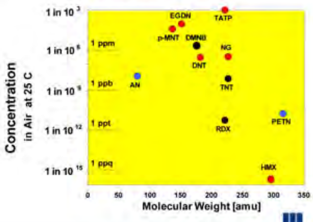
Do explosives emit signatures?

- Does stuff flake off?
  - Studies show explosives end up everywhere with sloppy handling of explosives
  - Just try to wash your hands to get rid of explosives
- Do explosives emit a plume?
  - Lot of people think so
  - Not much has been shown



From Dionne et al., J. Energetic Materials 4, 447-472 (1986)

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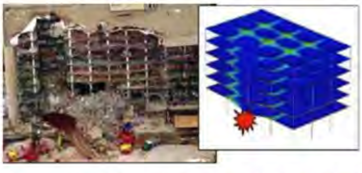
15

Amount of explosives that has to be detected

- Question: What is the minimum amount of explosive that needs detecting?
- Answer: This is the amount that is the boarder line between catastrophic and non catastrophic failure of the structure being protected
  - For office buildings, this can be fairly large
  - For airplanes, this can be fairly small
  - For humans, there is no minimum amount
  - Dependent on type of explosive
  - Dependent on the performance of the explosive
  - Dependent on how the structure responds



Catastrophic amount is a dependent on how the explosive performs and how the structure responds

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16

Summary

Things to remember about explosives:

- Are combinations of oxidizers and fuels
- Are monomolecular or be mixtures of components
- Some are simple to make by non-technical people
- Performance is total amount of energy and how the energy is applied
- Improvised materials can be just as damaging as military explosives
- Have large variations in physical properties—liquids, solids, goos, gels, etc.
- Some HMEs are highly chemically reactive
- Packing density, shape and form effect performance and detection
- Signatures are the key to detection, elusive as they are
- Detection limits depend on what is being protected

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Supplementary Material

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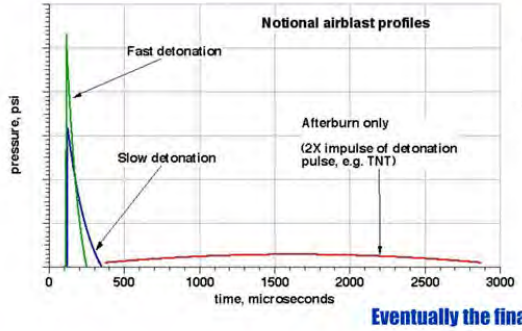
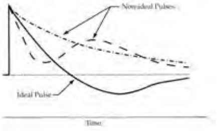
Energy may be released on very different time scales





Eventually the final products are CO_2 and H_2O

This distribution varies based on explosive type and structure

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Outline

- What is an explosion (oxidation-reduction)
- Examples of explosives
- What makes explosives different (the way they output energy)
- Comparison of energy output of explosives
- Performance characterization of explosives
- Varied physical and chemical properties of explosives
- Various form effects of explosives
- Real life examples
- Implications for detection

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Performance Factors affecting Detection

- **Materials**
  - **Composition of explosive (endless combinations)**
- **Density**
  - **Density ranges for each explosive**
- **Critical diameter**
  - **Thickness**
  - **shape**
- **Shape**
  - **Sphere in all directions**
  - **Sheet directs energy in two directions**
  - **EFP direct the energy in one direction**

Detonability Studies

Experiment	Average Velocity (km/s)	Plate Dent Depth (mm)	Result
Composition B	7.82	9.5	Detonation
Base line	-	none	A mess
IE-019	1.94	none	Deflagration
IE-020	1.99	scoring	Deflagration
IE-021	2.17	none	Deflagration
IE-017	-	none	Deflagration
IE-003	6.77	6.0	**Detonation**
IE-016	6.56	5.08	**Detonation**
IE-004	6.24	3.02	**Detonation**
IE-022	7.01	5.33	**Detonation**

Some HMEs detonate, some do not detonate

Cylinder tests give quantitative energy release information

- Cylinder test - a pipe full of explosive, detonated at the bottom
- Detonation proceeds up the pipe, blowing the pipe outward
- Wall velocities are measured at various points on the tube
- Heterodyne PDV records and curvature measured with a streak camera
- Data placed in hydrocode with boundary conditions set by the copper cylinder
- Equation of state obtained from fitting the wall velocity data to the cylinder model with the hydrocode
- Equation of state now usable in other configurations that specify boundary conditions
- Hydrocode gives a pressure time history output usable in blast effects models

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Cylinder explosion shows results of reaction occurring in microseconds

Frame interval = 1 microsecond

Pipe diameter ~ 50 mm

Wall velocity ~ 2 mm/µs or 2000 m/s or >1 mile/s

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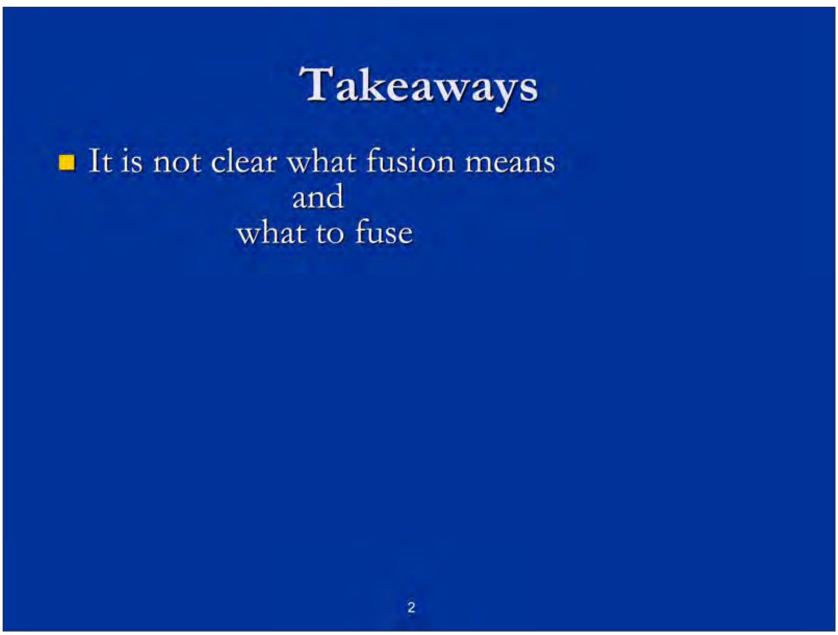
16.4 Harry Martz: Existing technology overview: strengths and weaknesses



Takeaways continued

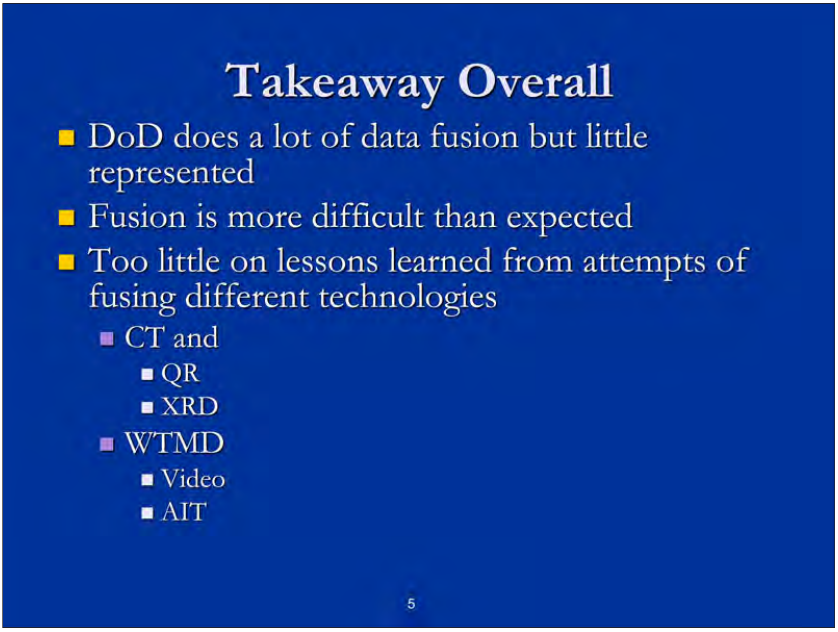
- Emerging technologies could be deployed with
  - Deployed technologies
  - Other emerging technologies
  - Humans
- For technologies discussed Security and Medical
  - There was too much on strengths
  - Too little on weaknesses
  - *Both* are needed to enable ideas on fusion

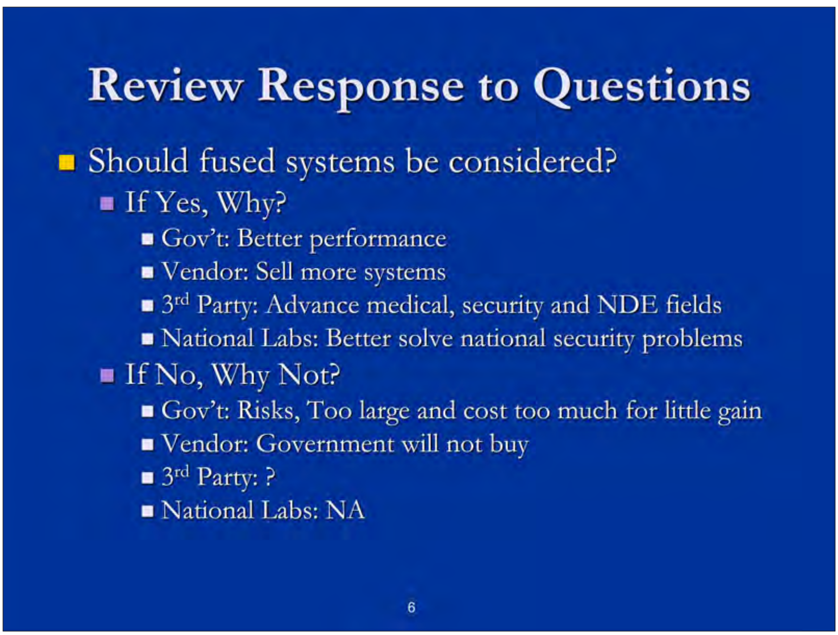
3

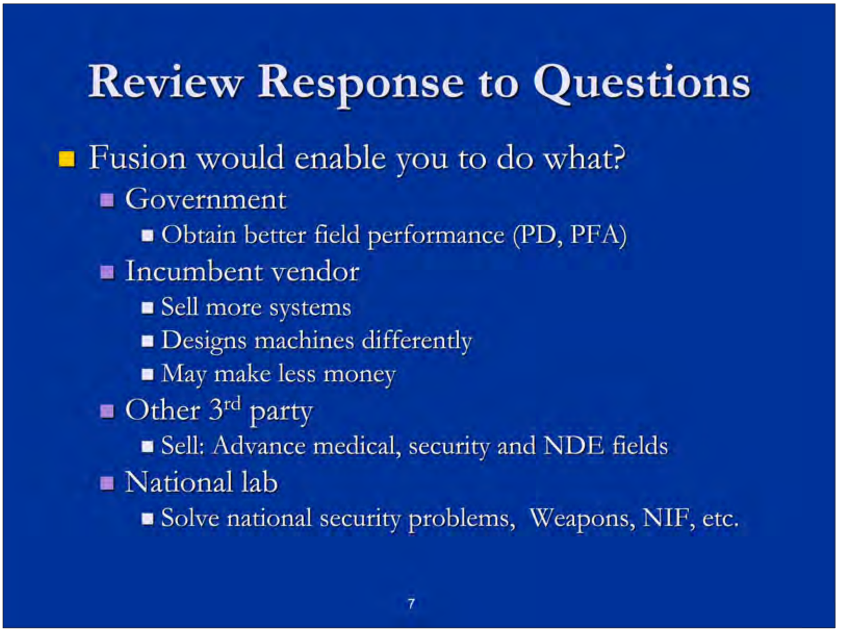
Takeaways continued

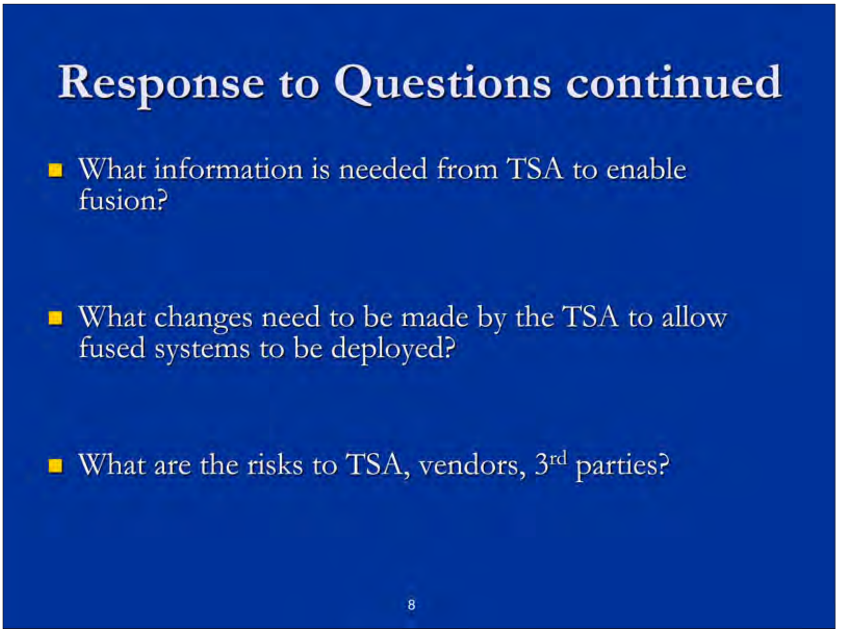
- Mathematics of fusing systems
  - There are different
    - Places where information can be fused
    - Methods used to fuse information
  - Complex math to human fusion
  - It is possible to degrade performance by fusing systems
  - No prescription for doing it right
- Third party experiences
  - Appling their ATR algorithms to incumbent vendors

4


Takeaway Overall
DoD does a lot of data fusion but little represented
Fusion is more difficult than expected
Too little on lessons learned from attempts of fusing different technologies
CT and
QR
XRD
WTMD
Video
AIT
5


Review Response to Questions
Should fused systems be considered?
If Yes, Why?
Gov't: Better performance
Vendor: Sell more systems
3rd Party: Advance medical, security and NDE fields
National Labs: Better solve national security problems
If No, Why Not?
Gov't: Risks, Too large and cost too much for little gain
Vendor: Government will not buy
3rd Party: ?
National Labs: NA
6


Review Response to Questions
Fusion would enable you to do what?
Government
Obtain better field performance (PD, PFA)
Incumbent vendor
Sell more systems
Designs machines differently
May make less money
Other 3rd party
Sell: Advance medical, security and NDE fields
National lab
Solve national security problems, Weapons, NIF, etc.
7


Response to Questions continued
What information is needed from TSA to enable fusion?
What changes need to be made by the TSA to allow fused systems to be deployed?
What are the risks to TSA, vendors, 3rd parties?
8

Questions for Vendors

- How could fusion benefit your company?
  - Create a more competitive edge, sell more systems
- How could fusion hurt your company?
  - They could leave the impression that they have solved a problem when they haven't
  - Advance a competitor, could loose competitive edge
- Do you support DICOS?
  - How can it be accelerated
  - Issues

9

Questions for 3rd Parties

- What information and material would you need to fuse systems?
- What issues would be barriers for your participation?
  - Lack of data, scan parameters, funding, classification issues
- How much time would you need to develop fused systems?
  - 3 months for low hanging fruit, 1 year for optimization of harder problems
- Do you want to get involved in the security field?
  - Still deciding still not clear if there is a market here

10

Questions for Everyone

- Do you have recommendations to enable fusion?
  - Standard format such as DICOS
  - Access to raw (straight off the detector) data
- What did you like about this workshop?
- What would you like to see changed for future workshops?

11

Next Steps Issues to be Resolved

- How do we learn from past and current fusion attempts?
- How to access field and lab data to test different fusion ideas?
- How to deal with real threats if the data is classified?
  - Create a set of phantoms that TSA, Vendors, etc. agree upon that are representative of real threats

12

Discussion

- Around the room

13

Response to Questions continued

- What did you like about this workshop?
- What would you like to see changed for future workshops?
- What topics would you like to see addressed in future workshops?

14

Response to Questions continued

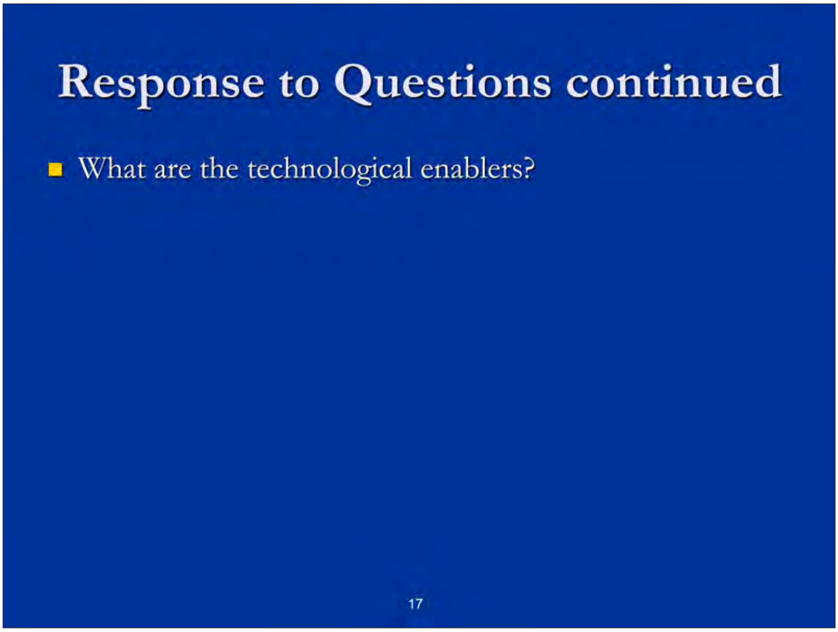
- What analytical basis or metric should be used to decide which technologies to fuse for what effect?

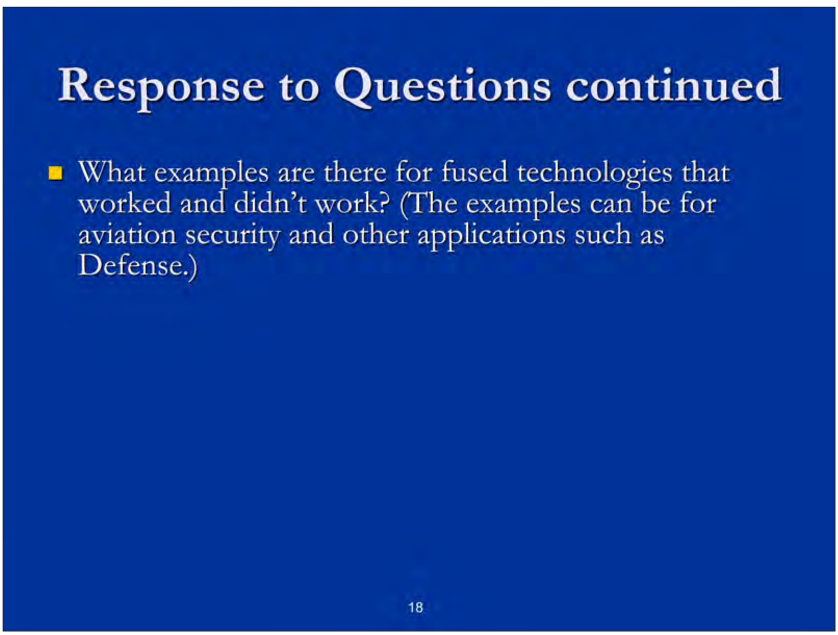
15

Response to Questions continued

- What technologies could be fused and for what application?

16


Response to Questions continued
What are the technological enablers?
17


Response to Questions continued
What examples are there for fused technologies that worked and didn't work? (The examples can be for aviation security and other applications such as Defense.)
18

Response to Questions continued

- What information needs to be made available so that people can do research

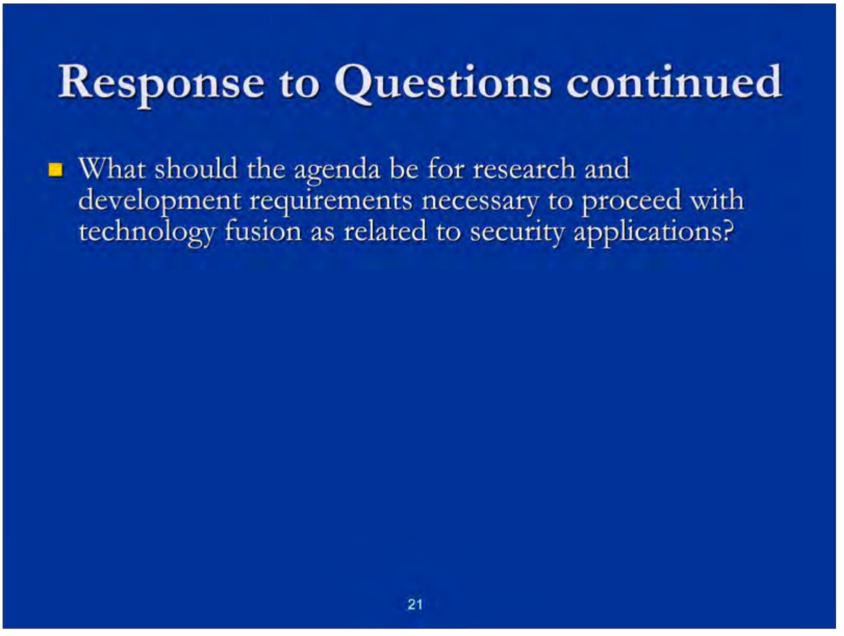
- What information needs to be made available so that companies develop and deploy technologies?

19

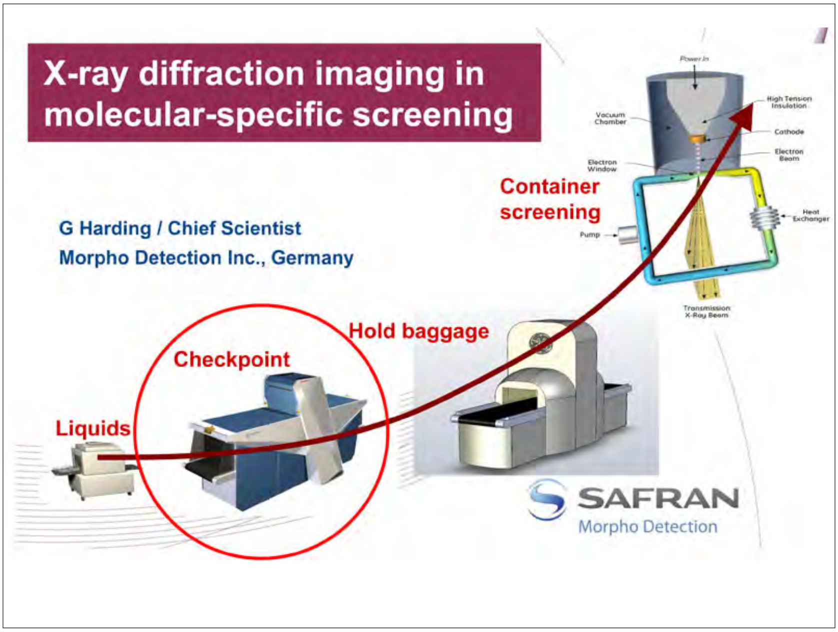
Response to Questions continued

- What are the boundary conditions or rules should be put in place to use fused systems?

20


Response to Questions continued
What should the agenda be for research and development requirements necessary to proceed with technology fusion as related to security applications?
21

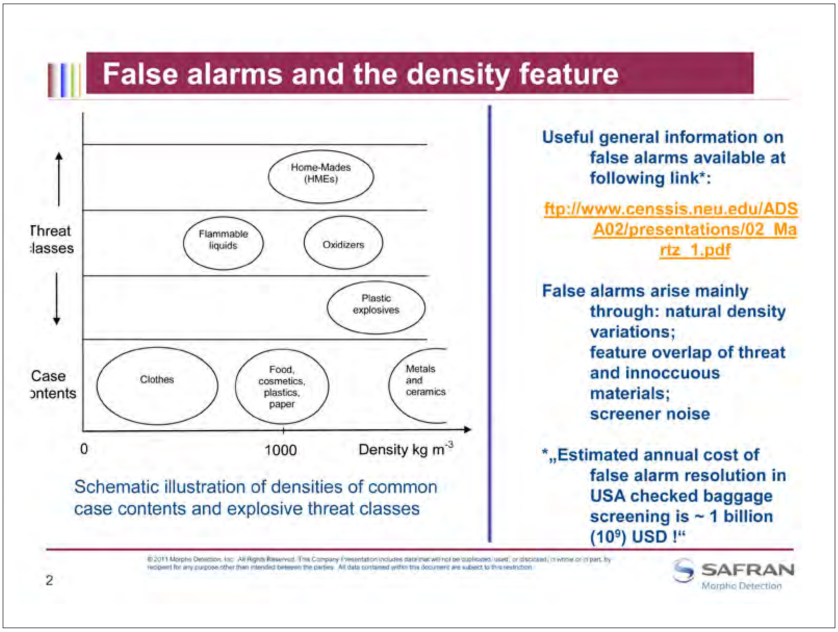
16.5 Geoffrey Harding: X-ray diffraction (XRD)



Summary / Conclusions

- There has been a steady increase in the range of explosive threat classes (plastics, LAGs, HMEs …) used in airplane bomb attempts
- In general, each new threat degrades screener false alarm rate (FAR)
- False alarm resolution is very expensive!
- Screening modalities that provide multiple, uncorrelated features (molecular-specific) counter the trend that new threat classes increase FAR
- X-ray diffraction (XRD) is a molecular-specific modality that can target explosives over a wide range of threat classes (good results also with liquids)
- Conventional energy-dispersive XRD can be modified to form the basis of an imaging modality: XD*i* (x-ray diffraction imaging)
- Scan speed of XD*i* can be significantly increased with multiple x-ray beams; multiple detectors and innovative beam topologies (MIFB)
- MorphoDetection Inc., is developing a 3rd Generation XD*i* Check Point screener with Class D liquids identification capability, to be show-cased at end of 2011

1 SAFRAN Morpho Detection


False alarms and the density feature
Home-Mades
(HMEs)
Threat
classes
Flammable
liquids
Oxidizers
Plastic
explosives
Case
contents
Clothes
Food,
cosmetics,
plastics,
paper
Metals
and
ceramics
0
1000
Density kg m-3
Schematic illustration of densities of common case contents and explosive threat classes
Useful general information on false alarms available at following link*:
ftp://www.censsis.neu.edu/ADSA02/presentations/02_Martz_1.pdf
False alarms arise mainly through: natural density variations;
feature overlap of threat and innocuous materials;
screener noise
*„Estimated annual cost of false alarm resolution in USA checked baggage screening is ~ 1 billion (10⁹) USD !“
2
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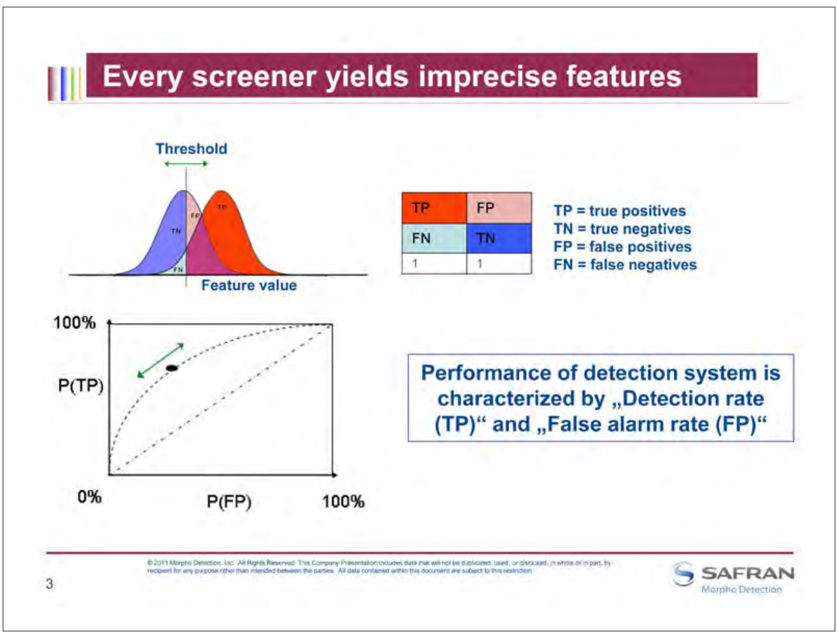
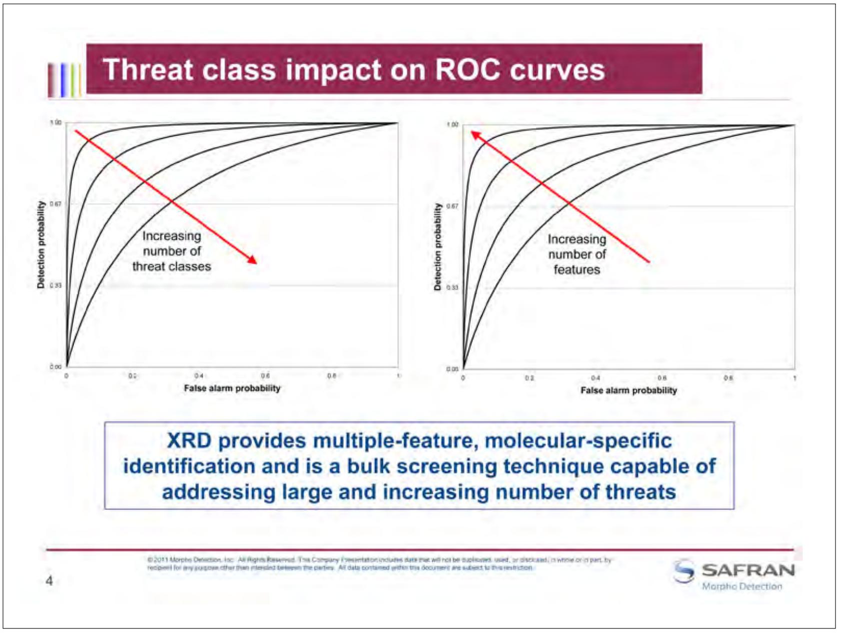
Morpho Detection


Every screener yields imprecise features
Threshold
Feature value
TP
FP
FN
TN
1
1
TP = true positives
TN = true negatives
FP = false positives
FN = false negatives
100%
P(TP)
0%
P(FP)
100%
Performance of detection system is characterized by „Detection rate (TP)“ and „False alarm rate (FP)“
3
SAFRAN
Morpho Detection


Threat class impact on ROC curves
Detection probability
False alarm probability
Increasing number of threat classes
Increasing number of features
XRD provides multiple-feature, molecular-specific identification and is a bulk screening technique capable of addressing large and increasing number of threats
4
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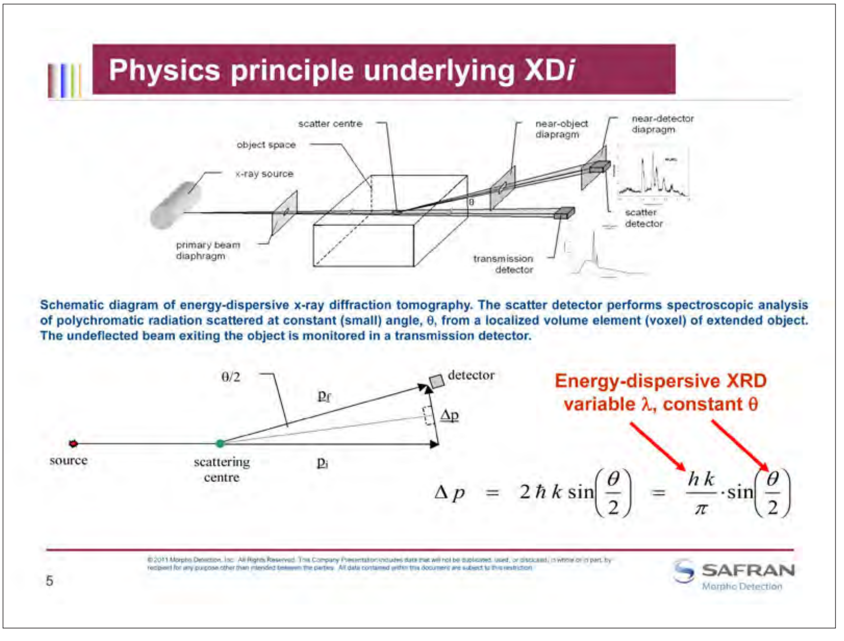
Morpho Detection


Physics principle underlying XDi
scatter centre
object space
x-ray source
near-object diapragm
near-detector diapragm
scatter detector
primary beam diaphragm
transmission detector
Schematic diagram of energy-dispersive x-ray diffraction tomography. The scatter detector performs spectroscopic analysis of polychromatic radiation scattered at constant (small) angle, θ, from a localized volume element (voxel) of extended object. The undeflected beam exiting the object is monitored in a transmission detector.
θ/2
detector
source
scattering centre
Energy-dispersive XRD
variable λ, constant θ
$\Delta p = 2\hbar k \sin\left(\frac{\theta}{2}\right) = \frac{h k}{\pi} \cdot \sin\left(\frac{\theta}{2}\right)$
5
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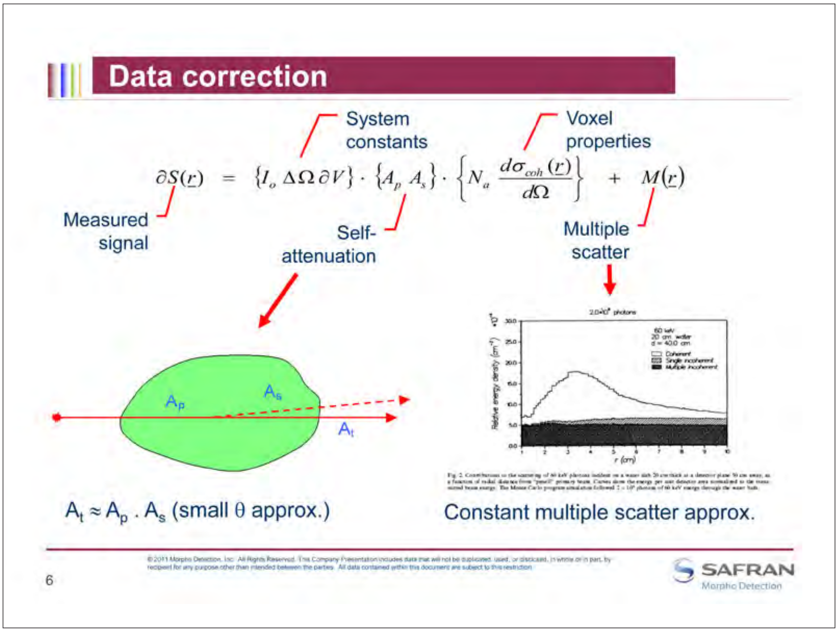
Morpho Detection


Data correction
System constants
Voxel properties
$\partial S(\underline{r}) = \{I_o\, \Delta\Omega\, \partial V\} \cdot \{A_p\ A_s\} \cdot \left\{N_a \frac{d\sigma_{coh}(\underline{r})}{d\Omega}\right\} + M(\underline{r})$
Measured signal
Self-attenuation
Multiple scatter
A_p
A_s
A_t
$A_t \approx A_p \cdot A_s$ (small θ approx.)
Constant multiple scatter approx.
6
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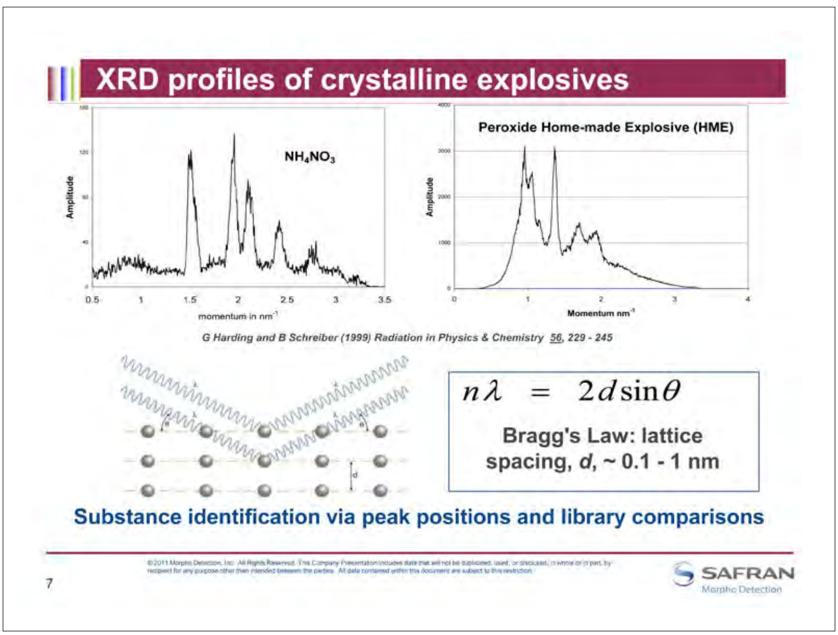
Morpho Detection


XRD profiles of crystalline explosives
Amplitude
NH_4NO_3
momentum in nm^{-1}
Peroxide Home-made Explosive (HME)
Momentum nm^{-1}
G Harding and B Schreiber (1999) Radiation in Physics & Chemistry 56, 229 - 245
$n\lambda = 2d\sin\theta$
Bragg's Law: lattice spacing, d, ~ 0.1 - 1 nm
Substance identification via peak positions and library comparisons
7
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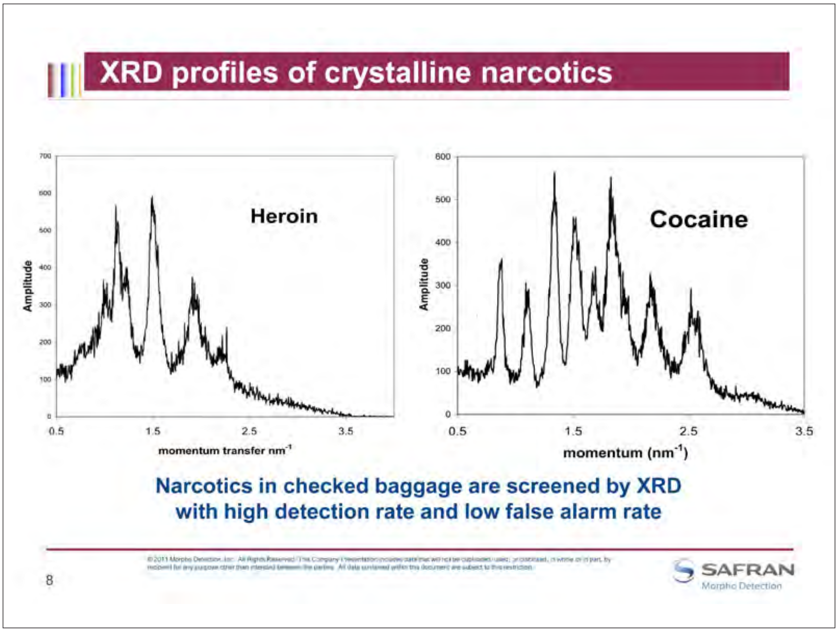
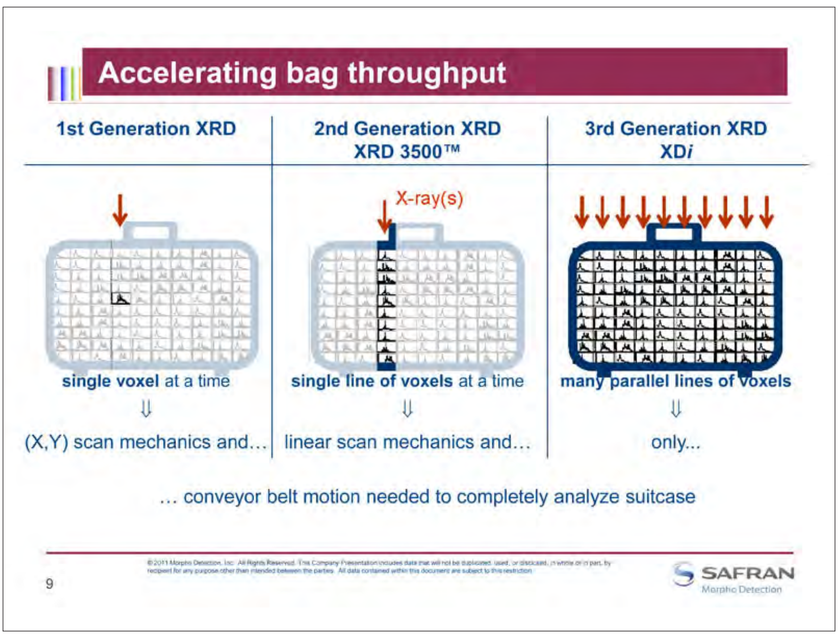
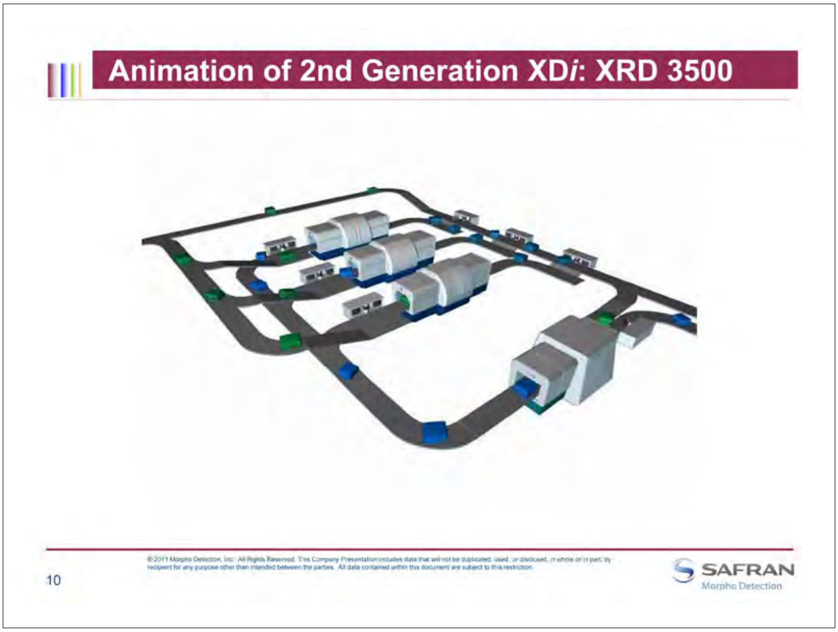
Morpho Detection


XRD profiles of crystalline narcotics
Heroin
Amplitude
momentum transfer nm-1
Cocaine
Amplitude
momentum (nm-1)
Narcotics in checked baggage are screened by XRD
with high detection rate and low false alarm rate
8
SAFRAN
Morpho Detection


Accelerating bag throughput
1st Generation XRD
2nd Generation XRD
XRD 3500™
3rd Generation XRD
XDi
X-ray(s)
single voxel at a time
⇓
(X,Y) scan mechanics and…
single line of voxels at a time
⇓
linear scan mechanics and…
many parallel lines of voxels
⇓
only...
… conveyor belt motion needed to completely analyze suitcase
9
SAFRAN
Morpho Detection


Animation of 2nd Generation XDi: XRD 3500
10
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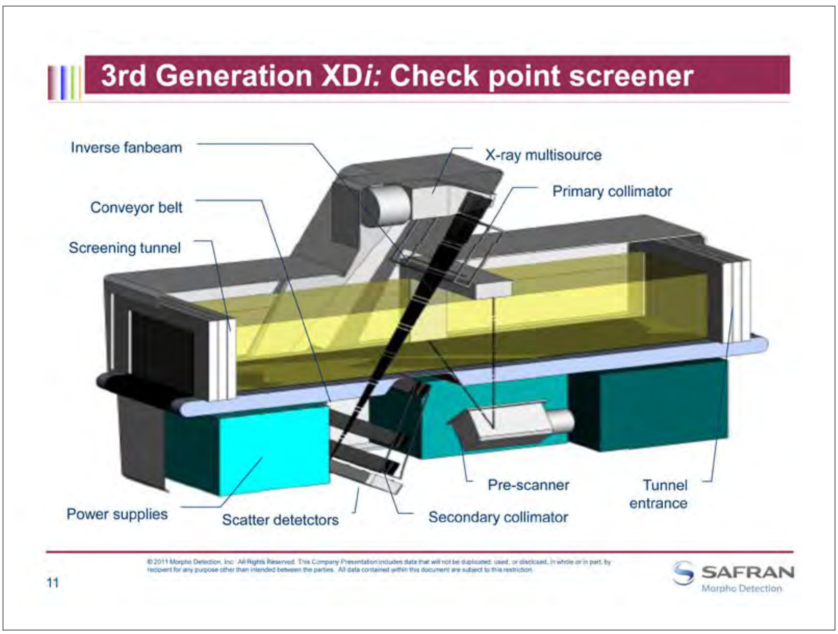
Morpho Detection


3rd Generation XDi: Check point screener
Inverse fanbeam
Conveyor belt
Screening tunnel
X-ray multisource
Primary collimator
Pre-scanner
Tunnel entrance
Power supplies
Scatter detetctors
Secondary collimator
11
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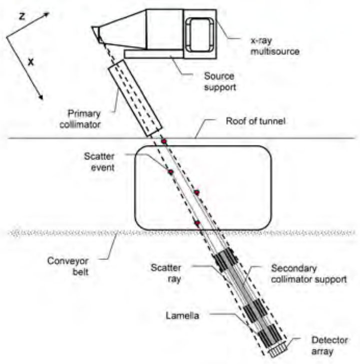
Morpho Detection

Projection of x-ray beams on *XZ* plane



- Two beams (leading and trailing fans) propagate through object
- Primary beams are angled at 30° to vertical for improved spatial resolution
- Low-angle coherent scatter induced in object is emitted in direction of detector array
- Detector modules are segmented in *Z*
- Fixed-angle secondary collimator (FASC) is realized as „triple stack Soller slit“
- Secondary collimator codes *X* coord of scatter voxel onto corresponding detector segment

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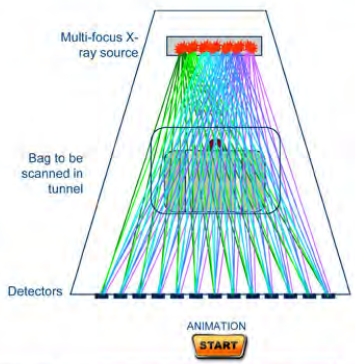
Next-Generation XD*i* schematics

- Multiple x-ray beams interrogate luggage simultaneously
- Electronic scanned x-ray multisource obviates mechanical movement
- Room-temperature detectors provide high resolution without cryostat cooling
- LAGs algorithms and conventional crystalline identification address widest threat spectrum



High speed multi-ray scanning replaces the slow mechanical sampling

13

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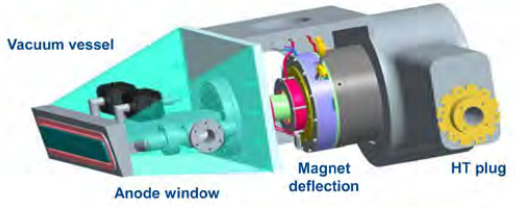
Possible X-ray multisource realization



Schematic of swept-beam x-ray multisource

X-ray multisource characteristics

- Single dispenser cathode with magnetic deflected electron beam (CRT principle)
- Combines high pulse power (Osterkamp formula) with high DC power (large area anode, grounded anode, water cooling)
- Long life-time (stationary anode), compared to rotating anode x-ray tubes

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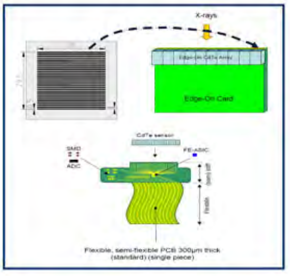
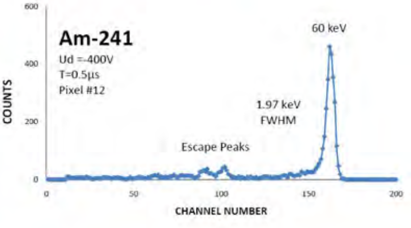
Possible detector module realization





- Edge-on geometry exploits thin CdTe crystals to minimize charge trapping
- Deep, thin CdTe crystals maximize detection efficiency
- Room-temperature design eliminates cryostatics; reduces cost; extends lifetime
- Current design envisages 17 modules x 22 strips / module x 15 crystals / strip
- Energy resolution of ≤ 3% @ 60 keV with ASIC readout already demonstrated

15

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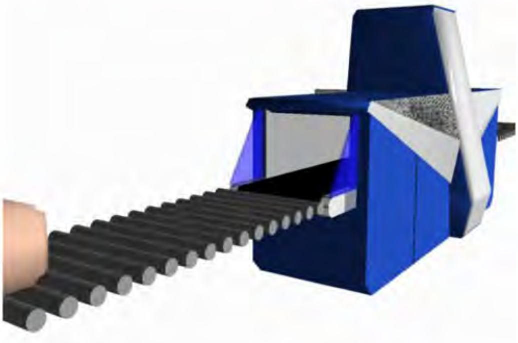
Morpho Detection

Type-D XD*i* checkpoint animation



- **DE** projection image for visual inspection
- **Real time XRD inspection** of the entire bag
- **True identification** (molecular specific) & outstanding detection of LAGs
- Expandability of libraries to **other threats** (e.g. HME)
- Expected **FAR << 10%**

16

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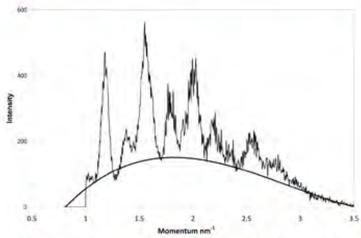
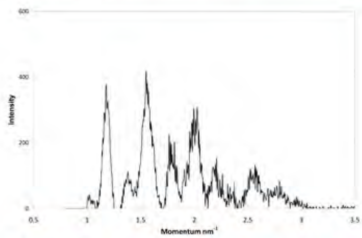
Morpho Detection

The crystalline to amorphous continuum



Energy-dispersive XRD profile of plastic explosive



Crystalline component after removal of amorphous background

Most explosives comprise both crystalline and amorphous components

Liquids (amorphous) detection capability is necessary both for liquid threats; and also to improve detection with solid-state explosives

17

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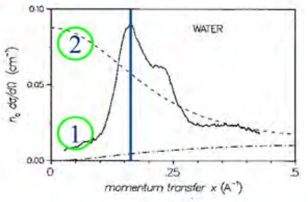
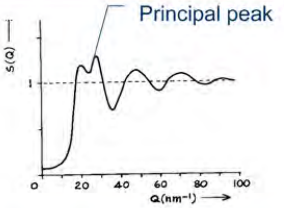
Morpho Detection

XRD of water





Cross-section for x-ray scatter from liquid water

Unbroken line, 1: measured XRD liquid profile
Dashed line, 2: XRD free atom (steam) profile
Dash - dot line, 3: Compton scatter component

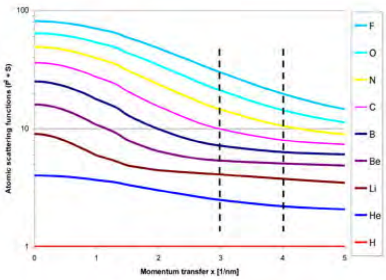
Molecular interference function, *s(x)*, for water. This is derived by normalizing measured data #1 against the atomic scatter function #2.

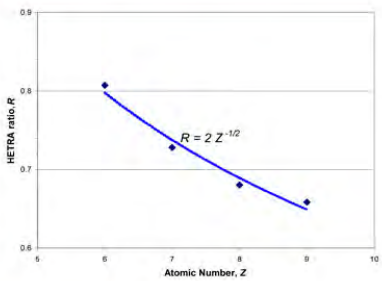
Data from Narten and Levy:
J. Chem. Phys 55, 2263, (1971).

Molecular interference function is Fourier pair with radial charge distribution: a fingerprint for molecular structure of liquid

18 SAFRAN Morpho Detection

High energy tip analysis (HETRA) for LAGs





Need to know mean atomic number of sample to extract MIF.
XRD profile intensity at neighbouring momenta yields yields this information

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XRD-based liquids classification

- X-ray diffraction (XRD) provides molecular "signature" of liquid, amorphous and gel materials
- XRD signature is related to spatial distribution of charge in liquids
- MDI-Hamburg uses a five-fold classification scheme:

Non-threats

A. Dilute aqueous (e.g. tea & coffee without additives; mineral water)
B. Concentrated aqueous (e.g. drinks; spirits; cosmetics; detergents)
C. Low aqueous amorphous (e.g. glass; preserves; some plastics)

Threats

D. Hydrocarbon fuels (e.g. diesel; gasoline; nitromethane; hydrazine)
E. Oxidizers (e.g. aqueous hydrogen peroxide solutions; nitric acid)

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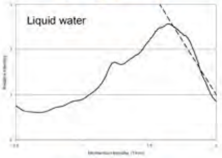
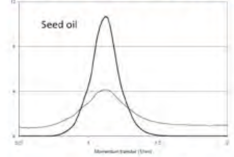
Three levels of liquid XRD analysis

Level A: XRD profile



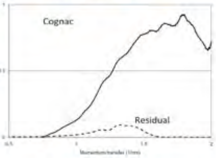
XRD profile of water corrected for attenuation and normalized against beam spectrum

Level B: Molecular Interference Function



MIF for seed oil
(MIF = Molecular Interference Function)

Level C: Residual MIF



Residual for cognac
(after subtracting water MIF)

Useful features (15 in all) for identification:

- total area (scatter strength);
- high – low band ratio (aquaticy);
- parameters of linear high-end fit.

- peak parameters (area, width & shape);
- low-end amplitude (compressibility);

- number of peaks
- peak parameters (area, width & shape);

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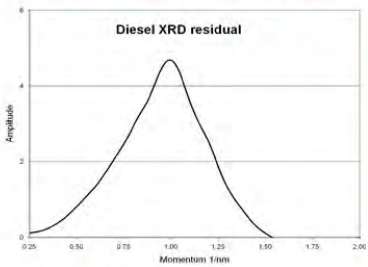
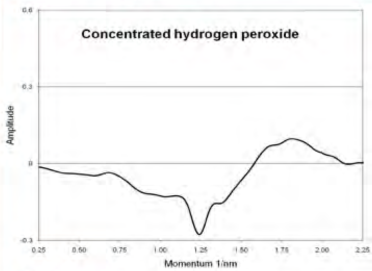
XRD signatures of threat categories





Category D
Hydrocarbon fuel

XRD signature shows very pronounced, well-defined peak centred around 1 nm^{-1}, indicating large concentration of C – C bonds

Category E
Oxidizer

XRD signature exhibits unique positive peak at ~ 1.8 nm^{-1} owing to hydrogen bonding. Peak is preserved in hydrogen peroxide / fuel mixtures.

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XRD liquid feature tabulation

Feature	Symbol	Derivation	Physical significance
Scatter strength	Σ	Integrated scatter intensity	Product of mean atomic number and density of scatter centers
Aquaticy	α	Ratio of counts in high energy to low energy band	Spatial order in sample; used to separate aqueous from non-aqueous liquids
High-energy tail ratio (HETRA)	G	Ratio of counts in neighbouring high momentum bands	Gradient is related to mean atomic number of sample
Momentum intercept	Cx	Intercept of IAM best straight line fit to XRD profile between 1.5 and 2.5 nm^{-1}	Increases with mean atomic number for gas samples
Molecular interference function	$s(x)$	Divide attenuation corrected XRD profile by linear IAM fit	Related to Fourier transform of charge distribution function
Isothermal compressibility index	χ	Mean amplitude of s(x) in lowest momentum band centered on 0.5 nm^{-1}	In limit as $x \rightarrow 0$, s(x) approaches bulk compressibility
Baseline	B	Line running from χ at low x limit to unity at high x	
Area ratio	A	Ratio of +ve area of [s(x) – 1] to total area underneath s(x)	If $\alpha \geq 0.8$ the sample is aqueous. In this case, s(x) for water is subtracted from the MIF, B = 0 and following features refer to difference function: $s_{obj}(x) - s(x)_{water}$
Principal s(x) peak position	$P1$	Largest amplitude peak in s(x), which is median smoothed.	Position is related to inverse of mean particle diameter.
Peak width	$\Delta P1$	Second moment of s(x)	Uniformity of bond lengths & molecular diameters
Peak amplitude	$AP1$	Maximum value of s(x) following baseline correction	Related to particle packing fraction
Peak shape	$\kappa P1$	3rd moment of s(x) around peak P1	Inter-particle potential

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XRD liquids detection trial

- Trial performed on set of 40 innocuous liquids (households, cosmetics, drinks, pharmaceuticals etc.)
- Trial liquid set also included several threat candidates, including: oxidizers and flammable liquids (unmixed)
- Two data sets were measured: Long-term were used for library reference and short-term were used for classification trial
- Each XRD profile was evaluated to yield ~ 15 features from total XRD profile, MIF (molecular interference function) and Residual functions
- Features input to a simple "minimum distance classifier"

Results of trial:

Detection rate better than 90% at low single digit false alarm rate

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Conclusions

- XRD offers unique capabilities for the **identification** and **detection** of LAGs <u>in addition</u> to solid threats
- Performance has been demonstrated on the existing XRD 3500 system and SALOME lab XRD demonstrator
- The novel "XD*i*" geometry will allow ultra fast scan times with no moving part to overcome speed limitations of current systems
- "XD*i*" represents the first implementation of a true "**Type D**" screening system with **ultra high Pd** and **ultra low FAR** for both solids and LAGs, paving the way to the **ACBX** specifications
- MDI will showcase first hardware implementation of "XD*i*" end 2011.

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Thank you for your time and attention

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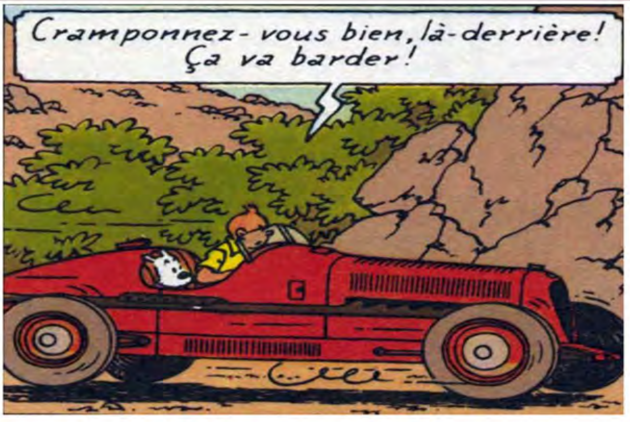
An open word to all ...



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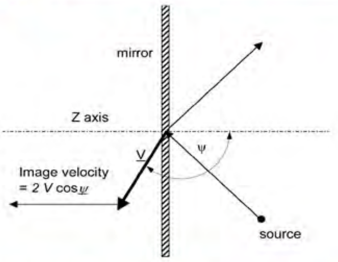
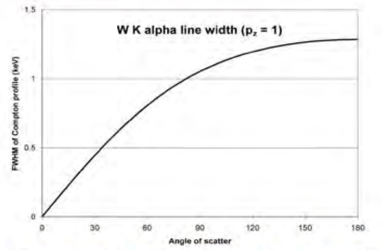
"Doppler" origin of Compton profile



Radiation reflected from moving mirror is Doppler-shifted such that $\Delta\lambda/\lambda = \Delta u/u$



Energy width of "Doppler-broadened" peak is greatest for scatter angle of 180° Graph is plotted for hydrogen ground state momentum (= 2 10^{-24} kg m / s)

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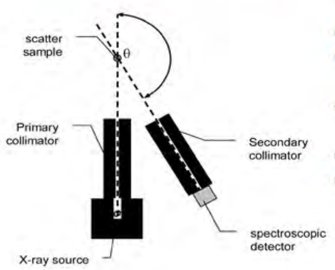
Measurement principle of Claris*



- Fundamental physical principle is Doppler-broadened Compton profile
- 3-D localized tomography
- Sensitive region defined by overlap of primary and scatter beams
- Parallelization possibility with detector array and multi-channel collimator
- Room temperature detector array (e. g. CZT)
- Same physics, effects, information and data processing applies to Photon-Induced Positron Annihilation Spectroscopy (PiPAS)

***Compton line analysis of reflected inelastic scatter**

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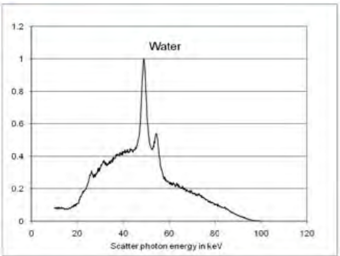
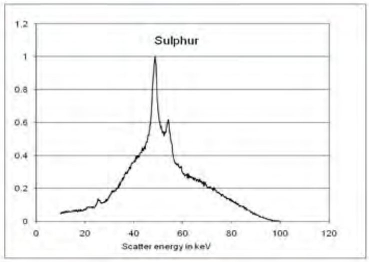
Doppler-broadened Compton spectra





- Kα and β line complexes are resolved as two peaks
- Peaks are shifted and broadened by Compton profile effects
- There are significant changes in background shape (attenuation!) as atomic number increases

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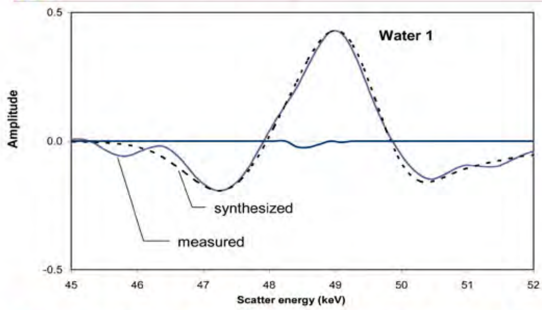
Line width analysis



Synthetic and measured profiles are shifted before cross-correlation so that peaks occupy same energy channel

Synthesize Compton profile for all K lines & edges present in spectrum (W/Re)

Use line positions and relative intensities from standard texts (Dyson)

2nd differentiate this peak; and adjust width to maximize correlation coefficient

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Some width results for representative liquids

Material	H2O 1	H2O 2	CH3NO2	C2H6O	C3H6O	C3H8O	C5O2H8
Width	5.057	5.104	5.293	4.617	4.756	4.648	4.385

- Error in width determination (assessed from water values) ≤ 1%
- So accuracy in mean Z determination much superior to dual energy CT (10%)
- Consider results for C3H6O:
  removing C (to form C2H6O) lowers <Z>;
  adding H (to form C3H8O) also lowers <Z>.

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Towards elemental analysis with Claris

		H	O	N	C
H2O 1	Actual	0.67	0.33	0.00	0.00
	Derived	0.74	0.33	0.02	-0.09
H2O 2	Actual	0.67	0.33	0.00	0.00
	Derived	0.77	0.33	0.04	-0.14
CH3NO2	Actual	0.43	0.29	0.14	0.14
	Derived	0.44	0.35	0.12	0.09
C2H6O	Actual	0.67	0.11	0.00	0.22
	Derived	0.72	0.12	-0.04	0.20
C3H6O	Actual	0.60	0.30	0.00	0.10
	Derived	0.65	0.16	0.03	0.15
C3H8O	Actual	0.67	0.25	0.00	0.08
	Derived	0.70	0.13	-0.02	0.19
C5O2H8	Actual	0.53	0.33	0.00	0.13
	Derived	0.66	0.07	-0.03	0.30

Use peak shape features to address chemical composition of sample

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In summary

- **Interesting avenues for further research in x-ray scatter systems based on x-ray tube sources**
- **Technological advances in x-ray multisources and room-temperature semiconductor detectors enable new, perhaps useful modalities**
- **It is envisaged that molecular-specific screening will increase in future importance owing, to capability to achieve improved detection rates and lower false alarm rates**

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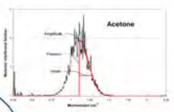
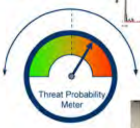
XD*i*: Synthesis of x-ray analysis and imaging

1. **Novel x-ray modality:**
   - X-ray diffraction imaging (XD*i*) is a novel x-ray modality combining radiographic imaging with molecular-specific XRD material analysis



2. **Novel application:**
   - Molecular-specific detection/identification of explosives and drugs in air passenger luggage



3. **Novel business proposition:**
   - Reduce cost of airport luggage screening by minimizing false alarms

4. **Novel XD*i* measurement topology:**
   - Highly-parallel (10^5 channels) energy-dispersive x-ray diffraction tomography.

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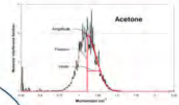
XD*i*: Synthesis of x-ray analysis and imaging



1. **Novel x-ray modality:**
   - X-ray diffraction imaging (XD*i*) is a novel x-ray modality combining radiographic imaging with molecular-specific XRD material analysis
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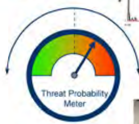

4. **Novel XD*i* measurement topology:**
   - Highly-parallel (10^5 channels) energy-dispersive x-ray diffraction tomography.

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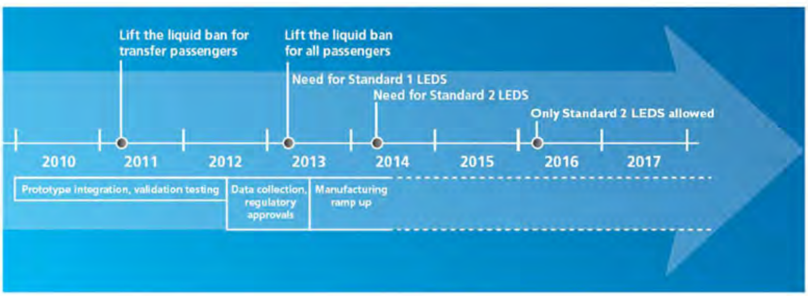
XD*i* Timeline



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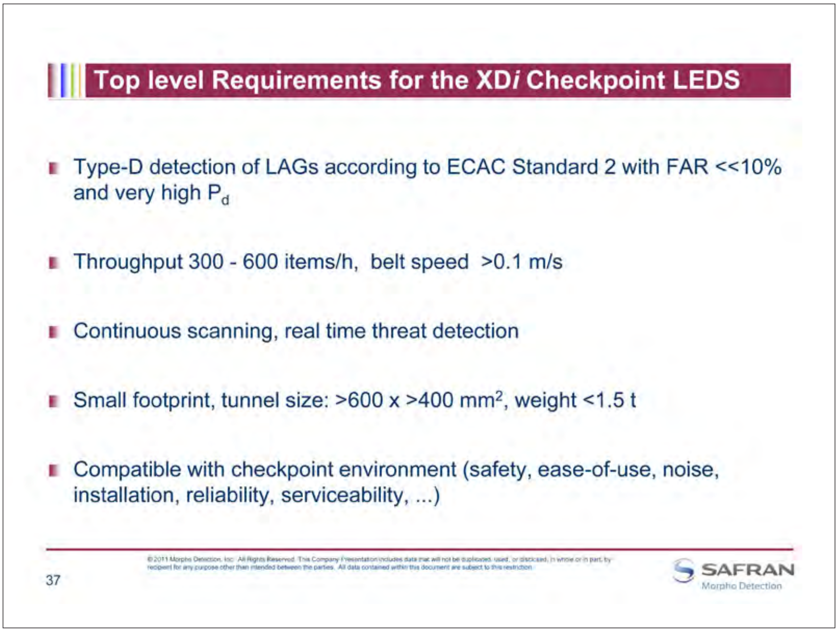
Top level Requirements for the XD*i* Checkpoint LEDS
Type-D detection of LAGs according to ECAC Standard 2 with FAR <<10% and very high P_d
Throughput 300 - 600 items/h, belt speed >0.1 m/s
Continuous scanning, real time threat detection
Small footprint, tunnel size: >600 x >400 mm², weight <1.5 t
Compatible with checkpoint environment (safety, ease-of-use, noise, installation, reliability, serviceability, ...)
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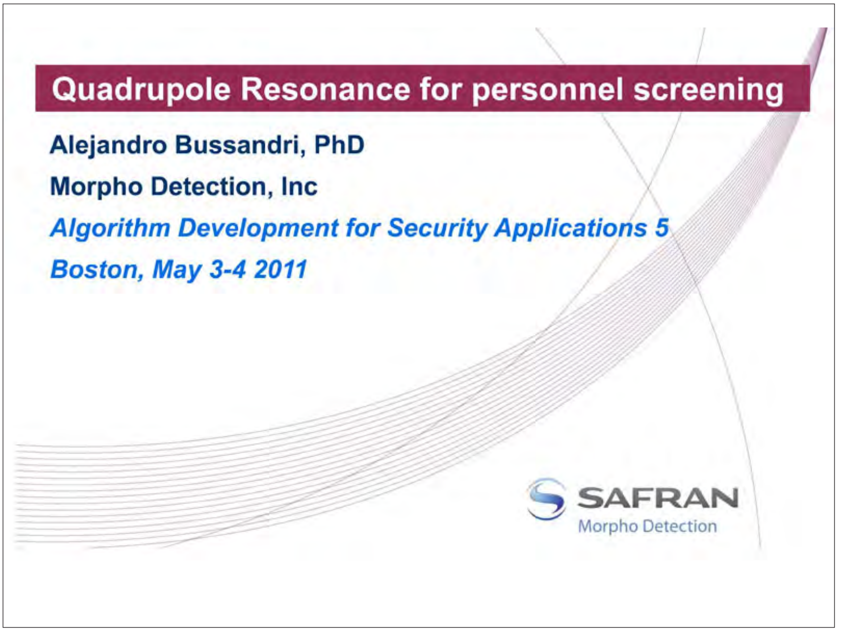
16.6 Alejandro Bussandri: Quadrupole Resonance



Conclusions - Handheld QR Wand

- ***MDI has developed a Handheld QR Wand prototype***
- ***Detects plastic explosives and metal weapons under clothing and inside body cavities - up to ~ 5 inches deep***
- ***Total Scan time less than 6 sec.***
- ***Complies with IEEE safety guidelines for human exposure to radio frequency***

Department / Title / Date

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Applications in security checkpoints

Threats Under clothing

- **AIT anomaly resolution tool**
  - **No privacy concerns**
  - **Improves throughput**
- **Casts, bulky clothing, headwear screening**
  - **Less divesture**
- **Can see optically obscured concealments**
  - **Improves AIT threat detection capabilities**

Threats Inside body cavities

- **Fusion AIT ⟺ QR**

QR detect explosives hidden inside body cavities or implants.

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Handheld QR Wand – Primary Objectives

- Develop a lightweight, handheld QR sensor for detecting plastic explosives concealed ON/IN the body up to ~5in deep
- Complies with safety guidelines for human exposure to radio frequency waves
- High reliability

QR Wand

Material	Alarm
Detasheet	PETN
C4	RDX
Primasheet-1000	PETN
Primasheet-2000	RDX
Semtex A	PETN
Semtex H	RDX

Feasibility detection tests carried out inside an RF shielded room

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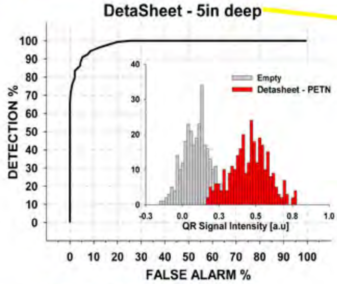
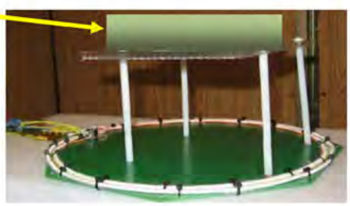
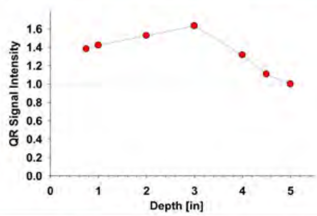
DetaSheet - PETN detection performance







- ✓PD ≥ 90% FA < 5%
- ✓Scan time = 2sec
- ✓Room temperature (23 °C)

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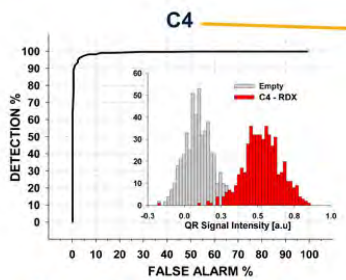
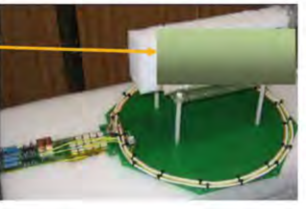
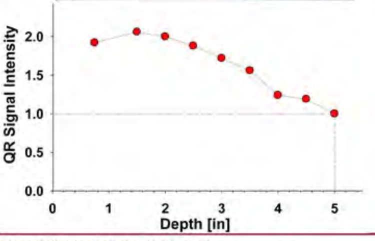
C4 – RDX detection performance



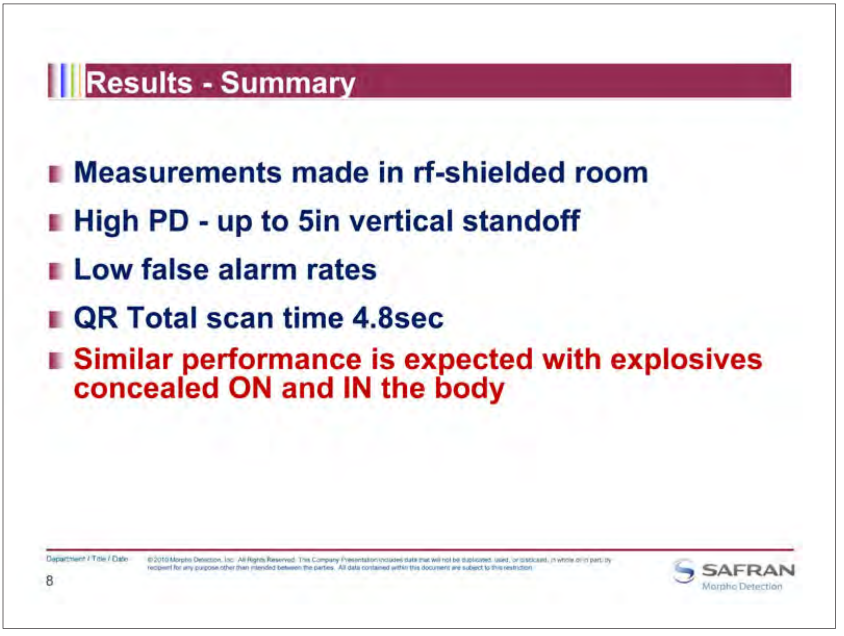




✓High PD from 0.75in to 5in

✓Scan time = 2.8sec

✓Room temperature ~23°C


Results - Summary
Measurements made in rf-shielded room
High PD - up to 5in vertical standoff
Low false alarm rates
QR Total scan time 4.8sec
Similar performance is expected with explosives concealed ON and IN the body
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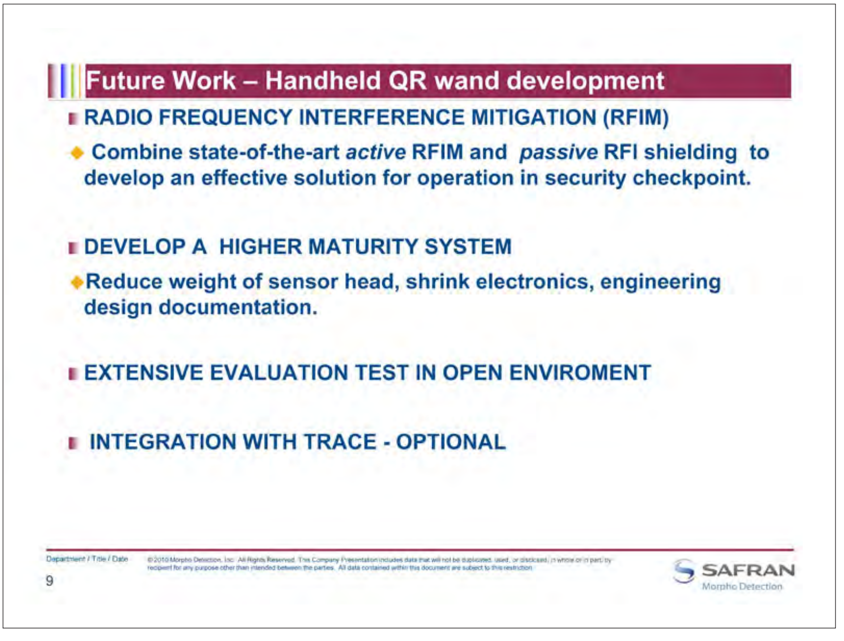
Future Work – Handheld QR wand development
RADIO FREQUENCY INTERFERENCE MITIGATION (RFIM)
Combine state-of-the-art active RFIM and passive RFI shielding to develop an effective solution for operation in security checkpoint.
DEVELOP A HIGHER MATURITY SYSTEM
Reduce weight of sensor head, shrink electronics, engineering design documentation.
EXTENSIVE EVALUATION TEST IN OPEN ENVIROMENT
INTEGRATION WITH TRACE - OPTIONAL
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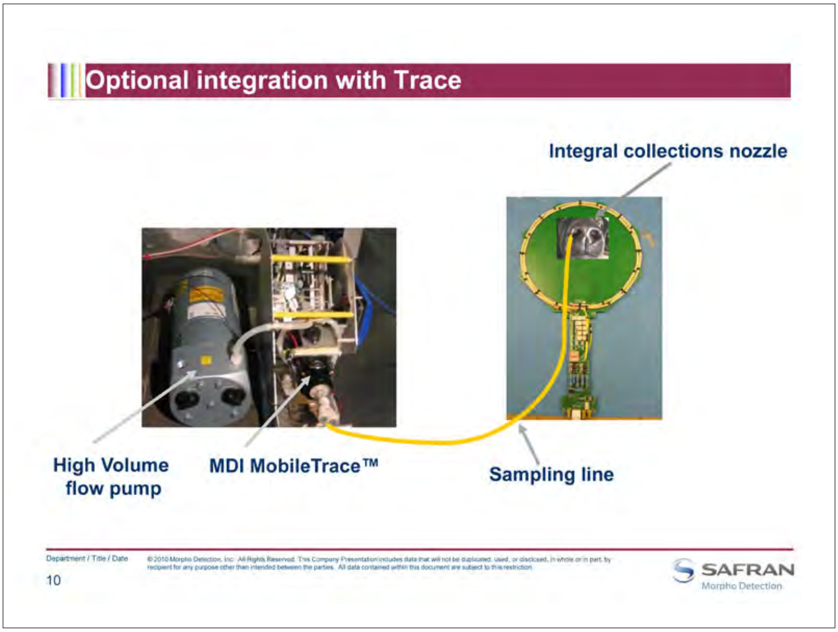
Optional integration with Trace
Integral collections nozzle
High Volume flow pump
MDI MobileTrace™
Sampling line
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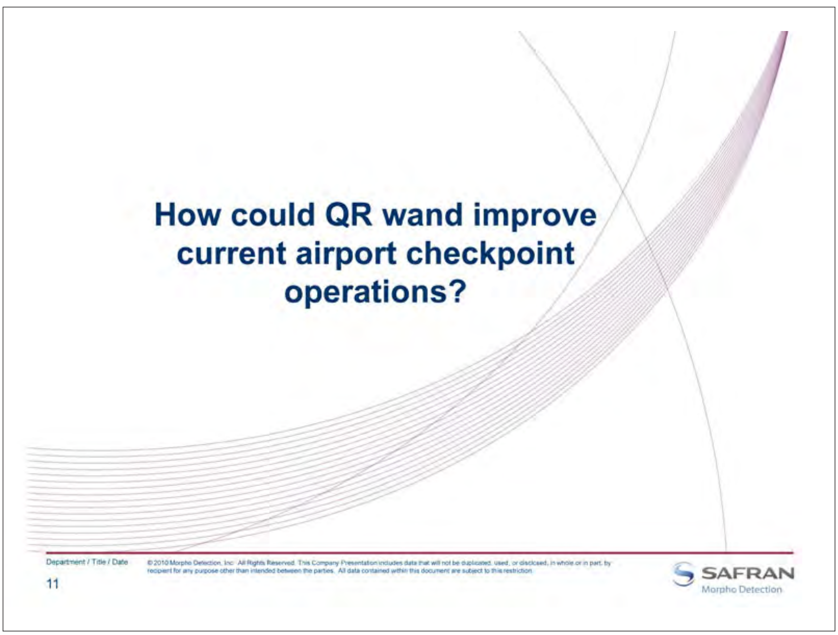
How could QR wand improve current airport checkpoint operations?
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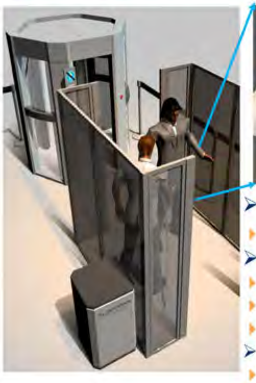
AIT-guided Anomaly Resolution Tool



AIT Alarm

Handheld QR Wand
safe-reliable-easy to operate

- **Highly localized sensing**
  - **Improves QR wand performance (better fill factor)**
- **Easy to operate**
  - **One button; No monitor/keyboard; *clear/alarm* indicator**
  - **Metal & plastic explosives are distinguished by blink rate**
  - **Maintain privacy**
- **Less than 6sec scan time**
  - **Improves throughput**
- **Combines active and passive RFI mitigation**
  - **Minimum footprint impact**

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QR coils Gantry Mounted

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How Could QR Be configured to Complement AIT?

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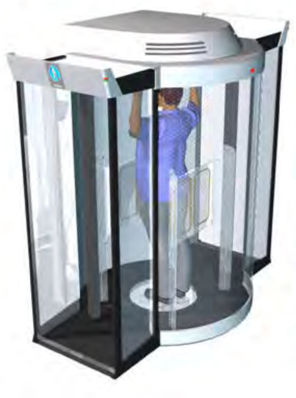
Primary Screening – Fusion AIT ⟺ QR



Synergies

1)AIT Whole Body can *clear* most of body:
QR for targeted Spot Checks =>
Surface Coils = Better "Fill Factor"

2) AIT Concealments = ~body temp:
Narrower QR temperature band=better performance

3) QR can See:
Optically obscured concealments
Internal Concealments
Secondary Spot checks

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Final Thoughts

Secondary

AIT-guided

Primary

AIT add-on

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Acknowledgements

MDI Team, San Diego

- David Petry
- Christopher Crowley
- Erik Magnuson
- Lon Ficke
- Hector Robert
- Young Lee

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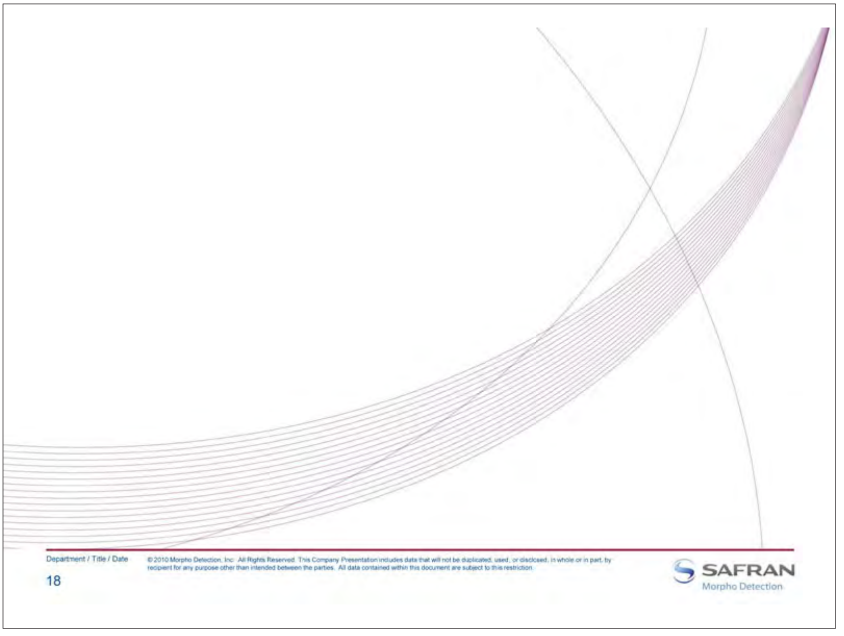
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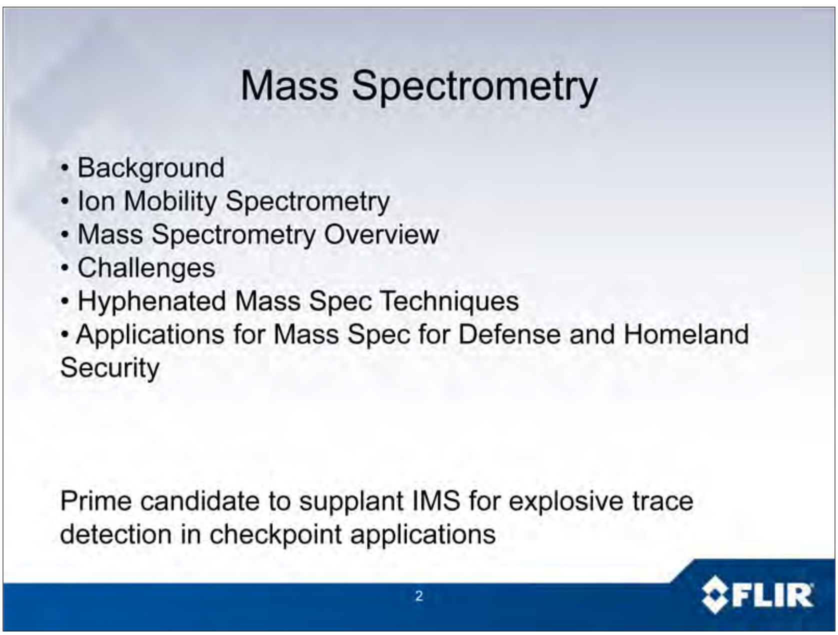
16.7 Dennis Barket: Explosive Trace Detection (EDT)



FLIR Mass Spectrometry

Timeline:
Founded in 2001
Merged into ICx Technologies in late 2005
ICx purchased by FLIR October 2010

GRIFFIN → icx griffin analytical → FLIR

Location:
Purdue Research Park
West Lafayette, IN USA

Size:
15,000 Square Feet
50 full time employees
3/4 staff is technical (scientists and engineers)

Technology:
Fieldable Mass Spectrometers
Differentiated Inlet Technologies
Full System Software

3 FLIR

Explosive Detection

Non Computed Tomography (Non-CT) Transmission X-ray Devices
For screening a cargo piece these devices must provide at a minimum one digitized transmission radiographic image to support detection of explosive threats by a qualified operator

Explosive Trace Detection (ETD) Devices
Consists of desk top or hand held devices that detects explosive residual material on typical cargo substrates through the application and analysis of a swab based collection process

Electronic Metal Detection (EMD) Devices
Consists of devices that utilize electromagnetic fields to detect the presence of electrically conductive materials by measuring alterations in the field strength or pattern

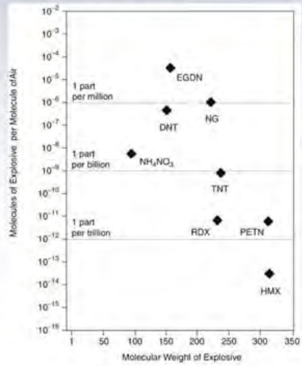
Explosive Detection Systems (EDS)
Consists of systems that utilize computed tomography (CT) to automatically detect explosive threats

Air Cargo Screening Qualification Test
Solicitation Number: HSTS04-09-BAA-ST2132

4 FLIR

Explosives Trace Detection

- Low vapor pressure targets
- Necessitates sensitive instruments (capable of low limit of detection)
- “Sniffer” class of sensors and instruments
- Need to allow for some amount of target analyte to move into the instrument for analysis
- Vapor or particle sampling



5

Ion Mobility Spectrometry

- Ion Separation Technique
  - Based on ion motion through gas induced by electric field

$$v_d = KE$$

v_d : *ion drift velocity*
K : *ion mobility constant*
E : *applied electric field*

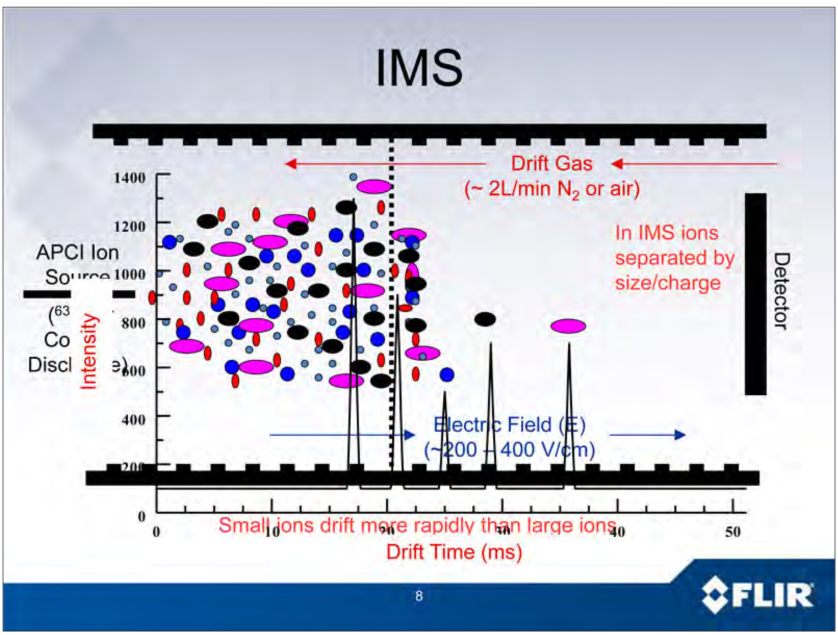
- Two Main Types
  - Ion Mobility Spectrometry (IMS)
    - Most common in commercial instruments
  - High-Field Asymmetric Waveform Ion Mobility Spectrometry (FAIMS or DMS)

6

Ion Mobility Spectrometry

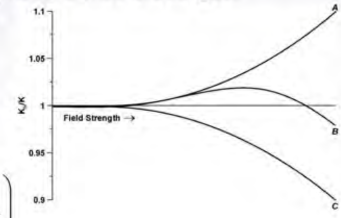
- Low Electric Field
  - ~100-500 V/cm
- Ion Mobility (K) Independent of Applied Field Strength
- Ions Propelled Through Separation Region by Electric Field
- Drift Gas Flowing Counter-Current to Direction of Ion Travel
- Pulsed Packets of Ions

7 FLIR



High-Field Asymmetric Waveform Ion Mobility Spectrometry

- High Electric Field Applied Perpendicular to Separation Path > 10,000 V/cm
- Ion Mobility Dependent on Applied Field Strength
- Ions Moved Pneumatically
- Continuous Ion Beam



$$K_h = K\left(1+\alpha\left(\frac{E}{N}\right)^2+\beta\left(\frac{E}{N}\right)^4+\ldots\right)$$

9

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Ion Mobility Spectrometry

IMS Based

FAIMS Based

Benchtop

Smiths 500 DT

Morpho Itemiser 3 Enhanced

Thermo EGIS Defender

Handheld

Smiths Sabre 4000

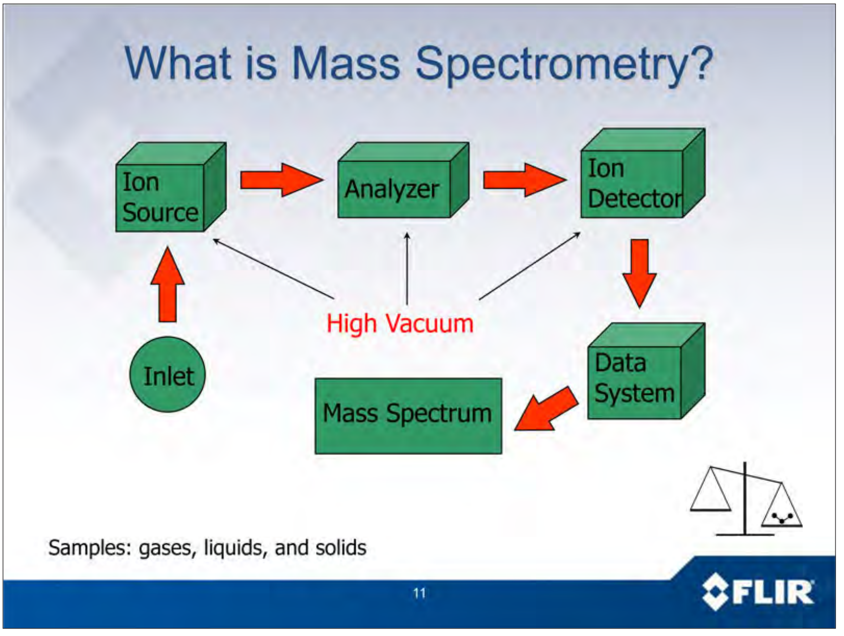
Morpho MobileTrace

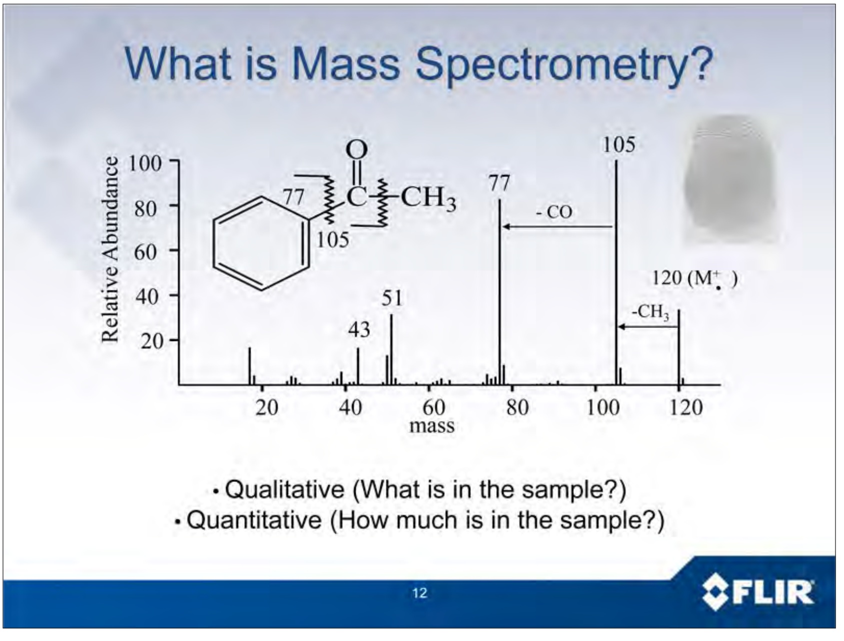
http://www.smithsdetection.com/tabletop_explosives_detection.php

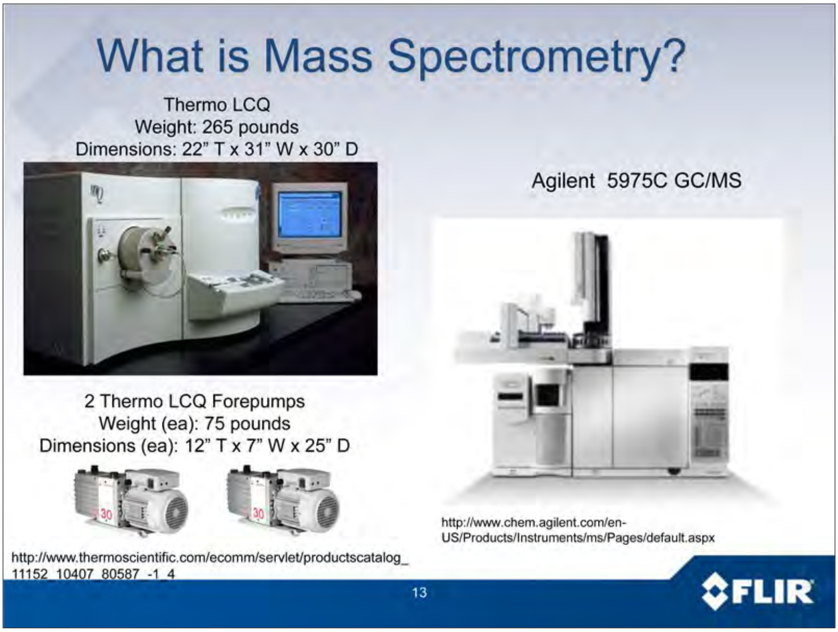
http://www.morpho.com/detection/see-all-products/?lang=en

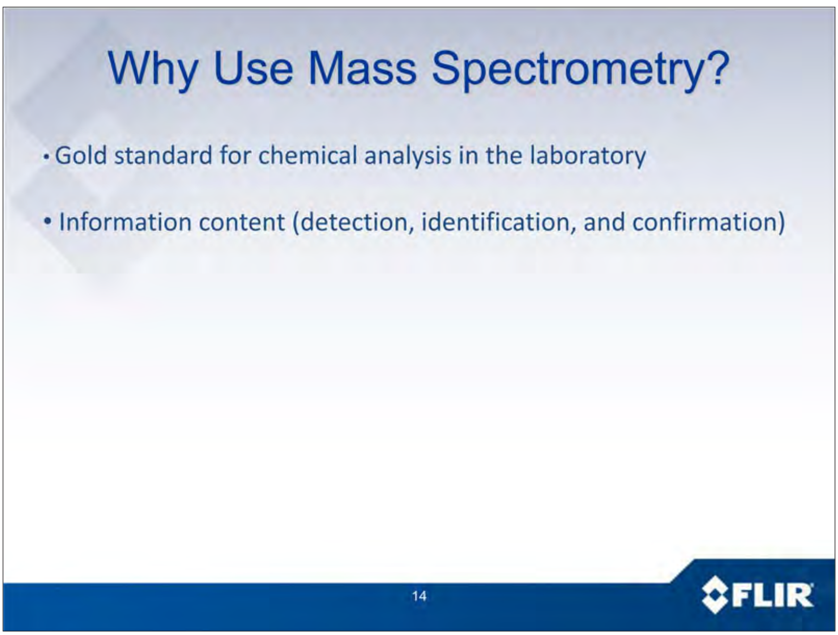
10

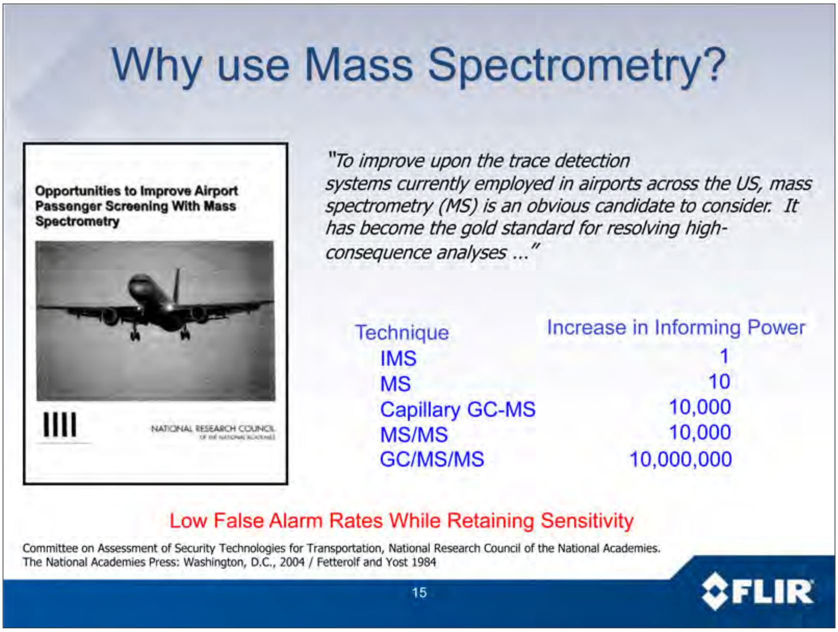
FLIR

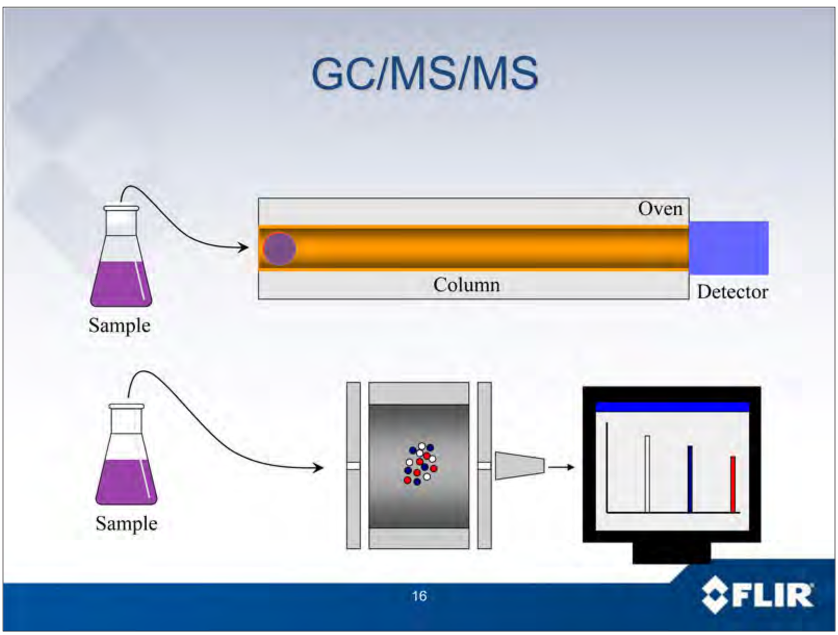

What is Mass Spectrometry?
Ion Source
Analyzer
Ion Detector
High Vacuum
Inlet
Data System
Mass Spectrum
Samples: gases, liquids, and solids
11
FLIR

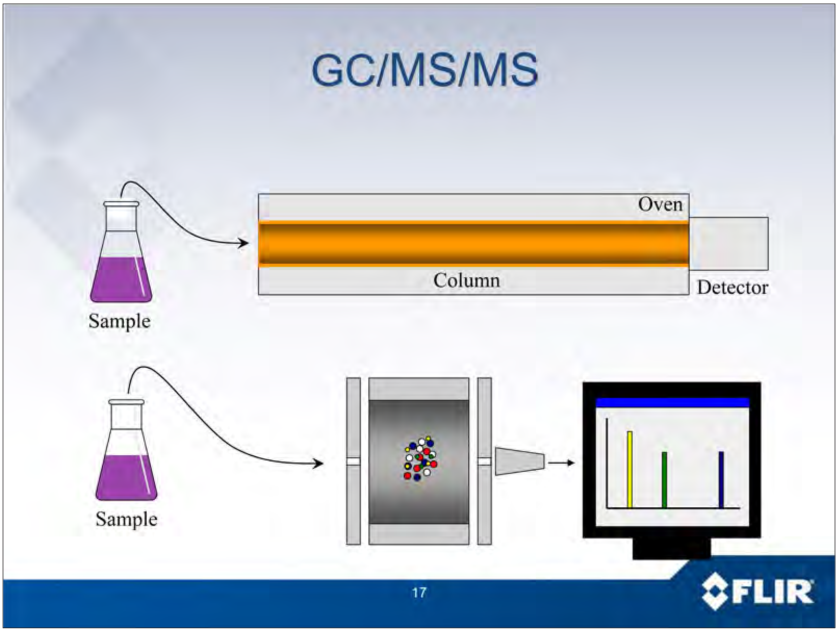

What is Mass Spectrometry?
Relative Abundance
100
80
60
40
20
20
40
60
80
100
120
mass
O
C
CH3
77
105
77
- CO
105
120 (M+.)
-CH3
51
43
• Qualitative (What is in the sample?)
• Quantitative (How much is in the sample?)
12
FLIR

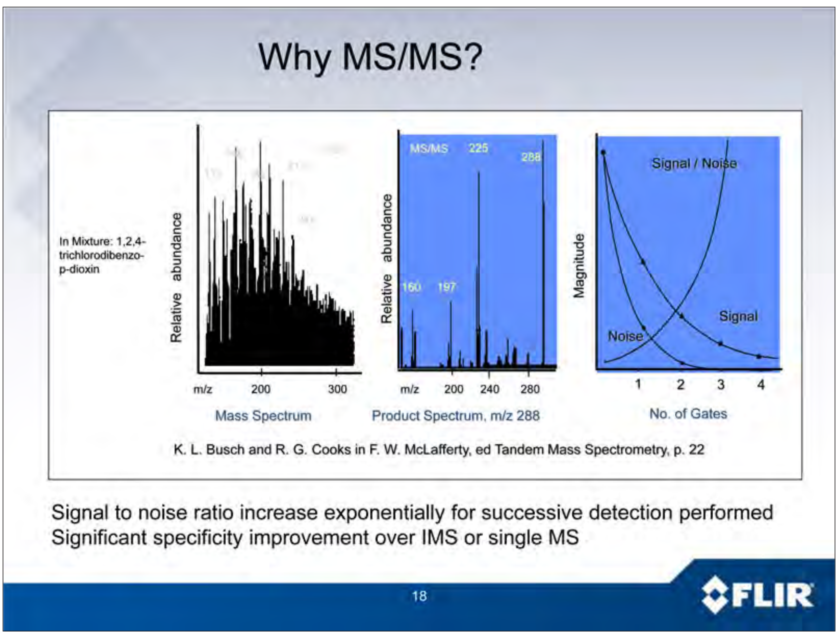

What is Mass Spectrometry?
Thermo LCQ
Weight: 265 pounds
Dimensions: 22" T x 31" W x 30" D
Agilent 5975C GC/MS
2 Thermo LCQ Forepumps
Weight (ea): 75 pounds
Dimensions (ea): 12" T x 7" W x 25" D
http://www.chem.agilent.com/en-US/Products/Instruments/ms/Pages/default.aspx
http://www.thermoscientific.com/ecomm/servlet/productscatalog_11152_10407_80587_-1_4
13
FLIR


Why Use Mass Spectrometry?
• Gold standard for chemical analysis in the laboratory
• Information content (detection, identification, and confirmation)
14
FLIR


Why use Mass Spectrometry?
Opportunities to Improve Airport Passenger Screening With Mass Spectrometry
NATIONAL RESEARCH COUNCIL
"To improve upon the trace detection systems currently employed in airports across the US, mass spectrometry (MS) is an obvious candidate to consider. It has become the gold standard for resolving high-consequence analyses ..."
Technique
Increase in Informing Power
IMS 1
MS 10
Capillary GC-MS 10,000
MS/MS 10,000
GC/MS/MS 10,000,000
Low False Alarm Rates While Retaining Sensitivity
Committee on Assessment of Security Technologies for Transportation, National Research Council of the National Academies.
The National Academies Press: Washington, D.C., 2004 / Fetterolf and Yost 1984
15
FLIR


GC/MS/MS
Oven
Column
Detector
Sample
Sample
16
FLIR


GC/MS/MS
Oven
Column
Detector
Sample
Sample
17
FLIR


Why MS/MS?
In Mixture: 1,2,4-trichlorodibenzo-p-dioxin
Relative abundance
m/z
200
300
Mass Spectrum
MS/MS
225
288
160
197
Relative abundance
m/z
200
240
280
Product Spectrum, m/z 288
Magnitude
Signal / Noise
Signal
Noise
1
2
3
4
No. of Gates
K. L. Busch and R. G. Cooks in F. W. McLafferty, ed Tandem Mass Spectrometry, p. 22
Signal to noise ratio increase exponentially for successive detection performed
Significant specificity improvement over IMS or single MS
18
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Challenges

- Ruggedness for outside the lab applications
- Ease of use
- Sample Introduction / How to get the sample in the vacuum system?
- Time to result (sample prep, measurement and analysis time)
- Meet an acceptable price point

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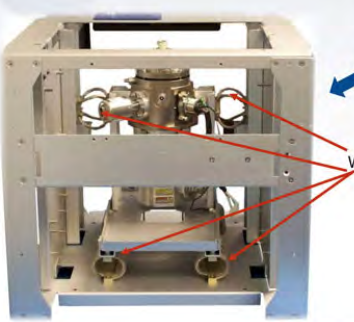
RUGGED FOR FIELD USE

Used in:

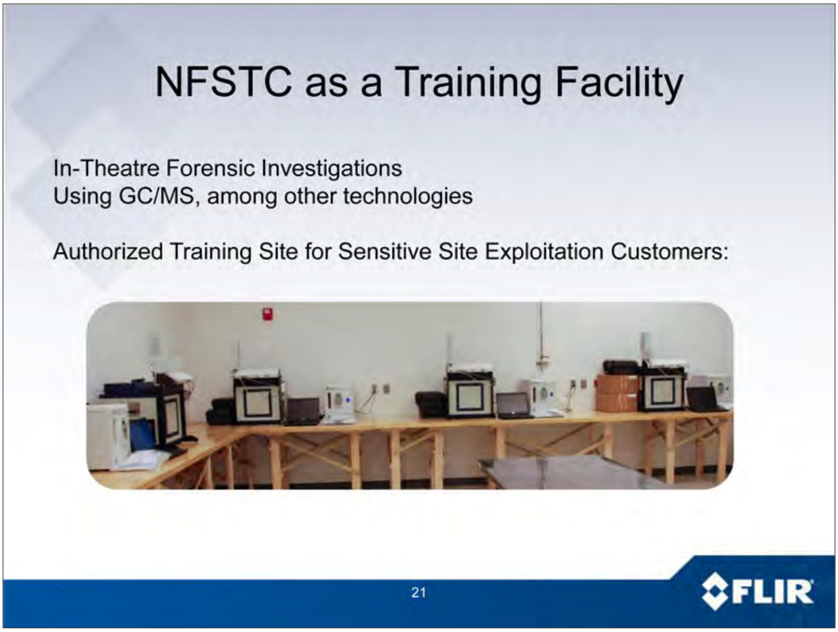
- Griffin 450
- Griffin 460



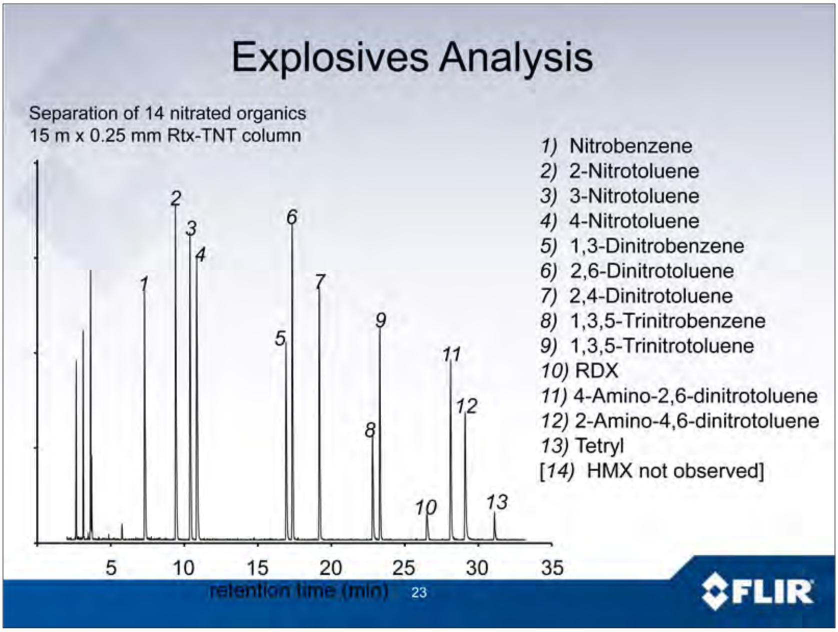
Griffin 460 Tested to MilSpec810F

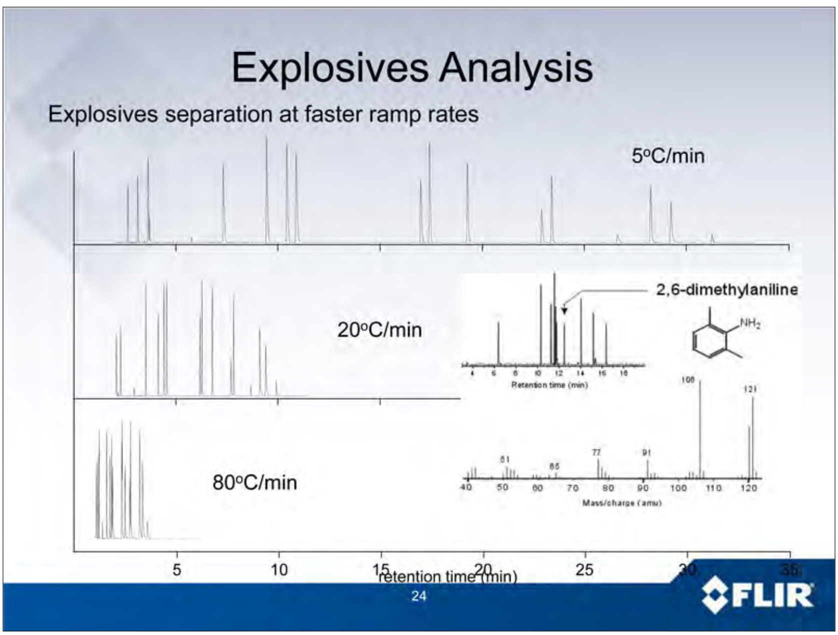
20

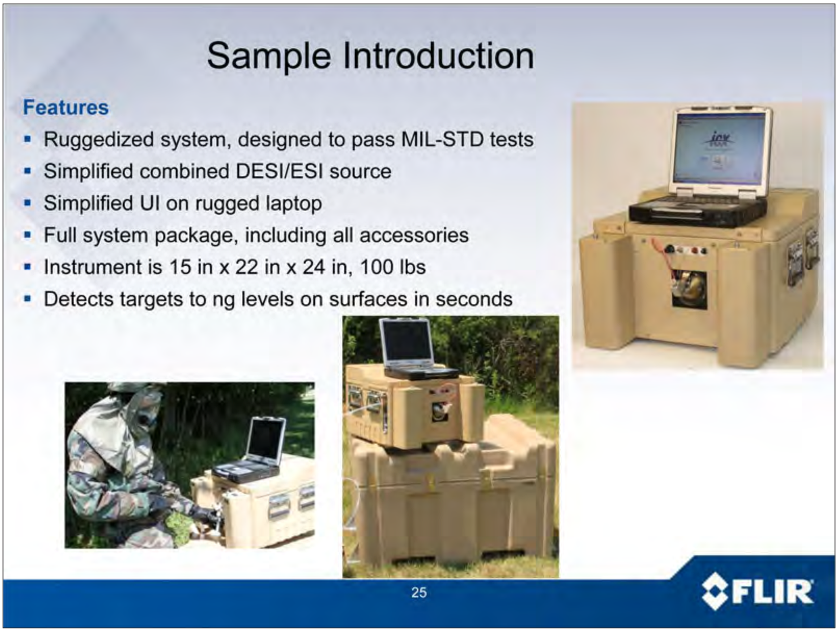
FLIR

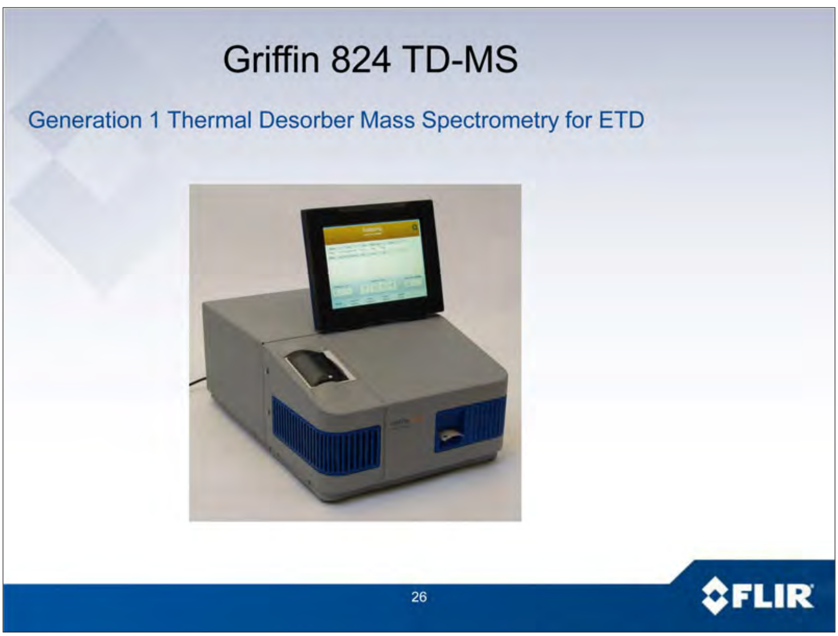

NFSTC as a Training Facility
In-Theatre Forensic Investigations
Using GC/MS, among other technologies
Authorized Training Site for Sensitive Site Exploitation Customers:
21
FLIR

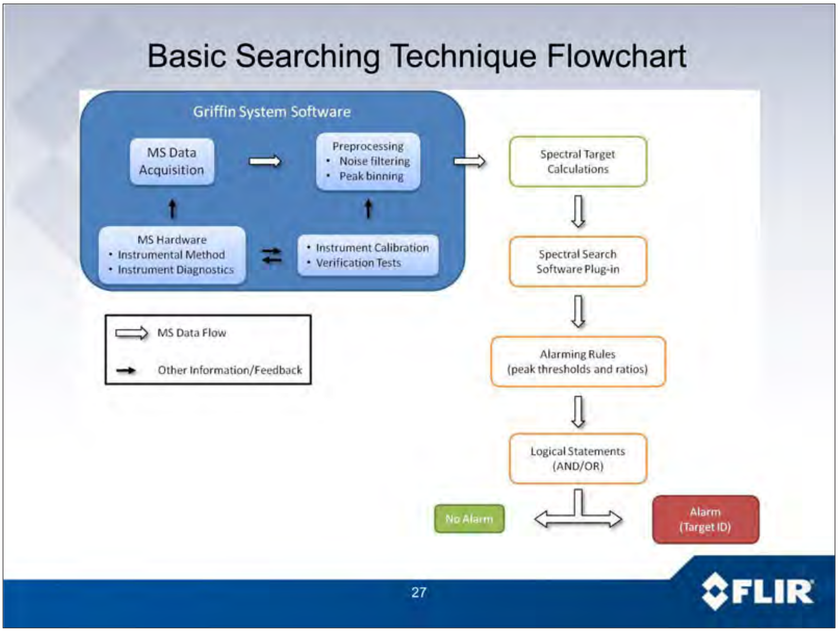

Ease of Use
GSS Level 1 Software
Home
Detection Status:
Disconnect
Connected to SIMBTC
icx TM
griffin analytical
Methods
View Data
Instrument Health
Instrument Power
Help
Connected To: SIMBTC
Instrument Status: Ready
22
FLIR

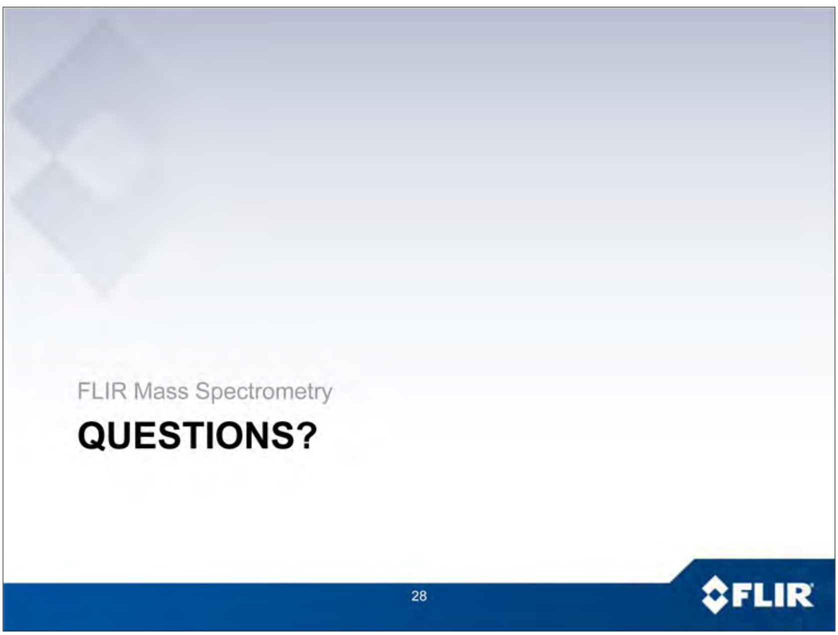

Explosives Analysis
Separation of 14 nitrated organics
15 m x 0.25 mm Rtx-TNT column
1) Nitrobenzene
2) 2-Nitrotoluene
3) 3-Nitrotoluene
4) 4-Nitrotoluene
5) 1,3-Dinitrobenzene
6) 2,6-Dinitrotoluene
7) 2,4-Dinitrotoluene
8) 1,3,5-Trinitrobenzene
9) 1,3,5-Trinitrotoluene
10) RDX
11) 4-Amino-2,6-dinitrotoluene
12) 2-Amino-4,6-dinitrotoluene
13) Tetryl
[14) HMX not observed]
5 10 15 20 25 30 35
retention time (min)
23


Explosives Analysis
Explosives separation at faster ramp rates
5°C/min
20°C/min
80°C/min
2,6-dimethylaniline
NH_2
5 10 15 20 25 30 35
retention time (min)
24

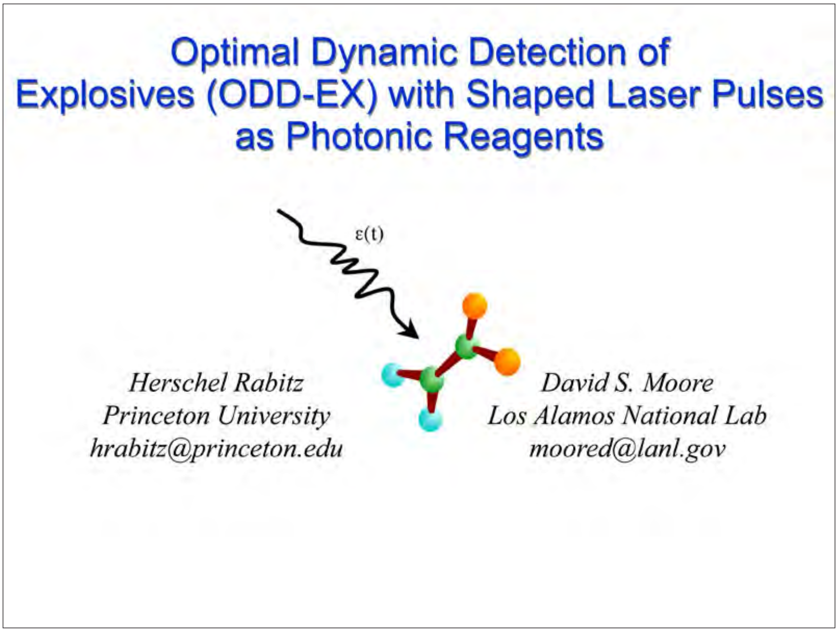

Sample Introduction
Features
Ruggedized system, designed to pass MIL-STD tests
Simplified combined DESI/ESI source
Simplified UI on rugged laptop
Full system package, including all accessories
Instrument is 15 in x 22 in x 24 in, 100 lbs
Detects targets to ng levels on surfaces in seconds
25
FLIR

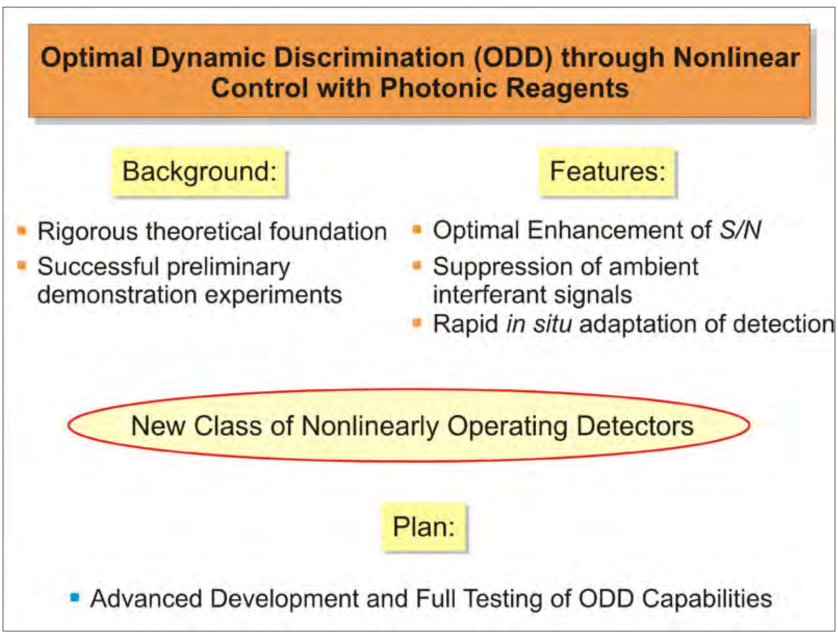

Griffin 824 TD-MS
Generation 1 Thermal Desorber Mass Spectrometry for ETD
26
FLIR


Basic Searching Technique Flowchart
Griffin System Software
MS Data Acquisition
Preprocessing
• Noise filtering
• Peak binning
MS Hardware
• Instrumental Method
• Instrument Diagnostics
• Instrument Calibration
• Verification Tests
Spectral Target Calculations
Spectral Search Software Plug-in
Alarming Rules (peak thresholds and ratios)
Logical Statements (AND/OR)
No Alarm
Alarm (Target ID)
MS Data Flow
Other Information/Feedback
27
FLIR


FLIR Mass Spectrometry
QUESTIONS?
28
FLIR

16.8 Herschel Rabitz: Explosive trace detection (ETD)





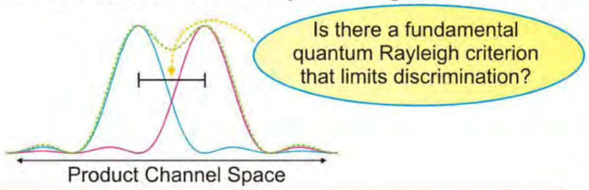
Optimal Dynamic Discrimination (ODD)

- Examine and control molecular dynamics on their own natural time-scales for discriminatory purposes
  - Dynamics provide information not afforded with steady-state techniques
- ODD is an ***optimal***, ***flexible***, ***adaptive*** concept for Selective detection
  - → Not constrained to a particular spectroscopy
- Interface ODD with new and established analytical techniques
  - → **Specificity and Sensitivity**

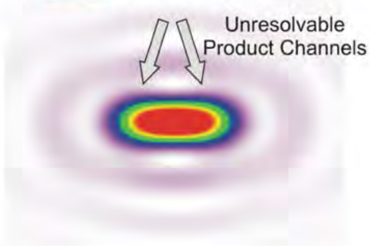
- Study applicability of ODD for rapid identification of target dynamic signatures

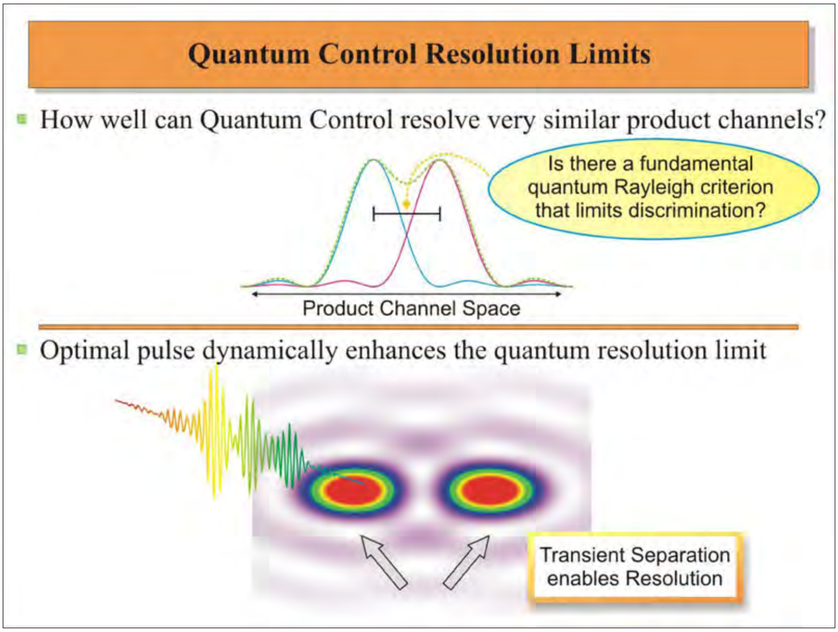
Quantum Control Resolution Limits

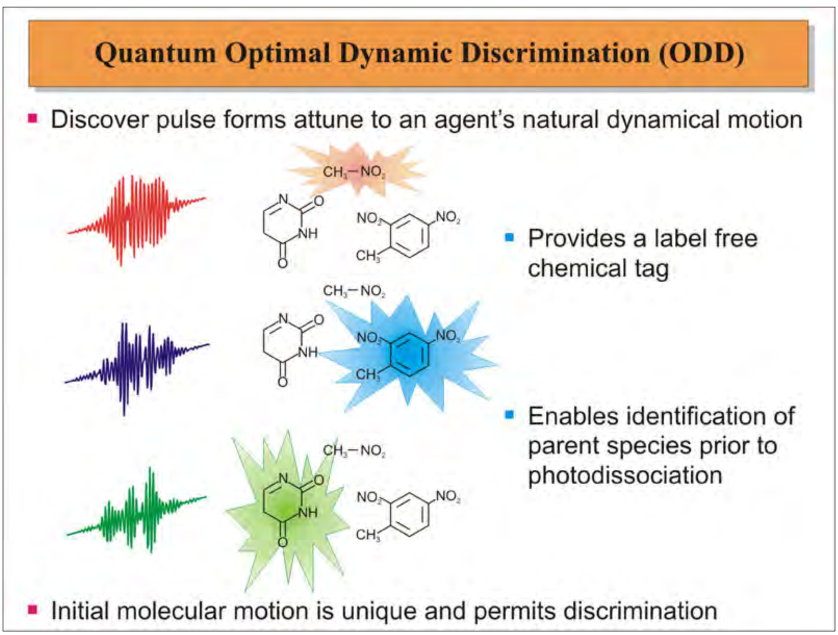
- How well can Quantum Control resolve very similar product channels?



- Is this resolution limit ***Static*** or can it be altered with an optimal pulse?



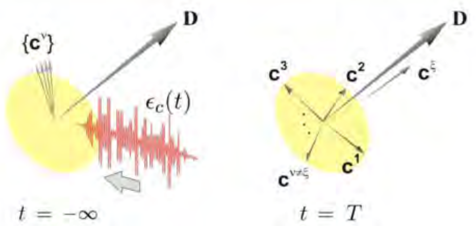

Quantum Control Resolution Limits
How well can Quantum Control resolve very similar product channels?
Is there a fundamental quantum Rayleigh criterion that limits discrimination?
Product Channel Space
Optimal pulse dynamically enhances the quantum resolution limit
Transient Separation enables Resolution


Quantum Optimal Dynamic Discrimination (ODD)
Discover pulse forms attune to an agent's natural dynamical motion
CH_3-NO_2
N
O
NH
O
NO_2
NO_2
CH_3
Provides a label free chemical tag
Enables identification of parent species prior to photodissociation
Initial molecular motion is unique and permits discrimination

Simultaneous Control of Multiple Species

- Quantum Control is fundamentally a matter of discrimination
- What is the attainable level of control when accessible states are extremely similar?

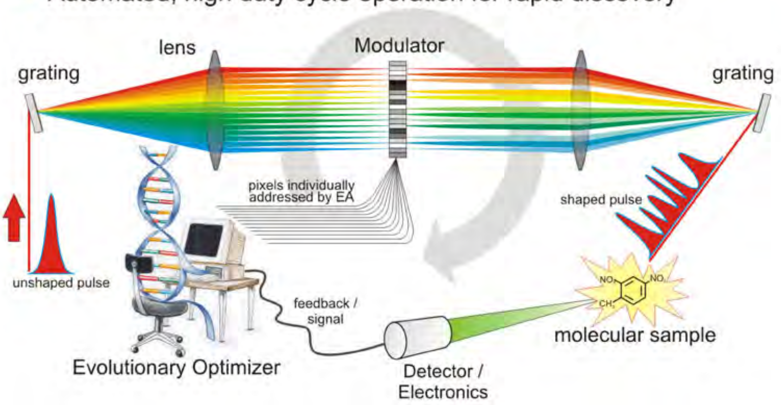
Quantum Optimal Dynamic Discrimination (ODD)



- Use Quantum Control to dynamically separate nearly identical systems

Learning of Optical Signatures

- Automated, high duty cycle operation for rapid discovery

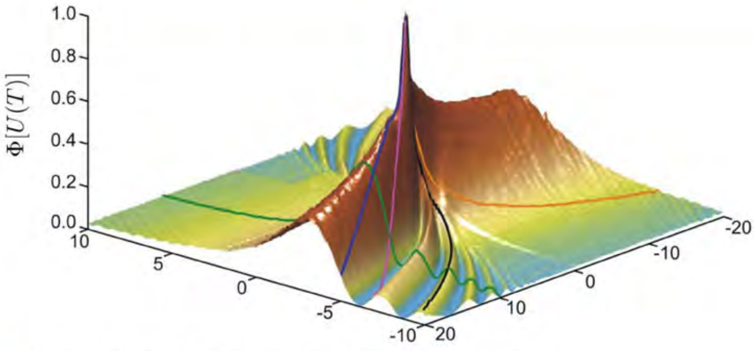


- No model necessary of physical sample
- The discovered signature often enables reverse engineering

Hiking over Quantum Control Landscapes

$$J = \Phi[U(T)] - \lambda \int_0^T f[\epsilon(t)]dt$$

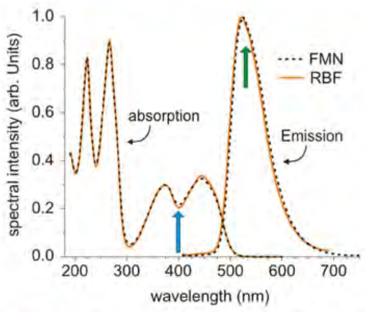
$$\Phi[U(T)] = Tr[U(T)\rho(0)U^{\dagger}(T)\Theta]$$



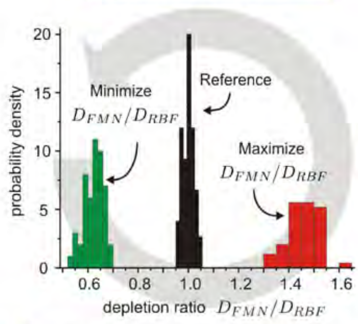
- Generic lack of traps allows "easy" optimization

The Basics with ODD: Achieving Selectivity

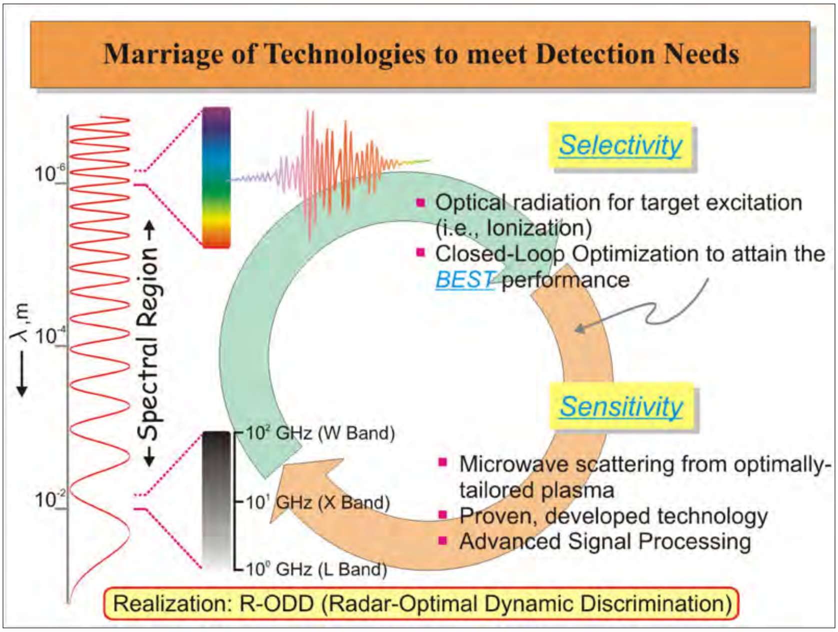
Steady-State Response:

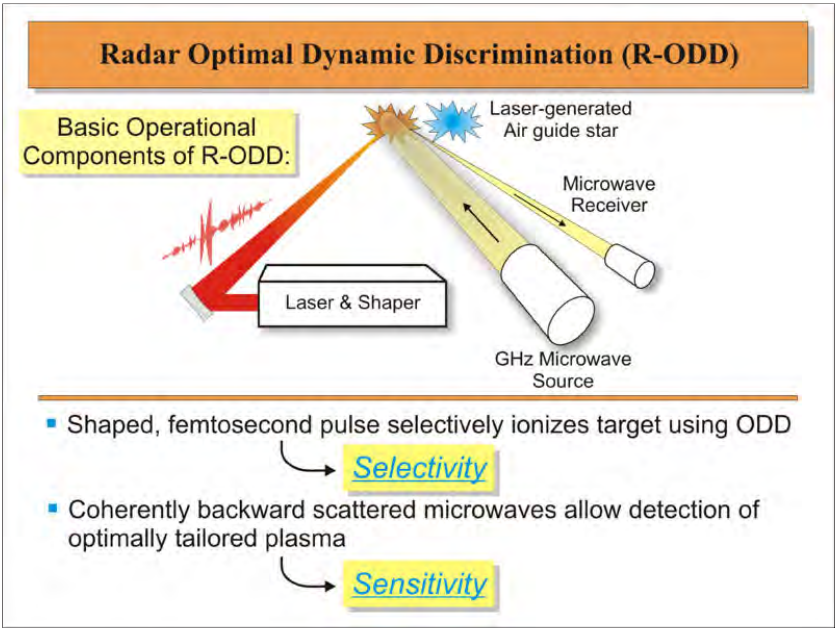


Dynamic Response:



- *Static* spectroscopic methods fail to differentiate RBF and FMN
- Create distinct spectral signatures by optimal tailoring of the *dynamics*
- While steady-state signatures are statistically indistinguishable, optimal pulse varies fluorescence depletion ratio by +/- 42% (Flavin discrimination of 16 σ)


Marriage of Technologies to meet Detection Needs
Selectivity
Optical radiation for target excitation (i.e., Ionization)
Closed-Loop Optimization to attain the BEST performance
Sensitivity
Microwave scattering from optimally-tailored plasma
Proven, developed technology
Advanced Signal Processing
λ, m
10-6
10-4
10-2
Spectral Region
10² GHz (W Band)
10¹ GHz (X Band)
10⁰ GHz (L Band)
Realization: R-ODD (Radar-Optimal Dynamic Discrimination)


Radar Optimal Dynamic Discrimination (R-ODD)
Basic Operational Components of R-ODD:
Laser-generated Air guide star
Microwave Receiver
Laser & Shaper
GHz Microwave Source
Shaped, femtosecond pulse selectively ionizes target using ODD
Selectivity
Coherently backward scattered microwaves allow detection of optimally tailored plasma
Sensitivity

Hiking over Quantum Control Landscapes

$$J = \Phi[U(T)] - \lambda \int_0^T f[\epsilon(t)]dt$$

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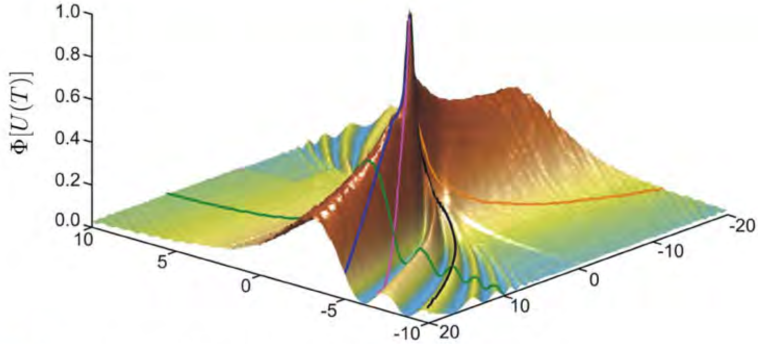

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The Basics with ODD: Achieving Selectivity

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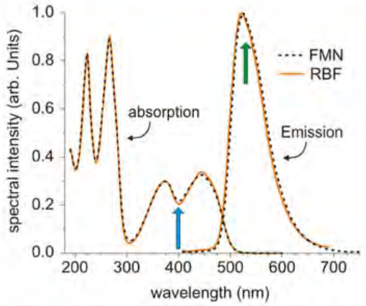
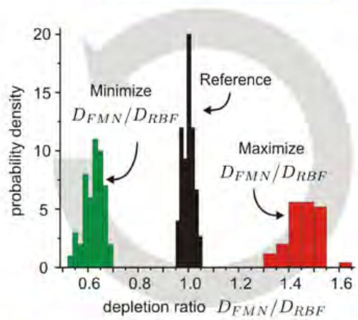


Dynamic Response:



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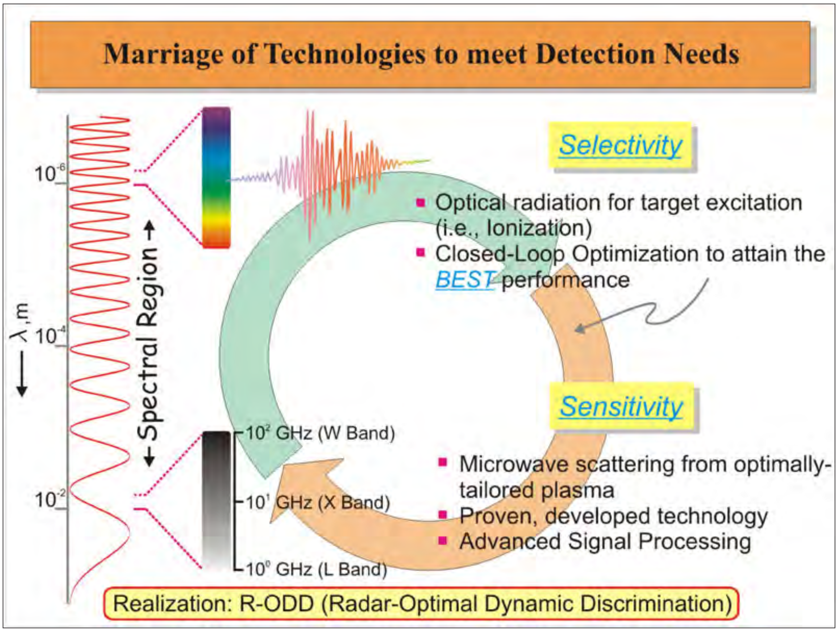
Marriage of Technologies to meet Detection Needs
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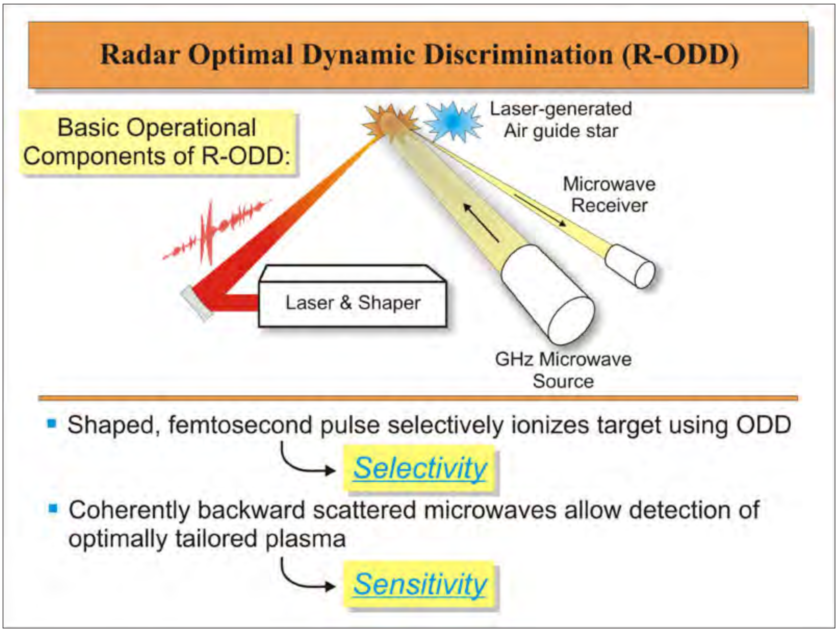
Sensitivity
Microwave scattering from optimally-tailored plasma
Proven, developed technology
Advanced Signal Processing
10^-6
10^-4
10^-2
λ, m
Spectral Region
10^2 GHz (W Band)
10^1 GHz (X Band)
10^0 GHz (L Band)
Realization: R-ODD (Radar-Optimal Dynamic Discrimination)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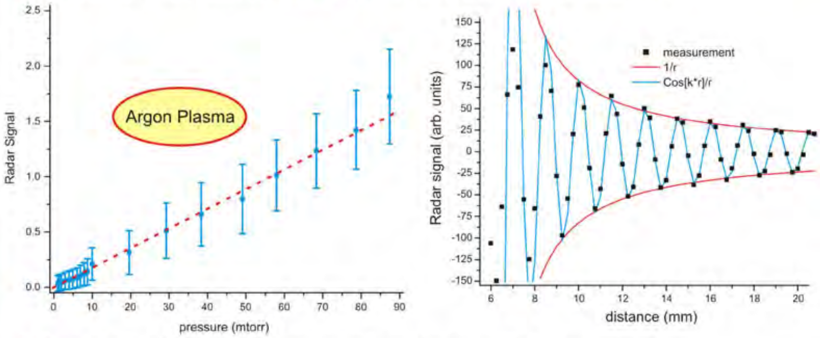
Laser & Shaper
GHz Microwave Source
Shaped, femtosecond pulse selectively ionizes target using ODD
Selectivity
Coherently backward scattered microwaves allow detection of optimally tailored plasma
Sensitivity

R-ODD - Detection Sensitivity and Linearity

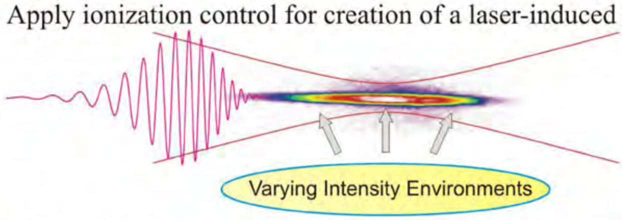
- Linearity of scattered *Field* confirms Coherent Detection



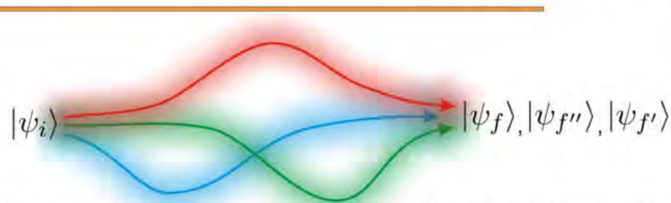
- Scattering from low plasma densities readily measured
  - Pulsed microwave source for increased sensitivity and detection in the **ppt** regime
- Linearity enables concentration determination through R-ODD

Efficient Macroscopic Plasma Creation with ODD

- Apply ionization control for creation of a laser-induced discharge



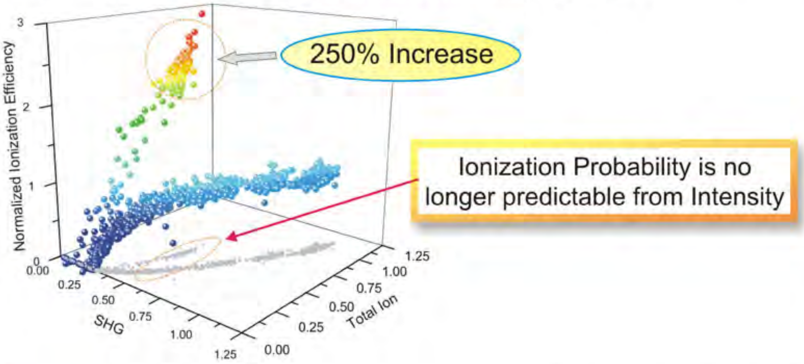
- Maximally discriminating response is desired at every spatial location



- Do the pathway interferences wash out and preclude discrimination?

Use Pulse Shaping to selectively enhance Ionization Rate

- Optimal pulse shaping using $J = \mathcal{J}_{ion}/SHG^{\alpha}$ as a feedback signal is now able to increase the ionization efficiency by 250%



- Algorithm rapidly learns how to enter a region of parameter space that went unnoticed even with thousands of randomly sampled fields

R-ODD - Detection Sensitivity Features

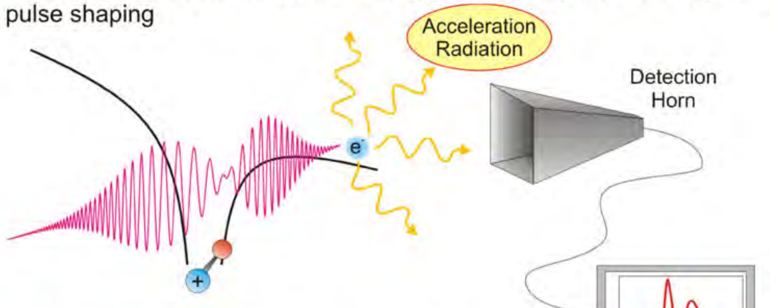
- Distance Scaling: Coherent microwave detection suppresses background and measures scattered *field* rather than *intensity*
- Polarization: Scattered signal is highly polarized (filtering possibility)
- Good S/N: (a) High photon yield per target molecule

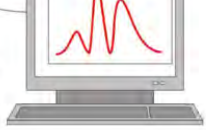
  ≤ 1 Luminescence photon per target
  $\gg 1$ Microwave photons scattered per target

  (b) Differential, time-gated detection with pulsed radar
- Normalization: air breakdown at range as guide star for adaptive optics, pulse tuneup, etc.
- Low Shot Noise: High microwave photon density
- Signal Enhancement: Avalanche and phased array
- Day and Night Operation: Narrowband radar eliminates spectral interferents (i.e., Solar spectrum)

Passive Radar Optimal Dynamic Discrimination (R-ODD)

- Control molecular ionization and free electron acceleration with optical pulse shaping

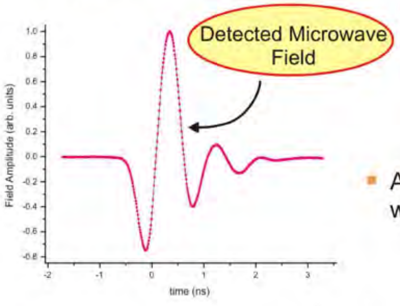




- Resultant microwave spectrum of this nascent radiation is extremely sensitive to optical pulse form
- Utilize ODD to control emitted microwave spectrum based upon molecular structure and electron kinetic energy

Nascent Photocurrent Plasma Radiation

- Heterodyne detection of optically-induced free electron photocurrent

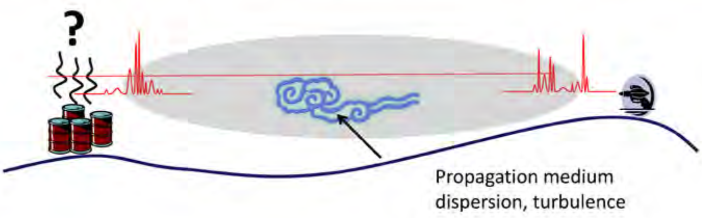


$$e(\vec{r},t) \sim \frac{dI_{PC}(\vec{r},t)}{dt}$$

- Atmospheric transmission water window below ~22GHz

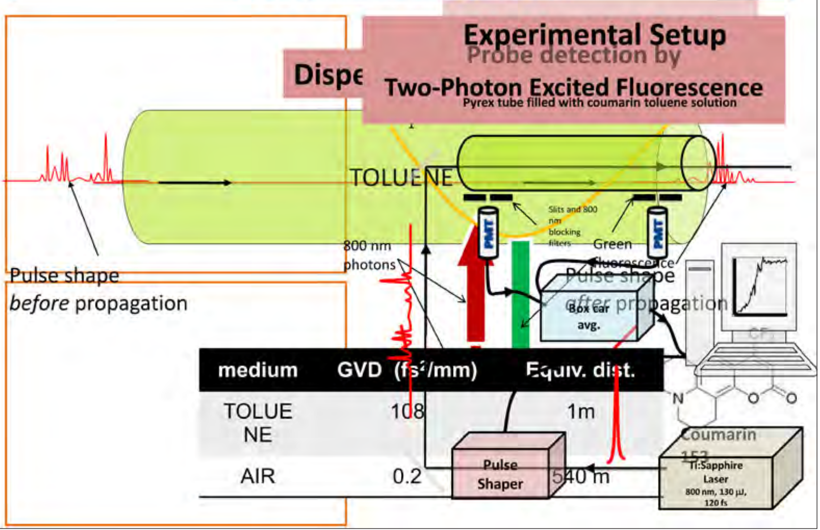
- Coherent, polarized emission detected at ~12 Ghz via three distinct mechanisms
  - Unique *directivity*, *polarization*, and *spectral* characteristics
- Exercise direct control over this emitted microwave radiation

Medium Dispersion and Turbulence Management for Remote Detection using Shaped Pulses



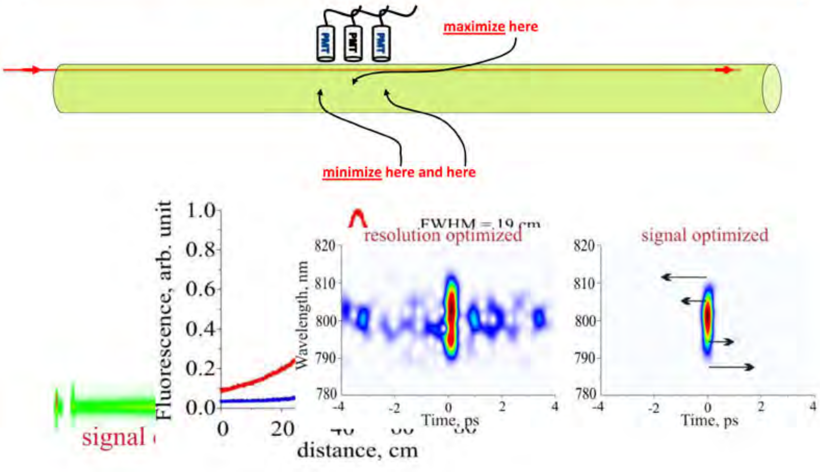
1. Can we "compensate" for the effects on the pulse shape due to propagation?
2. Could we manage these effects in order to achieve new practical goals?

Control of Two-Photon Excited Fluorescence through Pulse Propagation

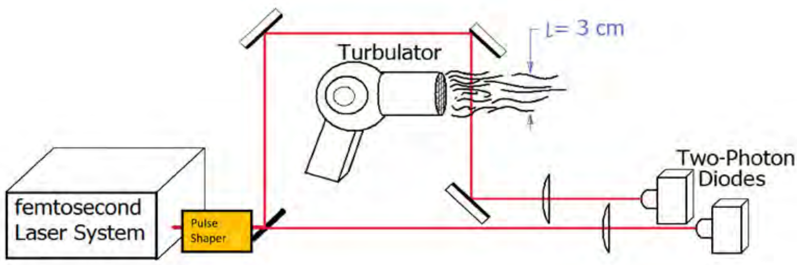


medium	GVD (fs²/mm)	Equiv. dist.
TOLUENE	108	1m
AIR	0.2	540 m

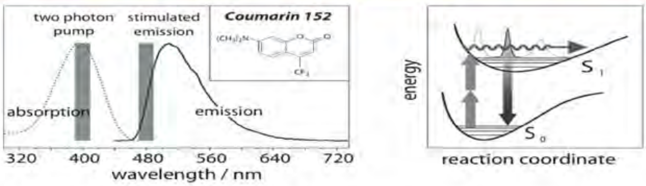
Optimization of Longitudinal Resolution



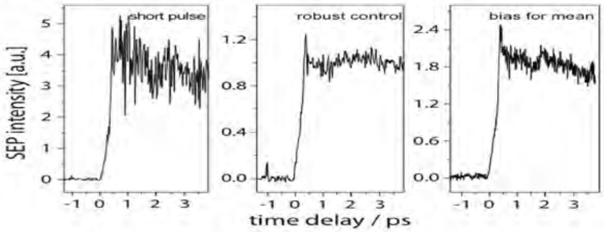
Managing the Effects of Turbulence



Analogy with Fighting Noise: Quality Assurance through Optimal Control



- Balancing the mean signal and the signal quality



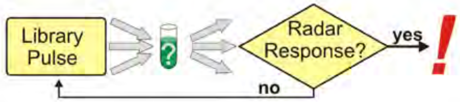
Features of ODD-Ex

- Employs closed-loop adaptive control for detection specificity in complex environments
- Reconfigurable set of tools may be implemented with traditional high sensitivity spectroscopic techniques
- Ability to combine different spectral regimes for best sensitivity and selectivity
- Solution multiplicity enables detection multiplexing for increased confidence
- High selectivity melded with high sensitivity for reduced false positive and negative probabilities

ODD relies on synthesis of Science, Engineering, and Technology

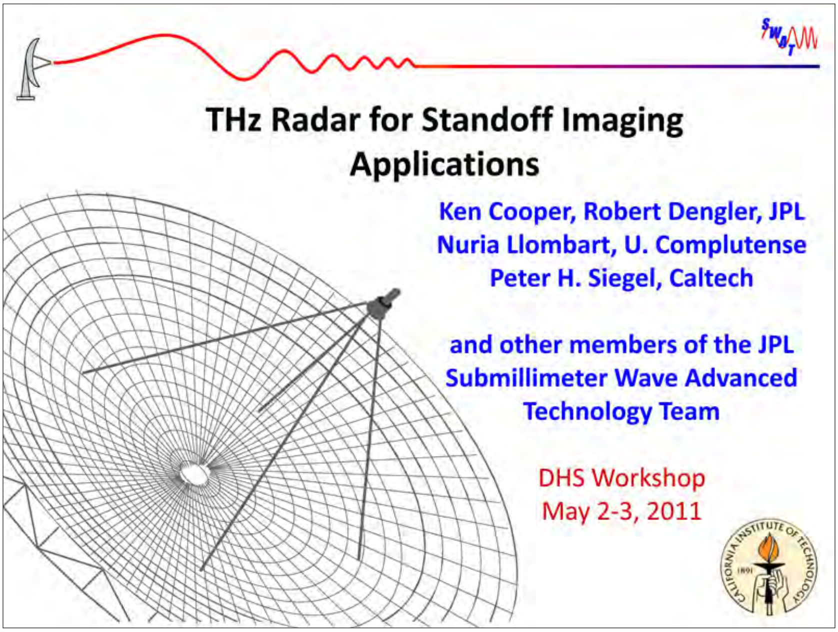
Next Steps...

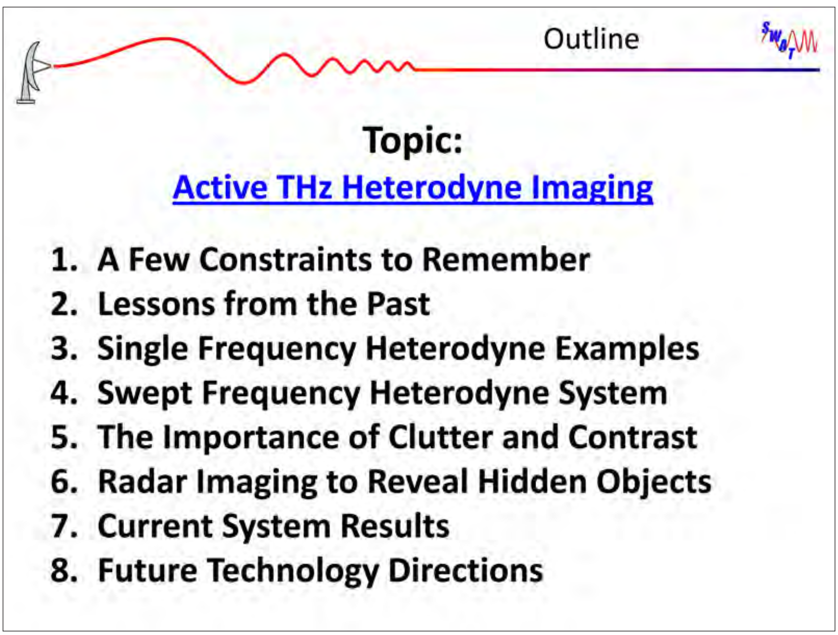
- Full development of Active and Passive R-ODD capabilities
  - Assembly of ODD-Ex optimal pulse library

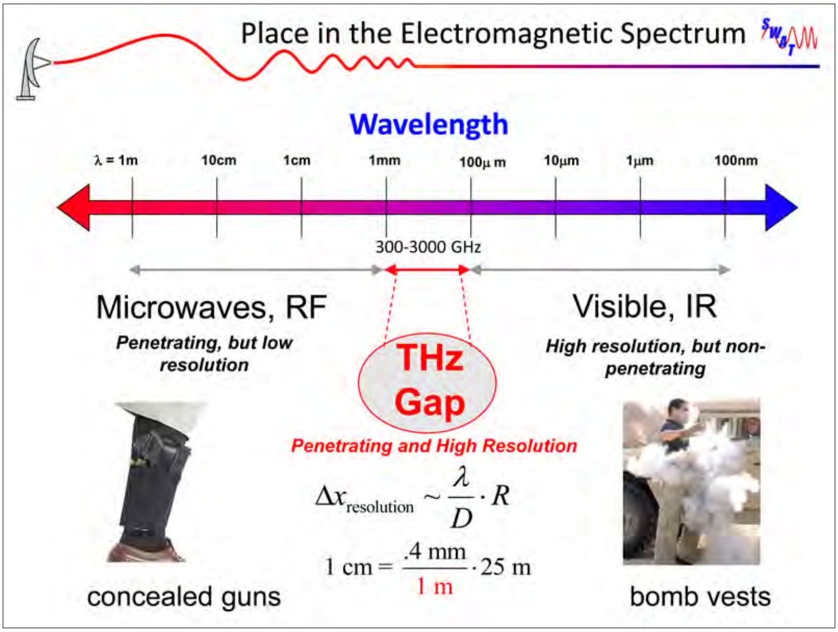


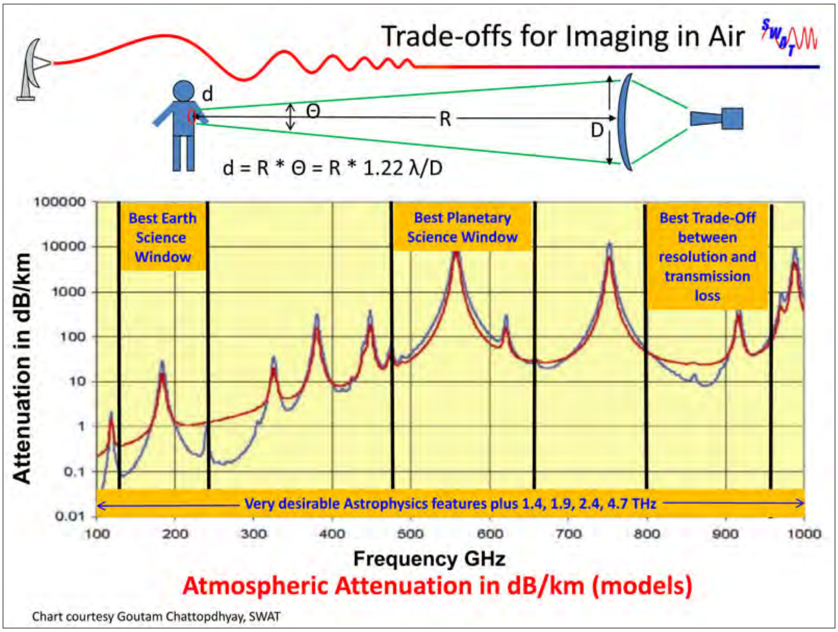
  - Detailed analysis of R-ODD sensitivity limits
- Transfer of ODD toolbox to other nonlinear spectroscopies
  - Tailored nondestructive excitation-stimulated emission in a single temporally shaped pulse
  - Optimally designed fragmentation signature
- Realistic exploration of ODD-Ex capabilities

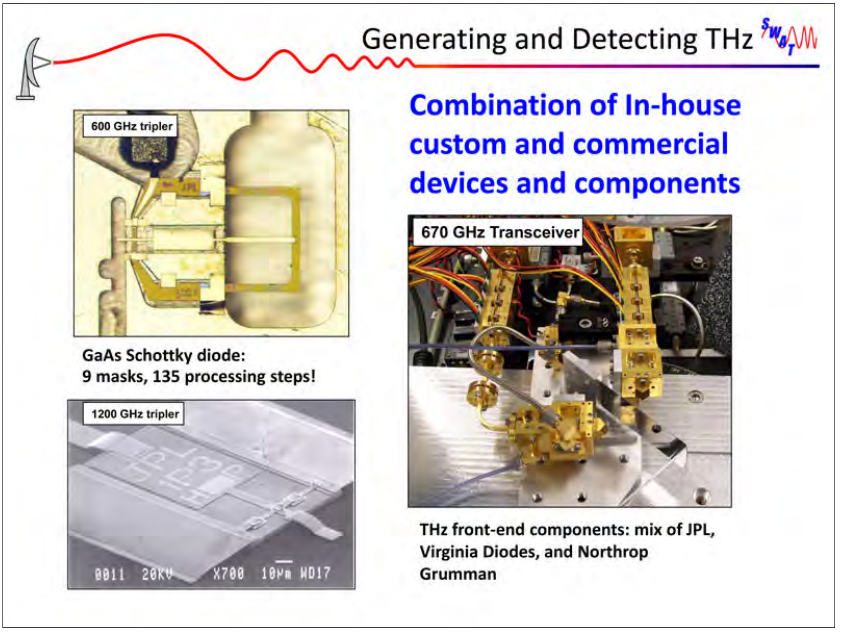
16.9 Peter Siegel: Terahertz imaging and spectroscopy

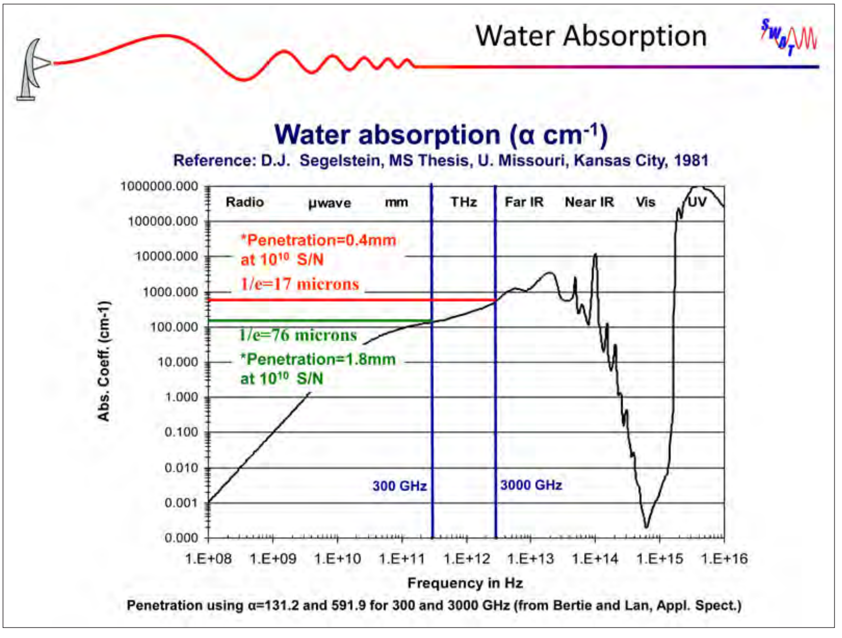


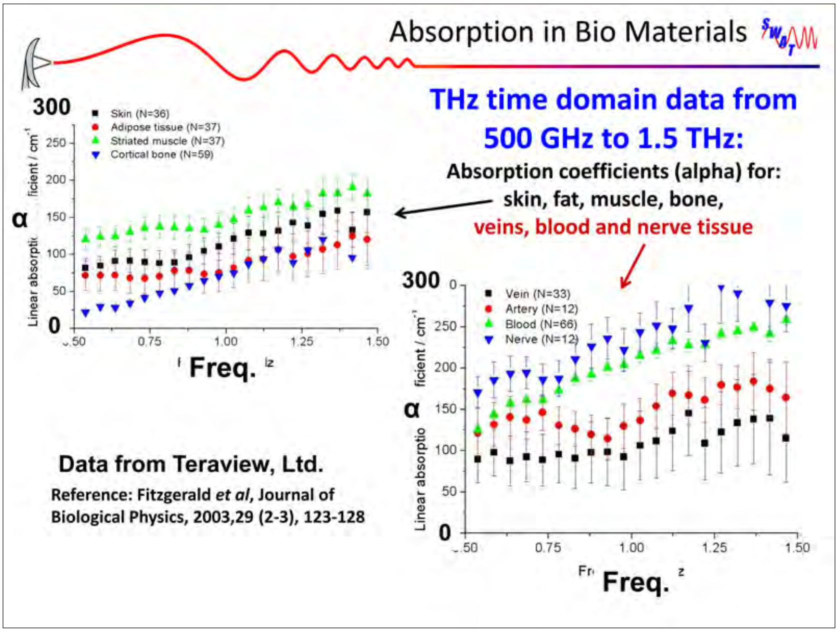


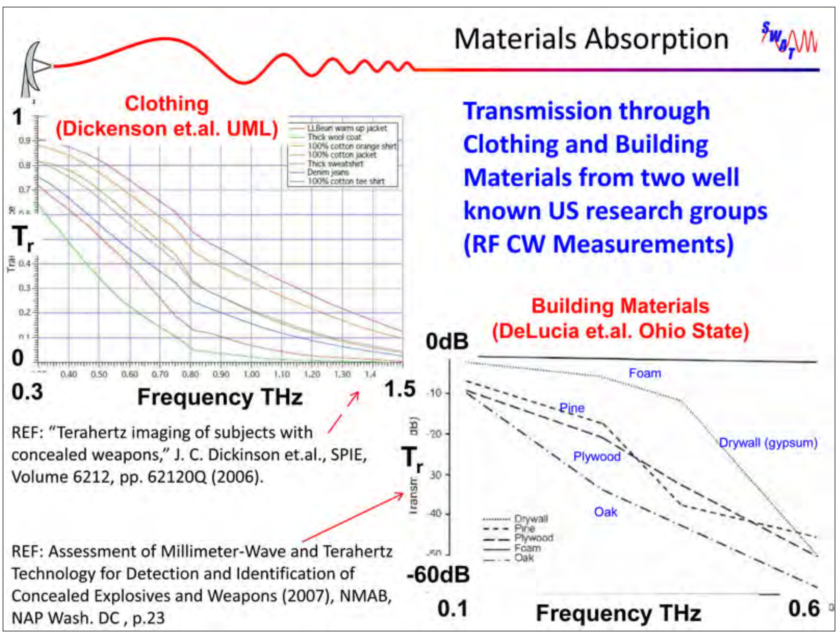

Place in the Electromagnetic Spectrum
Wavelength
λ = 1m
10cm
1cm
1mm
100μ m
10μm
1μm
100nm
300-3000 GHz
Microwaves, RF
Penetrating, but low resolution
THz Gap
Penetrating and High Resolution
Visible, IR
High resolution, but non-penetrating
$\Delta x_{\text{resolution}} \sim \frac{\lambda}{D} \cdot R$
$1 \text{ cm} = \frac{.4 \text{ mm}}{1 \text{ m}} \cdot 25 \text{ m}$
concealed guns
bomb vests


Trade-offs for Imaging in Air
d
Θ
R
D
d = R * Θ = R * 1.22 λ/D
Best Earth Science Window
Best Planetary Science Window
Best Trade-Off between resolution and transmission loss
Very desirable Astrophysics features plus 1.4, 1.9, 2.4, 4.7 THz
Attenuation in dB/km
100000
10000
1000
100
10
1
0.1
0.01
100
200
300
400
500
600
700
800
900
1000
Frequency GHz
Atmospheric Attenuation in dB/km (models)
Chart courtesy Goutam Chattopdhyay, SWAT


Generating and Detecting THz
Combination of In-house custom and commercial devices and components
600 GHz tripler
GaAs Schottky diode:
9 masks, 135 processing steps!
1200 GHz tripler
0011 20KV X700 10µm WD17
670 GHz Transceiver
THz front-end components: mix of JPL, Virginia Diodes, and Northrop Grumman


Water Absorption
Water absorption (α cm-1)
Reference: D.J. Segelstein, MS Thesis, U. Missouri, Kansas City, 1981
Radio
µwave
mm
THz
Far IR
Near IR
Vis
UV
*Penetration=0.4mm at 10^10 S/N
1/e=17 microns
1/e=76 microns
*Penetration=1.8mm at 10^10 S/N
300 GHz
3000 GHz
Abs. Coeff. (cm-1)
1000000.000
100000.000
10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
0.000
1.E+08
1.E+09
1.E+10
1.E+11
1.E+12
1.E+13
1.E+14
1.E+15
1.E+16
Frequency in Hz
Penetration using α=131.2 and 591.9 for 300 and 3000 GHz (from Bertie and Lan, Appl. Spect.)


Absorption in Bio Materials
THz time domain data from
500 GHz to 1.5 THz:
Absorption coefficients (alpha) for:
skin, fat, muscle, bone,
veins, blood and nerve tissue
Skin (N=36)
Adipose tissue (N=37)
Striated muscle (N=37)
Cortical bone (N=59)
Vein (N=33)
Artery (N=12)
Blood (N=66)
Nerve (N=12)
α
Freq.
Data from Teraview, Ltd.
Reference: Fitzgerald et al, Journal of Biological Physics, 2003,29 (2-3), 123-128


Materials Absorption
Clothing
(Dickenson et.al. UML)
Transmission through
Clothing and Building
Materials from two well
known US research groups
(RF CW Measurements)
Building Materials
(DeLucia et.al. Ohio State)
Tr
Frequency THz
0.3
1.5
0dB
-60dB
0.1
0.6
Foam
Pine
Plywood
Oak
Drywall (gypsum)
REF: "Terahertz imaging of subjects with concealed weapons," J. C. Dickinson et.al., SPIE, Volume 6212, pp. 62120Q (2006).
REF: Assessment of Millimeter-Wave and Terahertz Technology for Detection and Identification of Concealed Explosives and Weapons (2007), NMAB, NAP Wash. DC , p.23

Heterodyning

- HETERODYNE – literally *other* or *different power* is the beating together of two closely spaced sinusoidal signals to produce the sum or DIFFERENCE frequency. The principle was patented by Reginald Fessenden (chief chemist for Thomas Edison) in 1902 but not demonstrated until invention of audion tube (triode) by Lee De Forest in 1906. Also patented by Lucien Levy in 1917 (France).
- First put into practice with the demonstration of the super heterodyne receiver by Edwin Armstrong in 1917 (patented 1919).
- Heterodyning is the underpinning principle of all modern radio and one of the most widely employed circuit concepts in RF.


Reginald Fessenden

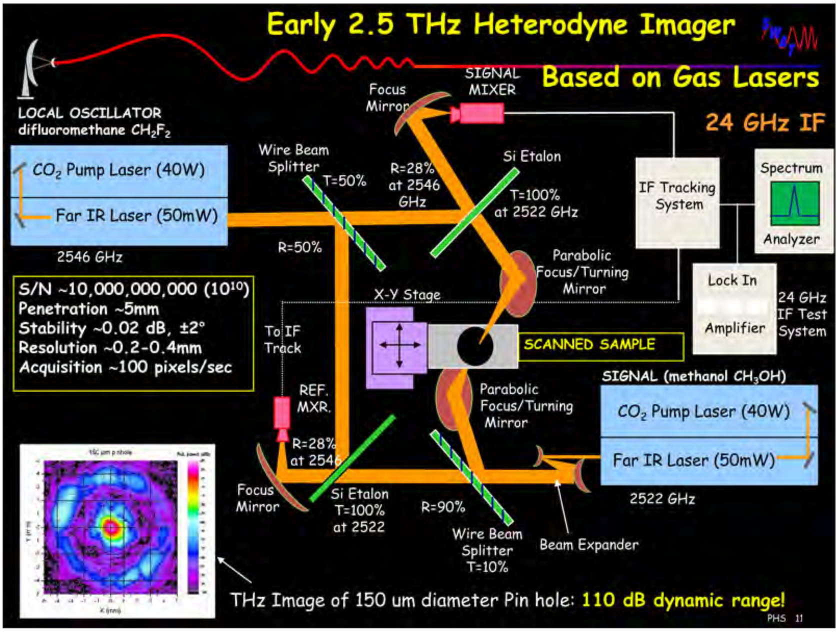

Lee de Forest

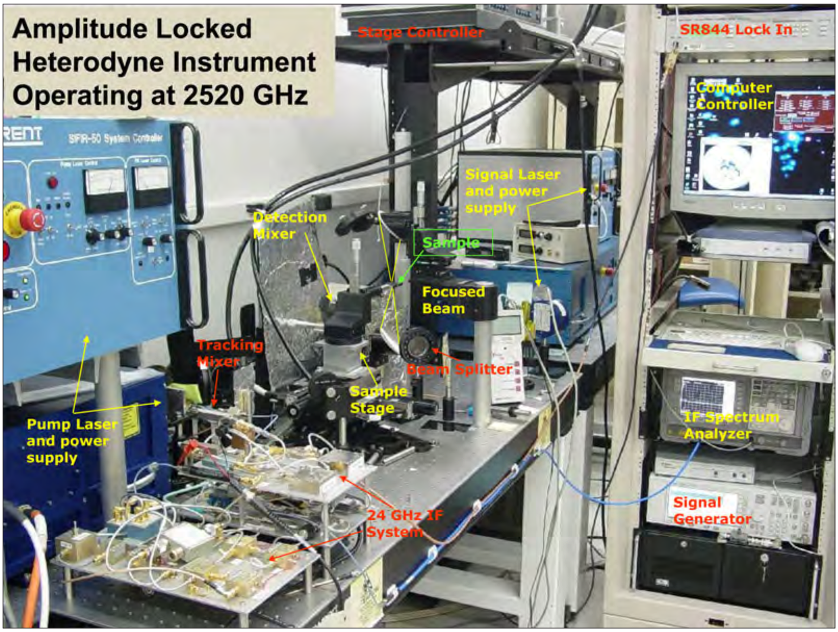

Edwin Armstrong

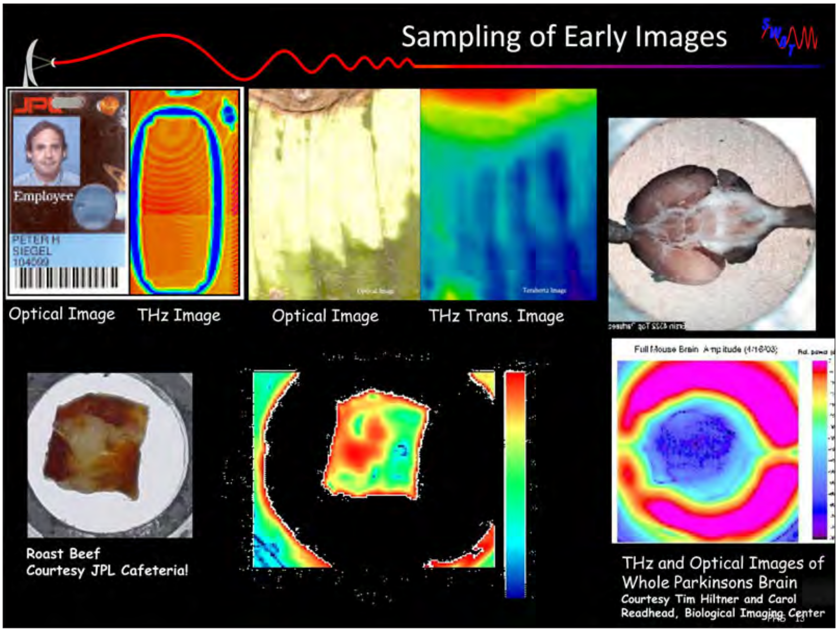
Heterodyne Imaging

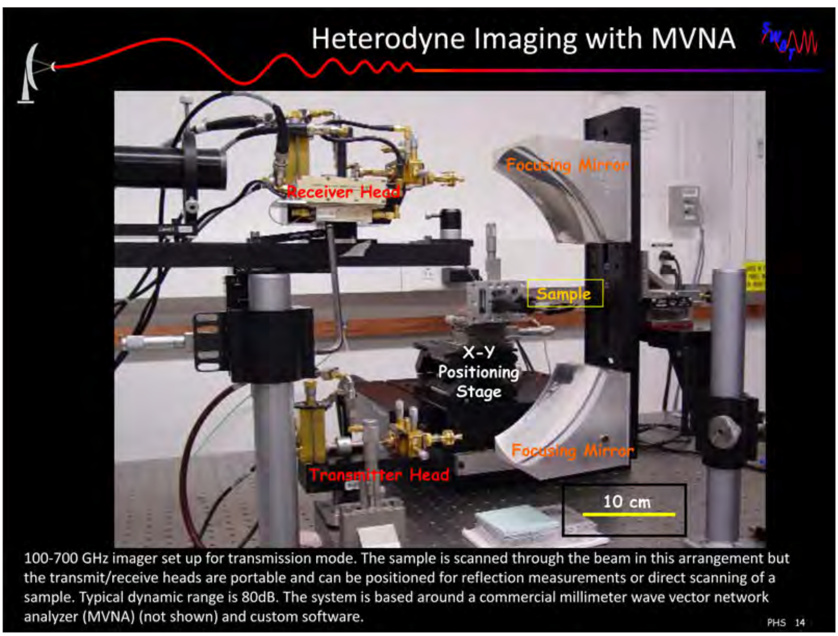
Some reasons for pursuing imaging using heterodyne techniques:

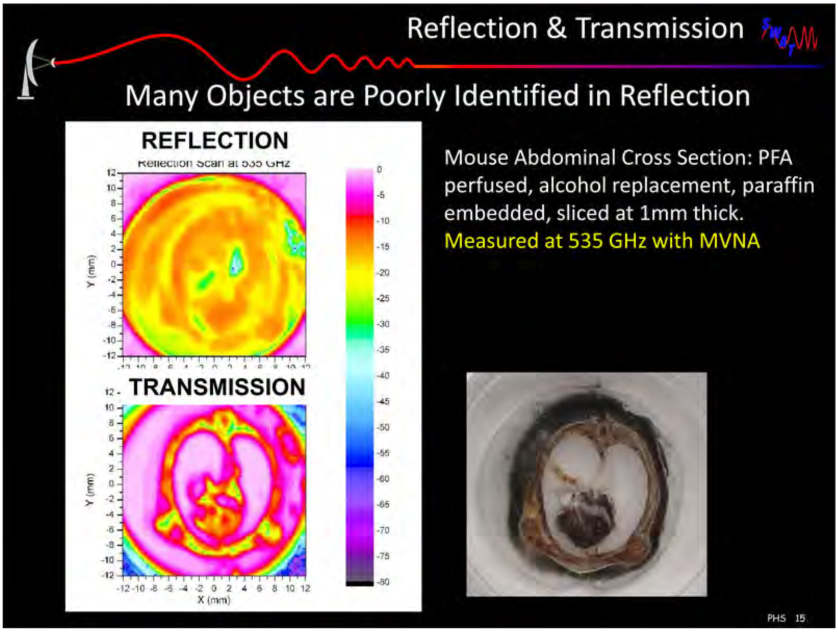
- High differential sensitivity (NEΔT) with room temperature detection
- Ability to perform Magnitude and Phase measurements on samples
- Extremely Large Dynamic Range - important for high loss materials
- Background limited S/N for narrow band observations
- Adequate S/N for passive detection if radiometric techniques are employed
- Potential for Spectral analysis
- Velocity sensing using Doppler shift at IF
- Chirp techniques provide 3D imagery or Time of Flight

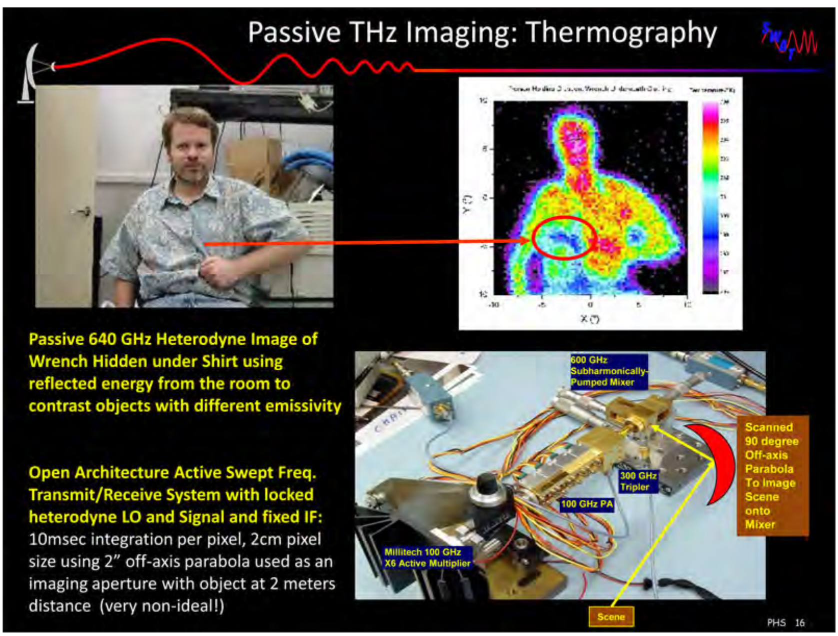

Early 2.5 THz Heterodyne Imager
Based on Gas Lasers
24 GHz IF
LOCAL OSCILLATOR
difluoromethane CH_2F_2
CO_2 Pump Laser (40W)
Far IR Laser (50mW)
2546 GHz
S/N ~10,000,000,000 (10^{10})
Penetration ~5mm
Stability ~0.02 dB, ±2°
Resolution ~0.2-0.4mm
Acquisition ~100 pixels/sec
Focus Mirror
SIGNAL MIXER
Wire Beam Splitter
T=50%
R=50%
R=28% at 2546 GHz
Si Etalon
T=100% at 2522 GHz
IF Tracking System
Spectrum
Analyzer
Parabolic Focus/Turning Mirror
Lock In
Amplifier
24 GHz IF Test System
X-Y Stage
To IF Track
SCANNED SAMPLE
SIGNAL (methanol CH_3OH)
REF. MXR.
Parabolic Focus/Turning Mirror
CO_2 Pump Laser (40W)
Far IR Laser (50mW)
R=28% at 2546
Focus Mirror
Si Etalon
T=100%
at 2522
R=90%
2522 GHz
Wire Beam Splitter
T=10%
Beam Expander
THz Image of 150 um diameter Pin hole: 110 dB dynamic range!
PHS 11

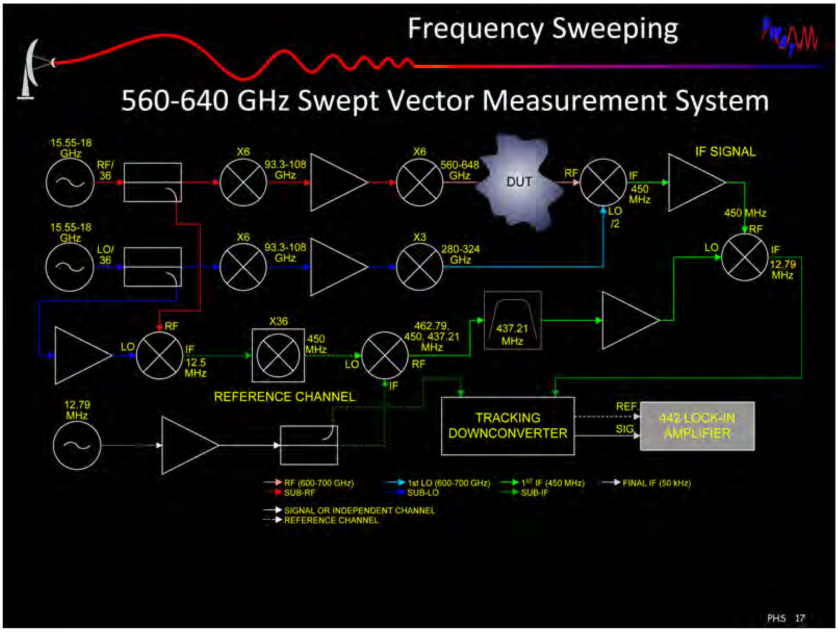

Amplitude Locked
Heterodyne Instrument
Operating at 2520 GHz
Stage Controller
SR844 Lock In
Computer Controller
Signal Laser and power supply
Detection Mixer
Sample
Focused Beam
Tracking Mixer
Beam Splitter
Sample Stage
Pump Laser and power supply
IF Spectrum Analyzer
24 GHz IF System
Signal Generator

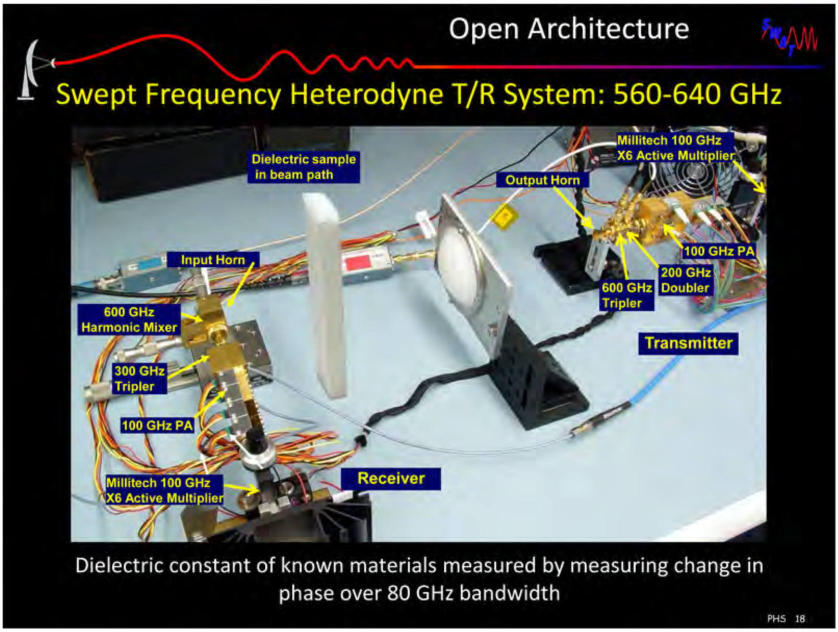

Sampling of Early Images
Employee
PETER H
SIEGEL
Optical Image
THz Image
Optical Image
THz Trans. Image
Roast Beef
Courtesy JPL Cafeteria!
THz and Optical Images of
Whole Parkinsons Brain
Courtesy Tim Hiltner and Carol
Readhead, Biological Imaging Center


Heterodyne Imaging with MVNA
Receiver Head
Focusing Mirror
Sample
X-Y
Positioning
Stage
Focusing Mirror
Transmitter Head
10 cm
100-700 GHz imager set up for transmission mode. The sample is scanned through the beam in this arrangement but the transmit/receive heads are portable and can be positioned for reflection measurements or direct scanning of a sample. Typical dynamic range is 80dB. The system is based around a commercial millimeter wave vector network analyzer (MVNA) (not shown) and custom software.
PHS 14

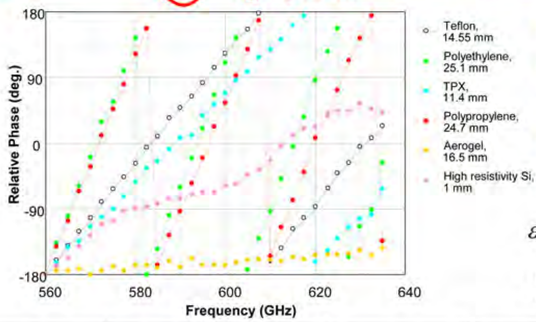

Reflection & Transmission
Many Objects are Poorly Identified in Reflection
REFLECTION
TRANSMISSION
Y (mm)
X (mm)
Mouse Abdominal Cross Section: PFA perfused, alcohol replacement, paraffin embedded, sliced at 1mm thick.
Measured at 535 GHz with MVNA
PHS 15


Passive THz Imaging: Thermography
Passive 640 GHz Heterodyne Image of Wrench Hidden under Shirt using reflected energy from the room to contrast objects with different emissivity
Open Architecture Active Swept Freq. Transmit/Receive System with locked heterodyne LO and Signal and fixed IF:
10msec integration per pixel, 2cm pixel size using 2" off-axis parabola used as an imaging aperture with object at 2 meters distance (very non-ideal!)
600 GHz Subharmonically-Pumped Mixer
300 GHz Tripler
100 GHz PA
Millitech 100 GHz X6 Active Multiplier
Scanned 90 degree Off-axis Parabola To Image Scene onto Mixer
Scene
PHS 16


Frequency Sweeping
560-640 GHz Swept Vector Measurement System
15.55-18 GHz
RF/36
X6
93.3-108 GHz
X6
560-648 GHz
DUT
RF
IF
450 MHz
IF SIGNAL
LO /2
450 MHz
RF
15.55-18 GHz
LO/36
X6
93.3-108 GHz
X3
280-324 GHz
LO
IF
12.79 MHz
RF
LO
IF
12.5 MHz
X36
450 MHz
LO
RF
462.79, 450, 437.21 MHz
437.21 MHz
IF
REFERENCE CHANNEL
12.79 MHz
TRACKING DOWNCONVERTER
REF
SIG
442 LOCK-IN AMPLIFIER
PHS 17


Open Architecture
Swept Frequency Heterodyne T/R System: 560-640 GHz
Dielectric sample in beam path
Millitech 100 GHz X6 Active Multiplier
Output Horn
Input Horn
100 GHz PA
200 GHz Doubler
600 GHz Tripler
600 GHz Harmonic Mixer
Transmitter
300 GHz Tripler
100 GHz PA
Receiver
Millitech 100 GHz X6 Active Multiplier
Dielectric constant of known materials measured by measuring change in phase over 80 GHz bandwidth
PHS 18

Dielectric Constants



Measure phase change vs. frequency to find ε_r given t

$$\varepsilon_r = \left(\frac{\partial \phi}{\partial f} \cdot \frac{c}{360 \cdot t} + t \right)^2$$

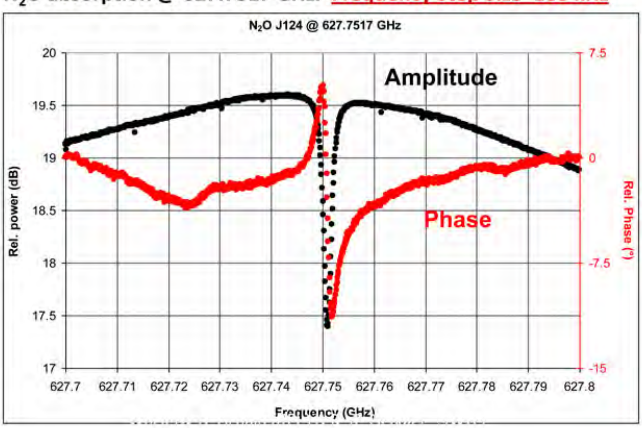
t = thickness of material
d*Φ*/d*f* = rate of phase change

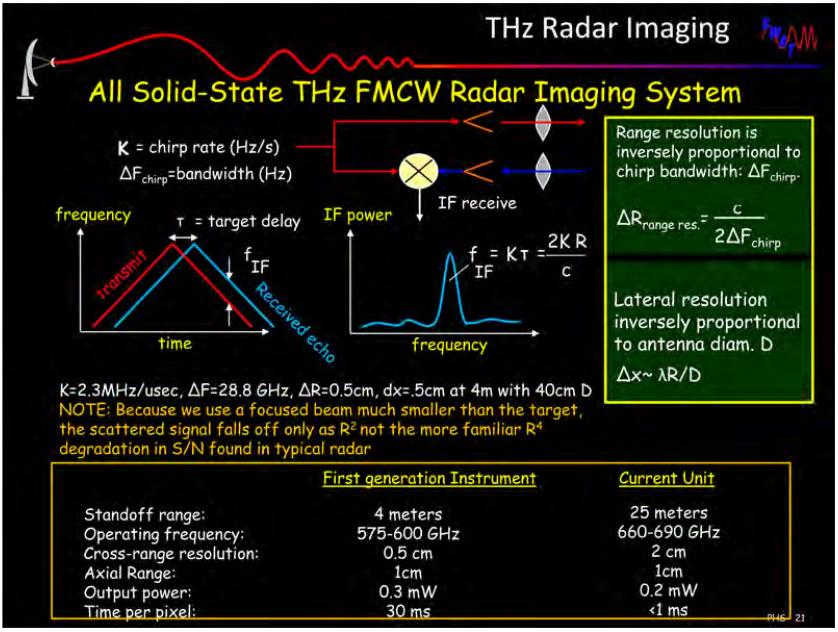
Material	Thickness t (mm)	dΦ/df (°/GHz)	Measured Dielectric Constant	Dielectric Constant from published data	% Error from Published data
Teflon	14.55	7.73	2.080	2.0532 [15]	1.3
Polyethylene	25.1	16.35	2.379	2.3247 [15]	2.3
TPX	11.4	6.36	2.144	2.1318 [15]	0.57
Polypropylene	24.7	15.14	2.284	2.255 [17]	1.3
Aerogel	16.5	0.47	1.048	-	-
Hi-Resistivity Si	1.0	2.96	12.03	11.67 [17]	3.1

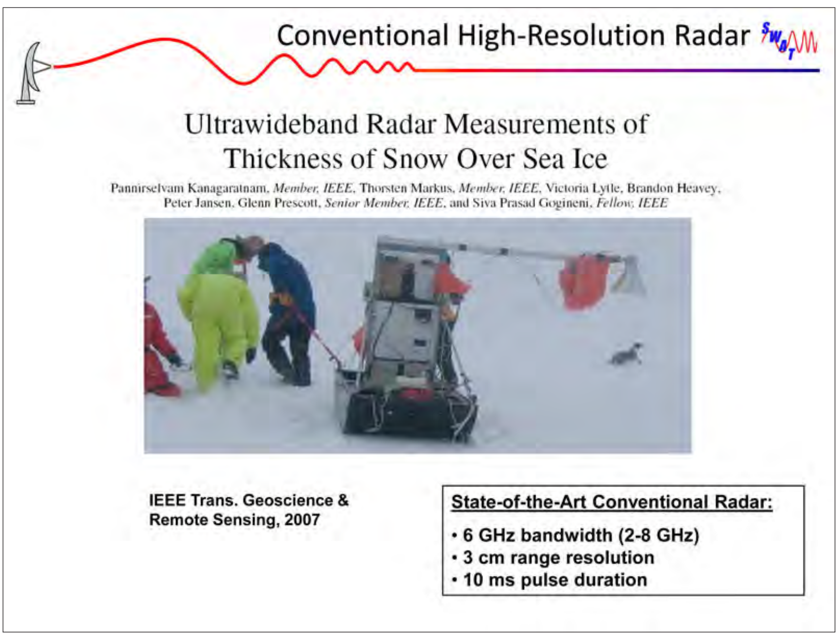
Spectral Signatures

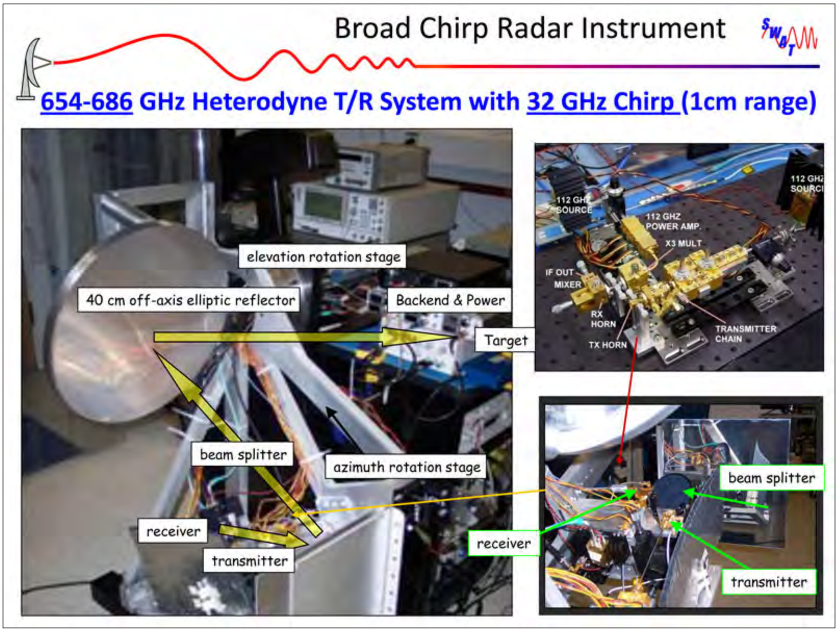
Narrow Line Spectroscopy (Gas Phase)

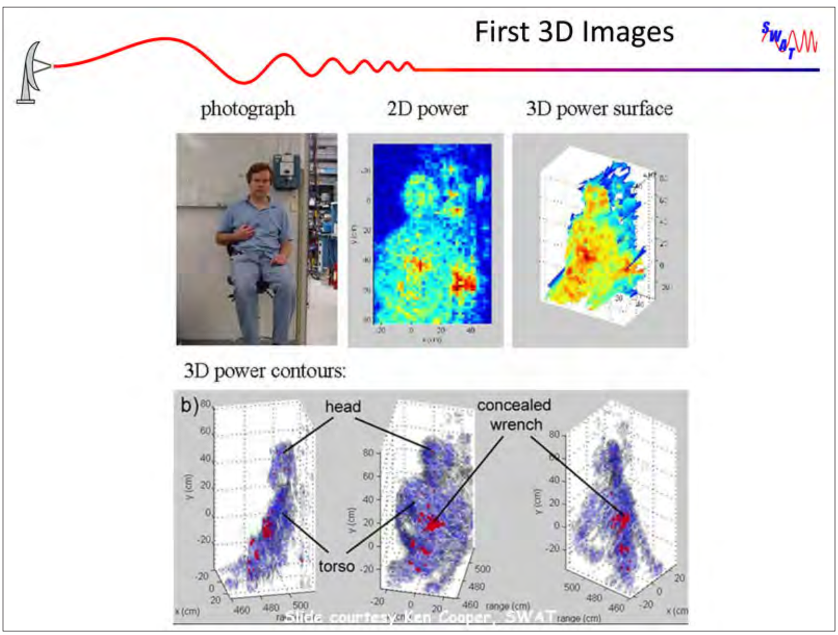
N_2O absorption @ 627.7517 GHz. <u>Frequency Step Size=100 kHz</u>

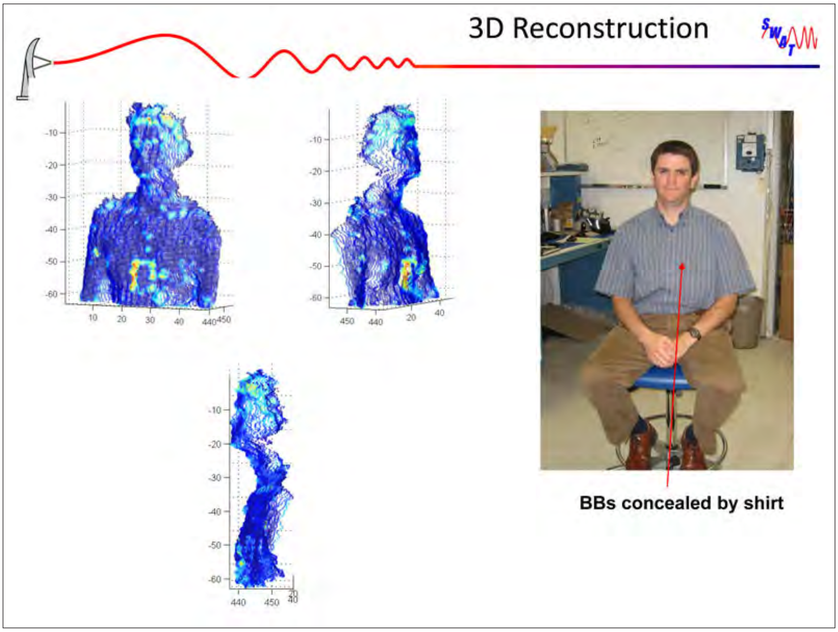


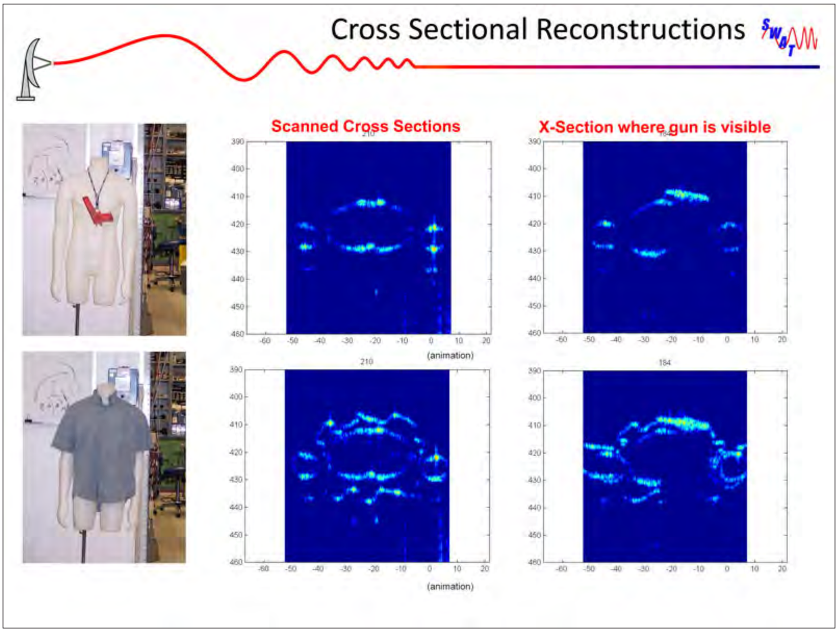

THz Radar Imaging
All Solid-State THz FMCW Radar Imaging System
K = chirp rate (Hz/s)
ΔF_chirp=bandwidth (Hz)
IF receive
frequency
τ = target delay
IF power
f_IF
transmit
Received echo
time
frequency
f_IF = Kτ = 2KR/c
Range resolution is inversely proportional to chirp bandwidth: ΔF_chirp.
ΔR_range res. = c / 2ΔF_chirp
Lateral resolution inversely proportional to antenna diam. D
Δx~ λR/D
K=2.3MHz/usec, ΔF=28.8 GHz, ΔR=0.5cm, dx=.5cm at 4m with 40cm D
NOTE: Because we use a focused beam much smaller than the target, the scattered signal falls off only as R² not the more familiar R⁴ degradation in S/N found in typical radar
First generation Instrument | Current Unit
Standoff range: 4 meters | 25 meters
Operating frequency: 575-600 GHz | 660-690 GHz
Cross-range resolution: 0.5 cm | 2 cm
Axial Range: 1cm | 1cm
Output power: 0.3 mW | 0.2 mW
Time per pixel: 30 ms | <1 ms
PHS 21

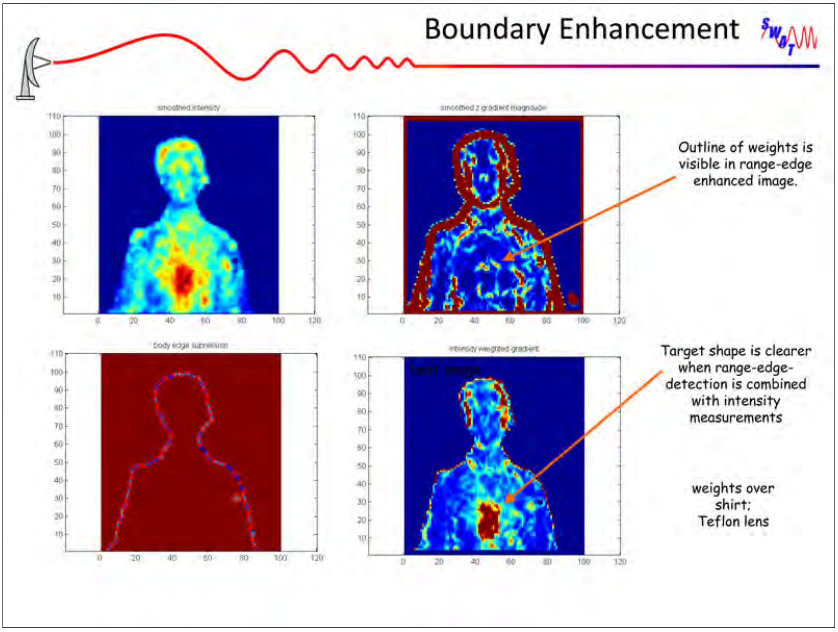

Conventional High-Resolution Radar
Ultrawideband Radar Measurements of Thickness of Snow Over Sea Ice
Pannirselvam Kanagaratnam, Member, IEEE, Thorsten Markus, Member, IEEE, Victoria Lytle, Brandon Heavey, Peter Jansen, Glenn Prescott, Senior Member, IEEE, and Siva Prasad Gogineni, Fellow, IEEE
IEEE Trans. Geoscience & Remote Sensing, 2007
State-of-the-Art Conventional Radar:
• 6 GHz bandwidth (2-8 GHz)
• 3 cm range resolution
• 10 ms pulse duration

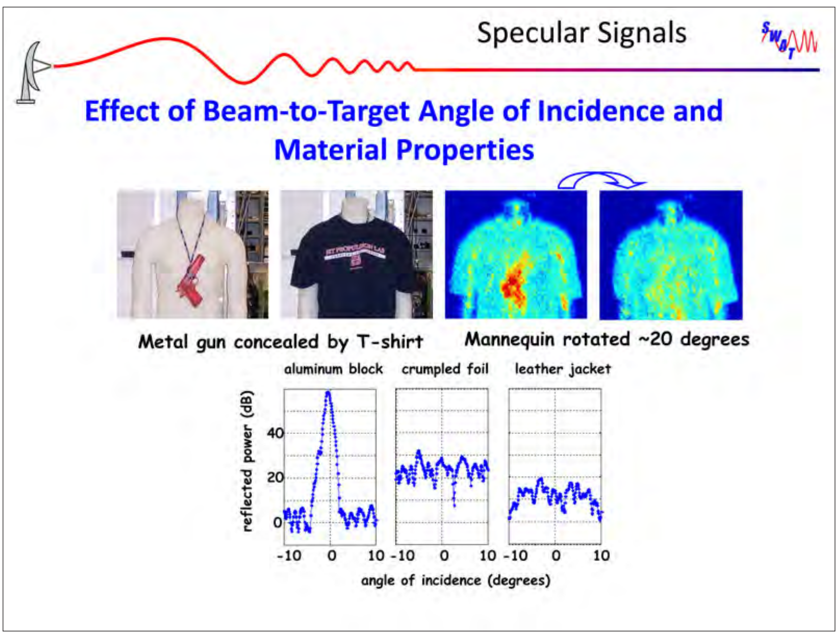

Broad Chirp Radar Instrument
654-686 GHz Heterodyne T/R System with 32 GHz Chirp (1cm range)
elevation rotation stage
40 cm off-axis elliptic reflector
Backend & Power
Target
beam splitter
azimuth rotation stage
receiver
transmitter
112 GHZ SOURCE
112 GHZ POWER AMP.
X3 MULT
IF OUT
MIXER
RX HORN
TX HORN
TRANSMITTER CHAIN
beam splitter
receiver
transmitter


First 3D Images
photograph
2D power
3D power surface
3D power contours:
b)
head
concealed wrench
torso
Slide courtesy Ken Cooper, SWAT


3D Reconstruction
BBs concealed by shirt


Cross Sectional Reconstructions
Scanned Cross Sections
X-Section where gun is visible
(animation)
(animation)


Boundary Enhancement
Outline of weights is visible in range-edge enhanced image.
Target shape is clearer when range-edge-detection is combined with intensity measurements
weights over shirt;
Teflon lens

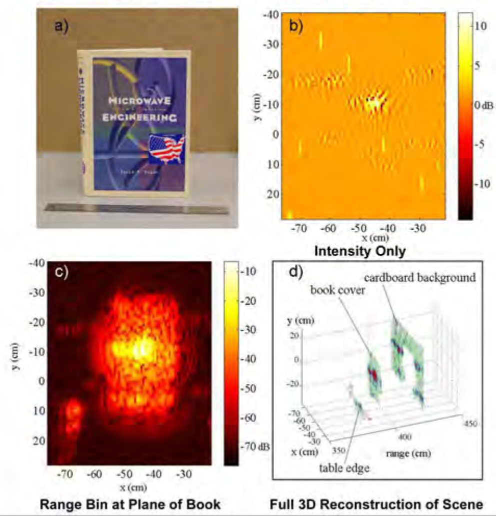

Specular Signals
Effect of Beam-to-Target Angle of Incidence and Material Properties
Metal gun concealed by T-shirt
Mannequin rotated ~20 degrees
aluminum block
crumpled foil
leather jacket
reflected power (dB)
40
20
0
-10
0
10
angle of incidence (degrees)

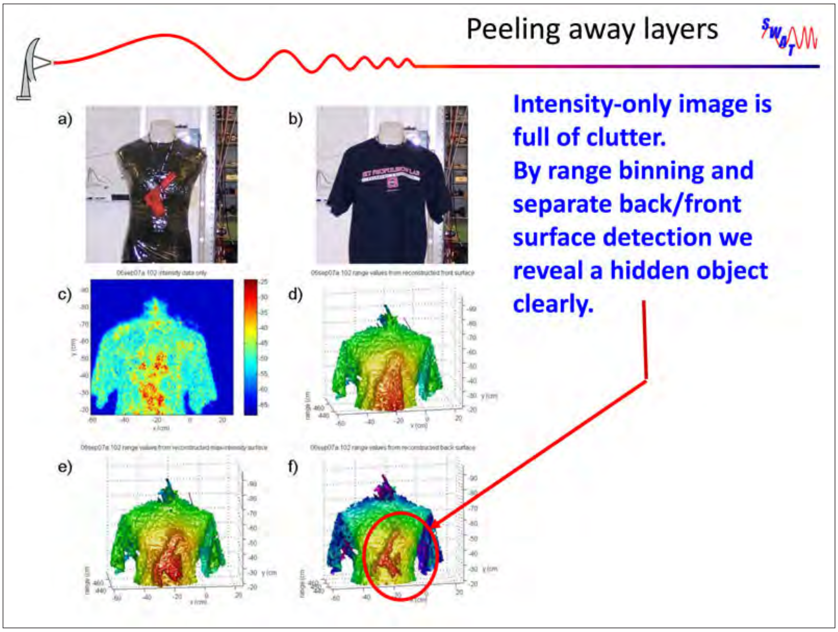
Cardboard Gun!

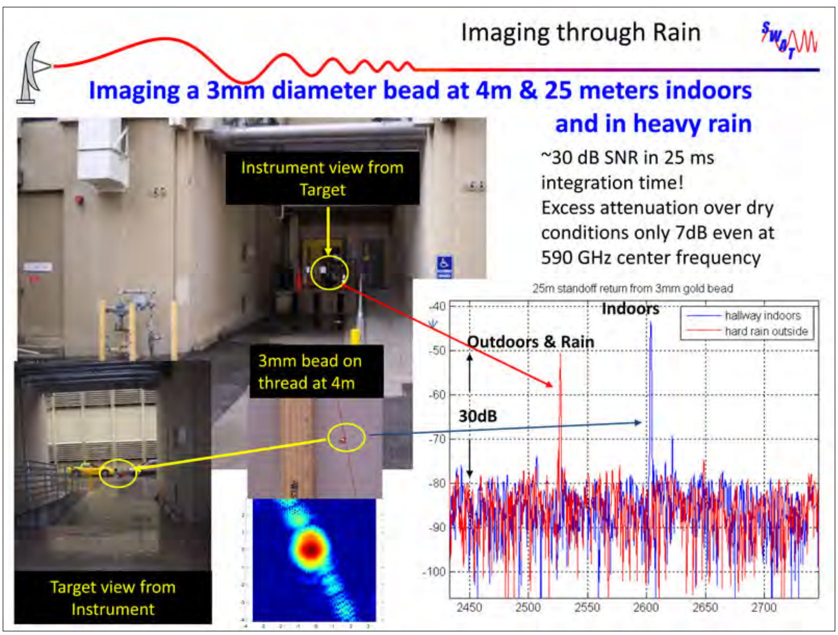
Intensity-only image of a concealed cardboard "gun" indicating that near-specular return from dielectric materials can yield a signal nearly as large as that from metallic objects

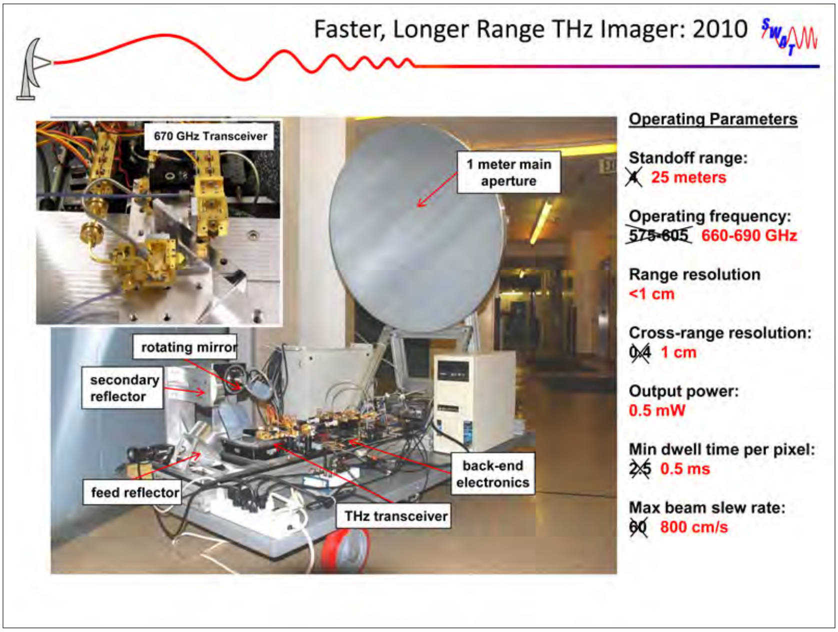
Scene Clutter

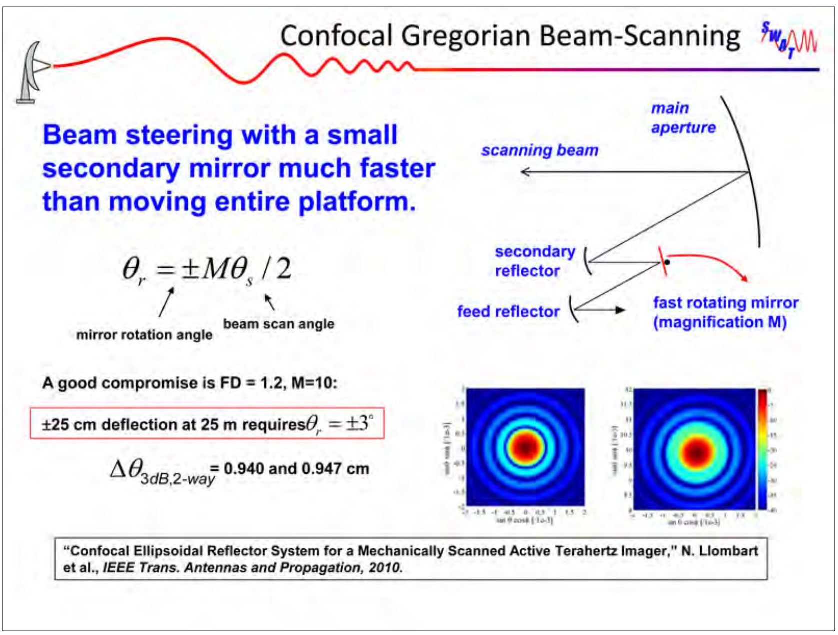
Intensity-only images of a book and 3D reconstruction

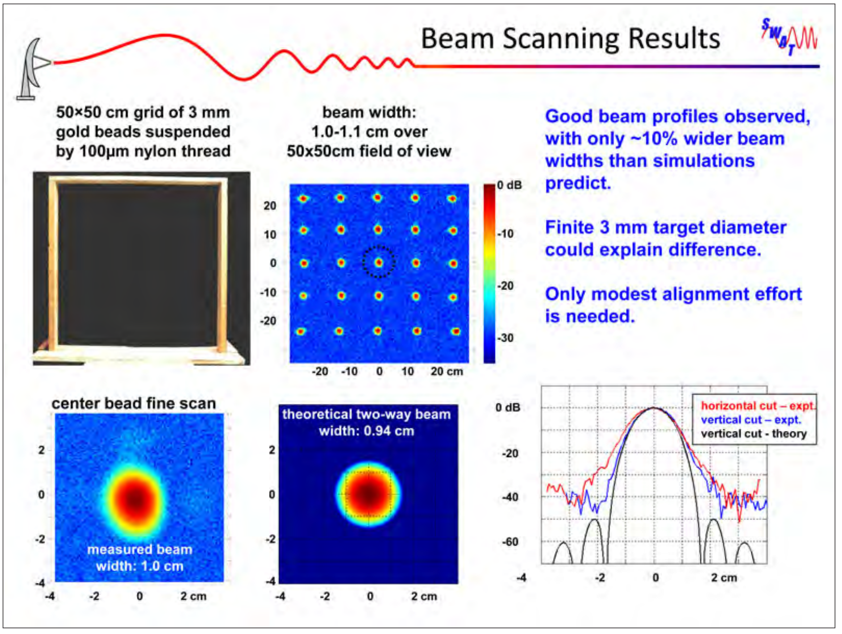


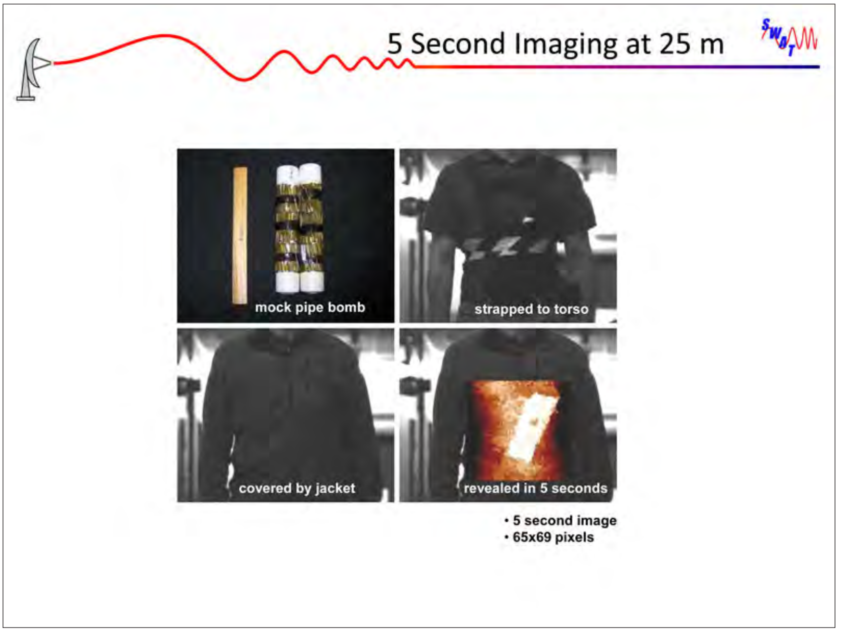

Peeling away layers
a)
b)
c)
d)
e)
f)
Intensity-only image is full of clutter.
By range binning and separate back/front surface detection we reveal a hidden object clearly.


Imaging through Rain
Imaging a 3mm diameter bead at 4m & 25 meters indoors and in heavy rain
~30 dB SNR in 25 ms integration time!
Excess attenuation over dry conditions only 7dB even at 590 GHz center frequency
Instrument view from Target
3mm bead on thread at 4m
Target view from Instrument
25m standoff return from 3mm gold bead
Indoors
Outdoors & Rain
30dB
hallway indoors
hard rain outside
-40
-50
-60
-70
-80
-90
-100
2450
2500
2550
2600
2650
2700


Faster, Longer Range THz Imager: 2010
670 GHz Transceiver
1 meter main aperture
rotating mirror
secondary reflector
feed reflector
back-end electronics
THz transceiver
Operating Parameters
Standoff range:
~~4~~ 25 meters
Operating frequency:
~~575-605~~ 660-690 GHz
Range resolution
<1 cm
Cross-range resolution:
~~0.4~~ 1 cm
Output power:
0.5 mW
Min dwell time per pixel:
~~2.5~~ 0.5 ms
Max beam slew rate:
~~60~~ 800 cm/s


Confocal Gregorian Beam-Scanning
Beam steering with a small secondary mirror much faster than moving entire platform.
$\theta_r = \pm M\theta_s / 2$
mirror rotation angle
beam scan angle
A good compromise is FD = 1.2, M=10:
±25 cm deflection at 25 m requires $\theta_r = \pm 3^\circ$
$\Delta\theta_{3dB,2\text{-}way}$ = 0.940 and 0.947 cm
main aperture
scanning beam
secondary reflector
feed reflector
fast rotating mirror (magnification M)
"Confocal Ellipsoidal Reflector System for a Mechanically Scanned Active Terahertz Imager," N. Llombart et al., *IEEE Trans. Antennas and Propagation, 2010.*


Beam Scanning Results
50×50 cm grid of 3 mm gold beads suspended by 100μm nylon thread
beam width: 1.0-1.1 cm over 50x50cm field of view
Good beam profiles observed, with only ~10% wider beam widths than simulations predict.
Finite 3 mm target diameter could explain difference.
Only modest alignment effort is needed.
center bead fine scan
measured beam width: 1.0 cm
theoretical two-way beam width: 0.94 cm
horizontal cut – expt.
vertical cut – expt.
vertical cut - theory


5 Second Imaging at 25 m
mock pipe bomb
strapped to torso
covered by jacket
revealed in 5 seconds
• 5 second image
• 65x69 pixels

25 meter Images

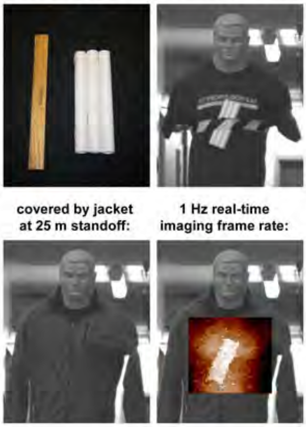
Overview of 5 sec. image results

pipe bomb/pouch: 2 in. thick	hand gun: 1 in. thick	bb/rubber belt 0.9 in. thick	ceramic/simulant belt 1 in. thick	Play-Doh/fishing vest 2.75 in. thick

pipe bomb/pouch	hand gun	bb/rubber belt	ceramic/simulant belt	Play-Doh/fishing vest

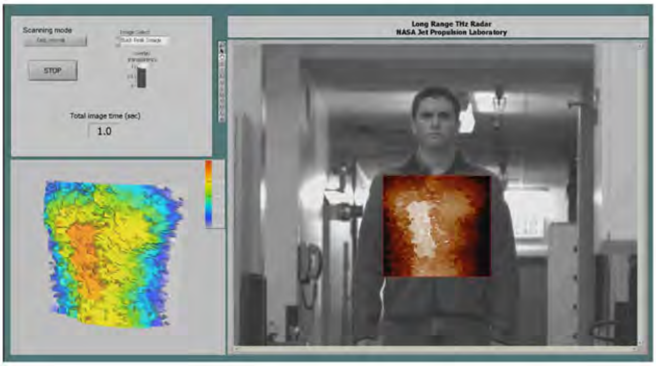
1 Hz Imaging Example

three 1" PVC pipes: | strapped to torso: | covered by jacket at 25 m standoff: | 1 Hz real-time imaging frame rate:



1 Hz Imaging: Real-Time GUI

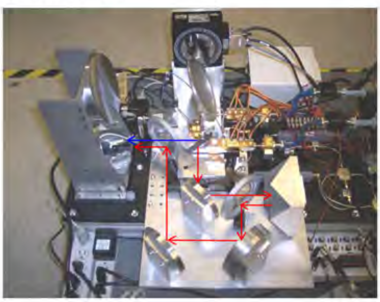
Show video here.



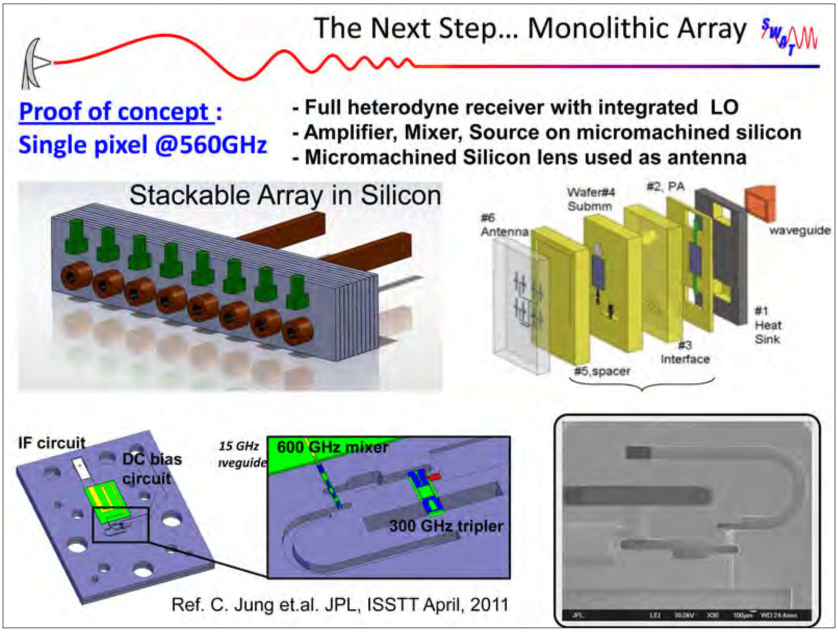
Continuing Innovation

Time-delay two-beam multiplexing

Split one beam into two: doubles the frame rate without additional transceivers.



2 second image using two simultaneous beams at different places on the target

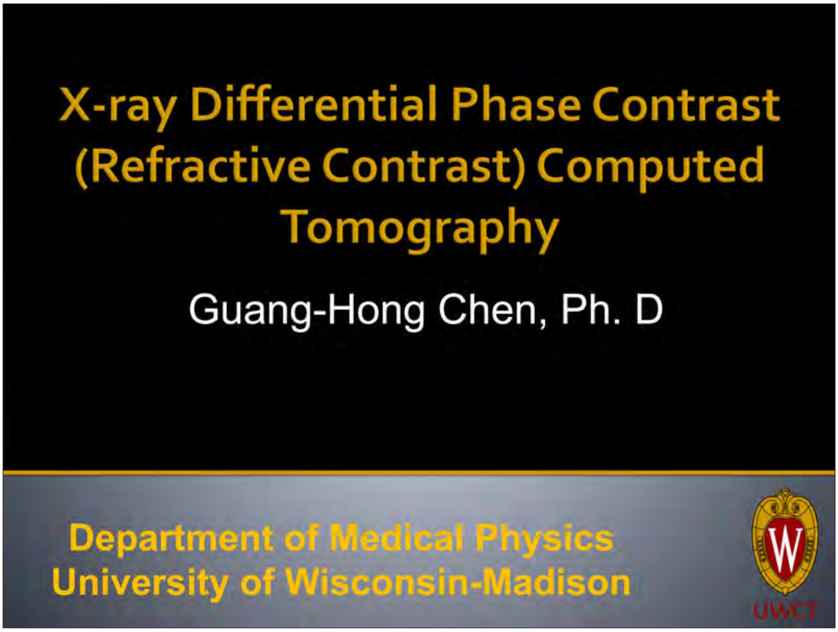


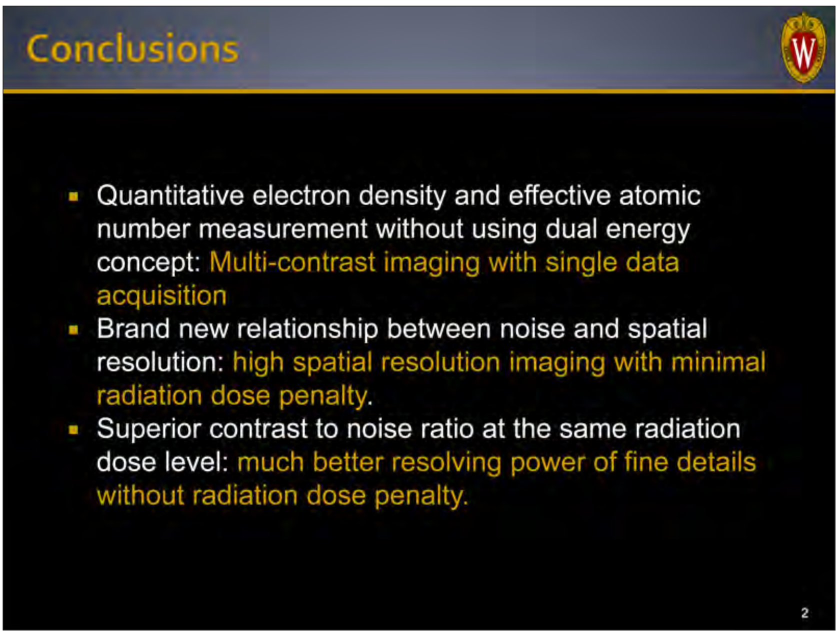
SUMMARY

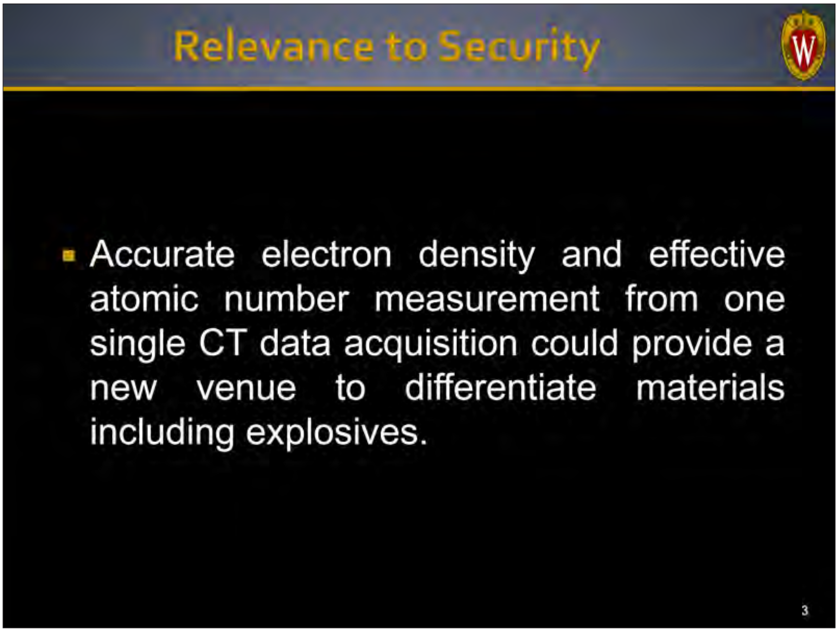
- Heterodyne techniques originally developed for radio detection have extremely high dynamic range and excellent signal to noise in the submillimeter or terahertz frequency range ($S/N>10^{10}$) and can make excellent imagers
- Heterodyning provides magnitude and phase information
- Room temperature detectors have sufficient sensitivity for both active and even passive imaging
- Passive radiometric imaging or active intensity imaging suffer from poor contrast, widespread clutter and specular signatures that severely degrade resulting imagery. A metal gun can "disappear". A cardboard gun can stand out!
- However, by adding a fast RF sweep capability and realizing an FMCW radar, range binning and 3D image reconstruction are possible, greatly enhancing object recognition
- We have just begun to scratch the surface of this field with the development of single pixel scanned systems. Fast scanning multi-pixel instruments are now under development for real time imaging over a modest angular scene.

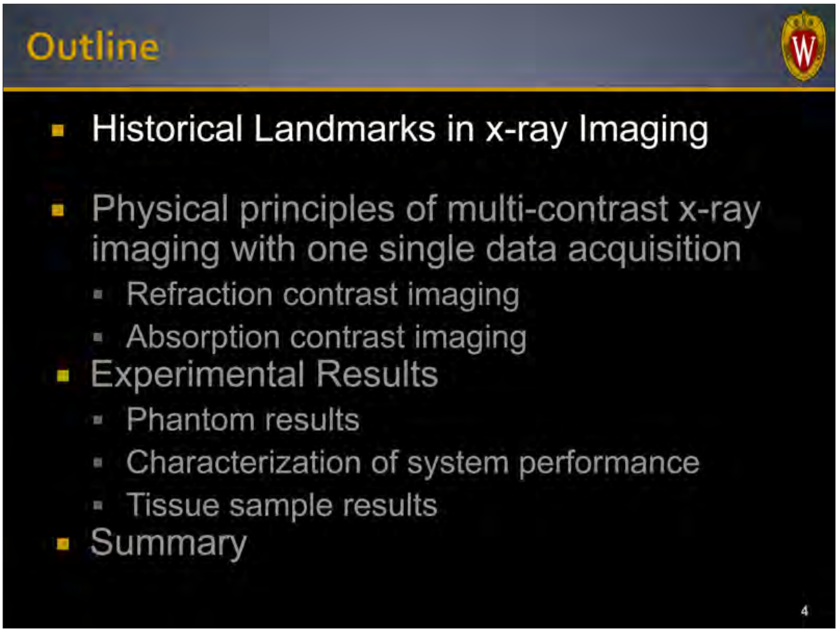

Faouzi Boussaha
Soutam Chattopadhyay
Ken Cooper
Robert Dengler
Andy Fung
John Gill
Hamid Javadi
Cecile Jung
Boris Karasik
Anders Skalare
Jon Kawamura
JPL
NASA
SUBMILLIMETER-WAVE ADVANCED TECHNOLOGY
SWAT
2011-2012
Seth Sin
Choonsup Lee
Jose Siles
Karen Lee
Theodore Reck
Peter Siegel
Erich Schlecht
Lorene Samoska
David Pukala
Alex Peralta
Imran Mehdi
Nuria Llombart-Juan
Robert Lin

16.10 Guang-Hong Chen: Differential phase contrast x-ray CT

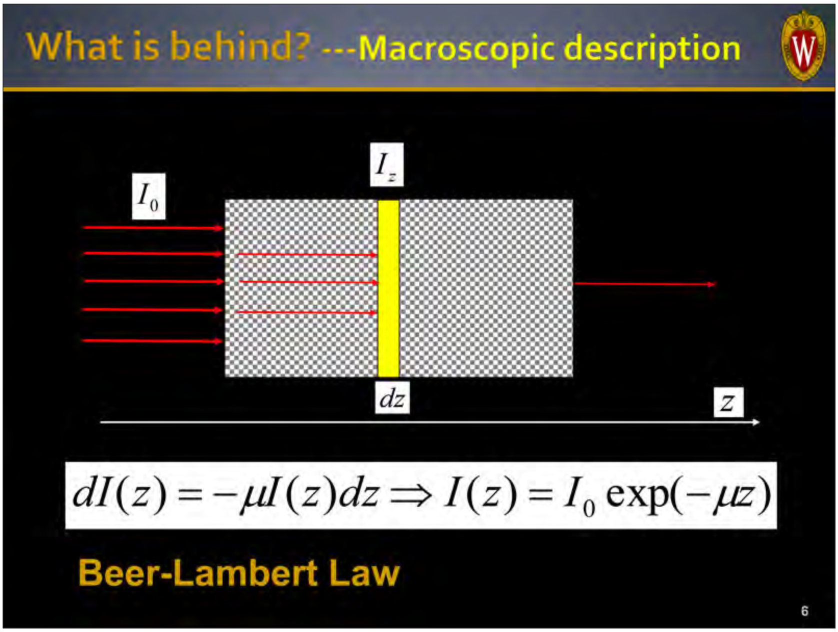


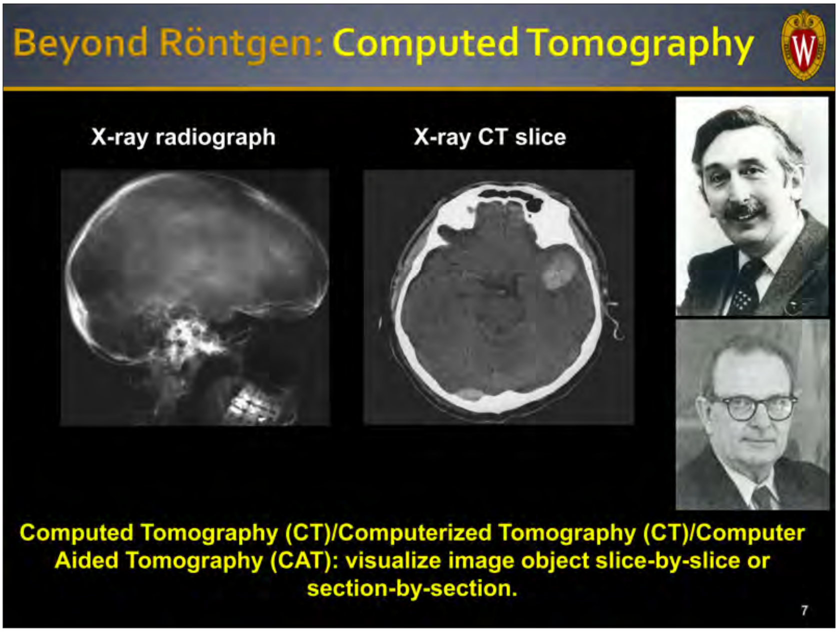


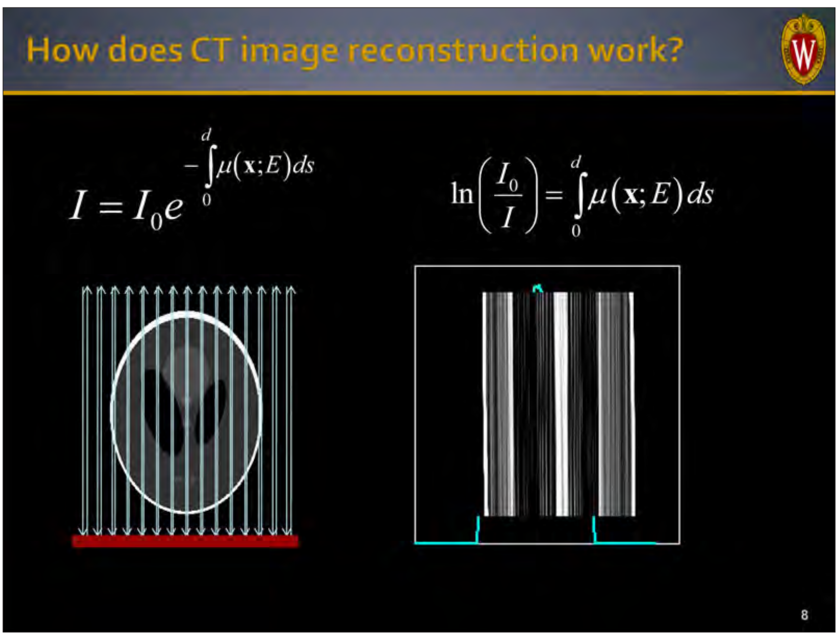

Relevance to Security
Accurate electron density and effective atomic number measurement from one single CT data acquisition could provide a new venue to differentiate materials including explosives.
3


Outline
Historical Landmarks in x-ray Imaging
Physical principles of multi-contrast x-ray imaging with one single data acquisition
Refraction contrast imaging
Absorption contrast imaging
Experimental Results
Phantom results
Characterization of system performance
Tissue sample results
Summary
4


Röntgen's Leagacy
5


What is behind? ---Macroscopic description
I_0
I_z
dz
z
$dI(z) = -\mu I(z)dz \Rightarrow I(z) = I_0 \exp(-\mu z)$
Beer-Lambert Law
6


Beyond Röntgen: Computed Tomography
X-ray radiograph
X-ray CT slice
Computed Tomography (CT)/Computerized Tomography (CT)/Computer Aided Tomography (CAT): visualize image object slice-by-slice or section-by-section.
7


How does CT image reconstruction work?
$I = I_0 e^{-\int_0^d \mu(\mathbf{x};E)ds}$
$\ln\left(\frac{I_0}{I}\right) = \int_0^d \mu(\mathbf{x};E)\,ds$
8

Dual Energy Computed Tomography

Essentially, there are two unknowns in x-ray projection image:

$$I = I_0 \int_0^{E_{\max}} dE\Omega(E)\exp[-\int_0^d ds\mu(x,y,z;E)]$$

$$= I_0 \int_0^{E_{\max}} dE\Omega(E)\exp[-P_1\frac{1}{E^3} - P_2 f_{KN}(E)]$$

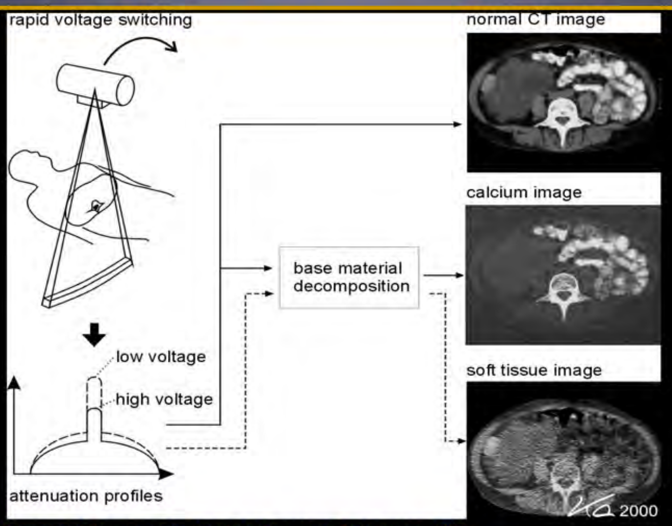
To figure out the two unknown line integrals P_1 and P_2, we will have to have two independent measurements using two different x-ray spectra.

$$P_1 = K_1 \int_0^d ds\rho_e(x,y,z)Z^4(x,y,z),$$

$$P_2 = K_2 \int_0^d ds\rho_e(x,y,z)$$

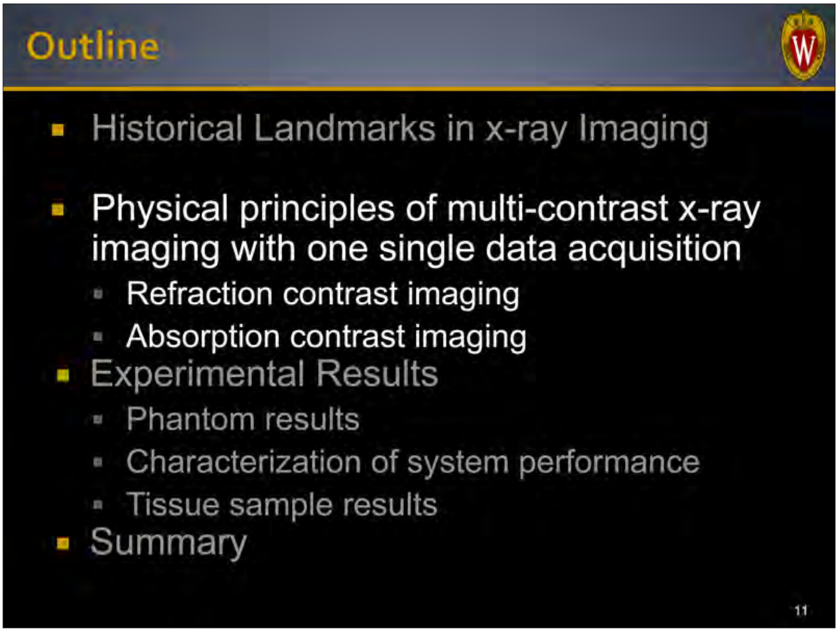
9

Dual Energy Computed Tomography



Kalender, Computed Tomography, Publicis Corporate Publishing, 2005.

10


Outline
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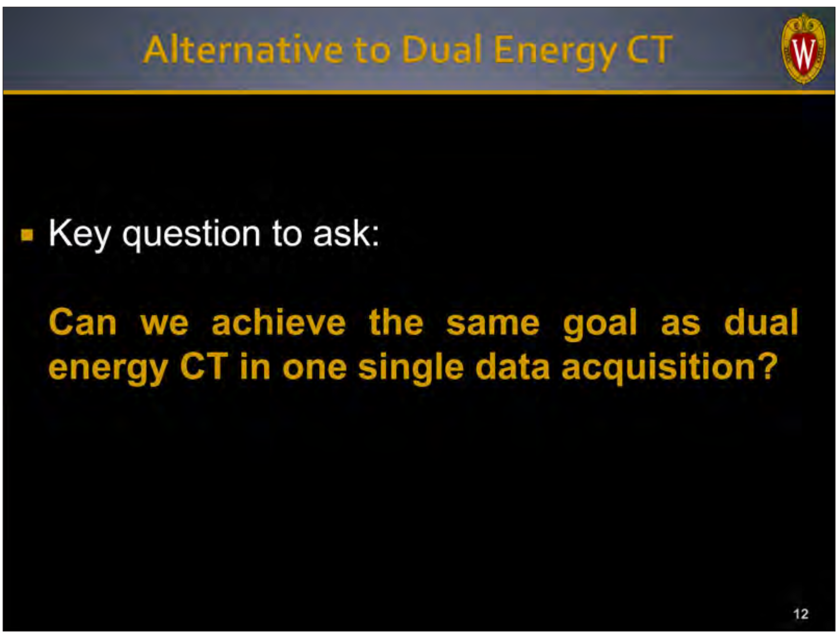
Refraction contrast imaging
Absorption contrast imaging
Experimental Results
Phantom results
Characterization of system performance
Tissue sample results
Summary
11


Alternative to Dual Energy CT
Key question to ask:
Can we achieve the same goal as dual energy CT in one single data acquisition?
12

Quantify wave-matter interaction

- Physical Foundation
  - The interaction of photon beams with matter is characterized by the complex refractive index:

$$n = 1 - \delta + i\beta$$

Real Part (refraction)

Imaginary Part (absorption)

13

Microscopic description of the index

- Physical Foundation
  - Each part of the index of refraction is dictated by a different physical phenomena. Each has a different energy dependence.

$$n = 1 - \delta + i\beta$$

$$\delta = \frac{\rho_e r_e \lambda^2}{2\pi} \qquad \beta = \frac{\lambda}{4\pi}(\tau + \sigma)$$

$$\lambda \propto E^{-1} \qquad \tau \propto \frac{Z^4}{E^3}$$

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What do we know about wave phenomena?

- Refraction
- Reflection
- Interference
- Diffraction
- …

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Refraction of Visible and X-ray Photons

- Why has δ been neglected in x-ray medical imaging while β has been used for more than a hundred years?
- Consider the following:
  - At visible wavelengths (~600 nm), the refractive index of water is 1.33, in this case refraction is easy to observe
  - For water at 30 keV (0.04 nm), the refractive index, $1-\delta$, is about 0.9999997.
    As a result, the corresponding refraction angle is about one millionth of degree. Very difficult to experimentally measure it!

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Refraction Contrast Imaging

- The refraction angle of the x-ray beam, Θ, can be directly measured, and can then be related to the phase shift.

$$\Theta(x,y)=\frac{\lambda}{2\pi}\frac{\partial}{\partial x}\varphi(x,y)=\frac{\partial}{\partial x}\int_l \delta(l)dl$$

- I will illustrate for you how to measure one millionth degree of refraction angle in the rest of my presentation!

17

One word on image reconstruction: Similarity to Absorption Imaging

- Note the similarity of the line integral for refraction index decrement to the line integral for standard absorption CT shown below.

$$\Theta(x,y)=\frac{\partial}{\partial x}\int_l \delta(l)dl \qquad \ln\frac{I_0}{I}=\int_l \mu(l)dl$$

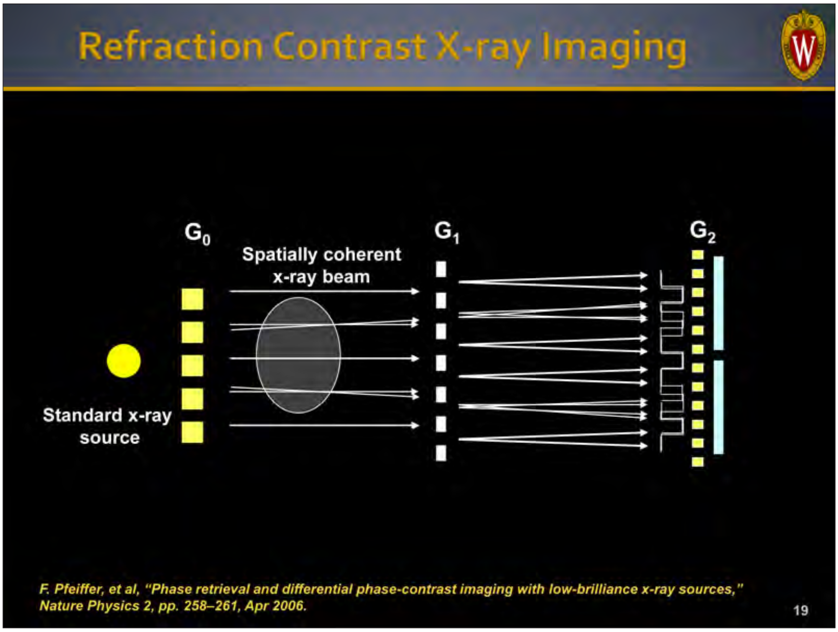
- This allows us to reconstruct an image of δ, and therefore electron density, using the same approach we use for absorption images.
- The only difference is that a Hilbert filter is used in the reconstruction of δ images instead of a ramp filter.

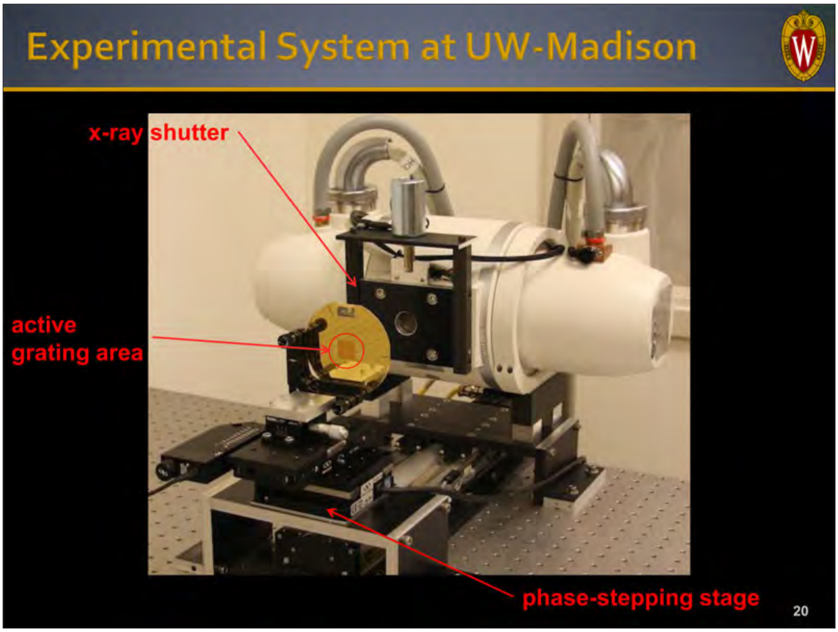
1. F. Pfeiffer, C. Kottler, O. Bunk, and C. David, "Hard x-ray phase tomography with low-brilliance sources," Phys. Rev.Let. 98(108105), p. 108105, 2007.

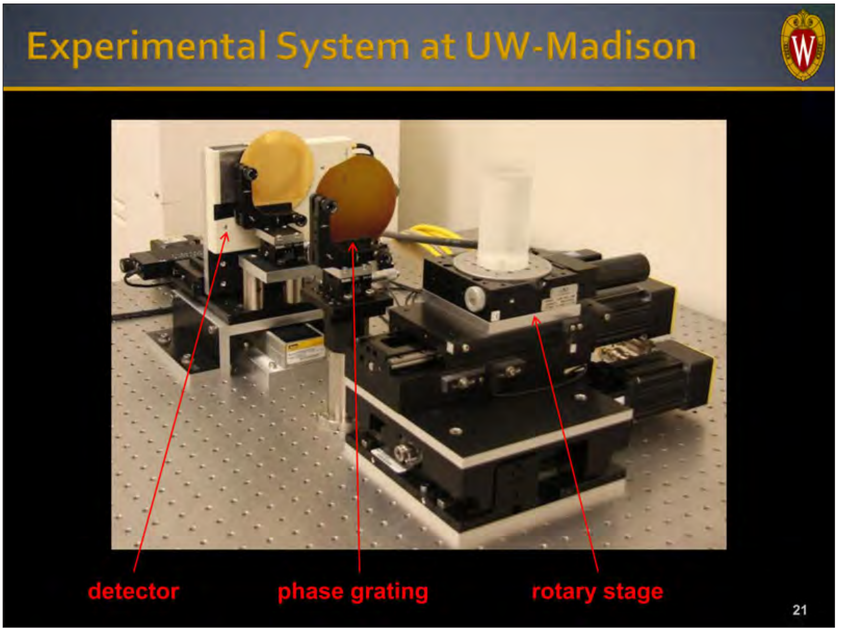
2. Z. Qi and G.H. Chen, "A local region of interest image reconstruction via filtered backprojection for differential phase contract CT ," Phys. Med. Biol., N417-N423, (2007).

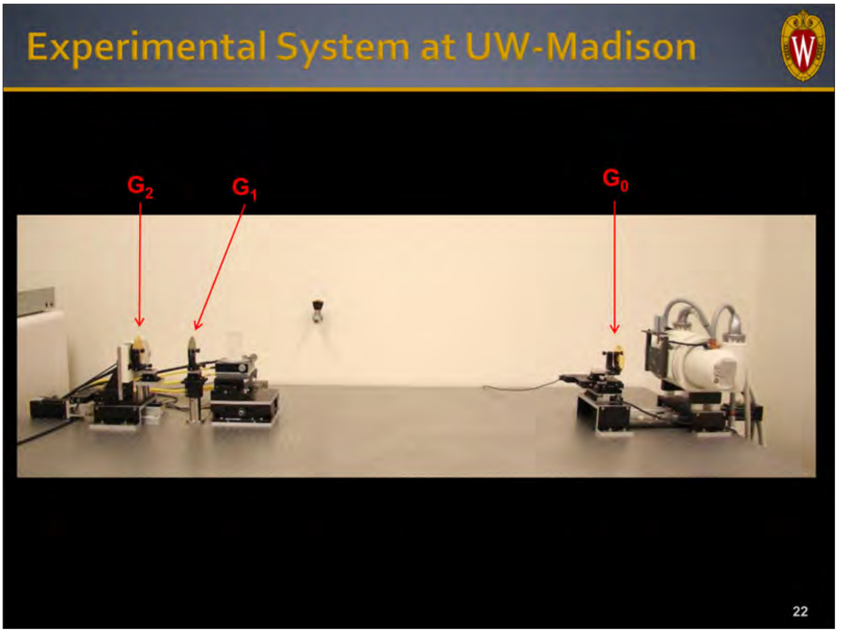
3. Z. Qi and G. H. Chen, "Direct fan-beam reconstruction algorithm via filtered backprojection for differential phase-contrast computed tomography," X-ray Opt. and Instr. 53, pp. 1015–25(2008).

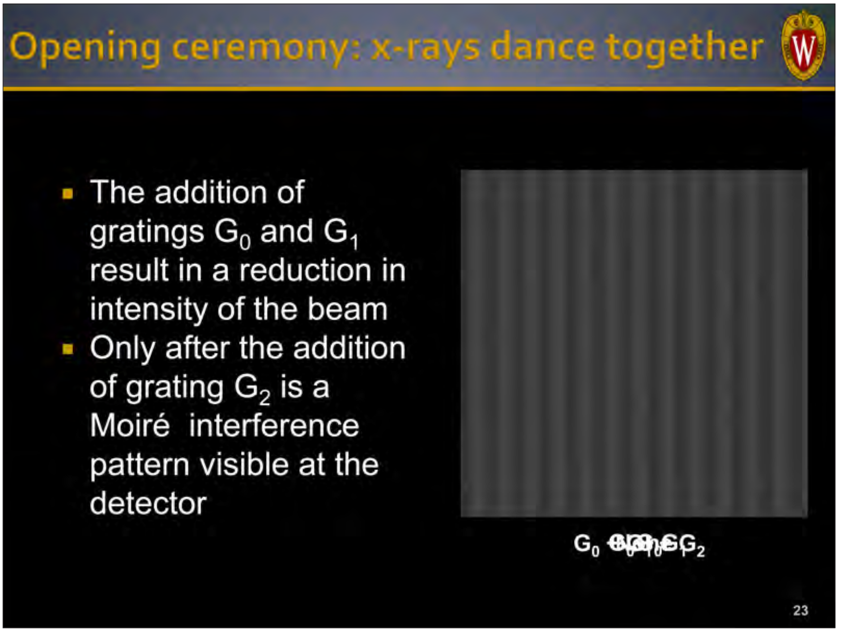
18

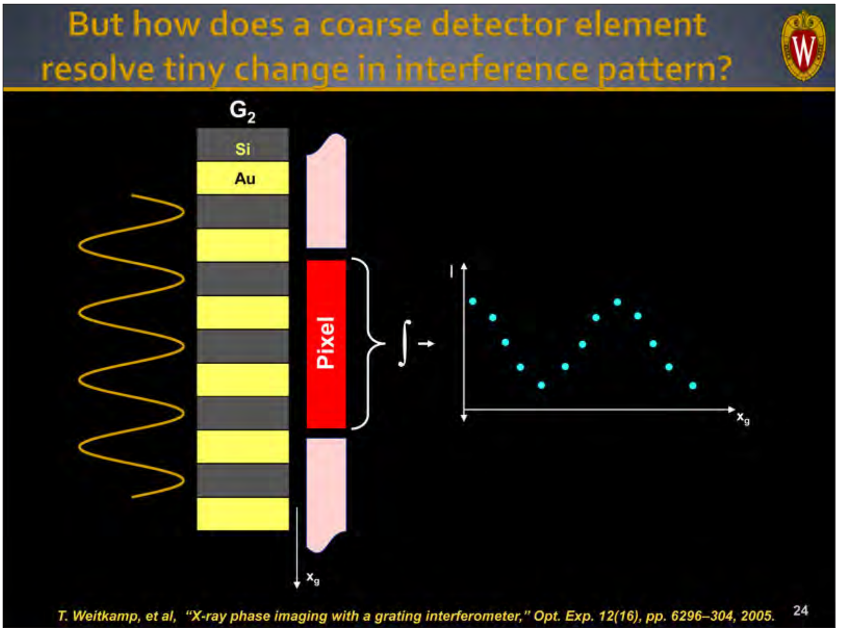

Refraction Contrast X-ray Imaging
G0
Spatially coherent
x-ray beam
G1
G2
Standard x-ray
source
F. Pfeiffer, et al, "Phase retrieval and differential phase-contrast imaging with low-brilliance x-ray sources," Nature Physics 2, pp. 258–261, Apr 2006.
19

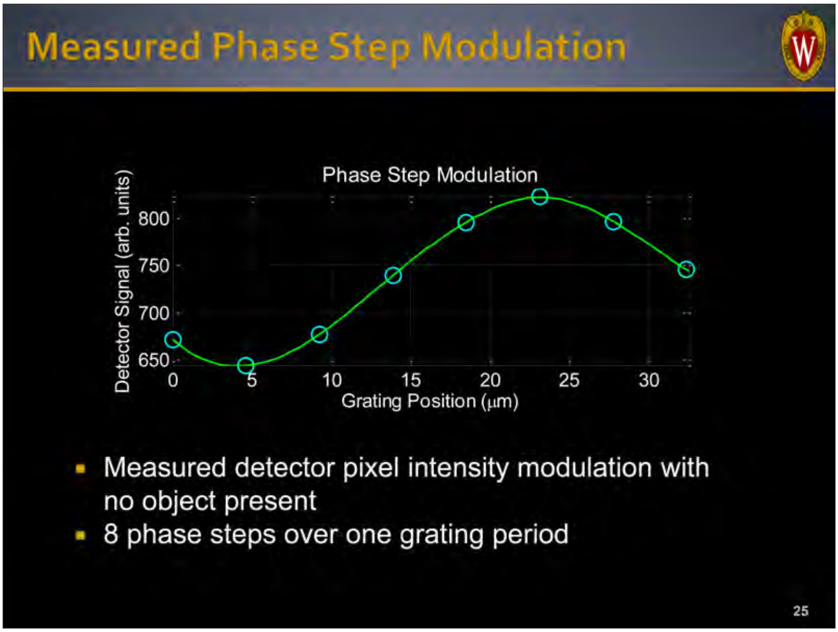

Experimental System at UW-Madison
x-ray shutter
active
grating area
phase-stepping stage
20

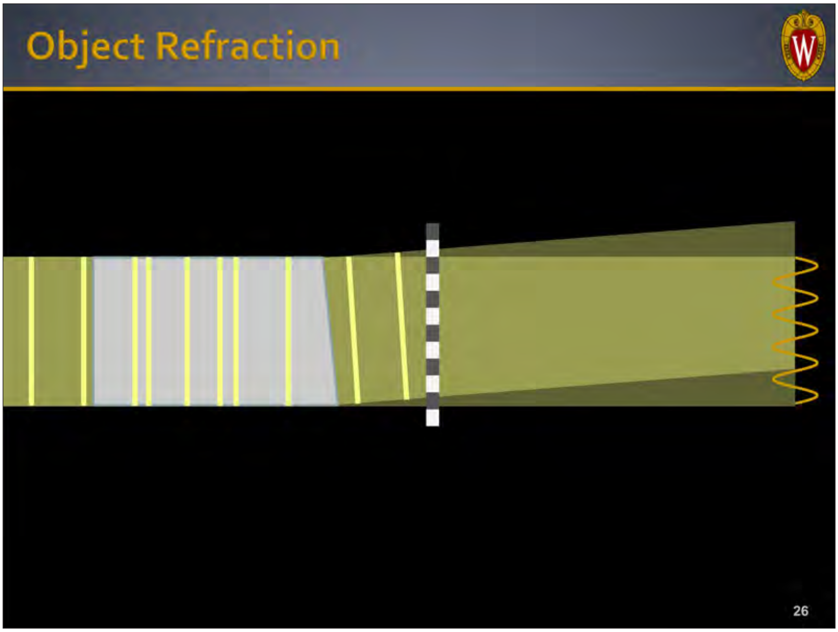

Experimental System at UW-Madison
detector
phase grating
rotary stage
21

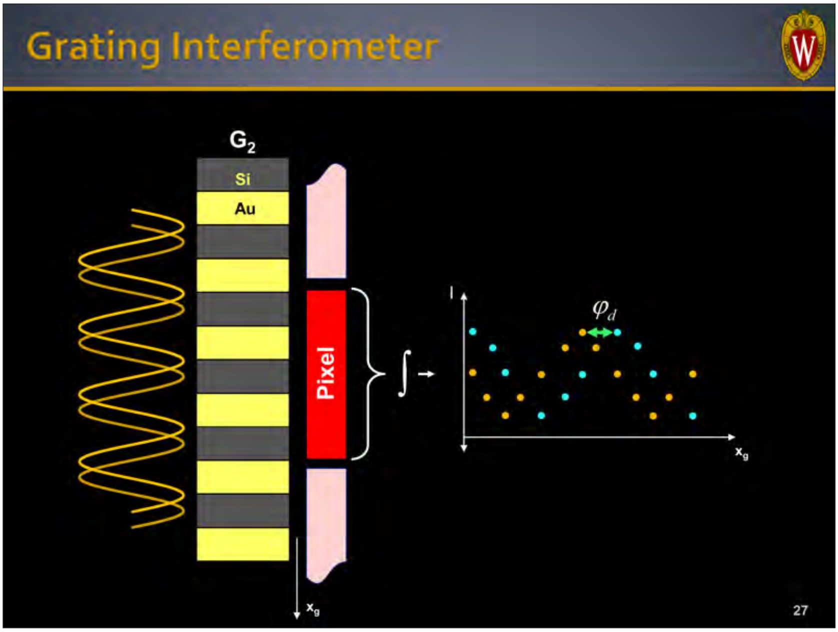

Experimental System at UW-Madison
G_2
G_1
G_0
22


Opening ceremony: x-rays dance together
The addition of gratings G_0 and G_1 result in a reduction in intensity of the beam
Only after the addition of grating G_2 is a Moiré interference pattern visible at the detector
23


But how does a coarse detector element resolve tiny change in interference pattern?
G_2
Si
Au
Pixel
I
x_g
x_g
T. Weitkamp, et al, "X-ray phase imaging with a grating interferometer," Opt. Exp. 12(16), pp. 6296–304, 2005.
24


Measured Phase Step Modulation
Phase Step Modulation
Detector Signal (arb. units)
800
750
700
650
0
5
10
15
20
25
30
Grating Position (μm)
Measured detector pixel intensity modulation with no object present
8 phase steps over one grating period
25


Object Refraction
26



Refraction Angle Measurement

- The phase offset is measured when the object is present and when it is not. The difference between the two gives a measurement which is related to the refraction angle through the object.

$$\varphi_d = \varphi_d^{object} - \varphi_d^{background}$$

$$\Theta = \frac{p_2}{2\pi d} \cdot \varphi_d$$

$$\Theta = 4.28 \times 10^{-6} \cdot \varphi_d$$

Now you see how the one millionth degree of refraction angle get amplified by million times which allow us to measure it !!

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Absorption signal from the same acquisition

$$I(m,n;x_g) = I_0(m,n) + I_1(m,n)\cos\left[\frac{2\pi}{p_2}x_g + \varphi_d(m,n)\right]$$

- The DC term (mean intensity value within a detector pixel) yields the standard absorption image:

$$T(m,n) = \frac{I_0^{\text{obj}}(m,n)}{I_0^{\text{bkgd}}(m,n)}$$

- Logarithmic transformation of $T(m,n)$ yields absorption projections which can be reconstructed with a standard FBP technique.

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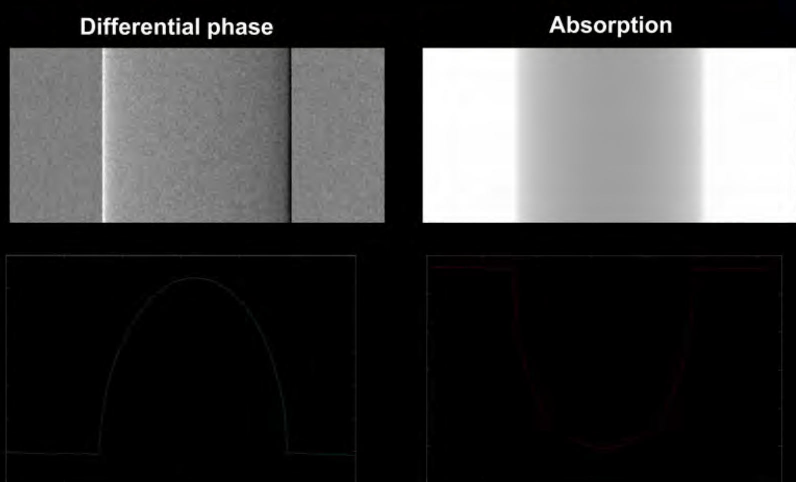
X-ray Grating Interferometry



30

Outline

- Historical Landmarks in x-ray Imaging
- Physical principles of multi-contrast x-ray imaging with one single data acquisition
  - Refraction contrast imaging
  - Absorption contrast imaging
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  - Phantom results
  - Characterization of system performance
  - Tissue sample results
- Summary

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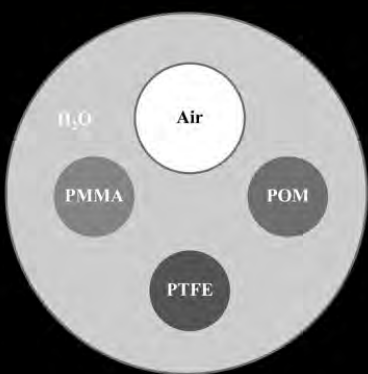
Phantom Results: Phantom construction



Phantom is constructed from a 28.5 mm PMMA tube containing 4.8 mm inserts with the remaining volume filled with water.

32

Phantom Results: images

Refraction | Absorption | Effective Z

[2.0x10^{-7} ,5.5x10^{-7}] | [0.02, 0.09] mm^{-1} | [5, 9.5]

Qi, Z., Zambelli, J., Bevins, N. & Chen, G.-H. *Quantitative imaging of electron density and effective atomic number using phase contrast CT* Phys. Med. Biol., 2010, Vol. 55, pp. 2669-2677

Zambelli, J., Bevins, N., Qi, Z. & Chen, G.-H. *Measurement of contrast-to-noise ratio for differential phase contrast computed tomography* Med. Phys., 2010, Vol. 37, pp. 2473-2479

33

Electron Density Measurement

$$\rho_e^{\text{ref}} = \rho \frac{ZN_A}{A} \qquad \rho_e^{\text{cal}} = \frac{2\pi\delta E^2}{r_0\hbar^2 c^2}$$

	Reference ρ_e (10^{23} cm^{-3})	Measured ρ_e (10^{23} cm^{-3})
Water	3.34	3.34
LDPE	3.23	3.25
PS	3.40	3.42
PMMA	3.87	3.86
POM	4.53	4.55
PTFE	6.36	6.04

- The mean beam energy E is calibrated by matching the electron density value for water.

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Effective Z - μ/δ Ratio

$$\mu \approx \rho_e \left[k_1 \frac{Z^4}{E^3} + k_2 f_{\mathrm{KN}}(E) \right] \qquad \delta = \frac{\rho_e r_0 \hbar^2 c^2}{2\pi E^2}$$

$$\frac{\mu}{\delta} \approx \frac{2\pi E^2}{r_0 \hbar^2 c^2} \left[k_1 \frac{Z^4}{E^3} + k_2 f_{\mathrm{KN}}(E) \right]$$

$$\frac{\mu}{\delta} \approx p \cdot Z^n + q$$

- The ratio reflects information about the effective atomic number of a material. The coefficients of the ratio can be determined by scanning a set of known materials. Decomposition of μ into ρ_e and Z_{eff} may improve material differentiation.

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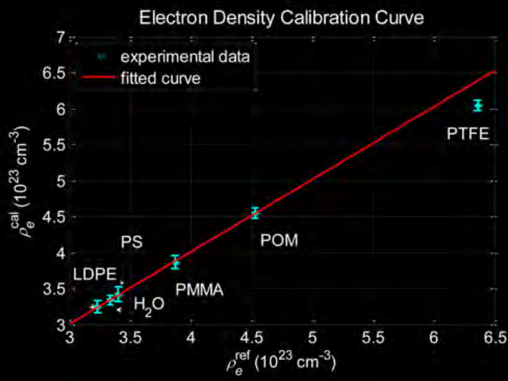
Electron Density Calibration



$$\rho_e^{\mathrm{cal}} = a \times \rho_e^{\mathrm{ref}} + b$$

$a = 1.0055$

$b = -0.0123$

$R^2 = 0.9996$

Potential error sources:
- Inaccurate knowledge of the mass density of the materials
- Beam hardening effects

Qi, Z., Zambelli, J., Bevins, N. & Chen, G.-H. *Quantitative imaging of electron density and effective atomic number using phase contrast CT* Phys. Med. Biol., 2010, Vol. 55, pp. 2669-2677

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Effective Z Measurement

	LDPE	PS	PMMA	POM	Water	PTFE
Z_{eff}	5.44	5.70	6.47	6.95	7.42	8.43
μ/δ (10^6 cm^{-1})	0.891	0.923	1.07	1.15	1.26	1.62

- Z_{eff} is calculated using[1]

$$Z_{eff} = \sqrt[2.94]{\sum_i f_i \times (Z_i)^{2.94}}$$

- μ/δ and Z_{eff} are assumed to follow

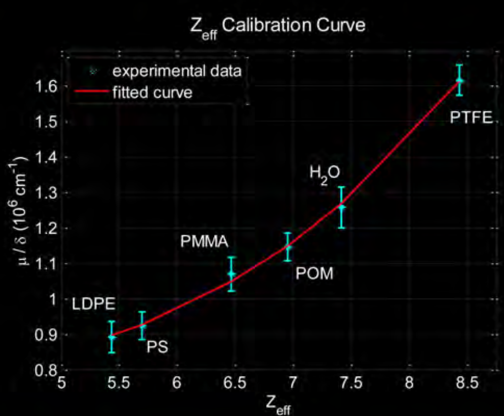
$$\frac{\mu}{\delta} = p \times Z^n + q$$

- A non-linear least squares fit using a quasi-Newton method was applied to determine the parameters.

1 F. W. Spiers, "Effective atomic number and energy absorption in tissues," British Journal of Radiology 19,pp. 52-63, 1946.

37

Effective Z Calibration



$$\frac{\mu}{\delta} = p \times Z^n + q$$

$n = 3.906$

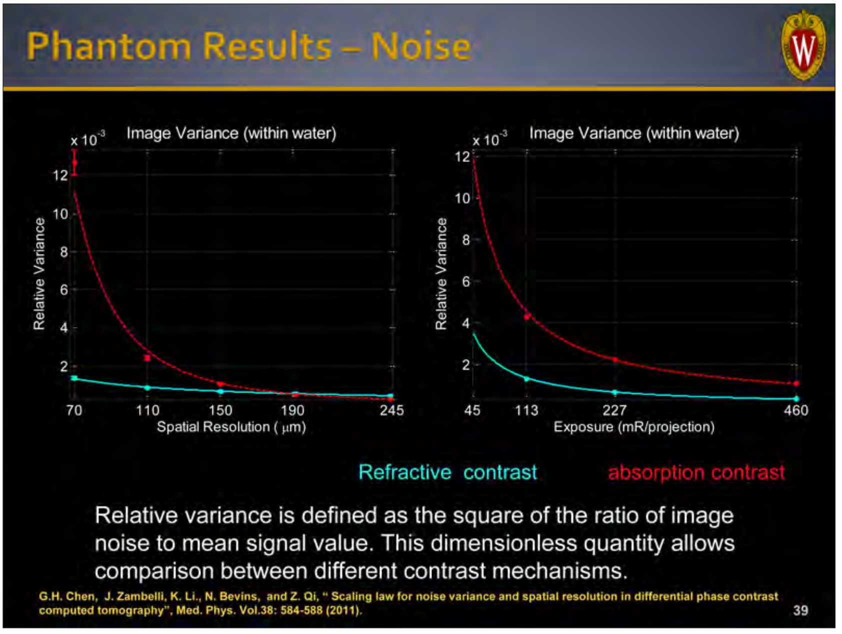
$p = 211.9 cm^{-1}$

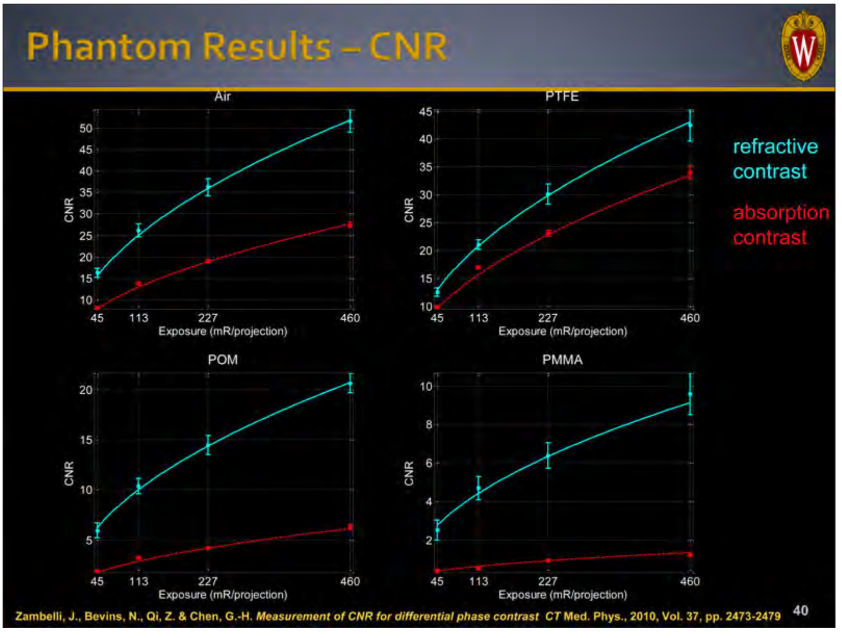
$q = 7.375 \times 10^5 cm^{-1}$

$R^2 = 0.998$

Qi, Z., Zambelli, J., Bevins, N. & Chen, G.-H. *Quantitative imaging of electron density and effective atomic number using phase contrast CT* Phys. Med. Biol., 2010, Vol. 55, pp. 2669-2677

38


Phantom Results – Noise
Image Variance (within water)
Relative Variance
Spatial Resolution (μm)
Image Variance (within water)
Relative Variance
Exposure (mR/projection)
Refractive contrast
absorption contrast
Relative variance is defined as the square of the ratio of image noise to mean signal value. This dimensionless quantity allows comparison between different contrast mechanisms.
G.H. Chen, J. Zambelli, K. Li., N. Bevins, and Z. Qi, " Scaling law for noise variance and spatial resolution in differential phase contrast computed tomography", Med. Phys. Vol.38: 584-588 (2011).
39


Phantom Results – CNR
Air
PTFE
POM
PMMA
CNR
Exposure (mR/projection)
refractive contrast
absorption contrast
Zambelli, J., Bevins, N., Qi, Z. & Chen, G.-H. Measurement of CNR for differential phase contrast CT Med. Phys., 2010, Vol. 37, pp. 2473-2479
40

Breast Tissue Imaging

- Tissue samples from breast mastectomies have been imaged to determine:
  - Benefits of the ability to measure both electron density and effective atomic number
  - Possible clinical utility of dark-field imaging
  - Imaging performance gain over conventional imaging technologies
  - Correlation of imaging findings to underlying pathology as determined by histology

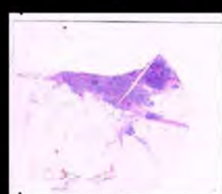
41

Breast Tissue Results

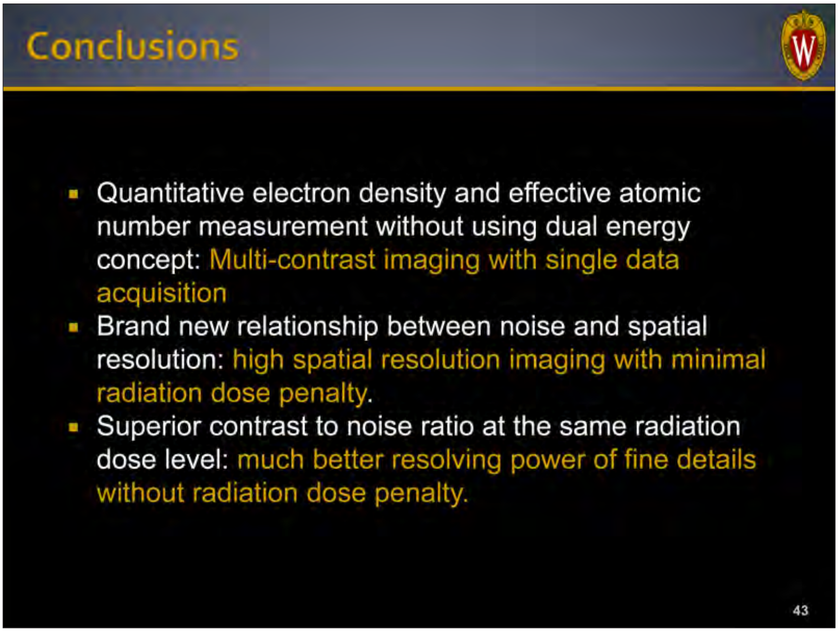

Electron Density

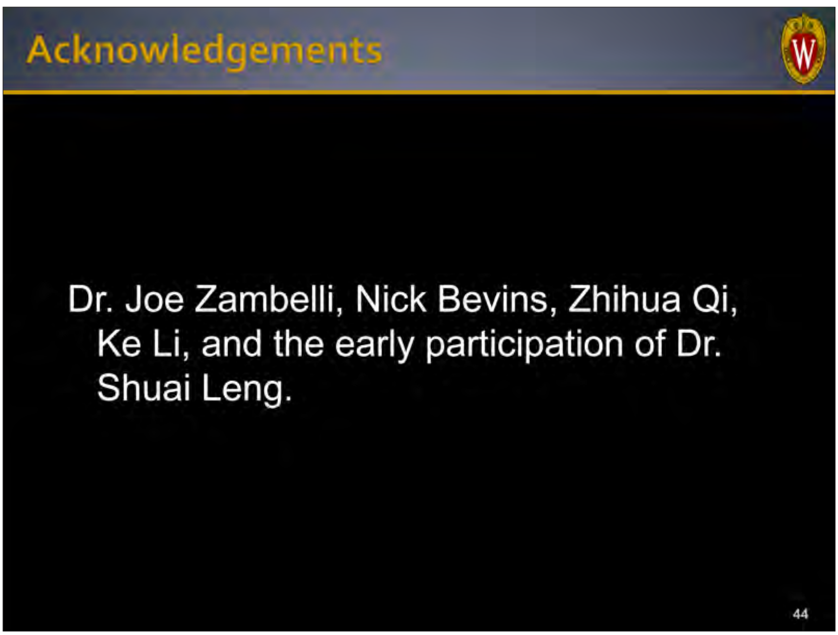

Attenuation


Effective Z

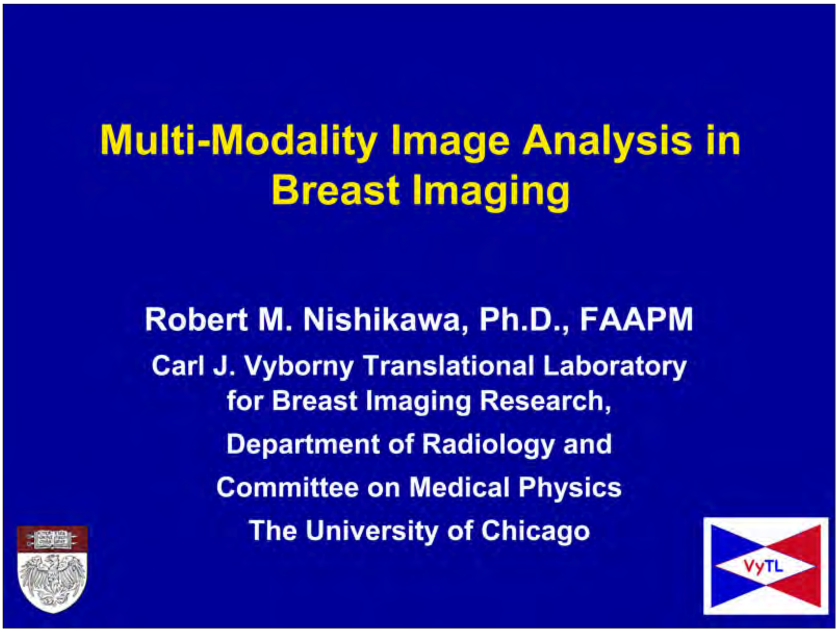

Histology

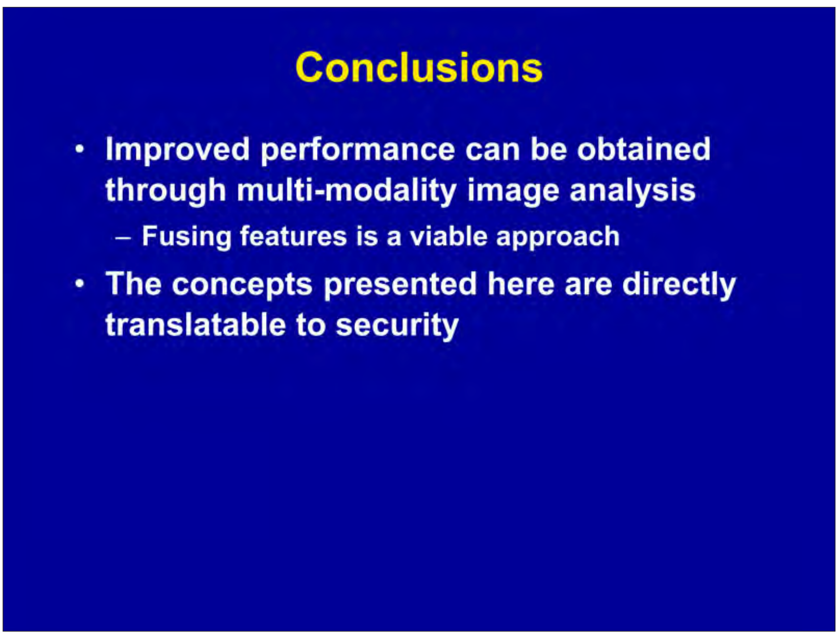
42


Conclusions
Quantitative electron density and effective atomic number measurement without using dual energy concept: Multi-contrast imaging with single data acquisition
Brand new relationship between noise and spatial resolution: high spatial resolution imaging with minimal radiation dose penalty.
Superior contrast to noise ratio at the same radiation dose level: much better resolving power of fine details without radiation dose penalty.
43


Acknowledgements
Dr. Joe Zambelli, Nick Bevins, Zhihua Qi, Ke Li, and the early participation of Dr. Shuai Leng.
44

16.11 Robert Nishikawa: Image fusion for improved diagnostics





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- **Scientific Board member, Dexela Ltd.**
- **Research funding from Usystems, Inc.**

Maryellen Giger,

Neha Bhooshan, Karen Drukker, Yading Yuan,
Hui Li, Stephanie McCann,

Gillian Newstead, Charlene Sennett

Committee on Medical Physics
Carl J. Vyborny Translational Laboratory
for Breast Imaging Research
Department of Radiology

The University of Chicago

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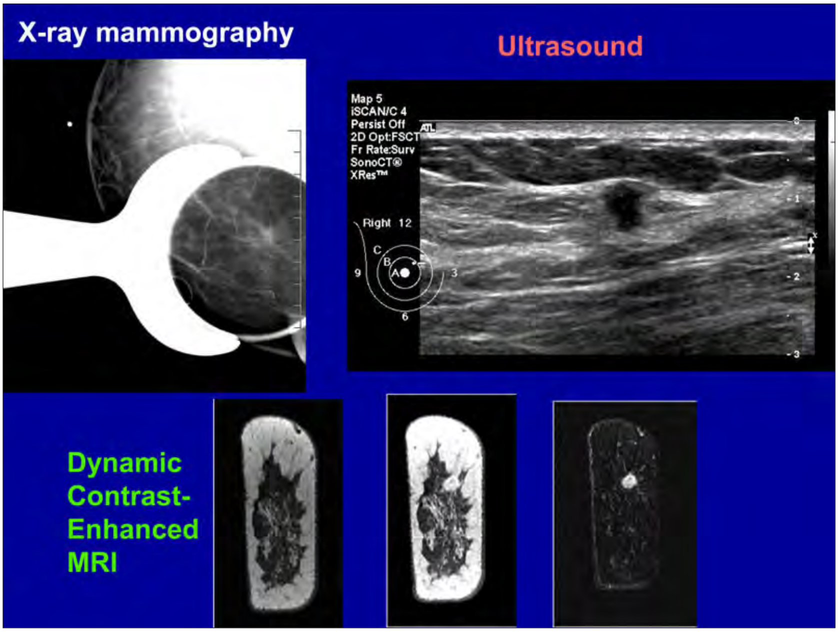
Clinical Question

- Is the breast lesion malignant or benign?
  - Does this woman need a breast biopsy?
- Is the suspicious object a threat?

Clinical Protocol

- Women with either a breast complaint or an abnormal screening mammogram
  - Diagnostic workup
- Undergoes up to 3 or more imaging exams
  - Specialized mammograms (e.g. magnification)
  - Ultrasound
  - Dynamic contrast-enhanced MRI



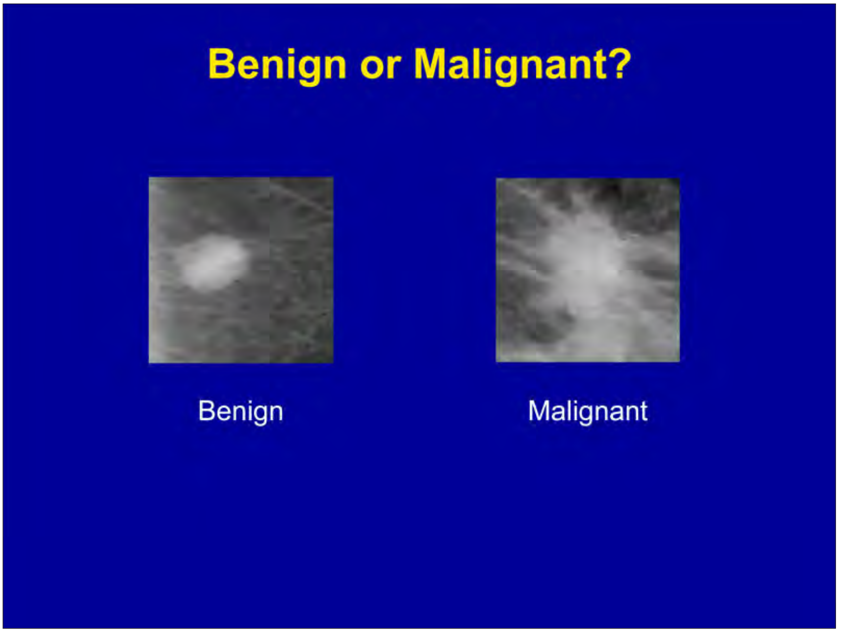
Imaging Modalities

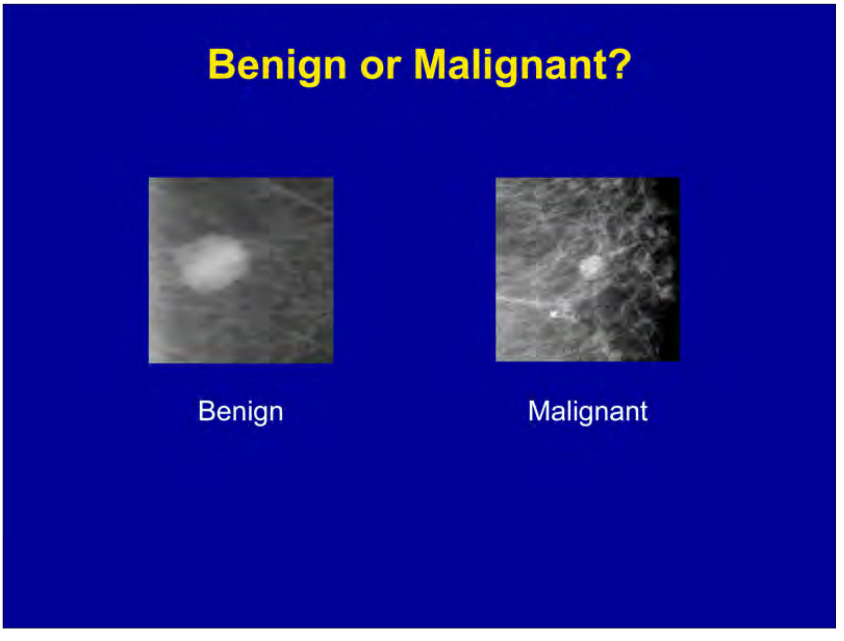
- Mammography
  - X-ray attenuation (atomic number)
  - Lesion morphology
- Ultrasound
  - Wave propagation in tissue (absorption of sound)
  - Lesion morphology and background characteristics
- Dynamic contrast-enhanced (DCE) MRI
  - Contrast uptake and clearance (tumor vascularity)
  - Temporal and morphological information

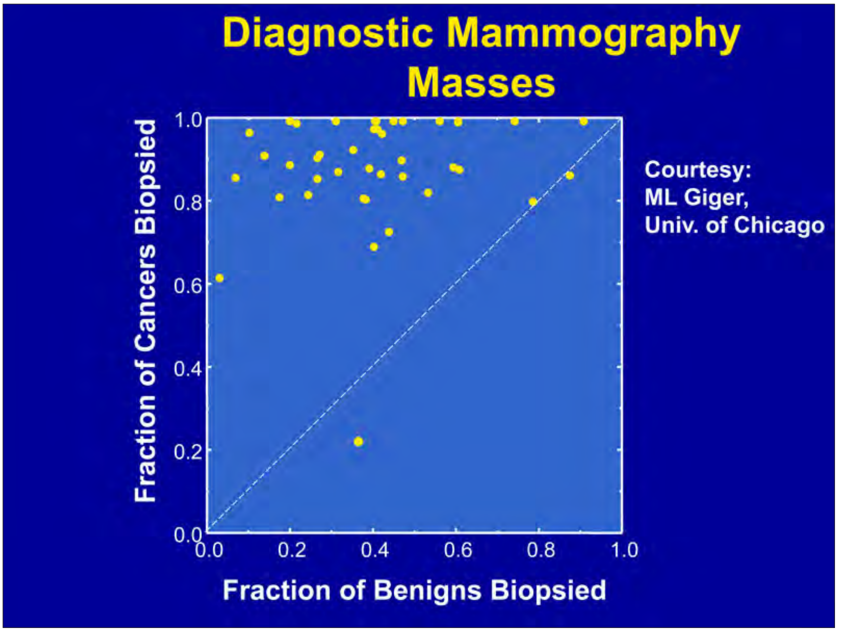
Strengths and Weakness of Modalities

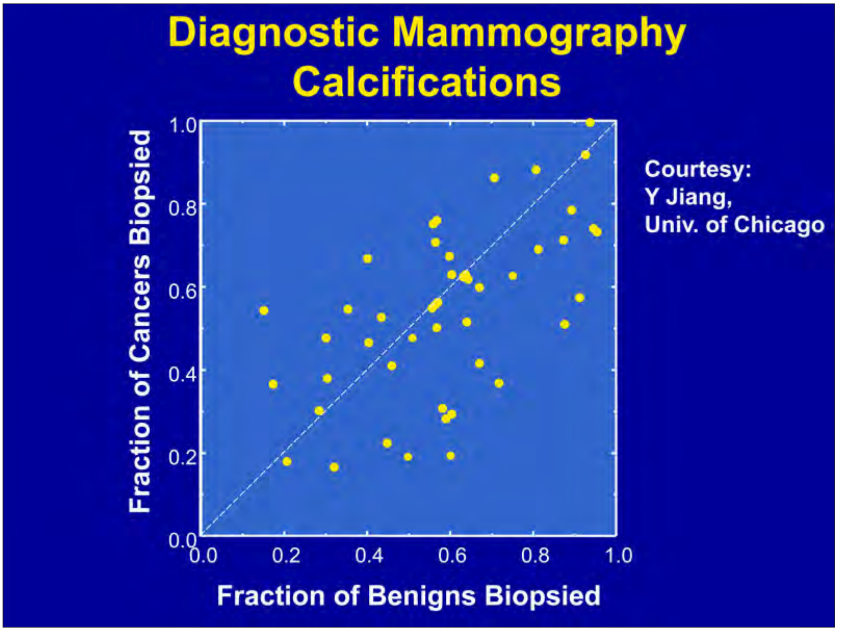
Modality	Strengths	Weaknesses
X-ray	• High spatial resolution - spiculation - microcalcifications	• Overlapping tissue • Radiation
US	• No radiation • Best CADx performance • Can assess axilla	• Image quality dependent on technician skill
MRI	• Assess kinetics • 3D assessment • High sensitivity	• High false-positive rate • Invasive (contrast injection)

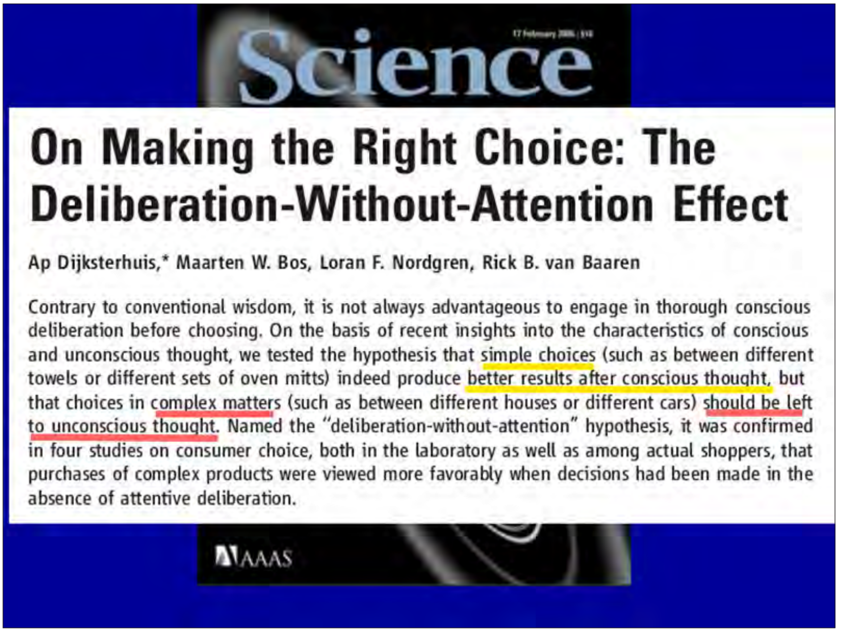
Multimodality Breast Imaging


Benign or Malignant?
Benign
Malignant


Benign or Malignant?
Benign
Malignant


Diagnostic Mammography
Masses
Fraction of Cancers Biopsied
Fraction of Benigns Biopsied
0.0
0.2
0.4
0.6
0.8
1.0
Courtesy:
ML Giger,
Univ. of Chicago


Diagnostic Mammography
Calcifications
Fraction of Cancers Biopsied
Fraction of Benigns Biopsied
0.0
0.2
0.4
0.6
0.8
1.0
Courtesy:
Y Jiang,
Univ. of Chicago



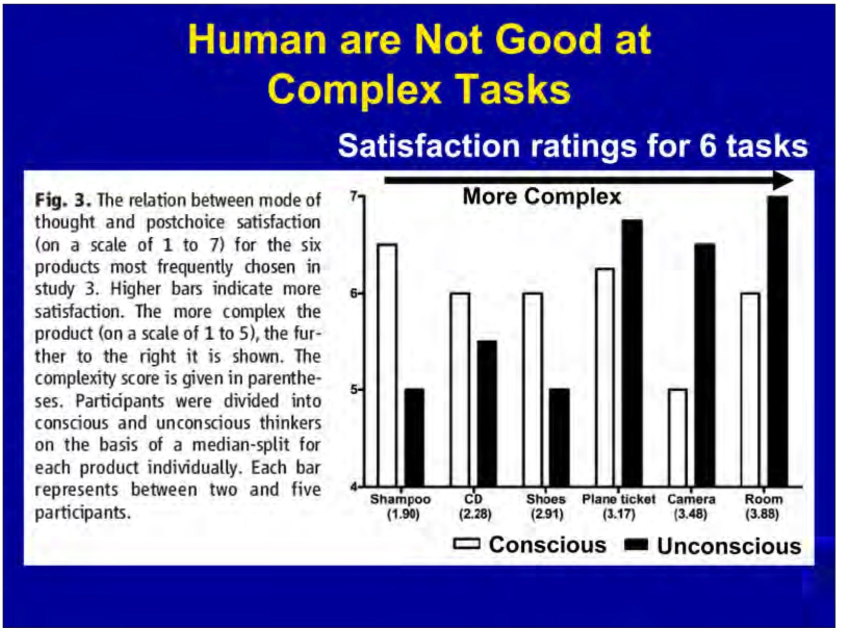
Science

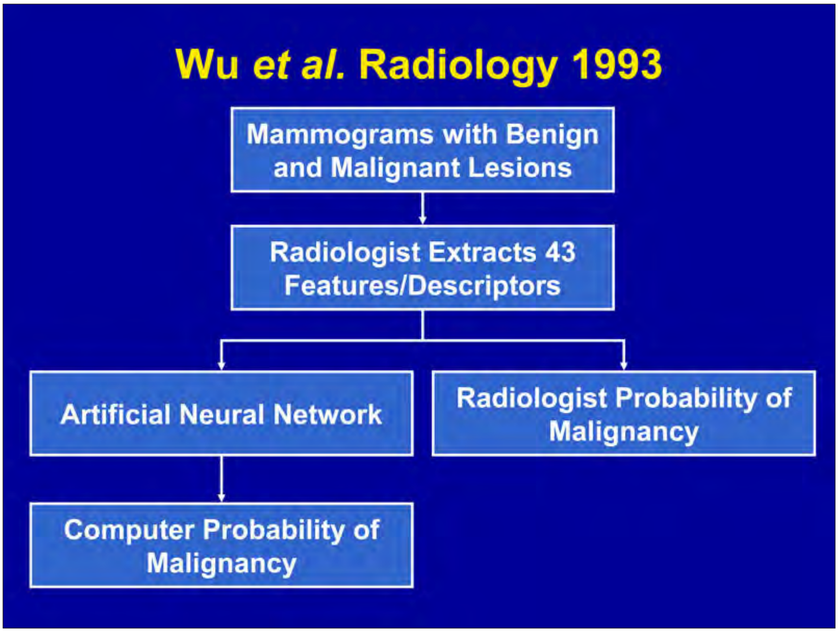
On Making the Right Choice: The Deliberation-Without-Attention Effect

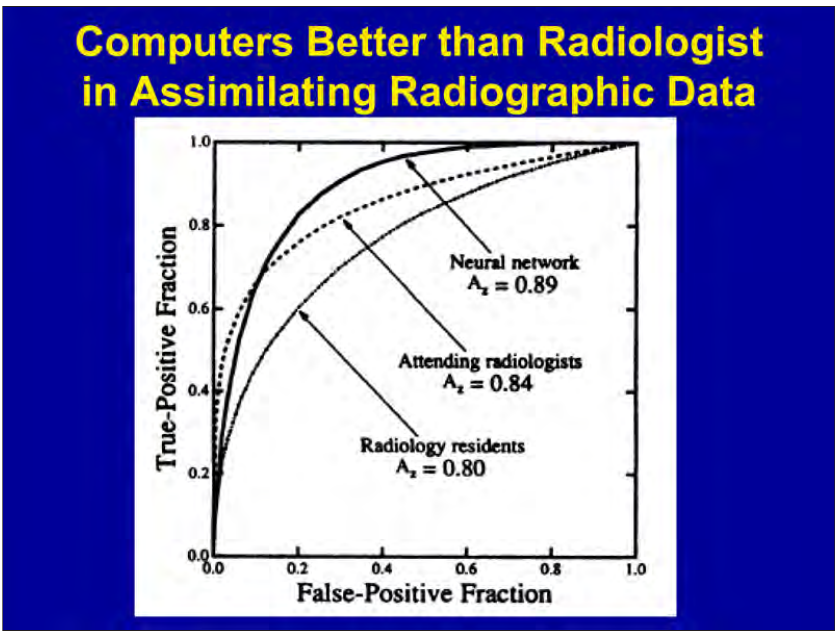
Ap Dijksterhuis,* Maarten W. Bos, Loran F. Nordgren, Rick B. van Baaren

Contrary to conventional wisdom, it is not always advantageous to engage in thorough conscious deliberation before choosing. On the basis of recent insights into the characteristics of conscious and unconscious thought, we tested the hypothesis that simple choices (such as between different towels or different sets of oven mitts) indeed produce better results after conscious thought, but that choices in complex matters (such as between different houses or different cars) should be left to unconscious thought. Named the "deliberation-without-attention" hypothesis, it was confirmed in four studies on consumer choice, both in the laboratory as well as among actual shoppers, that purchases of complex products were viewed more favorably when decisions had been made in the absence of attentive deliberation.

AAAS

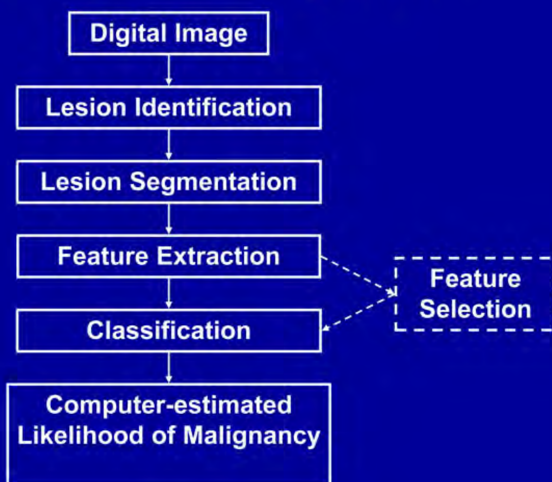


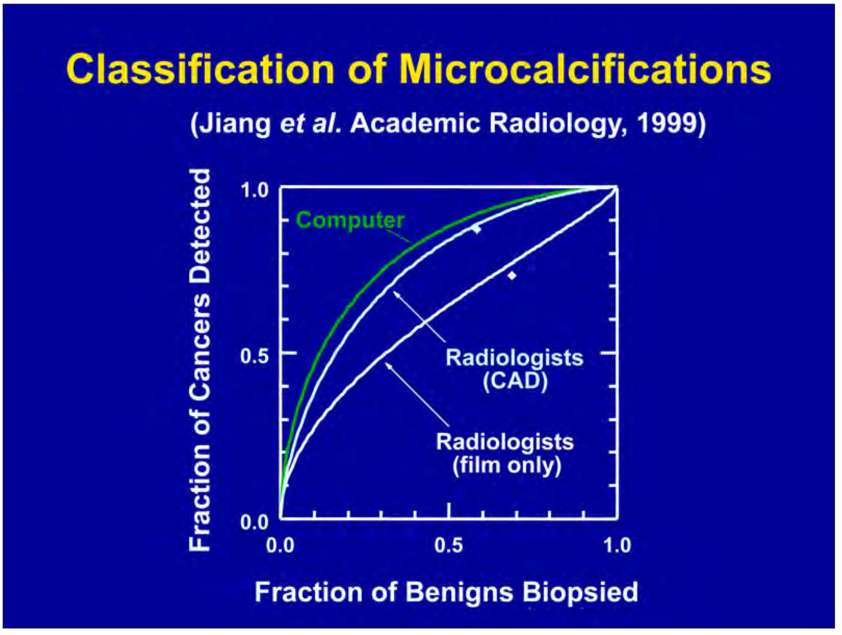

Wu *et al.* Radiology 1993
Mammograms with Benign and Malignant Lesions
Radiologist Extracts 43 Features/Descriptors
Artificial Neural Network
Radiologist Probability of Malignancy
Computer Probability of Malignancy

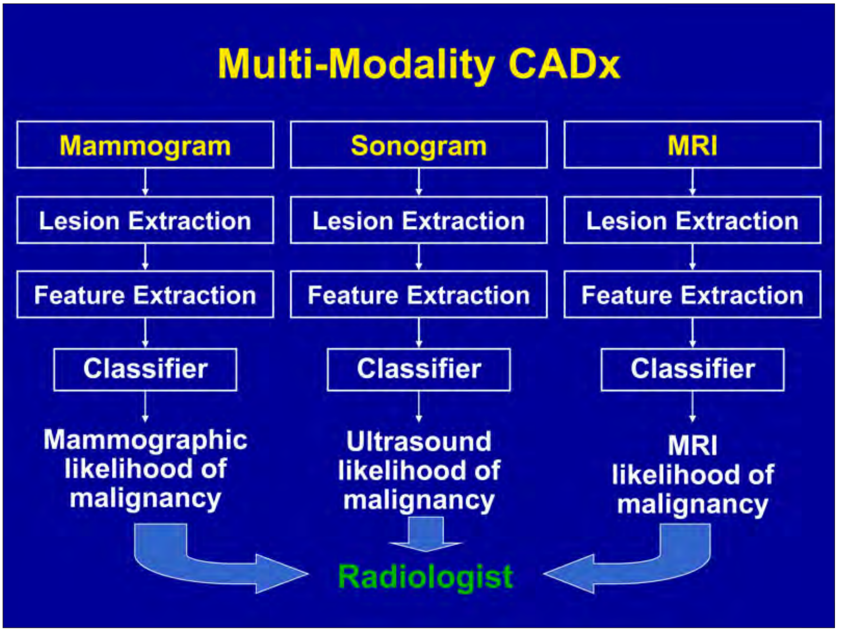

Computers Better than Radiologist in Assimilating Radiographic Data
True-Positive Fraction
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
False-Positive Fraction
Neural network
$A_z = 0.89$
Attending radiologists
$A_z = 0.84$
Radiology residents
$A_z = 0.80$

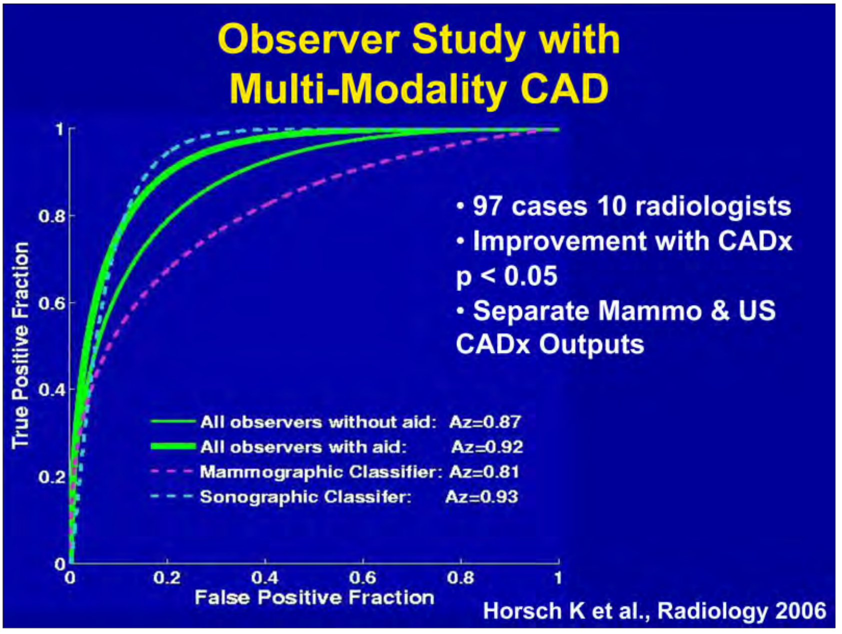
Multimodality Breast Imaging

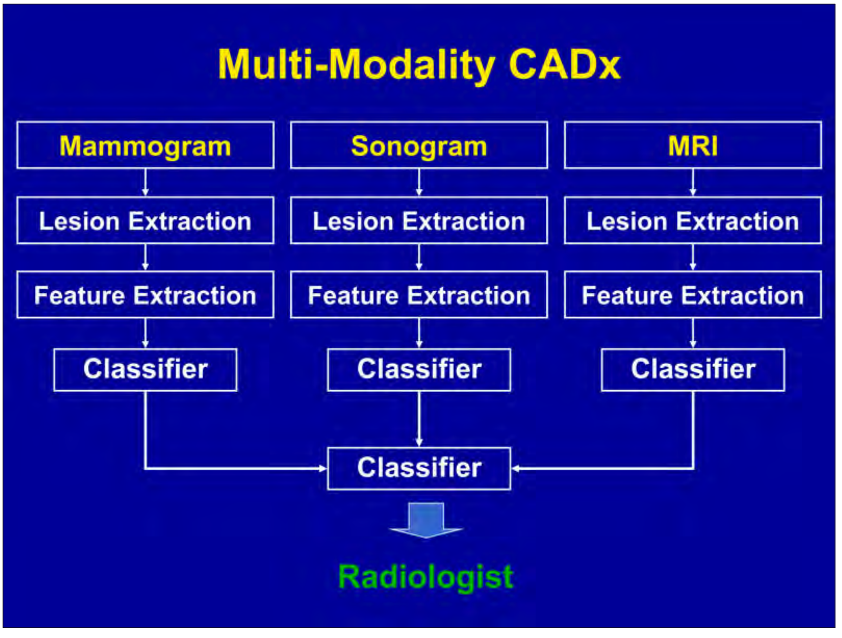
Computer-Aided Diagnosis

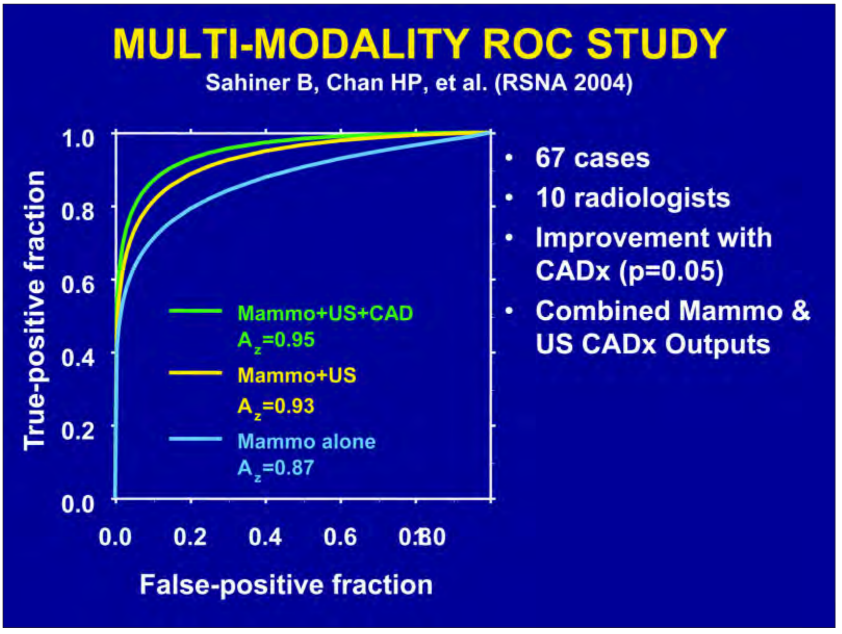


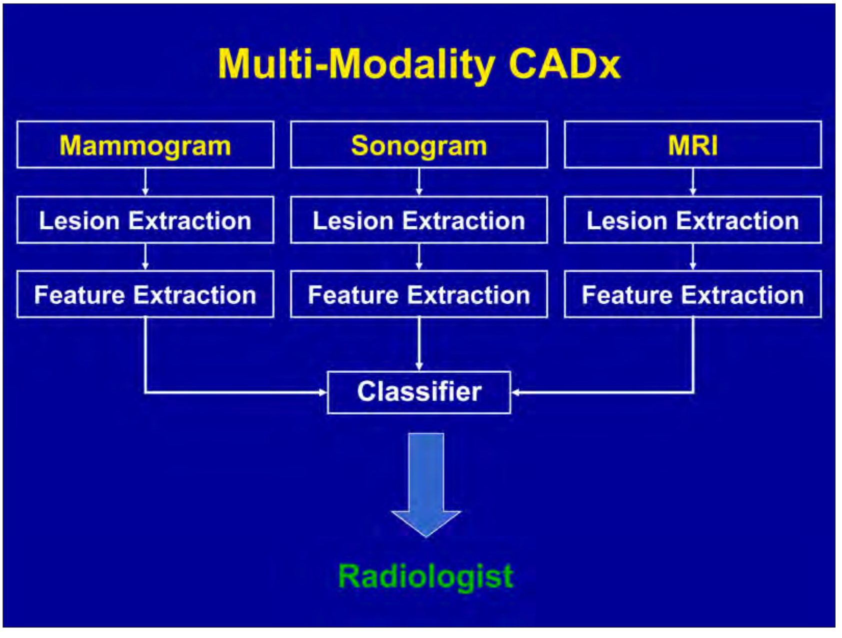

Classification of Microcalcifications
(Jiang et al. Academic Radiology, 1999)
Fraction of Cancers Detected
1.0
0.5
0.0
Computer
Radiologists (CAD)
Radiologists (film only)
0.0
0.5
1.0
Fraction of Benigns Biopsied

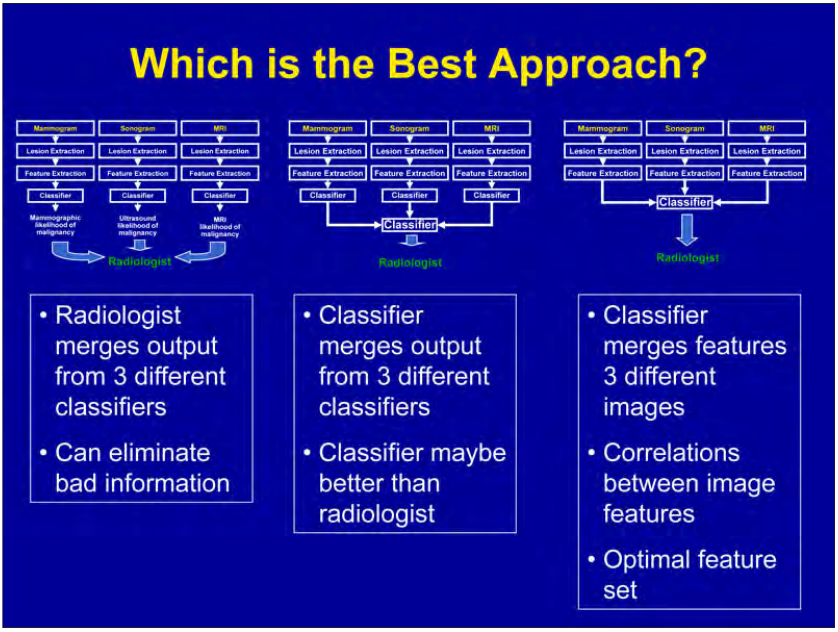

Multi-Modality CADx
Mammogram
Sonogram
MRI
Lesion Extraction
Lesion Extraction
Lesion Extraction
Feature Extraction
Feature Extraction
Feature Extraction
Classifier
Classifier
Classifier
Mammographic likelihood of malignancy
Ultrasound likelihood of malignancy
MRI likelihood of malignancy
Radiologist

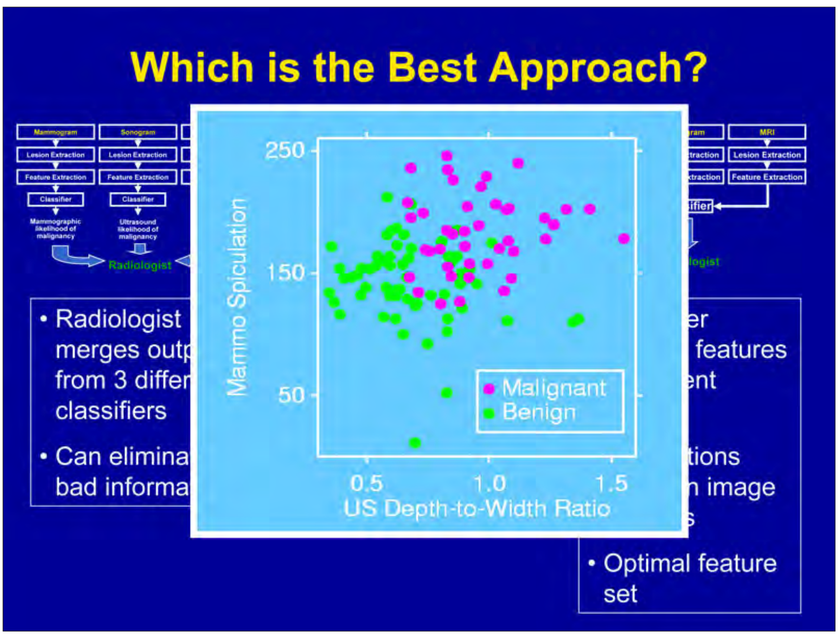

Observer Study with
Multi-Modality CAD
True Positive Fraction
False Positive Fraction
0
0.2
0.4
0.6
0.8
1
• 97 cases 10 radiologists
• Improvement with CADx
p < 0.05
• Separate Mammo & US
CADx Outputs
All observers without aid: Az=0.87
All observers with aid: Az=0.92
Mammographic Classifier: Az=0.81
Sonographic Classifer: Az=0.93
Horsch K et al., Radiology 2006


Multi-Modality CADx
Mammogram
Sonogram
MRI
Lesion Extraction
Lesion Extraction
Lesion Extraction
Feature Extraction
Feature Extraction
Feature Extraction
Classifier
Classifier
Classifier
Classifier
Radiologist

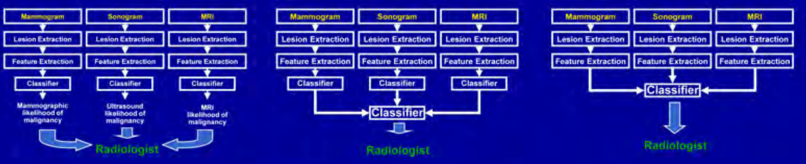

MULTI-MODALITY ROC STUDY
Sahiner B, Chan HP, et al. (RSNA 2004)
True-positive fraction
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
False-positive fraction
Mammo+US+CAD
A_z=0.95
Mammo+US
A_z=0.93
Mammo alone
A_z=0.87
• 67 cases
• 10 radiologists
• Improvement with CADx (p=0.05)
• Combined Mammo & US CADx Outputs


Multi-Modality CADx
Mammogram
Sonogram
MRI
Lesion Extraction
Lesion Extraction
Lesion Extraction
Feature Extraction
Feature Extraction
Feature Extraction
Classifier
Radiologist


Which is the Best Approach?
Mammogram
Sonogram
MRI
Lesion Extraction
Feature Extraction
Classifier
Radiologist
• Radiologist merges output from 3 different classifiers
• Can eliminate bad information
• Classifier merges output from 3 different classifiers
• Classifier maybe better than radiologist
• Classifier merges features 3 different images
• Correlations between image features
• Optimal feature set


Which is the Best Approach?
250
150
50
Mammo Spiculation
0.5
1.0
1.5
US Depth-to-Width Ratio
Malignant
Benign

Which is the Best Approach?



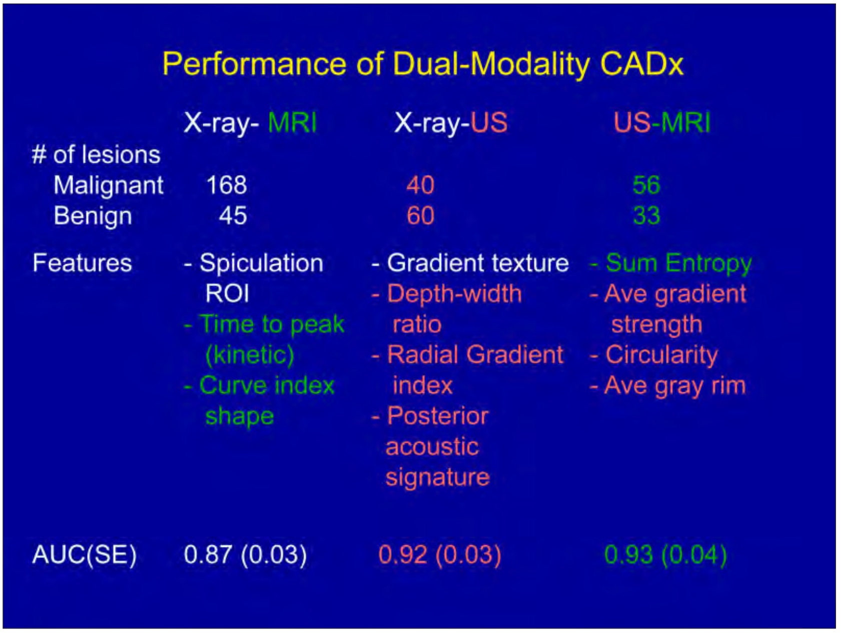
- Radiologist merges output from 3 different classifiers
- Can eliminate bad information

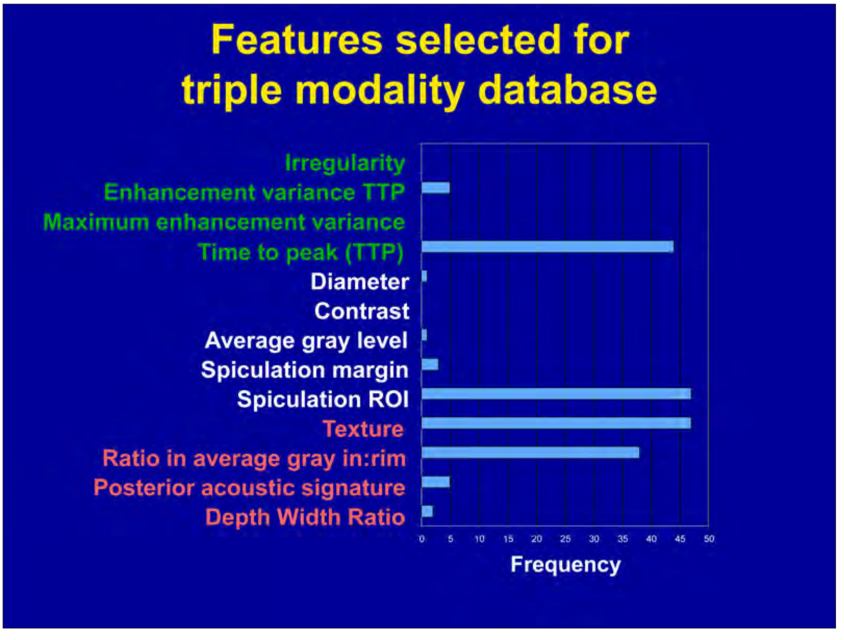
- Classifier merges output from 3 different classifiers
- Classifier maybe better than radiologist

- Classifier merges features 3 different images
- Correlations between image features
- Optimal feature set

Performance of Single-Modality CADx

	X-ray	US	DCE-MRI
# of lesions			
Malignant	255	968	347
Benign	177	158	129
Features	- Diameter - Ave PV - Contrast - Spiculation margin - Spiculation ROI	- Texture - Depth-width ratio - Ratio ave PV in:rim - Posterior acoustic signature	- Irregularity - Time to peak (kinetic) - Time to peak (enhancement variance) - Max enhancement variance
AUC(SE)	0.75 (0.04)	0.88 (0.01)	0.79 (0.04)


Performance of Dual-Modality CADx
X-ray- MRI
X-ray-US
US-MRI
# of lesions
Malignant 168 40 56
Benign 45 60 33
Features
- Spiculation ROI
- Time to peak (kinetic)
- Curve index shape
- Gradient texture
- Depth-width ratio
- Radial Gradient index
- Posterior acoustic signature
- Sum Entropy
- Ave gradient strength
- Circularity
- Ave gray rim
AUC(SE) 0.87 (0.03) 0.92 (0.03) 0.93 (0.04)


Features selected for
triple modality database
Irregularity
Enhancement variance TTP
Maximum enhancement variance
Time to peak (TTP)
Diameter
Contrast
Average gray level
Spiculation margin
Spiculation ROI
Texture
Ratio in average gray in:rim
Posterior acoustic signature
Depth Width Ratio
0 5 10 15 20 25 30 35 40 45 50
Frequency

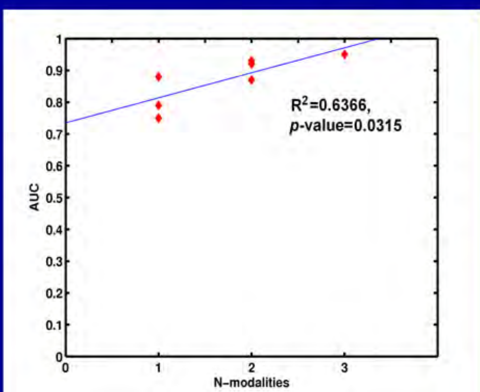
Performance of Triple-Modality CADx

X-ray – US – DCE-MRI

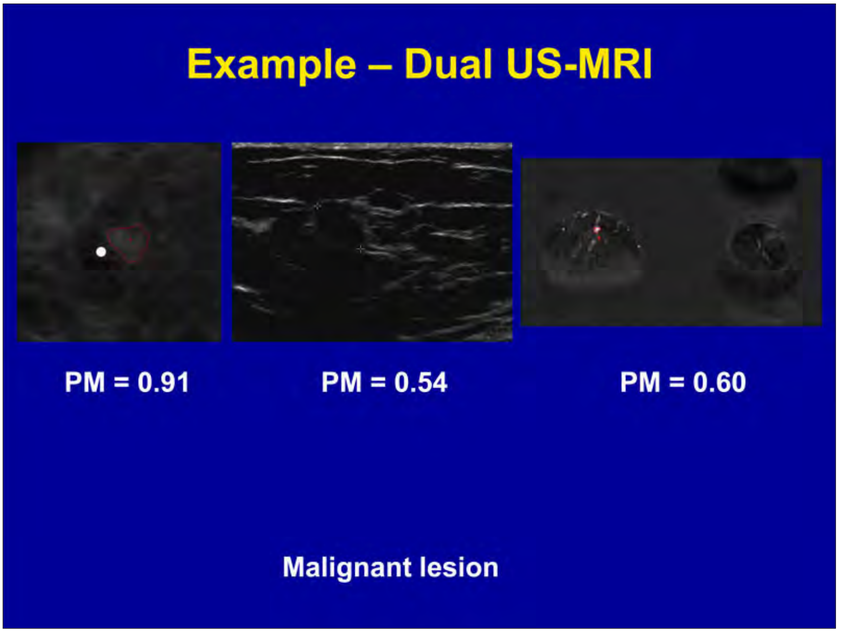
No of Lesions	31 Malignant 17 Benign
Features	• Time to Peak (MRI) • Spiculation ROI (X-ray) • Texture (US) • Ratio of ave PV in:rim (US)
AUC ± SE	0.95 ±0.03

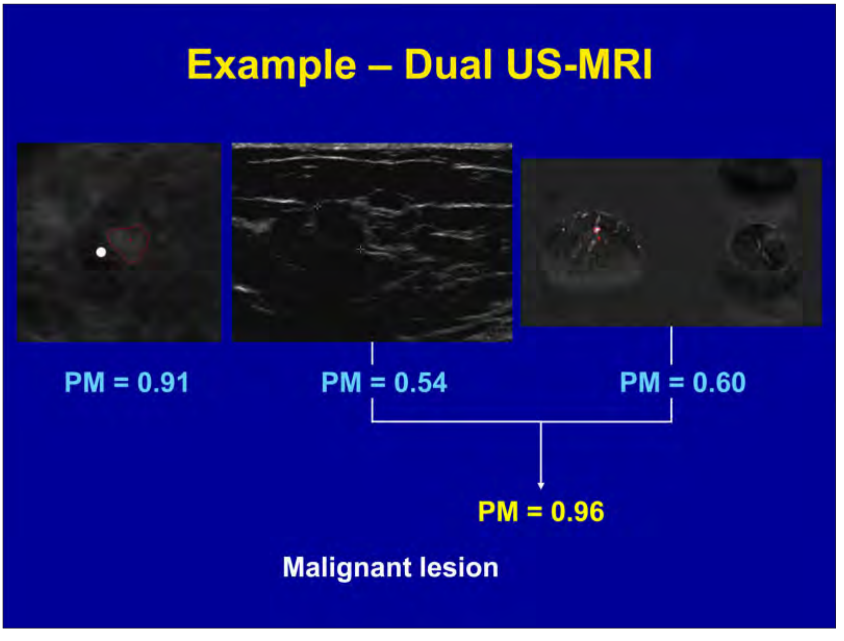
- **Time to peak: time point at which signal intensity is highest in lesion**
- **Spiculation ROI: radial gradient of the pixels based on the ROI**
- **Texture: autocorrelation of pixel values (PV) within lesion**
- **Ratio in ave gray in:rim: ratio of the average gray value within the lesion and that in the 2-mm rim around it**

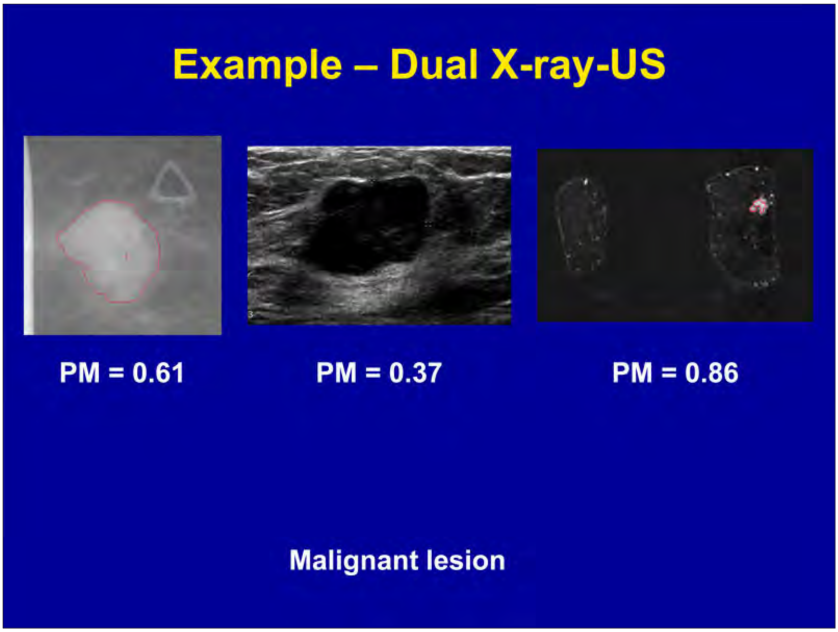
Trend in AUCs with Additional Modalities

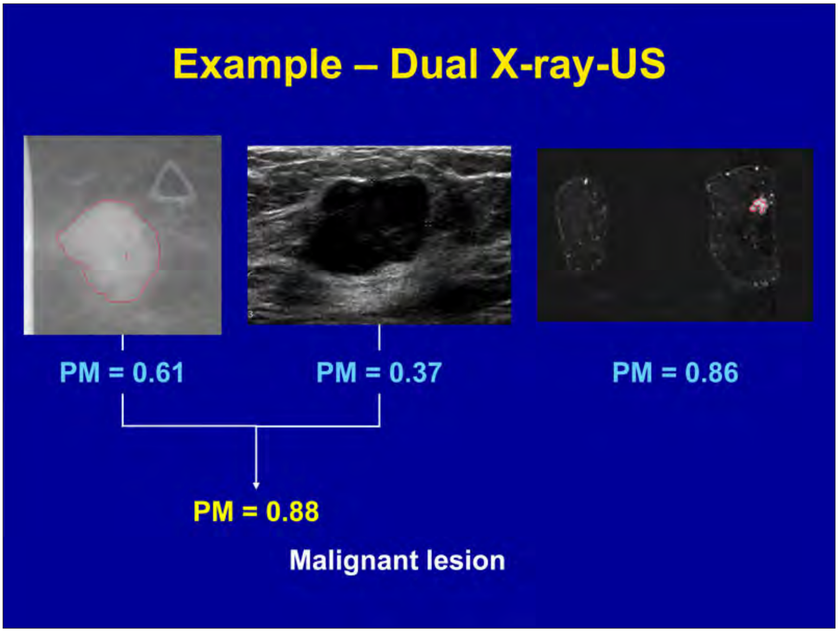


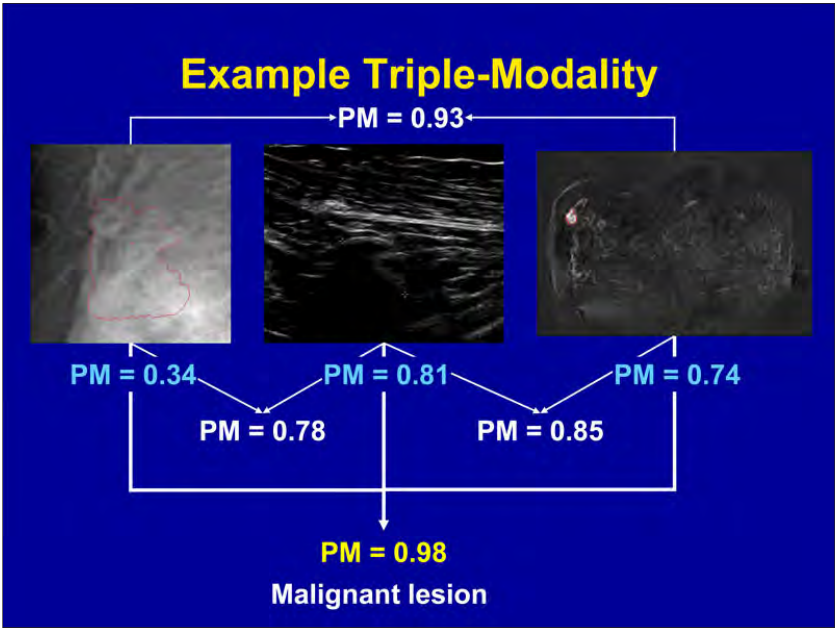
Database	No of lesions
Single X-ray	255 Ca 177 B9
Single US	968 Ca 158 B9
Single DCE-MRI	347 Ca 129 B9
Dual X-ray-MRI	168 Ca 45 B9
Dual X-ray-US	40 Ca 60 B9
Dual US-MRI	56 Ca 33 B9
Triple X-ray-US-MRI	31 Ca 17 B9

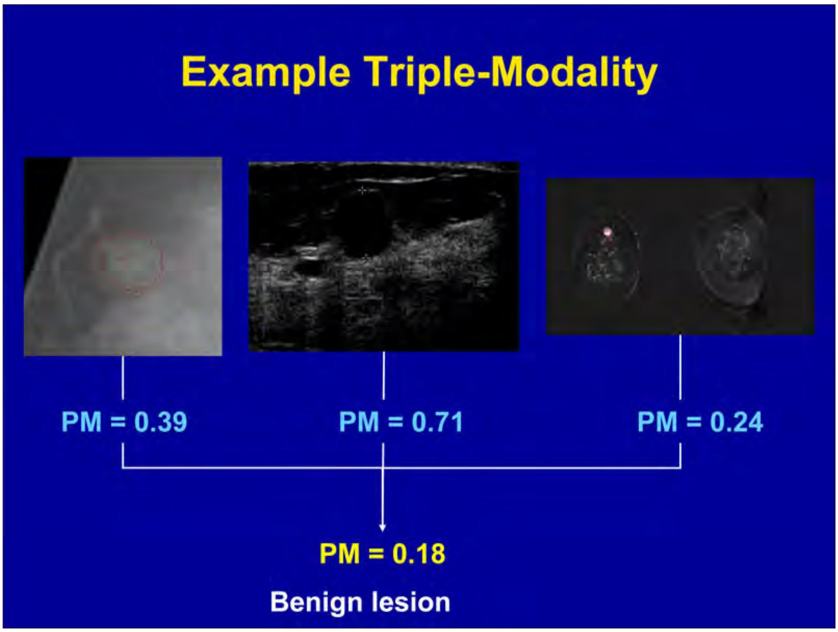

Example – Dual US-MRI
PM = 0.91
PM = 0.54
PM = 0.60
Malignant lesion


Example – Dual US-MRI
PM = 0.91
PM = 0.54
PM = 0.60
PM = 0.96
Malignant lesion


Example – Dual X-ray-US
PM = 0.61
PM = 0.37
PM = 0.86
Malignant lesion


Example – Dual X-ray-US
PM = 0.61
PM = 0.37
PM = 0.86
PM = 0.88
Malignant lesion


Example Triple-Modality
PM = 0.93
PM = 0.34
PM = 0.81
PM = 0.74
PM = 0.78
PM = 0.85
PM = 0.98
Malignant lesion


Example Triple-Modality
PM = 0.39
PM = 0.71
PM = 0.24
PM = 0.18
Benign lesion

Conclusions

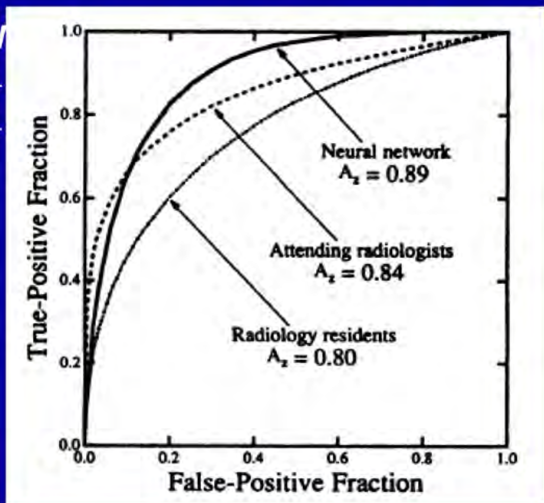
- Improved performance can be obtained through multi-modality image analysis
  - Fusing features is a viable approach
- The concepts presented here are directly translatable to security

Unrelated Questions

- What is the "value" of TP and FP?
  - Need for optimization
  - Shape of curve

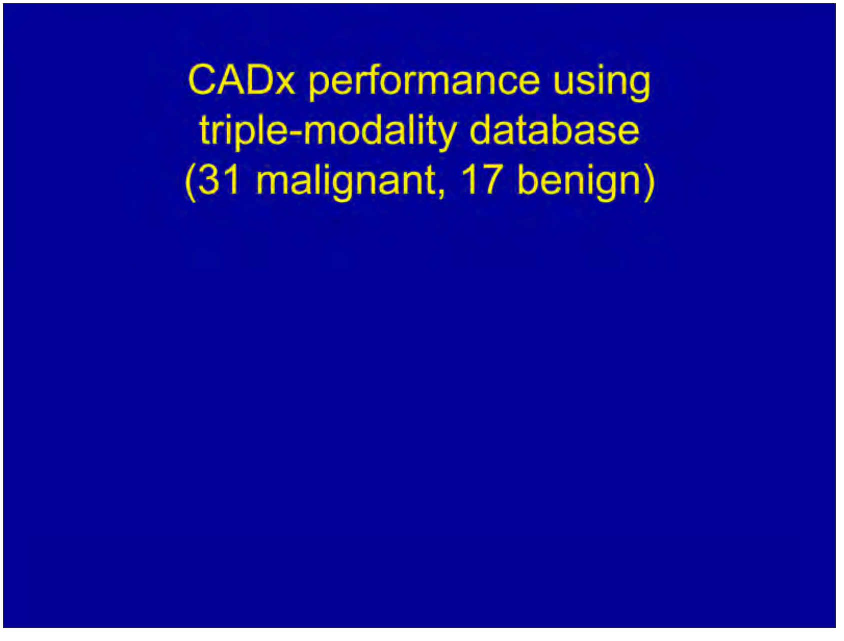
Unrelated Questions

- W
  -
  -



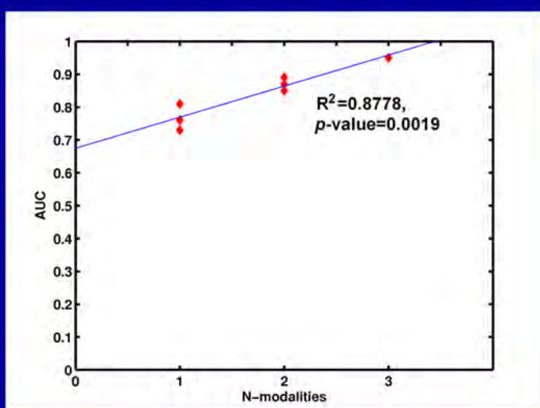
Unrelated Questions

- What is the "value" of TP and FP?
  - Need for optimization
  - Shape of curve
- Open databases


CADx performance using
triple-modality database
(31 malignant, 17 benign)

Database	Selected Features	AUC ± SE
X-ray	Contrast Average pixel value (PV) Spiculation Margin	0.76 ± 0.07
US	Ratio in pixel value (PV) in:rim Posterior Acoustic Signature	0.81 ± 0.06
DCE-MRI	Curve Shape Index Variance in Margin Sharpness	0.73 ± 0.07
X-ray-MRI	Variance in Margin Sharpness Spiculation ROI	0.89 ± 0.05
X-ray-US	Ratio in pixel value (PV) in:rim Texture Spiculation ROI	0.87 ± 0.05
US-MRI	Posterior Acoustic Signature Texture Curve Shape Index	0.85 ± 0.06
X-ray-US-MRI	Texture Ratio in average gray in/rim Spiculation ROI Time to Peak (kinetic)	0.95 ± 0.03

AUC vs Number of Modalities



using cases in triple-modality database (31 malignant, 17 benign)

Summary

- Performance of the CADx scheme increased as the number of modalities used as input increased

Limitations

- Due to the limited size of the triple-modality database at this time, one can only assess trends in performance as more modalities are added to the classification

Summary

- Features from all three modalities were selected as the most effective features for distinguishing malignant from benign lesions in the triple-modality database, and the resulting performance of our CADx method yielded an AUC of 0.95±0.03.

References

- Huo Z, Giger ML, Vyborny CJ et al. Automated computerized classification of malignant and benign masses on digitized mammograms. Acad Radiol 5, 155-168, 1998
- Li H, Giger ML, Yuan Y, et al. Evaluation of computer-aided diagnosis on a large clinical FFDM dataset. Acad Radiol 15, 1437-1445, 2008
- Chen W, Giger ML, Bick U, Newstead GM. Automatic identification and classification of characteristic kinetic curves of breast lesions on DCE-MRI. Med Phys 33, 2878-2887, 2006
- Chen W, Giger ML, Lan L, Bick U: Computerized interpretation of breast MRI: Investigation of enhancement-variance dynamics, Med Phys 31, 1076-1082, 2004
- Chen W, Giger ML, Li H, Bick DCE- MRI. Mag Reson Med 58, 562-571, 2007
- Drukker K, Horsch K, Giger ML. Multimodality Computerized Diagnosis of Breast Lesions Using Mammography and Sonography. Acad Radiol 12, 970-9, 2005
- Yuan Y, Giger ML, Li H, Bhooshan N, Sennett C. Multi-modality computer-aided breast cancer diagnosis with FFDM and DCE-MRI. Acad Radiol (in press)

Strengths and Weakness of Modalities

Modality	Strengths	Weaknesses
FFDM	• High spatial resolution - spiculation - microcalcifications	• Overlapping tissue • Radiation
US	• No radiation • Best CADx performance • Can assess axilla	• Image quality dependent on technician skill
MRI	• Assess kinetics • 3D assessment • High sensitivity	• High false-positive rate • Invasive (contrast injection)

Feature Definitions

- Depth to width ratio – describes shape; cysts and benign solids tend to be wider than deep, thus benign lesions have smaller values than malignant lesions
- Texture – autocorrelation of gray-levels within lesion
- Posterior acoustic signature – compare gray-level values posterior to lesion to those in adjacent tissue at the same depth; malignant lesions tend to have posterior acoustic shadowing while cystic lesions tend to have posterior acoustic enhancement
- Average gradient strength – gradients within the lesion, influenced by the echogenicity and texture.
- Average gray rim – average gray value within a rim of 2 mm around the segmented lesion
- Average gray in/rim – ratio of the average gray value within the lesion and that in the 2mm rim around it

kinetics geometric texture spiculation spatial-enhancement variance

Feature Definitions

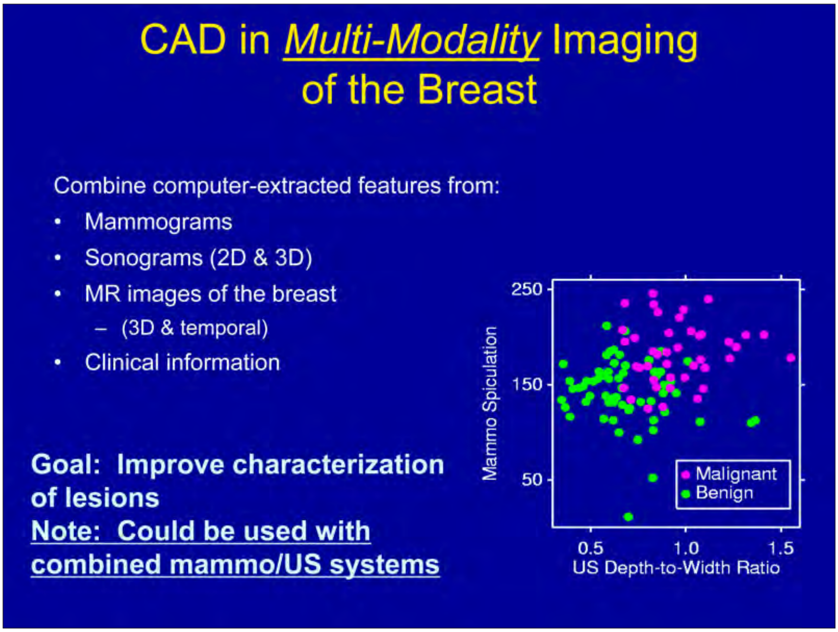
FFDM

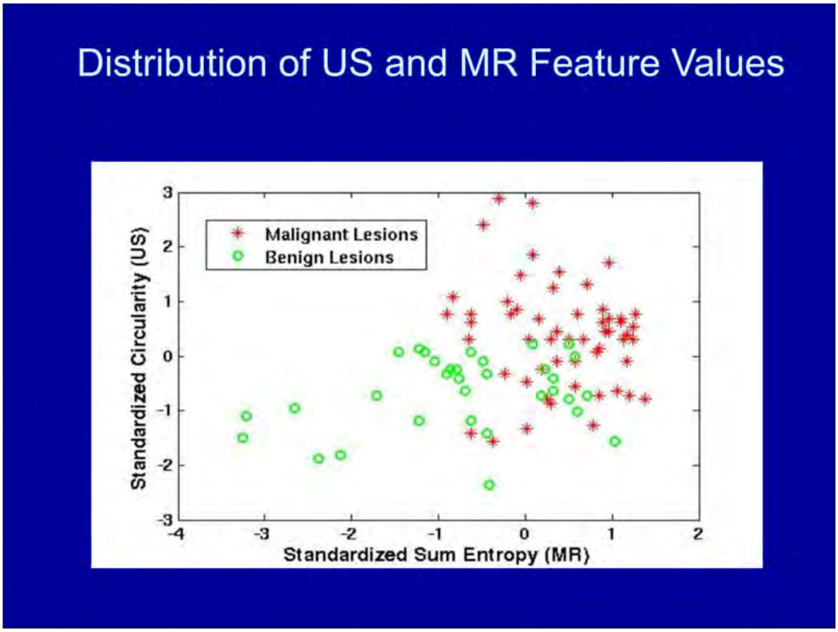
- Average gray level – averaging gray level values of each pixel within the segmented lesion
- Contrast – difference of average gray levels between the segmented lesion and surrounding parenchyma
- Spiculation – radial gradient of the pixels based on the ROI or the margin of lesion
- Gradient texture – standard deviation of gradient within mass lesion

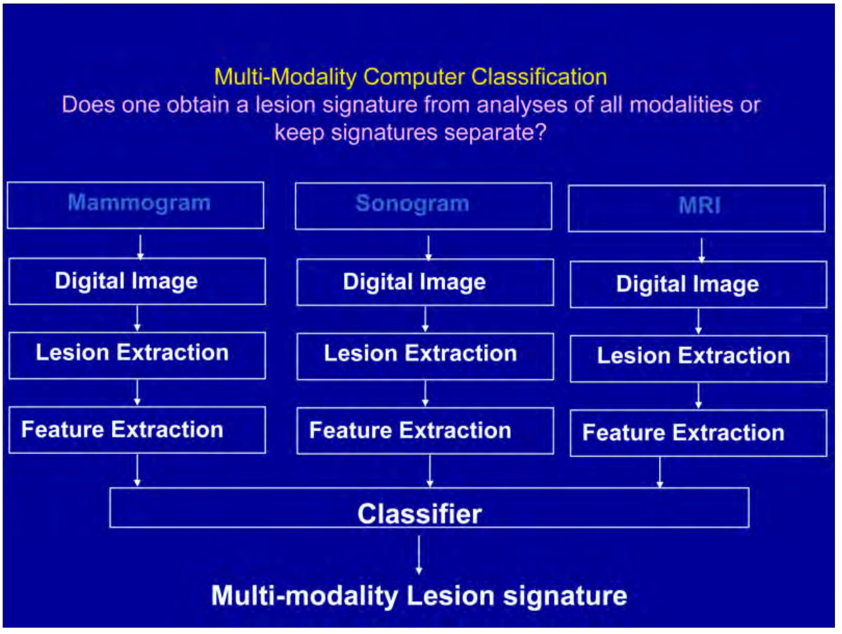
MRI

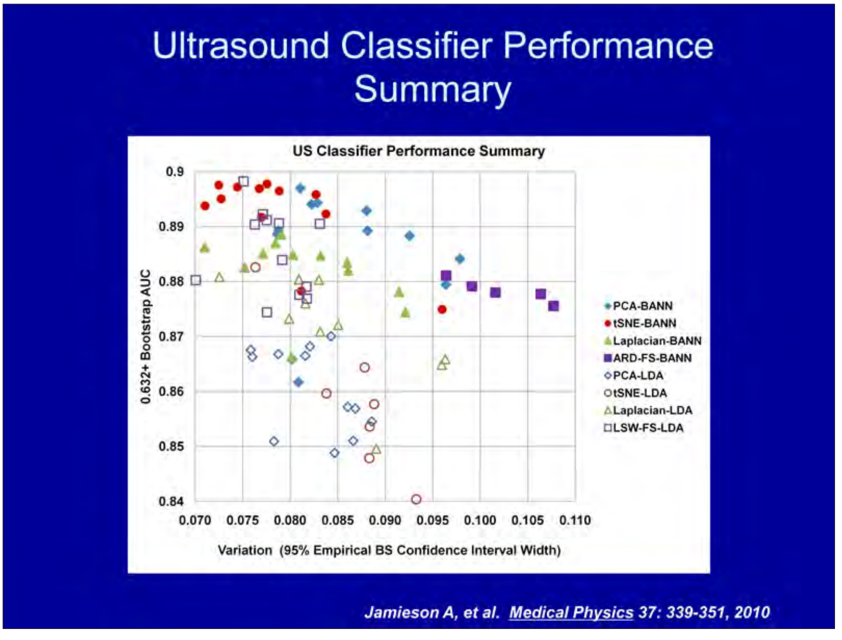
- Irregularity – roughness of lesion surface
- Time to peak – timepoint at which signal intensity is highest in lesion
- Enhancement variance – measure variance of lesion at each timepoint; time to peak – timepoint at which varianceCurve Shape index – ratio of late enhancement to initial enhancement (describes shape of kinetic curve)
- Sum Entropy – GLCM (gray-level co-occurrence matrix) feature that describes randomness of sum of gray-levels of voxel pairs

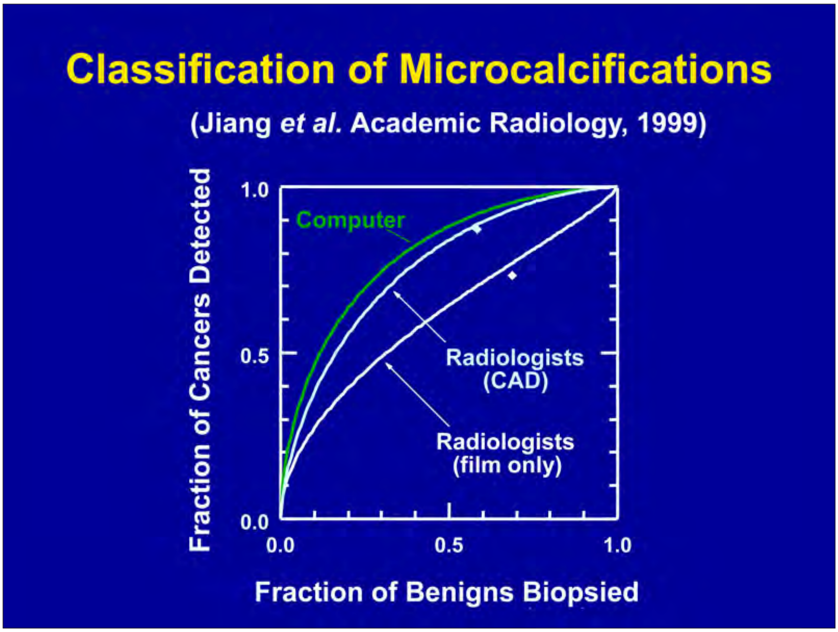
kinetics geometric texture spiculation spatial-enhancement variance

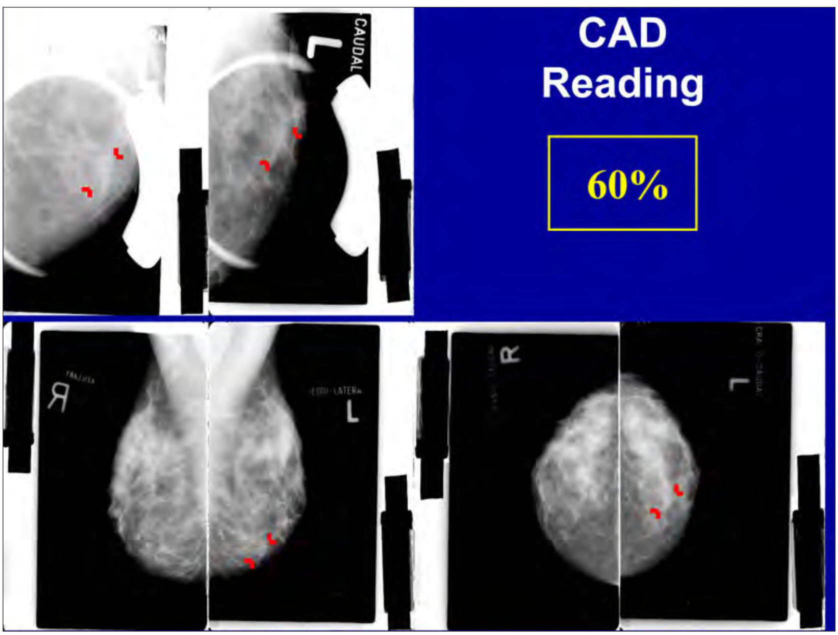

CAD in Multi-Modality Imaging of the Breast
Combine computer-extracted features from:
• Mammograms
• Sonograms (2D & 3D)
• MR images of the breast
– (3D & temporal)
• Clinical information
Goal: Improve characterization of lesions
Note: Could be used with combined mammo/US systems
Mammo Spiculation
250
150
50
Malignant
Benign
0.5
1.0
1.5
US Depth-to-Width Ratio

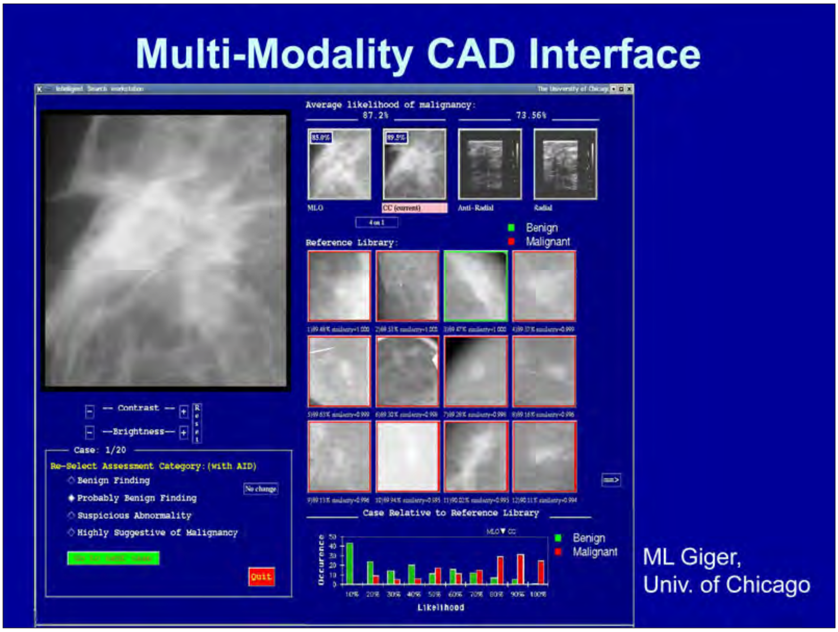

Distribution of US and MR Feature Values
Malignant Lesions
Benign Lesions
Standardized Circularity (US)
3
2
1
0
-1
-2
-3
-4
-3
-2
-1
0
1
2
Standardized Sum Entropy (MR)

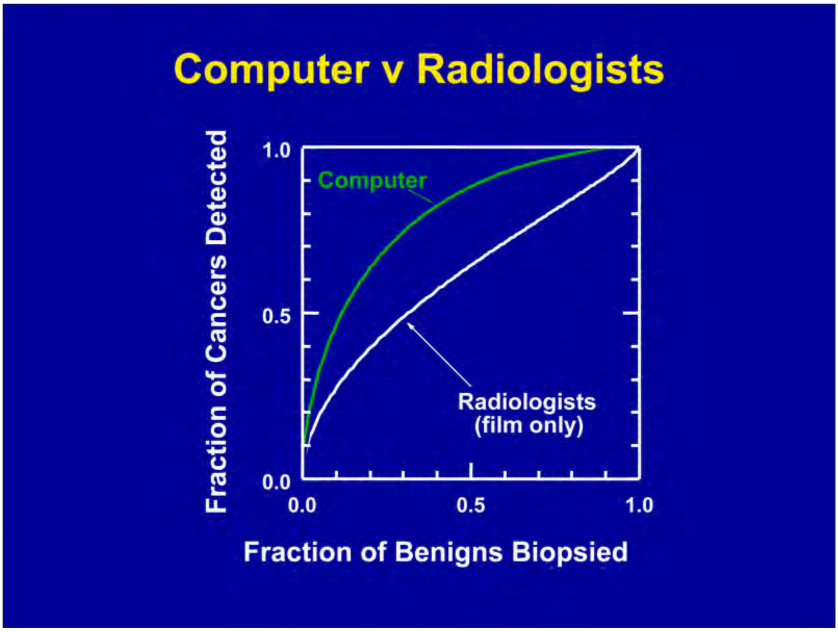

Multi-Modality Computer Classification
Does one obtain a lesion signature from analyses of all modalities or keep signatures separate?
Mammogram
Sonogram
MRI
Digital Image
Digital Image
Digital Image
Lesion Extraction
Lesion Extraction
Lesion Extraction
Feature Extraction
Feature Extraction
Feature Extraction
Classifier
Multi-modality Lesion signature

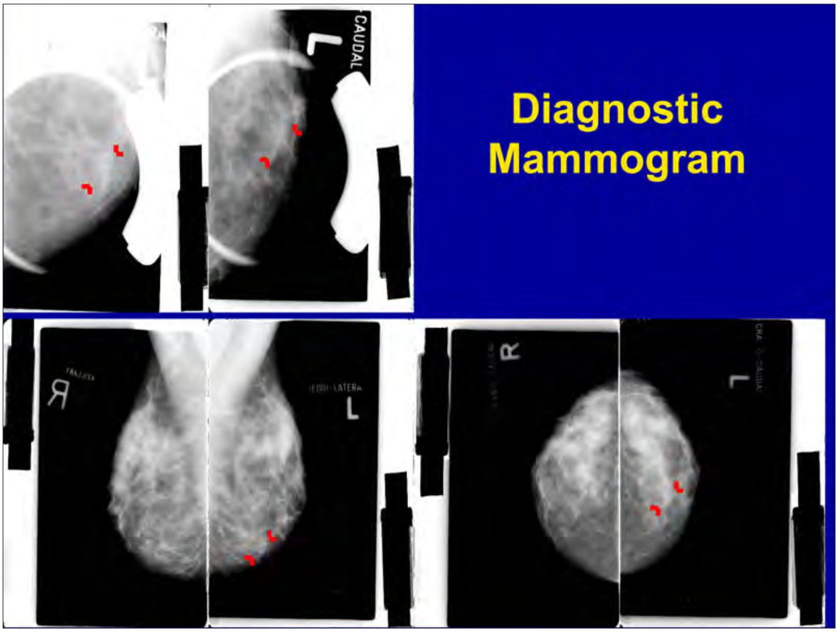

Ultrasound Classifier Performance Summary
US Classifier Performance Summary
0.632+ Bootstrap AUC
Variation (95% Empirical BS Confidence Interval Width)
PCA-BANN
tSNE-BANN
Laplacian-BANN
ARD-FS-BANN
PCA-LDA
tSNE-LDA
Laplacian-LDA
LSW-FS-LDA
Jamieson A, et al. Medical Physics 37: 339-351, 2010


Classification of Microcalcifications
(Jiang et al. Academic Radiology, 1999)
Fraction of Cancers Detected
1.0
0.5
0.0
0.0
0.5
1.0
Fraction of Benigns Biopsied
Computer
Radiologists
(CAD)
Radiologists
(film only)


CAD
Reading
60%

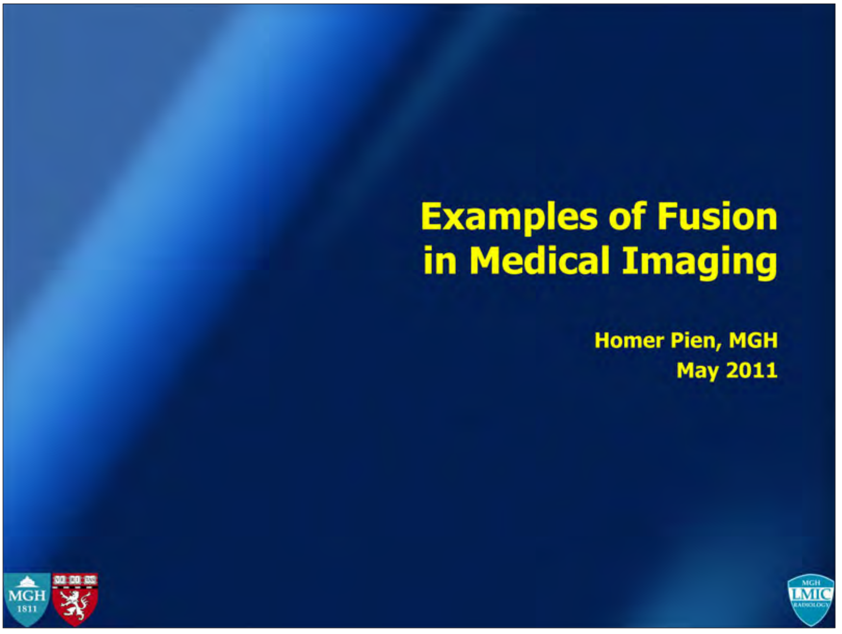

Multi-Modality CAD Interface
Average likelihood of malignancy:
87.2%
73.56%
MLO
CC (current)
Anti-Radial
Radial
Reference Library:
Benign
Malignant
Contrast
Brightness
Case: 1/20
Re-Select Assessment Category: (With AID)
Benign Finding
Probably Benign Finding
Suspicious Abnormality
Highly Suggestive of Malignancy
No change
Quit
Case Relative to Reference Library
Likelihood
ML Giger,
Univ. of Chicago

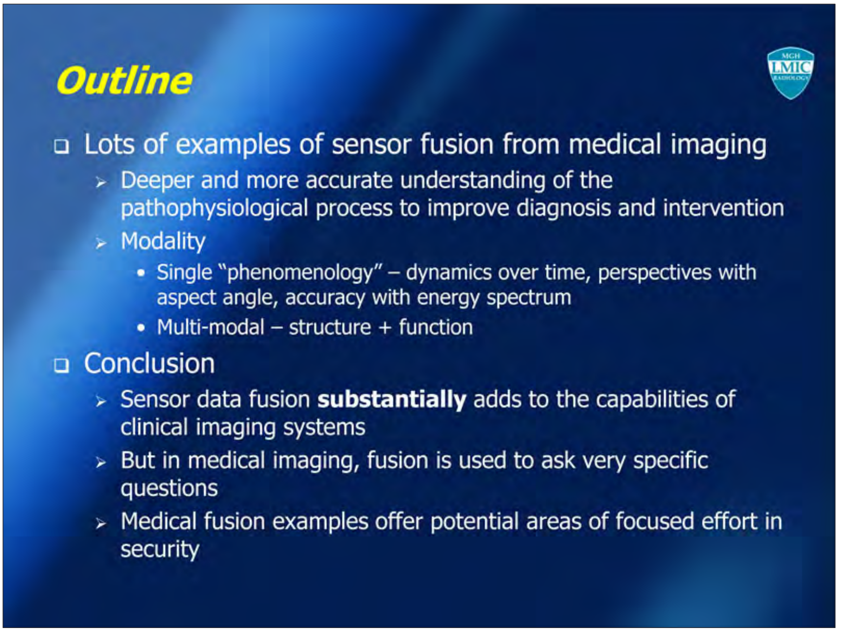

Computer v Radiologists
Fraction of Cancers Detected
1.0
0.5
0.0
Computer
Radiologists
(film only)
0.0
0.5
1.0
Fraction of Benigns Biopsied


Diagnostic
Mammogram
CAUDAL
L
R


Computer v Humans
GARRY
KASPAROV
DEEP
BLUE
May 1997: Deep Blue 3.5 Kasparov 2.5
Dec. 2006: Deep Fritz 4 Valdimir Kramnik 2

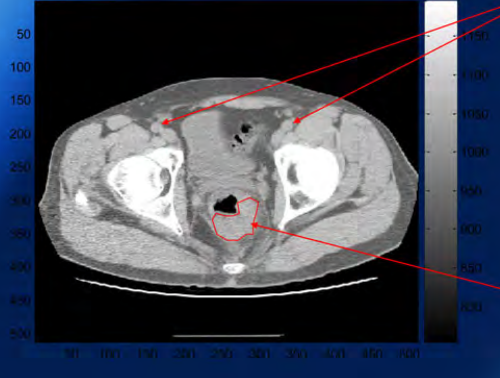
16.12 Homer Pien: Image Fusion for Improved DIagnostics



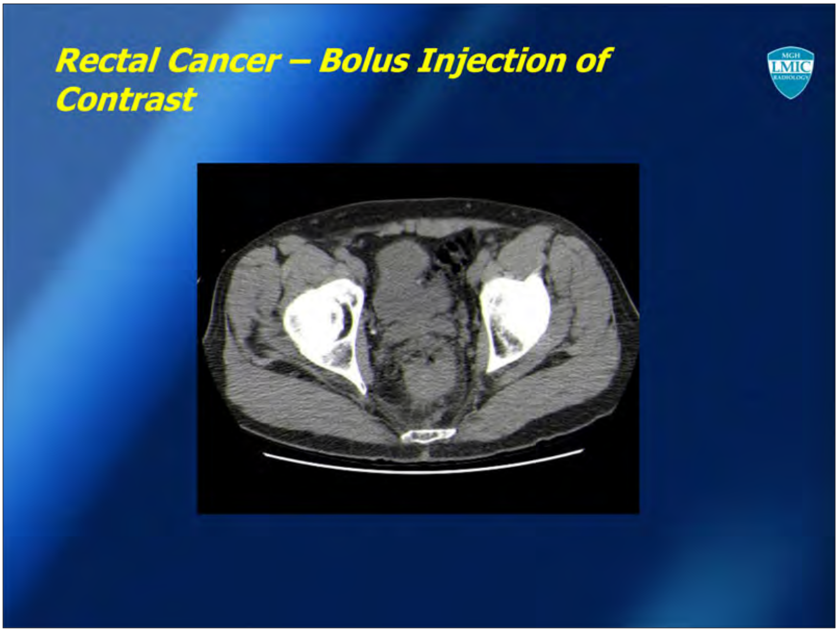


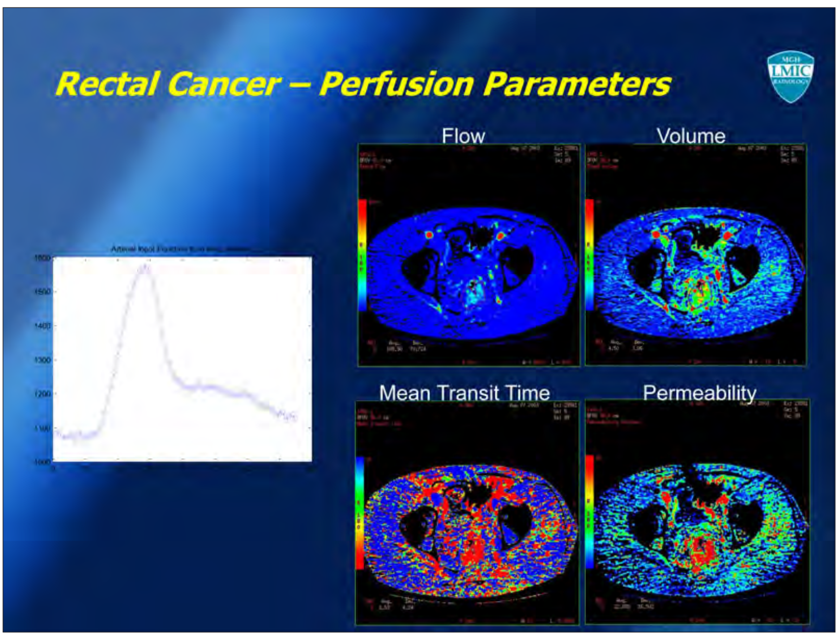
DYNAMICS OVER TIME

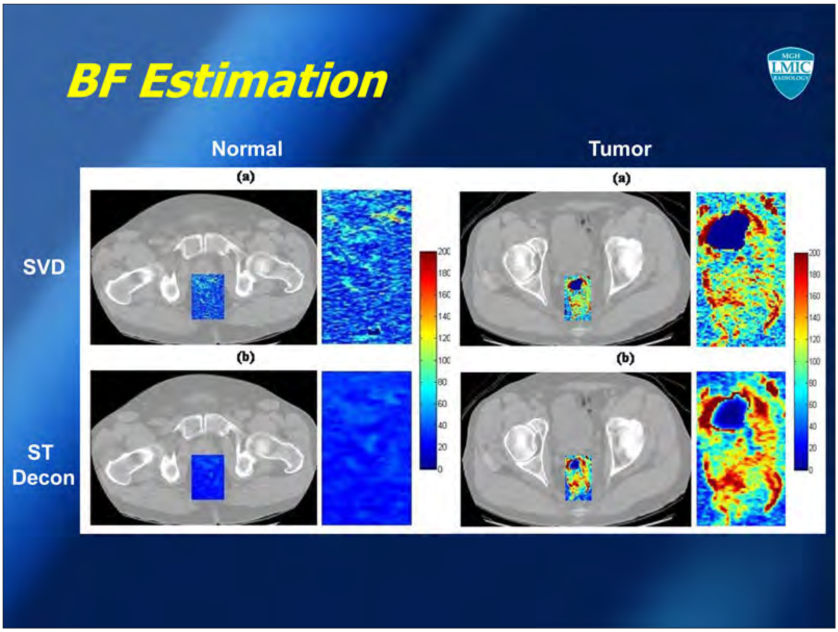
Rectal Cancer CT Example



Sequence DT, 2003.08.07; acquired by Dushant Sahani, MGH; bevacizumab trial


Rectal Cancer – Bolus Injection of Contrast


Rectal Cancer – Perfusion Parameters
Flow
Volume
Mean Transit Time
Permeability

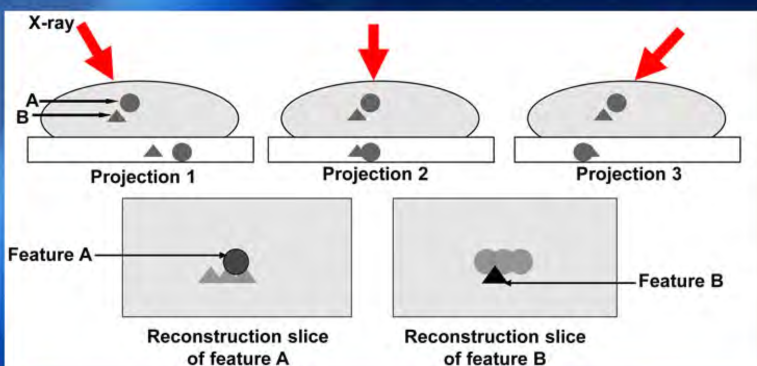

BF Estimation
Normal
Tumor
(a)
(a)
SVD
(b)
(b)
ST
Decon
200
180
160
140
120
100
80
60
40
20
0


CHANGES IN ASPECT

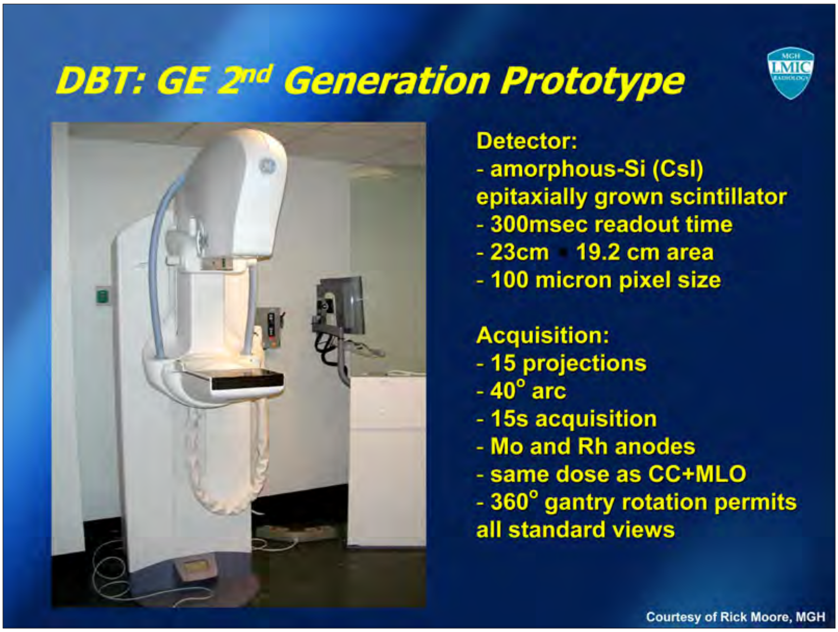
Aim

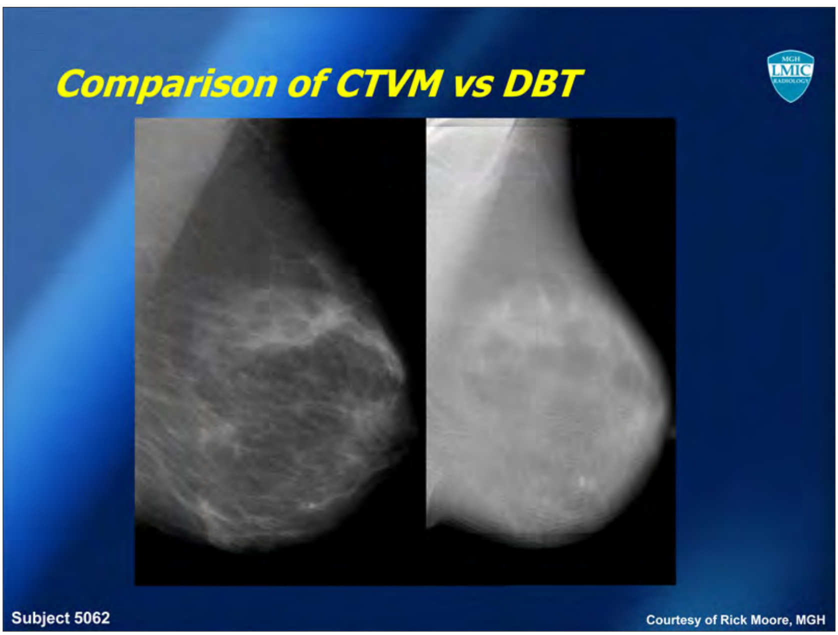
- Conventional two-view mammography (CTVM) problems are caused by:
  - Missed cancers: cancers obscured by overlaying dense tissue
  - Unnecessary call-backs: superimposed breast tissue may have appearance of tumors
- Approach: Tomosynthesis
  - Utilize multiple perspectives to form a 3-D image
  - DBT: digital breast tomosynthesis

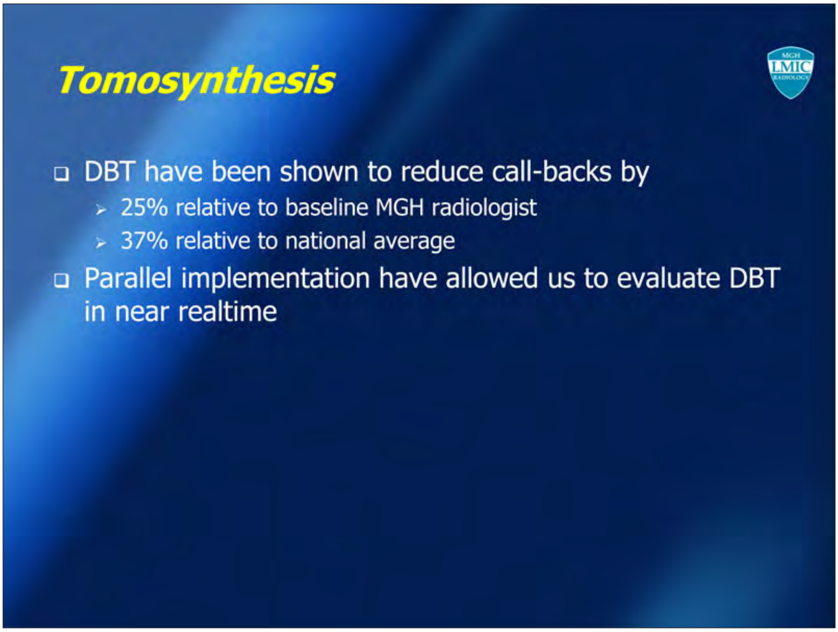
Tomosynthesis: Principle

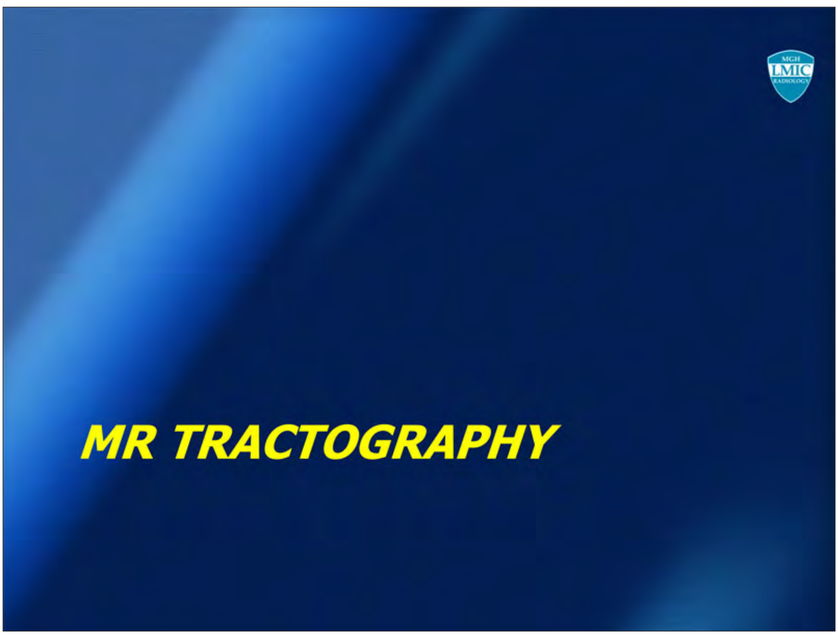


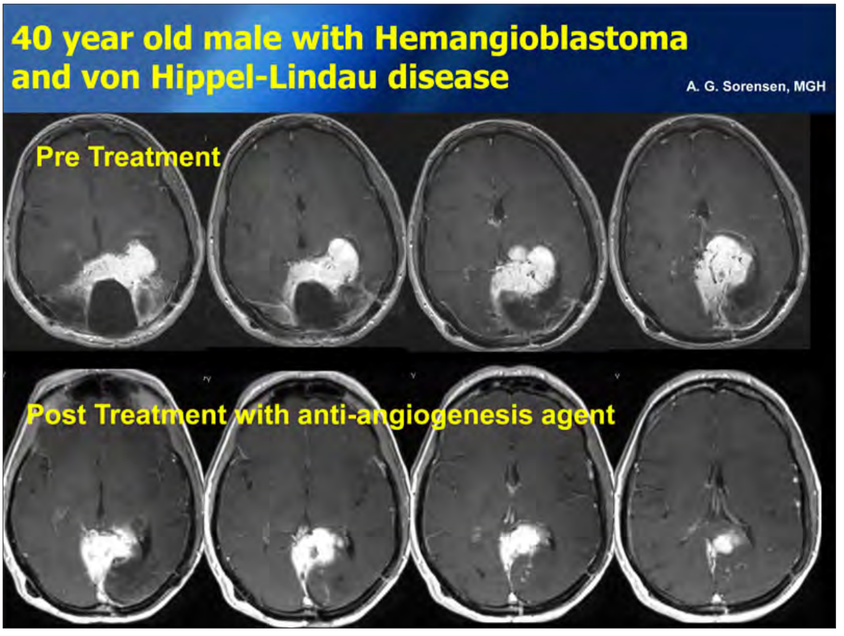
Courtesy of Rick Moore, MGH


DBT: GE 2nd Generation Prototype
Detector:
- amorphous-Si (CsI) epitaxially grown scintillator
- 300msec readout time
- 23cm 19.2 cm area
- 100 micron pixel size
Acquisition:
- 15 projections
- 40° arc
- 15s acquisition
- Mo and Rh anodes
- same dose as CC+MLO
- 360° gantry rotation permits all standard views
Courtesy of Rick Moore, MGH


Comparison of CTVM vs DBT
Subject 5062
Courtesy of Rick Moore, MGH

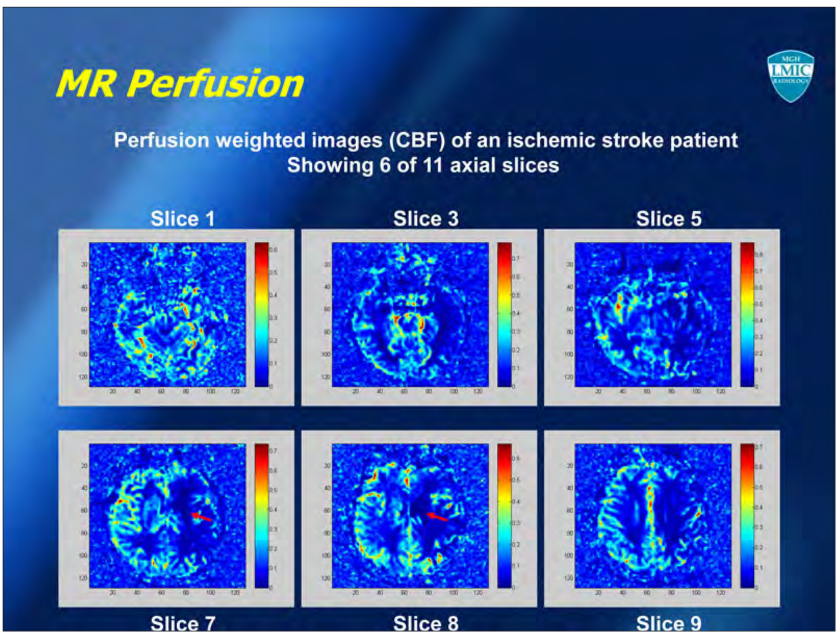

Tomosynthesis
MGH LMIC RADIOLOGY
DBT have been shown to reduce call-backs by
25% relative to baseline MGH radiologist
37% relative to national average
Parallel implementation have allowed us to evaluate DBT in near realtime

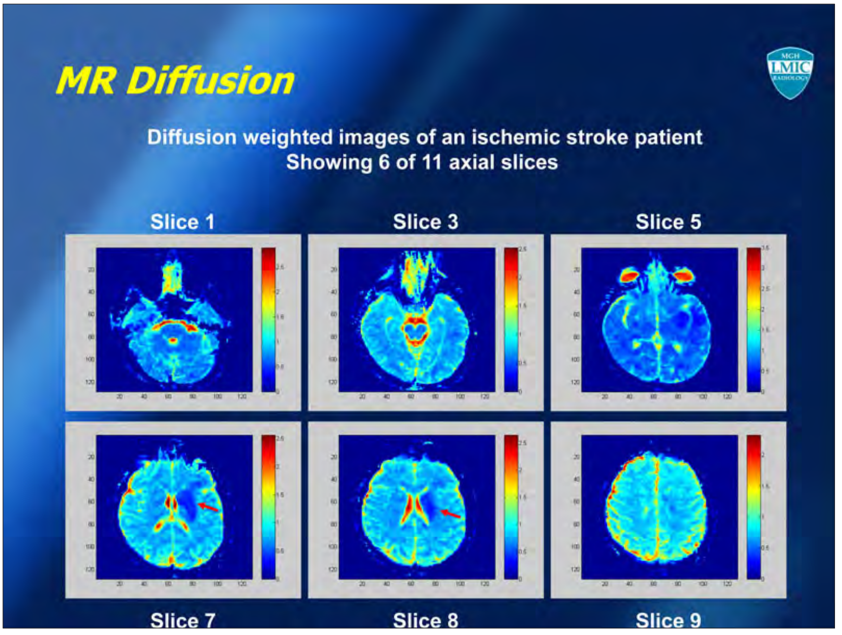

MGH LMIC RADIOLOGY
MR TRACTOGRAPHY

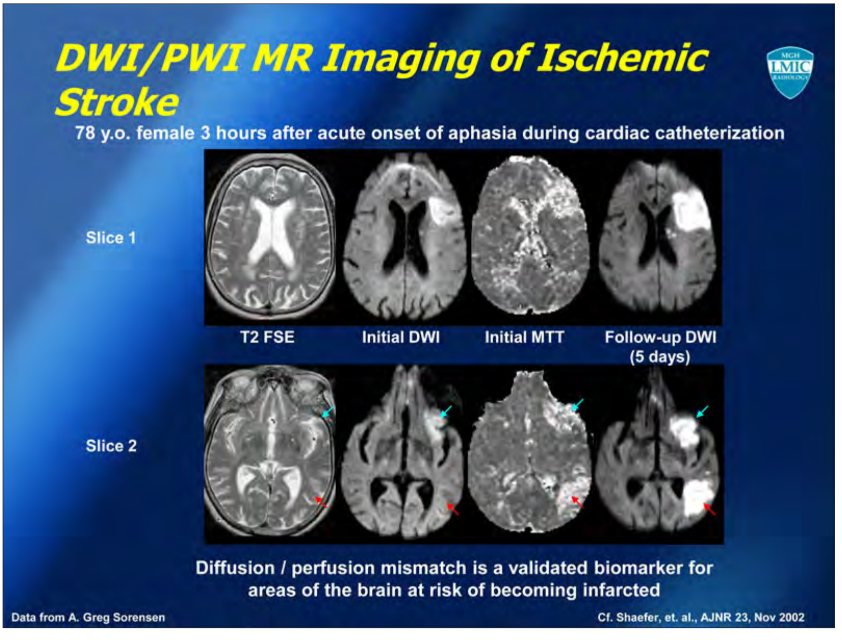

40 year old male with Hemangioblastoma
and von Hippel-Lindau disease
A. G. Sorensen, MGH
Pre Treatment
Post Treatment with anti-angiogenesis agent


A. G. Sorensen, MGH


LMIC
MR PERFUSION AND
DIFFUSION


MR Perfusion
LMIC
Perfusion weighted images (CBF) of an ischemic stroke patient
Showing 6 of 11 axial slices
Slice 1
Slice 3
Slice 5
Slice 7
Slice 8
Slice 9


MR Diffusion
Diffusion weighted images of an ischemic stroke patient
Showing 6 of 11 axial slices
Slice 1
Slice 3
Slice 5
Slice 7
Slice 8
Slice 9

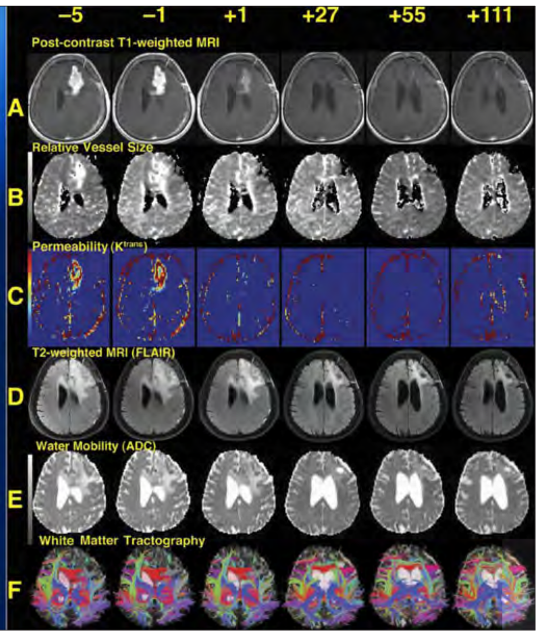

DWI/PWI MR Imaging of Ischemic Stroke
78 y.o. female 3 hours after acute onset of aphasia during cardiac catheterization
Slice 1
Slice 2
T2 FSE
Initial DWI
Initial MTT
Follow-up DWI (5 days)
Diffusion / perfusion mismatch is a validated biomarker for areas of the brain at risk of becoming infarcted
Data from A. Greg Sorensen
Cf. Shaefer, et. al., AJNR 23, Nov 2002

TUMOR PATHOPHYSIOLOGY

Vascular Normalization
- **AZD2171**

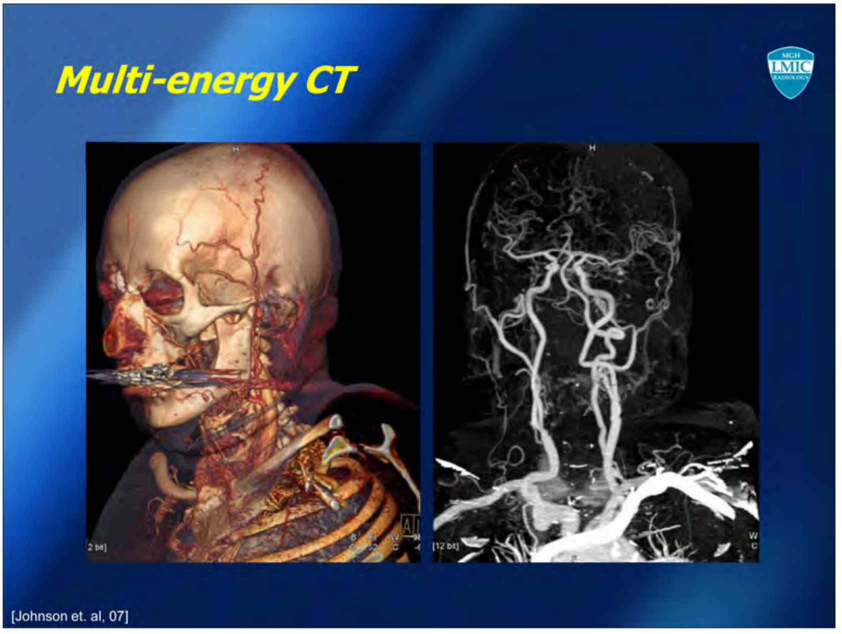
Hypothesized effects:
- **Smaller vessels**
- **Less permeability**
- **Less edema**
- **Decreased mass effect**

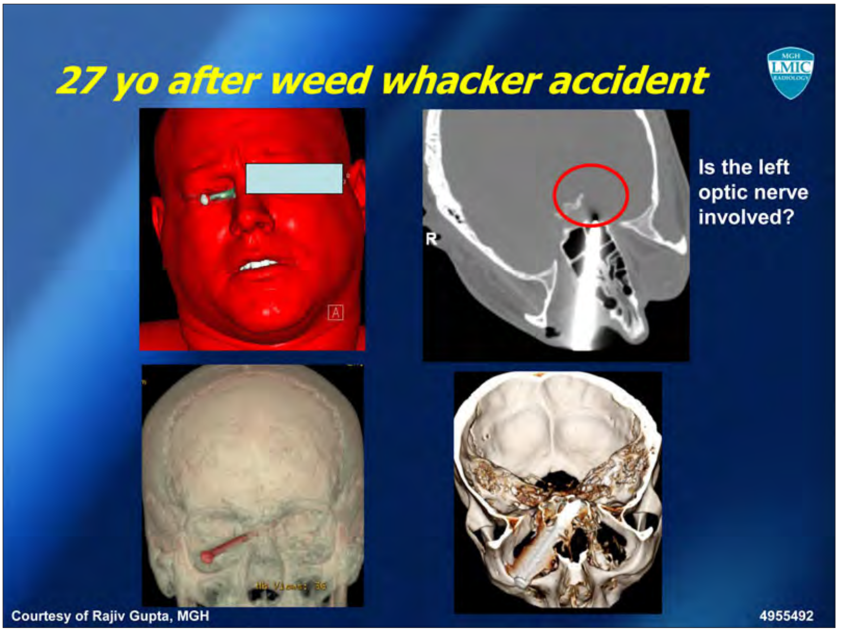
Bachelor, et al,
"AZD2171, a pan-VEGF receptor tyrosine kinase inhibitor, normalizes tumor vasculatorye and alleviates edema in glioblastoma patients"
Cancer Cell, 1/2007: 11, 83-95

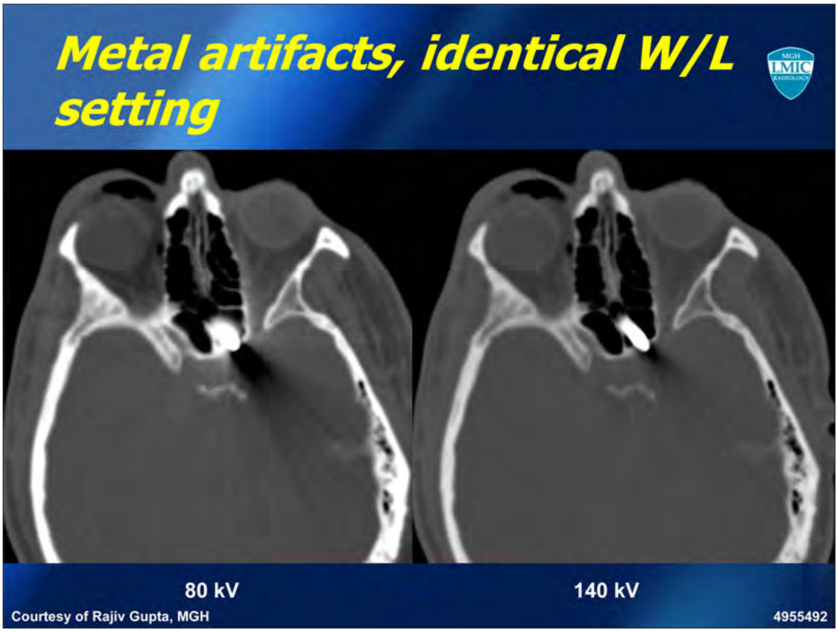


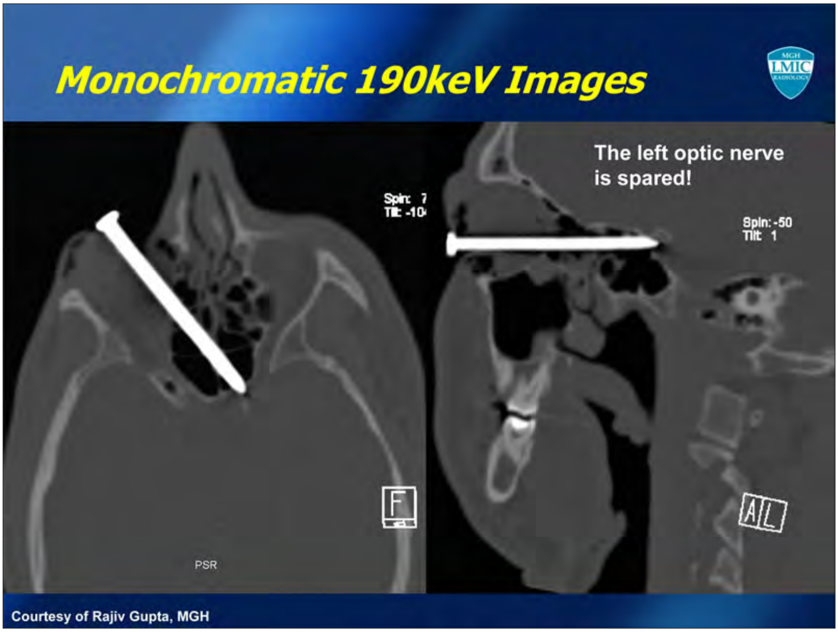
MULTI-SPECTRAL CT

Conventional Skull CT VR

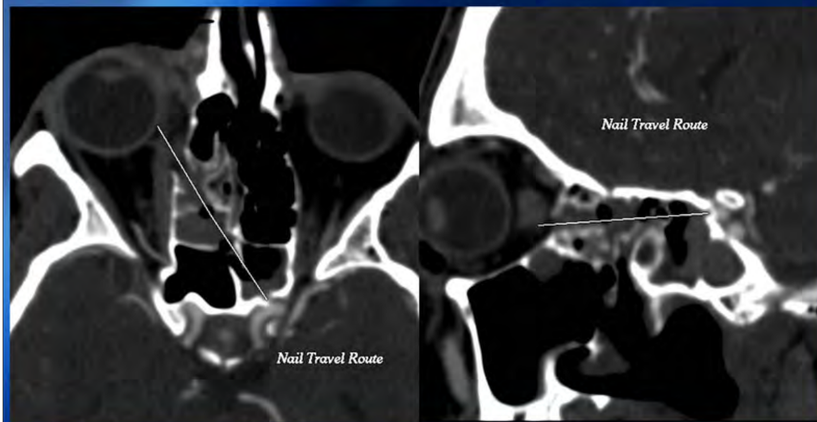

Multi-energy CT
[Johnson et. al, 07]


27 yo after weed whacker accident
Is the left optic nerve involved?
R
Courtesy of Rajiv Gupta, MGH
4955492


Metal artifacts, identical W/L setting
80 kV
140 kV
Courtesy of Rajiv Gupta, MGH
4955492

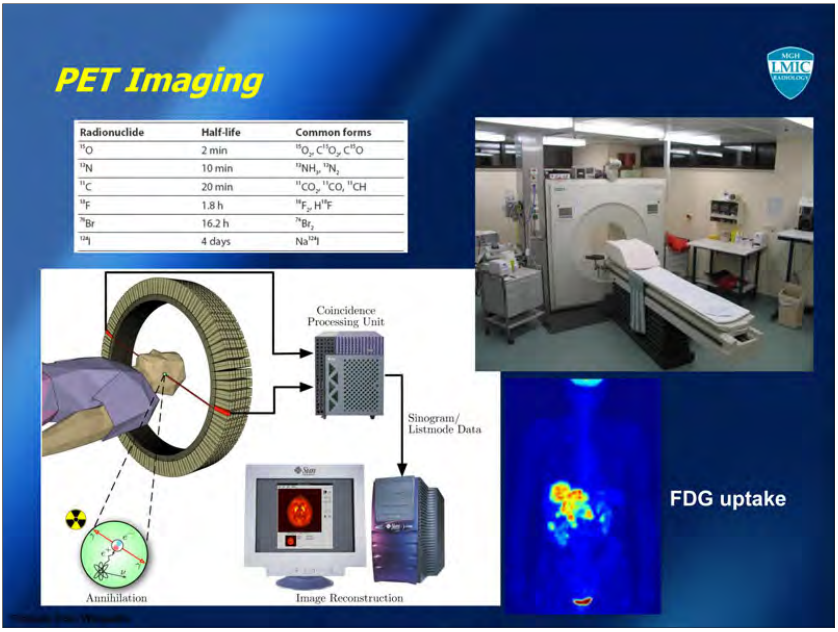

Monochromatic 190keV Images
The left optic nerve is spared!
Spin: -50
Tilt: 1
PSR
Courtesy of Rajiv Gupta, MGH

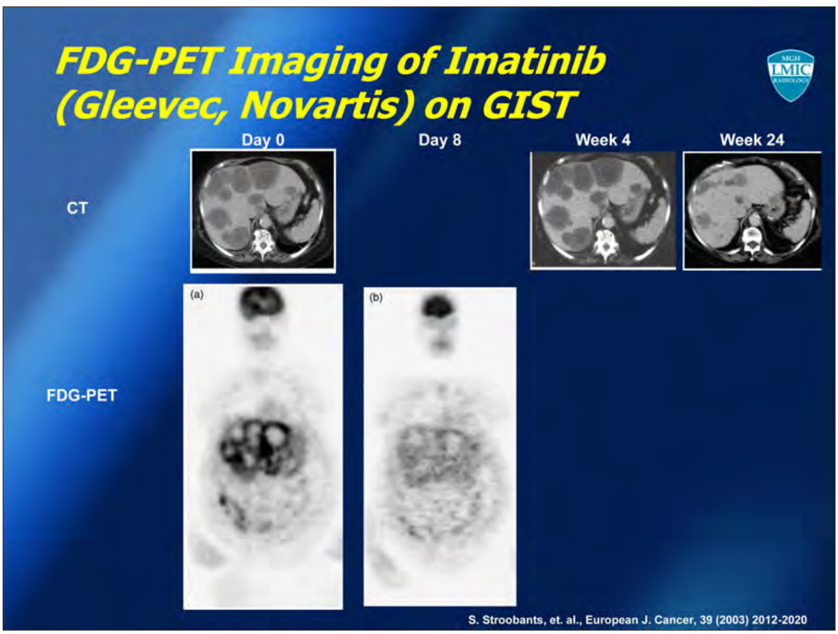
Post-Op CTA

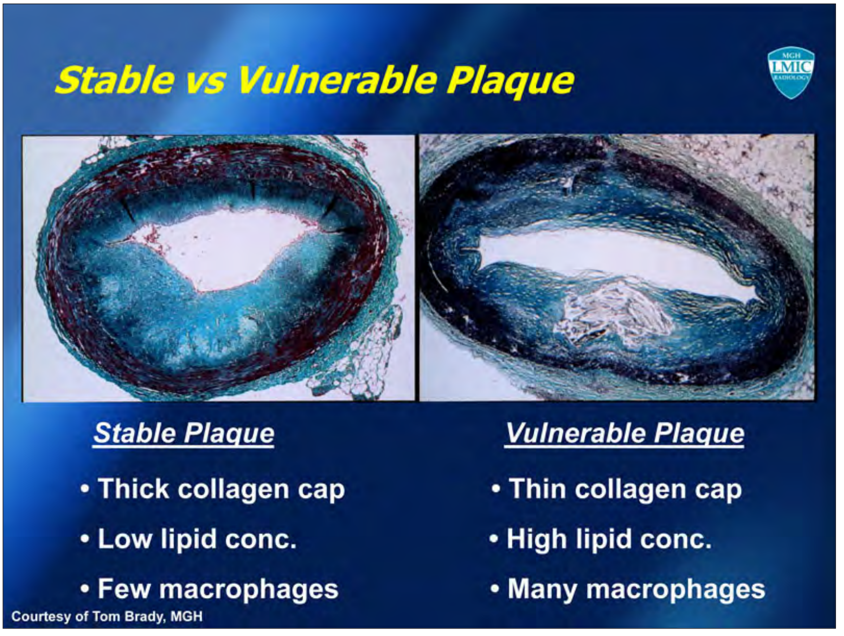


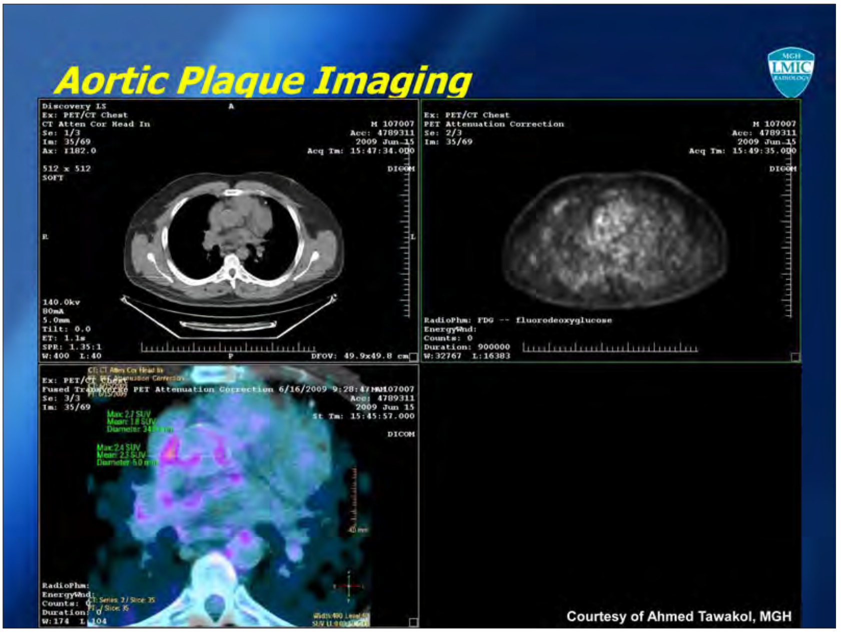
Courtesy of Rajiv Gupta, MGH

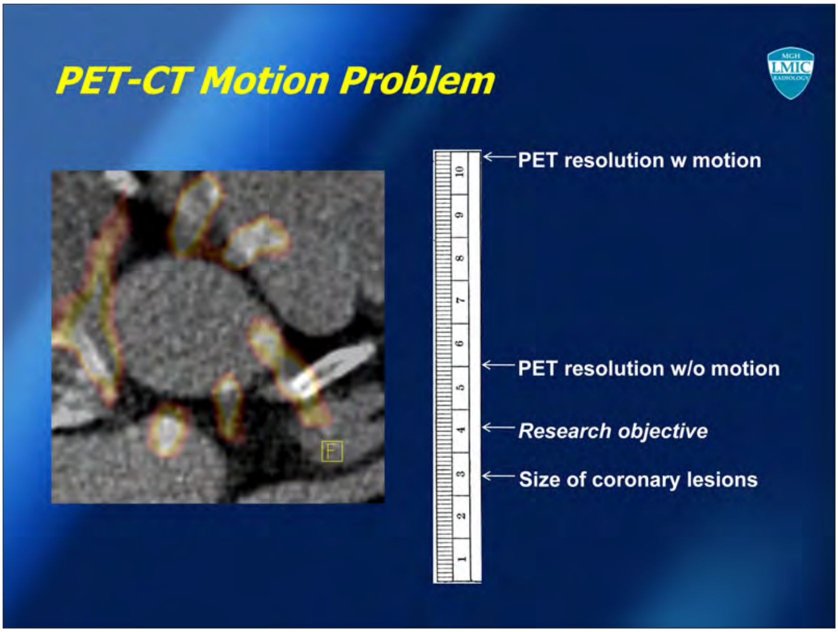
PET-CT
STRUCTURE + FUNCTION

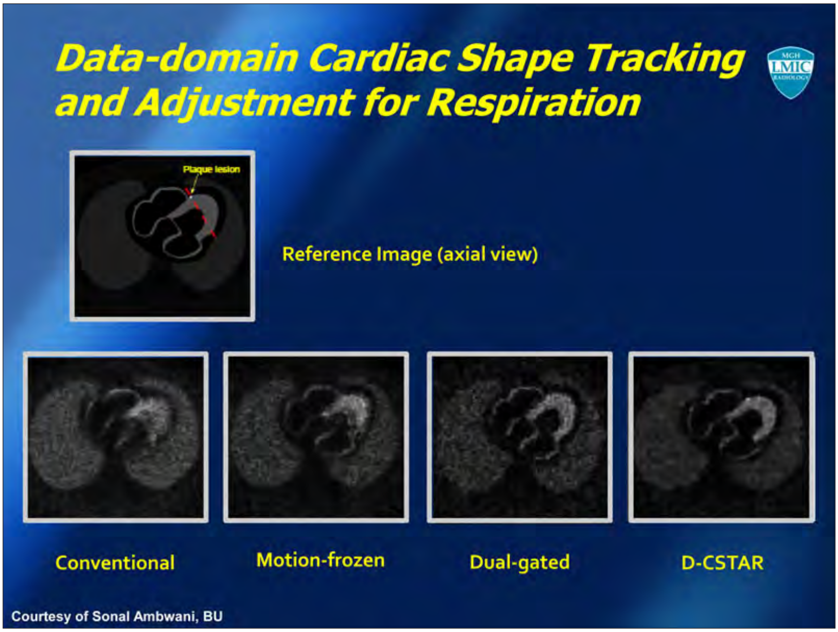

PET Imaging
Radionuclide | Half-life | Common forms
^{15}O | 2 min | $^{15}O_2$, $C^{15}O_2$, $C^{15}O$
^{13}N | 10 min | $^{13}NH_3$, $^{13}N_2$
^{11}C | 20 min | $^{11}CO_2$, ^{11}CO, ^{11}CH
^{18}F | 1.8 h | $^{18}F_2$, $H^{18}F$
^{76}Br | 16.2 h | $^{76}Br_2$
^{124}I | 4 days | $Na^{124}I$
Coincidence Processing Unit
Sinogram/ Listmode Data
Annihilation
Image Reconstruction
FDG uptake

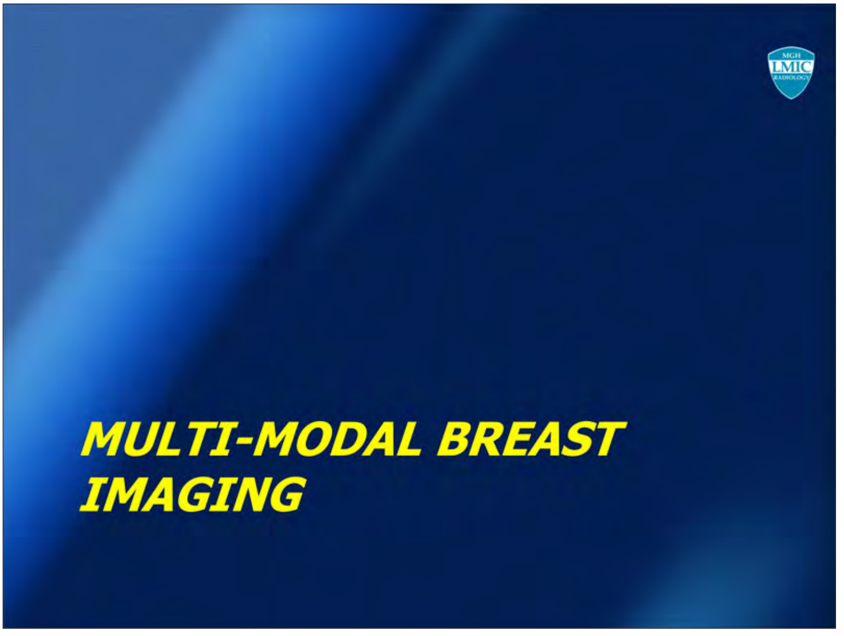

FDG-PET Imaging of Imatinib (Gleevec, Novartis) on GIST
Day 0
Day 8
Week 4
Week 24
CT
FDG-PET
(a)
(b)
S. Stroobants, et. al., European J. Cancer, 39 (2003) 2012-2020

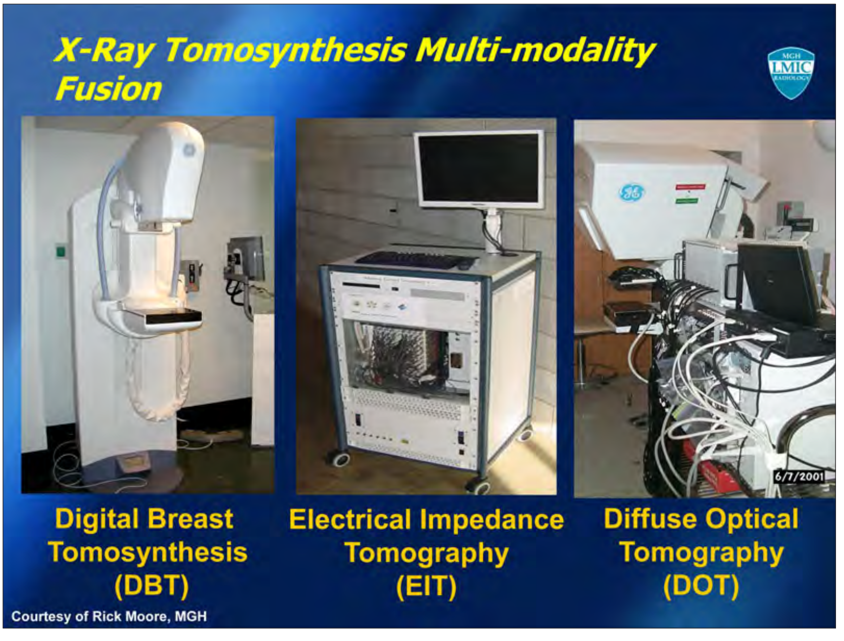

Stable vs Vulnerable Plaque
Stable Plaque
• Thick collagen cap
• Low lipid conc.
• Few macrophages
Vulnerable Plaque
• Thin collagen cap
• High lipid conc.
• Many macrophages
Courtesy of Tom Brady, MGH

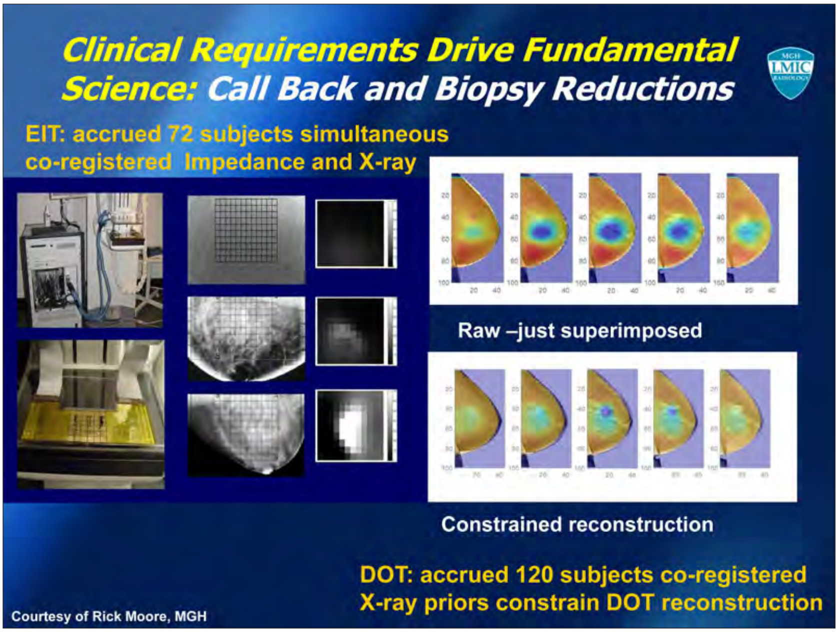

Aortic Plaque Imaging
Courtesy of Ahmed Tawakol, MGH


PET-CT Motion Problem
PET resolution w motion
PET resolution w/o motion
Research objective
Size of coronary lesions


Data-domain Cardiac Shape Tracking and Adjustment for Respiration
Plaque lesion
Reference Image (axial view)
Conventional
Motion-frozen
Dual-gated
D-CSTAR
Courtesy of Sonal Ambwani, BU

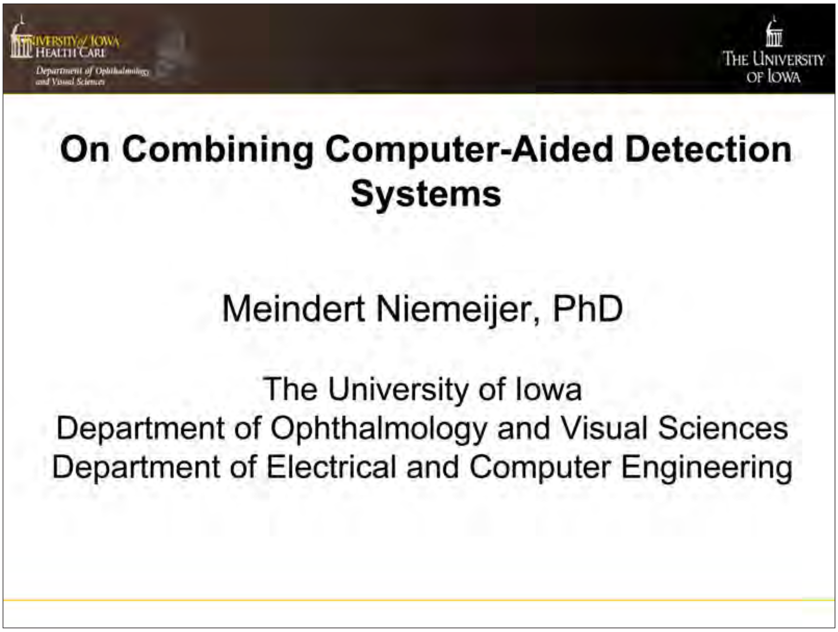

MULTI-MODAL BREAST IMAGING

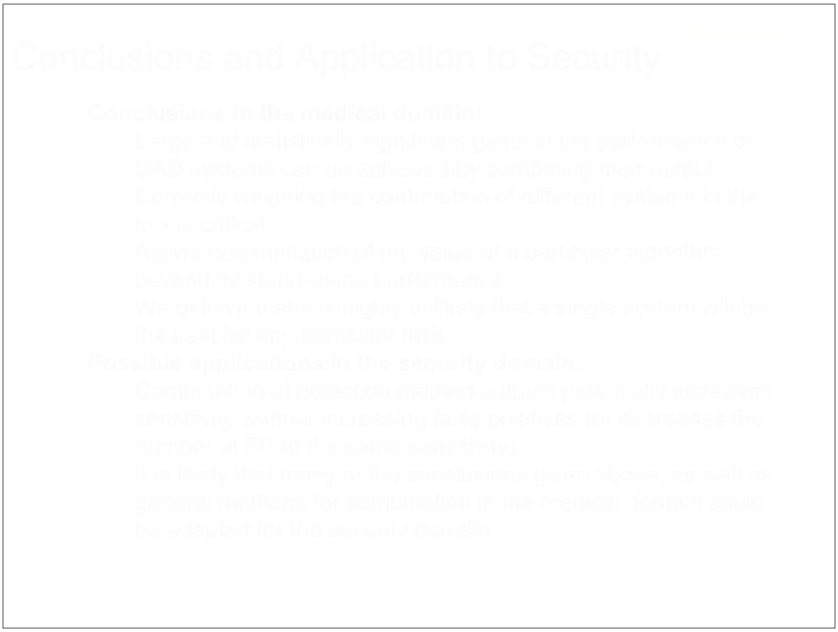

X-Ray Tomosynthesis Multi-modality Fusion
Digital Breast Tomosynthesis (DBT)
Electrical Impedance Tomography (EIT)
Diffuse Optical Tomography (DOT)
6/7/2001
Courtesy of Rick Moore, MGH


Clinical Requirements Drive Fundamental Science: Call Back and Biopsy Reductions
MGH LMIC RADIOLOGY
EIT: accrued 72 subjects simultaneous co-registered Impedance and X-ray
Raw –just superimposed
Constrained reconstruction
DOT: accrued 120 subjects co-registered X-ray priors constrain DOT reconstruction
Courtesy of Rick Moore, MGH


Summary
MGH LMIC RADIOLOGY
Sensor data fusion is commonplace in medical imaging
Used to answer very specific questions
Fusion improves the quality of our diagnoses and interventions
Considerable anecdotal evidence that fusion reduces cost
Numerous tools at the medical community's disposal - what are security domain's analogs?
Perspective changes
Dynamics over time
Use of exogenous contrast agent
Long imaging time with cooperative subjects
Ability to "personalize" imaging needs to the particular conditions of the patient
Open research community with suitable safeguards in place (IRB, HIPPA, anonymization)

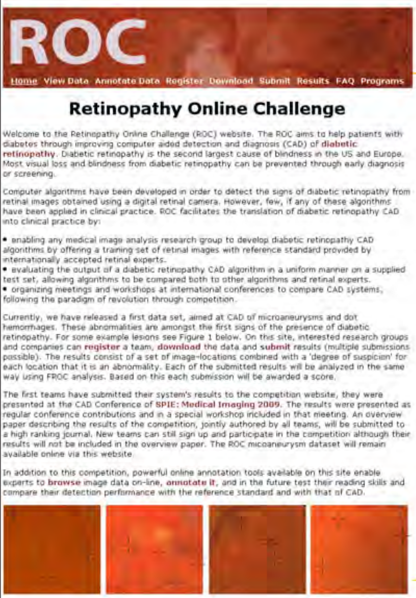
16.13 Meindert Niemeijer: Classifier fusion





Motivation

- Fusing of classifiers is common in pattern recognition
- "Fusing" of human experts is an accepted practice in medicine
- Double reading has been shown to increase screening performance for several applications
- Even combining medical specialists with technicians is beneficial
- Combination of independent CAD systems:
  - difficult to test, research groups and commercial vendors focus on single systems
  - if a single group designs multiple systems, are they really independent?
- We were able to conduct an interesting experiment due to our involvement in CAD competitions



ROC

Home View Data Annotate Data Register Download Submit Results FAQ Programs

Retinopathy Online Challenge

Welcome to the Retinopathy Online Challenge (ROC) website. The ROC aims to help patients with diabetes through improving computer aided detection and diagnosis (CAD) of **diabetic retinopathy**. Diabetic retinopathy is the second largest cause of blindness in the US and Europe. Most visual loss and blindness from diabetic retinopathy can be prevented through early diagnosis or screening.

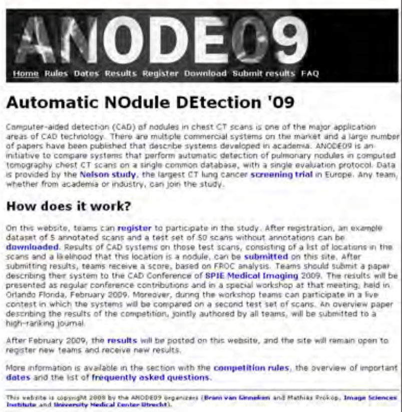
Computer algorithms have been developed in order to detect the signs of diabetic retinopathy from retinal images obtained using a digital retinal camera. However, few, if any of these algorithms have been applied in clinical practice. ROC facilitates the translation of diabetic retinopathy CAD into clinical practice by:

- enabling any medical image analysis research group to develop diabetic retinopathy CAD algorithms by offering a training set of retinal images with reference standard provided by internationally accepted retinal experts.
- evaluating the output of a diabetic retinopathy CAD algorithm in a uniform manner on a supplied test set, allowing algorithms to be compared both to other algorithms and retinal experts.
- organizing meetings and workshops at international conferences to compare CAD systems, following the paradigm of revolution through competition.

Currently, we have released a first data set, aimed at CAD of microaneurysms and dot hemorrhages. These abnormalities are amongst the first signs of the presence of diabetic retinopathy. For some example lesions see Figure 1 below. On this site, interested research groups and companies can **register** a team, **download** the data and **submit** results (multiple submissions possible). The results consist of a set of image-locations combined with a 'degree of suspicion' for each location that it is an abnormality. Each of the submitted results will be analyzed in the same way using FROC analysis. Based on this each submission will be awarded a score.

The first teams have submitted their system's results to the competition website, they were presented at the CAD Conference of **SPIE: Medical Imaging 2009**. The results were presented as regular conference contributions and in a special workshop included in that meeting. An overview paper describing the results of the competition, jointly authored by all teams, will be submitted to a high ranking journal. New teams can still sign up and participate in the competition although their results will not be included in the overview paper. The ROC micoaneurysm dataset will remain available online via this website.

In addition to this competition, powerful online annotation tools available on this site enable experts to **browse** image data on-line, **annotate it**, and in the future test their reading skills and compare their detection performance with the reference standard and with that of CAD.



ANODE09

Home Rules Dates Results Register Download Submit results FAQ

Automatic NOdule DEtection '09

Computer-aided detection (CAD) of nodules in chest CT scans is one of the major application areas of CAD technology. There are multiple commercial systems on the market and a large number of papers have been published that describe systems developed in academia. ANODE09 is an initiative to compare systems that perform automatic detection of pulmonary nodules in computed tomography chest CT scans on a single common database, with a single evaluation protocol. Data is provided by the **Nelson study**, the largest CT lung cancer **screening trial** in Europe. Any team, whether from academia or industry, can join the study.

How does it work?

On this website, teams can **register** to participate in the study. After registration, an example dataset of 5 annotated scans and a test set of 50 scans without annotations can be **downloaded**. Results of CAD systems on those test scans, consisting of a list of locations in the scans and a likelihood that this location is a nodule, can be **submitted** on this site. After submitting results, teams receive a score, based on FROC analysis. Teams should submit a paper describing their system to the CAD Conference of **SPIE Medical Imaging** 2009. The results will be presented as regular conference contributions and in a special workshop at that meeting, held in Orlando Florida, February 2009. Moreover, during the workshop teams can participate in a live contest in which the systems will be compared on a second test set of scans. An overview paper describing the results of the competition, jointly authored by all teams, will be submitted to a high-ranking journal.

After February 2009, the **results** will be posted on this website, and the site will remain open to register new teams and receive new results.

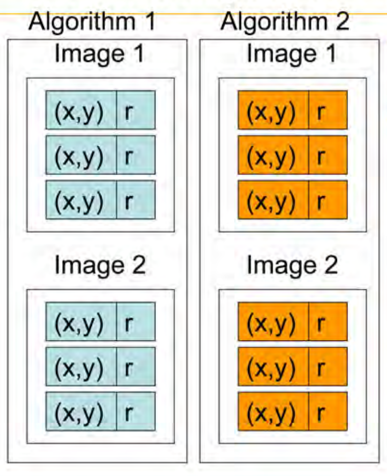
More information is available in the section with the **competition rules**, the overview of important **dates** and the list of **frequently asked questions**.

This website is copyright 2008 by the ANODE09 organizers (**Bram van Ginneken** and Mathias Prokop, **Image Sciences Institute** and **University Medical Center Utrecht**).

What are ROC09/ANODE09?

- Web-based comparison of:
  - ROC: CAD of microaneurysms in retinal images (2D)
  - ANODE: CAD of lung nodules in high resolution chest CT (3D)
- Training Data: 50 images with each lesion marked
- Testing Data: 50 images with withheld reference standard
- Teams can download data and upload locations (x,y,z) and ranking of findings produced by their CAD system
- All results are evaluated using the same protocol

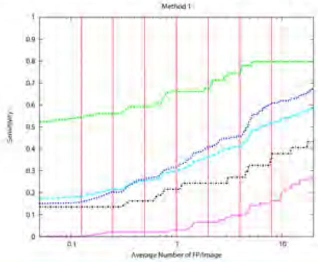
Competition Results



- Here r indicates the “degree of suspicion”
- Scaling of r is free as long as r is higher for more suspicious findings

FROC analysis

- Free-response Receiver-Operator Characteristic analysis plots the sensitivity against the average false positive rate
- To rank the methods, summarize the FROC curve
- Average the sensitivity at 0.125, 0.25, 0.5, 1.0, 2.0, 4.0 and 8.0 FP/image
- Competition Performance Metric (CPM)



Competitions are popular

Average nr. of false positives per image:	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	Final score
Method 1	0.19	0.22	0.25	0.30	0.36	0.41	0.52	0.32
Method 2	0.06	0.11	0.18	0.21	0.25	0.30	0.33	0.21
Method 3	0.17	0.23	0.32	0.38	0.43	0.53	0.60	0.38
Method 4	0.20	0.27	0.31	0.36	0.39	0.47	0.50	0.36
Method 5	0.18	0.22	0.26	0.29	0.35	0.40	0.47	0.31

- Both competitions have received a number of submissions and are still accepting new submissions

Possible fusion scenarios for CAD

- Scenario 1:
  - Only CAD markers are available
- Scenario 2:
  - CAD markers and degrees of suspicion available
- Scenario 3:
  - Same as 2 but with a small set of data with reference standard available
- Scenario 4:
  - Access to the internals of the system

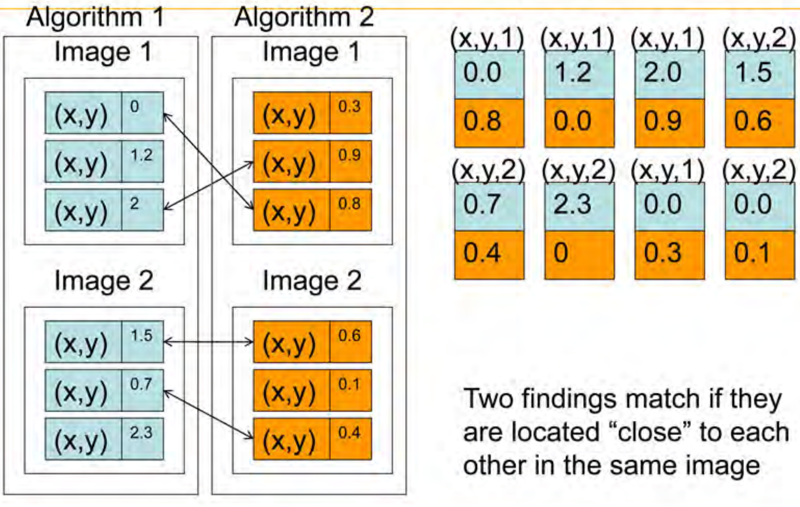
How to fuse these results?

- Step 1: Transform the degree of suspicion
- Step 2: Merge findings of different systems that indicate the same object
- Step 3: Estimate a new degree of suspicion for the merged findings using a fixed or supervised fusion rule

S1: Transform the degree of suspicion

- Scaling of degree of suspicion is unknown
- We tested two different approaches:
  - Linear Scaling (LIN):
  - Cumulative Scaling (CUMU):
- For CUMU we need a trainingset with reference standard
- In this dataset we count the number of TP and FP at each unique value of *r, T*
- Now a lookup table can be created mapping *r* -> *r'* for each *T* in the training set

S2: Matching of findings

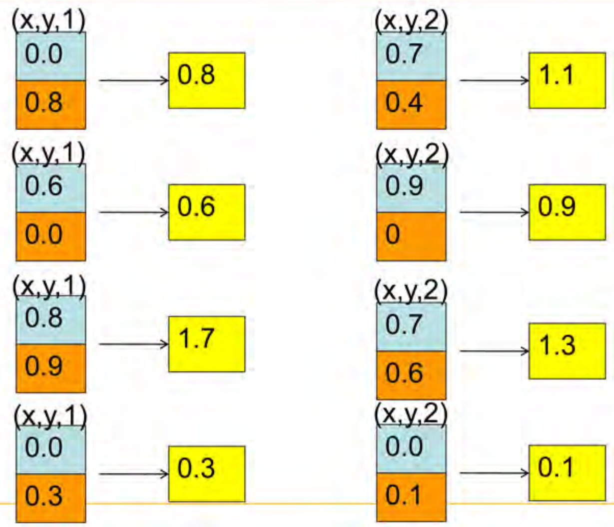


Two findings match if they are located "close" to each other in the same image

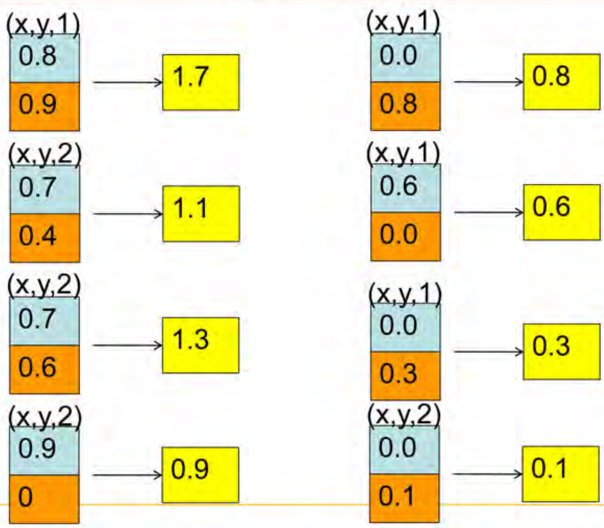
S3: Choosing a fusion method

- We examined three basic approaches to fusion:
  - Voting (Scenario 1):
    - Count the number of systems that detect a lesion (VR)
    - Limit the number of FP to 100 (VR2)
  - Static combination rules (Scenario 2):
    - Sum Rule (SR)
    - Product Rule (PR)
    - Maximum Rule (MR)
  - Supervised combination (Scenario 3):
    - Linear Discriminant Analysis (LDC)
    - Quadratic Discriminant Analysis (QDC)
    - Support Vector Machine (SVM)
- In supervised combination the vector of likelihoods is directly used as a feature vector

Fusion

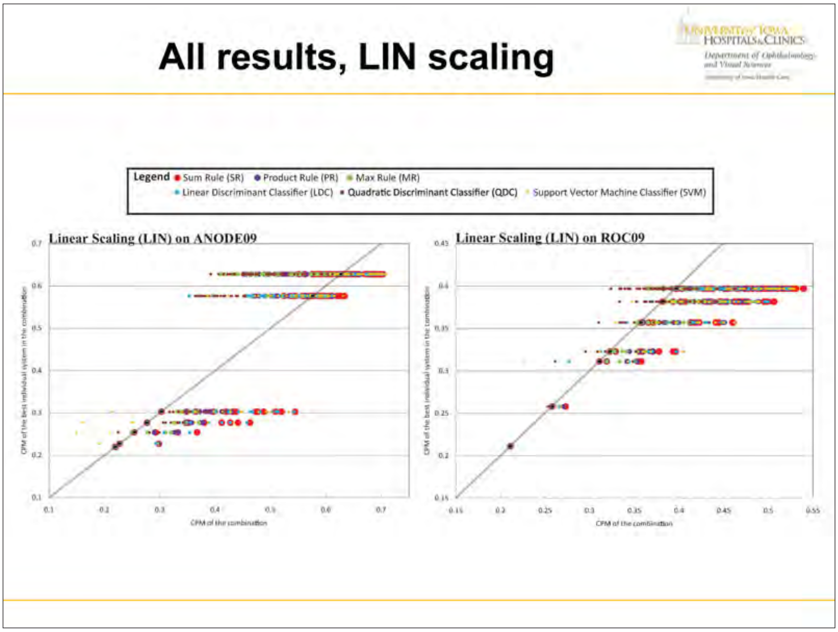


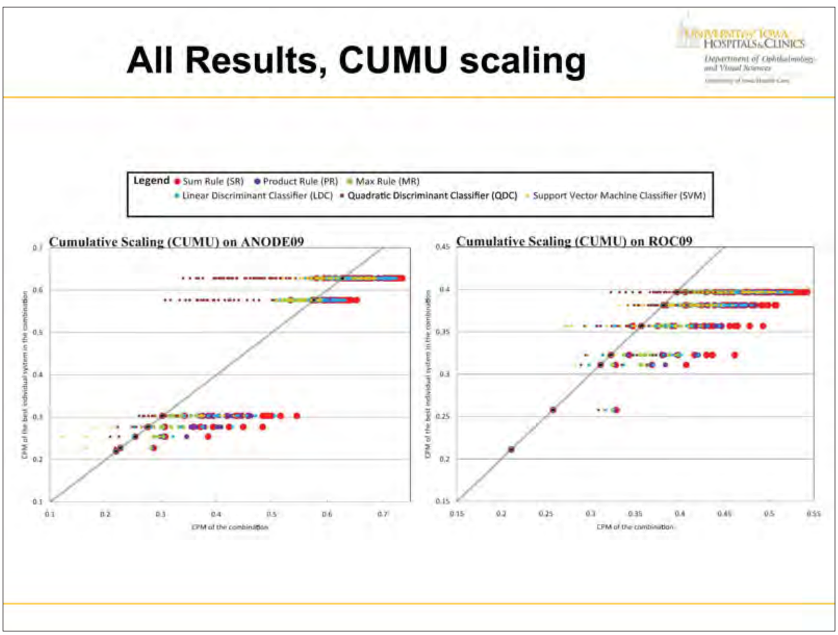
Global Ranking



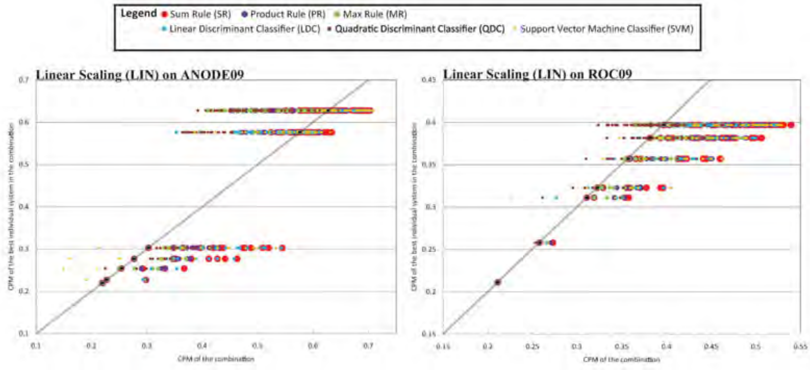
Experiments

- Both competitions featured 7 teams which can be combined in 127 ways each
- Testing all combinations of teams, scaling methods and fusion methods:
  - 127 x 2 x 6 = 1524
  - 127 x 2 = 254
  - 1778 performed experiments per competition
- Apply the CPM based evaluation method to the combined systems


All results, LIN scaling
Legend
Sum Rule (SR)
Product Rule (PR)
Max Rule (MR)
Linear Discriminant Classifier (LDC)
Quadratic Discriminant Classifier (QDC)
Support Vector Machine Classifier (SVM)
Linear Scaling (LIN) on ANODE09
CPM of the best individual system in the combination
CPM of the combination
Linear Scaling (LIN) on ROC09
CPM of the best individual system in the combination
CPM of the combination


All Results, CUMU scaling
Legend
Sum Rule (SR)
Product Rule (PR)
Max Rule (MR)
Linear Discriminant Classifier (LDC)
Quadratic Discriminant Classifier (QDC)
Support Vector Machine Classifier (SVM)
Cumulative Scaling (CUMU) on ANODE09
CPM of the best individual system in the combination
CPM of the combination
Cumulative Scaling (CUMU) on ROC09
CPM of the best individual system in the combination
CPM of the combination

All results, LIN scaling

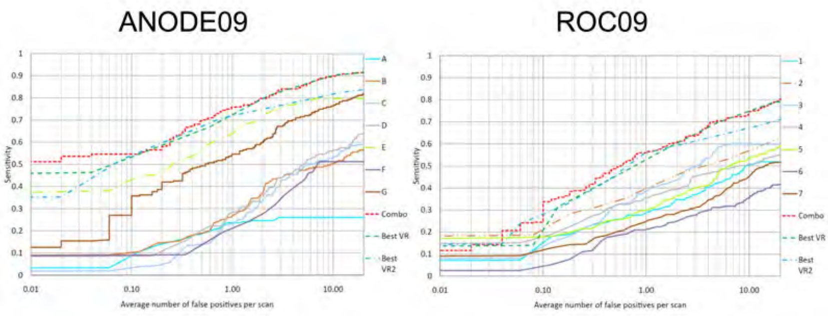


Specific Results

nr. of combined systems	ANODE09 best CPM	scaling method	combination method	combined systems	ROC09 best CPM	scaling method	combination method	combined systems
1	0.632	None	None	E	0.395	None	None	2
2	0.709	CUMU	PR	E,G	0.497	CUMU	SR	2,3
3	0.727	CUMU	SR	E,F,G	0.530	CUMU	SR	2,3,7
4	0.736	CUMU	SR	C,E,F,G	0.536	CUMU	SR	2,3,5,7
5	0.732	CUMU	SR	B,C,E,F,G	0.539	LIN	SR	2,3,4,5,7
6	0.730	CUMU	SR	A,B,C,E,F,G	0.540	CUMU	SR	1,2,3,5,6,7
7	0.725	CUMU	SR	A,B,C,D,E,F,G	0.543	CUMU	SR	1,2,3,4,5,6,7

combination method	ANODE09 best CPM	scaling method	combined systems	ROC09 best CPM	scaling method	combined systems
SR	0.736	CUMU	C,E,F,G	0.543	CUMU	1,2,3,4,5,6,7
PR	0.715	CUMU	E,F,G	0.523	LIN	2,3,4,5,7
MR	0.707	CUMU	E,G	0.492	CUMU	2,3
LDC	0.725	CUMU	B,C,D,E,F,G	0.526	CUMU	1,2,3,4,5,6,7
QDC	0.660	CUMU	E,G	0.499	CUMU	2,3,7
SVM	0.709	LIN	A,B,C,E,F,G	0.524	LIN	2,3,4,5,6,7
VR	0.696	None	B,C,D,E,F,G	0.515	None	1,2,3,4,5,6,7
VR2	0.670	None	A,B,C,D,E,F,G	0.494	None	1,2,3,4,5,6,7

Results



Results

- Performance difference between best single and combined system are statistically significant (p=0.01)
- Results make intuitive sense, it is unlikely that a single group will develop the "ultimate" algorithm
- Different algorithms have different strengths and weaknesses
- Combination, when done in the right way, often leads to a performance improvement
  - Diversity in approaches that are combined is very important

Questions

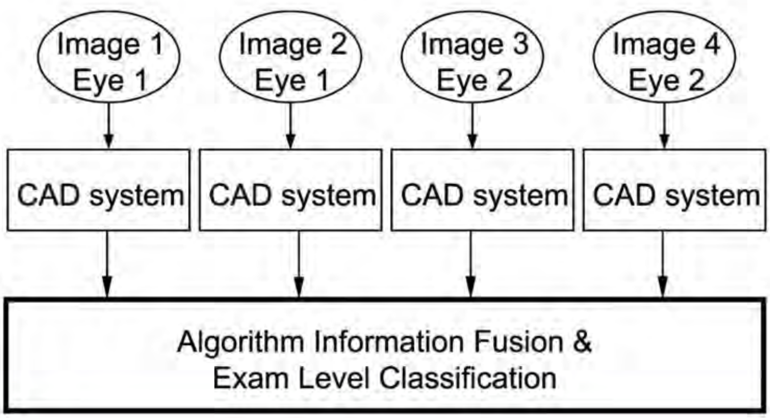
Signs of the presence of DR

- First: presence of red lesions.
- Second: presence of bright lesions.

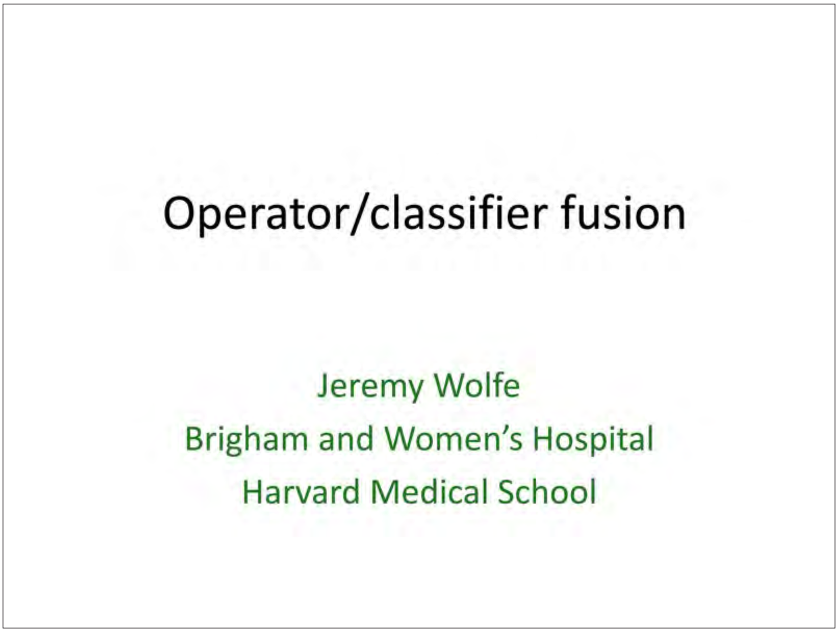
DR screening - background

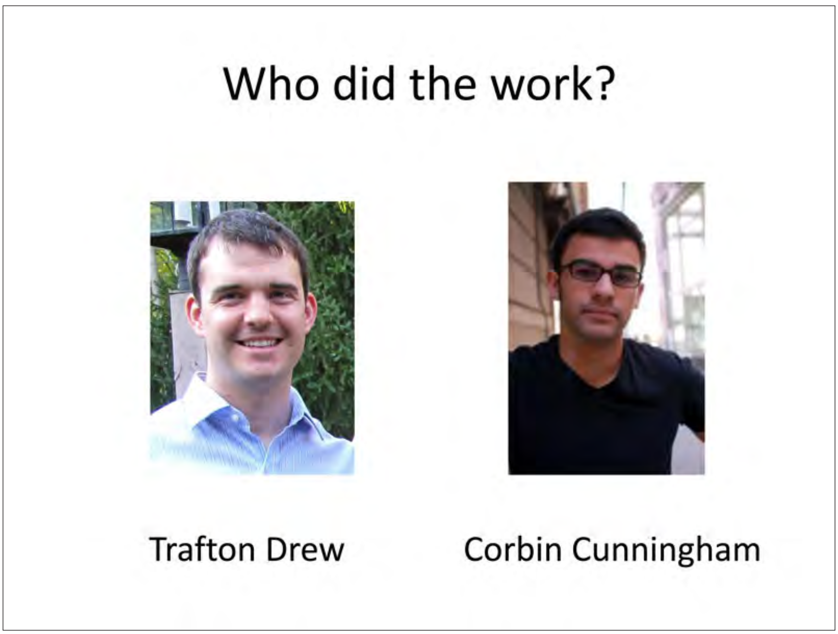
- Most of my work has been in the automated screening for diabetic retinopathy (DR)
- In DR screening programs only 2-5% of subjects are positive
- 4 images per subject are produced
- A set of detection algorithms are applied giving probabilistic output
- To generate a single output number we utilize supervised fusion algorithms

Structure



16.14 Jeremy Wolfe: Operator/classifier fusion





What does that title mean?

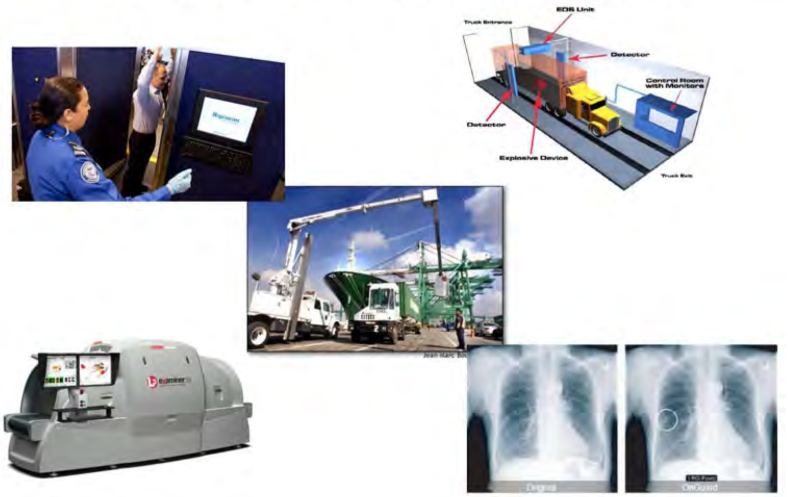
Conclusion: (Carl said I need a conclusion on this slide)

True fusion (says Mike Silevitch) is when Sensor A informs Sensor B.

I am going to remind you that Sensor Z is the human observer.

E.g. XDi – how can I, the observer, use the several thousand sugar cube voxels full of spectra.

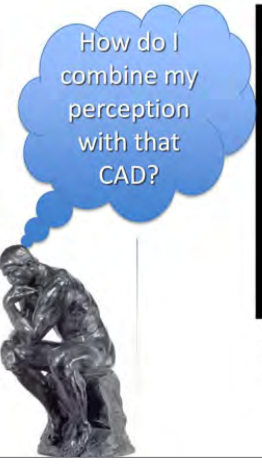
The basic issue:
A human has to use these tools

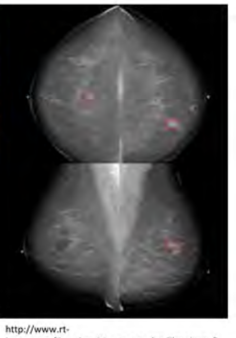


Sensor fusion: The usual idea

(Northrop Grumman)

Human / CAD fusion





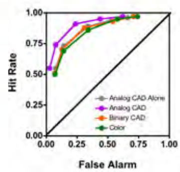
http://www.rt-image.com/Examine_Mammography_The_Case_for_CAD_Examining_the_technology_and_its_implicatio/content=9504J05C4856869640769A72448080441

Today's Talk
Two problems and an opportunity

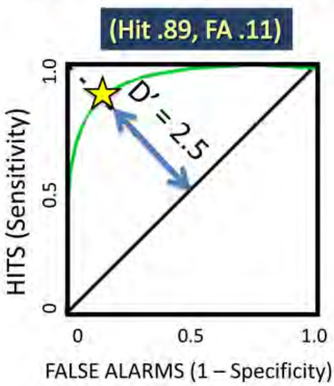
1. A Math Problem

2. An old joke

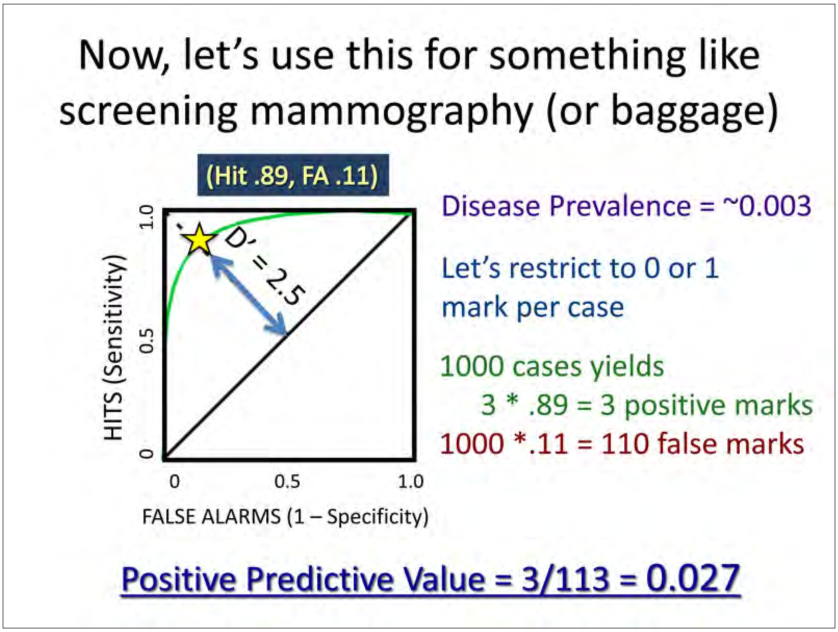
3. The uses of analog CAD

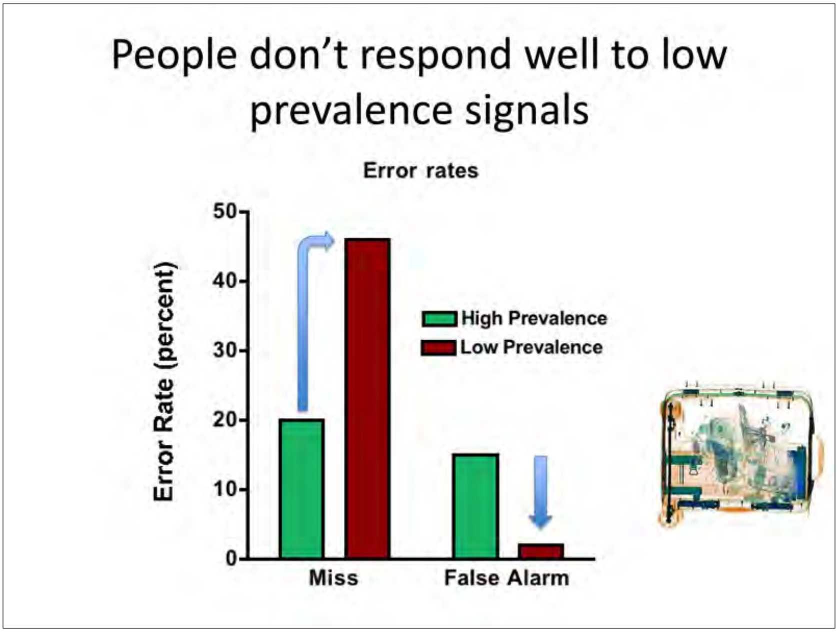


The Math Problem:
Suppose you have a decent CAD system



That isn't bad

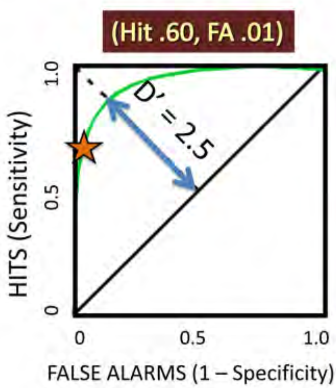

Now, let's use this for something like screening mammography (or baggage)
(Hit .89, FA .11)
D' = 2.5
HITS (Sensitivity)
0
0.5
1.0
0
0.5
1.0
FALSE ALARMS (1 – Specificity)
Disease Prevalence = ~0.003
Let's restrict to 0 or 1 mark per case
1000 cases yields
3 * .89 = 3 positive marks
1000 *.11 = 110 false marks
Positive Predictive Value = 3/113 = 0.027


People don't respond well to low prevalence signals
Error rates
Error Rate (percent)
50
40
30
20
10
0
Miss
False Alarm
High Prevalence
Low Prevalence

This isn't *really* a math problem.

The real problem is that, if a signal rarely designates a target, you aren't that interested in the signal.

You could move the CAD criterion



1000 cases yields
3 * .6 < 2 positive marks
1000 *.01= 10 false marks

PPV = 2/12= 0.17
But your are missing 40% of the targets

And Bob Nishikawa has data suggesting that radiologists won't trust a CAD that doesn't find everything that they find

Summary

The math and the human search engine work against you when targets are rare.

Part 2: An old joke

A drunk was crawling around on the street under the street light.

Cop: What are you doing?

Drunk: I dropped my car keys and I'm looking for them.

Cop: Where did you drop them?

Drunk: Half a block down the street.

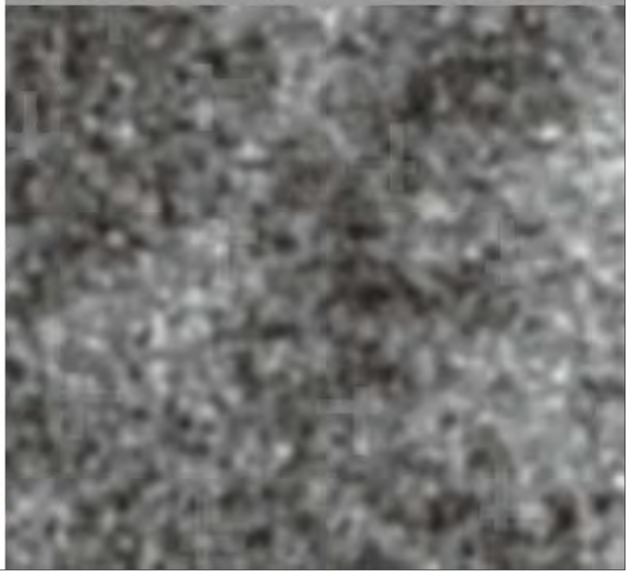
Cop: What are you doing looking for them here?

Drunk: "The light is better here"

What does this have to do with the topic at hand…?

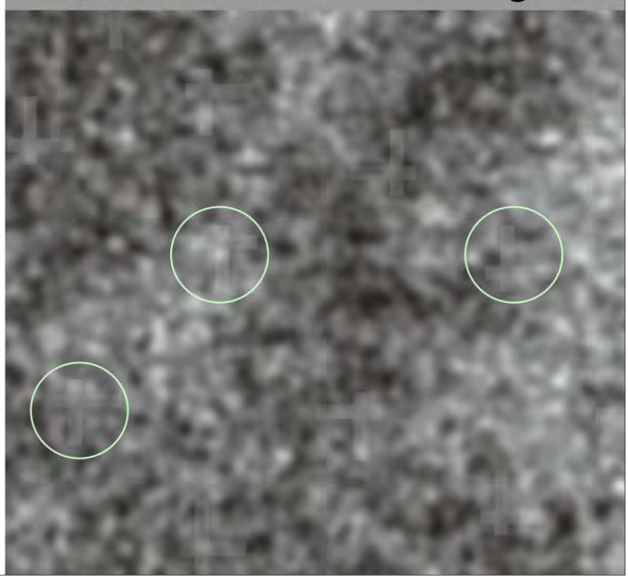
An experiment

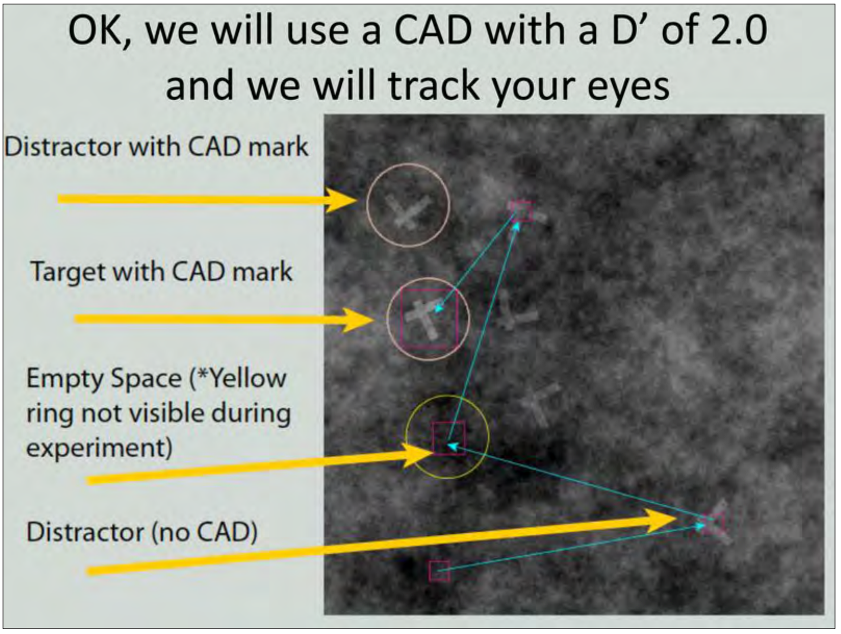
Look for the letter “T” among “L”s

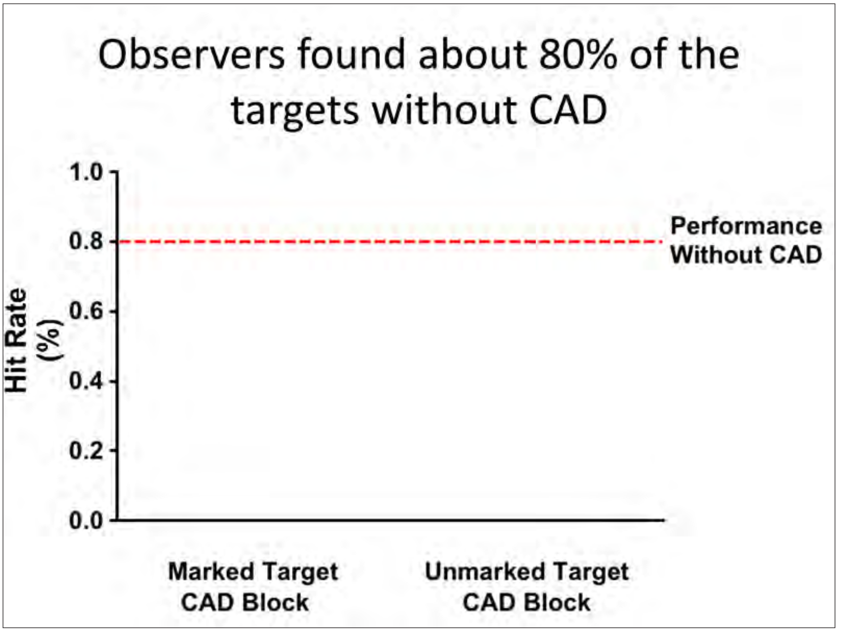


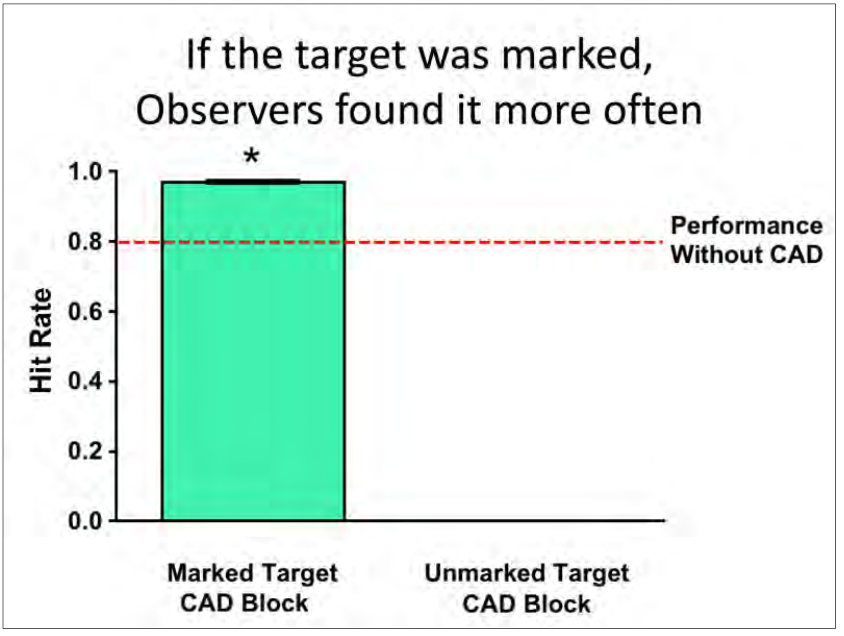
Need a little help?

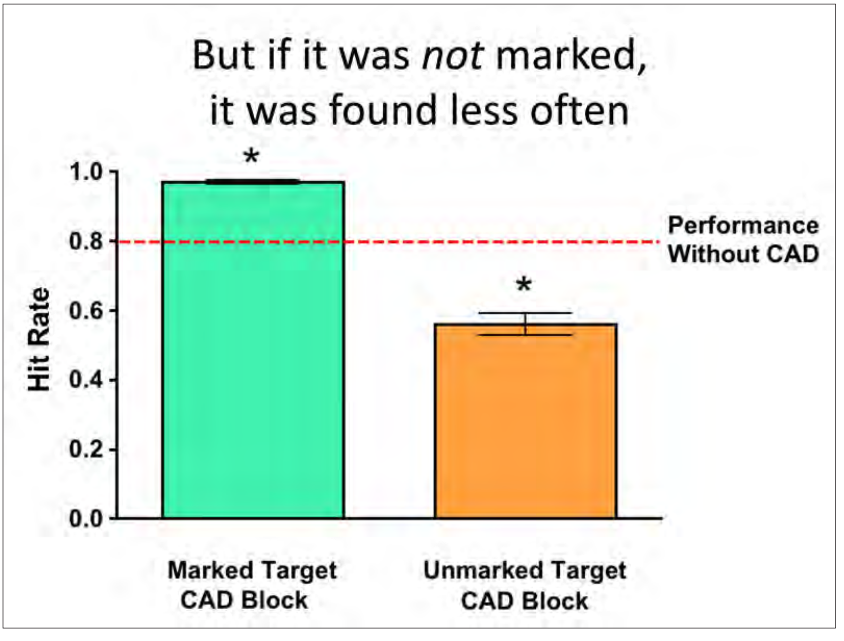
Look for the letter “T” among “L”s

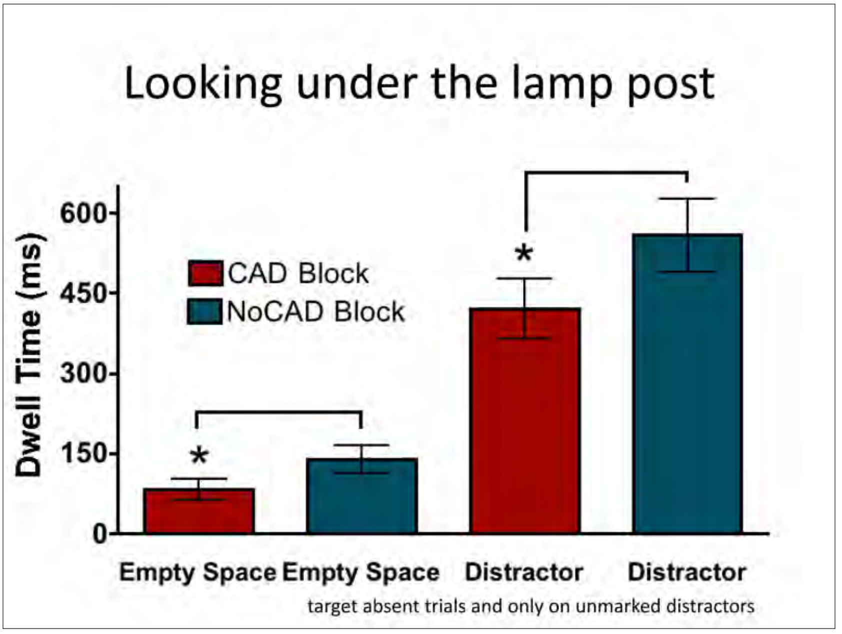



OK, we will use a CAD with a D' of 2.0 and we will track your eyes
Distractor with CAD mark
Target with CAD mark
Empty Space (*Yellow ring not visible during experiment)
Distractor (no CAD)

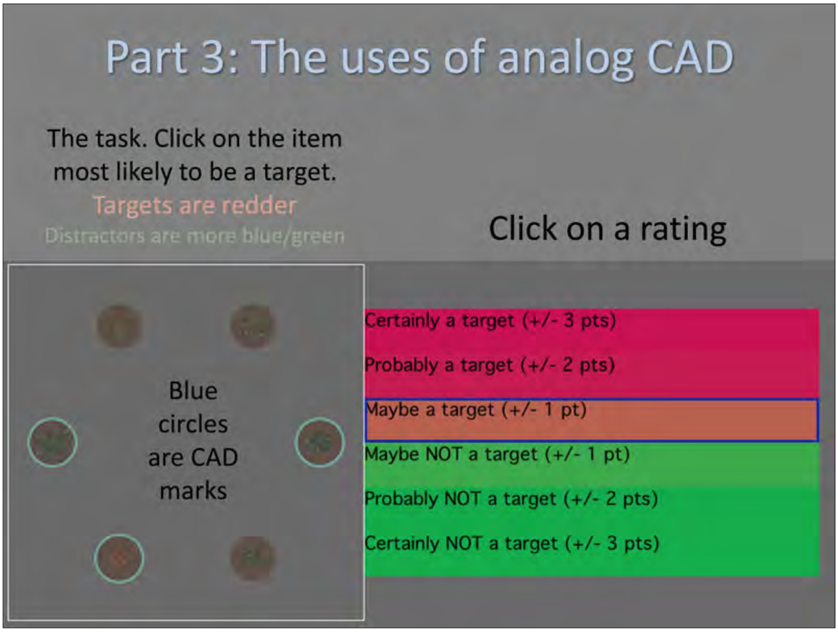

Observers found about 80% of the targets without CAD
Hit Rate (%)
1.0
0.8
0.6
0.4
0.2
0.0
Performance Without CAD
Marked Target CAD Block
Unmarked Target CAD Block

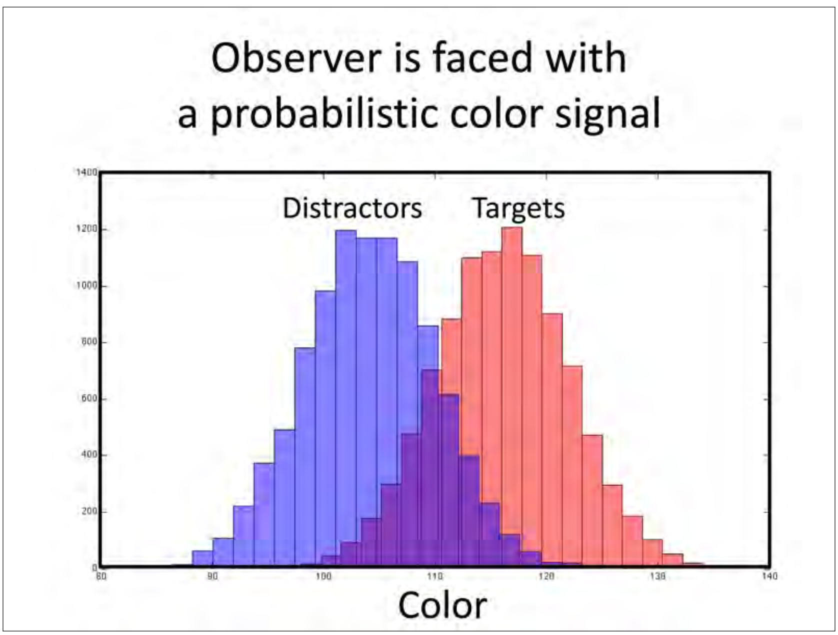

If the target was marked,
Observers found it more often
*
1.0
0.8
0.6
0.4
0.2
0.0
Hit Rate
Performance
Without CAD
Marked Target
CAD Block
Unmarked Target
CAD Block

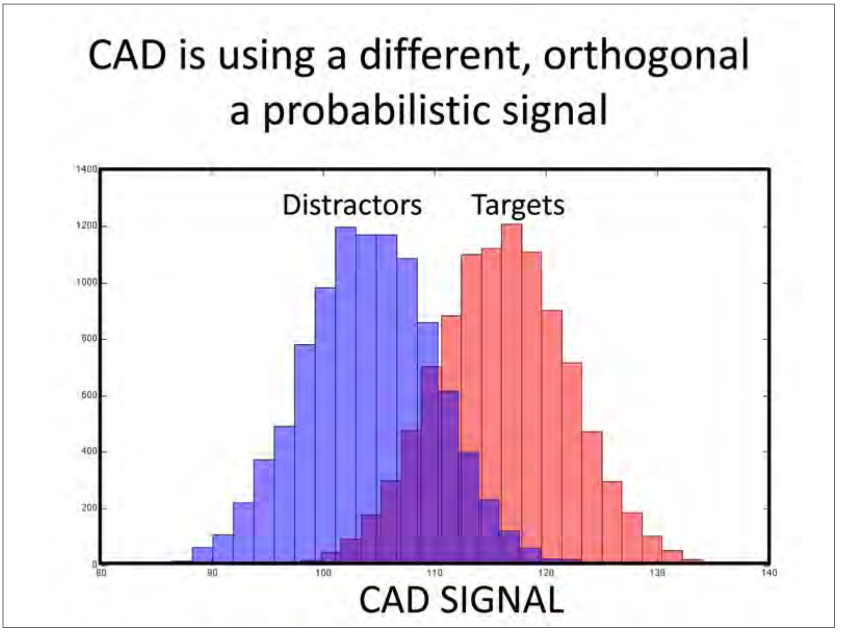

But if it was *not* marked,
it was found less often
*
*
1.0
0.8
0.6
0.4
0.2
0.0
Hit Rate
Performance
Without CAD
Marked Target
CAD Block
Unmarked Target
CAD Block

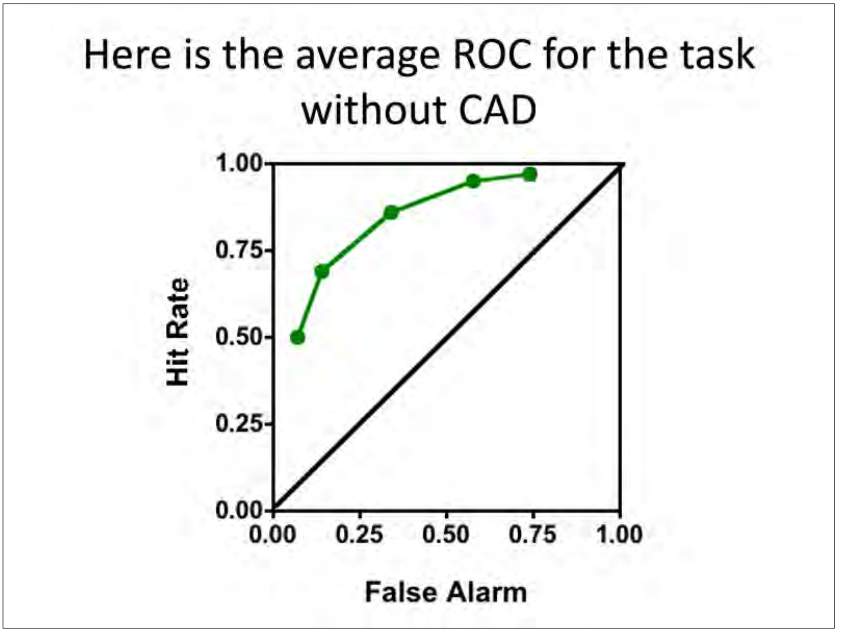


Observers may not believe the marks (the math problem) but they will look at them at the expense of other parts of the image

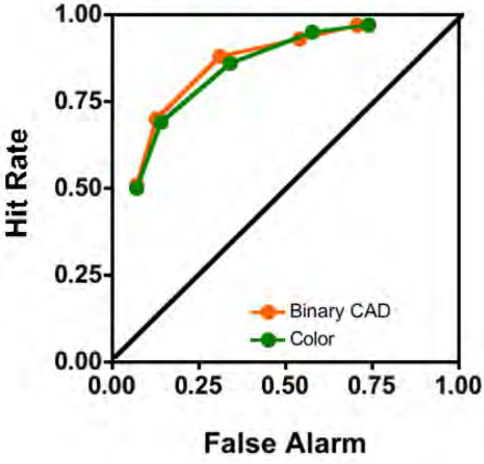

Part 3: The uses of analog CAD
The task. Click on the item most likely to be a target.
Targets are redder
Distractors are more blue/green
Click on a rating
Blue circles are CAD marks
Certainly a target (+/- 3 pts)
Probably a target (+/- 2 pts)
Maybe a target (+/- 1 pt)
Maybe NOT a target (+/- 1 pt)
Probably NOT a target (+/- 2 pts)
Certainly NOT a target (+/- 3 pts)


Observer is faced with a probabilistic color signal
Distractors
Targets
1400
1200
1000
800
600
400
200
0
80
90
100
110
120
130
140
Color


CAD is using a different, orthogonal
a probabilistic signal
Distractors
Targets
1400
1200
1000
800
600
400
200
0
80
90
100
110
120
130
140
CAD SIGNAL


Here is the average ROC for the task
without CAD
1.00
0.75
0.50
0.25
0.00
Hit Rate
0.00
0.25
0.50
0.75
1.00
False Alarm

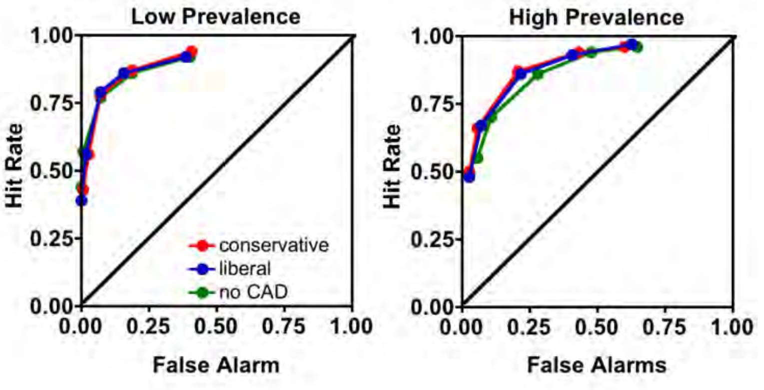
Binary CAD doesn't do much good in this case



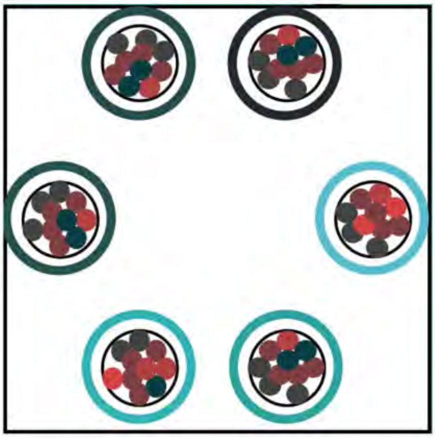
Same absence of much CAD benefit

at low or high target prevalence

and with liberal or conservative CAD threshold



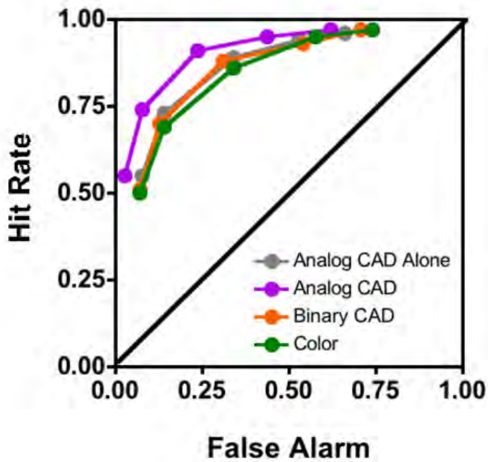
Let's try *Analog* CAD



Every item gets a CAD marking

Color indicates CAD's confidence from LOW to HIGH

Analog CAD is more effective



And this would bring us back to sensor fusion

Visual signal | Fused imagery | Analog CAD

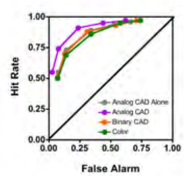
Analog CAD would be another visual stimulus, rather than being “advice”

In summary: Humans are the end users

1. A Math Problem: They don’t like signals with low predictive value

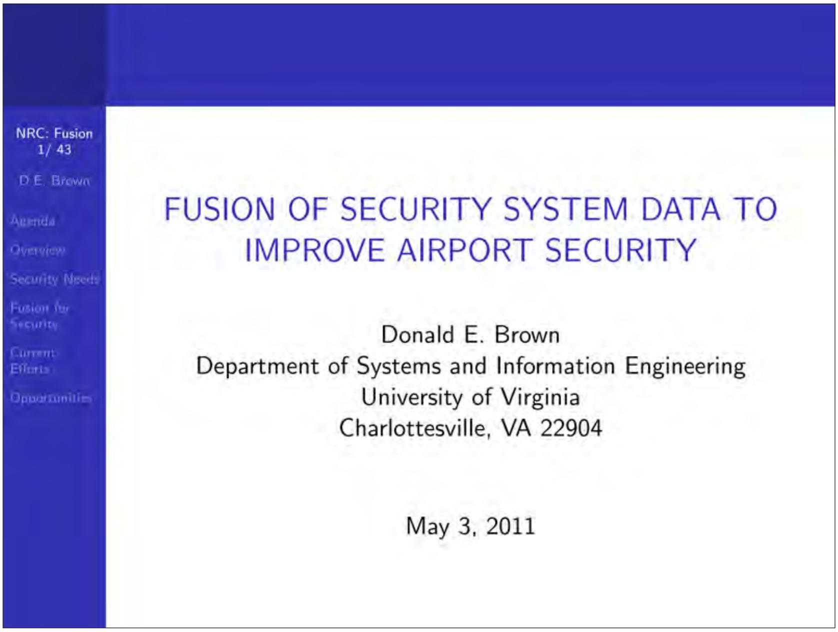
2. An old joke: Attention directed toward something may be attention drawn away from something else.

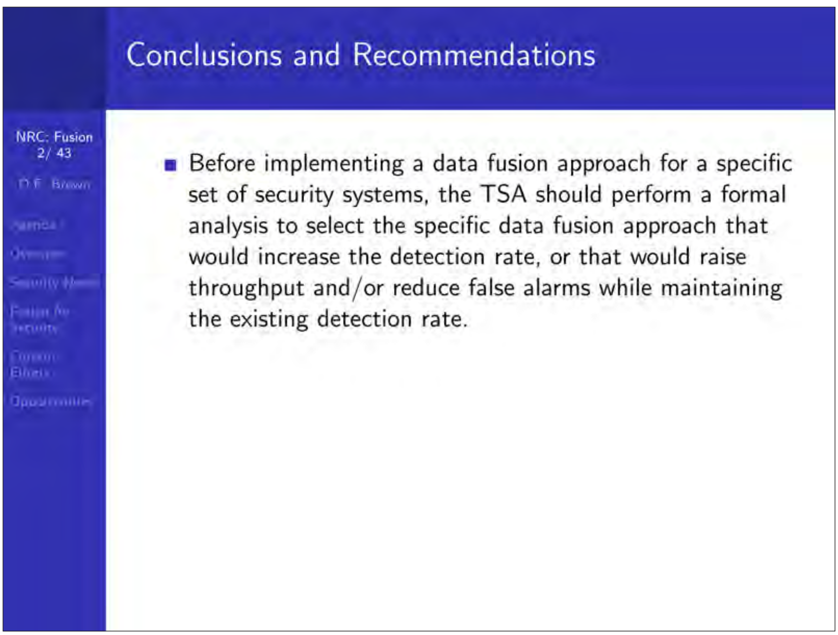
3. Analog CAD signals might be useful.



Thanks

16.15 Donald Brown: National Academy of Sciences study on fusion





Conclusions and Recommendations

NRC: Fusion
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- Before implementing a data fusion approach for a specific set of security systems, the TSA should perform a formal analysis to select the specific data fusion approach that would increase the detection rate, or that would raise throughput and/or reduce false alarms while maintaining the existing detection rate.
- The TSA should establish a systems approach to fusion implementation and operation.

Conclusions and Recommendations

NRC: Fusion
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- Before implementing a data fusion approach for a specific set of security systems, the TSA should perform a formal analysis to select the specific data fusion approach that would increase the detection rate, or that would raise throughput and/or reduce false alarms while maintaining the existing detection rate.
- The TSA should establish a systems approach to fusion implementation and operation.
- The TSA should implement any data fusion systems through a series of staged deployments at an operational testbed as designated by the TSA and/or at selected airports. The experience from these early staging events can then be incorporated and used in the data fusion systems rolled out in later implementations.

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D.E. Brown

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5. Opportunities for Data Fusion

NRC Study on Air Transportation Security

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Overview

- **Overall Study Objective:** The Committee on Assessment of Security Technologies for Transportation was appointed by the National Research Council (NRC) in response to a request from the Transportation Security Administration (TSA) for a study of technologies to protect the nations air transportation system from terrorist attacks.

NRC Study on Air Transportation Security

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NRC Study on Air Transportation Security

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  - Assessment of Millimeter-Wave and Terahertz Technology for Detection and Identification of Concealed Explosives and Weapons

NRC Study Committee Members

- JAMES F. OBRYON, Chair, The OBryon Group
- SANDRA L. HYLAND, Vice Chair, Tokyo Electron Technology Center, America
- CHERYL A. BITNER, Pioneer Unmanned Aerial vehicles, Inc.
- DONALD E. BROWN, University of Virginia
- JOHN B. DALY,1 Consultant, Arlington, Virginia
- COLIN G. DRURY, State University of New York, Buffalo
- PATRICK GRIFFIN, Sandia National Laboratories
- HARRY E. MARTZ, JR., Lawrence Livermore National Laboratory
- RICHARD McGEE, Army Research Laboratory, Aberdeen Proving Ground (retired)
- RICHARD L. ROWE, SafeView (retired)
- H. BRUCE WALLACE, MMW Concepts LLC

Fusion Subcommittee Committee Members

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- CHERYL A. BITNER, Pioneer Unmanned Aerial vehicles, Inc.
- DONALD E. BROWN, Chair, University of Virginia
- COLIN G. DRURY, State University of New York, Buffalo

Fusion Subcommittee Support Members

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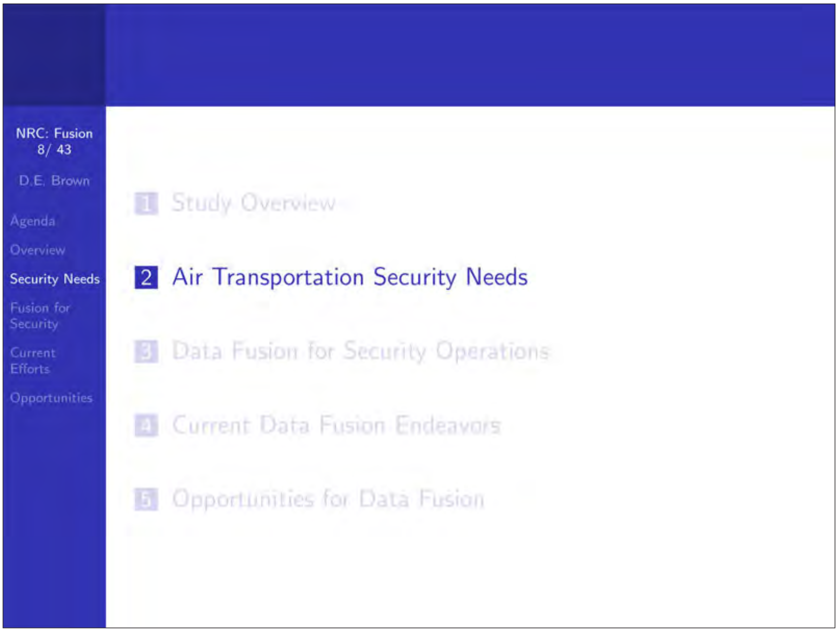
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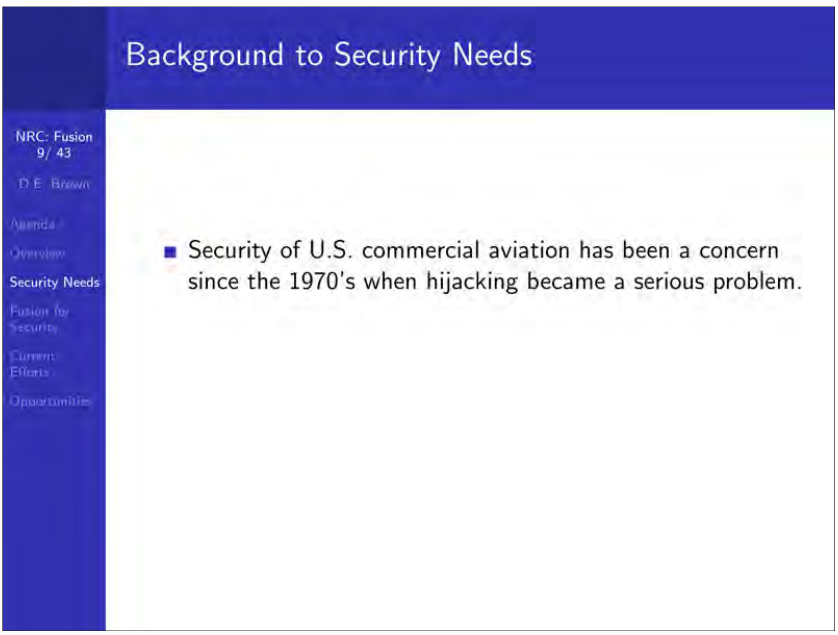
Background to Security Needs
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Security of U.S. commercial aviation has been a concern since the 1970's when hijacking became a serious problem.

Background to Security Needs

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Security Needs

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Background to Security Needs

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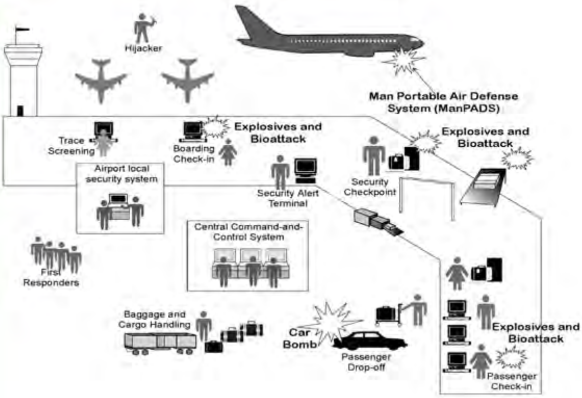
Security Needs

- Security of U.S. commercial aviation has been a concern since the 1970's when hijacking became a serious problem.
- The attacks of 9/11/2001 highlighted the ability of terrorists to exploit security weaknesses.
- Providing daily security for hundreds of commercial airports, tens of thousands of flights, and millions of passengers is a daunting task.

Multiple Points of Vulnerability



Shortcomings of Existing Systems

- More than 1,100 bulk explosive detection systems (EDSs) and 6,000 explosive trace detection (ETD) systems have been deployed in the 438 commercial airports that service the United States.

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Shortcomings of Existing Systems

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Security Needs

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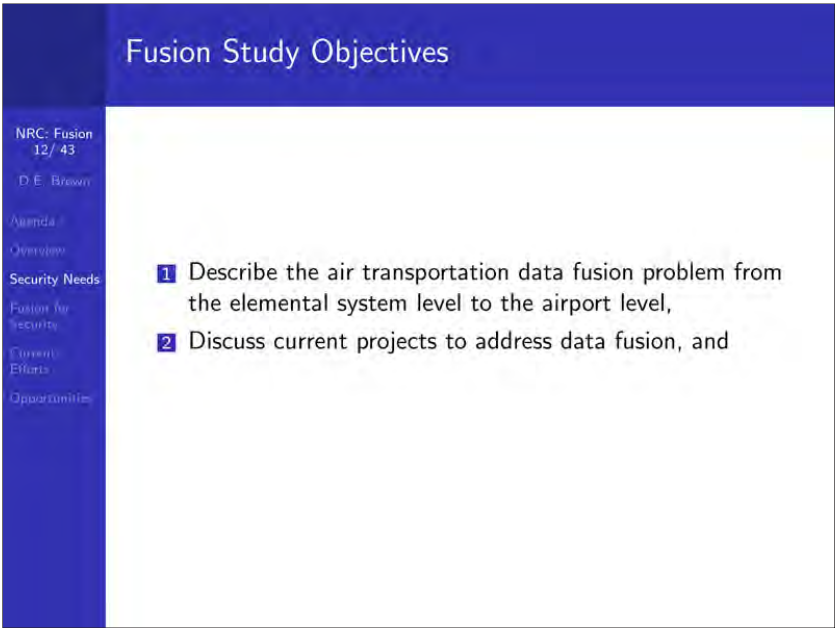
- These detection systems often stand alone, and only direct interaction by the operators enables coordination among them.
- Access-control security systems also operate primarily in stand-alone configurations.
- The current widespread existence of stand-alone inspection systems and the uncoordinated operation of inspection and access-control systems leave the nations airports and transportation network more vulnerable to a variety of potentially significant attacks than they would be if these systems were integrated.

Fusion Study Objectives

1. Describe the air transportation data fusion problem from the elemental system level to the airport level,


Fusion Study Objectives
NRC: Fusion
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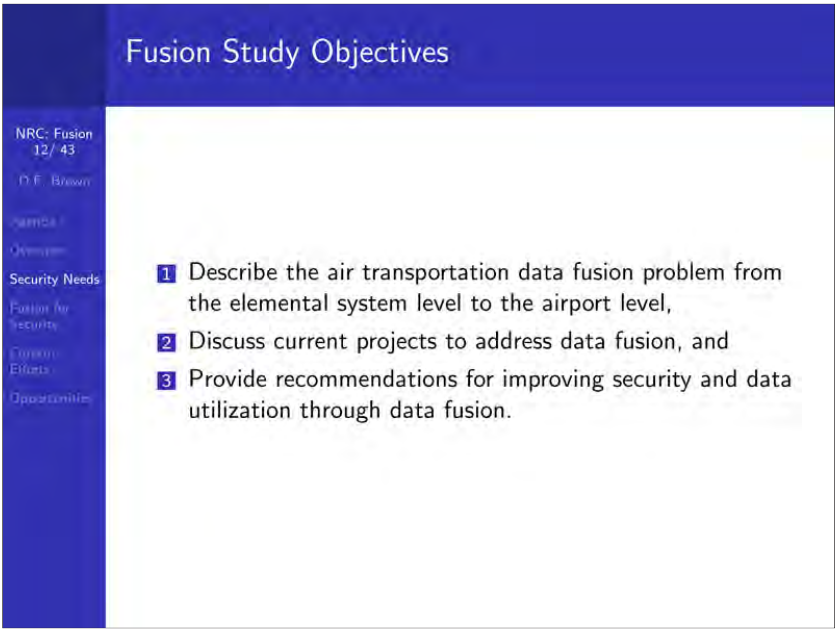
Security Needs
1 Describe the air transportation data fusion problem from the elemental system level to the airport level,
2 Discuss current projects to address data fusion, and


Fusion Study Objectives
NRC: Fusion
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Security Needs
1 Describe the air transportation data fusion problem from the elemental system level to the airport level,
2 Discuss current projects to address data fusion, and
3 Provide recommendations for improving security and data utilization through data fusion.

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4 Current Data Fusion Endeavors

5 Opportunities for Data Fusion

Concepts

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Concepts

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Concepts

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Fusion for Security

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Concepts

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Fusion for Security

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Concepts

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Fusion for Security

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- **Parametric-data fusion:** The combination of measurements from multiple sources to produce a state estimate.

Data Fusion for Security Operations

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- Data fusion for security operations is a state-estimation process based on data from multiple security systems or data sources.

Data Fusion for Security Operations

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- Data fusion for security operations is a state-estimation process based on data from multiple security systems or data sources.
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- Some transportation security data fusion systems may involve information extracted from hundreds of thousands of files or records, the processing of results, and the selection and the transfer of the proper information. However, they may be tested on only a dozen files.
- Unique simulators and emulators may need to be designed and built to exercise these systems in a realistic way during development.

Security Reasons for Data Fusion

1. Improve or maintain detection accuracy while decreasing false alarms;

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Security Reasons for Data Fusion

1. Improve or maintain detection accuracy while decreasing false alarms;
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3. Reduce staffing requirements by automating information processes.

Possible Data Fusion Advantages

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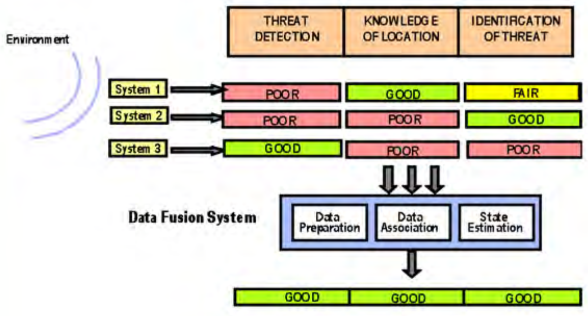

Steps in Data Fusion

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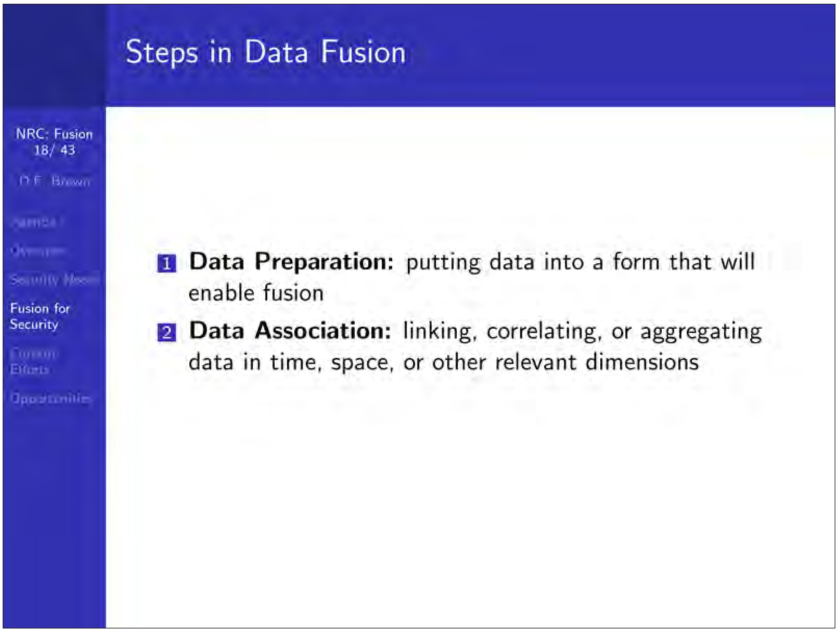
1. **Data Preparation:** putting data into a form that will enable fusion


Steps in Data Fusion
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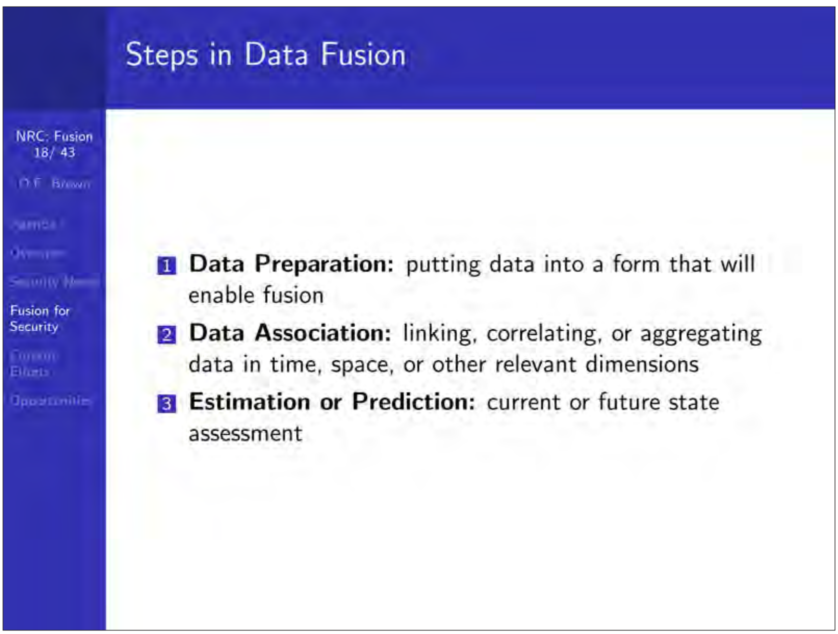
Fusion for Security
1 Data Preparation: putting data into a form that will enable fusion
2 Data Association: linking, correlating, or aggregating data in time, space, or other relevant dimensions


Steps in Data Fusion
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Fusion for Security
1 Data Preparation: putting data into a form that will enable fusion
2 Data Association: linking, correlating, or aggregating data in time, space, or other relevant dimensions
3 Estimation or Prediction: current or future state assessment

Decision vs. Parametric Data Fusion

- Decision data fusion takes the decision outputs from each separate security system and combines them into a global (SoS) decision.

Decision vs. Parametric Data Fusion

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Fusion for Security

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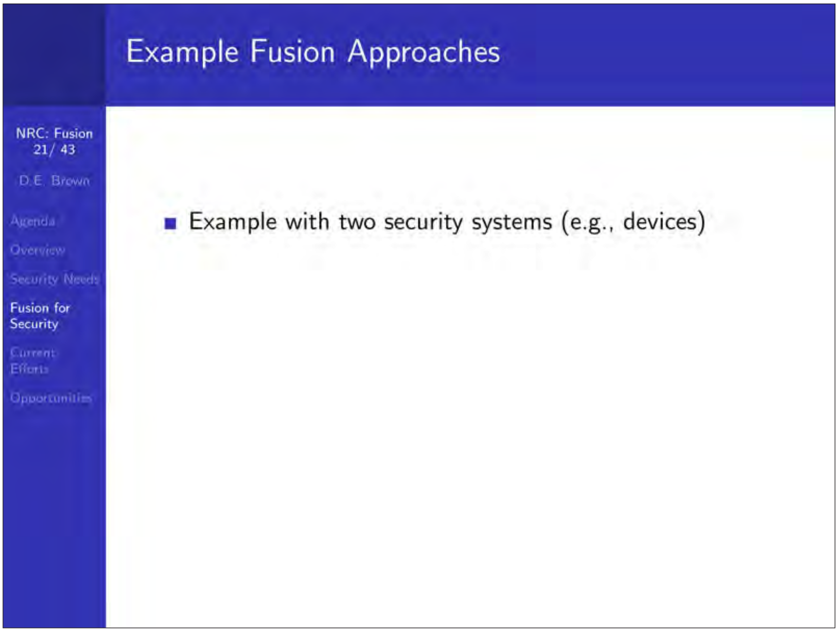
- Parametric data fusion combines the measurements from the separate systems to provide one state estimate which is then used for decision making.
- Parametric fusion is based on fundamental results in optimal estimation and multi-level modeling.

Parametric Fusion: Optimal Estimation

Theorem: The minimum mean square error and maximum a posteriori estimator of the random variable Y given measurements $X = x$ is the conditional mean $E[Y|X = x]$.


Example Fusion Approaches
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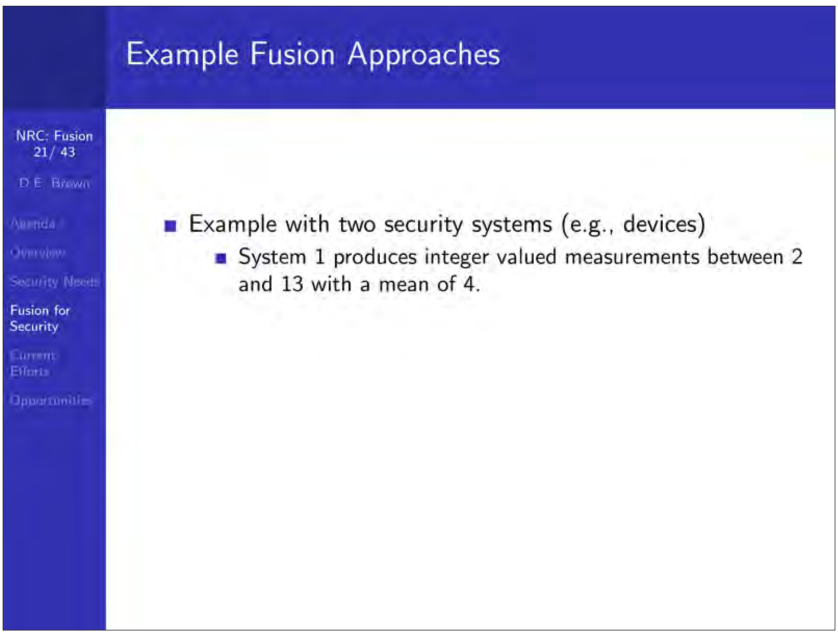
Example with two security systems (e.g., devices)


Example Fusion Approaches
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Example with two security systems (e.g., devices)
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Example Fusion Approaches

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Fusion for Security

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Example Fusion Approaches

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Example Fusion Approaches

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  - Decision fusion with OR logic
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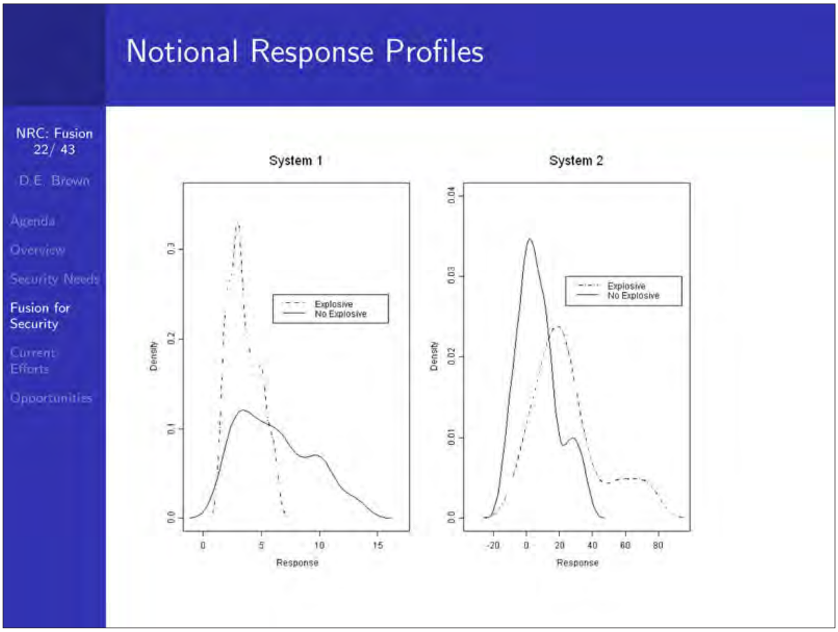
Notional Response Profiles
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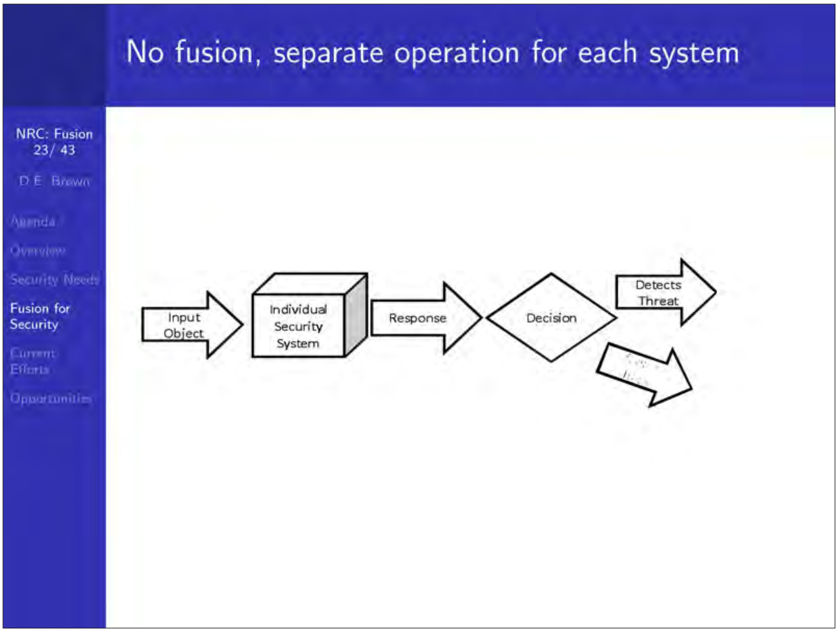
System 1
System 2
Explosive
No Explosive
Density
Response


No fusion, separate operation for each system
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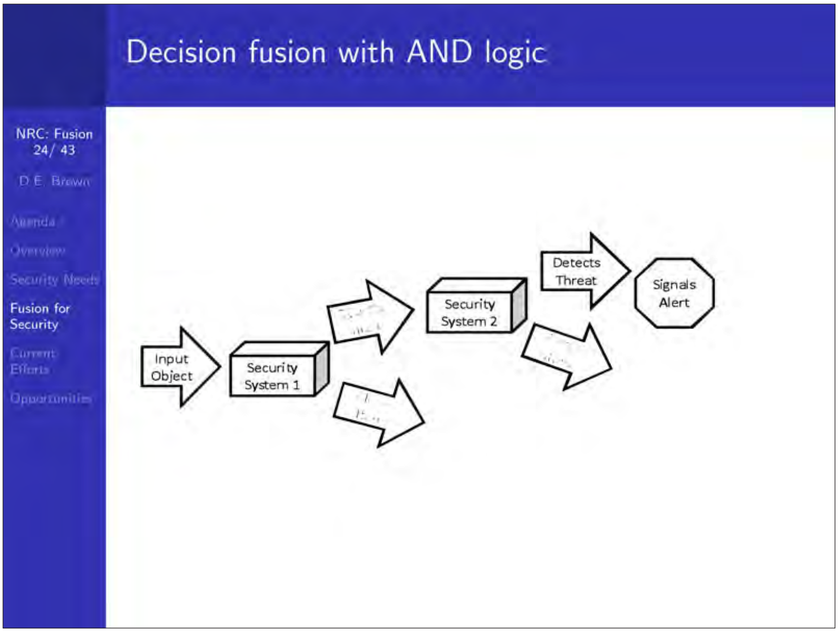
Input Object
Individual Security System
Response
Decision
Detects Threat


Decision fusion with AND logic
NRC: Fusion
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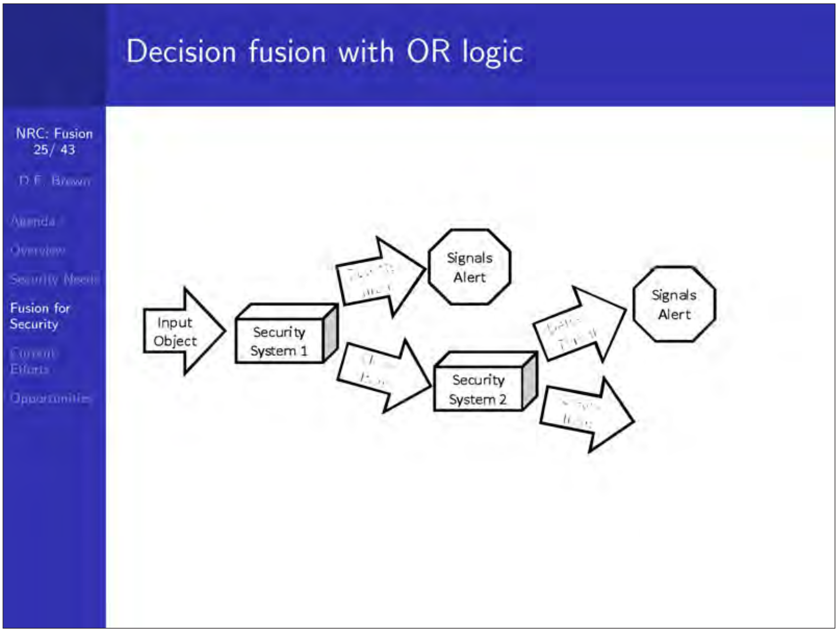
Fusion for Security
Input Object
Security System 1
Security System 2
Detects Threat
Signals Alert


Decision fusion with OR logic
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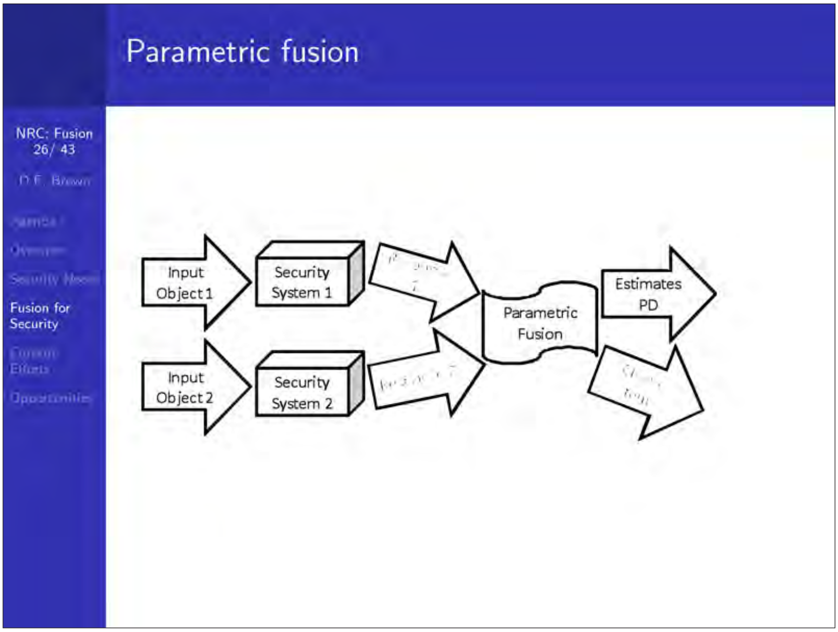
Fusion for Security
Input Object
Security System 1
Signals Alert
Security System 2
Signals Alert


Parametric fusion
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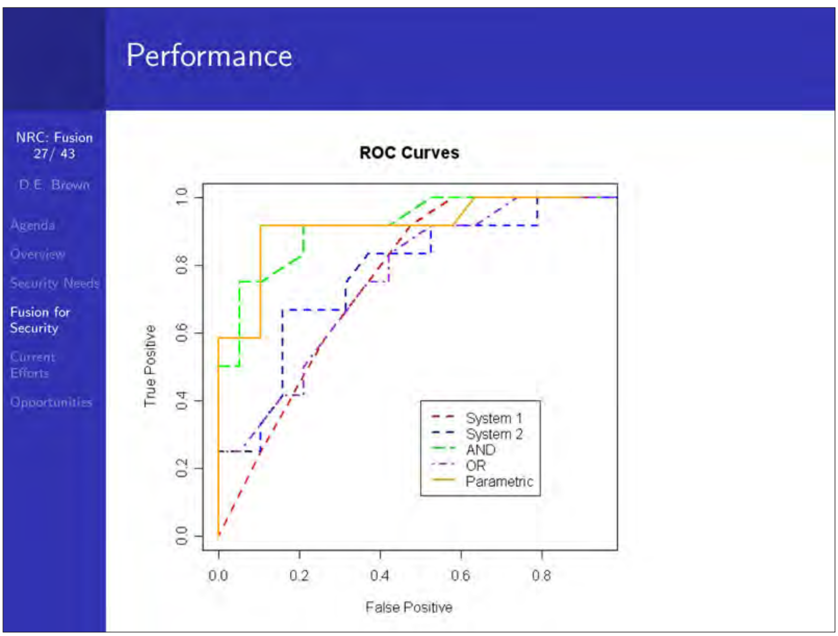
Fusion for Security
Input Object 1
Security System 1
Input Object 2
Security System 2
Parametric Fusion
Estimates PD


Performance
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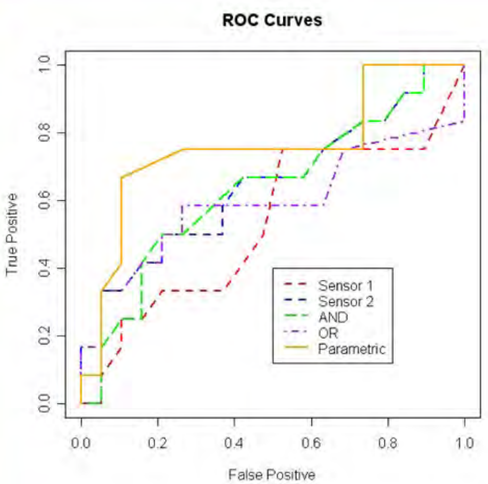
ROC Curves
True Positive
False Positive
0.0
0.2
0.4
0.6
0.8
1.0
System 1
System 2
AND
OR
Parametric

Performance with Added Gaussian Noise



Fusion Mode Finding

Decision-data (versus parametric-data) fusion does not necessarily allow for the greatest improvements in throughput, reduction of false alarms, or improvements in probability of detection. Most TSA data fusion efforts in current programs employ decision-data fusion.

Fusion Mode Recommendation

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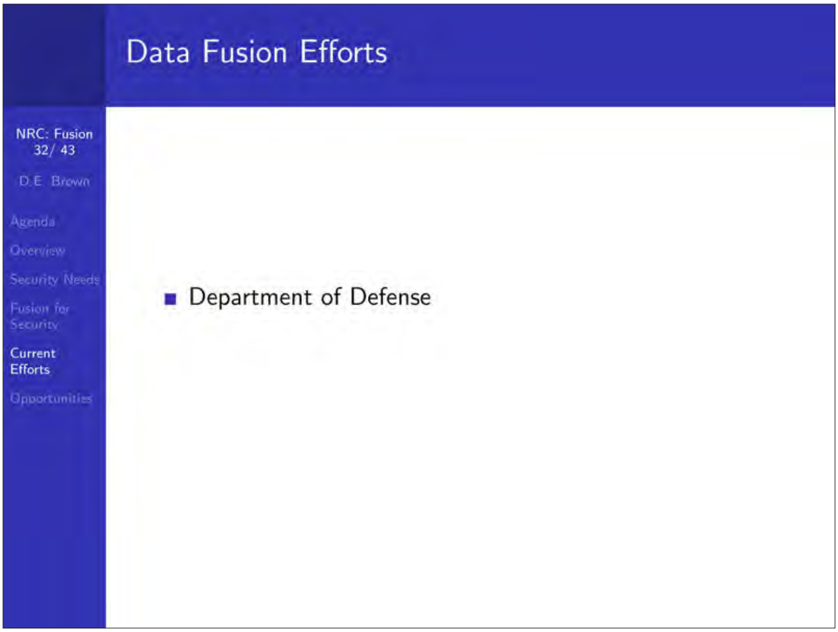
Data Fusion Efforts
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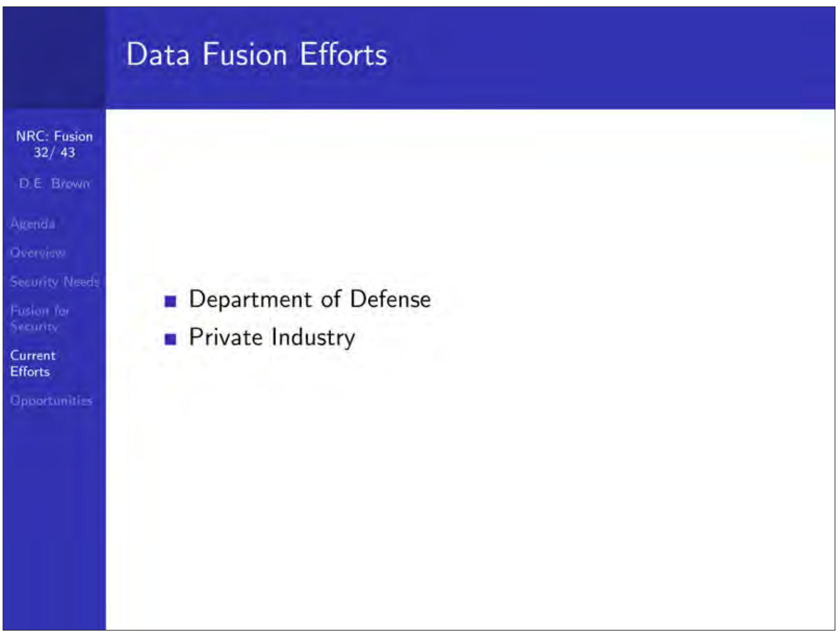
Department of Defense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Current Efforts
Opportunities
Department of Defense
Private Industry

Data Fusion Efforts

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- Private Industry
- Transportation Security

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- Automatic Target Recognition

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- Automatic Target Recognition
- Joint Surveillance and Target Attack Radar System

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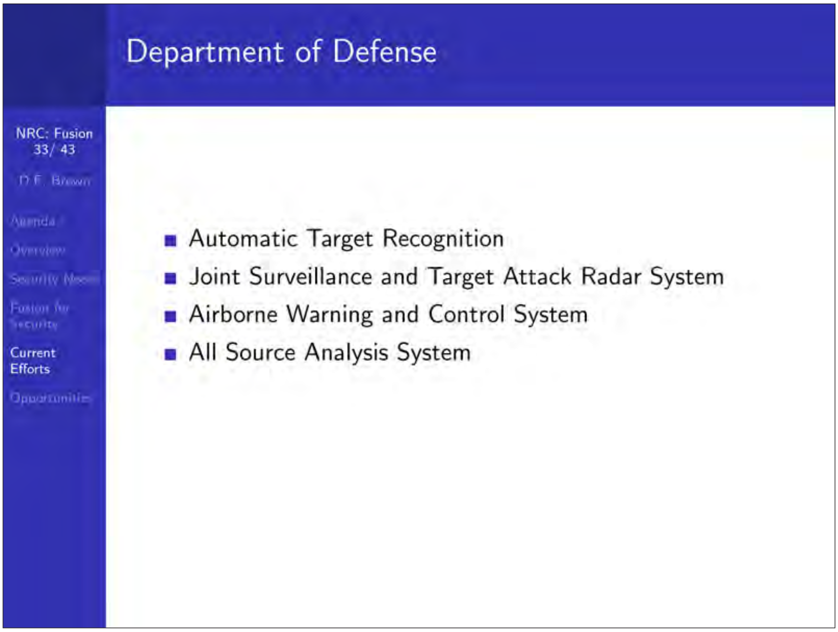
- Automatic Target Recognition
- Joint Surveillance and Target Attack Radar System
- Airborne Warning and Control System


Department of Defense
NRC: Fusion
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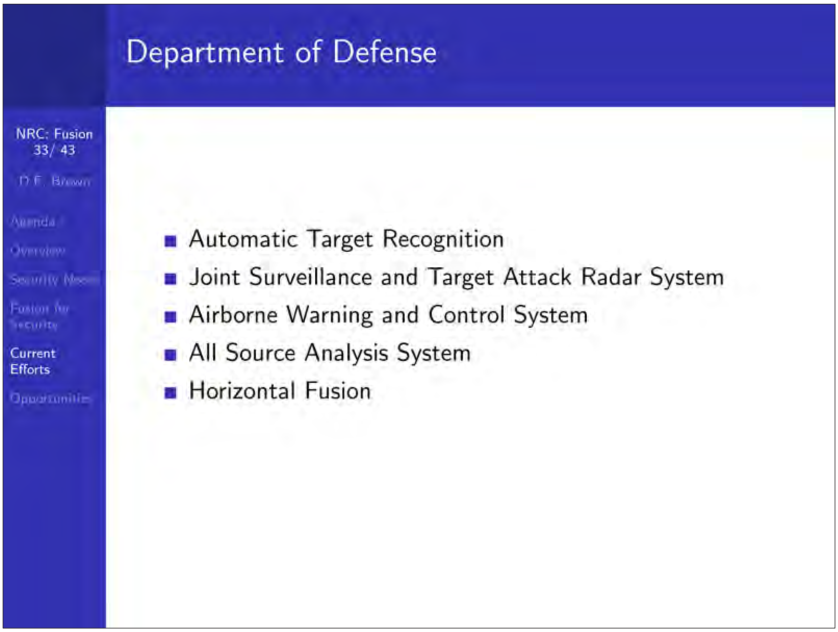
Current
Efforts
Automatic Target Recognition
Joint Surveillance and Target Attack Radar System
Airborne Warning and Control System
All Source Analysis System


Department of Defense
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Current
Efforts
Automatic Target Recognition
Joint Surveillance and Target Attack Radar System
Airborne Warning and Control System
All Source Analysis System
Horizontal Fusion

Department of Defense

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Current Efforts

- Automatic Target Recognition
- Joint Surveillance and Target Attack Radar System
- Airborne Warning and Control System
- All Source Analysis System
- Horizontal Fusion
- Advanced Research Solutions – Fused Intelligence with Speed and Trust

Private Industry

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Current Efforts

- Private industry uses data fusion to increase production, decrease costs, and minimize the need for operator attention during manufacturing activities.

Private Industry

- Private industry uses data fusion to increase production, decrease costs, and minimize the need for operator attention during manufacturing activities.
- An example of data fusion needs in private industry can be drawn from the manufacture of computer chips. This manufacturing activity requires more than 200 individual process steps, each of which must be controlled within a well-characterized range to produce a profitable yield of usable chips

Transportation Security

- 10 Transportation Security Laboratory (TSL) projects in following categories

Transportation Security

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- 10 Transportation Security Laboratory (TSL) projects in following categories
  - Infrastructure for data fusion

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- 10 Transportation Security Laboratory (TSL) projects in following categories
  - Infrastructure for data fusion
  - Data integration

Transportation Security

- 10 Transportation Security Laboratory (TSL) projects in following categories
  - Infrastructure for data fusion
  - Data integration
  - Data fusion

Transportation Security

- 10 Transportation Security Laboratory (TSL) projects in following categories
  - Infrastructure for data fusion
  - Data integration
  - Data fusion
    - SUB-DAX Fusion - Fuse sensors in subterranean environments (rail, light rail, vehicular traffic, tunnels)

Transportation Security

- 10 Transportation Security Laboratory (TSL) projects in following categories
  - Infrastructure for data fusion
  - Data integration
  - Data fusion
    - SUB-DAX Fusion - Fuse sensors in subterranean environments (rail, light rail, vehicular traffic, tunnels)
    - Ship Commerce Integrity - Fusion of software and models into ship routing/rerouting tool

Other Transportation Security Fusion Projects

- Perimeter Surveillance - e.g., Secure Perimeter Awareness Network (SPAN) program

Other Transportation Security Fusion Projects

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- Perimeter Surveillance - e.g., Secure Perimeter Awareness Network (SPAN) program
- Access-Control Systems - e.g., Airport Access Control Pilot Program

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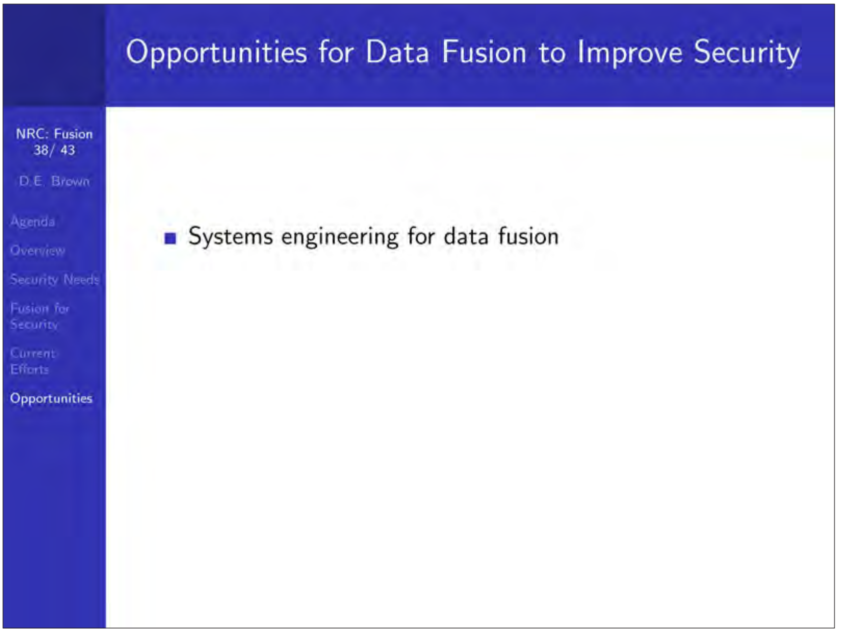
1. Study Overview
2. Air Transportation Security Needs
3. Data Fusion for Security Operations
4. Current Data Fusion Endeavors
5. Opportunities for Data Fusion


Opportunities for Data Fusion to Improve Security
NRC: Fusion
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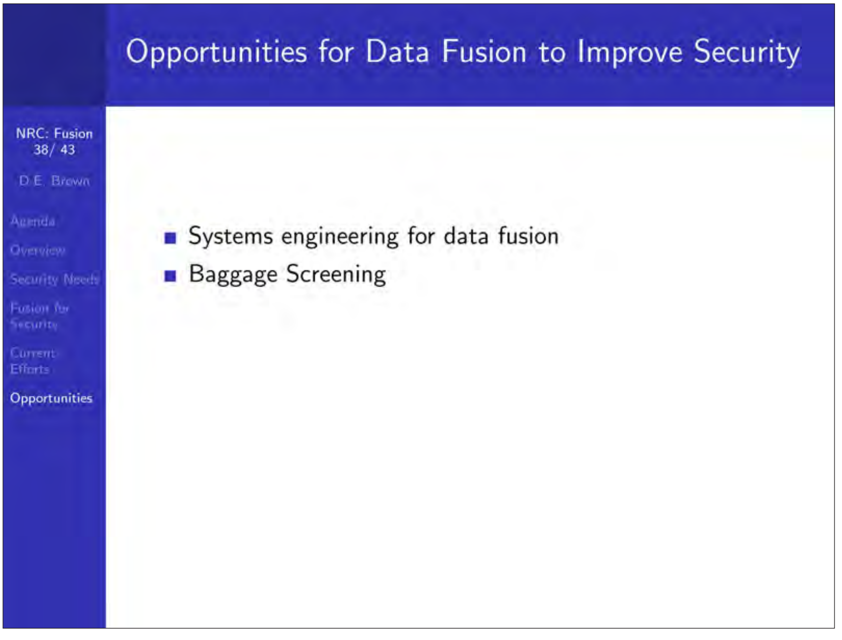
Systems engineering for data fusion


Opportunities for Data Fusion to Improve Security
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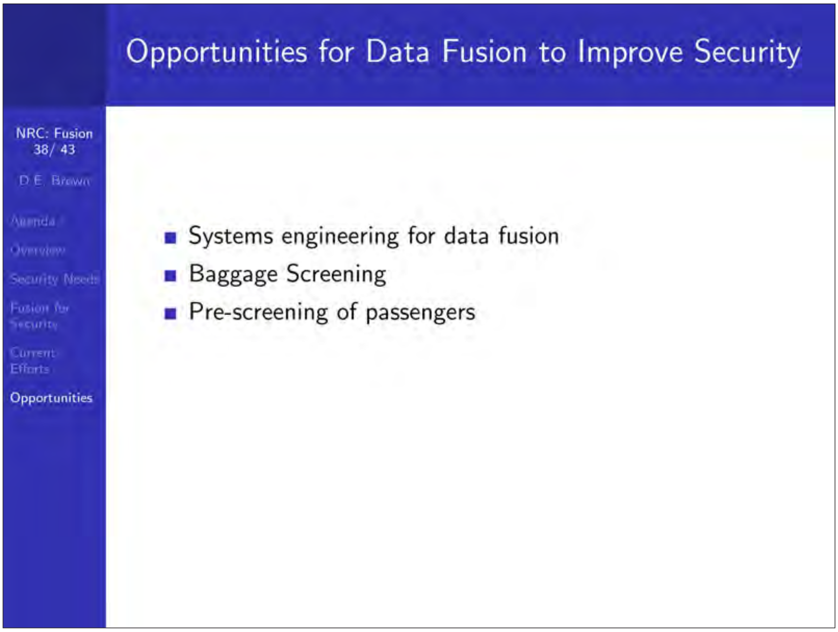
Baggage Screening


Opportunities for Data Fusion to Improve Security
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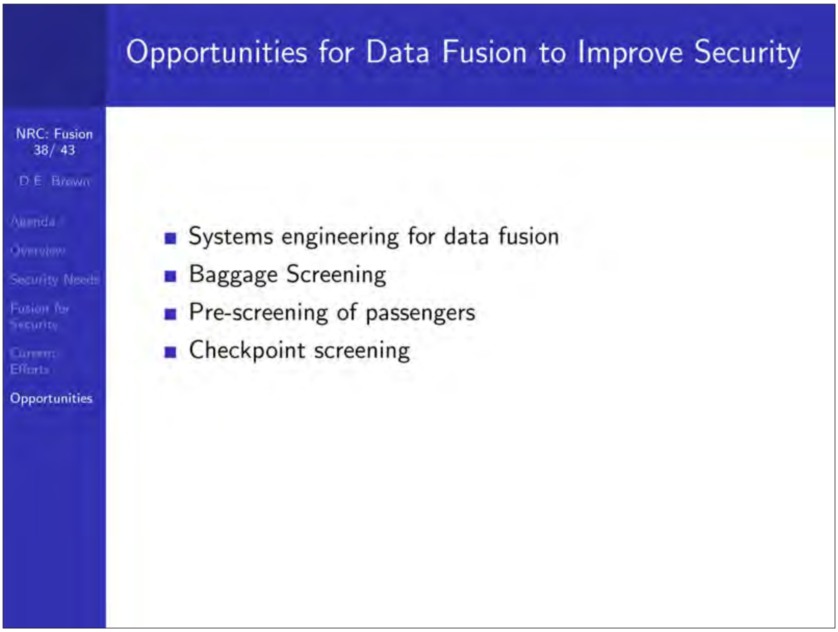
Baggage Screening
Pre-screening of passengers


Opportunities for Data Fusion to Improve Security
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Baggage Screening
Pre-screening of passengers
Checkpoint screening

Opportunities for Data Fusion to Improve Security

- Systems engineering for data fusion
- Baggage Screening
- Pre-screening of passengers
- Checkpoint screening
- Perimeter surveillance

Opportunities for Data Fusion to Improve Security

- Systems engineering for data fusion
- Baggage Screening
- Pre-screening of passengers
- Checkpoint screening
- Perimeter surveillance
- Human sensors

Opportunities for Data Fusion to Improve Security

- Systems engineering for data fusion
- Baggage Screening
- Pre-screening of passengers
- Checkpoint screening
- Perimeter surveillance
- Human sensors
- Airport-wide fusion models

Baggage Screening Data Fusion

- Candidates for fusion include x-rays, pulsed fast neutron analysis (PFNA), and nuclear quadrupole resonance (NQR).

Baggage Screening Data Fusion

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Opportunities

- Candidates for fusion include x-rays, pulsed fast neutron analysis (PFNA), and nuclear quadrupole resonance (NQR).
- Vendors were exploring a two-level bag screening process that involved a high-throughput projection x-ray system that screened all bags and directed any bag with objects matching a broad threat profile to a more sensitive CT-based system.

Baggage Screening Data Fusion

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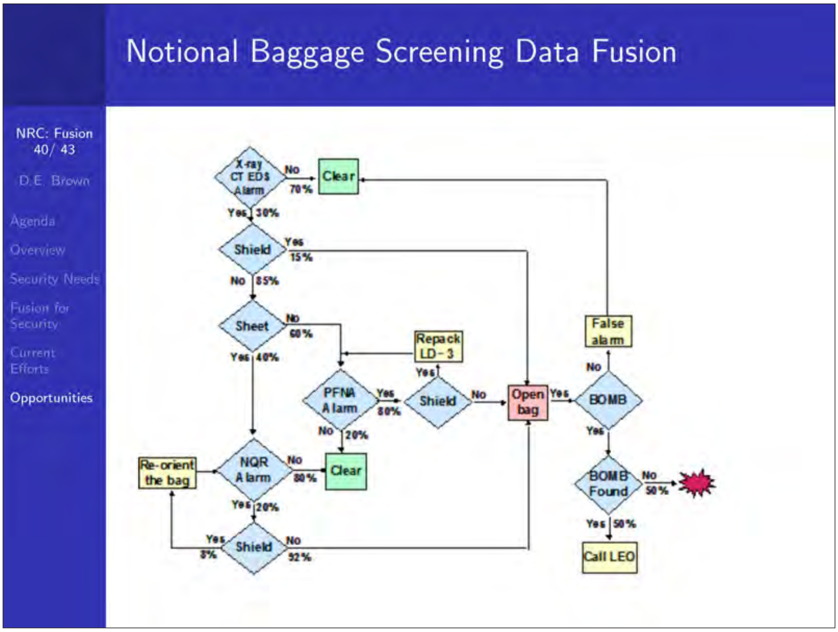
Opportunities

- Candidates for fusion include x-rays, pulsed fast neutron analysis (PFNA), and nuclear quadrupole resonance (NQR).
- Vendors were exploring a two-level bag screening process that involved a high-throughput projection x-ray system that screened all bags and directed any bag with objects matching a broad threat profile to a more sensitive CT-based system.
- Fusion of x-ray CT explosive detection system (EDS) outputs with data from other technologies most likely will provide the biggest reduction in the false-alarm rate in the near term.


Notional Baggage Screening Data Fusion
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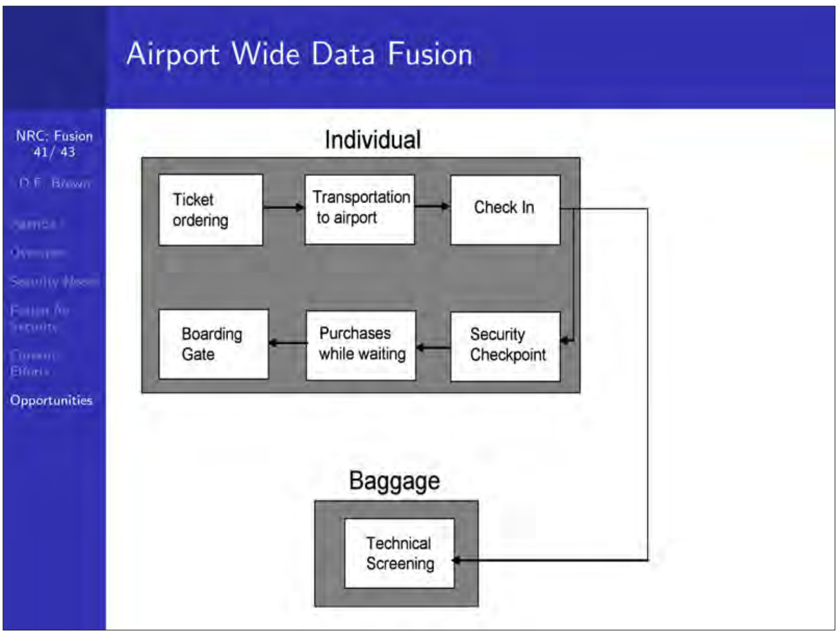
X-ray CT EDS Alarm
No
70%
Clear
Yes
30%
Shield
Yes
15%
No
85%
Sheet
No
60%
Yes
40%
Repack LD-3
Yes
PFNA Alarm
Yes
80%
No
20%
Shield
No
Open bag
Yes
BOMB
No
False alarm
Yes
Re-orient the bag
NQR Alarm
No
80%
Clear
Yes
20%
Yes
8%
Shield
No
92%
BOMB Found
No
50%
Yes
50%
Call LEO


Airport Wide Data Fusion
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Opportunities
Individual
Ticket ordering
Transportation to airport
Check In
Boarding Gate
Purchases while waiting
Security Checkpoint
Baggage
Technical Screening

Recommendation 2: Systems Engineering

The TSA should establish a means to ensure that the following tasks and functions are carried out:

Recommendation 2: Systems Engineering

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The TSA should establish a means to ensure that the following tasks and functions are carried out:

- Creation of a set of system-level data fusion requirements for the checked-baggage screening, checkpoint, and access-control systems;

Recommendation 2: Systems Engineering

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Opportunities

The TSA should establish a means to ensure that the following tasks and functions are carried out:

- Creation of a set of system-level data fusion requirements for the checked-baggage screening, checkpoint, and access-control systems;
- Performance of a systems engineering analysis of these areas;

Recommendation 2: Systems Engineering

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Opportunities

The TSA should establish a means to ensure that the following tasks and functions are carried out:

- Creation of a set of system-level data fusion requirements for the checked-baggage screening, checkpoint, and access-control systems;
- Performance of a systems engineering analysis of these areas;
- Validation of these requirements against threat projections, current and projected security systems, and facility idiosyncrasies; and

Recommendation 2: Systems Engineering

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Opportunities

The TSA should establish a means to ensure that the following tasks and functions are carried out:

- Creation of a set of system-level data fusion requirements for the checked-baggage screening, checkpoint, and access-control systems;
- Performance of a systems engineering analysis of these areas;
- Validation of these requirements against threat projections, current and projected security systems, and facility idiosyncrasies; and
- The monitoring of fundamental research in the field and adjustment of requirements where appropriate.

Recommendation 5: Operational Testing

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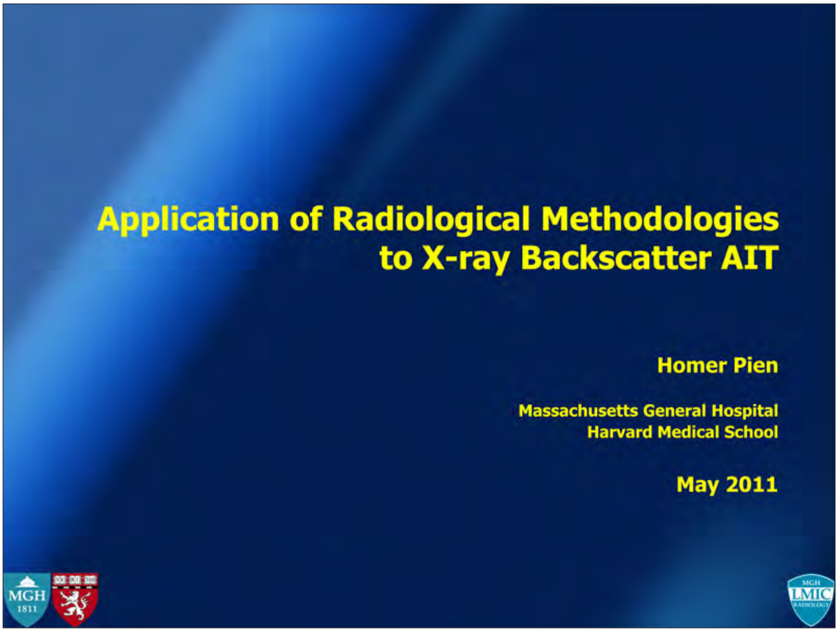
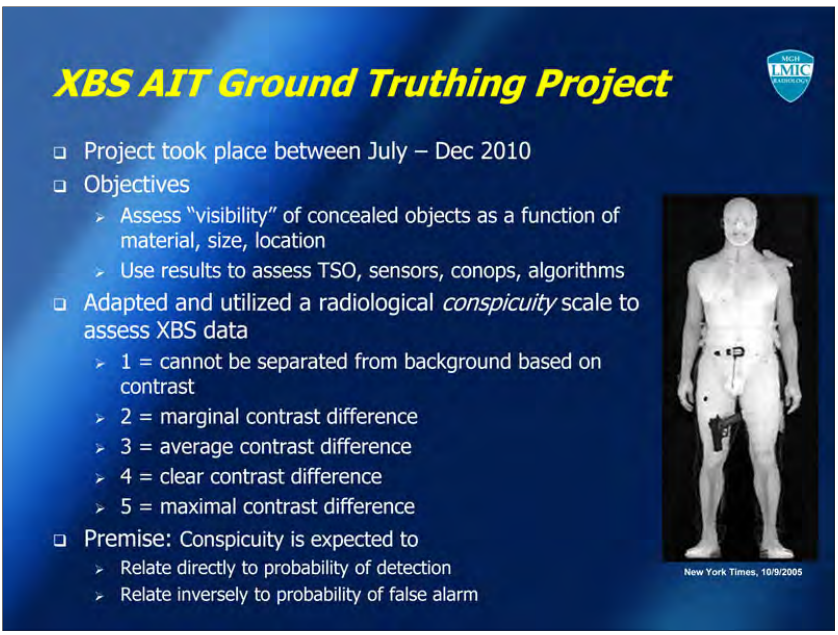
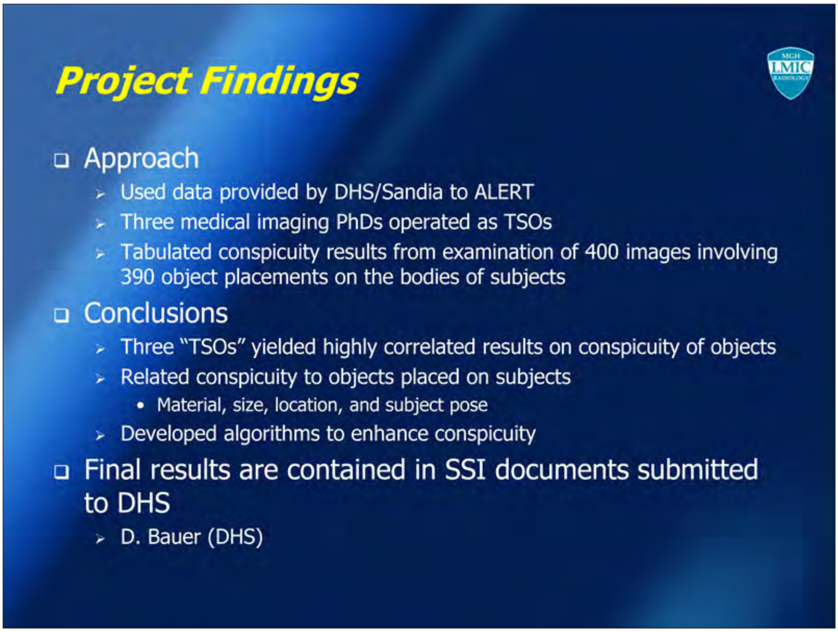
Opportunities

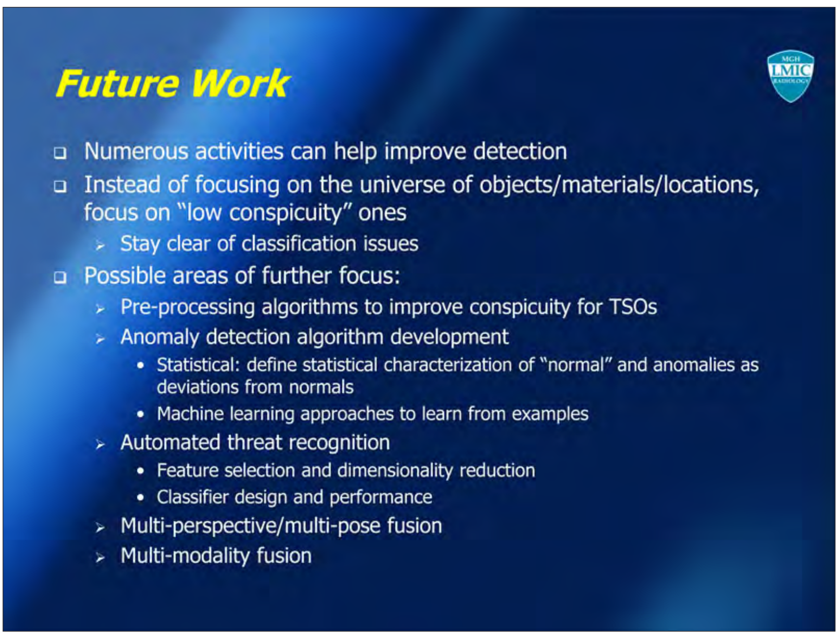
The TSA should implement any data fusion systems through a series of staged deployments at an operational testbed as designated by the TSA and/or at selected airports. The experience from these early staging events can then be incorporated and used in the data fusion systems rolled out in later implementations.

16.16 Homer Pien: AIT ground truth project



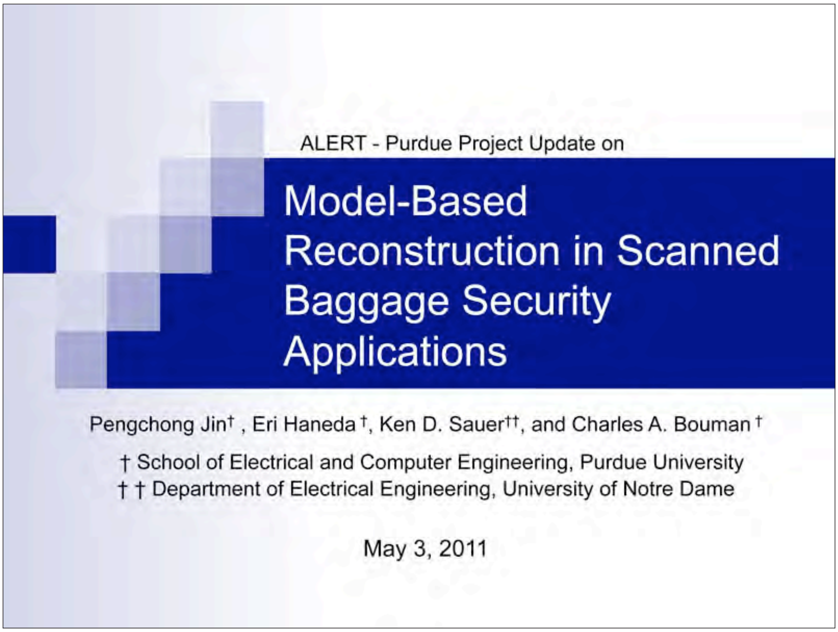


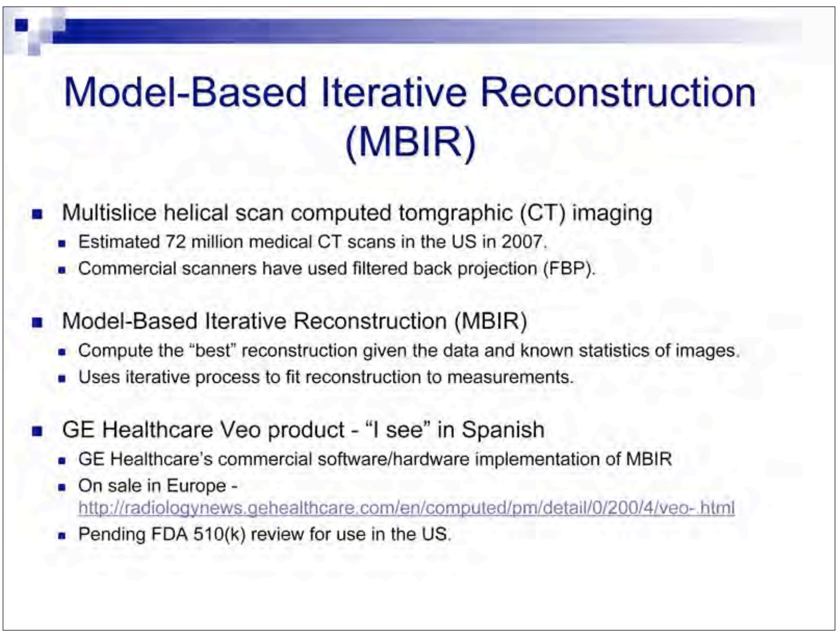

Project Findings
Approach
Used data provided by DHS/Sandia to ALERT
Three medical imaging PhDs operated as TSOs
Tabulated conspicuity results from examination of 400 images involving 390 object placements on the bodies of subjects
Conclusions
Three "TSOs" yielded highly correlated results on conspicuity of objects
Related conspicuity to objects placed on subjects
Material, size, location, and subject pose
Developed algorithms to enhance conspicuity
Final results are contained in SSI documents submitted to DHS
D. Bauer (DHS)
MGH LMIC RADIOLOGY

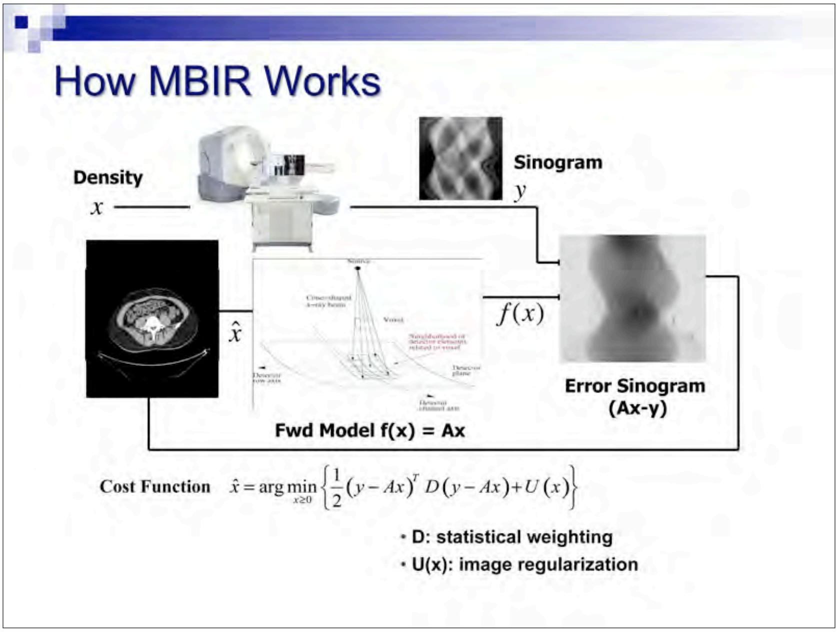

Future Work
Numerous activities can help improve detection
Instead of focusing on the universe of objects/materials/locations, focus on "low conspicuity" ones
Stay clear of classification issues
Possible areas of further focus:
Pre-processing algorithms to improve conspicuity for TSOs
Anomaly detection algorithm development
Statistical: define statistical characterization of "normal" and anomalies as deviations from normals
Machine learning approaches to learn from examples
Automated threat recognition
Feature selection and dimensionality reduction
Classifier design and performance
Multi-perspective/multi-pose fusion
Multi-modality fusion
MGH LMIC RADIOLOGY

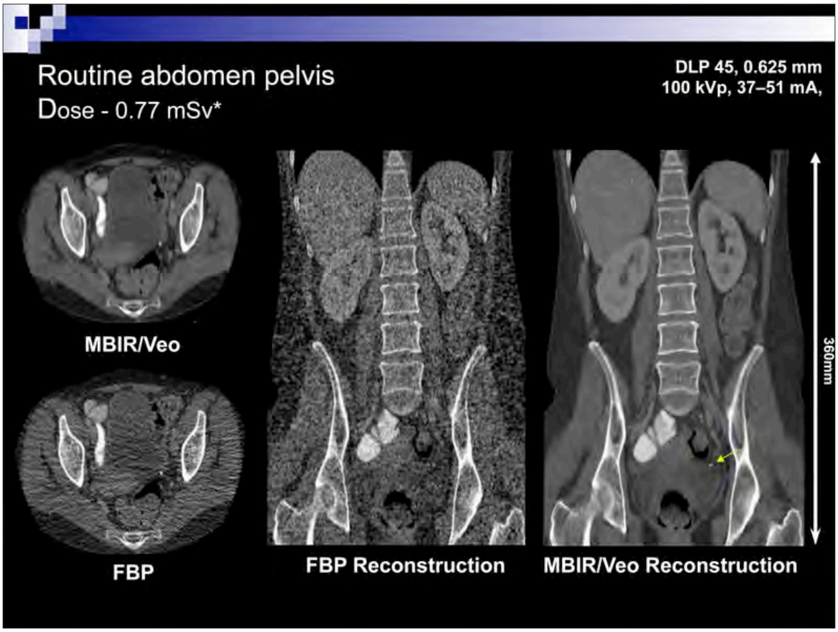

Lessons Learned
MGH
LMIC
RADIOLOGY
With proper safeguards in place, academics can work within the constraints of SSI
Much synergy between medical imaging and security communities remains to be exploited

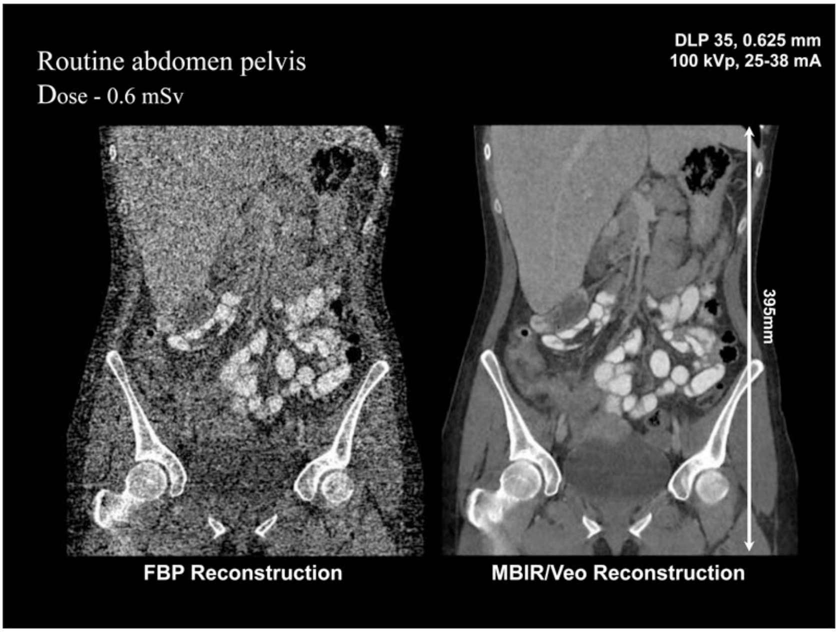
16.17 Charles Bouman: CT iterative reconstruction

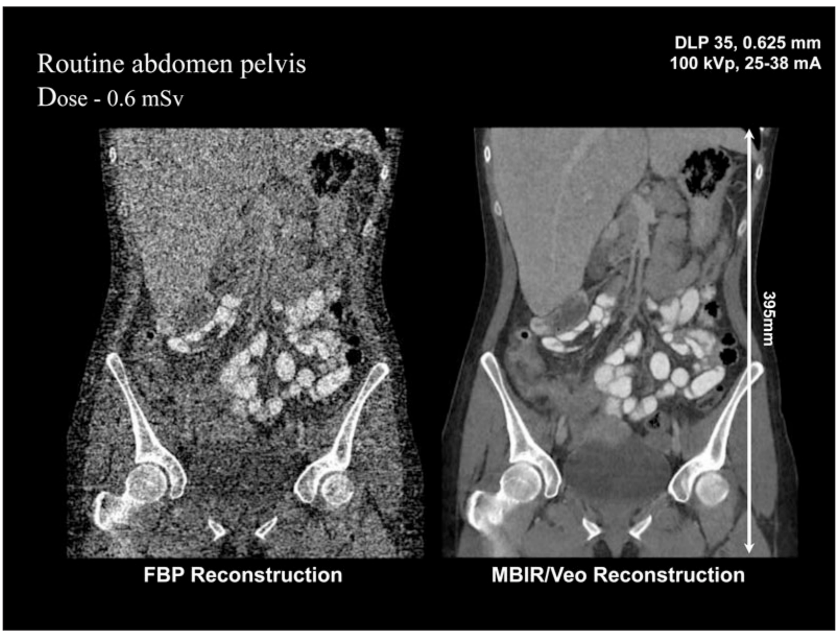





How MBIR Works
Density
x
Sinogram
y
$\hat{x}$
$f(x)$
Error Sinogram
(Ax-y)
Fwd Model f(x) = Ax
Cost Function $\hat{x} = \arg\min_{x \geq 0} \left\{ \frac{1}{2}(y - Ax)^T D(y - Ax) + U(x) \right\}$
• D: statistical weighting
• U(x): image regularization

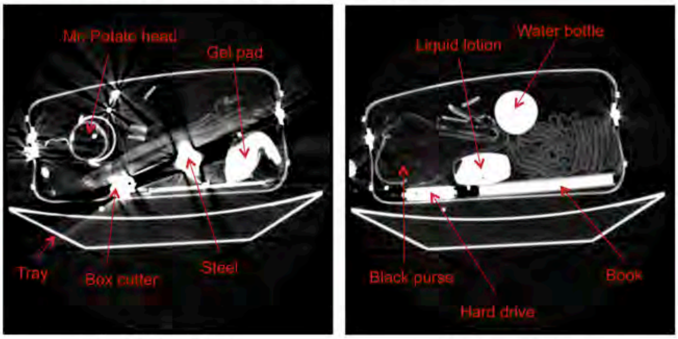

Routine abdomen pelvis
Dose - 0.77 mSv*
DLP 45, 0.625 mm
100 kVp, 37–51 mA,
MBIR/Veo
FBP
FBP Reconstruction
MBIR/Veo Reconstruction
360mm


Routine abdomen pelvis
Dose - 0.6 mSv
DLP 35, 0.625 mm
100 kVp, 25-38 mA
395mm
FBP Reconstruction
MBIR/Veo Reconstruction


Routine abdomen pelvis
Dose - 0.6 mSv
DLP 35, 0.625 mm
100 kVp, 25-38 mA
395mm
FBP Reconstruction
MBIR/Veo Reconstruction

Model-Based Reconstruction for Security

- Potential:
  - Reduction of streaks => Better segmentation
  - Reduction of artifacts => Nontraditional geometries
  - Increased resolution => Better separation of objects
  - Better object models => High quality with few views



400th slice, axial view   510th slice, axial view

FBP reconstruction examples for a suitcase

Simulation Results

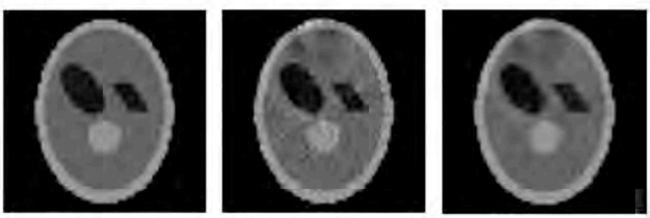
- CT Simulated noise was added to sinogram
- Cost function for MAP estimate

$$\hat{x}_{MAP} = \arg\min_{x \geq 0} \left\{ \frac{1}{2}(y - Ax)^T D(y - Ax) + U(x) \right\}$$

x: Reconstructed image values
y: Measured sinogram
D: weighting factor
U(x): regularization term

- Used a quadratic GMRF prior for U(x)
- Reconstruction resolution is 64x64x64

Axial view 64x64



Ground truth | **ML estimate (U(x)=0)** | **MAP estimate (U(x): Quadratic prior)**

Project Status

- Implemented forward model for cone-beam helical CT
  - Models 3D detector and voxel geometry
- Implemented maximum a posteriori (MAP) reconstruction using ICD optimization and simple Bayesian prior
- Implemented basic noise and prior models
- Successfully reconstructed data from simulated data
- Successfully reconstructed low resolution image from ALERT data set using subsampled views.

- Near-term goals:
  - Port to multi-core architecture using P-threads and/or MPI
  - Implement improved non-Gaussian prior model
  - Fine-turn selection of scanner geometry and data parameters
- Longer-term goals:
  - Access image quality improvements
  - Investigate limited data reconstruction
  - Develop advanced prior models for security imaging applications

MBIR/Veo Publications and Patents

- Some key publications:

K. Sauer and C. Bouman, "A Local Update Strategy for Iterative Reconstruction from Projections," *IEEE Trans. on Sig. Proc.*, vol. 41, no. 2, pp. 534-548, Feb. 1993.

C. A. Bouman and K. Sauer, "A Unified Approach to Statistical Tomography using Coordinate Descent Optimization," *IEEE Trans. on Image Processing*, vol. 5, no. 3, pp. 480-492, March 1996.

J.-B. Thibault, K. Sauer, C. Bouman, and J. Hsieh, "A Three-Dimensional Statistical Approach to Improved Image Quality for Multi-Slice Helical CT," *Medical Physics*, pp. 4526-4544, vol. 34, no. 11, November 2007.

- Issued patents:

1 J. Hsieh, J.-B. Thibault, C. A. Bouman, and K. Sauer, "An Iterative Method for Region-of-Interest Reconstruction," US Pat. 6,768,782, July 27, 2004.

2 9. K. Sauer, C. A. Bouman, J.-B. Thibault, and J. Hsieh, "Iterative Reconstruction Methods for Multi-Slice CT," US Pat. 6,907,102, June 14, 2005.

3 K. D. Sauer, J.-B. Thibault, C. A. Bouman, and J. Hsieh, "Methods, Apparatus, and Software to Facilitate Iterative Reconstruction of Images," US Pat. 7,251,306, July 31, 2007.

4 J.-B. Thibault, K. D. Sauer, C. A. Bouman, and J. Hsieh, "Methods, Apparatus, and Software to Facilitate Computing the Elements of a Forward Projection Matrix," US Pat. 7,272,205, Sep. 18, 2007.

5 C. A. Bouman, K. D. Sauer, J. Hsieh, and J.-B. Thibault, "Methods, Apparatus, and Software for Reconstructing an Image," US Pat. 7,308,071, Dec. 11, 2007.

6 K. D. Sauer, J.-B. Thibault, C. A. Bouman, and J. Hsieh, "Method, Apparatus, and Software for Reconstructing an Image," US Pat. 7,327,822, Feb. 5, 2008.

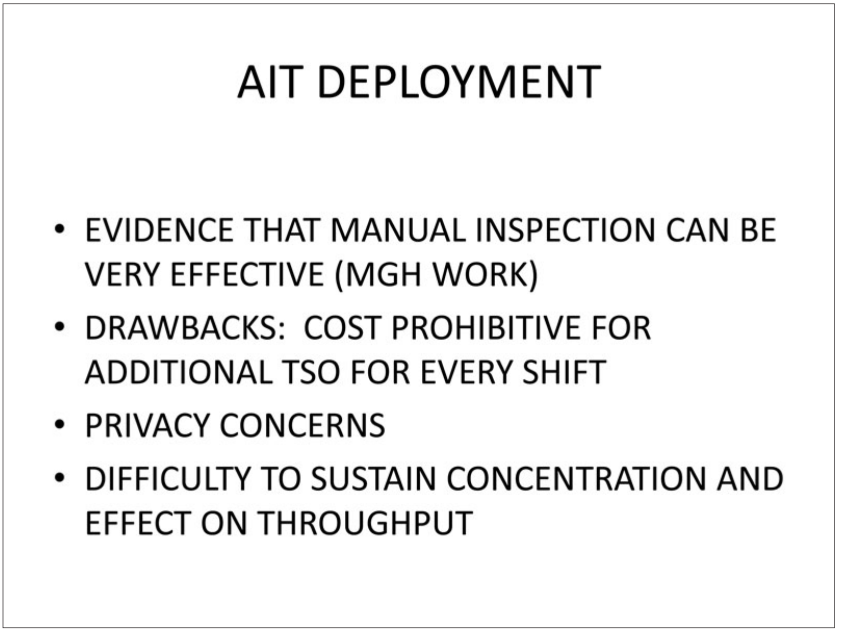
7 J. Hsieh, C. A. Bouman, K. D. Sauer, and J.-B. Thibault, "Methods, Apparatus, and Software for Failed or Degraded Components," US Pat. 7,440,602, Oct. 21, 2008.

8 J. Hsieh, J.-B. Thibault, K. D. Sauer, and C. A. Bouman, "Method and System for Improving a Resolution of an Image," US Pat. 7,583,780, Sept. 1, 2009.

9 K. D. Sauer, C. A. Bouman, J. Hsieh, and J.-B. Thibault, "Systems and Methods for Filtering Data in Medical Imaging Systems," US Pat. 7,676,074, Mar. 9, 2010.

10 K. D. Sauer, C. A. Bouman, J. Hsieh, and J.-B. Thibault, "Method and System for Image Reconstruction," US Pat. 7,885,371, Feb. 8, 2011.

16.19 Carl Crawford: Day 2 Objectives



AIT

- TRUE PERFORMANCE STILL UNKNOWN EVEN WITH EVIDENCE THAT SMALL ANOMALIES (SURFACE AREA AND THICKNESS) CAN BE DETECTED. BASELINE ASSESSMENT OF CAPABILITES. USE OF HUMAN SUBJECTS VERSUS MEDICAL PHANTOMS FOR DATA COLLECTION.
- NO UNIFORM DETECTION CAPABILITY FOR VARIOUS MATERIAL AND LOCATIONS.

AIT AUTOMATION

- COST EFFECTIVE AND FAST
- Pd AND Pfa DEPEND ON SIZE AND THICKNESS IN THE SPECIFICATION. SELECTION OF DETECTION CRITERION TO MATCH BEST MANUAL PERFORMANCE MAY LEAD TO UNSUSTAINED FALSE ALARMS
- TOO LARGE OF TARGET LEADS TO RISK OF DETECTION MISS OF OBJECTS VISIBLE BY VISUAL INSPECTION.

CHALLENGES

- HARDWARE IMPROVEMENT FOR INCREASED PERFORMANCE WITHOUT RISK OF ADDITIONAL RADIATION
- FUSION OF TRACE AND AIT FOR ORTHOGONAL PERFORMANCE
- ADDON CAPABILITY FOR SHOE SCREENING
- OPEN SYSTEMS FOR THIRD PARTY COMPETITION

TRACE INSPECTION

- LIMIT OF DETECTION AS A SMALL PERCENT OF AMBIENT VAPOR PRESSURE WITH IMPROVED PARTICULATE HARVESTING
- ABILITY TO DETECT NEWER MORE COMPLICATED HME THREATS
- SAMPLING EFFICIENCIES WITH NON CONTACT CAPABILITY TO REMOVE DEPENDENCE ON OPERATOR (DART, DESI AND PLASMA)
- STANDARD INTERFACES FOR SAMPLING

CHECKPOINT XRAY

- REDUCE THE NUMBER OF IMAGES SCANNED PER PASSENGER.
- MULTIVIEW AT LIMITATIONS: LIQUID THREAT DETECTION IN THE CARRY ON IN PRESENCE OF OTHER LIQUIDS
- LIMITED ALGORITHM CAPABILITY FOR AUTOMATED DETECTION; ALLOW LAPTOPS TO REMAIN INSIDE BAGS.

CHECKPOINT XRAY

- EXIT TUNNEL ALLOWS FOR ORTHOGONAL SENSORS, TRACE OR OPTICAL FOR EXTERNAL SURFACE INSPECTION
- LIMITATIONS ON FOOTPRINT, SIZE AND POWER REQUIREMENTS.
- PROVISION OF HIGHER RESOLUTION IMAGES WITH 3D IMAGE CAPABILITY. STANDARD IMAGES ACROSS VENDORS HARDWARE.
- ADHERENCE TO DICOS AND THIRD PARTY ALGORTIHMS- DIGITAL TIP IMAGES EMBEDDED IN DICOS

CHECKED LUGGAGE

- UPDATE METHODS AND PROCEDURES FOR ALGORITHM DEVELOPMENT. CURTAIL NEED FOR DATA AND IMAGE ACQUISITION ON EVERY THREAT.
- DETERMINATION OF RESPONSE FUNCTION OF VENDOR CT TECHNOLOGY WITH UPLOAD OF DETECTION PARAMETRS FROM HIGH RESOLUTION CT SYSTEMS.
- DISSEMINATE PERFORMANCE INFORMATION ON IDEAL CT SYSTEM, SOURCE PARAMETERS, DETECTORS, IMAGE RECONSTRUCTION, SEGMENTATION AND CLASSIFICATION. EXPLOIT FULLY ADVANCES IN MEDICAL RESEARCH.

CHECKED LUGGAGE

- PREDICITVE CAPABILITY BASED ON PARAMETRS COLLECTED FROM HIGH RESOLUTION CT TO DETERMINE EXPECTED FALSE ALARM RATE SUBJECT TO BEST Pd.
- COLLAPSE TIME FOR ALGORTIHM UPDATE TO REFLECT NEW AND INNOVATIVE THREATS. MONTHS NOT YEARS.
- ADAPT ORTHOGONAL SENSORS SUCH AS TRACE OR OPTICAL METHODS FOR SIMULTANEOUS SCREENING.

INHERENT DIFFICULTIES

- LACK OF LONG RANGE PLANNING AND BUDGETING WITH LIFECYCLE REPLACEMENTS
- LACK OF APPRECIATION THAT ACQUISITION COSTS ARE OFTEN DWARFED BY OPERATIONAL COSTS. IN TIMES OF LEAN BUDGETS, LABOR COSTS ARE ESPECIALLY CRITICAL.
- ADAPT DOD MODEL FOR SYSTEM INTEGRATION.

EMERGING INNOVATIVE TECHNOLOGY

- MMWAVE/TERAHERTZ FOR HIGHER RESOLUTION IMAGES AND MATERIAL DISCRIMINATION
- EFFICIENT IMAGE RECONSTRUCTION METHODS
- CARBON NANOTUBE XRAY SOURCES
- PORTABLE MASS SPECTROSCOPY/CONTACTLESS SAMPLING

EMERGING INNOVATIVE TECHNOLOGY

- EYE SAFE LASER SYSTEMS/STANDOFF/IMPROVED SENSITIVITY AND SELECTIVITY
- ADAPTION OF OPEN SYSTEMS/DICOS

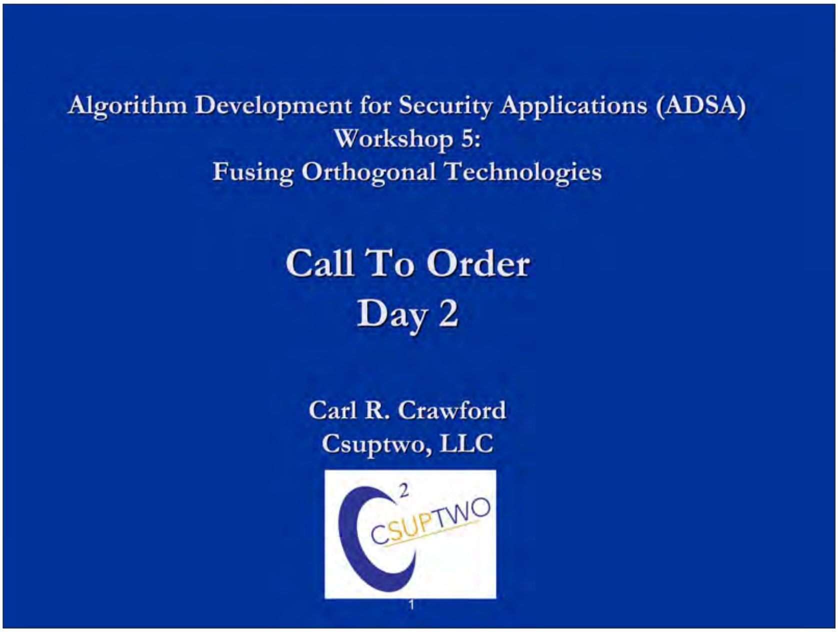
SUCCESS STORY

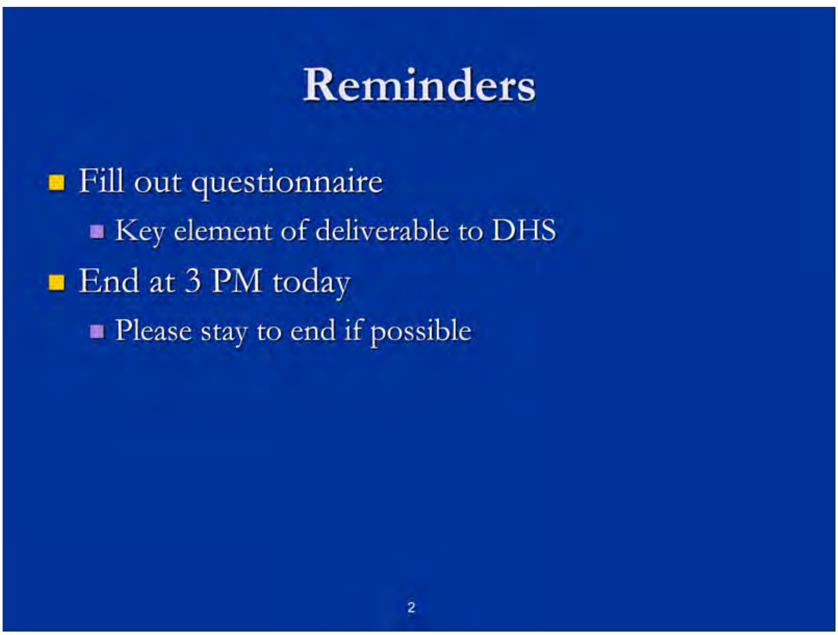
- EFFECTIVE AND FLEXIBLE IT&E WELL ESTABLISHED AND EXPERIENCED.

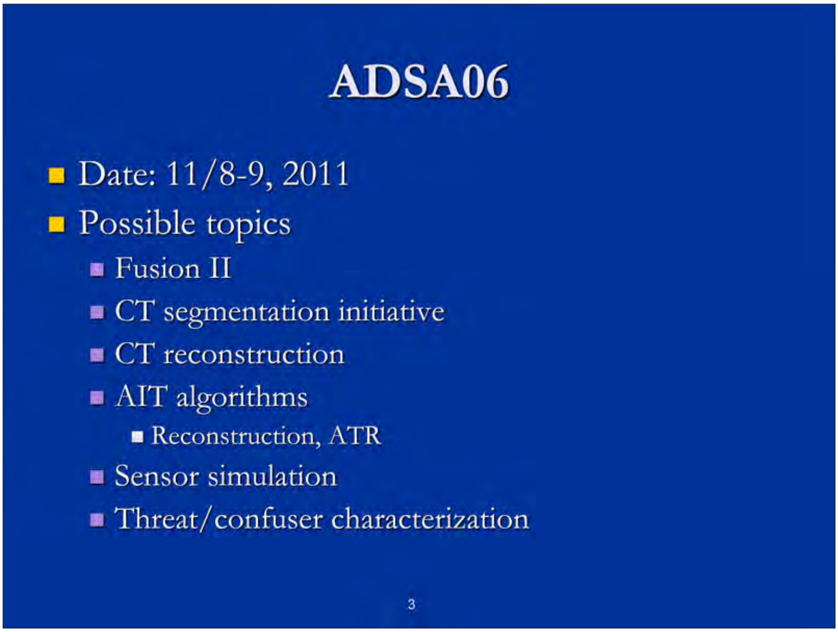
ACCUMULATED WISDOM

- IT IS NOT POSSIBLE TO OBTAIN A FERRARI BY IMPLEMENTING ENGINEERING CHANGES TO A YUGO
- CONTRARY TO PREVALENT ACQUISITION POLICY

16.19 Carl Crawford: Day 2 Objectives






ADSA06
Date: 11/8-9, 2011
Possible topics
Fusion II
CT segmentation initiative
CT reconstruction
AIT algorithms
Reconstruction, ATR
Sensor simulation
Threat/confuser characterization
3

16.20 Tim Johnson: Raman Spectroscopy

Guidelines

Your presentation can address sensors, algorithms or operational aspects of developing and deploying fused systems.

· Your second slide should be your conclusions, which should include a discussion of the applicability of your work to security.

· Present many pictures and diagrams. The feedback from previous workshops is that we need to show more images.

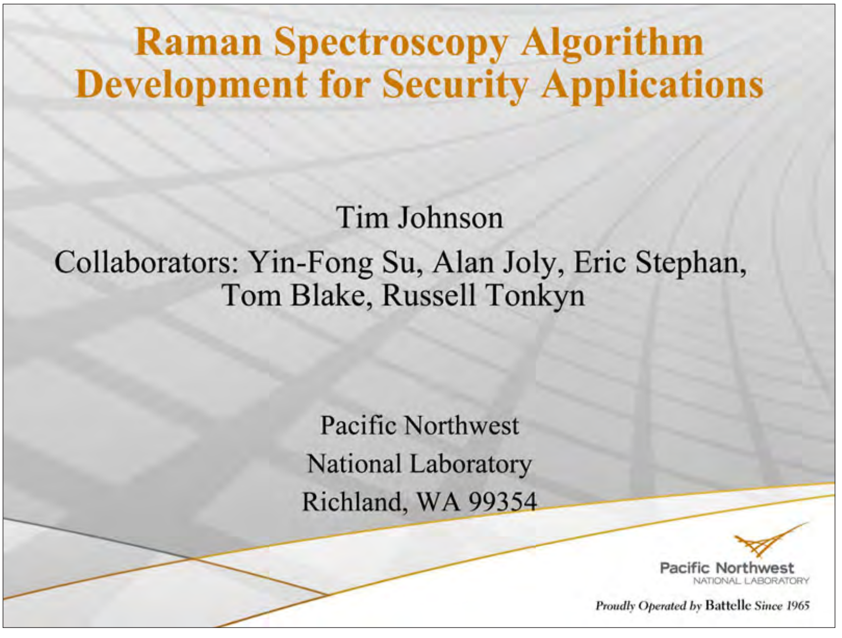
· You may include a slide about yourself or your company.

· The enclosed agenda indicates the duration of your presentation, which includes time for taking questions. Assume discussion will take place during your presentation. However, questions will be discouraged for the first ten minutes of your presentation.

· Bring your presentation on a USB memory stick in PowerPoint (PPT) or PDF. A PC will be provided with PowerPoint 2007 and Adobe Acrobat.

· It is our intent to put your presentation into the public domain. However, you will be allowed to redact some of your slides after you give your presentation.

· There will probably be duplicated material in the presentations; you may have to eliminate duplicated material in real-time.



Standoff Raman

Very Powerful Method for (standoff) solid/liquid Detection

- Data are highly specific (chemical fingerprint) – few false positives or false negatives
- Essentially any solid/liquid can be measured – explosive, chem., bio
- Inexpensive, easy to use, in theatre
- Standoff Raman demonstrated, imaging in infancy
- Need ~~smaller~~, better, faster, cheaper…
- Need more eyesafe lasers

Cons

- Raman inherently weak effect (gas)
- Interference from Daylight
- Need high power lasers and sensitive detectors
- Eyesafe? (dep. wavelength)

Pros

- No Sample preparation
- Solids, liquids much easier
- (near) Real-time analysis
- Very narrow linewidths, so great specificity, few false positives
- Light, portable, robust (now)
- Relatively inexpensive
- Standoff detection realized

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Related Optical Methods for (remote) Standoff Sensing

- Standoff: Some (large) distance from sensor to object (42 m)
- Non-contact: Smaller distance (42 cm or mm) to object
- Laser-induced breakdown spectroscopy (LIBS)
- Laser-induced fluorescence Spectroscopy (LIF)
- Mid-infrared laser imaging spectroscopy
- Mid-infrared laser acoustic spectroscopy
- THz (Terahertz) laser imaging spectroscopy
- Optical Dynamic Detection (pulse shaping) Spectroscopy

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Outline

- Some General Considerations about Optical (Laser) Methods for Remote Explosives Detection
- Laser Spectroscopic Methods
  - Raman / Stand-off Raman
  - UV Raman LIDAR
  - Laser Induced Breakdown Spectroscopy (LIBS)
- Infrared (IR) Passive and Active Methods

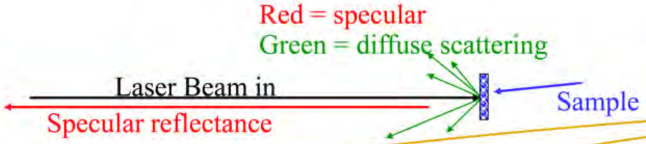
Some Considerations for (Standoff) Detection

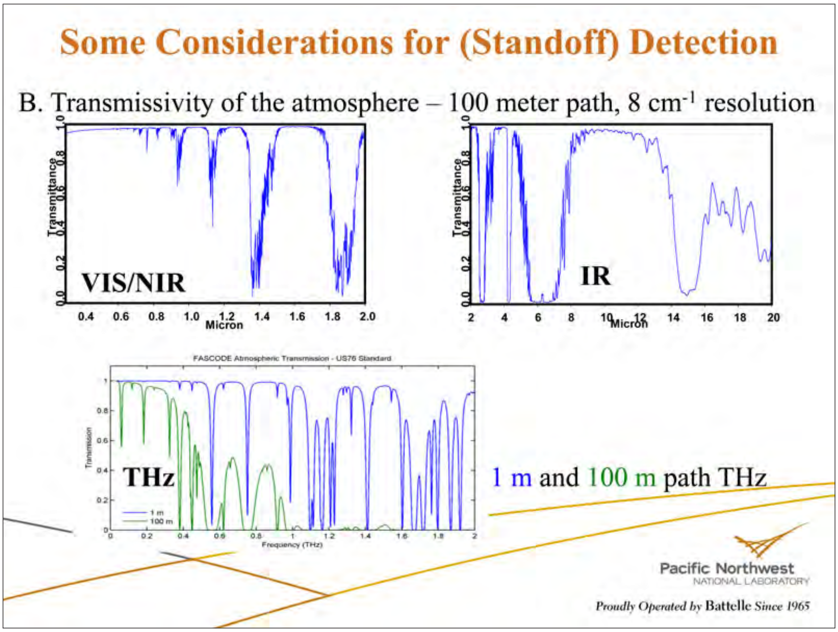
A. There is a $1/r^2$ Dependence for Return Signal

Most cases the light scattering or emission is a diffuse process

α $1/r^2$ Signal Strength

SAMPLE CAN BE ANY (solid or liquid) CHEMICAL OR MATERIAL




Some Considerations for (Standoff) Detection
B. Transmissivity of the atmosphere – 100 meter path, 8 cm-1 resolution
Transmittance
VIS/NIR
Micron
IR
Micron
FASCODE Atmospheric Transmission - US76 Standard
Transmission
THz
1 m
100 m
Frequency (THz)
1 m and 100 m path THz
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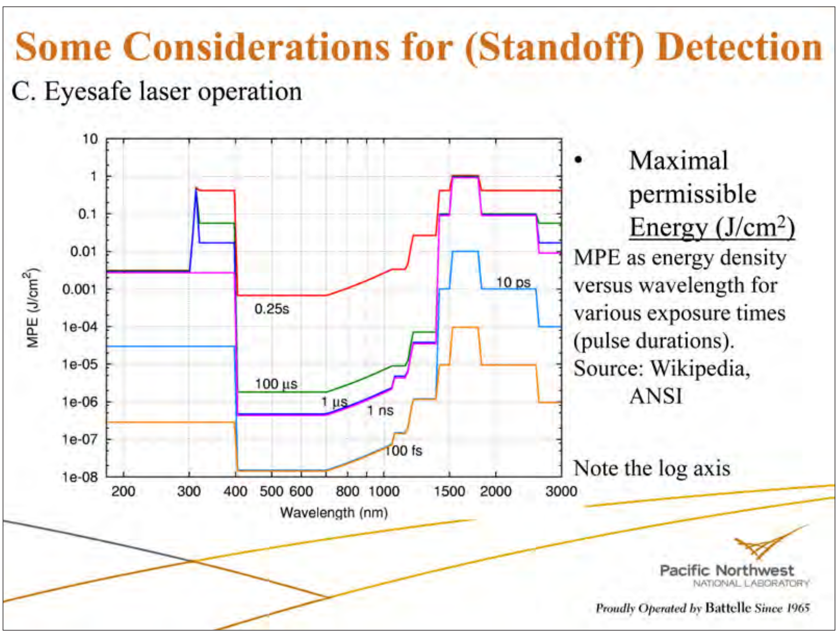
Some Considerations for (Standoff) Detection
C. Eyesafe laser operation
MPE (J/cm2)
Wavelength (nm)
0.25s
100 µs
1 µs
1 ns
10 ps
100 fs
• Maximal permissible Energy (J/cm2)
MPE as energy density versus wavelength for various exposure times (pulse durations).
Source: Wikipedia, ANSI
Note the log axis
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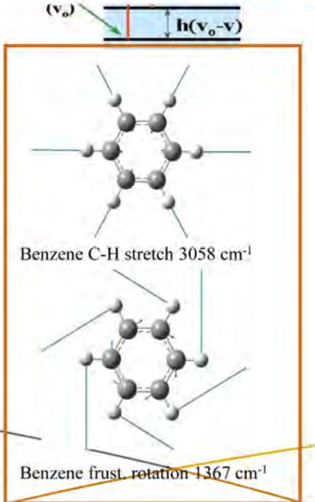
Introduction to IR/Raman: Molecular Vibrations and IR absorption



- Molecules vibrate at very discrete frequencies determined by the masses of the individual atoms and the strength of the bonds between the atoms.
- Example: H_2O – three frequencies, two stretches, one bend.
- Typical frequencies range from about 400 to 4,000 cm^{-1}, in the 10^{13} to the 10^{14} Hz range, typ. 1000 cm^{-1}
- Infrared spectroscopy is DIRECT absorption by light of same frequency – exact match of light frequency to vibrational freq.
- Raman spectroscopy is frequency difference corresponds to 1 quantum of vibration. Different selection rules IR

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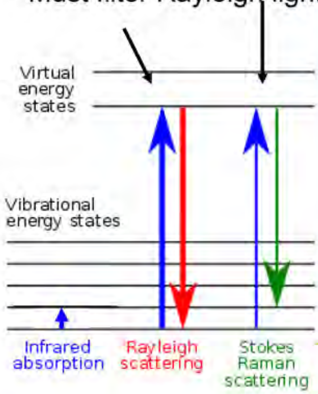
The Raman Effect

1,000,000x less Raman than Rayleigh scattering. Must filter Rayleigh light!



- Two-photon process: The Incident (laser) photon & scattered photon.
- Uses UV/Vis/NIR lasers and detectors
- Raman effect goes at $1/v^4$
- MOST (99.9999+%) of light is scattered at same frequency (Rayleigh effect) – no info. Raman effect is VERY weak!
- Need extreme care at signal collection and filtering
- For Raman effect, scattered photon usually of lower frequency.
- Frequency difference corresponds to one quantum of vibrational energy.
- Can be performed at distances
- Note: Zero background experiment

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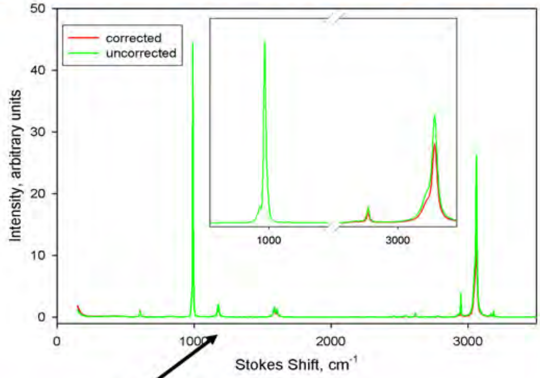
Raman Example: Benzene, note sharp lines!

Benzene Example

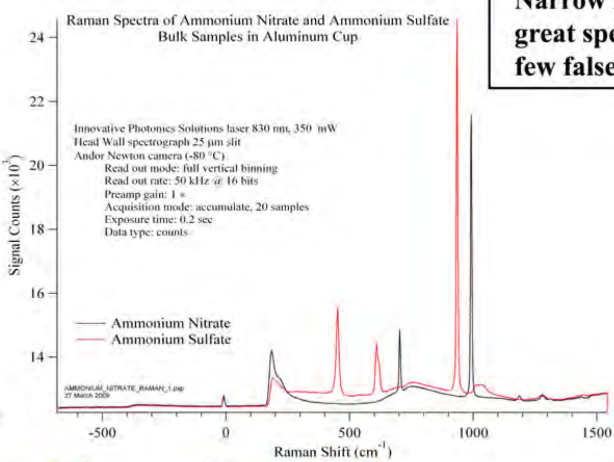
Some vibrations: Say laser frequency is at 10,000 cm^{-1}, so e.g. we see scattered light at 9,000 and 7,000 cm^{-1} frequencies that correspond to the vibrational frequencies of 1,000 and 3,000 cm^{-1}, respectively



Example peak: Light scattered at 9,000 cm^{-1} corresponds to 1,000 cm^{-1} vibrational frequency

This is an example spectrum produced by Raman Spectroscopy for a single Sample it corresponds to a chemical fingerprint.

Advantages and Disadvantages



Narrow linewidths, so great specificity, i.e. few false positives

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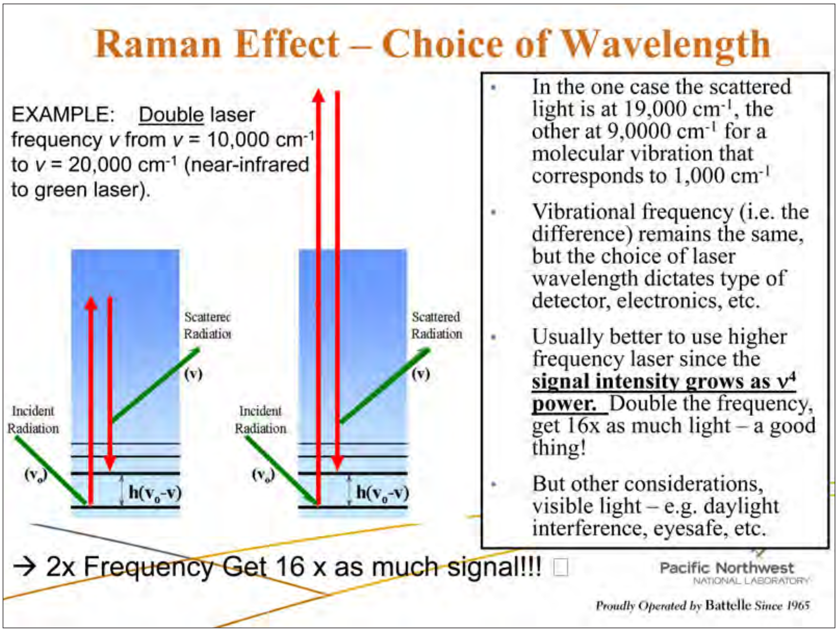
Raman Effect – Choice of Wavelength
EXAMPLE: Double laser frequency v from v = 10,000 cm-1 to v = 20,000 cm-1 (near-infrared to green laser).
Incident Radiation
(vo)
Scattered Radiation
(v)
h(vo-v)
In the one case the scattered light is at 19,000 cm-1, the other at 9,0000 cm-1 for a molecular vibration that corresponds to 1,000 cm-1
Vibrational frequency (i.e. the difference) remains the same, but the choice of laser wavelength dictates type of detector, electronics, etc.
Usually better to use higher frequency laser since the signal intensity grows as v4 power. Double the frequency, get 16x as much light – a good thing!
But other considerations, visible light – e.g. daylight interference, eyesafe, etc.
→ 2x Frequency Get 16 x as much signal!!!
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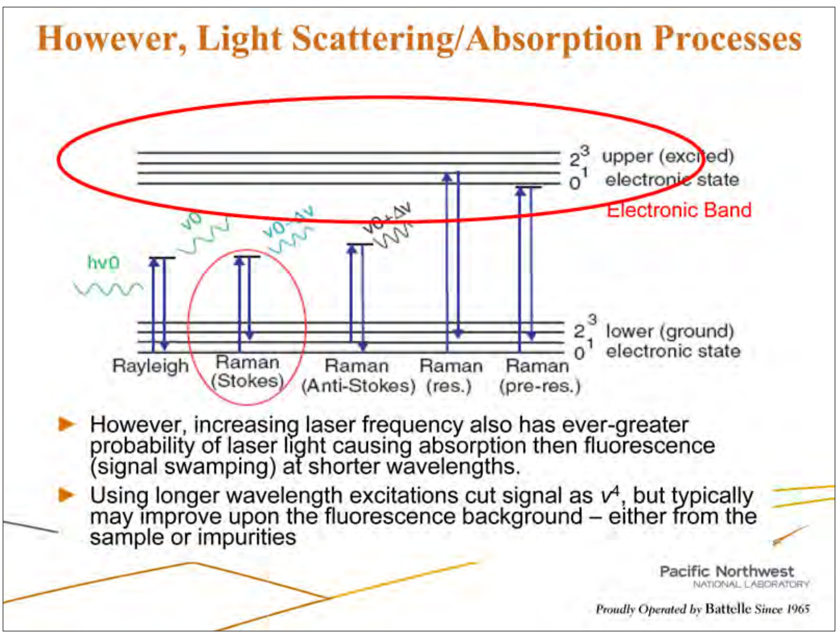
However, Light Scattering/Absorption Processes
2 3 upper (excited)
0 1 electronic state
Electronic Band
hv0
v0
v0-Δv
v0+Δv
2 3 lower (ground)
0 1 electronic state
Rayleigh
Raman (Stokes)
Raman (Anti-Stokes)
Raman (res.)
Raman (pre-res.)
However, increasing laser frequency also has ever-greater probability of laser light causing absorption then fluorescence (signal swamping) at shorter wavelengths.
Using longer wavelength excitations cut signal as v4, but typically may improve upon the fluorescence background – either from the sample or impurities
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Wavelength Selection

References:

I.R. Lewis, N.W. Daniel Jr., N.C. Chaffin, P.R. Griffiths and M.W. Tungol, *Spectrochimica Acta A,* **51,** 1985-200, (1995).

I.R. Lewis, N.W. Daniel Jr., and P.R. Griffiths, *Appl. Spec,* **51(12),** 1854-1867 (1997).

M.R. Lewis, I.R. Lewis and P.R. Griffiths *Appl. Spec,* **58(4),** 420-427 (2004).

N.W. Daniel Jr., I.R. Lewis and P.R. Griffiths, *Appl. Spec,* **51(12),** 1868-1879 (1997).

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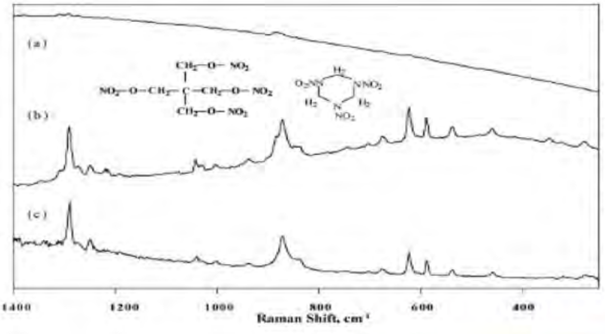
Wavelength Selection

Lewis, Griffiths *et al.*



Semtex **RAW** spectra:

785 nm – Stokes data ($12{,}700\ cm^{-1}$)

830 nm – Stokes data ($12{,}000\ cm^{-1}$)

1064 nm - anti-Stokes ($9{,}400\ cm^{-1}$)

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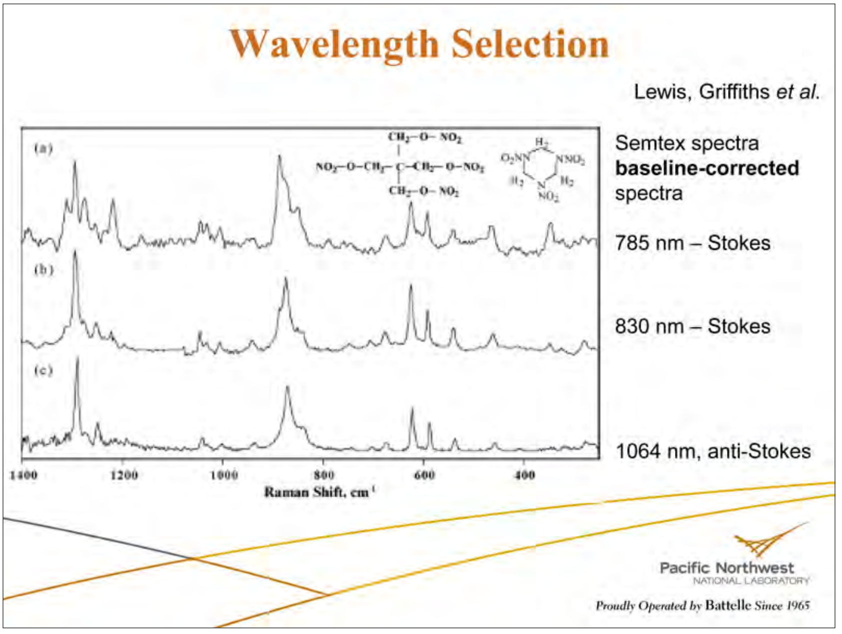
Wavelength Selection
Lewis, Griffiths et al.
Semtex spectra
baseline-corrected
spectra
785 nm – Stokes
830 nm – Stokes
1064 nm, anti-Stokes
Raman Shift, cm-1
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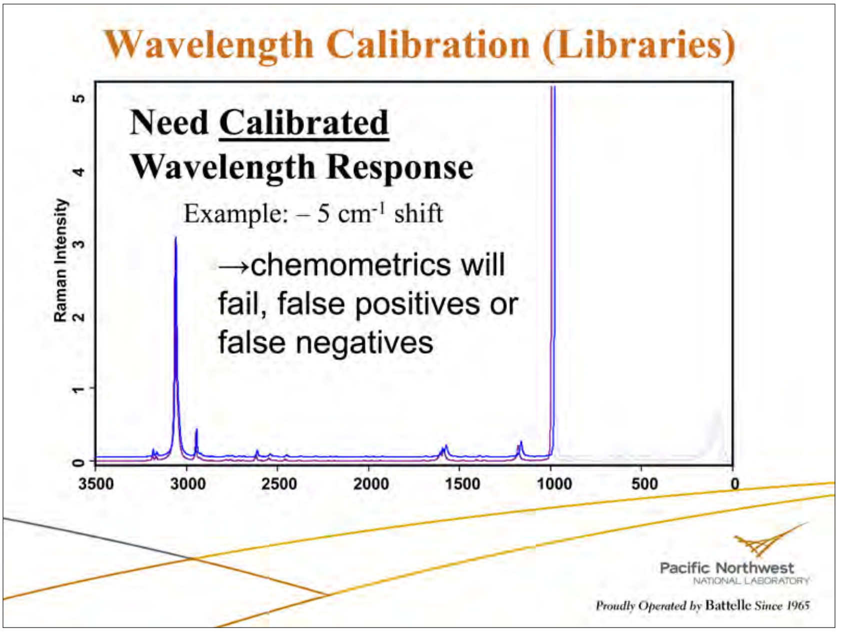
Wavelength Calibration (Libraries)
Need Calibrated
Wavelength Response
Example: – 5 cm-1 shift
→chemometrics will
fail, false positives or
false negatives
Raman Intensity
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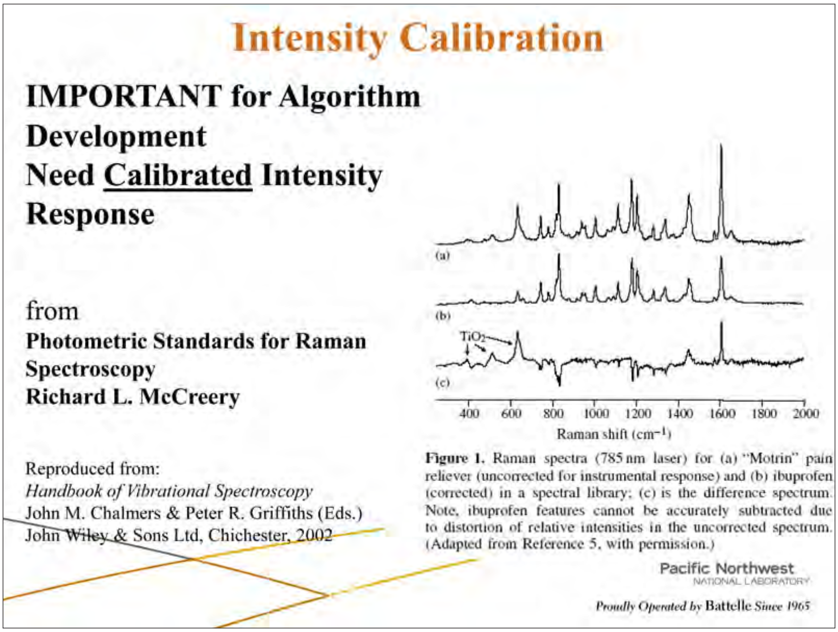
Intensity Calibration
IMPORTANT for Algorithm Development
Need Calibrated Intensity Response
from
Photometric Standards for Raman Spectroscopy
Richard L. McCreery
Reproduced from:
Handbook of Vibrational Spectroscopy
John M. Chalmers & Peter R. Griffiths (Eds.)
John Wiley & Sons Ltd, Chichester, 2002
(a)
(b)
TiO2
(c)
400 600 800 1000 1200 1400 1600 1800 2000
Raman shift (cm−1)
Figure 1. Raman spectra (785 nm laser) for (a) "Motrin" pain reliever (uncorrected for instrumental response) and (b) ibuprofen (corrected) in a spectral library; (c) is the difference spectrum. Note, ibuprofen features cannot be accurately subtracted due to distortion of relative intensities in the uncorrected spectrum. (Adapted from Reference 5, with permission.)
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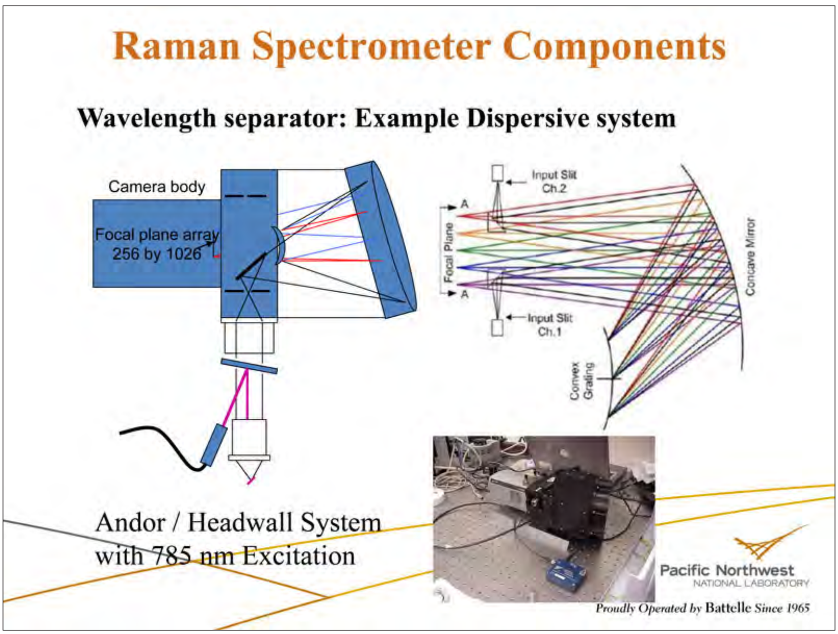
Raman Spectrometer Components
Wavelength separator: Example Dispersive system
Camera body
Focal plane array
256 by 1026
Input Slit
Ch.2
A
Focal Plane
A
Input Slit
Ch.1
Concave Mirror
Convex Grating
Andor / Headwall System
with 785 nm Excitation
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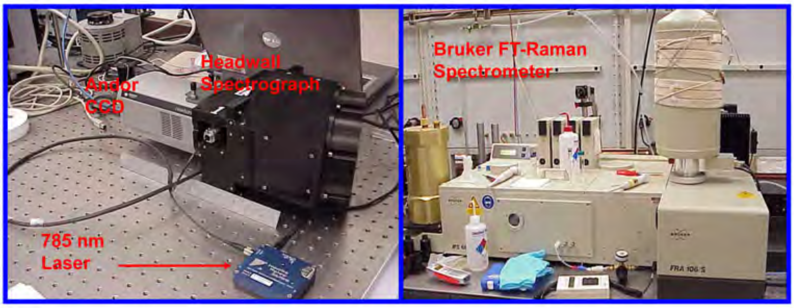
Typical (portable v. lab) Raman systems



System on left represents typical compact (industrial) type system, though some are now even smaller, and system at right represents a typical laboratory spectrometer

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Contact Raman Examples

Real World Examples: Smaller, cheaper, faster, better…

- Just a few of the newer more portable systems – no endorsements or anti-endorsements

FIBER OPTIC / INDUSTRY	PORTABLE (no fiber)	IMAGING (standoff)
Andor	Ahura FirstDefender	ChemImage
Enwave optics	B&W Tek	
Inphotonics Inphotote	DeltaNu Inspector Raman	
Kaiser Optical	ICX Technology	…. more…
Lambda Solutions	Smiths Detection	
Ocean Optics	BaySpec Raman	
Perkin Elmer (Avalon)		
Raman Explorer	…. more…	
…. more…		

Also IR for (standoff) detection……

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Raman Practical Limitations

Limitations: Weak signal, (interferent) fluorescence, drop-off with distance, reference data compatibility

A. Fluorescence problems – both analytes and impurities

B. Even though you can point the laser, the scattered Raman signal drops as $1/r^2$ with distance

C. Good reference libraries / methods are critical – need excellent wavelength calibration, good intensity calibration / portability major issue

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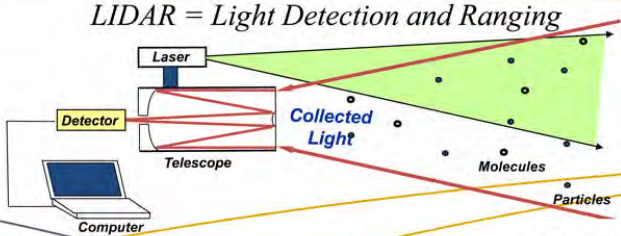
Standoff Raman- Basic Concepts
Light Detection and Ranging (LIDAR) Technique

Radar = Radio Detection and Ranging

SOURCE: Sedlacek et al.

LIDAR = Light Detection and Ranging



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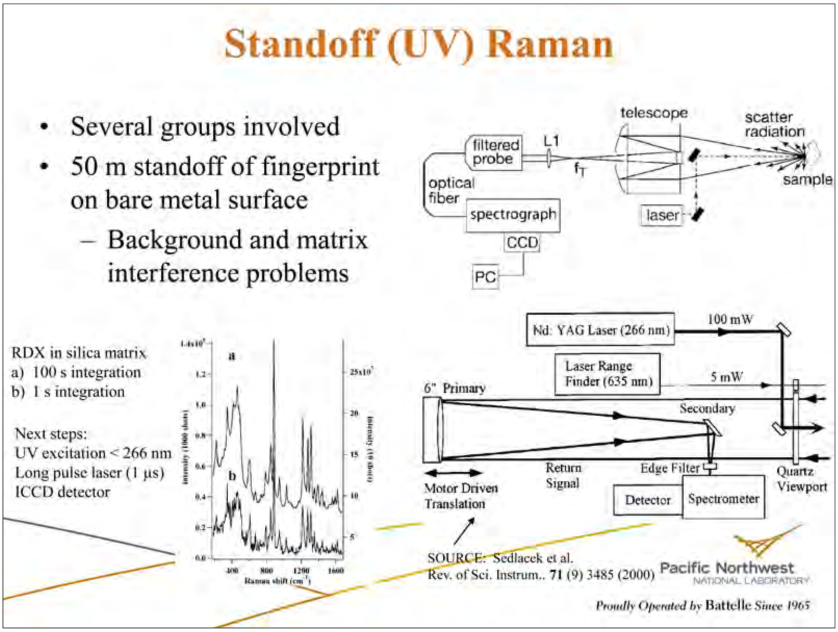
Standoff (UV) Raman
Several groups involved
50 m standoff of fingerprint on bare metal surface
Background and matrix interference problems
telescope
scatter radiation
filtered probe
L1
optical fiber
sample
spectrograph
laser
CCD
PC
RDX in silica matrix
a) 100 s integration
b) 1 s integration
Next steps:
UV excitation < 266 nm
Long pulse laser (1 µs)
ICCD detector
Raman shift (cm⁻¹)
Nd: YAG Laser (266 nm)
100 mW
Laser Range Finder (635 nm)
5 mW
6" Primary
Secondary
Motor Driven Translation
Return Signal
Edge Filter
Detector
Spectrometer
Quartz Viewport
SOURCE: Sedlacek et al.
Rev. of Sci. Instrum.. 71 (9) 3485 (2000)
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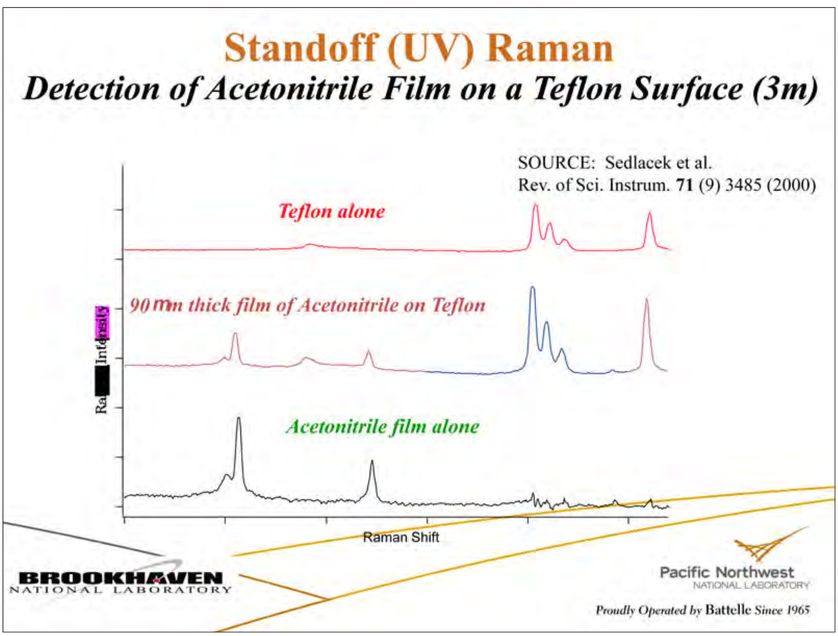
Standoff (UV) Raman
Detection of Acetonitrile Film on a Teflon Surface (3m)
SOURCE: Sedlacek et al.
Rev. of Sci. Instrum. 71 (9) 3485 (2000)
Teflon alone
90 mm thick film of Acetonitrile on Teflon
Acetonitrile film alone
Ra[redacted]Intensity
Raman Shift
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Los Alamos UV Raman System

- Los Alamos Raman system shown at right
- Excimer laser – 0.20J/pulse – 100 Hz
  - KrF – 248 nm
  - XeF – 351 nm
  - Coaxial Beam divergence – 0.4 mrad
  - Beam expanded for eye-safe operation
  - 0.15 X 0.1 m beam profile on-target
- Telescope – 24 inch F/8
- Scanner mounted for 360 degree azimuthal field of regard, +/- 15 degree elevation
- PMT detector package, replaceable with UV Spectrometer and enhanced CCD
- Day/Night operation
- Operates using standard industrial power

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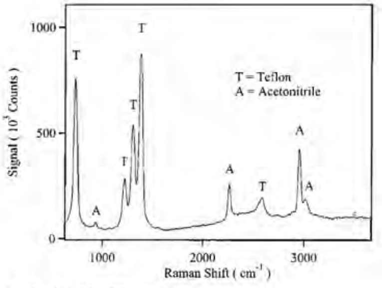
UV Raman System Concept

- Raman scattering provides direct information on the molecular structure of the sample
  - A molecular fingerprint
  - Incident light is red or blue shifted
  - UV incident light yields strongly enhanced signals
- Very limited studies of energetic materials on surfaces
  - Low power-aperture systems
  - Sufficient to estimate performance of larger systems
- Raman spectrum shown to right
  - Acetonitrile on Teflon substrate
  - 266 nm excitation energy
  - 5 second integration time
  - 3 meter range
  - Very low power-aperture system



- LANL Team
  - Sam Clegg (C-CDE)
  - Dan Cooper (D-3)
  - Raytheon

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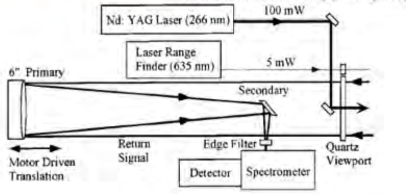
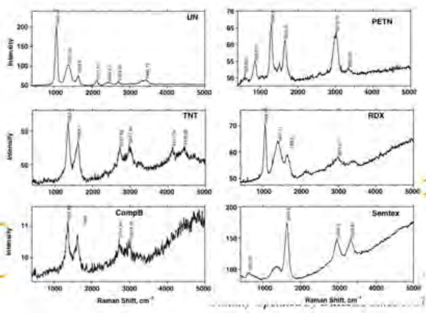
Other Standoff Raman

SOURCE: Sedlacek et al.
Rev. of Sci. Instrum. **71** (9) 3485 (2000)

- Univ. of Hawaii, Sharma, Misra et al.
  - 532 doubled Nd:YAG, compact 50 m
- C. Carter et al, LLNL gated detection to avoid daytime solar background
- Östmark, Wallin, Pettersson, Sweden
  - 532 nm at 55 meter thru snow!
- Sedlacek et al, Brookhaven Nat'l Lab
  - UV mini Raman LIDAR
  - 266 nm excitation
- Signature studies - several
- Nagli and Gaft, Israel
  - Compare several UV wavelengths
    - 785, 355, 266, 248 nm





Standoff Raman

Cons

- Raman inherently weak effect
- Interference from Daylight
- Need high power lasers and sensitive detectors
- Eyesafe? (dep. wavelength)

Pros

- No Sample preparation
- Solids, liquids much easier
- (near) Real-time analysis
- Very narrow linewidths, so great specificity, few false positives
- Light, portable, robust (now)
- Relatively inexpensive
- Standoff detection realized

Future directions

- Highly specific, better instrumentation needed, filters, detectors, lasers (NIR or UV, eyesafe).
- Raman IMAGING – just coming of age (Chemimage)
- smaller, better, faster, cheaper…
- Any material: explosives, chem, bio, rad

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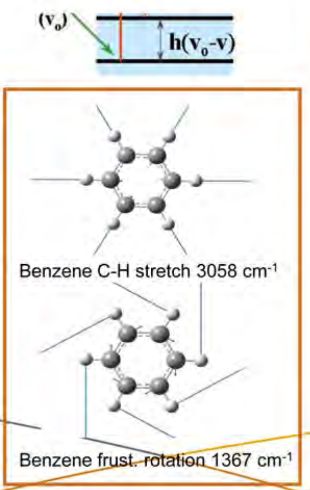
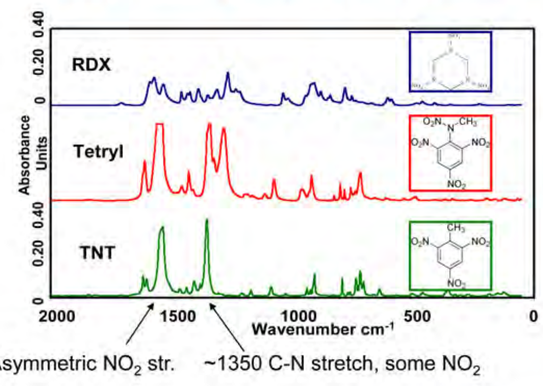
IR Standoff Absorption/Reflection Spectroscopy



- Molecules vibrate at very discrete frequencies determined by the masses of the individual atoms and the strength of the bonds between the atoms.
- Example: H_2O – three frequencies, two stretches, one bend.
- Typical frequencies range from about 400 to 4,000 cm^{-1}, in the 10^{13} to the 10^{14} Hz range, typ. 1000 cm^{-1}
- Infrared spectroscopy is DIRECT absorption by light of same frequency – exact match of light frequency to vibrational freq.

IR Solid-phase Detection



Many of the IR methods either probe/excite or image the strong bands near 1350 and 1550 cm^{-1}, but these can pose problems from vapor phase H_2O lines, sometimes 900 or 1000 cm^{-1} band used

Passive IR Imaging

NO lasers! Use passive downwelling radiation (skyshine) to create ΔT difference for signal

Bruker OPAG 22 sensor, Telops FIRST imager
Standoff distances 14, 31 and 51 meters
Tom Blake, PI

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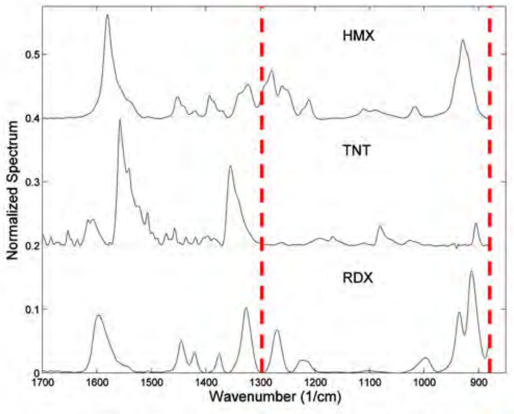
Laboratory Reflection Spectra for Target Detection



Telops operation range between red-dashed lines.

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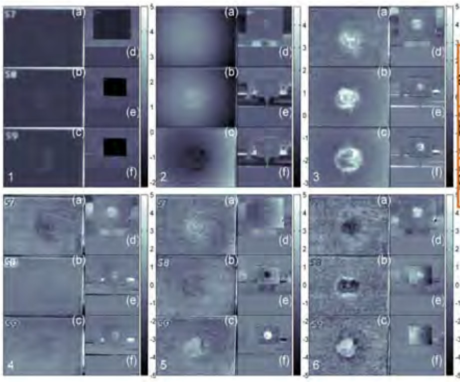
RDX on Metal Plates Field Experiments: General Anomaly Detection



a. 14 m, 16 mg/cm^2	d. 31 m, 40 mg/cm^2
b. 14 m, 40 mg/cm^2	e. 51 m, 40 mg/cm^2
c. 14 m, 90 mg/cm^2	f. 51 m, 90 mg/cm^2

"Passive standoff detection of RDX residues on metal surfaces via infrared hyperspectral imaging"
T.A. Blake et al., Anal. Bioanal. Chem. (2009) 395:337–348

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IR – Summary

Pros

- Standoff detection realized 50m+
- No Sample preparation
- Solids, liquids much easier
- Imaging, both laser and passive
- Passive – NO lasers, or many (eyesafe) IR lasers.
- Light, portable, robust (now)
- QC systems not too expensive

Cons

- IR is naturally a 2- beam experiment – need to deal with background
- Passive imaging expensive
- Works best bare metal surface
- HEs: Low VPs for gas sensing

Future directions

- More sensitive IR detectors needed, more powerful IR lasers, most at >1.4 μm are very eyesafe
- IR IMAGING – rapidly coming of age
- smaller, better, faster, cheaper…

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Backup Slides – OTHER METHODS

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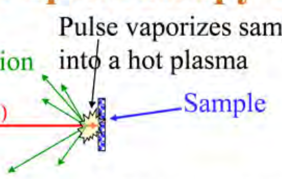
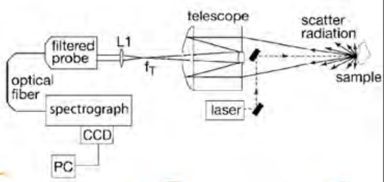
Laser-Induced Breakdown Spectroscopy-LIBS



- Similar instrumentation to Raman
- Thermally ablate the sample, create plasma – look at emission spectra of atomic and molecular fragments (ions) mostly small…..
- Background and matrix interference problems – double pulsing helps these problems
- Demonstrated standoff of > 40m!

See e.g.: F.C. De Lucia, Gottfried, Miziolek et al., Ex: Spectrochim Acta B. **62:** 1405-1411



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Laser-Induced Breakdown Spectroscopy-LIBS

- Also known as laser induced plasma spectroscopy
- Full spectral window (200-1000 nm) can provide a fingerprint
  - Mostly atomic fragment emission
  - Timing can reduce interference from plasma emission
- Demonstrated simultaneous Raman/LIBS
- Eyesafe lasers an issue? Detonation for shock-sensitive?

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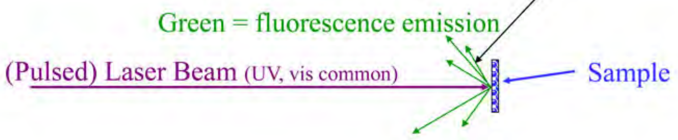
Standoff Detection: Laser Induced Fluorescence LIF

Pulse stimulates fluorescence
in solid sample – strong phenomenon
but broad peaks for large molecules



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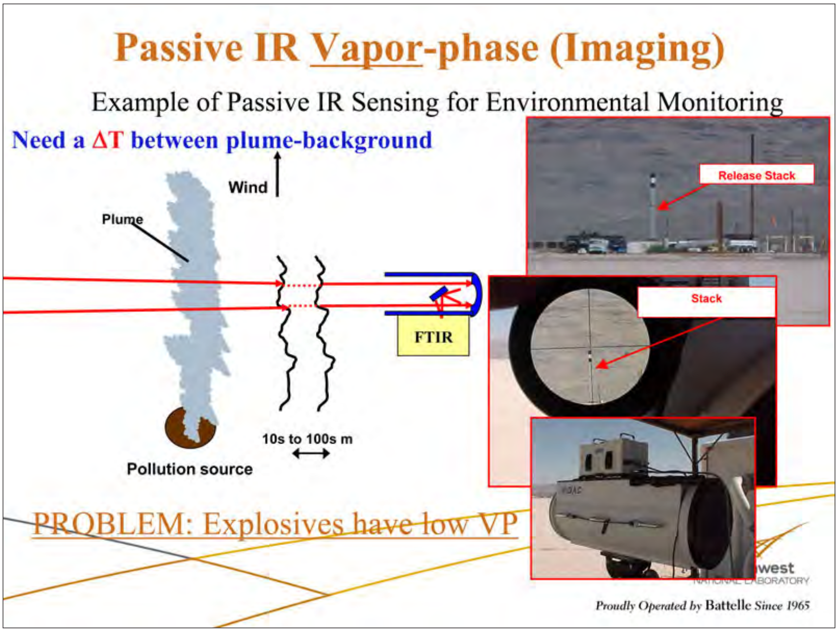
Passive IR Vapor-phase (Imaging)
Example of Passive IR Sensing for Environmental Monitoring
Need a ΔT between plume-background
Wind
Plume
FTIR
Release Stack
Stack
10s to 100s m
Pollution source
PROBLEM: Explosives have low VP
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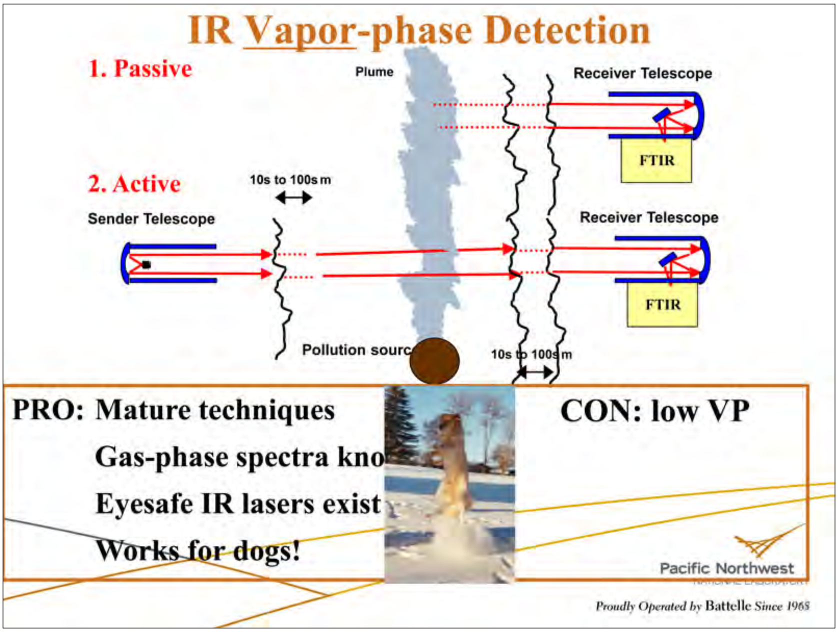
IR Vapor-phase Detection
1. Passive
Plume
Receiver Telescope
FTIR
2. Active
10s to 100s m
Sender Telescope
Receiver Telescope
FTIR
Pollution sourc
10s to 100s m
PRO: Mature techniques
Gas-phase spectra kno
Eyesafe IR lasers exist
Works for dogs!
CON: low VP
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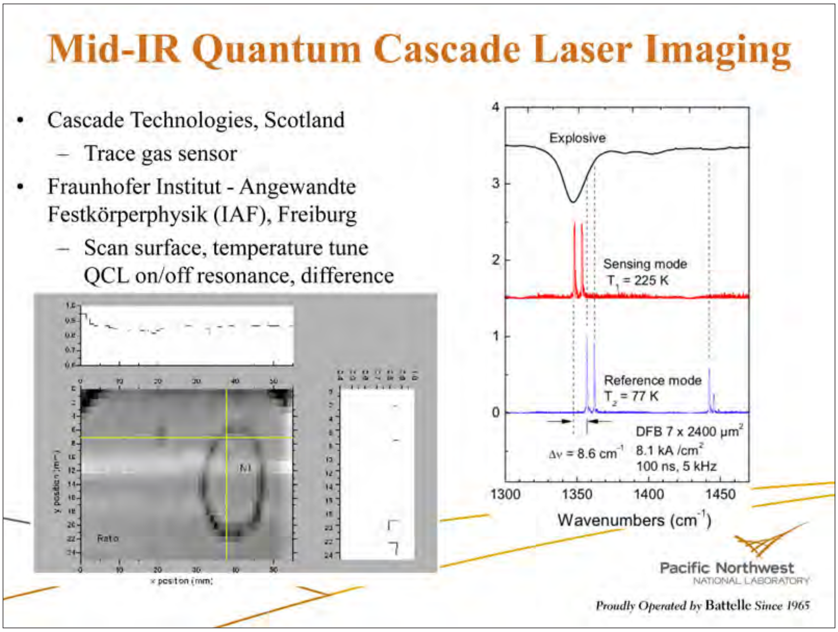
Mid-IR Quantum Cascade Laser Imaging
• Cascade Technologies, Scotland
– Trace gas sensor
• Fraunhofer Institut - Angewandte Festkörperphysik (IAF), Freiburg
– Scan surface, temperature tune QCL on/off resonance, difference
Explosive
Sensing mode
T_1 = 225 K
Reference mode
T_2 = 77 K
DFB 7 x 2400 µm²
Δν = 8.6 cm⁻¹
8.1 kA /cm²
100 ns, 5 kHz
1300
1350
1400
1450
Wavenumbers (cm⁻¹)
x position (mm)
y position (mm)
Ratio
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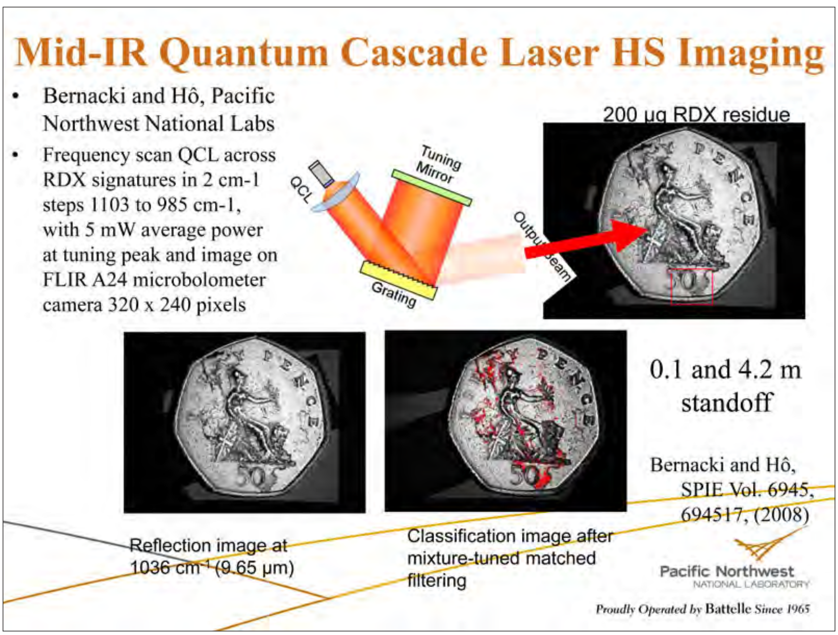
Mid-IR Quantum Cascade Laser HS Imaging
• Bernacki and Hô, Pacific Northwest National Labs
• Frequency scan QCL across RDX signatures in 2 cm-1 steps 1103 to 985 cm-1, with 5 mW average power at tuning peak and image on FLIR A24 microbolometer camera 320 x 240 pixels
QCL
Tuning Mirror
Grating
Output beam
200 µg RDX residue
0.1 and 4.2 m standoff
Bernacki and Hô, SPIE Vol. 6945, 694517, (2008)
Reflection image at 1036 cm⁻¹ (9.65 µm)
Classification image after mixture-tuned matched filtering
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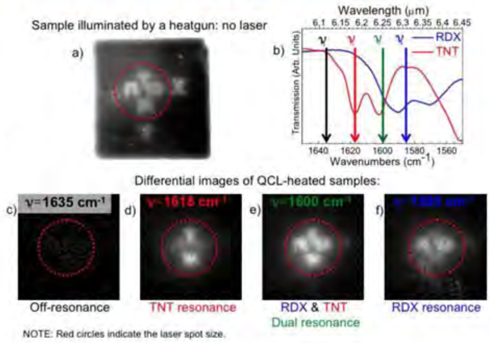
Mid-IR QCL Photothermal Detection

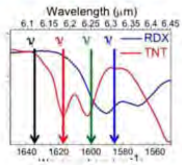
- Chris Kendziora et al. NRL
  - Illuminate surface, alternate QCL on/off resonance, detect thermal emission

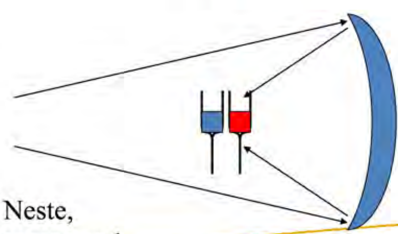


Mid-IR QCL Photoacoustic Detection

Thomas Thundat et al. Oak Ridge NL

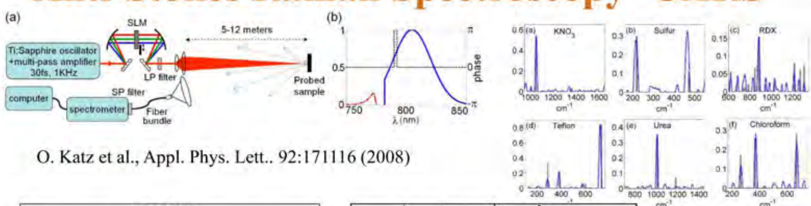
- Focus 2 (or more) IR lasers on surface at IR absorptions, the specularly reflected IR light is focused onto two tuning forks that detect the acoustic signal generated by IR absorption that generates pressure difference



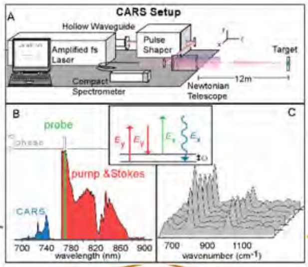


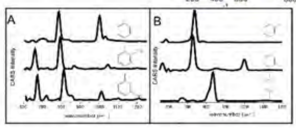
Van Neste, Senesac and Thundat, Analytical Chem. 81, 1952, (2009)

Nonlinear Spectroscopies – Coherent Anti-Stokes Raman Spectroscopy -CARS



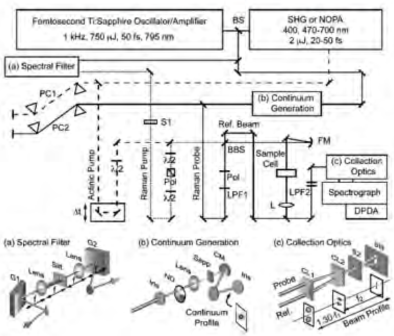
O. Katz et al., Appl. Phys. Lett.. 92:171116 (2008)

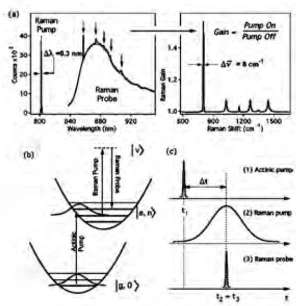




H.W. Li et al., Optics Express 16:5499 (2008)

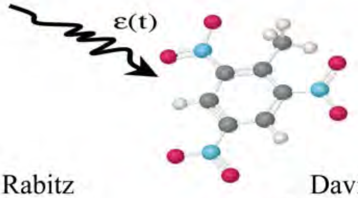
Nonlinear Spectroscopies - fSRS





D.W. McCamant et al., Rev. Sci.. Instr. 75:4971 (2004)

Optimal Dynamic Detection of Explosives (ODD-EX) with Shaped Laser Pulses as Photonic Reagents



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Princeton University

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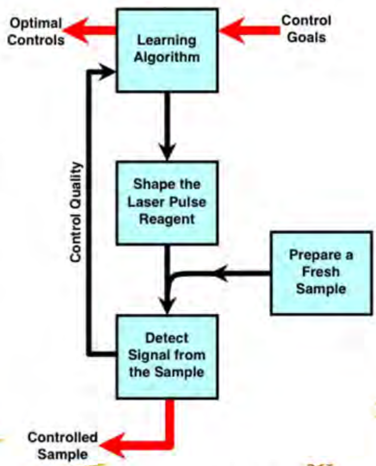
How is Quantum Control Optimized?

- Closed loop adaptive machine using tailored laser pulses as photonic reagents
  - A shaped ultrashort laser pulse excites the sample
  - A suitable detection scheme measures the effect of the particular pulse on the sample (the fitness function)
  - The signal is fed back to the learning algorithm
  - The learning algorithm proposes a new excitation pulse shape
  - The process repeats to maximize the fitness function
  - Adaptive learning is fast and efficient
    - Minutes to hours
  - Process designed in 1992
  - First demonstrations in 1997
  - 70 labs worldwide have capability and are applying to a wide variety of problems



Princeton University

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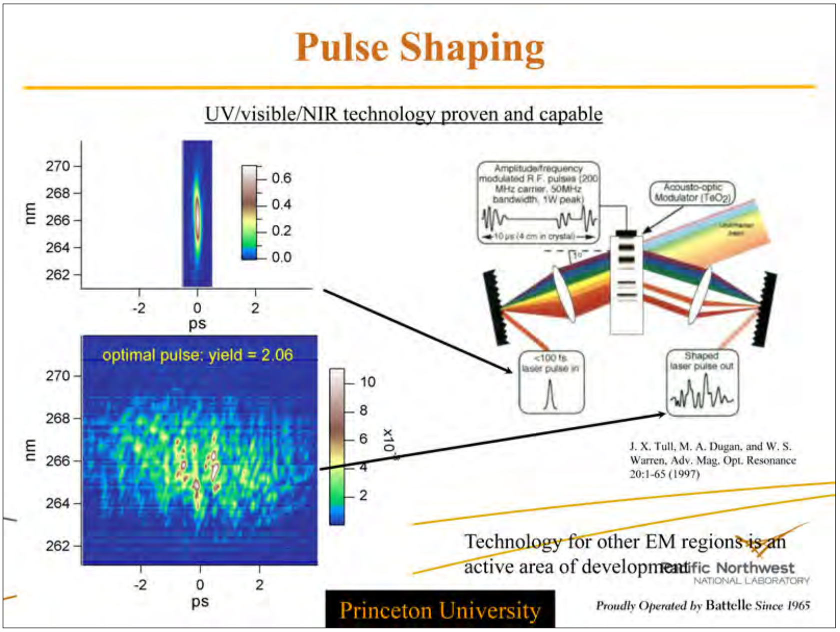
Pulse Shaping
UV/visible/NIR technology proven and capable
optimal pulse: yield = 2.06
J. X. Tull, M. A. Dugan, and W. S. Warren, Adv. Mag. Opt. Resonance 20:1-65 (1997)
Technology for other EM regions is an active area of development
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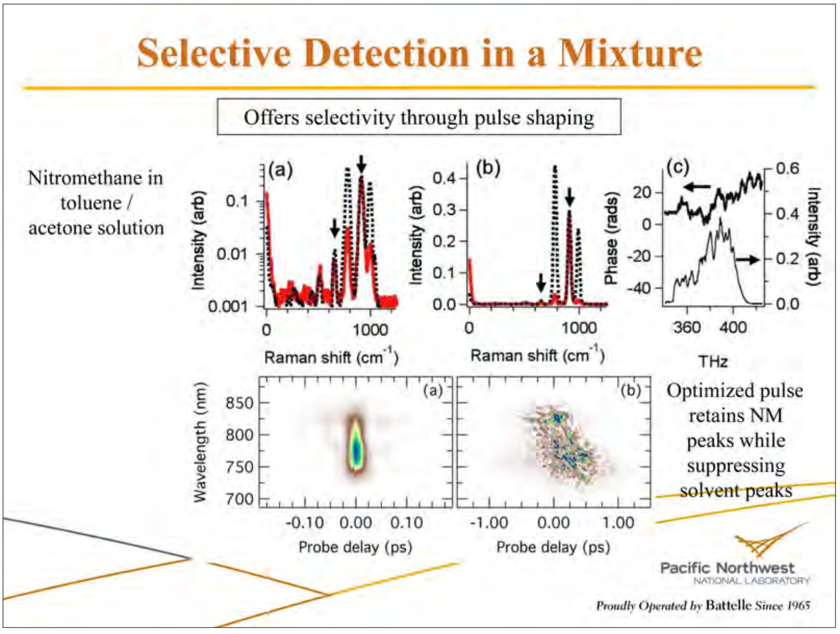
Selective Detection in a Mixture
Offers selectivity through pulse shaping
Nitromethane in toluene / acetone solution
Raman shift (cm-1)
Probe delay (ps)
Wavelength (nm)
Optimized pulse retains NM peaks while suppressing solvent peaks
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Acknowledgments

We thank our USG sponsors for funding the PNNL works.

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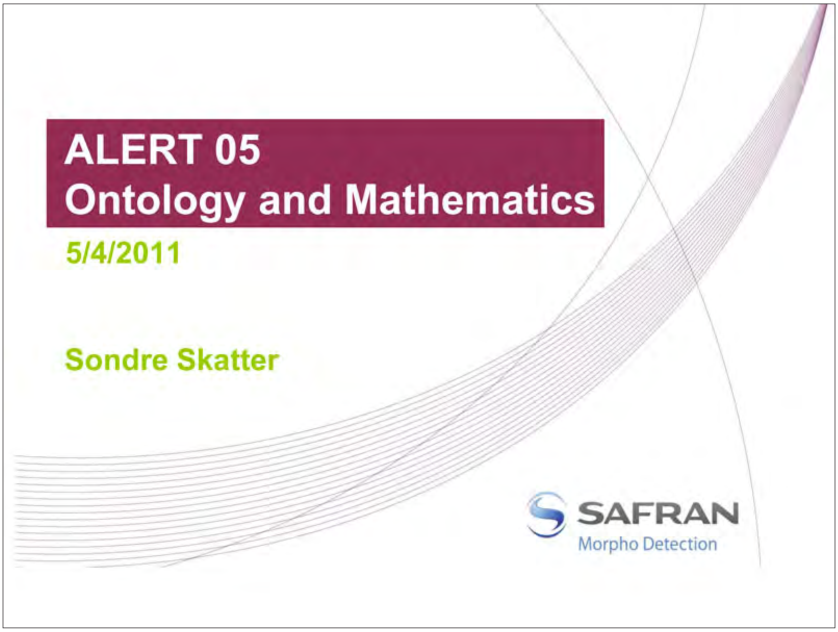
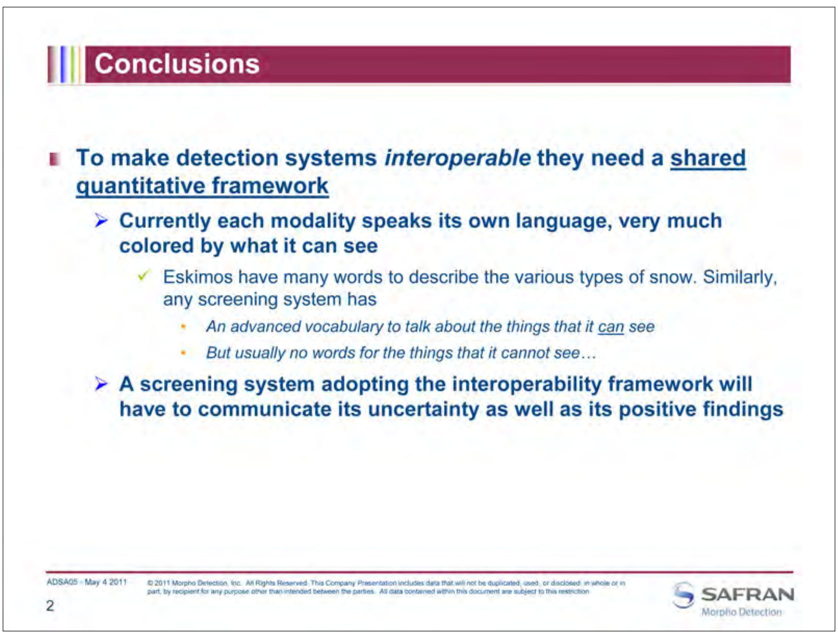
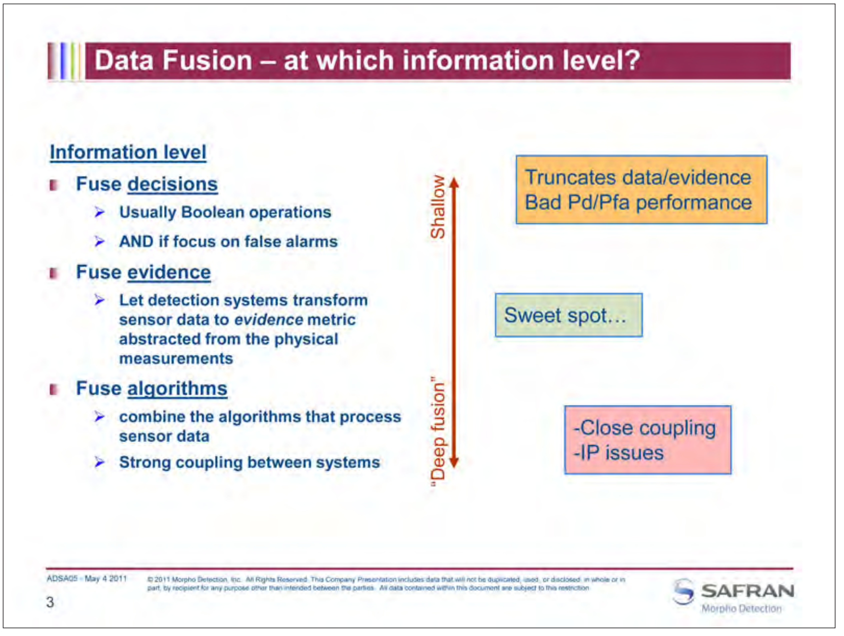
16.21 Sondre Skatter: Ontology for connecting classifiers






Data Fusion – at which information level?
Information level
Fuse decisions
Usually Boolean operations
AND if focus on false alarms
Fuse evidence
Let detection systems transform sensor data to evidence metric abstracted from the physical measurements
Fuse algorithms
combine the algorithms that process sensor data
Strong coupling between systems
Shallow
"Deep fusion"
Truncates data/evidence
Bad Pd/Pfa performance
Sweet spot…
-Close coupling
-IP issues
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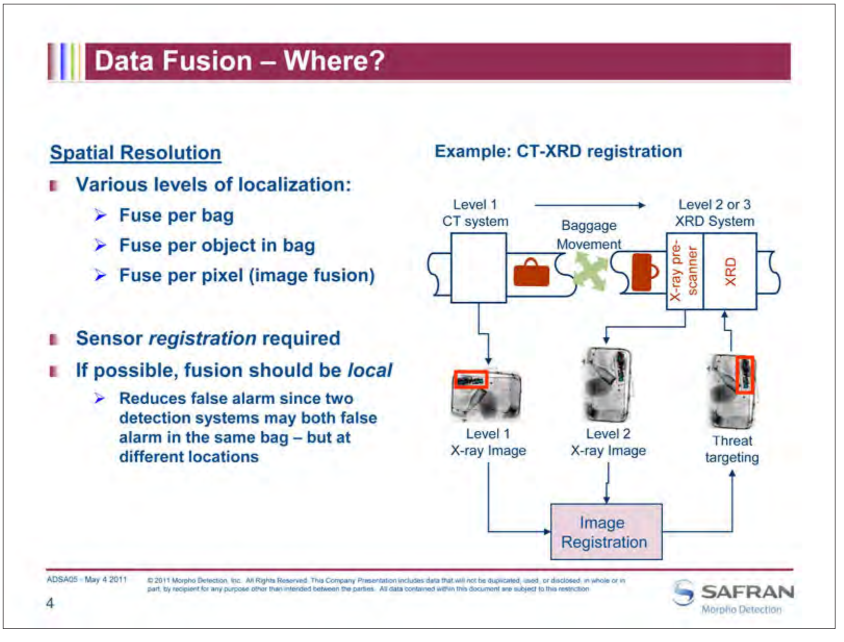
Morpho Detection


Data Fusion – Where?
Spatial Resolution
Various levels of localization:
Fuse per bag
Fuse per object in bag
Fuse per pixel (image fusion)
Sensor registration required
If possible, fusion should be local
Reduces false alarm since two detection systems may both false alarm in the same bag – but at different locations
Example: CT-XRD registration
Level 1
CT system
Baggage
Movement
Level 2 or 3
XRD System
X-ray pre-scanner
XRD
Level 1
X-ray Image
Level 2
X-ray Image
Threat
targeting
Image
Registration
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Morpho Detection

MDI Lessons Learned from Data Fusion

Prerequisites for Data Fusion Development:

1. Core sensor knowledge for <u>both</u> systems
   - Full cooperation from sensor experts and algorithm people
2. Access to threat and false alarm data
   - <u>Joint</u> data collection desirable for test & validation

- **Both conditions requires tapping into IP**
  - **Difficult playing field between manufacturers**
- **Could two vendors make the needed contributions without sharing IP?**
  - **With a shared framework, sure**

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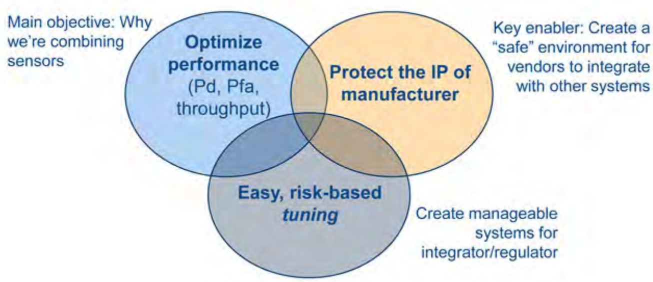
Goal: Data Fusion framework

<u>Three main objectives</u>



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Ontology…

- Ontology, from Wikipedia
  - *…formal representation of knowledge as a set of concepts within a domain, and the relationships between those concepts*
  - *An ontology provides a shared vocabulary, which can be used to model a domain — that is, the type of objects and/or concepts that exist, and their properties and relations.*
- For our problem, the ontology entails:
  - Threat vectors (bag, person, etc.)
  - Threat types
    - Threat subcategories
  - Sensors, detection systems
  - Detection *capability* of a sensor
  - Evidence for a given scan
  - The mathematics to combine evidence from different sources

Also: ontology is the philosophical study of the nature of being, existence or reality as such

… we won't go there

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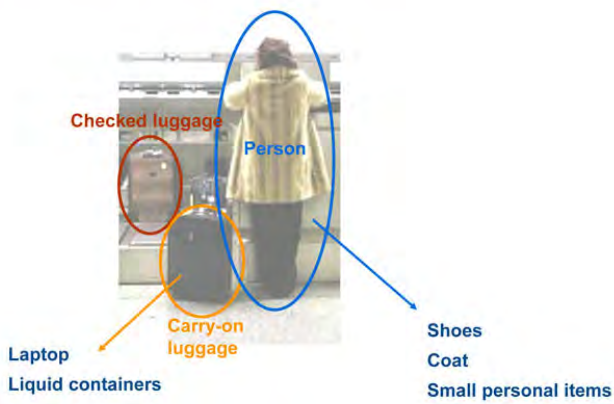
Vector: Scan Object



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Threat Space – valid threat scenarios

- **Threat space: the types of threats deemed likely**
- **For aviation security: mainly explosives and weapons**
  - ✓ neglecting weapons of mass destruction for now

Threat	Sub-category
Explosive	E_1
	…
	E_n
Weapons	Guns
	Blades

	BAG	LAPTOPS	COATS	SHOES	SMALL PERSONAL EFFECTS	LIQUID CONTAINER	PERSON	CHECKED BAG
Explosives	1	1	1	1	0	1	1	1
Guns	1	1	1	0	0	0	1	0
Blades	1	1	1	1	1	0	1	0

1 Valid threat scenario
0 Unlikely/invalid threat scenario

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Sensors

- **In the ontology a sensor can be characterized by**
  - ➢ **What type of objects it can scan**
  - ➢ **What types of threats it can detect**

Capability Matrix for a CT based EDS

	Checked bags	Carry-on bags & items	Liquid container	Shoes	Person
E_1	✓	✓	✓	✓	x
…	✓	✓	✓	✓	x
E_n	✓	✓	✓	✓	x
Gun	x	x	x	x	x
Blades	x	x	x	x	x

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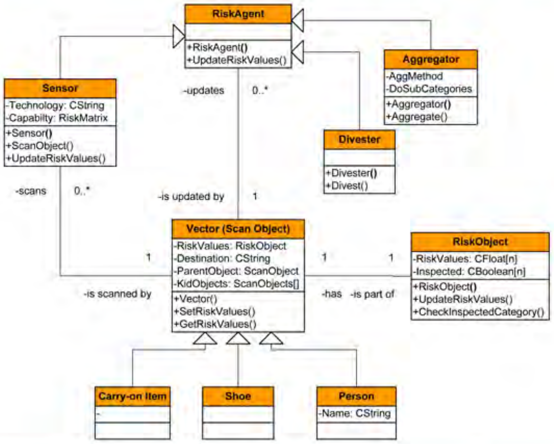
Risk and scan data

- For each scan object:
  - The relevance of each threat type (from previous page)
  - Risk/Evidence data
  - Inspected?
    - More on this when we get to the mathematics…

Threat/risk status in a checked bag

Threat category	Threat relevant in vector?	Risk value	Inspected? Has the object been screened with a sensor capable of detecting this threat category?
E_1	✓	43%	✓
…	✓	10%	✓
E_n	✓	20%	x
Gun	x	-	-
Blades	x	-	-

Concepts and relationships for the security ontology



The Mathematics

- There are several evidence frameworks
  - Bayesian
  - Dempster-Shafer
  - Possibility theory (extension of fuzzy logic)
  - Probability theory
- Must capture:
  - Probability/evidence assessed by sensor
  - Lack of evidence
  - Capability
    - If you ask someone a question, and
      - *Don't get an answer, vs*
      - *Get the answer: "I don't know"*
      - *Is there a difference?*
      - *Or, was the person competent on the subject to begin with?....*
      - *These are all analogous to the issues at hand*

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The mathematics – choice of theory

	Bayesian	Dempster-Shafer	Possibility theory
Required Input	Likelihoods for scan result given threat type (Pd, Pfa, etc)	In addition to Bayesian likelihoods, also joint likelihoods of combination of threats	??
Basic concepts	Probability	Belief & Plausibility	Possibility & Necessity
Priors	Must be defined	Not required	??
Captures various types of uncertainty			
Ease of adoption	Easy	Moderate	Moderate
Ease of interpretation	Easy	Harder	Harder

- Bayesian theory easy to apply because
  - Required input are naturally determined in typical security tests and algorithm development
    - Eg. Pd, Pfa, or histograms for features
  - Additional input and characterizations needed for the other theories
- Bayesian probability easy to interpret
  - compared to belief, plausibility, possibility and necessity
- Disadvantages of Bayesian framework
  - Requires prior probabilities
  - Does not distinguish well between different types of uncertainty
    - This is mitigated by adding capability and inspected property on top of the Bayesian probability

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Bayesian probability for security

Operational scenario: scan a bag

Given:
Sensor response, *X*

Unknown:
The truth: bomb (*B*) or not?

Desired:
Probability that bag contains a threat given the sensor response

$P(B \mid X)$

Data collection/training scenario

Measure sensor response over a representative sample of
- Threats
- Non-threats

Given:
The truth (type of threat, if any)

Output:
Likelihood distribution of sensor response given each possible truth

$P(X \mid B) \quad P(X \mid \bar{B})$

Bayes' rule:

$$P(B \mid X) = \frac{P(X \mid B)P(B)}{P(X \mid B)P(B) + P(X \mid \bar{B})P(\bar{B})}$$

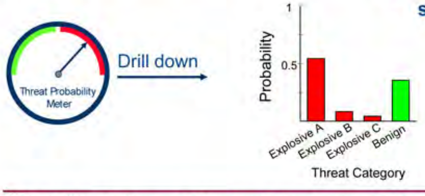
More on the Bayesian adaptation

- **Extend to sub-categories**
  - Explosive types, E_1, E_n and benign, E_0

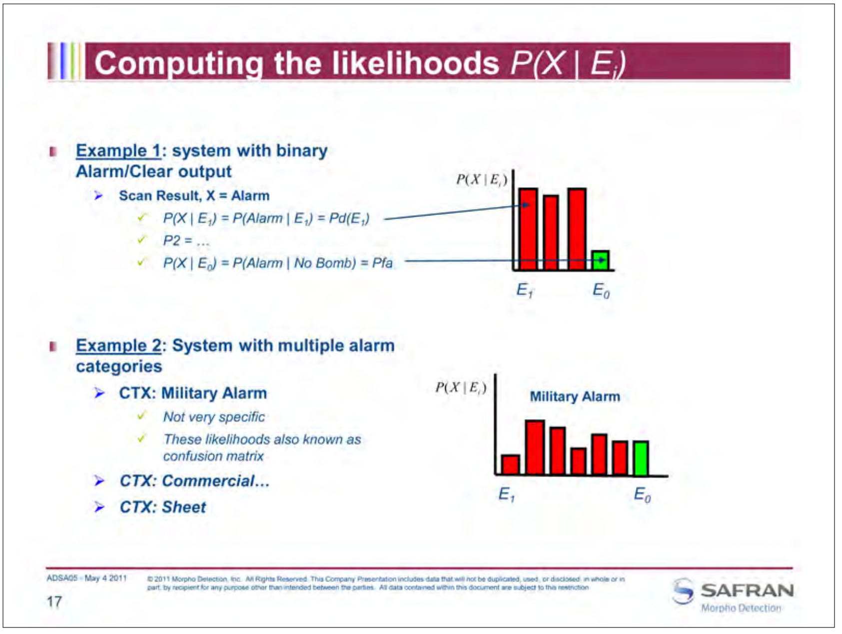
Bayes' rule:

$$P(E_i \mid X) = \frac{P(X \mid E_i)P(E_i)}{\sum_{j=0}^{n} P(X \mid E_j)P(E_j)}$$

- **Visual representation**



- **Prior probabilities**
  - **Initial values can be seen as a bootstrap**
  - **Can also choose a realistic priors based on assessed risk of terror attack**
    - No big advantage
    - Very small nominal values
- **Still a degree of freedom in selecting alarm/clear threshold**


Computing the likelihoods P(X | Ei)
Example 1: system with binary Alarm/Clear output
Scan Result, X = Alarm
P(X | E1) = P(Alarm | E1) = Pd(E1)
P2 = …
P(X | E0) = P(Alarm | No Bomb) = Pfa
P(X | Ei)
E1
E0
Example 2: System with multiple alarm categories
CTX: Military Alarm
Not very specific
These likelihoods also known as confusion matrix
CTX: Commercial…
CTX: Sheet
P(X | Ei)
Military Alarm
E1
E0
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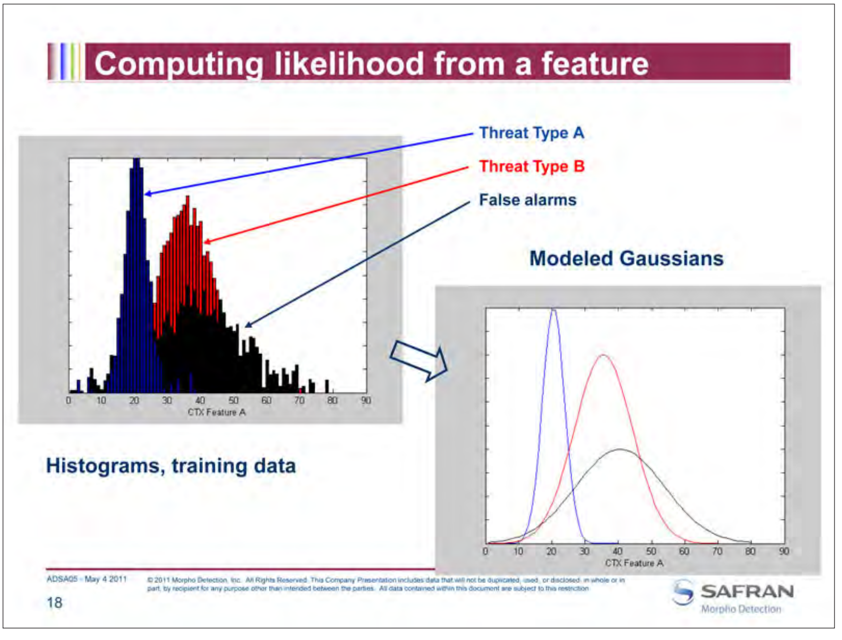
Computing likelihood from a feature
Threat Type A
Threat Type B
False alarms
Modeled Gaussians
0 10 20 30 40 50 60 70 80 90
CTX Feature A
Histograms, training data
0 10 20 30 40 50 60 70 80 90
CTX Feature A
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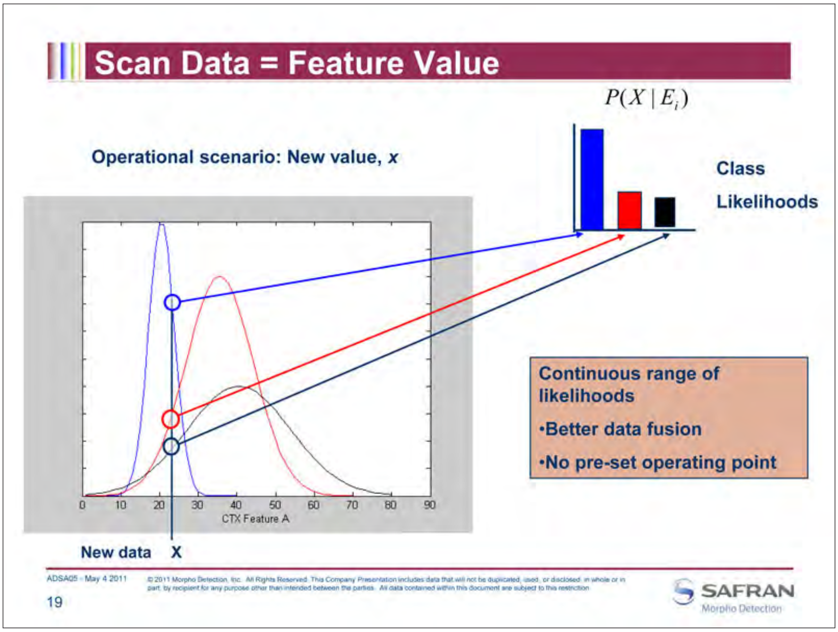
Scan Data = Feature Value
$P(X \mid E_i)$
Operational scenario: New value, x
Class
Likelihoods
Continuous range of likelihoods
•Better data fusion
•No pre-set operating point
0 10 20 30 40 50 60 70 80 90
CTX Feature A
New data X
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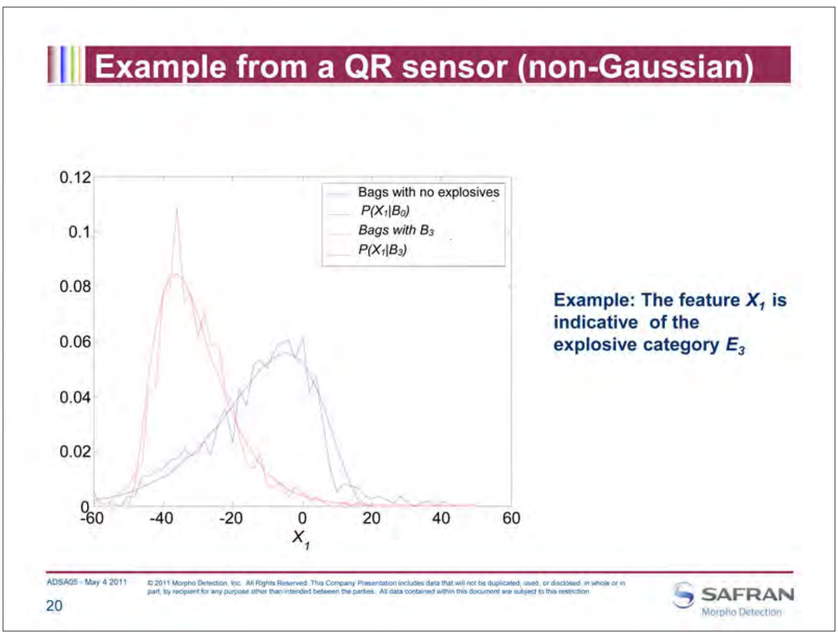
Example from a QR sensor (non-Gaussian)
0.12
0.1
0.08
0.06
0.04
0.02
0
-60 -40 -20 0 20 40 60
X_1
Bags with no explosives
$P(X_1|B_0)$
Bags with B_3
$P(X_1|B_3)$
Example: The feature X_1 is indicative of the explosive category E_3
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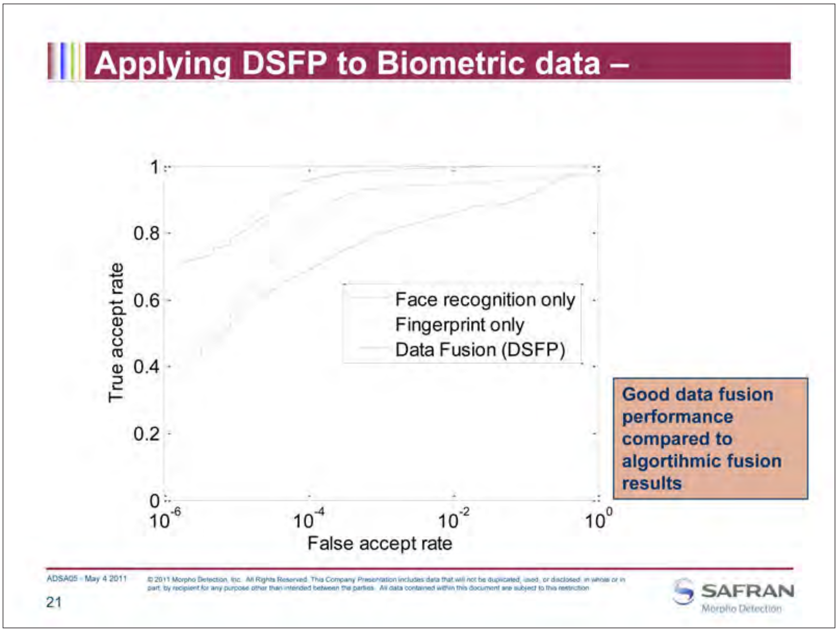
Applying DSFP to Biometric data –
True accept rate
1
0.8
0.6
0.4
0.2
0
10^{-6}
10^{-4}
10^{-2}
10^{0}
False accept rate
Face recognition only
Fingerprint only
Data Fusion (DSFP)
Good data fusion performance compared to algortihmic fusion results
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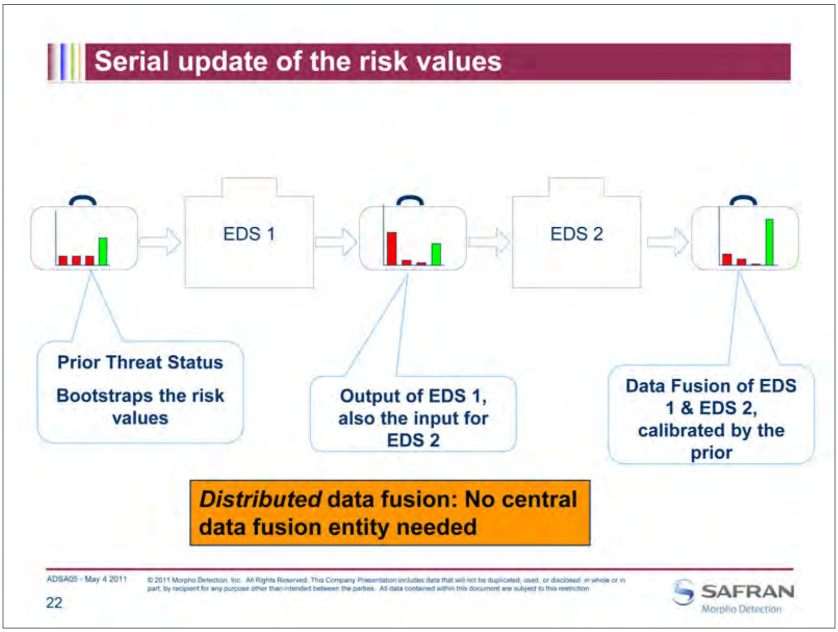
Morpho Detection


Serial update of the risk values
EDS 1
EDS 2
Prior Threat Status
Bootstraps the risk values
Output of EDS 1, also the input for EDS 2
Data Fusion of EDS 1 & EDS 2, calibrated by the prior
Distributed data fusion: No central data fusion entity needed
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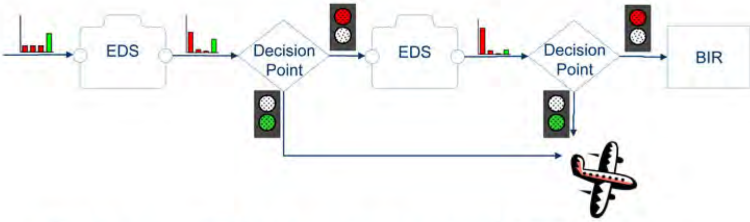
Morpho Detection

Separation of scanning and decision?



- Vendors own EDS nodes: computes probabilities
- Regulator own Decision Point Nodes, tied into cert etc.

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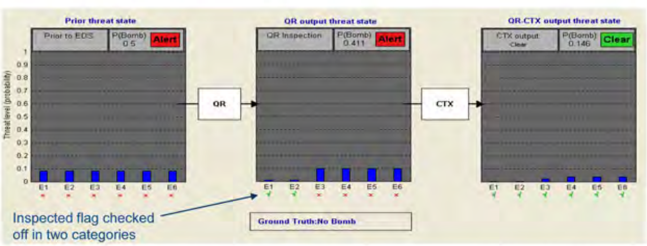
The inspected flag

- 'Inspected' flag solves Bayesian shortcomings:
  - Lack of capability
  - Lack of scanning
  - Unsuccessful scan
- Initially this flag is <u>unchecked</u> for all categories
- Upon successful scan the flag is checked
  - If scan is obstructed the 'inspected' flag cannot be checked:
    - Shield (dark) alarm in CT
    - Excessive external noise
    - Known contamination in trace



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Meta Sensors: other information sources

- The risk framework can incorporate information from non-sensors sources:
  - DHS threat level
  - Risk assessment on individual passengers (profiling)
- This information can be general
  - Affect risk values for all threat categories
- Or, specific
  - Affect risk value of specific threat types, e.g. liquids

- Example: Passenger classification
  - 2 classes: Normal and Selectee
  - Likelihoods to be quantified:
    - ✓ False positive rate: Rate at which "normal" passengers are assigned selectee status: say 5% (use operational numbers)
    - ✓ False negative rate: Rate at which terrorist on mission is designated as normal. Would be based on expert judgement. Example 50%.

$$P(Selectee \mid E_i) = \begin{cases} 0.5 & , \quad i = 1,2,..n \\ 0.05 & , \quad i = 0 \end{cases}$$

$$P(Normal \mid E_i) = \begin{cases} 0.5 & , \quad i = 1,2,..n \\ 0.95 & , \quad i = 0 \end{cases}$$

  - Bayes' rule yields:
    - ✓ Using prior risk value of 50%,
    - ✓ Selectee -> 91%
    - ✓ Normal -> 35%

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Morpho Detection

Other operations: Aggregation and Divestiture

- Divestiture
  - When passenger checks bag, any pre-existing risk value should be extended to the bags on their journey through BHS
  - Same at checkpoint
  - Ontology needs to set guidelines for this as well

- Aggregation
  - Often it is desirable to aggregate risk value over multiple objects
    - ✓ Examples:
      - *Multiple alarm object s in a bag*
      - *Multiple items belonging to passengers*
      - *All passengers boarding a plane*
  - Can be for Command & Control purposes
  - Depending on scenario different aggregation calculus can be used

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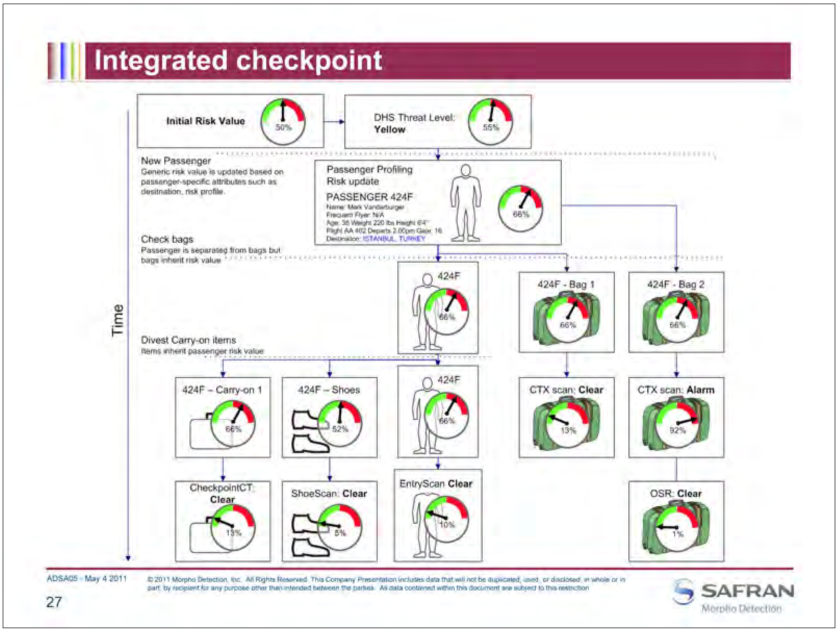
Morpho Detection


Integrated checkpoint
Initial Risk Value
50%
DHS Threat Level: Yellow
55%
New Passenger
Generic risk value is updated based on passenger-specific attributes such as destination, risk profile.
Passenger Profiling
Risk update
PASSENGER 424F
66%
Check bags
Passenger is separated from bags but bags inherit risk value
Time
424F
424F - Bag 1
424F - Bag 2
Divest Carry-on items
Items inherit passenger risk value
424F – Carry-on 1
424F – Shoes
424F
CTX scan: Clear
CTX scan: Alarm
CheckpointCT: Clear
ShoeScan: Clear
EntryScan Clear
OSR: Clear
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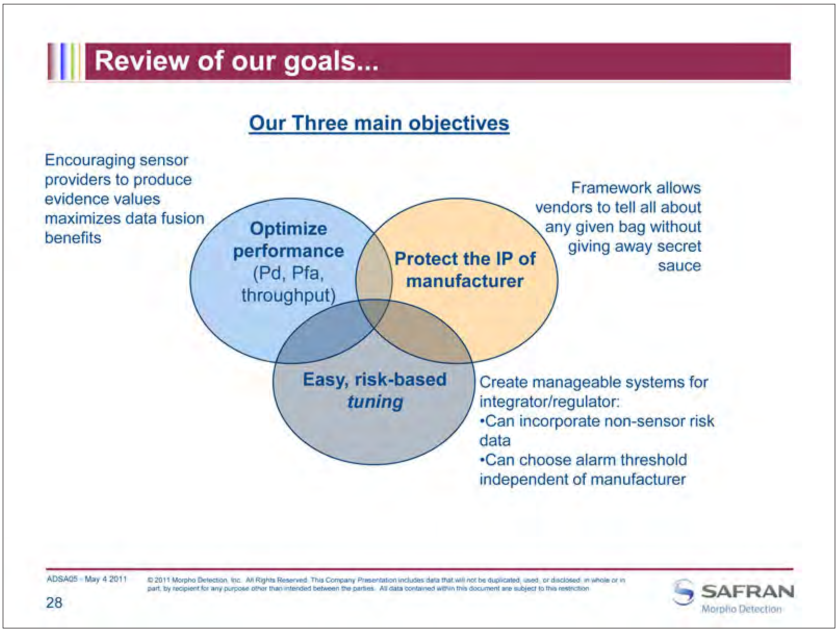
Morpho Detection


Review of our goals...
Our Three main objectives
Encouraging sensor providers to produce evidence values maximizes data fusion benefits
Optimize performance (Pd, Pfa, throughput)
Protect the IP of manufacturer
Framework allows vendors to tell all about any given bag without giving away secret sauce
Easy, risk-based tuning
Create manageable systems for integrator/regulator:
•Can incorporate non-sensor risk data
•Can choose alarm threshold independent of manufacturer
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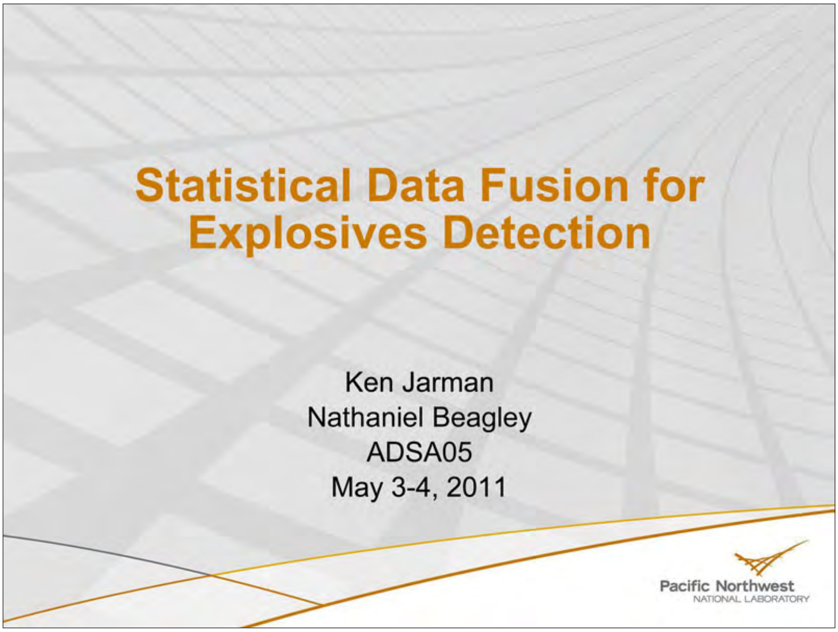
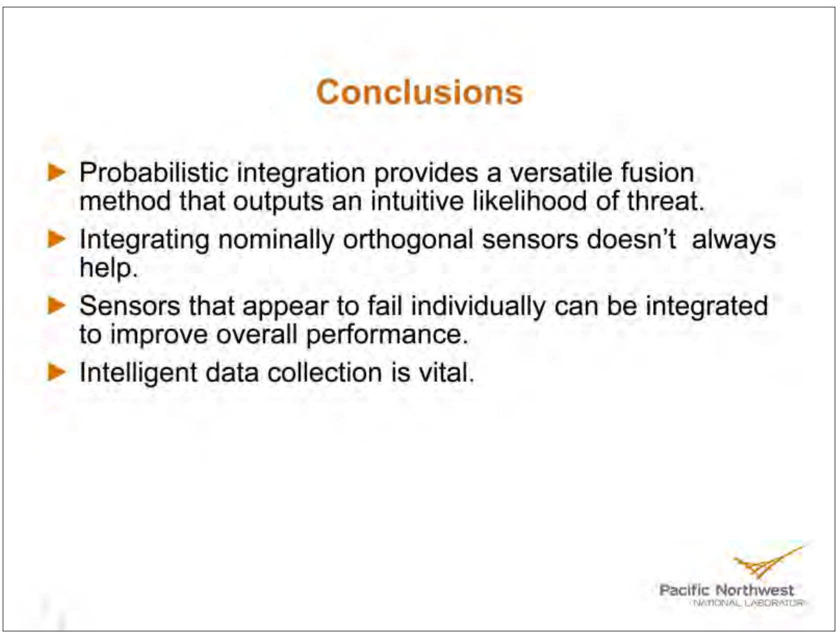
Morpho Detection

16.22 Nat Beagley and Ken Jarman: Mathematics



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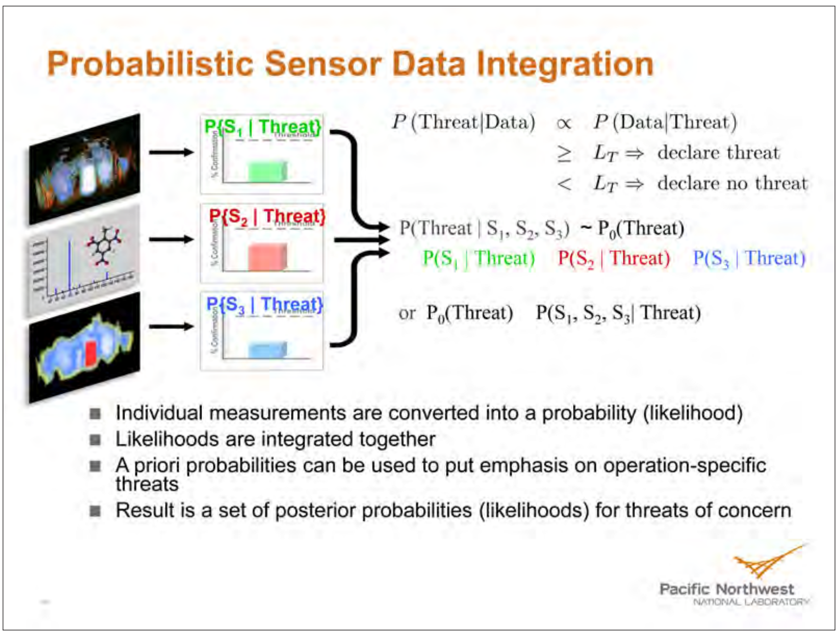
Probabilistic Sensor Data Integration
$P\{S_1 \mid Threat\}$
$P\{S_2 \mid Threat\}$
$P\{S_3 \mid Threat\}$
$P(\text{Threat}|\text{Data}) \propto P(\text{Data}|\text{Threat})$
$\geq L_T \Rightarrow$ declare threat
$< L_T \Rightarrow$ declare no threat
$P(\text{Threat} \mid S_1, S_2, S_3) \sim P_0(\text{Threat})$
$P(S_1 \mid \text{Threat})$ $P(S_2 \mid \text{Threat})$ $P(S_3 \mid \text{Threat})$
or $P_0(\text{Threat})$ $P(S_1, S_2, S_3 \mid \text{Threat})$
Individual measurements are converted into a probability (likelihood)
Likelihoods are integrated together
A priori probabilities can be used to put emphasis on operation-specific threats
Result is a set of posterior probabilities (likelihoods) for threats of concern
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Probabilistic Integration Pros and Cons

Pros

- Intuitive probability scores (e.g. likelihood of threat)
- Bayesian fusion well suited to disparate sensor data types
  - Chemical/physical understanding can be incorporated
  - Dependencies between "nominally independent" sensors can be taken into account
  - Modeled sensor data easily integrated with experimental data

Cons

- Bayesian requires some choice of prior threat probability—challenging for extremely rare events (e.g. actual explosives events)
- Conditional independence assumptions—unless coordinated data available to account for correlation

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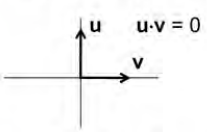
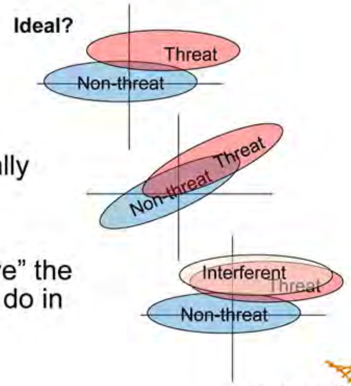
Orthogonal Technology/Sensors/Data

- More independent attributes → better discrimination
- Orthogonality vs. (conditional) independence





- Pitfall #1: Data aren't actually conditionally independent
- Pitfall #2: Interferents "move" the data the same way threats do in feature space

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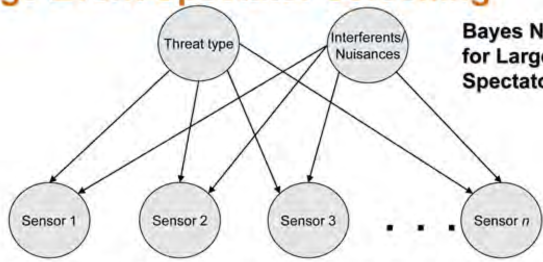
Case Study: Large Event Spectator Screening



Bayes Net Framework for Large Event Spectator Screening

Multiple stand-off detection devices monitoring individuals at entry
Accounting for nuisance factors:

$$P(\text{Threat} \mid S_1, S_2, S_3) \sim P_0(\text{Threat}) \quad P(S_1, S_2, \ldots, S_n \mid \text{Threat})$$
$$= P_0(\text{Threat}) \quad \{ P(S_1, S_2, \ldots, S_n \mid \text{Threat; high nuisance}) \, P(\text{high nuisance})$$
$$+ P(S_1, S_2, \ldots, S_n \mid \text{Threat; low nuisance}) \, P(\text{low nuisance}) \}$$

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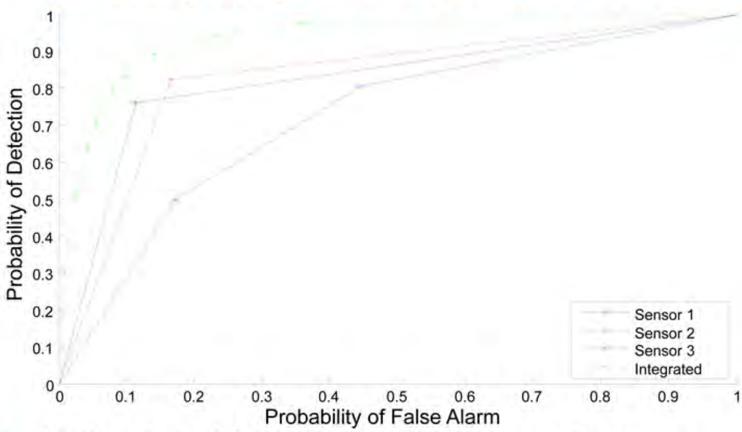
Case Study: Large Event Spectator Screening



- On the whole, integrating the three sensors improves performance, but…

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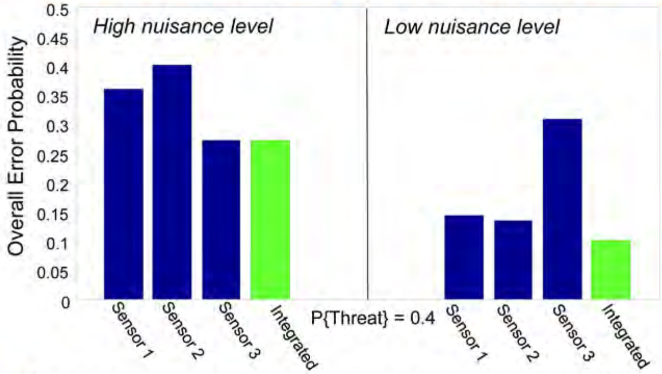
Large Event Spectator Screening: Effects of Nuisance (environmental factor)

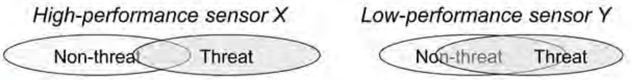


- Sensor 1 error increases with nuisance; sensor 3 doesn't
- Optimal sensor configuration depends on the nuisance level!

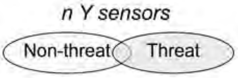
Sensor Fusion: Is More Always Better?

N poor sensors can beat one great sensor

- Separation between threat and non-threat sensor response (data) determines performance



- Using n Y sensors reduces the distance by a factor proportional to $n^{1/2}$ (equivalent to increasing sample size) — eventually enough to beat sensor X



- But, there are diminishing returns…

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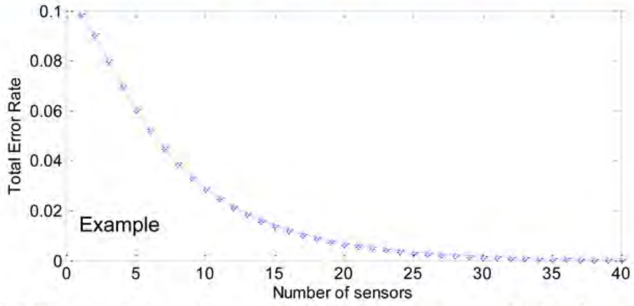
Sensor Fusion: Is More Always Better?



- Adding sensors always lowers the error rate, but depending on cost and operational requirements, more isn't always better.
- Optimal sensor configuration and performance depend on P_D, P_{FA}, and potential nuisances or interferents!

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Case Study: Fusion of Classifiers Detection of Tularemia

- Detection of host exposure to the bio-pathogen: Francisella Tularensis
- University of Washington Department of Pathology:
  Mice in an Inhalation chamber exposed to:
  - Control: Normal air
  - Ftn: (Francisella Tularensis) : lethal pathogen
  - PA: (Pseudomonas aeruginosa) : non lethal pathogen
  - Ftn-Atn: (mutated Francisella Tularensis): non pathogen
- Pacific Northwest National Laboratory:
  Common BALF samples analyzed with 4 sensors / instruments
  - NMR
  - MALDI Mass Spectrometry
  - Proteomics (Orbitrap MS)
  - Immunology: Cell Count

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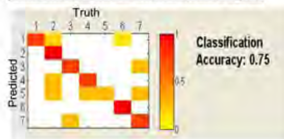
Build a classification model for each sensor

- 7 data classes: different pathogens at different exposure times
- A classification model is constructed for each sensor/instrument
  - Algorithm depends on each sensors data characteristics (PLS-DA, SVM, …)
  - Cross Validation Approach
- For each sample i and each class k calculate: $P(E_k \mid D_M, S_i)$
- Decision Rule: Maximal posterior probability => Evaluate overall CA
- A decision is made for each sample for this sensor, but the full probability model is carried on to the data fusion step

Classification for sample i:

1. $P(\text{Control} \mid D_M, S_i)$ = 0.00
2. $P(\text{PA 4hr} \mid D_M, S_i)$ = 0.01
3. $P(\text{PA 24hr} \mid D_M, S_i)$ = 0.01
4. $P(\text{Ftn 4hr} \mid D_M, S_i)$ = 0.10
5. $P(\text{Ftn 24hr} \mid D_M, S_i)$ = 0.81
6. $P(\text{Ftn-Atn 4hr} \mid D_M, S_i)$ = 0.04
7. $P(\text{Ftn-Atn 24hr} \mid D_M, S_i)$ = 0.03

Classification results for Mass Spec



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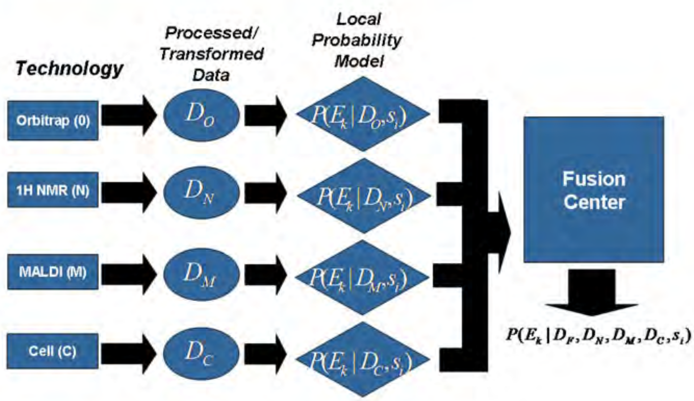
Probabilistic Fusion Model



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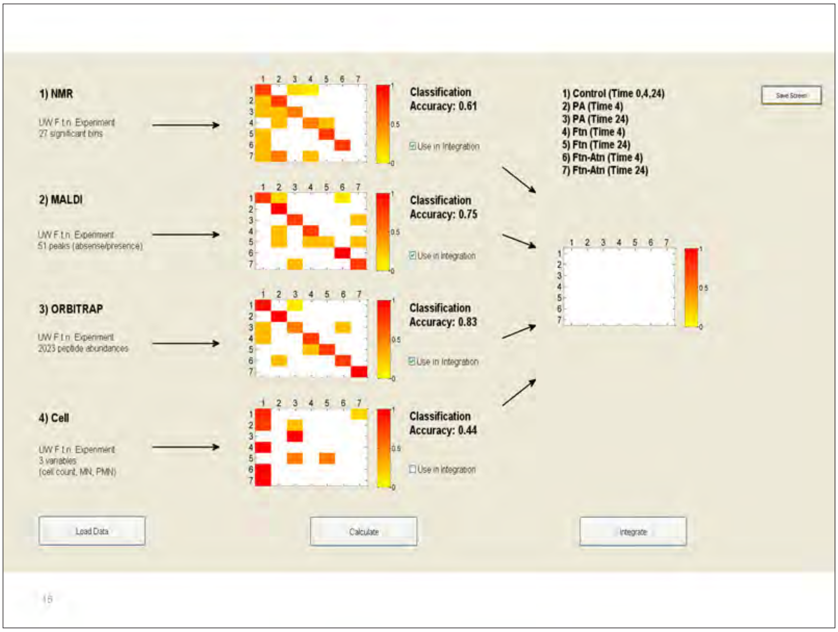
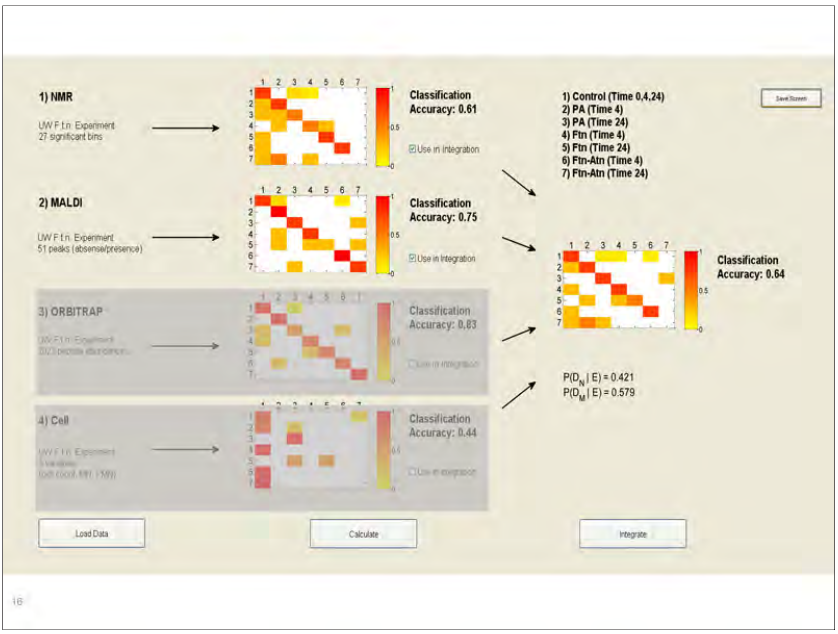

1) NMR
UW F.t.n. Experiment
27 significant bins
Classification
Accuracy: 0.61
Use in Integration
2) MALDI
UW F.t.n. Experiment
51 peaks (absense/presence)
Classification
Accuracy: 0.75
Use in Integration
3) ORBITRAP
UW F.t.n. Experiment
2023 peptide abundances
Classification
Accuracy: 0.83
Use in Integration
4) Cell
UW F.t.n. Experiment
3 variables
(cell count, MN, PMN)
Classification
Accuracy: 0.44
Use in Integration
1) Control (Time 0,4,24)
2) PA (Time 4)
3) PA (Time 24)
4) Ftn (Time 4)
5) Ftn (Time 24)
6) Ftn-Atn (Time 4)
7) Ftn-Atn (Time 24)
Save Screen
Load Data
Calculate
Integrate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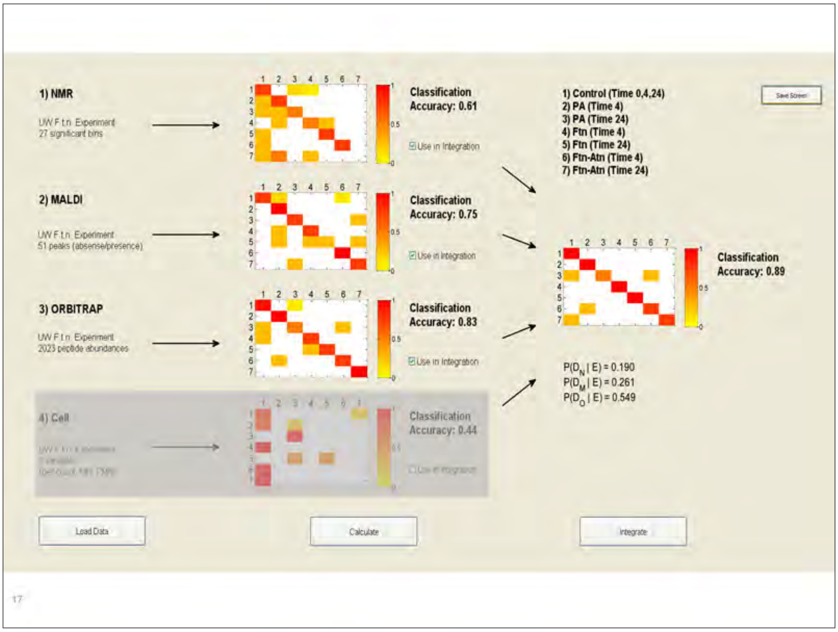
Classification
Accuracy: 0.44
1) Control (Time 0,4,24)
2) PA (Time 4)
3) PA (Time 24)
4) Ftn (Time 4)
5) Ftn (Time 24)
6) Ftn-Atn (Time 4)
7) Ftn-Atn (Time 24)
Classification
Accuracy: 0.64
P(D_N | E) = 0.421
P(D_M | E) = 0.579
Save Screen
Load Data
Calculate
Integrate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Classification
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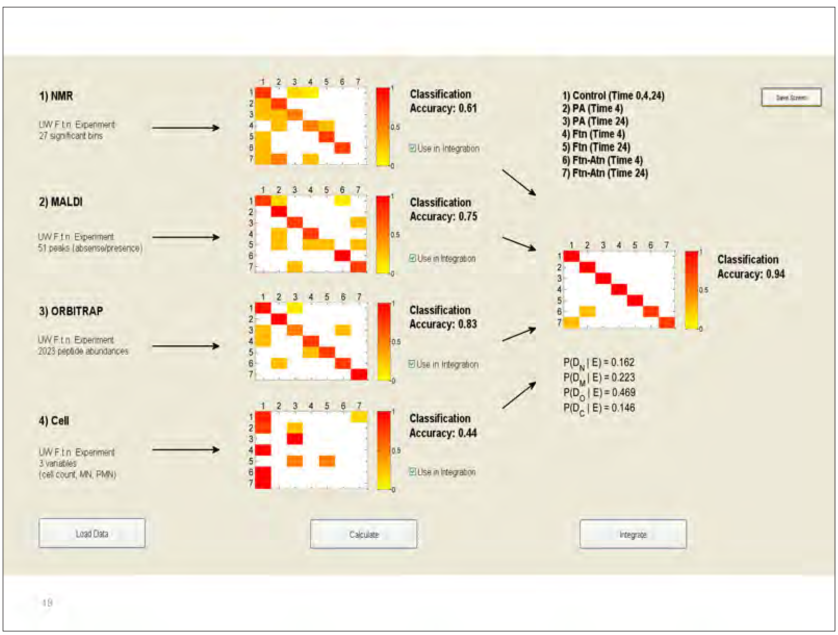
4) Cell
Classification
Accuracy: 0.44
1) Control (Time 0,4,24)
2) PA (Time 4)
3) PA (Time 24)
4) Ftn (Time 4)
5) Ftn (Time 24)
6) Ftn-Atn (Time 4)
7) Ftn-Atn (Time 24)
Classification
Accuracy: 0.89
P(D_N | E) = 0.190
P(D_M | E) = 0.261
P(D_O | E) = 0.549
Load Data
Calculate
Integrate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UW F.t.n. Experiment
27 significant bins
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Accuracy: 0.61
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Classification
Accuracy: 0.83
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UW F.t.n. Experiment
3 variables
(cell count, MN, PMN)
Classification
Accuracy: 0.44
Use in Integration
1) Control (Time 0,4,24)
2) PA (Time 4)
3) PA (Time 24)
4) Ftn (Time 4)
5) Ftn (Time 24)
6) Ftn-Atn (Time 4)
7) Ftn-Atn (Time 24)
Classification
Accuracy: 0.94
P(D_N | E) = 0.162
P(D_M | E) = 0.223
P(D_O | E) = 0.469
P(D_C | E) = 0.146
Load Data
Calculate
Integrate

Case Study Conclusions:

- Integrating sensors that are not orthogonal doesn't necessarily improve performance: in fact, it can decrease performance!
  - Sensors validate each others misclassifications.
  - Can change correct classifications to incorrect.
- Adding in orthogonal data (with no apparent skill in classification) can help improve performance.

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Algorithm and Data Considerations

- When developing a classification algorithm, need to avoid overfitting:
  - Classifying on the noise
  - Being dependent on a non-robust feature
  - Result => good classification on the training set, poor performance on non-trained validation data set.
- Need a comprehensive enough training data set to account for:
  - Instrument variability (e.g. peak shift)
  - Sample variability (e.g. quantity of explosive)
  - Environmental variability (e.g. humidity)
  - Interference / nuisance materials (e.g. kitty litter)
- For fusion problems, a coordinated data set is invaluable.

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The Data Reality:

- Data is expensive, time consuming, and sometimes impossible to get
  - You can't always (ever?) get a coordinated data set covering all threats and operational scenarios with multiple sample and instrument repetitions
- Solutions:
  - Make use of statistics and experimental design early and often:
    - How to make best use of samples you are able to run
    - How to best augment existing data
    - Determine if you have enough data to robustly make the decision you are trying to make
  - Hold the variables you do control (i.e. instrument parameters) as constant as possible.
  - Build a conceptual/mathematical model from your data to account for missing experimental data:
    - Distribution representations of features in different scenarios
    - Allows simulation
    - Include physical knowledge
  - Collect data at critical boundary conditions
    - Example: detection thresholds

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Questions? Comments? Ideas?

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KJ@pnl.gov

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16.23 Larry Carin: Feature identification from compressive measurement

Compressive Measurement and Analysis

Lawrence Carin, Mauro Maggioni and David Brady
Department of Electrical & Computer Engineering
Department of Mathematics
Duke University
Durham, NC

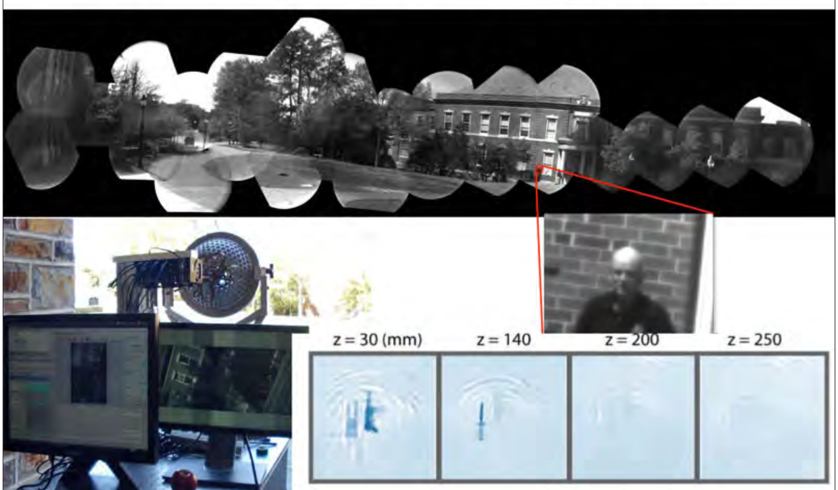
Conclusions

- Low-dimensional signal representations can mitigate the curse of dimensionality
- Can significantly reduce quantity of data that need be measured to extract underlying information
- Integrating sensing and processing optimally utilizes multi-modality resources
- Bayesian CS and geometric multi-resolution representations attractive tools for signal representation and data recovery
- POMDP methodologies may be employed to optimize adaptive multi-sensor systems

Outline

- Compressive sensor modalities at Duke
- Dictionary learning and decompressive inference
- Non-Gaussian noise, outliers, background/foreground
- Geometric multiresolution analysis
- Partially observed Markov decision process (POMDP) for multi-modality sensor management
- Summary and conclusions

Duke Computational Sensor Systems

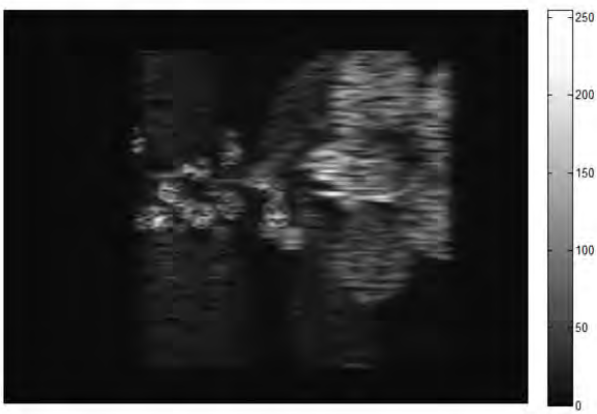


Duke Computational Sensor Systems

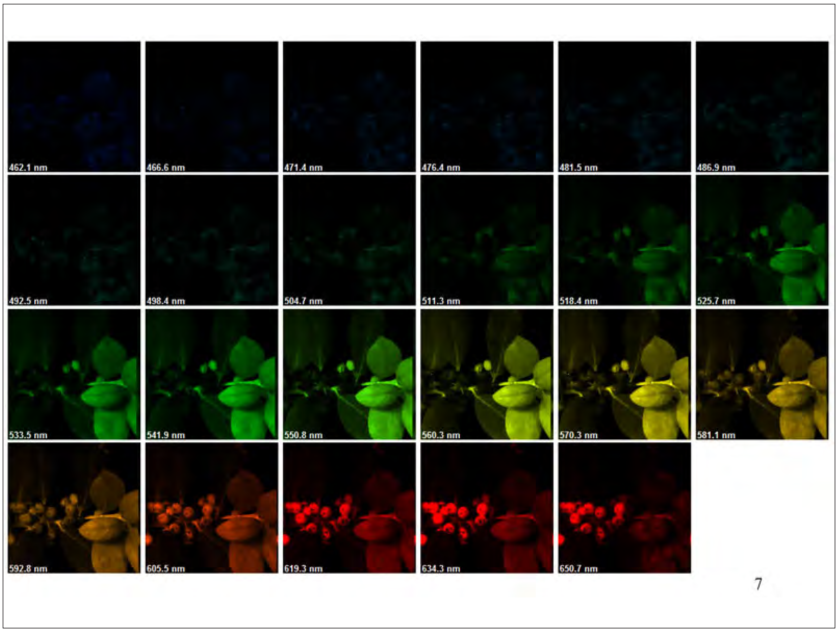
- Multiscale gigapixel cameras (compact starring wide field persistent surveillance)
- Snapshot coded aperture Raman imaging
- Coded aperture mass spectroscopy
- Compressive MMW and Terahertz imaging
- Coded aperture x-ray spectral imaging

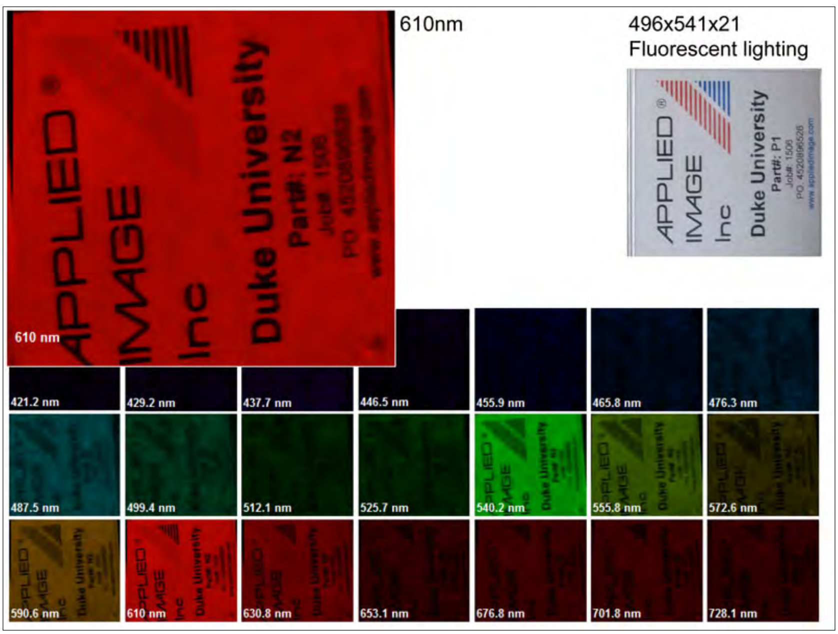
Example: Coded Aperture HSI

Raw data from one frame

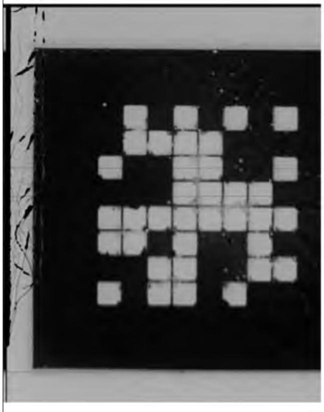


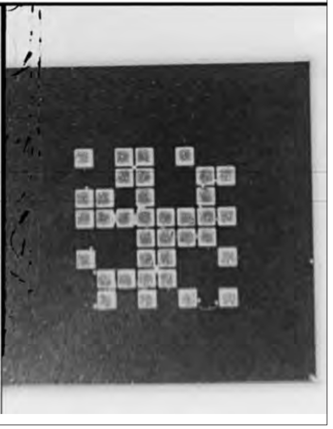
6


462.1 nm
466.6 nm
471.4 nm
476.4 nm
481.5 nm
486.9 nm
492.5 nm
498.4 nm
504.7 nm
511.3 nm
518.4 nm
525.7 nm
533.5 nm
541.9 nm
550.8 nm
560.3 nm
570.3 nm
581.1 nm
592.8 nm
605.5 nm
619.3 nm
634.3 nm
650.7 nm
7


610nm
496x541x21
Fluorescent lighting
APPLIED IMAGE Inc
Duke University
Part#: N2
610 nm
APPLIED IMAGE Inc
Duke University
Part#: P1
421.2 nm
429.2 nm
437.7 nm
446.5 nm
455.9 nm
465.8 nm
476.3 nm
487.5 nm
499.4 nm
512.1 nm
525.7 nm
540.2 nm
555.8 nm
572.6 nm
590.6 nm
610 nm
630.8 nm
653.1 nm
676.8 nm
701.8 nm
728.1 nm

X-ray CASSI





Real-Time CS for Video

GPU Implementation

32 Frames in < 1 sec

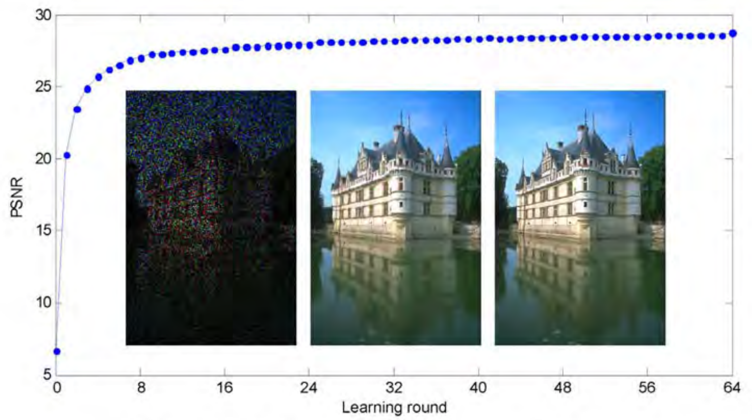
Measure 0.5% of traditional video

Joint with UTRC

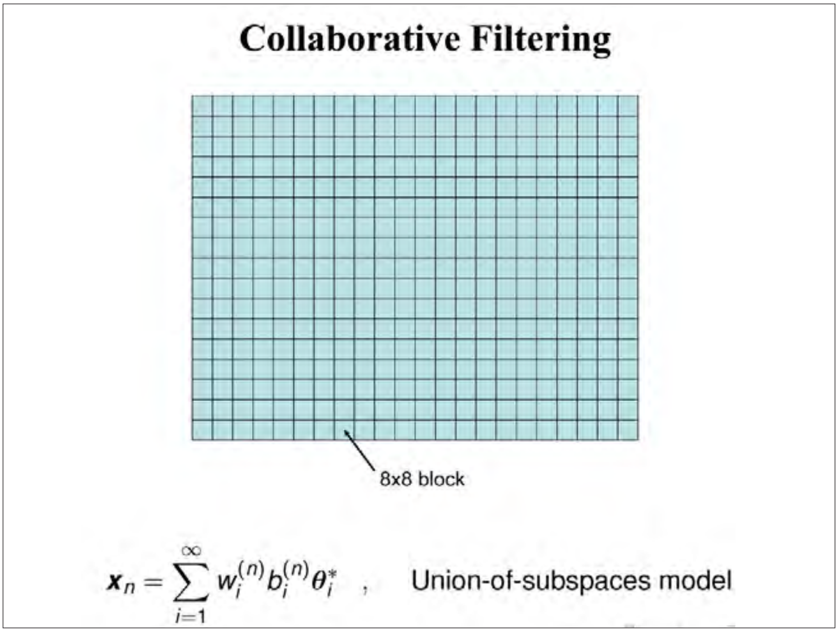
Outline

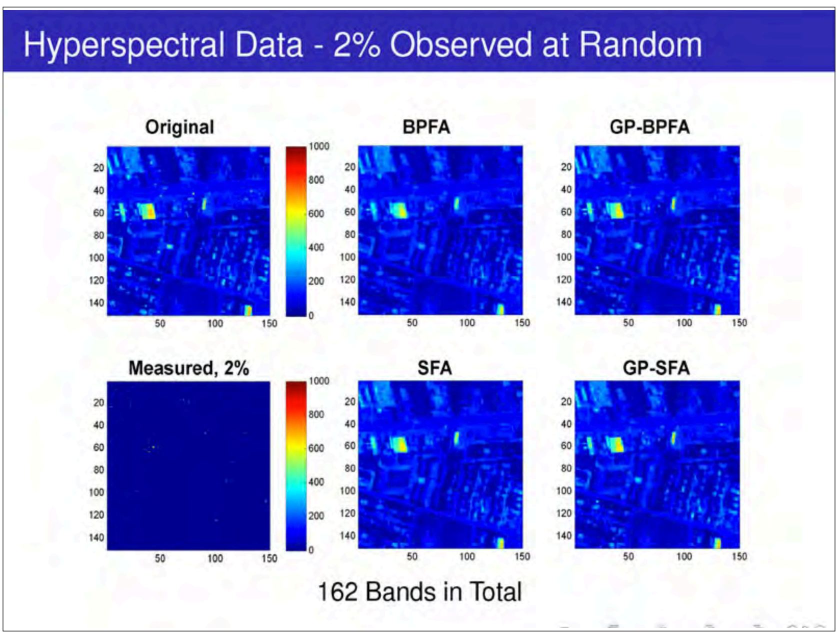
- Compressive sensor modalities at Duke
- Dictionary learning and decompressive inference
- Non-Gaussian noise, outliers, background/foreground
- Geometric multiresolution analysis
- Partially observed Markov decision process (POMDP) for multi-modality sensor management
- Summary and conclusions

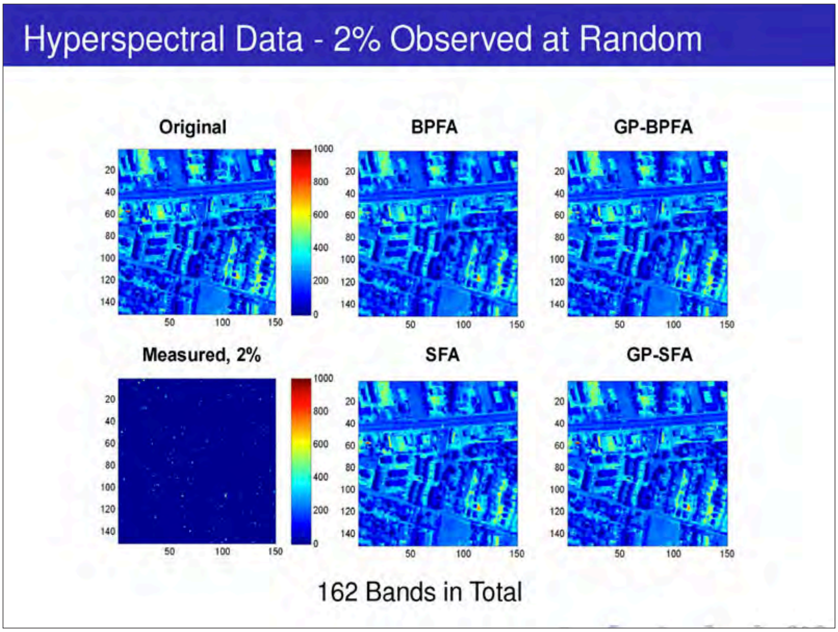
Exploiting Low-Dimensional Structure in Natural Imagery

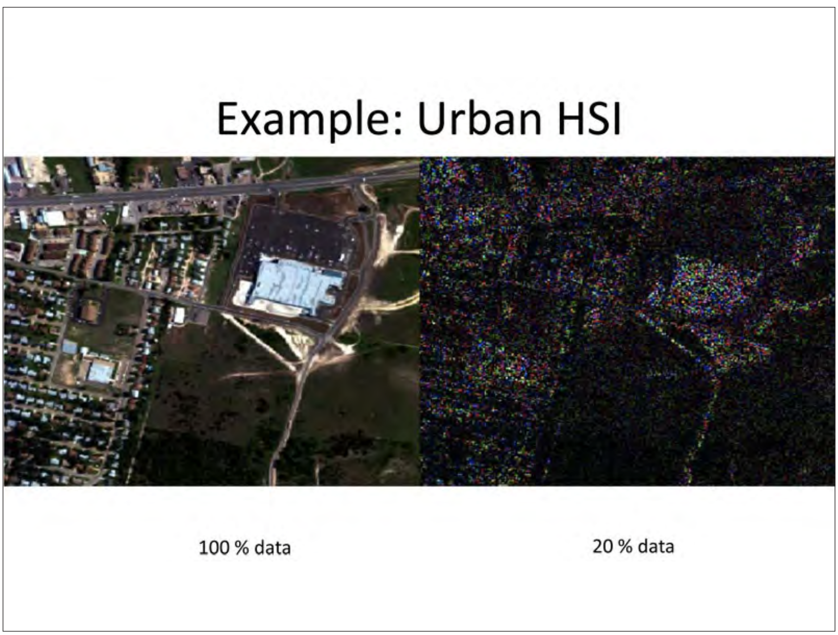


80% of RGB pixels missing at random

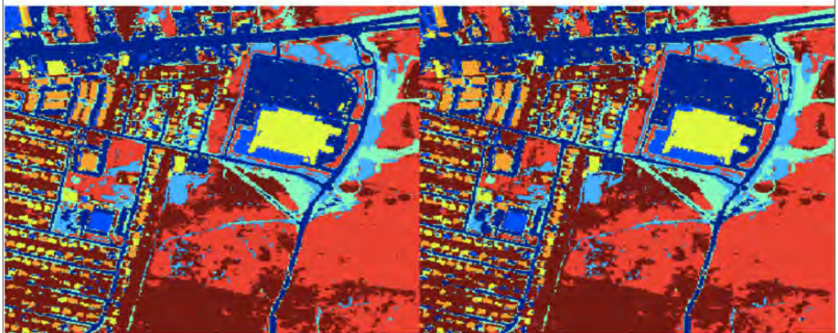

Collaborative Filtering
8x8 block
$\mathbf{x}_n = \sum_{i=1}^{\infty} w_i^{(n)} b_i^{(n)} \theta_i^*$,
Union-of-subspaces model


Hyperspectral Data - 2% Observed at Random
Original
BPFA
GP-BPFA
Measured, 2%
SFA
GP-SFA
162 Bands in Total


Hyperspectral Data - 2% Observed at Random
Original
BPFA
GP-BPFA
Measured, 2%
SFA
GP-SFA
162 Bands in Total


Example: Urban HSI
100 % data
20 % data

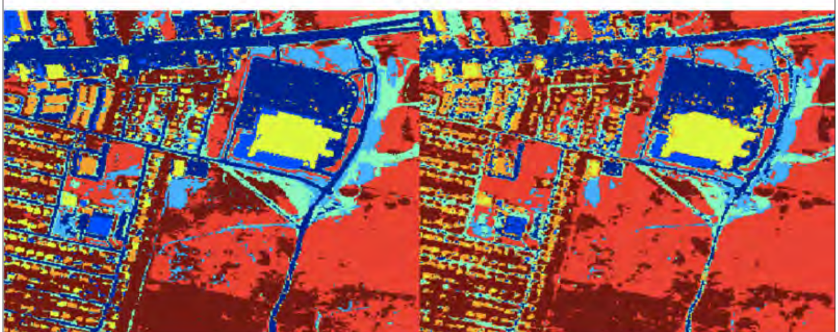
Mapping



100% measured
99.94% accuracy

20% measured
99.88% accuracy

Mapping



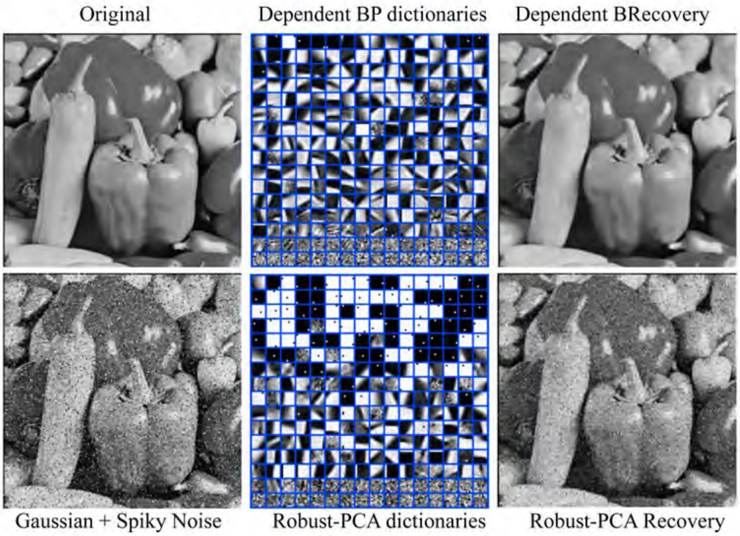
100% measured
99.94% accuracy

2% measured
92.88% accuracy

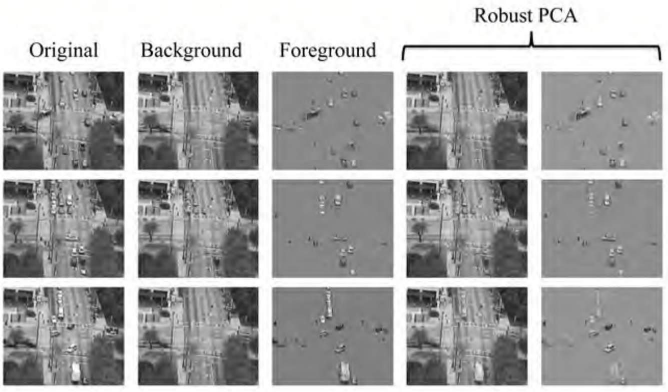
Outline

- Compressive sensor modalities at Duke
- Dictionary learning and decompressive inference
- Non-Gaussian noise, outliers, background/foreground
- Geometric multiresolution analysis
- Partially observed Markov decision process (POMDP) for multi-modality sensor management
- Summary and conclusions

Non-Gaussian Noise



Foreground, Background & Tracking



Example Video

Bayesian Robust PCA

Outline

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Geometric Multi-Resolution Analysis (GMRA): Multiscale Data-Adaptive Dictionaries, Fast Transforms, Compressive Measurements

. GMRA generates a well-organized data-adaptive dictionary Φ for a data set; fast algorithms exist for the construction of Φ and for finding sparse nonlinear representations of a data point x.

. GMRA may be used to represent efficiently large data sets, and extracting features for classification and other tasks.

. Compressed sensing type of ideas may be extended to the general setting of GMRA's: a small number of measurements is enough to reconstruct a data point even in this highly nonlinear, adaptive setting.

. GMRA may be used to develop novel fast multiscale transforms of images, to extract features we expect to be useful for tasks such as classification/detection/anomaly detection.

. GMRA may be used to quantify and detect changes in time-varying data.

Geometric Multi-Resolution Analysis: Multiscale Data-Adaptive Dictionaries

- Many constructions of "general-purpose" dictionaries [Fourier, wavelets, curvelets, ...], especially for low-dimensional signals (sounds, images,...).

  Motivation: pretend we have rather good tractable models (e.g. function spaces), construct good dictionaries by hand.

  Goals: compression, signal processing tasks (e.g. denoising), etc...

- Recently, many constructions of data-adaptive dictionaries [K-SVD, K-planes, ...].

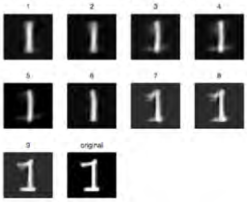
  Motivation: we do not have tractable good models, need to adapt to data.

  Goals: as before, albeit hopes for more general types of high-dimensional data.

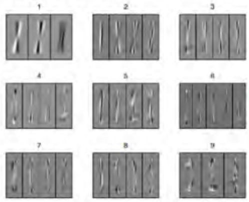
- Important role of sparsity in statistics, learning, design of measurements, ...: seek dictionaries that yield sparse representations of the data.

GMRA: Handwritten Digits

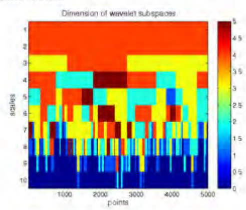
Multiscale approximation with GWT for one data point (digit)



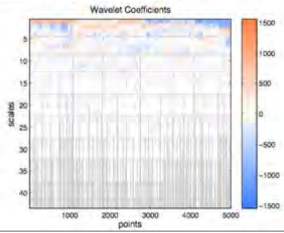
Subset of the dictionary used for the digit on the left

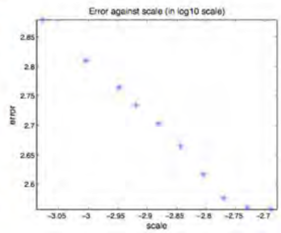


The GWT subspaces have small dimension



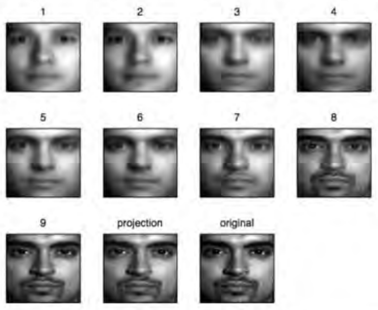
The GWT of the data is sparse (left), and the approximation error decays fast, even when a manifold structure is missing.



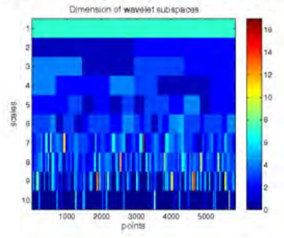


GMRA's: Yale Faces database

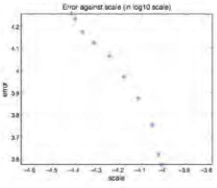
Multiscale approximation with GWT for one data point (face, 640x480)

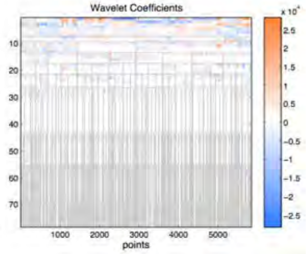


The dimension of the wavelet subspaces are very small, except at some of the finest scales.



Data represented in the GWT domai is sparse, and even when manifold i not present, we have rapid decay o approximation error. It takes around minute to process the whole database with Matlab code.





Outline

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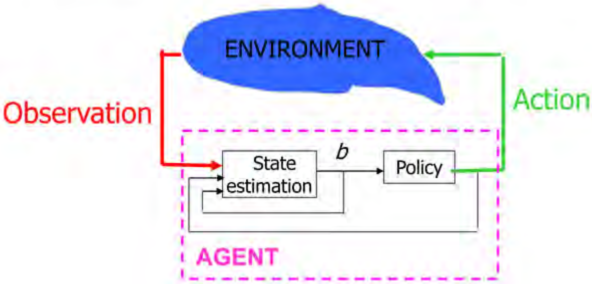
Partially Observed Markov Decision Process

POMDP = HMM + controllable actions + rewards

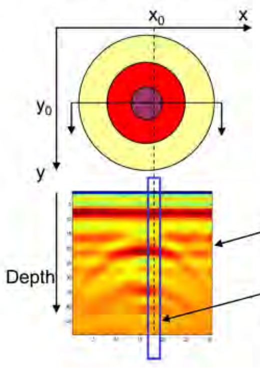
A POMDP is a model of an agent interacting synchronously with its environment. The agent takes as input the observations of the environment, estimates the state according to observed information, and then generates as output actions based on its policy. During the periodic observation-action loops, the agent gets maximal reward or, equivalently, minimal cost.



Landmine POMDP model (2) – observation

GPR feature extraction

GPR sensing data → energy features and moment features → vector quantization → code index



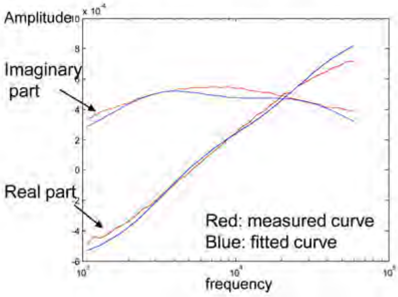
Left figure is an illustration of landmine signature.

Energy and moment features for point (x_0, y_0) are extracted using the sensing data of all depth in this point.

Landmine POMDP model (2) – observation

EMI feature extraction

EMI sensing data → model fitting to extract EMI model parameters → vector quantization → code index



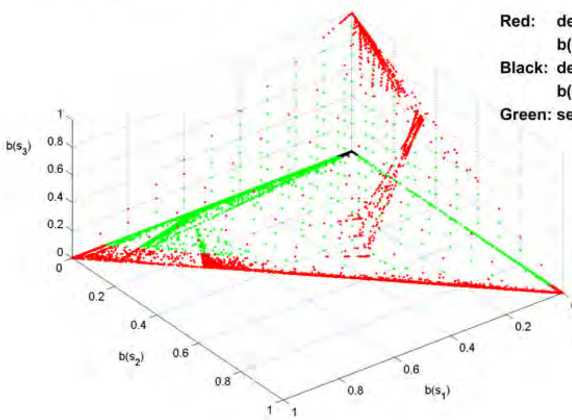
Left figure shows real part and imaginary part curves of EMI responses vs. frequency for a particular point (x_0, y_0). The fitted curves for feature extraction are also plotted.

EMI model for one point (x_0, y_0): $H(\omega) \propto a + \frac{b_1\omega}{\omega - j\omega_1} + \frac{b_2\omega}{\omega - j\omega_2}$

Non-linear fitting method extracts model parameters (a, b_1, w_1, b_2, w_2).

Policy Solution

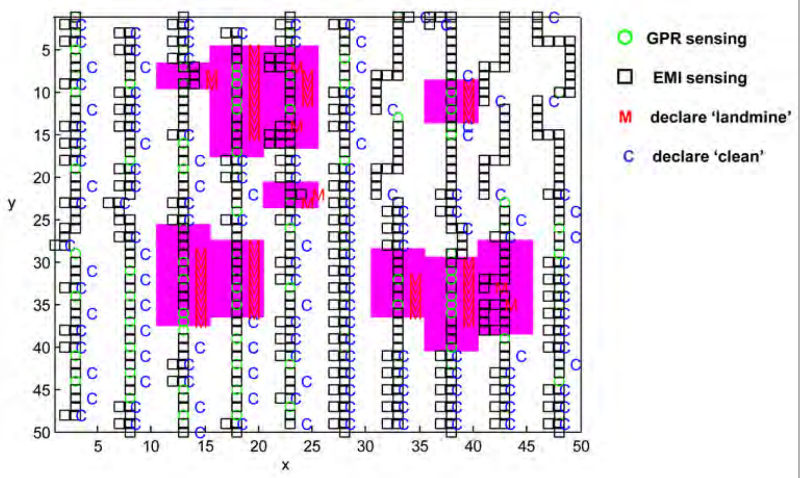
Policy is a mapping from belief states to actions, which tells agent which action to choose based on current belief state.



Red: declare 'landmine';
$b(s_1)$ or $b(s_2)$ or $b(s_3)$ ~ 1
Black: declare 'clean';
$b(s_4)=1-b(s_1)-b(s_2)-b(s_3)$ ~ 1
Green: sensing actions.

See that only when the agent is very sure about 'landmine' ($b(s_1)$ ~1 or $b(s_2)$ ~1 or $b(s_3)$ ~1) or 'clean' ($b(s_4)$~1), it makes declarations; otherwise, it keeps sensing to acquire more information.

Real-Time Detection (4) – sensing record



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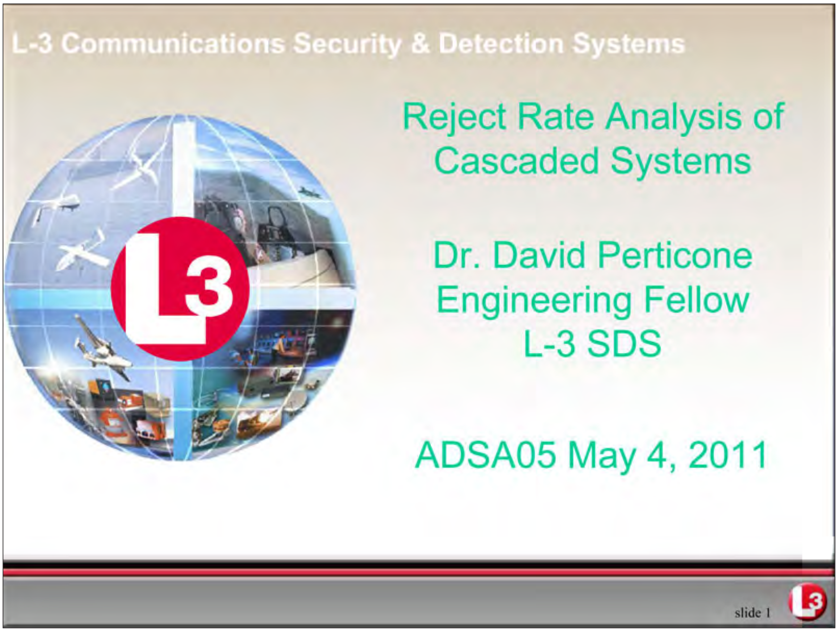
Summary/Conclusions

- Low-dimensional signal representations can mitigate the curse of dimensionality
- Significantly reduce quantity of data that need be measured to extract underlying information
- Integrating sensing and processing optimally utilizes multi-modality resources
- Bayesian CS and geometric multi-resolution representations attractive tools for signal representation and data recovery
- POMDP methodologies may be employed to optimize adaptive multi-sensor systems

16.24 David Perticone: Reject rate analysis of cascaded systems



Summary

- Two detection systems (A & B) are cascaded when both are required to alarm to reject an object. Let P(A) and P(B) be the individual alarm rates (0 <= P <= 1). The following outcomes are possible:

Outcome	Combined Detection	Comments
Maximum	Min(P(A),P(B))	Systems correlated
Most Likely	P(A)*P(B)	Systems independent
Minimum	Max((P(A) + P(B) -1),0)	Systems anti-correlated

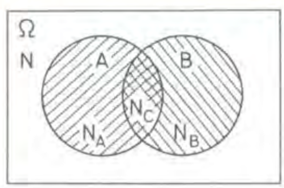
slide 2

Outline

- Brief discussion of probability
- Example studies using a fictitious 100 bag set
- 1 slide infomercial

Probability

- Define probability P to be in range 0 <= P <= 1. P=1 event always occurs. P=0 event never occurs.
- $P(A) = N_A/N$
- $P(B) = N_B/N$
- $P(A \cap B) = N_C/N$
- $P(B|A) = N_C/N_A$
- $P(B|A)P(A) = P(A \cap B)$
- $P(A \cap B) = P(A)P(B)$ (*independent*)



Circuit Example- Switches closed with probability P

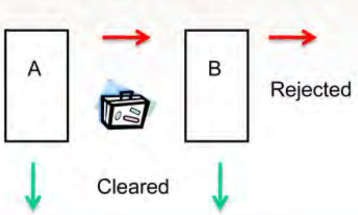
- $P(A \cap B)$ *"AND"*
- $= P(B|A)P(A)$
- $= P(B)P(A)$ *if independent*

- $P(A \cup B)$ *"OR"*
- $= P(A) + P(B) - P(A \cap B)$
- $= P(A) + P(B) - P(A)*P(B)$ *if independent*

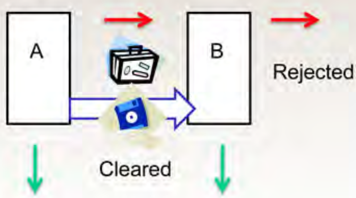
slide 5

Cascaded System Architecture

- For this presentation we will consider the simplest case, items which alarm or are rejected by system A are passed to system B



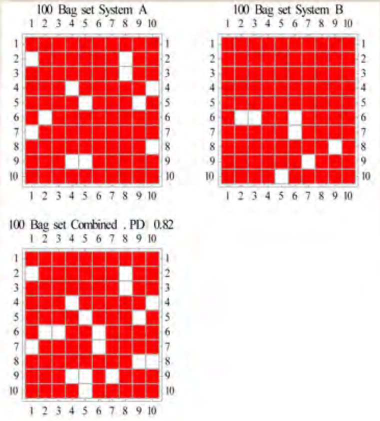
- Other architectures are possible.



slide 6

Illustration with 100 Bag Set

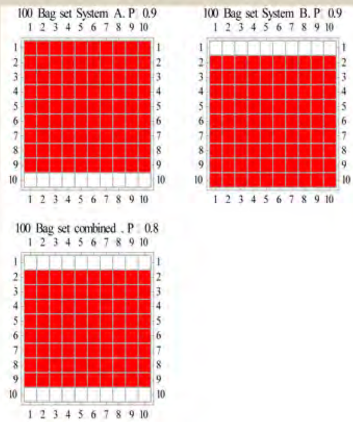
- P(A)=P(B)=0.9
- Red is detection
- White is miss
- 100 Bags arranged sequentially in a 10 x 10 grid
- Overall P(A ∩ B) = 0.82 ~ P(A)P(B)



slide 7

Minimum Detection for two P=0.9 systems

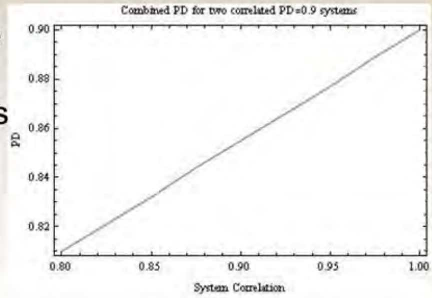
- System 1 misses last 10 bags
- System 2 misses first 10 bags
- Overall P(A ∩ B) = 0.8 =P(A) + P(B) -1
- $P(B|A) = N_{AB}/N_A$
- $P(A \cap B)= P(B|A)P(A) = N_{AB}/N$



slide 8

Maximum Detection for two P=0.9 systems

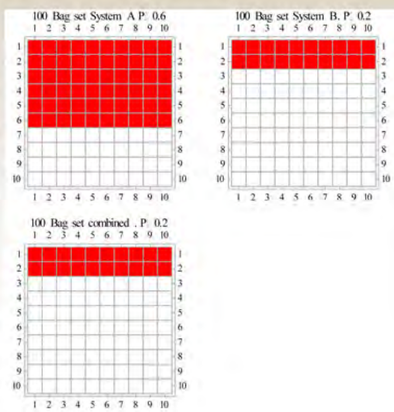
- If the two systems are perfectly correlated (two well built systems with same model number from manufacturer X) then P(A∩B)=P(A)=0.9



slide 9

Second Case P(A)=0.6 P(B)=0.2

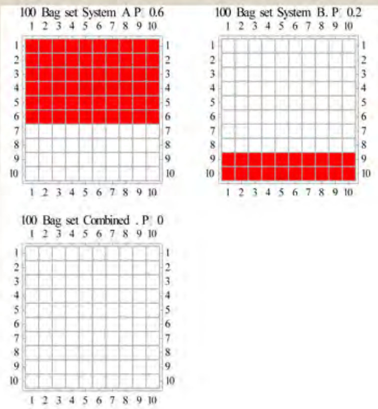
- Maximum P = 0.2
- Min[P(A),P(B)]
- Limited by smallest detection system



slide 10

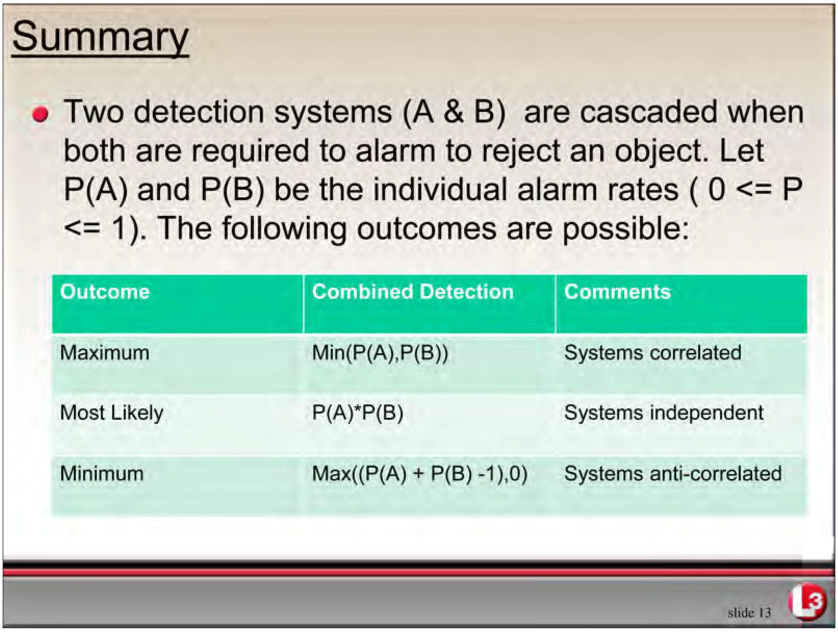
Second Case P(A)=0.6 P(B)=0.2

- Minimum P = 0
- Max[(P(A)+P(B) -1),0]



slide 11

slide 12


Summary
Two detection systems (A & B) are cascaded when both are required to alarm to reject an object. Let P(A) and P(B) be the individual alarm rates (0 <= P <= 1). The following outcomes are possible:
Outcome
Combined Detection
Comments
Maximum
Min(P(A),P(B))
Systems correlated
Most Likely
P(A)*P(B)
Systems independent
Minimum
Max((P(A) + P(B) -1),0)
Systems anti-correlated
slide 13

16.25 Ritesh Patel: Integrated check point

SPAWAR Systems Center PACIFIC

Homeland Security

Integrated Checkpoint Project (ICP)

Presented at ADSA05 workshop

Northeastern University, Boston

May 4th 2011

1

SPAWAR Systems Center PACIFIC

Homeland Security

Conclusion

- System Engineering Approach key to an integrated solution
- Focus on building systems of system
- Checkpoint is a decision process
- Utilize User Centric Design (UCD) principles
  - Human factors approach
  - TSO task analysis
  - Advanced display concepts

ICP Background

3

ICP User Requirements

- **Capability Shortfalls**
  - Information sharing environment
  - Airport wide linkage
  - Dynamic threat model- flexible
  - Centralized monitoring

- **Operational Needs**
  - Technology integration
  - Integration flexibility
  - Network connectivity
  - Data Sharing

- **Performance Goals**
  - *Threat reduction*
  - Maximized throughput
  - *Optimize screening operations*
  - Screening accuracy
  - Privacy concerns

ICP Logic and Relevance

SPAWAR Systems Center PACIFIC — Homeland Security

The Current ICP could:

- Promote information sharing within/across a checkpoint
- Allow information access beyond the checkpoint
- Contribute to inter-agency collaboration
- Connect to external data sources
- Enhance situational awareness
- Provide better decision support for TSA Officers (TSOs)

5

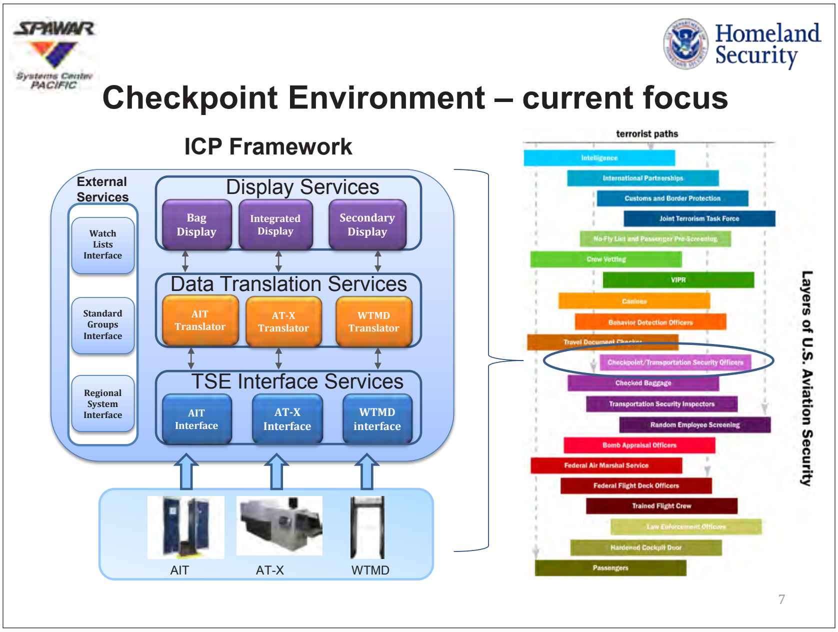
ICP Capabilities

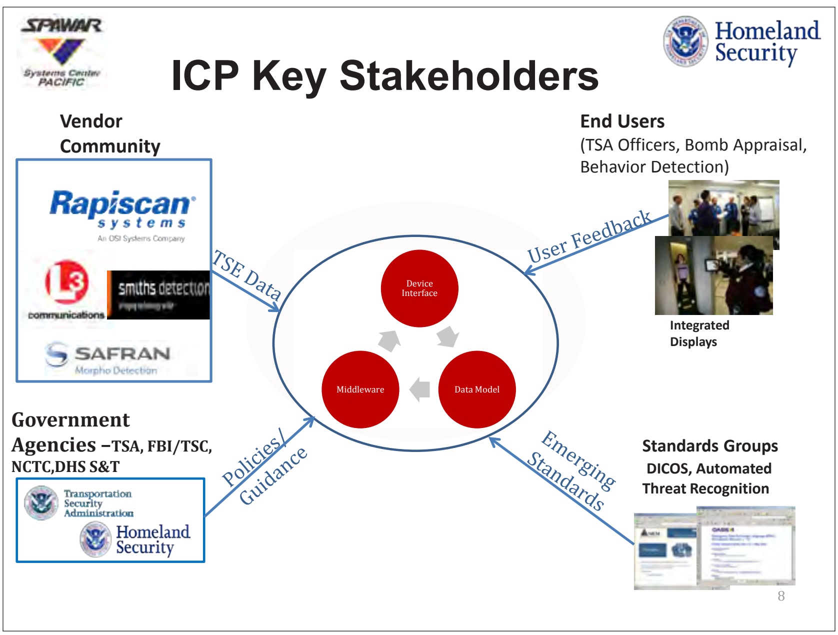
SPAWAR Systems Center PACIFIC — Homeland Security

- **The Current ICP capability enables *information sharing* within and across the checkpoint**
  - Current checkpoint environment isolated
  - ICP could *enhance situational awareness through* ***networked data sharing***
  - ICP ***Correlates passenger- baggage information*** - could add more…
  - TSA Officers (TSOs) and others could have ***better decision support***
  - ***Distributed information*** means distributed screening action – *beyond* checkpoint

- **ICP framework enables additional capabilities for data sharing and reach back beyond the checkpoint**
  - External data sources could now be possible as inputs
  - ***Enables Inter-agency collaboration****, further augmenting transportation security*

- **Universal information sharing possibilities**
  - Within and across checkpoints
  - All levels of the transportation security enterprise – enhancing ***improved security awareness across regional transportation hubs***


SPAWAR
Systems Center PACIFIC
Homeland Security
Checkpoint Environment – current focus
ICP Framework
External Services
Watch Lists Interface
Standard Groups Interface
Regional System Interface
Display Services
Bag Display
Integrated Display
Secondary Display
Data Translation Services
AIT Translator
AT-X Translator
WTMD Translator
TSE Interface Services
AIT Interface
AT-X Interface
WTMD interface
AIT
AT-X
WTMD
terrorist paths
Intelligence
International Partnerships
Customs and Border Protection
Joint Terrorism Task Force
No-Fly List and Passenger Pre-Screening
Crew Vetting
VIPR
Canines
Behavior Detection Officers
Checkpoint/Transportation Security Officers
Checked Baggage
Transportation Security Inspectors
Random Employee Screening
Bomb Appraisal Officers
Federal Air Marshal Service
Federal Flight Deck Officers
Trained Flight Crew
Law Enforcement Officers
Hardened Cockpit Door
Passengers
Layers of U.S. Aviation Security
7


SPAWAR
Systems Center PACIFIC
Homeland Security
ICP Key Stakeholders
Vendor Community
Rapiscan systems
An OSI Systems Company
L3 communications
smiths detection
SAFRAN
Morpho Detection
TSE Data
End Users
(TSA Officers, Bomb Appraisal, Behavior Detection)
User Feedback
Integrated Displays
Device Interface
Middleware
Data Model
Government Agencies –TSA, FBI/TSC, NCTC,DHS S&T
Transportation Security Administration
Homeland Security
Policies/ Guidance
Emerging Standards
Standards Groups
DICOS, Automated Threat Recognition
8

ICP User Validation

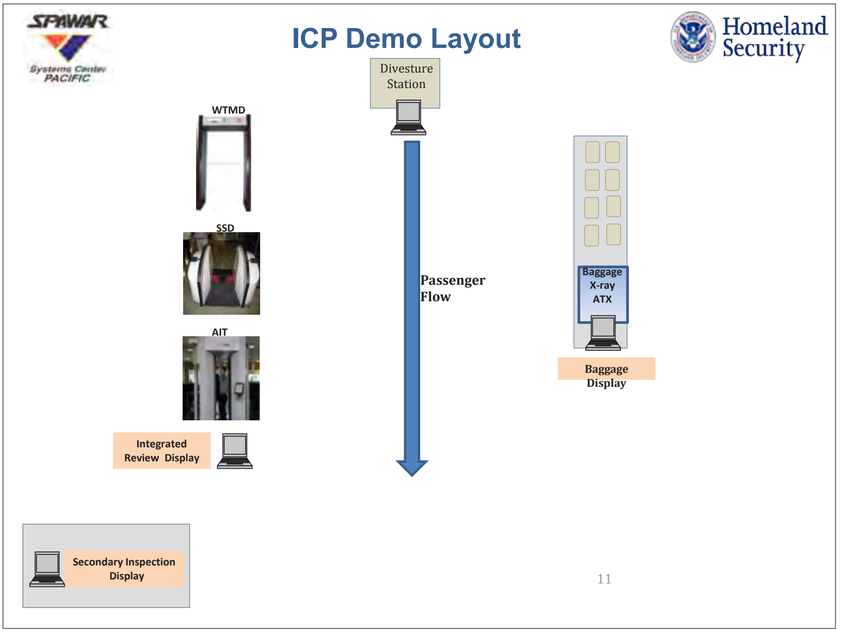
User Interactions
- 7 Airport visits
- 4 onsite demos
- 4 vendors visited
- Usability testing
- Multiple Discussions
- Hands on feedback

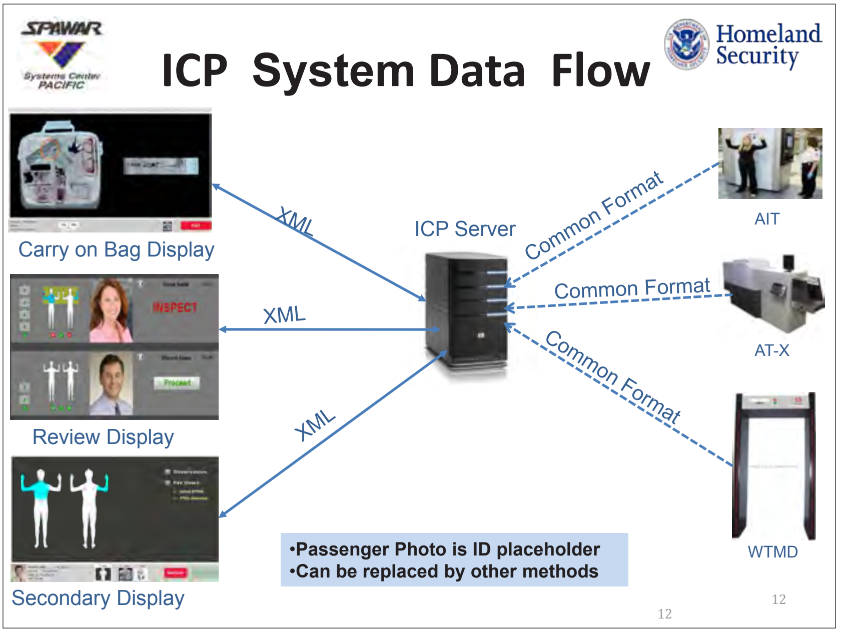
Airports Engaged
- SAN - San Diego CA
- SNA- Santa Anna CA
- LGB - Long Beach
- ONT -Ontario CA
- DFW -Dallas TX
- BNA- Nashville TN
- ACY- Atlantic City NJ

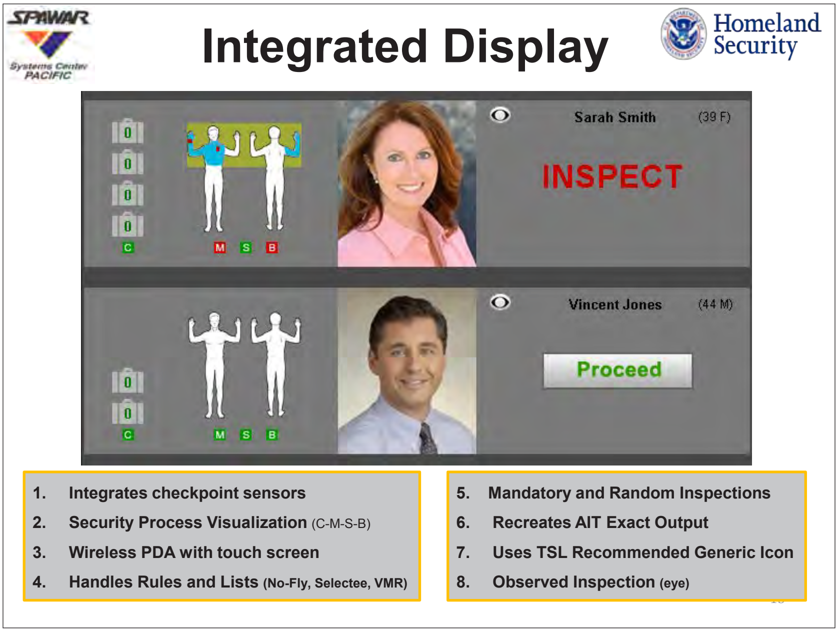
9

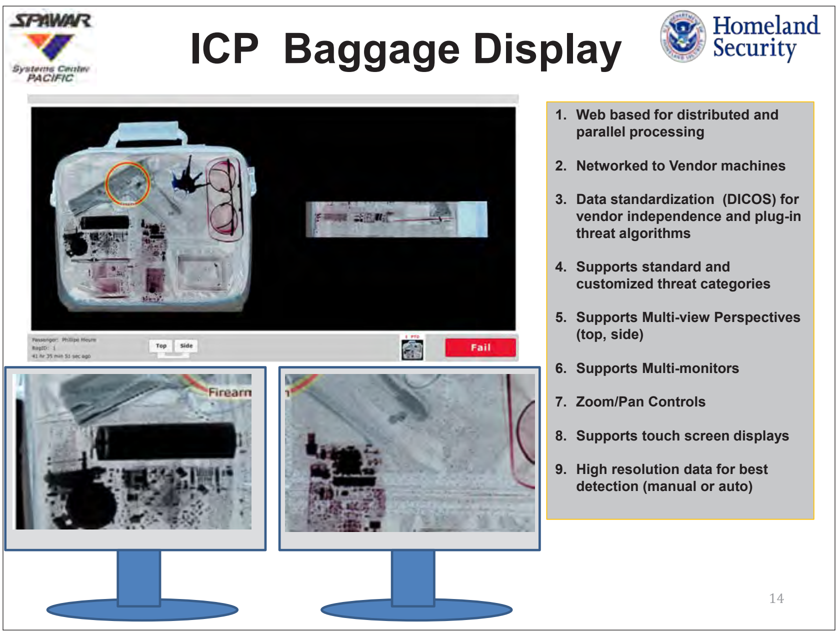
ICP System Overview

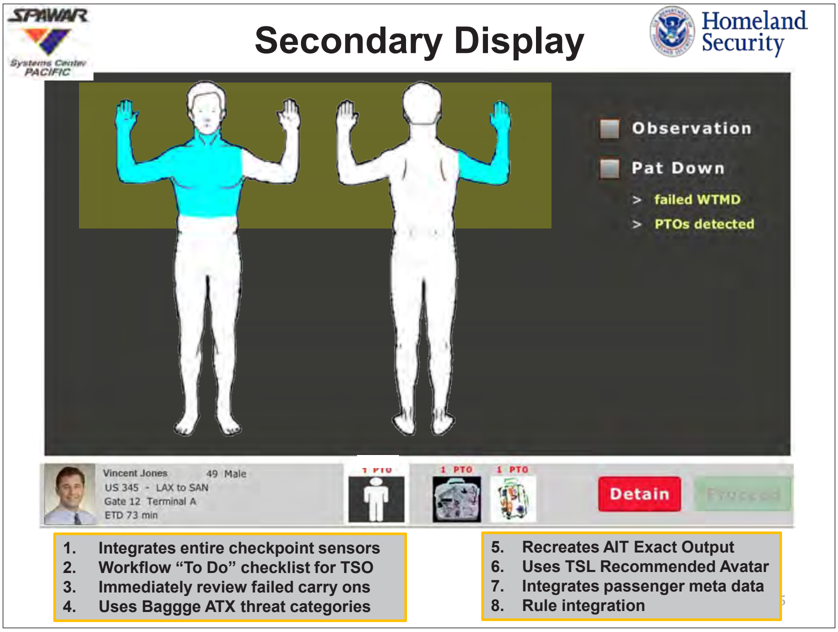
10


SPAWAR
Systems Center
PACIFIC
ICP Demo Layout
Homeland
Security
Divesture
Station
WTMD
SSD
AIT
Passenger
Flow
Baggage
X-ray
ATX
Baggage
Display
Integrated
Review Display
Secondary Inspection
Display
11

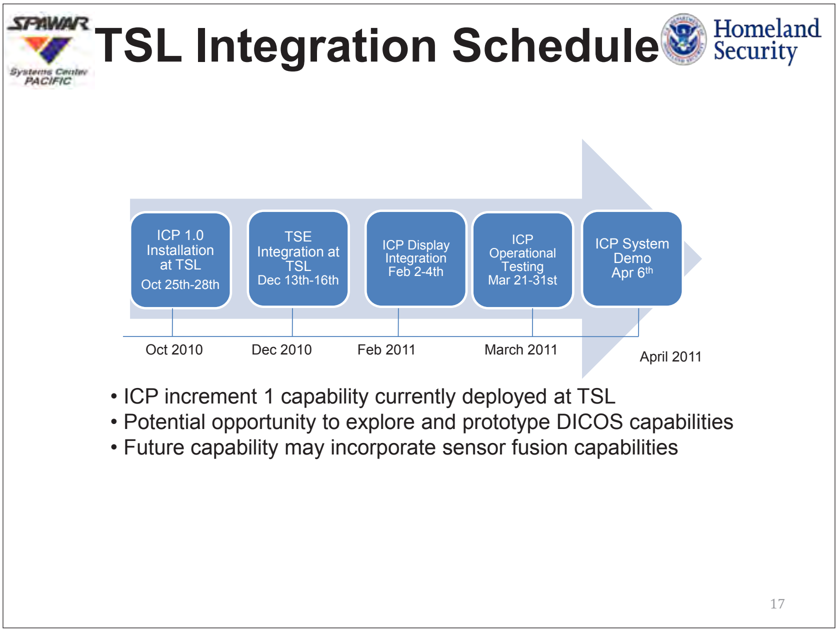

SPAWAR
Systems Center
PACIFIC
ICP System Data Flow
Homeland
Security
Carry on Bag Display
Review Display
Secondary Display
XML
XML
XML
ICP Server
Common Format
Common Format
Common Format
AIT
AT-X
WTMD
•Passenger Photo is ID placeholder
•Can be replaced by other methods
12

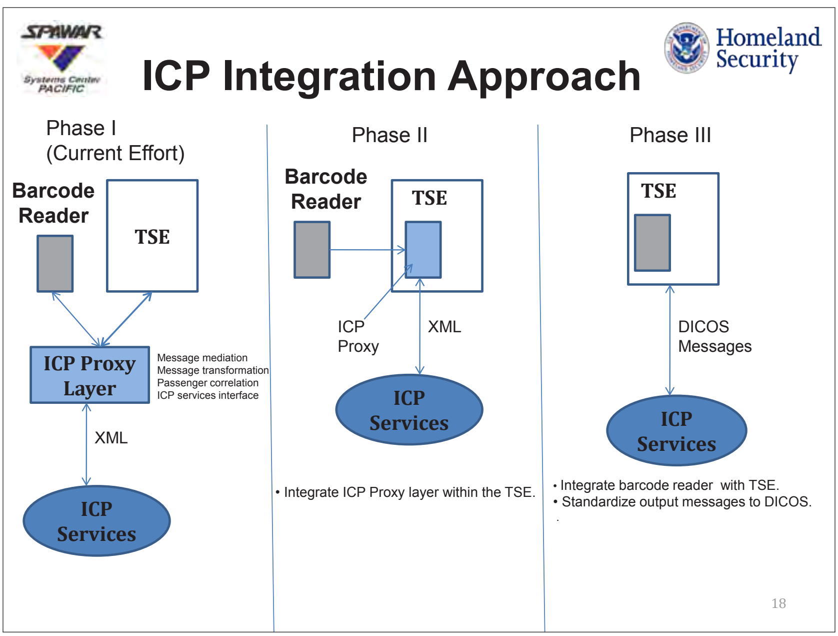

SPAWAR
Systems Center PACIFIC
Integrated Display
Homeland Security
Sarah Smith (39 F)
INSPECT
Vincent Jones (44 M)
Proceed
1. Integrates checkpoint sensors
2. Security Process Visualization (C-M-S-B)
3. Wireless PDA with touch screen
4. Handles Rules and Lists (No-Fly, Selectee, VMR)
5. Mandatory and Random Inspections
6. Recreates AIT Exact Output
7. Uses TSL Recommended Generic Icon
8. Observed Inspection (eye)


SPAWAR
Systems Center PACIFIC
ICP Baggage Display
Homeland Security
Fail
1. Web based for distributed and parallel processing
2. Networked to Vendor machines
3. Data standardization (DICOS) for vendor independence and plug-in threat algorithms
4. Supports standard and customized threat categories
5. Supports Multi-view Perspectives (top, side)
6. Supports Multi-monitors
7. Zoom/Pan Controls
8. Supports touch screen displays
9. High resolution data for best detection (manual or auto)
14


SPAWAR
Systems Center PACIFIC
Secondary Display
Homeland Security
Observation
Pat Down
> failed WTMD
> PTOs detected
Vincent Jones 49 Male
US 345 - LAX to SAN
Gate 12 Terminal A
ETD 73 min
1 PTO
1 PTO
Detain
1. Integrates entire checkpoint sensors
2. Workflow "To Do" checklist for TSO
3. Immediately review failed carry ons
4. Uses Baggge ATX threat categories
5. Recreates AIT Exact Output
6. Uses TSL Recommended Avatar
7. Integrates passenger meta data
8. Rule integration


SPAWAR
Systems Center PACIFIC
Homeland Security
ICP Current Activities
16


SPAWAR
Systems Center PACIFIC
TSL Integration Schedule
Homeland Security
ICP 1.0 Installation at TSL Oct 25th-28th
TSE Integration at TSL Dec 13th-16th
ICP Display Integration Feb 2-4th
ICP Operational Testing Mar 21-31st
ICP System Demo Apr 6th
Oct 2010
Dec 2010
Feb 2011
March 2011
April 2011
• ICP increment 1 capability currently deployed at TSL
• Potential opportunity to explore and prototype DICOS capabilities
• Future capability may incorporate sensor fusion capabilities
17


SPAWAR
Systems Center PACIFIC
ICP Integration Approach
Homeland Security
Phase I
(Current Effort)
Barcode Reader
TSE
ICP Proxy Layer
Message mediation
Message transformation
Passenger correlation
ICP services interface
XML
ICP Services
Phase II
Barcode Reader
TSE
ICP Proxy
XML
ICP Services
• Integrate ICP Proxy layer within the TSE.
Phase III
TSE
DICOS Messages
ICP Services
• Integrate barcode reader with TSE.
• Standardize output messages to DICOS.
18

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ICP DICOS Integration

19

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Homeland Security

Integrated Checkpoint (ICP) Data Standards Initiative

Key Objectives:

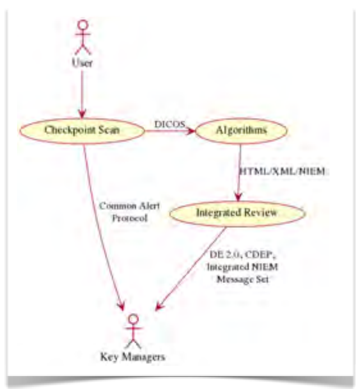
•To Enable a Standardized Interoperable ICP Message Set to improve information flow and sharing

• Collaborate with National Electrical Manufactures Association (NEMA) related to standards such as Digital Imaging and Communications in Security (DICOS)

- to ensure appropriate reuse of existing standards

- to ensure developing standards match needs of ICP users and stakeholders

ICP DICOS Use Case:



20

ICP DICOS Integration current progress

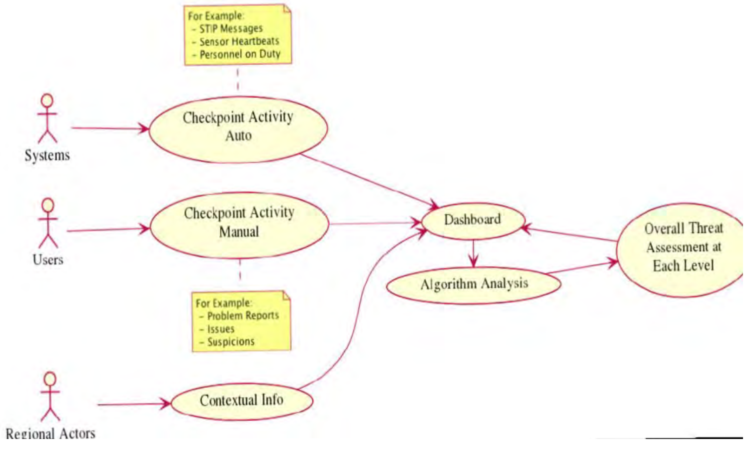
SPAWAR Systems Center PACIFIC — Homeland Security

- Developed ICP data model based on DICOS standard.
- Testing DICOS toolkit with ICP system
  - Created DICOS messages from XML templates
  - Developing parsers to convert .DCS format into ICP
  - Developing parsers to convert ICP format into .DCS
- Collaborate with National Electrical Manufactures Association (NEMA) related to standards such as Digital Imaging and Communications in Security (DICOS)
  - to ensure appropriate reuse of existing standards
  - to ensure developing standards match needs of ICP users and stakeholders

FOR OFFICIAL USE ONLY

Information Exchanges at the Checkpoint

SPAWAR Systems Center PACIFIC — Homeland Security

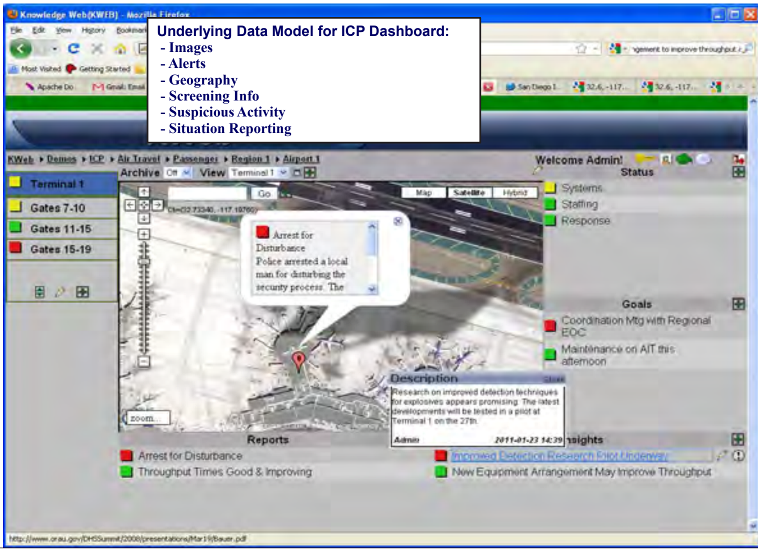


22

SPAWAR Systems Center PACIFIC

Homeland Security

Example Dashboard Capability



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Homeland Security

Questions ????

Mike Barrientos
mike.barrientos@dhs.gov
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cbarton@spawar.navy.mil
Ritesh Patel
ritesh.patel@navy.mil
Jeff Waters
jeff.waters@navy.mil

24

16.26 Doug Bauer and Suriyun Whitehead: DICOS

Overview: DICOS

DICOS
Digital Imaging and Communications in Security

Doug Bauer, Ph.D.
PROGRAM MANAGER
Explosives Division
Department of Homeland Security

3 May 2011

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Science and Technology

1

DICOS is

standard interfaces / mechanisms / data formats for

- information sharing
  - scan data
  - detection results
  - instructions
- system integration

an enabler to connect multiple TSA initiatives

adapted from DICOM

- systems and algorithm vendor participation

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2

Aviation Screening Environment

Tradeoffs and Balance

Detection performance is paramount, but security screening equipment also represents a balance among the following goals:

- Throughput
- Purchase Cost
- Serviceability
- Reliability

Standalone processing; may involve human operator for detection / alarm resolution.

Evolution

- Additional Risk Based Screening
- Accommodate / integrate New Technology

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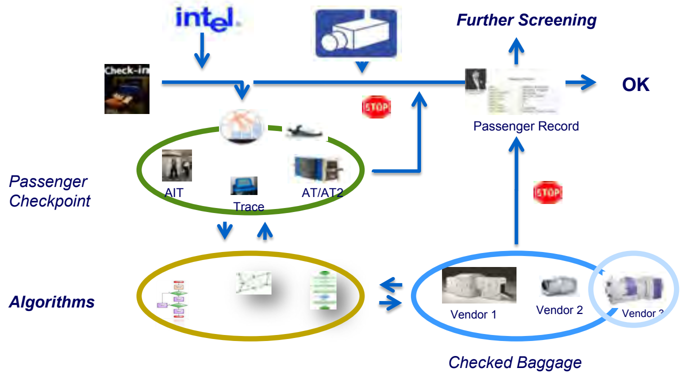
3

Airport Screening

Detection
Fusion



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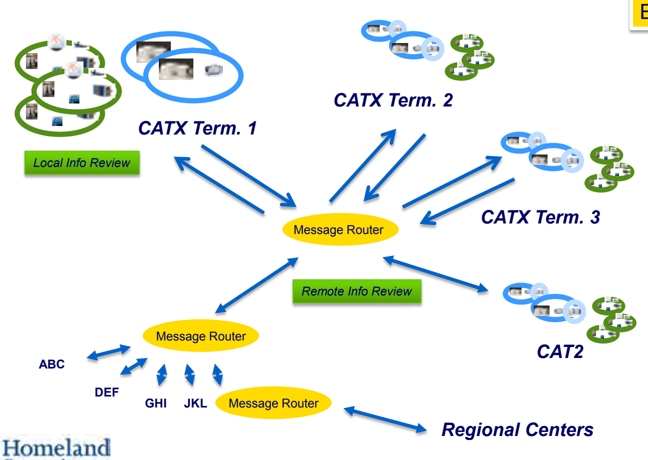
4

Airport Screening

- Detection
- Fusion
- Efficiency



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Leveraging DICOS

Vendor-independent (common)
- Workstations
- Networks

Third-party involvement
- Reconstruction
- ATR
- Display
- OSARP assist
- Maintenance
- TIP
- Data mining
- System fusion

Continual improvements to:
- Detection
- Efficiency

Facilitate more rapid innovation through broader participation

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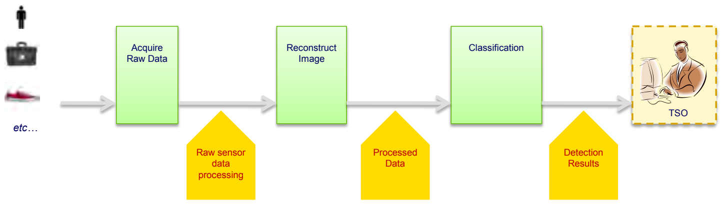
6

From Scan to Resolution



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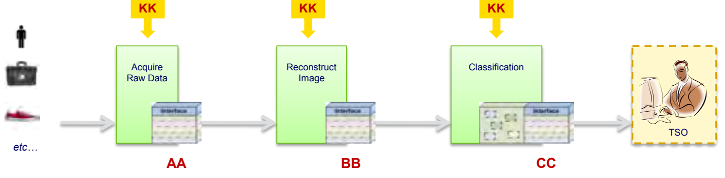
DICOS Interfaces



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DICOS "BB" & "CC" Interfaces

Standard format for screening images and ATR / ATD detection results

Enables multiple suppliers / deployment of

- detection algorithms; tailored algorithm libraries
  (standalone configuration or centralized on the network)
- workstation displays for OSR, conforming to a single design

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DICOS "AA" Interface

Standard format for raw data

- detector, sensor, projection, and corrected data

Enables multiple suppliers / deployment of

- new raw data processing techniques for mining the data
  - Tailored outputs for inputs to algorithms
  - Compressive sensing

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DICOS "KK" Interface

Standard format for control of scan, of algorithm selection, and information routing.

Enables dynamic adjustments to screening system configuration

- triggered by risk basis, security posture
- control of scanner to change scan, image quality, throughput, algorithm sequence
- adjust operating point and ROC curve.

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Status

Phase I COMPLETED

- DICOS v1 released for
  - Checked Baggage
  - Carryon Baggage
  - Threat Detection Report Format

  } *EDS, AT, TRX…*
- DICOS roadmap
- Data transmission proof of concept.

Phase II Underway

- Test DICOS v1.
- Develop and Release DICOS v2
  - AIT (XBS, MMWave, TX, THx, IR, QR)
  - Updated Threat Detection Report Format
  - Address deficiencies uncovered in testing DICOS v1.
- Data transmission use cases.

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TSA Initiatives: Risk Based Screening

TSA plans to implement a new "risk-based" screening method over the next year that will tailor-fit airport security procedures to individuals based on intelligence and suspicious behavior.

House Homeland Security subcommittee on Transportation Security (2/11/2011)

Challenge:

- Rolling out tailored adjustments to screening procedures and systems in a timely, responsive and consistent manner.
- Maintaining vigilance over threat space when tools are less adaptable.

Potential Approach:

- Leverage greater flexibility and automated configuration adjustments; real-time triggering of screening systems.
- Automated selection from a robust and dynamic library of algorithms.

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Summary

DICOS development supports a risk based screening approach and systems of systems deployments.

DICOS testing tools available.

DICOS v2 development underway.

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August 2010

The Science and Technology Directorate (S&T) strongly agrees that standard data formats are a key enabler to improving the capabilities of scanning devices.

To accelerate standard image format and data interchange interfaces for Security Screening technologies, S&T has partnered with the Transportation Security Administration (TSA) to invest in the Digital Imaging and Communications for Security (DICOS) project. By providing an industry-wide standard, DICOS will lower barriers to entry and enable new entrants and qualified businesses of all sizes to contribute to the development of security screening technologies. Investments in DICOS are designed to enable future procurements to separately source the best hardware systems and the best algorithms to secure the checkpoint, checked baggage, and cargo domains.

Tara O'Toole, M.D., M.P.H.
Under Secretary for Science and Technology

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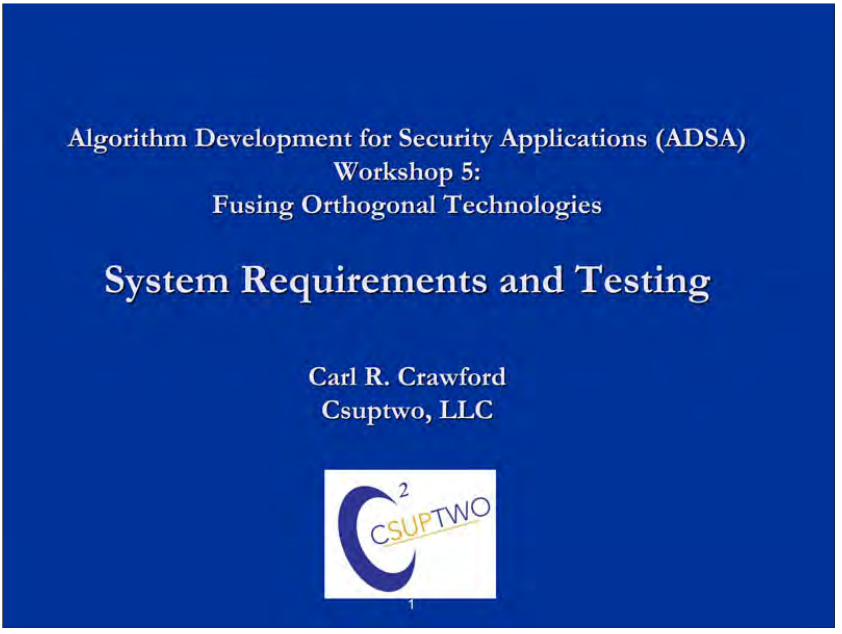
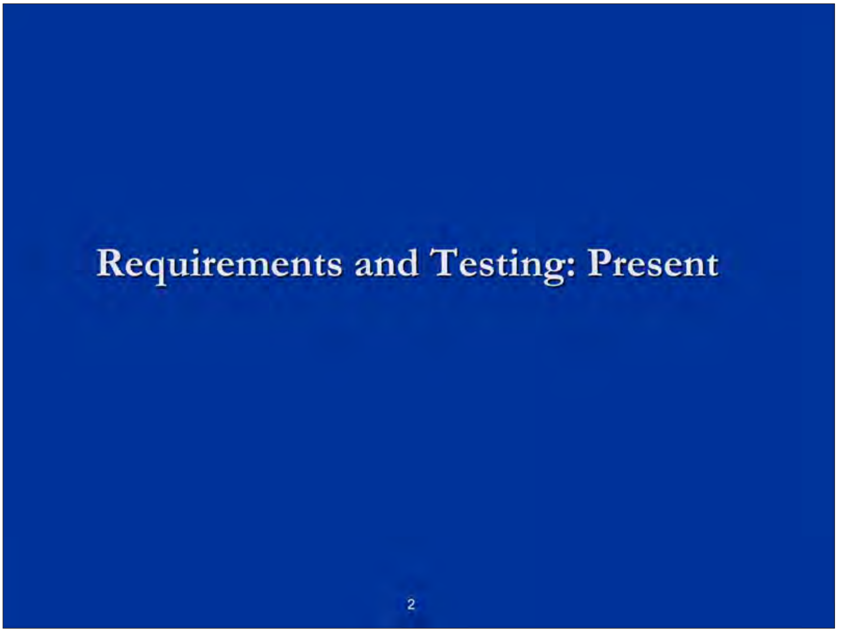
Science and Technology

16.27 Carl Crawford: Certification and qualification testing





Detection Requirements

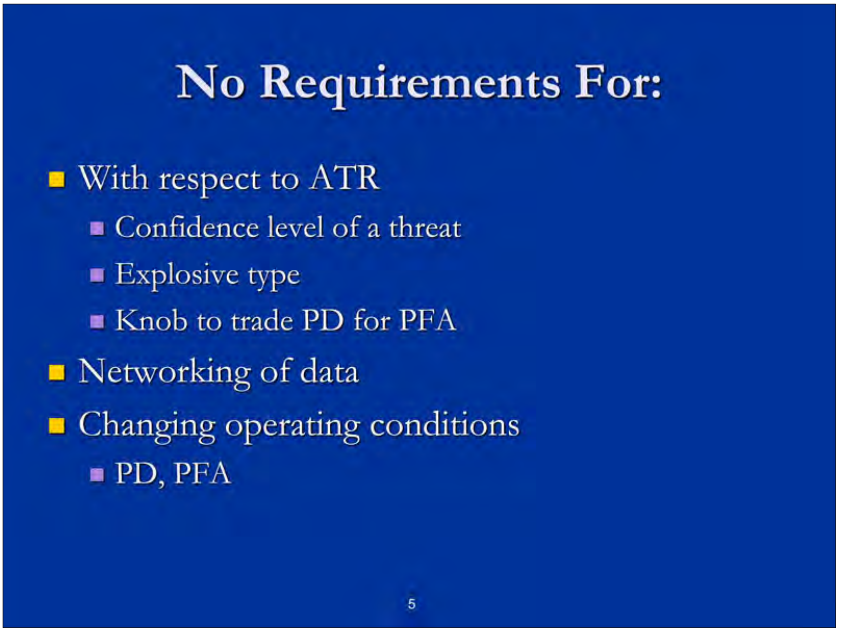
- N classes of explosives: type and min mass
- PD/class > X
- PD average > Y > X
- PFA < Z
- Preferable with automated threat recognition (ATR)
- Imaging device required for false alarm mitigation

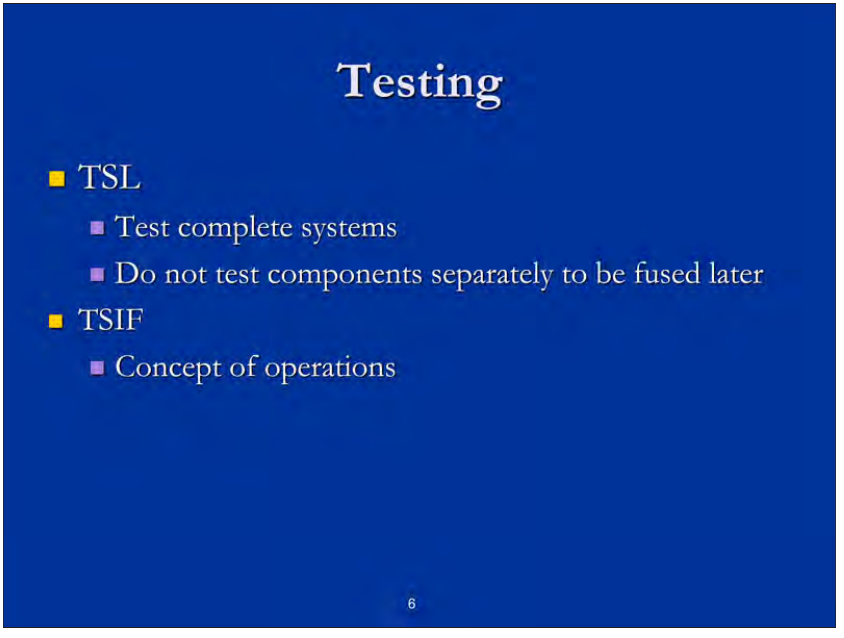
3

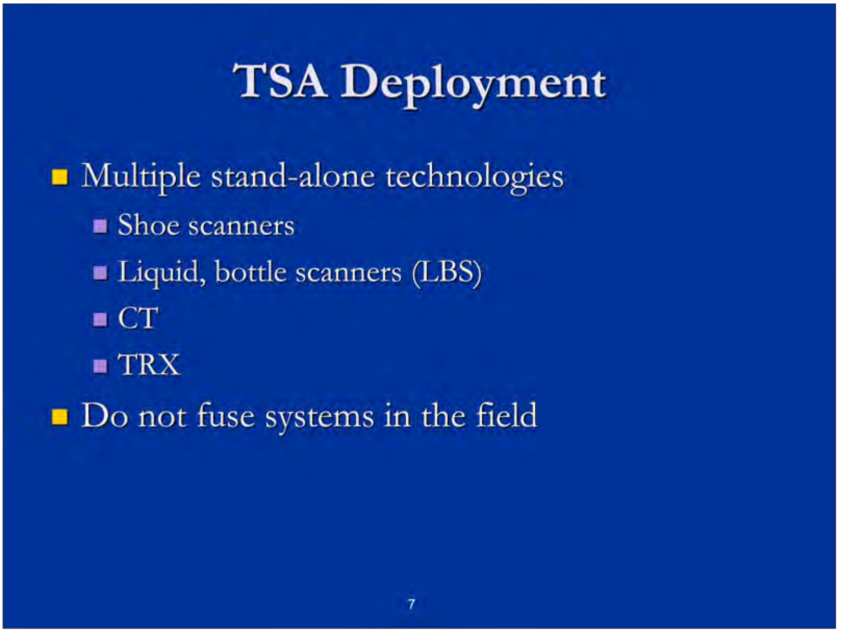
Other Requirements

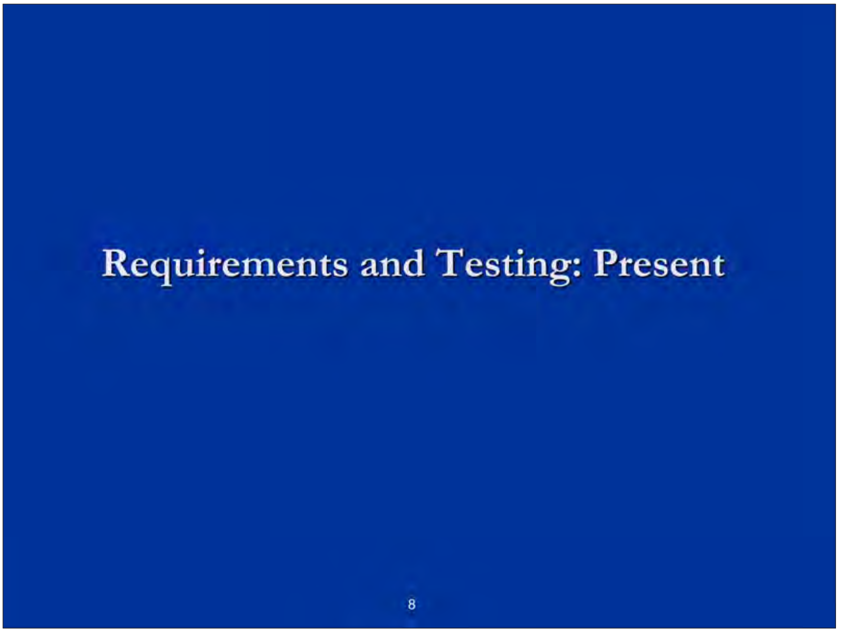
- Networking to support remote viewing stations
- Withing concept of operations to support flow of bags, cargo, passengers

4


No Requirements For:
With respect to ATR
Confidence level of a threat
Explosive type
Knob to trade PD for PFA
Networking of data
Changing operating conditions
PD, PFA
5


Testing
TSL
Test complete systems
Do not test components separately to be fused later
TSIF
Concept of operations
6


TSA Deployment
Multiple stand-alone technologies
Shoe scanners
Liquid, bottle scanners (LBS)
CT
TRX
Do not fuse systems in the field
7


Requirements and Testing: Present
8

Technology Requirements

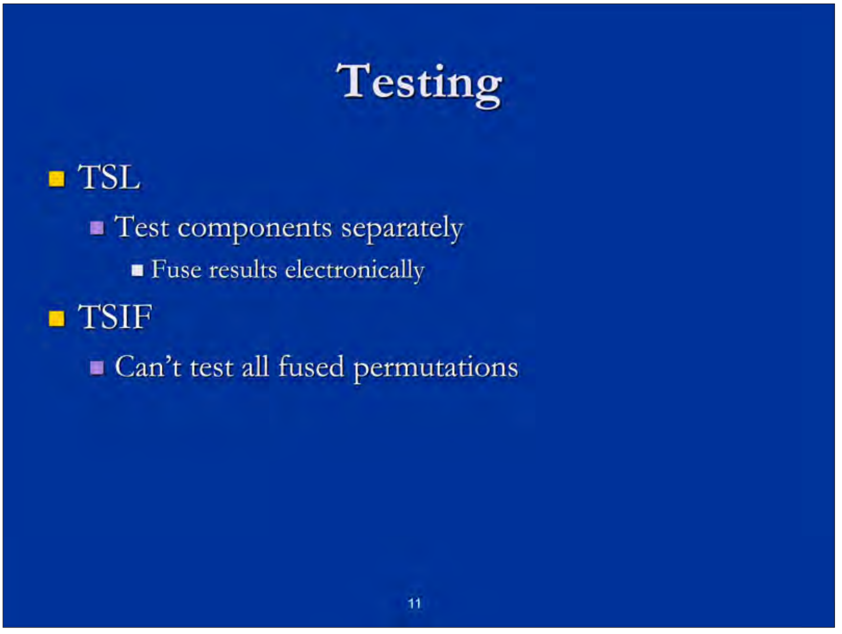
- Networking
  - Images, raw/corrected data, spectra
  - Control to set risk-level or specific areas to scan
  - DICOS
- ATR
  - Confidence level
    - Intermediate results
  - Classify type of threat
- Risk-based
  - Different ATR
  - PD v. PFA trade-off (move along ROC)

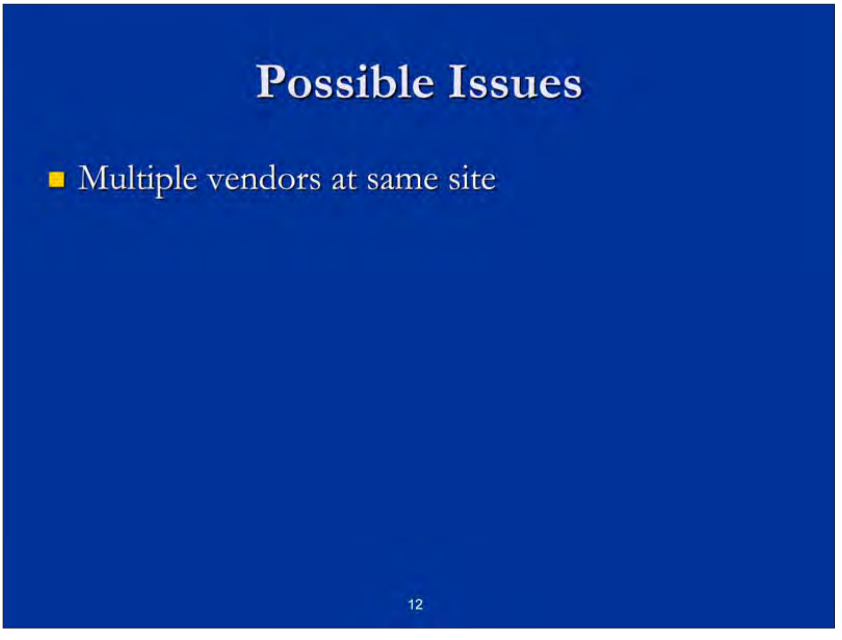
9

TSA Changes

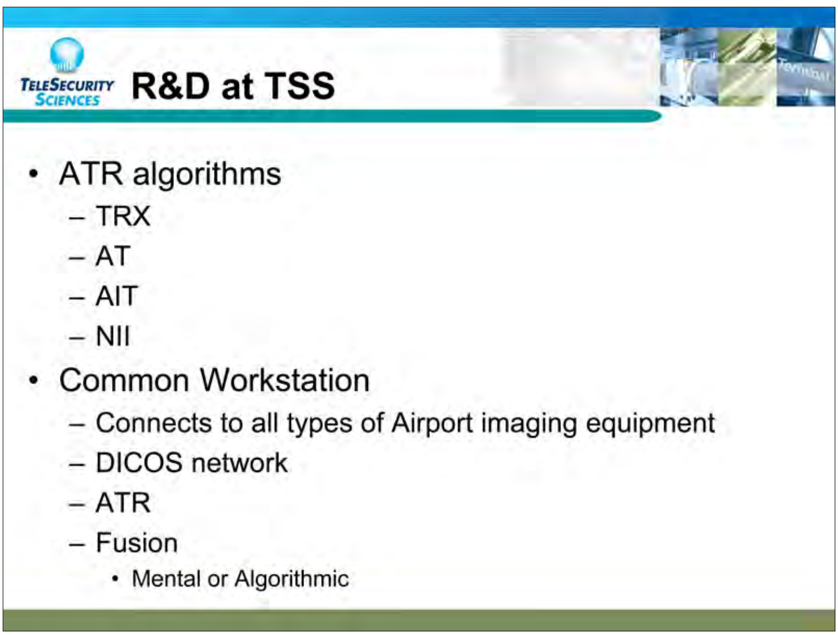
- Procurement
  - Fusion-centric
- Fuse in field
- Concept of operations
  - Process required to quickly adapt to fused systems with ever-changing technologies and threats

10


Testing
TSL
Test components separately
Fuse results electronically
TSIF
Can't test all fused permutations
11


Possible Issues
Multiple vendors at same site
12

16.28 Doug Boyd: Telesecurity sciences



TeleSecurity Sciences

Conclusions

- ATR can become competitive with human observers
- Common workstation can receive images from multiple scanners to facilitate "Mental Fusion" by an operator or "Algorithmic Fusion" by an algorithm
- "Algorithm Fusion" is effective in combining ROC results from multiple ATR algorithms

TeleSecurity Sciences

History of TSS

- 2006 started with 2 engineers with the intention of improving EDS threat resolution with electronic unpacking-- discovered the problem of connecting to airport networks
- 2007 participated in the development of DICOS
- 2008 participated in Grand Challenge for liquid detection
- 2009 first contracts with industry for algorithmic support
- 2010 won first DHS contracts for ATR for AIT, NII, and SNM
- 2011 participation in Grand Challenge for EDS segmentation

4

Financial

- 4.8 million USD in investment capital so far
- Reached neutral cash flow in 2011

Some Plans for the Future

- Need to develop international presence
  - Invision sales were overseas for first 7 years
  - Diverse customers in overseas markets
  - Overseas success may help develop interest by TSA
- Expand more into medical applications to provide revenue stability
- Both of these objectives will require much more capital

TeleSecurity Sciences

ATR Methods

- Reconstruction
  - 1 view (exploit attenuation profiles to determine shape)
  - 2, 3 and 4 views (discrete reconstruction algorithms)
  - Many views from 8-40 (iterative optimization algorithms)
  - CT with 1000 or more views (Direct Fourier or Iterative)
  - Simultaneous reconstruction and segmentation algorithms
- Dual-Energy
  - Photoelectric, Compton, Pair-production
  - Checked and carryon luggage, low energy
  - Freight and cargo: high energy
- Segmentation and classification
  - Feature extraction
  - 2D and 3D
  - Detection of faint objects
- Databases of Features

TeleSecurity Sciences

Common Workstation Medical

PACS Workstations (DICOM)

Mental Fusion

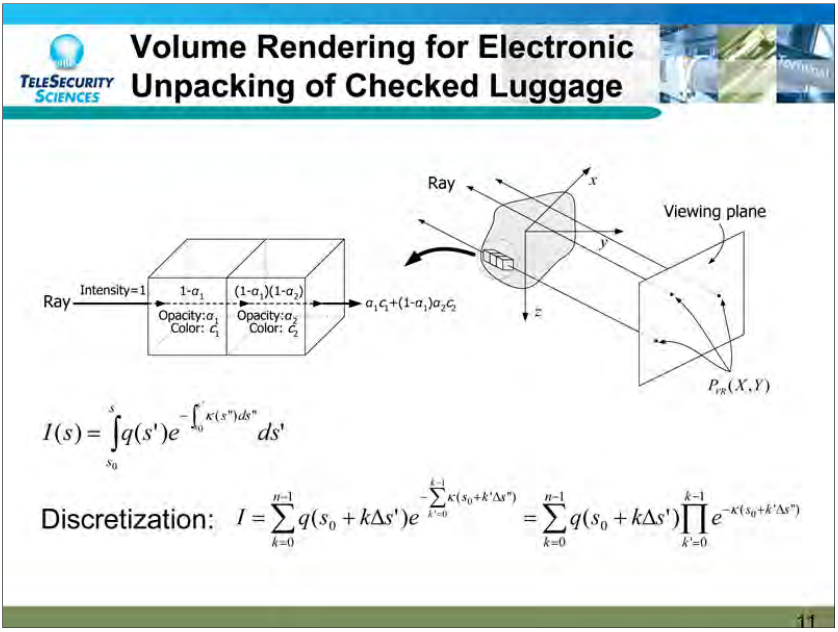
8

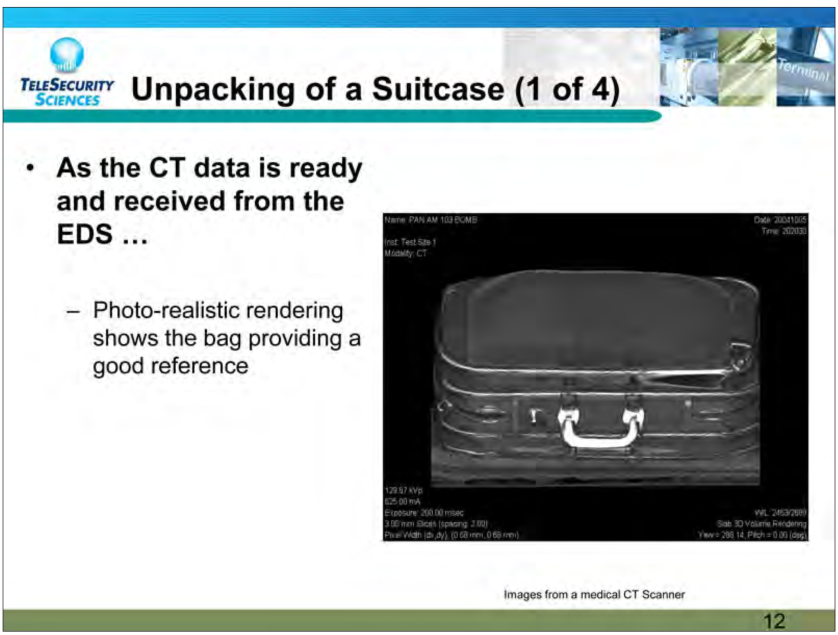
TeleSecurity Sciences

ATR for EDS

- Volume rendering techniques to improve onscreen threat resolution
- Could reduce the bags flowing to the Baggage Inspection Room

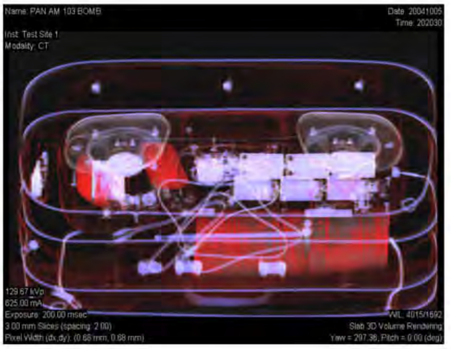
10


TeleSecurity Sciences
Volume Rendering for Electronic Unpacking of Checked Luggage
Ray
Viewing plane
Ray
Intensity=1
$1-\alpha_1$
$(1-\alpha_1)(1-\alpha_2)$
Opacity: α_1 Color: c_1
Opacity: α_2 Color: c_2
$\alpha_1 c_1+(1-\alpha_1)\alpha_2 c_2$
x
y
z
$P_{VR}(X,Y)$
$I(s)=\int_{s_0}^{s} q(s')e^{-\int_{s_0}^{s'}\kappa(s'')ds''}ds'$
Discretization: $I=\sum_{k=0}^{n-1} q(s_0+k\Delta s')e^{-\sum_{k'=0}^{k-1}\kappa(s_0+k'\Delta s'')}=\sum_{k=0}^{n-1} q(s_0+k\Delta s')\prod_{k'=0}^{k-1} e^{-\kappa(s_0+k'\Delta s'')}$
11


TeleSecurity Sciences
Unpacking of a Suitcase (1 of 4)
• As the CT data is ready and received from the EDS ...
– Photo-realistic rendering shows the bag providing a good reference
Images from a medical CT Scanner
12

Unpacking of a Suitcase (2 of 4)

- **At the Click of a Button ...**
  - The volume rendering of the entire bag clearly reveals the cassette radio and other miscellaneous objects.



Images from a medical CT Scanner

13

Unpacking of a Suitcase (3 of 4)

- **For further scrutiny …**
  - The cassette radio can be electronically unpacked and rendered as a surface image.

Images from a medical CT Scanner

14

Unpacking of a Suitcase (4 of 4)

- **At the click of a button …**
  - Localized volume rendering clearly reveals all components within the cassette radio, e.g., speakers, battery back, and two explosive simulants

Images from a medical CT Scanner

15

ATR for TRX and AT

Current checkpoint scanners may have between 1 and 4 views

16

Liquid Screening with checkpoint scanners

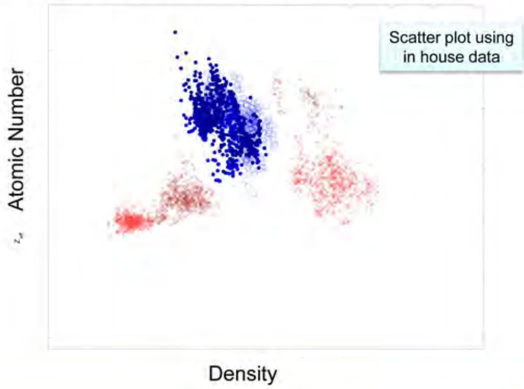
- Classification of liquids in bin mode or divested bags
- Precision measurements of density and Z
- Use for dual-energy single and multi-view line scanners

A common workstation module for checkpoint scanners

17

Liquid Classification Results

Blue points are water and common beverages, the other points are for prohibited liquids



18

ATR for AIT Passenger Scanners

- Backscatter X-ray Scanners
- Millimeter Wave Scanners

19

Backscatter X-ray ATR for AIT

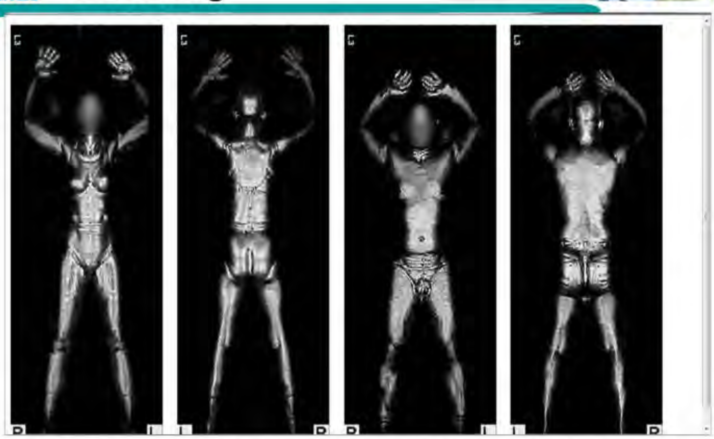
(a) (b) (c)

A schematic illustration of automated threat recognition and reporting of the location and type of threat without intrusion on passenger privacy. This would be a common workstation module for passenger screening. (Image from Internet)

20

TeleSecurity Sciences

Millimeter Wave Passenger Screening



These systems reconstruct a holographic display of the body surface using a rotating millimeter wave antenna system. (Images from internet)

21

TeleSecurity Sciences

Detection of Faint Objects

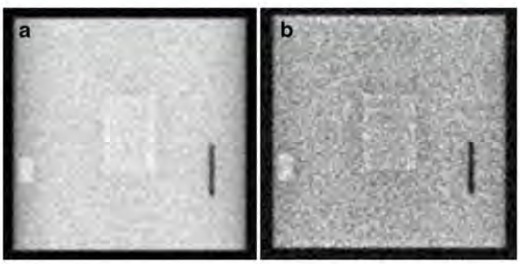


Image from Kaufman and Carlson, J Transsp Secur

Algorithm A
Algorithm B
Algorithm C
.
.
Algorithm N

- All Algorithms run simultaneously
- Each Algorithm has a different ROC depending on body region and threat type
- The Final Decision is made by Fusion of the results of each Algorithm

22

TeleSecurity Sciences

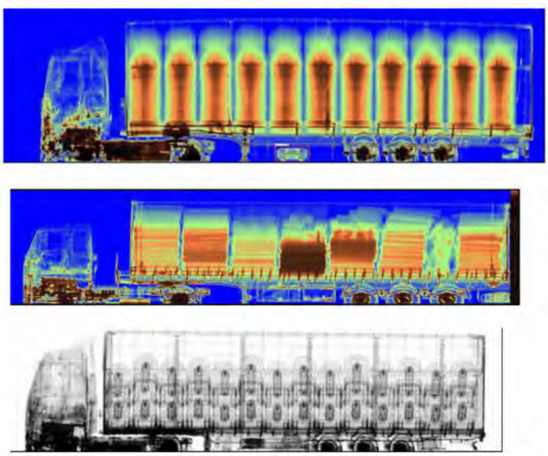
ATR for NII

- Trucks and cargo are scanned using dual-energy linacs up to 8 MeV

23

TeleSecurity Sciences

NII for Truck and Cargo Inspection



Projection mages are formed using high-energy X-rays produced by single or dual-energy linacs in the MeV range

Images from the internet

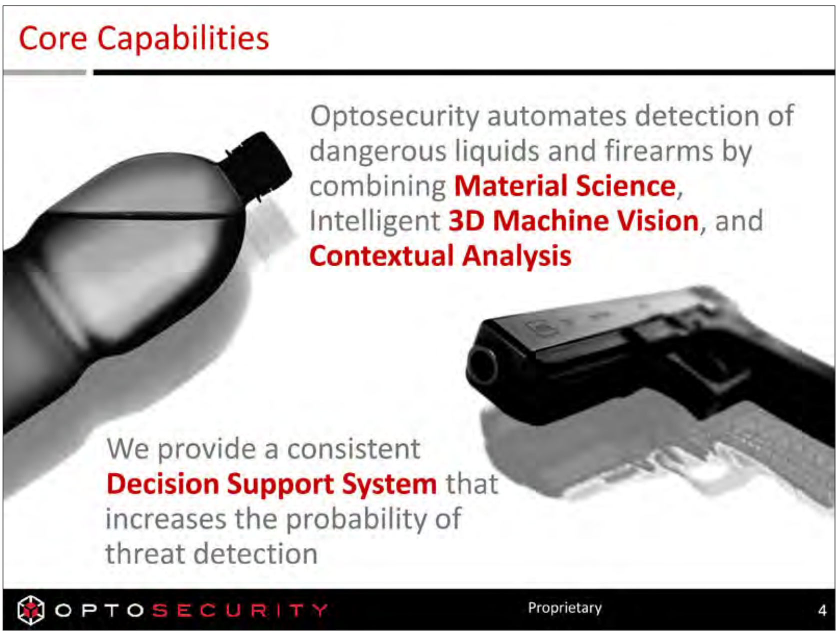
24

16.29 Luc Perron: Optosecurity

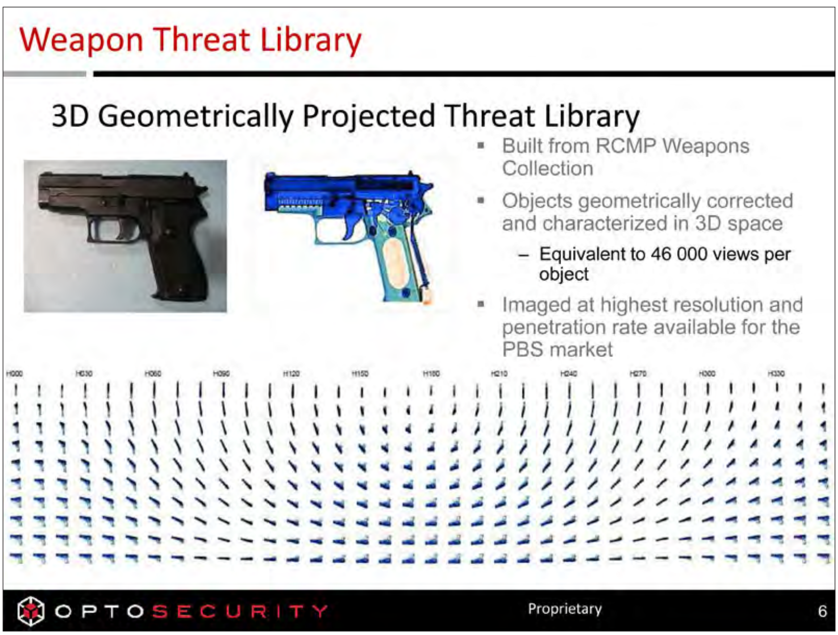
Lessons Learned

1. Multi-Vendor Automated Detection is no longer a dream: It's REAL
   - But it requires much more than simply sharing images
2. We could significantly improve security screening by focusing more on Process Efficiency
   - Today's X-ray data is still under-exploited
   - We need a paradigm shift: « **Thinking Outside the Box** »
3. Integrated Security Screening at the Checkpoint is available NOW

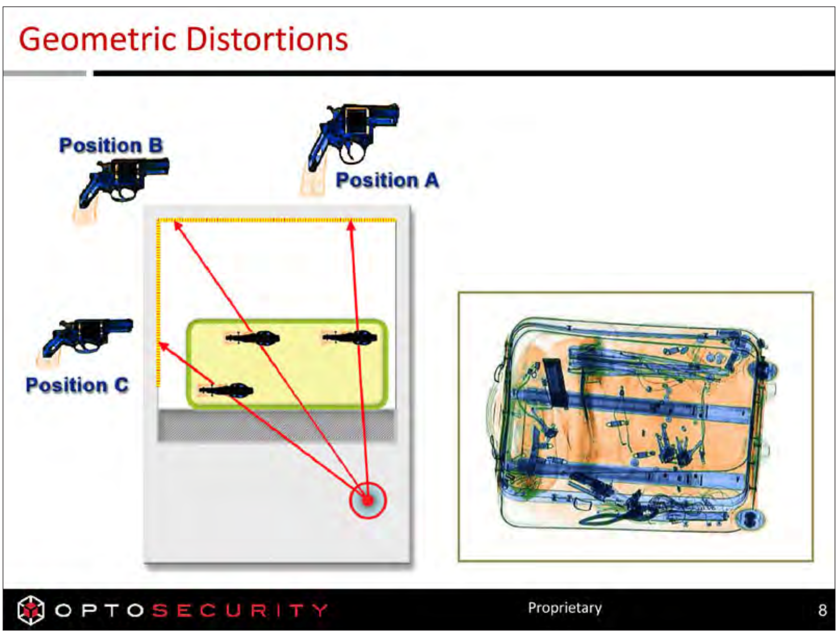
OPTOSECURITY Proprietary 3

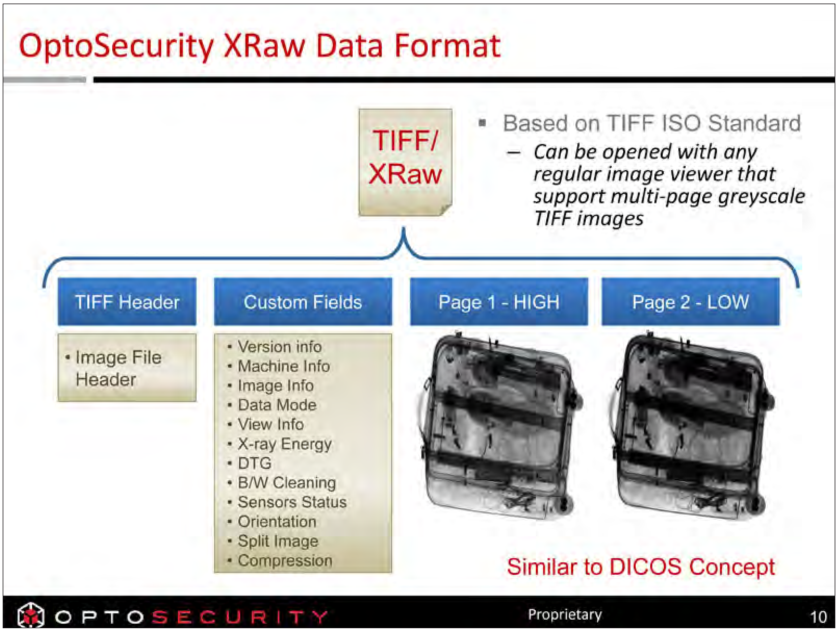



Weapon Threat Detection
Firearms are not always easy to find
Operator-Assisted Weapon Threat Detection improves the overall probability of detection
WARNING: Suspicious Content
Patent Issued: Screening Luggage • Geometric Distortion
OPTOSECURITY
Proprietary
5


Weapon Threat Library
3D Geometrically Projected Threat Library
Built from RCMP Weapons Collection
Objects geometrically corrected and characterized in 3D space
– Equivalent to 46 000 views per object
Imaged at highest resolution and penetration rate available for the PBS market
OPTOSECURITY
Proprietary
6


Weapon Threat Library
World's Largest X-ray Library of Handguns
OPTOSECURITY
Proprietary
7


Geometric Distortions
Position B
Position A
Position C
OPTOSECURITY
Proprietary
8


OptoSecurity XRaw Data Format
TIFF/ XRaw
Based on TIFF ISO Standard
– Can be opened with any regular image viewer that support multi-page greyscale TIFF images
TIFF Header
Custom Fields
Page 1 - HIGH
Page 2 - LOW
• Image File Header
• Version info
• Machine Info
• Image Info
• Data Mode
• View Info
• X-ray Energy
• DTG
• B/W Cleaning
• Sensors Status
• Orientation
• Split Image
• Compression
Similar to DICOS Concept
OPTOSECURITY
Proprietary
10

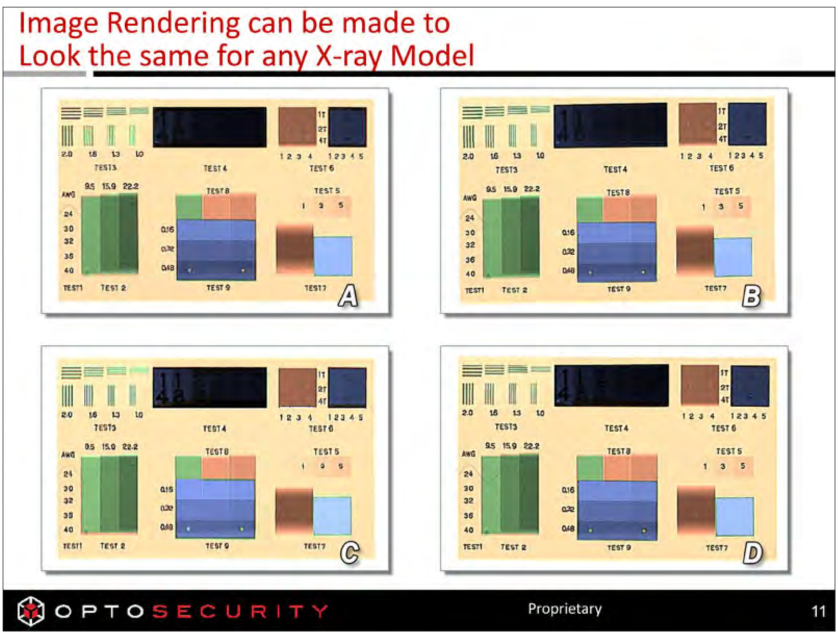
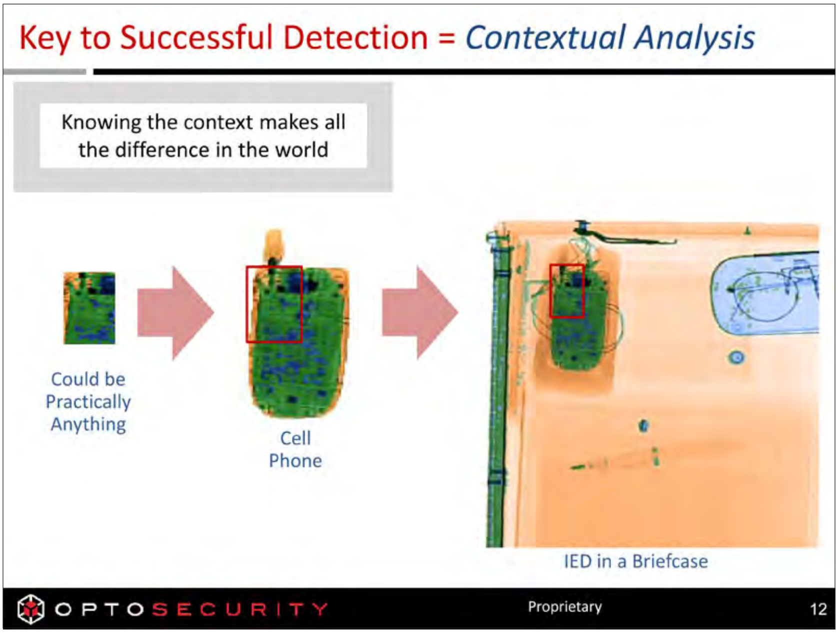
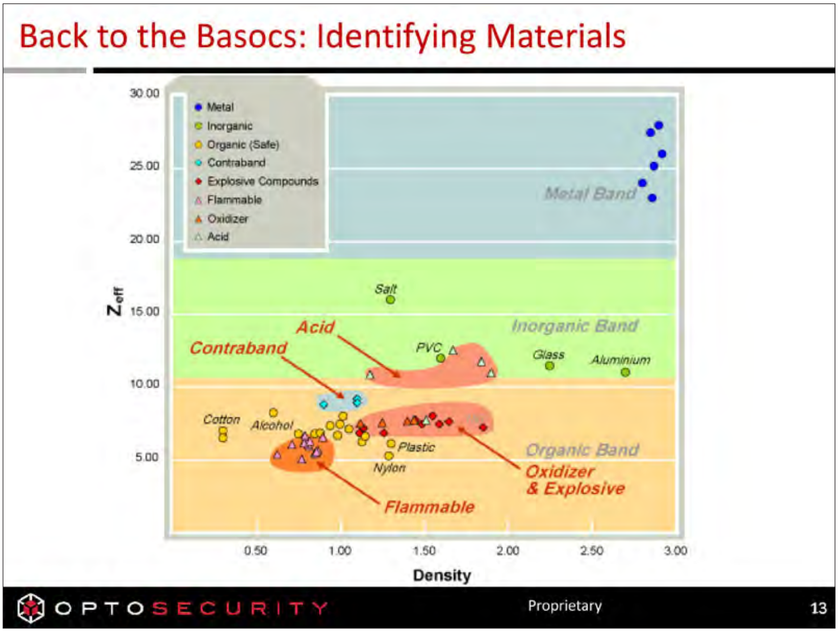


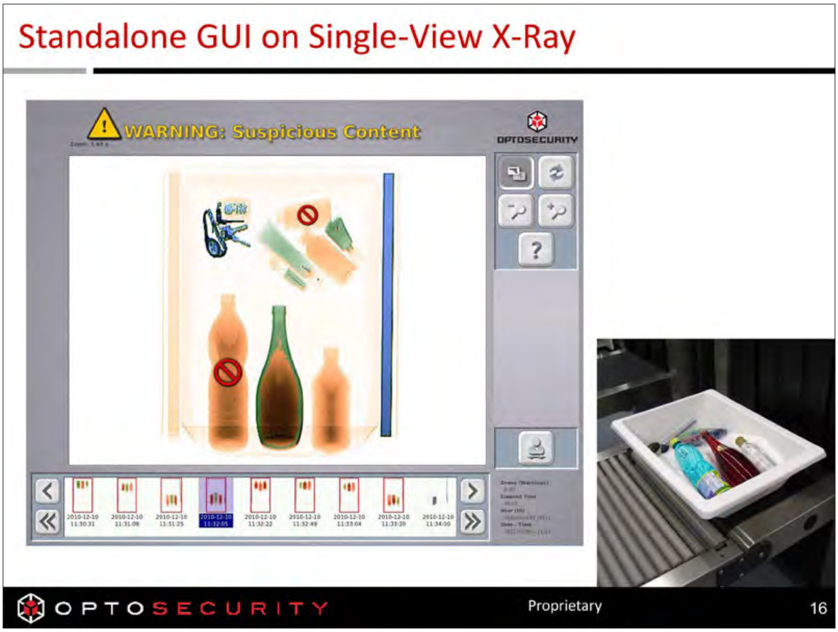
Image Rendering can be made to Look the same for any X-ray Model
A
B
C
D
OPTOSECURITY
Proprietary
11

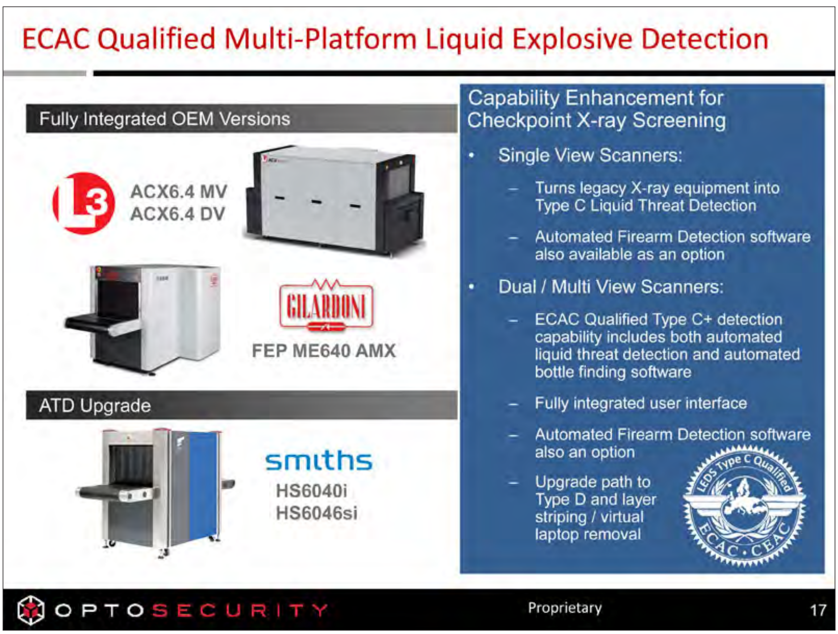

Key to Successful Detection = Contextual Analysis
Knowing the context makes all the difference in the world
Could be Practically Anything
Cell Phone
IED in a Briefcase
OPTOSECURITY
Proprietary
12

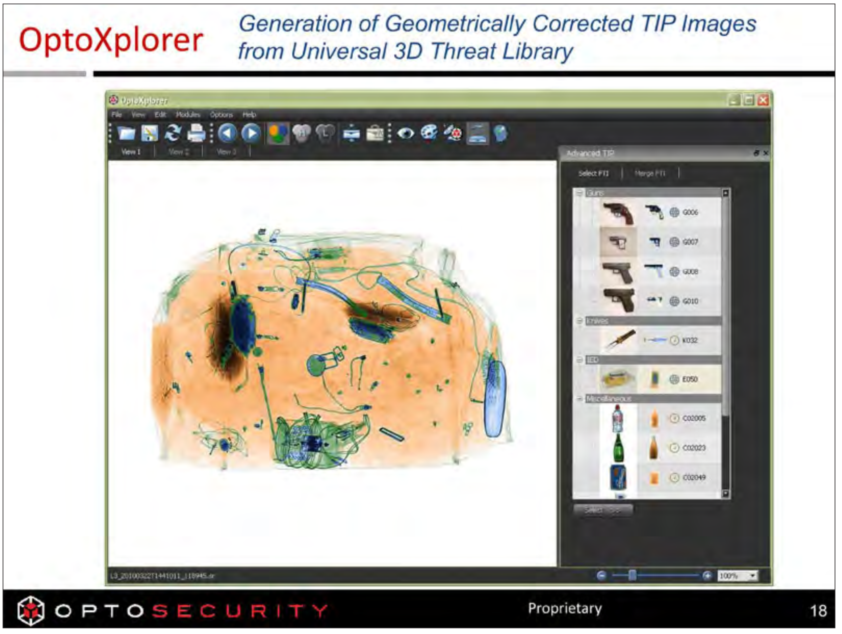

Back to the Basocs: Identifying Materials
Metal
Inorganic
Organic (Safe)
Contraband
Explosive Compounds
Flammable
Oxidizer
Acid
Metal Band
Salt
Inorganic Band
Acid
Contraband
PVC
Glass
Aluminium
Cotton
Alcohol
Plastic
Nylon
Organic Band
Oxidizer & Explosive
Flammable
Zeff
30.00
25.00
20.00
15.00
10.00
5.00
0.50
1.00
1.50
2.00
2.50
3.00
Density
OPTOSECURITY
Proprietary
13

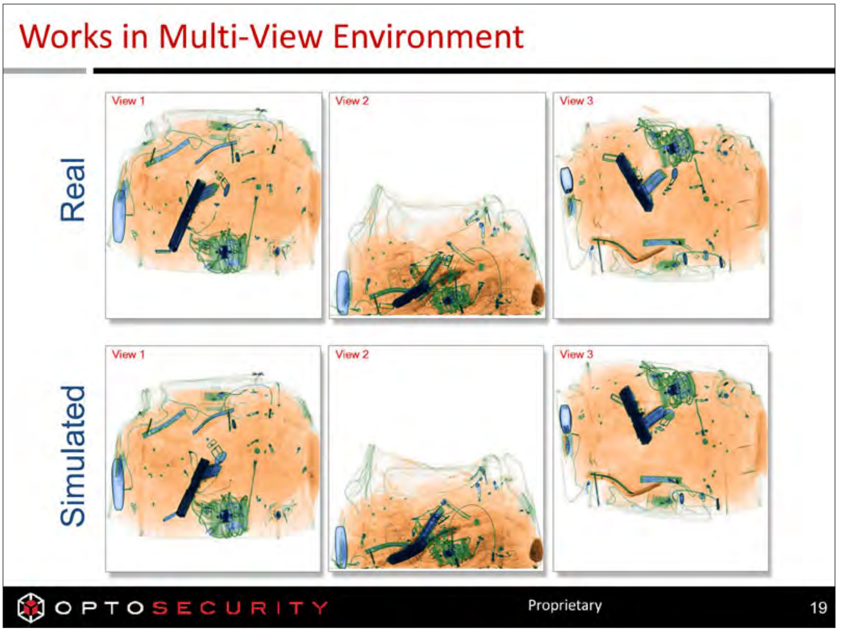

CT-like 3D Reconstruction of Container
Patents Issued: Assessing Properties of LAGS • Screening of Liquids
OPTOSECURITY
Proprietary
14


Supports Partially Filled Containers
100% Full
60% Full
30% Full
Automatic Meniscus Finding for Partially Filled Bottles
Multiple patents issued in Canada, pending in Europe
OPTOSECURITY
Proprietary
15

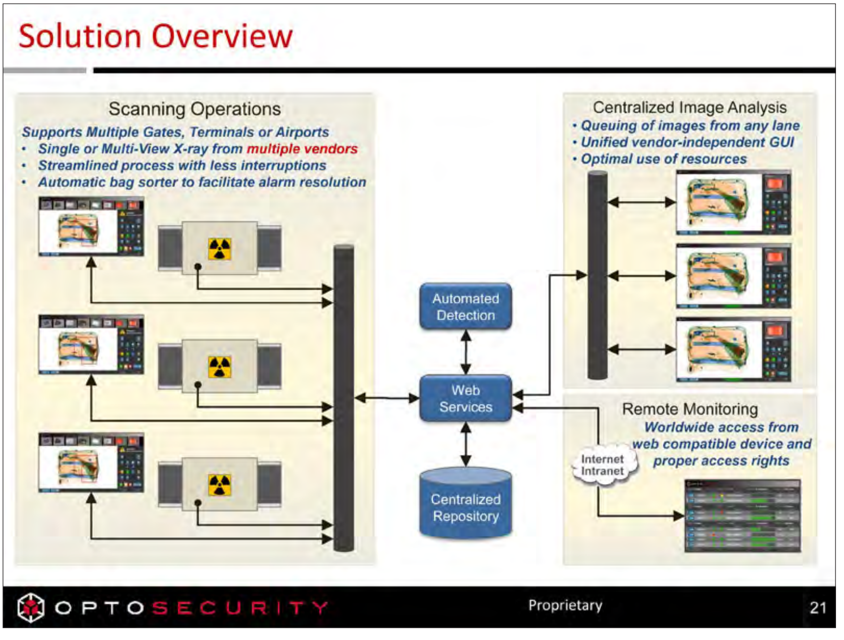

Standalone GUI on Single-View X-Ray
WARNING: Suspicious Content
OPTOSECURITY
?
OPTOSECURITY
Proprietary
16

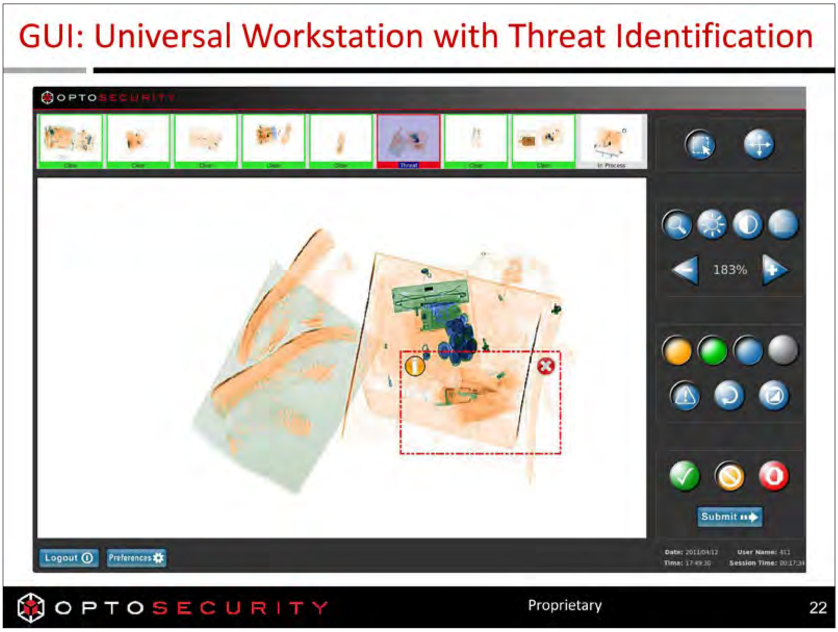

ECAC Qualified Multi-Platform Liquid Explosive Detection
Fully Integrated OEM Versions
L3
ACX6.4 MV
ACX6.4 DV
GILARDONI
FEP ME640 AMX
ATD Upgrade
smiths
HS6040i
HS6046si
Capability Enhancement for Checkpoint X-ray Screening
• Single View Scanners:
– Turns legacy X-ray equipment into Type C Liquid Threat Detection
– Automated Firearm Detection software also available as an option
• Dual / Multi View Scanners:
– ECAC Qualified Type C+ detection capability includes both automated liquid threat detection and automated bottle finding software
– Fully integrated user interface
– Automated Firearm Detection software also an option
– Upgrade path to Type D and layer striping / virtual laptop removal
LEDS Type C Qualified
ECAC · CEAC
OPTOSECURITY
Proprietary
17

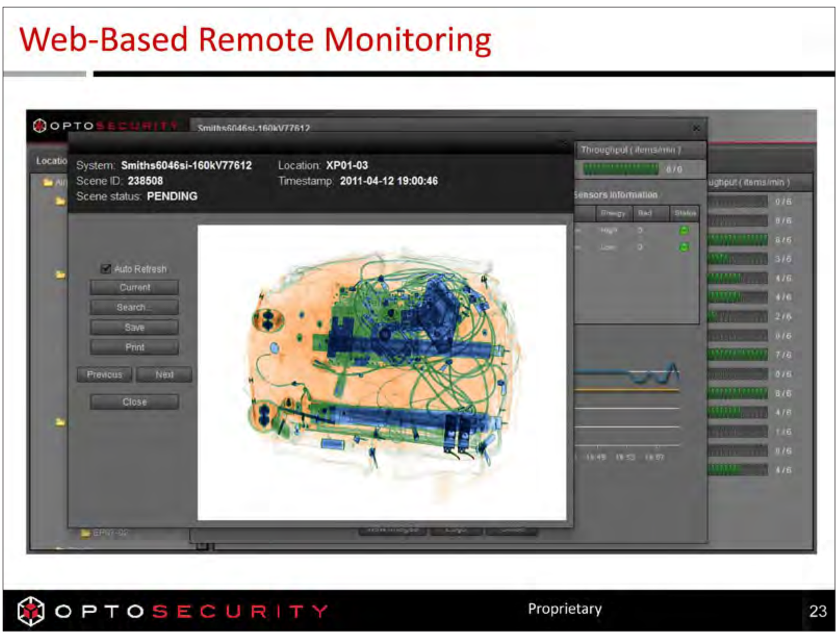

OptoXplorer
Generation of Geometrically Corrected TIP Images from Universal 3D Threat Library
OPTOSECURITY
Proprietary
18


Works in Multi-View Environment
Real
Simulated
View 1
View 2
View 3
OPTOSECURITY
Proprietary
19


Improving
Screening Efficiency
at Lower Cost
Through Multi-Vendor
Remote Operations
eVelocity
Integrated Security Screening Software
OPTOSECURITY
Proprietary
20


Solution Overview
Scanning Operations
Supports Multiple Gates, Terminals or Airports
• Single or Multi-View X-ray from multiple vendors
• Streamlined process with less interruptions
• Automatic bag sorter to facilitate alarm resolution
Centralized Image Analysis
• Queuing of images from any lane
• Unified vendor-independent GUI
• Optimal use of resources
Automated Detection
Web Services
Centralized Repository
Remote Monitoring
Worldwide access from web compatible device and proper access rights
Internet Intranet
OPTOSECURITY
Proprietary
21


GUI: Universal Workstation with Threat Identification
183%
Submit
Logout
Preferences
OPTOSECURITY
Proprietary
22

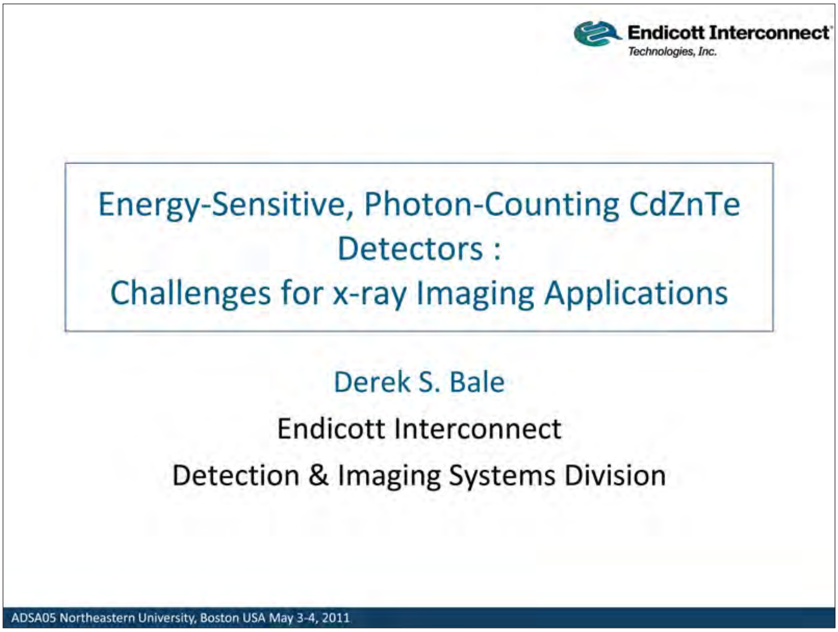

Web-Based Remote Monitoring
System: Smiths6046si-160kV77612
Scene ID: 238508
Scene status: PENDING
Location: XP01-03
Timestamp: 2011-04-12 19:00:46
Auto Refresh
Current
Search
Save
Print
Previous
Next
Close
OPTOSECURITY
Proprietary
23

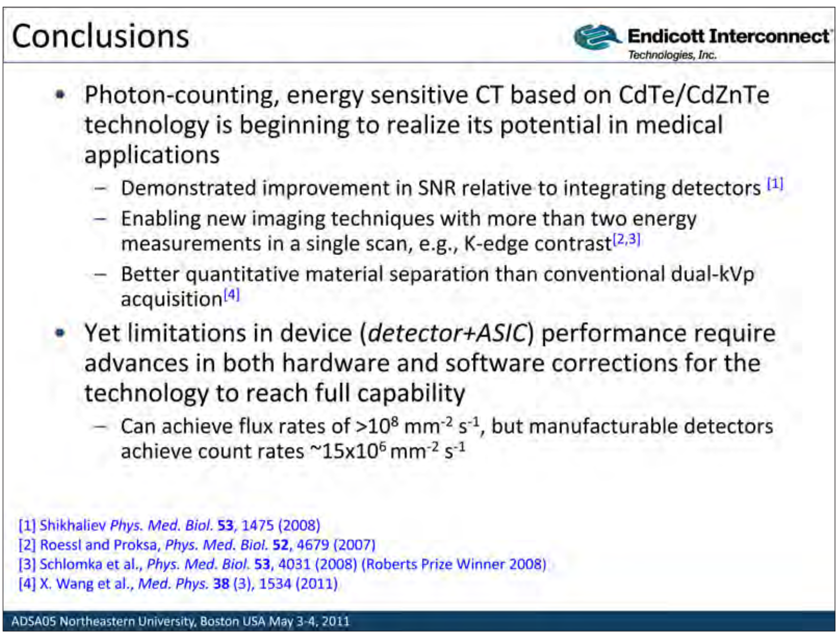
More Lessons Learned…

- For Developers:
  - « Impossible » means it hasn't been done before
  - Efficient ATD requires predictability and repeatability
  - Live ATD requires real-time computing approach
  - Do not under estimate certification efforts
- For DHS/TSA:
  - How can one expect third parties to help without sharing info about deficiencies and expectations
  - Current acquisition rules do not encourage innovation

OPTOSECURITY Proprietary 24

16.29 Derek Bale: Endicott Interconnect





Conclusions

Endicott Interconnect Technologies, Inc.

- Lower flux level requirements for security make manufacturing these detectors possible today
  - **Still crystal growth, detector fabrication, detector physics, and electronics readout technologies are all being stressed** (e.g., non-linearly coupled together)
- Understanding the **full** set of device performance limitations at operating conditions for security is critical – detector sensitivity
  - Low hanging fruit {absorption efficiency, pulse pileup, charge sharing}
  - Point-defect material-coupling {high-flux polarization, temporal response, pulse-height sensitivity} [1,2,3]
  - Response uniformity {dynamic lateral polarization, inclusions, macroscopic crystal defects} [4,5,6]
- **How does this inherent detector sensitivity propagate through material decomposition & image reconstruction?**
  - **This is what will ultimately define a cost-effective detector**

[1] D. S. Bale and C. Szeles, *Phys. Rev. B* **77**, 035205 (2008)
[2] M. Prokesch et al., *IEEE Trans. Nucl. Sci.* **57** (4), 2397 (2010)
[3] D. S. Bale and C. Szeles, *J. Appl. Phys.* **107**, 114512 (2010)
[4] S. A. Soldner et al., *IEEE Trans. Nucl. Sci.* **54** (2007)
[5] D. S. Bale et al., *Appl. Phys. Lett.* **92**, 2101 (2008)
[6] D. S. Bale, *J. Appl. Phys.* **108**, 024504 (2010)

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Overview of Talk

Endicott Interconnect Technologies, Inc.

- Motivation for Photon-Counting
- How do Energy-Sensitive Photon-Counting Detectors Operate?
- Few Examples of PC
- Device Challenges for Security CT operating conditions

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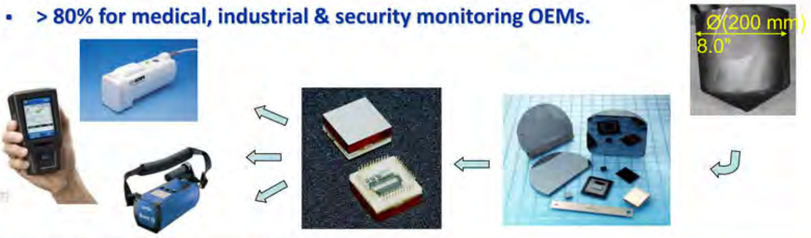
EI-DIS Company

Endicott Interconnect Technologies, Inc.

Detection & Imaging Systems,
a division of Endicott Interconnect Technologies, Inc.

- **Before June 12th, 2009: *eV Products, a division of II-VI, Inc.***
- **Located in Saxonburg, Pennsylvania (USA), ~ 70 employees.**
- **Product integration comprises all stages from single crystal blanks to complete imaging devices.**
- **Volume growth of up to 130 kg of CZT crystals per month.**
- **> 10,000 detector modules sold per year.**
- **> 80% for medical, industrial & security monitoring OEMs.**



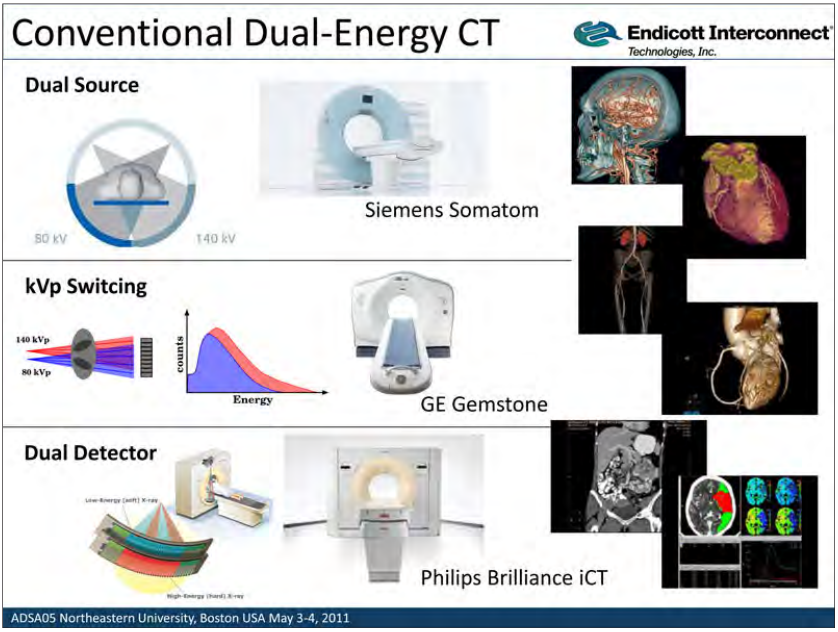
Motivation for PC Spectral CT

Endicott Interconnect Technologies, Inc.

- Demonstrated SNR improvement relative to conventional integrating detectors for medical applications. [1,2]
- Improved material separation, and ability to separate more materials relative to conventional dual-kVp techniques. [3]
- Reduction of beam hardening artifacts, and improve lesion SNR compared to conventional detectors. [4]
- Enabling novel imaging techniques (e.g., K-edge imaging) [5,6]

→ Given the different operating conditions and larger dynamic range of densities and effective Z-values for security applications, how will the relevant metrics for security imaging translate?

[1] Shikhaliev *Phys. Med. Biol.* **53**, 1475 (2008)
[2] Lundquist et al., IEEE Trans. Nucl. Sci. 48, 1530 (2001)
[3] X. Wang et al., Med. Phys. **38** (3), 1534 (2011)
[4] Shikhaliev *Phys. Med. Biol.* **50** (24) 5813 (2005)
[2] Roessl and Proksa, *Phys. Med. Biol.* **52**, 4679 (2007)
[3] Schlomka et al., *Phys. Med. Biol.* **53**, 4031 (2008)


Conventional Dual-Energy CT
Endicott Interconnect Technologies, Inc.
Dual Source
80 kV
140 kV
Siemens Somatom
kVp Switching
140 kVp
80 kVp
counts
Energy
GE Gemstone
Dual Detector
Philips Brilliance iCT
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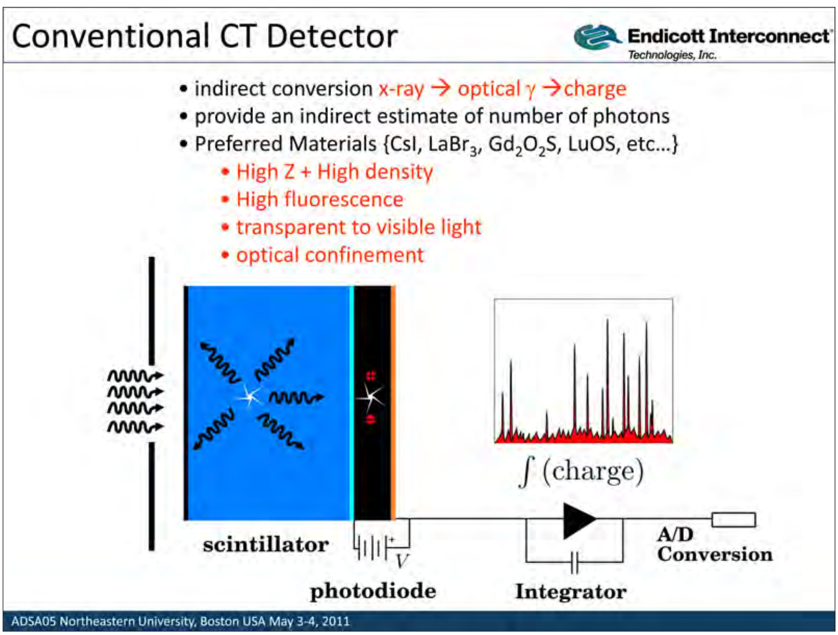
Conventional CT Detector
Endicott Interconnect Technologies, Inc.
• indirect conversion x-ray → optical γ → charge
• provide an indirect estimate of number of photons
• Preferred Materials {CsI, LaBr3, Gd2O2S, LuOS, etc...}
• High Z + High density
• High fluorescence
• transparent to visible light
• optical confinement
∫ (charge)
scintillator
V
photodiode
Integrator
A/D Conversion
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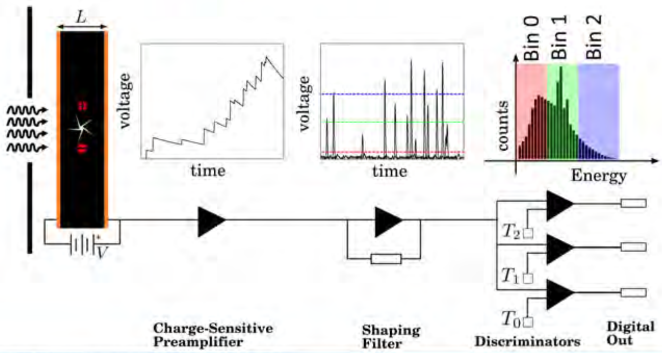
Photon Counting Detector

Endicott Interconnect Technologies, Inc.

- direct conversion x-ray → charge
- direct measure of # of photons & their energy
- Preferred Materials {CdTe, CdZnTe, InP, etc…}
  - High Z + High density
  - High charge carrier transport properties
  - High resistivity



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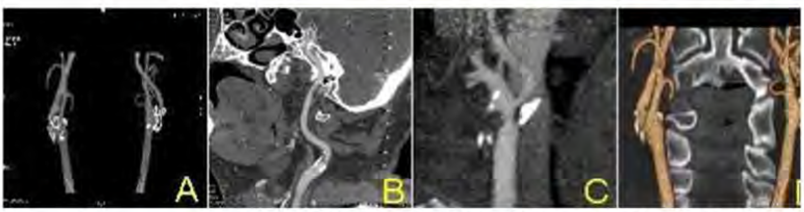
CdTe-based CT Images

Endicott Interconnect Technologies, Inc.

Collaboration of DxRay & GE Global Research

- fit CdTe detectors into GE LightSpeed VCT
- known carotid artery disease
- Rabin Medical Center in Israel
- low x-ray tube current (1/10 conventional scan)
- images demonstrate the vascular and stenotic elements with good image quality

Iwanczyk et al., *IEEE Trans. Nucl. Sci.* **56** (3) 535 (2009)



3D | Curved Oblique | Coronal MIP | Volume rendering

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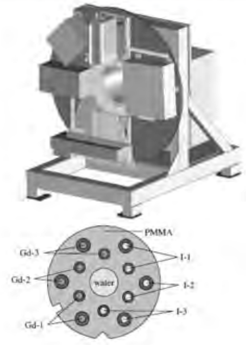
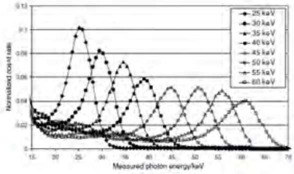
K-edge Imaging at Philips

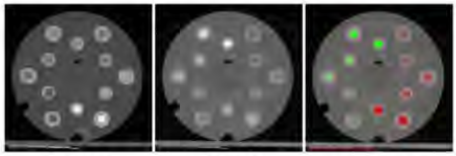
Endicott Interconnect Technologies, Inc.



- CdTe detector array from GMI
- true detector performance calibrated using mono-energetic synchrotron radiation
- used four attenuation basis functions {photoelectric, Compton, Iodine, Gadolinium}
- basis component images combined to approximate monochromatic images at arbitrary photon energies
- "Color Image" combined with Iodine marked red, and gadolinium marked green

$$\mu(\vec{x},E)=\sum_{n=0}^{N} a_n(\vec{x})\, f_n(E)$$





34 keV 51 keV combined

[3] Schlomka et al., *Phys. Med. Biol.* **53**, 4031 (2008)

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Photon Counting in Security

Endicott Interconnect Technologies, Inc.

SureScan X1000

- photon counting
- spectral CT (> 2 energy bins)
- rotationless CT

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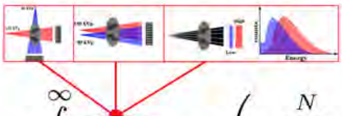
Conventional Dual-Energy CT

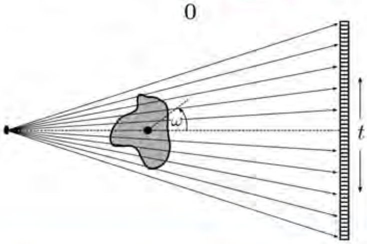
Endicott Interconnect Technologies, Inc.

In order to reconstruct the N material components, K intensity measurements are made (two material components requires at least two different spectra):



- two source
- kVp switching
- sandwich detectors

$$C_k(t,\omega) = \int_0^{\infty} S_k(E)\, \exp\left(-\sum_{n=0}^{N} \mathscr{R}a_n(t,\omega)\, f_n(E)\right) dE$$



Line Integrals:

$$\mathscr{R}a_n(t,\omega) = \int_{-\infty}^{\infty} a_n(t\hat{\theta} + s\hat{\theta}_{\perp})\, ds$$

ω → rotation

t → affine

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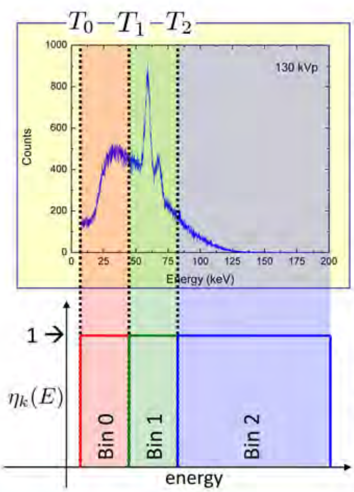
Spectral CT for Photon Counting

Endicott Interconnect Technologies, Inc.



→ one detector, one spectrum, single scan

$$C_k(t,\omega) = \int_0^{\infty} \eta_k(E)\, S(E)\, e^{\sum_{n=0}^{N} \mathscr{R}a_n(t,\omega)\, f_n(E)}\, dE$$

$k \in \{0, 1, \cdots, K\}$ → # Energy bins (3 here)

$n \in \{0, 1, \cdots, N\}$ → # Material components

$\eta_k(E)$ → Detector Sensitivity in k[th] energy bin

- ideal detector produces unit sensitivity in all energy bins as shown at left
- **what does the sensitivity look like for a <u>realistic</u> energy-sensitive photon-counting detector?**

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→**How does the detector sensitivity propagate through various material separation & image reconstruction algorithms?**

Define the projection vector :

$$\mathscr{R}\vec{a}(t,\omega) = [\mathscr{R}a_0, \mathscr{R}a_1, \cdots, \mathscr{R}a_N]^T$$

The K-attenuation measurements become :

$$\vec{C}(t,\omega) = F\Big(\mathscr{R}\vec{a}(t,\omega)\Big) + \vec{\Delta}(t,\omega)$$

$\vec{\Delta}$ → Additive noise (background, scatter, etc...

$F()$ → **Dependence on detector sensitivity** $\eta_k(E)$

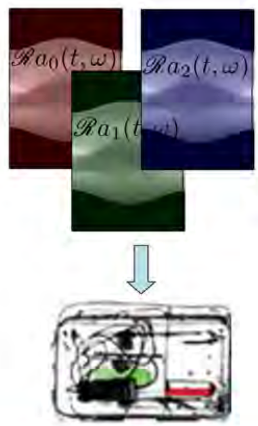
→ K equations in N unknowns

Inversion yields N sinograms (3 in this example)

$$\mathscr{R}\vec{a}(t,\omega) = F^{-1}\Big((\vec{C}(t,\omega) - \vec{\Delta}(t,\omega)\Big)$$

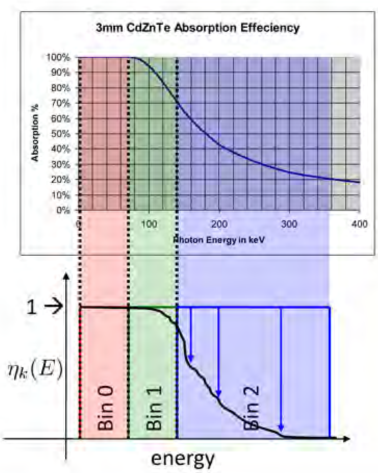
Image reconstruction of each "material component"

$$a_n(\vec{x}) = \mathscr{R}^{-1}\left(\mathscr{R}a_n(t,\omega)\right)$$



Absorption Efficiency

Endicott Interconnect Technologies, Inc.



- fraction of photons that interact within a 3mm thick CdZnTe detector as a function of energy
- large dynamic range of density and Z-values for security force x-ray energies ~ 160-180 kVp
- trade-off between detector thickness and charge-collection time (slides to come)

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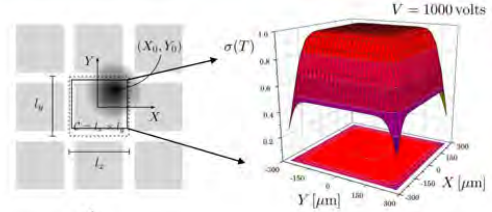
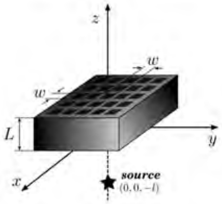
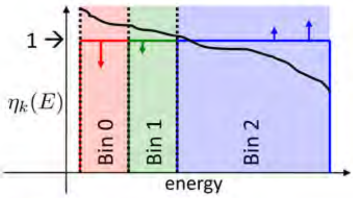
Charge sharing

Endicott Interconnect Technologies, Inc.



- charge collection efficiency can reflect
  - charge carrier diffusion[1]
  - fluorescence
  - Compton scatter
- **result is a detector sensitivity that translates counts to lower energy**

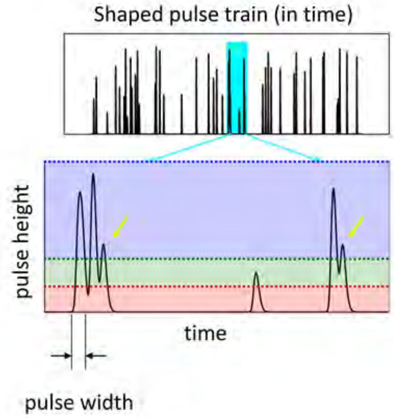


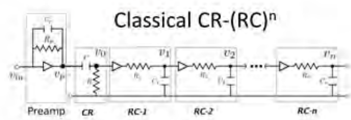


1) Kozorezov and Wigmore, *J. App. Phys.* **97**, 074502 (2005)

Pulse Pileup

Endicott Interconnect Technologies, Inc.



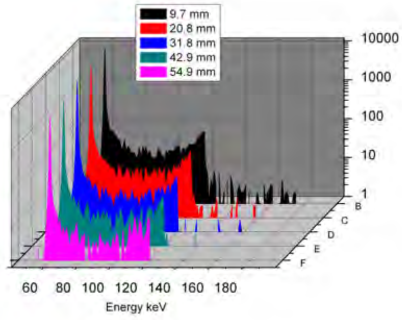


- Pulse width controlled by RC timing and # of poles in shaping circuit
- Pileup occurs when the time between arriving photons approaches the electronics pulse width
  - **drives a non-linear loss of photon count**
  - **results in an inaccurate energy measurement**

Pulse Pileup

Endicott Interconnect Technologies, Inc.

Simple mono-energetic experiment :



- 60 keV mono-energetic source
- 5 acrylic thicknesses
- 900 V bias
- 3 mm thick detector
- 1 mm^2 pixel
- 160 ns peaking time
- high mutauH (1.5e-5)
- 1e6 photons per pixel s^{-1}

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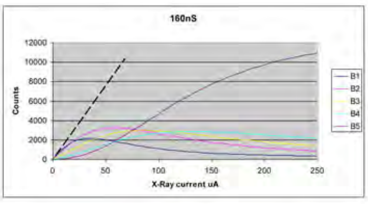
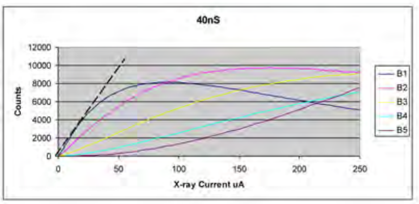
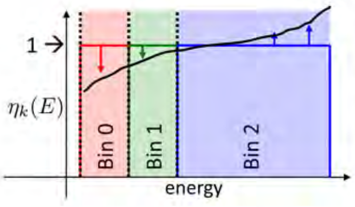
Pulse Pileup

Endicott Interconnect Technologies, Inc.







- five energy bins measuring 120 kVp x-ray spectrum
- 160 ns peaking time demonstrates the upward shift in energy measurement due to pileup
- corrections for this effect is an active area of research [1]
- why not shrink pulse width smaller?

1) Taguchi et al., *Medical Physics* **37** (8) (2010)

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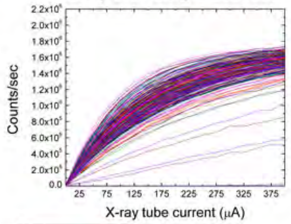
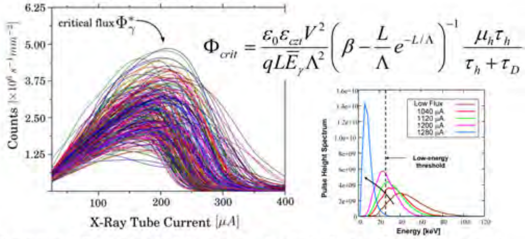
High-Flux Polarization

Endicott Interconnect Technologies, Inc.

Non-polarizing Detector



Polarizing Detector



Sensor: 16×16 channel 2D monolithic array, 3 mm thick, 500 μm pixel pitch, guard ring, FE-ASIC.

C. Szeles et al., IEEE TNS **55**, 572 (2008)

- We have developed a theoretical model for the high-flux polarization: space charge of photo-generated holes accumulates near cathode → electric field is suppressed or pinched → electron transport is slowed due to field pinch → increased trapping + ballistic deficit reduces pulse height below low-energy threshold

Bale and Szeles, *J. Electron. Mat.* **38** (1) (2009)

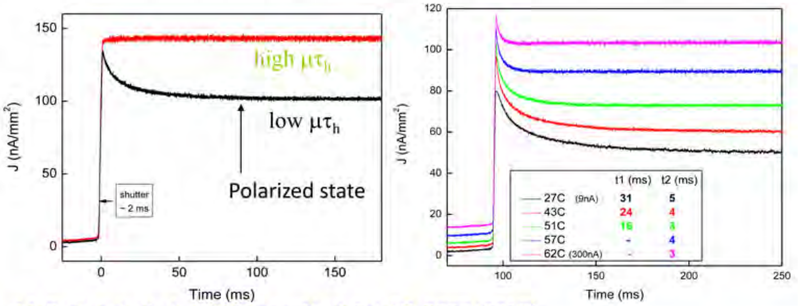
Bale and Szeles *Phys. Rev. B* **77** 035205 (2008)

Temporal Response

Endicott Interconnect Technologies, Inc.

Detectors for CT need a rapid response to abrupt changes in flux (>10^8 mm^{-2} s^{-1})?

- This timescale is controlled by the same dynamics driving polarization.
- (Left) High hole transport shows rapid (<3ms) transition to stable response, while low hole transport material is forced to stationary state of polarization (~20 ms timescale).
- (Right) Raising temperature eliminates long-time scale due to polarization



M. Prokesch et al., *IEEE Trans. Nucl. Sci.* **57**, 2397 (2010)

Pulse-Height Sensitivity

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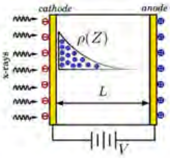
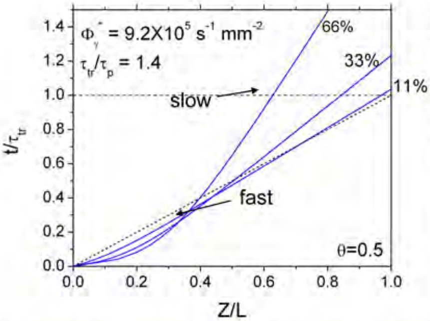


$$t = \frac{\lambda}{\epsilon\lambda - 1}\left[\frac{\xi - z}{\lambda} + \ln\left(\frac{\beta + \epsilon(e^{-\xi/\lambda} - \lambda\beta)}{\beta + \epsilon(e^{-z/\lambda} - \lambda\beta}\right)\right]$$



Electron trajectories are modified well before catastrophic field pinch and polarization

- electrons travel fast at first in response to positive space charge ahead of them
- later they slow down due to the same space charge behind them
- deviation has logarithmic dependence on amount of charge

D.S. Bale & Cs. Szeles, *J. Appl. Phys.* **107** 114512 (2010)

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Pulse-Height Sensitivity

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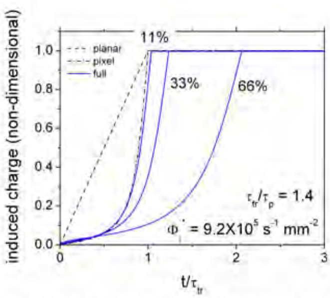
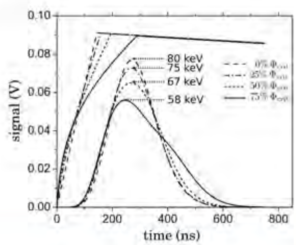


Example for 3mm detector with 1mm pixel:

- at 11% of critical flux the induction is nearly equivalent to low-flux pixel induction
- an induction delay appears at one-third the critical flux
- by two-thirds critical flux, the delay is quite significant



- Resulting induced signals exhibit a significant delay in the signal rise.
- ballistic deficit will be enhanced by this effect
- Effect on shaped pulse height (i.e., energy measurement) is more dramatic with pixel detector

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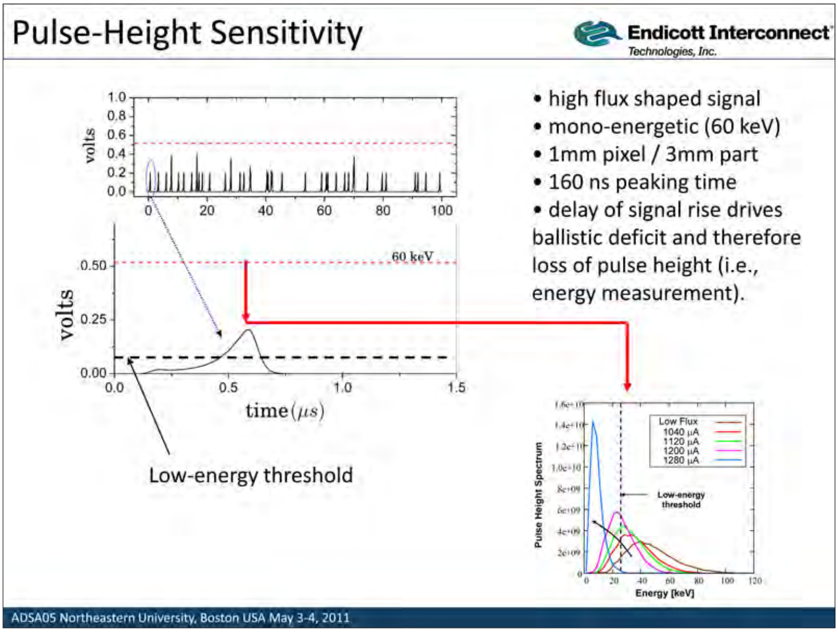
Pulse-Height Sensitivity
Endicott Interconnect Technologies, Inc.
• high flux shaped signal
• mono-energetic (60 keV)
• 1mm pixel / 3mm part
• 160 ns peaking time
• delay of signal rise drives ballistic deficit and therefore loss of pulse height (i.e., energy measurement).
volts
60 keV
time (μs)
Low-energy threshold
Pulse Height Spectrum
Low Flux
1040 μA
1120 μA
1200 μA
1280 μA
Low-energy threshold
Energy [keV]
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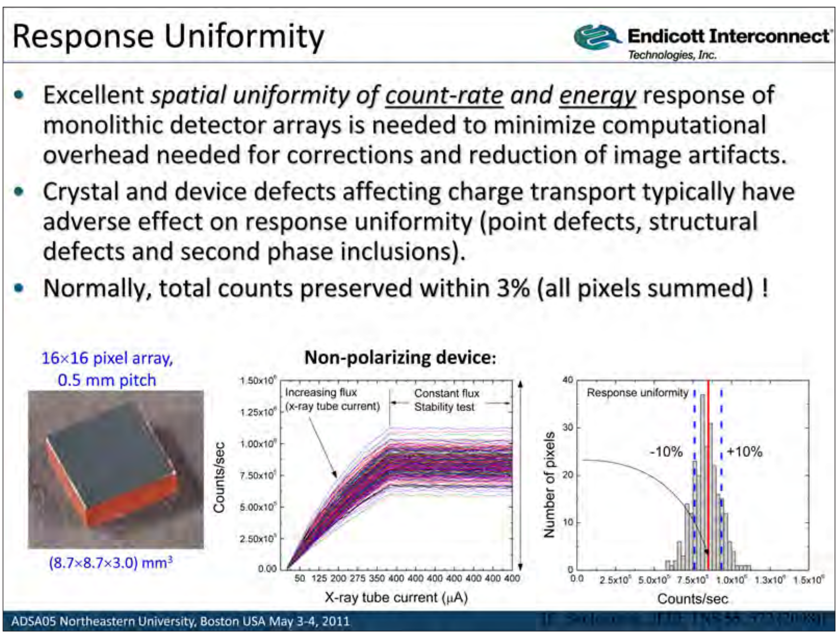
Response Uniformity
Endicott Interconnect Technologies, Inc.
• Excellent spatial uniformity of count-rate and energy response of monolithic detector arrays is needed to minimize computational overhead needed for corrections and reduction of image artifacts.
• Crystal and device defects affecting charge transport typically have adverse effect on response uniformity (point defects, structural defects and second phase inclusions).
• Normally, total counts preserved within 3% (all pixels summed) !
16×16 pixel array, 0.5 mm pitch
(8.7×8.7×3.0) mm³
Non-polarizing device:
Increasing flux (x-ray tube current)
Constant flux Stability test
Counts/sec
X-ray tube current (μA)
Response uniformity
-10%
+10%
Number of pixels
Counts/sec
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Dynamic Lateral Polarization

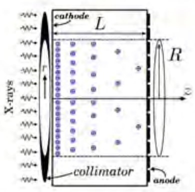
Endicott Interconnect Technologies, Inc.

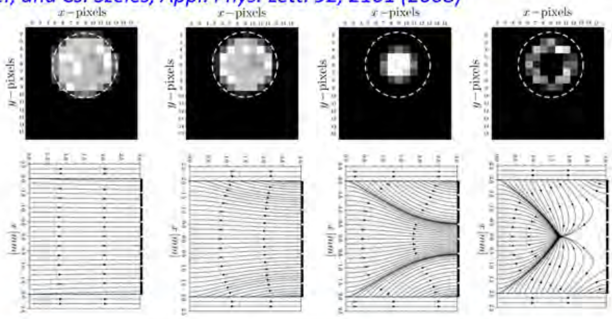
- it was observed in practice that pixilated detectors fabricated from low-hole transport material exhibited a dynamic focusing of counts when subjected to a collimated beam of high-flux x-rays

– S.A.Soldner, D.S. Bale, and Cs. Szeles, IEEE Trans. Nucl. Sci. 54 (2007)

- We have shown that such focusing of the counts is consistent with the electric field lines due to the time-asymptotic positive charge density derived from the multiple scale analysis

– D.S. Bale, S.A. Soldner, and Cs. Szeles, Appl. Phys. Lett. 92, 2101 (2008)





$$\lim_{T\to\infty} \rho(Z,T) \square\, q \frac{\Phi_\gamma E_\gamma}{\Lambda v_{eff}} e^{-\frac{Z}{\Lambda}}$$

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Macroscopic Crystal Defects

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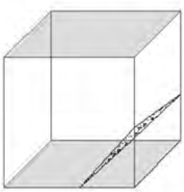
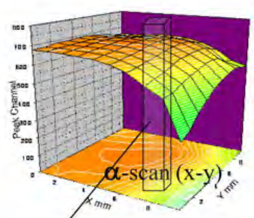
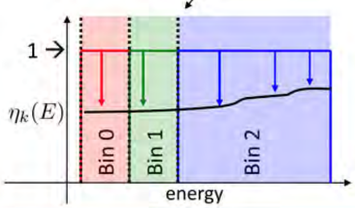
IR image

10 mm

twin plane schematic







[S. Soldner, IEEE RTSD, 2003]

See also work from BNL and LBL.

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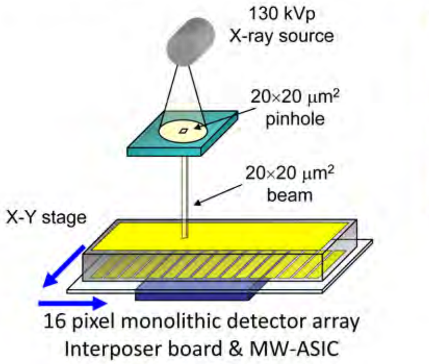
Response Uniformity

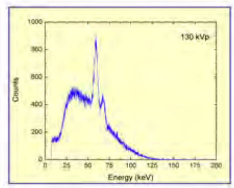
Endicott Interconnect Technologies, Inc.

- Scanning x-ray study of response uniformity.



Test system features:

- High-Speed Multi-Window ASIC (MW-ASIC).
- 64 input channels.
- 5 window discriminators.
- Programmable peaking times (40, 80, 160, and 320 ns).



Linear array: 2.3 mm wide pixels on a 0.8 mm pitch.

D. Rundle, eV Products, 2008

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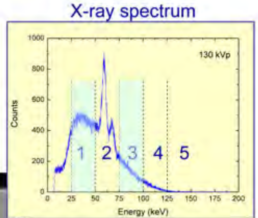
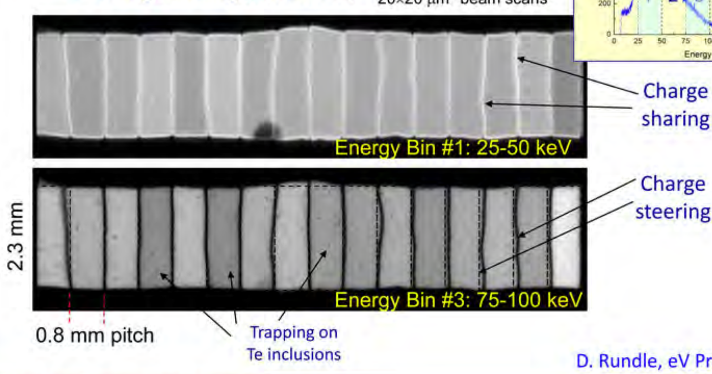
Response Uniformity

Endicott Interconnect Technologies, Inc.

- Spatial, count-rate and energy response uniformity is limited by:
  1. Trapping on structural defects (inclusion related)
  2. Charge steering (structural and point defects)
  3. Charge sharing (no defects)

X-ray spectrum





D. Rundle, eV Products, 2008

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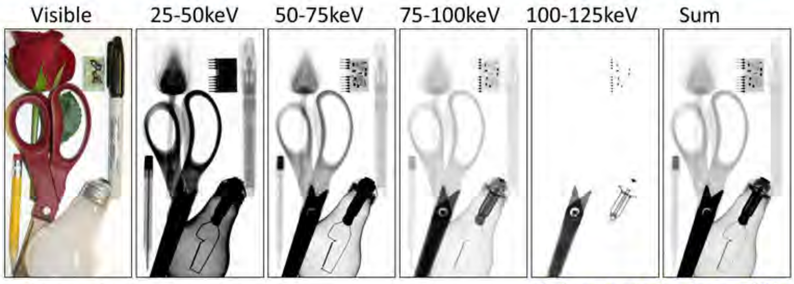
Thank you

Endicott Interconnect Technologies, Inc.



D. Rundle, eV Products, 2008

Acknowledgments:

Contributions from: M. Prokesch, S. Soldner, D. Rundle, and C. Szeles (EI-DIS).

EI-DIS team and former eV PRODUCTS employees.

Defense Threat Reduction Agency (DTRA).

United States Army Armament Research, Development and Engineering Center (ARDEC).

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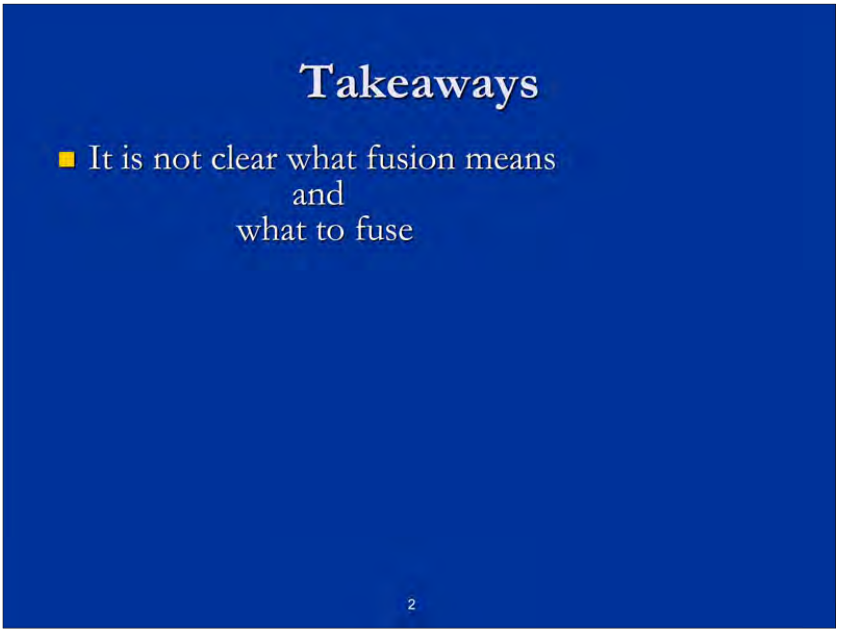
16.30 Harry Martz: Review, Next Steps and Discussion



Takeaways continued

- Emerging technologies could be deployed with
  - Deployed technologies
  - Other emerging technologies
  - Humans
- For technologies discussed Security and Medical
  - There was too much on strengths
  - Too little on weaknesses
  - *Both* are needed to enable ideas on fusion

3

Takeaways continued

- Mathematics of fusing systems
  - There are different
    - Places where information can be fused
    - Methods used to fuse information
  - Complex math to human fusion
  - It is possible to degrade performance by fusing systems
  - No prescription for doing it right
- Third party experiences
  - Appling their ATR algorithms to incumbent vendors

4

Takeaway Overall

- DoD does a lot of data fusion but little represented
- Fusion is more difficult than expected
- Too little on lessons learned from attempts of fusing different technologies
  - CT and
    - QR
    - XRD
  - WTMD
    - Video
    - AIT

5

Review Response to Questions

- Should fused systems be considered?
  - If Yes, Why?
    - Gov't: Better performance
    - Vendor: Sell more systems
    - 3rd Party: Advance medical, security and NDE fields
    - National Labs: Better solve national security problems
  - If No, Why Not?
    - Gov't: Risks, Too large and cost too much for little gain
    - Vendor: Government will not buy
    - 3rd Party: ?
    - National Labs: NA

6

Review Response to Questions

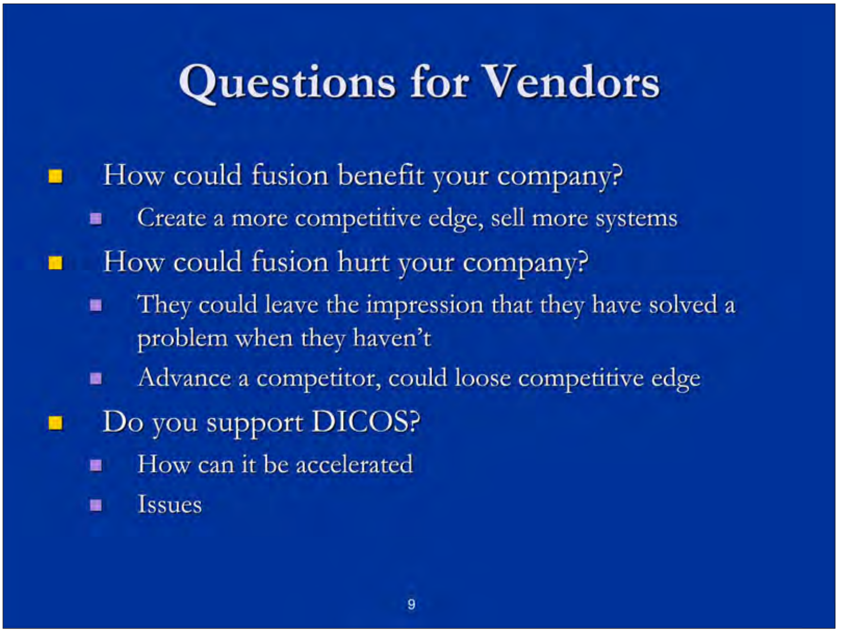
- Fusion would enable you to do what?
  - Government
    - Obtain better field performance (PD, PFA)
  - Incumbent vendor
    - Sell more systems
    - Designs machines differently
    - May make less money
  - Other 3rd party
    - Sell: Advance medical, security and NDE fields
  - National lab
    - Solve national security problems, Weapons, NIF, etc.

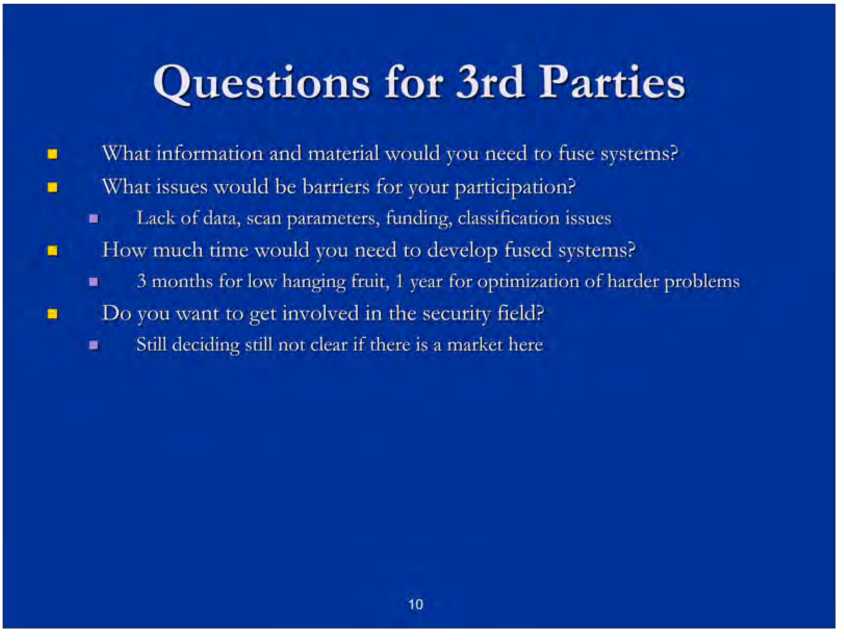
7

Response to Questions continued

- What information is needed from TSA to enable fusion?
- What changes need to be made by the TSA to allow fused systems to be deployed?
- What are the risks to TSA, vendors, 3rd parties?

8


Questions for Vendors
How could fusion benefit your company?
Create a more competitive edge, sell more systems
How could fusion hurt your company?
They could leave the impression that they have solved a problem when they haven't
Advance a competitor, could loose competitive edge
Do you support DICOS?
How can it be accelerated
Issues
9


Questions for 3rd Parties
What information and material would you need to fuse systems?
What issues would be barriers for your participation?
Lack of data, scan parameters, funding, classification issues
How much time would you need to develop fused systems?
3 months for low hanging fruit, 1 year for optimization of harder problems
Do you want to get involved in the security field?
Still deciding still not clear if there is a market here
10

Algorithm Development
for Security Applications

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