Algorithm Development for Security Applications 6

November 2011 Final Report

ALERT

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 screening for explosives in order to protect aviation infrastructure was held at Northeastern University in Boston on November 8-9, 2011. This workshop was the sixth in a series dealing with algorithm development for security applications. This workshop addressed specific topics related to developing and deploying fused systems.

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 may eventually be unable to satisfy DHS's requirements for improved performance unless they are upgraded or fused with other technologies.

The key topics that were addresses at the workshop are as follows.

- General topics related to fusing technologies. Examples of this topic are concept of operations, acceptance testing by the TSA and establishing requirement specifications.
- Improving AIT equipment by fusing systems.
- Adaptive screening.

The key findings from the workshop are as follows.

- Fusion can be defined as any one of the following methods.
    - Combining the outputs (i.e., data) from multiple systems with and without using electronic networks.

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

    - Changing the protocol of concept of operations of explosive detection equipment using some other source of information

- Many of the general findings noted above have to be addressed before fused systems can be developed and deployed.

- Methods were noted by the workshop participants to have a high probability of success to significantly improve MMW and XBS AIT through fusion.

- Adaptive screening[2] should be explored in additional detail. Adaptive screening means changing the operating protocol of an explosive detection device based on an assessment of risk of a particular passenger or based on general intelligence information.

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[2] This discussion is not related to TSA's program denoted risk-based screening.

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 by discussions and/or presentations. The views in this summary are those of ALERT and do not necessarily reflect the views of all the participants. All errors and omissions are the sole responsibility of ALERT.

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001.

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 threat mass and lower total operating costs. There is evidence that existing technologies may eventually be unable to satisfy DHS's requirements for improved performance unless they are upgraded or fused with other technologies.

One tactic that DHS is pursuing to increase detection performance is to create an environment in which the capabilities and capacities of the established vendors can be augmented or complemented 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 by the medical imaging industry, in which university researchers and small commercial companies develop algorithms that are eventually deployed in commercial medical imaging equipment.

A 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 "Algorithm Development for Security Applications (ADSA)." An overview of the first five ADSA workshops can be found in Appendix 16. 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 dealt with fusing orthogonal technologies from a high-level point of view.

The sixth workshop in the ADSA series was held on November 8-9, 2011, at NEU. The workshop addressed the generalities of fusing systems with specific application to advanced imaging technology (AIT). The generalities

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

include how to specify, test, procure, field, operate and maintain equipment that, when fused, leads to improvements in detection performance. The specific application of fusion to advanced imaging technology (AIT) MMW and XBS was discussed in order to understand the generalities. The topics that were discussed include the following items (specifics can be found in the next section).

- Definitions of fusion, orthogonal and technology.
- TSA requirements (non-classified) for new equipment that could be fused.
- Identification of strengths of existing equipment without having classified discussions.
- TSA procurement policies.
- Networking.
- Testing by DHS and TSA.
- Concepts of operation.
- Adaptive screening.
- Third-party involvement, including dealing with SSI and classified requirements.

The discussion of fusion in the AIT application included addressing the following topics.

- Unclassified TSA requirements for detection and concept of operations.
- AIT technology review including mainly strengths and some weaknesses for the following aspects of existing AIT equipment.
    - Millimeter Wave (MMW).
    - X-ray backscatter (XBS).
    - Automated threat recognition (ATR).
- Opportunities for fusing technologies leading to better detection of explosives.

In addition, the workshop also discussed successful and failed implementations of fusion in screening for explosives in aviation security and medical imaging.

The purpose of this document is to report a summary of the findings and recommendations from the workshop.

4. Findings and Recommendations[4]

Definitions for fusion

The following definitions should be used for fusion.

- Combining the outputs (i.e., data) from multiple systems with and without electronic networks.
- Changing the protocol of concept of operations of explosive detection equipment using some other source of information.

Advancing AIT

The following recommendations were made to improve AIT systems and other types of equipment used for aviation security.

1. Vendors and TSL should present classified briefs to address the detection performance of various types of threats in different locations and configurations. The briefs should lead to the ability to set the requirements for equipment that could be fused with existing equipment leading to upgraded systems.
2. Predictive studies of performance of individual and fused systems should be performed. The studies should be based on the physics and engineering of the interactions of the energy source (millimeter waves or x-rays) with threats and their confusers. The studies should also consider body type, location of threats on passenger's body, concealment under clothing and the presence of other non-divested items.
3. A simulation capability should be developed to simulate the performance of scanners to reduce the need to develop expensive

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[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. The basis of this section is the presentation entitled "Next Steps," which was presented by Harry Martz at this workshop.

prototypes. The government should fund third parties, vendor or national labs to accomplish this task.

4. Specifications should be written enable new and different modality, orthogonal systems to fuse with existing technologies.
5. Prototypes should be emulated if possible with existing equipment instead of developing production-ready systems. There is evidence in medical imaging that the performance of fused systems can be predicted without building a prototype. An example is the use software to generate simulated images of computerized medical imaging equipment.
6. Explore the use of model-based methods for developing advanced reconstruction and ATR algorithms. See the presentation by Eric Miller (Tufts University) in the appendices of this report for additional information.
7. Fuse XBS and MMW systems to create a combined system that may yield higher PD and lower PFA.
8. Learn why security fused systems have failed so far and develop lessons learned to be successful in the future.

MMW Recommendations

The following recommendations were made to advance MMW equipment.

1. Irrespective of fusion, investigate the following topics:
    a. Optimum frequency.
    b. Polarization.
    c. Advanced reconstruction.
    d. Increased solid angle, meaning exposing more of the passenger’s body with radiation.
2. Deploy technologies that can provide:
    a. Depth information meaning the distance of a possible threat to the antennas to gain an additional feature about threats and non-threats.

    b. Understand and document the detection capabilities for certain threats in certain locations.[5]

XBS Recommendations

The following recommendations were made to improve XBS equipment with and without fusion.

1. Irrespective of fusion, investigate the following topics:
    a. Solutions to corner cases, where corner cases are issues related to specific threats in specific locations if they exist.
    b. Fractionate dose for more views.
    c. Anatomical subtractions.
    d. Use transmission information.
2. Fuse with other technologies that can provide:
    a. Depth information, for example, using laser range finders.
    b. Understanding and documention of the detection capabilities for certain threats in certain locations.

DHS Recommendations

The following recommendations are made for actions that DHS could take:

1. Fund studies of detection performance for existing equipment and fused equipment. Make available to those with clearances and a need to know.
2. Fund simulation capability including standard mathematical phantoms.
3. Review NDE, medical, DHS and DoD positive and negative examples of fusion. There are positive and negative examples of fusion in all four of these areas.
4. Understand the DoD model of funding and adapt what applies to DHS.
5. Develop and use a common fusion language for security applications.

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[5] Details are not presented here and at certain other places in this report because they may be SSI or classified.

6. Fund development of explosive detection systems that lead to anti-correlation of non-threats, even if threats are correlated.

DHS Acceptance Testing Recommendations

The following recommendations were made for actions that DHS and TSA could take to develop methods to test fused systems. The testing is known as certification and qualification.

1. Allow testing of systems that will not pass complete tests.
2. Allow virtual combinations for said systems. That is electronically combining or emulating the results of testing individual systems to determine if the fusion of the separate pieces of equipment would pass the certification requirement for a stand-alone system.
3. Assess impact of testing on ability to predict fused performance.
4. Assess how adaptive screening (or risk-based screening) would be tested.
5. Understand how the European Civil Aviation Conference (ECAC, European equivalent of TSA) is allowing testing of liquid detection algorithms.

TSA Recommendations

The following recommendations were made for TSA:

1. Change procedures to allow procurement, deployment, operation and maintenance of fused systems.
2. Test and deploy Digital Imaging and Communications in Security (DICOS) Standard.
3. Concept of operations for fused systems should be developed. The following topics should be addressed:
   a. Throughput
   b. Reliability
   c. Space
   d. Power
   e. Heat
   f. Cost
   g. Ergonomics for the passenger and the operator
   h. Radiation safety

Adaptive Screening Recommendations

The following recommendations were made for adaptive screening:

1. Determine how equipment could adjust its operations to vary its detection capabilities based on risk. This discussion should be beyond the usual things that could be done with risk such as: sliding on the ROC curve to trade-off PD for PFA, changing the threat list, and changing the minimum mass.
2. Determine how adaptive screening affects the TSO performance.
3. Quantify the deterrence value of current screening to set baseline and proposed future adaptive screening.
4. Understand and deal with the impact of displacement of the threat vector from one vector to another.

ADSA Workshop Recommendations

The following recommendations were made about ADSA workshops:

1. The following tactics should be used to increase to amount of discussion at future ADSA workshops.
    a. Limit the number of attendees to fewer than seventy people.
    b. Lunches and breaks should not be working sessions.
    c. Allocate time in the agenda for discussions.
    d. Reduce the number of presentations.
    e. Limit slides to 15 total.
    f. Ask presenters to allocate 50% of their time slot to discussion.
2. Start a new series of workshops on video analytics instead of changing the focus of the present series of ADSA workshops, especially since this will be a very different audience.
3. Increase student participation at future ADSA workshops by:
    a. Inviting more students.
    b. Having student presentations in topic areas at each ADSA.
    c. Finding thesis topics for students, especially in the area of fusion.
4. Give a presentation at the next ADSA workshop about how equipment is tested and deployed.
5. Consider having a SSI or classified breakout session.

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.
- Greg Struba, DHS, and Suriyun Whitehead, Booz Allen Hamilton, for coordinating the participation of DHS and TSA.
- Northeastern University for hosting the workshop.
- Suriyun Whitehead, Booz Allen Hamilton, for reviewing this report.

The workshop would not have been a success without the participants and the speakers. 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:

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
Harry Martz, Lawrence Livermore National Laboratory
Mariah Nobrega, Northeastern University

Logistics, including minute taking and audiovisual assistance, for the workshop were handled by:

Rachel Parkin, Northeastern University
Mariah Nobrega, Northeastern University
Brian Loughlin, Northeastern University

The SSI review was done 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, and via the Internet on digital media, 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

Time	Topic	Speaker	Affiliation
8:15 AM	Registration/Continental breakfast		
9:00 AM	Call to order	Carl Crawford	Csuptwo
9:05 AM	Welcoming remarks - ALERT	Michael Silevitch	Northeastern University / ALERT
9:15 AM	Welcoming remarks - DHS	Doug Bauer	DHS
9:25 AM	Logistics	Mariah Nóbrega	Northeastern University / ALERT
9:35 AM	Workshop objectives and ADSA06 review	Carl Crawford	Csuptwo
10:15 AM	Break		
10:45 AM	Fusion development and deployment - Part I	Matthew Merzbacher	Morpho Detection
11:15 AM	Fusion development and deployment - Part II	Carl Crawford	Csuptwo
12:00 PM	Lunch		
1:00 PM	Examples of fusion in medical imaging	Homer Pien	Massachusetts General Hospital
1:30 PM	Combined optical and x-ray Mammography	Qianqian Fang	Massachusetts General Hospital
2:00 PM	Millimeter-wave AIT review	David Sheen	Pacific Northwest National Lab
2:40 PM	Break		
3:10 PM	Discussion - opportunities for fusion in AIT	All	
3:50 PM	X-ray backscatter AIT review	Homer Pien	Massachusetts General Hospital
4:20 PM	DHS comments on involvement of third parties	Laura Parker	DHS S&T
4:35 PM	Third party success stories	Michael Silevitch	Northeastern University / ALERT

4:50 PM	Topics for next workshop (ADSA07)	Carl Crawford	Csuptwo
5:00 PM	Reception sponsored by Csuptwo		
6:00 PM	Dinner		
	Dinner Speech - Fostering innovation in aviation security	Michael Ellenbogen	General Catalyst
7:45 PM	End Day 1		

Time	Topic	Speaker	Affiliation
7:30 AM	Continental breakfast		
8:00 AM	Day 2 objectives	Carl Crawford	Csuptwo
8:05 AM	Sensor Fusion for PBIED Detection	Scott MacIntosh	Reveal
8:40 AM	Fusion in DoD and discussion	Ross Deming	US Air Force
9:00 AM	Fusion opportunities at the checkpoint	Kevin Johnson	Naval Research Laboratory
9:30 AM	Fusing MMW technologies	Carey Rappaport	Northeastern University
10:15 AM	Break		
10:35 AM	MMW using backscatter and quantitative material characterization	Steve Johnson	Telesecurity Sciences
11:05 AM	Thoughts on fusion	Eric Miller	Tufts University
11:55 AM	Adaptive screening (presentation and discussion)	Harry Martz	Lawrence Livermore National Laboratory
12:55 PM	Lunch		
1:45 PM	How might technology improve human detection performance	Jeremy Wolfe	Harvard Medical School
2:15 PM	Next steps	Harry Martz	Lawrence Livermore National Laboratory
3:05 PM	Open discussion	All	
3:50 PM	Closing remarks - DHS	Laura Parker	DHS
3:55 PM	Closing remarks - ALERT	Michael Silevitch	Northeastern University
4:00 PM	Adjourn	Carl Crawford	Csuptwo

9. Appendix: Previous Workshops

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

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

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

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

ADSA 05

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 report can be accessed at:
httkps://myfiles.neu.edu/m.nobrega/Strategic_Studies_Reports/ADSA05_final_report.pdf

10. Appendix: List of Participants

William Aitkenhead	Reveal Imaging Technologies, Inc.
Doug Bauer	Department of Homeland Security
Nathaniel Beagley	Pacific Northwest National Lab.
John Beaty	Northeastern University
Guy Besson	Analogic Corporation
Richard Bijjani	Reveal Imaging Technologies, Inc.
Carl Bosch	SureScan
Douglas Boyd	Telesecurity Sciences
Barry Bunin	Stevens Institute of Technology
John Bush	Battelle
David Castañón	Boston University
Joseph Cook	Department of Homeland Security
Carl Crawford	Csuptwo
Ross Deming	Air Force
Chuck Divin	Lawrence Livermore National Laboratory
Vincent Eckert	Department of Homeland Security
Limor Eger	Boston University
Michael Ellenbogen	General Catalyst
Qianqian Fang	Massachusetts General Hospital
Xin Feng	Marquette University
Michael Fleisher	L-3 Communications
Chris Gregory	Smiths Detection
Bernard Harris	Raytheon Company
Dale Henderson	Pacific Northwest National Lab.
Jay Hill	Morpho Detection
Alex Hudson	Rapiscan Systems
Jason Hull	TSA
Prakash Ishwar	Boston University
Ken Jarman	Pacific Northwest National Lab.
Kevin Johnson	Naval Research Laboratory
Steve Johnson	TeleSecurity Sciences, Inc.
Clem Karl	Boston University
Don Kim	TSA

Omar Kofahi	American Science and Engineering, Inc.
Timo Kohlberger	Siemens Corporate Research
Ronald Krauss	Department of Homeland Security
Richard Lareau	Department of Homeland Security
David Lieblich	Analogic Corporation
Scott MacIntosh	Reveal Imaging Technologies, Inc.
Spiros Mantzavinos	Northeastern University
Harry Martz	Lawrence Livermore National Laboratory
Tim Mathews	Optosecurity
Matthew Merzbacher	Morpho Detection
Eric Miller	Tufts University
Christian Minor	Naval Research Laboratory
Richard Moore	Massachusetts General Hospital
John O'Connor	Analogic Corporation
Jody O'Sullivan	Washington University
Laura Parker	Department of Homeland Security
Douglas Pearl	Insight Consulting
Homer Pien	Massachusetts General Hospital
Carey Rappaport	Northeastern University
Dave Schafer	Reveal Imaging Technologies, Inc.
Theodore Schnackertz	American Science and Engineering, Inc.
Jean-Pierre Schott	Lawrence Livermore National Laboratory
David Sheen	Pacific Northwest National Lab.
Michael Silevitch	Northeastern University
Sergey Simanovsky	Analogic Corporation
Stephen Skrzypkowiak	TSA
Adel Slamani	Quasars
Simon Streltsov	LongShortWay
Greg Struba	Department of Homeland Security
Zachary Sun	Boston University
Ling Tang	Rapiscan Labs
Brian Tracey	Tufts University
Whitney Weller	L-3 Communications
Dana Wheeler	Radio Physics Solutions
Alyssa White	Massachusetts General Hospital
Suriyun Whitehead	Department of Homeland Security

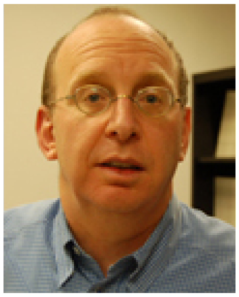
Jeremy Wolfe	Harvard Medical School
Zhengrong Ying	Zomographic LLC
George Zarur	Department of Homeland Security

11. Appendix: Speaker Biographies

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 technical coordination 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.

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.

Ross Deming
U.S. Air Force (consultant)

Ross Deming is a consultant for commercial industry and the U.S. Air Force. His main interests are radar and acoustic signal processing, inverse problems, and automatic pattern recognition. He received a BS in Electrical Engineering from Cornell University in 1985, and a PhD from Northeastern University in 1996.

Michael Ellenbogen
General Catalyst

Qianqian Fang
Massachusetts General Hospital

Qianqian Fang received his PhD degree in Biomedical Engineering in 2005 at Dartmouth College, USA. His PhD research focused on developing tomographic microwave imaging system and algorithm for breast cancer detection. From 2005 to 2009, he was a postdoctoral fellow at the Martinos Center for Biomedical Imaging, Massachusetts General Hospital (MGH), where he studied multi-modality near-infrared breast imaging and brain functional imaging. He is currently an Instructor at MGH and Harvard Medical School. His current research interests include multi-modality imaging, translational near-infrared breast imaging, portable optical imaging devices, dynamic imaging and massively parallel computing using graphics processing units (GPU) for medical imaging applications.

Kevin Johnson
Naval Research Laboratory

Steve Johnson
Telesecurity Sciences

Scott MacIntosh
Reveal Imaging Technologies

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.

Matthew Merzbacher
Morpho Detection

Dr. Matthew Merzbacher has managed the Machine Vision group - responsible for detection and image processing algorithms - since January 2005. He originally joined InVision Technologies (subsequently aquired by GE) in January 2003, where he applied his doctoral expertise in data mining to image processing and the problem of identifying and eliminating false positives. He works closely with the TSL on certification and explosives detection and testing. Prior to joining InVision, Dr. Merzbacher was a distinguished visiting research scholar in Computer Science at the University of California, Berkeley. There, he was part of the Recovery-Oriented Computing group, studying software and network reliability. Dr. Merzbacher also spent ten years as a collegiate computer science faculty member and corporate training consultant. Dr. Merzbacher has a B.S. in Applied Mathematics and an M.S. in Computer Science, both from Brown University. He has a Ph.D. in Computer Science from UCLA. His specializations are databases (particularly data mining), artificial intelligence, and computer graphics.

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.

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 also has management responsibility for 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.

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.

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.

David Sheen
Pacific Northwest National Laboratory

David Sheen is a Staff Scientist at the Pacific Northwest National Laboratory (PNNL). Dr. Sheen received a bachelor's degree from Washington State University and M.S. and Ph. D. degrees from the Massachusetts Institute of Technology, all in electrical engineering. His research interests include electromagnetic wave propagation, millimeter-wave imaging, antenna design, numerical methods, and infrared technologies. Dr. Sheen has developed millimeter-wave imaging systems for a variety of applications including concealed weapon detection imaging, radar cross-section imaging, ground penetrating radar, and other applications. He currently has 9 US patents for millimeter-wave imaging systems and related technologies, and has written numerous journal and conference papers. Awards and honors include a Federal Laboratory Consortium (FLC) Award in 2005, R&D 100 Award in 2004, PNNL's Directors Award in 1991, and several PNNL Outstanding Performance Awards.

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.

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.

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 questionnaire.

1. What should the definitions be for fusion, orthogonal and technology?
    a. Are *layered* systems (humans plus technology) the same as *fused* systems?
    b. Are PET and CT systems *orthogonal*? Are they *fused* in current medical applications for cancer detection?
    c. Do systems have to "talk with/guide each other" to be fused?
2. Are there existing technologies that have sufficient evidence for their potential as a fused system with improved detection performance?
    a. What is the *evidence* (e.g., literature, internet, reports) that fusing existing technologies would lead to improved detection performance?
    b. What would be *attributes* of technologies which would best fuse with each of these systems? Do such technologies exist today?
    c. What is the evidence to support that AIT and x-ray backscatter technologies are attractive fusion candidates?
    d. What other technologies could be fused to improve the detection performance of AIT systems?
3. How is detection performance improved with adaptive screening?
    a. What is the definition of adaptive screening?
    b. How should risk be assessed?
    c. How should risk be fused to explosive detection equipment?
    d. Should adaptive screening be used?

4. Which investment is likely to have the highest rate of return?
    a. Fused system identification and performance evaluation
    b. Algorithm development (segmentation, reconstruction, artifact reduction)
    c. Sensor simulations
    d. Integrating systems and then fusing their results
5. What changes need to be made by the TSA to allow fused systems to be deployed?
    a. What are the developmental steps between identification of attractive fused detection systems and acquisition of such systems by TSA? (Describe the research, DT&E, OT&E, and acceptance testing required, necessary resource levels and the timeframe to accomplish it)
    b. What are the implications of fused technologies on the DICOS development effort and emphasis?
    c. What is needed by traditional vendors to gain their enthusiasm for fused system development? (e.g. IP and patent protections, data on real threats, etc)
6. What changes need to be made by DHS S&T to fund the research and development of fused systems?
7. How can third parties better be marshaled to accelerate development of optimally fused detection systems?
    a. How can projects be given to third parties who cannot access classified information?
    b. Which projects are suitable for third parties?
8. What did you like about this workshop?
9. What would you like to see changed for future workshops?

13. Appendix: Questionnaire responses

Questionnaire A

1. Fusion. Sensor date fusion in an information theoretical sense.
   Orthogonal: mutually exclusive in terms of detectable events
   1a. It's a sub-set of fused systems since fusions can xxx xxx different layers
   1b. mathematically not, since they're somewhat correlated, but in terms of diagnostic value definitely. Yes it is a fusion.
   1c. Only if there are dynamic parameters in the fusion step.
2. PET/CT, PET/MR,SPECT/CT, 2D/3D ultrasound
   2a. improving the ROC curve
   2b. blank
   2c. improvement of ROC curve for the particular application
   2d. Infused, structured light, acoustic imaging
3. If the sensitivity of the detector can be focused reliably on the threat.
   3a. see above
   3b. with respect so its probability to change the ROC curve
   3c. as a confidence measure attached to a particular price of sensors data.
   3d. if tested successfully, yes
4. B
5. Change test requirements to also allow for sensors-fusion system of all levels of data processing
   5a. blank
   5b. DICOS need to be flexible enough to either store fused, e.g. registered, data as to link two data sets by an identifier
   5c. N.A
6. Adapt acceptance and testing criteria
7. Conduct a data fusion challenge, provide publicly available data sets for fusion
   7a.same way as the luggage screening, segmentation challenge
   7b. blank
8. Being new to the field (coming from medical imaging) many aspects were very interesting. In particular the major application scenarios, the general constraints, the players, the interests, the mathematical

and engineering approaches. Overall the very high quality of xxx and discussions.

9. Blank
10. Blank
11. How to improve collaboration between academia and industry in the security field. (technology xxx)
12. Blank

Questionnaire B

1. Blank

   1a. no. Fusion implies a technological approach-including human performance is referred to as "integrated". Having layered security is different than fusion

   1b. So long as each sub-system provides features that are somewhat uncorrelated then yes. If not then they are merely "integrated".

   1c. Not necessarily but that might help for reasons unrelated to detection. Or it could be related. E.G. single view projection fused with CT or just integrated? (CTX5500)

2. NQR + CT + XRD + metal detection
   XRBS +MMW+ Metal detect
   Neutron + xray
   Hostile intent detection + ALT
   2a. experience with CT + XRD
   Xxx+xxx (BLS
   2b. blank
   2c.For one thing they have less than ideal performance. They have somewhat "open" architectures, ie there is room to incorporate other sensors
   2d. acoustic metal detection
   NQR
   Use camera to look at person's face, eyes, for hostile intent
   Trace/place detection
   Shoe screener

3. Blank
   3a.blank
   3b. blank

3c.blank
3d. blank

4. D, identify potential fusion candidates, take data using separate platforms, fuse data, integrate systems later
5. The problem is bigger than the TSA. The airport environment is not controlled by TSA but by local governments and airport operators.
   5a. controlled data collection for sub-systems
   Data fusion
   Independent verification of fusion benefit
   Integration of sub-systems
   Controlled data collection with integrated system
   DT&E
   QT&E
   OT&E limited production
   FAT&SAT for production units
   Process through QT can take 5 years
   5b. blank
   5c.I think they already have some enthusiasm but they need to be willing to partner with others by means other than acquiring them. Acquiring them is ok too but not everyone can afford that.
6. There's not a lot of funding available- there's a need for compelling evidence that fused systems will be successful. At some point the customer, e.g.TSA, needs to get the technology on their acquisition plan. They don't care if its fused or not.
7. What is the definition of a third-party?
   7a. even within vendor's corporate structures there are ways to control access to classified information. There are ways to do this, e.g using codenames, surrogate materials, fictitious threats
   7b. if 3rd party means someone who analyzes data from a system separate from the OEM, then virtually every project is suitable in this technology-driver field.
8. Good for networking
   Good for discussion
   Good to limit scope
   Good food

9. Provide power for laptops! Treat the government as a partner, not necessarily only the customer. Parts of the government are the sponsor, parts can be partners, parts are independent testers, parts are customers
10. –smaller focus groups with specific taking e.g. simulants
11. How to evaluate/certify systems that are adaptive or have learning, e.g. xxx networks. Same question for adaptive systems.
    Large cargo (palletized and up from there) aviation, maritime, trucking
    VBIED-borders, tunnels and bridges, airports
12. Please inform ALERT about ORISE (oak ridge) visiting student/scientist, program for TSL and other DHS elements.

Questionnaire C

1. Ultimately semantics should be tied with how important it is to frame the problem in such a context. Fusion- joining of multiple systems to provide a joint action. Orthogonal- systems that provide information that are independent of each other
   1a. yes, how good of a "fusing" then depends on the application
   1b. Somewhat still correlated on what they are imaging, but provide different type of info. Fused via providing joint information.
   1c. Needs to have some sort of communication with each other or to an intermediary, for some sort of "joint" action.
2. Possibly MMW and XBS? PEC+ CT/MR
   2a. blank
   2b. blank
   2c.blank
   2d. blank
3. Blank
   3a. selective screening based on some a prior probability
   3b. a number of ways but each with their flaws e.g. history, certain screening methods, behavior
   3c. risk can help direct EDs's focus on certain targets
   3d. depends on if we can accurately measure risk? Racial profiling is adaptive screening based on poor risk assessment. No fly list has

been shown to be a flawed form of adaptive screening due to abuse/mistakes

4. a. fused system of identification and performance evaluation –on a single system this should give the best but its least modular and upgrades are harder
   b. Algorithm development (segmentation, reconstruction, artifact reduction)- ideally best fused performance while maintaining flexibility.
5. More flexibility in lofting researchers know what would make their jobs easier
   5a. blank
   5b. DICOS will help fuse technologies but needs to evolve to remain flexible for various fusion configurations going forward.
   5c.core fundamental setup, systems are typically based on some basic open literature concepts with modifications. What is at the core of their setups? Barriers they want to overcome?
6. Willingness to fund long-term projects
   How do we integrate the next generation systems as they develop or are we always stuck in this cycle of trying to use current gen. systems.
7. Willingness to create joint products
   7a. create some sort of surrogate project(not always feasible though
   7b. blank
8. Networking opportunities with people working in the field
9. Blank
10. Blank
11. Blank
12. Not sure if vendors/national labs are interested, but more student interaction opportunities? Conferences tend to be too big of a forum for networking effectively. Workshops provide a closer knit interaction forum.

Questionnaire D

1. What should the *ADSA community's* definitions be for *fusion, orthogonal,* and *technology*?

1st, ADSA recognizes past efforts to define {data, information, decision, sensor, etc.} fusion, especially that of the DoD (e.g. Handbook of Multisensor Data Fusion by Liggins, Hall, and Llinas), and myriad disagreements over some of those definitions. 2nd, ADSA recognizes that it matters far more that we define and find ways to solve the tasks than to define these terms, but that some level of definition is necessary to facilitate common understanding and communication. 3rd, I propose that we keep the definitions rather broad, while recognizing that there may be fields in which versions of "fusion", for example, are narrowly defined.

For reference, relevant Merriam-Webster definitions:

Fusion: a merging of diverse, distinct, or separate elements into a unified whole.

Technology: a manner of accomplishing a task especially using technical processes, methods, or knowledge.

Orthogonal: statistically independent.

(My choices among definitions provided by www.m-w.com)

Now, here are very draft-y definitions I propose:

ADSA definition of (data/sensor) fusion: Any combined use of diverse, distinct, or separate *sources of data or information* (whichever is more general) to *make a decision* [optional addition: …about the presence of a *threat*, absence of a *threat*, or the occurrence of an *anomaly*] (of course this requires definitions of the italic terms, but perhaps those are more readily agreed upon).

ADSA definition of technology: Any means of acquiring information or data (whichever is deemed more general) using technical processes, methods, or knowledge. Thus, a human can be a technology too.

ADSA definition of technology variables: *features* or other types of output from technology

ADSA definition of orthogonal variables: variables that are statistically independent (thus *data* cannot be orthogonal, but the *variables* that are being observed or produced from observations may be).

ADSA definition of orthogonal technologies: technologies for which some *reductions* (or no reductions) of the data or information (whichever is more general) associated with each technology correspond to orthogonal variables (variables that are statistically independent).

Distinguishing between (possibly overlapping) *categories* of fusion: distinguish between fusion automated all the way to decision (e.g. Boolean, Bayesian, or other combinations of output from multiple technologies that results in a single 0/1, probability, or some type of score that directly indicates alarm or not) from partially automated versions such as automated fusion of data that then need to be further interpreted by a human operator (e.g. overlay of imaging modalities or a peak spectrum generated by fusing different spectral modalities) and from fusion that is not automated and is entirely done by an operator (e.g. operator looking at three distinct images from three distinct technologies). Similarly, distinguish between kinds of fusion in which data are effectively visually layered or overlaid in some fashion (e.g. MMW and IR), versus kinds of fusion in which one modality informs the actual reconstruction or inversion of another (e.g. CT gives attenuation characteristics that then enable anomaly localization using transmission X-ray or other technologies), versus other kinds of fusion in which the separate output of multiple sensors is combined to do classification (e.g. fusing classifiers based on multiple mass spec modalities), versus kinds of fusion in which the actual operation of a detection system is modified on the basis of prior information (e.g. risk-based information on a given person being scanned determines whether a full system or reduced system is applied to scanning that person, or thresholds are modified, etc.). Also make the usual (though not always consistent in the literature) distinction between decision-level, feature-level, and data-level fusion.

a. By the definition above, layered systems must be fused systems, but may be recognized as sharply different from purely non-human/automated fusion systems.

   b. By the definition above (orthogonality = statistical independence) we are likely to find that no two systems can be rigorously shown to be truly orthogonal, but most have orthogonal components. We may instead talk of a degree of orthogonality. PET and CT may be "nearly orthogonal". (a quick/dirty way to check statistical independence: pixel-by-pixel gray level scatter plot). By the definition above, PET and CT appear to have been fused in medical apps.
   c. No, systems do not have to talk with or guide each other to be fused. That represents one particular kind of highly interactive fusion.

2. There appear to be many existing technologies with evidence of potential as fused systems with improved detection performance (and reduced FAR). I won't go into which here but rather talk about the problem of trying to rigorously argue for sufficient evidence. If my discussion is misplaced here, you could move it to #12 (Other comments).
   a. From the discussion at the workshop in attempts to answer Carl's excellent question "How did you know it would work," evidence appears to be based on intuition, experience, and physical understanding, and varying amounts of existing literature. Ideally, one actually has data from two distinct technologies on exactly the same test populations of objects (threat, benign, confusant, etc.) *at the same time* by which to estimate the correlation between technology variables (see definition above). Coupled to an attempt at physical explanation for the degree of orthogonality (to first order approximated in terms of the linear correlation), some level of orthogonality by this measure indicates some level of benefit in combining the technologies (unless the correlation is the same for confusants as for threats!).
      Short of the full data set described above, simulated data may be used in the same way.
      Short of data that show correlation, perhaps we may have data from systems used alone but no data that would

    indicate correlation. Ideally the data would at least be on the same or roughly the same populations of objects, but in this case without a means to pair up data points from each technology. In this case, the physical/intuition argument might be able to provide the correlation/orthogonality statement. Physical models in particular could be used to posit correlation. One could then approximate a joint data set that would enable a 1^{st}-order estimate of performance increases from fusion that could be used to justify further research.

    Short of any of the scenarios above, the physical/intuition argument may be all there is.

    b. No response
    c. No response
    d. No response

3. Using the definition below, it remains difficult to understand rigorously (mathematically) how detection performance is improved with adaptive screening (and how it should be implemented operationally).
    a. ADSA definition of adaptive screening: I would take Harry Martz's definition, which I understand to be: screening of persons and/or objects using prior information about the likelihood or level of risk that that particular person and/or object is carrying a threat. This appears to be a kind of risk-based screening, but the phrase "risk-based" has been removed due to conflict with an existing program or initiative of that name.
    b. Risk should be assessed in as many possible ways as we could constitutionally, legally, morally, etc. expect to find any information that clearly and directly indicates level of risk of that person and/or object. I think the list of exclusions from risk calculations may be easier and necessary to write: religious beliefs and practices, gender, etc.—anything within the scope of special protection of information by law.
    c. Given the animated discussion about how this might possibly be allowed, perhaps one way of fusing risk to detection

    equipment is to have the risk level guide which subset of detection equipment, and possibly level of alarm thresholds, is used on each individual person. For example, rather than risk legal violations or infuriated passengers, perhaps all passengers continue to be required to go through the same screening system, but the system is set to be more sensitive to a particular set of threats for a particular individuals. The system being more likely to indicate anomaly or presence of threat could then lead to more likely secondary inspection for the higher-risk individual (pat-down, etc.). Thus the individual is not explicitly "hand-picked" for secondary inspection, but is more likely to be indicated by the standard system because of the risk information integration. Perhaps this doesn't look any different than the current situation (and high-risk individuals would still recognize that they are pulled out more often than others).
    Yet it is not clear that this would really provide better performance anyway. If an individual is more likely to carry a threat, then isn't the system already more likely to indicate it? The math for this is not clear. Simple arguments can and need to be made to show that incorporating risk in *any* way that treats the riskier person differently than the less-risky person really makes a difference to overall performance in some way.

    d. Benefits of adaptive screening need to be clearly demonstrated mathematically before this question should be answered. If a benefit is clearly indicated, then it should be balanced against costs (social, political, operational, etc.).

4. I expect highest rate of return on the following, in order:
   - *Sensor simulations*—if they can be highly vetted/verified, this provides a much-needed and unprecedented (in aviation security) avenue for developing fused systems. HOWEVER, the real utility of simulation lies in the potential for creating simulated data of *representative* passengers and/or objects with and without threats and nuisances over a wide range of environments and environmental conditions. Until "representative" is defined, the

simulations will not realize their full potential, and we cannot use them to provide reasonable estimates of performance. This is true of real data as well. It may end up being just as easy to create a way for real data to be made broadly available. Best option: keep going down both fronts (“free up” real data *and* develop simulators, all the while banging against the problem of defining representative scenarios).

- *Fused system identification and performance evaluation*. Not exactly clear what is meant by “fused system identification” so I’m going to take it to mean the attempt to identify modalities that when fused should improve detection. I believe we can gain a lot by the combination of really cheap technology with advanced technology, and we have only scratched the surface of fusion options. I actually think there are ways to systematically and rigorously obtain first-order estimates of fused system performance above individual system performance, as I suggested in my answer to question #2.

5. Changes TSA needs to make:
   - Some version of formalized interoperability standards must be required of vendors by TSA.
   - Certification testing needs to be developed to allow systematic updating and broadening to guarantee statistical significance, relevance, and representativeness (this may already exist and I am just not privy to it).
   - Allowance needs to be made for a combination of individual system testing and fused system testing that recognizes that the individual systems may not need to achieve the same performance level of the fused system. Allowance needs to be made to study performance when only components of a system fail.
6. DHS S&T should develop a list of required components of any proposed fused system research and/or development, containing things like the following: demonstration of understanding of the various kinds of fusion, and a clear description of the kind of fusion represented by the proposer; a clear argument for why the fused system should perform better than the individual systems or other possible alternatives; demonstration of understanding of potential pitfalls of fusion (when does it break, and how will those possibilities

be explored); data collection plan driven by the typ of fusion (explicitly describing the need for estimates of correlation in data from multiple modalities); how the results may be shared with others and a plan for interoperability or data sharing; a plan for how performance will be measured.

7. No response
8. Workshop went very smoothly, allowing for short, detailed presentations and plenty of discussion. Excellent breadth of material presented (especially appreciated the human perspective discussion which was a welcome break in the non-human technology discussions surrounding it—maybe put that sort of thing in earlier next time). Location great, refreshments great, community great. Grateful to be a part of it.
9. The one thing I'd like to see is *more real statisticians*! It was said that there were several in the audience—but I was unaware of any (I think I have been mistaken for one, but it is not my training). There are plenty of people who analyze data, use statistical methods, etc. in the audience but no honest-to-goodness statisticians that I know of—and this is sorely needed to check some of the blanket statements we have been making about orthogonality, fusion, detection, algorithms, and the utility of information. Analysis of data and value of information are the crux here. We should encourage statisticians to be involved in the ADSA community!
10. I think the format is right on target for now.

Questionnaire E

1. Blank

1a. Not always (see c)

1b. Yes.

1c. Yes. Or, at a minimum, their performance has to be tuned to account for the presence of other systems

2. Blank
   2a. blank

   2b. provide additional data that is relevant to either threats or typical false alarms
   2c. blank
   2d. blank

3. Blank
   3a. Time/resources spent to screen a subject are determined by an assigned risk level
   3b. profiling (behavior and other)
   3c. blank
   3d. Yes
4. A
5. Blank
   5a. blank
   5b. blank
   5c. have sub-certification level specs for systems to be fused. Then procure those that meet the specs.
6. Blank
7. Blank
   7a. blank
   7b. blank
8. Realistic talks and discussions. Very frank talk by mike Ellenbogen
9. Presentation/ slides distributed prior to actual talks
10. Current format is great!
11. Testing/acceptance criteria (not sure if this can be done in an open forum). Multi-sensor simulants(x-ray, mmw, NQR)
12. Blank

Questionnaire F

1. Blank
   1a. no
   1b. 1.) They add incremental information to each other, as used
      2.) yes they are fused
   1c. yes

2. Scott Naahtash of reveal showed improved detection at constant P(FA), for DMAP and other modelities. TBD if implement is worth "cost" (complexity, space, xxx, etc)
   2a. see above
   2b. want incremental information on matters of interest
   2c. see above
   2d. blank
3. Blank
   3a. blank
   3c. blank
   3d. remember that public perception can have a real (not just perceived) effect on operation of security oerations at airports etc. (Hawthorne effect). And not think about this for a sub-group that you think have a higher. A prior risk ….could this further increase the prior. Or willingness to cooperate w/ law enforcement?
4. Need to model w/ more information to estimate the answer
5. Blank
   5a. blank
   5b. do you need to be (xxx) to have "non-imaging" in DICOS for fusion in the future (NQR,etc.)
   5c. Pay for performance
6. Blank
7. Blank
   7a.blank
   7b.blank
8. Nice mix of technical, questions, comments, conversation, etc.
9. blank
10. blank
11. blank
12. -Carl was great
    - Both homer Pier's talks were great
    - Organizers xxx want to put forward a 'straw mar" set of definitions of words like
        - Fusion
        - Orthogonal
        - Lazered

- Etc- for common use (or discussion)

Questionnaire G

1. Blank
   1a. no, like in classic fior, humans are behaving like hierarchical classifier
   1b. Yes, one is providing special features, the other one functional (xxx). Yes in medical sense
   1c. Not necessarily. Fusion can be a supervisor/mo6ss, independent of fused system
2. Blank
   2a. blank
   2b. special info and functional info
   (xpay) nnw
   T^2
   2c. Different information domain (spatial is xxxx)
3. Blank
   3a. second process algorithm steps influenced by xxx process. Feedback loop needed
   3b. lo minimize risk, feedback loop needed
   3c. xxx xxx xxx/xxx of both system depends a overall usb and screening
   3d. yes
4. A
5. Blank
   5a. blank
   5b. blank
   5c.blank
6. Blank
7. Give them useful data
   7a. blank
   7b. blank
8. Much deeper interaction xxx participants
   Sense of synergy between medical and security participants
9. Blank
10. Blank

11. Blank
12. Blank

Questionnaire H

1. Fusion is the combination of data/ information/ knowledge/decisions from multiple sources that are joined to do a better job than can be done separately. Orthogonal means “to vary independently. It can be used lazily to indicate that there are independent components, even if the data is not 100% orthogonal in the mathematical sense. This is valid because data is never truly orthogonal. Life carries redundancy. So data miners and architects use the term “orthogonal” to mean “carries new useful information not seen before”

Technology- no definition provided

1a. layered systems are an example (albeit simple) of fusion. However, they are not the same, as they are fused systems that are not layered.

1b.yes per definitions above and on back

1c. no, but it helps. The “primary”/”secondary” fusion model wasn’t discussed, but it is a really easy way

2. Yes
   2a. experience-it works. However it is a tough engineering problem (the science is evident)
   2b. it can be features, information, knowledge, or decisions. All these fuse (easily or no so easily). There are frameworks for sure fusion.
   2c. there is probably additional knowledge/info available. And the current solutions are so unattractive that we can’t help but improve on them.
3. Blank
   3a. using prior info about passenger/security threat level/other to change/tune defector assessment
   3b. very carefully
   3c. as an explicable prior or to set thresholds at end to fully understand the consequences.

3d. Strongly prefer not (politically, I am opposed). However, if it is used, it should be done very carefully

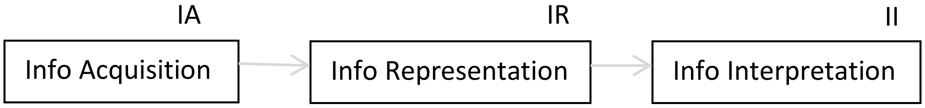
4. D, D solves the “80/20” rule. To get the best systems, other approaches must come into play.
5. Devise a simple FRAMEWORK for supporting various levels of fusion
   5a. The complexity must be well-understood. That means that any weakness or failure must have and explanation. Otherwise, fused systems have no chance of being fielded.
   5b. DICOS needs to support fusion. It does not (yet), but it could. Also, DICOS is not suitable for fielding. As an evaluation/ research tool for independent parties, it is the right solution.
   5c. Any indication that procurement would actually follow its obligatory. TSA is change-averse (and also complexity averse) there is a lot of inertia to field new systems.
6. Support a series of small case studies to attempt fusion (even when it seems dumb). Those efforts should yield papers on the framework needed for the fusion. Then fuse the frameworks into a master framework. REMEMBER: FAILURE IS THE BEST INSTRUCTOR
7. Bring in the experts
   7a. data can be obfuscated, allowing feature/data fusion without releasing classified or sensitive information.
   7b. ‘Here is data from two sensors-Fuse!”
8. Variety of presentations, hallway chatter
   No enough discussion about how to achieve fusion. One of the great things about fusion is that a simple fusion can get you a great deal. However, there are pitfalls, such as over-fitting or noisy data.
9. A breakout/small-group/brainstorming session
   More students 9advanced ones) to bring in
   New experts (a few each time)
10. I like the small/collegial approach.
11. –classification research in security (including discussions of complexity and hypothesis space evaluations)
    - Check point-of-the-future
    - Data quality/dirty data- how do we make good decisions with bad data? (how do you know?)

  - Physical interpretation- is a physical interpretation of the data required to make a good decision?

12. Excellent size and length. Could use it combined/wrapped with another workshop to reduce travel overhead. For example, maybe put one day as half-day before the RICC for brainstorming and one day after for case studies. Or vice versa.

Questionnaire I

1.



1a. No. Fusion can occur at either IA, IR, or II. However at II Humans make final decisions but can be computer assisted
1b. Yes
1c. Yes

2. No. Each system is already complex enough (or (?????)). We need simple and elegant systems
   2a. Its engineering efforts, need to fund R&D
   2b. Lots of tech can be fused to spend R&D money will lead to the success
   2c. Not clear without demonstrated performance
   2d. More advanced IA, IR, and II processing can be employed to improve A&I performance alone by at least 10 times
3. Adaptatism should also put screeners background. IG into consideration
   3a. No idea
   3b. Passenger info
   3c. At II stage with computer assisted to human making decision
   3d. Screening should be adaptive and random
4. B, Acquired, we have tons of (?????) un-processed or un-represented for interpretation
5. First fund more R&D activites
   5a. Blank
   5b. Blank
   5c. Fund private companies to develop fused systems
6. Increase funding by 20-30 times
7. Blank
   7a. Looks like not likely

7b. New sensors (Infor Acq.). New information representation Algorithm

8. Blank
9. Blank
10. Better food, more varieties!
11. Bridge DHS/TSA R&D funding with small businesses e.g. next topics: small business opportunities presented by DHS/TSA funding officers
12. Blank

Questionnaire J

1. Fusion – combination of data elements from 1 or more sensors to improve “system” performance

Orthogonal – NOT important to define – a (???????) given above fusion defn.

1a. Yes – it is a type of fusion or framework/method for fusing i.e. series/parallel, adaptive – these use utilization (?????)

1b. Yes

1c. No, but “talking” is almost always better than not

2. Yes – see macintosh presentation on PBIED detection

2a. There were many medical applications discussed at the meetings

2b. Blank

2c. Don’t know of any but expect that combing dielectric map w/ higher resolution image from BS could be better

2d. Chemical, acoustic, THZ,…?

3. Blank

3a. Change either the screening date collection or date analysis based on information external to “scanner”

3b. Use any and all available data

3c. Baseline min screening for all – (???????) increase for “higher” threats

3d. Yes

4. A – required (for d); B – shortest to morlet; D – biggest potential

5. Need mission plan, boundary conditions for amount of screening $$ albrated, commitment to test and deploy

5a. Depends on the mission requirements and specific fusion applications. In General collect as much data as possible from each sensor so that adaptive approaches do not require (?????) of new data on filtered use of (?????) data.

5b. Dicos should grow to cover as many sensors and data types as we can consider and may need to be modified in a planned way as new data is developed

5c. Commercial roadmap to support investment – ROI must be clearer

6. Try to cover R policy questions and create clear roadmap. Support deployments and testing

7. Once question 6 is covered, the business of third party involvement needs to be considered (whether the third parties are companies, universities, or gov labs the still need "business" model to work.)

7a. Difficult

7b. Depends on above answers

8. Good discussions, networking

9. Need at least to consider a classified or SSI level even if it reduces the number of attendees

10. See above. Could use more mingle breaks but was ok.

11. It might be useful to focus on a particular subset of TL problem - re – fusion for personnel screening at aviation checkpoints or fusion for personnel screening non-aviation or maybe breakout sessions to focus

12. I think the conclusions as 2nd slide should be slightly modified to “3rd” slide – sometime there was little or no context for the conclusions since slide #1 was a title only

Reduce the number of questions in this questionnaire

If you want to incorporate students more in this forum make it a formal part of each presentation i.e. each speaker has a bullet titled student perspective – open discussion – where the students are expected to speak from the audience

Questionnaire K

1. Orthogonal – measures distinct properties of fusion – value ass combination of data

1a. If the layers intercommunicate dynamically, Yes

1b. PET measures molecular amount (moles of label); CT measure regional (0.3 x 0.3mm) (?????)
these aspects are orthogonal. The combination are fused

1c. Yes – for (?????) fusion
No – for interpretation (????) fusion

2. Yes so long as AUC ↑

2a. medical world (????)

2b. At Feature level; problem – specs are @ object level

2c. (?????? ????? ??????); Xray (XBS) (?????) mass; knowing where to increase knowledge of object

2d. NQR + mmwave, NOR +XBS

3. Blank

3a. using priors to (????) constrained resources

3b. Baysion

3c. Baysion

3d. Yes (limited resources)

4. A – cases

5. Standard interconnect, API’s for downstream (product life cycle) (?????)

   5a. Demo/spec/MFg/(????)/ ConOpp

   5b. API leverages Dicos standard

   5c. $ from market

6. Test bed. Targeted Test bed

7. Make and analyze (????); simulate or case studies

   7a. Use medical

   7b. Blank

8. Free wheel

9. Pick on people that aren’t (??????)

10. Good format virtual watercooler

11. (???????); standard reporting language (???????) for even (?????); SIMTE, Geotag, Descriptor, (???????)

12. Blank

Questionnaire L

1. Fusion = use of multiple diverse data to increase division confidence
Orthogonal = high degree of independence in source of informational
Technology = a means to extract data

1a. Yes. Fusion can be concurrent, sequential, triage, or other combination of gathering data and
making decision

1b. Yes, yes

1c. No… fusion can occur in human interpretation; ex. Simultaneous review of separate CT & PET
accquisitions

2. Ct and XRD

2a. improves material discrimination of XRD has been published

2b. cost effective sources of data; correlated in detection and anti-correlates in FA (or vice verse); practical implementation in reasonable footprint

2c. unknown – have not evaluated

2d. unknown – have not evaluated

3. Many allow more time/resources for better detection of high probability targets

3a. using different operation point on ROC based on predicted risk

3b. Can be based on many demographic and behavior factors

3c. Many potentials ways… such as increased Pc algorithm for bags from increased risk passengers… lower FA algorithm for low risk "trusted" passengers

3d. Yes

4. A – need a context to evaluate, “certify” and gain field experience on the benefits of fused systems

5. Requirements and (??????) for adaptive algorithm selection; definition and implementation of a certification process for fused systems

5a. Depends on a lot on the maturity and status of the constituent detection systems. It is clear that above steps are required, esp DT&E and OT&E

5b. This is not clear. May provide framework for sharing risk attributes for adaptive screening. May also allow results from disparate sources (CT BXRD) to be efficiently shared… but is not necessary

5c. Need to work out ownership, rights, license to an technology that needs to be shared or developed to fuse proprietary systems

6. Need to define a set of user needs to evaluate fused systems, and desired objectives – what is the increased Pc or Decreased Fa desired for systems as a function of their increased cost, size, w/ consideration for any increase or decrease in thought put.

7. Increase funding and define the problem

7a. Need to abstract the specific application by defining analogous non-classified information/application

7b. reconstruction – registration – lots of the “generic” algorithms

8. Gives better awareness of AIT application and technologies

9. More TSA involvement/presence

10. Working sessions for group discussion of common issues is a good idea; develop common document for licensing of technology from academic to industry; develop (????) paper or requirements (?) or evaluation criteria (?) for fused systems

11. Reconstruction, on screen resolution… although gets into SSI and possibly classified areas; dealing with the "region of responsibility" in detection of future threats

12. Excellent facility and meeting management

Questionnaire L

1. Fusion- Joint use of multiple sensing modalities

Orthogonal – fundamentally different sensor technology

Technology- HW and SW based systems/sensors

1a. no.

1b. no-not orthogonal

Yes-fused

1c. no-that would be tipping and cueing

2. Yes-e.g. optics and acoustics

Visible light optics and IR

2a. Stevens Research

2b. current research question at Stevens

2c. xxx more clear

2d. don't know

3. Blank

3a. screening of people to various degrees of security scanning

3b. don’t know

3c. blank

3d. too complex for short answer- many regulatory/ political xxx

4. B

5. Don’t know

5a. blank

5b. blank

5c. blank

6. Blank

7. Blank

7a. blank

7b. blank

8. Participatory in interaction between DHS, academia, and industry partners

9. –Broader technical scope

-less emphasis on academic definitions of areas (e.g. fusion, orthogonal) and more focus on how to improve performance

10. This was a good mix

11. Other technologies of relevance

12. Thank you

Questionnaire M

1. What should the definitions be for *fusion*, *orthogonal* and *technology*?

Because we're new to the ADSA process and the ALERT community, we're providing a rather laborious response to this first question. Hopefully, it will serve as an introduction to our way of thinking and highlight our priorities for future research. FPS is responsible for security at over 9000 Federal buildings nationwide, from the sprawling Ronald Reagan complex in DC to your local IRS office. For over a year, we've been pursuing R&D support through DHS HQ to help us determine the optimum checkpoint explosives detection system to counter the IED threat at Federal buildings. DHS S&T EXD (explosives division) is setting up a new IPT to support our efforts in this regard. The DHS S&T human factors division (HFD), chemical-biological division (CBD), DNDO (Domestic Nuclear Detection Office), and GSA will also be involved. We're also supporting the new PBIED/VBIED detection test-bed facility that's being funded by DoD at Picatinny Arsenal.

As end users, our ultimate goal for all of these efforts is to favorably influence probability of detection (Pd), probability of false alarm (Pfa), and/or throughput (Tp) at Federal building security checkpoints. Pd, Pfa, and Tp are appropriate metrics for the T&E efforts mentioned above. However, as we work our way upstream to the R&D arena (through ALERT and others), we realize that these three metrics are difficult to apply, because they aren't normally characterized in basic research and they involve a "human in the loop" (from our specific guard population). Fortunately, NIST and others are helping us fill the gap between R&D metrics and OT&E metrics, so this problem is not insurmountable.

Furthermore, we can offer R&D advantages to the ALERT academic and vendor community because we're not as hampered by classification and SSI issues as TSA. For example, the design-basis threat (DBT) document, published by the Interagency Security Committee (ISC), applies to all non-DoD Federal buildings nationwide and is unclassified, protected only by the FOUO (for official use only) caveat. Certainly, specific FPS facility vulnerabilities may be classified, but we've established three tiers of explosive threat weights at the FOUO level, to which all our equipment will be tested and characterized. If the equipment is tested in the lab to the three threat weight tiers, the results will remain FOUO. If the equipment is tested by the FPS covert testing division at an FPS facility, as part of our comprehensive checkpoint system with our guard force, the results will be protected at a higher level.

In the next six months, with support from EXD and TSL, we'll be conducting a study at eleven FPS facilities nationwide to determine our baseline detection parameters (Pd, Pfa, and Tp) for all three tiers of threat weights. All future detection countermeasures will be compared to this baseline to determine if they provide cost-effective improvement when "fused" with our existing countermeasures system. So, to bring this dissertation back to "orthogonality," the most important question that FPS needs answered by the R&D community is, *"What is the most cost-effective addition to our existing explosives detection checkpoint technology that will enhance our Pd, Pfa, and/or Tp?"* Does the concept of "orthogonality" help us answer this question? Based on the discussion to follow, we don't think so.

Although we understand the desire to invoke an "orthogonality" convention for detection technologies and techniques, in our opinion, the term "orthogonal" should be abandoned. It's hard to conceive of a consistent set of orthogonal "eigenvectors" for our detection space that would add more value than confusion. It seems better to adopt a less confusing terminology or convention such as independence, correlation, complementary, supplementary, or even a brand new custom terminology for our specific use.

As previously discussed, we're most interested in Pd, Pfa, and throughput (Tp) for the entire system, to include the human operator. Of course, acquisition and life-cycle costs are equally important, and other factors such as system complexity, reliability, training requirements, and even aesthetics and physical size are also relevant. But, for the early R&D stage, metrics that appear to favorably impact Pd, Pfa, and Tp should be emphasized. So, we're primarily interested in incremental improvements to Pd, Pfa, Tp, or some combination of two or more of these, based on some pre-defined performance metric, which we'll refer to as "PM." In short, our ultimate goal is to maximize PM (which might involve minimizing Pfa.) Again, we understand that there can be a huge difference between early R&D metrics and actual operational improvements in detection performance, which can vary by user (through PM). OT&E must eventually sort this out, but there are ways to maximize the possibility that performance improvements in the lab will translate to performance improvements in the field. Nick Paulter at NIST is working on this problem in the context of objective imaging performance.

Getting back to "orthogonality," we see two possible definitions:

A posteriori argument: Would an effective "orthogonal" technology, *by definition*, tend to provide better incremental system performance (as defined by an agency-specific PM) than an effective non-orthogonal technology, when combined with the same baseline technology? In this case, "orthogonality" is determined (and defined) after the fact and is a matter of degree. Two technologies may be "orthogonal" in one case but not as "orthogonal" in another, depending on how PM is defined. And, very similar or even identical technologies might be relatively "orthogonal."

A priori argument: Is an "orthogonal" technology space pre-determined based on obvious differences in technologies and techniques? In other words, we know it when we see it. Transmission X-ray is obviously different than SERS, so the two are defined to be "orthogonal." Presumably, the combination of two effective "orthogonal" technologies would provide more independent information than the combination of two effective "non-orthogonal" technologies, but this does not mean that "orthogonality" is correlated with PM, as in the *a posteriori* case above. Identical technologies can't be "orthogonal" under this definition.

Both arguments (definitions) have problems and become untenable in the real world. In the *a posteriori* case, two different technologies may be "orthogonal" for one agency-specific metric (PM) and "non-orthogonal" for another. In the *a priori* case, "orthogonality" may not be correlated with PM, so what purpose does it serve, and how much time will we spend trying to reach a consensus on technological "orthogonality"?

To emphasize the problem, consider FPS, which currently uses a single-view, single-energy transmission cabinet X-ray machine (Smiths 6046si) for primary screening at Federal checkpoints. We're considering adding explosives trace detection technologies to our cabinet X-ray to improve detection performance for screened baggage. *A priori*, we would submit that most people would consider technology 1: a planar X-ray image interpreted by a human, to be completely "orthogonal" to technology 2: an explosives trace detection sniffer with automated output. But, what if a marginal increase in Pd does not make up for a massive increase in Pfa, as quantitatively captured by our pre-defined PM? In this case, the two technologies are "orthogonal" *a priori*, but not "orthogonal" *a posteriori.*

On the other hand, consider the same Smiths 6046si, but with a hypothetical modular retrofit consisting of a second transmission X-ray view. We don't think most people would consider a second transmission view from a different angle to be an "orthogonal" technology *a priori*. (The fact that it might be geometrically orthogonal but not technologically "orthogonal" further highlights the confusion that this concept brings.) Based on our experience, the addition of a second view would probably increase Pd and decrease Pfa for the system when compared to a planar projection. So, *a priori*, a completely "non-orthogonal" (identical) technology could very well provide better incremental performance metrics than an "orthogonal" technology. As we learned in ADSA06, there are highly correlated imaging technologies that greatly enhance overall system performance when combined. *A posteriori*, these two technologies would be considered "orthogonal" even though they're identical.

So, in the *a priori* case, it seems that the term "orthogonal" just adds confusion. In the *a posteriori* case, "orthogonality" is a matter of degree (after the fact), and two technologies may be "orthogonal" in one case and (relatively) "non-orthogonal" in another, depending on how PM is defined. Therefore, to capture incremental performance improvements with the addition of a second technology, we would abandon the concept of "orthogonality" and simply quantify the resulting impact on Pd, Pfa, and/or Tp to the best of your ability in the lab. End users can extrapolate these results to their unique PM. Of course, this argument is simplistic because researchers don't concentrate on Pd, Pfa, and Tp. But, once again, there are ways to link lab metrics such as resolution, SNR, contrast, etc. to Pd, Pfa, and Tp (and then to PM).

If the community at large still wants a way to categorize "orthogonal" (independent?) technologies, we would concentrate more on the detection scheme (technique) than the specific technologies. As stated in the most recent Northeastern University ALERT annual report (page 26), "Detection of hidden explosives depends on two fundamental techniques: spectroscopy and imaging." We add a third "fundamental technique" that concentrates on the human perpetrator rather than the "hidden explosives" to arrive at the proposed structure below.

Proposed Independent (Orthogonal?) Detection Schemes (Techniques):

> 1. Imaging: Technologies that provide detection based on geometry, such as size, shape, and location. (Transmission X-ray, XBS, MMW). Zeff would probably go here too, since it's derived from the same basic geometric data.
>
> 2. Spectroscopy: Technologies that provide detection based on chemical composition. (Sniffers, swab, Raman)
>
> 3. Human Factors: Technologies that provide detection based on the human subject. (ID, biometrics, video analytics, furtive behavior and deception detection, iris scan, elevated pulse, guard training, etc.) We would include random screening and other "smart" or threat-based screening and patrol protocols in this category.

We wouldn't be as opposed to using the term "orthogonal" to describe these overall detection schemes (techniques), but once again, this could invite confusion when the individual technologies within the three schemes are inevitably compared. For example, don't some THz-wave technologies straddle the boundary between imaging and spectroscopy? All that said, if the *a priori* argument is accepted and the possible inconsistencies in PM are understood, then this framework might serve to define "orthogonality".

The examples in the three schemes above show some examples of "technology" as we interpret the term. Technologies like NQR, FLIR, THz acoustic, SERS, infrared thermography, and many more can be added. We'll let somebody else formally define the term "technology." We don't think it will invite as much potential confusion as the concept of "orthogonality."

To us, "fusion" would mean any combination of detection technologies, techniques, and/or protocols that changes Pd, Pfa, and/or Tp for the system as a whole. Once again, to the first order, all that ultimately matters to us is Pd, Pfa, and Tp (as combined into a PM.) System cost is also important, and there are other factors as mentioned above, but Pd, Pfa, and Tp (or preliminary correlated laboratory metrics) are what the scientific community should concentrate on if you're trying to develop solutions that will eventually be commercialized and fielded. Sensors can be fused in the detection pipeline or fused at the very end, and the fusion can be accomplished by a computer algorithm or by a human. In any event, if more than one sensor (technology) is used to make the ultimate "go – no go" decision, then we would consider the technologies to be fused.

- Are *layered s*ystems (humans plus technology) the same as *fused s*ystems? Yes. Pd, Pfa, and Tp for the entire system, including the human operator, are ultimately what we care about, whether fused or layered. Until we develop a truly automated detection scheme, humans will be an integral part of the detection system. Actually, even with a fully automated "detection system," humans will probably still be part of the overall "security system", if only for exceptions.
- Are PET and CT systems *orthogonal*? Are they *fused* in current medical applications for cancer detection? See our comments for the definition of "orthogonal."
- Do systems have to "talk with/guide each other" to be fused? No, they can remain completely independent until the very end, when either a human or an algorithm must combine all the independent data to reach a "go - no go" decision. If the data is not fused in the detection pipeline, then it will ultimately be fused by the human operator (or an automated algorithm) at the very end.

2. Are there existing technologies that have sufficient evidence for their potential as a fused system with improved detection performance?

- What is the *evidence* (e.g., literature, internet, reports) that fusing existing technologies would lead to improved detection performance?
- What would be *attributes* of technologies which would best fuse with each of these systems? Do such technologies exist today?
- What is the evidence to support that AIT and x-ray back scatter technologies are attractive fusion candidates?
- What other technologies could be fused to improve the detection performance of AIT systems?

3. How is detection performance improved with adaptive screening?
   - What is the definition of adaptive screening?
   - How should risk be assessed? Risk assessment starts with the development of an intelligence-informed DBT (Design-Basis Threat) which is used to guide countermeasures acquisition and employment. This is a very formal process which varies slightly between agencies, but the basic template is fairly standard. I would refer you to the Interagency Security Committee (ISC) DBT, risk assessment process, and facility security system which are mandated for all (non-DoD) Federal buildings. There is no need to develop a new risk assessment process at the strategic level. FPS, USSS, DoD, TSA, and others do this well. Admittedly, getting supervisors and policy makers to draw a line at an acceptable risk level will always be a problem. But, if you use the same risk assessment process as the end users, you can draw your own line and they will be forced to take it (or draw their own.)
   - How should risk be fused to explosive detection equipment? The end user community, specifically senior policy makers, must provide guidance on this. The scientific community must translate this guidance into quantifiable metrics. The vendors must throw in cost estimates. Failing this, the R&D community should adopt the end-user risk assessment process and draw their own lines for Pd, Pfa, and Tp (or correlated preliminary lab metrics.)
   - Should adaptive screening be used? Anything that can be shown to enhance Pd, Pfa, and/or Tp in a cost effective manner should be used (assuming appropriate civil liberties are protected). I would refer you to the 3RAM project conducted by PNNL for the Washington State Ferry system for VBIED risk assessment and security asset allocation. The 3RAM program forces end users to make the cold

hard decisions required to minimize overall system risk with limited security resources. 3RAM may not be a true adaptive system, but the discipline it imposes on managers (by forcing them to quantify and minimize overall system risk) is applicable here.

4. Which investment is likely to have the highest rate of return?
    - Fused system identification and performance evaluation. This for long-term efforts.
    - Algorithm development (segmentation, reconstruction, artifact reduction)
    - Sensor simulations
    - Integrating systems and then fusing their results. This for short-term (COTS/GOTS) efforts.

5. What changes need to be made by the TSA to allow fused systems to be deployed?
    - What are the developmental steps between identification of attractive fused detection systems and acquisition of such systems by TSA? (Describe the research, DT&E, OT&E, and acceptance testing required, necessary resource levels and the timeframe to accomplish it.)
    - What are the implications of fused technologies on the DICOS developmental effort and emphasis?
    - What is needed by traditional vendors to gain their enthusiasm for fused system development? (e.g., IP and patent protections, data on real threats, etc.) Mobilize user consensus by DHS components (and State and local agencies) for a modular fused system architecture based on DICOS. DHS should do this.

6. What changes need to be made by DHS S&T to fund the research and development of fused systems? Mobilize user consensus by DHS components (and State and local agencies) for a modular fused system architecture based on DICOS. Fund consensus desires. Ignore lesser desires for now. We need a big win in a significant consensus area to build confidence in the ability of the DHS S&T community to shepherd real solutions that can be commercialized and deployed. DoD does this (well?) and some individual (legacy) DHS components (TSA, USSS, USCG, FEMA, CBP, etc.) do this, but DHS S&T does not coordinate this for the

Homeland Security Enterprise (HSE) as a whole. This results in inefficient R&D resource allocation across the HSE. We feel strongly that more emphasis should be placed on developing incremental cost-effective improvements to checkpoint security systems that can be fielded by FPS and State and local security agencies. Currently, most of these agencies use single-energy, single-view transmission X-rays for explosives detection. TSA continues to push detection technology to the limit, but TSA solutions are not affordable by the HSE as a whole. Someone needs to help the rest of us determine what the optimal cost-effective addition is to our existing equipment to maximize explosives detection so we can defeat the IED threat. DHS S&T should do this.

7. How can third parties better be marshaled to accelerate development of optimally fused detection systems?
    - How can projects be given to third-parties who cannot access classified information? Work with FPS datasets and technology at FPS facilities.
    - Which projects are suitable for third-parties?

8. What did you like about this workshop? Great introduction to the ALERT community. Lots of networking opportunities.

9. What would you like to see changed for future workshops? From an end user perspective, this is essentially a TSA workshop. Is broader participation by other end users desired? FPS requirements are much less stringent than those of TSA, and our classification and SSI issues are much less onerous. Do these two characteristics rule us out or do they offer opportunity? We're happy to let TSA push the "state of the art". However, we feel like there are many opportunities for R&D in the wake of TSA's advance that will allow the rest of us to make massive improvements in our explosives detection capability.

10. Do you have recommendations for future workshop formats? (e.g., smaller with more focused working groups, larger with speakers and breaks to mingle, etc.)

11. What topics would you like to see addressed in future workshops?

12. What other comments do you have? ALERT should highly recommend to any new attendees that they download and read all the previous ADSA minutes. This will minimize the need to re-visit and exhaustively discuss

the same issues that erupt at every workshop. These issues include TSA classification (SSI, etc.), the definition of a “third party”, where the national labs fit in, what are the basic technologies, definitions, etc. ALERT might even consider distilling the previous minutes into a synopsis that presents the evolving consensus on these issues so that we can advance them, instead of back-tracking for the sole benefit of one or two new attendees.

14. Appendix: Acronyms

Term	**Definition**
2D	Two-dimensional
3D	Three-dimensional
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 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
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
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

Term	**Definition**
COE	Center of excellence, a DHS designation
CONOP	Concept of operations
COP	Concept of Operation
CRT	Certification readiness testing
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
ECAC	European Civil Aviation Conference
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
FDA	Food and Drug Administration
HME	Homemade explosive
IED	Improvised explosive device
IMS	Ion mobility spectrometry
INL	Idaho National Laboratory
IQ	Image quality
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)
MMW	Millimeter wave
NDA	Non-disclosure agreement
NDE	Non-destructive evaluation
NEMA	National Electrical Manufacturers Association
NEU	Northeastern University

Term	**Definition**
OOI	Object of interest
OSARP	On screen alarm resolution protocol/process
OSR	On screen resolution
PD	Probability of detection
PFA	Probability of false alarm
PPV	Positive predictive value
QR	Quadruple resonance
RFI	Request for information
ROC	Receiver operator characteristic
ROI	Return on investment or region of interest
SAT	Site acceptance testing
SOC	Stream of commerce
SOP	Standard operating procedure
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

ADSA06 Minutes: Day 1 11/9/11

Carl Crawford

CC: There are far fewer presentations than earlier workshops and I want the emphasis to be on the conversation. Fusion is a complicated subject and we need discussion to take place for this to work.

Michael Silevitch

MBS: As Carl said, one of the things we want to do is create discussion. If conclusions are valid, what is impact of ideas? We want to break down the barriers of communication and collaboration. We want to establish our strength in partnerships with different communities. I'm delighted at the way that ADSA has nucleated through the six workshops and we're going to experiment with ADSA07, which will most likely focus on video-analytics, which is a different focus than CT based AIT.

We've been given funding through Eric Houser, Bauer, Parker at S&T to focus on transition. That's a new focus that we've been asked to and are embracing. When we start looking at applications of fusion, the question is, are we working directly with stakeholders? We were given $1.8M to divide into 3 areas of interest: video analytics, CT reconstruction and sensor fusion to see if we can create an environment that makes sense. That's not going to be an easy task. The other thing is that we want to couple the third party developments into vendor awareness.

XF: Will we have time to talk about funding opportunities?

MBS: Certainly, for example, spinoffs of the segmentation challenge. We may have to arm wrestle a bit with TSA. Bring it up, it's vague, but I think funding is what's driving a lot of how we are tied together.

XF: I'm asking because for the CT symposium, you are planning to focus on the applications. I think funding from private/public sectors would be a great way to stimulate this process. Otherwise everything dissipates after the conference.

MBS: There are industry/govt/investor representatives in the audience who have the ability to invest in technologies that interest them. I think that we can simply ask the question. Part of the problem is that the fiscal situation in Washington is somewhat confused right now. Hopefully things will sort them out but we will have to wait and see.

Another funding vehicle at NU is the Kostas Center that is geared toward classified/top-secret type work. That's another venue for govt/vendor investment. The idea would be that if this makes sense for vendors and govt customers, we'd be delighted to at least talk through what would it means. It's all a very preliminary thought in my mind but I welcome discussion on how to best proceed. The facility is in Burlington, about 20 minutes away. Peter Boynton, former Homeland Security director for Connecticut, and Stephen Flynn, a professor of political science, are the directors of the facility.

Doug Bauer

Welcome and thank you for attending. Our social and cultural objective is to try to bring together vendors and needs and expertise, universities and 3rd parties. This is a collaboration that we are trying to accentuate in a number of ways, for example, the DICOM standard to allow broad 3rd party participation. I want to cite the pillars of American strength that are currently under assault. The first is infrastructure, the infrastructure investments of the 21st century. We have grossly neglected infrastructure over the last 20 years and are losing reliability as a result. The second is education, to which we are deeply committed here. Our task is to bring the rising generation along and raise their standard of participation to excellence. Tom Friedman recommended on the subject. The point that Friedman makes about education is that average is over. Those at the top of the heap have to get better because they are literally in competition with engineers and scientists throughout the world. Those at the bottom of the educational system have to be pulled up. We need to address the dropout rate in S&T because it creates an inefficiency that we cannot afford. (Also Mandlebaum).

As a consequence of this inability to act, I haven't a clue as to what our budget will look like going forward. To govern 300 million people, we have a banana republic passing continuing resolution. It is an insult and a disgrace and it is impossible to make a long-term commitment to funding as long as this environment exists. Please make every effort to describe not only what you do, but the excellence and importance at being at the cutting edge and why it is so essential for funding.

MBS: Reception will start at 4:40 pm, in 440.

<u>Carl Crawford</u>

CC: Doug, you're the one who initiated these ADSA workshops. Are they working?

DB: I think the court is still out. There are 2 dimensions by which to discuss the worthwhileness of this workshop. The first is the advancement of technology to solve problems, and the second is the cultivation of relationships to make connections in ways that transcend each workshop. The only thing I can do is rearticulate those two fundamental objectives.

MBS: Another metric is the fact that we're building a community. The community is in fact building. We have double the attendance we thought that we would. If people didn't find these workshops were valuable and created networking opportunities, we wouldn't have this kind of participation. My gut is that these are creating the type of connections we want and what we need to do is look at transition of technology to the field.

<u>CC: ADSA05 review</u>

CC: Key component… how do you know that if you put A&B together, the result will be better, and how do you go to a funding organization and prove it up front?

MBS: In the room here there are a lot of people that have an interest in fusion. How many people have a sense that they've been successful at demonstrating, implementing fusion? (1/3 raise hands) Please share the road that it took to make the success happen, without revealing proprietary information.

Ling Tang: We have some preliminary studies about combining CT with dual-energy (?).

XF: How do you define the term success? Do you want to lower the false alarm rate or increase the accuracy?

MBS: I deliberately blurred that because success is in the eye of the beholder in a sense. We can explore the dimension of how you measure success.

XF: The way I look at it is by defining more features of the object, you increase accuracy/lower false alarm rate.

MBS: From the medical domain, we are clear that the whole is greater than the sum of the parts.

CC: From success, we are interested in detection performance. The bottom line is to increase the area under the ROC.

MF: The slides will be available within a couple weeks.

??: We've been successful integrating active and passive mm-wave into one antenna. It's more of a modality.

CC: The general answer to fusion is… everything. We tried to limit it last time, that's where we got into trouble.

CR: A mine detection project I worked on with David Castanon 12 years ago showed some success in that regard.

DC: I haven't necessarily found a good application in DHS domains, but we've definitely had some success in fusion.

CC: Why isn't it translatable into security?

DC: You know how objects manifest a lot better than you do in this domain, which allows us to integrate more successfully. The amount of clutter in those environments is significantly different than what you see in the AIT domain. (Gives examples) Some of the aspects of this domain tend to make it hard.

CC: Classified info, since you work at Boston University?

DC: Not at Boston University. I work with industry at their facilities.

MF: There is also room to talk about fusion within a single system. For example, two ATR algorithms can be fused together.

CC: The nomenclature on how we describe this defines how we're going to be doing this. All these things make a difference in terms of what we're doing. It turns out that risk-based screening is a TSA program, so we are going to call it adaptive screening.

HM: When people usually talk, they will typically point out strengths and gloss over weaknesses. But the weaknesses are the key part to the technology goal. This info could be proprietary/classified. How do we deal with that? If the weaknesses are important, how do we discuss that, or are strengths adequate?

MF: Talk about strengths, and use elimination. What are left are the weaknesses.

??: If you ignore the fact that people want to be x-rayed, that won't help. The perception of X-rays being bad for you needs to be taken care of.

CG: You could just lay out the entire domain so that the strengths and weakness are up for discussion and suggestion.

HM: But why avoid discussing the weaknesses?

CG: If it's sensitive in nature, obviously we can't go too far in an open discussion like this.

HM: So would it be useful to discuss this in a classified session?

Barry Bunim: Another problem is that there are too many parameters, so it's easy to slide the discussion away from weaknesses.

XF: So do you want A&B added in parallel or sequential? The customer going through the airport, going through 2 sets of sensors, is not as acceptable.

MBS: Is there some sort of value to some kind of a plug and play environment that could be created that would allow us to do tradeoff analysis in a particular scenario? It could be a simulation environment or it could actually be an experimental environment. In our segmentation discussion, there was no way of comparing apples with apples. So the initiative was formed to create a dataset and environment where we could actually compare different approaches around the same problem. Is it possible to create same thing in fusion arena?

HP: Another issue in respect to fusion is that there are targets and areas of interest that we in the non-classified world should not be looking at. Whether there are simulations or proxies that would allow us to engage…

DC: Well segmentation was definite as an operation with a well defined set of data. Fusion, you put it at your first word, it's very ambiguous in terms of data set an application. I think realistically, the exploration space is too large; we're not ready at this point. If you were to narrow this down to say fusion of A and B or C, okay, but right now we're not.

HP: Aren't we trying to focus this down in this workshop?

DC: If we get it there. Maybe that's an outcome.

BB: Why are we focusing on backscatter, etc?

HM: That's where we are presently. In the future that could be completely different.

BB: In my world, we're looking for small boats or scuba divers or people entering places they shouldn't; all sort of things like that. In my perspective fusion in the integration of all the technologies nobody knows about.

CC: (Describes airport screening process). Is that fusion or not?

XF: (shake head)

CC: Why not?

XF: They are looking for the same features.

MM: I have a broad notion of fusion and my first thought was exactly that. I think of our reconstruction and detection algorithms as fused together. We can do it one, we can do it in the other, we can do both together. To me, that is just as legitimate fusion as box, information, any of the different types of fusion. The crux of the problem to me is almost entirely an ontological one. We need to have a framework for representing these types of things or run into problems left right and center. My concern with challenges DICOS will face is that the interface will be overly rigid and that if you don't have room for fusion in that interface, you're crippling yourself. I think fusion is everywhere.

MBS: I don't think it's fusion, I think it's CONOPS.

HP: I would completely disagree with that. The fusion angle, aspect has changed; there is additional information to be changed. Anytime you add information to system, the diagnostics have changed and that is fusion.

CM: Adding and reducing components and changing performance based on the remaining components is fusion.

AH: The worst person to ask the weaknesses of is the person who sells the machine. If you want to know about the weaknesses of X-ray backscatter, ask Michael… if you want to know the weaknesses of L-3, ask me (Hudson is from Rapiscan) as a physicist. People who have a contract with TSA can abstain based on that contract. There are lots of anecdotes out there that you can bring together.

MM: It's a little risky though.

British: I think there are ways of progressing?

CC: Is it beneficial for Rapiscan for people to figure it out on there on?

British: For sure. (Cites a benefit of this). It is very relevant.

MBS: One thing I'd like to ask is the vendors and 3rd party people to think of thesis topics for students who want to get involved in sensor fusion.

CC: The issue is there has to be a language that describes the flow of work. It is hard to diagram the work flow. In other areas there is the language established already.

MM: I think the intelligence agencies can help here. I was at a CIA workshop

CC: DHS is not well educated in fusion and its terminology. We should help DHS define this.

Slide: Is this fusion

??: No, it's sequential layers. Not fusion.

HP: I think it is an ill-posed question. There are layers of checks which combine multiple modalities. Absolutely it is fusion.

DS: I think you should ask, "Does it add anything to the knowledge?" If it does it is fusion.

CC: So is it fusion?

DS: Yes

Tim Matthews: I think it depends on what your objective is. If your objective is to find anomalies on a person then it is fusion.

RK: It depends if you know what the machine is actually doing. In its current version I'd say no.

JB: I think the discussion is really interesting because we are trying to define what we are talking about. There is no framework with what we are working with. There is no discipline called fusion. It is a great discussion. I think there is a real lack of understanding about the fundamentals.

R. Bijjani: I think we need to be more precise with our language. It is a wide umbrella.

RM: What kind of fusion is it when you have attenuation of a PET scan?

RB: I called it directional fusion.

CC: Is the human in the slide a modality? Is she a technology?

NB: Yes because she is trained to flag.

HM: John, I think some colleagues at LLNL would disagree and say there is a fusion discipline. DHS doesn't have a fusion group.

MM: I hope there is a fusion discipline as I wrote a PhD dissertation about it.

MM: You left off the passenger out of the Look Deeper slide.

CC: How so?

MM: Some are cooperative, some aren't. It depends on how they participate. I don't know how to represent it.

MBS: I don't think the target is part of the fusion scenario. I think it is the focus of the fusion scenario. Cooperative or uncooperative.

CC: let's go back to it.

ADSA5 Experience Slide

MBS: There is evidence that some systems failed. We should discuss why this happened.

CC: Please fill out the questionnaire included in the packet you received first thing this morning. (Goes over questions on the questionnaire.)

MBS: The one thing I am not seeing is success stories outside of the United States. Countries that have had success in this domain. It might be helpful to know this.

CC: It is not on the agenda; it is an oversight.

Barriers for 3rd Parties

CC: This is not an easy topic.

Carl Crawford: Fusion Development and Deployment (Part II)

Conclusions

CC: The present environment is not optimized for fusion and modifications are required to the environment to support fusion.

Generalized Model

CC: What the boxes mean different things to different modalities. Fusion can change any of these boxes. What is not shown here is how the boxes are controlled?

MBS: In terms of the current TSA climate, is there motivation for a fusion strategy versus give me a better system?

Don Kim: I'm not sure they are mutually exclusive. I don't think just because something is certified fusion it will win our business. It needs to be a better solution in many areas. This includes TSO, passengers.

MBS: Fair enough.

CC: Technology-any source of data or information that is used to support a detection decision. The human itself is a technology. In some sense the last workshop we got into defining what is a technology. Something that assists another technology is also fusion. If it helps detect a passengers type of clothing this is fusion. It is unclear if reconstruction is fusion. Technology categories include existing and future. In the future we need to specify so they do not have to pass testing on their own. (Goes over the data types such as images, spectra, etc.) Definition of orthogonal-it essentially means that entirely different aspects of a given threat are considered. When two or more orthogonal technologies are fused, performance is improved.

MBS: Carl, I'm not sure that I agree that one has to avoid the situation when the different aspects of a threat are correlated.

MM: I'd amplify that. So far there has been no mention of false alarms.

XF: In terms of orthogonal, it means some things are measurable but they are uncorrelated.

KH: One thing that came out of the last workshop ……

CR: I take issue with the third point on the slide. Sometimes color doesn't' help you at all. It's only improved if it helps you. You might be better off fusing two technologies that aren't orthogonal. Sometimes it doesn't have to be different technologies; it could be different resolutions of the same technology. It could also be protocols which are set to detect certain types of explosives.

MBS: If you try to distort the definition of fusion, CT is a type of fusion. The CT machine is a device with a performance device. We think of it as a unit instead of as a series of devices. My point is we don't want to get pedantic. We want to think about macro-fusion, not micro-fusion.

CC: I agree with you. Fusion means that multiple technologies are deployed to improve detection requirements. We need to bound the discussion.

XF: Aggregator means fusion right?

CC: Yes, I am being loose with my own definition. Requirement specs based on passing tests for complete set of explosives. Right now the system only lets a vendor provide a fused system.

RB: This topic has been coming up quite a bit as to how you test fused components. There has been talk of doing this with an offline test.

CC: I do not believe that TSA and TSL are working in the same direction.

HM: Could you say that is something being considered?

DK: No, it's too forward looking for this group.

CC: I think an objective is to discuss this and come up with recommendations for the government.

HP: I think that the mathematical phantoms are always the first steps but nobody believes the result of an algorithm that's purely based on simulations.

??: If someone were to say, "a head is a head but a bag is not a bag"

HP: Certainly we have many pathologies that don't reflect how an algorithm will perform, e.g., vascular system. But as a broad step to standardize, it's a useful tool.

CC: Yes, they are overly simplistic. It's not so much having one phantom as having a series.

XF: One of the usefulness of these phantoms is that you can use that for a proof of concept project that will prove that certain technologies can be fused. You can fund some kind of a seed project.

EM: There's an alternative to fund the development of open systems. Qianqian will talk about that. In principle you could do that for some of these systems to build open hardware.

MBS: Going back to the comparison between the segmentation and fusion problem and the fact that segmentation seems to be a much more well-defined operation, maybe the gambit in the fusion domain is to posit a physical problem. Can you distinguish Pepsi from Diet Pepsi, create an environment where this is the physical configuration, now, show us what you can do? That might be a better framework for informing us all about fusion versus a standard data set.

EM: I disagree. I think fusion is so fuzzy and people are working on so many different kinds of fusion that to pick a narrow problem might limit the science or the interest, since this is such a broad area. The whole notion of fusion is kind of squirrely at best, so…

CC: Doug Pearl has a contract from DHS right now to compare DICOM and DICOS. He has talked to a lot of you and will be talking to more of you.

<u>Matthew Merzbacher</u>

MM: Mostly solving these things is just done by doing. I think there's more to a shared framework, it's a prerequisite and it's absolutely necessary. It's not just a first step, it's the first step… but it's not a last step. Framework, protocol, methodology…

CC: So in medical imaging, all the imaging performance is available, open, and transparent. Why the difference?

MM: I would argue the lack of an ATD in medicine in general; the size of the domain… medicine has lots and lots of niches

MBS: In order to do effective reconstruction, you need to know the details with the innards of the different machines. Homer, is that knowledge publicly available?

HP: No.

MM: If we can fuse systems, that's definitely a sign of success.

MBS: If there were specs like this, what would fusion do for you?

??: So there is a missed detection rate…

MM: So you can't afford to just have the missed detection here and the missed detection there… that may not be enough. We're in the position of clearing bags to go on airplanes.

CR: The miss rate is set by the first detector.

MM: In this model, yes, unless you scan with both.

CR: Confirmatory. That classifies a type of fusion.

MM: We have to have a discussion about what is helpful and what isn't helpful so the customer is aware of what we could potentially offer them. You have to have some sort of framework for that conversation; otherwise you're talking apples and oranges.

CC: So are there some threats that are more of a problem than others?

MM: Absolutely. You have to have some sort of method for sharing information. A corner case is a situation, configuration with a particular threat where the system underperforms. You can take care of the middle of the room easily, but making sure the corners are clear, that's hard. For fusion, there are systemic corner cases.

CC: It would be nice to test A&B separately, but if one system is informing the second one, is that even possible?

MM: Yes, if your framework is clear and understandable. But if you have a relatively rigid framework, you're going to give up a little bit of optimization. However, I think it's worth it to fuse.

HM: Have you ever used the second system to feed back to the first system?

MM: We tried an inverted architecture, yes. DSFP… Detection System Fusion Protocol. It's basically a mathematical framework with conditional probabilities for talking about fusion.

??: If you do this framework and limit the information, you're making the mathematics a lot easier by constraining the problem.

AH: Also, public acceptance of the technology and political policy are part of conops.

HM: So perhaps you could reduce some of the technologies.

MM: Sure, these are just the thresholds for acceptance.

??: The clearer that industry can be on the kinds of things you have on the side, the more helpful I would find it.

MM: I would say, write the BAA that says what you need.

HM: Have you implemented a framework and can you show an example?

MM: We have the DSFP, which we've used. Our threat vector is 7, 8 conditional probabilities to get past. We made it simple to make it easier to talk to the customer.

Ken Jarman: Can you say something about the correlation with someone else's instruments?

MM: Correlation for threats, you want everyone to agree, that's a threat. You don't want that to overlap on threats. I'm a big believer that you should try to work pair-wise to solve problems even if you're fusing 18 things together.

CC: Why did you fuse XRD and CT?

MM: To drive false alarm rate down without losing detection.

CC: What is it about XRD that led you to believe it is worth fusing?

MM: We believed that it could be done. You know the performance of them independently, you make assumptions about the orthogonality of the two technologies, ideally, if you want the max, you have to integrate these things into 1 box that's tightly coupled, but that means swapping/improvements are hard, so we wanted the minimum amount of glue that would allow for effective fusion.

CC: It seems like a lot of money to show this.

MM: The analysis suggested that you could get certifiable detection with a low false alarm rate. Your customer has what they tell you they want, what they really think they want, and what they actually need. Those three things can be very, very different.

MBS: What was the property of x-ray diffraction that you looked at?

MM: It has high detection, very low false alarm rate, but it's slow.

Jay Hill: We know this, and it didn't take a lot of money to figure it out.

AH: Do people outside the industry know what these machines do well at?

MM: The answer is not available, and that is a challenge I don't know how to answer.

JBeaty: I think the question is also about being able to predict in general which two systems will provide best results, and I think it's a very hard decision. What do you pick from that array of sensors? I don't want an answer, but I think it's an important question.

JHill: Let's also not minimize knowledge and experience. There's domain knowledge and a presumption of expertise that informed that decision. We don't want everyone off the street coming in and informing the decision. This was informed by a deep understanding of both systems and the problem at hand.

Lunch

Homer Pien

Fusion in Medical Imaging: Two Case Studies

HP: For today I am going through two case studies: one with PET CT and the other with PET. We hope to show the value of fusing the two. Here is a modern PET scanner so the patient lies on a bed and the patient moves into the machine. Brief history of PET-Gordon Brownell at MGH imaged a brain tumor in 1951 a good 20 years before MRI and CT. (Goes over more history) The tracers were 0^{15}-water and FDG. Positron annihilation- The point I am showing this is the poor resolution. In the 1990s PET transitioned to a clinical tool. PET gives you functional data. CT doesn't contain functional data. To do this you have to fuse it to a more functional modality. Using PET we can see if a patient will respond to a drug in 48 hours versus 6 months previously. This is a case for a priori reason for fusing it. The rational for combining PET and CT is so compelling that they would do the two tests separately and then try to fuse the images. In 2000 Time Magazine named the PET/CT machine as the Invention of the Year.

MBS: So they aren't co-registered?

HP: No but the cd [?] is relatively small.

MM: What is the relevant acquisition time?

HP: It depends. For a full positron water, you are looking at 5 minutes. For FDG you are looking at 2 hours.

MM: Is the PET informed by the CT?

HP: The current state of the art is that it isn't. There are research systems with which you localize with CT and move the PET closer and focus it. There are feedback systems like this currently being developed. By 2001 the literature is coming out as to the power of this fused approach.

HM: What is the tolerance?

HP: It depends what you are looking for. For 1-cm tumors it's perfectly fine. (Shows a movie with the title Attenuation Correction.)

HM: Are you doing absolute quantification?

HP: We are doing quantum quantification.

??: Are these patients healthy?

HP: No they are cardiovascular patients. Plays movie called Pet-CT Registration. The order of magnitude improvement for PET-CT is really making a case for the combined approach. Historically the most used test for deciding if cardio patients would stay overnight was the EKG. Circa 1988 they looked at pain levels and EKG to decide what to do with the patient. The problem with this is it doesn't tell you the extent of the problem and where the problem is. In circa 2009 we triage by looking at troponins [cardiac enzyme that is specific and sensitive to myocardial damage], imaging findings, and EKGs. These pieces of the information tells us more precisely where the problem is and what we should do for treatment/therapies. Again the primary point I am making is there is considerable a priori justification for the PET-CT approach. It is a similar story on the triage tree and it continues to evolve.

MM: When does it go wrong?

HP: Probably with respiration while the patient is in the scanner. It is very difficult for the patient to breathe normally. Regardless of these inaccuracies it still doesn't argue against the fused approach of PET-CT.

CC: Is there something in medical imaging that allowed this fusion to take place? Is there a medicine that drove this?

HP: In this case I don't think there is anything different that drove it. There is clearly an economic incentive.

Gregory: For the most part your patients are alive and cooperative.

HP: In that respect you are correct but I think what Carl was talking about was the market driving force.

Qianqian Fang

Combined Optical and X-Ray Mammography

QF: Good afternoon, I want to thank you for inviting me to speak. The talk I am going to give today is about combined mammography and x-ray for breast imaging. This is an outcome of work over 10 years begun by Dan Kopans and ___________ at MGH. We are inspired by the success of PET-CT. The conclusion is solving inverse problems with structural priors can enhance resolution and contrast in a functional imaging modality. (Goes over background of breast cancer imaging history). There is a lot of room for improvement over mammography. Mammography misses 44% of early cancers and has difficulty in detecting cancer in denser breasts. Good penetration and high contrast makes optical imaging a promising candidate. Talks about measuring absorptions at multiple wavelengths you can calculate concentration of chromaphores. Combined DOT with mammography slide. You see how we acquired two sets of data and with these we are going to do some processing. Here is an example which was on the cover of Radiology magazine. We showed the total hemoglobin concentration. For the healthy patient there is an increase of hemoglobin in the muscle tissue of the breast. For malignant tumors there is an increased hemoglobin concentration around the benign tumor shown.

MBS: The red stuff in the healthy tissue what does it show?

QF: We are showing the statistical difference in hemoglobin concentration between healthy and unhealthy breast tissue.

MBS: So this isn't fusion?

QF: No.

??: Did you do bilateral comparison?

QF: Yes.

CR: Do the numbers mean anything?

QF: They are of total hemoglobin concentration. If you look at the overall population there are significant differences but it's less apparent when looking at individual cases usually.

CC: How did you know a priori that this would give useful info?

RM: We thought the scattering property of fatty and glandular tissue would likely be different and that this would help, that was the initial thought.

MBS: I think a more simplistic answer to that question is that tumors have blood and they're conductive and they behave differently from non-conductive elements.

EM: All these functional modalities have pretty poor spatial resolution. You don't get data that's nearly as rich as CT. The original idea was that CT would help you spatially constrain diffuse optical data. The two of them together can generally provide improved resolution for that functional modality.

XF: At the beginning you talked about mammogram inefficiency. What is the improvement with this method?

QF: Criteria is what is improvement of ROC. We have statistics, but a small sample size thus far.

David Sheen

DS: The problem really does beg for an imaging system that is an anomaly detector, which really needs to be an imaging system, because otherwise everything's anomalous.

There's a tradeoff in frequency… you might be better off at a lower frequency where the clothing's more transparent. You can actually get multiple images at different aspects from the data… this is just the front and back aspect.

HM: So you don't get a pure side image.

MF: Typical number of views… anywhere between 10 and 60..

HM: So this one has less of the folds in the clothes etc. Is this different wavelength? It looks a little slower.

DS: It's 10-20 ghz. It's definitely a tradeoff for various things.

HP: Does the fact that you do a maximum testing projection contribute to the smoothing?

DS: There might be a slight bit of that because the resolution close to the aperture is slightly better, but most of the smoothing is due to the wavelength. It's possible to do the reconstructions based on all 360 degrees, but it gives undesirable side lobes and impulse response.

??: How well does the system work with prosthetics?

DS: We have it in the system, but I'm not privy to the data. It's going to see the gamut… I would assume all sorts of prosthetics are going to show within the image.

??: Will it detect an anomaly within a prosthetic?

DS: I think it will if it's transparent. It's a good question. Some of that may get sensitive but the means of prosthetic attachments are easily spotted. I think it's difficult to spoof.

??: From the standpoint of travelers who have prosthetics, they usually have to be x-rayed differently, so they wouldn't depend on the same machines.

XF: How could this be fusion with the backscatter x-ray?

DS: I think that's the topic for tomorrow, but on a pixel by pixel level it can be fused. Certainly the systems are sensitive in different ways. This technology might have a greater ability to see layers, X-ray to wires, stuff like that.

CR: Your depth views, i.e. the cross-section views, were pretty compelling. Do you know whether any manufacturers are taking advantage of this info? I mean it's there.

DS: It's there but only if you go wide bandwidth… it also sort of begs for the 360 degree viewpoint that's not being done. So there are implementation issues, but I'm excited about it from a future technologies standpoint.

CC: Do the simulations match the issues? Is it easy to match it?

DS: Point target, yes. 2-D simulations, yes. It might be difficult to simulate all potential effects. I think you can simulate a single surface pretty well. Adding layers of clothing on top of a model makes it sort of 3 dimensional.

<u>Homer Pien</u>

X-Ray Backscatter

HP: This is a nice follow up to mm wave. Conclusions are made on the basis of publicly available information. XBS systems may have relatively poor SNR. Poor SnR lowers conspicuity.

CC: Can you define conspicuity?

HP: We had an ALERT funded project. We have built a bank of radiologists to subjectively assess images. We reverse to this bank of data as conspicuous data. The more conspicuous an object is the higher the problem of detecting it and the lower the false alarm rate. We start off with an average 30-60KeV. The scattering angles are greater than 145 degrees. Resolution is approximately 2 mm/pixel. We are going to apply what we know about photon propagation. If we assume the energy regime what has been proven is how transmissive they are. Compton scattering of the photons depends on density which makes sense. Kaufman and Carlson's observations had many observations. The SNR is approximately 7.

MBS: What is a good SNR?

HP: 15-20 we could do some good things with. 7 is okay, you can see texture.

CR: What then are we looking at if we can see 2.5 cm in?

HP: I will show some additional samples and by the end of this we'll have a better idea.

CR: Is it just bone?

AH: No because it is backscatter.

HP: One of the thing the Kaufman paper talks about is edge effects. This is a Monte Carlo operating procedure.

HP: Conspicuity in XBS may be improved through fusion using multi-perspective, backscatter tomography, dual-panel x-ray system, multi-energy transmission x-ray, mmw, and thermal IR.

HP: We have a different set of protocols for people over 400 lbs.

CC: A lot of fusion work.

AH: I would do a lot of cleaning up before this though fusion would help.

CC: How is the comfort level having a discussion about potentially deployed equipment?

CC: Doug, at ADSA2 we talked about the need of disclosure.

DB: We have to be sensitive in terms of SSI but we don't want to be over paranoid which prevents a discussion. Clearly how to defense an available system is SSI. I don't want us to be so concerned that we don't look at our weaknesses and not figure out how to fix them.

MBS: I want to echo what Doug says. We are talking about fundamental physics at a certain level. We are looking at something and seeing if we can detect it. We aren't pointing at a specific machine. I could be wrong but I think we are on firm ground.

<u>Michael Silevitch</u>

MBS: You can get a sense that we're trying to integrate the competency of NU and URI, the two lead universities in ALERT. (Camp Edwards test-bed) When someone tries to penetrate a protected area, the multi-leveled sensor can probe the dielectric component of a person for abnormality. With an abnormal signature, the video analytics can take over and track it. We have ~150 students, undergrad through Ph.D., working on homeland security projects within the ALERT system. We have received funding from Eric Houser in 3 areas including Fusion, which we are here for today. (Video analytics) So we have software that forensically flagged the Times Square bomber. The question is how to do that in real time? Can we do that in real time?

CC: So should people be coming to you, or will you be going to them?

MBS: Both. We had 3 meetings with Massport at Logan Airport in the last month. We went to Cleveland and they talked about the problems that we would like to address, like people going in the outdoor and vice versa. The impact of something like that, if you can flag it, track it, and mitigate it, you can save hundreds of thousands of dollars, and that's also what this workshop is trying to get to with the industrial component.

Carl Crawford

Special Nuclear Materials

CC: So we pretty much converged on that we want to do video analytics for the next month. Any comments? Is there an interest?

MBS: My concern about the nuclear materials is that it would be awfully easy to jump into SSI sensitivity. Also, how pervasive is that problem in terms of the community that ALERT is dealing with. I would say to stay away from nuclear.

HM: There's some overlap I might think. What's been done on the explosives side could benefit the nuclear side and vice versa.

Jay Hill: They spent a ton of money on this. The problem has been transition. I'm a bit skeptical just given that there's a separate part of DHS that is struggling with this.

Cargo

John Bush: Transition, what's it going to take and what is the low hanging fruit from a transition perspective that DHS is looking for in the next few years. I think that should be a workshop topic, I think there's a lot of people who'd have a lot of things they want to say about that. A ton of money's gone into studying solutions, but the transition and implementation, e.g., space issues, are major issues.

Doug Boyd: It's surprising to me how much overlap there actually is between segmentation, nuclear materials.

JB: We all think it's really important but it's hard to find the avenue to traverse to get there, it's hard to find the customer that's willing to pay for it, as it's the airlines that would be paying for it as opposed to TSA/DHS. It's up to the airline to purchase those pieces of hardware, as far as I understand.

??: Are you talking about air cargo or ports?

CC: Yes. I didn't differentiate it.

LP: All the DHS people here are more aviation folks.

MBS: The one topic you don't have here is the continuation of the CT or the portal-based screening. That is also a common element and at some point we might want to gage interest in topic A, B, C, D.

JB: Right now we have a long-term thrust in that CT area. We've gathered a great deal of data specifically related to that area. That's a thrust that will be ongoing and that we plan to pursue for an extended period of time.

Jay Hill: Eric mentioned earlier, we've had all of this structural imaging discussion today and I think the fusion topic has a lot of energy behind it. What about expanding it to include some of these other modalities, chemical, etc? This would also be in line with the ALERT charter as I understand it.

CC: Should we come back and revisit the grand challenge process.

MBS: I think we should wait until the symposium is over.

XF: I think we are getting too broad. We need to get focused into certain areas so we don't talk about something we can't realize.

Don Kim: Is this definitely on for next time? Are you looking for another topic?

CC: We're just having another conversation. This opens up another issue, this is a whole different set of people to invite.

MBS: That's an issue because we don't want to lose the community we have fostered here.

DB: The video analytics interfaces with the checkpoint.

ADSA 6 Day 2 Minutes

MBS: Good morning. I'd like to introduce my colleague and the Dean of the College of Engineering.

D.Luzzi: I'd like to welcome everyone to the second day of this meeting. NU is committed to advancing all aspects of research and security. I will be moving into a new role to drive engagement with security in all aspects of the University. It is a very exciting direction for the University. Down in Washington you are hearing a very different story about universities. Normally when universities do work in this area they tell us not to worry, we'll work it out. Now they tell us if universities are going to make a contribution. The Kostas Facility's goal is to build up engagement with private industry, govt., and third parties across the board in the area of security. The team built up by MBS and C. Rappaport have been working in this area for years. We think we are putting together, here at NU, a community that is fully engaged. I look forward to future discussions.

MBS: We really are focused here on academic and industry linkages in this workshop so you should engage this group with the Kostas Facility.

DL: Absolutely. We can have this conversation.

MBS: Now I turn it over to Carl Crawford.

Day 2 Objectives

Carl Crawford

CC: Welcome to Day 2. Please fill out the questionnaire even if you are leaving early. It is a key source of information for this workshop. Please send any comments after end of workshop to Carey, Harry, or myself.

MBS: You might mention ADSA 7 feedback.

CC: Feedback is that video analytics isn't congruent with this group so we would not have most of the participants here at it if this was the topic. We will thus do ADSA7 as is and do a separate forum for video analytics.

??: I thought this group needed as much input from the users.

CC: You stated that we should do something on transition.

Scott MacIntosh

SM: Ross Deming will follow my talk. As Carl asked Conclusions: Multisensory inputs improved performance of a decision-fusion ATR algorithm PBIED detection. The data we collected showed that all these approaches being fused offered the best results. In reality it is sensor independent.

CC: PBIED?

SM: Person Born Improvised Explosives Device.

MBS: so it isn't portal based?

SM: It isn't portal based. As we work on this with DHS, the conops has evolved and it has been a checkpoint.

MBS: What is the through put?

SM: 20 frames.

MBS: so you are using video.

SM: Yes.

MBS: As an FYI, the Camp Edwards demo I talked about could be very relevant here. You should talk with John Beaty about this. It could be the basis for a JAII.

JB: We are already tied close together.

SM: A bit of background of the program. We are investigation fusion on the effectiveness of the program. We did a feasibility study. Phase 2 we screened real people. Phase 3 is doing further studies in mm wave and developing ATR. Most of the results here are from Phase 2. Phase 2 we did human subject scanning. We assembled a bunch of sensors together using sensors from PNNL. As we moved from Phase I to Phase 2 we had more realistic testing. What will come out of this is a standoff system (approx. 3-5 meters). We collected 129 scans. We also used a variety of simulated bomb devices. With each one we had an example with and without metal.

CC: Who provided the specs?

SM: DHS. So data processing, all the data gets registered and scaled to the mm wave dataset. The algorithm iterates as necessary.

MBS: So you have your primary mm wave sensor. Did you ask the other sensors how they supported it? How did you fuse? Ross, come on up. Ross did a lot of work on this area.

RD: So the mm wave radar was primary and the others we used to reduce false alarms so they were complementary. There are a million ways you can do it. We settled on doing it at the feature level. We compartmentalized and at the feature level we combined them.

MBS: At that level is there something each method can add to it?

RD: We went back and forth on the architecture for the final classifier. Phase 2 is wrapping up. We just wanted to show a result that is robust and showed that a multisensory approach being successful. It will never hurt you. You can have great information and mediocre info. And the mediocre info. Would help improve the great info.

MBS: What made it not hurt it?

SM: As long as your results are 50-50 it doesn't hurt. (Decision Fusion Scheme (continued) Slide)

MM: Did you do any pushing of the border towards clean or did you weight them evenly?

RD: What we did was pick on the ROC curve then you can choose.

CC: Can you give an example where active mmw needs improvement?

RD: Our best stuff is right here. Here is a thick bomb vest.

MBS: What is SWL?

SM: Structured White Light. It confines the area to what you are looking at.

CC: Did you know a priori that this was going to happen?

SM: No. I believed it would; we had intuition. I was happy with the results at how well it worked.

CR: Scott, would the fused results of the combined results get worse if you removed any single sensor.

SM: This graph show how each sensor performed. I think in any combination it improved over any single sensor.

JB: We went through DHS and got permission to have access to the data. We distributed it to one partner with an NDA. I think we could distribute the data to all under the same agreement.

SM: The results here are not definitively assessing any single sensor.

JB: The data frames are really interesting.

SM: This data collection had to be fast enough to collect. If you are going to collect at 20 frames/second you have to design it. Whatever system you dream up is going to have a give and take of the sensors.

DS: One thing we learned in this study is to say which sensors we really did need and which only helped marginally? What combinations help and not to worry about the ones that don't help.

MBS: One of the things I see you didn't do is a sensor sensitive to chemical trace. Did you think about that dimension?

SM: We discussed it for both this one and the next phase.

CC: I want to thank you for coming from Reveal to lead this discussion.

DS: I think one of the key things to take away from this is there's a ton of stuff you can do with this kind of data that we as a vendor with limited resources can't really do. It's a good tie-in to the academic community.

SM: We really just touched the surface.

DS: So many hundreds of man-hours are put into analyzing bag images to come up with algorithms. It's very draining and companies like us are limited. I think it's useful to show that this data's out there. It's unique situation, because we don't have a product that we're guarding the data of and protecting our IP for algorithms. I think this group has introduced industries to people who can look at data, like students and grad students, for many hours and can look at data for many hours compared to what we would spend.

JBeaty: We started an initiative with 2 groups using this data for a summer student program, so there will be analyses forthcoming from data set. I don't know what that means yet, but this data set is allowing an academic and an academic lab to pursue their interest in multi-modal systems. It's a privilege.

DS: We're all trying to protect the traveling public and there are vulnerable targets we don't have solutions for yet. This will help.

JBush: This is another DICOS modality that shows us opportunities for innovation and better algorithms.

TG: The cost to performance tradeoff also has to be raised.

DS: It's a good point. This isn't a few hundred checkpoints, it's thousands and thousands of places. It has to be cost-effective.

JB: Just rhetorically, what does the DOD do in the Green Zone in Iraq?

<u>Ross Deming</u>

MF: I saw results for some of the testing from a similar system and the errors are not random. You can usually find a systematic problem so that you can focus your work on specific issues.

RD: I'm not representing even the Air Force on this. I consult for them and SAIC and it's hard to talk about probably the most interesting stuff because it's interesting or classified. So I am presenting this as a private consultant. We need computers to essentially help human analysts and make them more productive, or automate analysis.

??: The government parses the problem and puts out BAAs, etc.

LP: This could take a whole afternoon to answer. They do everything from fundamental basic research all the way to advanced development. It's 50 years of a whole system.

JB: If you play consistently in the DoD arena and you know the people who are interested in the technology, that's how you know where to direct your efforts. It's cultivating contacts and relationships through a long period of time.

HP: I think it's an unfair comparison because DoD has such a long history of developing programs and many of them don't show up as BAAs.

LP: I think one sweeping statement you could make is that DoD controls its space much better than DHS in this way.

??: Also, there's multiple agencies with similar requests.

CC: Is there a science behind this?

??: There's an incredibly byzantine, formal process.

BB: On this one, the example you give is triangulation. What we're finding is using one set of sensors to tip another set of sensors to do something, a tiered process.

JW: Given these various sources of information, if you're asking humans to do the fusion themselves, they're actually quite bad at doing this themselves. It's possible, but it's painful.

SStreltsov: I agree.

RD: Another big question is, this isn't just sensor fusion, it's information fusion. How do you even quantify the intelligence so that you could put it in the same space as the radar data? That's kind of a big question. How do you combine disparate information? Simon has done a lot of work in that area. This process of matching the data to the different targets gets out of control in a hurry.

??: Is there a set of standards somewhere of how to scrub data so that it can be shared? A data analyst just needs representative features, not specific identification. Is there some common set of, scrub it this way, and pass it on?

SStreltsov: No, unfortunately, the way it goes now is that they define an imaginary scenario and create machines to specifically work with this scenario.

MM: There was some effort in the past to map the data through transitions but it was basically found that the data was still attackable (?), that it was almost impossible to make the data impenetrable.

SStr: There is a whole research field on data privacy and it is nowhere near perfected. Feedback comes from real data.

Kevin Johnson

KJ: I come from the naval research lab for the U.S. Navy. We've just started a study with DHS. I could not get a publication release in a timely fashion. My background is as an analytical chemist. Our group has been involved in a few different data fusion related activities. I'm going to talk about the program goals. We're doing a study on next-gen portable detection of explosives that you can imagine all the facets of DHS using. DHS is interested in detecting a wide range of different explosives, and that list is getting longer all the time. This puts a strain on explosives detection technology and leads us toward fused sensor design.

Goals: How do we know a priori that A+B has a chance of giving us a better answer? We hope to develop baseline performance metrics for notational fused baseline systems. We want to know if you went out today and bought sensors and combined them with algorithms, what's the best you could expect it to perform? Where are the gaps? We expect to find this out with data simulation and modeling.

Q for industry: What sorts of data are you comfortable sharing and what needs to be in place for the data to be shared?

Data fusion is not an end in of itself, it's a means to overcome technical challenges. The question is, do I need to do it to overcome performance requirement?

MBS: Are you approaching this problem with scenarios or multiple scenarios? Depending on venue answer could be different.

KJ: Yes and that is a big challenge, there are so many potential contexts. Narrowing it down to portable explosives detection and choosing representative targets helps with that.

MBS: But even that is so broad…

LP: It's checkpoint, aviation and checkpoint, but the application could also be buildings, things like that.

KJ: That's sort of the general outline of what we hope to accomplish. It's a new project. We've done an initial industry survey of cost technology. We found that we see around two dozen point detection portable explosive sensor technologies. Can we represent these classes of compounds with an archetypal sensor? What sort of variation do you see in each sensor type? We are also looking as to what is being developed in the next few years, and looking out that far, we see twice again as many technologies that could easily make it into a portable explosives detection type. We are going the simulation route because we don't want to have to buy every system and test it exactly. At some point the cost-benefit, the problem explodes. You also don't want to be in a position where you're picking two technologies randomly and going, let's try this.

We had a project a while back where we were looking at the damage control side for unmanned places on Navy ships. It becomes a big problem with say, a smoldering fire or pipe rupture. Video cameras were initial option, but you run into viewer fatigue. You have people staring at a screen looking for a rare occurrence. We moved toward autonomous detection, but there were an unacceptably high amount of false positives since a ship is an industrial environment for which commercial algorithms were not designed. We ended up settling on promising sensor subsystems. Even this approach leads to problem because we're still settling on a prototype before we have any idea what it's going to do, and testing is still very expensive. In the end this approach worked very well and we were able to add enhanced capabilities to the system while remaining in acceptable detection/false positive range. So this is a successful fusion story, and it points out that you really have to think about what's going into the system. Obviously for this project to work we need good relationships with industry. To generate simulated data we need to figure out certain parameters for detection systems – detection/false alarm rates under certain contexts, operations parameters, cost tradeoff.

MBS: There's a whole sector of the industry that are not here, there's the sensor developers, such as Lockheed Martin etc, who develop advanced sensors, not advanced algorithms. So you have a subset but not a full representative.

KJ: I am biased toward parallel analysis versus one sensor directing another, because of analysis time and the possibility of the first sensor failing.

CM: Optimal is very important, because you may find some benchmarks are unattainable and you know to strive for the highest that is attainable.

KJ: We don't make devices, we're generally interested in the fundamental and how information is flowing.

CC: What's your IP policy?

CM: It's very flexible, but we cannot enter into non-disclosure agreements with vendors.

KJ: The vendor has to enter into them on my behalf.

SStreltsov: Can you describe more when you talk about testing, are you looking for rare events? Can you use your cameras to collect real-time data?

KJ: One of the philosophical things about a system like that is you need it to be adaptable, learn, and only get smarter. You design a model for your ideal situation in the lab, you put it out in the field, and it generally falls down pretty hard. So that's a difficult problem, and you have to be adaptable and able to learn.

Carey Rappaport

CR: I am going to talk about fusing with regards to mmw radar. Conclusion-established the regime and parameters, etc. Outline of talk. What is the problem domain? Portals. There is 99.997% detection probability. What are the various sensing modalities? Optical imaging to detect suspicious shapes/size, also chemical trace detection and material ID and wave based imaging. Fusion is Necessary-there is no non0invasive sensor capable of unequivocal identification of all concealed threat sin reasonable time. There are limitations on all of the sensor types. Fusion is problematic-more sensors do not guarantee more useful information. Orthogonality of sensor information is worthwhile but only if added information is useful for detection. Additional sensors increase cost. You must be able to justify the higher cost for marginal additional information. Is a higher performance single sensor better than multiple fused sensors. What technologies are possible? I borrowed this from Tim White's slide at ADSA 3. There are a lot of sensors you can use. How about thinking this graphically? You have concealment depth, material id, and shape/size. There is a minimum region of acceptable effectiveness. The desired detection domain would look something like this. (see slide). Optical is not typically good at concealment. Trace chemical id's materials very well. MM-wave is better at concealment but not so good at concealment.

HR: So XBR will give you more depth?

CR: More towards the shape/size. One of the best sensors is the metal detector on all of these axes. What is wrong with mm wave? It has low resolution, no skin penetration, no material id, and it has a heavy computation. You could do simple union of sensor information where, or you could do front end fusion-joint inversion with an initial guess and focus on regions of particular interest. The Test bed we have a t NU. The portal we are developing; we would like to have a complete array enclosure but it is expressive. Our response is shown here on this slide. We take a slide the transmitter is an elliptical array it illuminates a slice of the sample as one moves up and down. Our array of the detectors is on a 90 degree arc. You get a beam illumination of the torso with foreign objects.

CC: Are you building this now?

CR: Yes.

CC: Will people outside have access to the data?

CR: Sure, it is our data. We are very happy that Neurologica donated this wheel. We developed a phantom material that mimics skin so we don't have to worry about human testing. It has similar amount of water as skin. We have a stimulant for explosives. This is a pretty close match; the jury is out as to whether this data is accurate but it isn't far off.

JB: How does it work for x-ray?

CR: I don't know.

JB: I was hoping you were correlating it.

CR: The modeled reconstruction based on our system. Here you see both an innocent example and one with pipes. It very clearly indicates these pipes.

MBS: Carey, you should mention we have the ability to fuse with x-rays.

CR: Here the slices stack up and give you the is-surface of the body. We have extended it to iterative field method (IFM) for high resolution surface imaging. The interesting thing about this is the range resolution is based on bandwidth. The modeling we do gives us a complete view of scattering. Here you can see the reflection off the plate. Without full wave modeling you don't see this rod if you add it to the object. You do need sophisticated modeling tools. Summary of Computational EM Models (slide) Fusion with XBS, why do we bother as they aren't orthogonal? You can find beads and wires as it has high resolution. Also it is fast mm wave advantages is that you get the full 3D shape and can look at thin layers. It is non-ionizing as well. THz, people like it but it is pretty complex. It takes a bunch of sloppy electronics to do the THz.

Eric Miller

ELM: The problem: Remediation-you have subsurface distribution of contaminant saturation. Common structure, everyone is looking at the same scene-this is what I call fusion. I am interested in models that will capture property of the data and the goal is to recover some aspect about the scene. From my experience it is important to be precise about what you want. We don't have much in the way of data. What do we want? Is there a material there? Give a rough characterization. Also you want a detailed image of the scene. Why? Desired info. Should impact the design of the processing and perhaps ….The issue is all about sensitivity. My approximate view of this is you have a finite amount of data. For these ill posed problems if you ask the pixels to describe more and more you diffuse the information in the data across a huge number of systems. We have done scans with dual energy CT reconstruction.

JB: Are you working in the image space?

ELM: We are working in radon. WE want to go back to how we form images. It is not a cheap process. My interest here is understanding info. Content in the data relative to what you want. The Model Based Approach to Fusion (slide) The end result is model based approach leads to variational methods for fusion. Other formulations are possible as well depending on the models. Here is one concrete example I have (see Example slide).

HP: How do you know if it is right?

ELM: This is all simulation? I want to compare this to this which is the truth. How do we know if we are right? We could get model based confidence bounds. Model based stuff is dangerous. So long as the model holds you are okay. We are getting there.

MBS: Have you collected data from the field.

ELM: We are getting there.

CR: Do you use a different model for synthetic data as opposed to the reconstruction?

EM: No, we're committing the inverse crime here. Arrest me.

??: Assuming we are trying to fuse modalities and come up with 2 separate models and 1 joint model, can we tell the joint model is adding information?

EM: Assuming the values are linear, you can look at singular value structure for the separate and joint model, and hopefully you will see an improved value structure.

CC: Nowadays you see the model with the iterative reconstructive process. So what you're saying is push the models further down the chain.

EM: Sure, if you have sufficient data/ground truth you can build all sorts of interesting models based on this. There's a lot of image processing work based on these fancy statistical models.

JBeaty: How many people are in fact considering materials projection within filtered-back or iterative projection?

EM: Anyone who has a dual (?) system is looking as characterization this way. We're interesting in figuring out how you can build models that do a better job estimating photoelectrics.

MM: The machine learning/geometric modeling is very appealing to me. The question becomes, how do you create these models from a data set? Suppose you have many weapons scans, can you build a geometric model for this?

EM: Yes. You can build the average gun and then you can build variations around that. There was a guy who did this with cups and their variations, the fact that cups have two different pieces and the variations in those. With a ton of data about guns, you can take those ideas and map them. Shape statistics stuff is pretty hot these days.

MM: With explosives detection there's additional issues, like how do you include something you're not allowed to include. With a fused system, two issues coming from different vendors… that combine to create a shape that is verboten.

CC: Can you put a homogeneous threat in the simulation?

EM: You can do joint shape texture models, etc… I haven't talked about the detection problem and I don't know how to map image performance to detection performance. David Castanon might, but it's not entirely clear how the hypothesis problem / data testing problem…

Steve Johnson

MBS: When you talk about this Born approximation, it only works for low-contrast features… it's not a very good approximation most of the time.

SJ: Yes… model-based.

MBS: The material characterization is basically the dielectric function and the conductivity. What's the mapping of the threat space in that many different materials have similar epsilon and sigma type characteristics?

SJ: It's a work in progress. Another accepted parameter would be the texture parameter. We'd have to do a statistical reconstruction.

There's no such thing as cancer, period. There's different types of cancer.

RM: Would you give the group the size of the lesions involved?

SJ: About a centimeter.

RM: Is this similar to the Carmano(?) system?

SJ: They don't have an inverse scattering algorithm, we do. Theirs is sparse and ours is dense.

CG: Did you notice any sensitivity to breast density?

SJ: Breasts that are dense tend to have a higher attenuation or speed of sound. The structures and the shapes and sizes are similar to tomography, but the sensitivity and specificity are much higher.

JW: Where did the gold standard come from for these patients?

SJ: The gold standard always ultimately comes from a sample.

JW: How do you know that there are no miss errors?

SJ: The doctor makes that decision. If there's any question, we do a biopsy.

RM: I believe you mentioned that this was in clinical trial.

SJ: At Mayo, UCSD, and (university) in Germany.

QF: What's the smallest size of the lesion on the target?

SJ: We've seen lesions of 3 millimeters.

MBS: So you're going to get a 3-D image of the solid speed, attenuation, and reflection for the radiologist to make diagnostics.

SJ: Yes, and there aren't many radiologists that can do this. We have our medical director training radiologists in this system with a flow chart.

??: How long does the procedure take?

SJ: One scan takes 13 seconds, full procedure takes 13 minutes.

DB: The point is that the inverse scattering algorithm can be applied to millimeter wave scanning for homeland security.

QF: How long will it take for one complete data acquisition for the security scanner?

SJ: 0.1 second if all electronic, with mechanical motors (?) a second or two.

DB: The scanner in the field today takes an image in about one second and has two vertical arrays of antennas. This idea adds two additional arrays and would increase the cost of the scanner by about 50%, take about the same time, and you'd get six additional material properties.

CC: And do you have evidence that this additional field will benefit?

DB: Yes, we've looked at tables of values for the explosives and non-explosives they are vastly different. If we get the funding we would like to do the full simulation of the problem.

HM: Are you going to have a multi (?)

SJ: It does it automatically.

MBS: I think the interaction with our capabilities here, it would be interesting to at least have a conversation about the simulation, the fidelity of the models, the sanity check, etc.

Adaptive Screening

Harry Martz

HM: What would be useful is that my talk sparks discussion, not just me talking here. What I'm going to be talking about is my view of the TSA program. Conclusions: assume that passengers have different a priori probabilities of transporting an explosive. Assume that threats will continue to evolve, increase, thus they may not be equally weighted.

RM: How do they know so they can adapt?

HM: If you look there is evidence that they went after different threat vectors. The terrorists are adapting to the production of explosives such as manufacturing it versus purchasing it.

CC: I think the purpose of the discussion is making the assumptions, how do you make the technology. We don't discuss the specific threats.

HM: If you talk to people in this field the threat is changing constantly.

CR: it will be different.

MBS: We had the shoe explosive attempt then the underwear attempt.

HM: Can we be proactive is the question. The next conclusion is we want to maximize PD and have PFA minimized by taking first two conclusions into account. Maximize performance given limited resources. We need to develop methods to associate risk per passenger, per threat, per time period, adapt screening based on risk, and quantify results of using adaptive screening.

CR: It's also based on the tolerance of the public. Is there a calculus as to how much you will spend based on what the public is willing to tolerate?

HM: I'm not aware of it.

JK: But the privacy concerns does have an impact.

HM: I agree.

CR: There may also be a price attached to this if every citizen had to pay $10k to screen they might be willing to undergo being pat down.

JB: Two mantras are you don't want to interrupt the commerce and the second is the dollars are limited, they have strict bounds.

HM: How many people used to arrive at the airport right before they closed the plane door and now you arrive 2-3 hours ahead of time.

??: People aren't traveling like they used to because of the security procedures in place. You have to take this into account.

HM: That is what DHS wants to do; can we make it better for the traveler with our new procedures.

??: One thing we don't take into account is passenger goodwill in terms of children being patted down. WE have to be aware of the overall conops. We want to enhance goodwill. It is a threat if we ignore it when we roll out new security measures.

DH: Does DHS have a concepts development such as , "What is the airport of 2050 going to look like?

HM: Yes.

DH: In DOE we have our conops tightly linked with acquisition.

HM: You mean from R&D all the way through transition.

DH: The linkage we don't have but we want to have is this.

LP: It is not as tight as your example but it is there.

HM: I think they have it but it isn't as formal.

DH: Another thing you have to do is have authoritative scenarios and you test your equipment against these. You don't get to create your own scenario.

LP: It just isn't as formal

HM: Use of adaptive screening is a policy decision. Policy is outside of scope.

JB: Talking with the customer they talk about risk based profiling.

CC: This is out of scope. It's TSA's or the government's decision to decide.

HP: There is something I can't figure out how to translate. If there are 300 million people in this country and 2 are terrorists. Let's say 3 more come in, so what?

HM: Let's say it's not the numbers you are talking. Let's say the numbers are higher; they are increasing.

HM: I was in a meeting where a colleague said there is no risk, he just wanted to remove all screening. Do you want to have a system like this?

HP: I understand you want to elevate risk.

??: Not everyone has an equal risk of being a terrorist.

RM: From a technical standpoint, the airplanes also have to be considered in this scenario.

HM: But that is out of scope.

??: I have a problem with removing engineers from policy issues.

DS: If I think there is a x2 chance of a person being a terrorist I want him checked x10.

SS: With all this info. how are you going to get it together in real time?

HM: The people in this room are going to make it happen.

Don Kim: If I'm told I'm twice Harry's risk, what would this mean in terms of your system? This is the conversation I want to have.

HM: Recall what Carl said earlier, if these are the pilots who have guns who cares? They could bring down the plane anyways.

HM: You are going to have outliers.

HM: One thing you are alluding to is deterrence. You can only rely on it so much.

MBS: When we talk to people at TSA about adaptive screening what they say is they don't catch terrorists but rather criminals, illegal aliens. As a method of deterrence this was effective even if it didn't deter the terrorists.

HM: But it might when they read about it. Did you get an answer to your question?

DK: I'm not expecting it right away. Our current systems and procedures don't have a PD of 100%.

DH: If you have a 50% chance of being detected this is not a game I would want to play.

JB: This all begins with when you buy a ticket. This type of screening, prior info., can begin weeks ahead of time. When you think of risk screening you start making time connectivity it starts to create a new paradigm.

HM: There use to be a program called CAPS.

??: It all comes down to the Constitution. You can't arbitrarily pull someone over. Just because someone was found guilty of something in the past you can't pull them over its double jeopardy.

HM: It is a complicated space.

Barry Bunin: We do different things on cargo containers depending on where they are coming from.

HM: you can inspect the cargo manifest and they also pull the cargo as well.

BB: Based on the threat levels in effect.

DH: As far as cargo there is no presumption of innocence. If it is cargo they can check it. The volumes are huge.

HM: This is the summary of my talk. Think of what Don is asking, "What can you do differently?"

RB: TSA doesn't want to broadcast the specific threats in effect. Maybe what we can do is come out with a menu that has all these algorithms and PFA, it's up to you what you want to run based on the threat level.

DK: What would the definition of certification should be?

HP: Can a response be binary given additional screening?

CC: Same as in medicine.

HP: I believe it is a continuous scale.

HM: I don't know if we thought of it at that level.

HP: I'm just thinking about instead of a continuous scale but rather a binary scale.

HM: You want to spend time on the risk passengers but you don't want to ignore the non-risk passengers.

HM: Screening Today and Future (Slide)The same screening protocol applied to passengers and divested objects. Future detection requirements- new threats, lower mass, higher PD, lower PFA. There is no silver bullet with technology which will meet future detection requirements. Fusion may solve this problem. Adaptive screening is a type of fusion. What is adaptive screening? Flexibility to optimize screening based on external triggers including dynamically selecting screening procedures and dynamically configure scanners to engage specific scan parameters or detection algorithms.

HM: I know TSA holds very tightly what they do or don't do, which is appropriate, but these are things they could do.

MF: You can do adaptive screening based on behavioral checks.

HM: But you will have some people who are just nervous flying. That is a risk. But is it a bigger risk than we are seeing today?

XF: You're talking about using some sort of expert, high-level decision making system. I think this adaptive screening is possible.

QF: The machine should respond to the different skill level of the screeners .

HM: Is the human part of technology? Whether they are or not, they're very important and we should be utilizing that.

MF: How do you account for the fact that it will become known what your profile is? So if grandmothers with grandchildren are passed through…

HM: So if you do it randomly, you can say, grandmothers are picked less, but there is a potential risk. Once they figure out what you're going to do, they adapt to do something different and they do it quickly.

CB: Yeah, but you don't want N vendors with M knobs to come up with stuff independently. Mission-based planning has got to come out of TSA.

HP: It's not clear that there's an analog on the security side from the medical side.

HM: But there's no reason there couldn't be.

JW: But it's hard to establish ground truth on the security side.

HP: But a lot of that got overthrown because the science didn't support the claims they were making.

DC: It can be done and it has been done in some other objects, but it has to be done carefully to ensure that you cover the potential traces throughout.

??: There also has to be a clear system effectiveness threshold.

<u>Jeremy Wolfe</u>

CC: Is there a way to learn contour completion from humans and take them back to computers?

JW: Well, we've been working on that for a generation. I gather edge completion algorithms are better than when I was in graduate school, and I can describe to you what we do, but nobody knows how we do it. If we go back to the pet CT example, what humans are built to do is allow the color fill into the region confined by the luminescence border it defines.

MBS: Is there a minimum level of shadowing where the human will complete the contour?

JW: The human system is always looking for information that supports the presence of a contour. They are constrained; they want a single inflection, not a double inflection. We think they are sensitive to the rules of contours in the real world. So I can tell you what humans are good at and there are plenty of people who are working to integrate human and computer vision… neuromorphic engineering.

HM: Could you give a simple example of how these strengths could be transferred into an algorithm?

JW: Stereo algorithms. I can't say I know what the state of the art is, but it's like… how do you match up the image in one eye to the image in another eye? So it's pretty clear that humans do a multi-scale analysis of this and do their first pass on lining up the big blobs, then work their way up the pyramid to a finer and finer resolution, and stereo algorithms have incorporated this.

HM: The old example is, how do you find edges in a noisy image? (Gaussian example).

JW: People are good at object recognition with remarkably little information, 13 milliseconds of time.

EM: Are there any people that have this ability, like savants who can do more, that have been FMRIed?

JW: Not of which I am aware.

??: Can you modify the reward structure to mitigate this?

JW: Yes, but not entirely.

MBS: What about the influence of something like hypnosis? You can hypnotize a person and affect their visual system pretty dramatically, I think.

JW: I have never seen evidence that you can basically bypass or expand one of these through hypnosis. I also don't know that anyone's ever tried to beat this with hypnosis.

Next Steps

Harry Martz

HM: There is so little peer review it would be useful to have some discussion in classified briefs.

MBS: Harry, what if we change it from classified to SSI briefing?

HM: That is the next level. It does take money. Predictive study of performance-would it be useful to do this? Develop simulation capability-this may help. Fused systems-spec systems to fuse with existing technologies. Develop simulation capability.

HM: MMW Investigations-optimize frequency. I've seen a lot in this business you go down a path but after doing that you would have done it a different way. Depth info to ATR. Increase solid angle. New/more sensor for specific threats and locations.

LP: You touched upon the lessons learned. I'm not sure for some fields do they publish what doesn't work. The flip side is when you don't have unlimited money there is some use to knowing what didn't work.

DAC: Reaction to previous slides. What is the spectrum of cases I'm worried about with current technologies. The real value of fusion at some point is what are you looking for. It's awfully tough to talk about it in a vacuum and currently a lot of discussion about fusion is in the vacuum.

MBS: The tradeoff between SSI and classified, at the SSI level can you get enough information at the SSI level? If so we should think about having the next meeting at the SSI level.

HM: You could but then you have the issue of making sure you don't go over the fine line.

MBS: You would have to have a moderator.

HM: I thought we could have an SSI meeting with vendors

DAC: We did with ________

HM: Would you be willing to have it with AIT?

HM: My understanding is any data from deployed equipment is SSI.

AH: It's my understanding that data from very obese people creating noise, that isn't SSI.

CC: To say you are having a vulnerability, isn't saying it's a weakness.

AH: How do you categorize the Sandia coupon codes?

HM: That's complicated.

JB: We ended up creating a body of data which is a simulation of what might be found coming through an airport. To highly document it, it became the body of data used in the segmentation challenge. This is a question of where the real problem is. We are spending a great deal of money if this little discussion is saying it is wrong.

MBS: Going back to the segmentation challenge you have a CT oriented machine representing all the scanning strategies and then you have additional parameters in terms of dual energy to enhance them. I don't know if there is that kind of baseline standard. If we tried to create this would this be of use as the segmentation challenge? I don't know, maybe the Sandia work is the beginning to this. This would be informative perhaps.

HM: That is an interesting idea. Sandia could say here is the data we've created.

HP: Isn't that the idea of the Sandia work?

HM: Yes. Would it be useful, for the next step, for Sandia, in an SSI setting, present some of the data and analysis. Basically it is a case study. Perhaps they were not ask to conceal the data but instead to collect it. We could have some discussion from vendors.

MBS: ALERT is the gateway for this data.

JB: For two of the three datasets.

CR: So we want U.S. best, not the world's best?

MBS: No, you can have foreign in SSI.

HM: If we had this kind of discussion including peer review it would take this work to the next level.

MBS: We could have the meeting at the new Burlington Facility. We would have to arrange transportation. I'm curious from TSA representation, does this sound like a viable strategy?

DK: Moving to an SSI discussion? Yes, I think this would be beneficial. Classified would be even better but this would reduce participation.

HM: DHS Recommendation-studies of performance, simulation capability including standard mathematical phantoms, review other DHS and DoD positive and negative examples of fusion (like Laura said). Finding out why something doesn't work is almost as important as to figuring out how to make it work.

MBS: The students who are present should be aware of the importance of documenting why something doesn't work. This is a valid type of work.

HM: Also we need to understand the DoD model of funding and adapt what applies to DHS and educate as needed. We also need to adapt a language for fusion.

HM: Testing Recommendation-allowing testing of systems that will not pass complete tests. Allow virtual combinations for said systems. Also assess impact of present tests on ability to predict fused performance.

CC: I did hear there is a danger of people doing regression analysis on this.

HM: So you change the test.

HM: TSA Recommendations-change procedures to allow procurement, deployment, operation and maintenance of fused systems both in separate boxes and from separate vendors. Test and deploy DICOS-modify as necessary to support fusion and be adaptive in the field. To adopt plug and play would help operation in the field. It seems easier for the terrorist, how can we change this?

<u>Overall Recommendations</u>

HM: Vendors ID the "Go To" person. Next recommendation is address the IP issues up front and not one off to enable technical people to deal with the technical problem.

EB: WE have a whole new team at the University trying to recognize and address these issues makes sense. It makes sense to adopt the Stanford Model (10% VC costs paid by the University). Stanford has spun off a lot of companies.

HM: Next we need more students to attend and participate in the workshops. Would any of the students like to say anything?

LE: Yes, it has been useful. From the talks we've been getting ideas. Mostly from the more technical talks but even from the broader view. In our labs we don't get this point of view. Also, we get to know people at the companies.

HM: And the National Labs.

SM: This workshop helps how my work fits into the overall, bigger picture.

HM: What would you like to see change?

CR: One problem is Carl wanted to keep attendance down to a reasonable level.

CC: That was not the intention; students get a free pass.

HM: Would it be of value to have more students come with new thoughts and new people.

LE: I think in this forum students might not be comfortable speaking. If it was in smaller breakout groups which reconvened it might be successful.

HP: In IEEE there is an emphasis on getting more students come to conferences, they are having experts come and talk and it has been pretty successful.

CC: Thanks everyone for attending.

LP: A few comments from the DHS perspective. ALERT COE doesn't get a big percentage of funding but the impact we get is large. Creating a venue such as this is very useful with third party groups included. Another comment from my perspective, I'm always trying to facilitate COEs and keep this going. Please contact me if you have questions or concerns. I wanted to thank Michael and Carl and their staff for their work. I think Michael and I will have further discussions about how to incorporate the idea of an SSI discussion.

MBS: I want to echo what Carl and Laura said. It's a real collaboration between DHS S&T and ALERT and Carl. It's gratifying to me to see how this is evolving and we want it to nurture and grow. The next conference will be in the early May timeframe. I want to thank you all and have a safe trip home.

16. Appendix: Presentations

This section contains the slides presented by speakers at the workshop. The slides appear in the order that talks were given as shown on the agenda. ALERT has redacted or edited some of the presentation slides to ensure their suitability for public distribution.

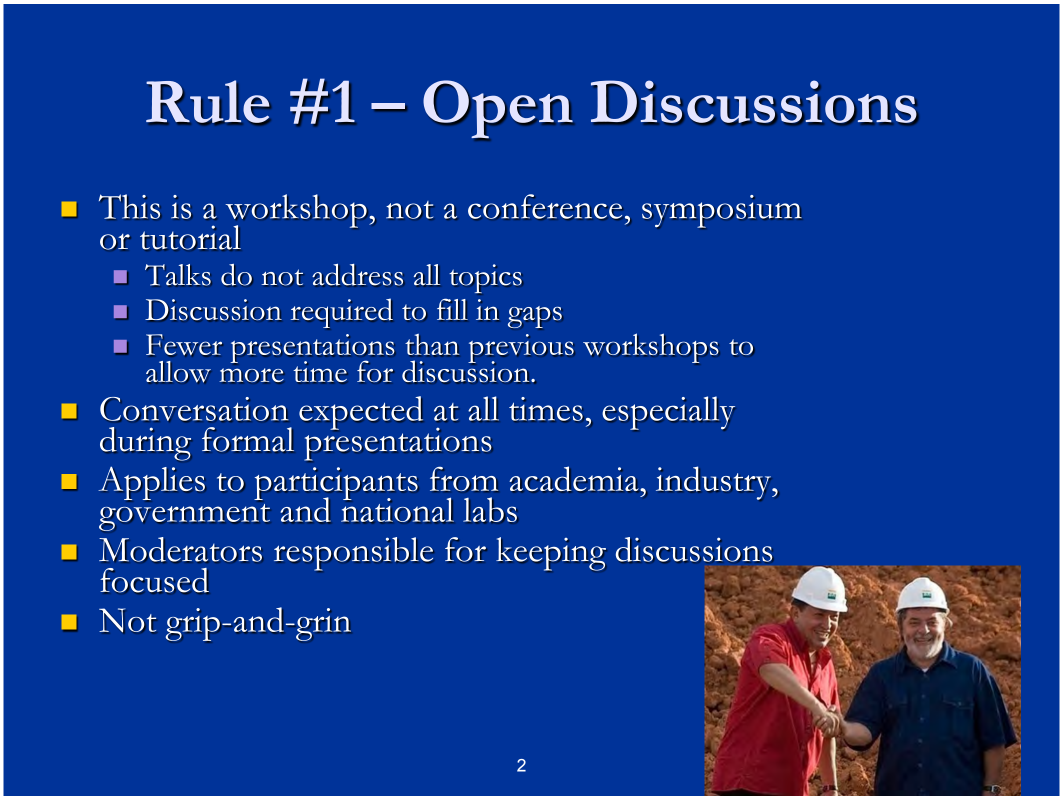
16.1 Carl Crawford: Call to Order

Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with Specific Application to Advanced Imaging Technology

Call To Order
Day 1

Carl R. Crawford
Csuptwo, LLC



Rule #1 – Open Discussions

- This is a workshop, not a conference, symposium or tutorial
    - Talks do not address all topics
    - Discussion required to fill in gaps
    - Fewer presentations than previous workshops to allow more time for discussion.
- Conversation expected at all times, especially during formal presentations
- Applies to participants from academia, industry, government and national labs
- Moderators responsible for keeping discussions focused
- Not grip-and-grin

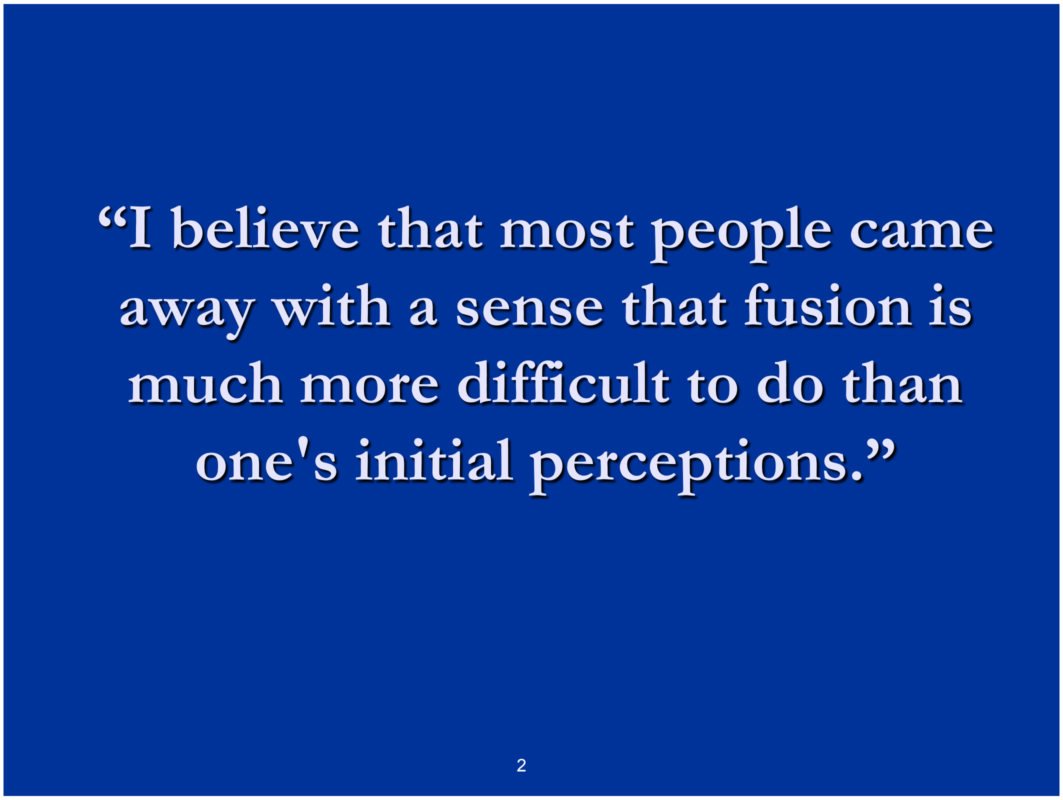
16.2 Carl Crawford: Workshop Objectives and ADSA06 Review

Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with Specific Application to Advanced Imaging Technology

Workshop Objectives
ADSA05 Review

Carl R. Crawford
Csuptwo, LLC



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

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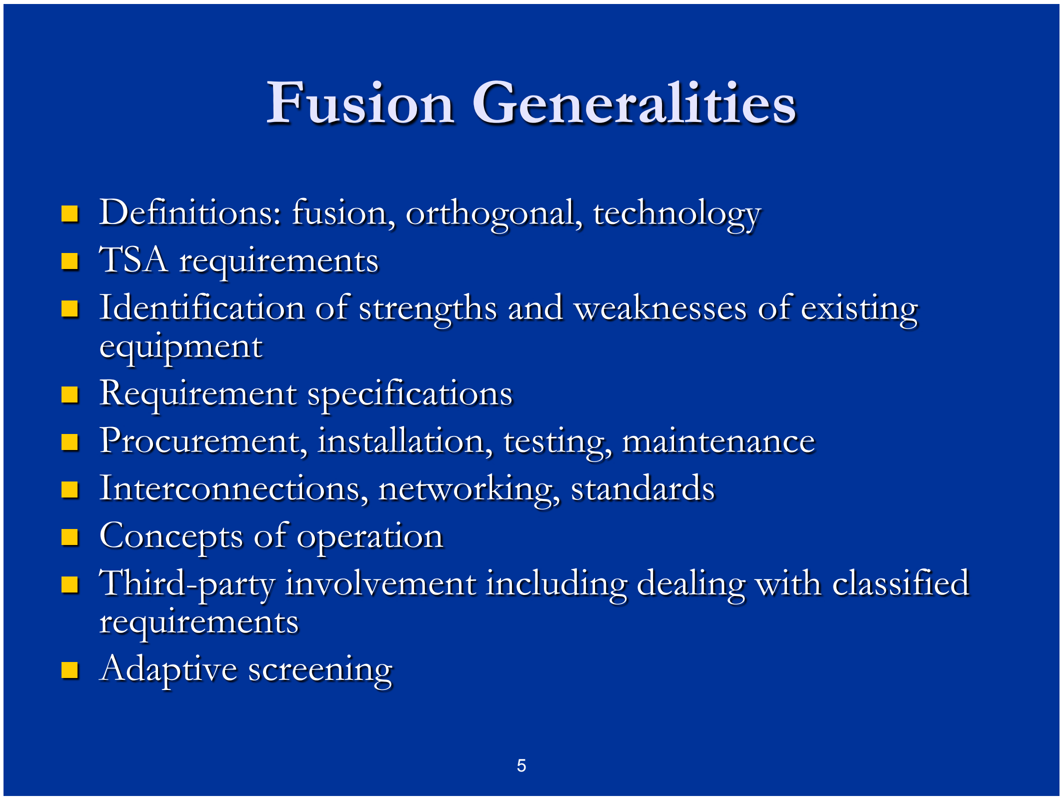
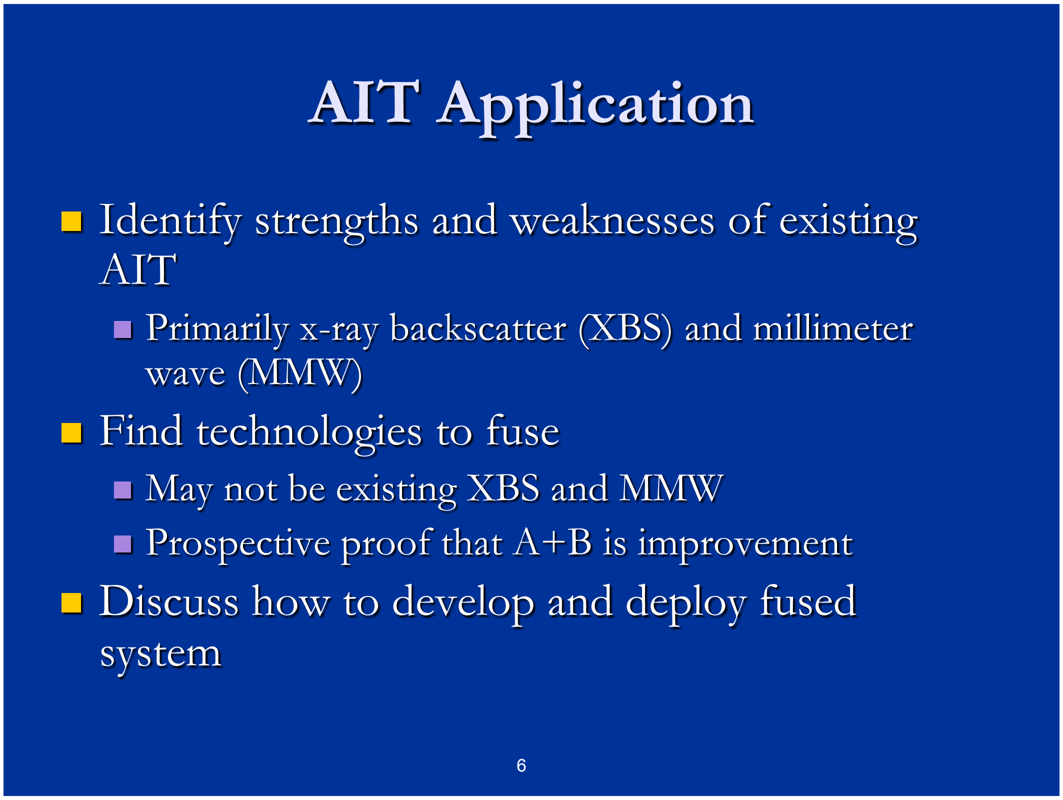
ADSA06 Objectives

- Address the generalities of fusing systems
- Specific application to AIT (Advanced Imaging Technology), which is personnel screening/imaging
- Discuss how to develop technologies when they are fused you know that better performance will be obtained
- Involve third parties in the development of and fusing new technologies



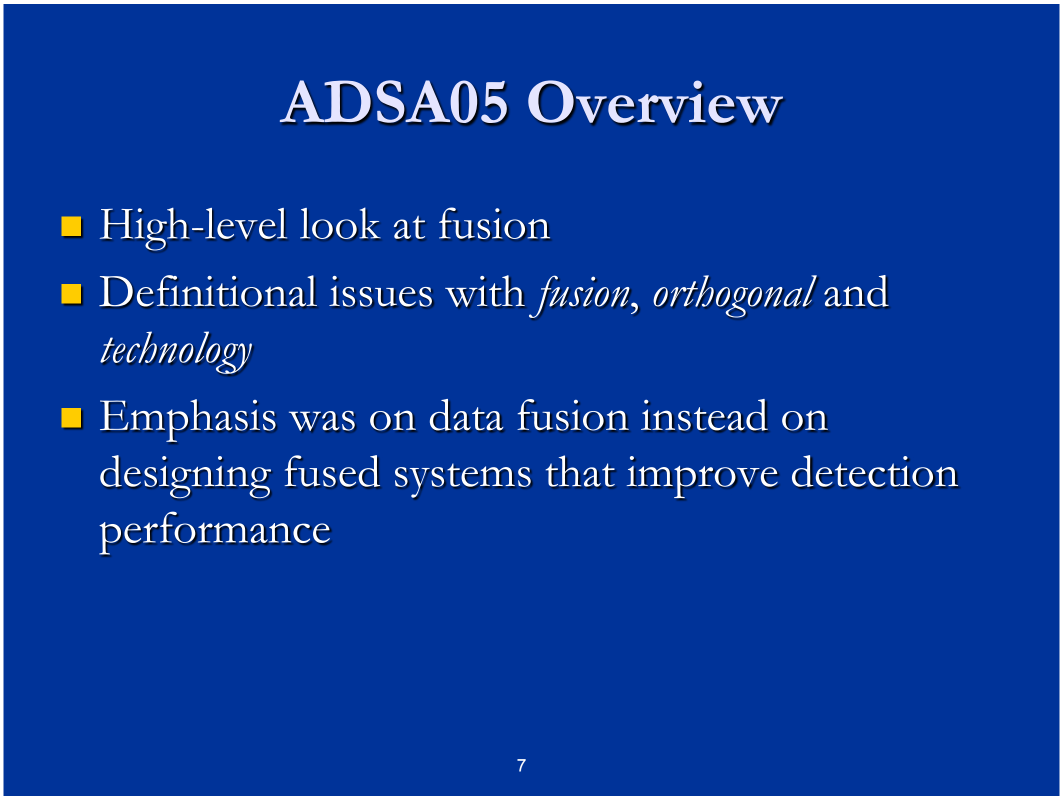
Fusion Generalities

- Definitions: fusion, orthogonal, technology
- TSA requirements
- Identification of strengths and weaknesses of existing equipment
- Requirement specifications
- Procurement, installation, testing, maintenance
- Interconnections, networking, standards
- Concepts of operation
- Third-party involvement including dealing with classified requirements
- Adaptive screening



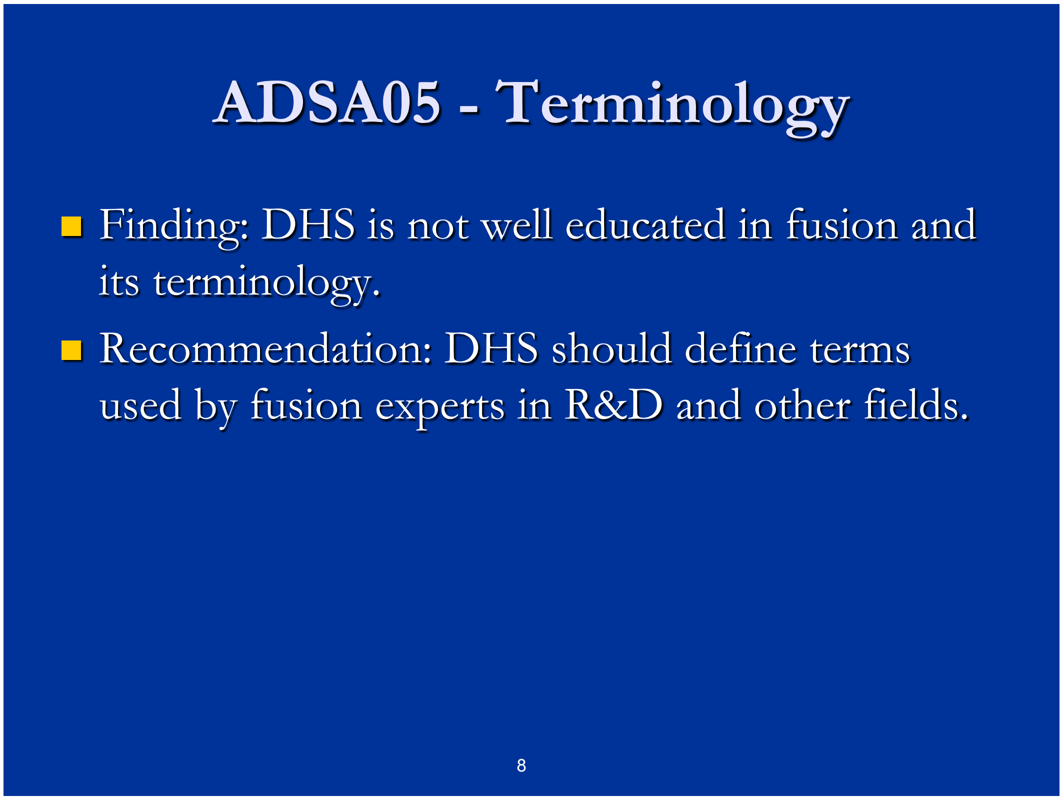
AIT Application

- Identify strengths and weaknesses of existing AIT
  - Primarily x-ray backscatter (XBS) and millimeter wave (MMW)
- Find technologies to fuse
  - May not be existing XBS and MMW
  - Prospective proof that A+B is improvement
- Discuss how to develop and deploy fused system



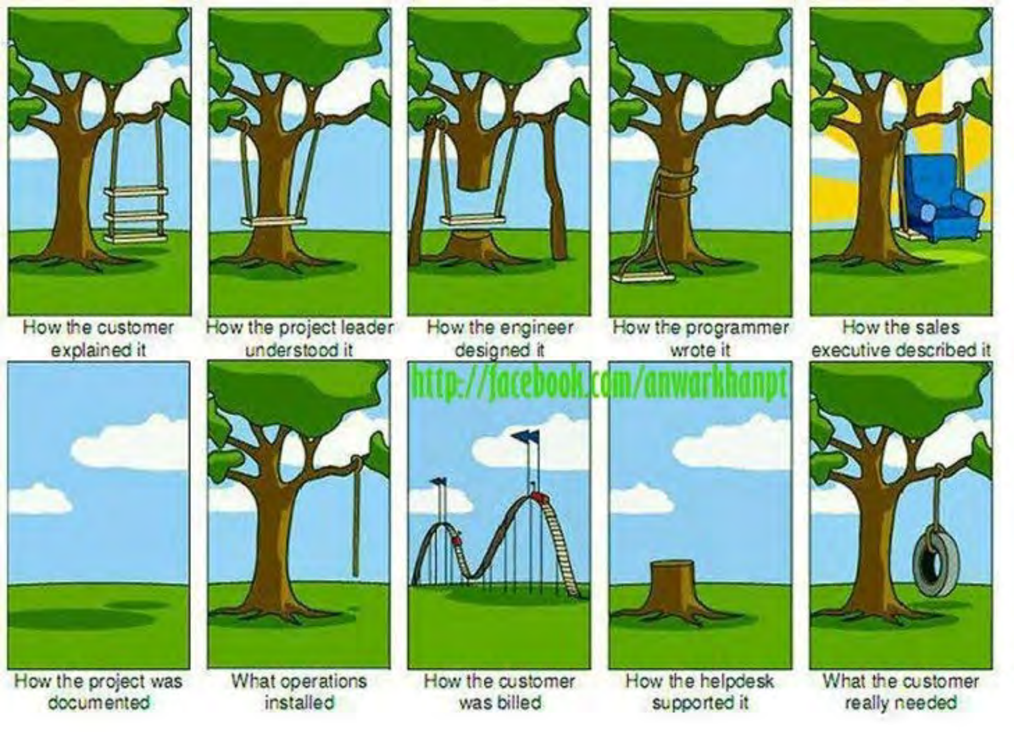
ADSA05 Overview

- High-level look at fusion
- Definitional issues with *fusion*, *orthogonal* and *technology*
- Emphasis was on data fusion instead on designing fused systems that improve detection performance



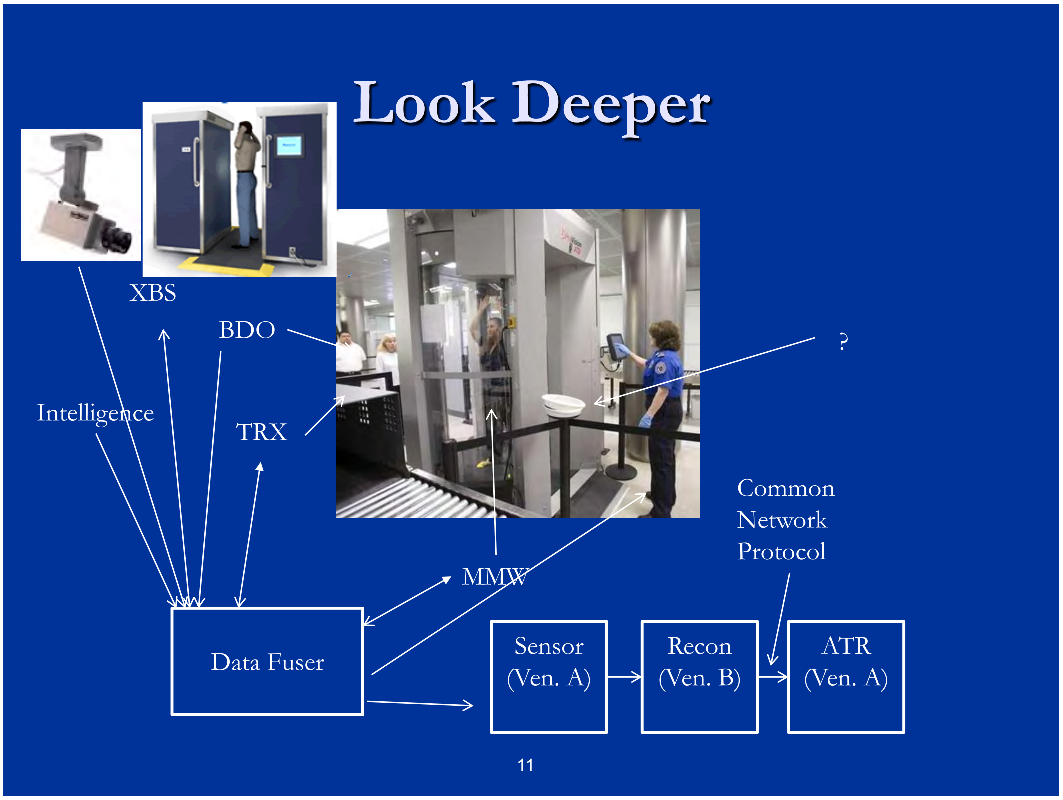
ADSA05 - Terminology

- 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.



Is this fusion?

Appears to be layered solution.



Look Deeper

XBS

BDO

Intelligence

TRX

?

Common
Network
Protocol

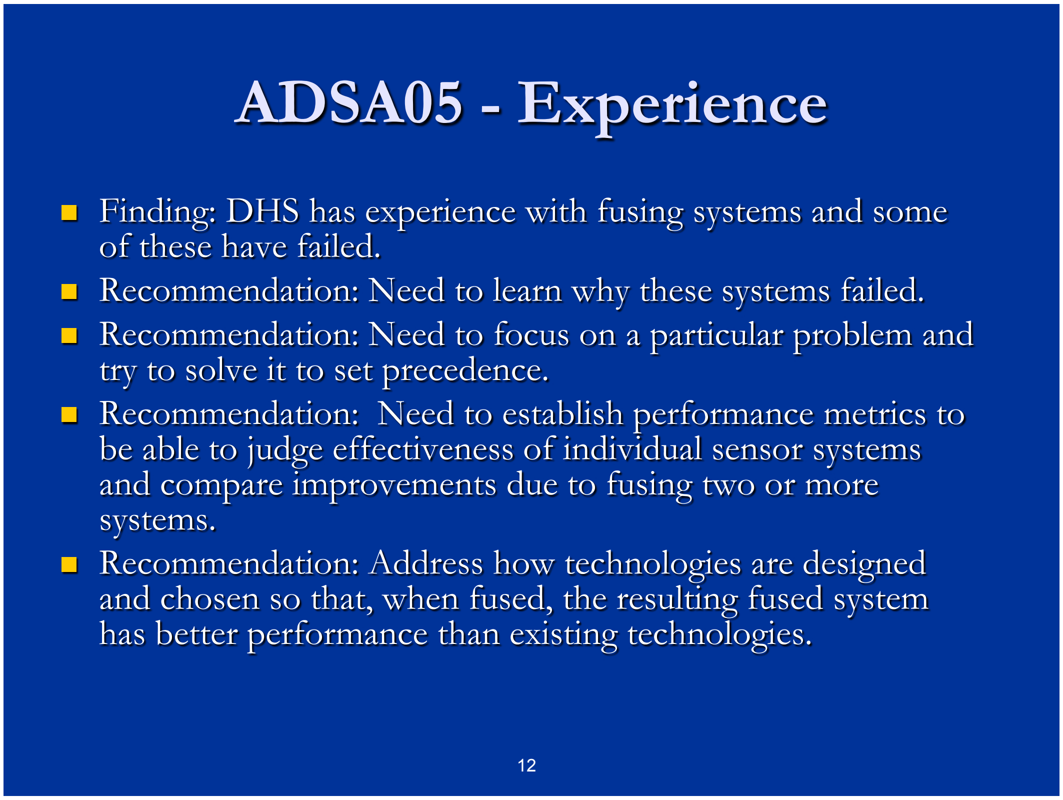
MMW

Data Fuser

Sensor
(Ven. A)

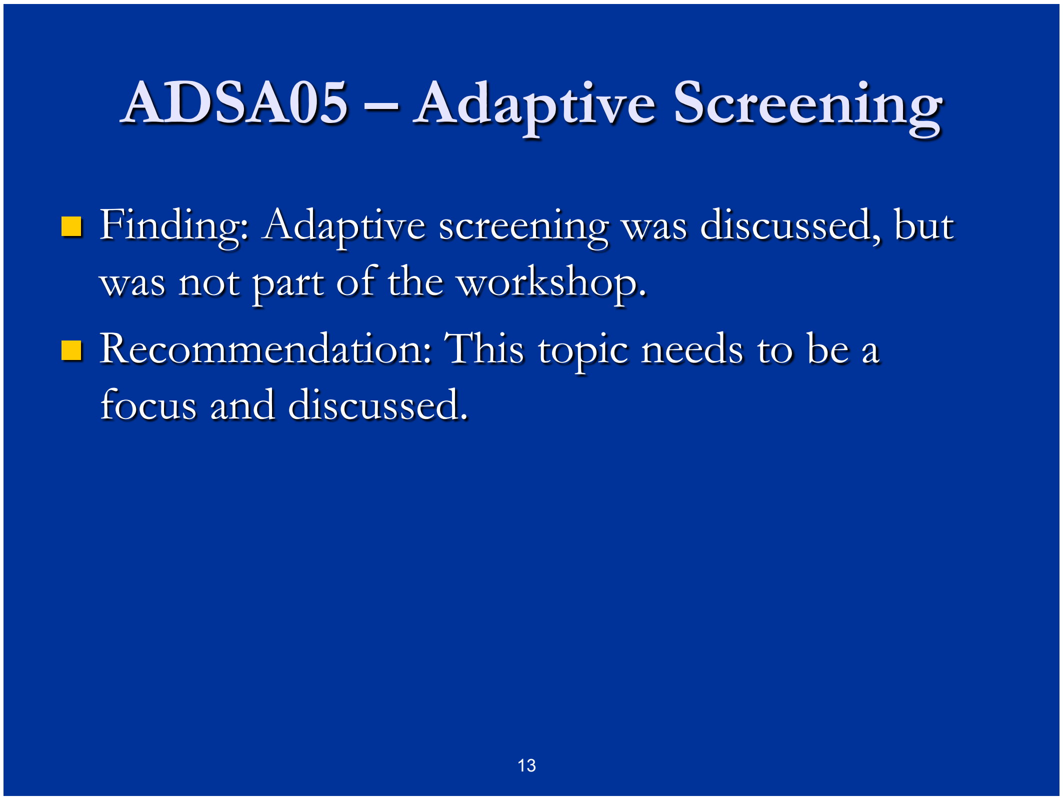
Recon
(Ven. B)

ATR
(Ven. A)



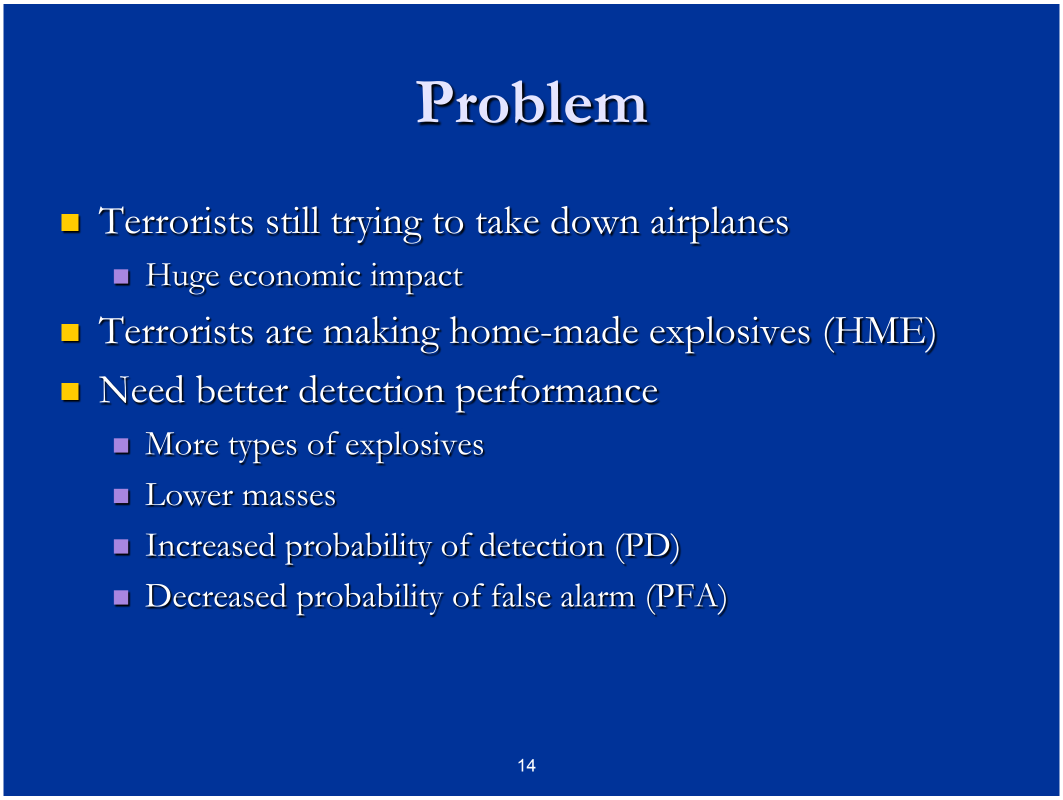
ADSA05 - Experience

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



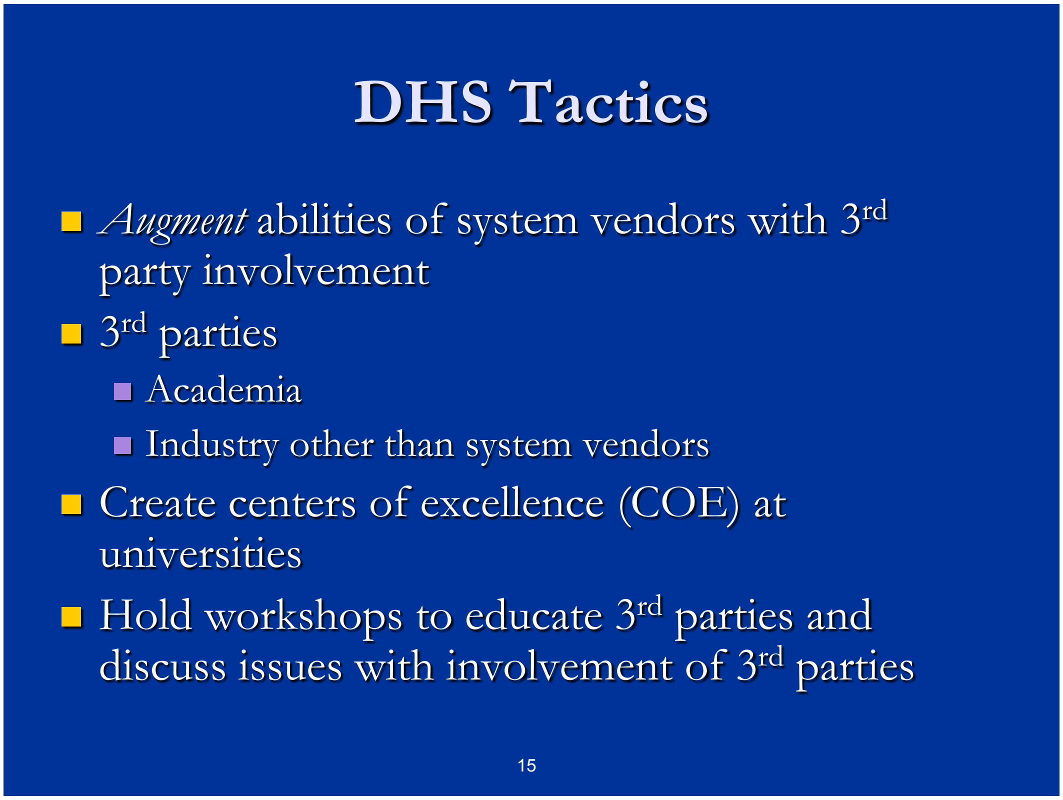
ADSA05 – Adaptive Screening

- Finding: Adaptive screening was discussed, but was not part of the workshop.
- Recommendation: This topic needs to be a focus and discussed.



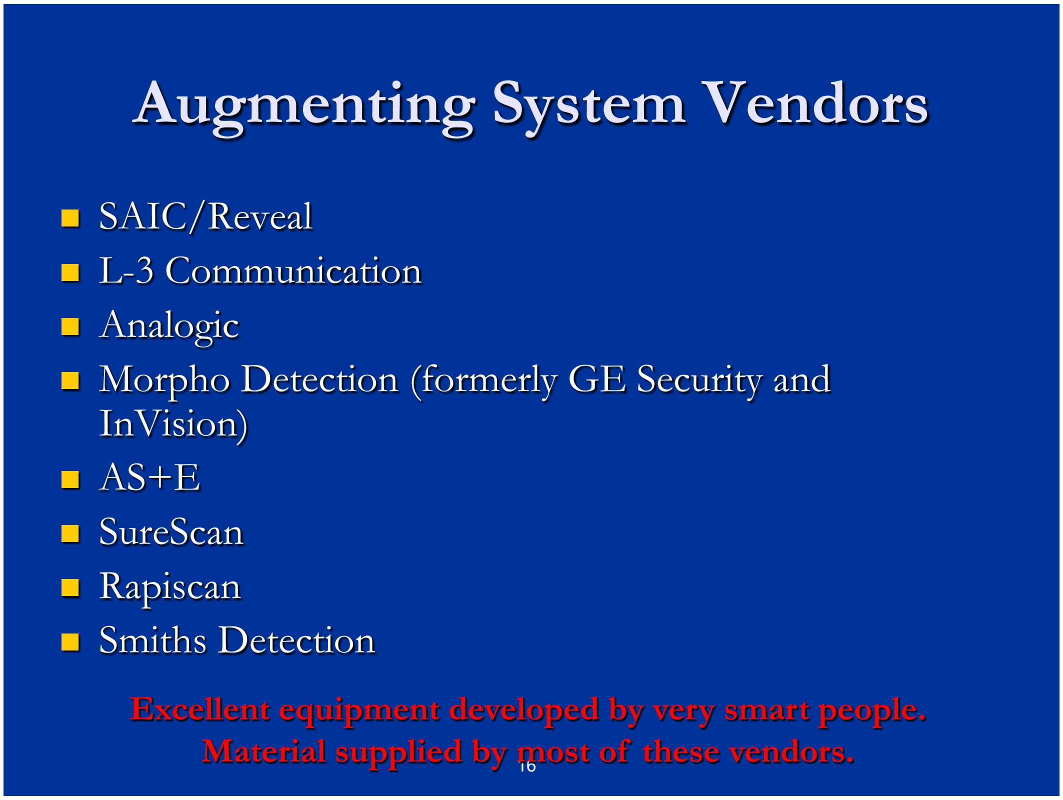
Problem

- 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)



DHS Tactics

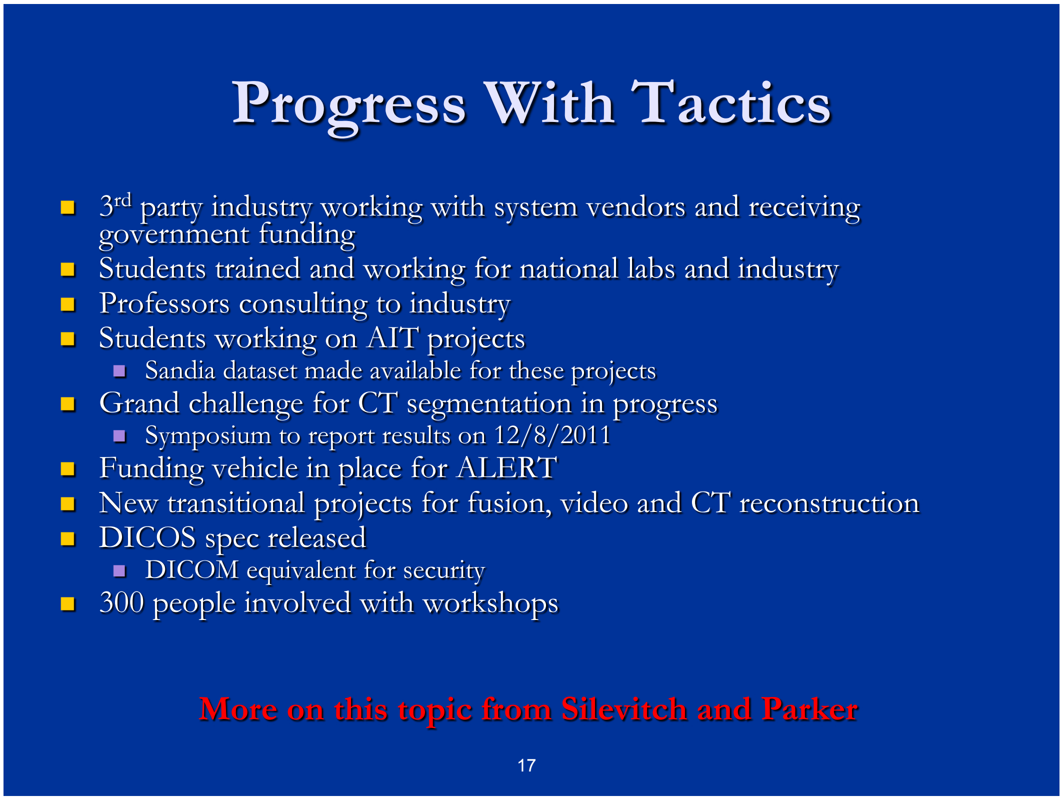
- *Augment* abilities of system vendors with 3rd party involvement
- 3rd parties
  - Academia
  - Industry other than system vendors
- Create centers of excellence (COE) at universities
- Hold workshops to educate 3rd parties and discuss issues with involvement of 3rd parties



Augmenting System Vendors

- SAIC/Reveal
- L-3 Communication
- Analogic
- Morpho Detection (formerly GE Security and InVision)
- AS+E
- SureScan
- Rapiscan
- Smiths Detection

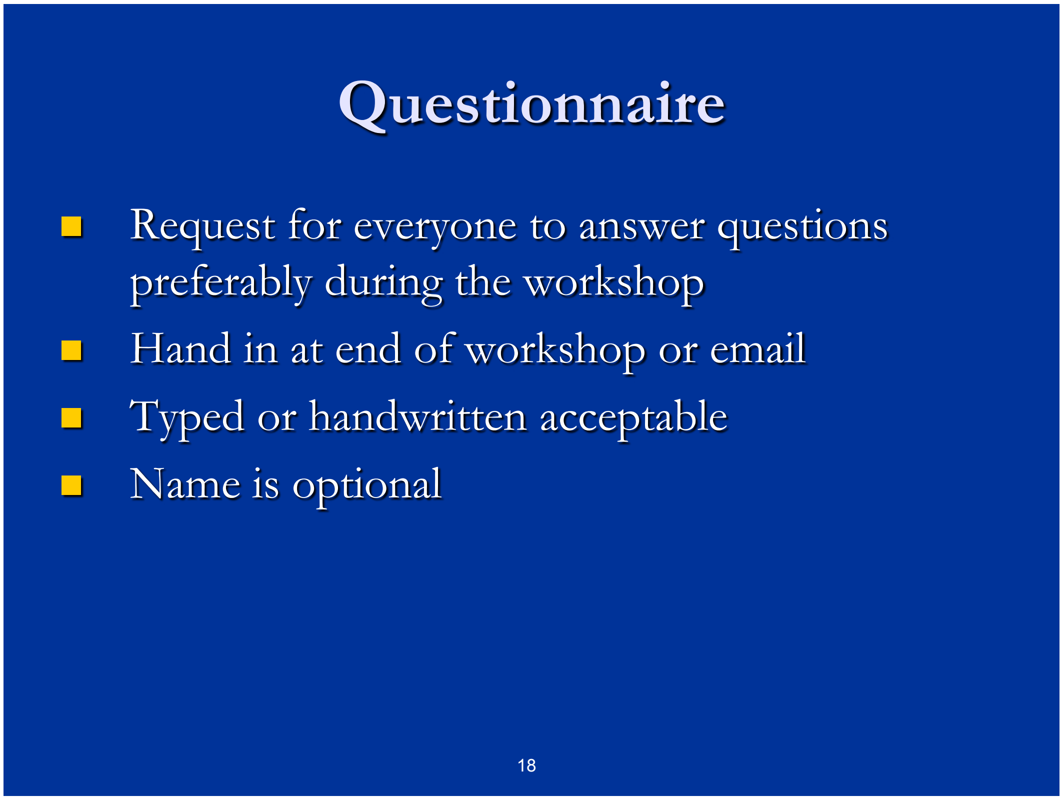
Excellent equipment developed by very smart people.
Material supplied by most of these vendors.



Progress With Tactics

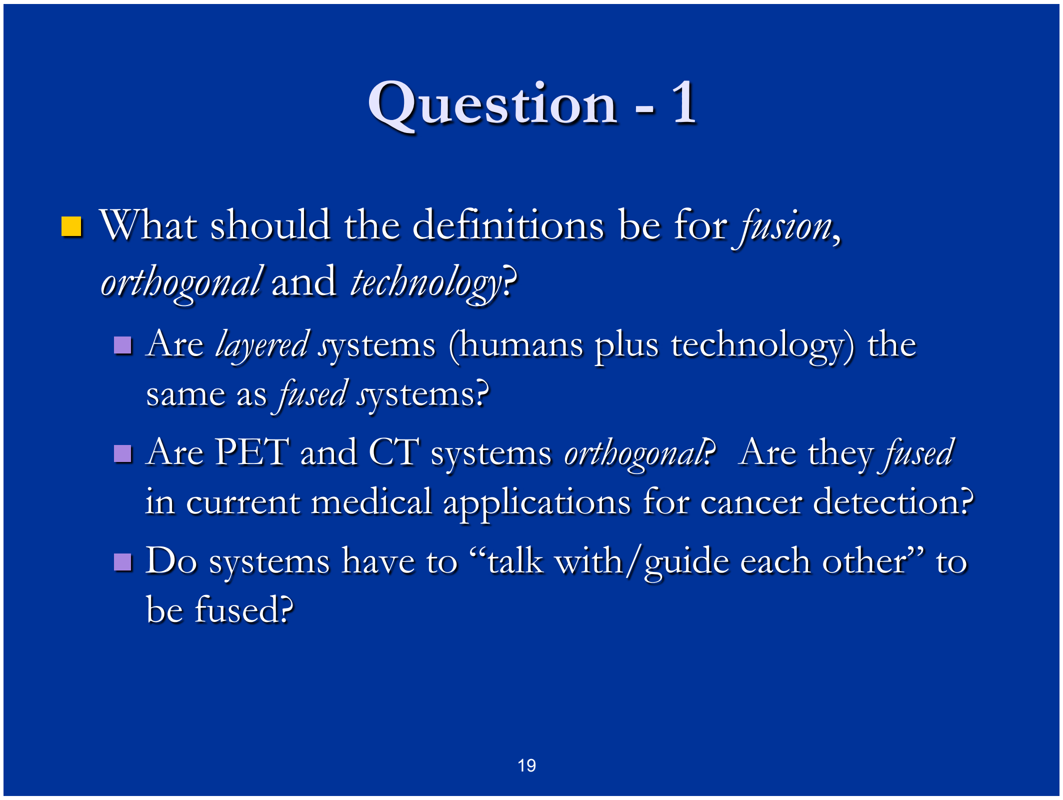
- 3rd party industry working with system vendors and receiving government funding
- Students trained and working for national labs and industry
- Professors consulting to industry
- Students working on AIT projects
  - Sandia dataset made available for these projects
- Grand challenge for CT segmentation in progress
  - Symposium to report results on 12/8/2011
- Funding vehicle in place for ALERT
- New transitional projects for fusion, video and CT reconstruction
- DICOS spec released
  - DICOM equivalent for security
- 300 people involved with workshops

More on this topic from Silevitch and Parker



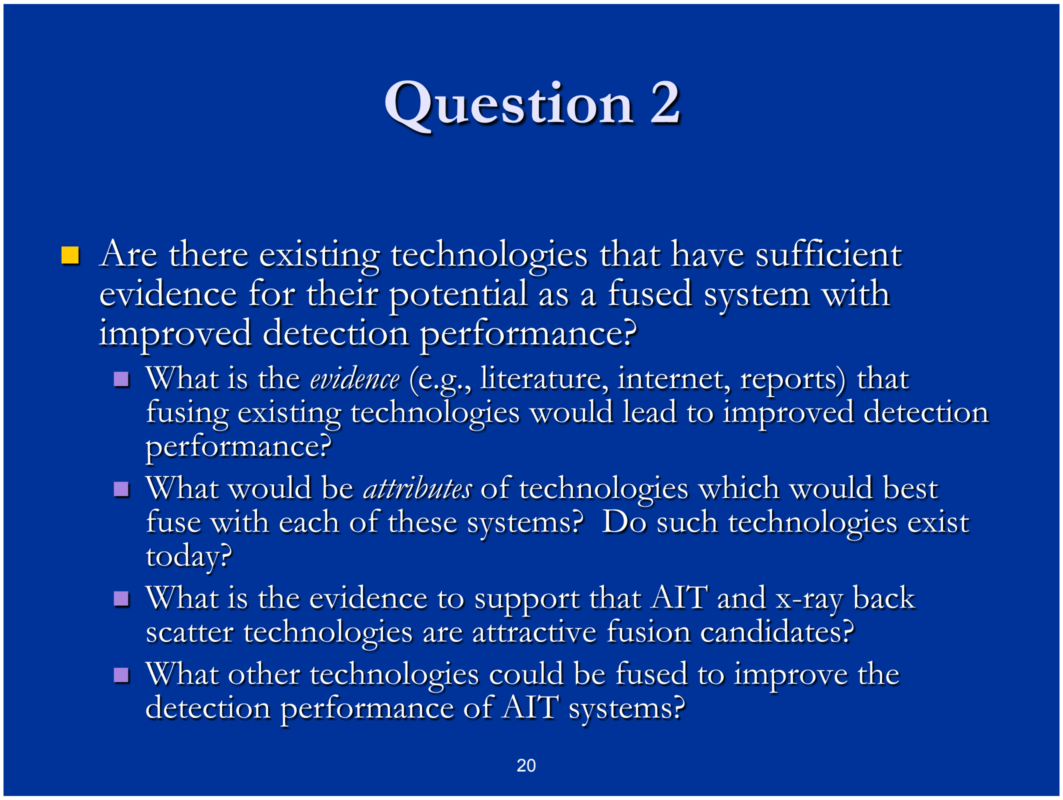
Questionnaire

- 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



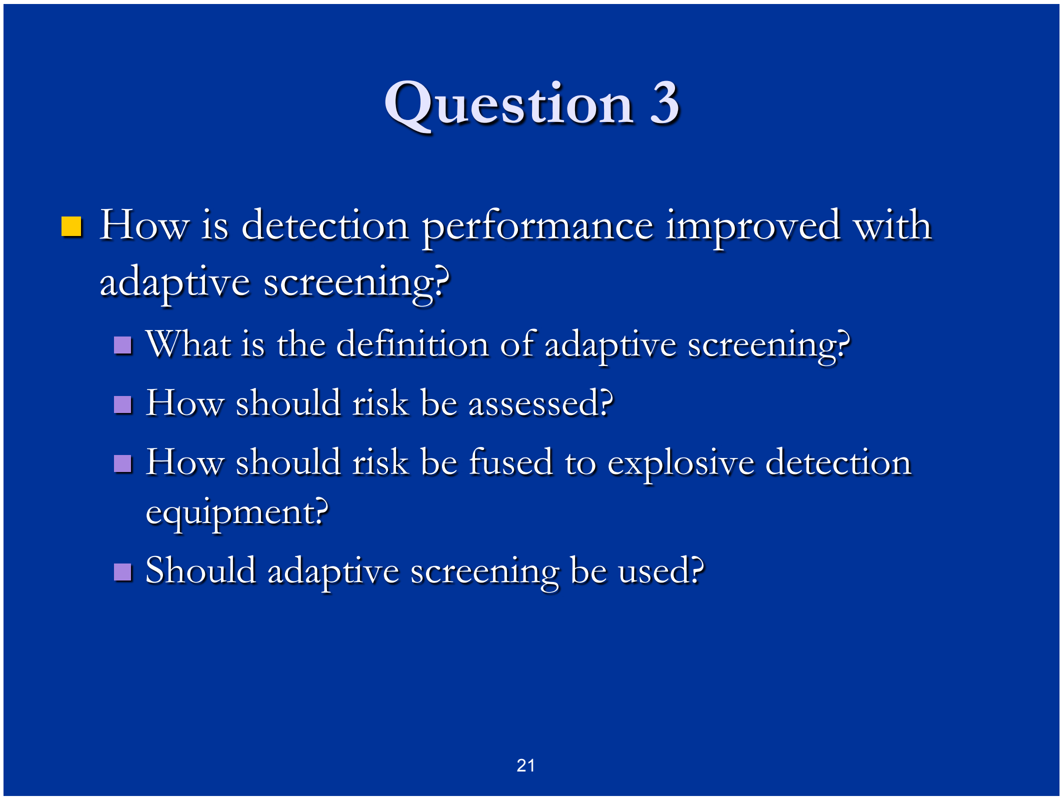
Question - 1

- What should the definitions be for *fusion*, *orthogonal* and *technology*?
  - Are *layered* systems (humans plus technology) the same as *fused* systems?
  - Are PET and CT systems *orthogonal*? Are they *fused* in current medical applications for cancer detection?
  - Do systems have to "talk with/guide each other" to be fused?



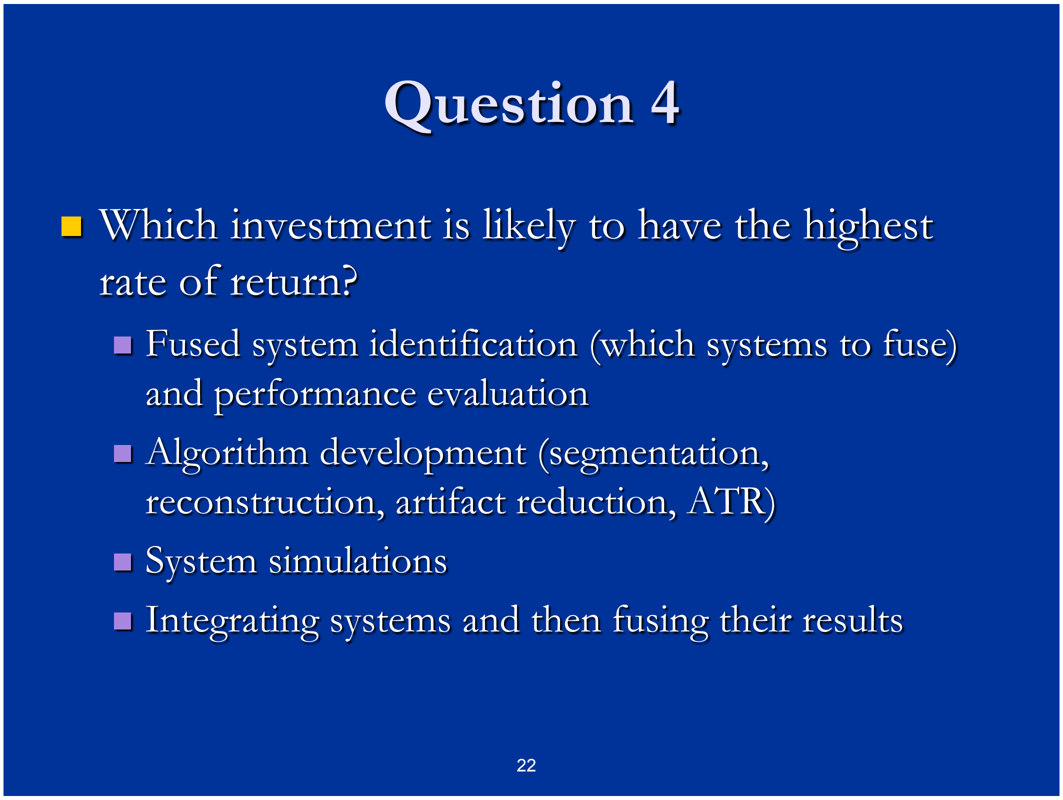
Question 2

- Are there existing technologies that have sufficient evidence for their potential as a fused system with improved detection performance?
  - What is the *evidence* (e.g., literature, internet, reports) that fusing existing technologies would lead to improved detection performance?
  - What would be *attributes* of technologies which would best fuse with each of these systems? Do such technologies exist today?
  - What is the evidence to support that AIT and x-ray back scatter technologies are attractive fusion candidates?
  - What other technologies could be fused to improve the detection performance of AIT systems?



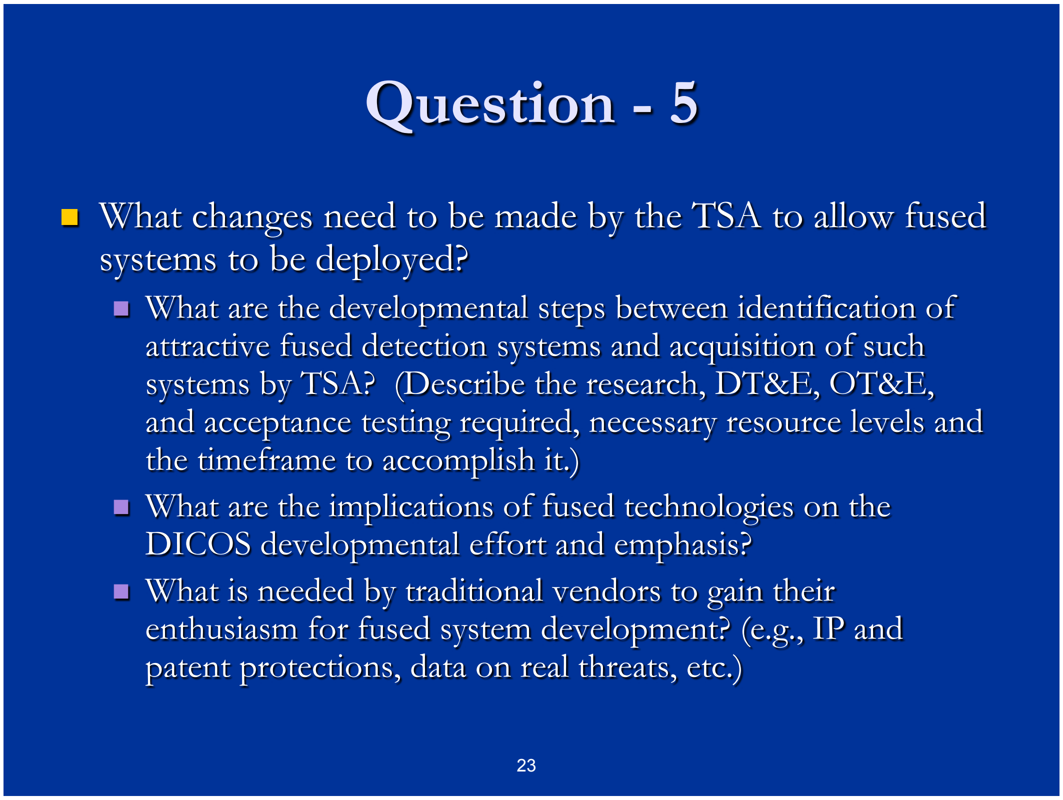
Question 3

- How is detection performance improved with adaptive screening?
  - What is the definition of adaptive screening?
  - How should risk be assessed?
  - How should risk be fused to explosive detection equipment?
  - Should adaptive screening be used?



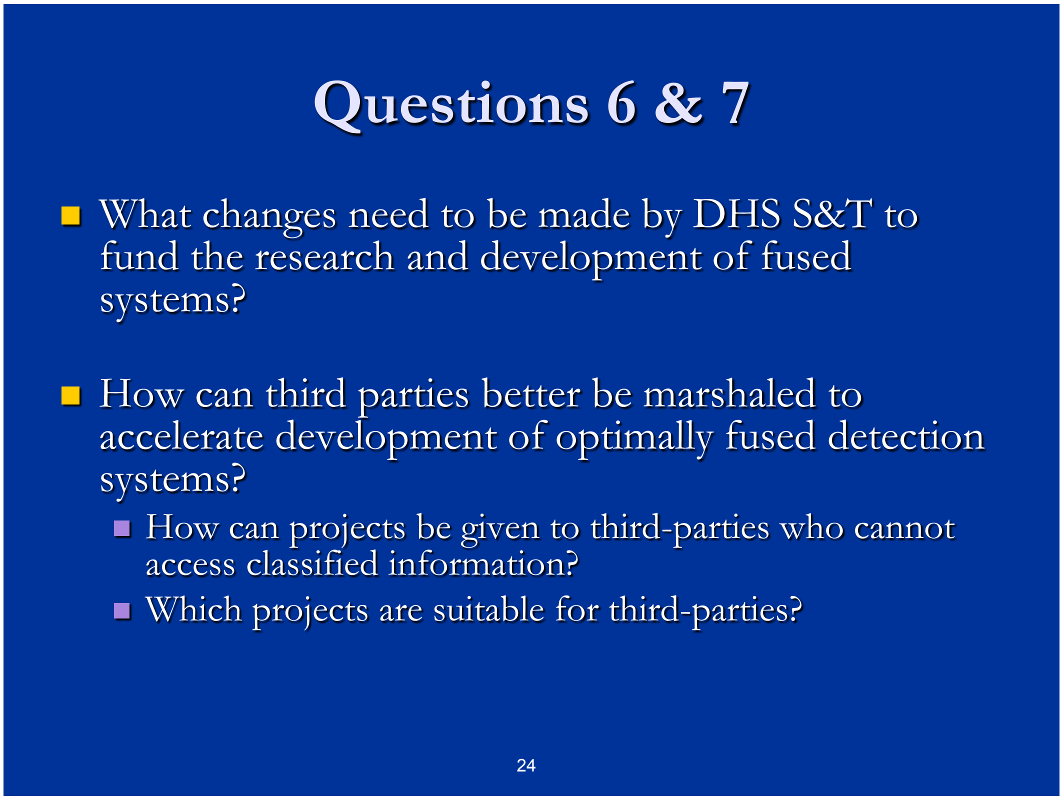
Question 4

- Which investment is likely to have the highest rate of return?
  - Fused system identification (which systems to fuse) and performance evaluation
  - Algorithm development (segmentation, reconstruction, artifact reduction, ATR)
  - System simulations
  - Integrating systems and then fusing their results



Question - 5

- What changes need to be made by the TSA to allow fused systems to be deployed?
  - What are the developmental steps between identification of attractive fused detection systems and acquisition of such systems by TSA? (Describe the research, DT&E, OT&E, and acceptance testing required, necessary resource levels and the timeframe to accomplish it.)
  - What are the implications of fused technologies on the DICOS developmental effort and emphasis?
  - What is needed by traditional vendors to gain their enthusiasm for fused system development? (e.g., IP and patent protections, data on real threats, etc.)

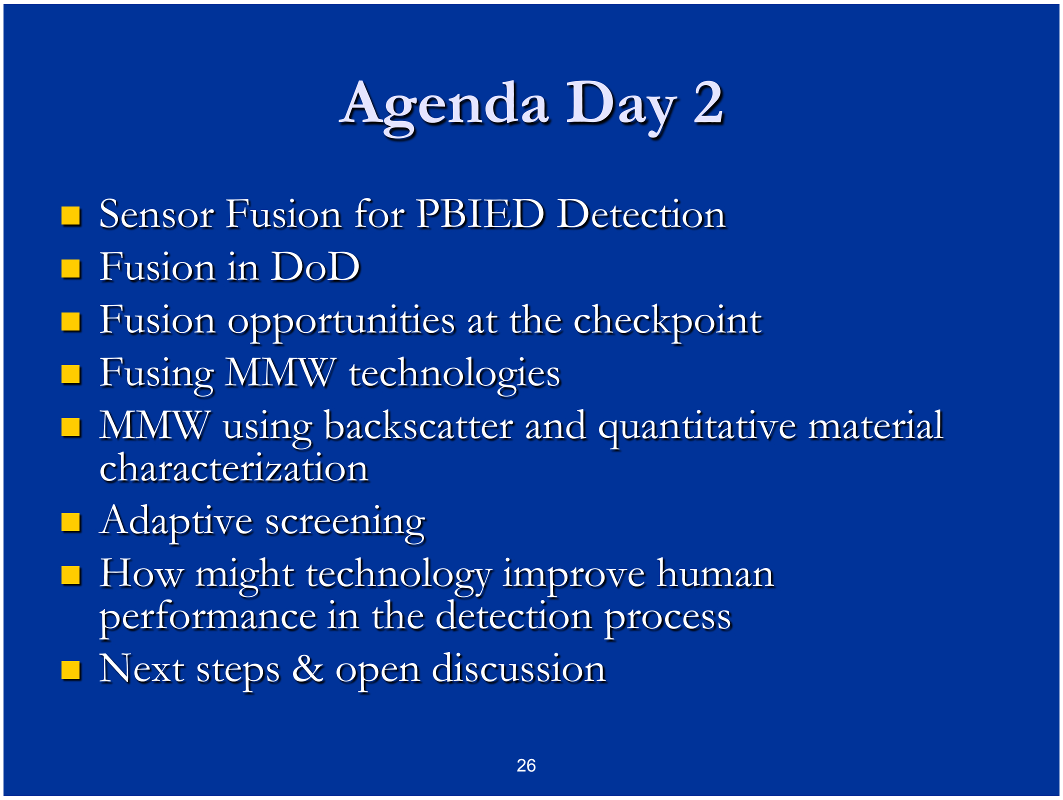


Questions 6 & 7

- What changes need to be made by DHS S&T to fund the research and development of fused systems?
- How can third parties better be marshaled to accelerate development of optimally fused detection systems?
  - How can projects be given to third-parties who cannot access classified information?
  - Which projects are suitable for third-parties?

Agenda Day 1

- Fusion development and deployment - Parts I&II
- Examples of fusion in medical imaging
  - PET/CT
  - Combined optical and x-ray Mammography
- AIT: X-ray backscatter & MMW review
- DHS comments on involvement of third parties
- Third party success stories
- Topics for next workshop (ADSA07)
- Reception sponsor
- Dinner Speech - Fostering innovation in aviation security



Agenda Day 2

- Sensor Fusion for PBIED Detection
- Fusion in DoD
- Fusion opportunities at the checkpoint
- Fusing MMW technologies
- MMW using backscatter and quantitative material characterization
- Adaptive screening
- How might technology improve human performance in the detection process
- Next steps & open discussion

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.

Workshop Changes

- More discussion time
  - Non-working and longer lunches, breaks and social period
  - Fewer speakers at dinner session
- Moderators being more active
  - Ask speakers for conclusions at start of talk
  - Ask audience to discuss presentation in real time
- Less adherence to agenda

Participant Identification

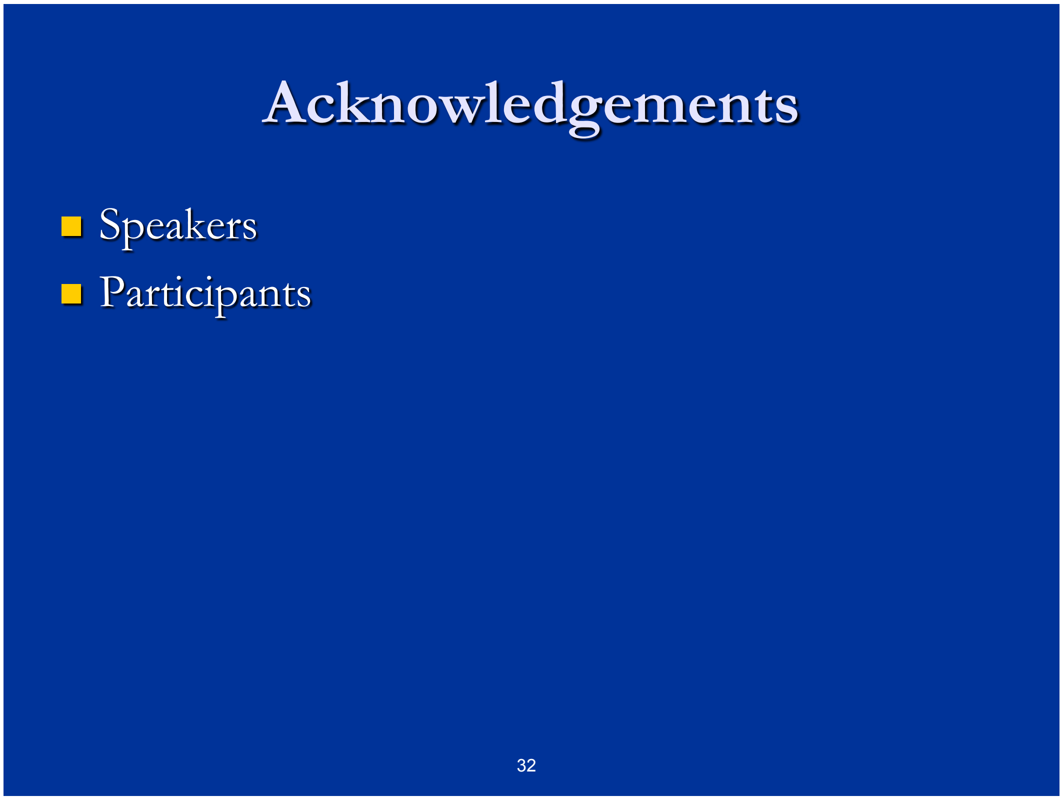
- Please identify yourself and institution first time you speak or ask questions
- Minutes will be taken, but edited for final report

Deliverables

- Written report to DHS addressing goals set forth on previous slides
  - Released to public
- Report written based on
  - Presentations
  - Discussion
  - Questionnaires
  - Minutes

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)



Acknowledgements

- Speakers
- Participants

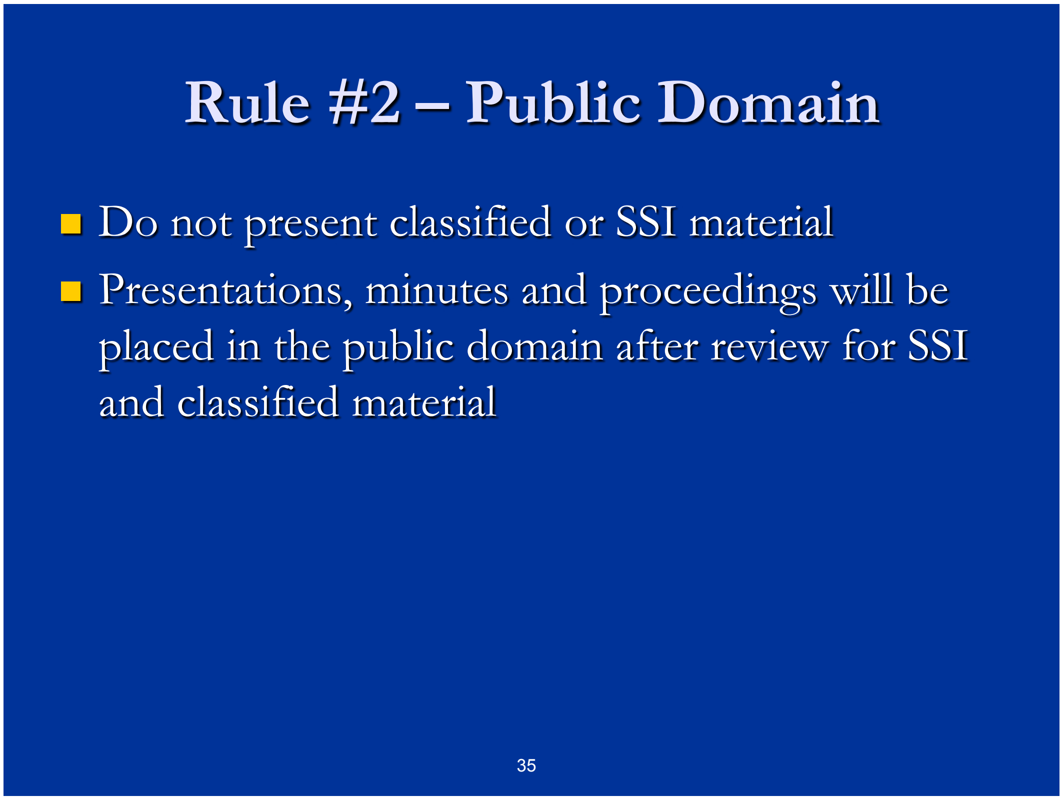
Logistics

- Mariah Nóbrega
- Rachel Parkin
- Brian Loughlin

Let them know if you need support during or after workshop.

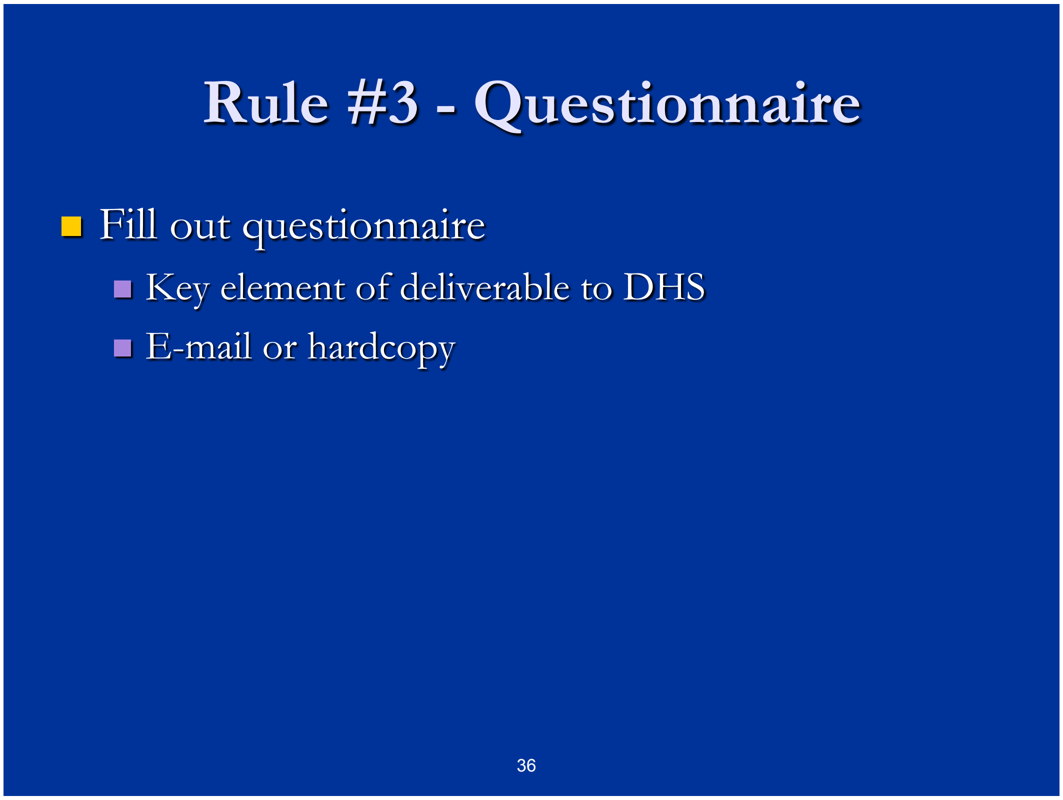
Rule #1 – Open Discussions

- This is a workshop, not a conference, symposium or tutorial
    - Talks do not address all topics
    - Discussion required to fill in gaps
    - Fewer presentations than previous workshops to allow more time for discussion.
- Conversation expected at all times, especially during formal presentations
- Applies to participants from academia, industry, government and national labs
- Moderators responsible for keeping discussions focused
- Not grip-and-grin



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



Rule #3 - Questionnaire

- Fill out questionnaire
  - Key element of deliverable to DHS
  - E-mail or hardcopy

Rule # 4 – Speaker Instructions

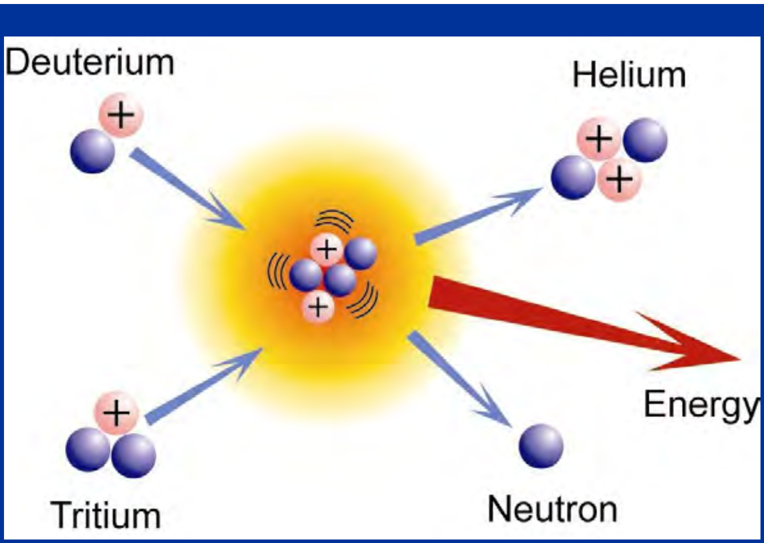
- 2nd slide should be conclusions
- Allocate 50% of time slot for discussion
- Do not repeat material from prior speakers
- Expect discussion during presentation
- Provide presentations in advance of your session to ALERT staff

Delete slides now if necessary!

Disclaimers

- This workshop 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.

Takeaway – Material does not necessary reflect DHS and TSA policies.



Learned much at ADSA05 (first workshop on fusion). Let's build on what we learned during this workshop.

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

16.3 Matthew Merzbacher: Fusion development and deployment - Part I

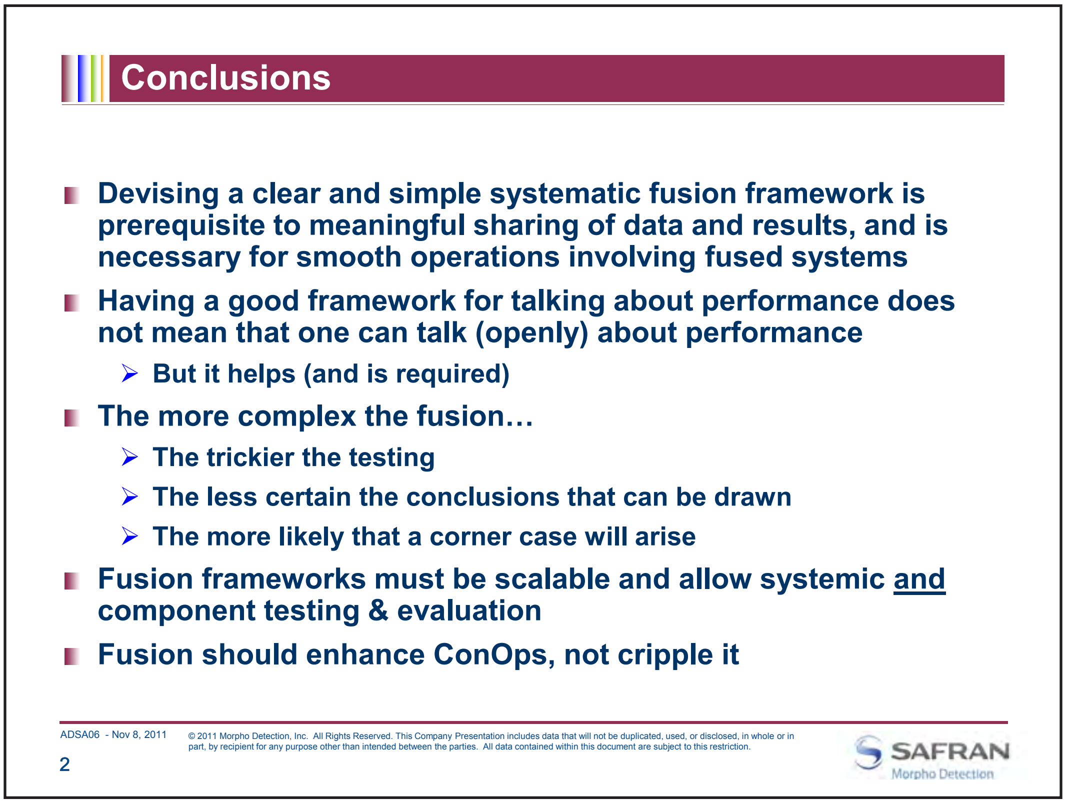
ADSA 06
Fusion Development and Deployment

November 8, 2011

Dr. Matthew Merzbacher

Manager, Machine Vision & Innovation

SAFRAN
Morpho Detection



Conclusions

- Devising a clear and simple systematic fusion framework is prerequisite to meaningful sharing of data and results, and is necessary for smooth operations involving fused systems
- Having a good framework for talking about performance does not mean that one can talk (openly) about performance
  - But it helps (and is required)
- The more complex the fusion…
  - The trickier the testing
  - The less certain the conclusions that can be drawn
  - The more likely that a corner case will arise
- Fusion frameworks must be scalable and allow systemic <u>and</u> component testing & evaluation
- Fusion should enhance ConOps, not cripple it

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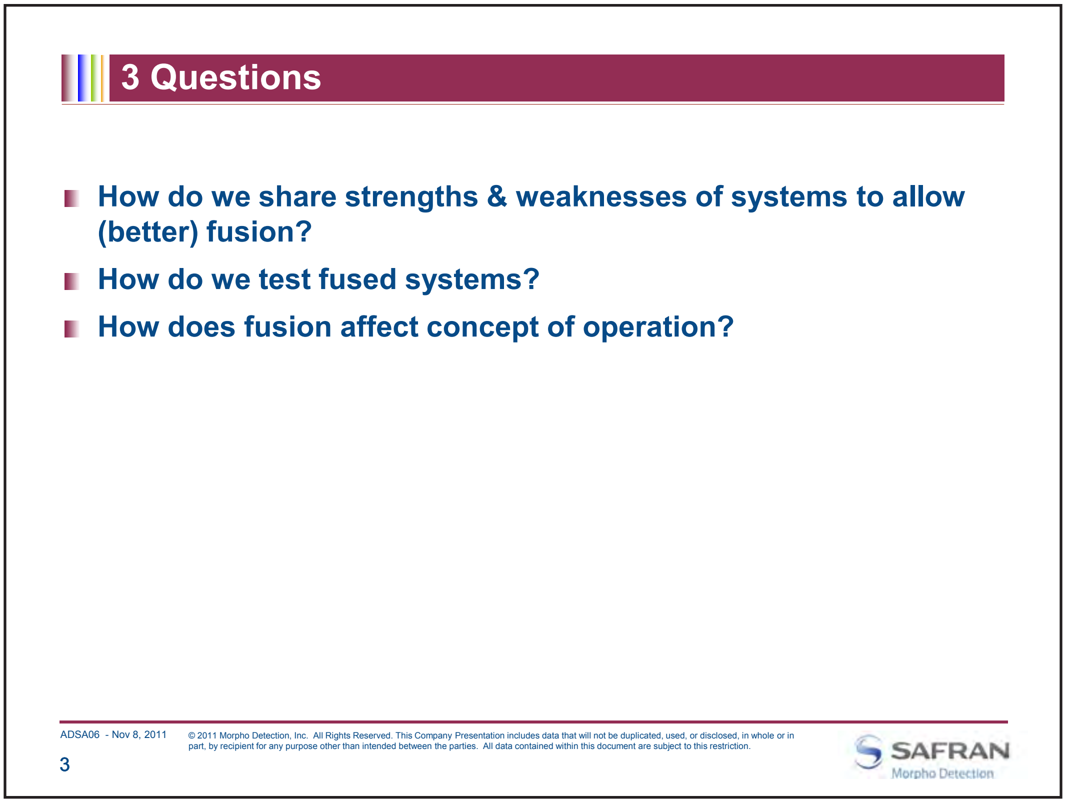
Morpho Detection



3 Questions

- How do we share strengths & weaknesses of systems to allow (better) fusion?
- How do we test fused systems?
- How does fusion affect concept of operation?

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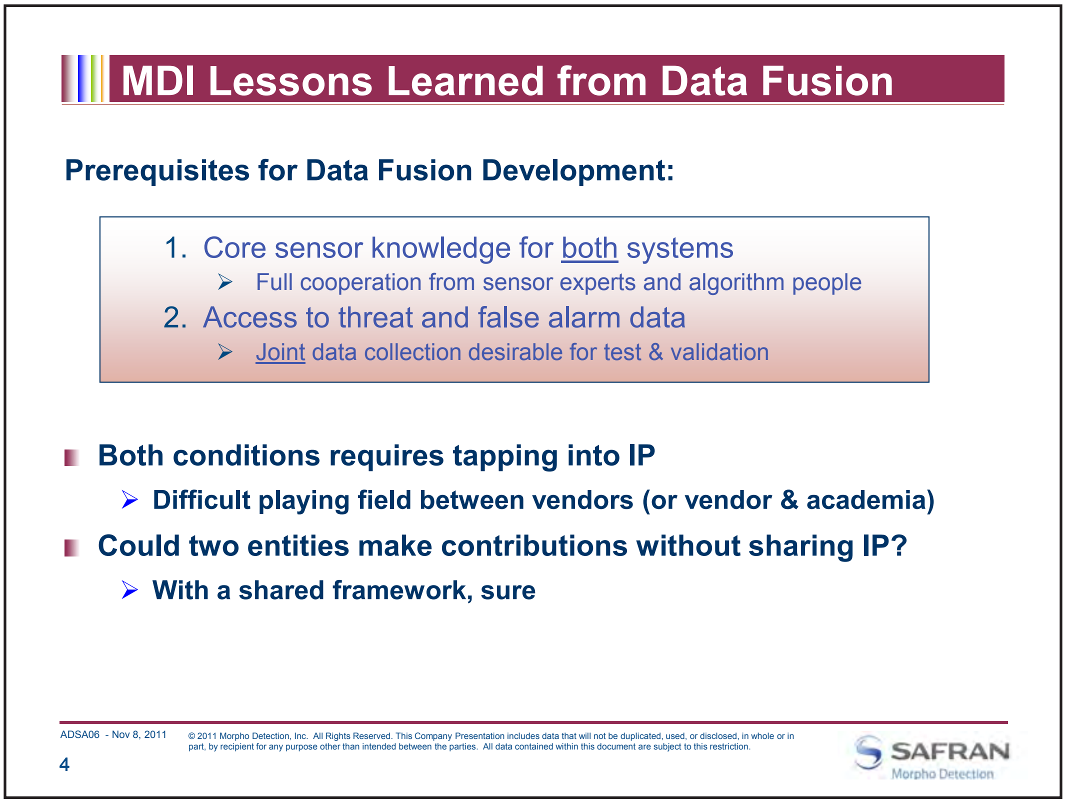
Morpho Detection



MDI Lessons Learned from Data Fusion

Prerequisites for Data Fusion Development:

1. Core sensor knowledge for both systems
   - ➢ Full cooperation from sensor experts and algorithm people
2. Access to threat and false alarm data
   - ➢ Joint data collection desirable for test & validation

- **Both conditions requires tapping into IP**
  - ➢ **Difficult playing field between vendors (or vendor & academia)**
- **Could two entities make contributions without sharing IP?**
  - ➢ **With a shared framework, sure**

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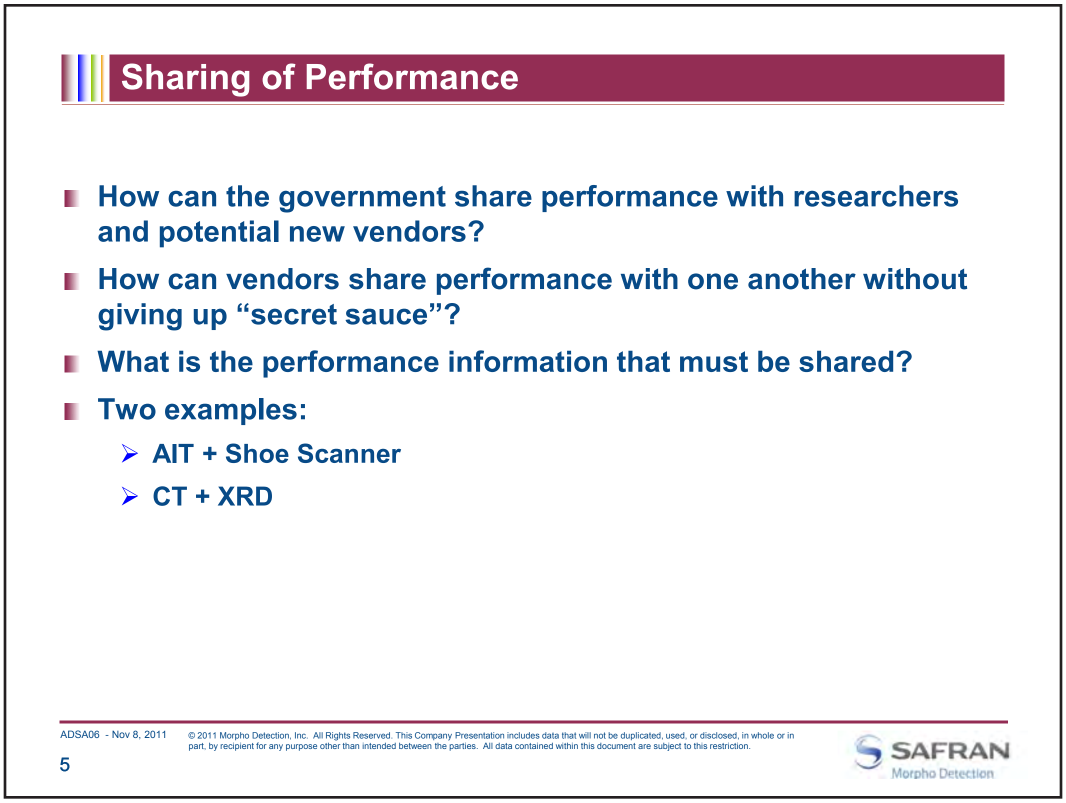
Morpho Detection



Sharing of Performance

- How can the government share performance with researchers and potential new vendors?
- How can vendors share performance with one another without giving up “secret sauce”?
- What is the performance information that must be shared?
- Two examples:
  - AIT + Shoe Scanner
  - CT + XRD

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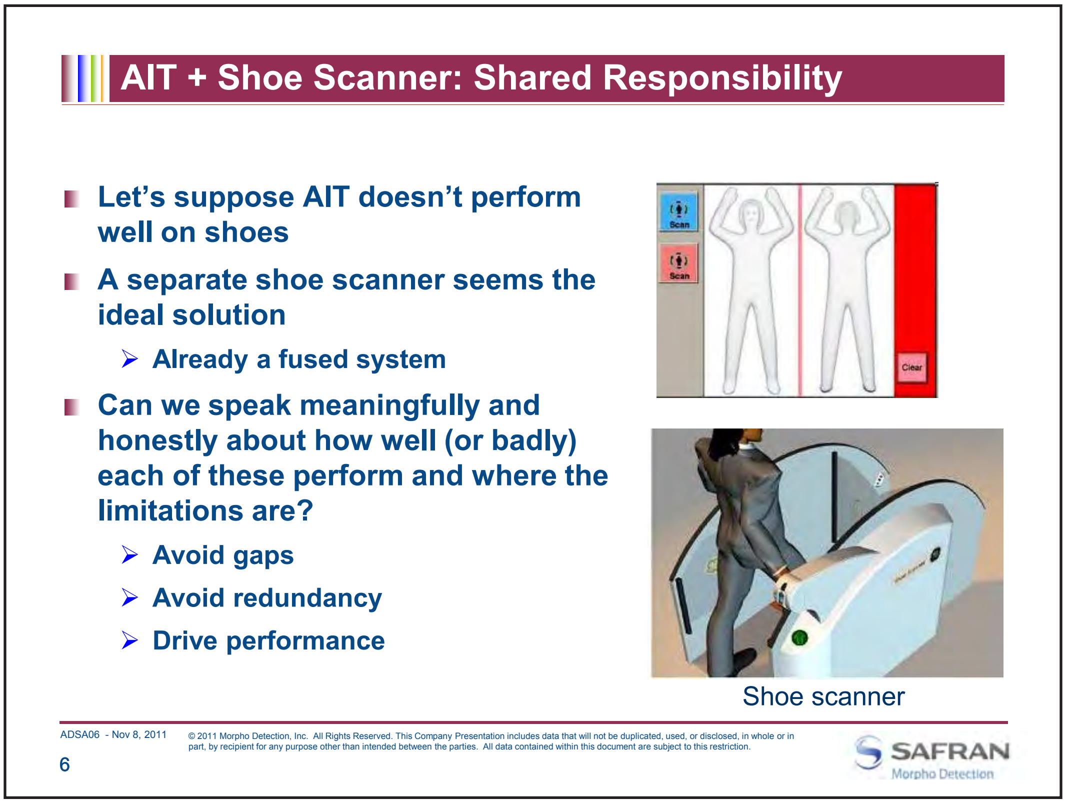

AIT + Shoe Scanner: Shared Responsibility

- Let’s suppose AIT doesn’t perform well on shoes
- A separate shoe scanner seems the ideal solution
  - Already a fused system
- Can we speak meaningfully and honestly about how well (or badly) each of these perform and where the limitations are?
  - Avoid gaps
  - Avoid redundancy
  - Drive performance

Shoe scanner

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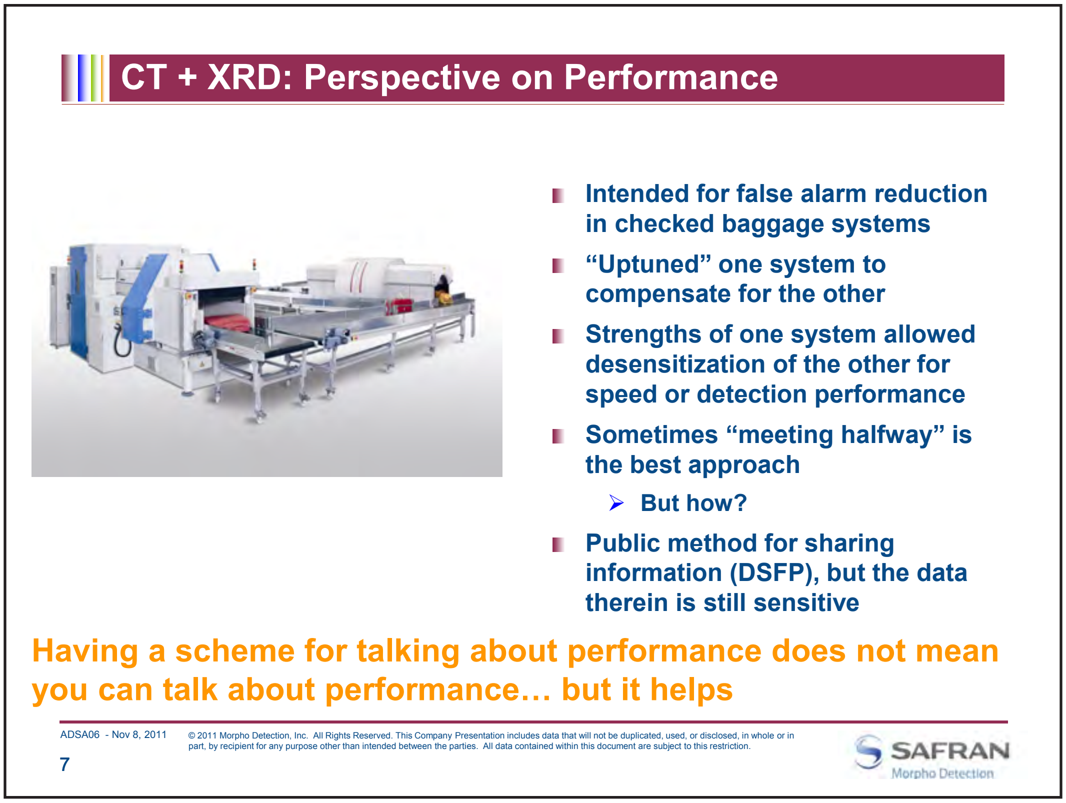
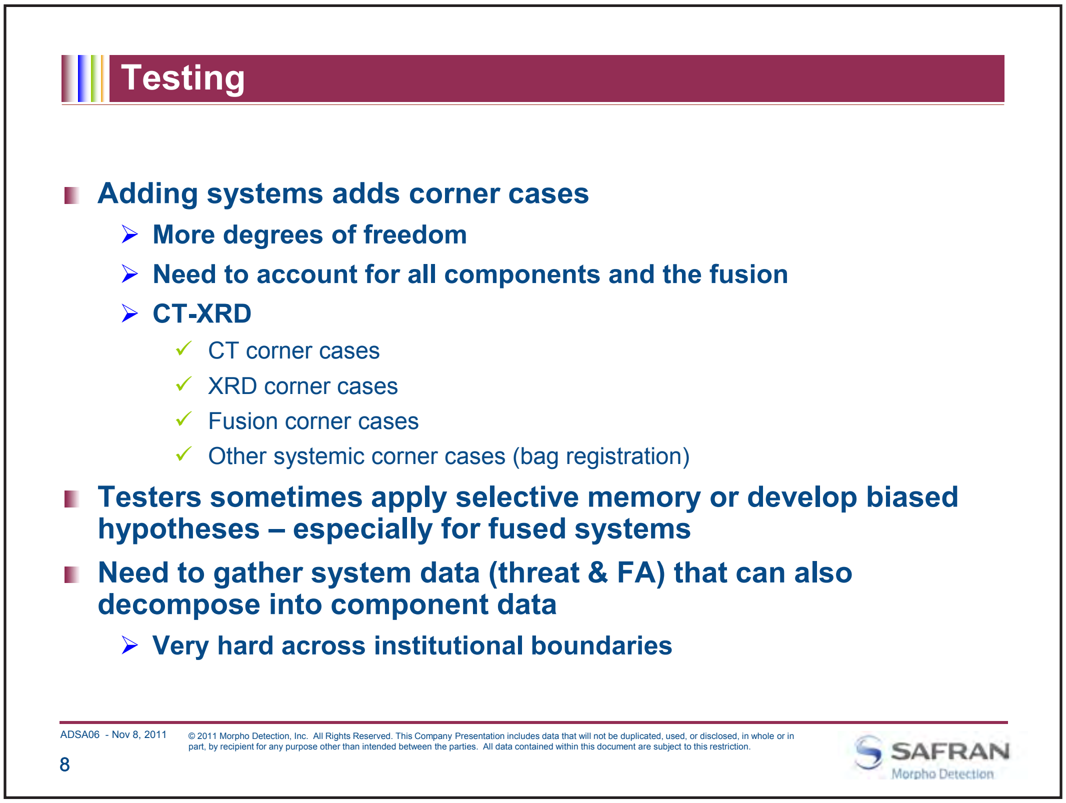


CT + XRD: Perspective on Performance

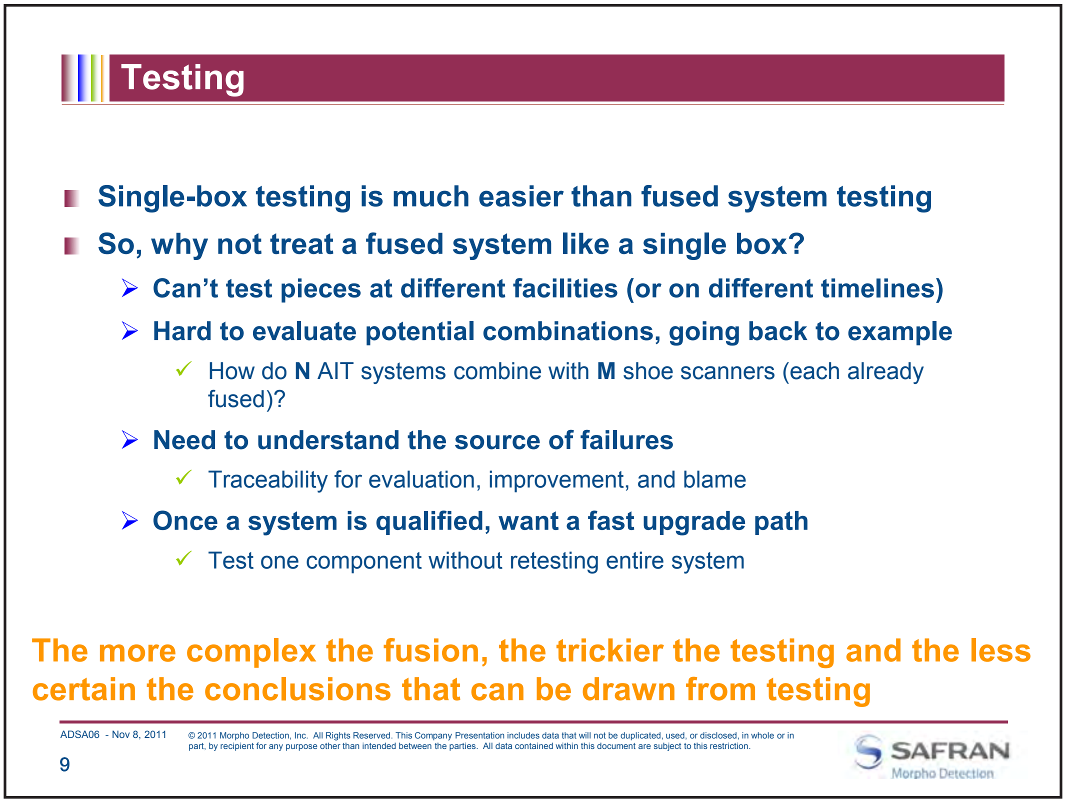
- Intended for false alarm reduction in checked baggage systems
- “Uptuned” one system to compensate for the other
- Strengths of one system allowed desensitization of the other for speed or detection performance
- Sometimes “meeting halfway” is the best approach
  - But how?
- Public method for sharing information (DSFP), but the data therein is still sensitive

Having a scheme for talking about performance does not mean you can talk about performance… but it helps



Testing

- Adding systems adds corner cases
  - More degrees of freedom
  - Need to account for all components and the fusion
  - CT-XRD
    - ✓ CT corner cases
    - ✓ XRD corner cases
    - ✓ Fusion corner cases
    - ✓ Other systemic corner cases (bag registration)
- Testers sometimes apply selective memory or develop biased hypotheses – especially for fused systems
- Need to gather system data (threat & FA) that can also decompose into component data
  - Very hard across institutional boundaries



Testing

- **Single-box testing is much easier than fused system testing**
- **So, why not treat a fused system like a single box?**
  - **Can’t test pieces at different facilities (or on different timelines)**
  - **Hard to evaluate potential combinations, going back to example**
    - ✓ How do **N** AIT systems combine with **M** shoe scanners (each already fused)?
  - **Need to understand the source of failures**
    - ✓ Traceability for evaluation, improvement, and blame
  - **Once a system is qualified, want a fast upgrade path**
    - ✓ Test one component without retesting entire system

The more complex the fusion, the trickier the testing and the less certain the conclusions that can be drawn from testing

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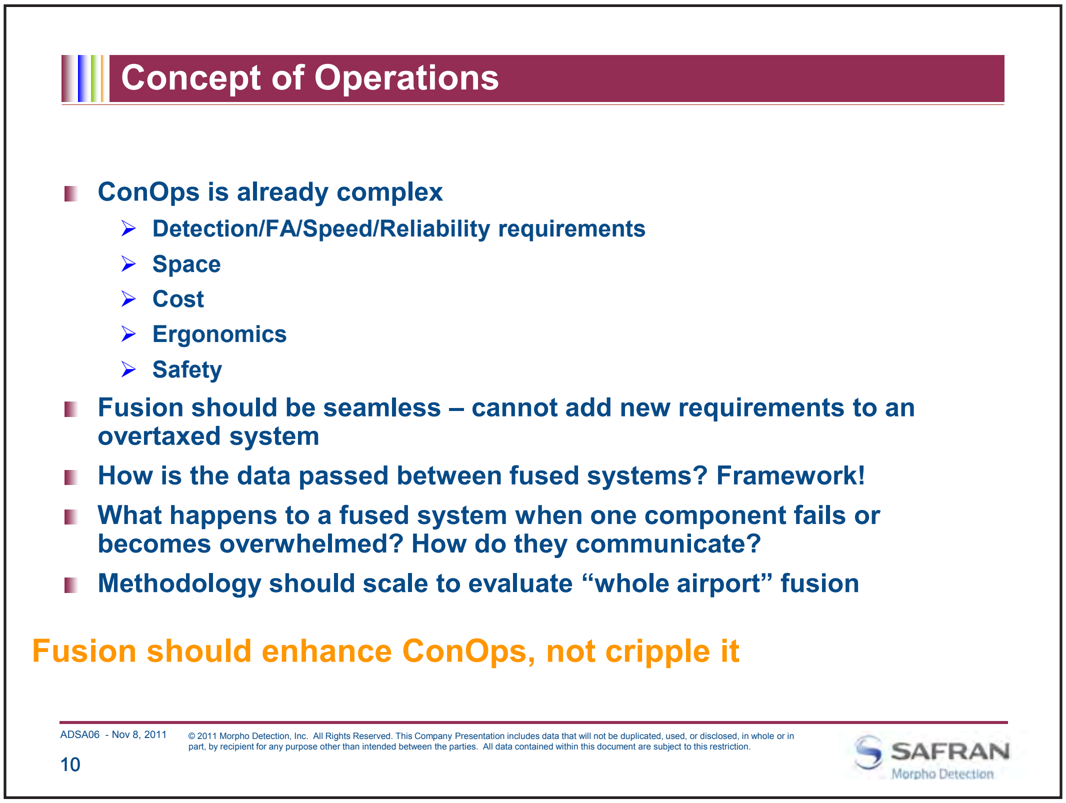

Concept of Operations

- **ConOps is already complex**
  - **Detection/FA/Speed/Reliability requirements**
  - **Space**
  - **Cost**
  - **Ergonomics**
  - **Safety**
- **Fusion should be seamless – cannot add new requirements to an overtaxed system**
- **How is the data passed between fused systems? Framework!**
- **What happens to a fused system when one component fails or becomes overwhelmed? How do they communicate?**
- **Methodology should scale to evaluate “whole airport” fusion**

Fusion should enhance ConOps, not cripple it

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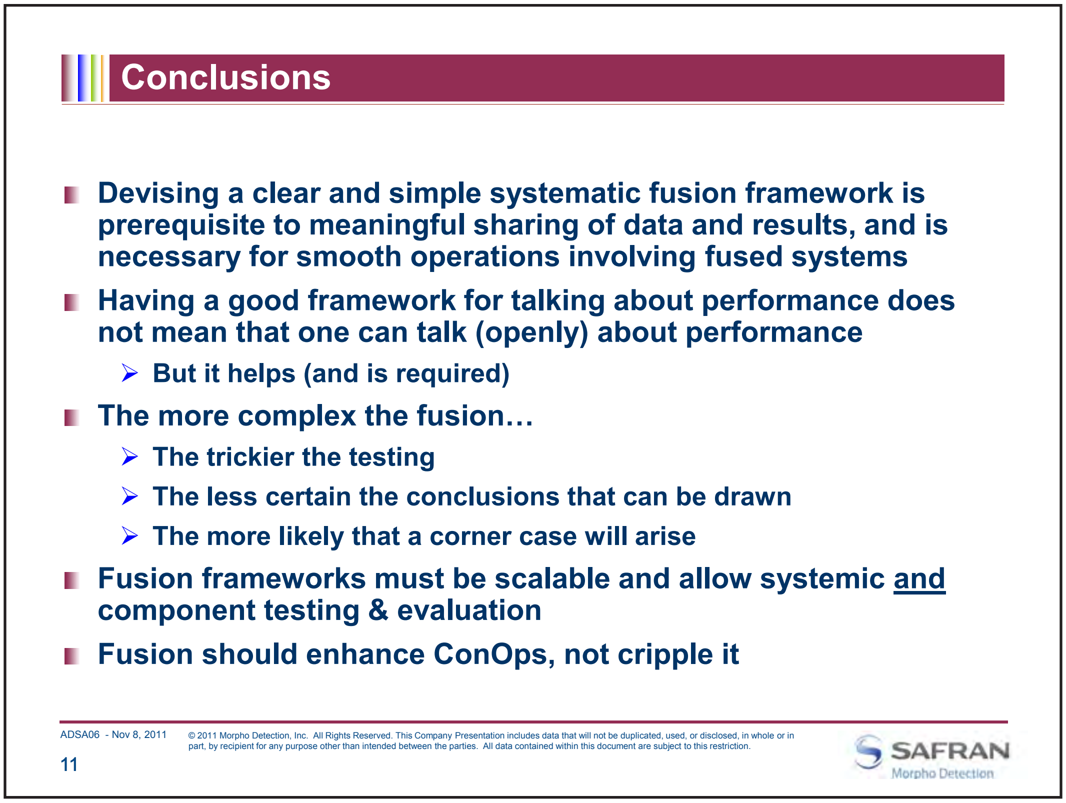
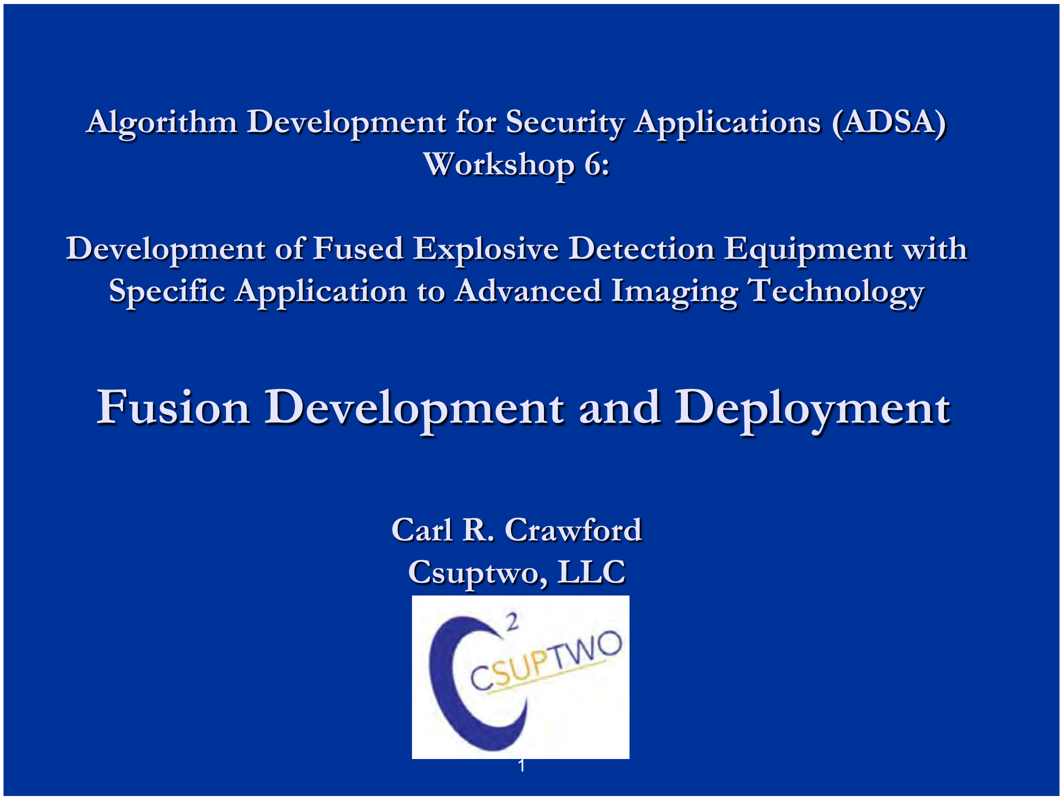


Conclusions

- **Devising a clear and simple systematic fusion framework is prerequisite to meaningful sharing of data and results, and is necessary for smooth operations involving fused systems**
- **Having a good framework for talking about performance does not mean that one can talk (openly) about performance**
  - **But it helps (and is required)**
- **The more complex the fusion…**
  - **The trickier the testing**
  - **The less certain the conclusions that can be drawn**
  - **The more likely that a corner case will arise**
- **Fusion frameworks must be scalable and allow systemic and component testing & evaluation**
- **Fusion should enhance ConOps, not cripple it**

SAFRAN
Morpho Detection

16.4 Carl Crawford: Fusion development and deployment - Part II

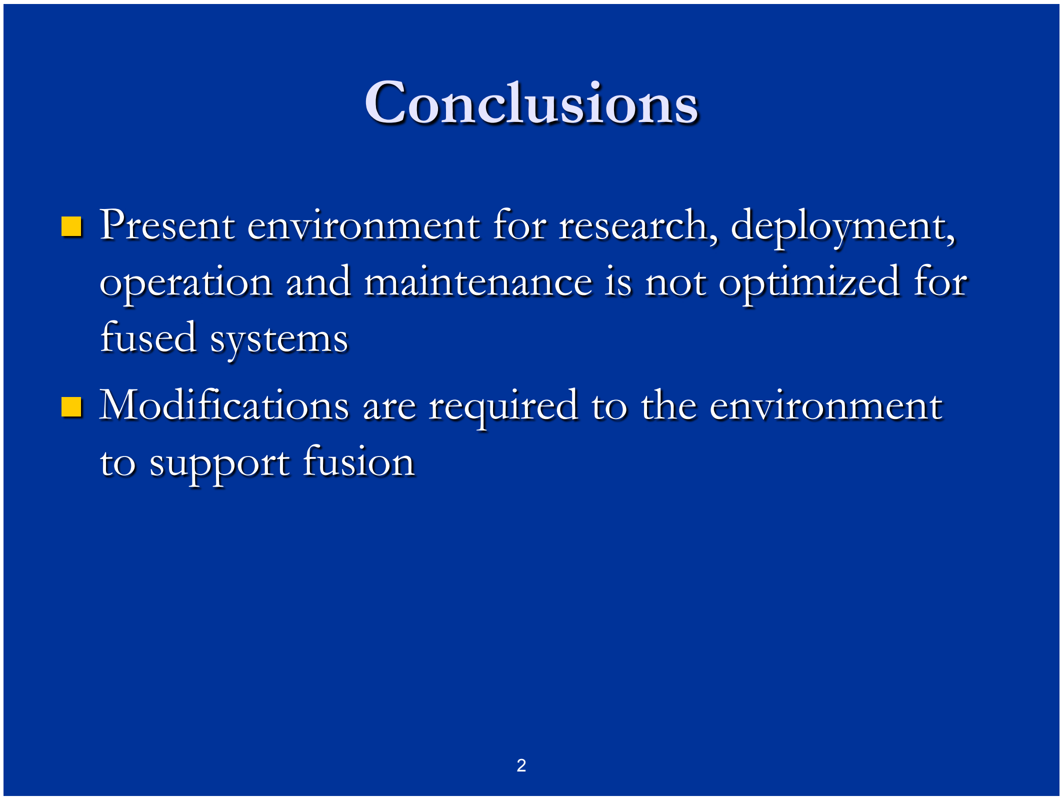


Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with
Specific Application to Advanced Imaging Technology

Fusion Development and Deployment

Carl R. Crawford
Csuptwo, LLC



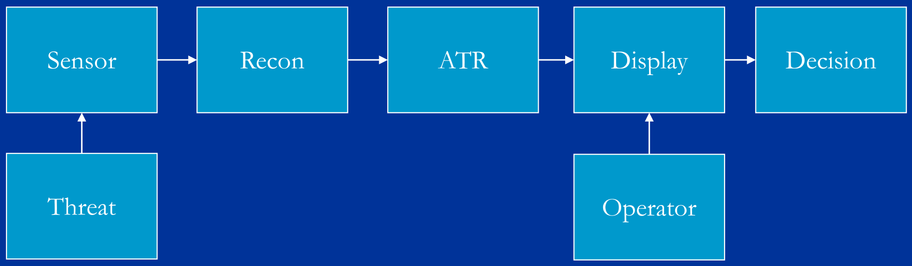
Conclusions

- Present environment for research, deployment, operation and maintenance is not optimized for fused systems
- Modifications are required to the environment to support fusion

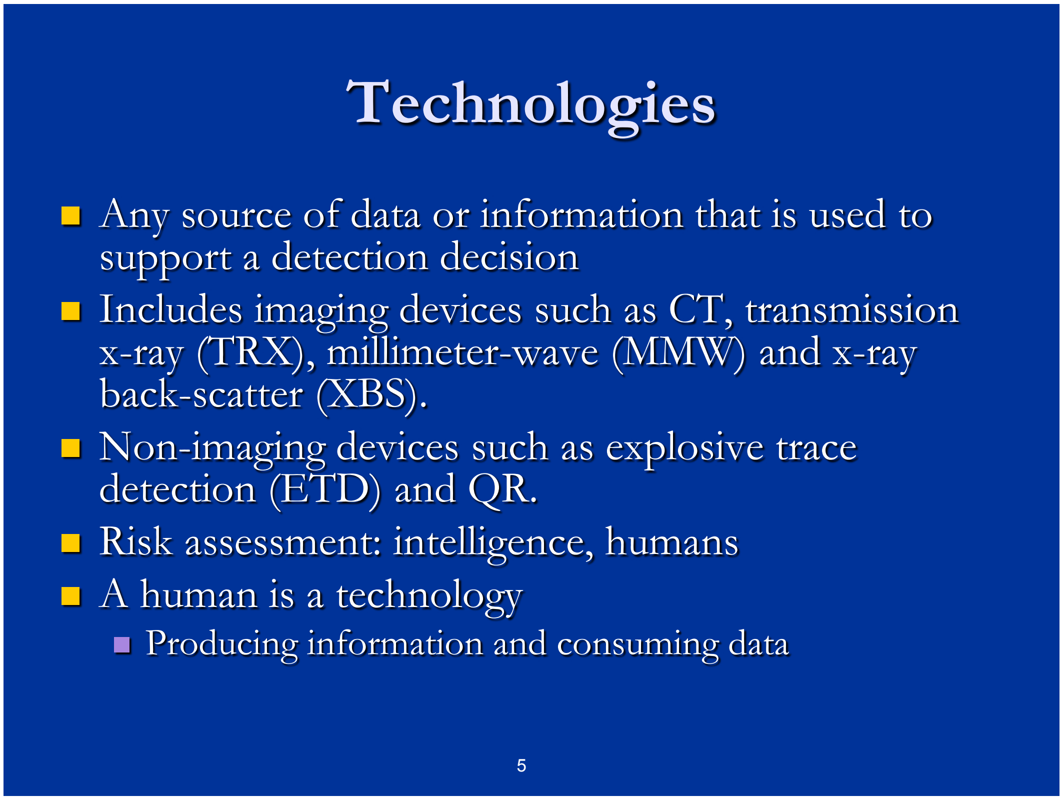
General Topics

- Definitions: fusion, orthogonal, technology
- TSA requirements
- Requirement specifications
- Procurement, installation, maintenance
- Interconnections, networking, standards
- Concepts of operation
- Third-party involvement including dealing with classified requirements
- Identification of strengths and weaknesses of existing equipment
- Testing, certification, qualification

Generalized Model

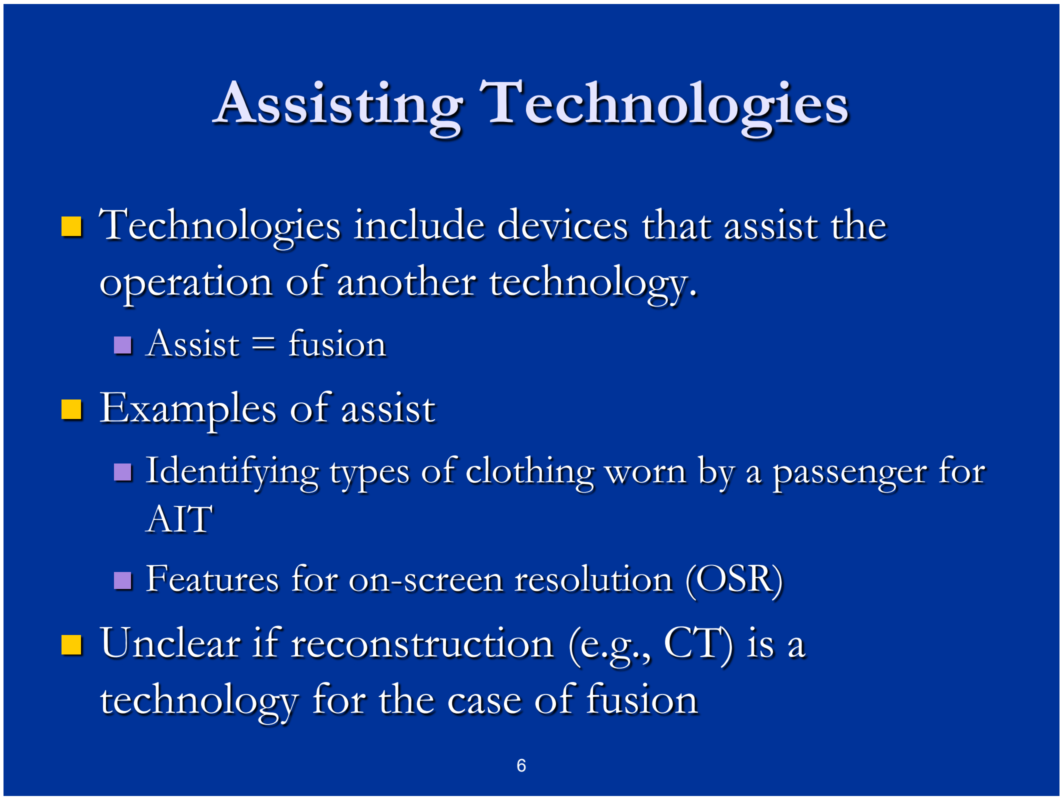


Boxes may mean different things to different modalities.
Some modalities may not have all boxes.



Technologies

- Any source of data or information that is used to support a detection decision
- Includes imaging devices such as CT, transmission x-ray (TRX), millimeter-wave (MMW) and x-ray back-scatter (XBS).
- Non-imaging devices such as explosive trace detection (ETD) and QR.
- Risk assessment: intelligence, humans
- A human is a technology
  - Producing information and consuming data



Assisting Technologies

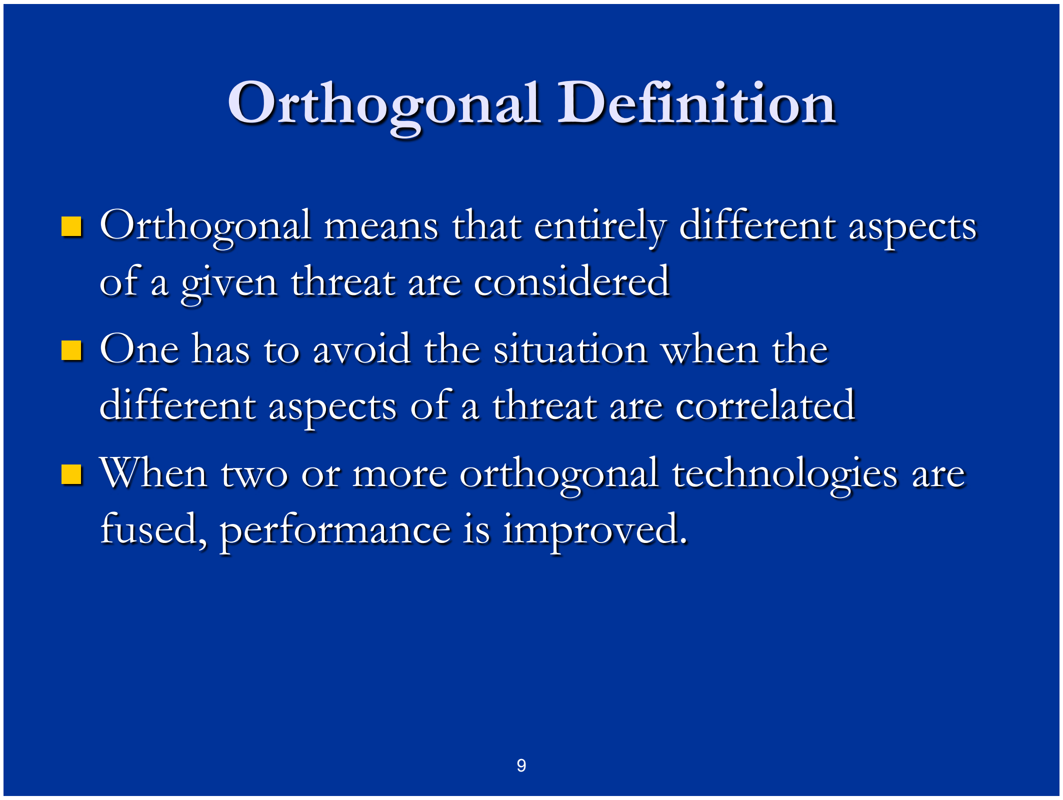
- Technologies include devices that assist the operation of another technology.
  - Assist = fusion
- Examples of assist
  - Identifying types of clothing worn by a passenger for AIT
  - Features for on-screen resolution (OSR)
- Unclear if reconstruction (e.g., CT) is a technology for the case of fusion

Technology Categories

- Existing
  - Modifications required to support sharing of results and controlling protocols
  - ATR may need to be revised to support fusion
- Future
  - Need to spec
  - Do not have to pass testing on their own

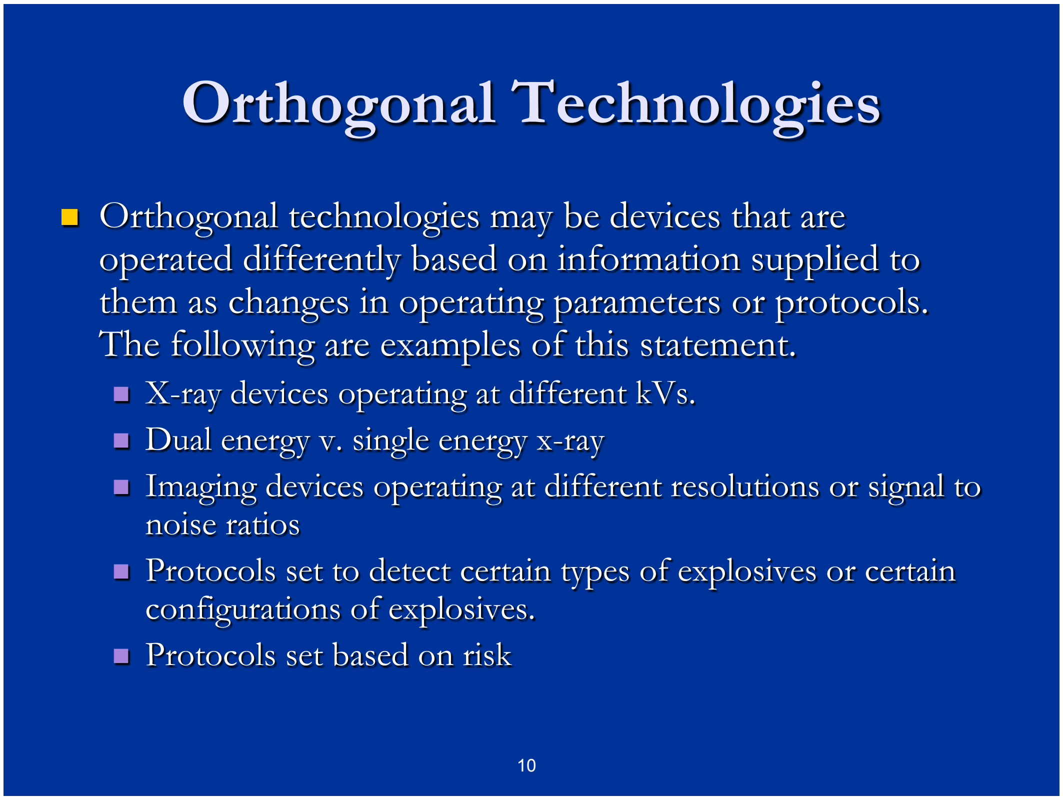
Data Types

- Images
- Spectra
- Analog and binary ATR results
- Features
- Human observations
- Level of risk – both input and output
- Aggregated information from different technologies
- Results from intelligence operations



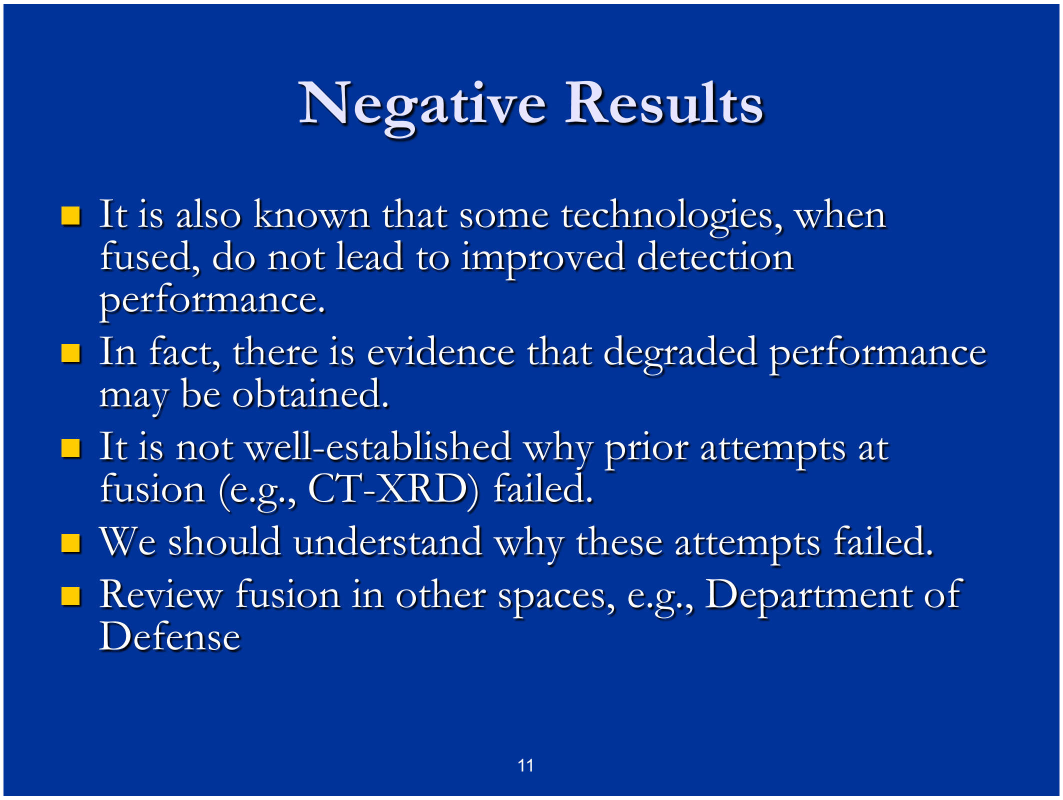
Orthogonal Definition

- Orthogonal means that entirely different aspects of a given threat are considered
- One has to avoid the situation when the different aspects of a threat are correlated
- When two or more orthogonal technologies are fused, performance is improved.



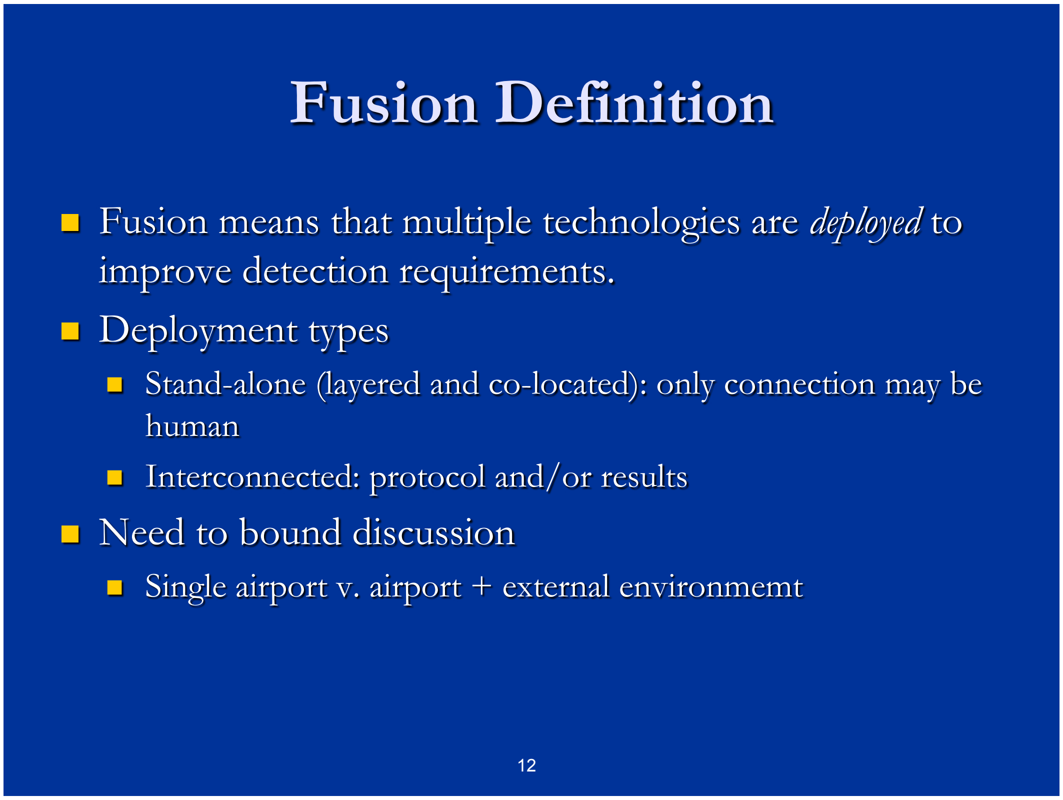
Orthogonal Technologies

- Orthogonal technologies may be devices that are operated differently based on information supplied to them as changes in operating parameters or protocols. The following are examples of this statement.
    - X-ray devices operating at different kVs.
    - Dual energy v. single energy x-ray
    - Imaging devices operating at different resolutions or signal to noise ratios
    - Protocols set to detect certain types of explosives or certain configurations of explosives.
    - Protocols set based on risk



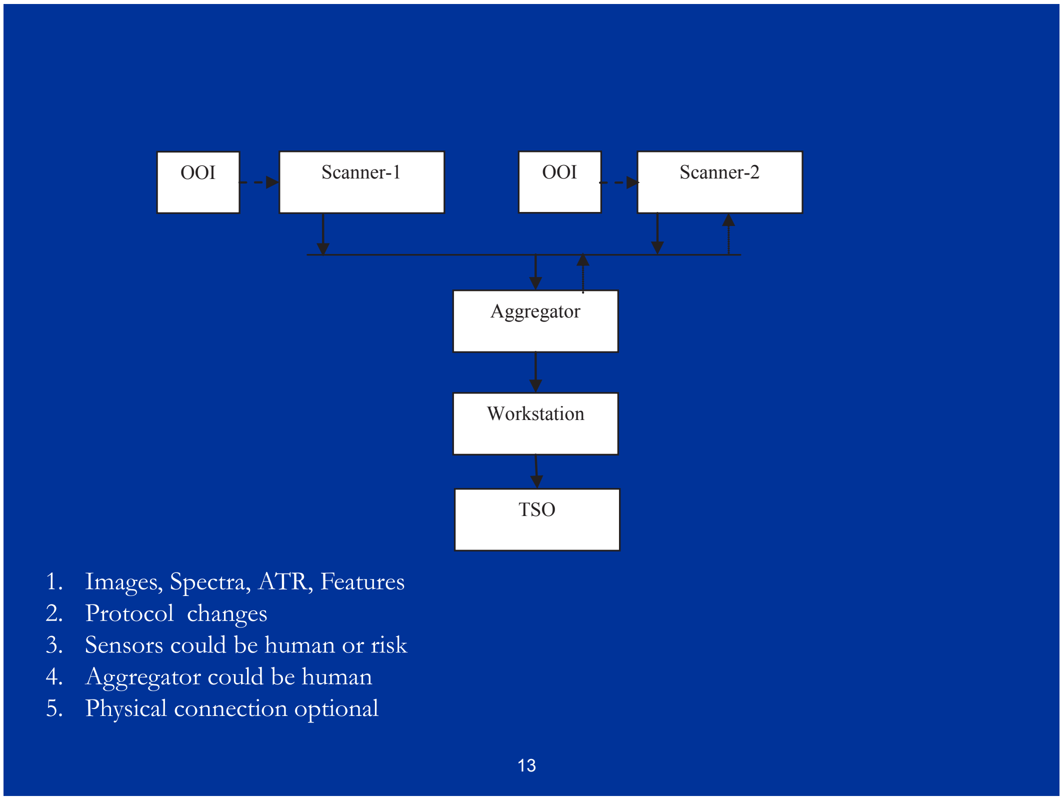
Negative Results

- 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.
- We should understand why these attempts failed.
- Review fusion in other spaces, e.g., Department of Defense



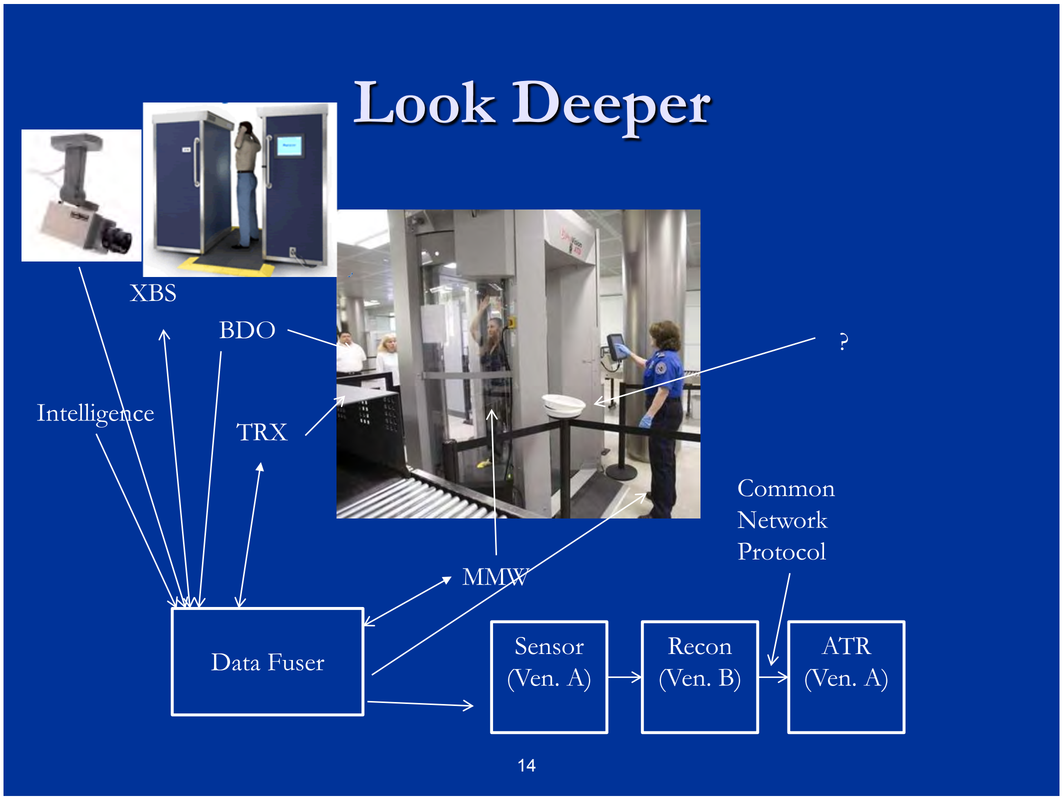
Fusion Definition

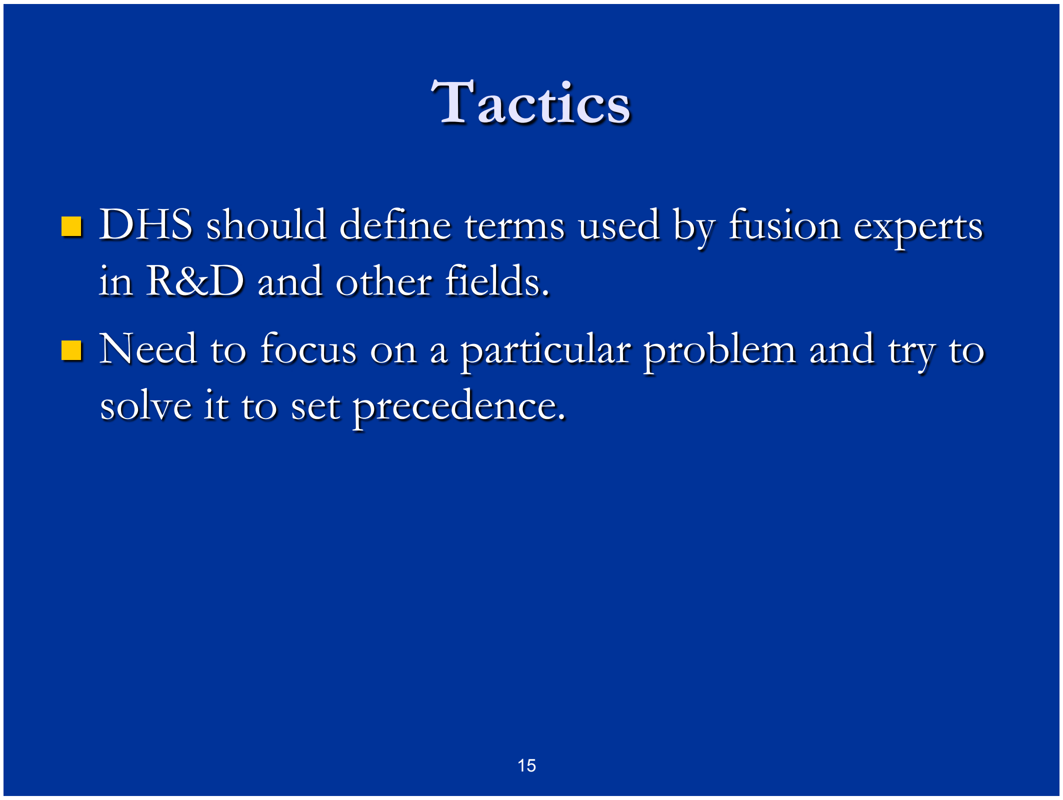
- Fusion means that multiple technologies are *deployed* to improve detection requirements.
- Deployment types
  - Stand-alone (layered and co-located): only connection may be human
  - Interconnected: protocol and/or results
- Need to bound discussion
  - Single airport v. airport + external environmemt



1. Images, Spectra, ATR, Features
2. Protocol changes
3. Sensors could be human or risk
4. Aggregator could be human
5. Physical connection optional

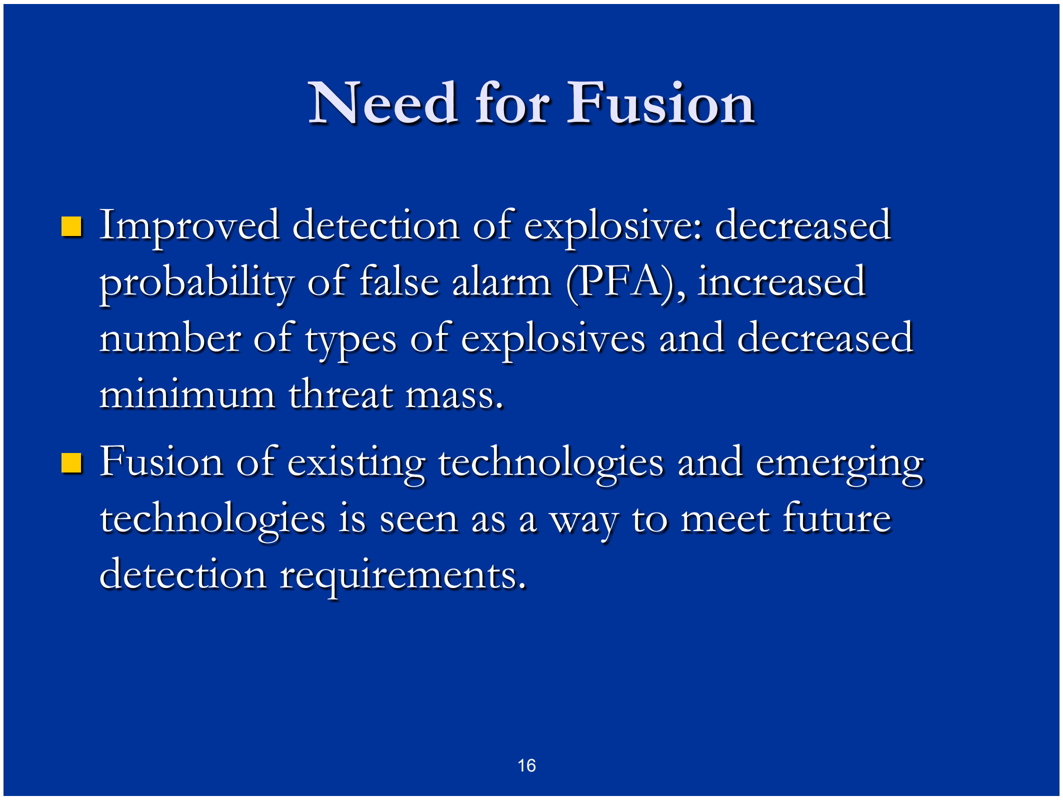
Look Deeper





Tactics

- DHS should define terms used by fusion experts in R&D and other fields.
- Need to focus on a particular problem and try to solve it to set precedence.



Need for Fusion

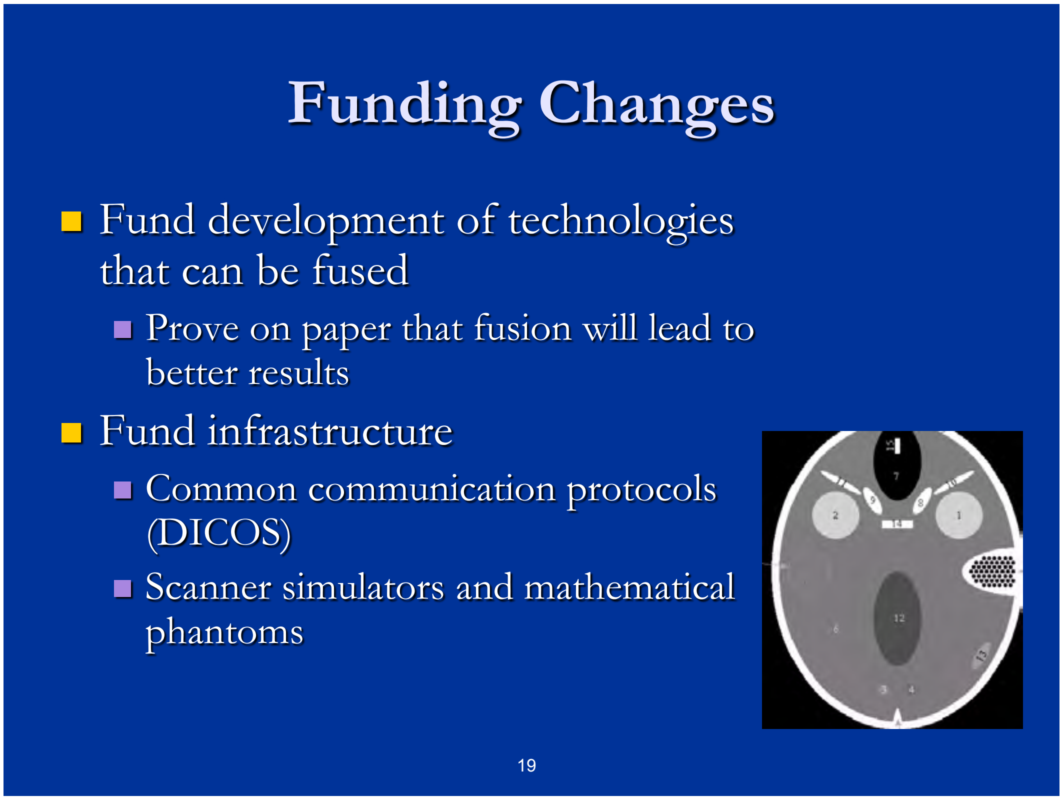
- Improved detection of explosive: decreased probability of false alarm (PFA), increased number of types of explosives and decreased minimum threat mass.
- Fusion of existing technologies and emerging technologies is seen as a way to meet future detection requirements.

Requirement Specs

- Current specs based on passing tests for complete set of explosives
  - Counter example may be check point with layered approach
  - Only allows for vendor to supply fused system
  - Does not allow for vendors to develop technologies to be fused at later date
  - Strengths and weaknesses of existing technologies not generally known
  - Support for fusion not required
    - Features not required; only pass/fail

TSA Future Specs

- Need to establish performance metrics to be able to judge effectiveness of individual systems and compare improvements due to fusing two or more systems.
- Complicated if operational protocols can be changed as part of fusion

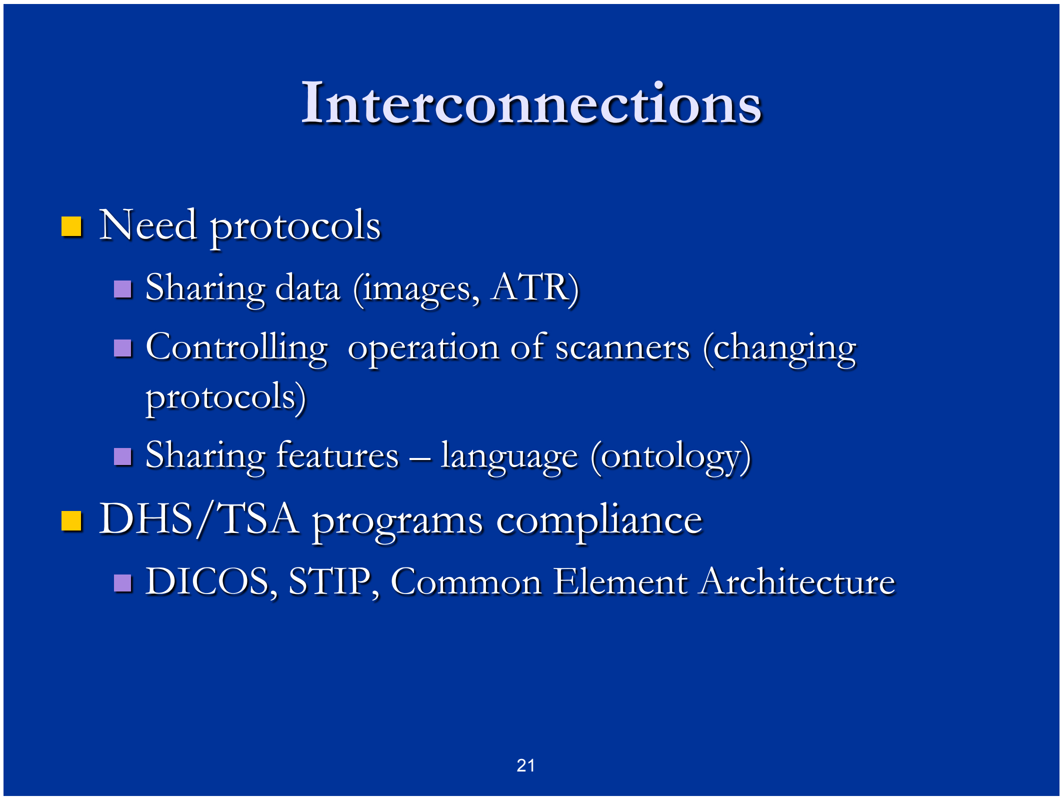


Funding Changes

- Fund development of technologies that can be fused
  - Prove on paper that fusion will lead to better results
- Fund infrastructure
  - Common communication protocols (DICOS)
  - Scanner simulators and mathematical phantoms

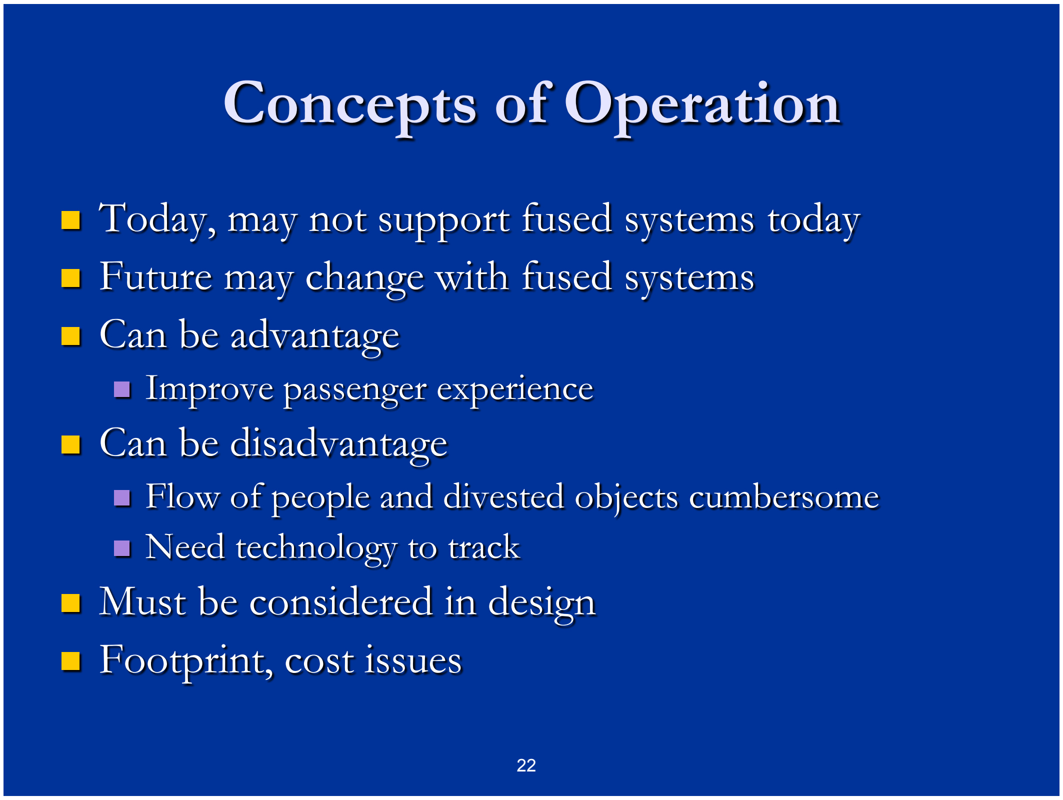
Procurement & Deployment

- Fuse systems in the field
  - Test at TSIF?
- Address issues in field
  - Interoperability
  - Problem isolation



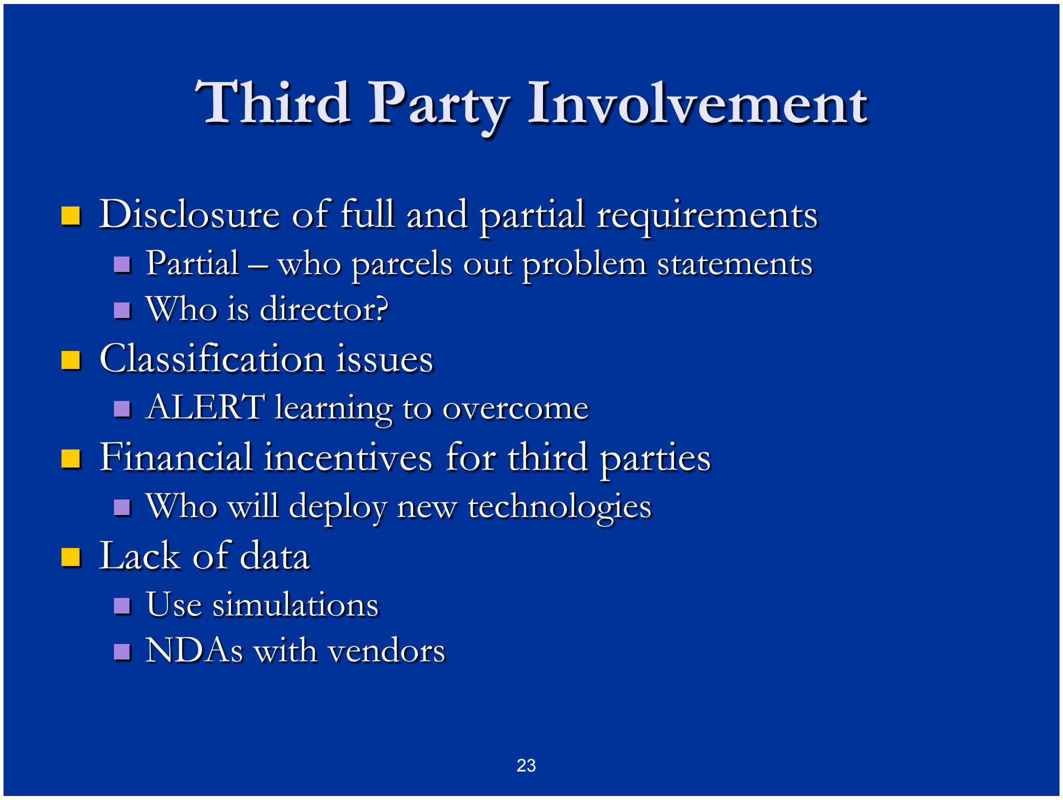
Interconnections

- Need protocols
  - Sharing data (images, ATR)
  - Controlling operation of scanners (changing protocols)
  - Sharing features – language (ontology)
- DHS/TSA programs compliance
  - DICOS, STIP, Common Element Architecture



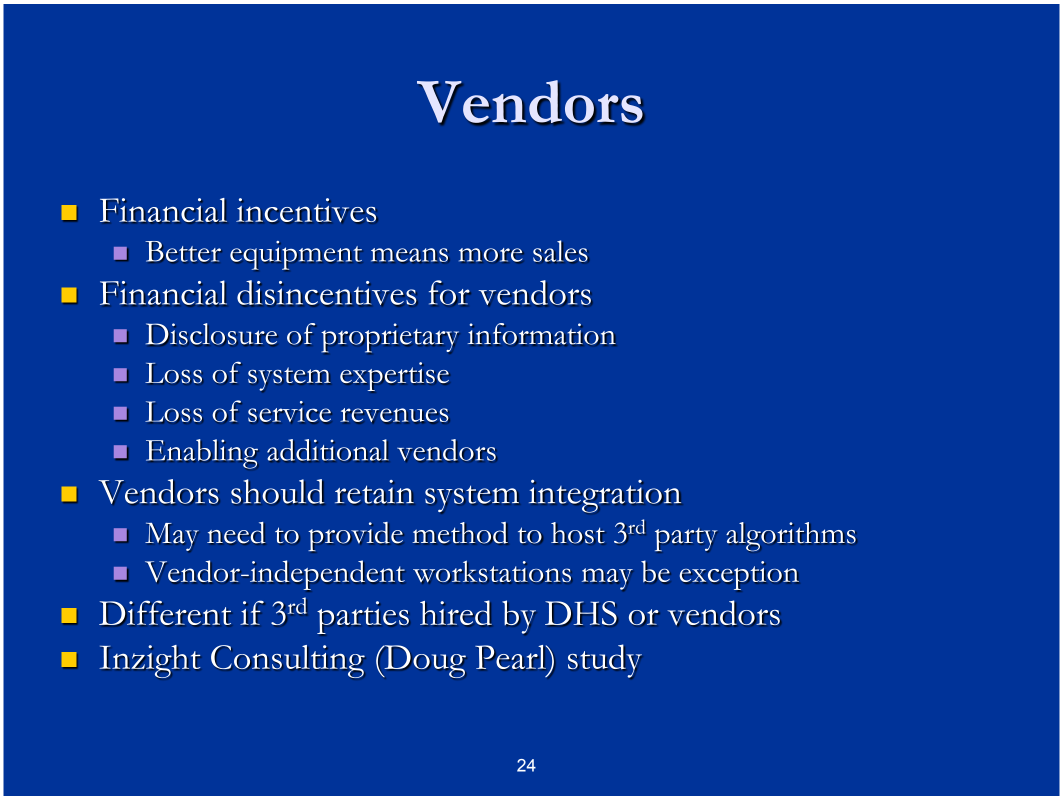
Concepts of Operation

- Today, may not support fused systems today
- Future may change with fused systems
- Can be advantage
  - Improve passenger experience
- Can be disadvantage
  - Flow of people and divested objects cumbersome
  - Need technology to track
- Must be considered in design
- Footprint, cost issues



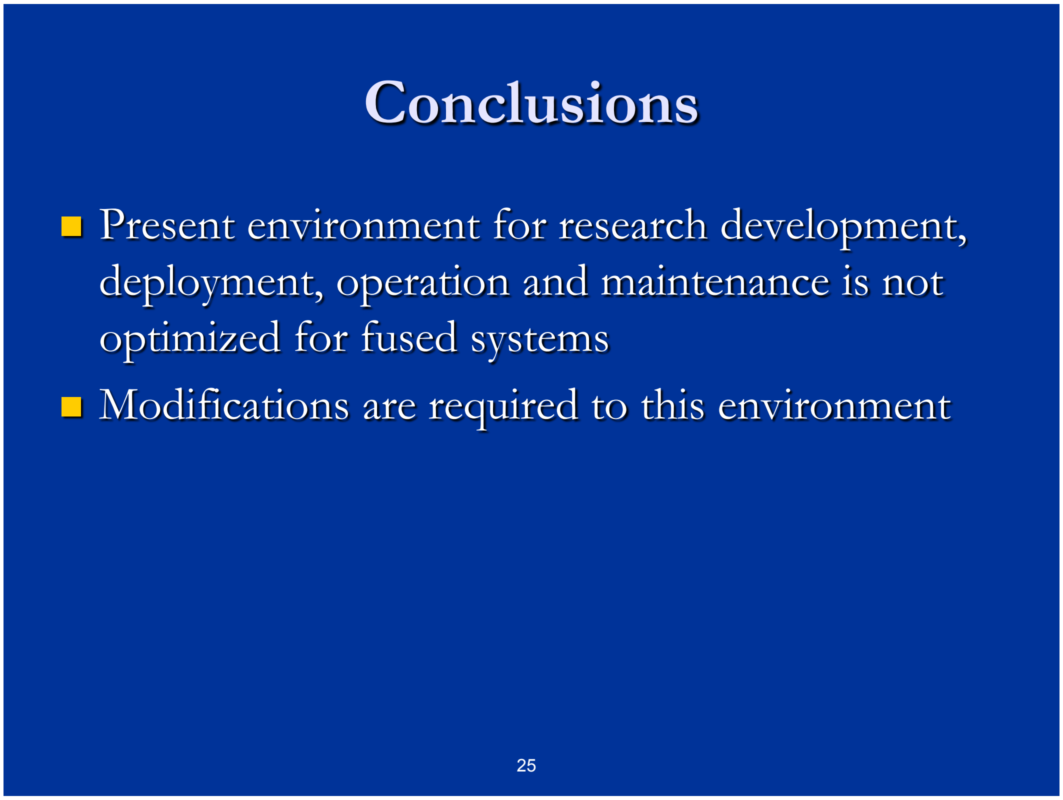
Third Party Involvement

- Disclosure of full and partial requirements
  - Partial – who parcels out problem statements
  - Who is director?
- Classification issues
  - ALERT learning to overcome
- Financial incentives for third parties
  - Who will deploy new technologies
- Lack of data
  - Use simulations
  - NDAs with vendors



Vendors

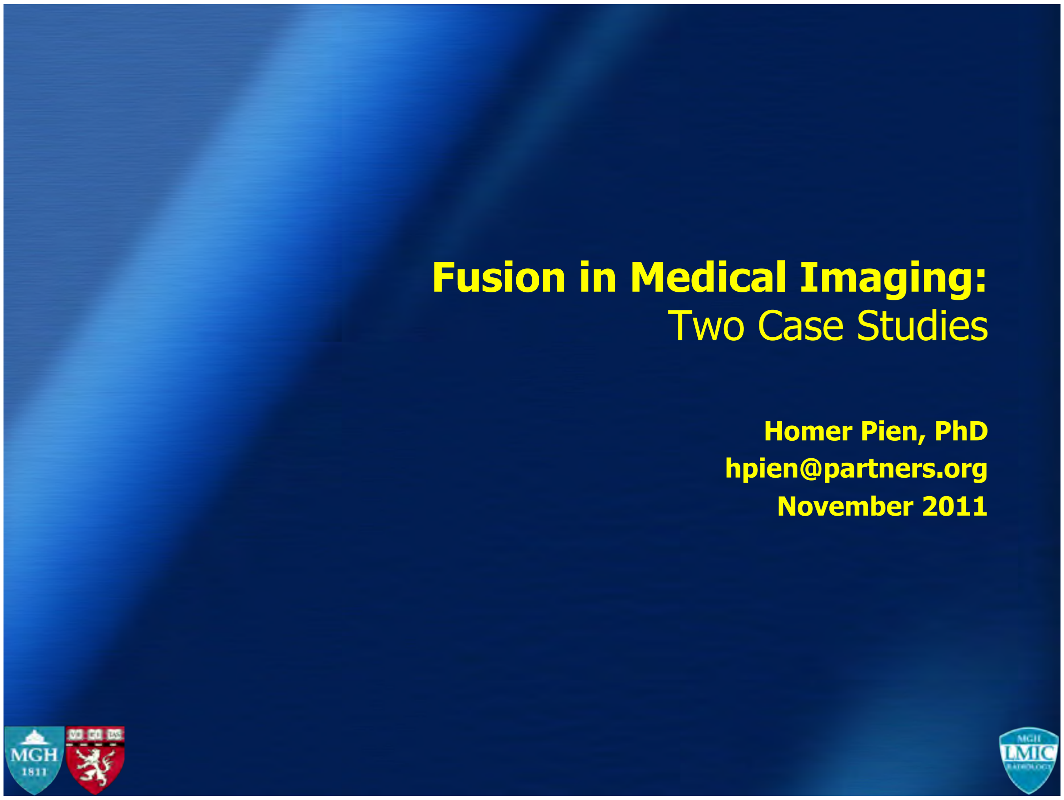
- Financial incentives
  - Better equipment means more sales
- Financial disincentives for vendors
  - Disclosure of proprietary information
  - Loss of system expertise
  - Loss of service revenues
  - Enabling additional vendors
- Vendors should retain system integration
  - May need to provide method to host 3rd party algorithms
  - Vendor-independent workstations may be exception
- Different if 3rd parties hired by DHS or vendors
- Inzight Consulting (Doug Pearl) study



Conclusions

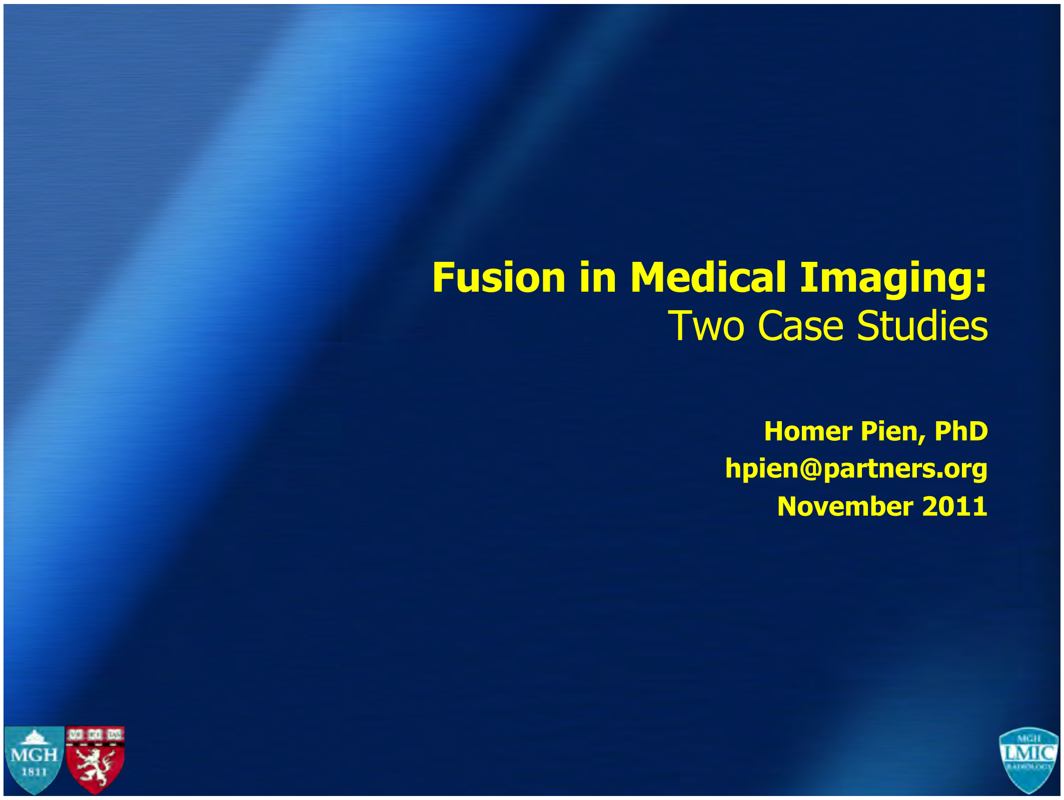
- Present environment for research development, deployment, operation and maintenance is not optimized for fused systems
- Modifications are required to this environment

16.5 Homer Pien: Examples of fusion in medical imaging



Fusion in Medical Imaging:
Two Case Studies

Homer Pien, PhD
hpien@partners.org
November 2011



Fusion in Medical Imaging:
Two Case Studies

Homer Pien, PhD
hpien@partners.org
November 2011

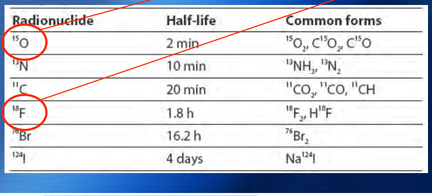
Summary

- Two case studies:
  - PET versus PET-CT
  - Triage of Acute Coronary Syndrome (ACS) patients in ERs
- PET-CT
  - There was considerable a priori justification why a fused system would be beneficial
    - Better registration, correlation between structure and function, attenuation correction, quantitation
  - PET-CT fusion were being done manually before hybrid systems came on the market
- ACS
  - While ACS triage continues to evolve, there is a priori justification why fusion of disparate sources of information is beneficial
    - Permits individualized assessment of the patient
    - Results in significantly better outcomes of patients

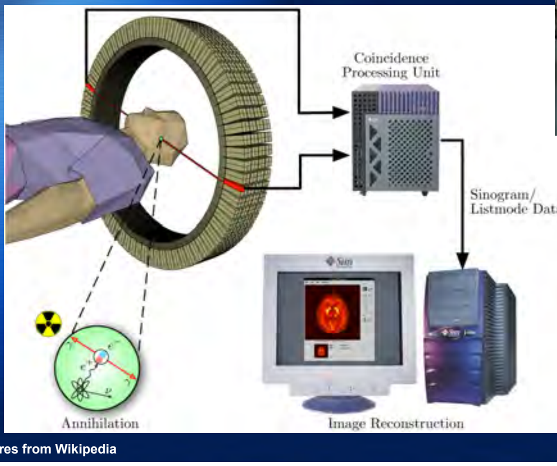
PET Imaging

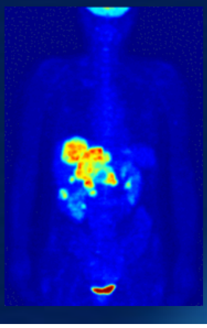
Positron emitting water

Positron emitting glucose



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	$Na^{124}I$





FDG uptake

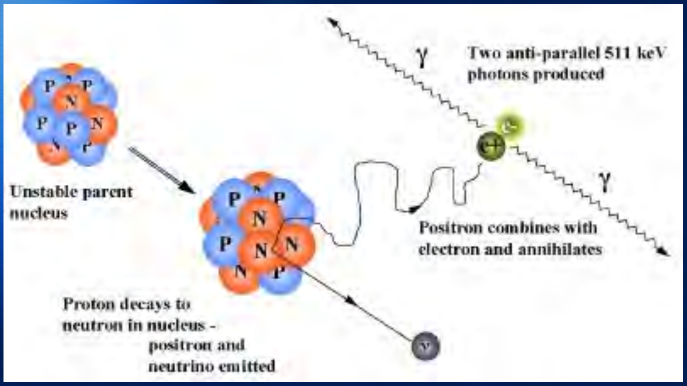
Pictures from Wikipedia

Brief History of PET

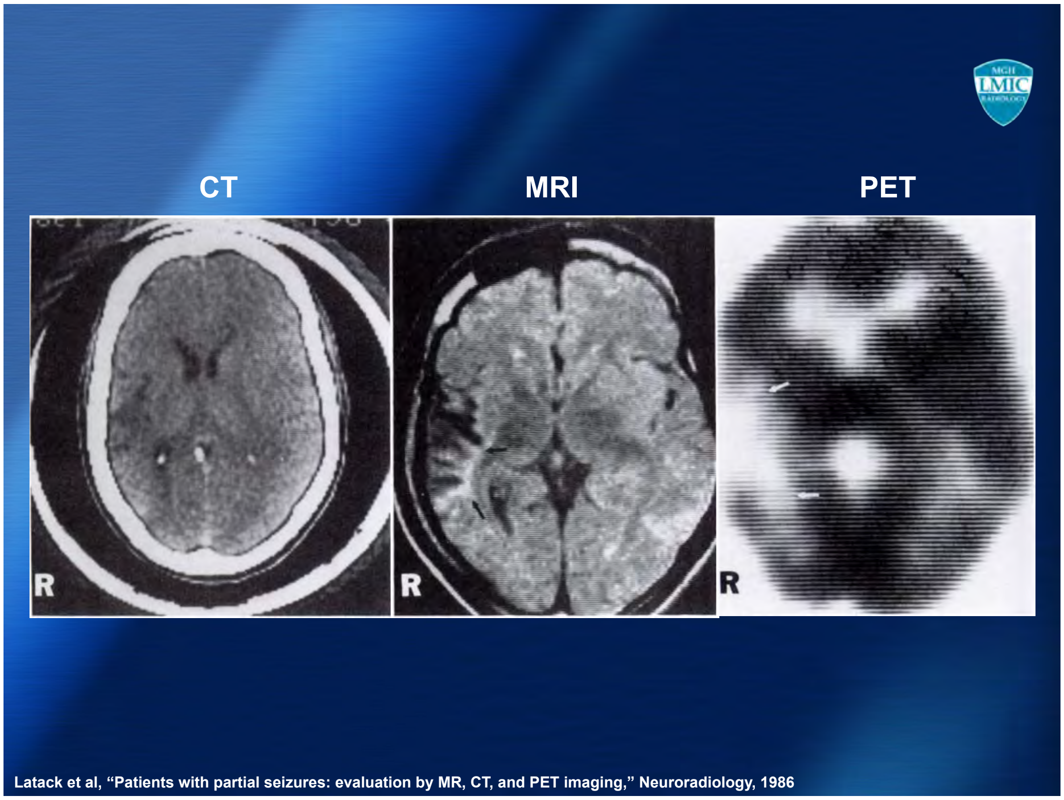
- 1950's
  - Gordon Brownell at MGH
  - First positron image – brain tumor localization (1951)
    - 2 decades before MRI and CT
- 1960's and 1970's
  - Emissions computed tomography and Mark-II scanner
  - Chesler's FBP 3-D recon applied to CT and PET
  - First commercial PET scanner (1970)
  - Phelps and the PETT-III (1974) – 2-cm resolution
  - Tracers: O15-water (1970) and FDG (1976)

Linton, *Radiology at Massachusetts General Hospital: 1896-2000*
Wacholtz, "History and development of PET," Cewebsource.com

Positron annihilation

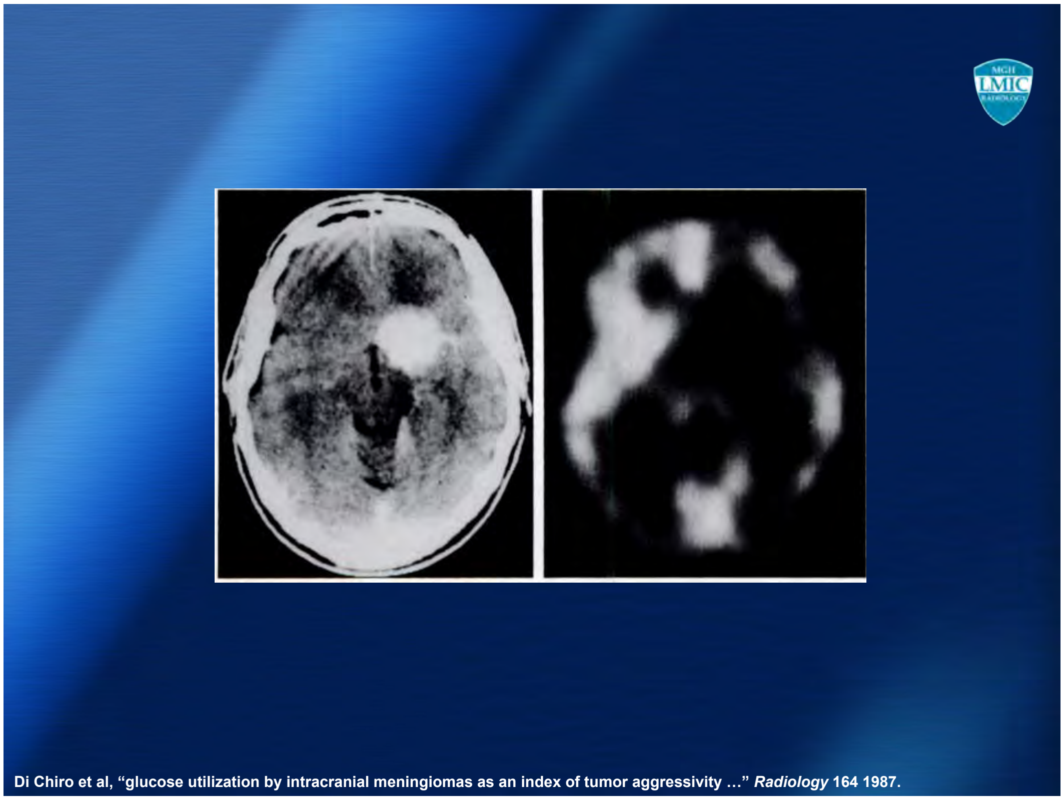


http://depts.washington.edu/nucmed/IRL/pet_intro/intro_src/section2.html



CT MRI PET

Latack et al, “Patients with partial seizures: evaluation by MR, CT, and PET imaging,” Neuroradiology, 1986



Di Chiro et al, “glucose utilization by intracranial meningiomas as an index of tumor aggressivity …” *Radiology* 164 1987.

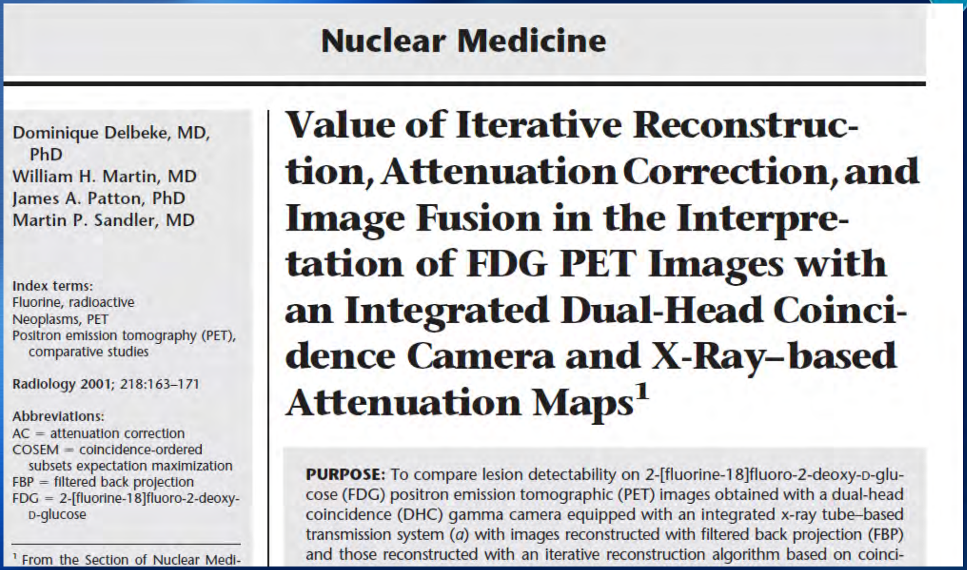
1980's and 1990's

- PET transitioned from research to clinical tool
- It was well recognized that PET, by itself, did not provide sufficient resolution or anatomic details
  - Used in conjunction with CT and MR to provide structural information to complement PET's functional information
- Separate PET and CT scans were performed, but patient movement made image registration an issue
- Also recognized that PET was not quantitative
  - Needed to properly account for vast attenuation differences between bone, tissue, and air

PET-CT

- Introduced in 2000
- Time Magazine's Invention of the Year
  - Dec 2000

Siemens Biograph 64 PET-CT



Nuclear Medicine

Dominique Delbeke, MD, PhD
William H. Martin, MD
James A. Patton, PhD
Martin P. Sandler, MD

Index terms:
Fluorine, radioactive
Neoplasms, PET
Positron emission tomography (PET), comparative studies

Radiology 2001; 218:163–171

Abbreviations:
AC = attenuation correction
COSEM = coincidence-ordered subsets expectation maximization
FBP = filtered back projection
FDG = 2-[fluorine-18]fluoro-2-deoxy-D-glucose

---

[1] From the Section of Nuclear Medi-

Value of Iterative Reconstruction, Attenuation Correction, and Image Fusion in the Interpretation of FDG PET Images with an Integrated Dual-Head Coincidence Camera and X-Ray–based Attenuation Maps[1]

PURPOSE: To compare lesion detectability on 2-[fluorine-18]fluoro-2-deoxy-D-glucose (FDG) positron emission tomographic (PET) images obtained with a dual-head coincidence (DHC) gamma camera equipped with an integrated x-ray tube–based transmission system (*a*) with images reconstructed with filtered back projection (FBP) and those reconstructed with an iterative reconstruction algorithm based on coinci-

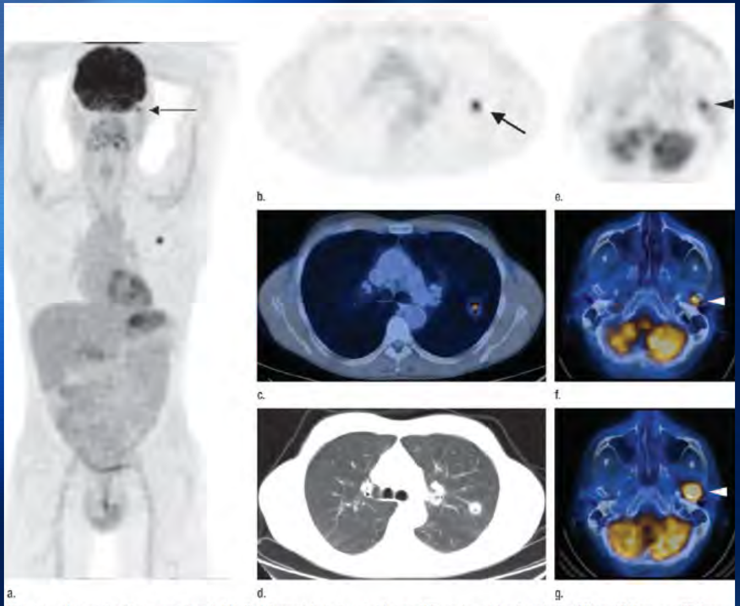
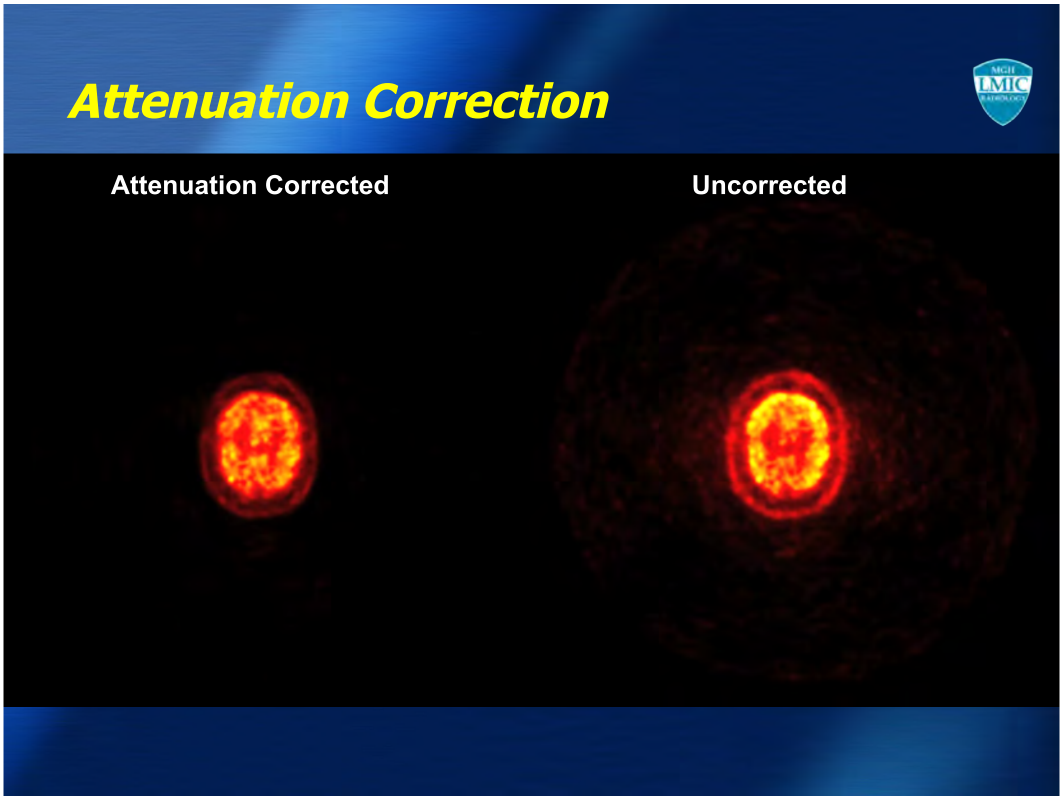


Figure 1: Non–small cell lung cancer (arrow in **b**) in the left upper lobe is shown in **(a)** coronal PET maximum intensity projection (MIP) and **(b)** transverse PET image, **(c)** transverse PET/CT image, and **(d)** transverse CT lung window image. **(e)** Transverse PET image shows small focus at left skull base (arrowhead, arrow in **a**); **(f)** on transverse PET/CT scan, focus appears to be a bone metastasis (arrowhead) in the mandibular condyle, which was not noted at CT alone (not shown). **(g)** This was confirmed with follow-up transverse PET/CT, where interval growth of the lesion (arrowhead) was seen. Osseous metastasis was confirmed at histologic examination.

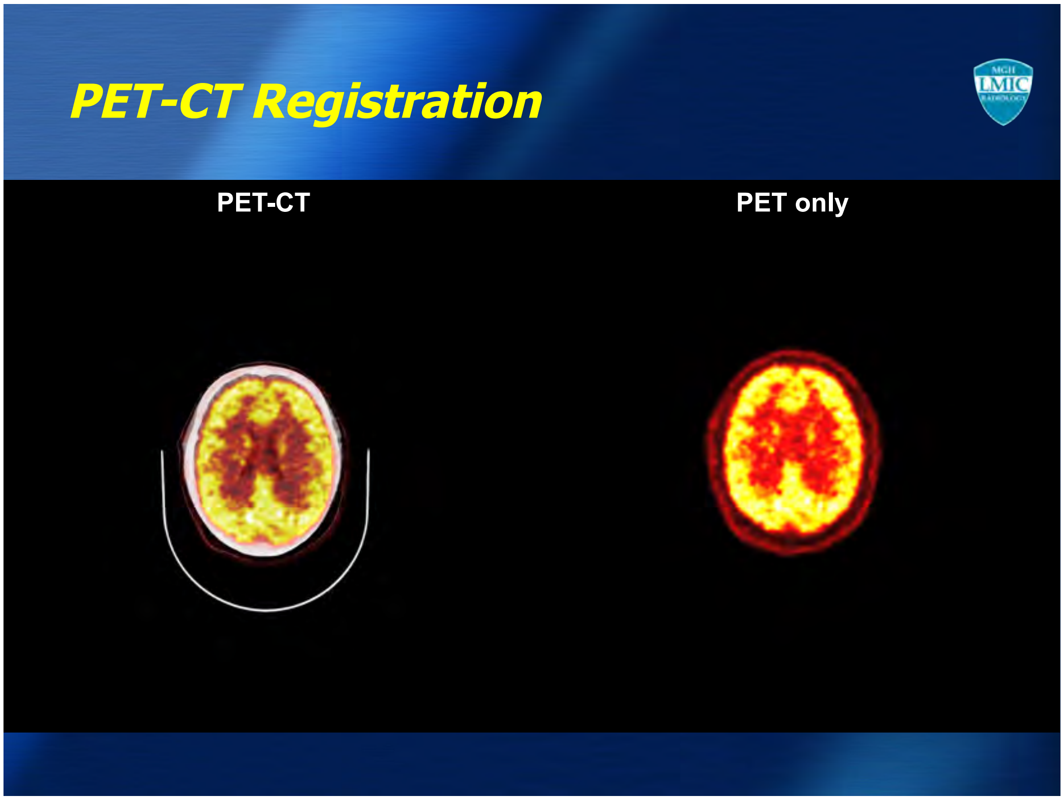
Von Schulthess et al, "Integrated PET/CT: current applications and future directions," Radiology, 328, 2006.



Attenuation Correction

Attenuation Corrected

Uncorrected



PET-CT Registration

PET-CT

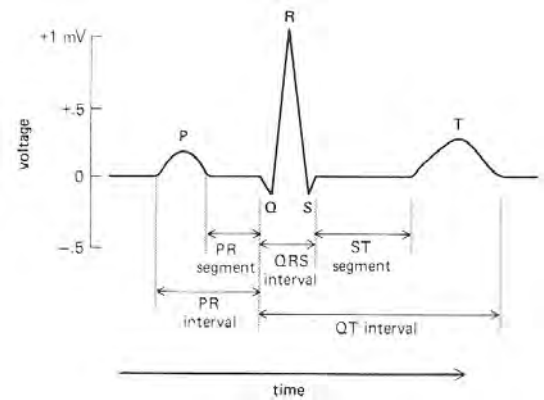
PET only

Problem

ACUTE CORONARY SYNDROME (ACS)

- ❑ Patient enters the Emergency Room complaining of sharp chest pains
- ❑ How should the ER triage the patient?

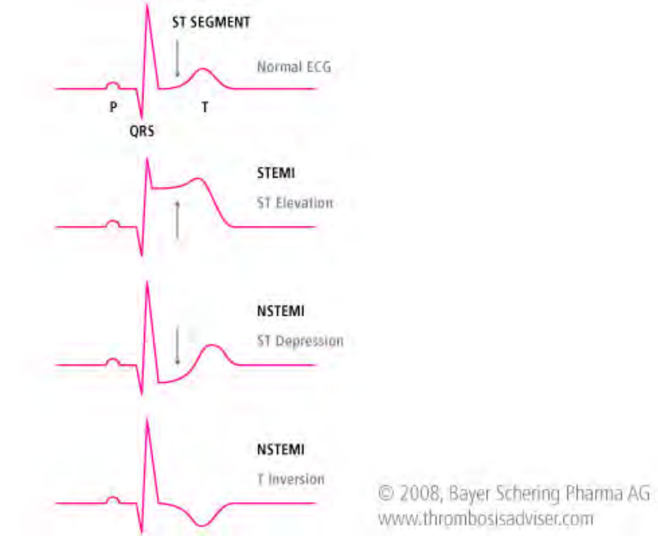
EKG



- ❑ QRS complex
  - ➢ Ventricular depolarization
- ❑ T
  - ➢ Ventricular repolarization
- ❑ ST
  - ➢ STEMI
  - ➢ NSTEMI

Mohrman and Heller, Cardiovascular Physiology, McGraw Hill, 2006.

EKG



© 2008, Bayer Schering Pharma AG
www.thrombosisadviser.com

ACS Triage- 1988

Triage decisions based on case history, symptoms, and EKG

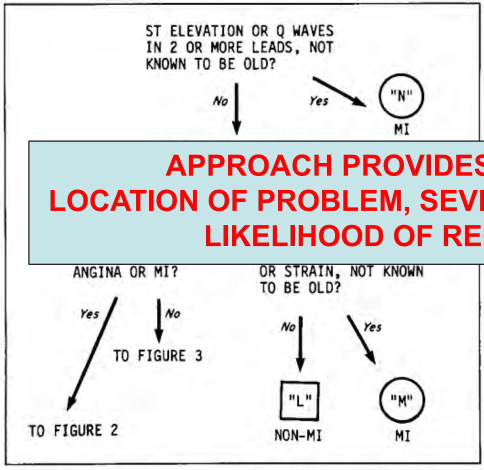


Figure 1. Computer Protocol for the Evaluation of Patients with Acute Chest Pain in the Emergency Department.

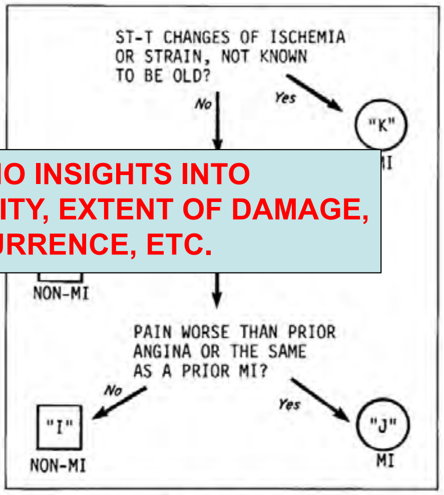


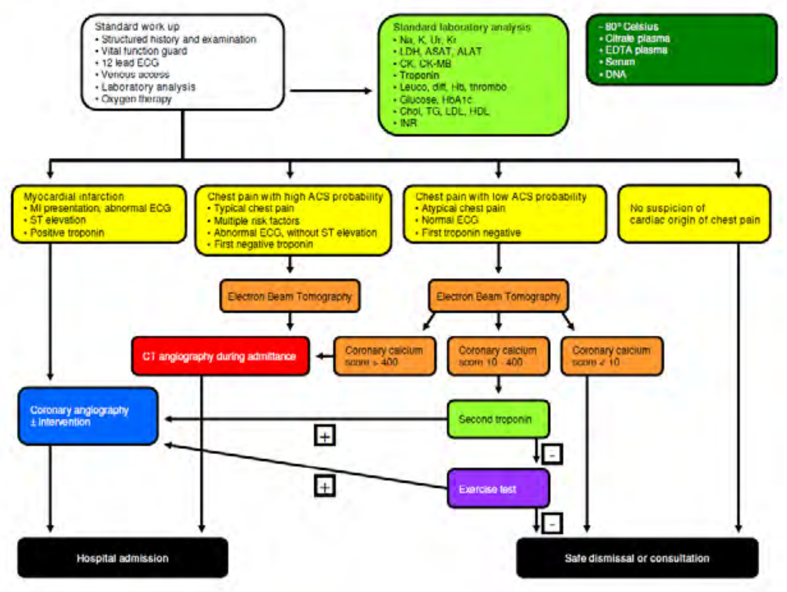
Figure 2. Questions to Be Asked of Patients with a History of Angina or Myocardial Infarction (MI) Who Do Not Have New ST Elevation or Q Waves and Whose Pain Began Less Than 48 Hours Previously.

APPROACH PROVIDES NO INSIGHTS INTO LOCATION OF PROBLEM, SEVERITY, EXTENT OF DAMAGE, LIKELIHOOD OF RECURRENCE, ETC.

Goldman et al, NEJM, 3/31/1988

ACS Triage - 2009

Triage now consists of:
- **History / risk factors**
- **Blood test / enzymes**
- **EKG**
- **Symptoms**
- **Imaging**
- **Progression of enzymes**

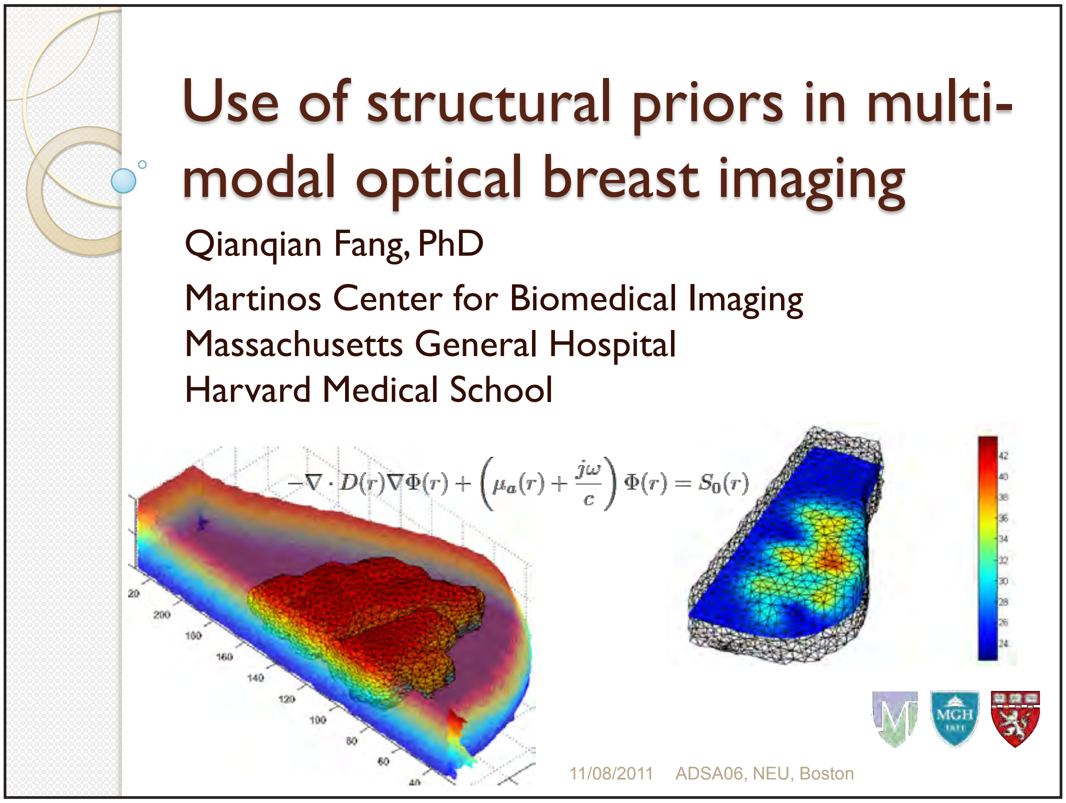


Willemsen et al, BMC Cardiovascular Disorders, 2009

Summary

- ❑ Two case studies:
  - PET versus PET-CT
  - Triage of Acute Coronary Syndrome (ACS) patients in ERs
- ❑ PET-CT
  - There was considerable a priori justification why a fused system would be beneficial
    - Better registration, correlation between structure and function, attenuation correction, quantitation
  - PET-CT fusion was being done manually before hybrid systems were commercially introduced
- ❑ ACS
  - While ACS triage continues to evolve, there is a priori justification why fusion of disparate sources of information is beneficial
    - Permits individualized assessment of the patient
    - Results in significantly better outcomes of patients

16.6 Qianqian Fang: Combined optical and x-ray Mammography



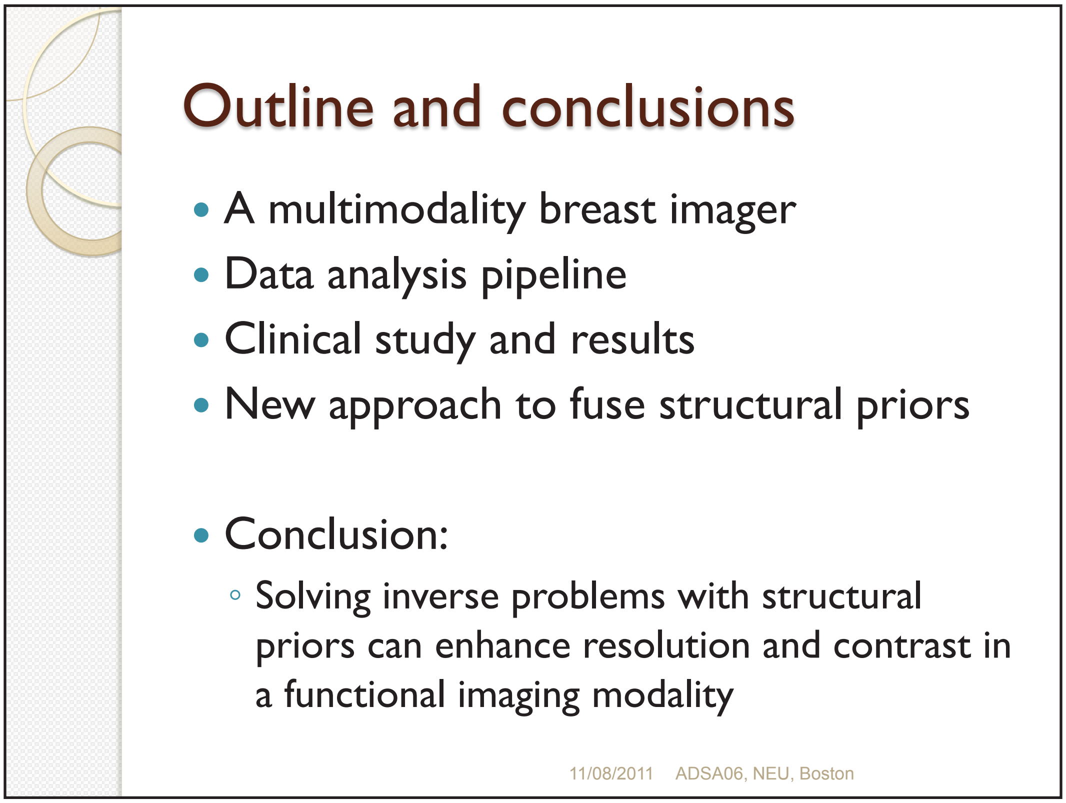
Use of structural priors in multi-modal optical breast imaging

Qianqian Fang, PhD

Martinos Center for Biomedical Imaging
Massachusetts General Hospital
Harvard Medical School

$$-\nabla \cdot D(r)\nabla\Phi(r) + \left(\mu_a(r) + \frac{j\omega}{c}\right)\Phi(r) = S_0(r)$$

11/08/2011 ADSA06, NEU, Boston



Outline and conclusions

- A multimodality breast imager
- Data analysis pipeline
- Clinical study and results
- New approach to fuse structural priors

- Conclusion:
  - Solving inverse problems with structural priors can enhance resolution and contrast in a functional imaging modality

11/08/2011 ADSA06, NEU, Boston

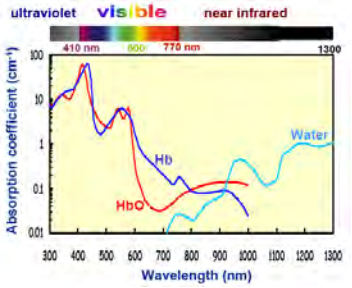
Breast imaging: clinical challenges

- Breast cancer results in ~40,000 death per year in the US
- Mammography discovers 80% of the cancers, but also results in unnecessary biopsy 70~80%
- Mammography misses 44% early cancers (DCIS)
- Difficulty in dense breasts (in younger people)

- Good penetration and high contrast makes optical imaging a promising candidate

Tissue absorption and chromophores

- Low absorption between 600nm-1000nm (near-infrared)
- Distinct absorption spectra:
  - Oxygenated hemoglobin (HbO)
  - Deoxygenated hemoglobin (HbR)
  - Water
  - Lipids



- By measuring absorptions at multiple wavelengths, one can calculate the concentrations of the chromophores

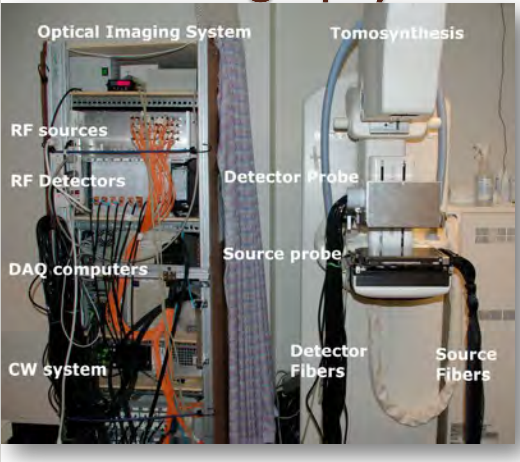
Near-infrared spectroscopy for the study of biological tissue
Angelo Sassaroli, et al. Tufts Univ

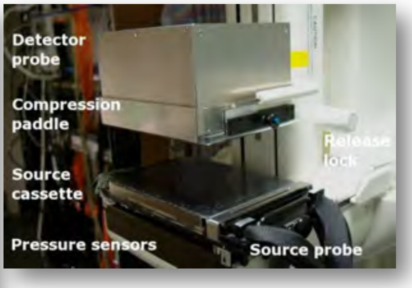
Difficulties in optical image reconstructions

- Photon transport is highly non-linear
  - Must use advanced computational models
- Inverse problem is ill-posed: sensitive to noise
  - Must smooth the solution to gain stability
- Sparse source/detector locations
  - Limited sampling of the target domain
- Generally resulting in functional images with poor resolution

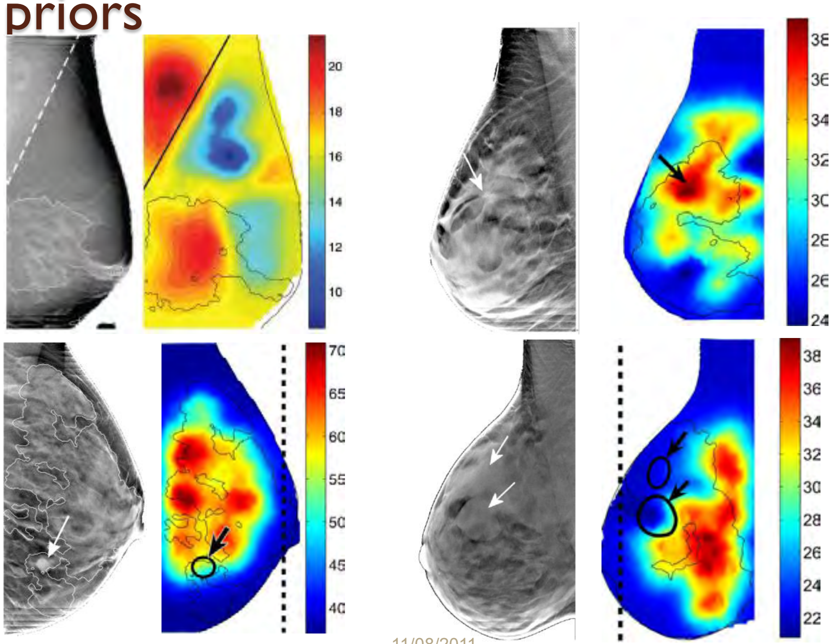
- **Win-win**: Data fusion from X-ray structure

Combined DOT with mammography



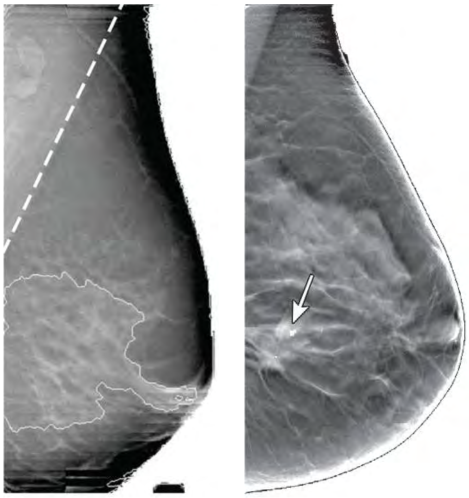


Reconstruction without structural priors

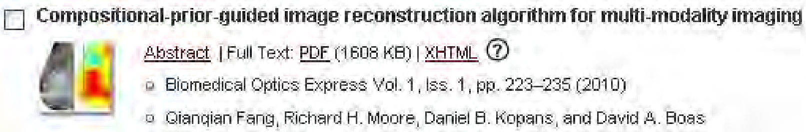


11/08/2011 Fang Q, et al., Radiology, 258(1): 89-97, 2011.

Limitations of binary segmentation



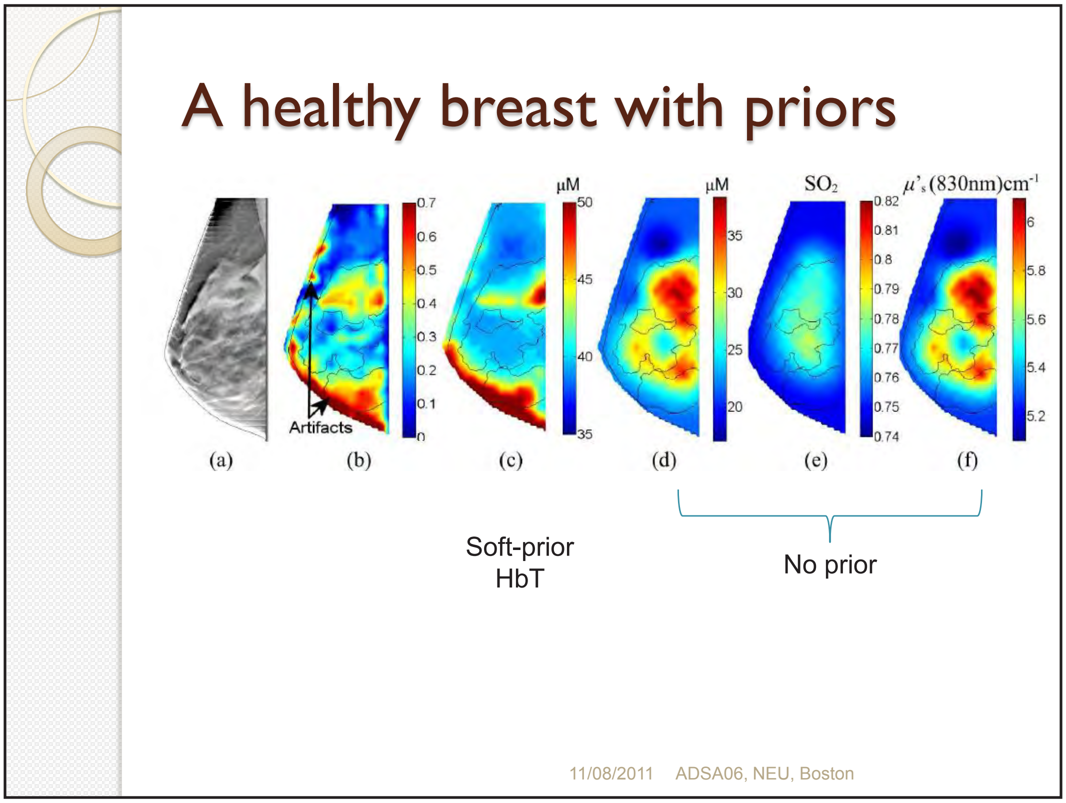
- Not all tissues can be well separated
- Fine structure info is lost
- Introduces segmentation error, sometimes it counter-weights the benefit of the prior



☐ **Compositional-prior-guided image reconstruction algorithm for multi-modality imaging**

Abstract | Full Text: PDF (1608 KB) | XHTML ?

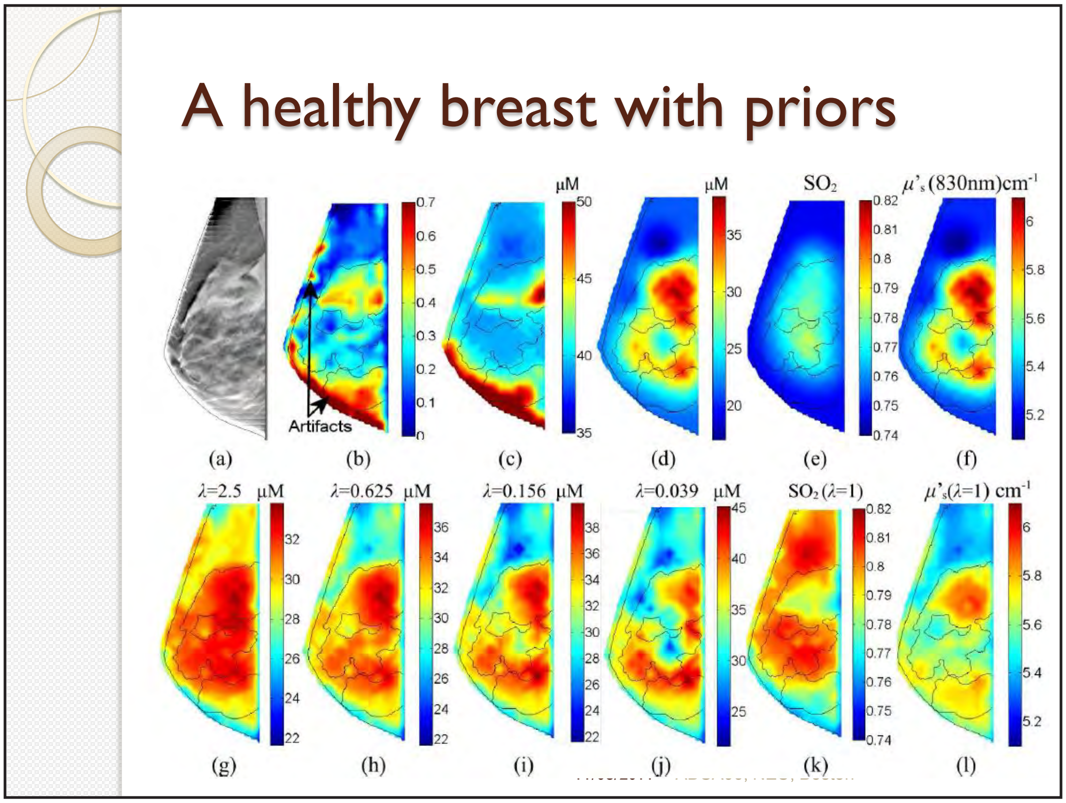
- Biomedical Optics Express Vol. 1, Iss. 1, pp. 223–235 (2010)
- Qianqian Fang, Richard H. Moore, Daniel B. Kopans, and David A. Boas



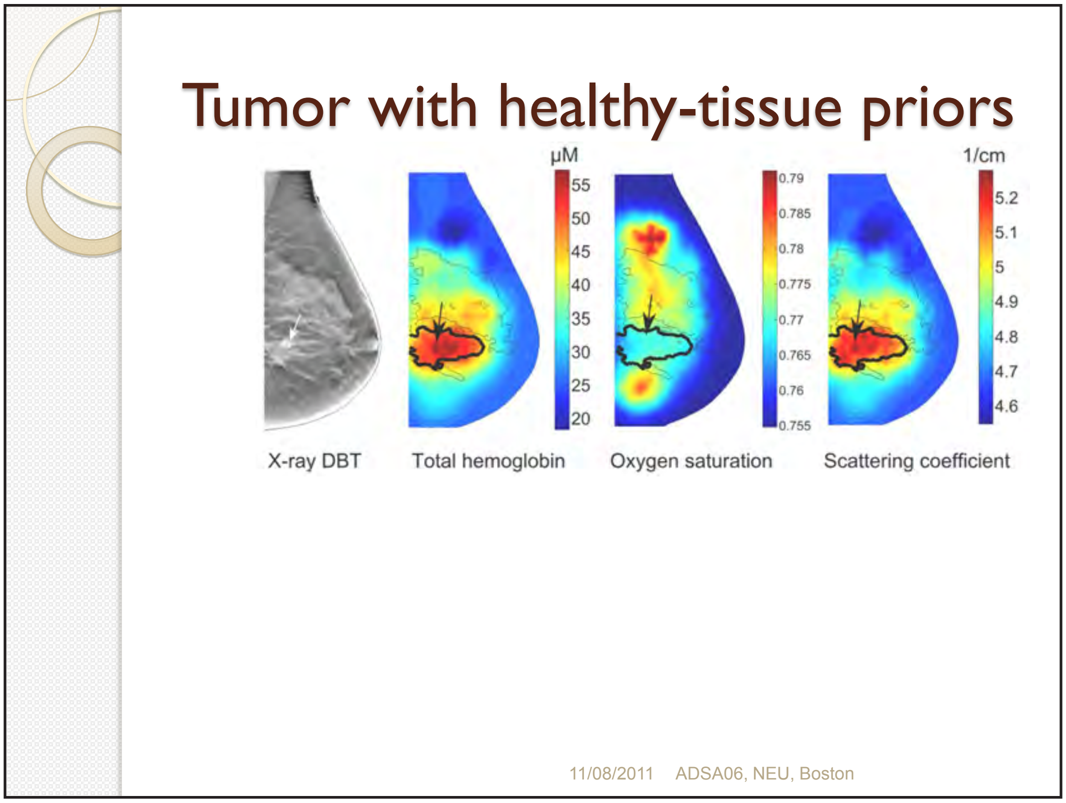
A healthy breast with priors

Soft-prior
HbT

No prior



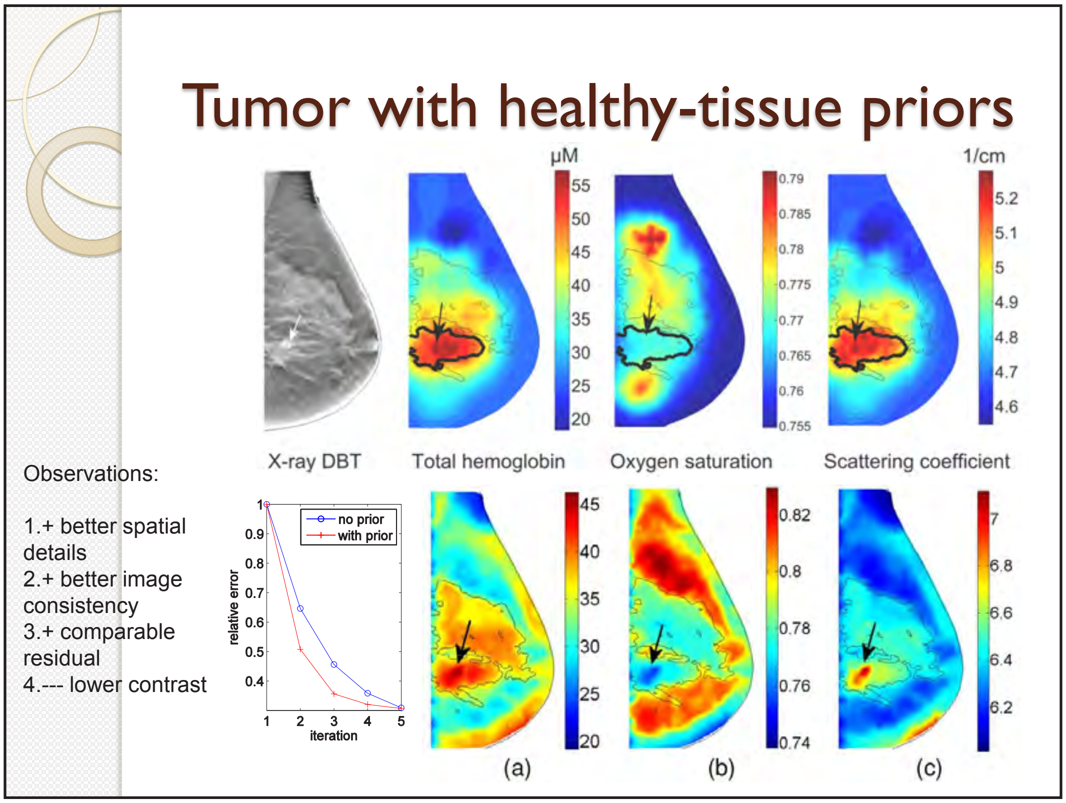
A healthy breast with priors



Tumor with healthy-tissue priors

X-ray DBT Total hemoglobin Oxygen saturation Scattering coefficient

11/08/2011 ADSA06, NEU, Boston



Tumor with healthy-tissue priors

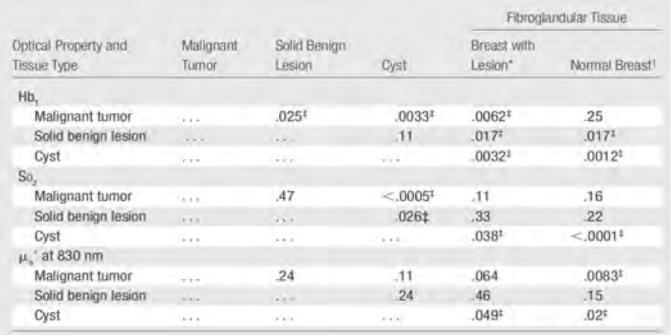
X-ray DBT Total hemoglobin Oxygen saturation Scattering coefficient

Observations:

1.+ better spatial details
2.+ better image consistency
3.+ comparable residual
4.--- lower contrast

(a) (b) (c)

Statistical tests (p-values)



Optical Property and Tissue Type	Malignant Tumor	Solid Benign Lesion	Cyst	Fibroglandular Tissue: Breast with Lesion*	Fibroglandular Tissue: Normal Breast†
Hb_T					
Malignant tumor	. . .	.025‡	.0033‡	.0062‡	.25
Solid benign lesion	. . .	. . .	.11	.017‡	.017‡
Cyst	. . .	. . .	. . .	.0032‡	.0012‡
So_2					
Malignant tumor	. . .	.47	<.0005‡	.11	.16
Solid benign lesion	. . .	. . .	.026‡	.33	.22
Cyst	. . .	. . .	. . .	.038‡	<.0001‡
μ_s' at 830 nm					
Malignant tumor	. . .	.24	.11	.064	.0083‡
Solid benign lesion	. . .	. . .	.24	.46	.15
Cyst	. . .	. . .	. . .	.049‡	.02‡

HbT	Malignant	Solid Benign	Cyst	Fibrogland.	Fibrogland.
Malignant (26)		0.04	0.13 x	0.08 x	0.48
Solid Benign (17)			0.49	0.07 x	0.19 x
Cyst (8)				0.03	0.02
SO_2					
Malignant (26)		0.23	0.35 x	0.36	0.46
Solid Benign (17)			0.19	0.26	0.46
Cyst (7)				0.06	0.44 x
μ_s' at 830nm					
Malignant (26)		0.41	0.24	0.008 v	0.46 x
Solid Benign (17)		0.41	0.13	0.21	
Cyst (7)				0.04	0.24 x

Using only the healthy tissue structures reduces tumor contrast and statistical significance

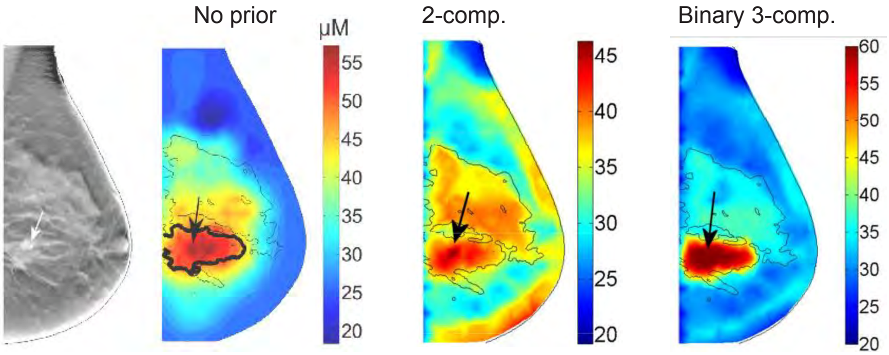
---

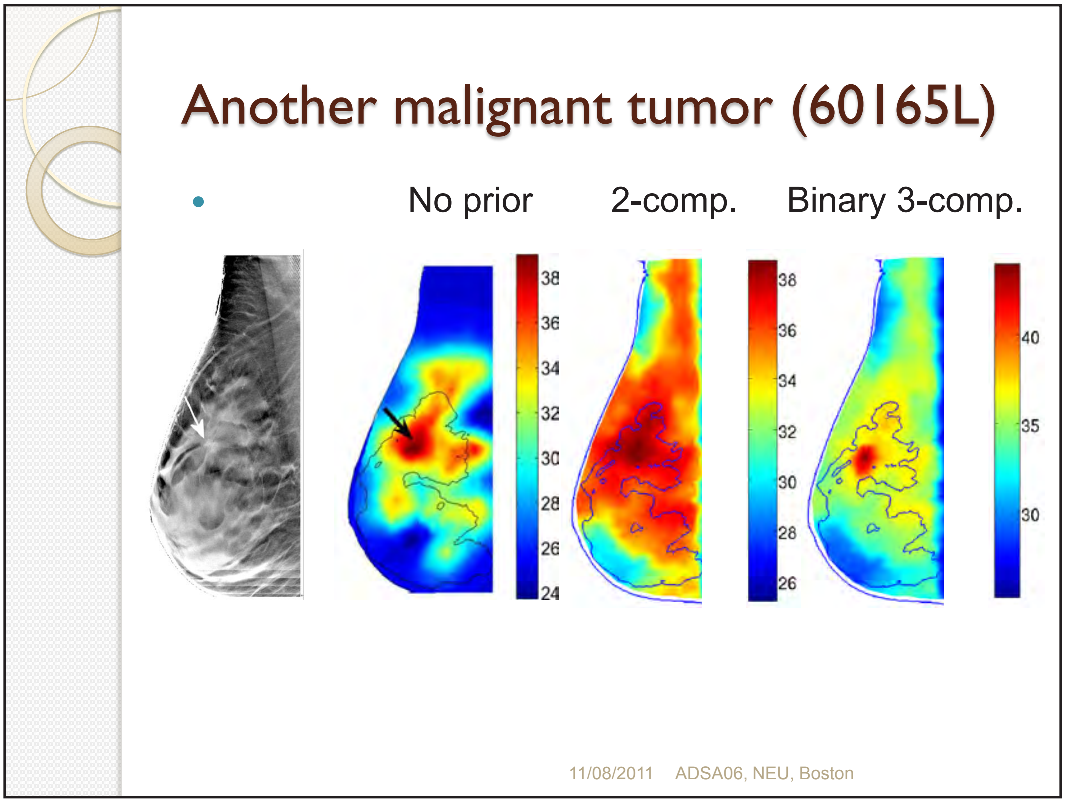
Add additional tumor priors

$$\mathbf{C}= \{C_a,\ C_f,\ C_t\}$$

$$\begin{array}{ccc} A_1 & F_1 & 0 \\ 0 & 0 & 1 \\ A_3 & F_3 & 0 \end{array}$$

→ inside tumor ROI





Another malignant tumor (60165L)

- No prior 2-comp. Binary 3-comp.

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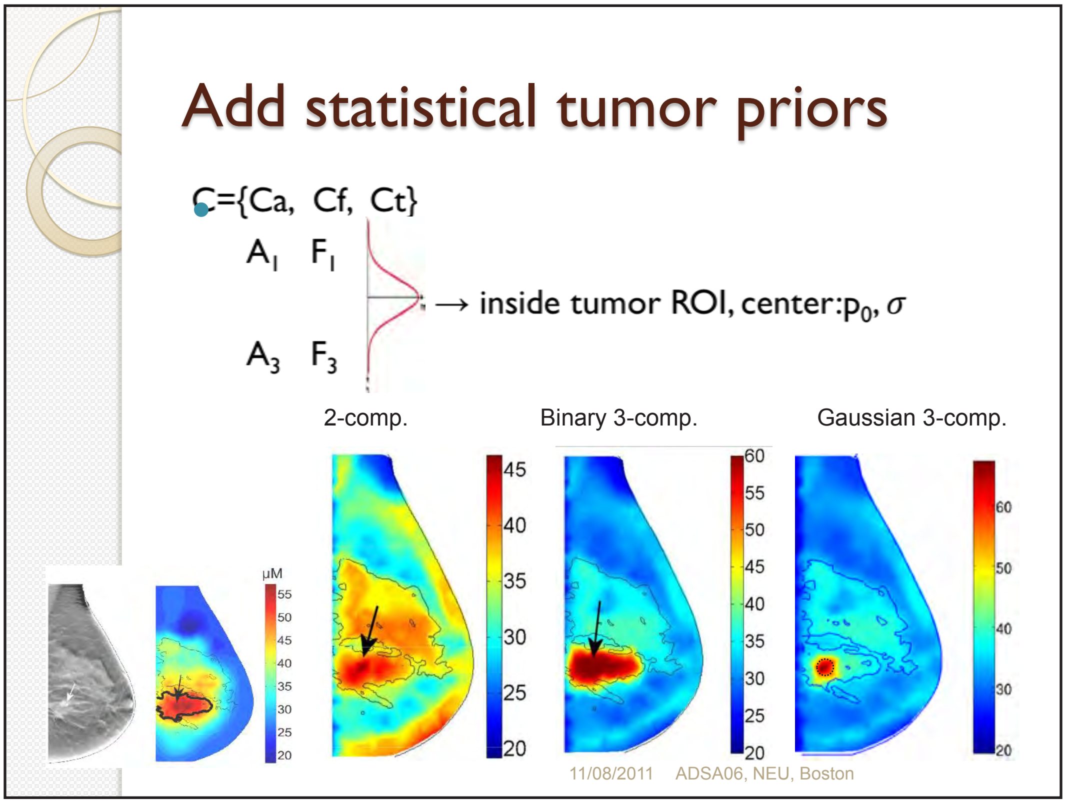


Add statistical tumor priors

- $C=\{Ca,\ Cf,\ Ct\}$

A_1 F_1

A_3 F_3

→ inside tumor ROI, center:p_0, σ

2-comp. Binary 3-comp. Gaussian 3-comp.

11/08/2011 ADSA06, NEU, Boston

Conclusions

- Optically derived physiological parameters correlate with tumor malignancy and can be potentially used to differentiate malignant from benign lesions and reduce false positives.
- Fusing x-ray tissue structure into optical image reconstruction is highly beneficial by dramatically improving the spatial resolution and contrast of the tumors.

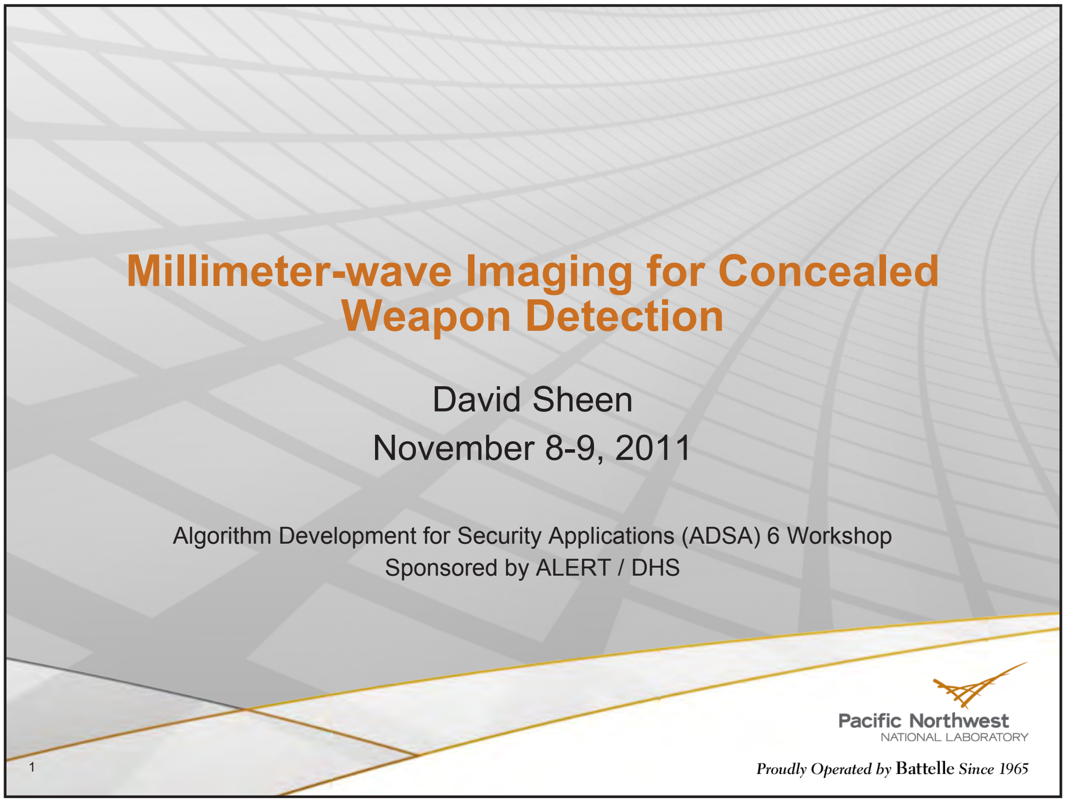
- TODO:
  - Statistical tests for tumor-prior reconstructions
  - Interactive diagnosis powered by real-time reconstruction
  - Efficient algorithm to define tumor priors (as part of the optimization, search algorithm, multi-foci, shape-based)

Acknowledgement

- Martinos Center
  - David Boas
  - Stefan Carp
- Avon Center
  - Daniel Kopans
  - Richard Moore
  - Jayne Cormier
  - Donna Burgess
- Collaborators
  - Dana Brooks
  - Eric Miller

- Funding support:
  - NIH R01-CA097305
  - NIH R01-CA142575
  - MLSC 2011D000334

16.7 David Sheen: Millimeter-wave AIT review



Millimeter-wave Imaging for Concealed Weapon Detection

David Sheen
November 8-9, 2011

Algorithm Development for Security Applications (ADSA) 6 Workshop
Sponsored by ALERT / DHS

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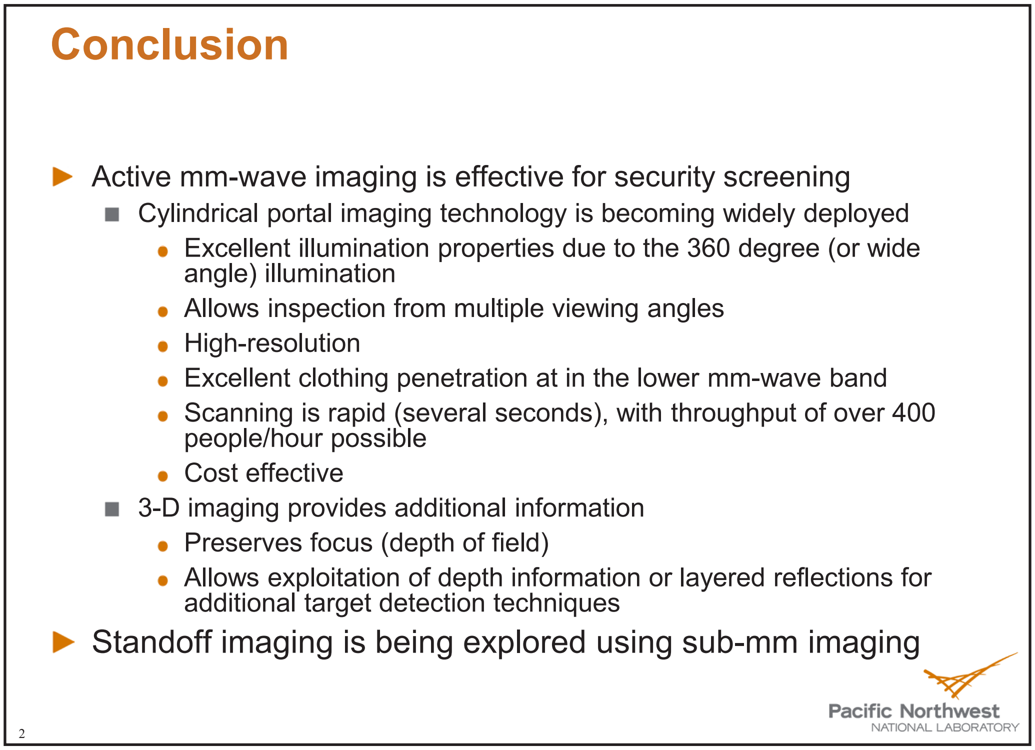

Conclusion

- Active mm-wave imaging is effective for security screening
  - Cylindrical portal imaging technology is becoming widely deployed
    - Excellent illumination properties due to the 360 degree (or wide angle) illumination
    - Allows inspection from multiple viewing angles
    - High-resolution
    - Excellent clothing penetration at in the lower mm-wave band
    - Scanning is rapid (several seconds), with throughput of over 400 people/hour possible
    - Cost effective
  - 3-D imaging provides additional information
    - Preserves focus (depth of field)
    - Allows exploitation of depth information or layered reflections for additional target detection techniques
- Standoff imaging is being explored using sub-mm imaging

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Terrorist Threats

- Explosives
- Suicide vests
- Weapons
  - Guns
  - Knives
  - Etc.
- Nuclear, biological, or chemical materials carried in sealed containers

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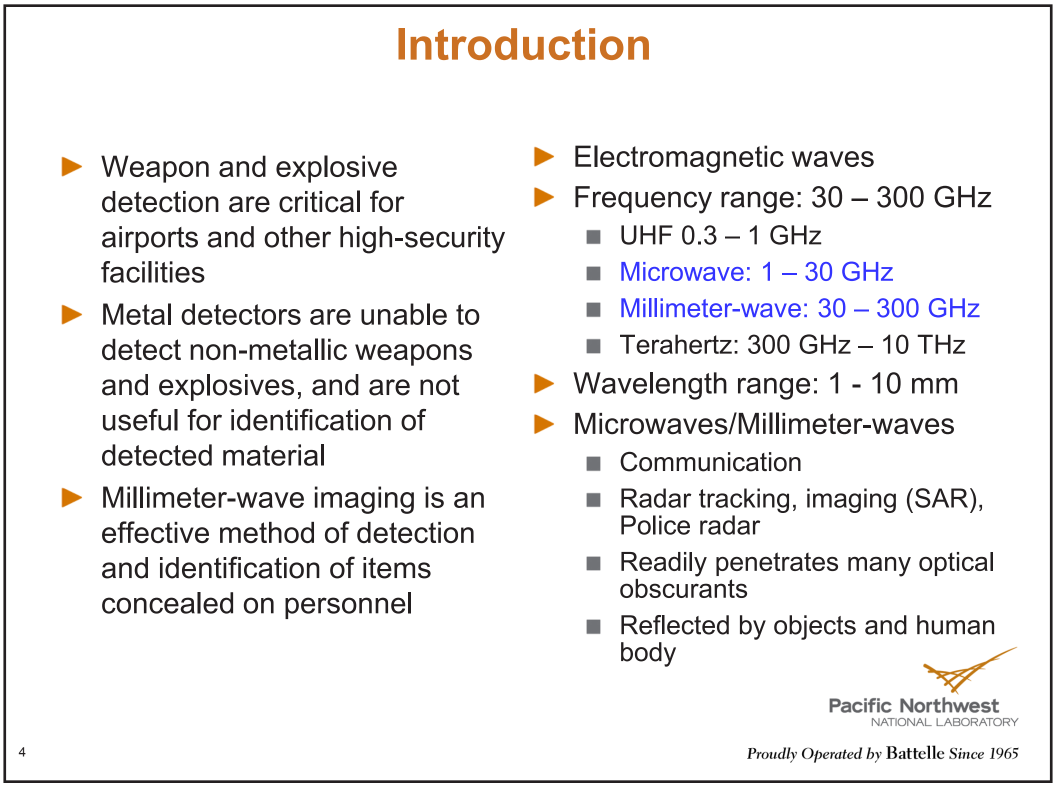

Introduction

- Weapon and explosive detection are critical for airports and other high-security facilities
- Metal detectors are unable to detect non-metallic weapons and explosives, and are not useful for identification of detected material
- Millimeter-wave imaging is an effective method of detection and identification of items concealed on personnel

- Electromagnetic waves
- Frequency range: 30 – 300 GHz
  - UHF 0.3 – 1 GHz
  - Microwave: 1 – 30 GHz
  - Millimeter-wave: 30 – 300 GHz
  - Terahertz: 300 GHz – 10 THz
- Wavelength range: 1 - 10 mm
- Microwaves/Millimeter-waves
  - Communication
  - Radar tracking, imaging (SAR), Police radar
  - Readily penetrates many optical obscurants
  - Reflected by objects and human body

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Weapon Detection Imaging Technologies

- Active millimeter-wave
  - Battelle, PNNL (wideband holographic)
  - L3-Communications / SafeView (commercial partner)
  - Smiths (Agilent technology)
- Passive millimeter-wave imaging systems using FPA's and high-speed scanning
  - Qinetic
  - Trex
  - ThruVision
  - Millivision
  - others
- Low-power X-ray backscatter imaging
  - AS&E Inc. (*BodySearch*)
  - Rapiscan (*Secure 1000*)

Brijot Passive Millimeter-wave Imaging System

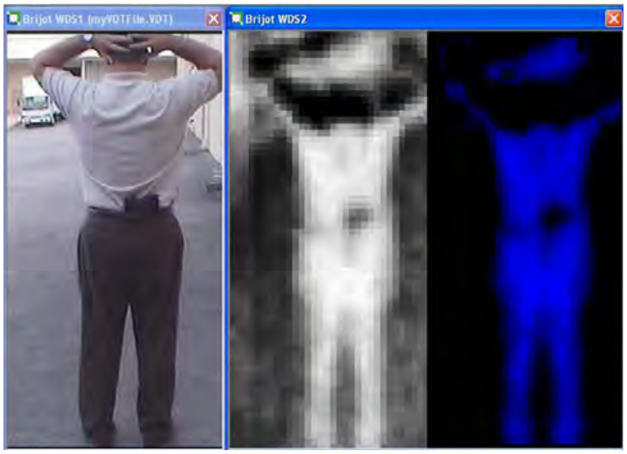
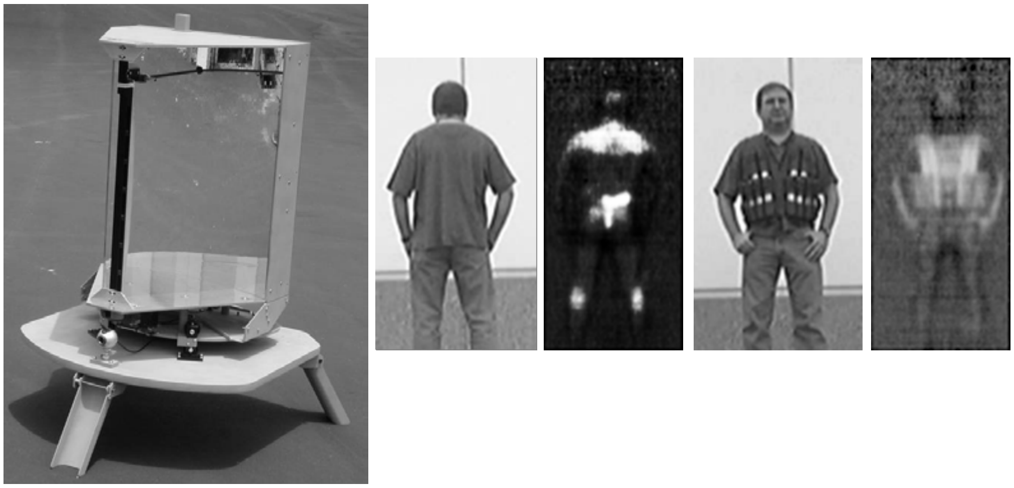


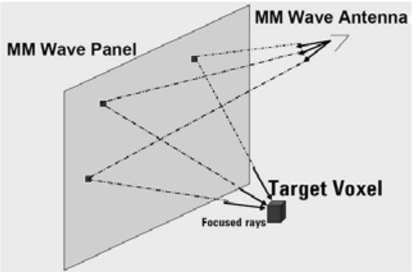
Image from the Brijot BIS-WDS™ Prime that shows a concealed handgun at the rear belt line (Images courtesy of Brijot Imaging Systems)

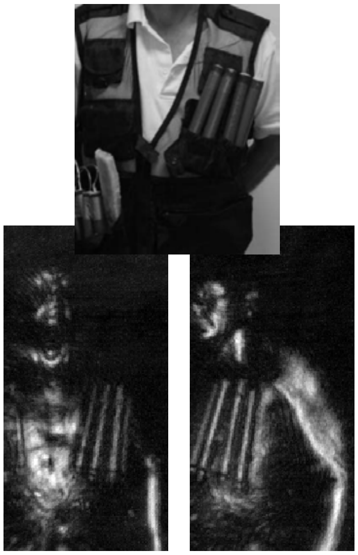
Trex / Sago Passive Millimeter-wave Imaging System



Sago ST150 passive millimeter-wave imaging concealed weapon detection system (Images courtesy of Trex Enterprises / Sago)

Agilent Active MM-wave Imaging Technology





Agilent reflector array operation. Millimeter-wave reflector array panel alters the phase of the transmitted wavefront to allow high-speed digitally controlled focusing over a range of target voxel locations. (Images courtesy of Agilent).

PNNL Active Wideband Holographic Imaging

Wideband Image of Mannequin and Concealed Glock 17 (100 - 112 GHz)

Optical

100 - 112 GHz

Advantages of Millimeter-wave Holographic Imaging Technique

- Active scanned source imaging results in 2X improvement in image resolution
- Near-field, large aperture, for simultaneous high resolution, wide illumination imagery
- Focusing done using computer reconstruction, no lens or reflector required
- Wideband techniques enable 3-D volumetric imaging
- Millimeter-waves are low power and non-ionizing and pose no health threat
- Wide angular illumination suppresses undesirable specular reflection of many targets

- Lateral Resolution

$$\delta_x = \frac{\lambda}{2} F\# \\ = 0.5 \text{ cm at } 30 \text{ GHz}$$

- Range Resolution

$$\delta_r = \frac{c}{2B} \\ = 2.5 \text{ cm at } 27 - 33 \text{ GHz}$$

Licensed Commercial Cylindrical Holographic Imaging Systems

PNNL cylindrical prototype system

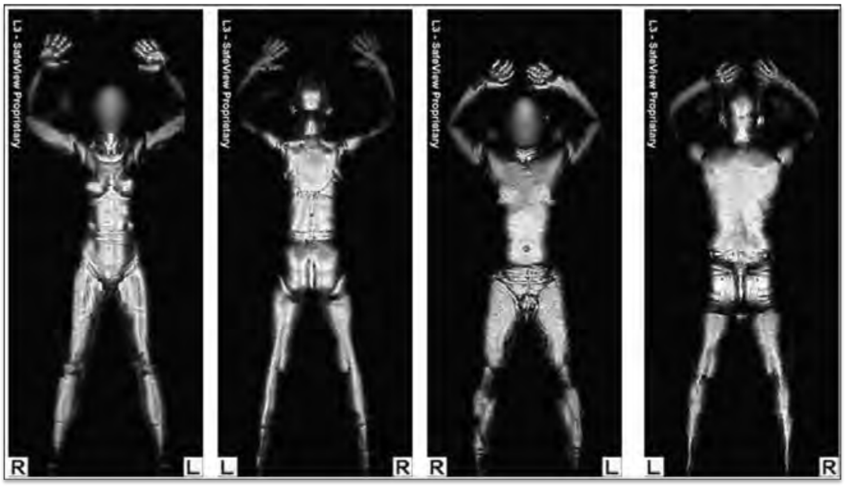
L-3 ProVision system deployed in London

Intellifit body measurement system

L-3 ProVision

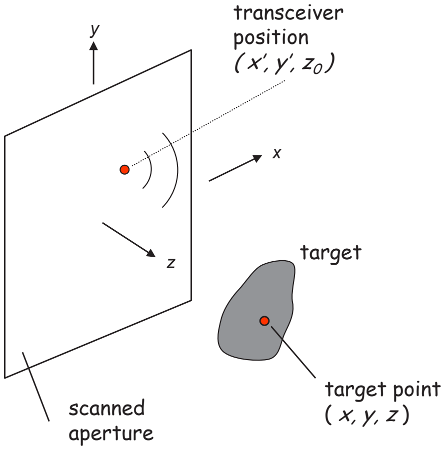
- Active Millimeter Wave Portal
  - 24.5-30 GHz
  - 2 384 element arrays
  - Detects metals, and non-metals (ceramics, wood, plastic, etc.)
  - Liquids and gels
  - Paper and coin currency
  - Safe radio waves, low power, non-ionizing (not x-ray)
  - Walk-through – stop 2 seconds
  - Fast: 300 – 600 people per hour

Millimeter-wave Images from the L-3 ProVision™ system

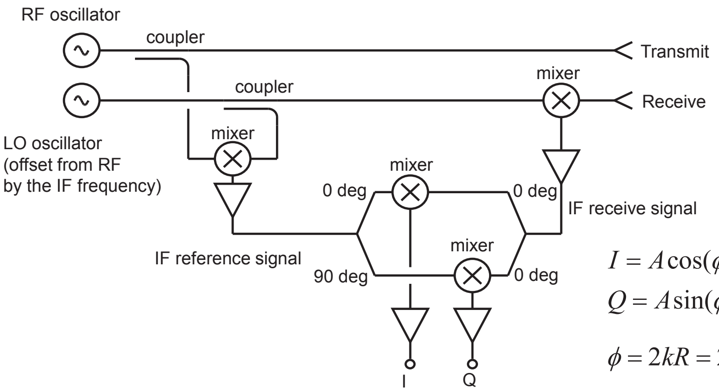


Holographic Millimeter-wave Imaging Technique

- Transmit antenna emits diverging (spherical) wave
- Receiver records amplitude and phase of scattered wavefront
- Transmitter/receiver, or transceiver, is scanned over a two-dimensional planar aperture and swept over a wide frequency bandwidth
- 3-D image formed using mathematical focusing
  - Holographic, wavefront reconstruction
  - Fourier transform based - efficient



Millimeter-wave Transceiver (Heterodyne)



$$I = A\cos(\phi)$$

$$Q = A\sin(\phi)$$

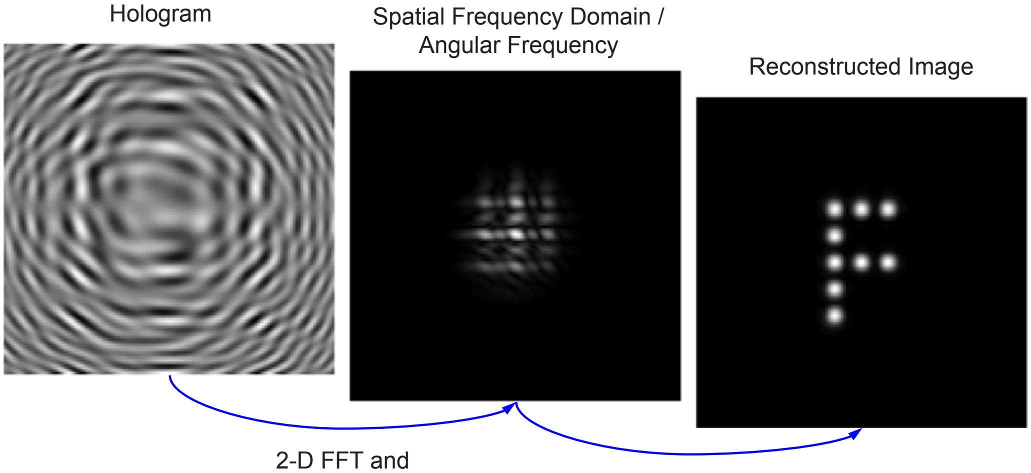
$$\phi = 2kR = 2\frac{2\pi}{\lambda}R = 2\frac{2\pi f}{c}R$$

$$\phi = \ 2\pi \text{ times the number of } \lambda\text{'s}$$
$$\text{to target and back}$$

Measures phase and amplitude of scattered wavefront with high sensitivity

---

Holographic Image Reconstruction

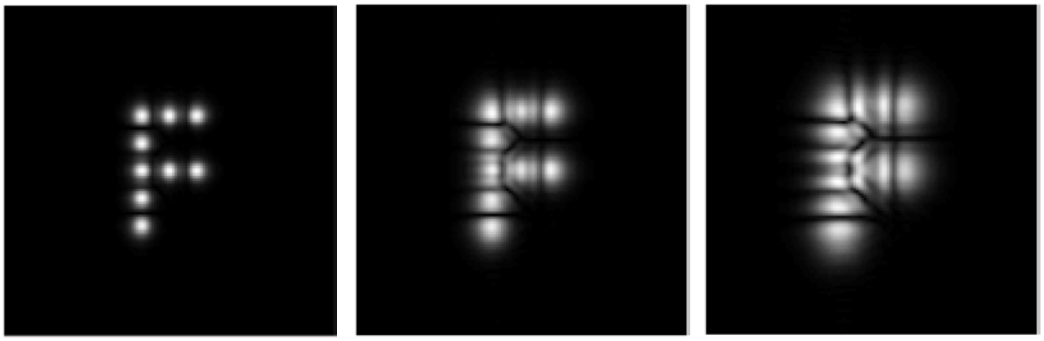


2-D FFT and
Back-propagator

Inverse 2-D FFT and
magnitude

Holographic Reconstruction – Depth of Focus

- A depth must be specified for single frequency holographic image reconstruction



50 cm (correct)　54 cm　58 cm

Increasing Reconstruction Depth →

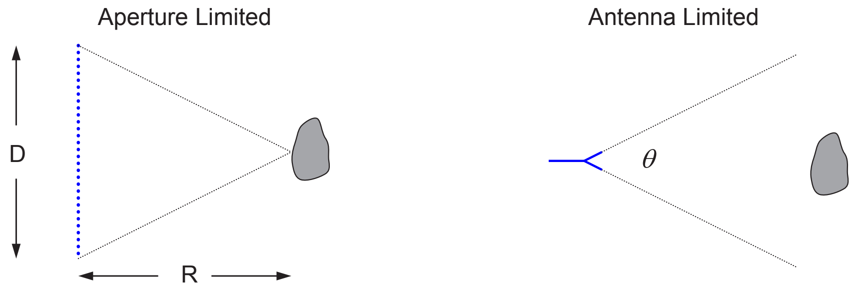
Image goes out of focus unless depth to target is known (and constant)

Wideband 3-D Image Reconstruction

- Limitations of single frequency holographic imaging
  - Cannot measure the range to the target and therefore the correct depth of focus is unknown
  - Images of objects that have a range of depths cannot be in complete focus, i.e. only portions of the image will be focus
- Recording the amplitude and phase of the wavefront over a range of frequencies can provide fully 3-D imaging
- 3-D Algorithm
  - 2-D Spatial Fourier Transforms decompose wavefronts into plane waves at known angles
  - Interpolation onto uniform 3-D spatial frequency domain grid
  - Phase term back-propagates the plane wave to the object's plane
  - 3-D Spatial Inverse Fourier Transform converts back to spatial domain
  - Maximum value projection typically shown – full 3-D information available

Image Resolution

- Image resolution is determined by the wavelength and the angular extent of the illumination
- The angular extent can be limited by the size of the aperture (aperture limited), or by the beamwidth of the antenna (antenna limited)



$$\delta_x = \frac{\lambda}{4\sin(\theta/2)} \approx \frac{\lambda}{2}F^{\#} \qquad \text{where } F^{\#} = \frac{R}{D}$$

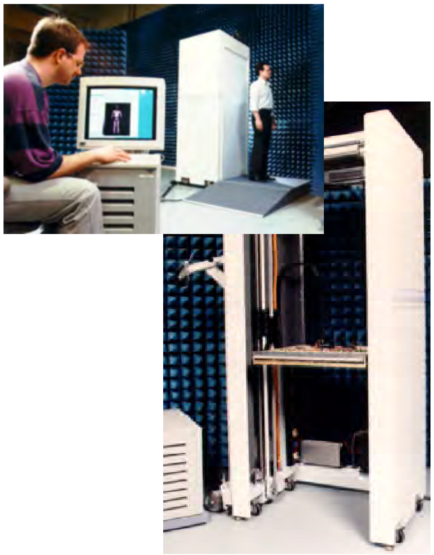
Range Resolution

- Range resolution is determined by the bandwidth of the system
- The distance between two distinct targets must be sufficiently large so that one additional cycle is generated in the I or Q waveforms during the sweep

$$\delta_r = \frac{c}{2B}$$

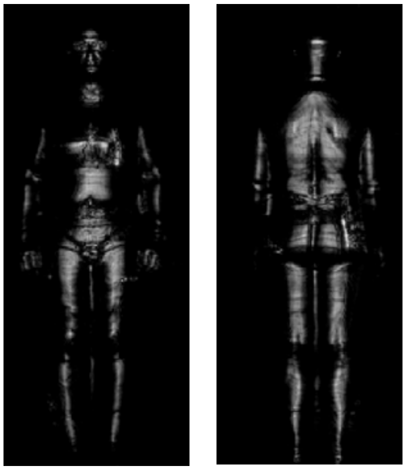
- For example, a bandwidth of 10 GHz (e.g. 10-20 GHz operation) results in a range resolution of 1.5 cm

Prototype Wideband Imaging System

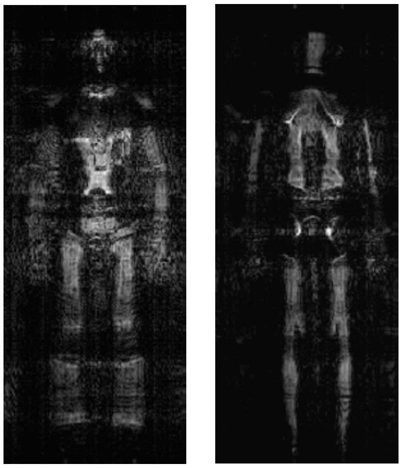


- K-a band switched linear array
- 27 - 33 GHz
- 128 elements
- Pin-diode switching
- 5.7 mm sampling
- 0.73 meter aperture

Comparison of Wideband and Narrow-band Millimeter-wave Images



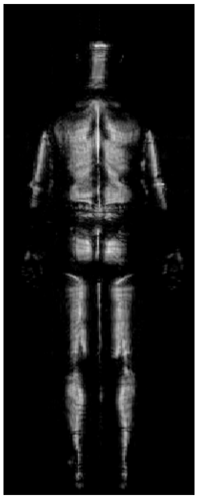
Wideband images of man at 27 - 33 GHz



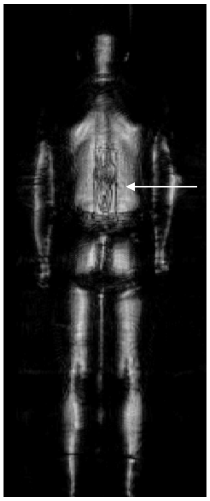
Narrowband images of man at 35 GHz

Wideband Image of a Man with Concealed RDX Plastic Explosive (27 – 33 GHz)

Optical - plastic explosive



No explosive



RDX

Concealed explosive

Wideband Images of Man with Plastic Explosive Simulant (27 – 33 GHz)

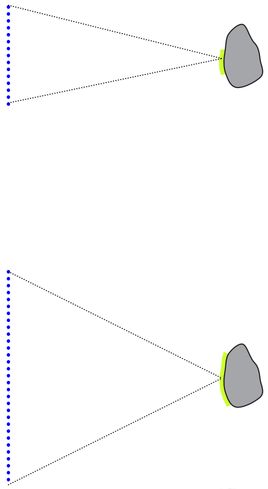
Optical - duct putty explosive simulant

No explosive

Concealed explosive

Wide Angle Illumination

- Wide-angle illumination is critical
  - Lateral resolution is proportional to 1/sin(θ)
  - Many targets are smooth compared to the wavelength in the microwave and millimeter-wave frequency ranges
  - Specular reflection will prevent scattered wavefront from returning to the transceiver
- Technique does not have inherent blind spots – images reflectivity, which can be low in the backscattered direction



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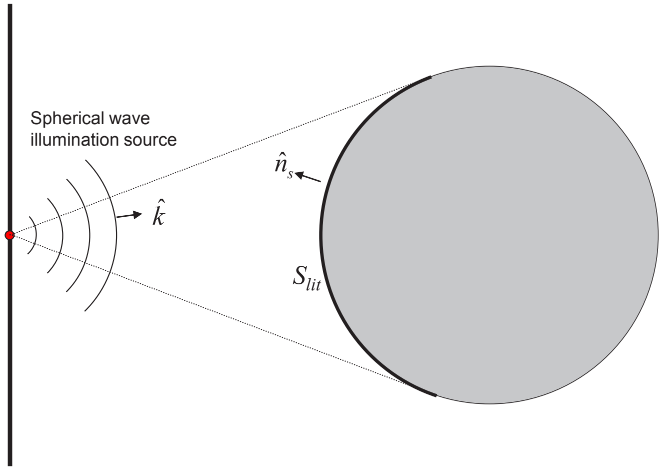
Physical Optics Scattering from a Cylinder



$$\bar{E}^s(\bar{r}) = \frac{jkZ_0}{4\pi}\iint_{S_{lit}} \hat{k}\times\hat{k}\times(2\hat{n}_s\times\bar{H}^i)\frac{e^{-jk|\bar{r}-\bar{r}'|}}{|\bar{r}-\bar{r}'|}dS$$

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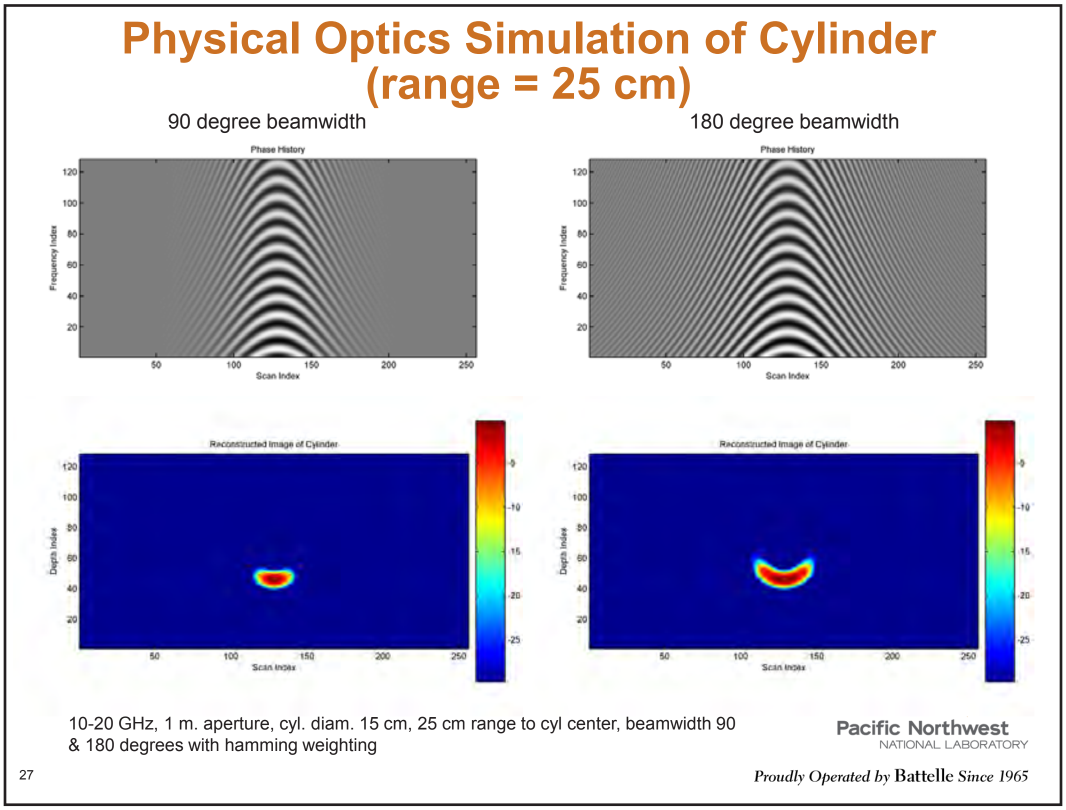
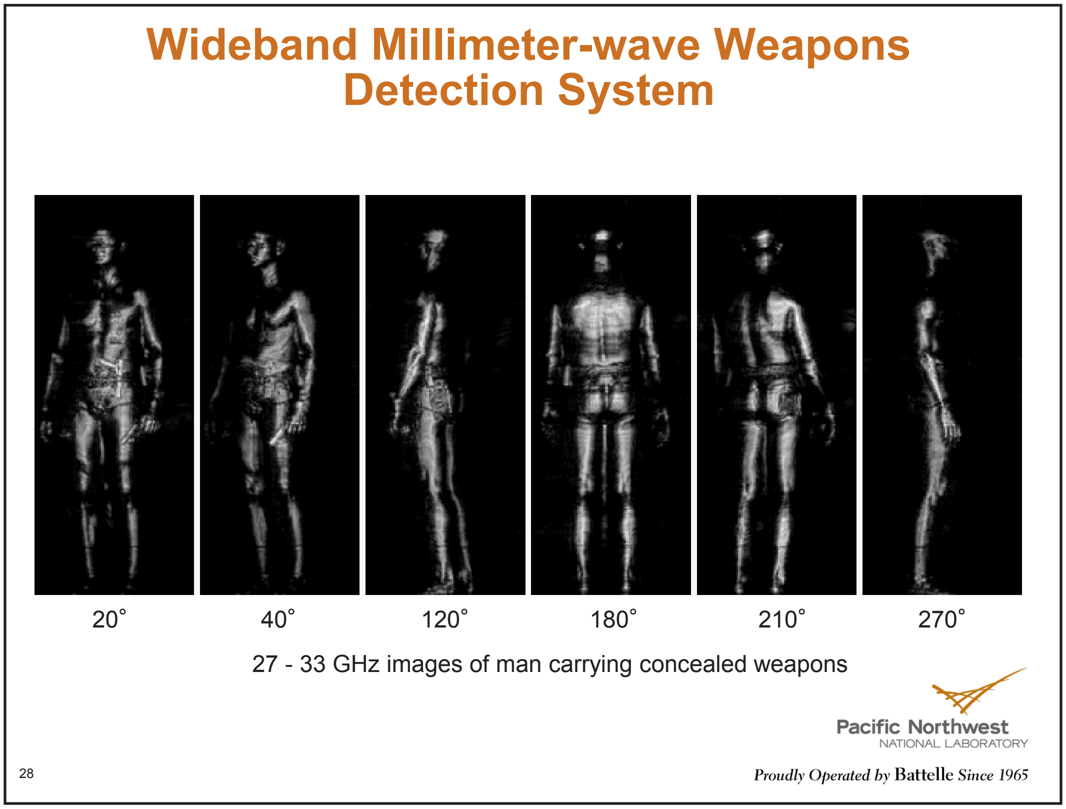


Physical Optics Simulation of Cylinder (range = 25 cm)

90 degree beamwidth

180 degree beamwidth

10-20 GHz, 1 m. aperture, cyl. diam. 15 cm, 25 cm range to cyl center, beamwidth 90 & 180 degrees with hamming weighting



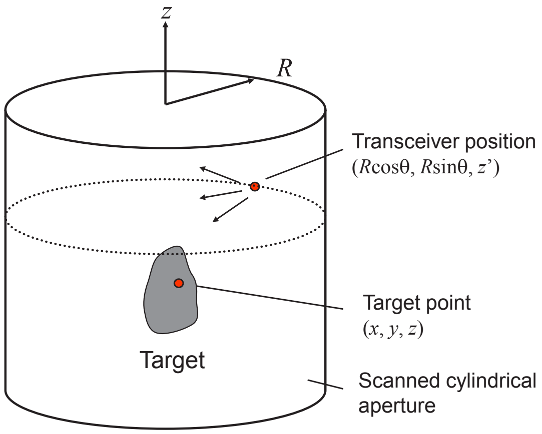
Wideband Millimeter-wave Weapons Detection System

20° 40° 120° 180° 210° 270°

27 - 33 GHz images of man carrying concealed weapons

Cylindrical Imaging Technique

- Novel wideband image reconstruction algorithm has been developed which allows for fully focused 3-D imagery from a single cylindrical data set
- Reconstruction algorithm based almost entirely on Fourier Transforms which are implemented efficiently using the FFT algorithm
- Algorithm is readily separated into parallel instructions for parallel processing computers
- Viewing angle may be rotated about the subject to form a 3-D video animation of the resulting image data



Transceiver position
$(R\cos\theta, R\sin\theta, z')$

Target point
(x, y, z)

Target

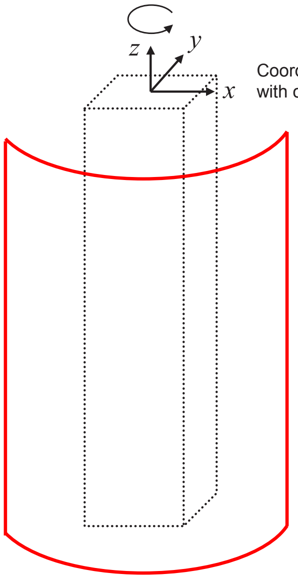
Scanned cylindrical aperture

Wideband reflection data gathered over a 2D cylindrical aperture

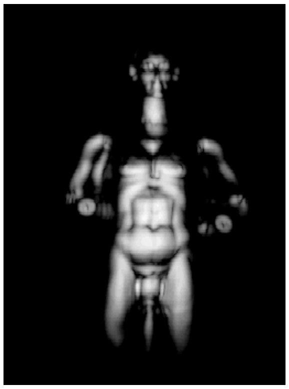
---

Rotating Target 3-D Reconstruction

- Reconstruction (x, y, z) volume rotates with angular arc segment
- Images are combined to form a video animation of the rotating target
- Bandwidth of millimeter-wave illumination is important for depth of field (focusing) only

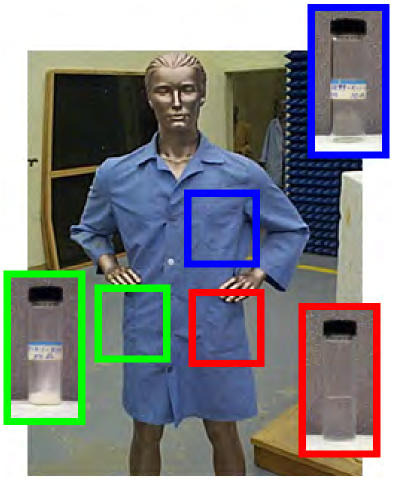


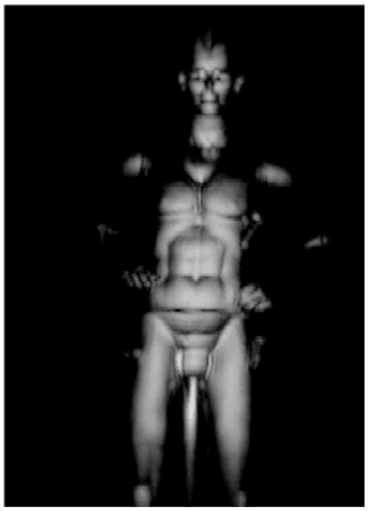
Coordinates rotate with center of arc



10-20 GHz cylindrical image reconstructions

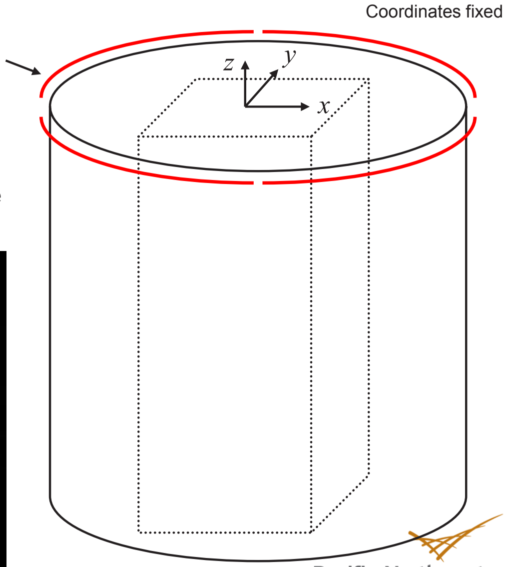
Cylindrical Imaging Results at 10 – 20 GHz


Optical – 3 glass vials

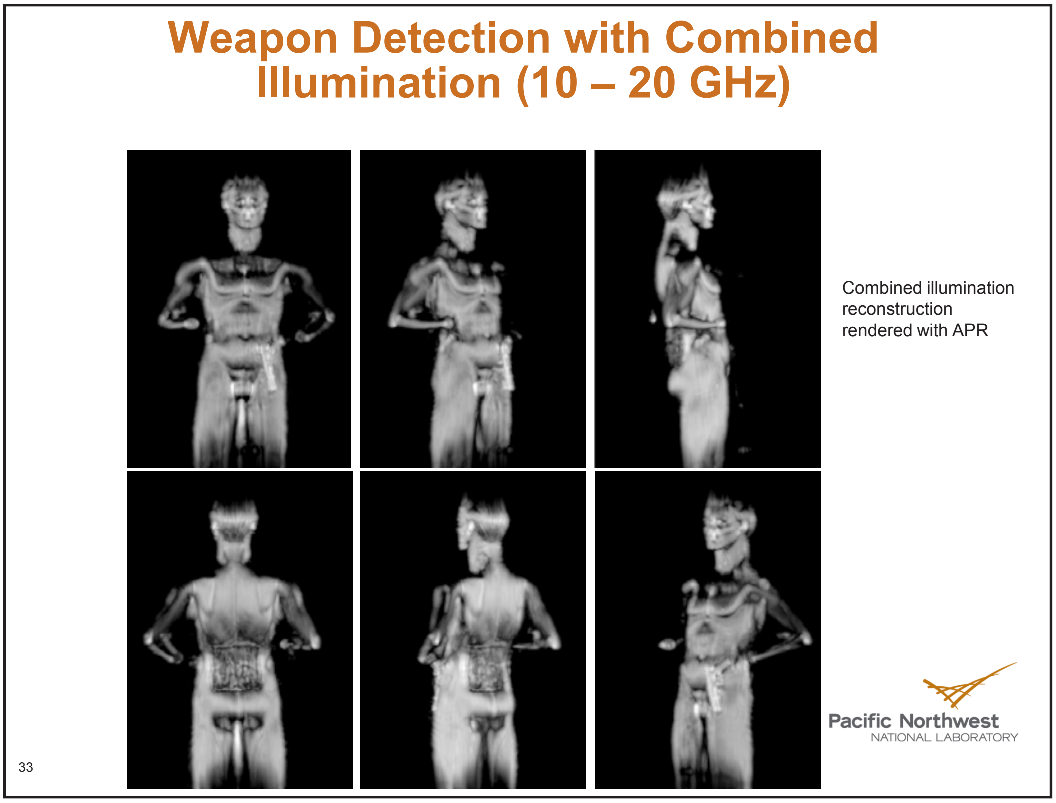

10 – 20 GHz

Combined Cylindrical 3-D Reconstruction

- Reconstruction angular segment shifts relative to fixed (x, y, z) volume
- 3-D (x, y, z) images are combined from 8 overlapping 90 degree arc segments to form complete reconstruction
- Bandwidth should be as wide as possible for depth resolution comparable to lateral resolution




10-20 GHz cylindrical image reconstructions



Weapon Detection with Combined Illumination (10 – 20 GHz)

Combined illumination reconstruction rendered with APR

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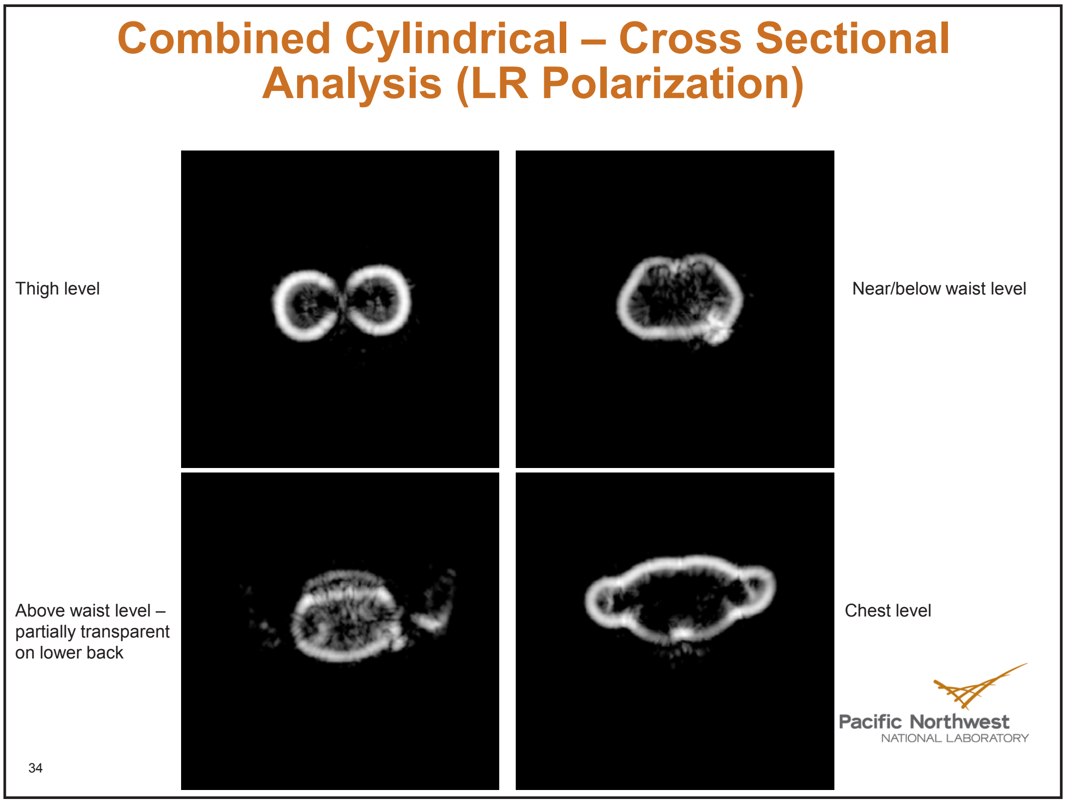

Combined Cylindrical – Cross Sectional Analysis (LR Polarization)

Thigh level

Near/below waist level

Above waist level – partially transparent on lower back

Chest level

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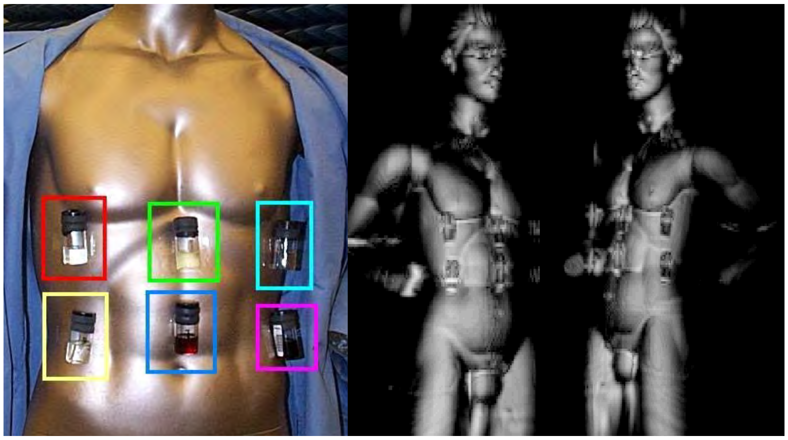
Ka Band Images of Mannequin and Concealed Glass Vials

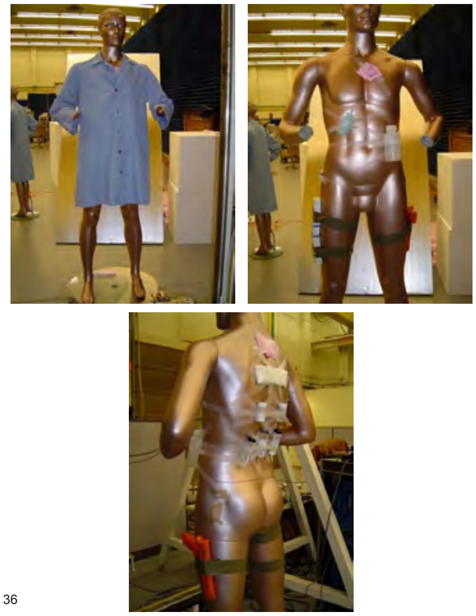


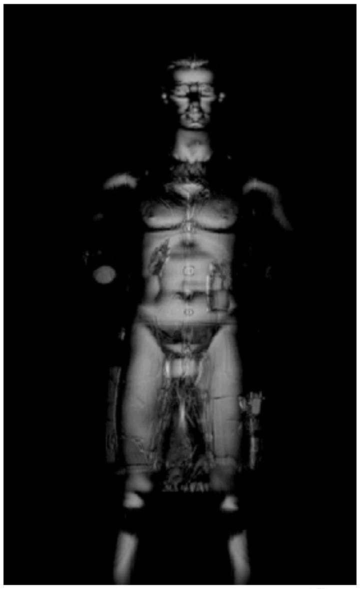
Optical

22 – 33 GHz Images

Cylindrical Holographic Radar Imaging Results (40 – 60 GHz)

Mannequin with Concealed Threats

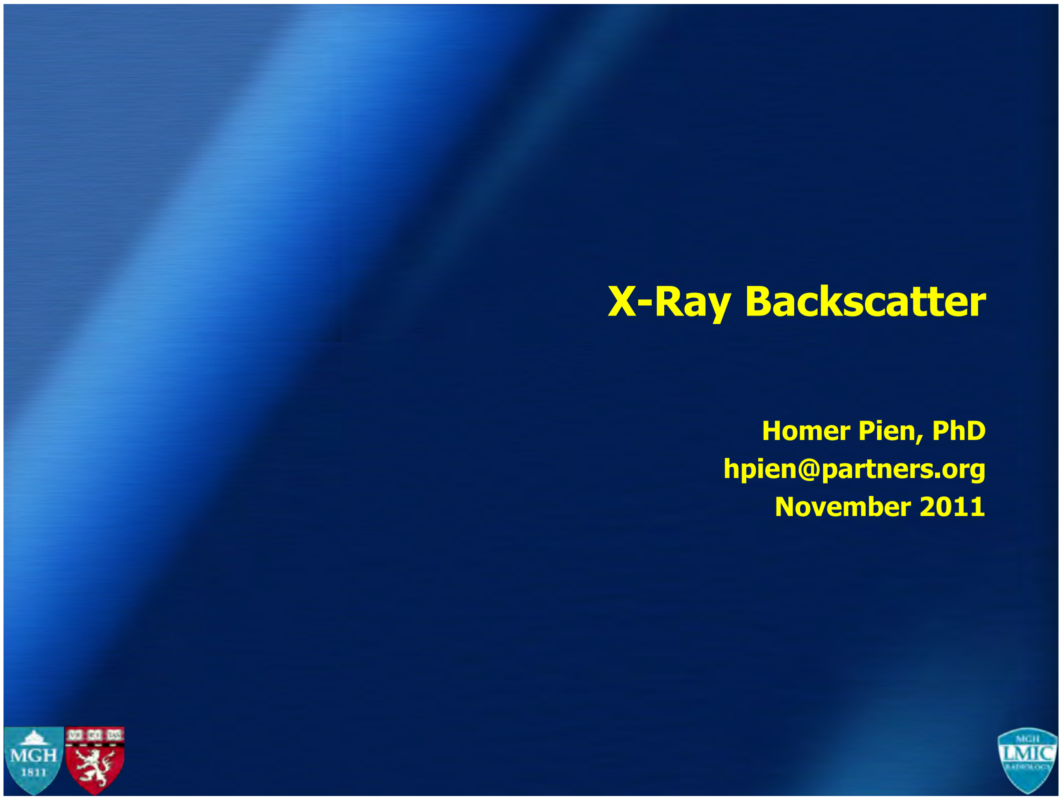




Conclusion

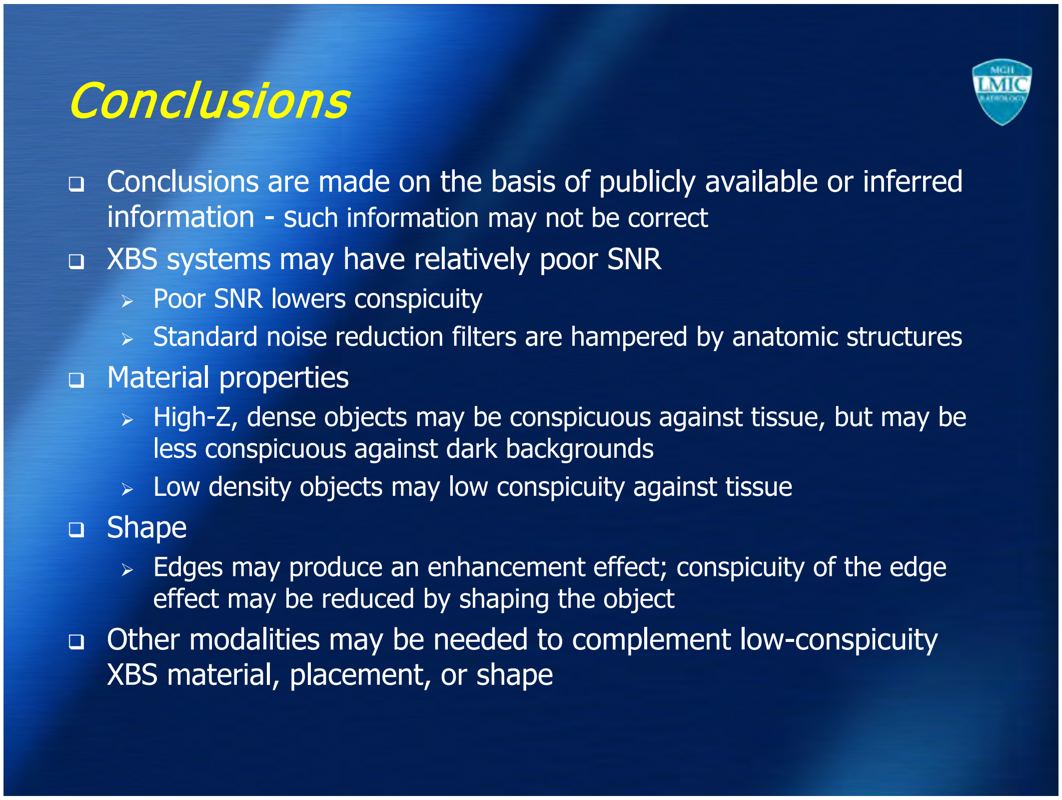
- Active mm-wave imaging is effective for security screening
  - Cylindrical portal imaging technology is becoming widely deployed
    - Excellent illumination properties due to the 360 degree (or wide angle) illumination
    - Allows inspection from multiple viewing angles
    - High-resolution
    - Excellent clothing penetration at in the lower mm-wave band
    - Scanning is rapid (several seconds), with throughput of over 400 people/hour possible
    - Cost effective
  - 3-D imaging provides additional information
    - Preserves focus (depth of field)
    - Allows exploitation of depth information or layered reflections for additional target detection techniques
- Standoff imaging is being explored using sub-mm imaging

16.8 Homer Pien: X-ray backscatter AIT review



X-Ray Backscatter

Homer Pien, PhD
hpien@partners.org
November 2011



Conclusions

- Conclusions are made on the basis of publicly available or inferred information - such information may not be correct
- XBS systems may have relatively poor SNR
  - Poor SNR lowers conspicuity
  - Standard noise reduction filters are hampered by anatomic structures
- Material properties
  - High-Z, dense objects may be conspicuous against tissue, but may be less conspicuous against dark backgrounds
  - Low density objects may low conspicuity against tissue
- Shape
  - Edges may produce an enhancement effect; conspicuity of the edge effect may be reduced by shaping the object
- Other modalities may be needed to complement low-conspicuity XBS material, placement, or shape

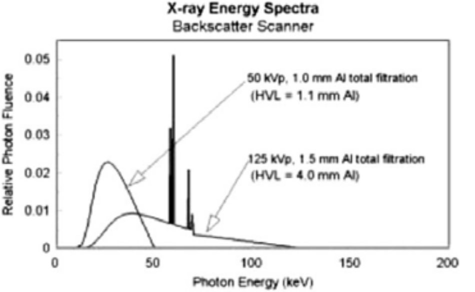
Caveats and Assumptions

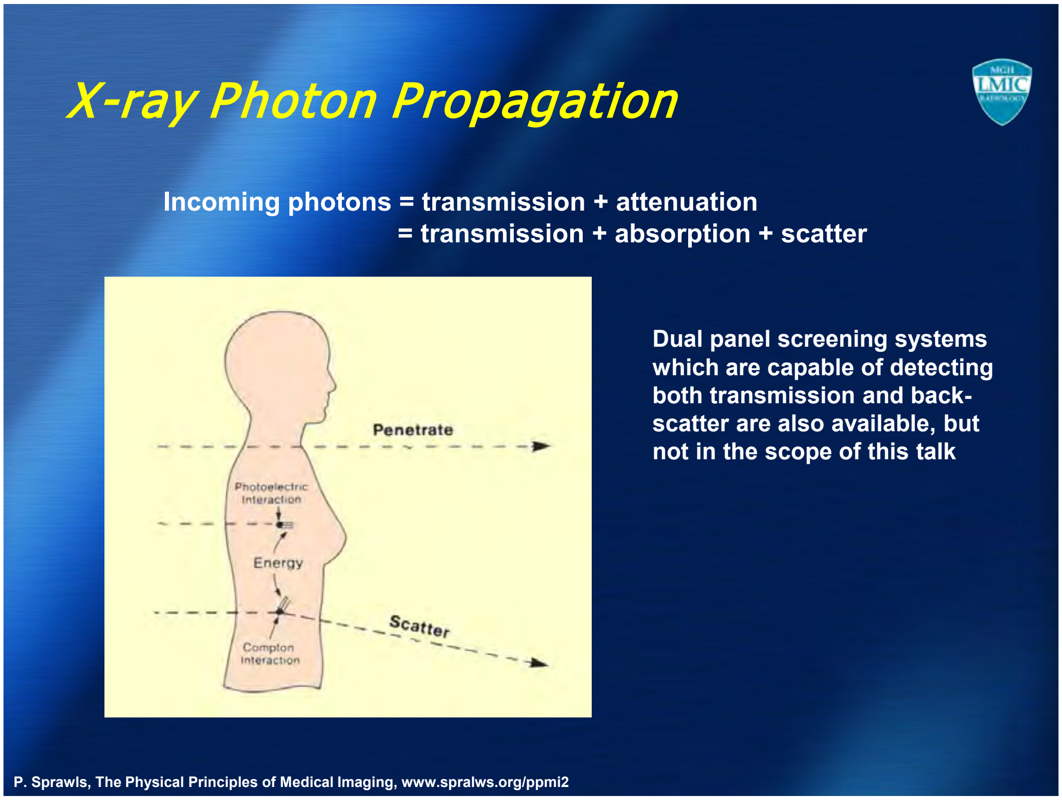
- We have worked through XBS data* examining the subjective conspicuity of different objects and imaging scenarios
  - Assumption: the more conspicuous an object, the higher the probability of detection (Pd), and lower the probability of false alarm (Pfa)
  - Conspicuity is assumed to be a function of atomic number (Z), mass density, shape, and location of object
- However, that dataset (and our conclusions) is SSI
  - We cannot present in this forum
- Instead we will rely on system parameters and performance numbers in the public domain
  - We neither confirm nor deny the findings in these sources

*Funding received through ALERT, final report: “Advanced Imaging Technology: MGH Ground Truth Effort Final Report,” SSI, 31 Dec 2010.

Assumed XBS Operating Parameters

- Energy regime
  - Average: 30 and 60 keV
  - Peak: 50 and 125 kVp
- Scattering angles of interest
  - > 145°
- Resolution
  - ~ 2-mm/pix



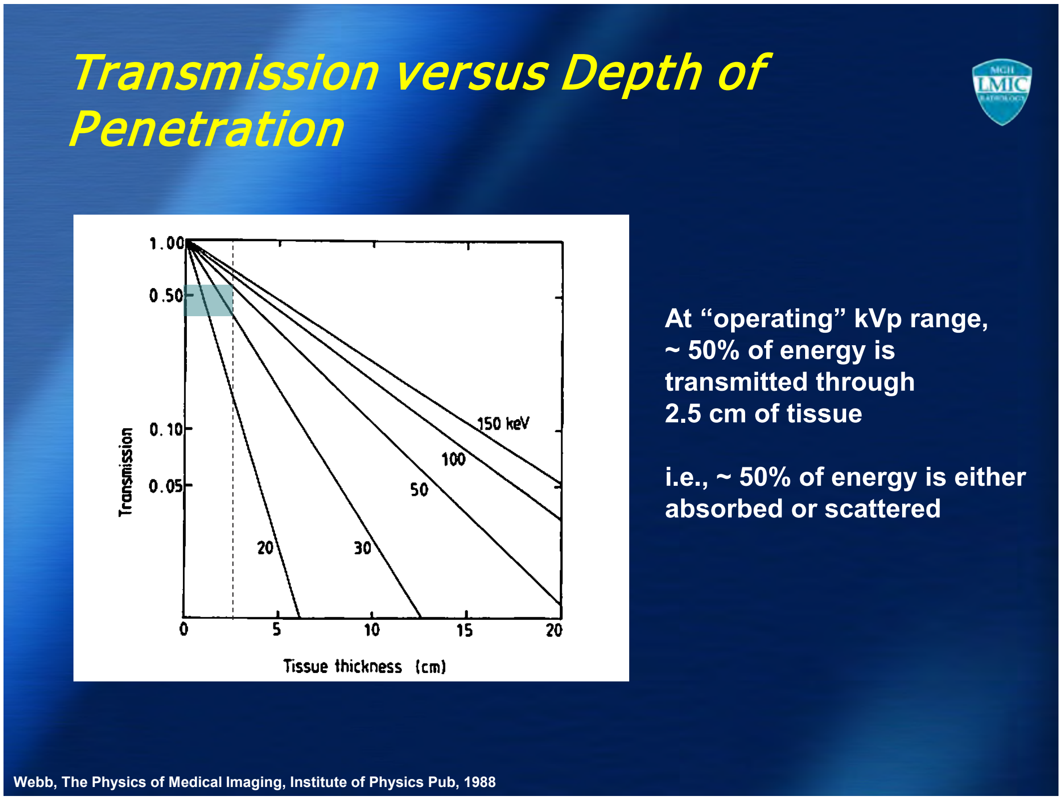


X-ray Photon Propagation

Incoming photons = transmission + attenuation
= transmission + absorption + scatter

Dual panel screening systems which are capable of detecting both transmission and back-scatter are also available, but not in the scope of this talk

P. Sprawls, The Physical Principles of Medical Imaging, www.spralws.org/ppmi2

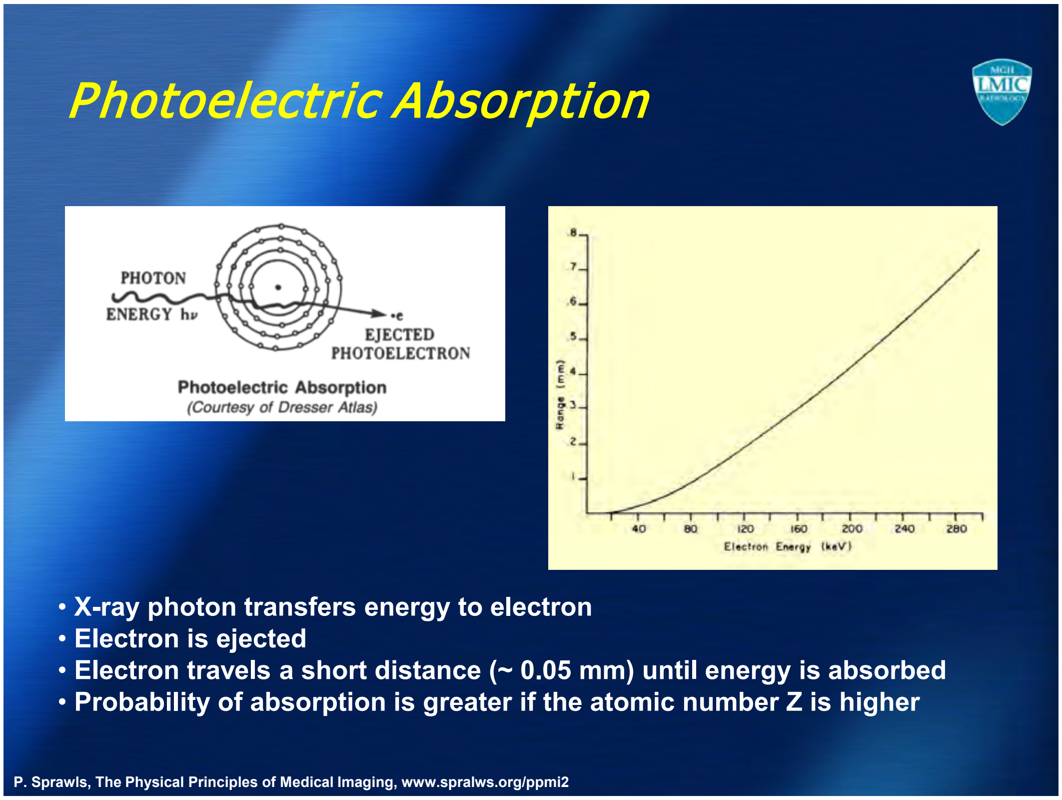


Transmission versus Depth of Penetration

At "operating" kVp range, ~ 50% of energy is transmitted through 2.5 cm of tissue

i.e., ~ 50% of energy is either absorbed or scattered

Webb, The Physics of Medical Imaging, Institute of Physics Pub, 1988

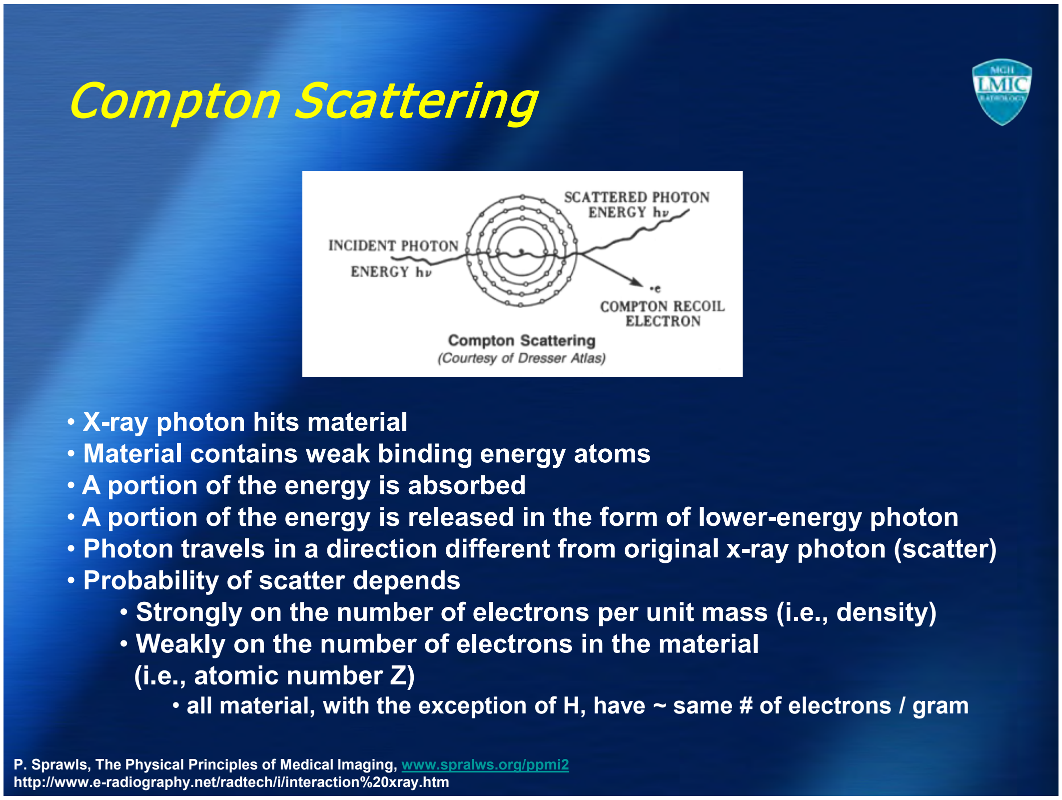


Photoelectric Absorption

Photoelectric Absorption
(Courtesy of Dresser Atlas)

- X-ray photon transfers energy to electron
- Electron is ejected
- Electron travels a short distance (~ 0.05 mm) until energy is absorbed
- Probability of absorption is greater if the atomic number Z is higher

P. Sprawls, The Physical Principles of Medical Imaging, www.spralws.org/ppmi2



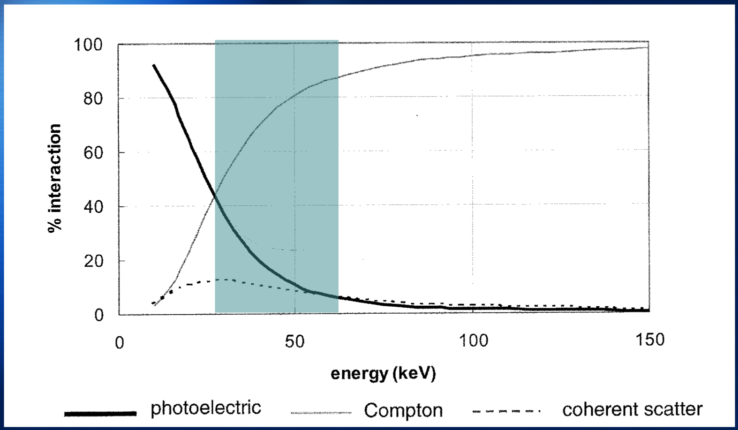
Compton Scattering

Compton Scattering
(Courtesy of Dresser Atlas)

- X-ray photon hits material
- Material contains weak binding energy atoms
- A portion of the energy is absorbed
- A portion of the energy is released in the form of lower-energy photon
- Photon travels in a direction different from original x-ray photon (scatter)
- Probability of scatter depends
  - Strongly on the number of electrons per unit mass (i.e., density)
  - Weakly on the number of electrons in the material (i.e., atomic number Z)
    - all material, with the exception of H, have ~ same # of electrons / gram

P. Sprawls, The Physical Principles of Medical Imaging, www.spralws.org/ppmi2
http://www.e-radiography.net/radtech/i/interaction%20xray.htm

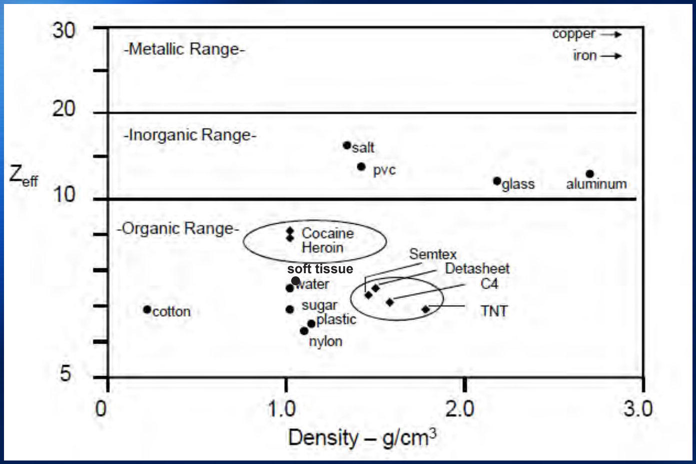
Relative Frequency of PE and CS in Water



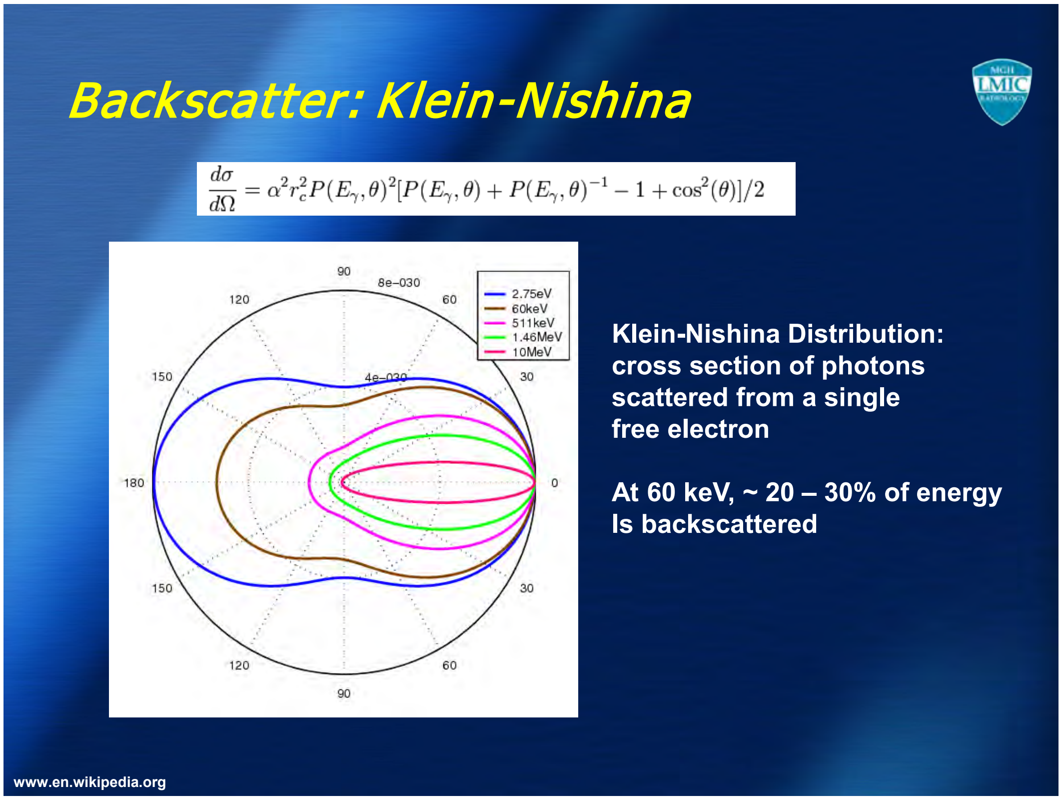
Of the attenuated energy, 40 – 85% will be Compton scattering

J. Hsieh, *Computed Tomography*, SPIE, 2003

Atomic Number and Mass Density



From L. Eger, BU
Graph from R. F. Eilbert and K. D. Krug, SPIE 1824, 127–143 (1993)



Backscatter: Klein-Nishina

$$\frac{d\sigma}{d\Omega} = \alpha^2 r_c^2 P(E_\gamma,\theta)^2 [P(E_\gamma,\theta) + P(E_\gamma,\theta)^{-1} - 1 + \cos^2(\theta)]/2$$

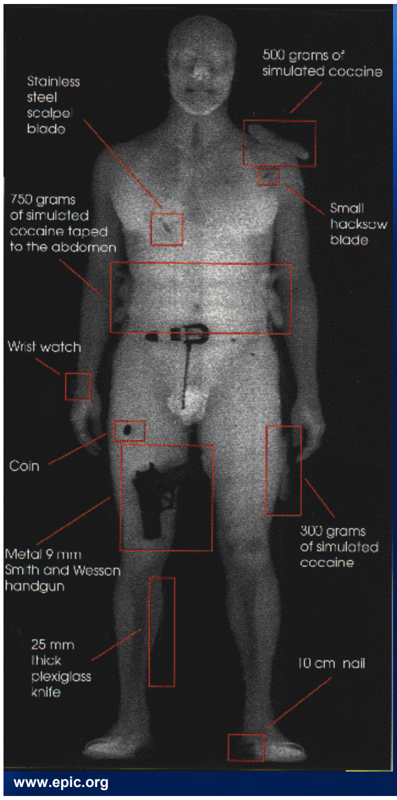
Klein-Nishina Distribution: cross section of photons scattered from a single free electron

At 60 keV, ~ 20 – 30% of energy Is backscattered

www.en.wikipedia.org

Observations

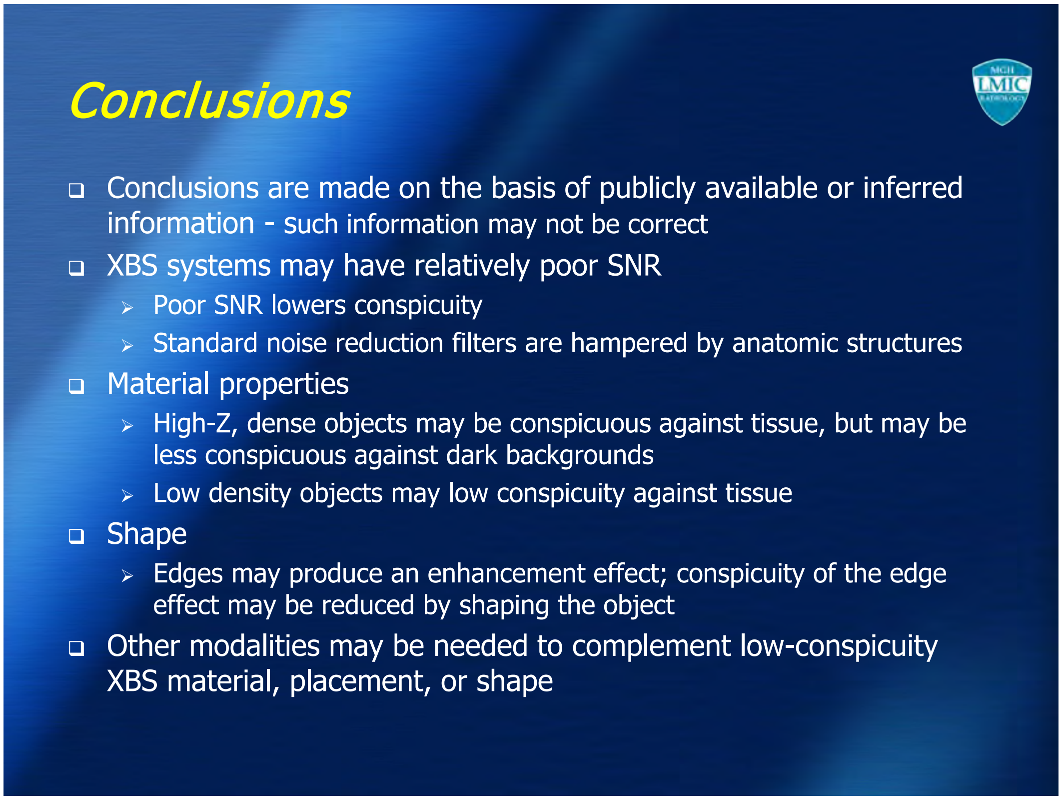
- ☐ With stated operating parameters, backscatter represents ~ 10% of the transmitted energy
  - Of 100% incident x-ray energy
  - ~ 50% is transmitted through 2.5 cm of tissue
  - Of the remaining 50%, 80% is scattering
  - Of the scattering component, about 25% is backscattered
  - Ignores detector efficiency
- ☐ Assumes soft tissue / water for material
- ☐ Minimization of radiation dose => SNR will not be great



www.epic.org

Opportunities for Fusion

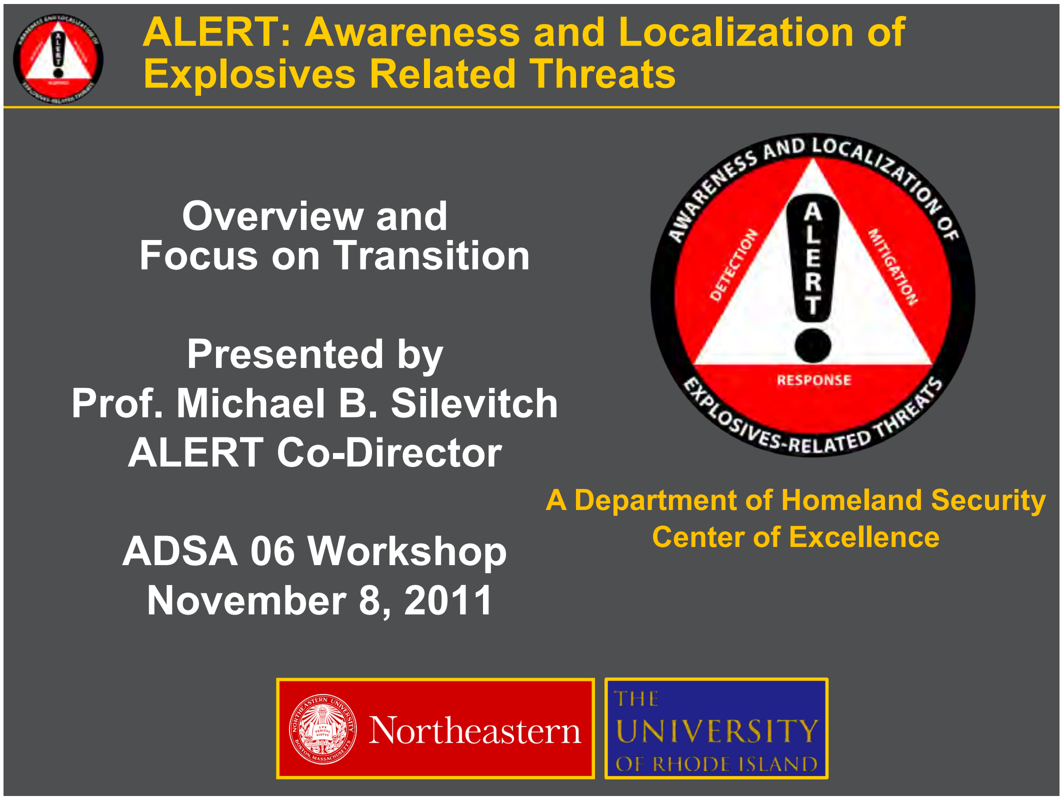
- Conspicuity in XBS may be improved through fusion
  - Multi-perspective XBS
    - Improves aspect angle geometry
  - Backscatter tomography
    - Derives 3-D information
  - Dual-panel x-ray system
    - Combines transmission and backscatter
  - Multi-energy transmission x-ray
    - (effective) atomic number and mass density
  - MMW
    - Dielectric differences between material
  - Thermal IR
    - Thermal occlusion, thermal inertia



Conclusions

- ❑ Conclusions are made on the basis of publicly available or inferred information - such information may not be correct
- ❑ XBS systems may have relatively poor SNR
  - Poor SNR lowers conspicuity
  - Standard noise reduction filters are hampered by anatomic structures
- ❑ Material properties
  - High-Z, dense objects may be conspicuous against tissue, but may be less conspicuous against dark backgrounds
  - Low density objects may low conspicuity against tissue
- ❑ Shape
  - Edges may produce an enhancement effect; conspicuity of the edge effect may be reduced by shaping the object
- ❑ Other modalities may be needed to complement low-conspicuity XBS material, placement, or shape

16.9 Michael Silevitch: Third-party Success Stories



ALERT: Awareness and Localization of Explosives Related Threats

Overview and
Focus on Transition

Presented by
Prof. Michael B. Silevitch
ALERT Co-Director

ADSA 06 Workshop
November 8, 2011

A Department of Homeland Security
Center of Excellence

Northeastern

THE
UNIVERSITY
OF RHODE ISLAND

The ALERT Mission: Help DHS Protect the Nation from Explosives Related Threats

Detection

Mitigation

Response

Education &
Outreach

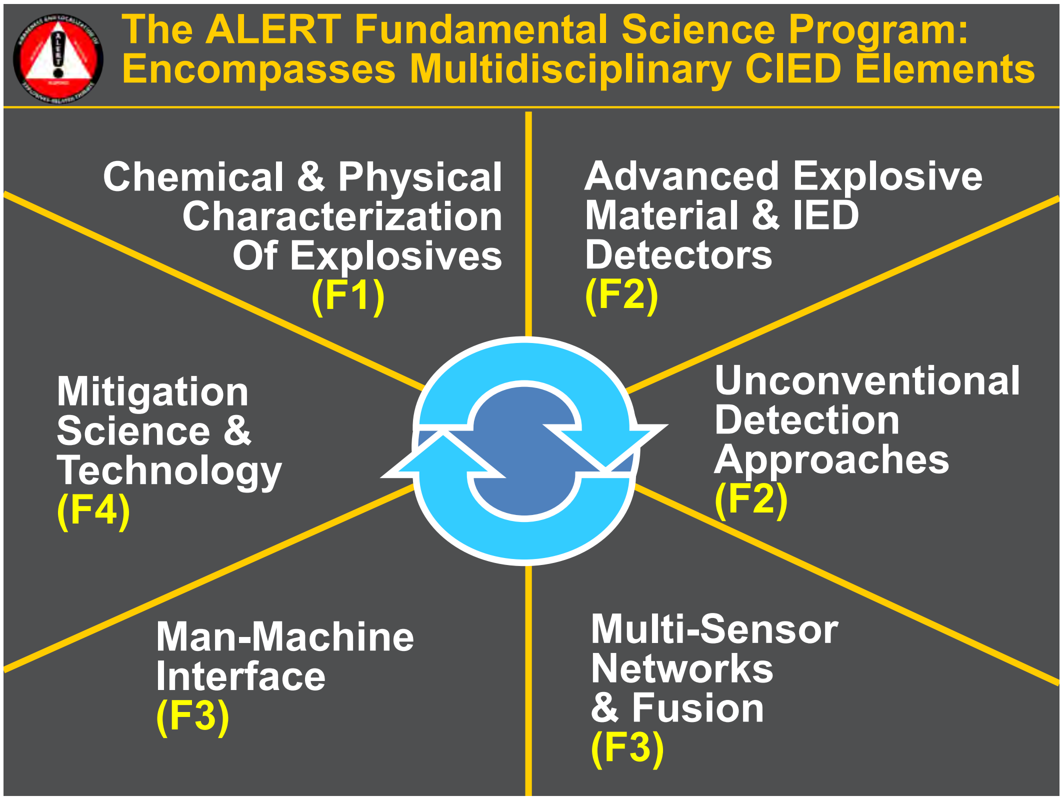
Research Defined by DHS Priorities

- ✓ Ultra-Reliable Screening
- ✓ > 50 meter Stand-Off Detection
- ✓ Unequivocal Pre and Post Blast Mitigation
- ✓ Rapid and Thorough Preparedness and Response

ALERT Research Addresses Standoff and Portal Systems

Standoff systems

Portal systems



The ALERT Fundamental Science Program: Encompasses Multidisciplinary CIED Elements

Chemical & Physical Characterization Of Explosives (F1)

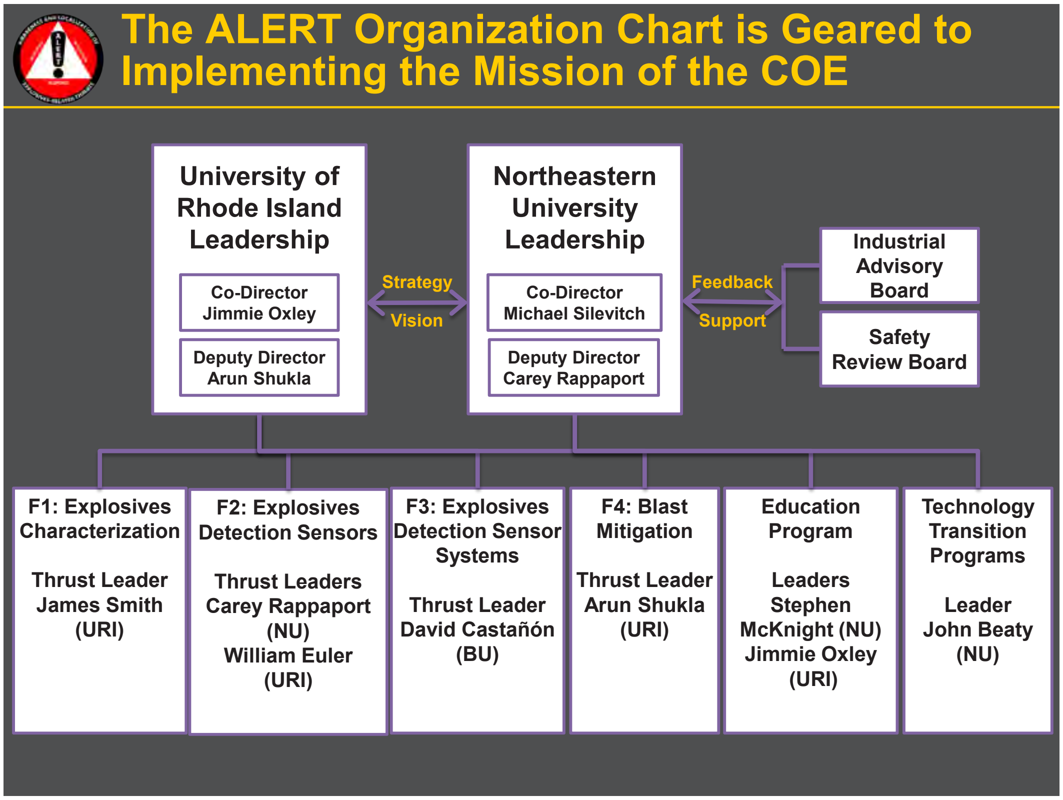
Advanced Explosive Material & IED Detectors (F2)

Mitigation Science & Technology (F4)

Unconventional Detection Approaches (F2)

Man-Machine Interface (F3)

Multi-Sensor Networks & Fusion (F3)



The ALERT Organization Chart is Geared to Implementing the Mission of the COE

University of Rhode Island Leadership
- Co-Director Jimmie Oxley
- Deputy Director Arun Shukla

Strategy ↔ Vision

Northeastern University Leadership
- Co-Director Michael Silevitch
- Deputy Director Carey Rappaport

Feedback ↔ Support

- Industrial Advisory Board
- Safety Review Board

F1: Explosives Characterization
Thrust Leader
James Smith
(URI)

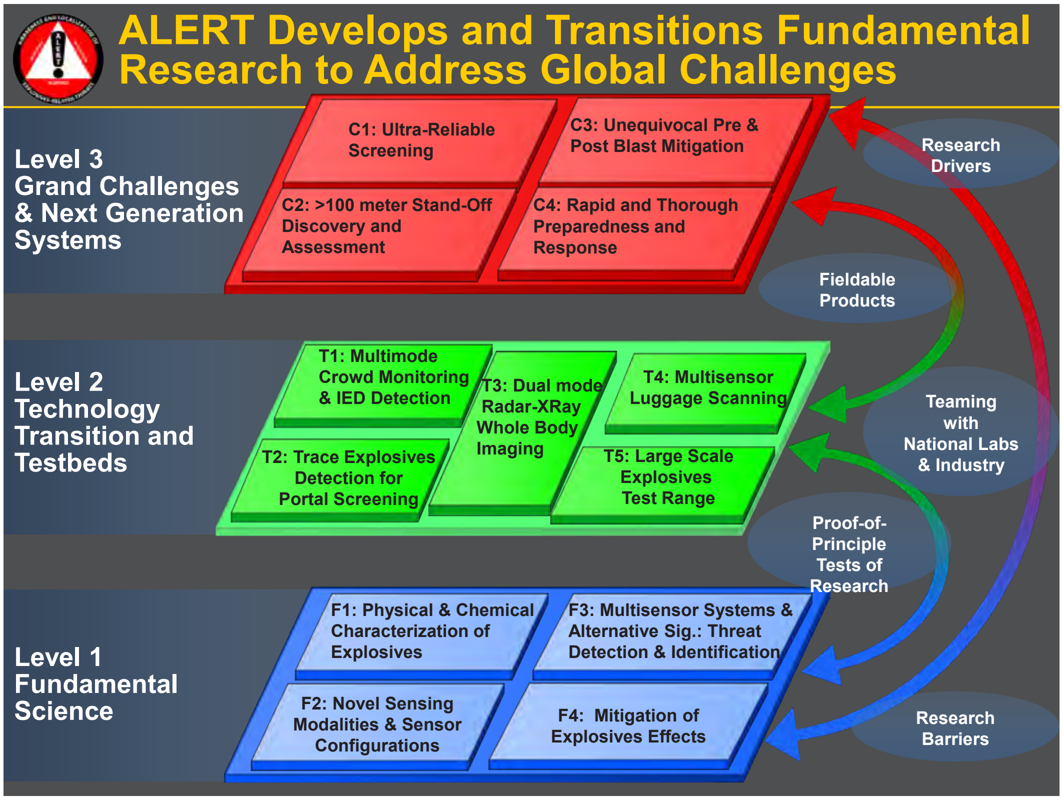
F2: Explosives Detection Sensors
Thrust Leaders
Carey Rappaport
(NU)
William Euler
(URI)

F3: Explosives Detection Sensor Systems
Thrust Leader
David Castañón
(BU)

F4: Blast Mitigation
Thrust Leader
Arun Shukla
(URI)

Education Program
Leaders
Stephen McKnight (NU)
Jimmie Oxley
(URI)

Technology Transition Programs
Leader
John Beaty
(NU)



ALERT Develops and Transitions Fundamental Research to Address Global Challenges

Level 3
Grand Challenges & Next Generation Systems

C1: Ultra-Reliable Screening

C3: Unequivocal Pre & Post Blast Mitigation

C2: >100 meter Stand-Off Discovery and Assessment

C4: Rapid and Thorough Preparedness and Response

Level 2
Technology Transition and Testbeds

T1: Multimode Crowd Monitoring & IED Detection

T3: Dual mode Radar-XRay Whole Body Imaging

T4: Multisensor Luggage Scanning

T2: Trace Explosives Detection for Portal Screening

T5: Large Scale Explosives Test Range

Level 1
Fundamental Science

F1: Physical & Chemical Characterization of Explosives

F3: Multisensor Systems & Alternative Sig.: Threat Detection & Identification

F2: Novel Sensing Modalities & Sensor Configurations

F4: Mitigation of Explosives Effects

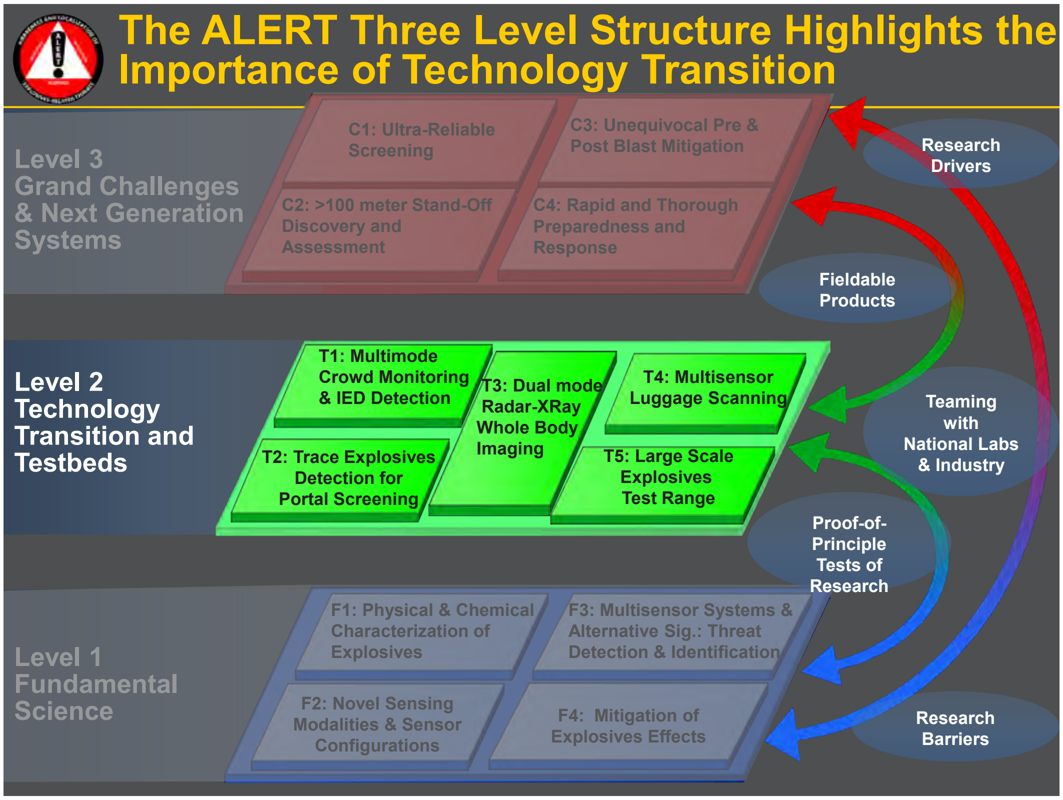
Research Drivers

Fieldable Products

Teaming with National Labs & Industry

Proof-of-Principle Tests of Research

Research Barriers



The ALERT Three Level Structure Highlights the Importance of Technology Transition

Level 3
Grand Challenges & Next Generation Systems

C1: Ultra-Reliable Screening

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Research Drivers

Fieldable Products

Teaming with National Labs & Industry

Proof-of-Principle Tests of Research

Research Barriers

A Key Element of the ALERT Mission: Technology Transition to Industry & Government Partners

ANALOGIC
REVEAL An SAIC Company
APPLIED SCIENCE FOUNDATION FOR HOMELAND SECURITY
Public Safety • Research • Economic Development • Education
ZOMEGA
Monitor Instruments
AGILTRON
FIRESTORM Emergency Services Ltd.
BaL Technologies
LINE-X PROTECTIVE COATINGS
Lawrence Livermore National Laboratory
DualAlign
BLOCK engineering
AS&E
Pacific Northwest NATIONAL LABORATORY
TEXTRON Systems
GE Healthcare
INL Idaho National Laboratory
NeuroLogica
NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY
LOCKHEED MARTIN
Sandia National Laboratories
Raytheon
MASSACHUSETTS TECHNOLOGY COLLABORATIVE
CONQUEST OF DARKNESS
SIEMENS
MRIGlobal National Solutions Worldwide Impact
AIR FORCE RESEARCH LABORATORY
Air Force Office of Scientific Research (AFOSR)
The Basic Research Manager of the Air Force Research Laboratory
ARMY NATIONAL GUARD

Outcomes of the ALERT Transition Strategy: Major Economic Impact For Industrial Partners

A Precursor of ALERT:
HSARPA $4.9 Million
Portal Monitoring Prototype
Northeastern Lead,
with Raytheon & BTI

→

Advanced DHS
Spectroscopic Portal
$400 Million
Production Contract
for Raytheon

Northeastern

Raytheon

BTI BUBBLE Technology Industries

The Camp Edwards Testbed: Now Producing Video Datasets for Transition

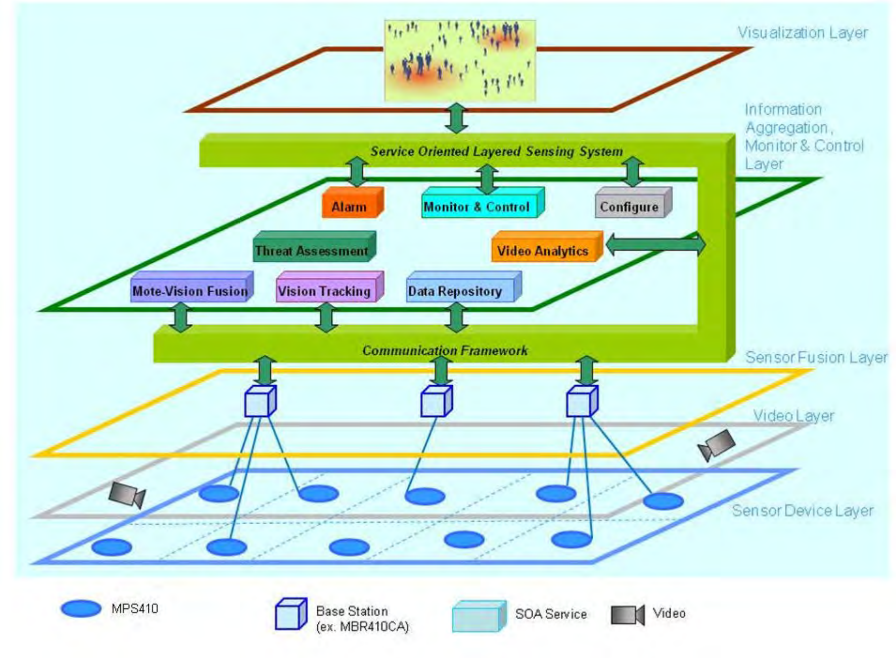
- Researchers have complete access to data
- No privacy restrictions because of the military site

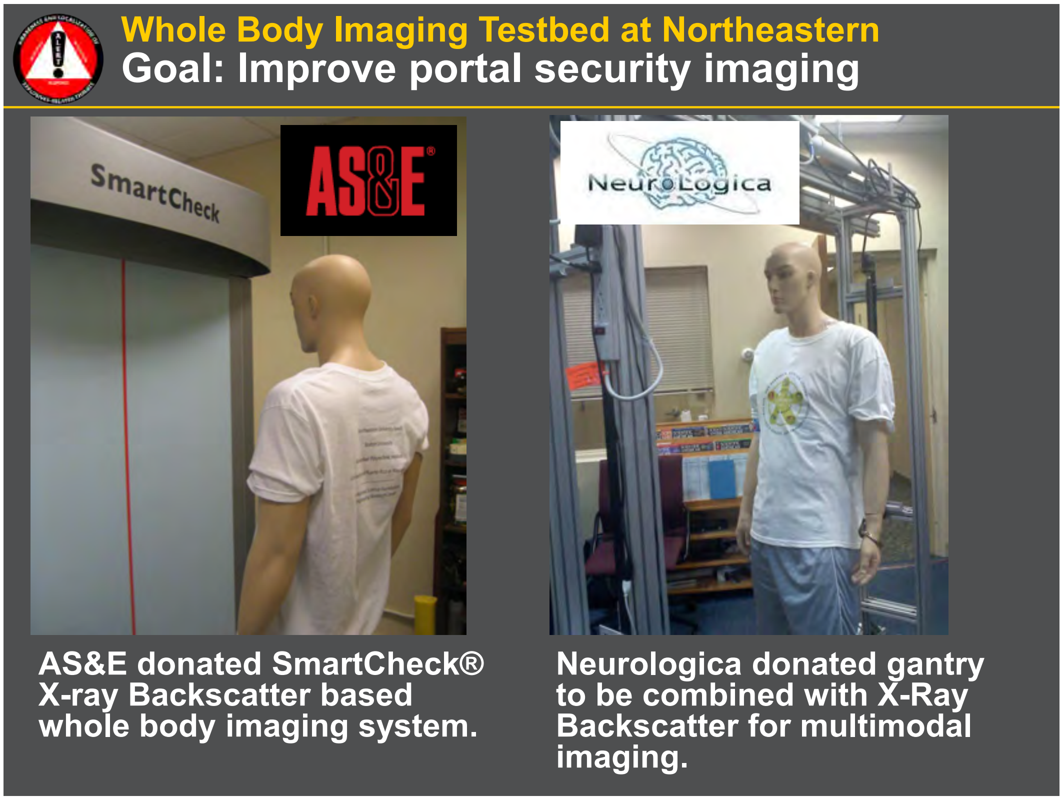
Massachusetts National Guard
The Nation's First

Raytheon

SIEMENS

The ALERT Team is Currently Deploying A Multi-Mode Layered Sensing System at Camp Edwards



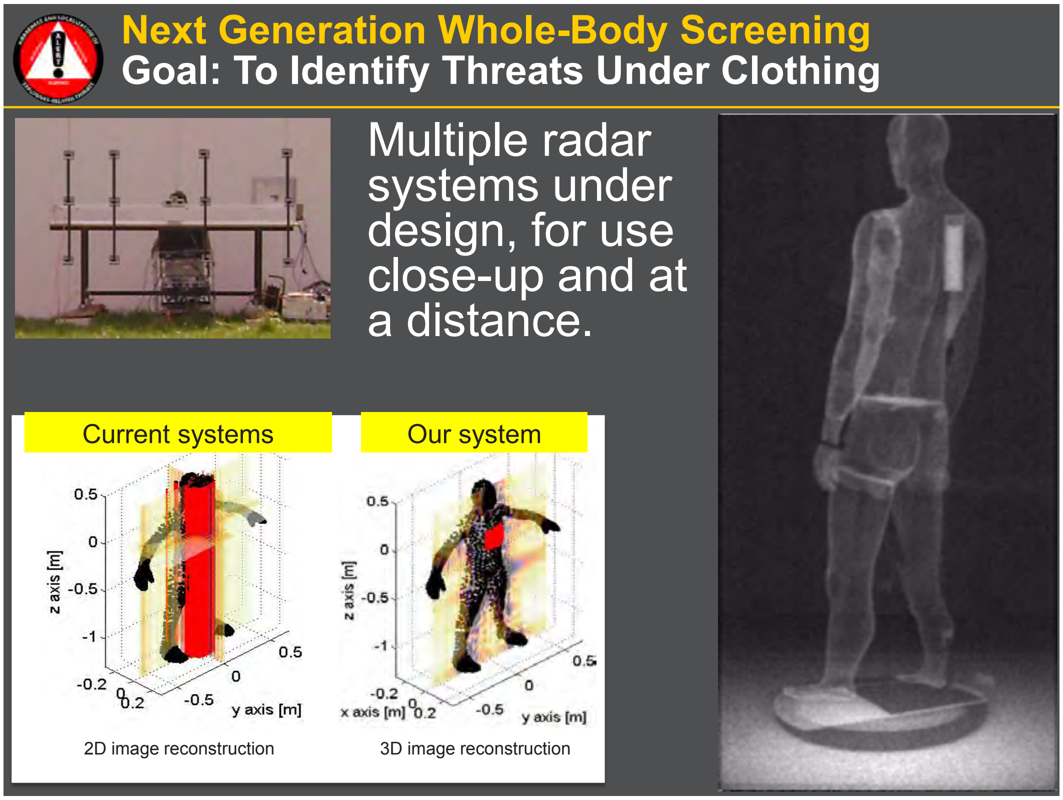


Whole Body Imaging Testbed at Northeastern

Goal: Improve portal security imaging

AS&E donated SmartCheck® X-ray Backscatter based whole body imaging system.

Neurologica donated gantry to be combined with X-Ray Backscatter for multimodal imaging.



Next Generation Whole-Body Screening

Goal: To Identify Threats Under Clothing

Multiple radar systems under design, for use close-up and at a distance.

Current systems

2D image reconstruction

Our system

3D image reconstruction

ALERT Strategic Study Workshops
Goal: To Identify Research/Capabilities Gaps

- Focused on ALERT Screening areas
  CT and Whole Body Imaging
- Brings together academia/government/industry
- Deliverable: reports and datasets that provide analysis of state-of-the-art and future directions for DHS consideration


Strategic Study
Workshop Series
Algorithm Development for Security Applications
April 2009 Workshop
Final Report

Strategic Study
Workshop Series
Algorithm Development for Security Applications
October 2009 Workshop
Final Report

ADSA Workshops Have Created A Vibrant Community Focused on Transition

- Combines Researchers, developers, vendors and Government representatives – networking key element
- ADSA01: Check-point algorithm gaps and future directions
- ADSA02: Implementation of segmentation grand challenge
- ADSA03: AIT gaps and future directions
- ADSA04: Reconstruction algorithms
  status and future directions
- ADSA05: Fusion of orthogonal technologies
- ~200 people in database
- Final reports are excellent repositories of information useful for people entering the field
- Literature identified
- Many technical solutions identified
- Many operational issues surfaced and are being worked

AIT Projects: Aimed at Transition of Next Generation Advances

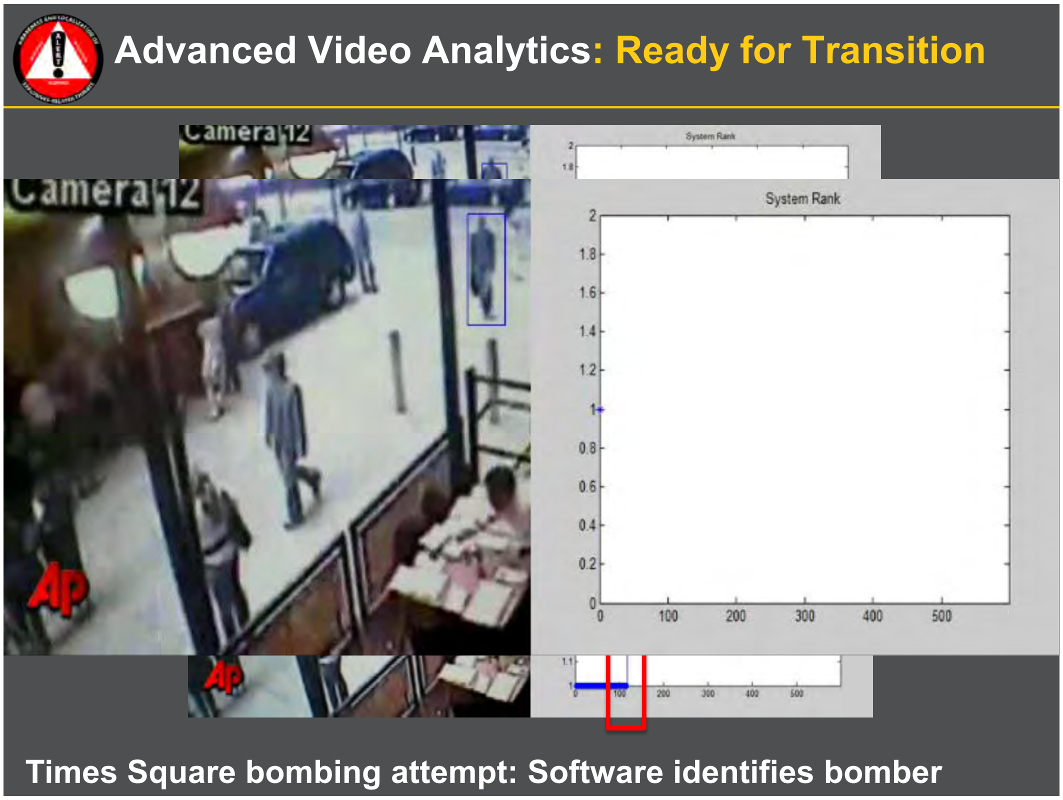
- Cemented collaboration between academia, industry and National Labs
  - AS&E Equipment donation and summer project
  - REVEAL student project
  - Three summer projects conducted with PNNL
  - Use of Sandia SSI datasets for MMW and XBS
    - Ground truth project with MGH
    - Applying radiological methods to assess coupon conspicuity
- Follow on projects underway
  - Focus on Fusion

Segmentation Challenge: Enables the Creation of Datasets and Assessment Metrics

- Implemented major recommendation from ADSA01 workshop
- Collaboration between ALERT and LLNL
-
- Funded by DHS via Basic Ordering Agreement
- Stream of commerce bags packed and scanned on medical CT scanner
- Five research groups funded
- Symposium on December 8th 2011

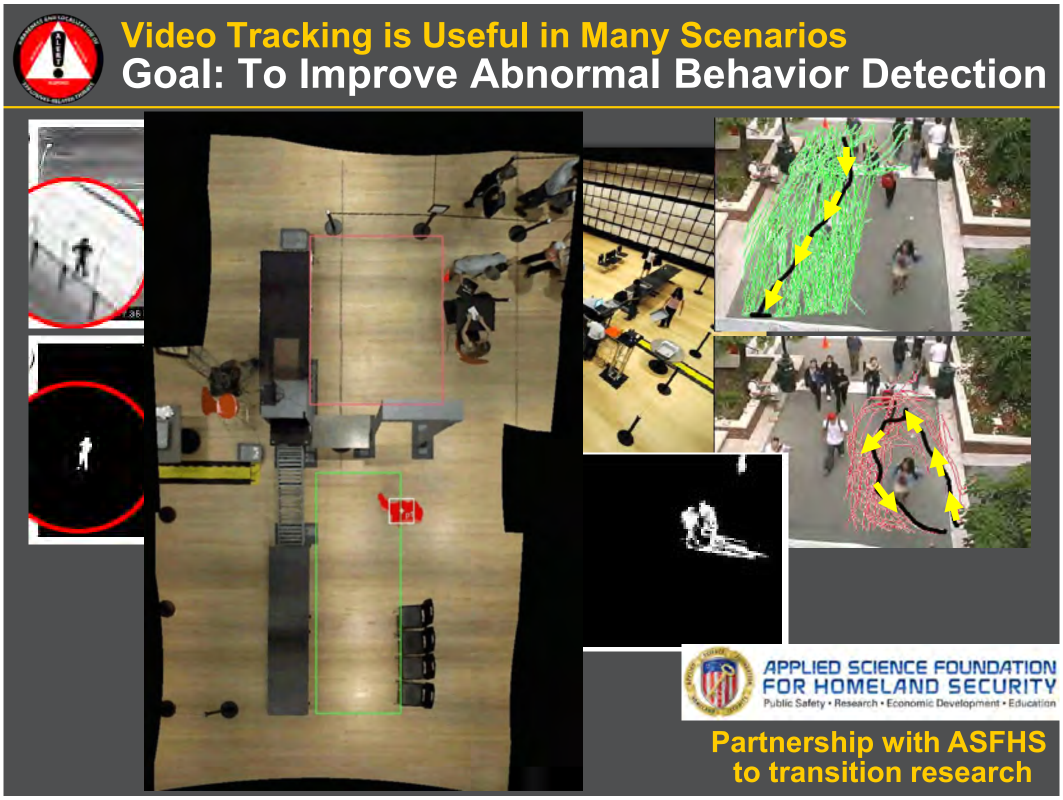
DHS Funded Transition Initiatives Will Augment Ongoing Efforts

- Additional funding to Spark ALERT Efforts
  - Announced by Dr. Eric Houser at ADSA05
- Focal Areas
  - Video analytics
    - Links with TSA
    - MassPort and Cleveland Airport
    - National Guard-Camp Edwards
    - Industry-Siemens
    - ADSA07 Focus
  - CT reconstruction-Work with Vendors
  - Fusion-Applied to AIT efforts
- Emphasis on “E2E” (Engage to Excel)
  - New DHS Focus for the Centers of Excellence



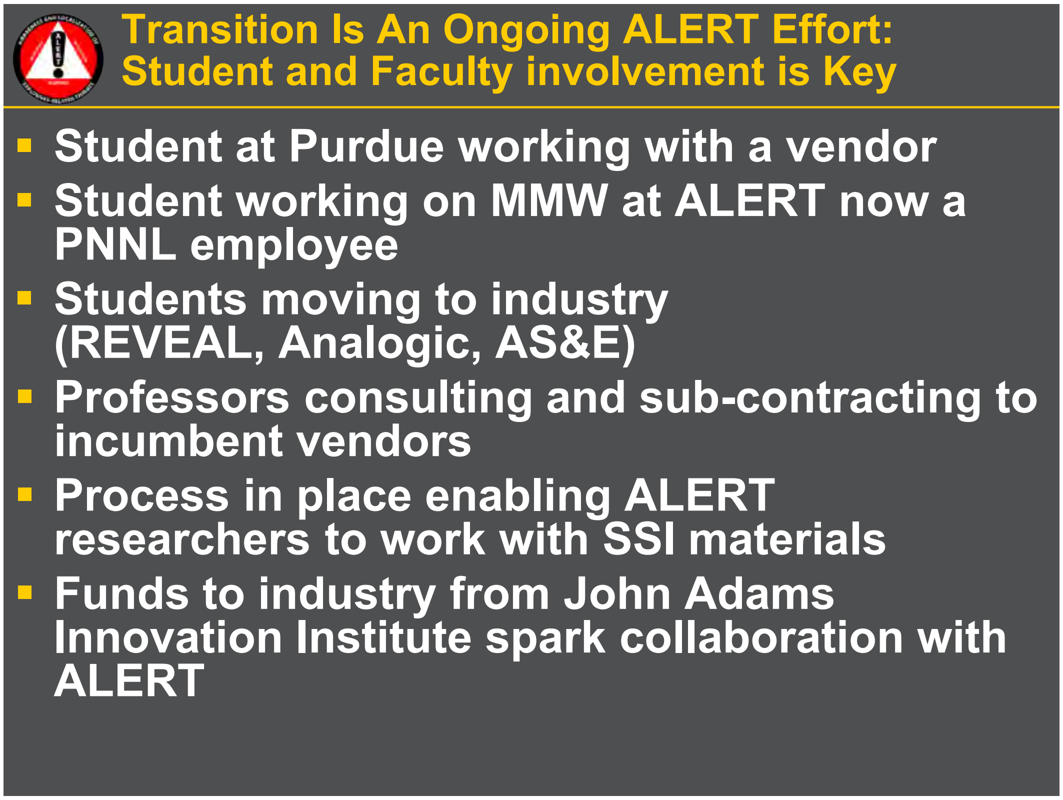
Advanced Video Analytics: Ready for Transition

Times Square bombing attempt: Software identifies bomber



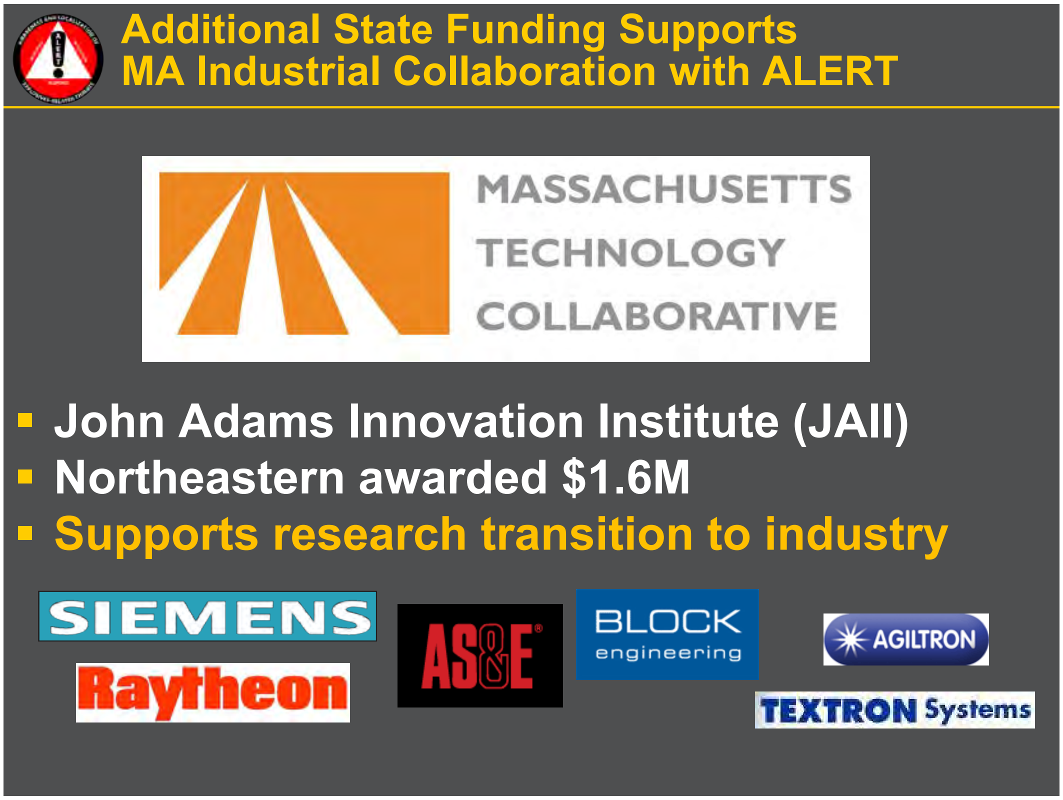
Video Tracking is Useful in Many Scenarios
Goal: To Improve Abnormal Behavior Detection

Partnership with ASFHS to transition research



Transition Is An Ongoing ALERT Effort: Student and Faculty involvement is Key

- Student at Purdue working with a vendor
- Student working on MMW at ALERT now a PNNL employee
- Students moving to industry (REVEAL, Analogic, AS&E)
- Professors consulting and sub-contracting to incumbent vendors
- Process in place enabling ALERT researchers to work with SSI materials
- Funds to industry from John Adams Innovation Institute spark collaboration with ALERT



Additional State Funding Supports MA Industrial Collaboration with ALERT

MASSACHUSETTS
TECHNOLOGY
COLLABORATIVE

- John Adams Innovation Institute (JAII)
- Northeastern awarded $1.6M
- Supports research transition to industry

JAII Funds Help ALERT Transition Research
Goal: Build Economy, Aid Emergency Workers

Explosives Proximity Detector

ALERT research teams will test the capability of the quantum cascade laser unit to detect explosives, as well as develop algorithms to enhance detection.

Mobile Device Operated Handheld Raman Spectrometer

Designed to be a handheld system that can detect and identify explosive materials. ALERT researchers are developing a database of explosives spectral signatures.

Our Conferences and Events
Promote Transition to a Wide Audience

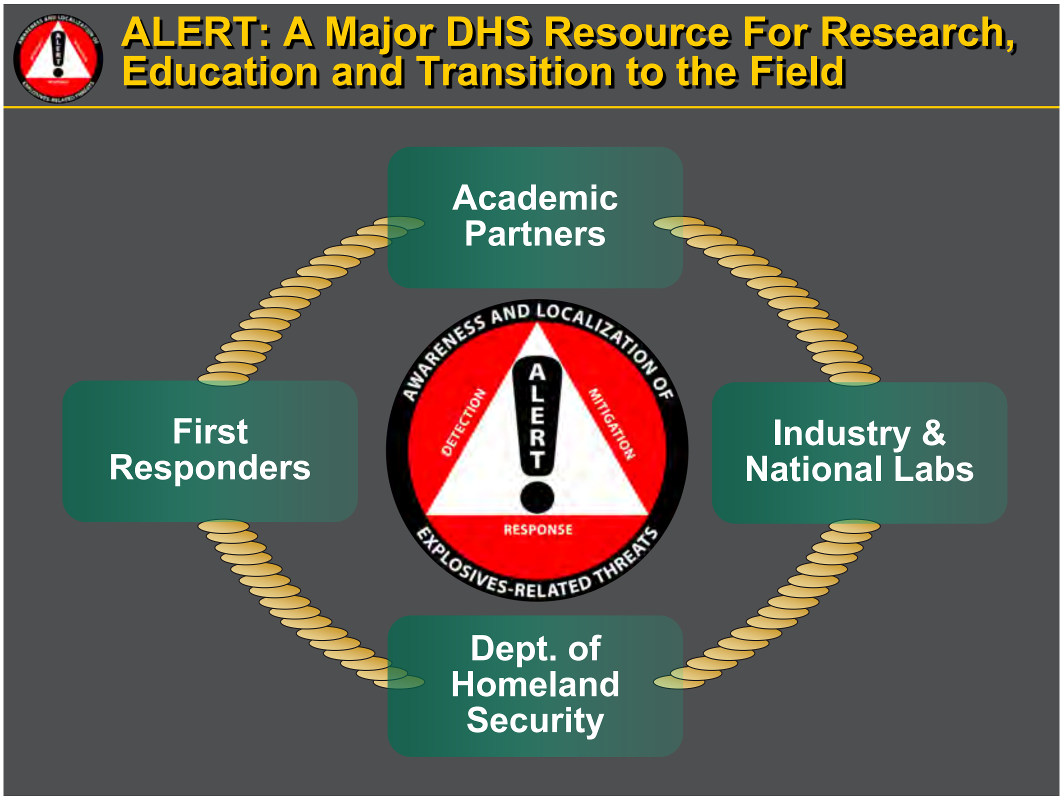
Research to Reality (R2R) Conferences

- Held In Yearly October
- ~ 400 Attendees
- Joint Presentations
  - Researcher + "Realist"

RICC 2010

Research to Reality R2R

Our Students:
The Next Generation of Engineering Leaders



ALERT: A Major DHS Resource For Research, Education and Transition to the Field

Academic Partners

First Responders

AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

ALERT

DETECTION

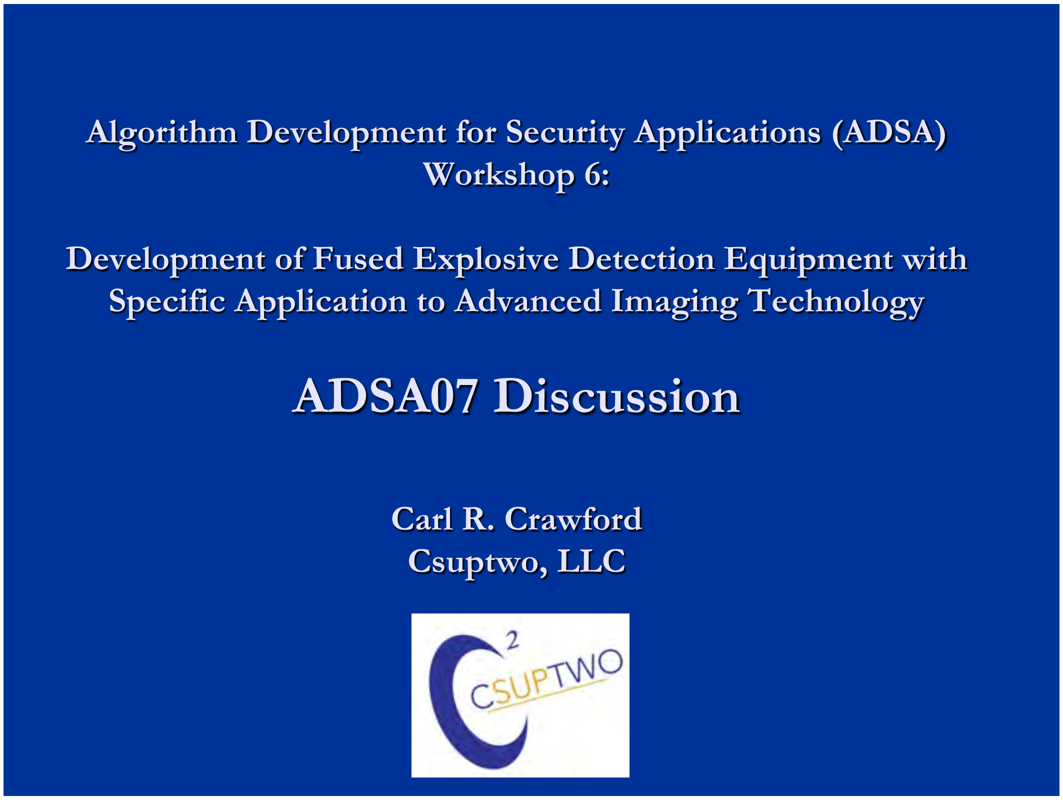
MITIGATION

RESPONSE

Industry & National Labs

Dept. of Homeland Security

16.10 Carl Crawford: Topics for Next Workshop

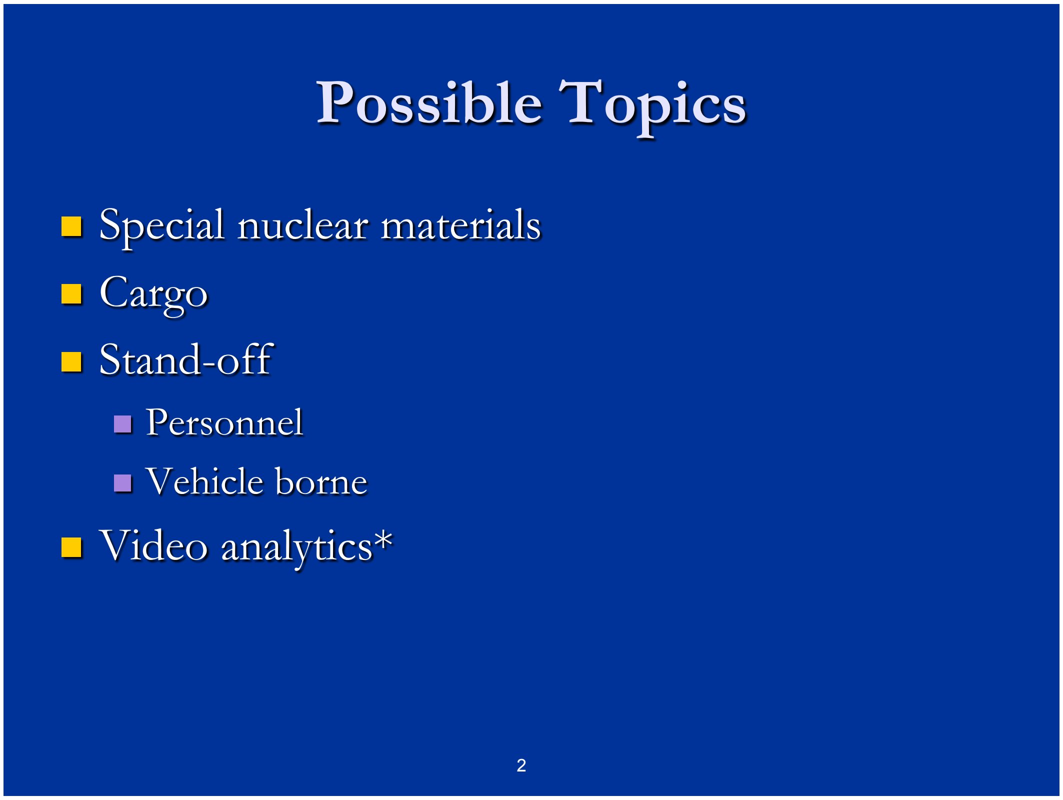


Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with
Specific Application to Advanced Imaging Technology

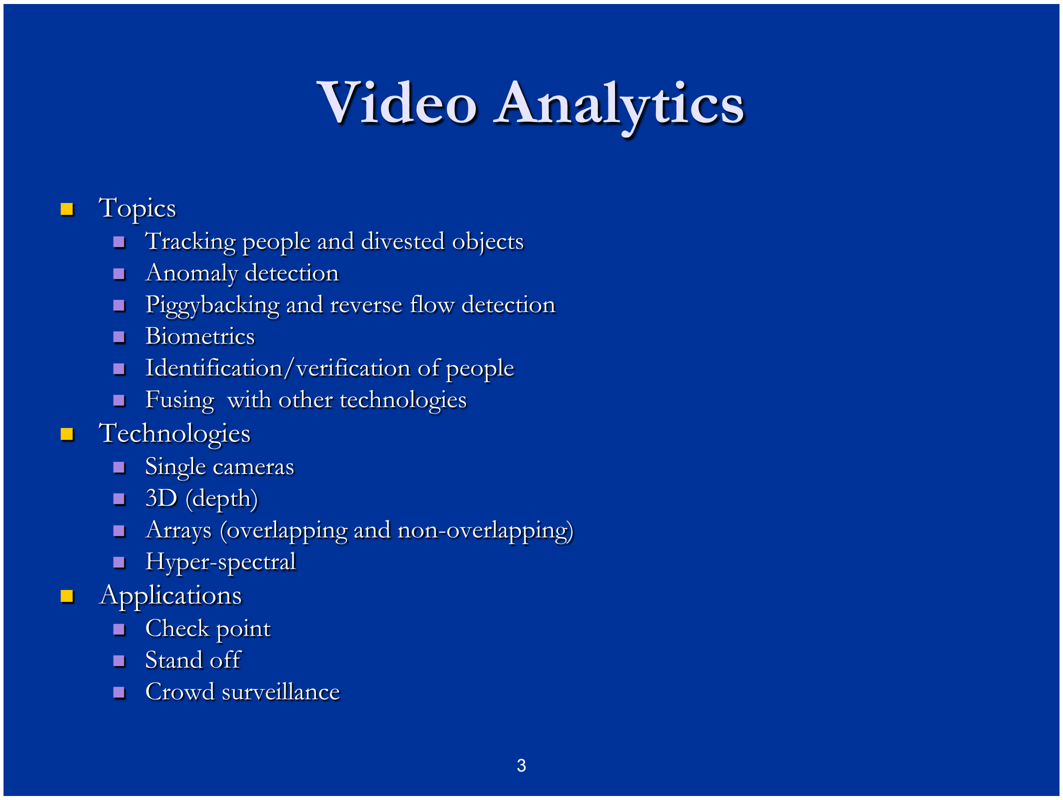
ADSA07 Discussion

Carl R. Crawford
Csuptwo, LLC



Possible Topics

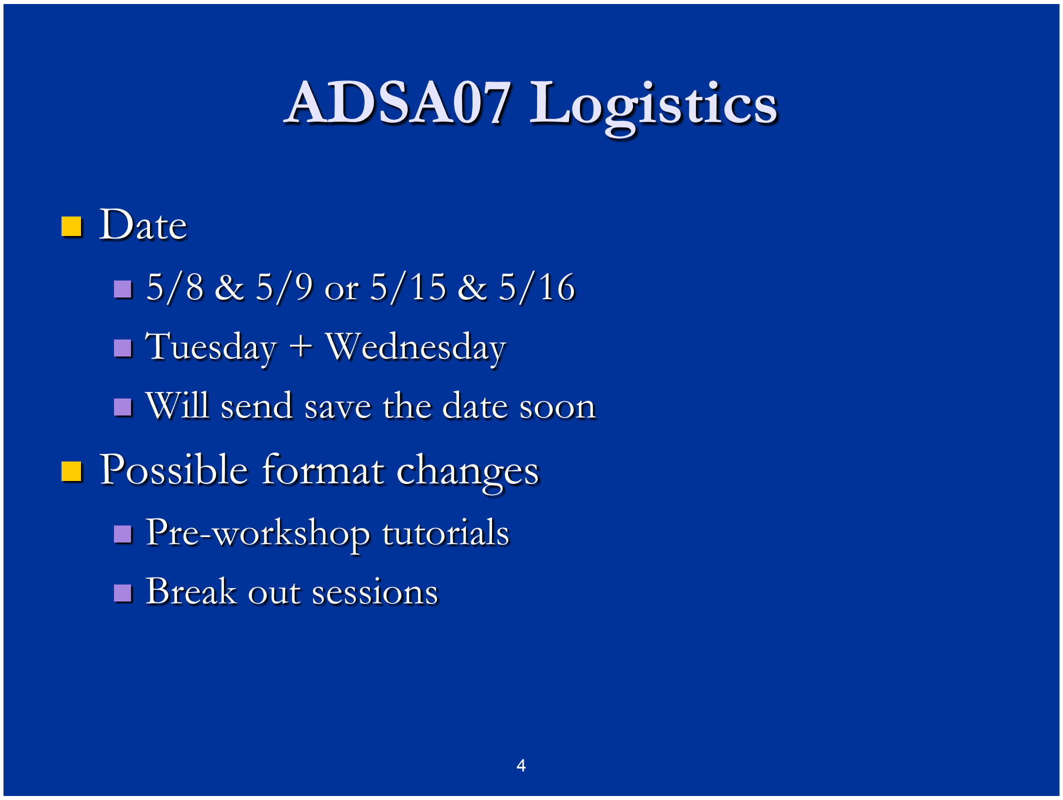
- Special nuclear materials
- Cargo
- Stand-off
  - Personnel
  - Vehicle borne
- Video analytics*



Video Analytics

- Topics
  - Tracking people and divested objects
  - Anomaly detection
  - Piggybacking and reverse flow detection
  - Biometrics
  - Identification/verification of people
  - Fusing with other technologies
- Technologies
  - Single cameras
  - 3D (depth)
  - Arrays (overlapping and non-overlapping)
  - Hyper-spectral
- Applications
  - Check point
  - Stand off
  - Crowd surveillance

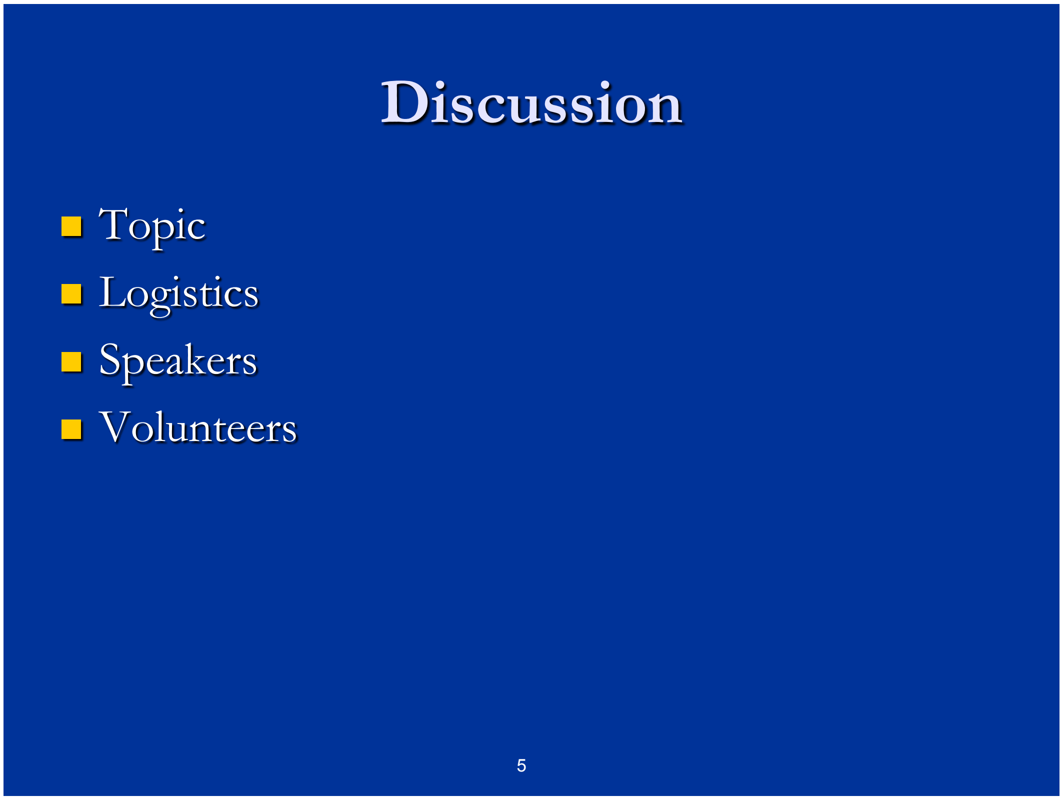
3



ADSA07 Logistics

- Date
  - 5/8 & 5/9 or 5/15 & 5/16
  - Tuesday + Wednesday
  - Will send save the date soon
- Possible format changes
  - Pre-workshop tutorials
  - Break out sessions

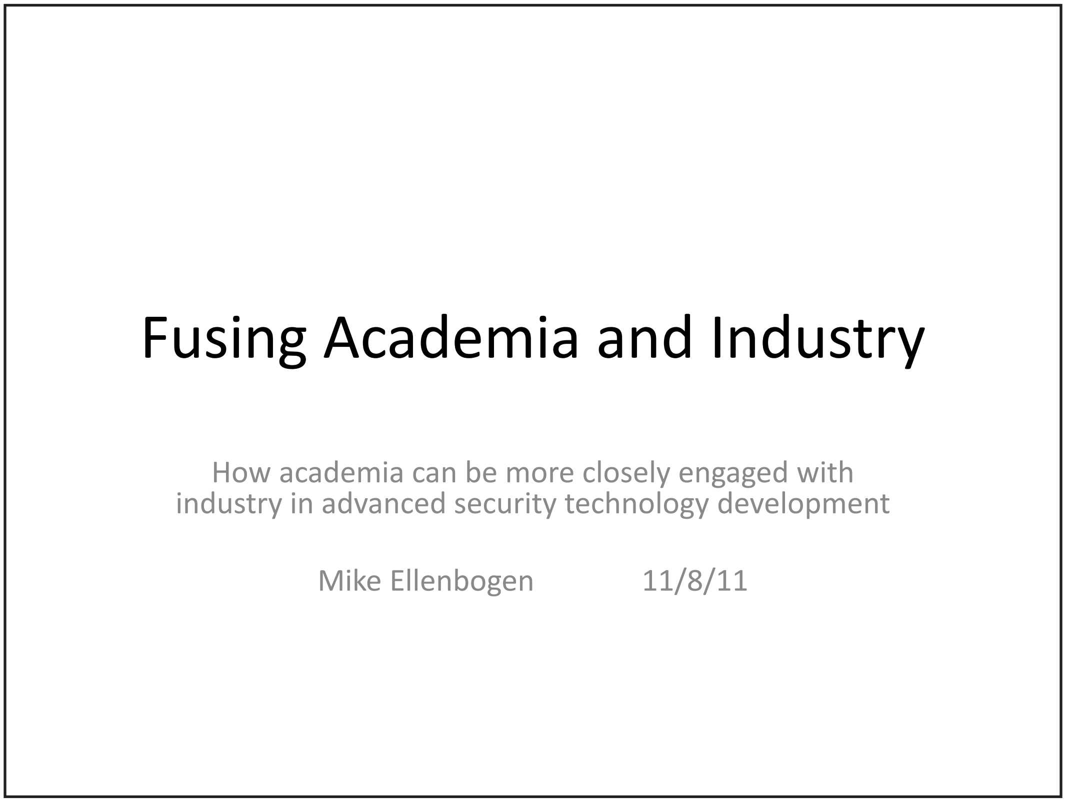
4



Discussion

- Topic
- Logistics
- Speakers
- Volunteers

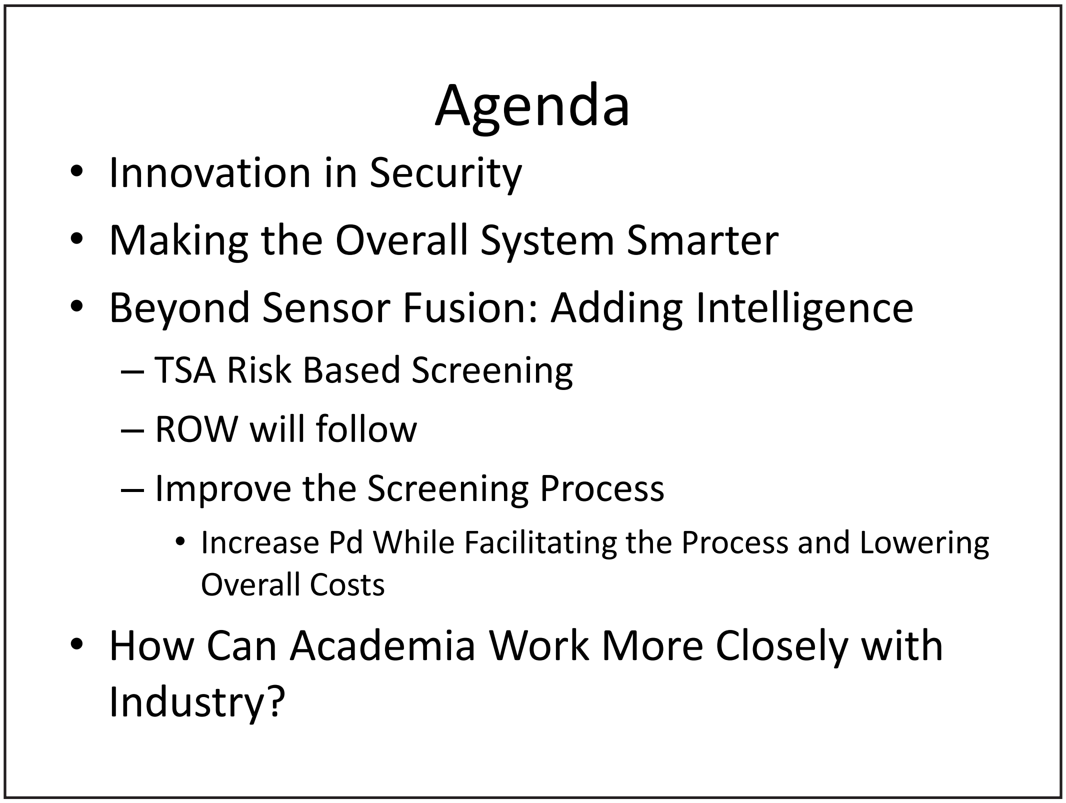
16.11 Michael Ellenbogen: Fostering Innovation in Aviation Security



Fusing Academia and Industry

How academia can be more closely engaged with
industry in advanced security technology development

Mike Ellenbogen 11/8/11



Agenda

- Innovation in Security
- Making the Overall System Smarter
- Beyond Sensor Fusion: Adding Intelligence
  - TSA Risk Based Screening
  - ROW will follow
  - Improve the Screening Process
    - Increase Pd While Facilitating the Process and Lowering Overall Costs
- How Can Academia Work More Closely with Industry?

Innovation - Academia and Industry

- Difference Between Product Development and "Big R" Research
- Industry is <u>Hungry</u> for New Ideas
  - New Ideas Should Significantly Enhance Product Performance or Open a New Market
- Understand the Goal!
  - Industry's goal is (usually) to build a product, not just to progress to the next research phase
- Understand Your Role
  - What do you bring to the table?
  - What piece of the puzzle are you contributing to?
- Set your goals to solve big problems, not just to publish
  - What's the impact of the problem you're trying to solve?

Product Development With Academia – What's Hard?

- Understand the Critical Path
  - Stay Off It!
  - Understand it's a deliverable <u>at a specific time</u>
- It's not the Money… It's the Time
  - Sometimes it's just easier to pay for it
- Academia
  - Hypothesis, Research, Peer Review, Publish.
  - Conflicts with "Agile Research" approach

Product Development With Academia – What's Hard?

- Publish and Perish
  - Industry usually doesn't want you to publish all your work!
- Intellectual Property
  - Always an issue. Who owns what?
  - Your favorite published paper just gave away the core IP…
  - File Patent(s) or Provisionals BEFORE Publishing Your Work
- Licensing Offices
  - Be Clear, PLEASE!!!
  - Every negotiation shouldn't be a new thesis project

"Selling" to Industry

- Who Decides Whether to Work with Academia?
  - CEO? CTO? VP Eng? Program Manager?
  - Whose Vision Is It?
- Why Bring in Academia?
  - "Big R" Research
  - Government Funding?
  - Are You Smarter Thank the Other Guys?
- What are the Alternatives?
  - Consultants
  - Other Industry Partners / Developers
- What's the Benefit?
- Why is *This Time* Going to be Different?

Recommendations

- Know What You’re “Selling”
- Big R - Opportunities Further Out in Time
  - Ideal for Industry / Academic Partnership
  - Moves More Slowly Than Product Development
  - Room for Big Ideas and Big Mistakes
- Find a Champion Within The Partner Company
- Help Sell the Vision – What COULD Be!

Thank You

Mike Ellenbogen

11/8/11

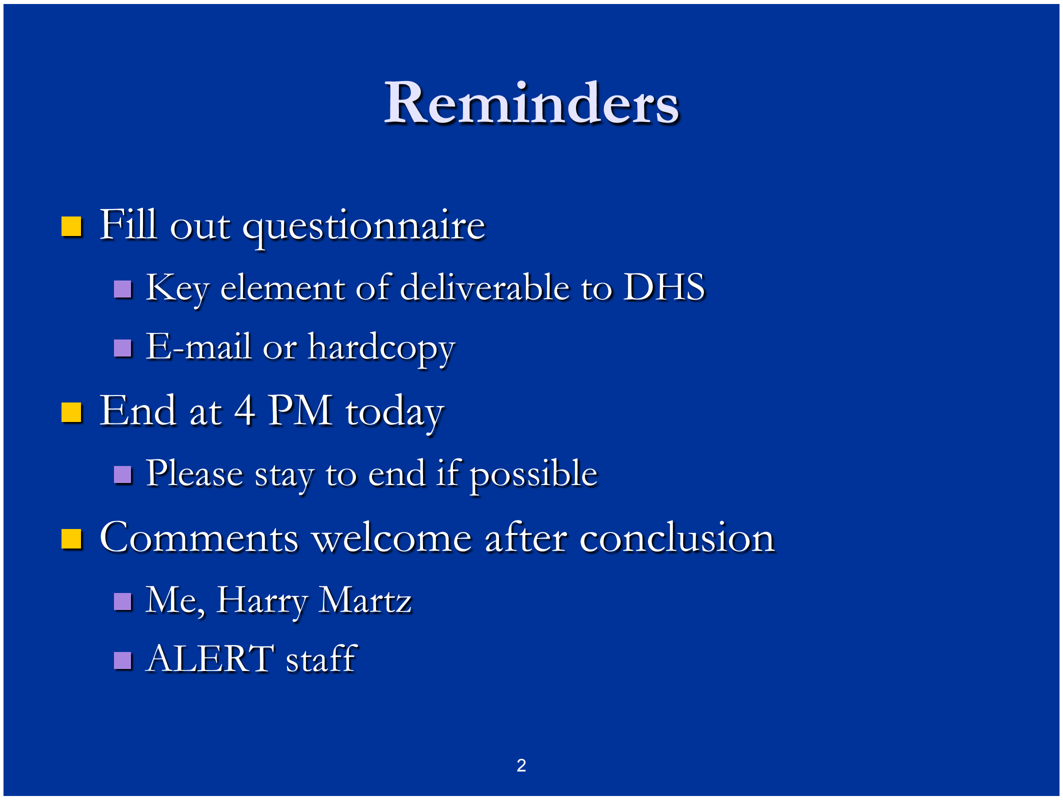
1.12 Carl Crawford: Day 2 Objectives

Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with Specific Application to Advanced Imaging Technology

Call To Order
Day 2

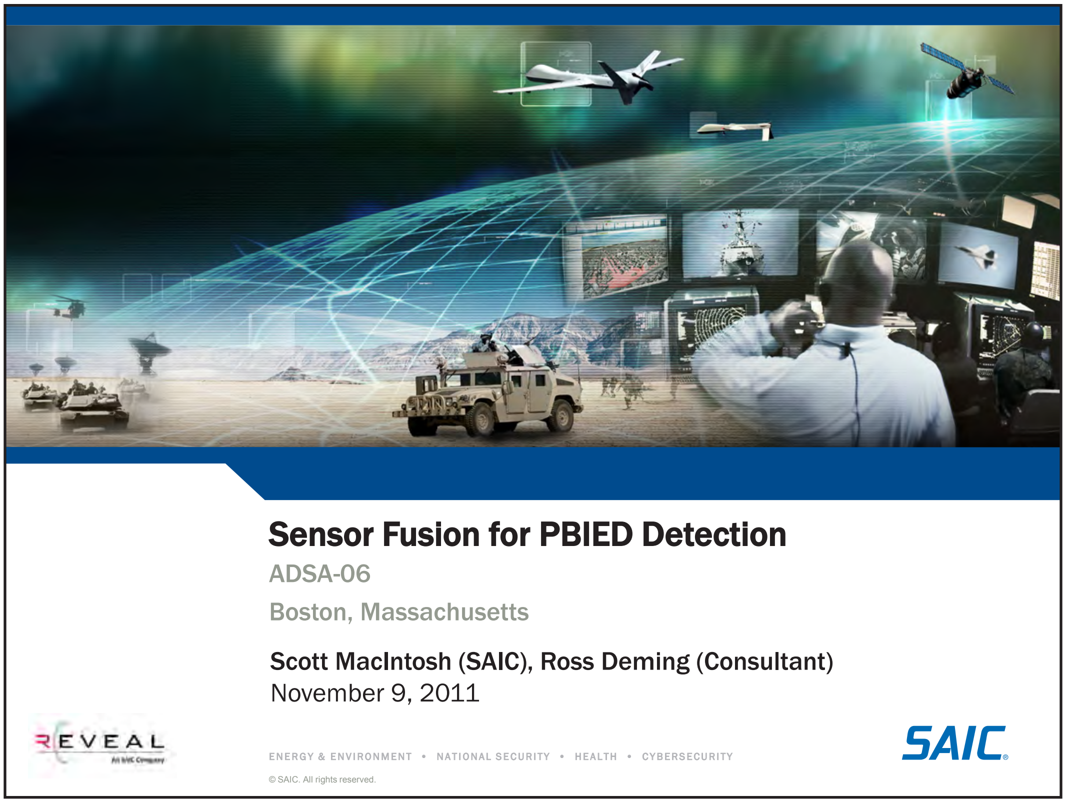
Carl R. Crawford
Csuptwo, LLC



Reminders

- Fill out questionnaire
  - Key element of deliverable to DHS
  - E-mail or hardcopy
- End at 4 PM today
  - Please stay to end if possible
- Comments welcome after conclusion
  - Me, Harry Martz
  - ALERT staff

16.13 Scott Macintosh: Sensor Fusion for PBIED Detection



Sensor Fusion for PBIED Detection

ADSA-06

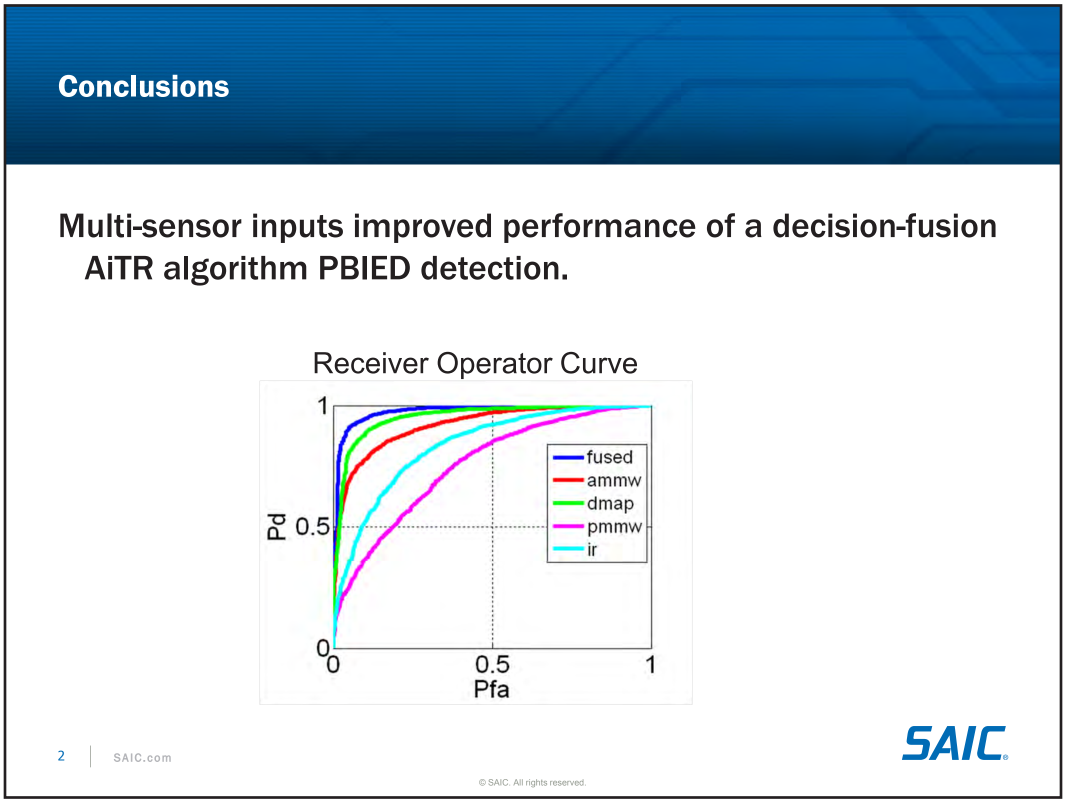
Boston, Massachusetts

Scott MacIntosh (SAIC), Ross Deming (Consultant)
November 9, 2011

REVEAL
An SAIC Company

ENERGY & ENVIRONMENT • NATIONAL SECURITY • HEALTH • CYBERSECURITY

SAIC

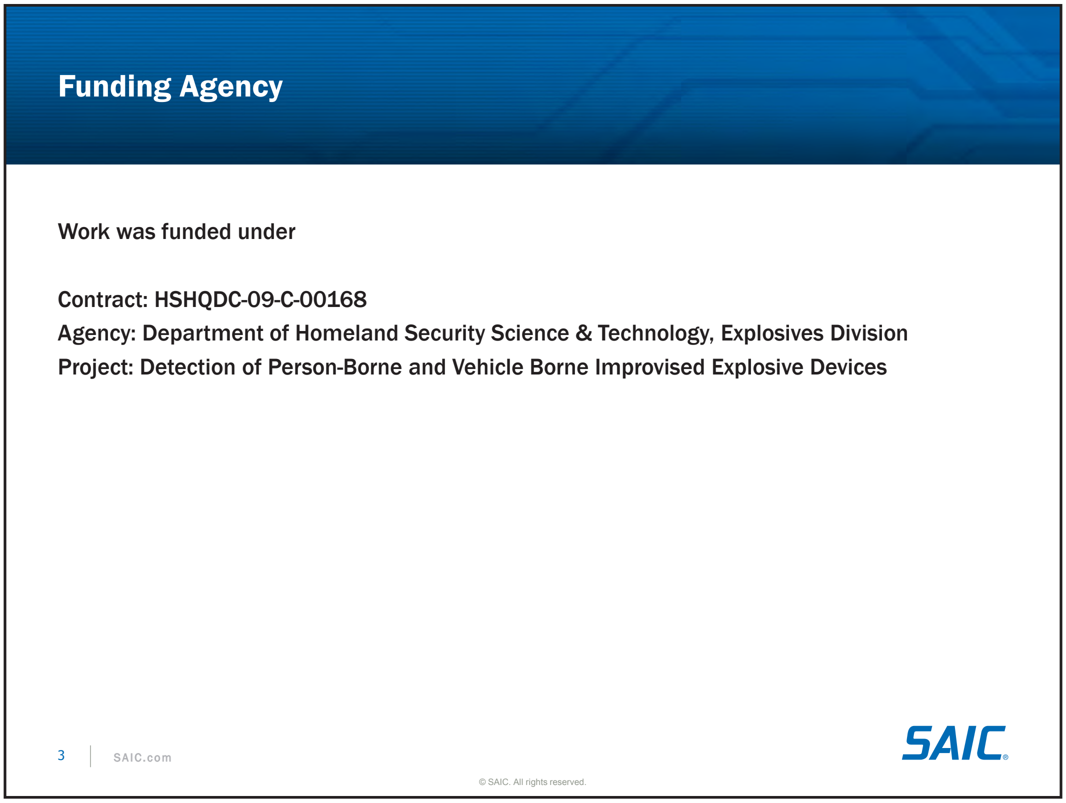


Conclusions

Multi-sensor inputs improved performance of a decision-fusion AiTR algorithm PBIED detection.

Receiver Operator Curve

SAIC



Funding Agency

Work was funded under

Contract: HSHQDC-09-C-00168
Agency: Department of Homeland Security Science & Technology, Explosives Division
Project: Detection of Person-Borne and Vehicle Borne Improvised Explosive Devices

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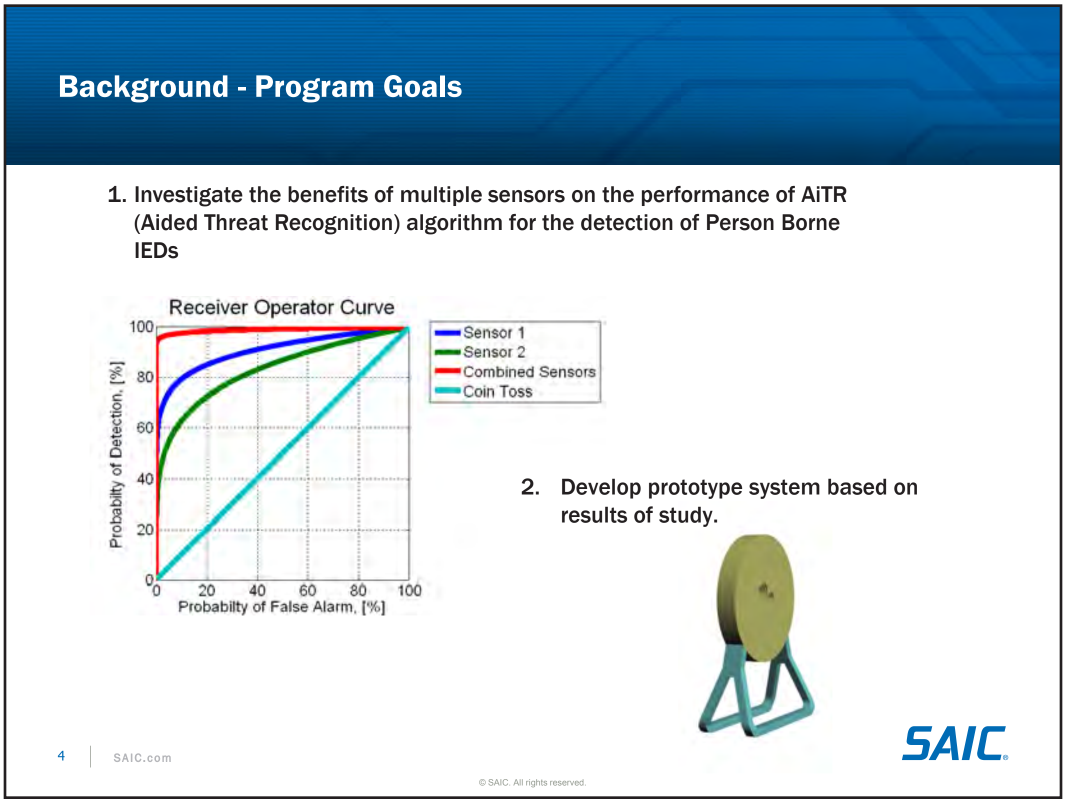
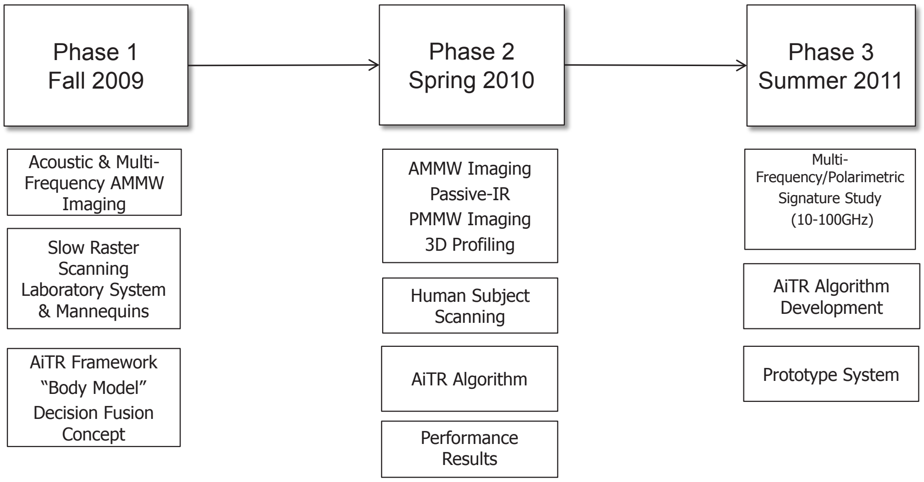


Background - Program Goals

1. Investigate the benefits of multiple sensors on the performance of AiTR (Aided Threat Recognition) algorithm for the detection of Person Borne IEDs

2. Develop prototype system based on results of study.

Program Overview


Phase 1
Fall 2009

- Acoustic & Multi-Frequency AMMW Imaging
- Slow Raster Scanning Laboratory System & Mannequins
- AiTR Framework "Body Model" Decision Fusion Concept

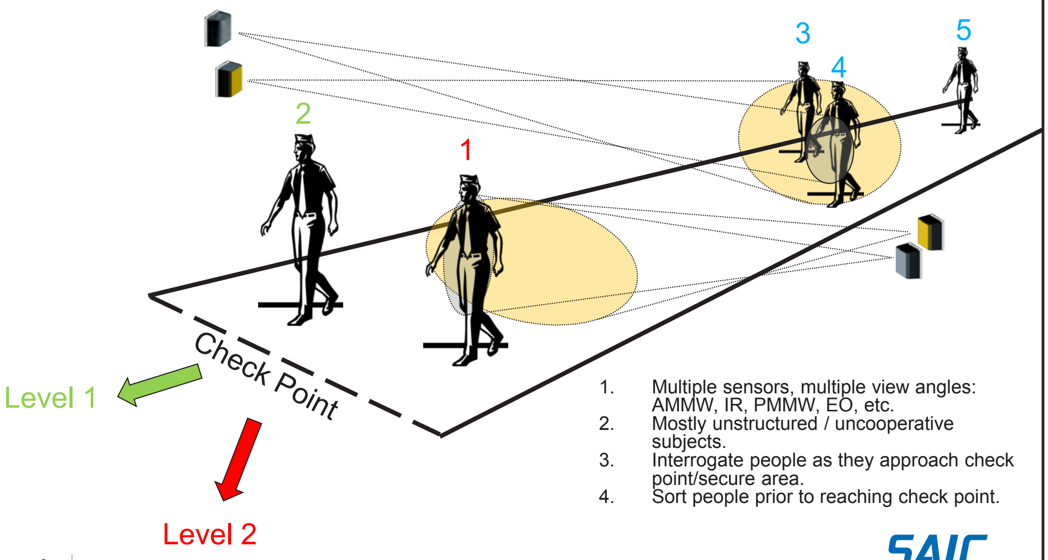
Phase 2
Spring 2010

- AMMW Imaging
Passive-IR
PMMW Imaging
3D Profiling
- Human Subject Scanning
- AiTR Algorithm
- Performance Results

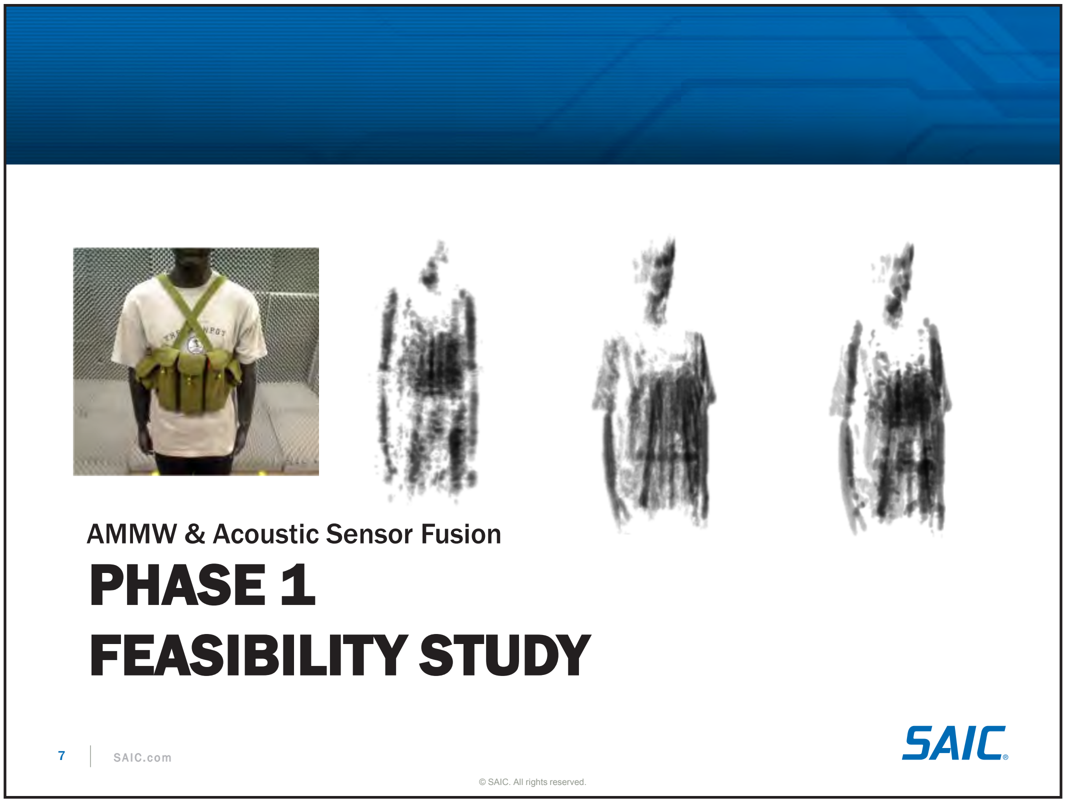
Phase 3
Summer 2011

- Multi-Frequency/Polarimetric Signature Study (10-100GHz)
- AiTR Algorithm Development
- Prototype System

CONOPS

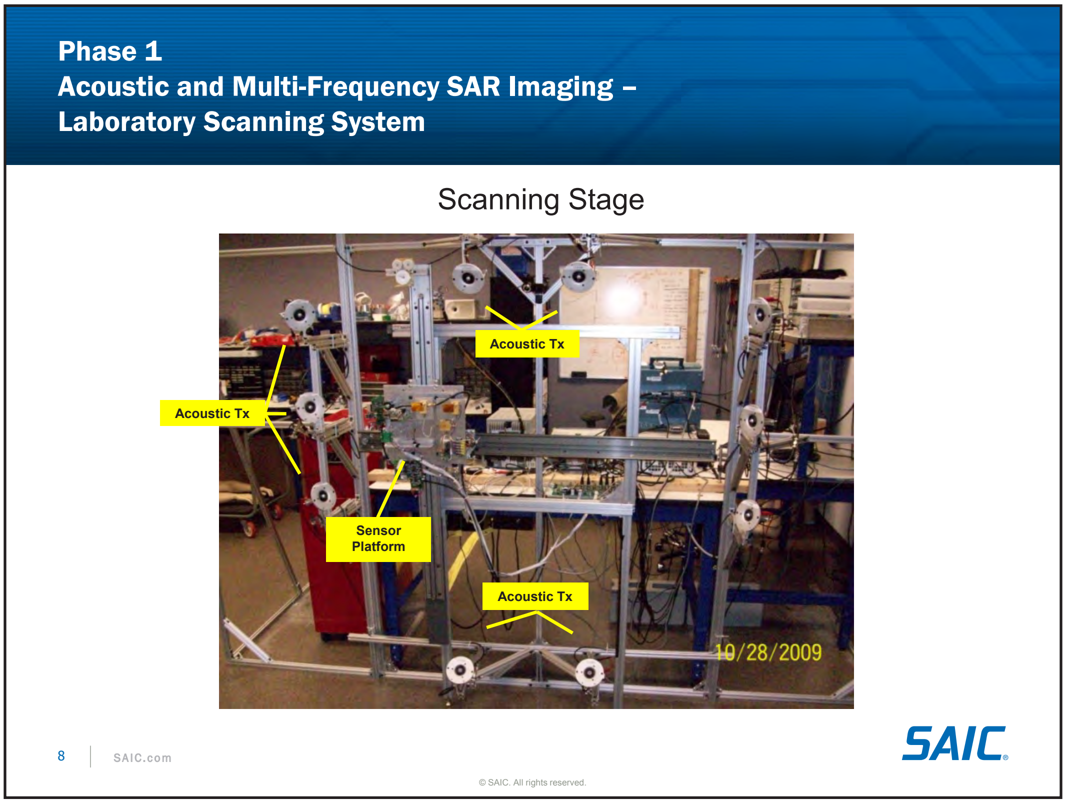


1. Multiple sensors, multiple view angles: AMMW, IR, PMMW, EO, etc.
2. Mostly unstructured / uncooperative subjects.
3. Interrogate people as they approach check point/secure area.
4. Sort people prior to reaching check point.



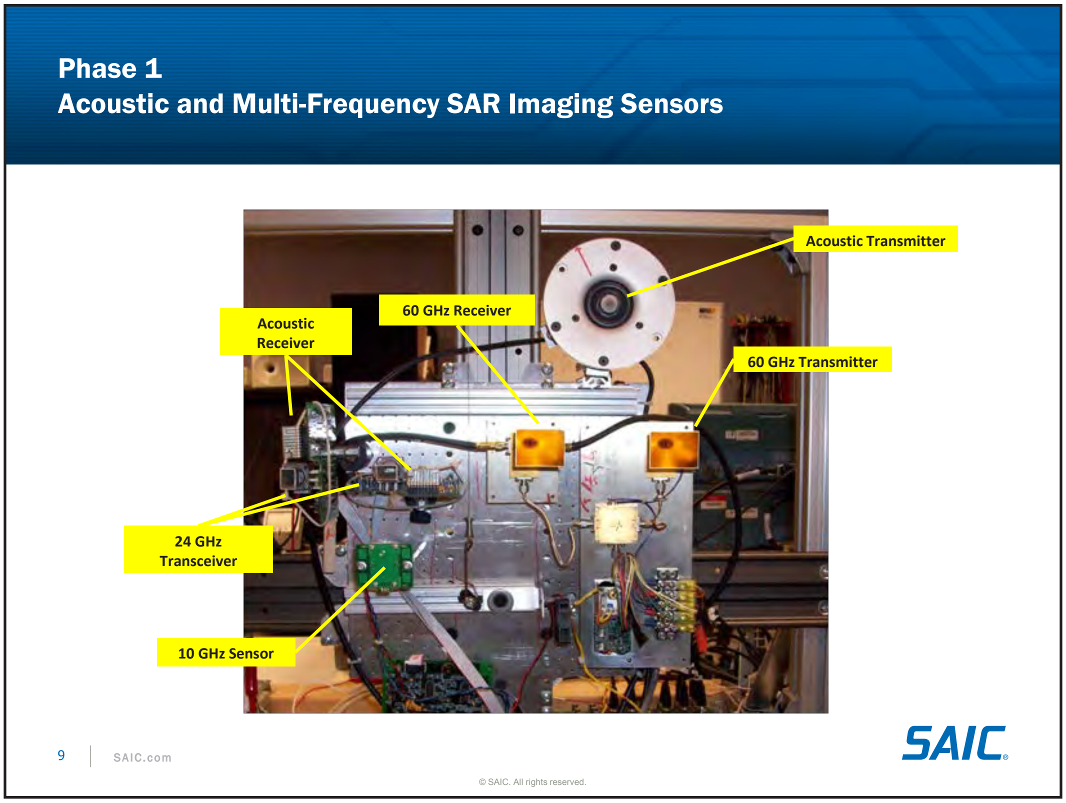
AMMW & Acoustic Sensor Fusion

PHASE 1
FEASIBILITY STUDY



Phase 1
Acoustic and Multi-Frequency SAR Imaging – Laboratory Scanning System

Scanning Stage



Phase 1
Acoustic and Multi-Frequency SAR Imaging Sensors

Acoustic Transmitter

60 GHz Receiver

Acoustic Receiver

60 GHz Transmitter

24 GHz Transceiver

10 GHz Sensor

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Phase 1
Test Object

Bare Mannequin

Under Layer

Under Layer with First Covering Layer

Under Layer with 2 Covering Layers

Under Layer with Low Metal Content Bomb-Vest

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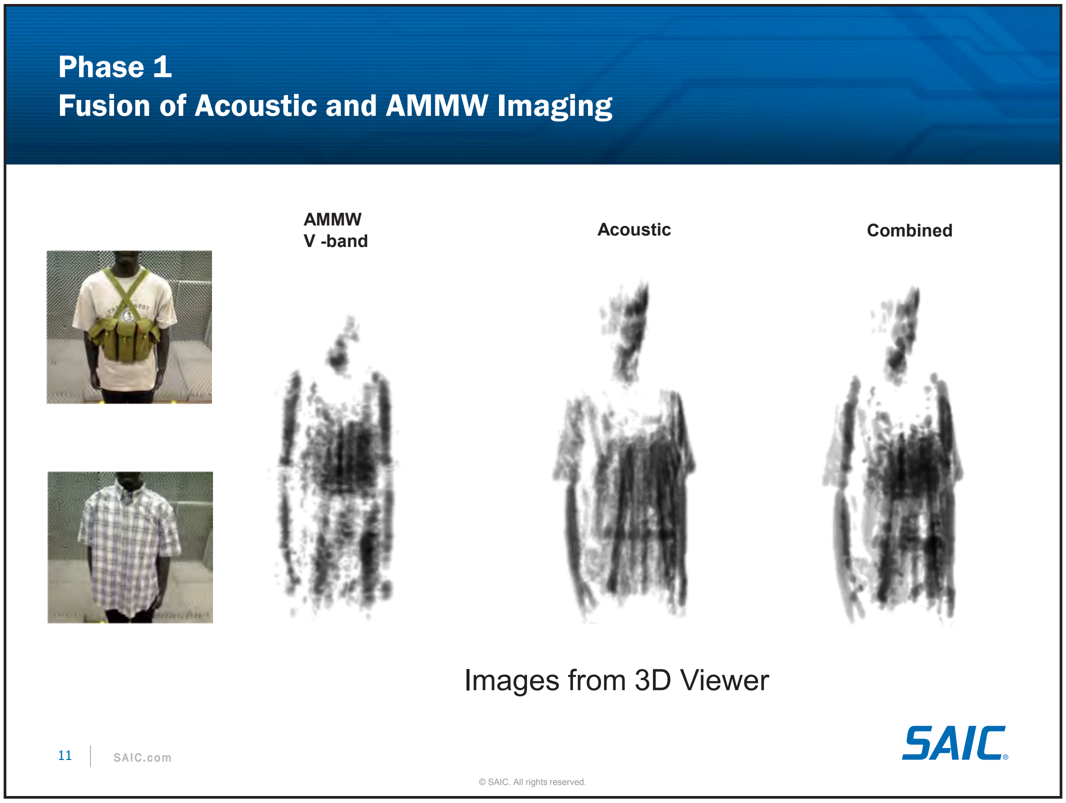

Phase 1
Fusion of Acoustic and AMMW Imaging

AMMW
V -band

Acoustic

Combined

Images from 3D Viewer

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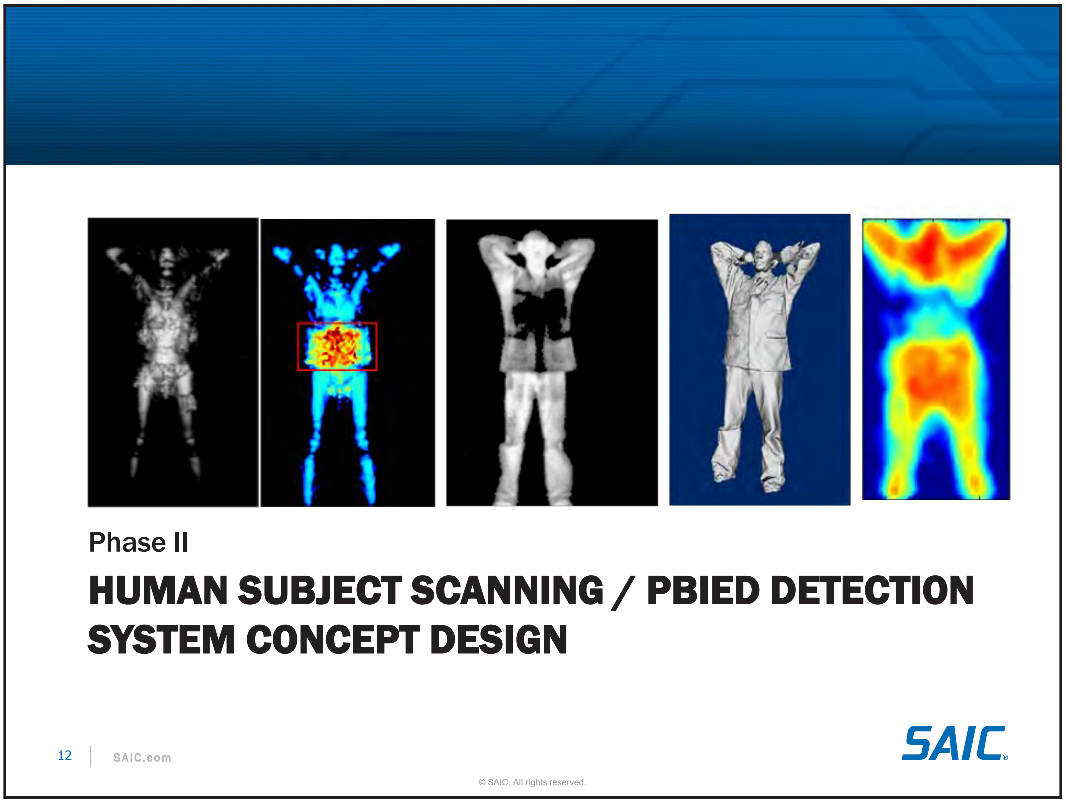

Phase II

HUMAN SUBJECT SCANNING / PBIED DETECTION SYSTEM CONCEPT DESIGN

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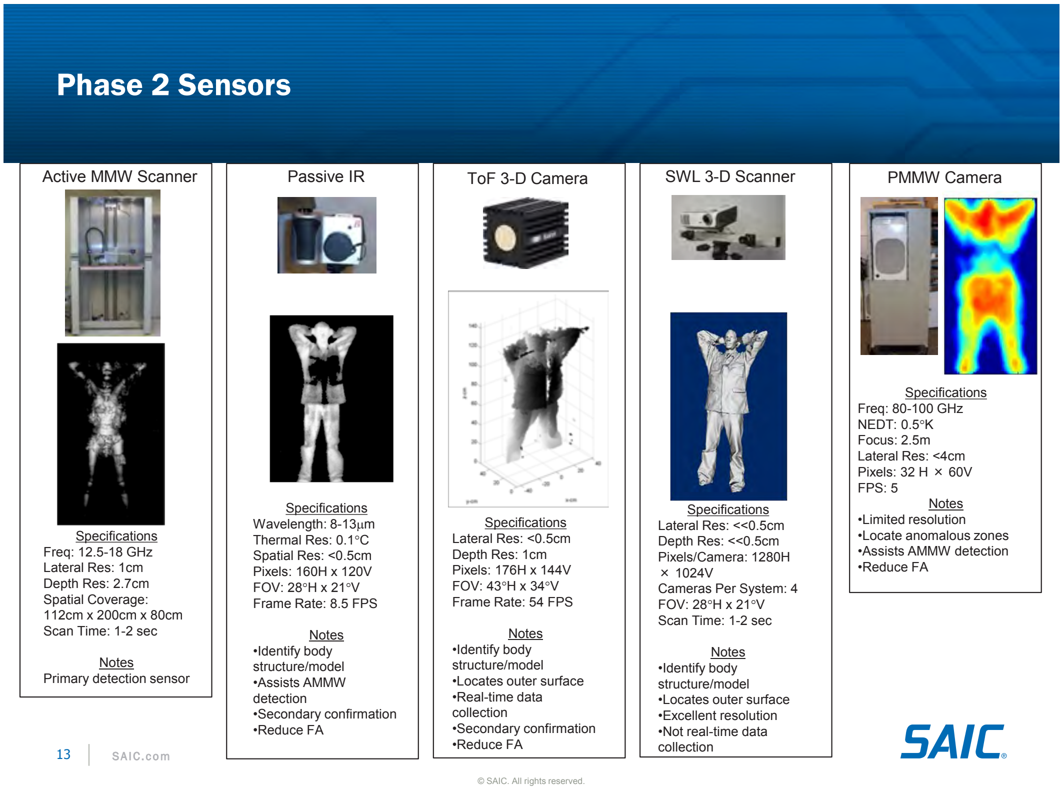

Phase 2 Sensors

Active MMW Scanner

Specifications
Freq: 12.5-18 GHz
Lateral Res: 1cm
Depth Res: 2.7cm
Spatial Coverage:
112cm x 200cm x 80cm
Scan Time: 1-2 sec

Notes
Primary detection sensor

Passive IR

Specifications
Wavelength: 8-13μm
Thermal Res: 0.1°C
Spatial Res: <0.5cm
Pixels: 160H x 120V
FOV: 28°H x 21°V
Frame Rate: 8.5 FPS

Notes
- •Identify body structure/model
- •Assists AMMW detection
- •Secondary confirmation
- •Reduce FA

ToF 3-D Camera

Specifications
Lateral Res: <0.5cm
Depth Res: 1cm
Pixels: 176H x 144V
FOV: 43°H x 34°V
Frame Rate: 54 FPS

Notes
- •Identify body structure/model
- •Locates outer surface
- •Real-time data collection
- •Secondary confirmation
- •Reduce FA

SWL 3-D Scanner

Specifications
Lateral Res: <<0.5cm
Depth Res: <<0.5cm
Pixels/Camera: 1280H × 1024V
Cameras Per System: 4
FOV: 28°H x 21°V
Scan Time: 1-2 sec

Notes
- •Identify body structure/model
- •Locates outer surface
- •Excellent resolution
- •Not real-time data collection

PMMW Camera

Specifications
Freq: 80-100 GHz
NEDT: 0.5°K
Focus: 2.5m
Lateral Res: <4cm
Pixels: 32 H × 60V
FPS: 5

Notes
- •Limited resolution
- •Locate anomalous zones
- •Assists AMMW detection
- •Reduce FA

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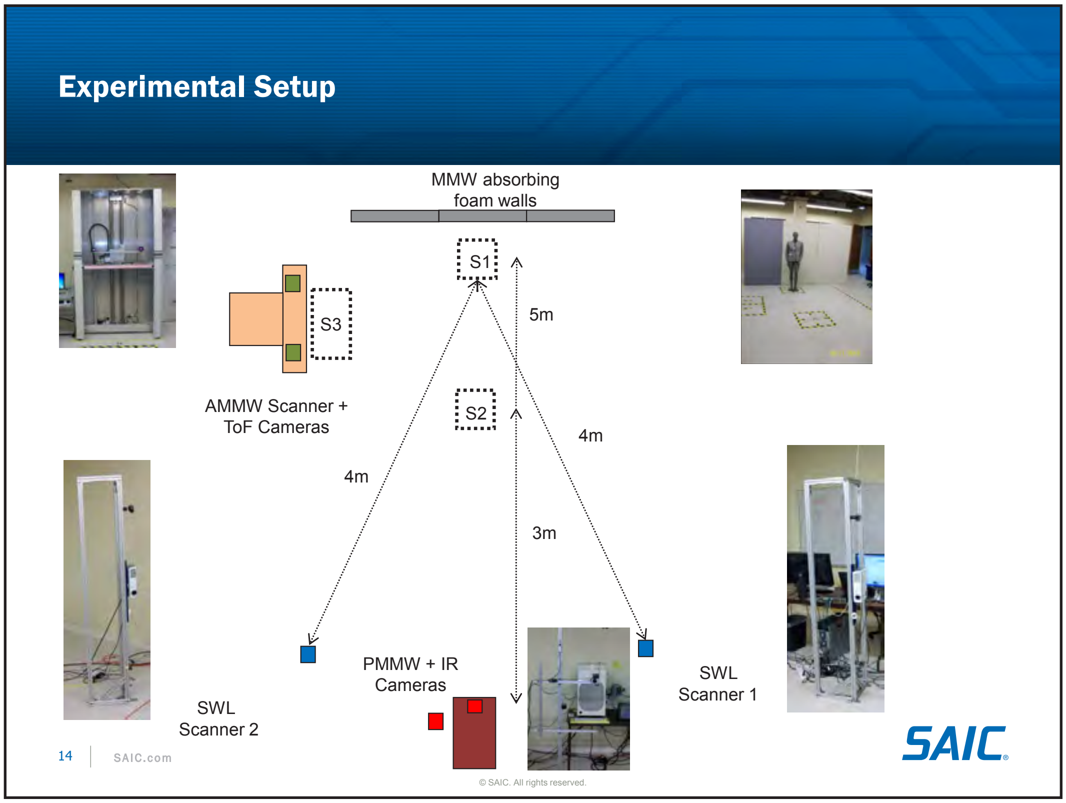


Experimental Setup

MMW absorbing foam walls

S1

S3

5m

AMMW Scanner + ToF Cameras

S2

4m

4m

3m

PMMW + IR Cameras

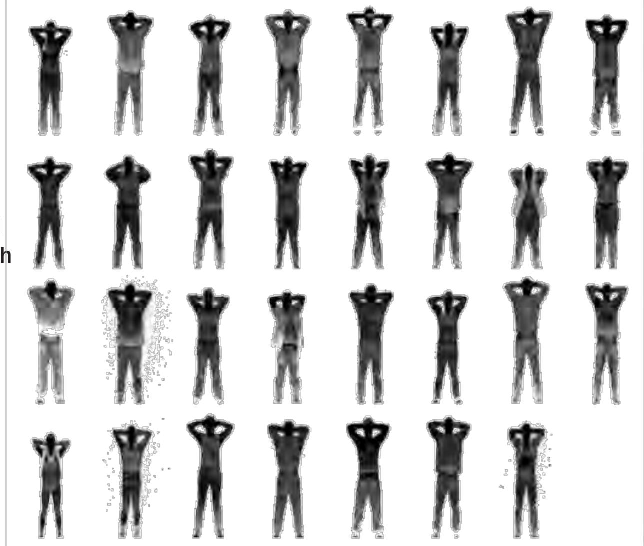
SWL Scanner 1

SWL Scanner 2

SAIC.

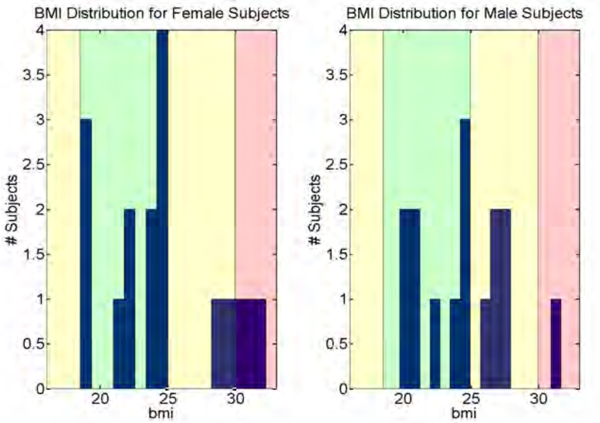
Scan Subjects

- 17 women and 16 men participated in the data collection.
- A total of 1,229 scans were collected
- Subjects were scanned with and without various simulated suicide bomb devices, and with and without common items.



Scan Subjects (continued)

- 17 women and 16 men participated in the data collection.
- A total of 1,229 scans were collected
- Subjects were scanned with and without various simulated suicide bomb devices, and with and without common items, such as cell phones, keys, wallets.
- Data was collected using smaller threat items such as handguns, knives and smaller explosive threat masses.



Simulated Bomb Devices

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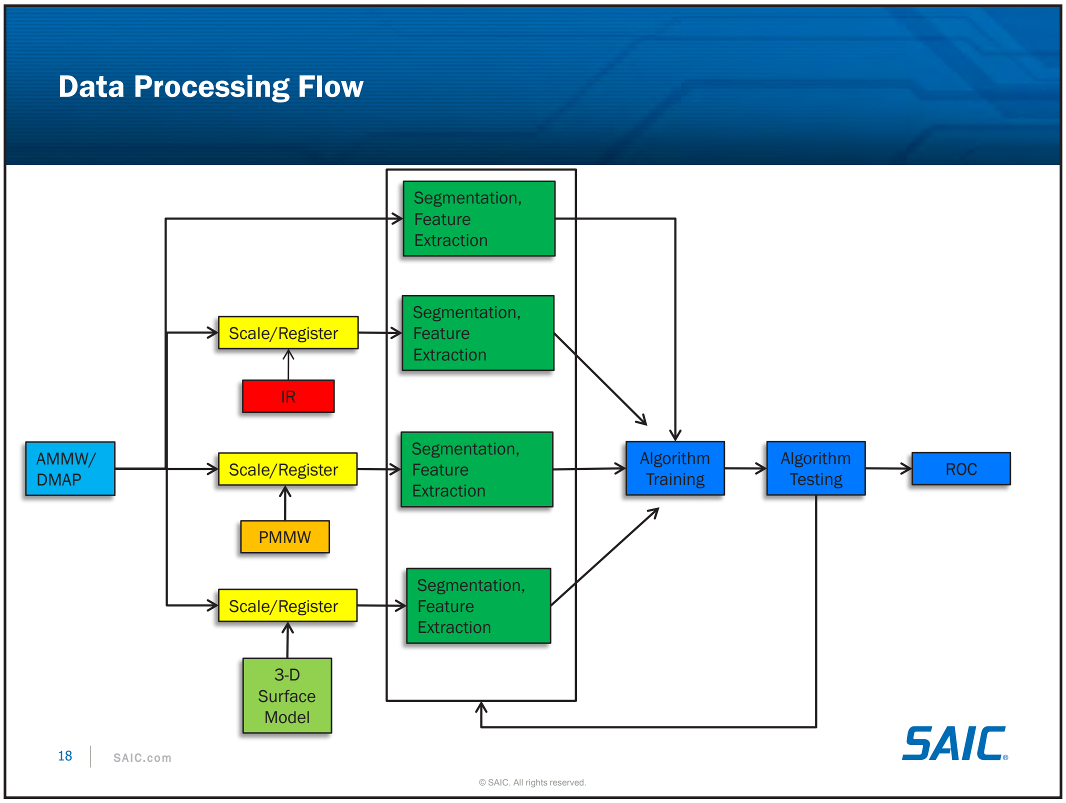

Data Processing Flow

AMMW/ DMAP

Scale/Register

IR

Scale/Register

PMMW

Scale/Register

3-D Surface Model

Segmentation, Feature Extraction

Segmentation, Feature Extraction

Segmentation, Feature Extraction

Segmentation, Feature Extraction

Algorithm Training

Algorithm Testing

ROC

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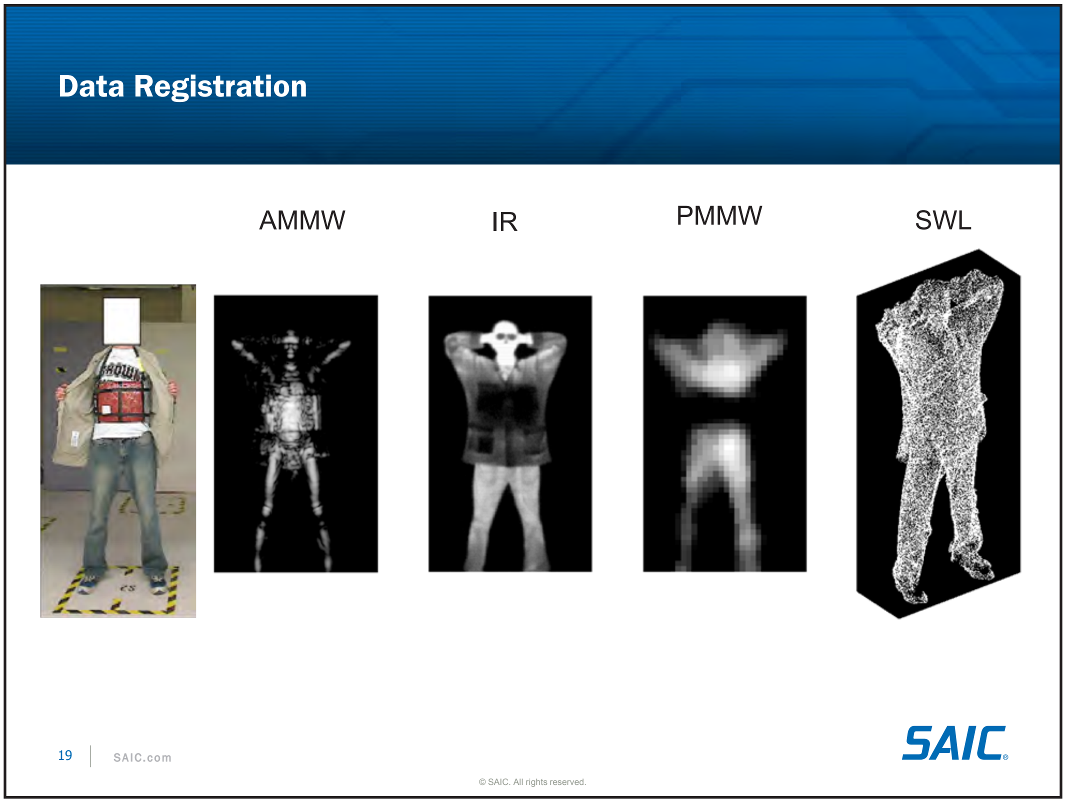

Data Registration

AMMW

IR

PMMW

SWL

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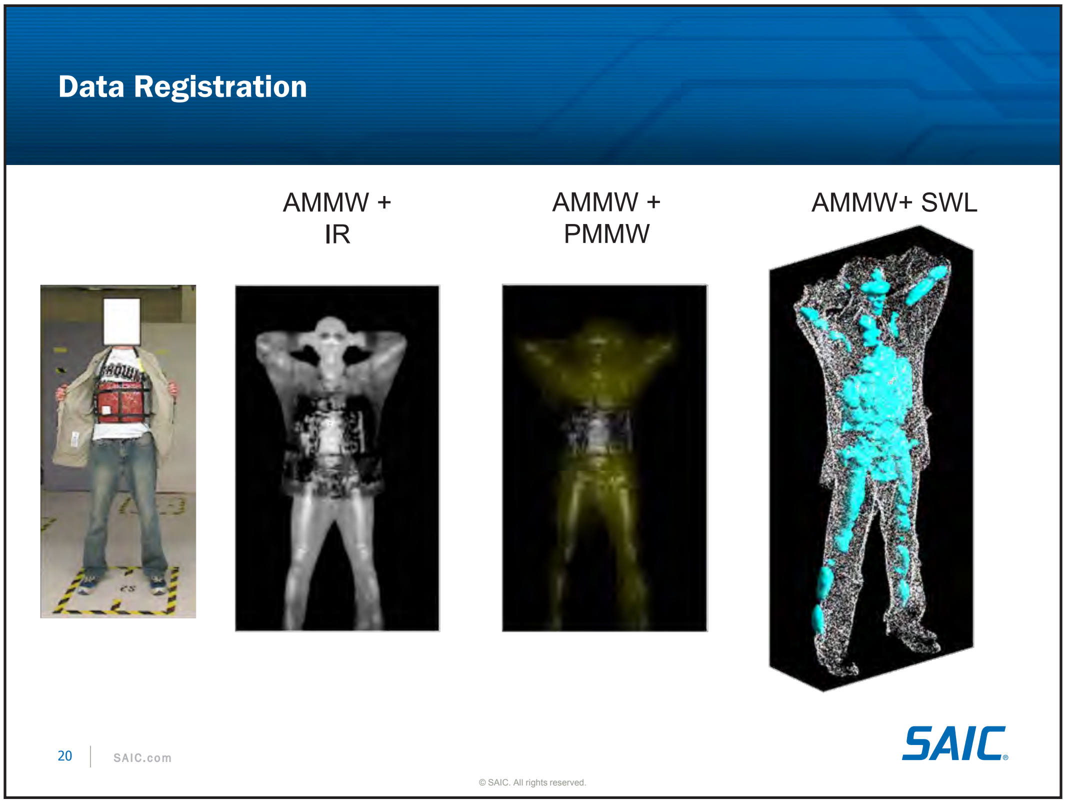

Data Registration

AMMW + IR

AMMW + PMMW

AMMW+ SWL

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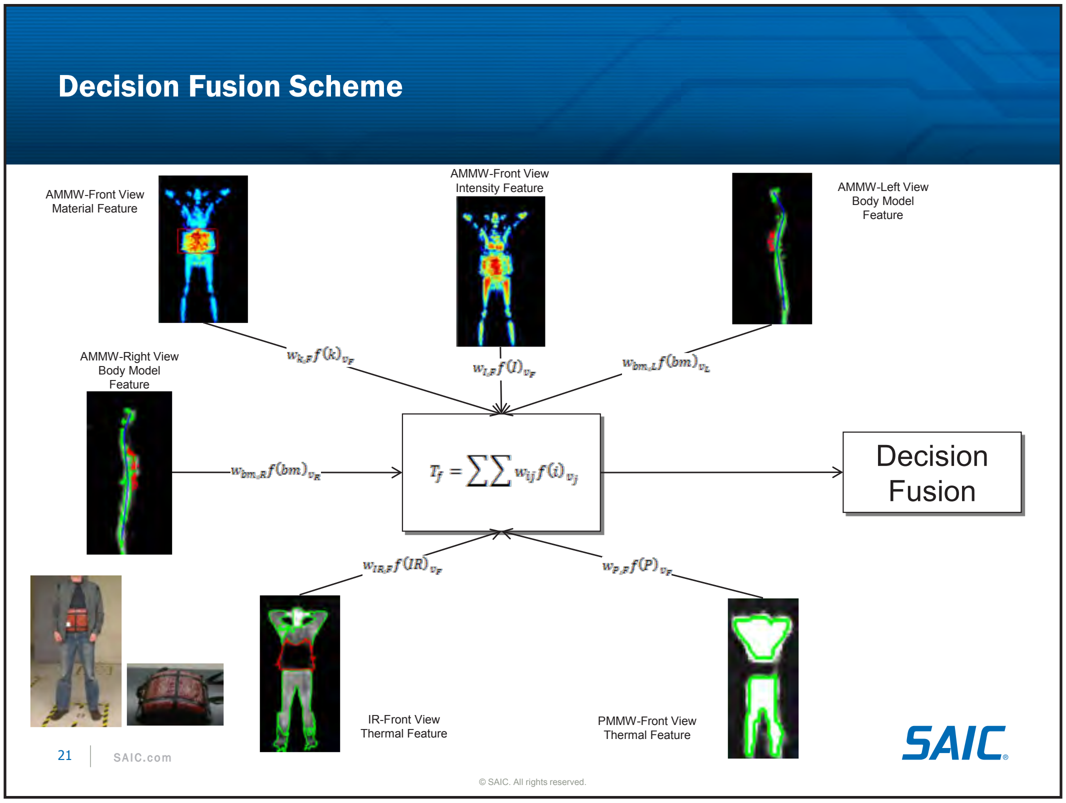


Decision Fusion Scheme

AMMW-Front View
Material Feature

AMMW-Front View
Intensity Feature

AMMW-Left View
Body Model
Feature

AMMW-Right View
Body Model
Feature

$w_{k,F}f(k)_{v_F}$

$w_{I,F}f(I)_{v_F}$

$w_{bm,L}f(bm)_{v_L}$

$w_{bm,R}f(bm)_{v_R}$

$$T_f = \sum\sum w_{ij}f(i)_{v_j}$$

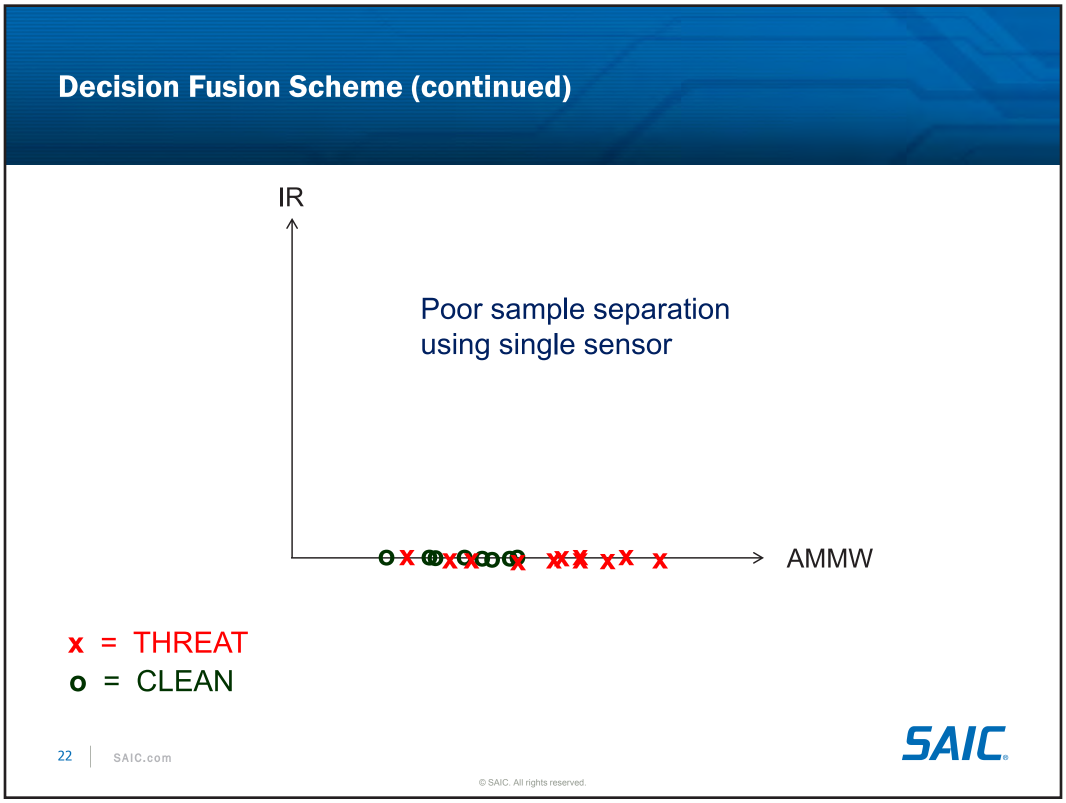
Decision
Fusion

$w_{IR,F}f(IR)_{v_F}$

$w_{P,F}f(P)_{v_F}$

IR-Front View
Thermal Feature

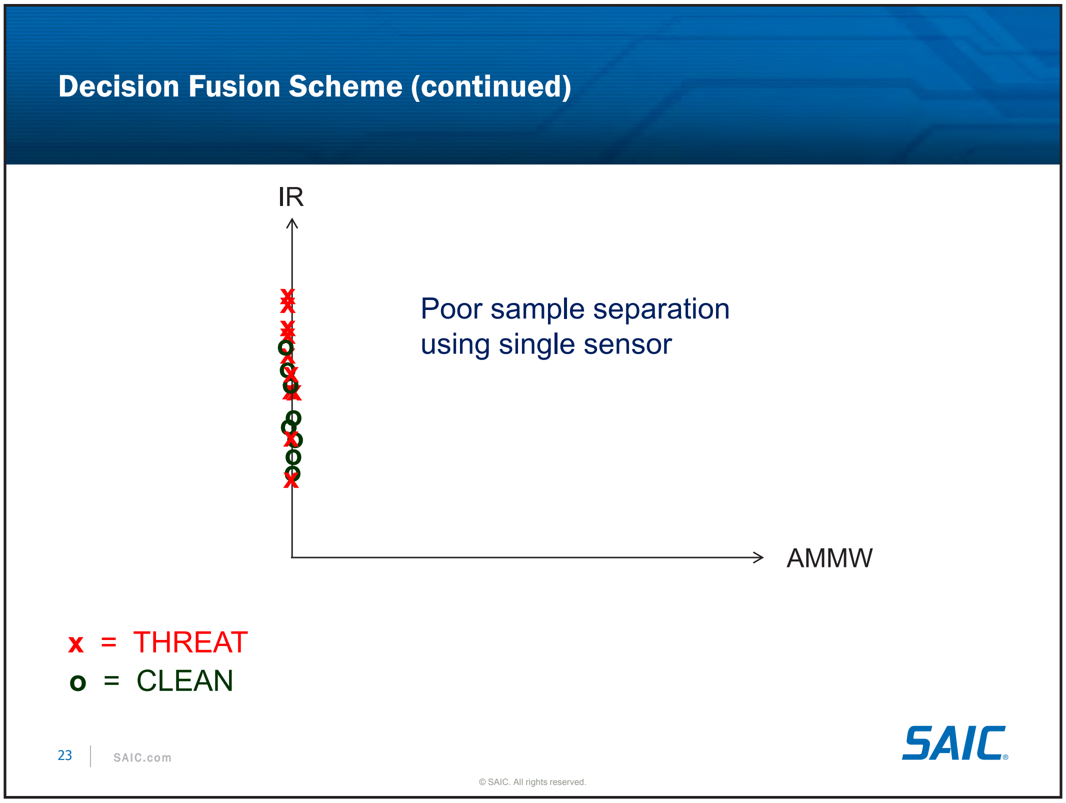
PMMW-Front View
Thermal Feature



Decision Fusion Scheme (continued)

Poor sample separation
using single sensor

x = THREAT
o = CLEAN



Decision Fusion Scheme (continued)

Poor sample separation using single sensor

x = THREAT
o = CLEAN

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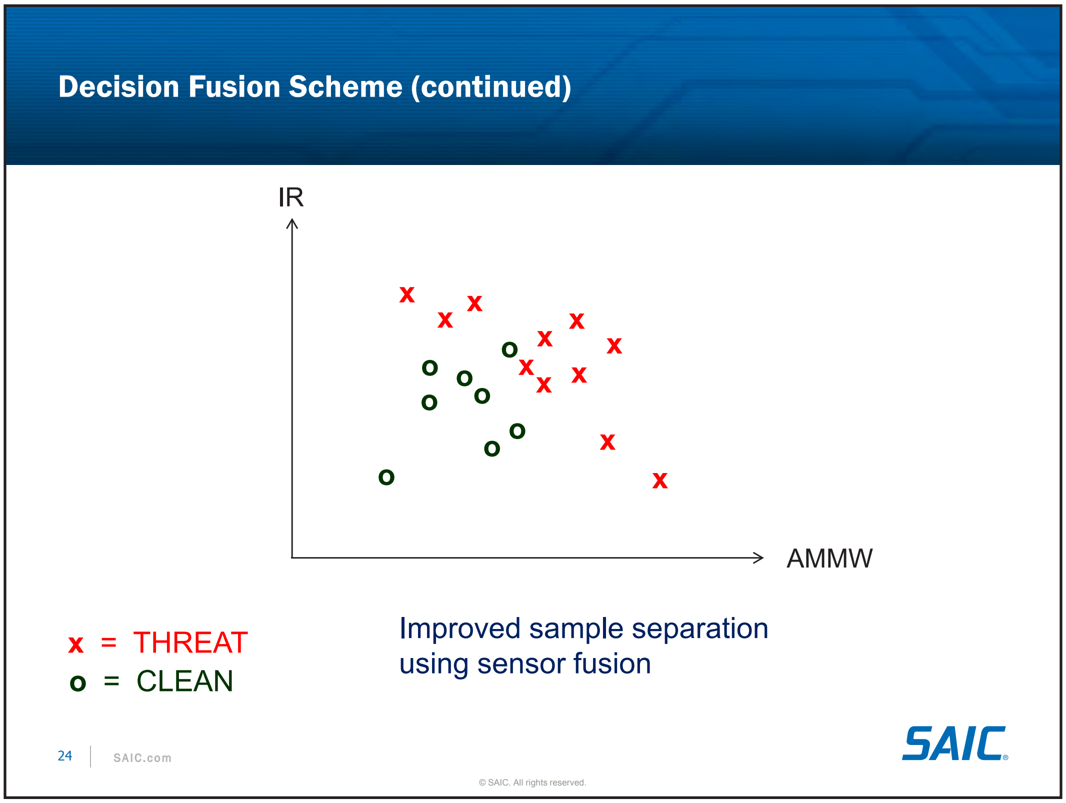

Decision Fusion Scheme (continued)

Improved sample separation using sensor fusion

x = THREAT
o = CLEAN

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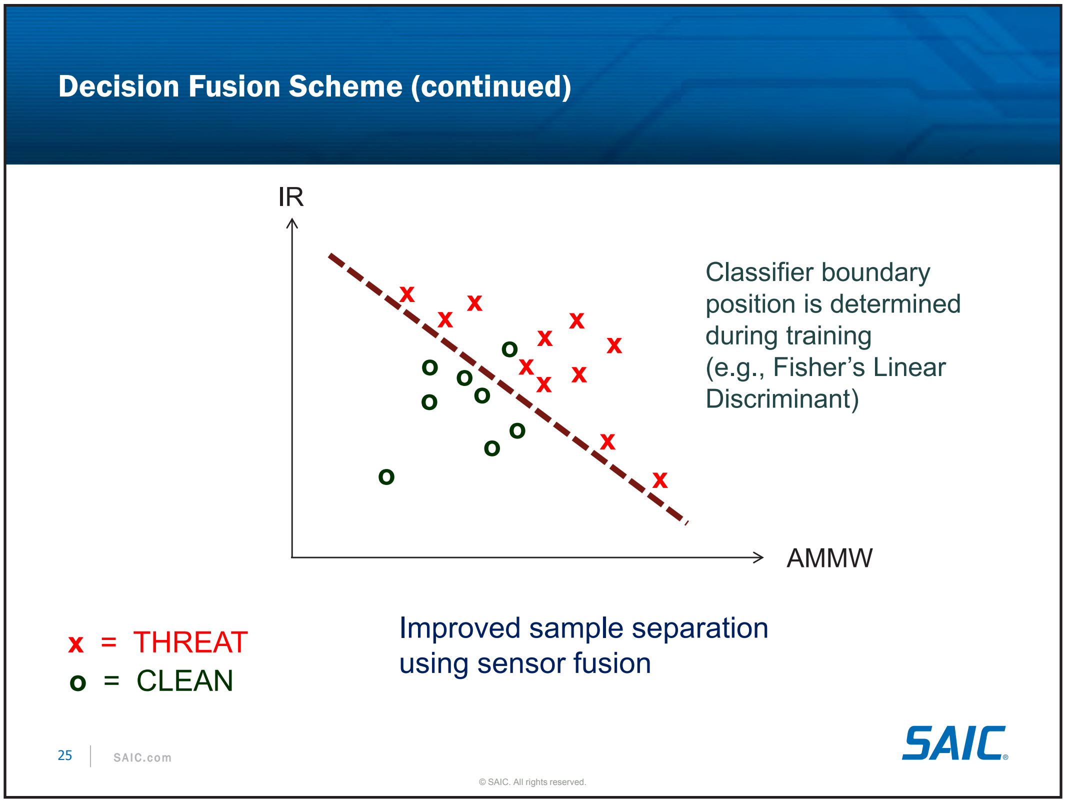

Decision Fusion Scheme (continued)

Classifier boundary position is determined during training (e.g., Fisher's Linear Discriminant)

x = THREAT
o = CLEAN

Improved sample separation using sensor fusion

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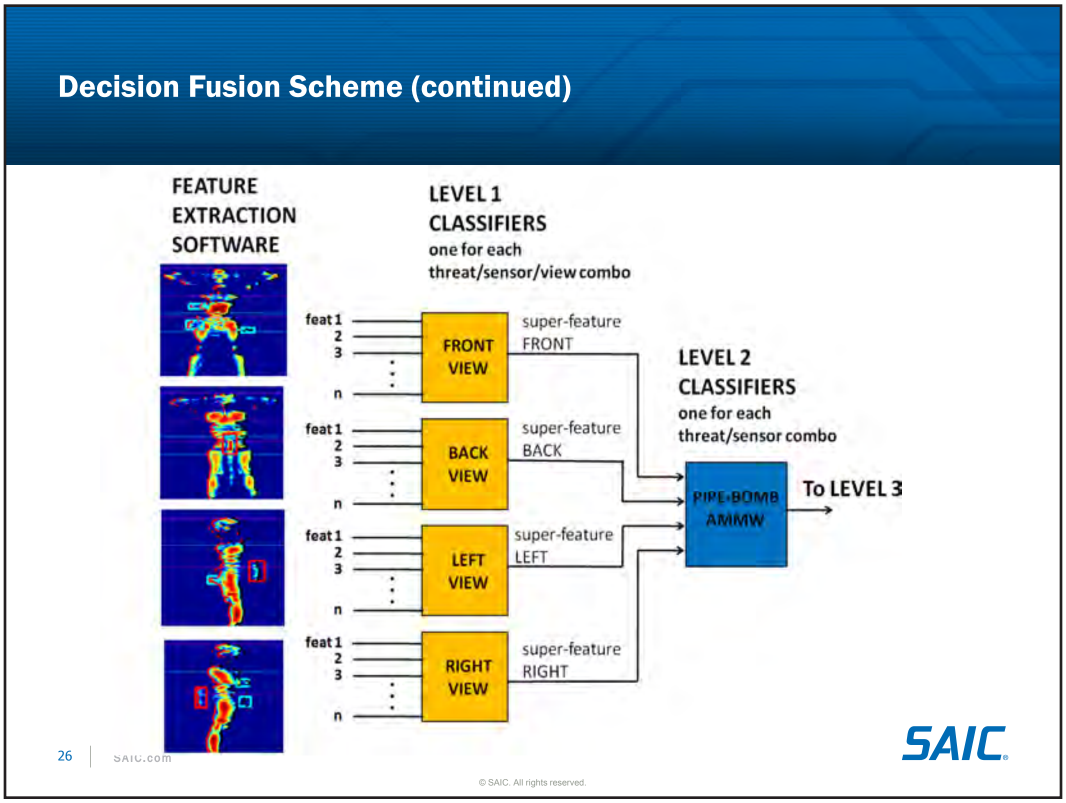

Decision Fusion Scheme (continued)

FEATURE EXTRACTION SOFTWARE

LEVEL 1 CLASSIFIERS
one for each threat/sensor/view combo

LEVEL 2 CLASSIFIERS
one for each threat/sensor combo

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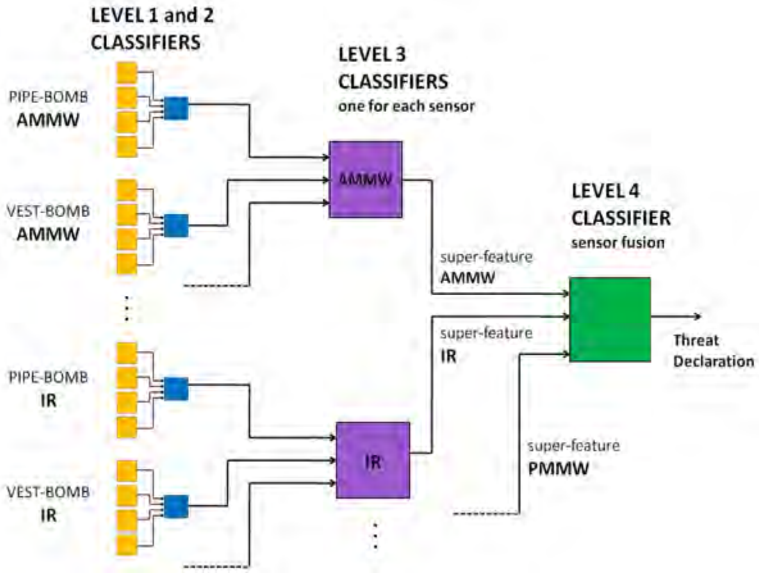
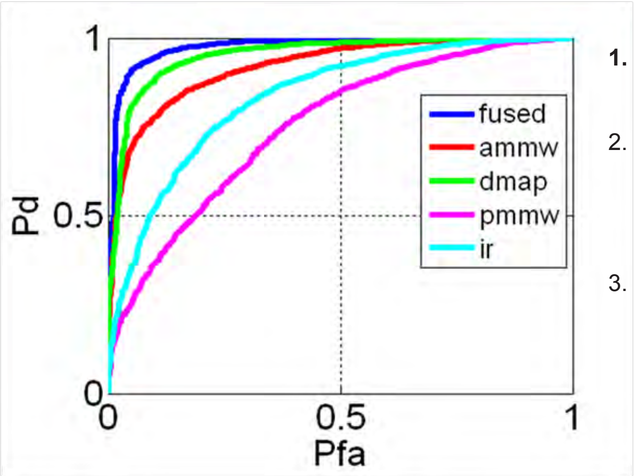
Decision Fusion Scheme (continued)



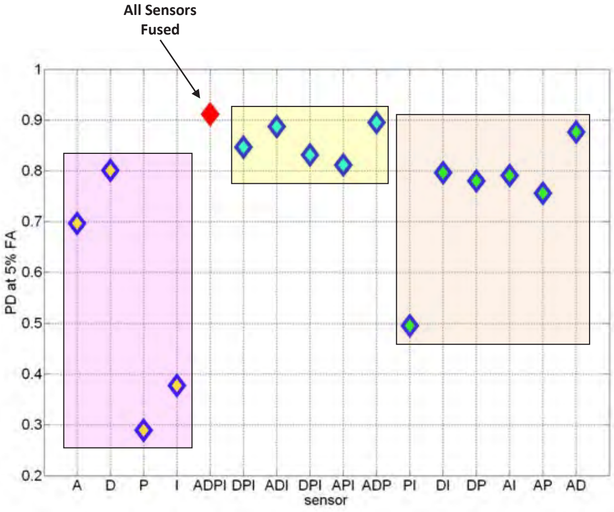
Performance Curve for Fused Sensors vs. Single Sensor, All Threats

Receiver Operator Curve



1. **Fusion of sensors increased performance of the AITR Algorithm.**
2. Sensor performance results is a function of the sensor's ability to "detect something", the quality of the features extracted and many other factors.
3. Results displayed should not be taken as a authoritative assessment on a particular sensor.

Probability of Detection at 5% False Alarm Rate for Different Sensor Combinations – All Threats



AMMW Intensity Image
Dielectric Map Image
PMMW Image
IR Image

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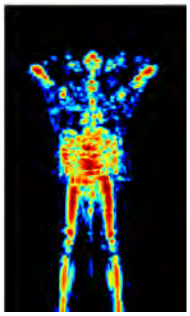
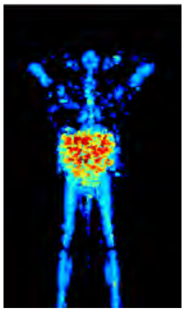
DMAP Examples

Maximum Intensity Projection Image

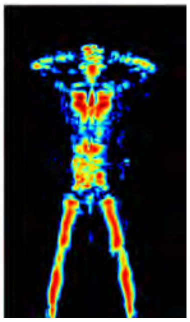


DMAP Image

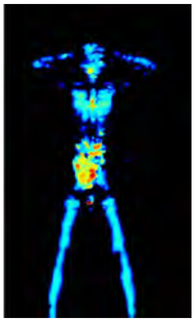


Sheet Explosive Simulant
1cm thick, with metal bb shrapnel
on steel plate

Maximum Intensity Projection Image



DMAP Image



Sheet Explosive Simulant
1.5cm thick, with ceramic ball shrapnel

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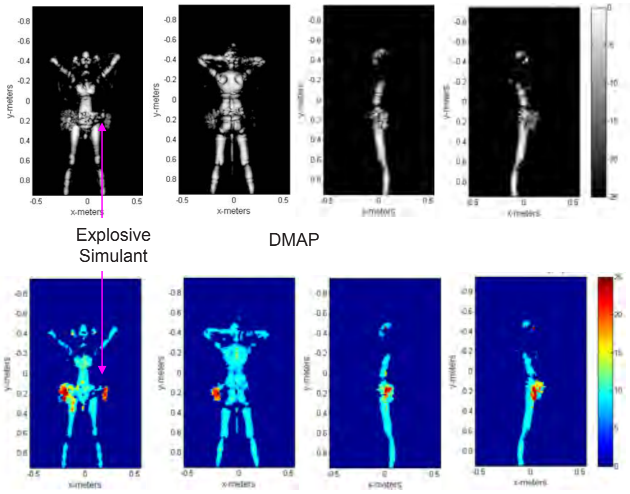
DMAP (Continued)

XY Max Projection Image [dB]



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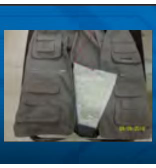
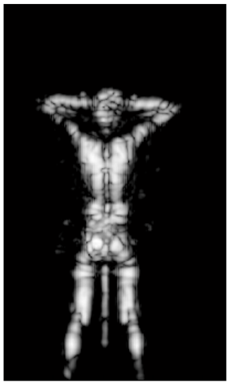
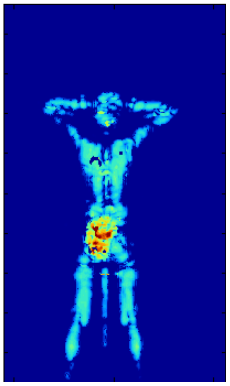
Because the DMAP effectively locates the human body in the image, this can be used to remove the human body from the image leaving only the area of interest for an operator or an algorithm



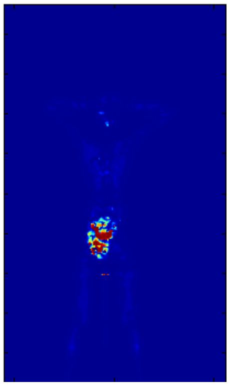
Intensity Image



DMAP



“Privacy Filter”/Regionizer



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Thank You

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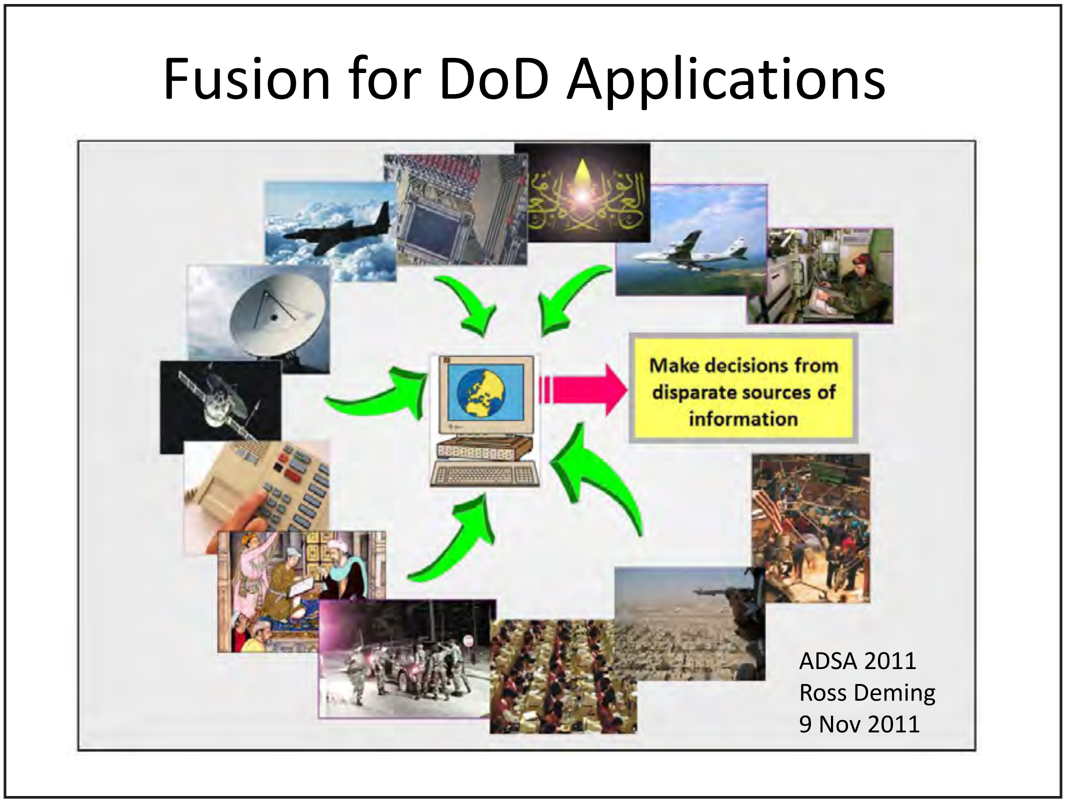
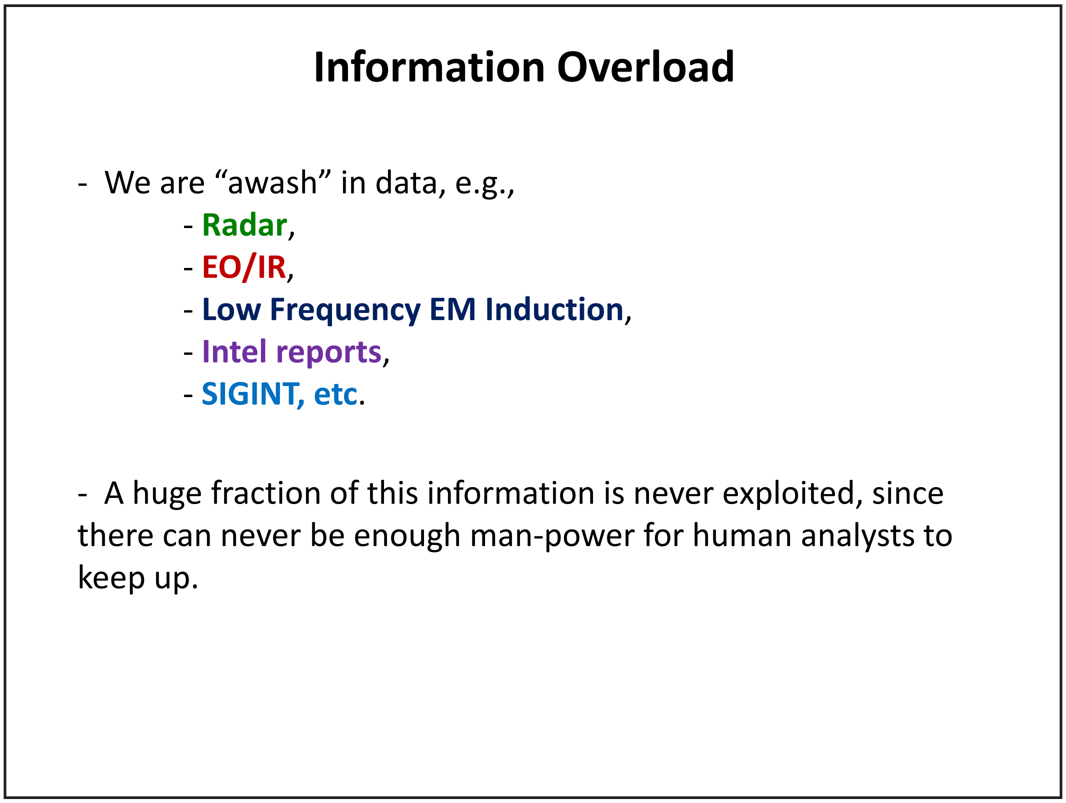
16.14 Ross Deming: Fusion in DoD and discussion



Fusion for DoD Applications

Make decisions from disparate sources of information

ADSA 2011
Ross Deming
9 Nov 2011



Information Overload

- We are “awash” in data, e.g.,
  - **Radar**,
  - **EO/IR**,
  - **Low Frequency EM Induction**,
  - **Intel reports**,
  - **SIGINT, etc**.

- A huge fraction of this information is never exploited, since there can never be enough man-power for human analysts to keep up.

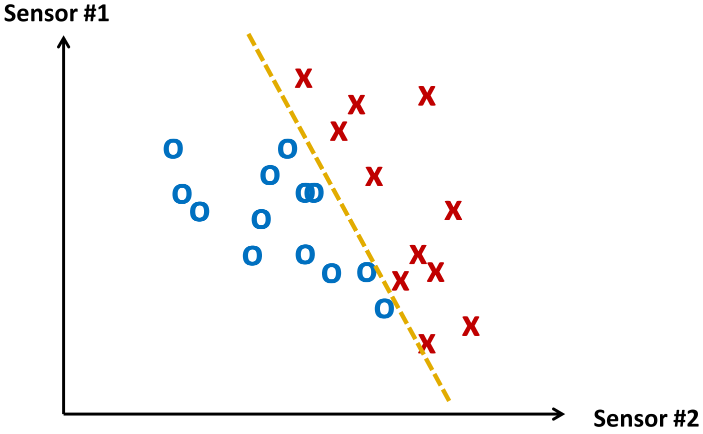
Information Overload

- Must better utilize computers to ease the burden on analysts:

  - **provide analysts with tools to increase productivity**,
  - **automatically "flag" suspicious activities**,
  - **make complicated decisions,**
  - **train a computer to "think" like a human (only faster)!**

Intriguing Idea: we can sometimes make great decisions based upon mediocre information if we have lots of independent sources.

Think of "Bones"!



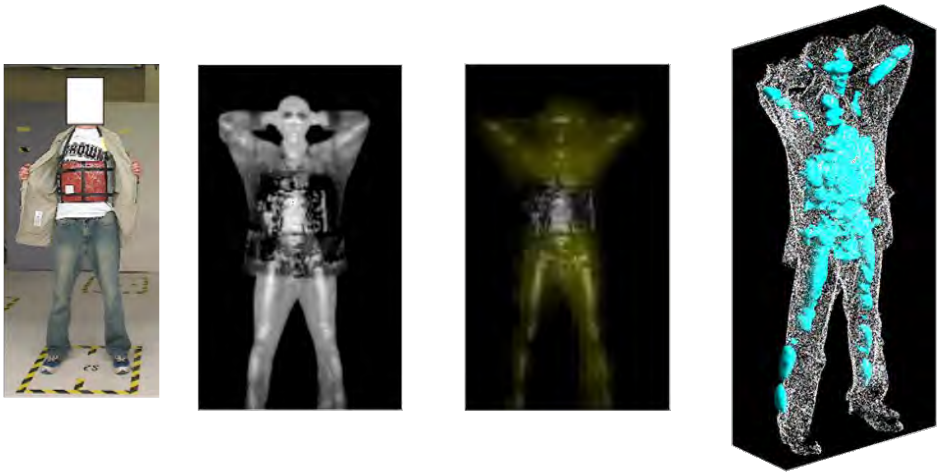
Adding dimensions increases class separation

Specific DoD Applications for Fusion

- Concealed weapon detection,
- Cargo inspection,
- Roadside IED prevention,
- Ballistic missile defense,
- De-mining, locating unexploded ordnance,
- Uncovering networks of insurgents.
- …many more....

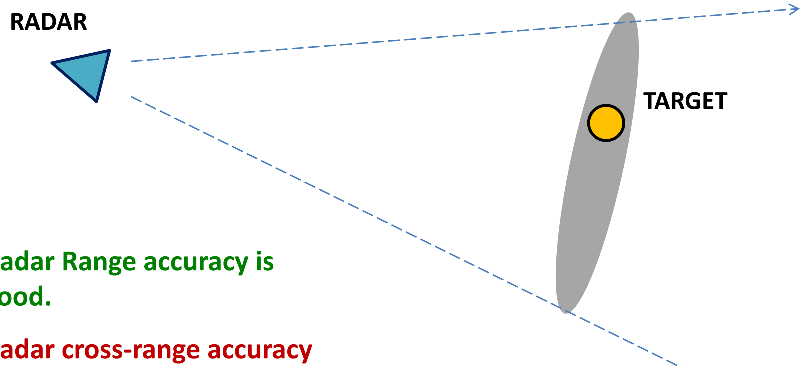
Fusion Example #1

- Different sensors may yield complementary information which can be used to reduce false alarms.



Fusion Example #2

- Improve tracking accuracy by exploiting orthogonality of different sensors.

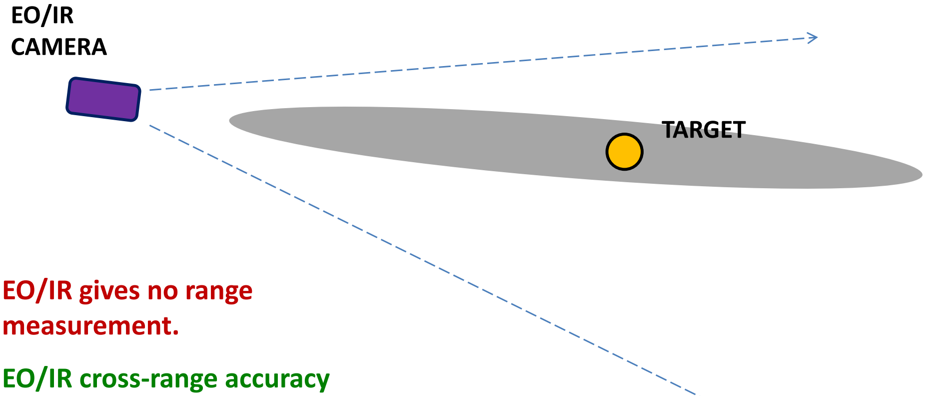


Radar Range accuracy is good.

Radar cross-range accuracy may be relatively poor.

Fusion Example #2

- Improve tracking accuracy by exploiting orthogonality of different sensors.

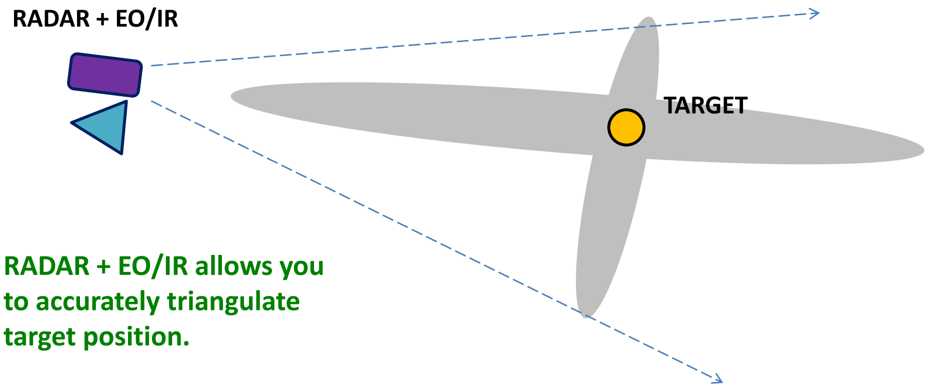


EO/IR gives no range measurement.

EO/IR cross-range accuracy is excellent.

Fusion Example #2

- Improve tracking accuracy by exploiting orthogonality of different sensors.

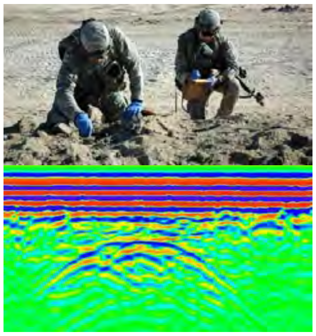


RADAR + EO/IR allows you to accurately triangulate target position.

Fusion Example #3

- **Huge Problem!** How can we perform fusion for IED Detection and Prevention?

Local sensor data



Wide Area Surveillance

Intel

Major Challenges in Fusion for DoD

-Data Association
  - combinatorial explosion!

-Feature Extraction
  - How to quantify subtle information?

-Integration of disparate information
  - e.g., text with sensor data.

-Development of Models
  - Incorporate prior knowledge and human understanding.

-Queuing/scheduling sensor resources
  - e.g., large scale surveillance can queue cameras.

- How can we get researchers access to classified/sensitive information to develop and test algorithms?.

Questions?

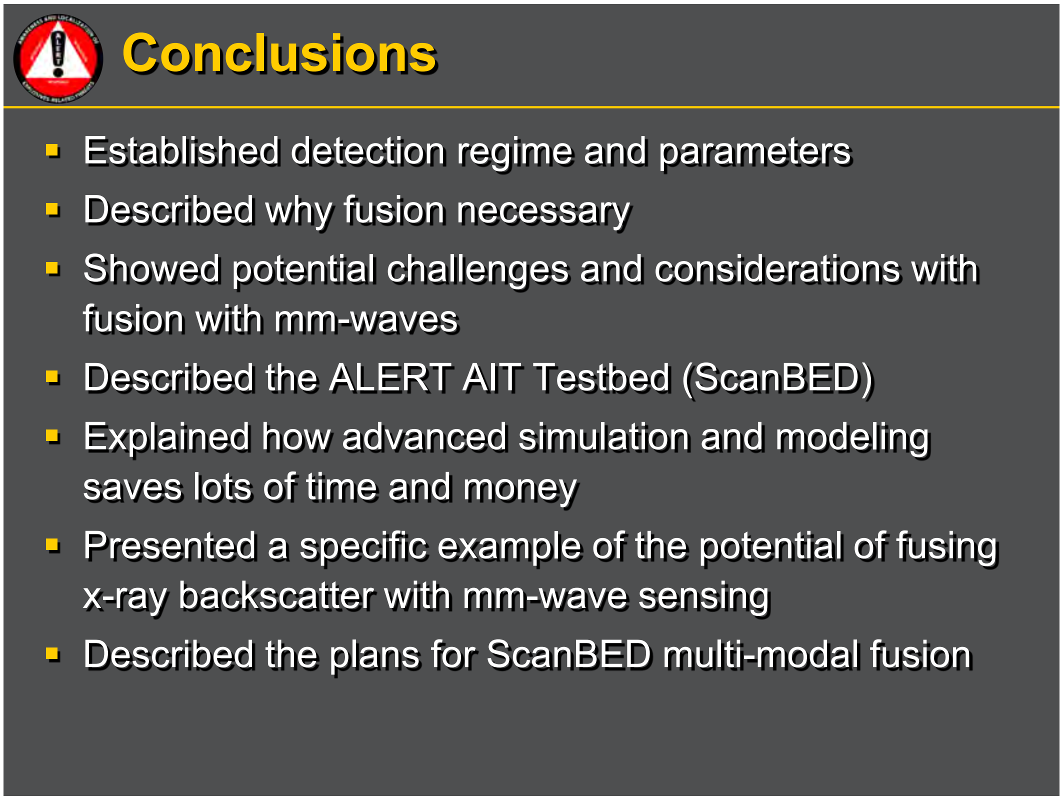
16.15 Carey Rappaport: Fusing MMW Technologies

ALERT: Awareness and Localization of Explosives-Related Threats

Fusing Millimeter-Wave Technologies for Advanced Imaging Technology

Carey Rappaport
Northeastern University
Boston, MA

ADSA06, November 2011



Conclusions

- Established detection regime and parameters
- Described why fusion necessary
- Showed potential challenges and considerations with fusion with mm-waves
- Described the ALERT AIT Testbed (ScanBED)
- Explained how advanced simulation and modeling saves lots of time and money
- Presented a specific example of the potential of fusing x-ray backscatter with mm-wave sensing
- Described the plans for ScanBED multi-modal fusion

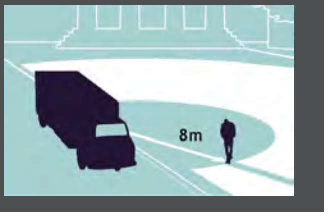
Outline

- What detection regime is examined?
- Why is fusion necessary?
- Why is fusion problematic?
- What must be considered for fusing with mm-waves?
- What is the ALERT AIT Testbed (ScanBED)?
- How can advanced simulation and modeling save lots of money?
- What is the specific potential of fusing x-ray backscatter with mm-wave?
- What are our plans for ScanBED multi-modal fusion?

Advanced Imaging Technology Problem Space

- **Intimately near targets (< 3 m)**
  - **Portal sensors**
  - **Non-invasive examination**
  - **Fast sensing, real time processing**
  - **99.997% detection probability**
  - ***Manageable* false alarm rate**
  - **Safe**
  - **Publicly acceptable**

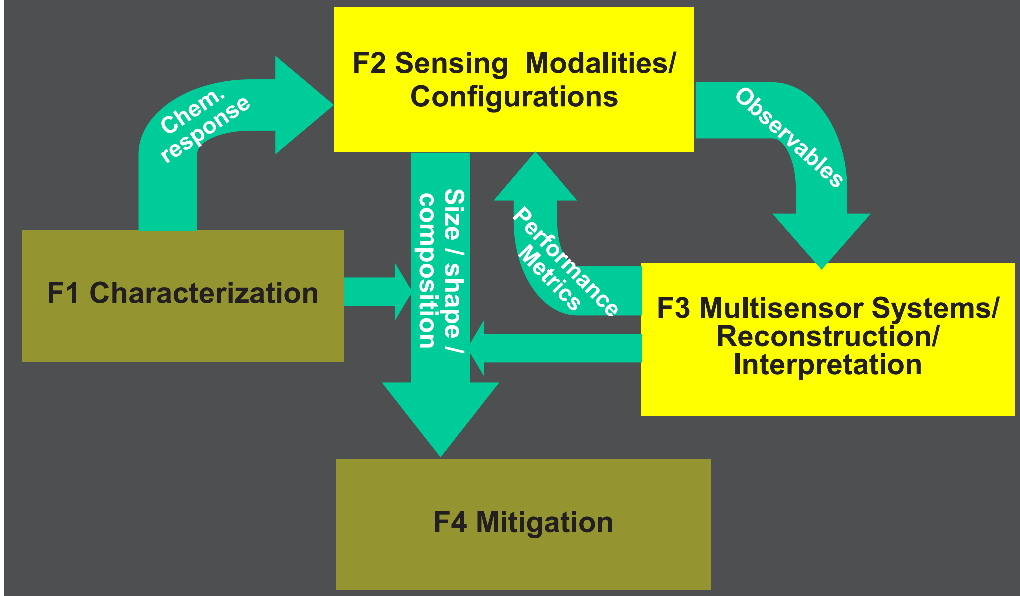
[Mm- wave sensing can also be fused with X-ray, THZ, video, trace for Mid-range targets (3 to 10m)]



Detecting and Identifying Explosives

- Sense within hidden / concealed / shielded / non-stationary environments
- Optical imaging to detect suspicious shapes/size (video, patterned video)
- Wave-based imaging to detect suspicious shapes/size (mm-wave radar, X-ray, THz, acoustics)
- Chemical trace detection of suspicious materials (Mass Spec., Ion Mobility Spec., Gas Chrom., "Artificial Dog Nose")
- Material ID spectral response to characterize molecular structure (Hyperspectral, IR, UV, THz, NQR, LIBS , NMR)

Sensing Thrust couples with Systems Thrust in ALERT Center



F2 Sensing Modalities/ Configurations

Chem. response

Observables

Size / shape / composition

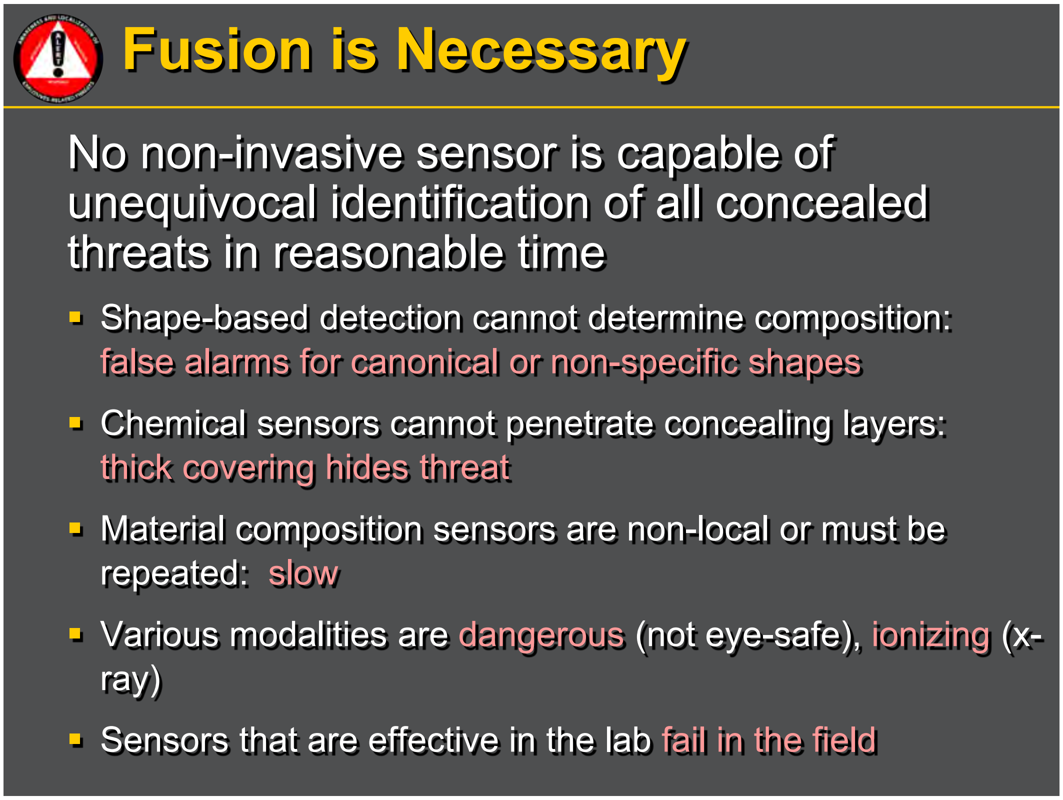
Performance Metrics

F1 Characterization

F3 Multisensor Systems/ Reconstruction/ Interpretation

F4 Mitigation

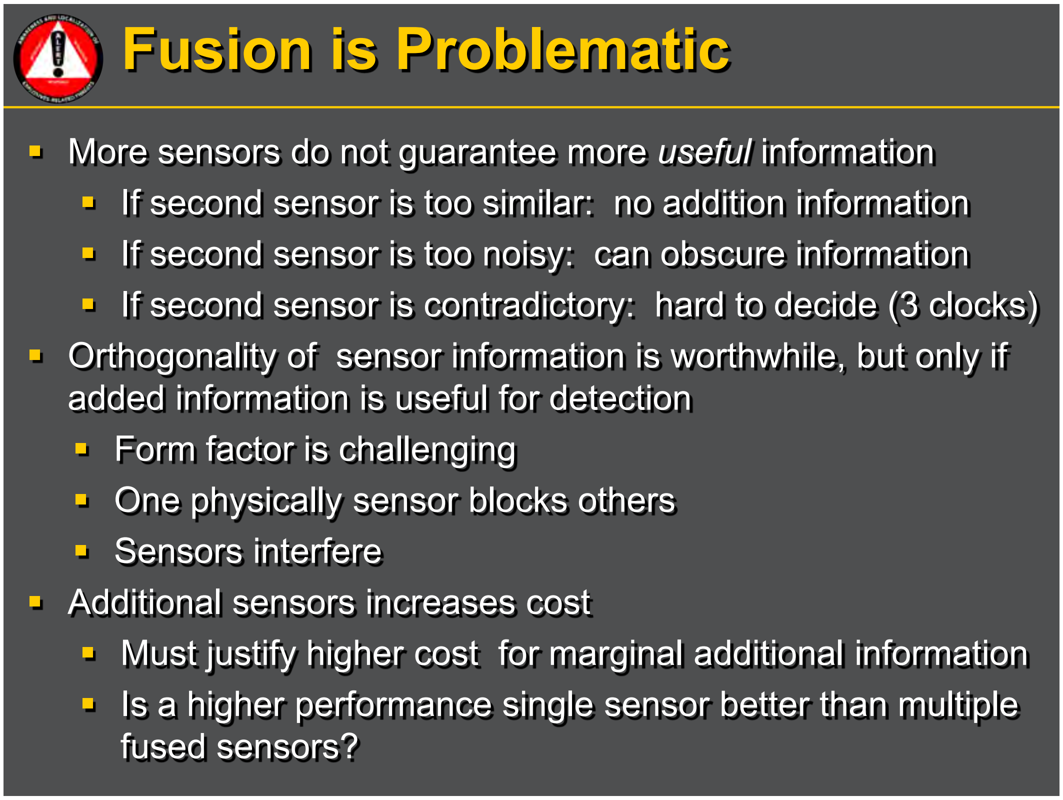
Coordination both across discipline and among thrusts is essential



Fusion is Necessary

No non-invasive sensor is capable of unequivocal identification of all concealed threats in reasonable time

- Shape-based detection cannot determine composition: false alarms for canonical or non-specific shapes
- Chemical sensors cannot penetrate concealing layers: thick covering hides threat
- Material composition sensors are non-local or must be repeated: slow
- Various modalities are dangerous (not eye-safe), ionizing (x-ray)
- Sensors that are effective in the lab fail in the field

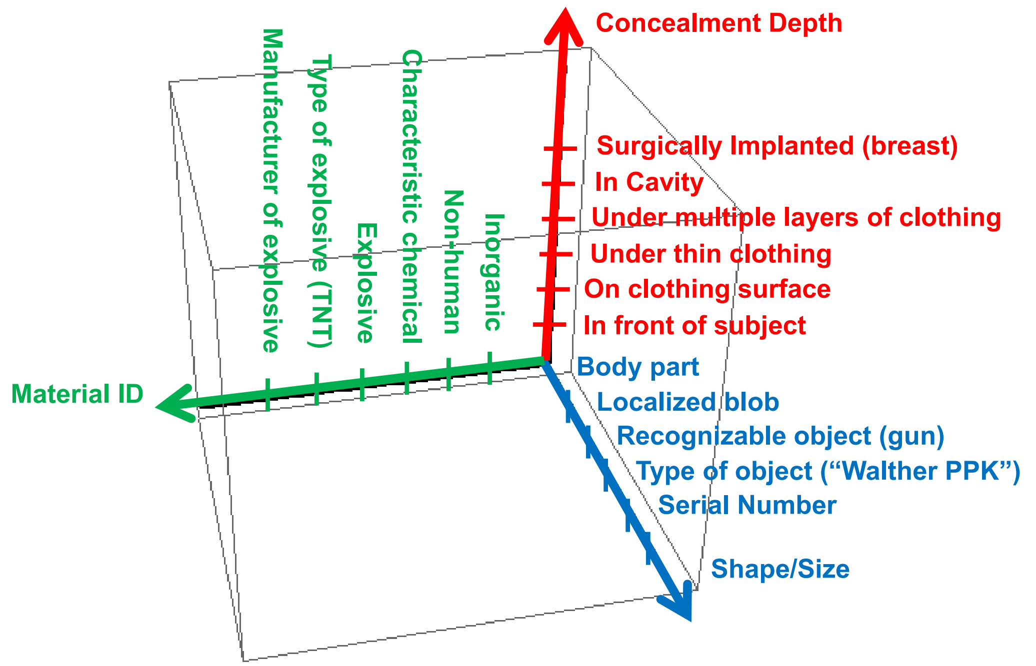


Fusion is Problematic

- More sensors do not guarantee more *useful* information
  - If second sensor is too similar: no addition information
  - If second sensor is too noisy: can obscure information
  - If second sensor is contradictory: hard to decide (3 clocks)
- Orthogonality of sensor information is worthwhile, but only if added information is useful for detection
  - Form factor is challenging
  - One physically sensor blocks others
  - Sensors interfere
- Additional sensors increases cost
  - Must justify higher cost for marginal additional information
  - Is a higher performance single sensor better than multiple fused sensors?

AIT Sensing Table (from White)

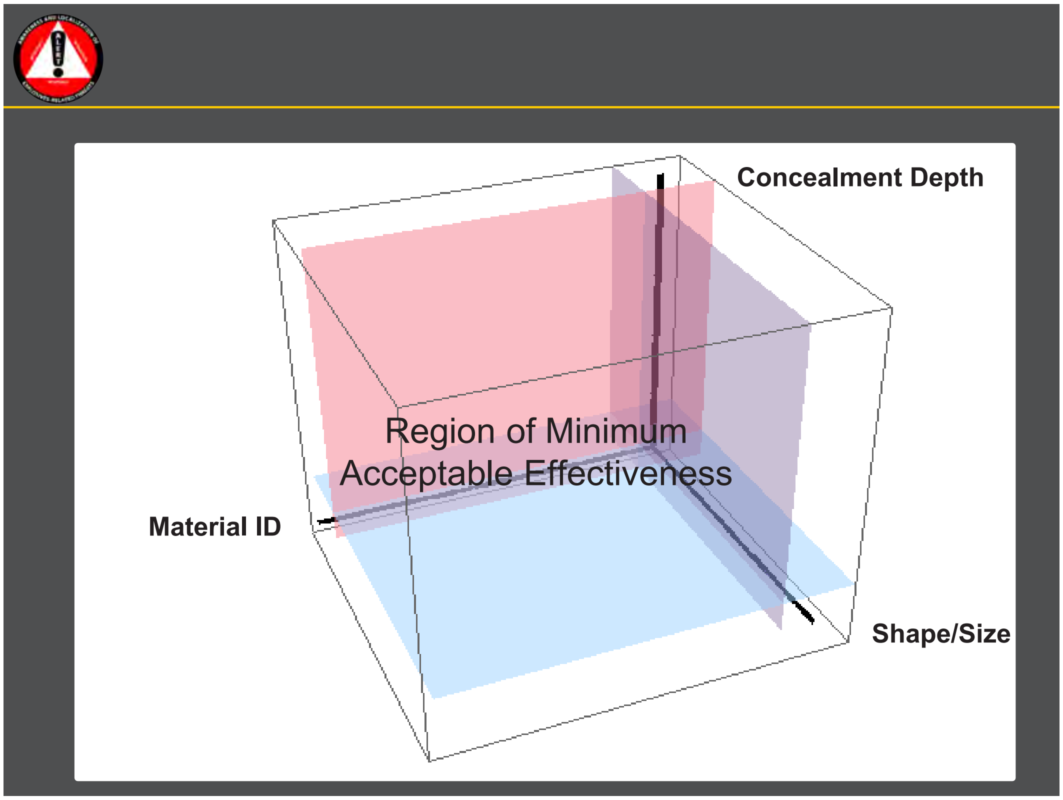
Sensor	Wavelength/energy	Signature	Detection Type
Metal Detectors	kHz	Eddy current induced in metals	Material ID
Active mm-wave	20-40GHz (15-7.5mm)	Dielectric scattering contrast	Shape/size
Passive mm-wave	30-300GHz (10-1mm)	Natural blackbody radiation	Shape/size
X-ray backscatter	50-125kVp	Differential scattering (Z_{eff}, ρ)	Shape/size
X-ray transmission	80-160kVp	Differential attenuation (Z_{eff}, ρ)	Shape/size
IR thermography	8-10μm	Thermal emission from body	Shape/size
IR spectroscopy	8-13μm	RF molecular vibration absorption	Material ID
Trace portal/puffer		IMS (or MS) spectral match	Material ID
THz imaging	0.1-3THz (3-0.01mm)	Attenuation /scattering from dielectrics	Shape/size
THz spectroscopy	0.1-3THz (3-0.01mm)	RF molecular vibration absorption	Material ID
NQR	0.5-5MHz	RF resonance (molecular/N environ.)	Material ID
NMR	kHz	Characteristic RF decay from ^{1}H	Material ID



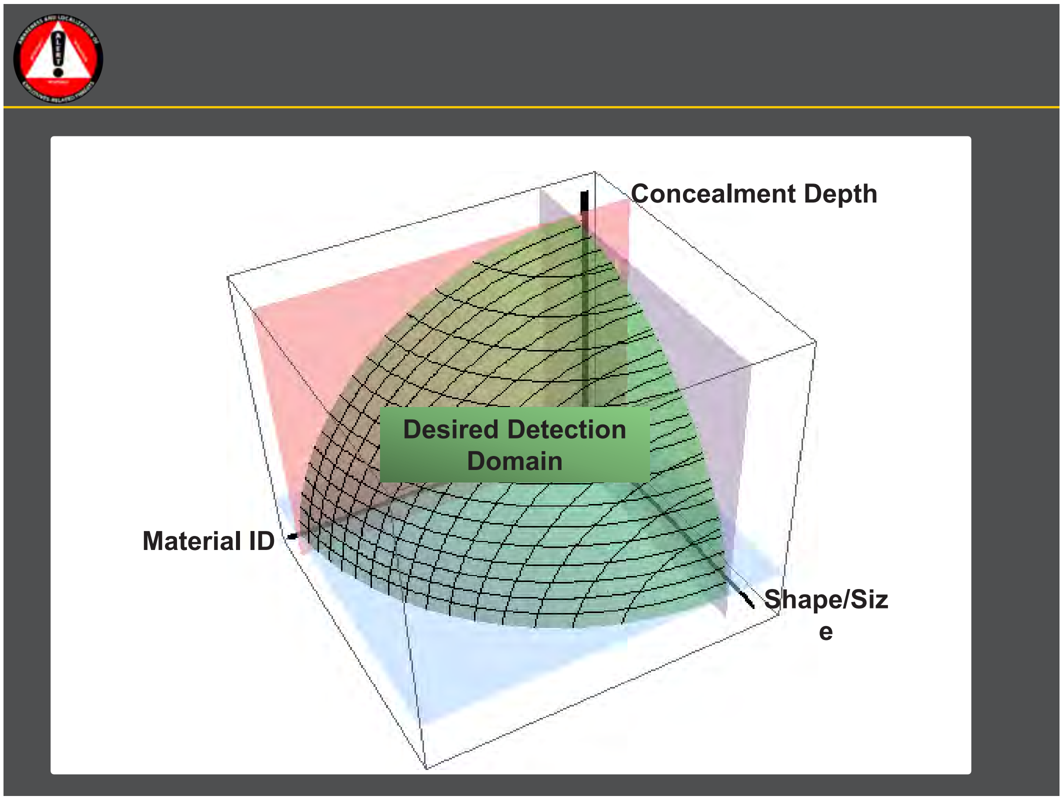
Concealment Depth
Surgically Implanted (breast)
In Cavity
Under multiple layers of clothing
Under thin clothing
On clothing surface
In front of subject

Material ID
Manufacturer of explosive
Type of explosive (TNT)
Explosive
Characteristic chemical
Non-human
Inorganic

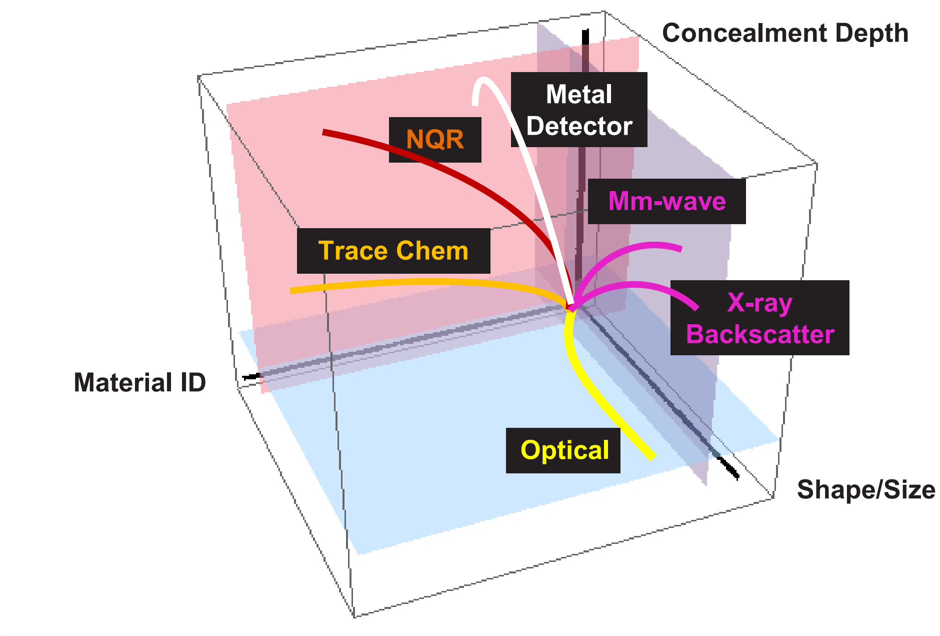
Body part
Localized blob
Recognizable object (gun)
Type of object (“Walther PPK”)
Serial Number
Shape/Size



Region of Minimum Acceptable Effectiveness



Desired Detection Domain



Considerations for Fusing Technologies with Mm-Wave Sensing

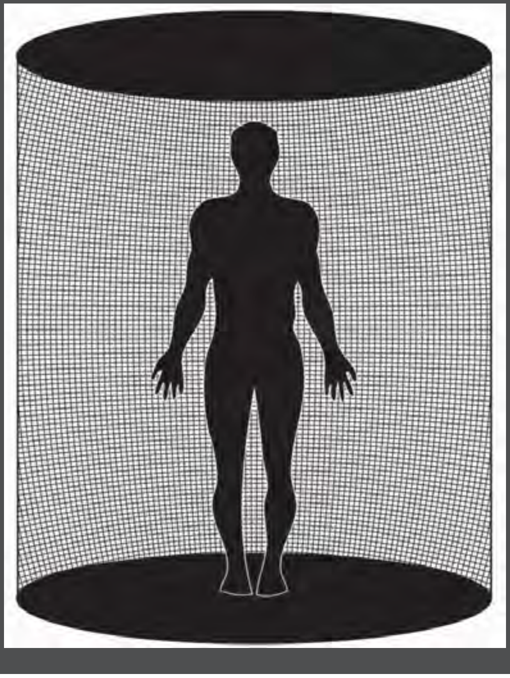
- Compensate for deficiencies of mm-wave sensing
  - Low resolution
  - No skin penetration
  - No material identification
  - Heavy computation
- Establish minimum desired sensing requirement
- Consider completely orthogonal sensor
  - No joint inversion – simple union of sensor info
- Consider front-end fusion – joint inversion
  - Initial guess
  - Regions of particular interest

Whole Body Imaging Testbed at NEU

- Precision portal multi-axis sensor array positioning system
  - Designed to accommodate various types of sensors
    - Separately, for analysis
    - Together, to test fused sensor information
    - Built to be flexible for reconfiguration
- Provide access to raw measurement data
  - Allows specific, modality-based inversion
  - Allows joint modality reconstruction
- Ultimate Goals
  - Establish performance metrics for sensor modalities
  - Develop and evaluate novel inversion and multi-modal threat detection algorithms

---

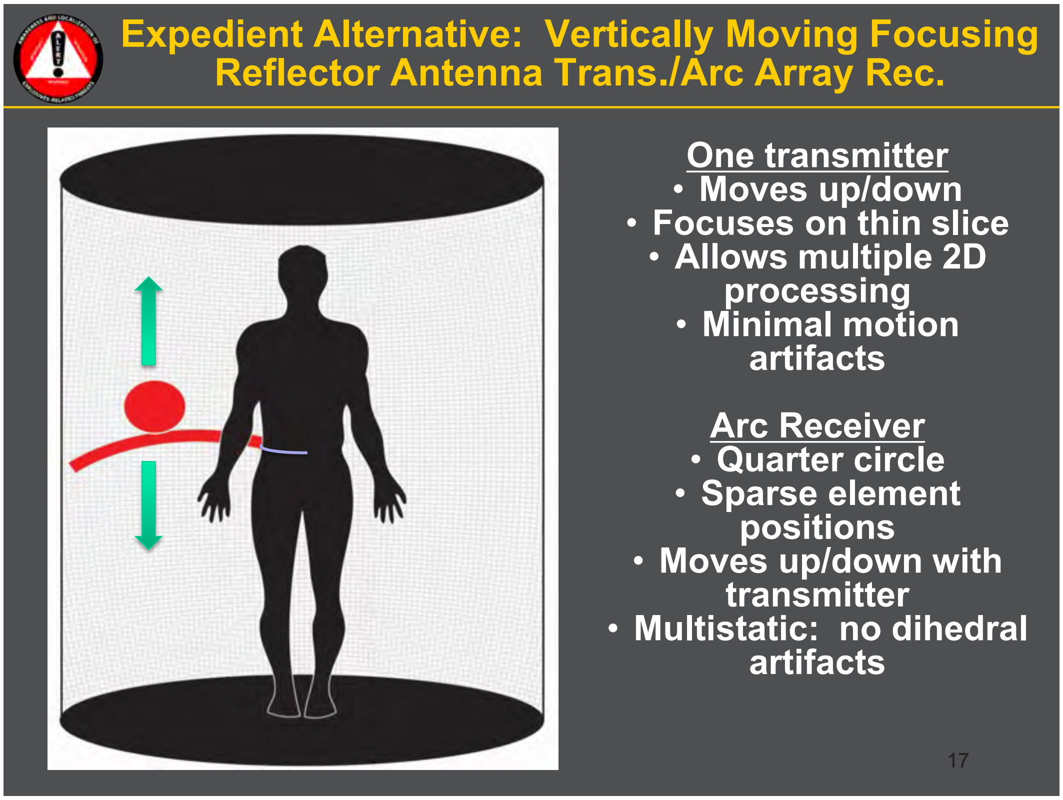
Portal Provides the Possibility for Full Aperture Sensing



Huge 360 deg. Aperture

•Almost perfect body surface reconstruction
•No motion artifacts

However:
•Very expensive
•Long acquisition time
•Long computation time and massive storage
(500 X 1000)^2 Tx/Rx
10,000 (cm^2) body pts.
= 2.5 10^{15} focusing calculations



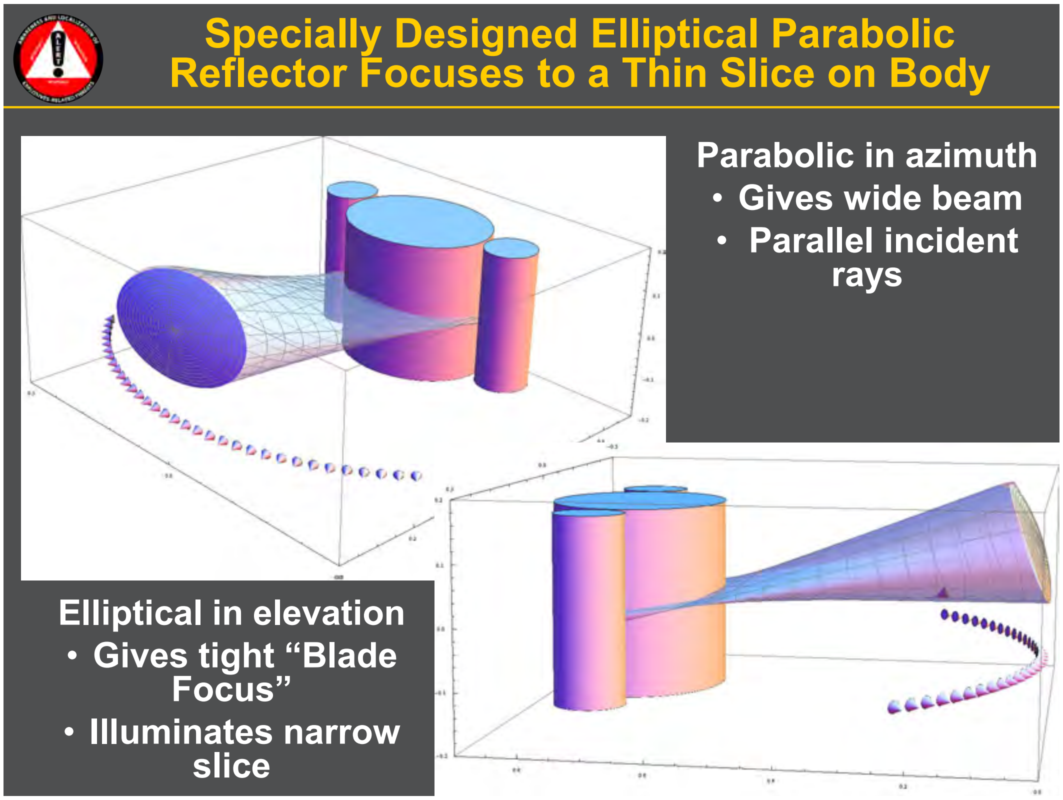
Expedient Alternative: Vertically Moving Focusing Reflector Antenna Trans./Arc Array Rec.

One transmitter

- Moves up/down
- Focuses on thin slice
- Allows multiple 2D processing
- Minimal motion artifacts

Arc Receiver

- Quarter circle
- Sparse element positions
- Moves up/down with transmitter
- Multistatic: no dihedral artifacts



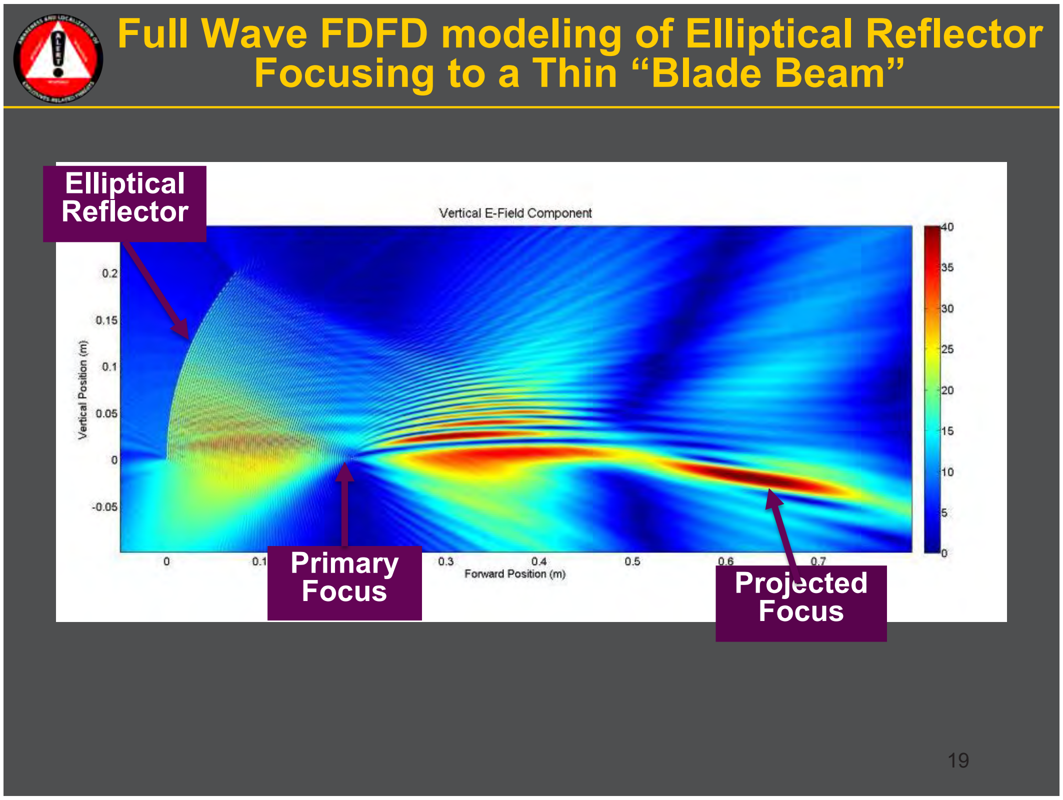
Specially Designed Elliptical Parabolic Reflector Focuses to a Thin Slice on Body

Parabolic in azimuth

- Gives wide beam
- Parallel incident rays

Elliptical in elevation

- Gives tight “Blade Focus”
- Illuminates narrow slice

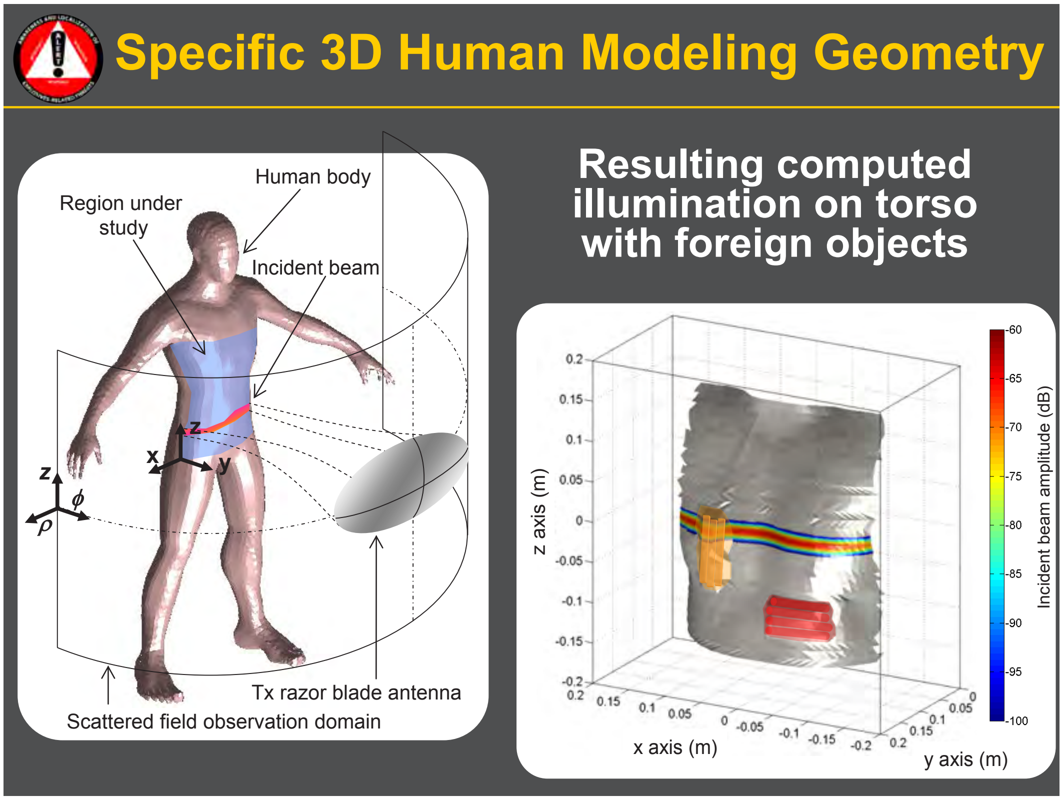


Full Wave FDFD modeling of Elliptical Reflector Focusing to a Thin "Blade Beam"

Elliptical Reflector

Primary Focus

Projected Focus



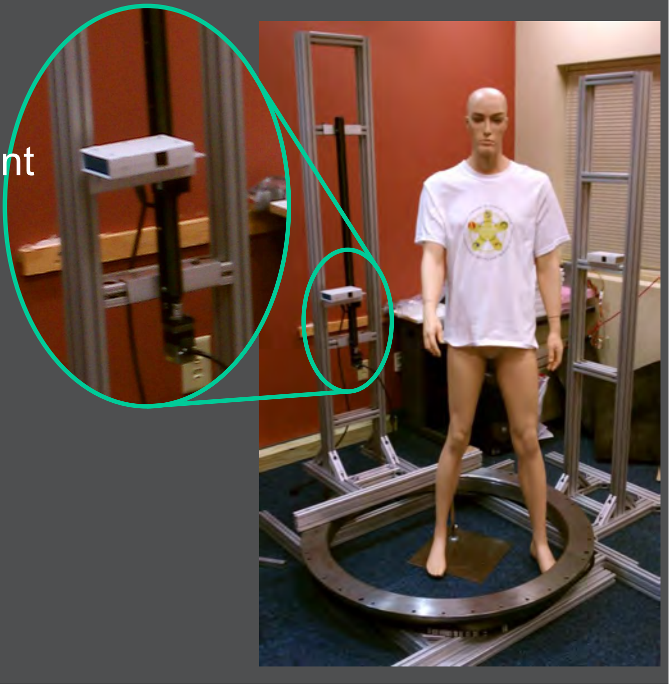
Specific 3D Human Modeling Geometry

Resulting computed illumination on torso with foreign objects

Rotating / Variable Height Cylindrical Scanning Stage and Mounted 60 GHz Radar

- Independent multistatic experimentation
- Open support: joint x-ray sensor placement

* Circular bearing donated by Neurologica, Inc.



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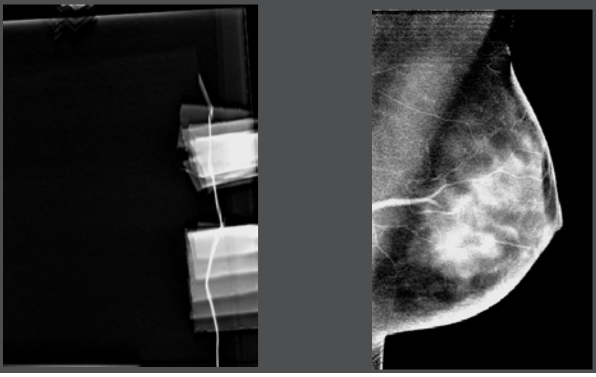
60 GHz Skin and Explosive Simulants

<u>Skin simulant for combined mm-wave / x-ray phantom</u>

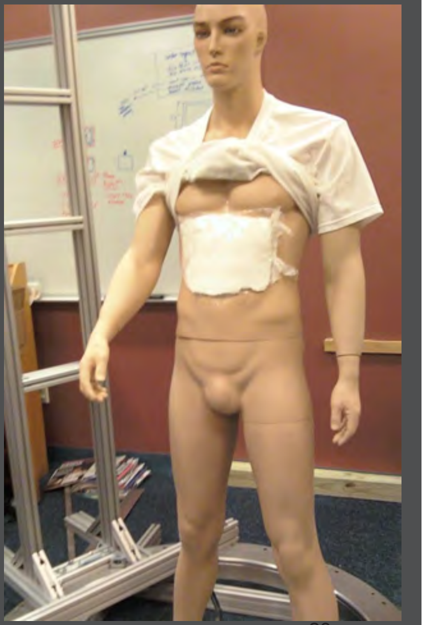
- 0.75 cm thick hydrogel layer has very similar water content as skin
- Much better dielectric match than metalized mannequin
- Fully absorbs mm-waves to conceals internal metal parts
- Same transparency to x-ray backscatter as skin
- Workable, smooth, safe, cheap



60 GHz Skin and Explosive Simulants

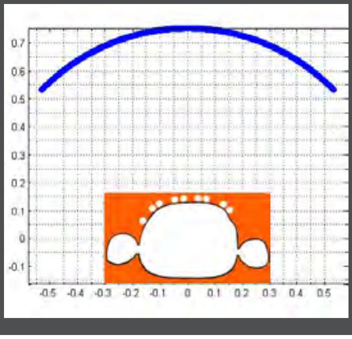
Explosive simulant for mm-waves

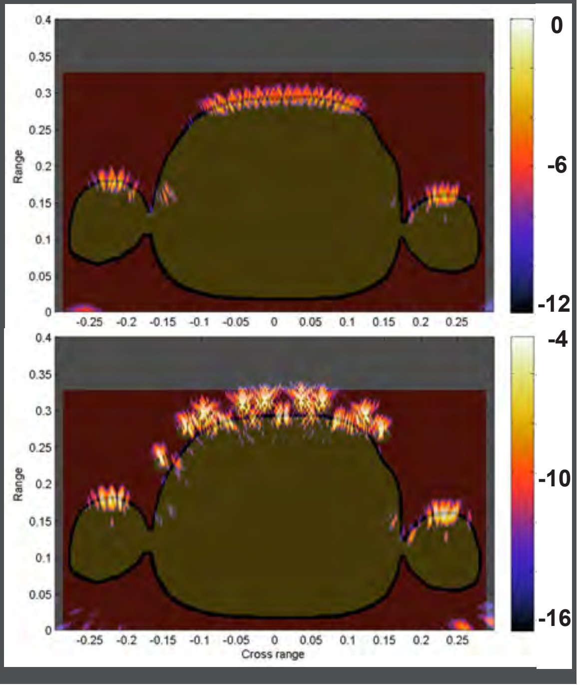
- Same electrical characteristics as TNT/RDX/PETN
- Paraffin and TiO_2
- Workable, stable, safe, cheap



Slice Reconstruction of Torso with and without metal pipe bomb simulants

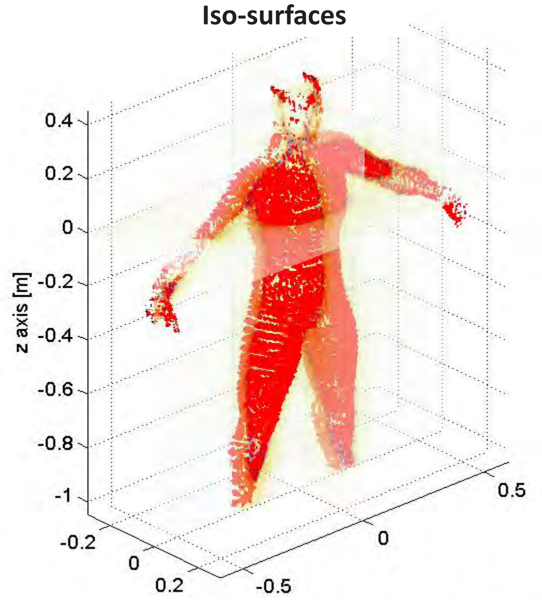
- 2D Multistatic imaging
- Shows smooth innocent body contour
- No dihedral artifacts.





Stacked Slice 3D Reconstruction

- Fast multistatic model-based imaging
- Shows smooth innocent body surface curvature
- High resolution
- No artifacts / dropouts

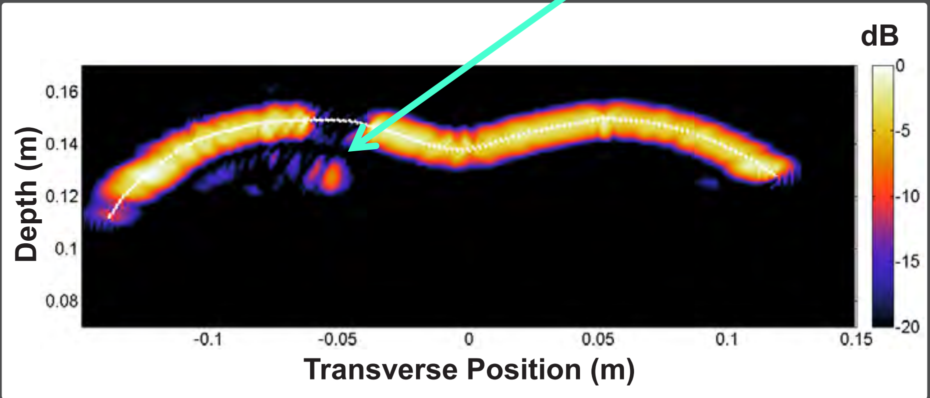


New model-based reconstructed 3D image (using synthetic data) with multistatic radar.

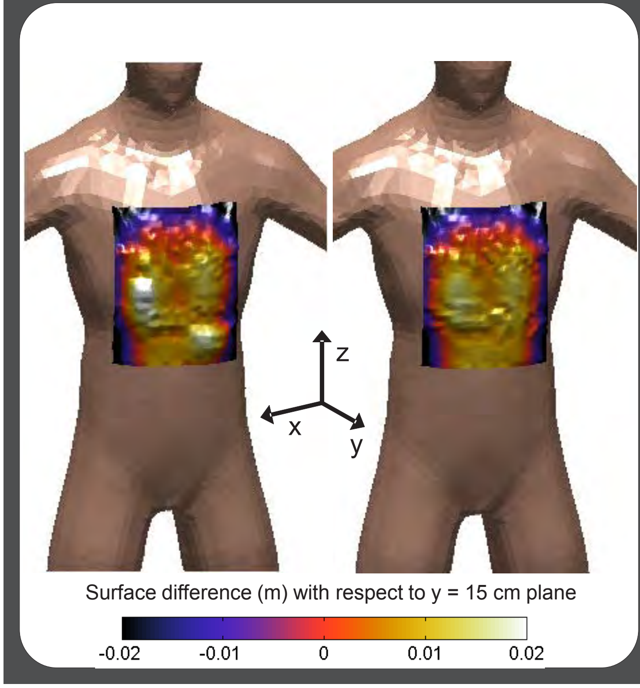
3D Reconstruction of Synthetic Data – Inverse Fast Multipole Method / SAR

- Adjust phase from radar antenna to each point in image space.
- Combine sources into a much smaller number of multipole sources
- High correlation indicates scattering center
- Display scattering centers as bright points – reflective surfaces

3 cm TNT rod (ε' = 3) on skin gives anomalous response within torso



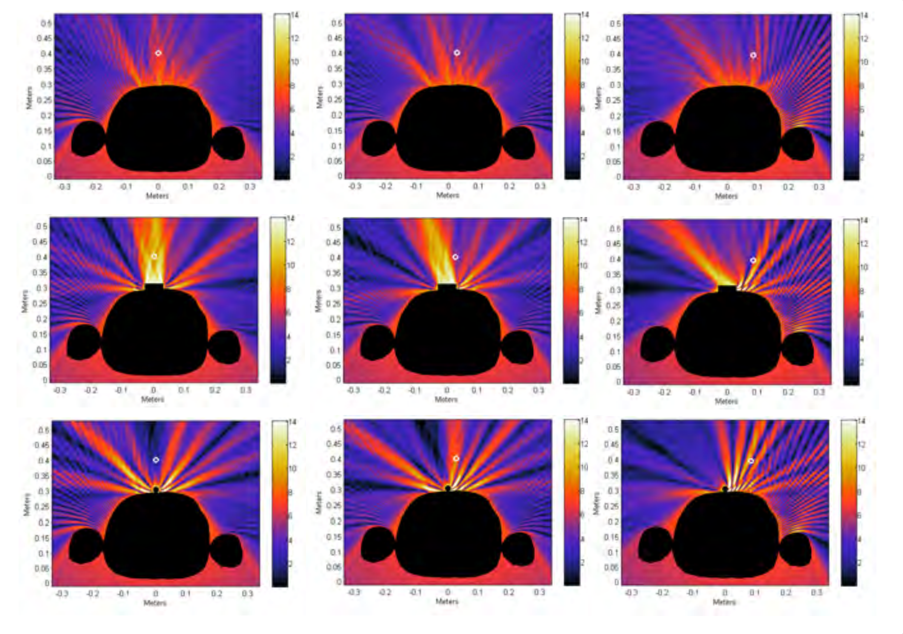
Iterative Field Method (IFM) used for High Resolution Surface Imaging



Surface difference (m) with respect to y = 15 cm plane

- Given estimate of range, estimate faceted surface
- Perturb surface facet positions based on linearized phase
- Iterate until convergence
- Surface reconstruction accuracy $\lambda/4$ ~ 1 mm

Finite Difference Frequency Domain Computational Model – Wand Scattered Field



Summary of Computational EM Models

Forward Models

- Finite difference Frequency Domain (FDFD) – 2D and 3D full wave with polarization: metal / dielectric
- Physical Optics (PO) – 2D and 3D surface scattering: metal
- Modified Equivalent Current Approximation (MECA): PO for dielectric
- Method of Moments (MoM) – 3D surface scattering: metal / dielectric

Inverse Models

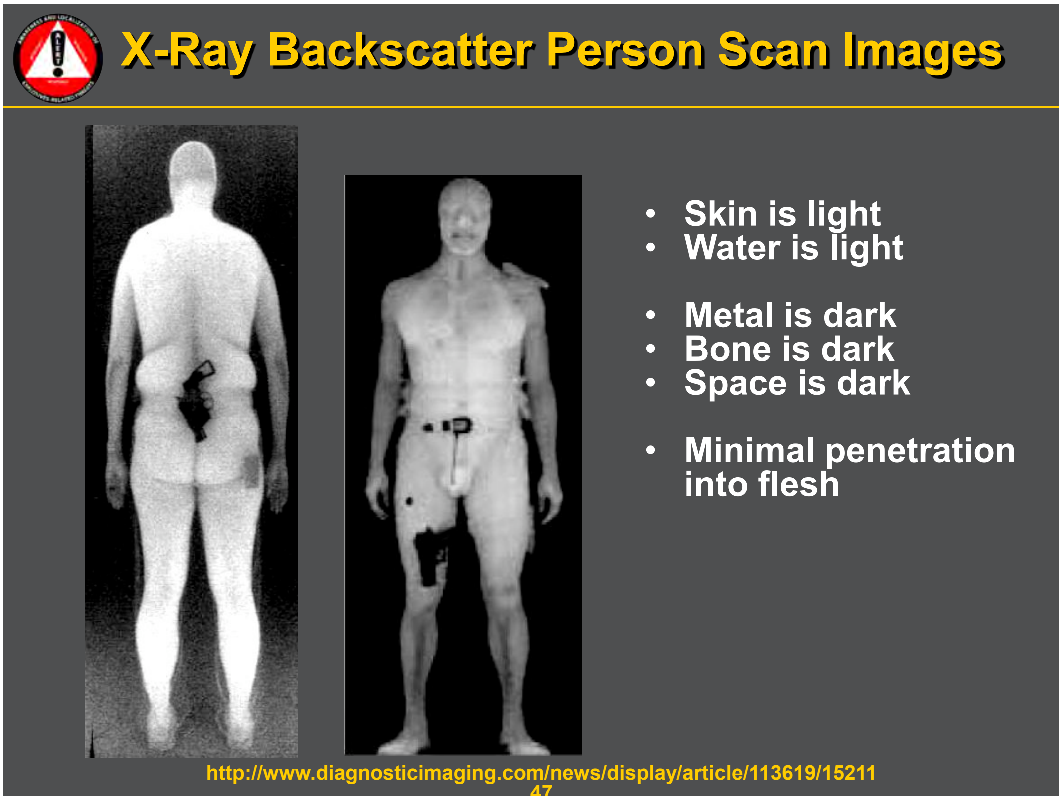
- Synthetic Aperture Radar processing (SAR) – Generalized, non-FFT based volume inversion
- Inverse fast multi-pole method (IFMM) – SAR accelerator
- Iterative Field Method (IFM) – Precise surface determination using center frequency

---

Fusion Example – X-Ray Backscatter with mm-wave

- XBS and mm-wave are NOT orthogonal
  - Both detect shape/size
  - Both sense material contrast relative to skin
  - Neither (appreciably) penetrates skin
- Both require sensor head movement

- XBS advantages
  - High resolution (wires, beads)
  - Fast
- Mm-wave advantages
  - Depth information (3D shape, thin layers)
  - Non-ionizing



X-Ray Backscatter Person Scan Images

- Skin is light
- Water is light

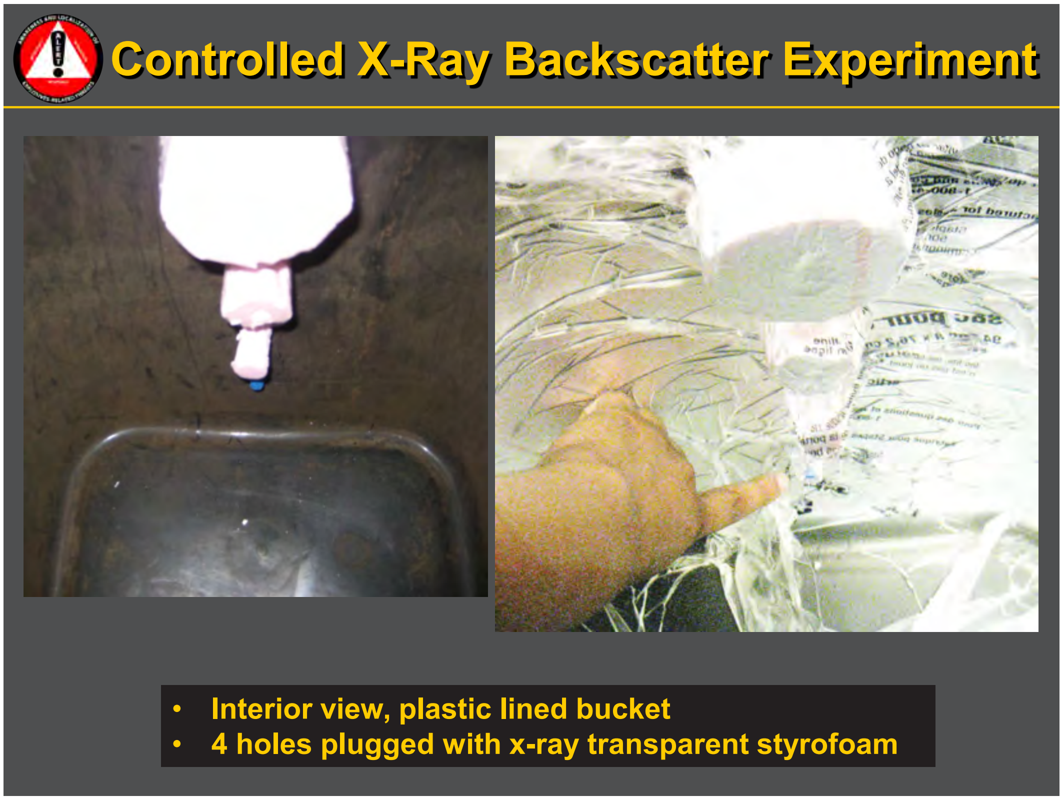
- Metal is dark
- Bone is dark
- Space is dark

- Minimal penetration into flesh

http://www.diagnosticimaging.com/news/display/article/113619/15211

Controlled X-Ray Backscatter Experiment

- Plastic lined bucket filled with water
- 4 holes with varying diameters
- Protrusions and Depressions



Controlled X-Ray Backscatter Experiment

- Interior view, plastic lined bucket
- 4 holes plugged with x-ray transparent styrofoam

Measured X-Ray Backscatter Image of Depressions in Water Volume

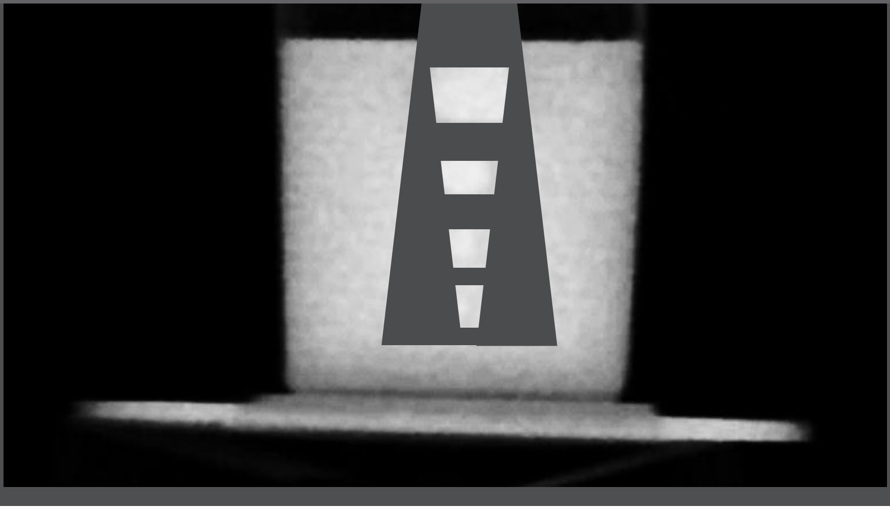
Depressions
…Or are they
metal disks?

Rotating X-Ray Backscatter Video 1

Measured X-Ray Backscatter Image of Protrusions in Water Volume

- No real depth information
- Edges give appearance of height

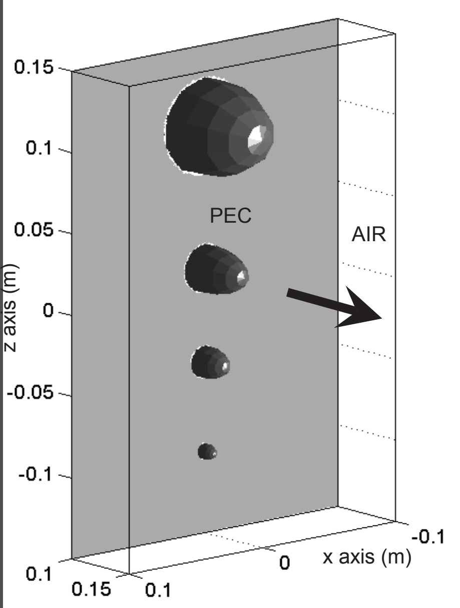
Masking edges eliminates appearance of height



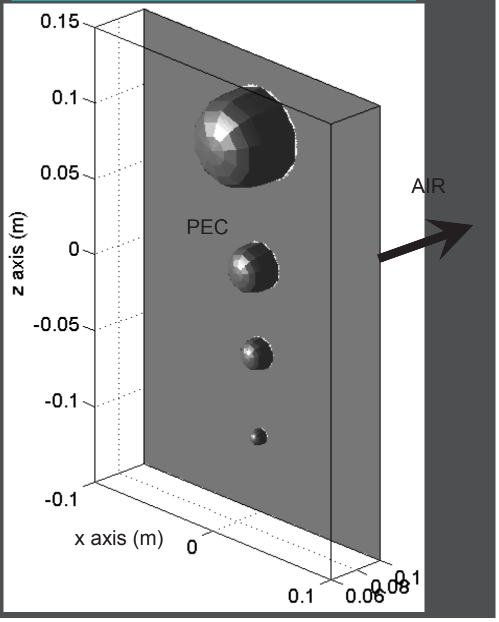
Rotating X-Ray Backscatter Video 2

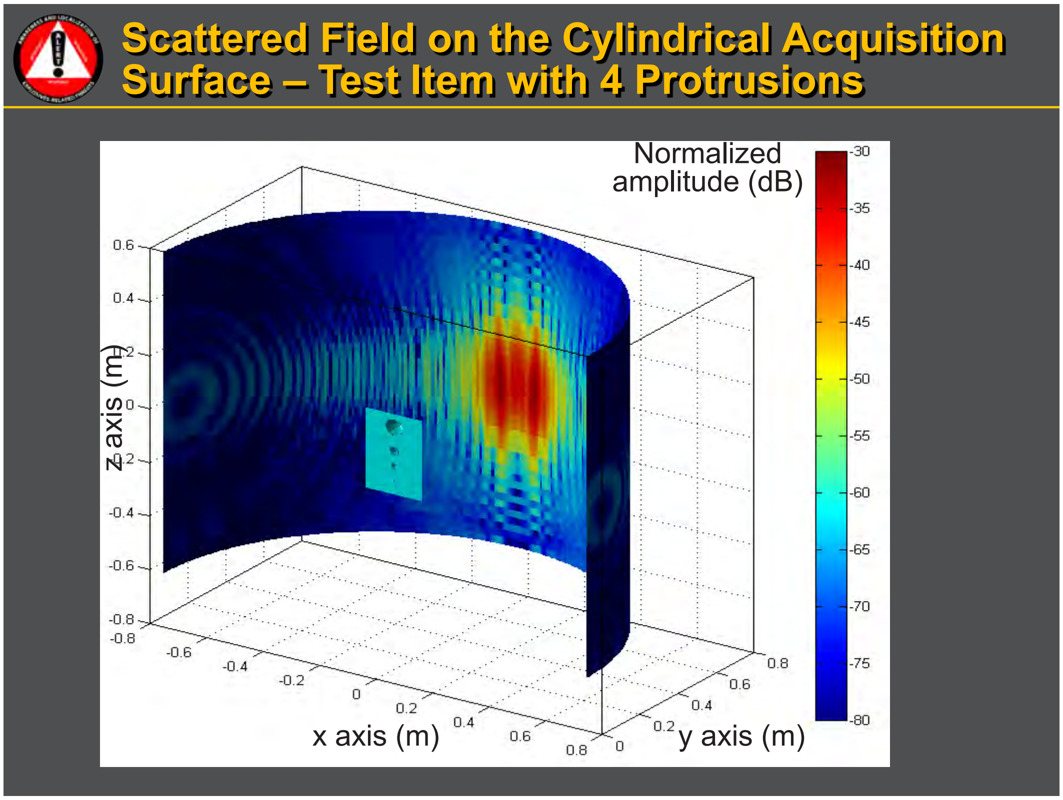
MM-Wave Forward and Inversion Modeling of Hole Series

Protrusions– Modeled geometry

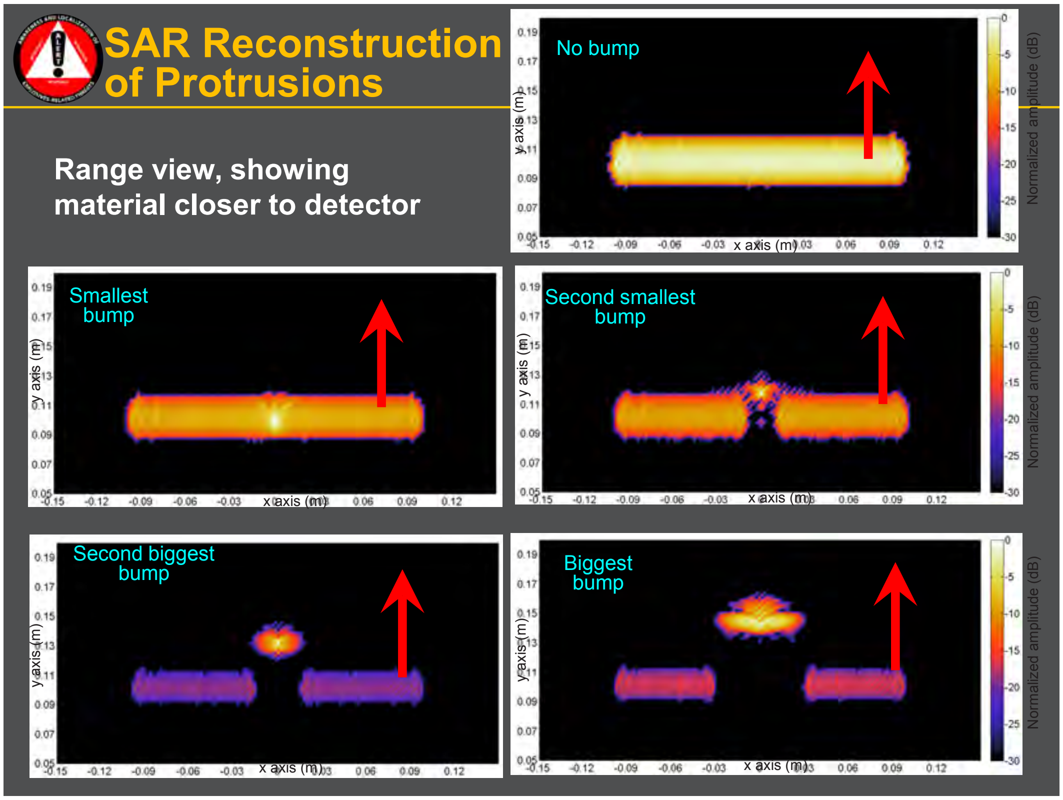


Depressions– Modeled geometry (inside view)





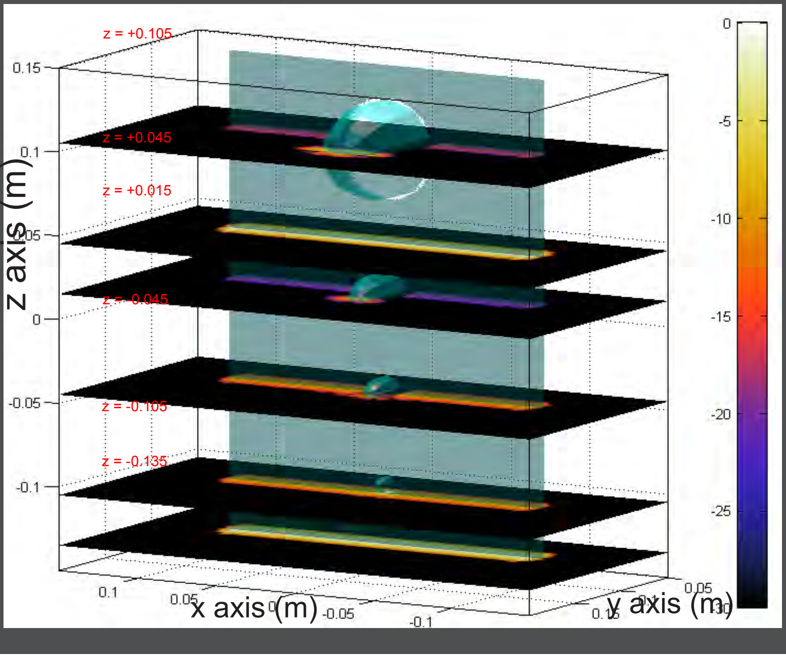
Scattered Field on the Cylindrical Acquisition Surface – Test Item with 4 Protrusions



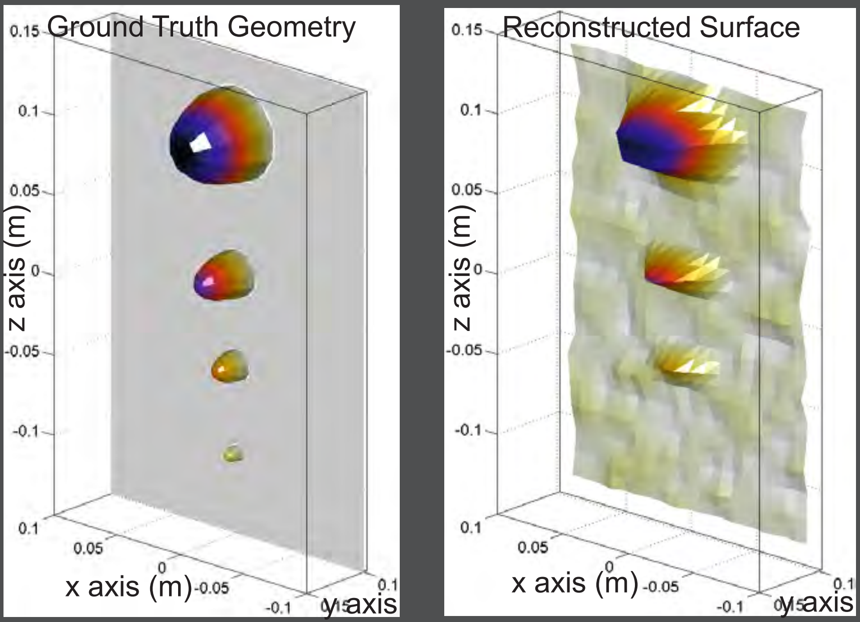
SAR Reconstruction of Protrusions

Range view, showing material closer to detector

Stacked slices – 4 Protrusions

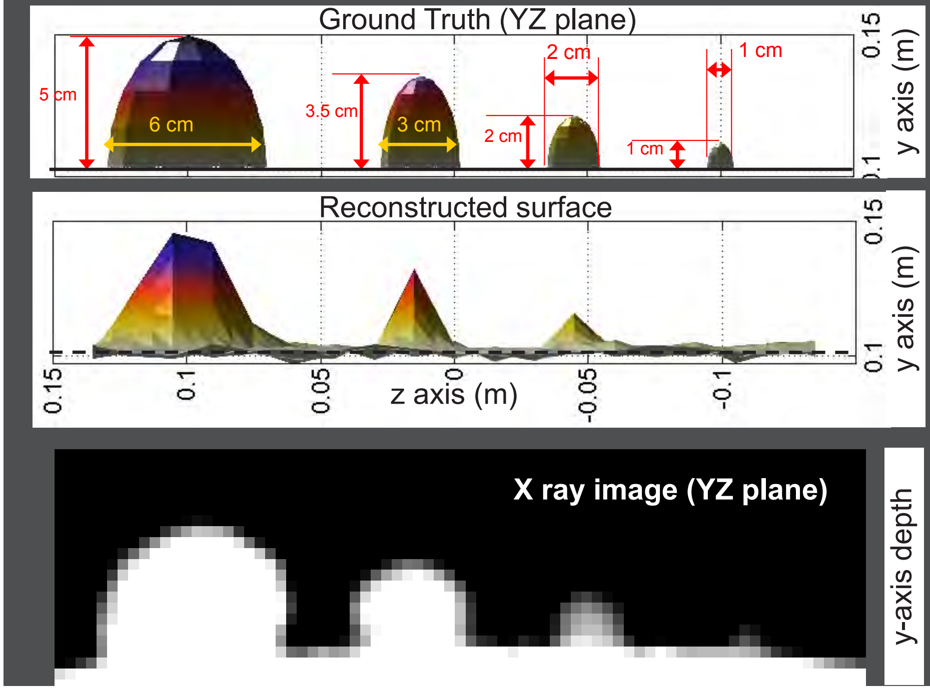


3D Surface Reconstruction: 4 Protrusions of Water from Water Plane

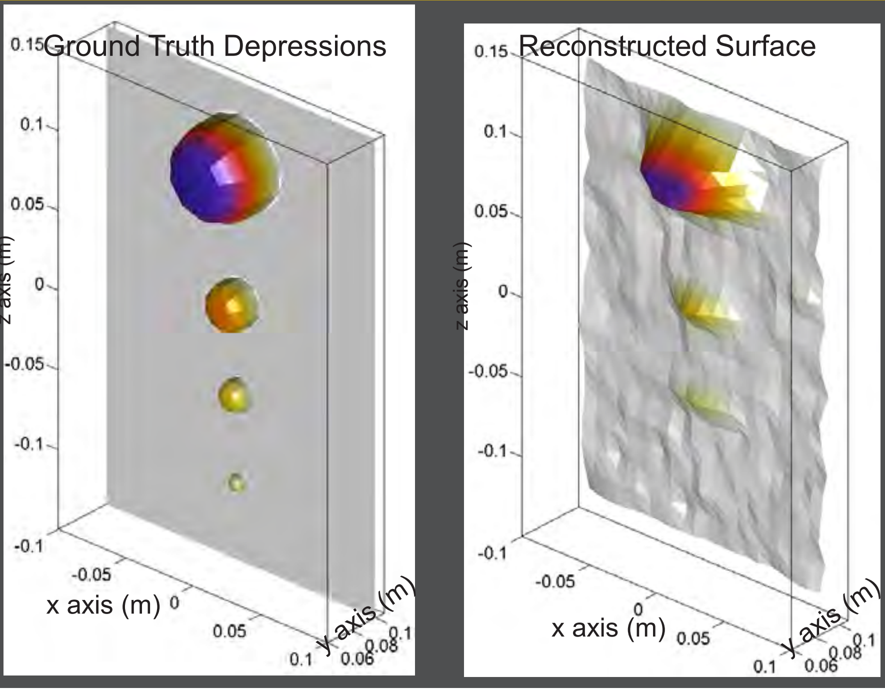

Ground Truth Geometry

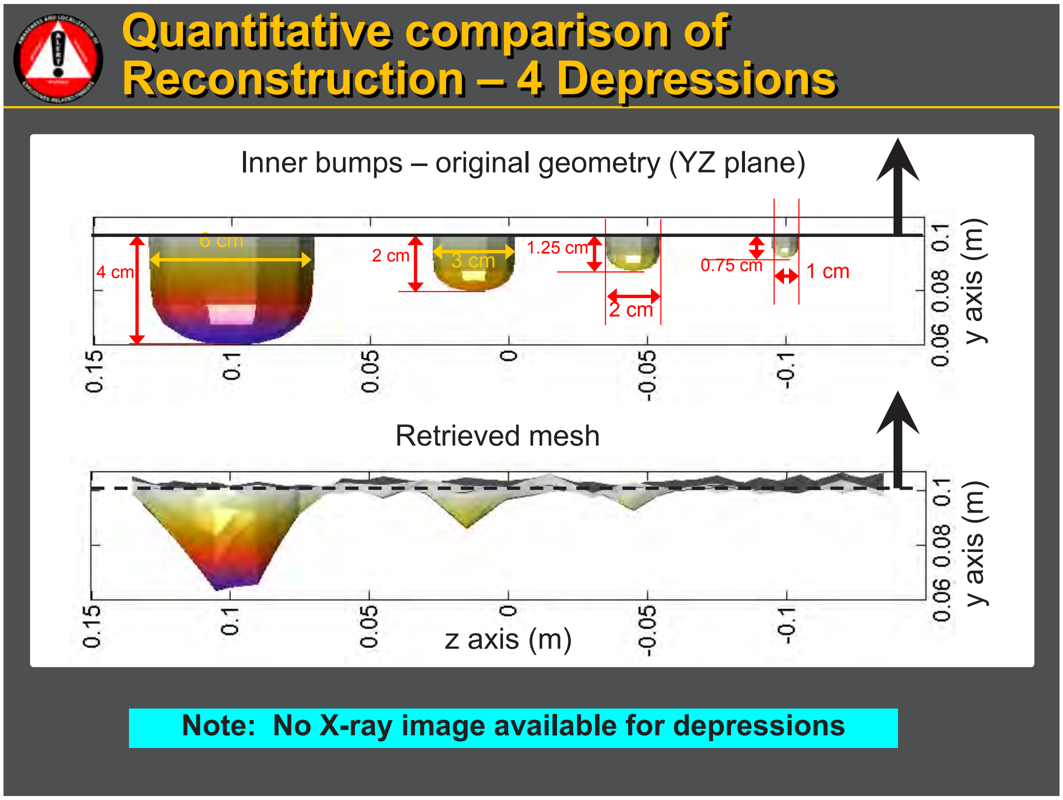
Reconstructed Surface

3D Height Reconstruction: 4 Protrusions



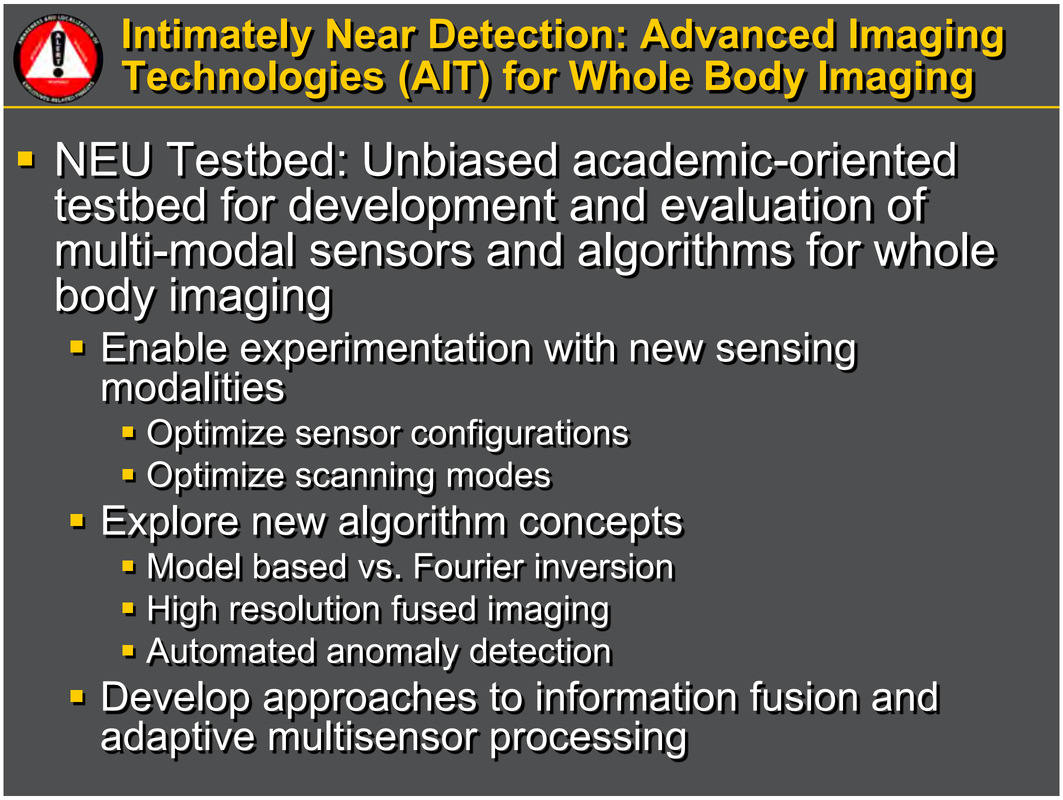
3D Height Reconstruction: 4 Depressions in Water Wall (Inside View)





Quantitative comparison of Reconstruction – 4 Depressions

Note: No X-ray image available for depressions



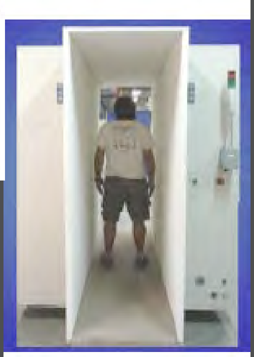
Intimately Near Detection: Advanced Imaging Technologies (AIT) for Whole Body Imaging

- NEU Testbed: Unbiased academic-oriented testbed for development and evaluation of multi-modal sensors and algorithms for whole body imaging
  - Enable experimentation with new sensing modalities
    - Optimize sensor configurations
    - Optimize scanning modes
  - Explore new algorithm concepts
    - Model based vs. Fourier inversion
    - High resolution fused imaging
    - Automated anomaly detection
  - Develop approaches to information fusion and adaptive multisensor processing

Whole Body Imaging Sensors to Fuse with Mm-Wave

- X-ray Backscatter
  - Penetrates all concealing layers
  - Dual energy distinguishes foreign materials
  - Ionizing radiation but very low dosage
- IR Thermography
- NQR
- THz

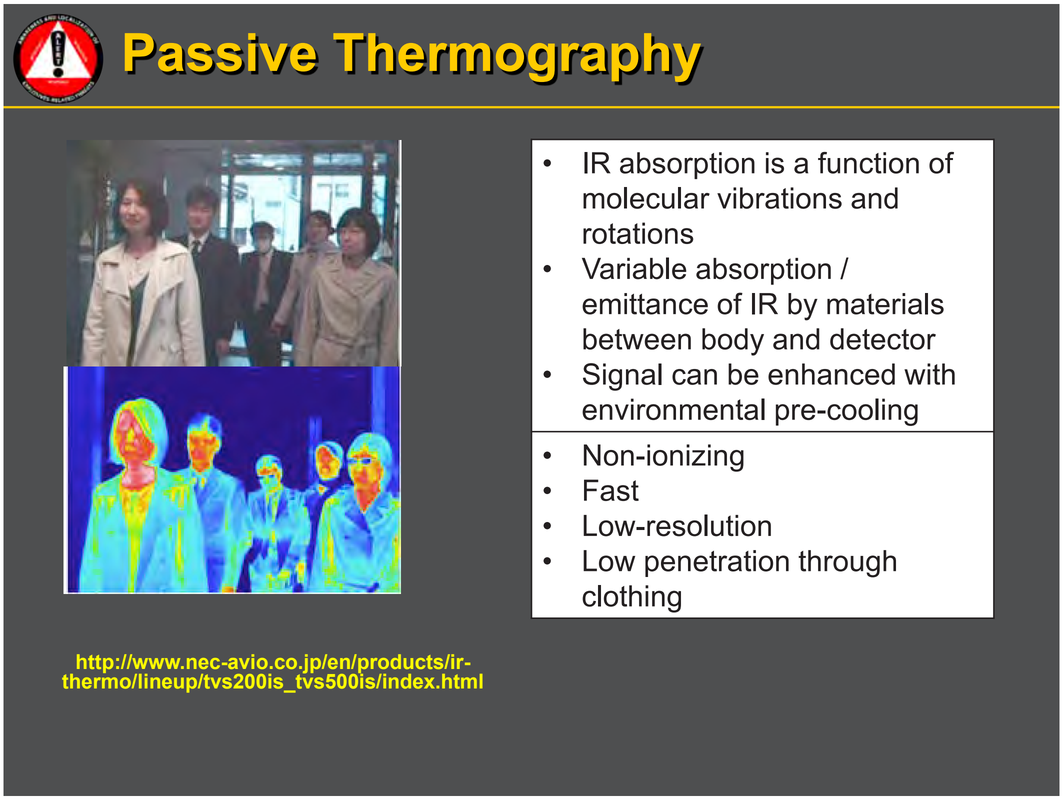
Nuclear Quadrupole Resonance (NQR)



- Detect local nuclear fields of nuclei with spin > 1 (^{14}N)
- Detect presence of ^{14}N

- Very specific to material ID
- Penetrates throughout body
- Close sensor proximity
- Must be solid phase
- Temperature dependent

http://www.morphodetection.com/technologies/quadrupole-resonance/

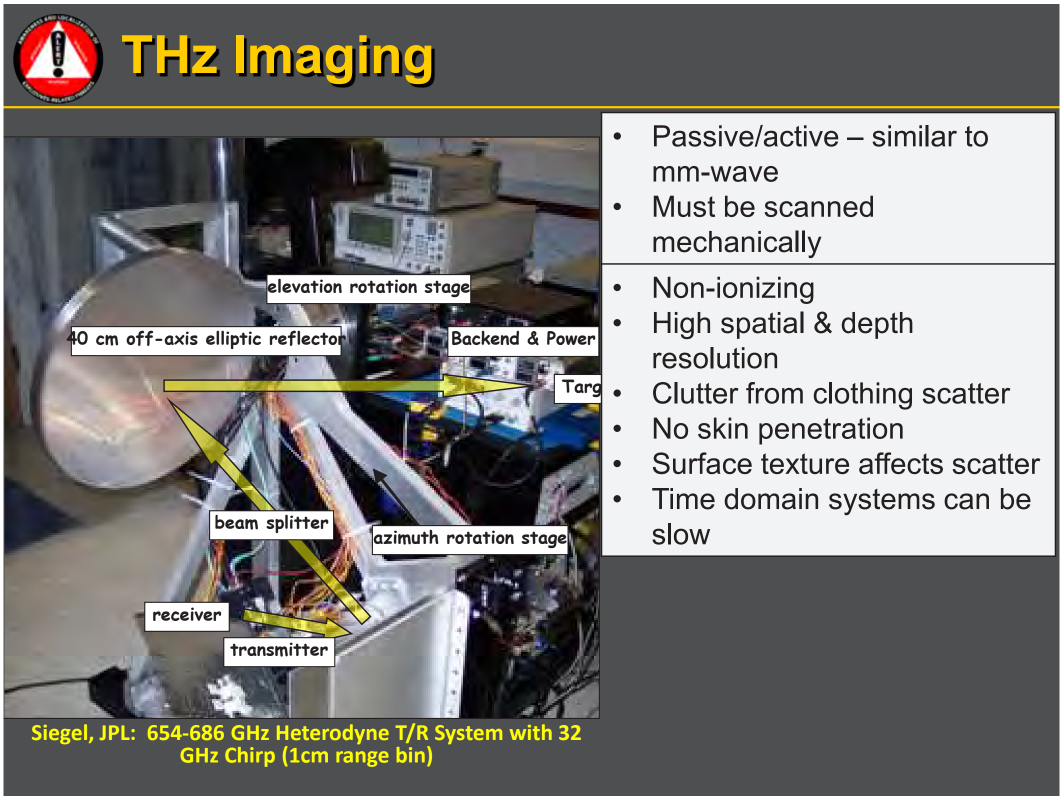


Passive Thermography

- IR absorption is a function of molecular vibrations and rotations
- Variable absorption / emittance of IR by materials between body and detector
- Signal can be enhanced with environmental pre-cooling

- Non-ionizing
- Fast
- Low-resolution
- Low penetration through clothing

http://www.nec-avio.co.jp/en/products/ir-thermo/lineup/tvs200is_tvs500is/index.html



THz Imaging

- Passive/active – similar to mm-wave
- Must be scanned mechanically

- Non-ionizing
- High spatial & depth resolution
- Clutter from clothing scatter
- No skin penetration
- Surface texture affects scatter
- Time domain systems can be slow

Siegel, JPL: 654-686 GHz Heterodyne T/R System with 32 GHz Chirp (1cm range bin)

Conclusions

- Established detection regime and parameters
- Described why fusion necessary
- Showed potential challenges and considerations with fusion with mm-waves
- Described the ALERT AIT Testbed (ScanBED)
- Explained how advanced simulation and modeling saves lots of time and money
- Presented a specific example of the potential of fusing x-ray backscatter with mm-wave sensing
- Described the plans for ScanBED multi-modal fusion

People Who Actually Did the Work…

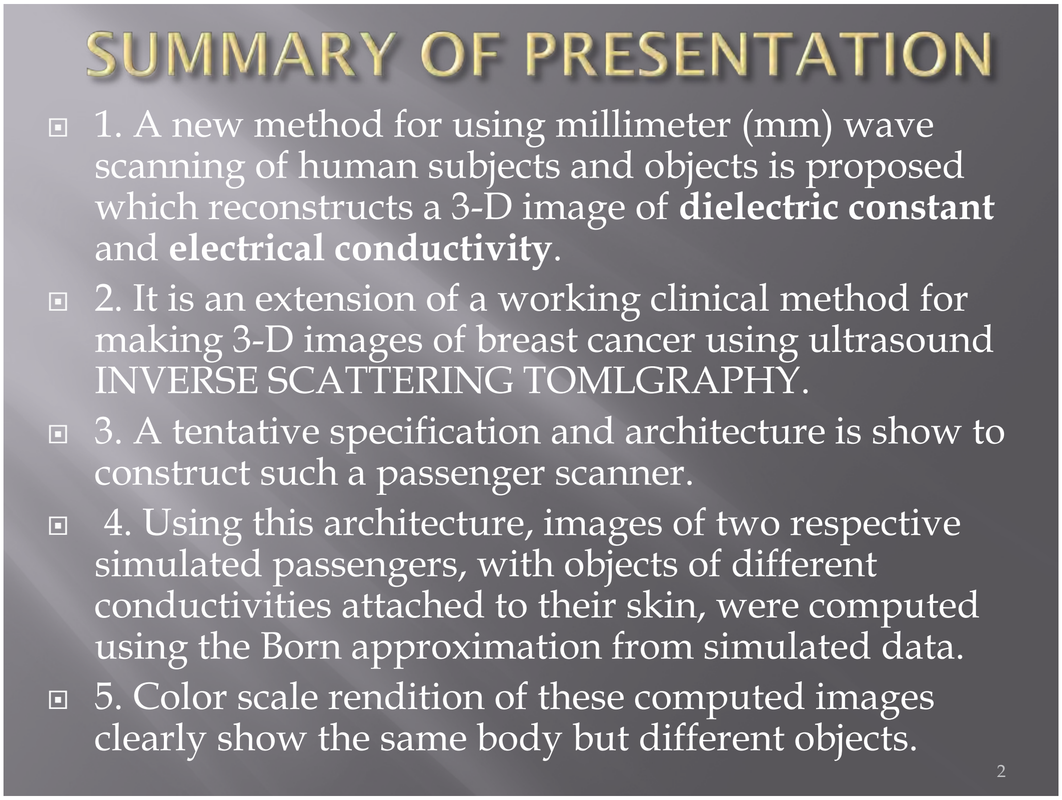
Prof. Jose Martinez
Prof. Yuri Alvarez
Dr. Borja Gonzalez Valdes
Spiros Mantzavinos
Kathryn Williams
Galia Ghazi
Luis Tirado
Dan Busioc
Melissa Buttimer
Tommy Hayes
Richard Moore

16.16 Steve Johnson: MMW using backscatter and quantitative material characterization

COMPLEX DIELECTRIC MATERIAL CHARACTERIZATION BY MM WAVES FOR 3-D PASSENGER SCREENING AND IMAGING

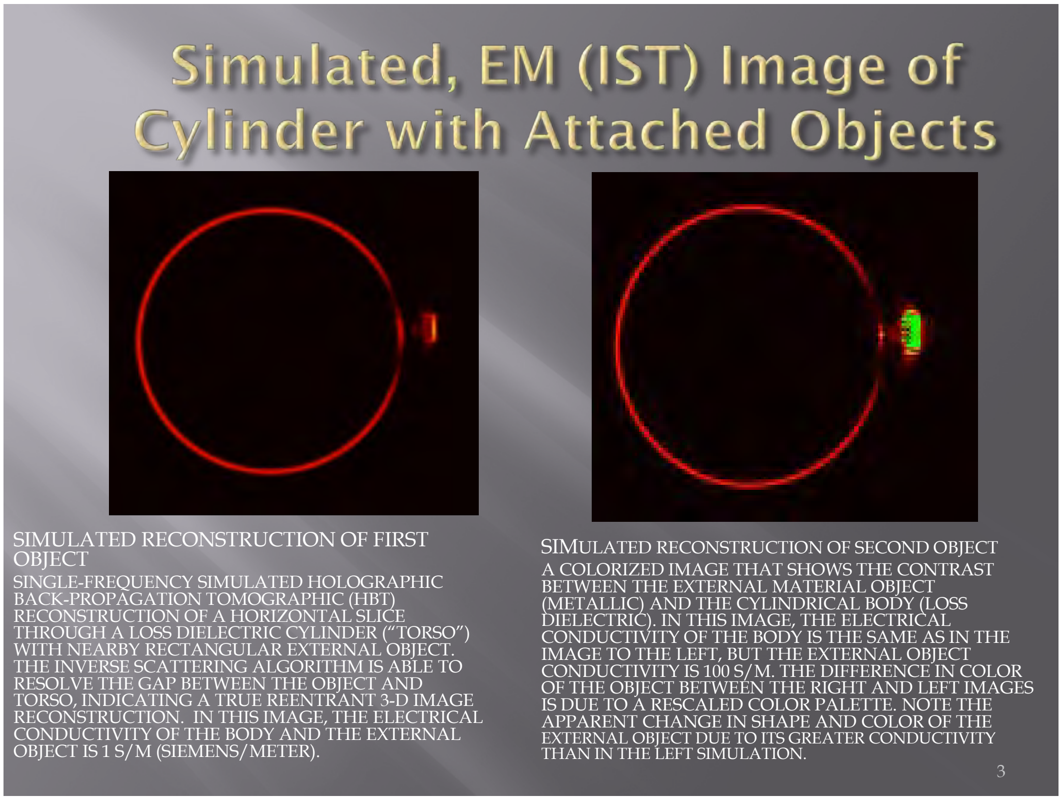
Steven A. Johnson
TeleSecurity Sciences
Las Vegas, NV

Department of Home Land Security (DHS) Conference/Workshop
ALERT
(Awareness and Localization of Explosives-Related Threats)
Northeastern University (NEU)
A DHS CENTER OF EXCELLENCE
Boston, MA
November 8-9, 2011
(Stayed at Holiday Inn, 69 Boson Street, Boston, MA)



SUMMARY OF PRESENTATION

- 1. A new method for using millimeter (mm) wave scanning of human subjects and objects is proposed which reconstructs a 3-D image of **dielectric constant** and **electrical conductivity**.
- 2. It is an extension of a working clinical method for making 3-D images of breast cancer using ultrasound INVERSE SCATTERING TOMLGRAPHY.
- 3. A tentative specification and architecture is show to construct such a passenger scanner.
- 4. Using this architecture, images of two respective simulated passengers, with objects of different conductivities attached to their skin, were computed using the Born approximation from simulated data.
- 5. Color scale rendition of these computed images clearly show the same body but different objects.



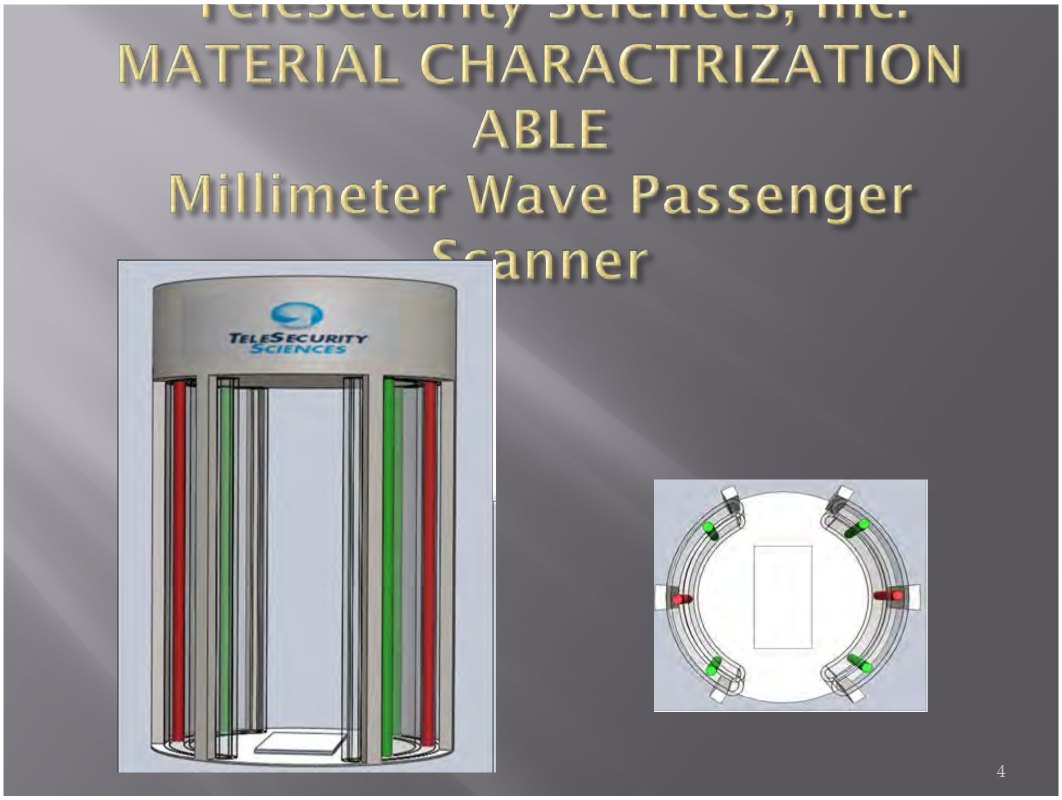
Simulated, EM (IST) Image of Cylinder with Attached Objects

SIMULATED RECONSTRUCTION OF FIRST OBJECT

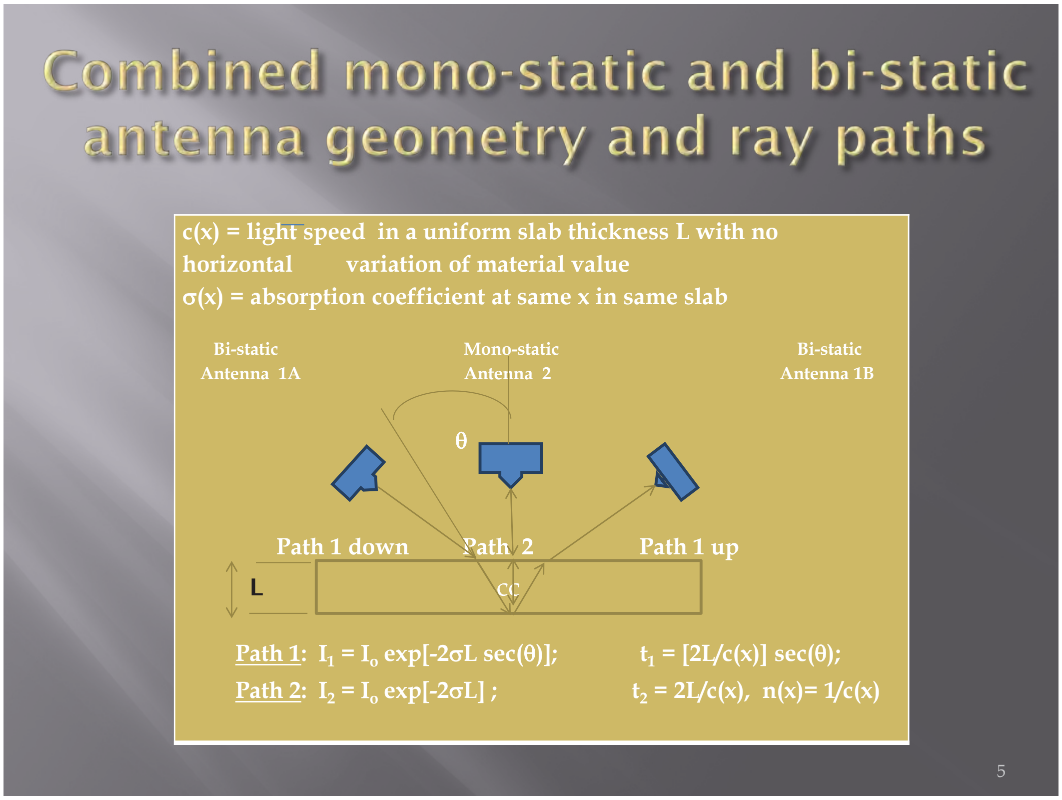
SINGLE-FREQUENCY SIMULATED HOLOGRAPHIC BACK-PROPAGATION TOMOGRAPHIC (HBT) RECONSTRUCTION OF A HORIZONTAL SLICE THROUGH A LOSS DIELECTRIC CYLINDER ("TORSO") WITH NEARBY RECTANGULAR EXTERNAL OBJECT. THE INVERSE SCATTERING ALGORITHM IS ABLE TO RESOLVE THE GAP BETWEEN THE OBJECT AND TORSO, INDICATING A TRUE REENTRANT 3-D IMAGE RECONSTRUCTION. IN THIS IMAGE, THE ELECTRICAL CONDUCTIVITY OF THE BODY AND THE EXTERNAL OBJECT IS 1 S/M (SIEMENS/METER).

SIMULATED RECONSTRUCTION OF SECOND OBJECT

A COLORIZED IMAGE THAT SHOWS THE CONTRAST BETWEEN THE EXTERNAL MATERIAL OBJECT (METALLIC) AND THE CYLINDRICAL BODY (LOSS DIELECTRIC). IN THIS IMAGE, THE ELECTRICAL CONDUCTIVITY OF THE BODY IS THE SAME AS IN THE IMAGE TO THE LEFT, BUT THE EXTERNAL OBJECT CONDUCTIVITY IS 100 S/M. THE DIFFERENCE IN COLOR OF THE OBJECT BETWEEN THE RIGHT AND LEFT IMAGES IS DUE TO A RESCALED COLOR PALETTE. NOTE THE APPARENT CHANGE IN SHAPE AND COLOR OF THE EXTERNAL OBJECT DUE TO ITS GREATER CONDUCTIVITY THAN IN THE LEFT SIMULATION.



TeleSecurity Sciences, Inc.
MATERIAL CHARACTRIZATION ABLE
Millimeter Wave Passenger Scanner



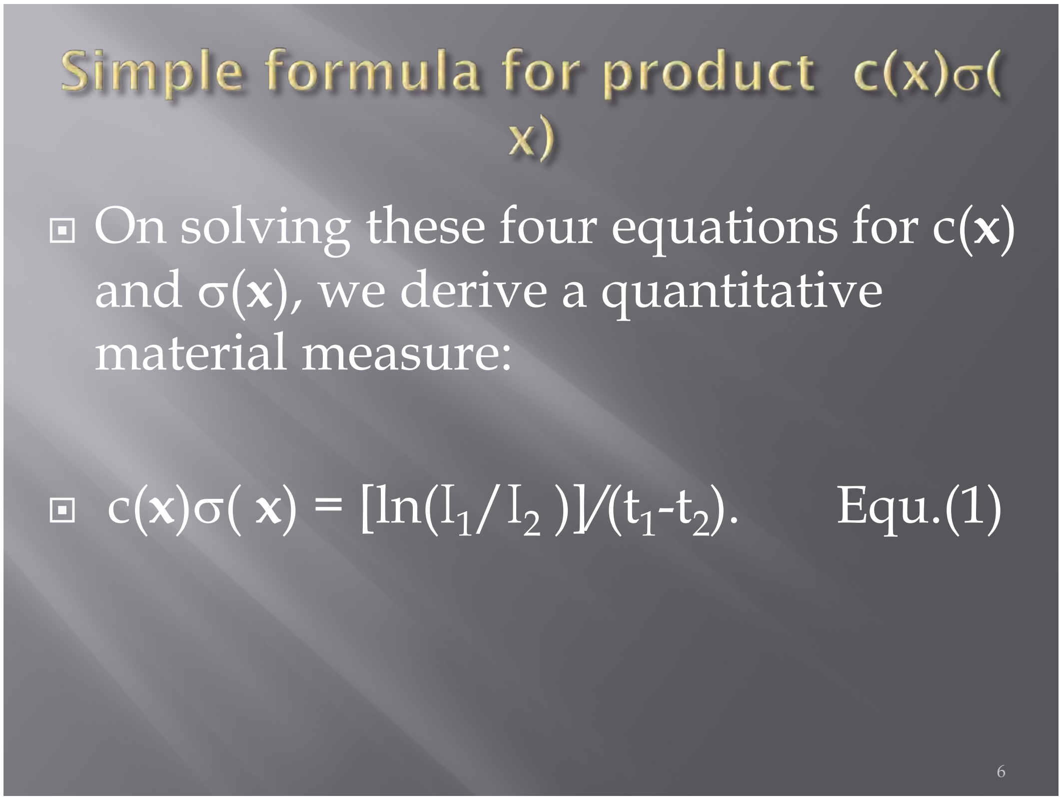
Combined mono-static and bi-static antenna geometry and ray paths

c(x) = light speed in a uniform slab thickness L with no horizontal variation of material value

σ(x) = absorption coefficient at same x in same slab

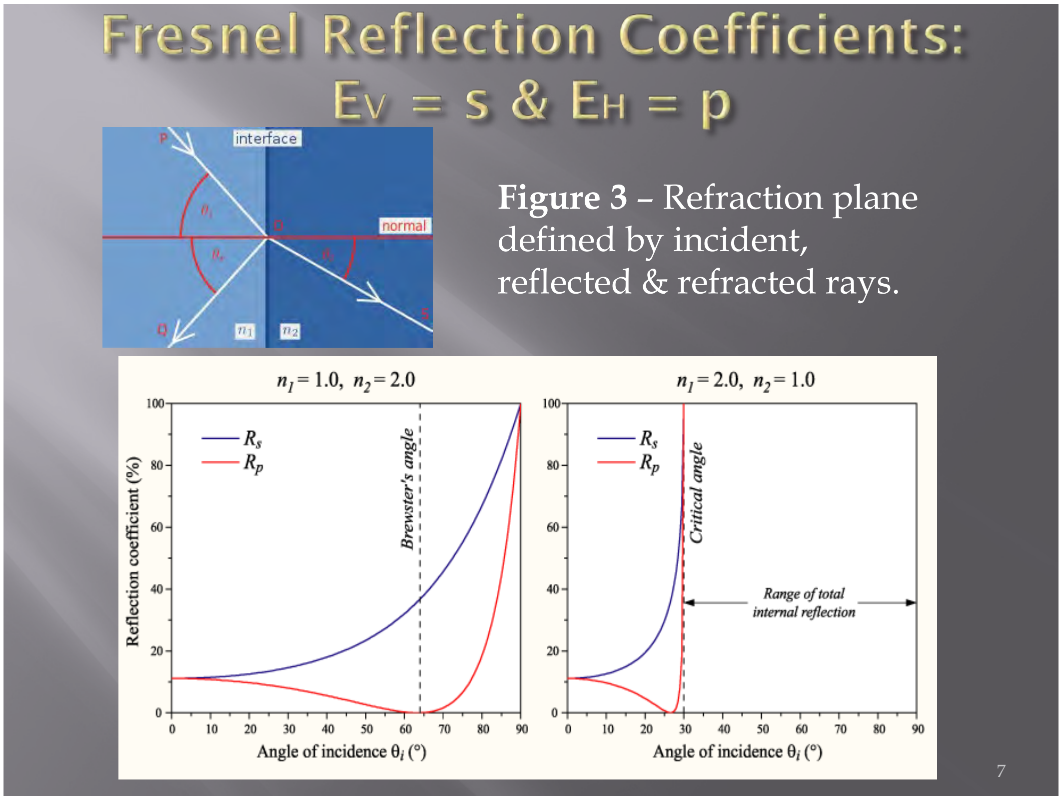
Path 1: $I_1 = I_o \exp[-2\sigma L \sec(\theta)]$; $t_1 = [2L/c(x)] \sec(\theta)$;

Path 2: $I_2 = I_o \exp[-2\sigma L]$; $t_2 = 2L/c(x)$, $n(x)= 1/c(x)$



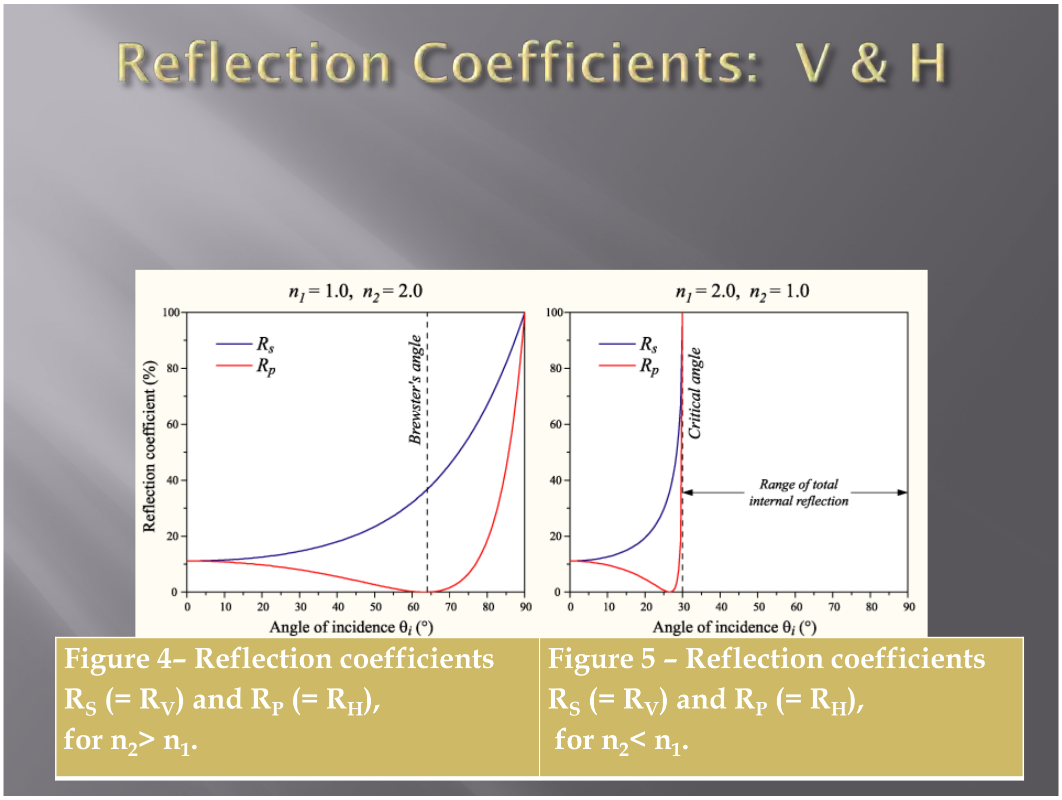
Simple formula for product c(x)σ(x)

- On solving these four equations for c(**x**) and σ(**x**), we derive a quantitative material measure:
- $c(\mathbf{x})\sigma(\mathbf{x}) = [\ln(I_1/I_2)]/(t_1-t_2)$. Equ.(1)



Fresnel Reflection Coefficients: Ev = s & EH = p

Figure 3 – Refraction plane defined by incident, reflected & refracted rays.



Reflection Coefficients: V & H

Figure 4– Reflection coefficients R_S (= R_V) and R_P (= R_H), for $n_2 > n_1$.

Figure 5 – Reflection coefficients R_S (= R_V) and R_P (= R_H), for $n_2 < n_1$.

Fresnel's Conservation of Energy Laws for Polarized Transmission and Reflection

However the laws of power (not amplitude) distribution among incident (I), reflected (R) and transmitted (T) rays is given by a third set of laws deduced by Fresnel, using conservation of energy, and are given for S polarization by

$$R_S = R_V = (n_1 \cos\theta_I - n_2 \cos\theta_T)^2 / (n_1 \cos\theta_I + n_2 \cos\theta_T)^2.$$

For S-polarized (also called V or vertical polarization, since the electric vector is perpendicular to the 2-D reflection-refraction plane) and by

$$R_P = R_H = (n_1 \cos\theta_T - n_2 \cos\theta_I)^2 / (n_1 \cos\theta_T + n_2 \cos\theta_I)^2 ,$$

for P polarization (also called H or horizontal, since the electric field vector is in the plane of reflection- refraction). Conservation of energy gives $T_V = 1 - R_V$ and $T_H = 1 - R_H$. From the figures below we note that the S = V and P = H polarizations behave very differently (they only take common values at 0 degree incident angles and at 90 degrees for non- internally reflection case.

Extension of above methods

$$c(\mathbf{x})\sigma(\mathbf{x}) = [\ln(I_1/I_2)]/(t_1 - t_2). \quad \text{Equ.(1)}$$

- Extension of above methods in a later version to use Fresnel reflection coefficients. As a refinement, we note that if the transmission (T_1 and T_2 for respective paths 1 and 2) and reflection coefficients R_1 and R_2 for respective paths

$$c(x)\sigma(x) = [\ln(I_1/I_2) - 2\ln(T_1/T_2) - \ln(R_1/R_2)]/(t_1 - t_2)$$

Equ.(2)

Finding Absorption Coefficient σ(x)

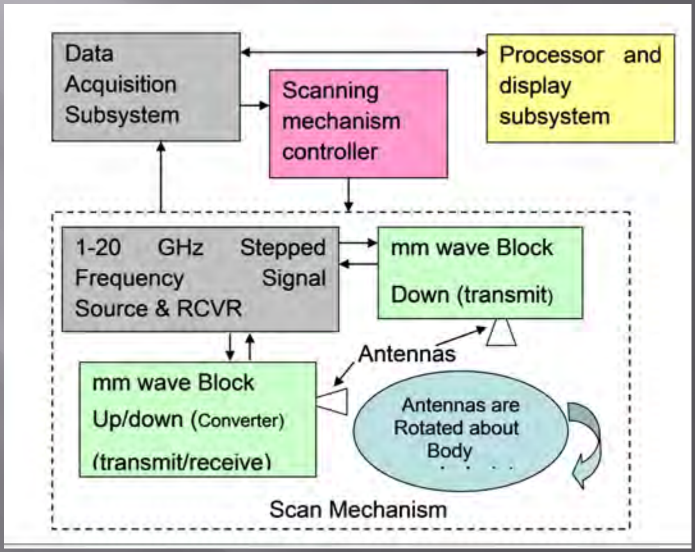
- From the Fresnel formulas and measurements of θ_I, θ_T, $R_S = R_V$, and $R_P = R_H$, it is possible to solve for n_1 and n_2. Once n_1 and n_2 are known it is possible to use the bi-static data to find the absorption coefficient from the product $c(\mathbf{x})\sigma(\mathbf{x})$. Then, $c_2(\mathbf{x}) = n_2(\mathbf{x})c_o(\mathbf{x})$, and the absorption coefficient

- $\sigma_2(\mathbf{x}) = \left[c(\mathbf{x})\sigma(\mathbf{x})\right]_2/c_2(\mathbf{x})$.

Comparison of Features

TABLE B -- Comparison of Features		
Feature	L-3 Provision	Proposed TSS System
Lateral Resolution on surface	8.3 mm (air)	4.7 mm (air)
Depth resolution	7.5 mm (air)	4.3 mm (air)
Material Characterization	none	(1) Fresnel Reflectivities: R_V, R_H for respective V, H Polarizations. (2) Product of attenuation coefficient and phase speed = $[(c_o n)s]$. (3) Attenuation = $\sigma_2 = [(c_o n)\sigma]_2/(c_o n)_2$. (4) Polarization: R_V / R_H or $(R_V - R_H)/ (R_V + R_H)$.

Block Diagram of proposed Scanner



Data Acquisition Subsystem

Scanning mechanism controller

Processor and display subsystem

1-20 GHz Stepped Frequency Signal Source & RCVR

mm wave Block Down (transmit)

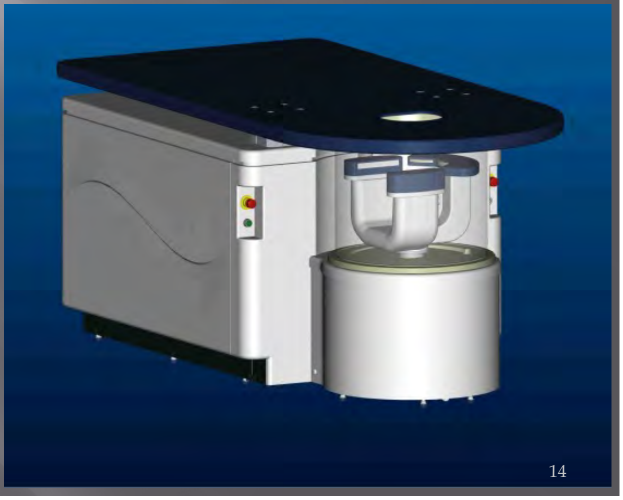
Antennas

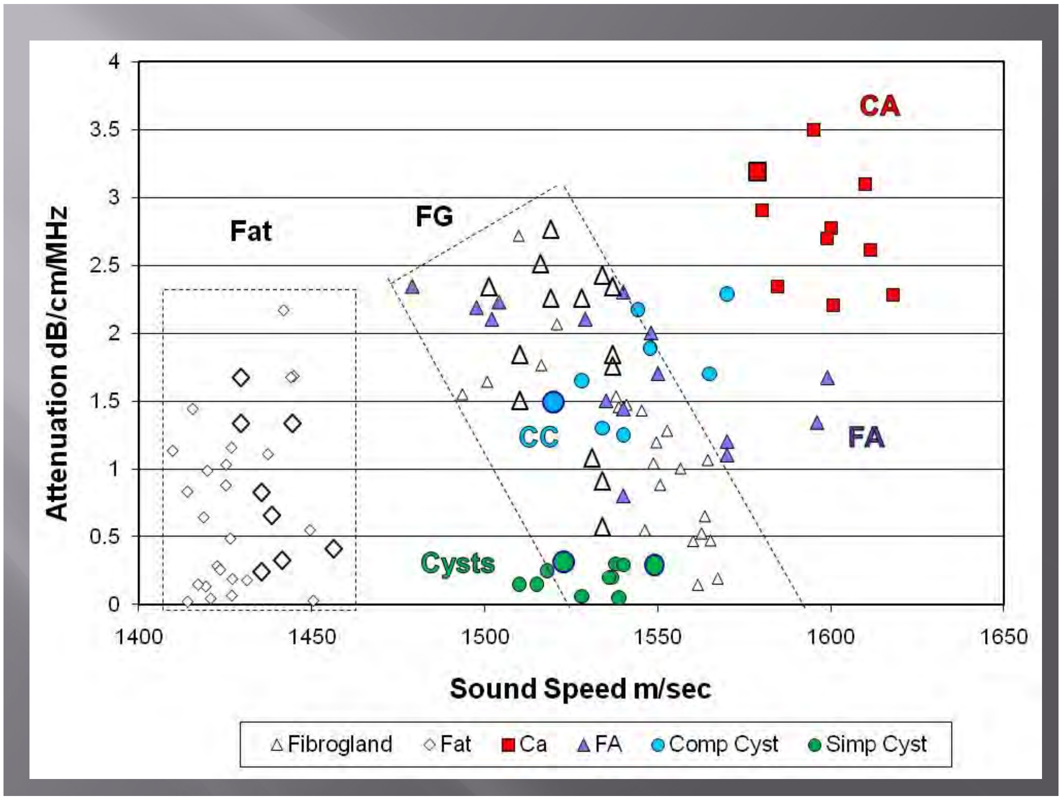
mm wave Block Up/down (Converter) (transmit/receive)

Antennas are Rotated about Body

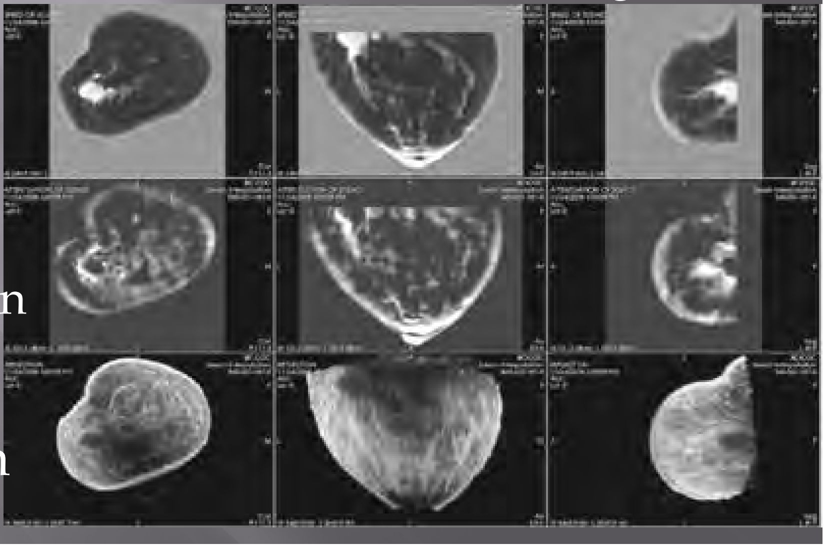
Scan Mechanism

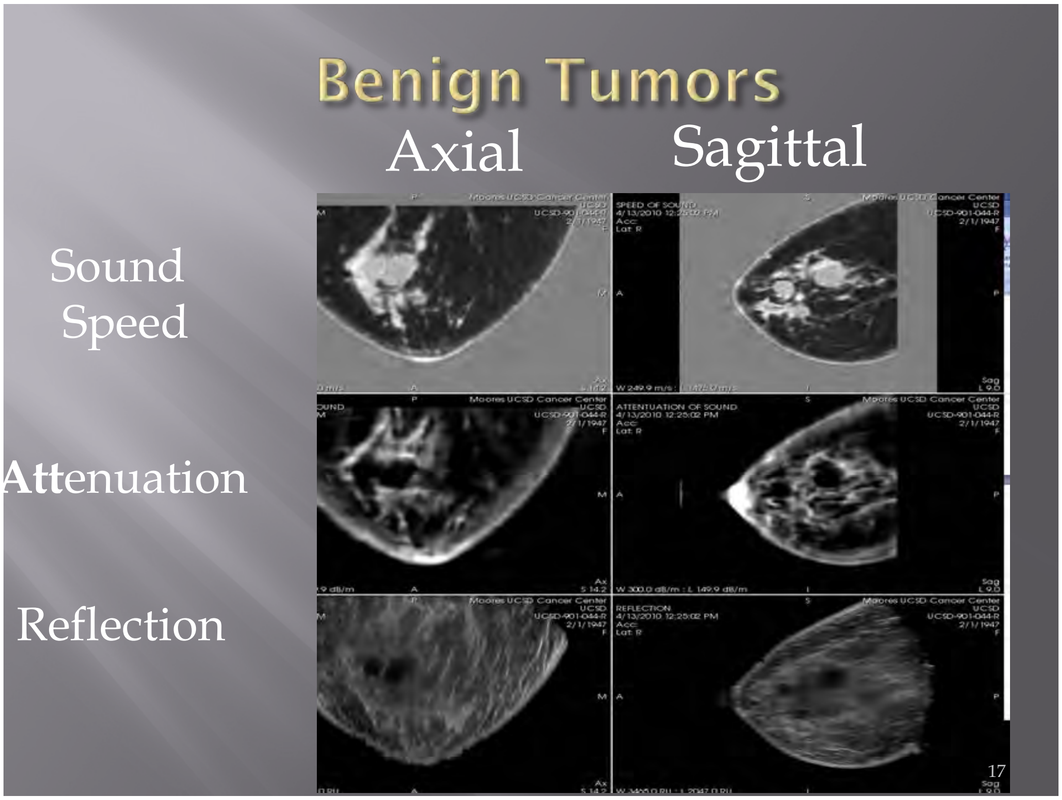
Inverse Scatter (Inversion) Tomography (IST) Ultrasound Breast Cancer Scanner





Ductal Carcinoma In Situ





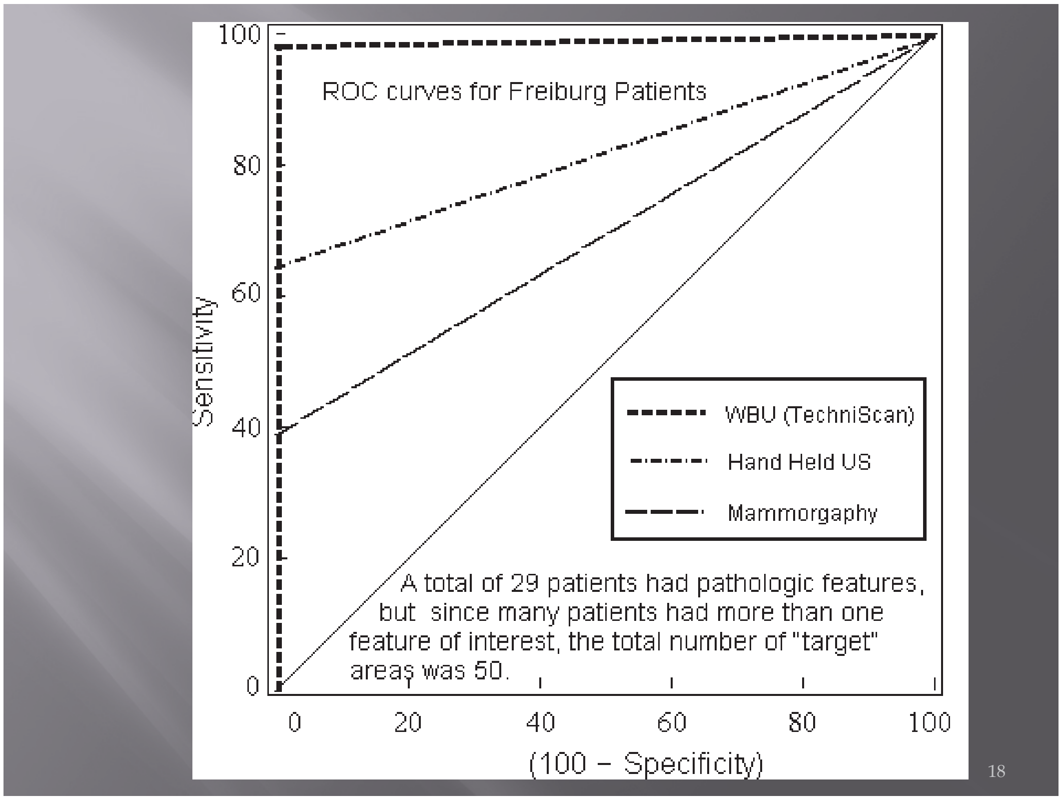
Benign Tumors

Axial Sagittal

Sound Speed

Attenuation

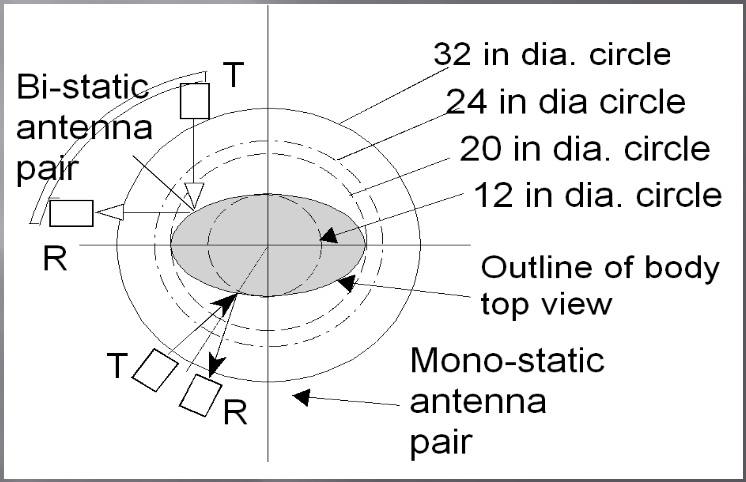
Reflection



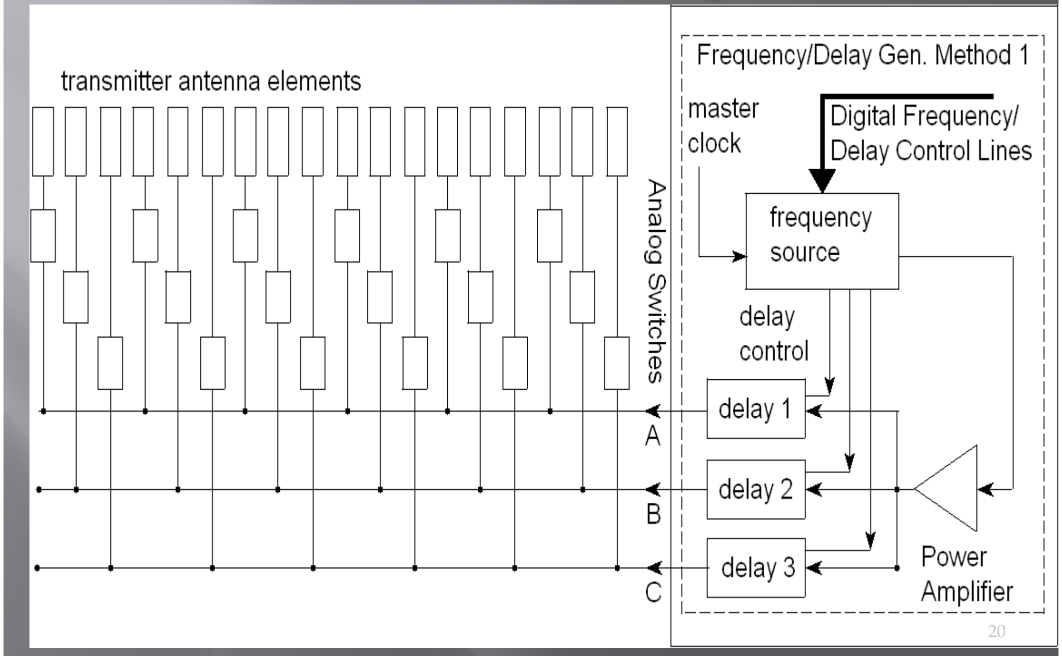
ROC curves for Freiburg Patients

A total of 29 patients had pathologic features, but since many patients had more than one feature of interest, the total number of "target" areas was 50.

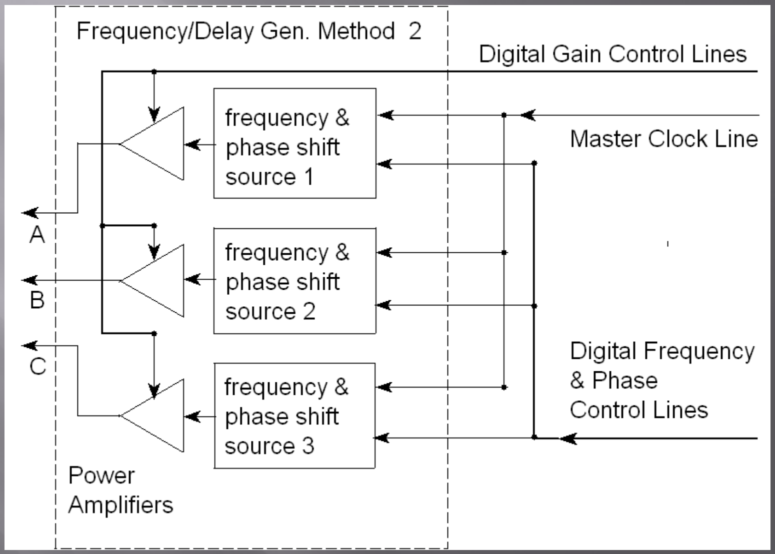
Top View of "phone booth scanner"



Transmitter switching circuits



Alternate way with amplitude control

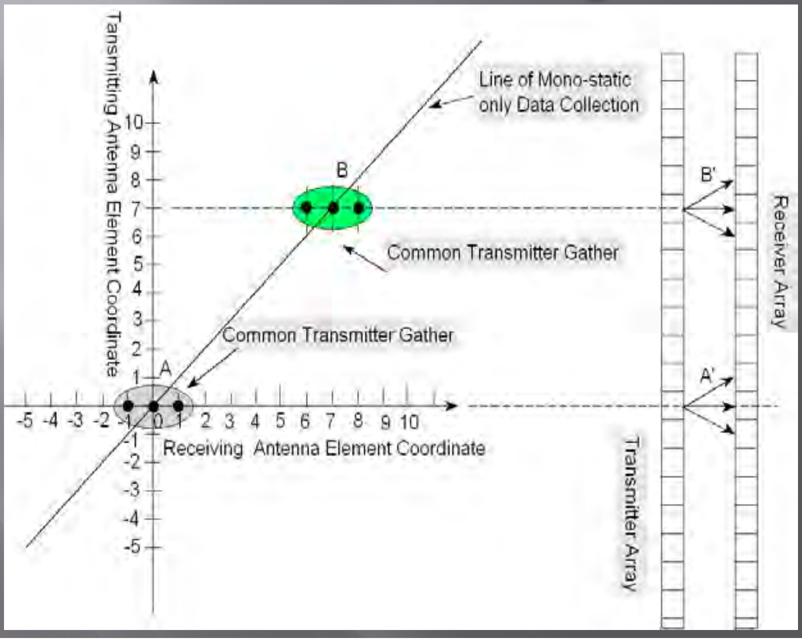


Finding absorption coefficient $\sigma_2(x)$

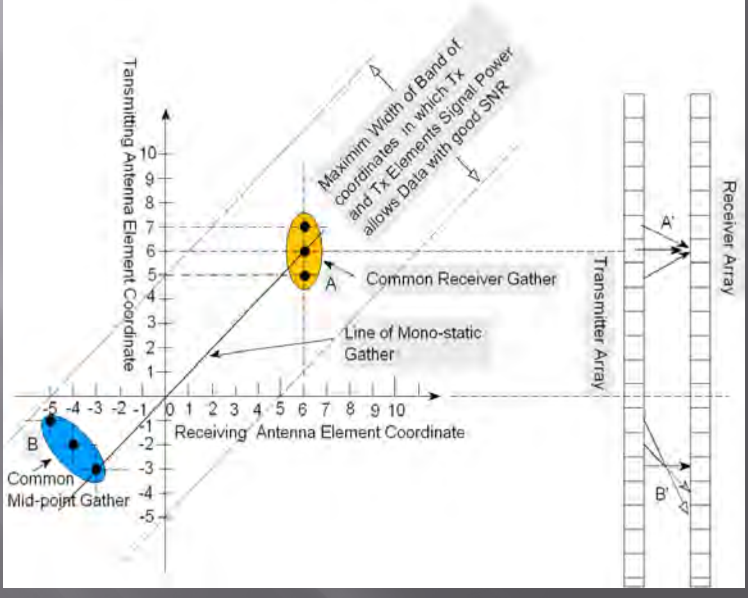
- From the Fresnel formulas and measurements of θ_I, θ_T, $R_S = R_V$, and $R_P = R_H$, it is possible to solve for n_1 and n_2. Once n_1 and n_2 are known it is possible to use the bi-static data to find the absorption coefficient from the product $c(\mathbf{x})\sigma(\mathbf{x})$. Then, $c_2(\mathbf{x}) = n_2(\mathbf{x})c_o(\mathbf{x})$, and the absorption coefficient

- $\sigma_2(\mathbf{x}) = [c(\mathbf{x})s(\mathbf{x})]_2/c_2(\mathbf{x})$.

Plots of Transmit vs. Receiver Plane Element Number (scattering not shown)



More Plots of Transmit vs. Receiver Plane Element Number (scattering not shown)

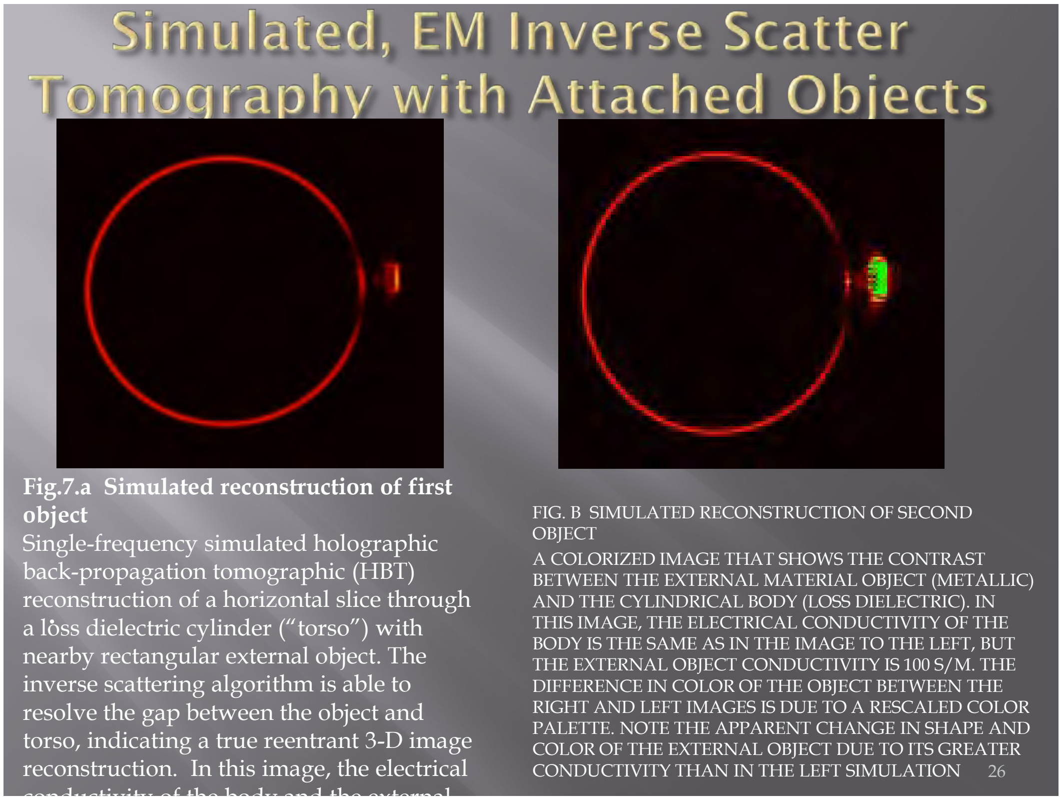


THE FINAL STEP: SIMULATION RESULTS

The above ray-based mathematics indicates that the problem for quantitative imaging of layers of materials is well posed and not singular.

Therefore, we skip ray-based inversion and pass on to finely sampled wave equation methods using an inverse scattering approach.

Use the Born approximation, since the simulated sample on the skin is thin (a few wave lengths thick).



Simulated, EM Inverse Scatter Tomography with Attached Objects

Fig.7.a Simulated reconstruction of first object

Single-frequency simulated holographic back-propagation tomographic (HBT) reconstruction of a horizontal slice through a lòss dielectric cylinder (“torso”) with nearby rectangular external object. The inverse scattering algorithm is able to resolve the gap between the object and torso, indicating a true reentrant 3-D image reconstruction. In this image, the electrical conductivity of the body and the external

FIG. B SIMULATED RECONSTRUCTION OF SECOND OBJECT

A COLORIZED IMAGE THAT SHOWS THE CONTRAST BETWEEN THE EXTERNAL MATERIAL OBJECT (METALLIC) AND THE CYLINDRICAL BODY (LOSS DIELECTRIC). IN THIS IMAGE, THE ELECTRICAL CONDUCTIVITY OF THE BODY IS THE SAME AS IN THE IMAGE TO THE LEFT, BUT THE EXTERNAL OBJECT CONDUCTIVITY IS 100 S/M. THE DIFFERENCE IN COLOR OF THE OBJECT BETWEEN THE RIGHT AND LEFT IMAGES IS DUE TO A RESCALED COLOR PALETTE. NOTE THE APPARENT CHANGE IN SHAPE AND COLOR OF THE EXTERNAL OBJECT DUE TO ITS GREATER CONDUCTIVITY THAN IN THE LEFT SIMULATION

Normalizing for Antenna Response

- Remove the angular, polarization, frequency, Tx and Rx coupling and noise properties of antenna

THE END

Thank you.

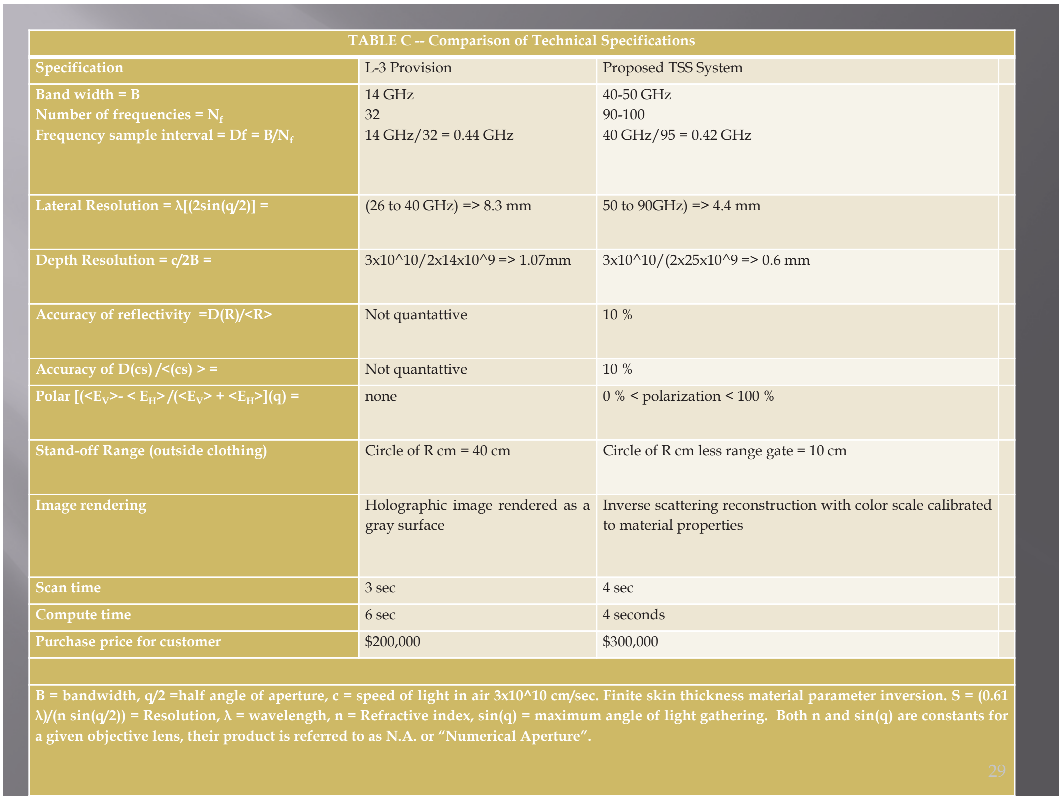


TABLE C -- Comparison of Technical Specifications		
Specification	L-3 Provision	Proposed TSS System
Band width = B **Number of frequencies = N_f** **Frequency sample interval = Df = B/N_f**	14 GHz 32 14 GHz/32 = 0.44 GHz	40-50 GHz 90-100 40 GHz/95 = 0.42 GHz
Lateral Resolution = λ[(2sin(q/2)] =	(26 to 40 GHz) => 8.3 mm	50 to 90GHz) => 4.4 mm
Depth Resolution = c/2B =	3x10^10/2x14x10^9 => 1.07mm	3x10^10/(2x25x10^9 => 0.6 mm
Accuracy of reflectivity =D(R)/<R>	Not quantattive	10 %
Accuracy of D(cs) /<(cs) > =	Not quantattive	10 %
Polar [(<E_V>- < E_H>/(<E_V> + <E_H>](q) =	none	0 % < polarization < 100 %
Stand-off Range (outside clothing)	Circle of R cm = 40 cm	Circle of R cm less range gate = 10 cm
Image rendering	Holographic image rendered as a gray surface	Inverse scattering reconstruction with color scale calibrated to material properties
Scan time	3 sec	4 sec
Compute time	6 sec	4 seconds
Purchase price for customer	$200,000	$300,000

B = bandwidth, q/2 =half angle of aperture, c = speed of light in air 3x10^10 cm/sec. Finite skin thickness material parameter inversion. S = (0.61 λ)/(n sin(q/2)) = Resolution, λ = wavelength, n = Refractive index, sin(q) = maximum angle of light gathering. Both n and sin(q) are constants for a given objective lens, their product is referred to as N.A. or "Numerical Aperture".

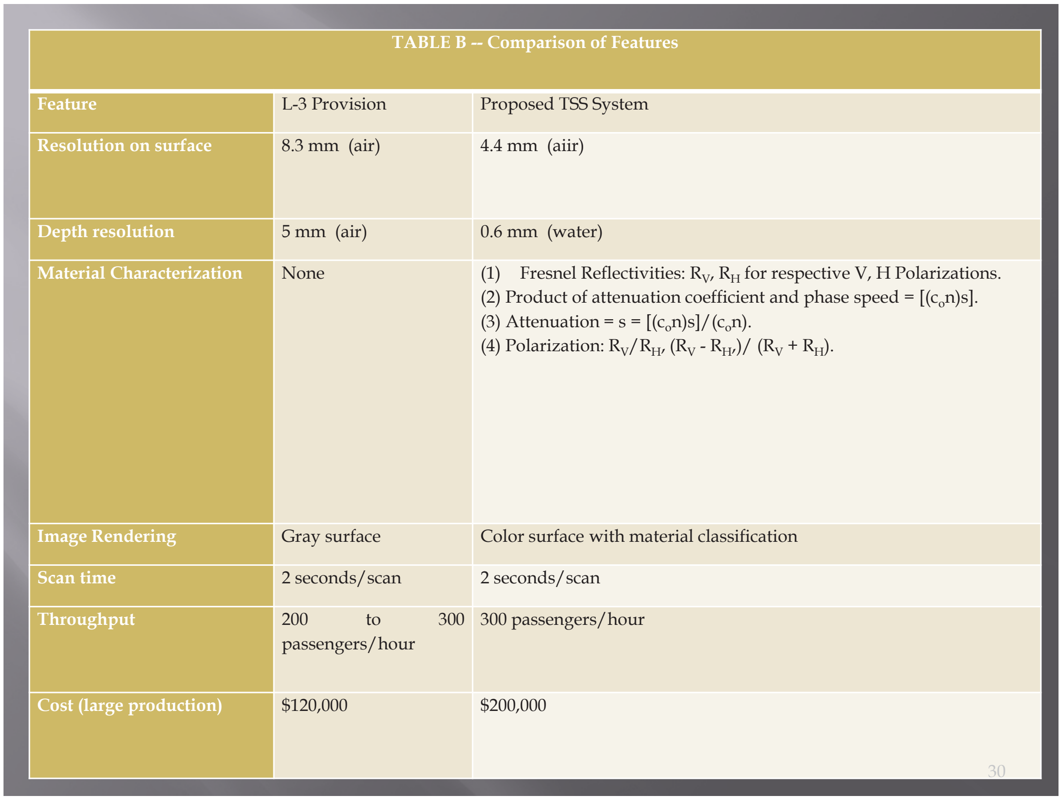


TABLE B -- Comparison of Features		
Feature	L-3 Provision	Proposed TSS System
Resolution on surface	8.3 mm (air)	4.4 mm (aiir)
Depth resolution	5 mm (air)	0.6 mm (water)
Material Characterization	None	(1) Fresnel Reflectivities: R_V, R_H for respective V, H Polarizations. (2) Product of attenuation coefficient and phase speed = [(c_on)s]. (3) Attenuation = s = [(c_on)s]/(c_on). (4) Polarization: R_V/R_H, (R_V - R_H,)/ (R_V + R_H).
Image Rendering	Gray surface	Color surface with material classification
Scan time	2 seconds/scan	2 seconds/scan
Throughput	200 to 300 passengers/hour	300 passengers/hour
Cost (large production)	$120,000	$200,000

TABLE C -- Comparison of Technical Specifications

Specification	L-3 Provision	Proposed TSS System
Band width = B Number of frequencies = N_f Frequency sample interval = Df = B/N_f	14 GHz 32 14 GHz/32 = 0.44 GHz	40-50 GHz 90-100 40 GHz/95 = 0.42 GHz
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Accuracy of D(cs) /<(cs) > =	Not quantattive	10 %
Polar [(<E_V>- < E_H> /(<E_V> + <E_H>](q) =	none	0 % < polarization < 100 %
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Image rendering	Holographic image rendered as a gray surface	Inverse scattering reconstruction with color scale calibrated to material properties
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Simulated, EM (IST) Image of Cylinder with Attached Objects

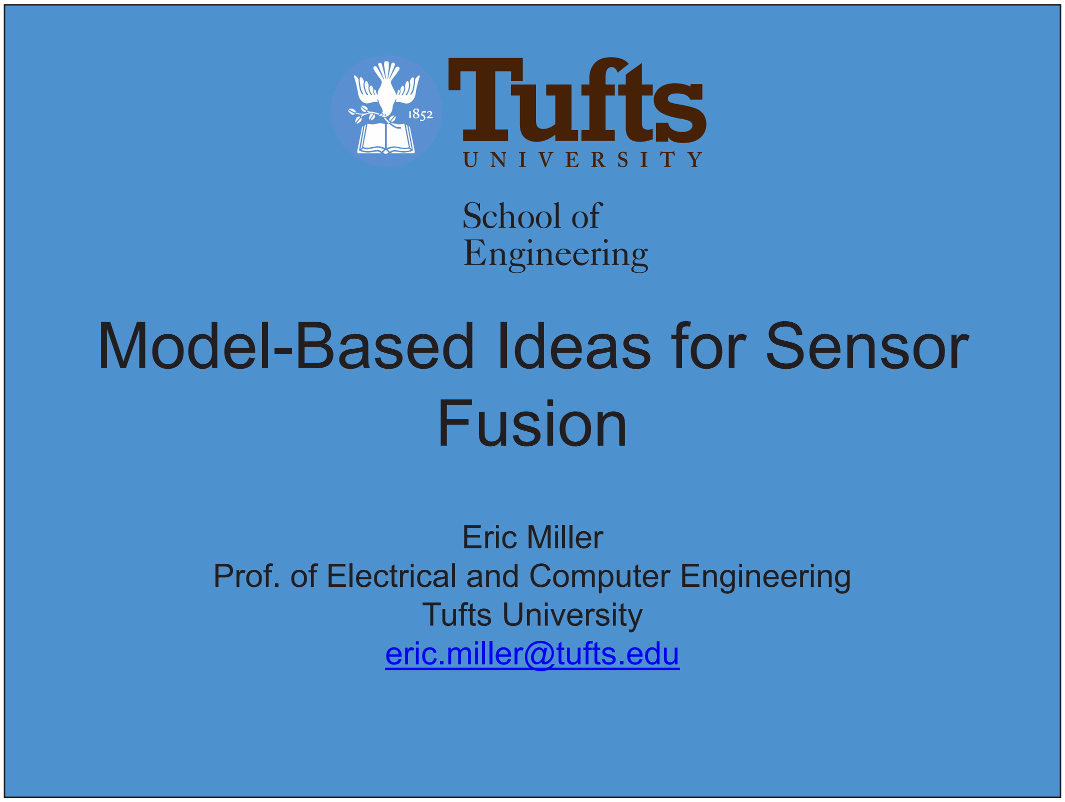
SIMULATED RECONSTRUCTION OF FIRST OBJECT

SINGLE-FREQUENCY SIMULATED HOLOGRAPHIC BACK-PROPAGATION TOMOGRAPHIC (HBT) RECONSTRUCTION OF A HORIZONTAL SLICE THROUGH A LOSS DIELECTRIC CYLINDER ("TORSO") WITH NEARBY RECTANGULAR EXTERNAL OBJECT. THE INVERSE SCATTERING ALGORITHM IS ABLE TO RESOLVE THE GAP BETWEEN THE OBJECT AND TORSO, INDICATING A TRUE REENTRANT 3-D IMAGE RECONSTRUCTION. IN THIS IMAGE, THE ELECTRICAL CONDUCTIVITY OF THE BODY AND THE EXTERNAL OBJECT IS 1 S/M (SIEMENS/METER).

SIMULATED RECONSTRUCTION OF SECOND OBJECT

A COLORIZED IMAGE THAT SHOWS THE CONTRAST BETWEEN THE EXTERNAL MATERIAL OBJECT (METALLIC) AND THE CYLINDRICAL BODY (LOSS DIELECTRIC). IN THIS IMAGE, THE ELECTRICAL CONDUCTIVITY OF THE BODY IS THE SAME AS IN THE IMAGE TO THE LEFT, BUT THE EXTERNAL OBJECT CONDUCTIVITY IS 100 S/M. THE DIFFERENCE IN COLOR OF THE OBJECT BETWEEN THE RIGHT AND LEFT IMAGES IS DUE TO A RESCALED COLOR PALETTE. NOTE THE APPARENT CHANGE IN SHAPE AND COLOR OF THE EXTERNAL OBJECT DUE TO ITS GREATER CONDUCTIVITY THAN IN THE LEFT SIMULATION.

16.17 Eric Miller: Thoughts on Fusion



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Engineering

Model-Based Ideas for Sensor Fusion

Eric Miller
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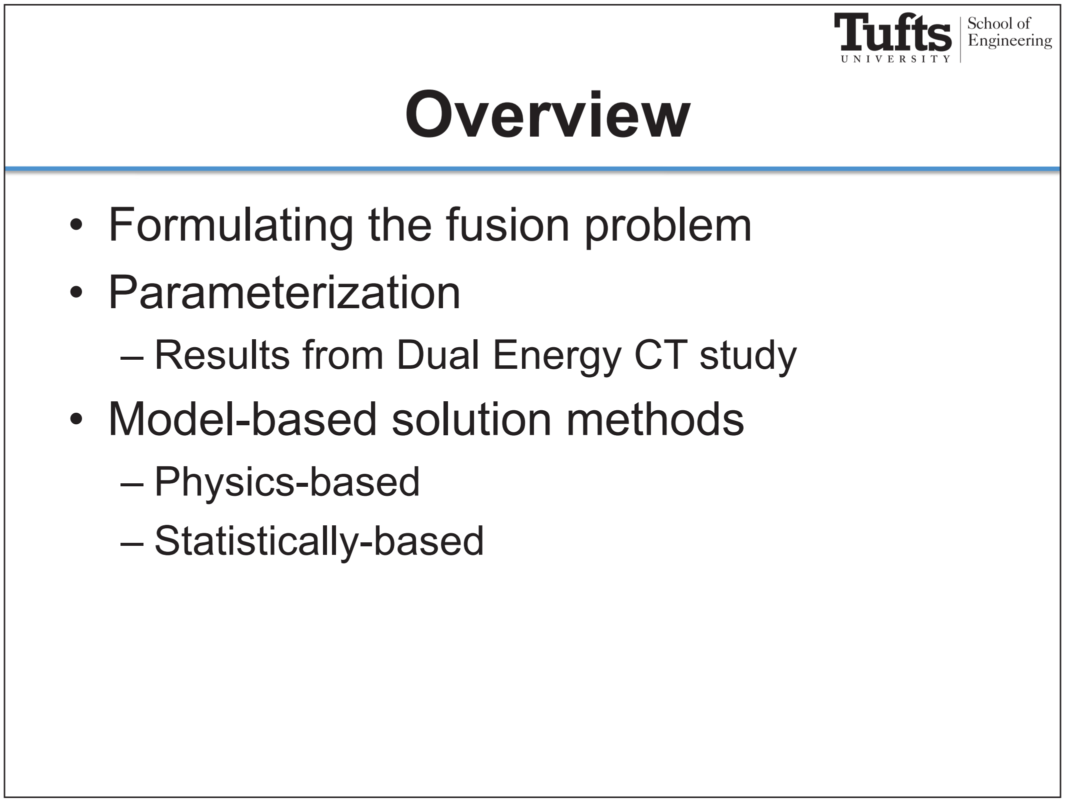
Tufts University
eric.miller@tufts.edu



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Overview

- Formulating the fusion problem
- Parameterization
  - Results from Dual Energy CT study
- Model-based solution methods
  - Physics-based
  - Statistically-based

Conclusions

- Model based methods have much to offer for fusion
- Principled approach to many issues associated with multi-sensor data acquisition, processing, and analysis
- Physics-based models allow for joint design and optimization of sensors and processing
- Statistically-based models allow for incorporation of prior information and exploitation of cross-modality correlations

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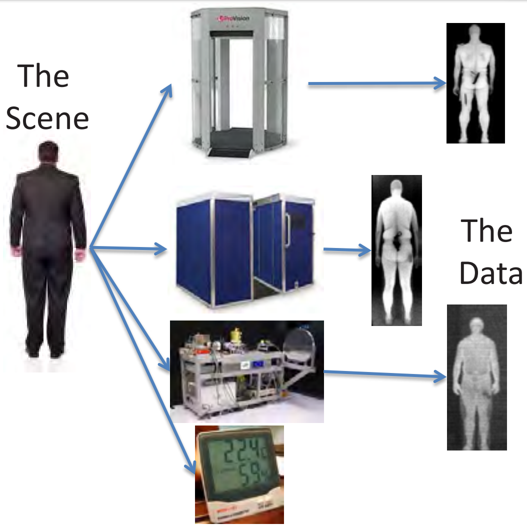
The Problem: Security



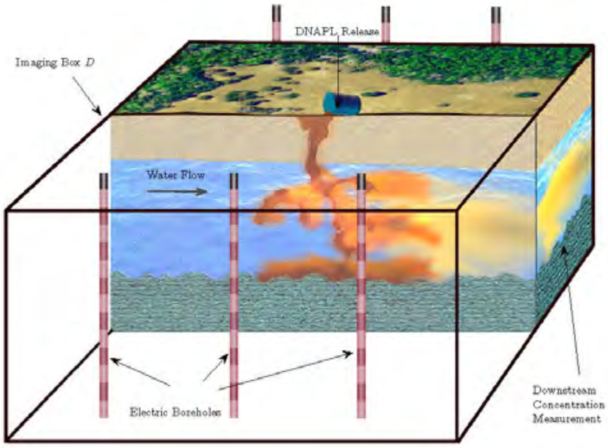
The Scene

The Data

The Instruments

http://www.dlr.de/desktopdefault.aspx/tabid-6214/10201_read-26109/
http://www.tsa.gov/approach/tech/ait/how_it_works.shtm
http://www.photonics.com/Article.aspx?AID=41330
http://www.diagnosticimaging.com/safety/content/article/113619/1521147
http://www.al-laporte.com/services

The Problem: Remediation



- The scene: subsurface distribution of contaminant saturation
- The instruments and data:
  - Downstream hydrogeochemical sampling of contaminant concentration
  - Cross-stream electrical resistance tomography

Common structure

- Everyone is looking at the same *scene*
- Each *instrument* produces data that is somehow related to a *property* of the scene
  - Security
    - “Reflectivity” or spectral structure for imaging-type modalities
    - Humidity, temperature, other environmental properties
    - Photoelectric and Compton scattering coefficients
  - Remediation
    - Electrical properties
    - Chemical composition
- Mapping from property to data can be highly complex, perhaps unknown, function of time, space, wavelength, etc.
- Goal: Recover some aspect about the scene in a manner that reflects the information in the various sources of data

What do we want?

- Important to be precise about what we want from the data
  - Presence of a material
  - Rough characterization (e.g., centroid and mass)
  - Detailed image of the scene
- Why?
  - Desired information should impact the design of the processing and perhaps even the instruments
  - May be possible to reduce quantity of data to be acquired, simplify equipment, etc.

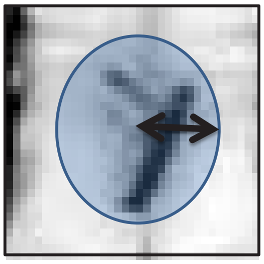
What do we want?

- To be a bit more quantitative, looking for high sensitivity of data to the parameters being sought

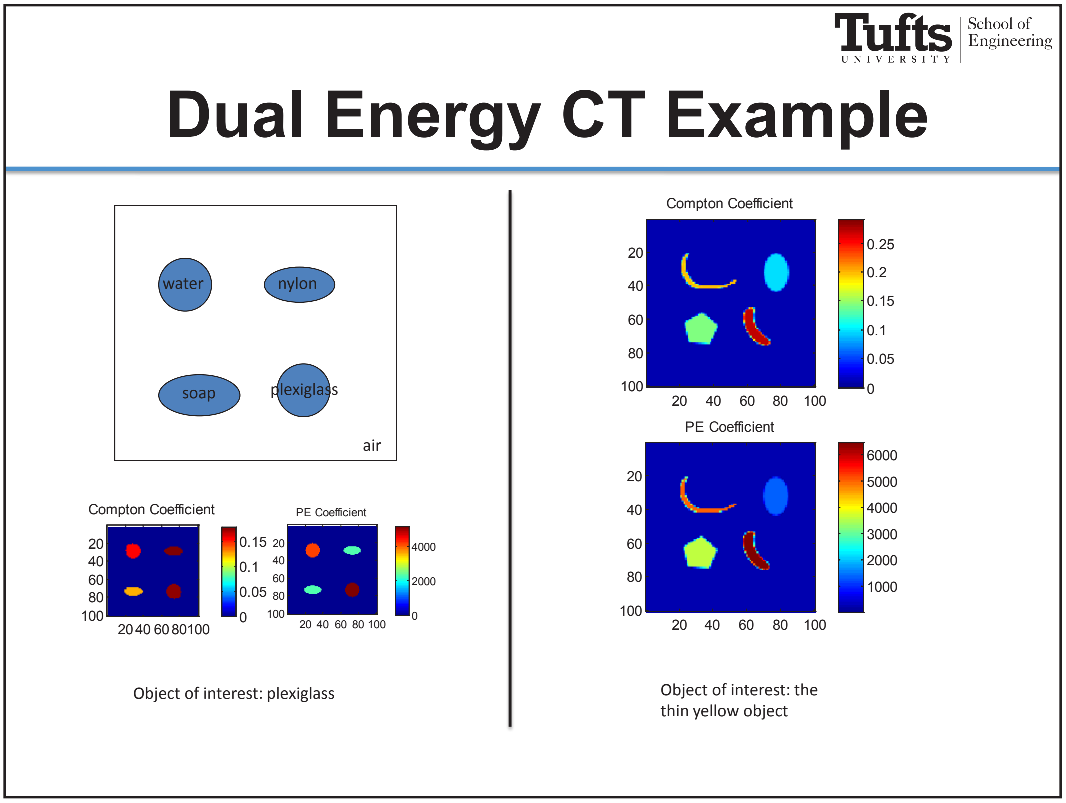
$$\frac{\partial \text{datum}_i}{\partial \text{pixel}_j} \text{ may be small}$$

but

$$\frac{\partial \text{datum}_i}{\partial \text{radius}} \text{ may be large}$$



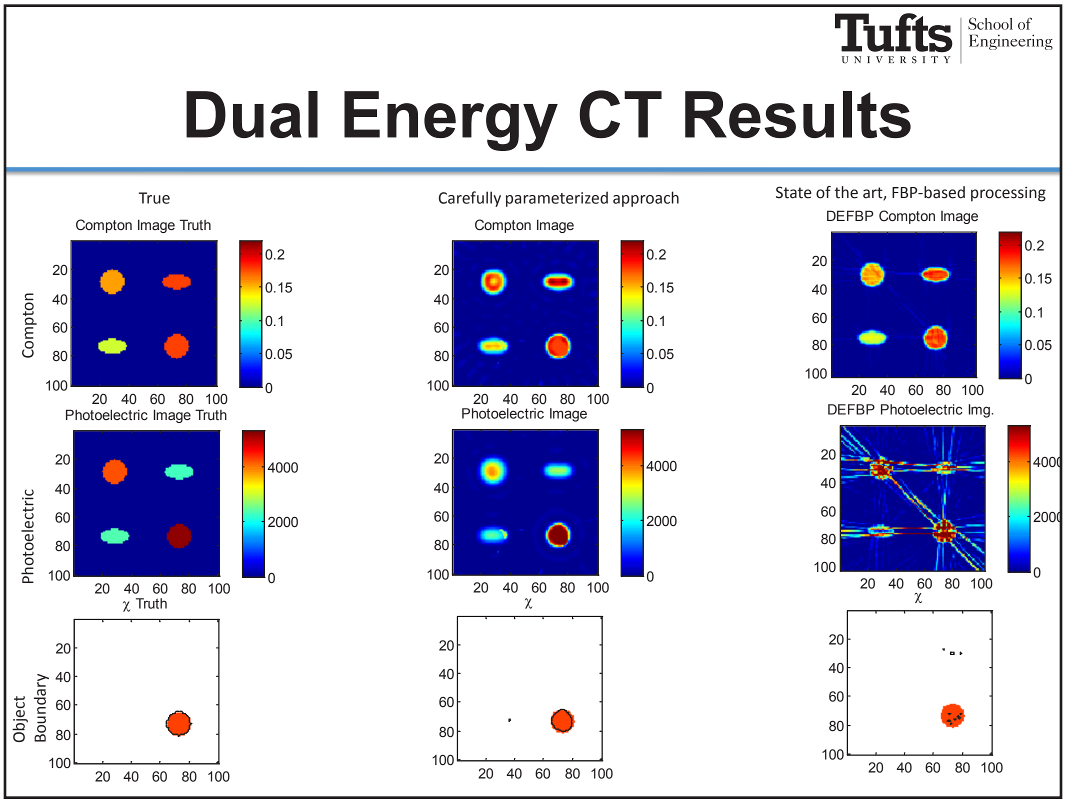
- Pixel-by-pixel approach "diffuses" information in the data across a huge number of unknowns
- More parametric methods may better concentrate the information to explain those degrees of freedom that actually are of most direct interest



Dual Energy CT Example

Object of interest: plexiglass

Object of interest: the thin yellow object



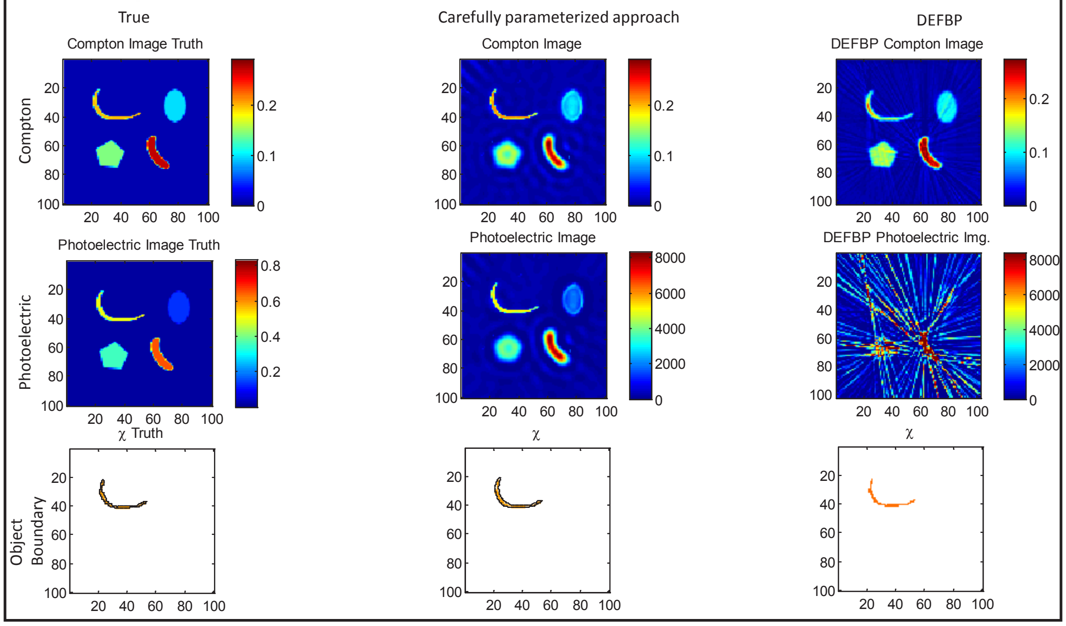
Dual Energy CT Results

True

Carefully parameterized approach

State of the art, FBP-based processing

More Results



Model Based Approach to Fusion

- Two sets of quantities
  - Data
  - Parameters
- Data:
  - Photon counts
  - Humidly levels
  - Voltages
  - Contaminant concentrations
- Parameters: derived from constitutive properties of the scene
  - Photoelectric or Compton scattering coefficients
  - Electrical permittivity and conductivity
  - Chemical concentrations
  - Contaminant saturation
- Models relate (1) data to parameters and (2) parameters to parameters

Data models

- From physics

$$d_i = f_i\left(x_i\right) \quad i = 1,2,\ldots,N$$

- Many forms
  - – Direct observation (*f* = identity)
  - – Matrix equation
    - Spectral unmixing
  - – Integral equation
    - Radon transform for CT
    - Kirchoff integral for some optics problems
  - – Partial differential equation
    - Flow and transport
    - Electrical resistance tomography

Property Models

- There has to be *some* relationship among the x_i otherwise there is no fusion.
- A number of options or such models
  - – Physics-based
  - – Statistical
  - – Geometric

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Physics-based

- Petro-physical relationships
- Archie's law (electrical conductivity to porosity, saturation..)

$$\sigma = a\sigma_b\phi^m$$

- Complex refractive index method (dielectric to porosity and saturation)

$$\sqrt{\varepsilon} = (1-\phi)\sqrt{\varepsilon_s} + \phi S\sqrt{\varepsilon_w} + n(1-S)\sqrt{\varepsilon_a}$$

- Gassmann (seismic velocities to bulk/shear modulus, density)

$$V_p^2 = \frac{K + 4/3\mu}{\rho} \quad V_s^2 = \frac{\mu}{\rho}$$

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Statistical Models

- Many, many options here
  - Lead to some type of maximum a posteriori or Bayesian approach to fusion
- Pairs of parameters are the same up to some noise

$$x_i = x_j + w_{i,j} \quad w_{i,j} \sim N(0, R_{i,j})$$

- Parameters are jointly Gaussian

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \sim N\left(\begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{bmatrix}, \begin{bmatrix} R_{1,1} & R_{1,2} & R_{1,3} \\ R_{2,1} & R_{2,2} & R_{2,3} \\ R_{3,1} & R_{3,2} & R_{3,3} \end{bmatrix}\right)$$

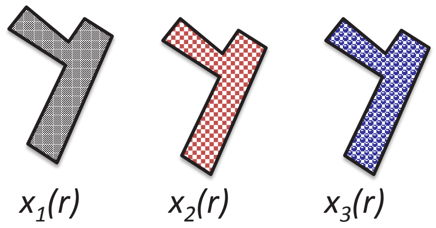
- Pairs of parameters have large mutual information

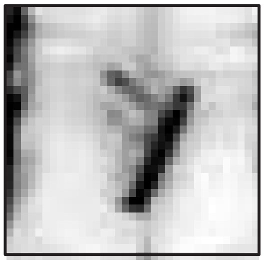
$$MI(x_1, x_2) = \sum p(x_1, x_2)\log\frac{p(x_1, x_2)}{p(x_1)p(x_2)}$$

Geometric Models

- An object in one property is an object in all properties

$$x_i(r) = c_i(r)\chi(r)$$





Same shapes, χ, different contrasts c_i

End Result

- Model based approach leads to variational methods for fusion

$$\hat{x}_1,\ldots,\hat{x}_N = \arg\min_{x_1,\ldots x_N} \sum_{i=1}^{N} \left\| d_i - f_i(x_i) \right\|_2^2 + \Omega(x_1,\ldots x_N)$$

Want to fit to the data

Encourage similarity based on property models

- Other formulations possible as well depending on the models
- Structure leads to interesting and efficient algorithms
- Variational approach can be used for
  - Performance analysis
  - Evaluation of information content of data sources
  - Optimization of data collection or instrument design
  - Etc

Example

Electrical Model

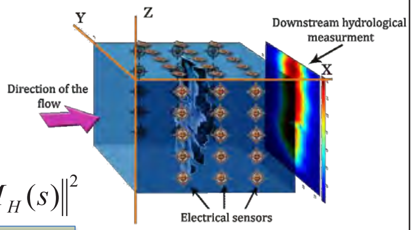
$$d_E = M_E(\sigma)$$

Hydrological Model

$$d_H = M_H(s_{NAPL})$$

Petrophysical Models, *Hunt's* Model, or *Archie's* Law

$$\sigma = T(s_{NAPL})$$



$$s_{NAPL} = \arg\min_{s} \quad \left\| d_E - M_E\left(T(s)\right) \right\|^2 + \lambda \left\| d_H - M_H(s) \right\|^2$$

$$s = s_i H\left(\phi(\alpha,\beta,\chi)\right) + s_0\left(1 - H\left(\phi(\alpha,\beta,\chi)\right)\right)$$

$$\begin{cases} \arg\min\limits_{s} \quad \left\| d_E - M_E\left(T(s)\right) \right\|^2 \\ \arg\min\limits_{s} \quad \left\| d_H - M_H(s) \right\|^2 \end{cases}$$

Forward Models

Poisson's Equation

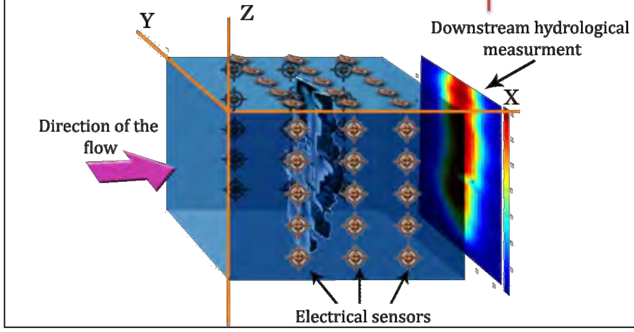
$$\nabla \cdot \left(\sigma(\mathbf{x}) \nabla v(\mathbf{x})\right) = i(\mathbf{x})$$

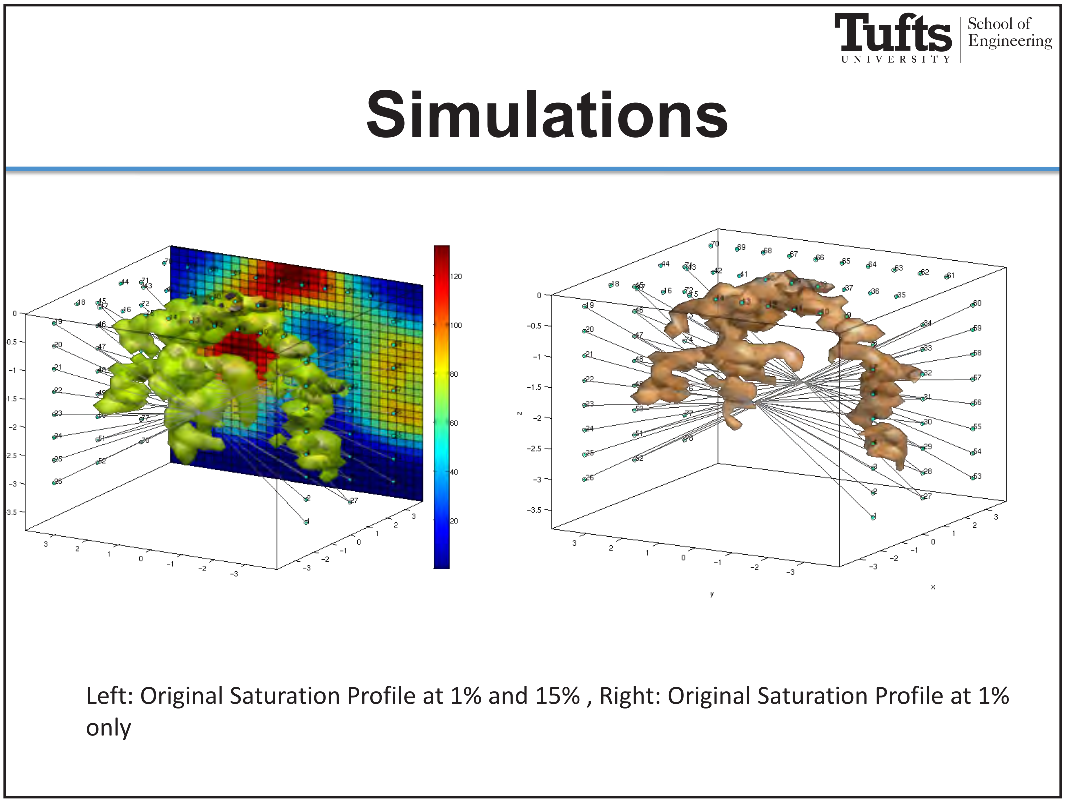
$\sigma(\mathbf{x})$	**Electrical Conductivity**
$i(\mathbf{x})$	**Current Source Distribution**
$v(\mathbf{x})$	**Electrical Potential**

Mass Transport Equation

$$\frac{\partial}{\partial t}\left(\theta_w C_i\right) + \nabla \cdot \left(C_i \vec{q} - \theta_w \mathbf{D}_H^i \cdot \nabla C_i\right) = E_{an_i}$$

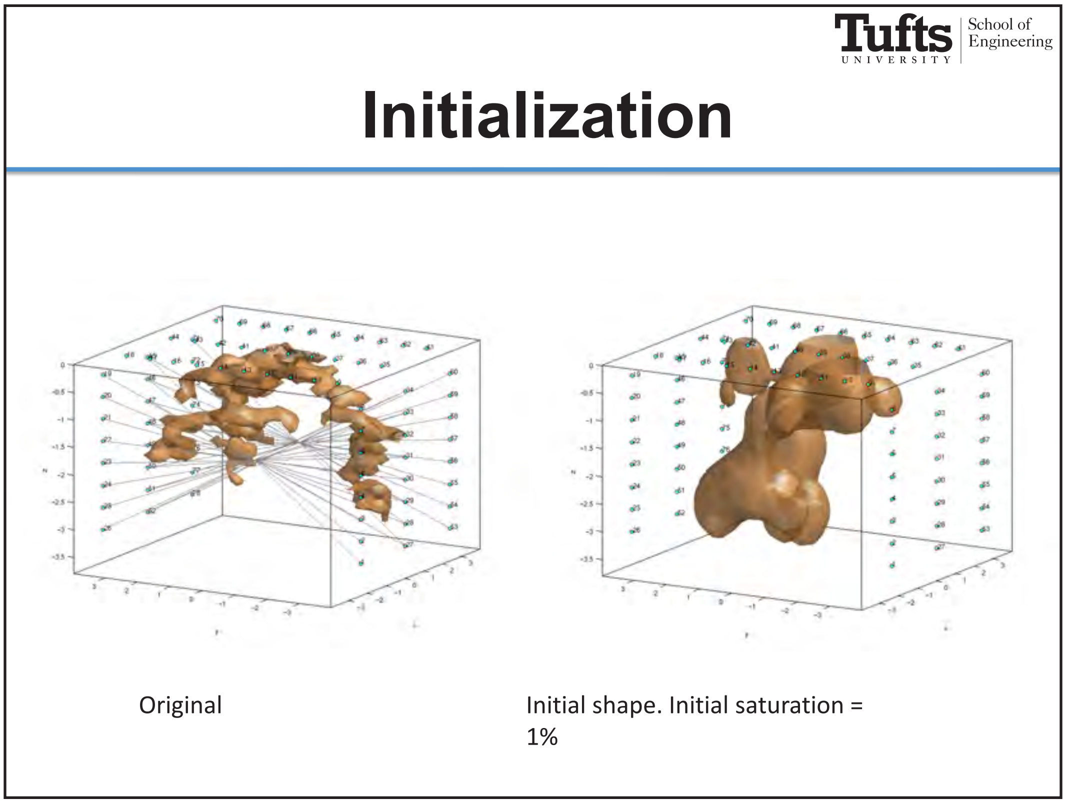
θ_w	**Volumetric Water Content**
C_i	**Mass Concentration of Component i**
$\vec{q}$	**Specific Discharge from Darcy's Law**
$\mathbf{D}_H^i$	**Hydrodynamic Dispersion Tensor**
E_{an_i}	**The Interphase Mass Exchange of Component i from the NAPL to aqueous phase**





Simulations

Left: Original Saturation Profile at 1% and 15% , Right: Original Saturation Profile at 1% only

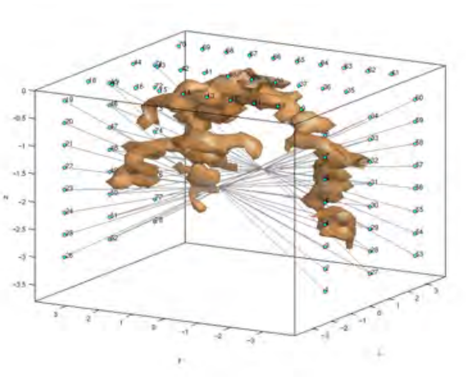


Initialization

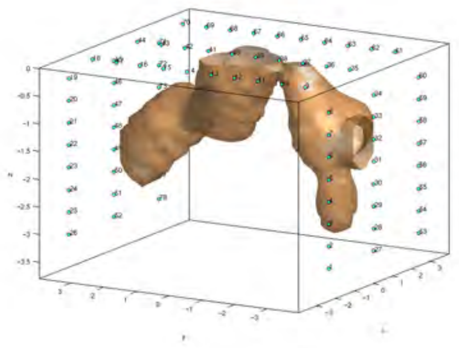
Original

Initial shape. Initial saturation = 1%

Results

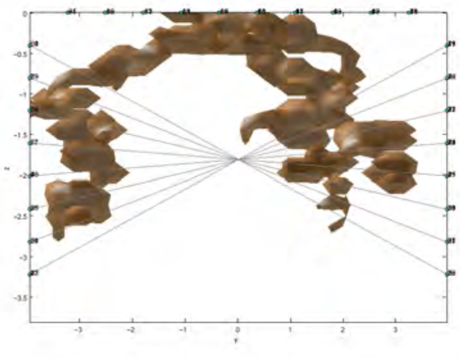


Original

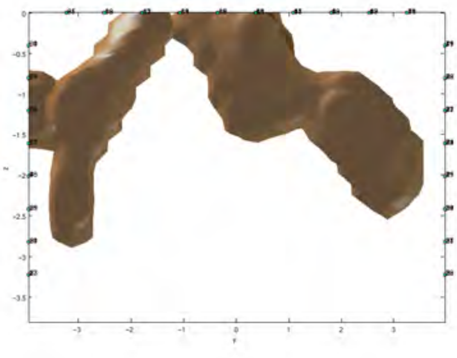


Final reconstruction, final saturation value= 2.92%

Results

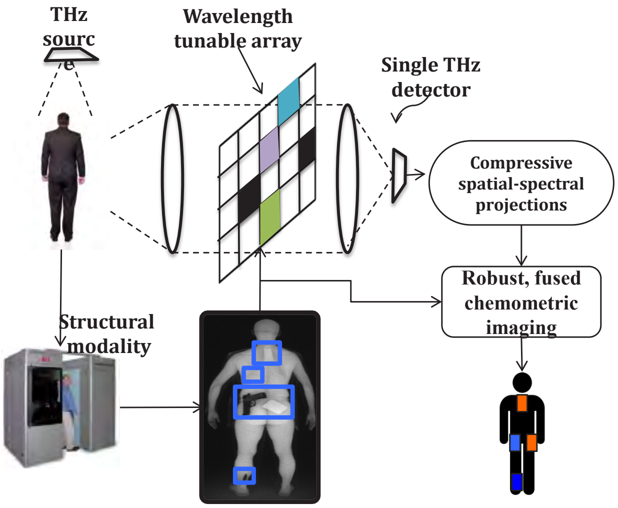


Original



Reconstruction side view

Security Application


THz source

Wavelength tunable array

Single THz detector

Compressive spatial-spectral projections

Robust, fused chemometric imaging

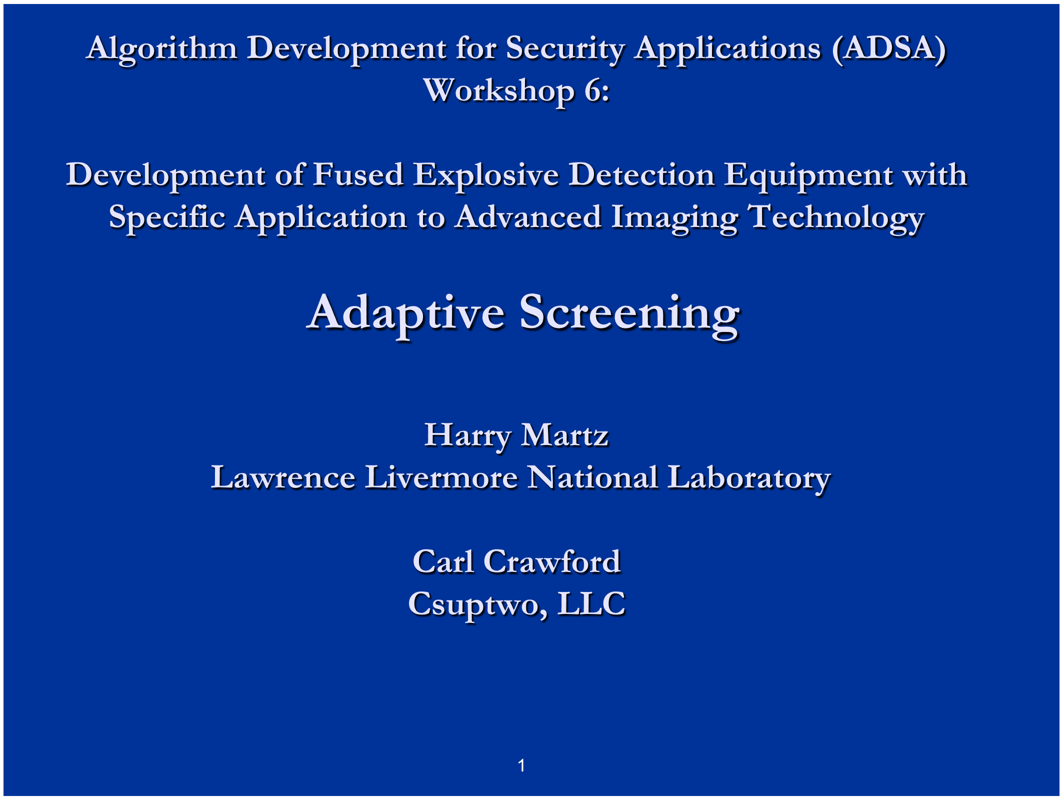
Structural modality

- Currently considering THz spectroscopy + structural modality(ies)
- Proposal under review at DHS involving team from Tufts (Miller, Tracey, Sonkulsale, Aeron) BC (Padilla), and Kaiserslautern (Rahm and Beigang)
- Characteristics
  - Tight integration of instruments and processing
  - Model based (physics sensor models and statistical/information theoretic property models)
  - Extensive experimental component

Conclusions

- Model based methods have much to offer for fusion
- Principled approach to many issues associated with multi-sensor data acquisition, processing, and analysis
- Physics-based models allow for joint design and optimization of sensors and processing
- Statistically-based models all for incorporation of prior information and exploitation of cross-modality correlations

16.18 Harry Martz: Adaptive screening (presentation and discussion)



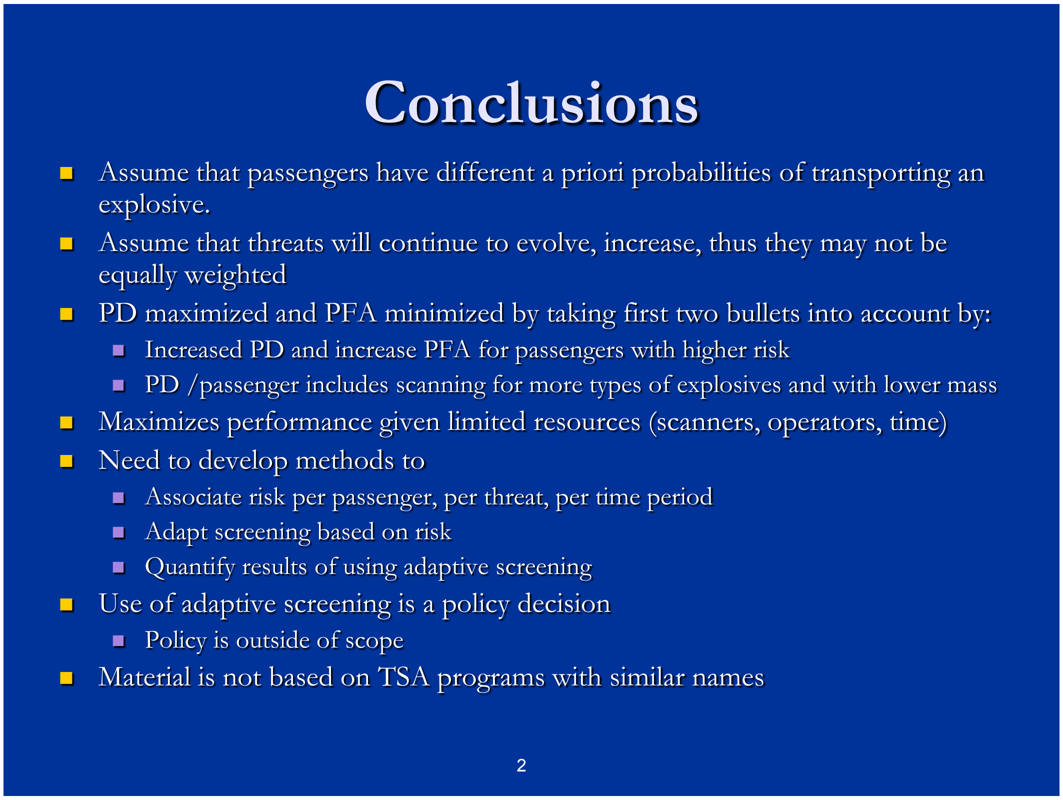
Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with Specific Application to Advanced Imaging Technology

Adaptive Screening

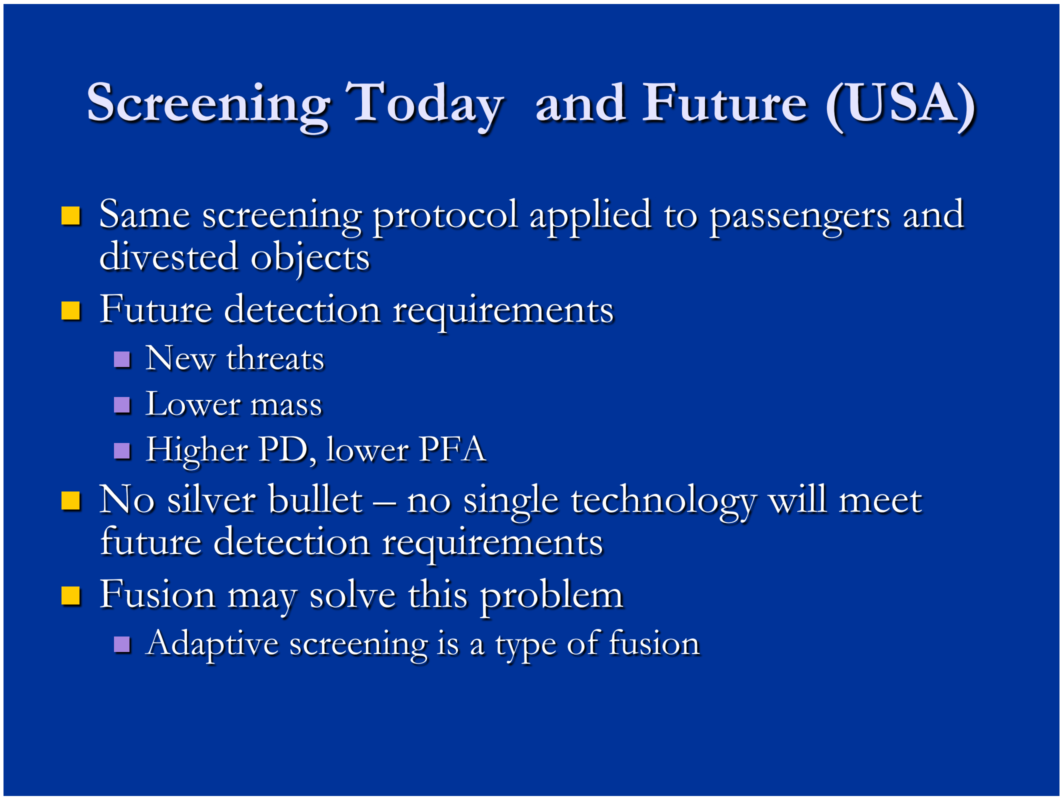
Harry Martz
Lawrence Livermore National Laboratory

Carl Crawford
Csuptwo, LLC



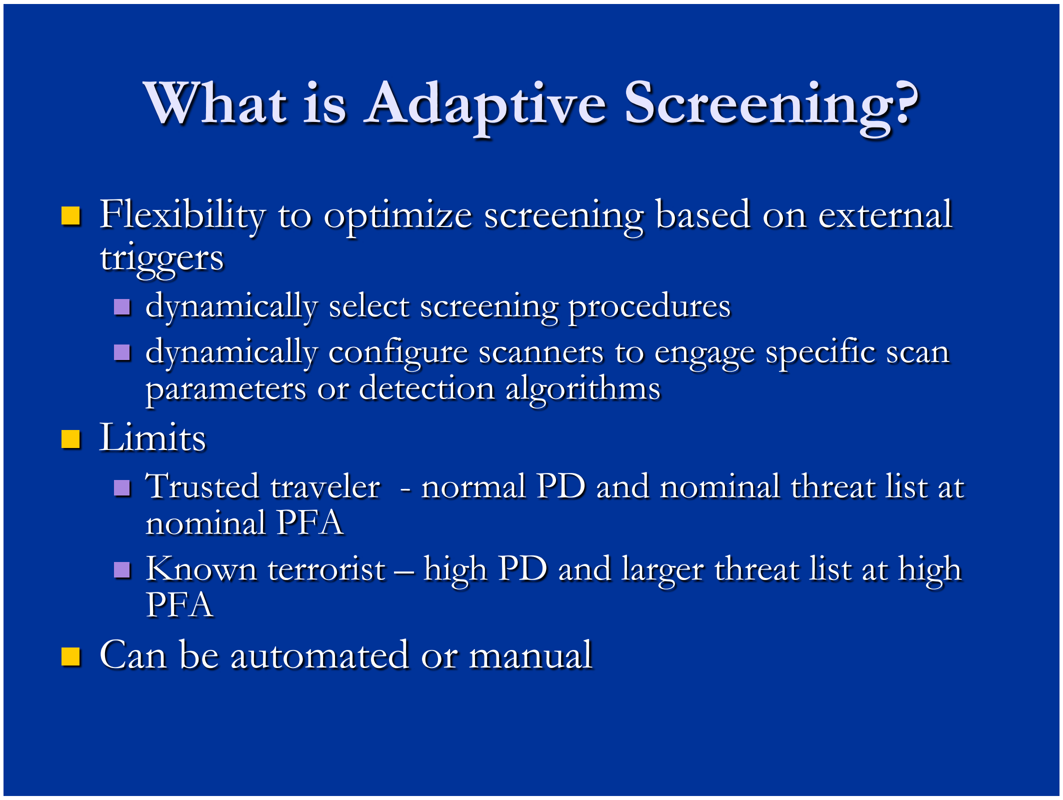
Conclusions

- Assume that passengers have different a priori probabilities of transporting an explosive.
- Assume that threats will continue to evolve, increase, thus they may not be equally weighted
- PD maximized and PFA minimized by taking first two bullets into account by:
  - Increased PD and increase PFA for passengers with higher risk
  - PD /passenger includes scanning for more types of explosives and with lower mass
- Maximizes performance given limited resources (scanners, operators, time)
- Need to develop methods to
  - Associate risk per passenger, per threat, per time period
  - Adapt screening based on risk
  - Quantify results of using adaptive screening
- Use of adaptive screening is a policy decision
  - Policy is outside of scope
- Material is not based on TSA programs with similar names



Screening Today and Future (USA)

- Same screening protocol applied to passengers and divested objects
- Future detection requirements
  - New threats
  - Lower mass
  - Higher PD, lower PFA
- No silver bullet – no single technology will meet future detection requirements
- Fusion may solve this problem
  - Adaptive screening is a type of fusion



What is Adaptive Screening?

- Flexibility to optimize screening based on external triggers
  - dynamically select screening procedures
  - dynamically configure scanners to engage specific scan parameters or detection algorithms
- Limits
  - Trusted traveler - normal PD and nominal threat list at nominal PFA
  - Known terrorist – high PD and larger threat list at high PFA
- Can be automated or manual

Examples

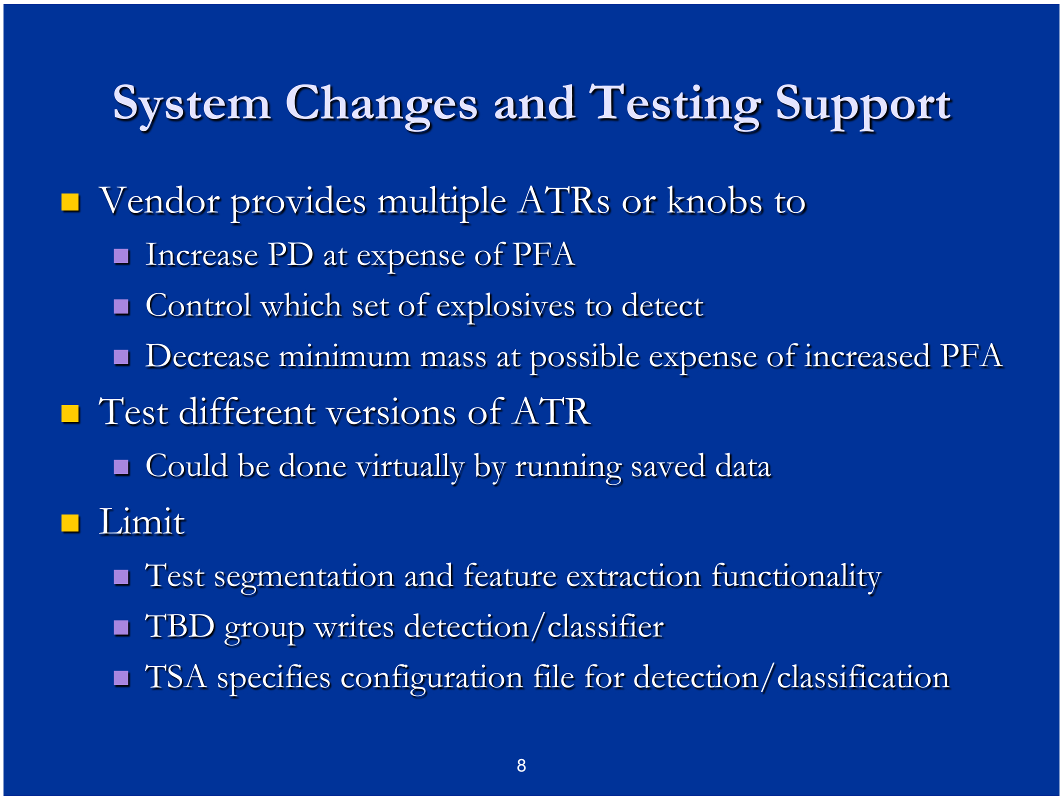
- Not Adaptive
  - All people and divested objects are treated the same way
- Adaptive
  - A scanner selects data acquisition parameters or detection algorithms based on external triggers.
  - Trusted traveler screening with nominal scrutiny
  - Selectees are screened with additional scrutiny.

Risk Association

- General threat level
- Intelligence on
  - Specific people
  - Threat
- Profiling
- Human observation (BDO)
- Biometrics
- Anomaly detection

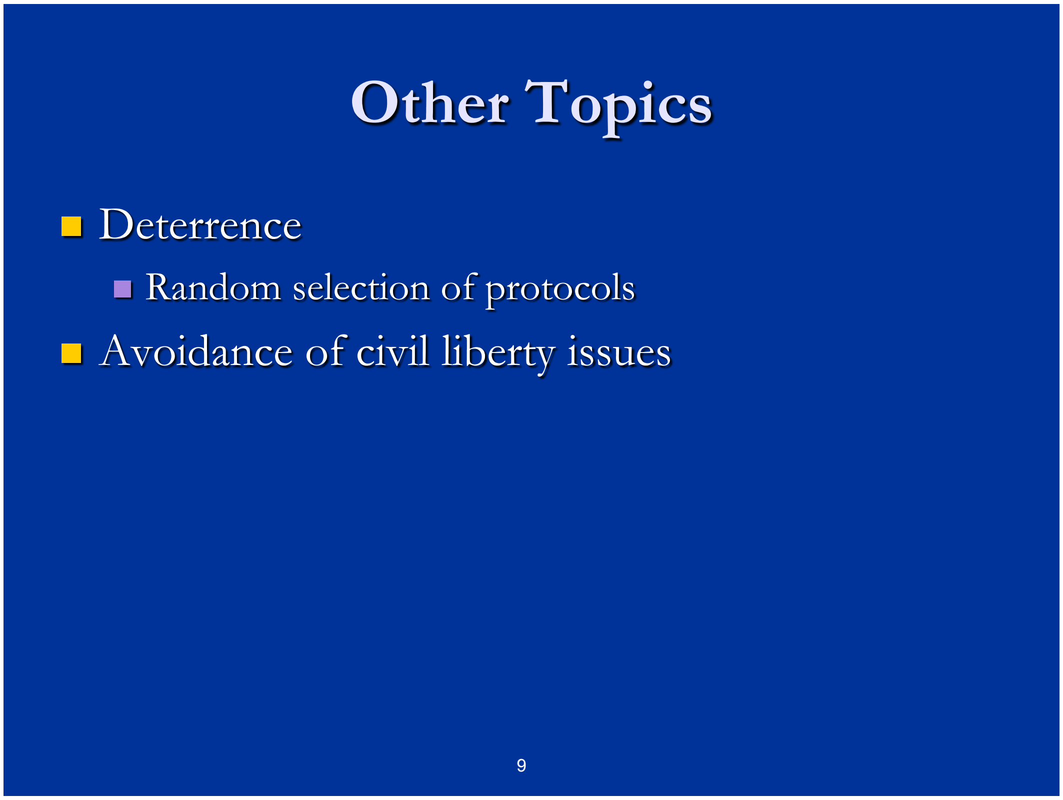
Developmental Needs

- Methods to
  - Associate risk
  - Communicate risk
  - Use risk
- Prove use of risk is important
  - Affect policy decisions



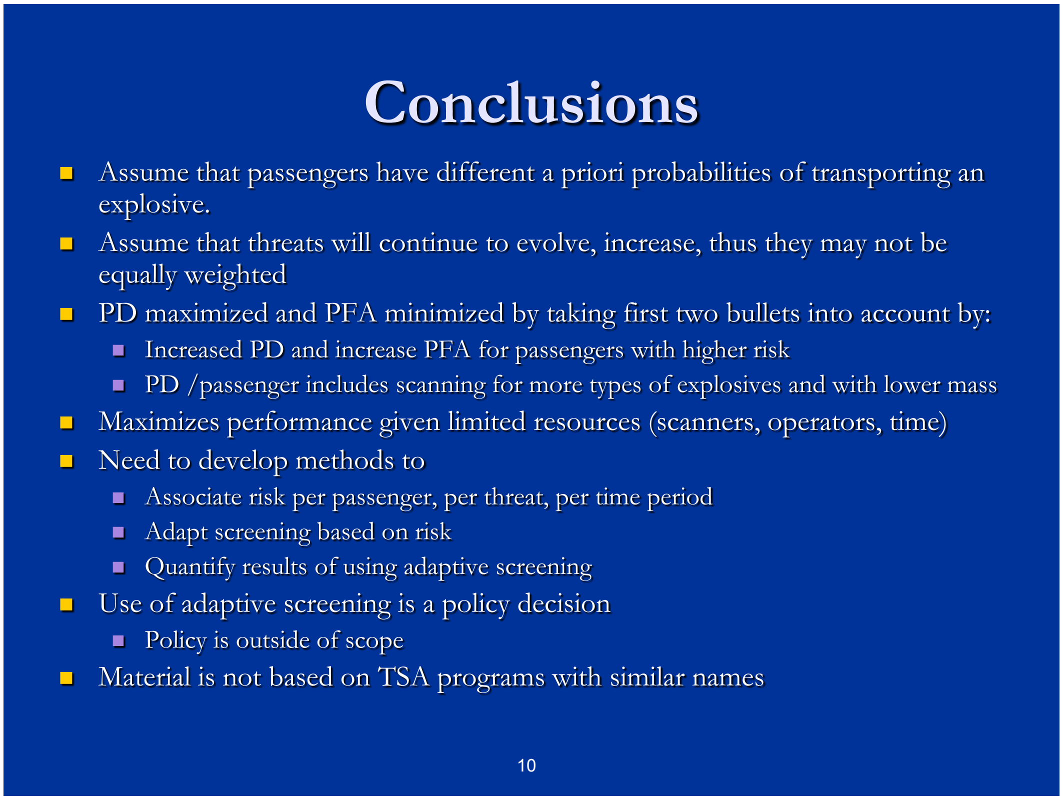
System Changes and Testing Support

- Vendor provides multiple ATRs or knobs to
  - Increase PD at expense of PFA
  - Control which set of explosives to detect
  - Decrease minimum mass at possible expense of increased PFA
- Test different versions of ATR
  - Could be done virtually by running saved data
- Limit
  - Test segmentation and feature extraction functionality
  - TBD group writes detection/classifier
  - TSA specifies configuration file for detection/classification



Other Topics

- Deterrence
  - Random selection of protocols
- Avoidance of civil liberty issues



Conclusions

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  - Quantify results of using adaptive screening
- Use of adaptive screening is a policy decision
  - Policy is outside of scope
- Material is not based on TSA programs with similar names

16.19 Jeremy Wolfe: How might technology improve human detection importance?

What does Carl want me to talk about?

?

Jeremy M Wolfe
Visual Attention Lab
Brigham and Women's Hospital
Harvard Medical School

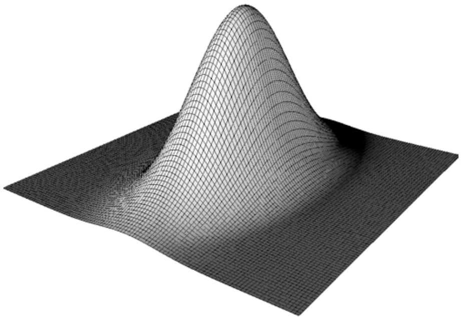
Five conclusions

1. Humans are "fusion" engines (we call it "cue combination". Very rule-governed)
2. Humans are really good at some tasks (e.g. contour completion, rapid object identification)
3. Humans are really bad at some tasks (e.g. profound capacity limits, Bayes gone bad)
4. Expert behavior is worth studying … and possibly modifying
5. You really want to work with researchers who know about the human angle (and I can help you find them…..*Ellenbogen's cautionary tale notwithstanding*)

1. Fusion (Cue Combination)

Awesome sensor fusion

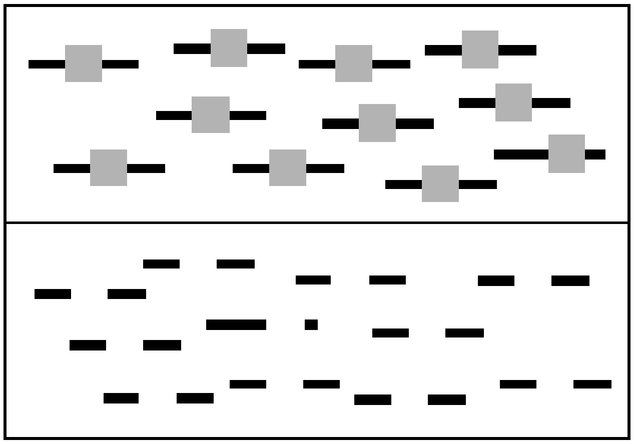
Cue Combination in human vision



Multiple cues to
bump height & shape
Lighting
Texture
Maybe touch
etc

Standard cue combination might be a weighted sum

Cue Combination in human vision



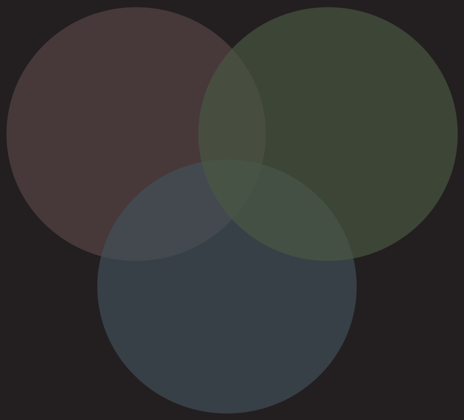
Find the tiny line segment

Sometimes one signal trumps or vetoes the others

Cue Combination in human vision

Sometimes cue combination produces an emergent property like stereoscopic depth

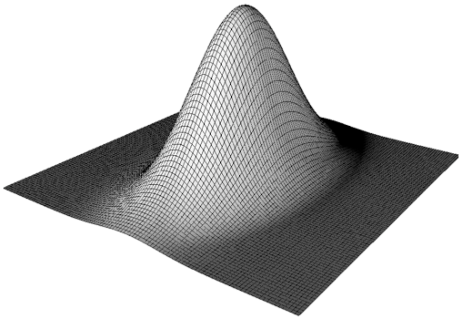
Cue Combination in human vision
The role of the observer



Peter Tse’s Demo

Humans are good

Remember this slide?



Multiple cues to bump height & shape
Lighting
Texture
Maybe touch
etc

shape

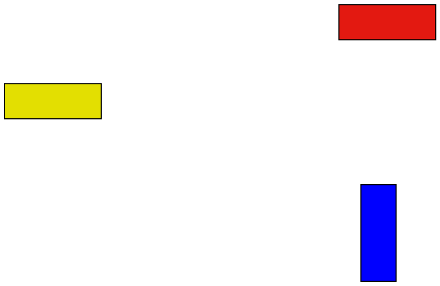
Humans are really good at inferring contours

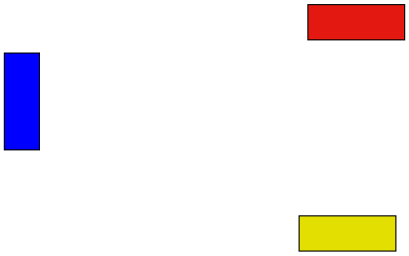
Look for the chimp

Humans can do recognition at high speed

When people fail

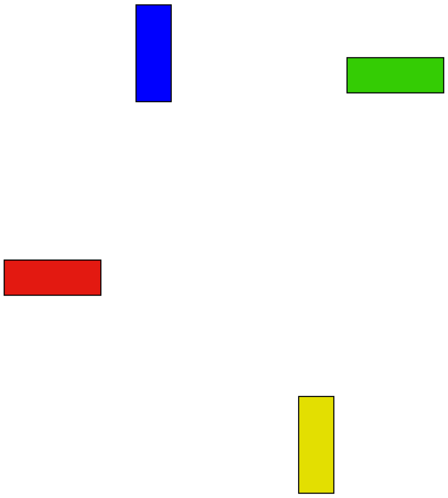
Remember this

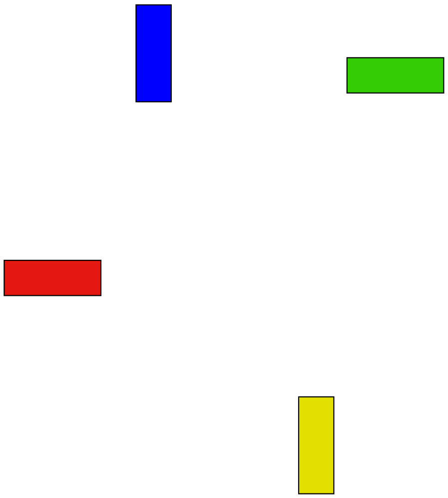




Any change?

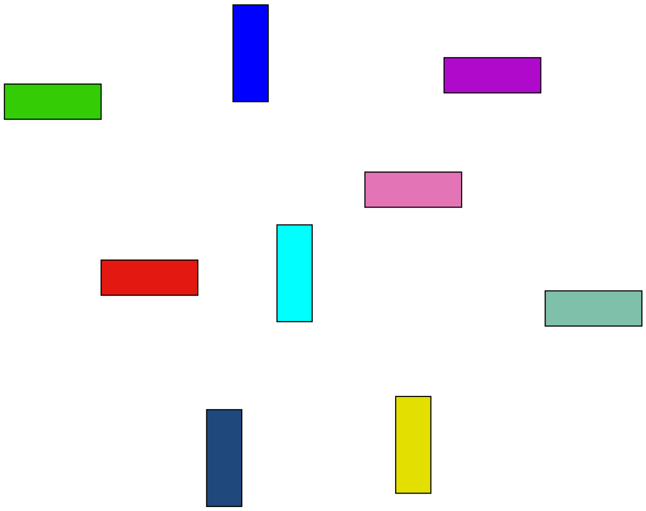
Remember this

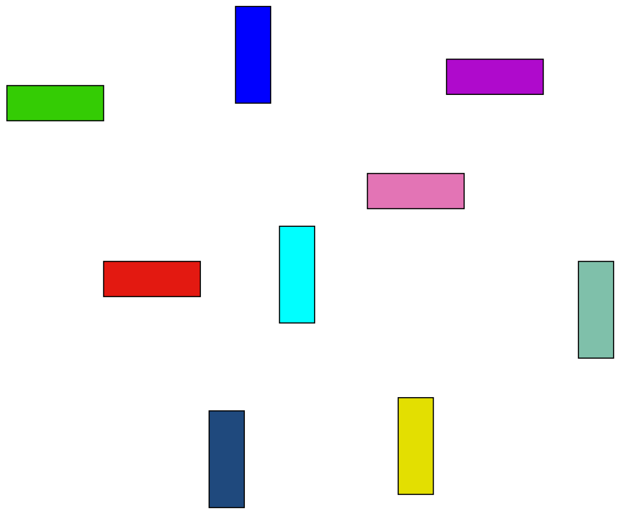




Any change?

Remember this





Any change?

Visual working memory has a capacity limit of ~4

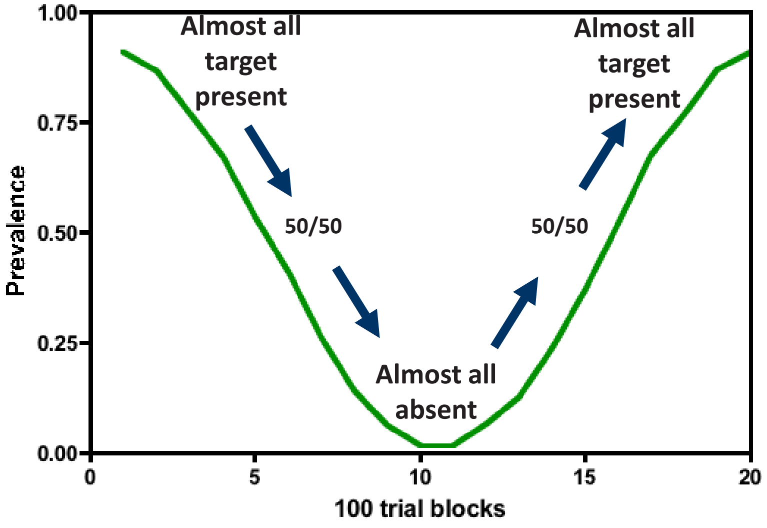
4 what?

Objects?

Features?

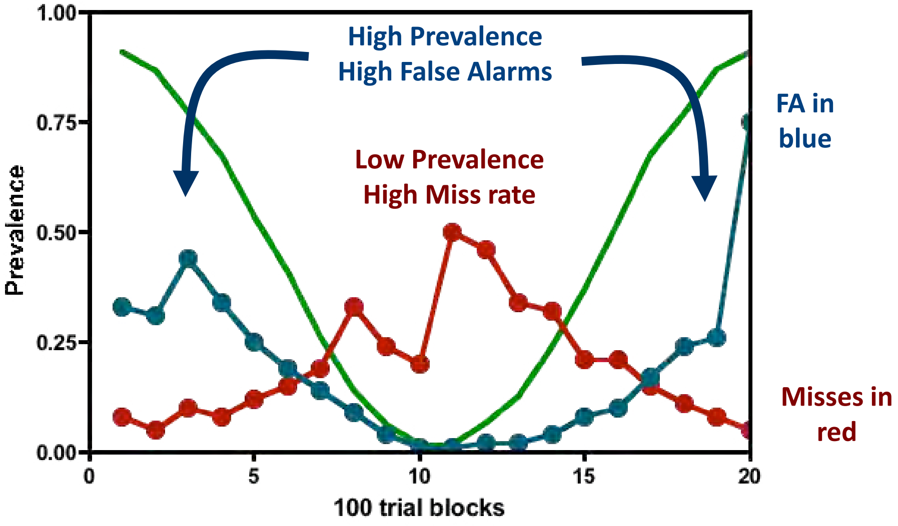
Humans respond to variables in ways that you may not want

Look for the same target at different prevalence



The errors trade off

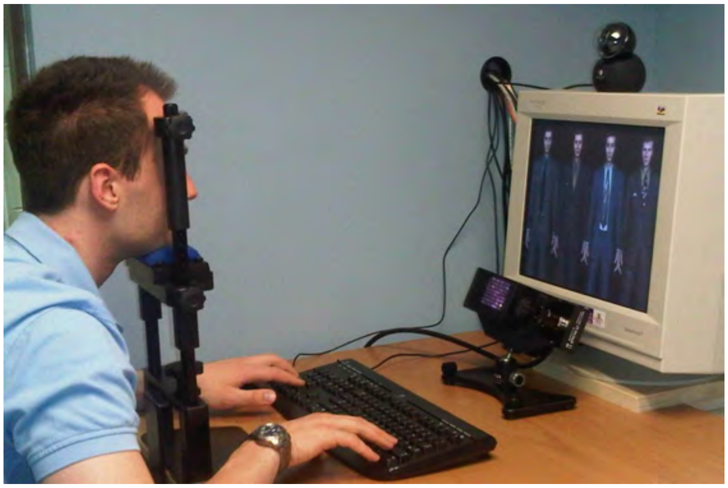
(remember, the stimuli are not changing)



Many other such variables

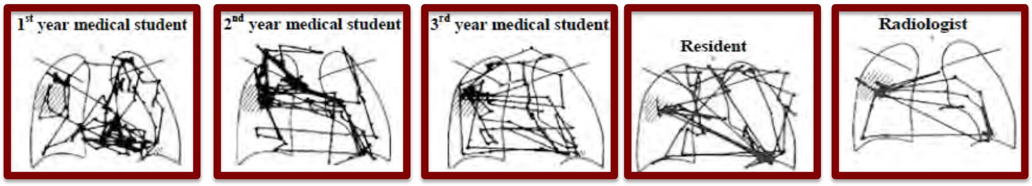
1. Reward structure
2. Fatigue
3. Circadian phase
4. Bias
5. Individual differences
6. etc

3. Understanding expert behavior

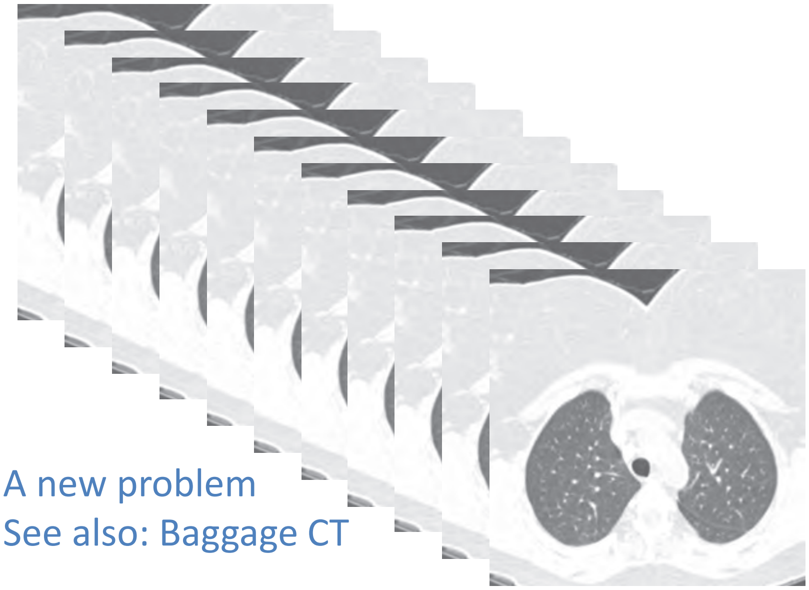


Eye tracking is a good example

The classic eye tracking result on the development of expertise



Eye movements in 3d volumes of images

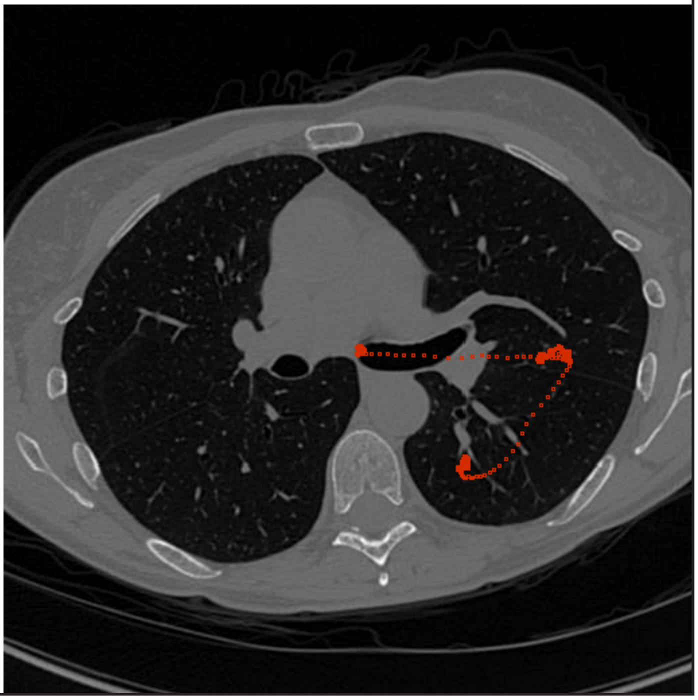


A new problem
See also: Baggage CT

What the behavior looks like

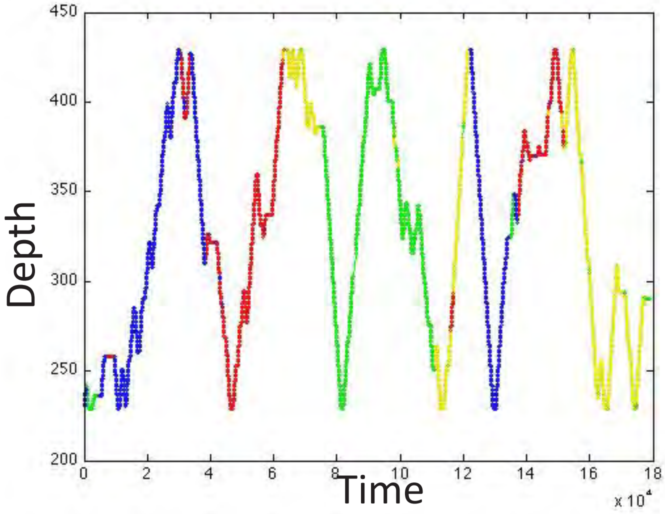
Red traces show eye movements in X & Y

We are also tracking the slice as a measure of Z position.

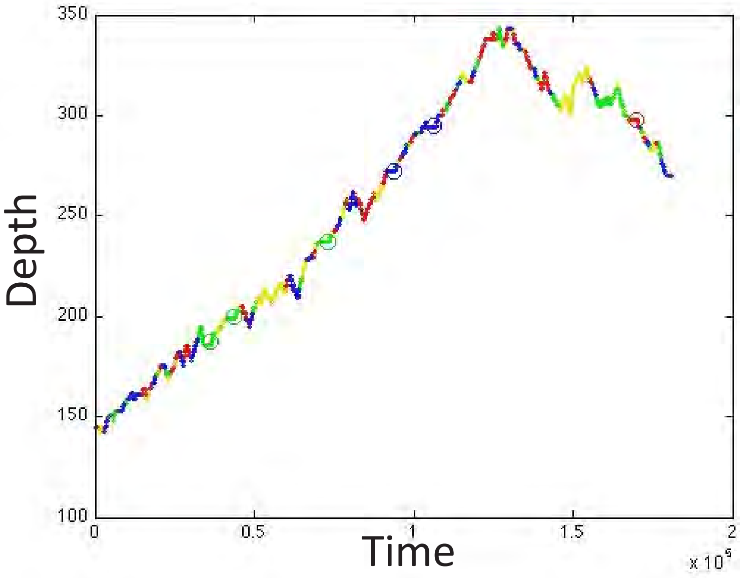


Let's color code the quadrants

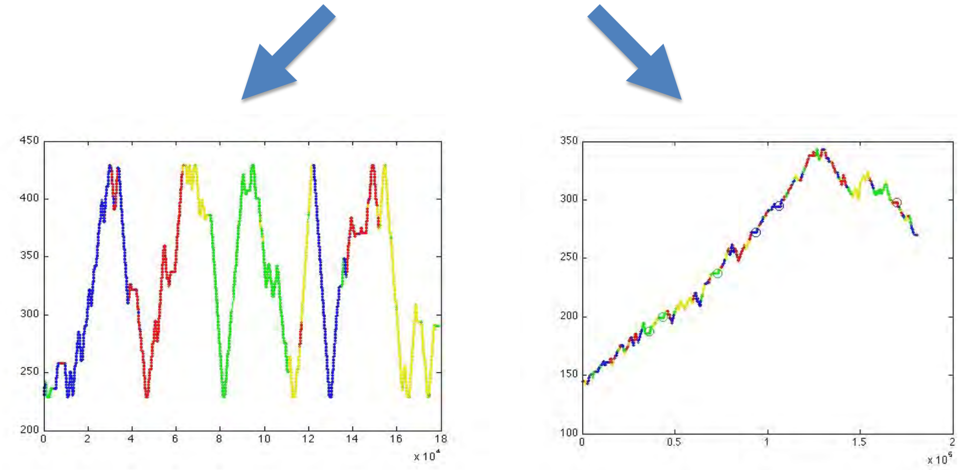
Here is Z with quadrants in XY color-coded for one expert radiologist



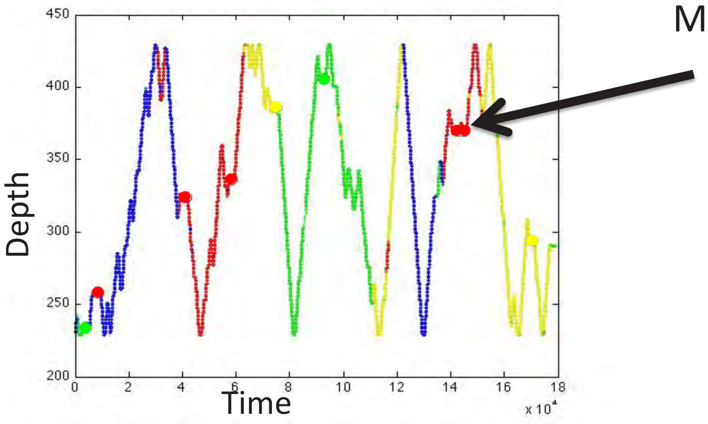
But here is another expert



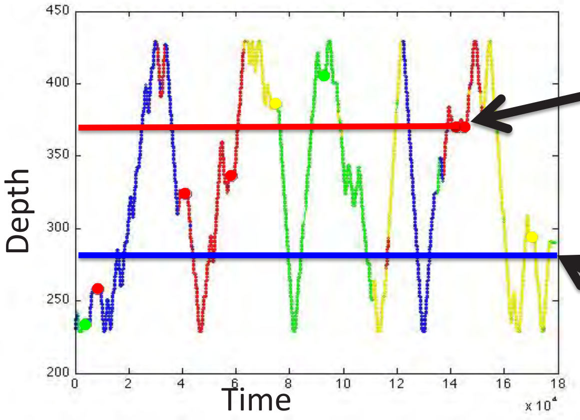
Drillers & Scanners



Does it matter?



Mark when a
target is
found

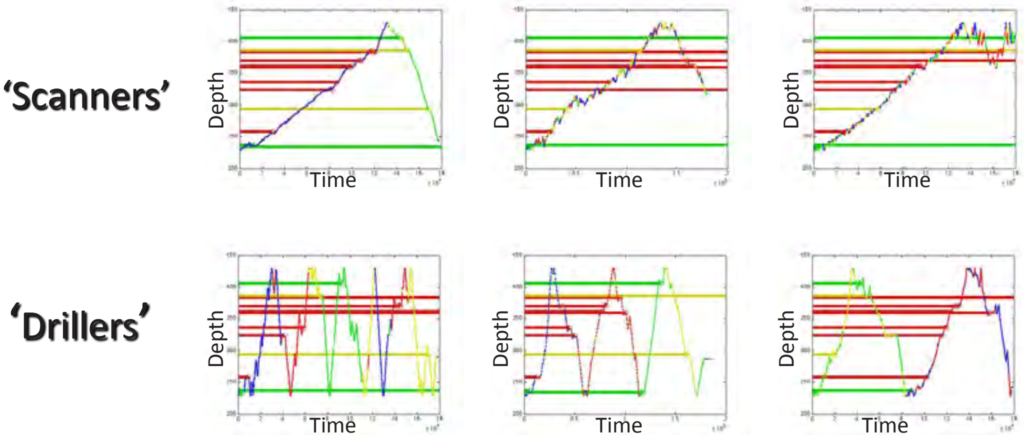


Use a line to show how long a target survives undetected

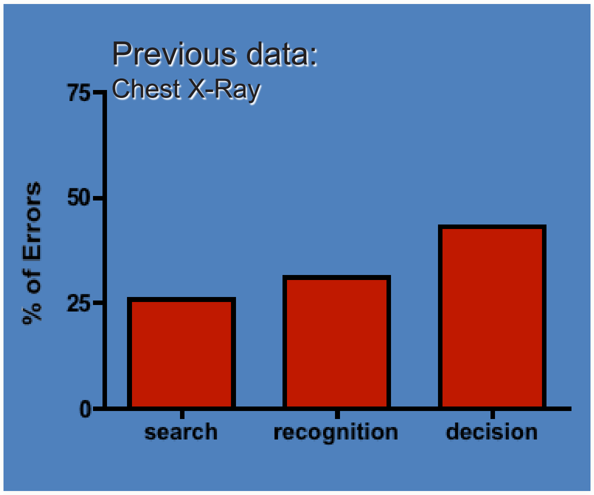
A line that makes it all the way across shows a target that was never found

---

6 experts

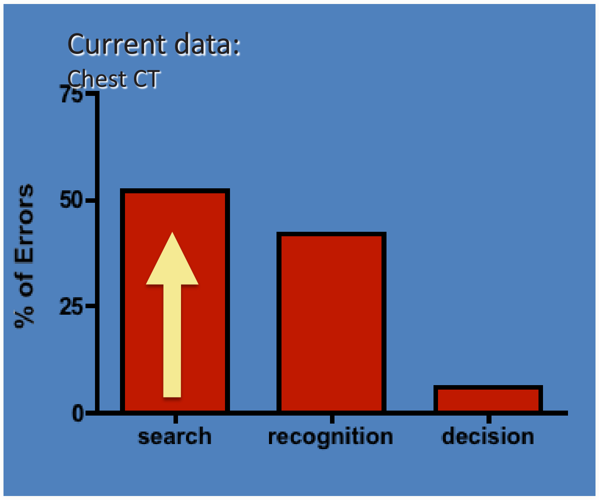


The classic 2D data



Many more search errors

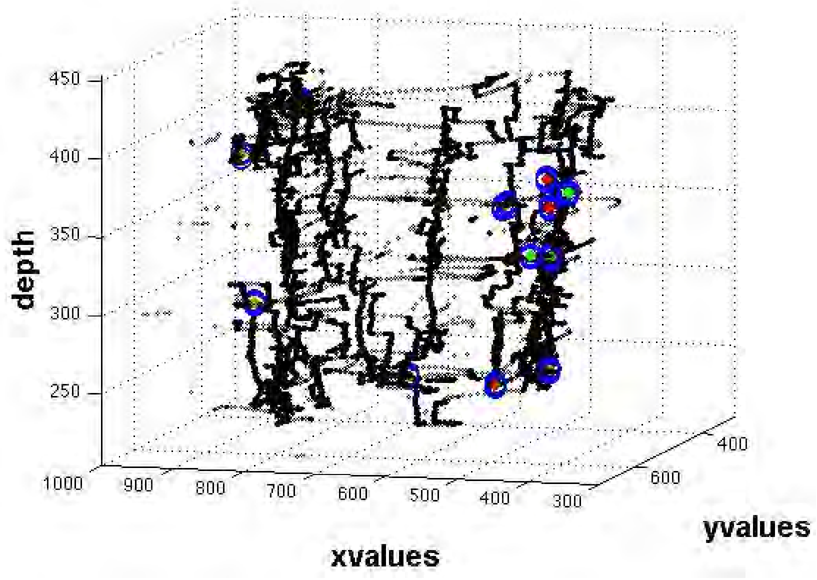
The 3D data



Why do search errors go up?

Many more search errors

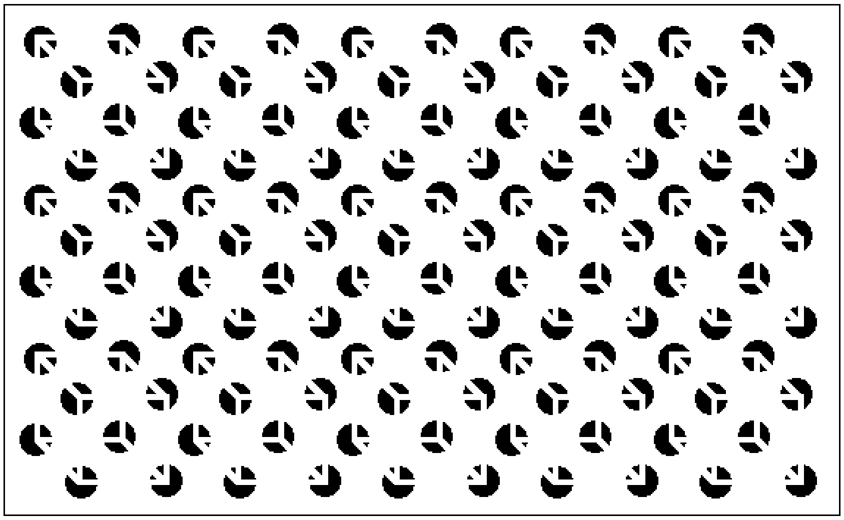
Might be useful to feedback eye movements to the observer.



Part 5: A research strategy

1. Bring in a perception / behavioral science person
2. Ask the right questions
3. Abstract those questions so that they can be studied in NON-experts
4. Transition the key findings into studies with experts.
5. Basic science gets into The Literature
6. Improvements get into design.

Thanks



If you want to follow-up
wolfe@search.bwh.harvard.edu

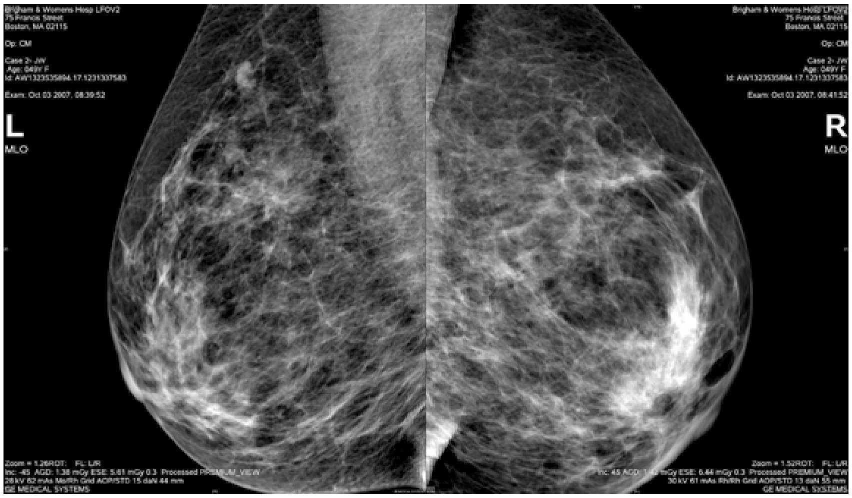
Part 3: A Novel Signal
Experts believe in the Force

Can radiologist beat chance in a glance?
We ran an experiment

Look here

Flash a mammogram for 250 msec

Can radiologist beat chance in a glance?
We ran an experiment

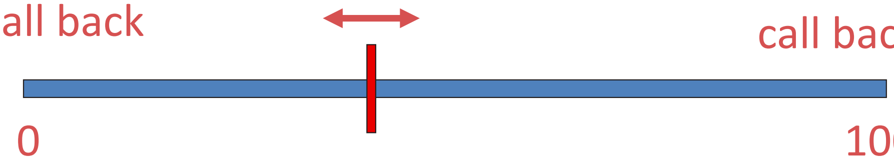


Flash a mammogram for 250 msec

Can radiologist beat chance in a glance?
We ran an experiment

Flash a mammogram for 250 msec

Would you call back this patient?



YES
Call back

No
Don't
call back

0

100

Use a 100-pt rating scale

We tested 40+ radiologists at the *Society for Breast Imaging*

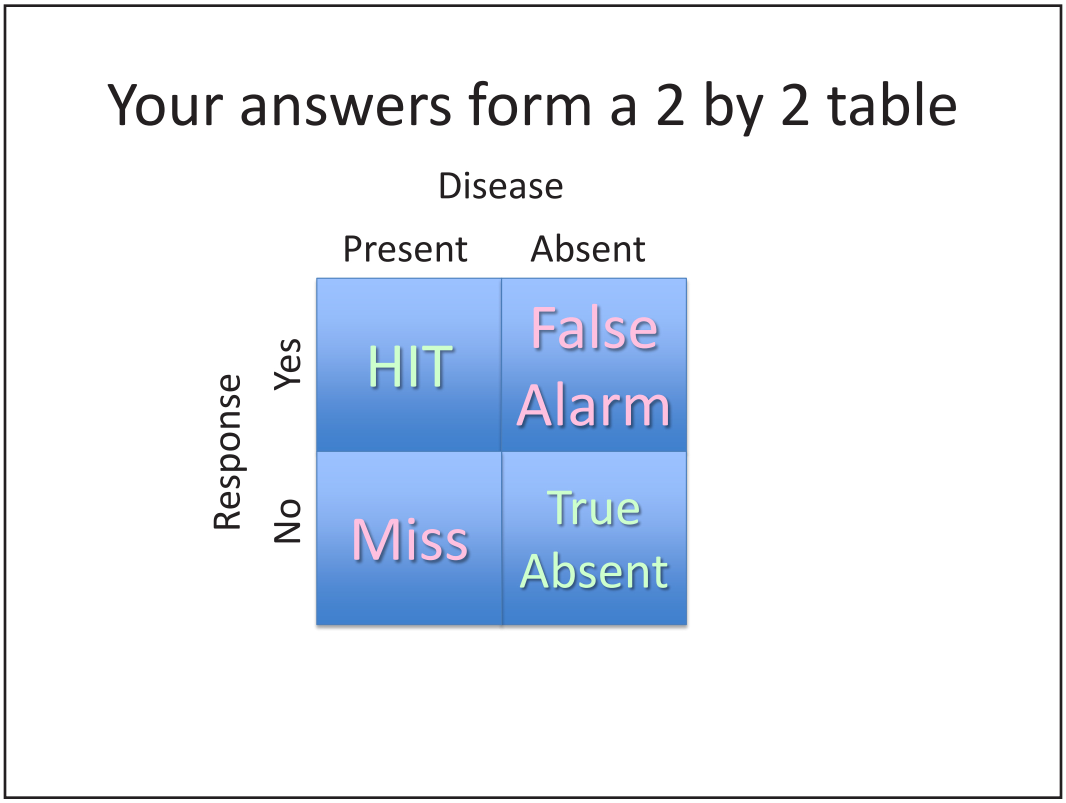
"We" =

Michelle
Greene
MIT

Karla
Evans
BWH

Dianne
Georgian-Smith
BWH

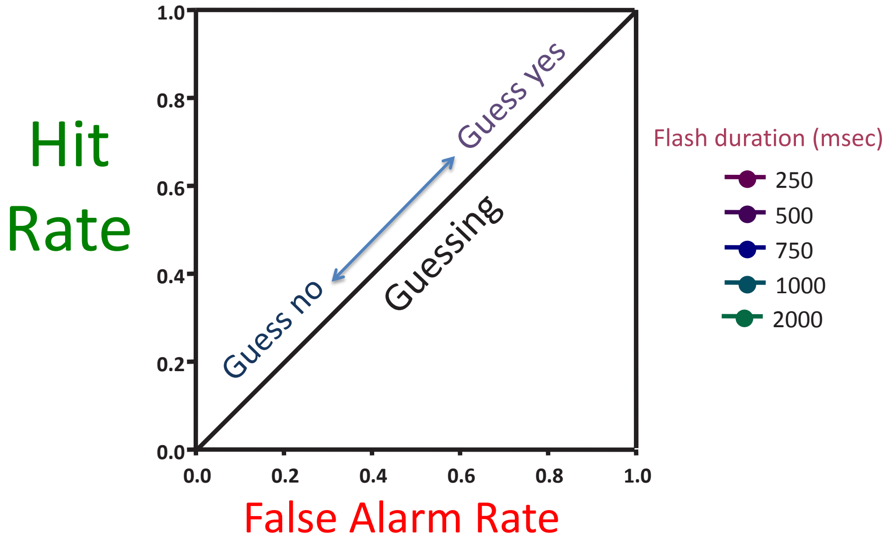
Robyn
Birdwell
BWH



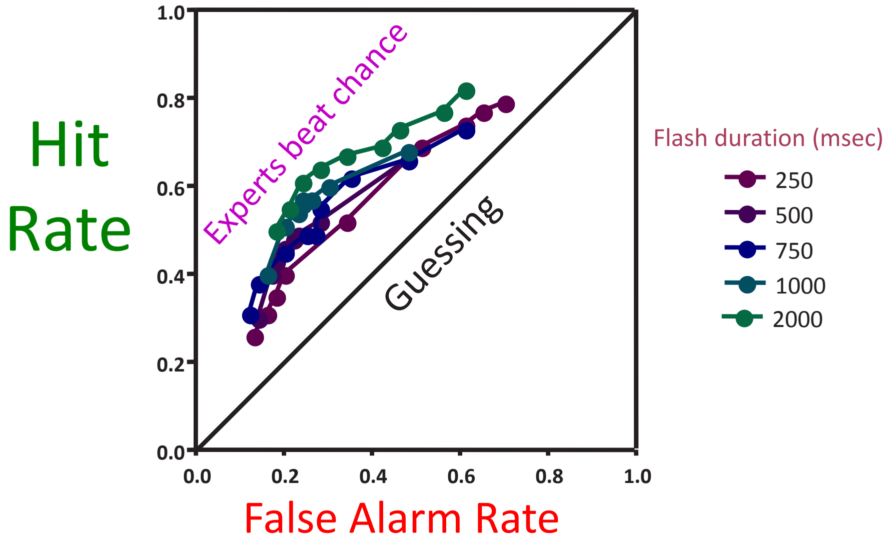
Your answers form a 2 by 2 table

		Disease	
		Present	Absent
Response	Yes	HIT	False Alarm
	No	Miss	True Absent

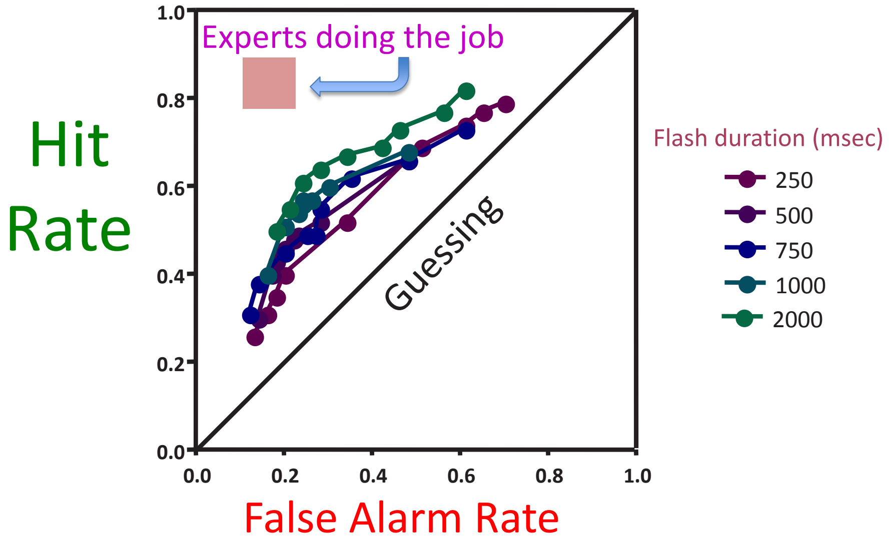
Here is how we are going to plot the data



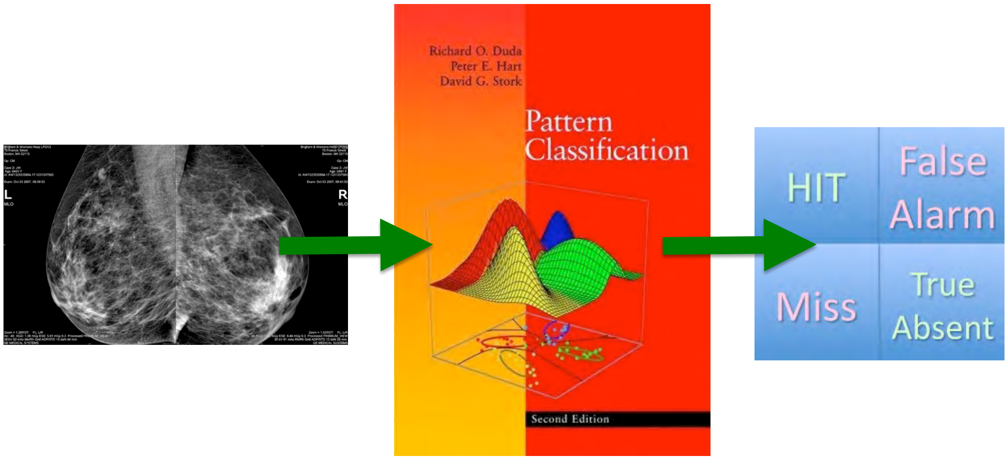
And here are the results



No one is suggesting that your radiologist should make a decision in a quarter second!

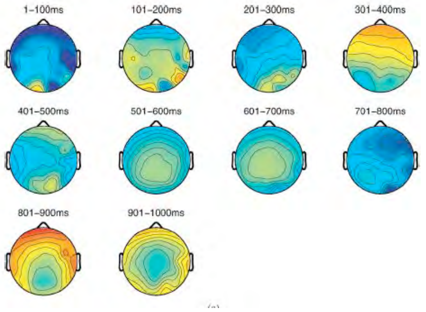


How do we exploit this signal?



Answer 1: Build a pattern classifier

How do we exploit this signal?



Answer 2: Brain based image triage

See Paul Sajda (Columbia),

Part 4: Do we have time for a little magic?

http://www.youtube.com/watch?v=2WZVlQNwF0E&feature=related

APOLLO ROBBINS

*an **artful** manipulator of awareness.*
Forbes

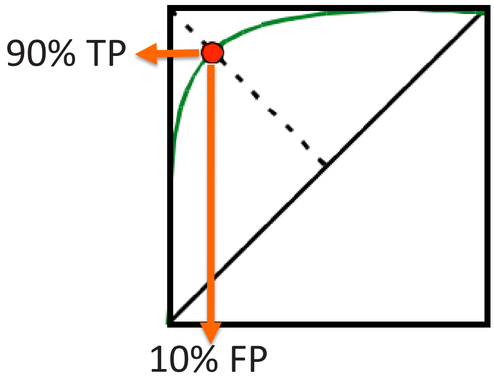
THE GENTLEMAN THIEF
ENTERTAINER • SPEAKER • CONSULTANT

For booking information, please contact your Event Specialist.

Why is this interesting?

Part 4: Do we have time for a little magic?

The Problem



When good CAD meets low prevalence, the marks are mostly false positives

AND

Experts don't like advice that is mostly wrong.

Suppose you reverse-engineered this

Sleight of CAD?

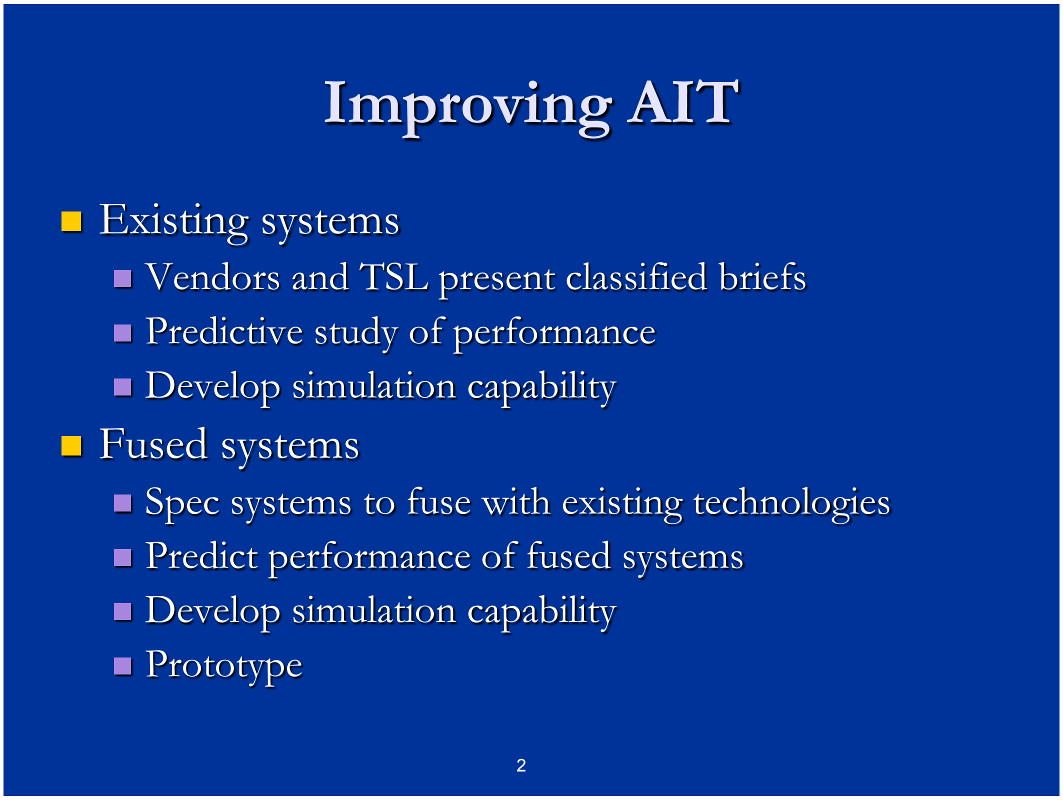
16.20 Harry Martz: Next Steps

Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with Specific Application to Advanced Imaging Technology

Next Steps

Harry Martz
Lawrence Livermore National Laboratory



Improving AIT

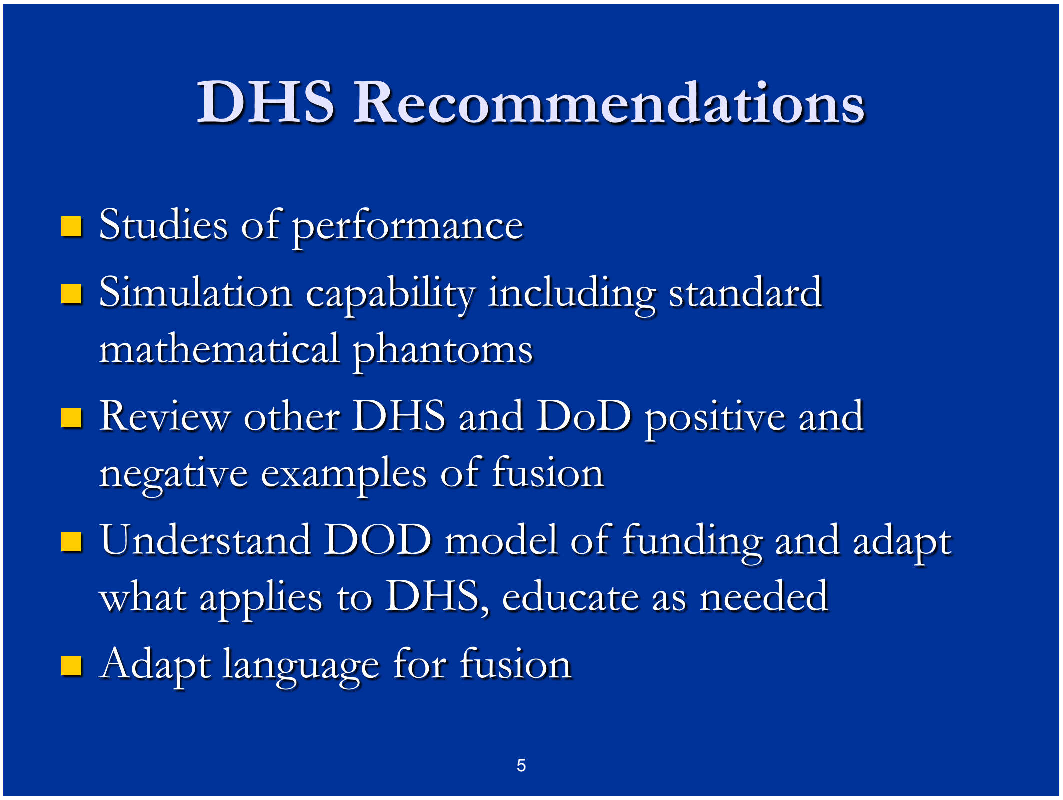
- Existing systems
  - Vendors and TSL present classified briefs
  - Predictive study of performance
  - Develop simulation capability
- Fused systems
  - Spec systems to fuse with existing technologies
  - Predict performance of fused systems
  - Develop simulation capability
  - Prototype

MMW Investigations

- Optimize frequency
- Investigate polarization
- Advanced reconstruction
- Depth info to ATR
- Increase solid angle
- New/more sensors for specific threats and locations
- Fuse with other technologies

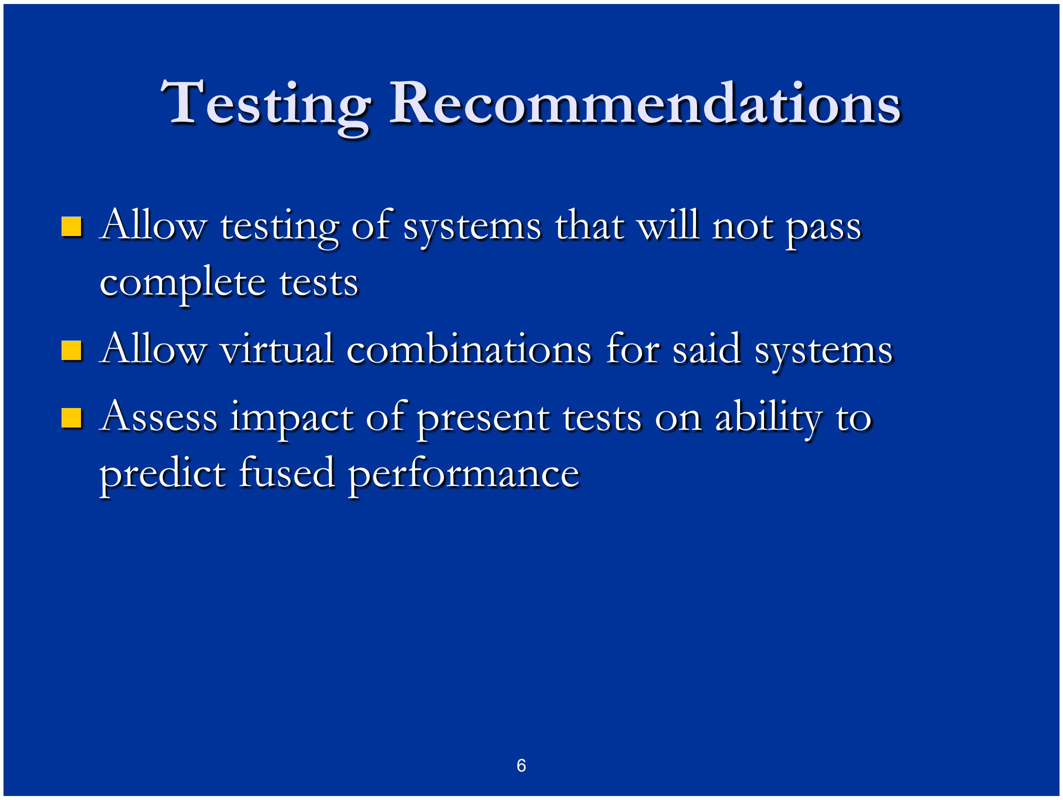
XBS Investigations

- Range finder
- Fractionate dose for more views
- Anatomical subtractions
- Use transmission information
- Fuse with other methods



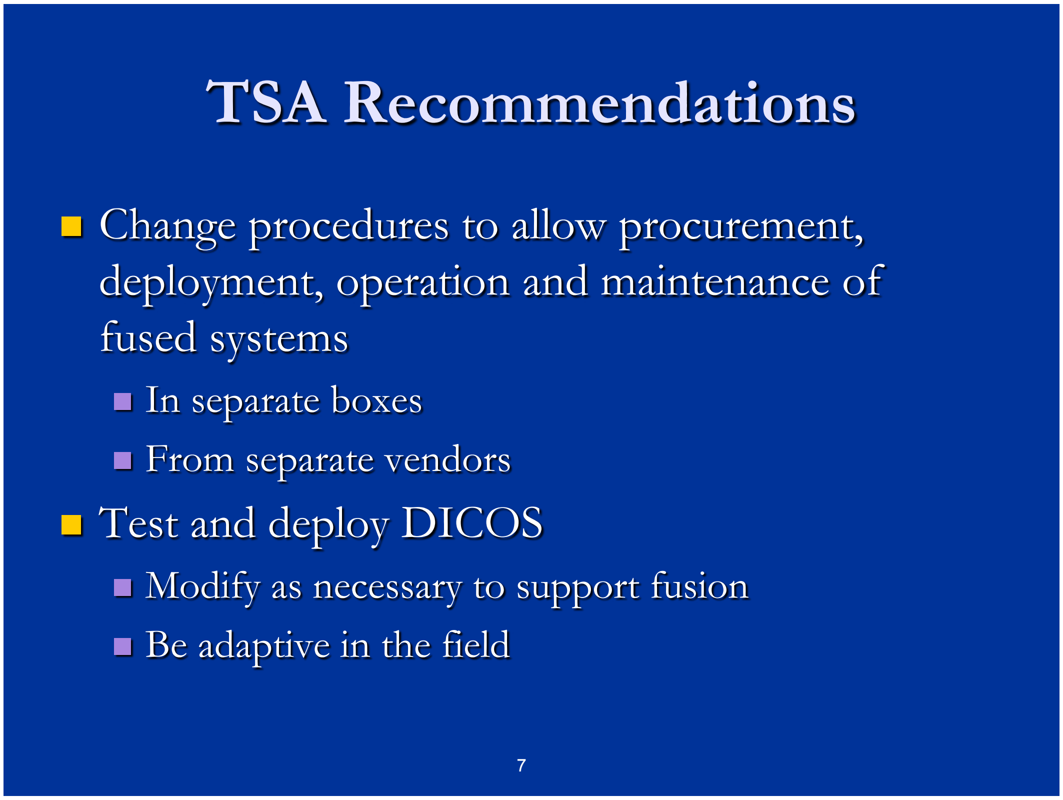
DHS Recommendations

- Studies of performance
- Simulation capability including standard mathematical phantoms
- Review other DHS and DoD positive and negative examples of fusion
- Understand DOD model of funding and adapt what applies to DHS, educate as needed
- Adapt language for fusion



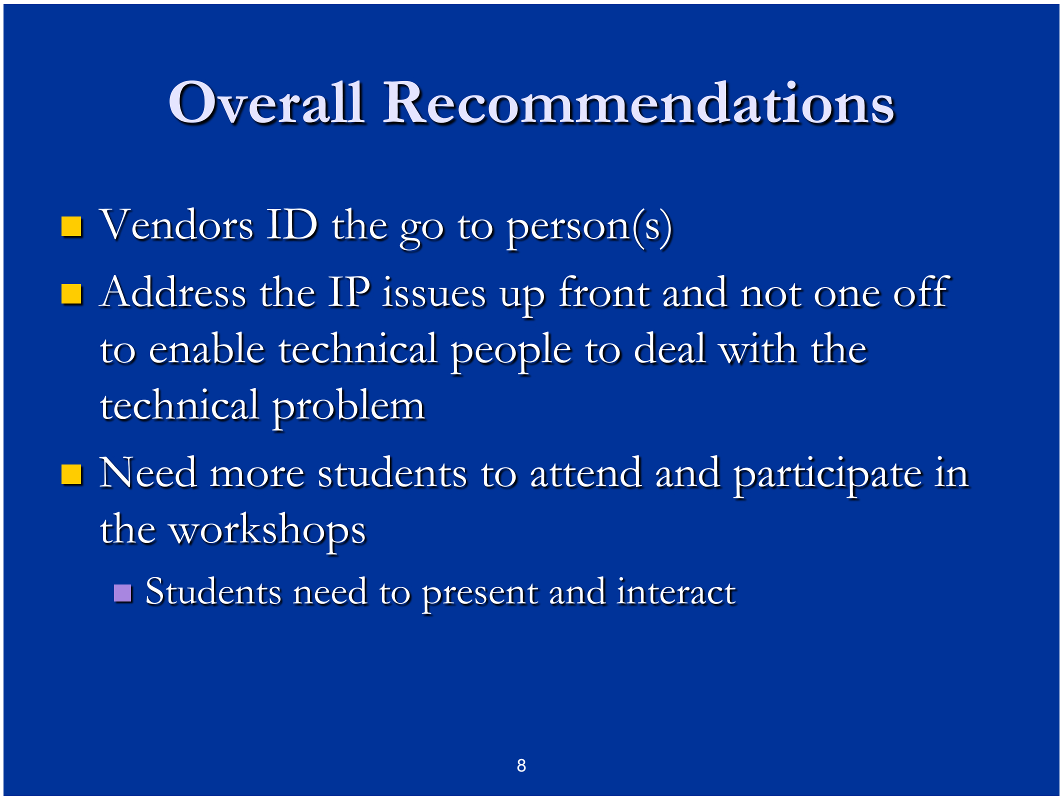
Testing Recommendations

- Allow testing of systems that will not pass complete tests
- Allow virtual combinations for said systems
- Assess impact of present tests on ability to predict fused performance



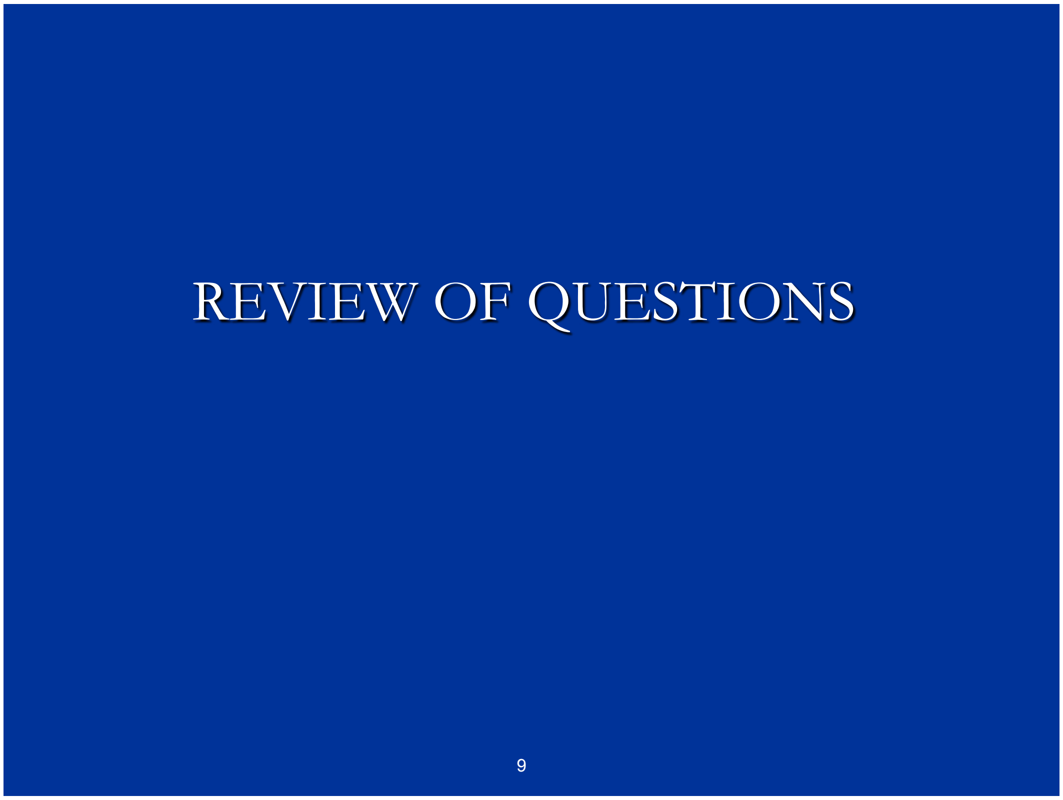
TSA Recommendations

- Change procedures to allow procurement, deployment, operation and maintenance of fused systems
  - In separate boxes
  - From separate vendors
- Test and deploy DICOS
  - Modify as necessary to support fusion
  - Be adaptive in the field

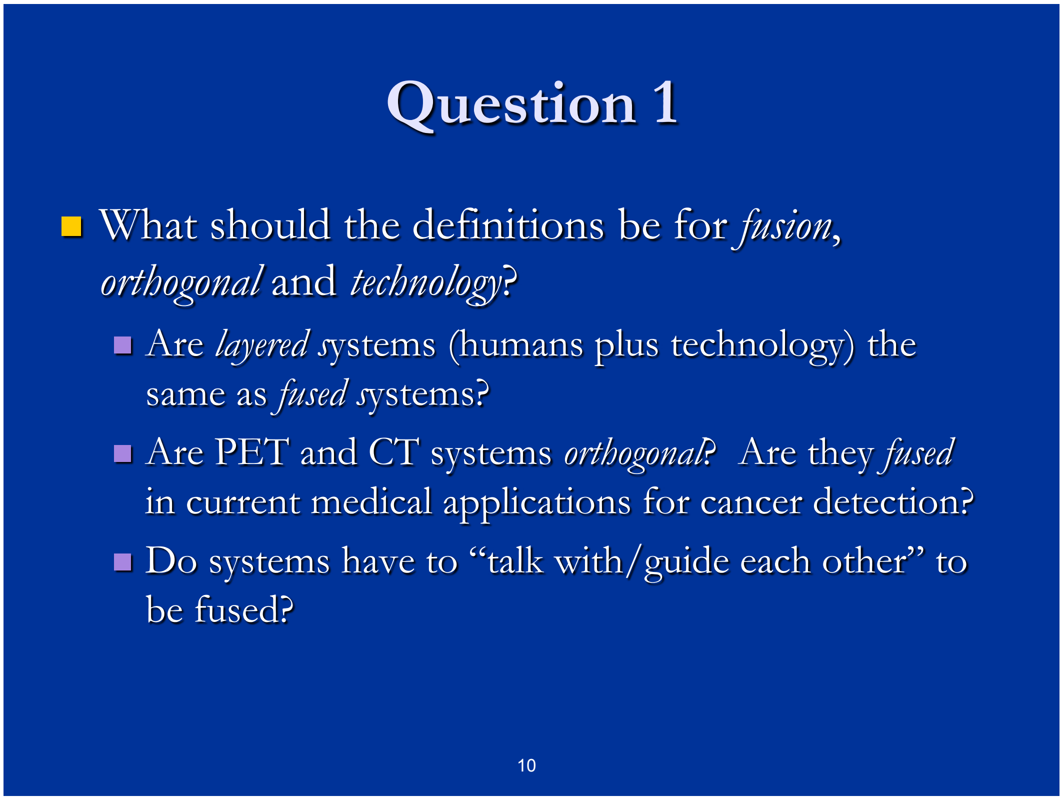


Overall Recommendations

- Vendors ID the go to person(s)
- Address the IP issues up front and not one off to enable technical people to deal with the technical problem
- Need more students to attend and participate in the workshops
  - Students need to present and interact

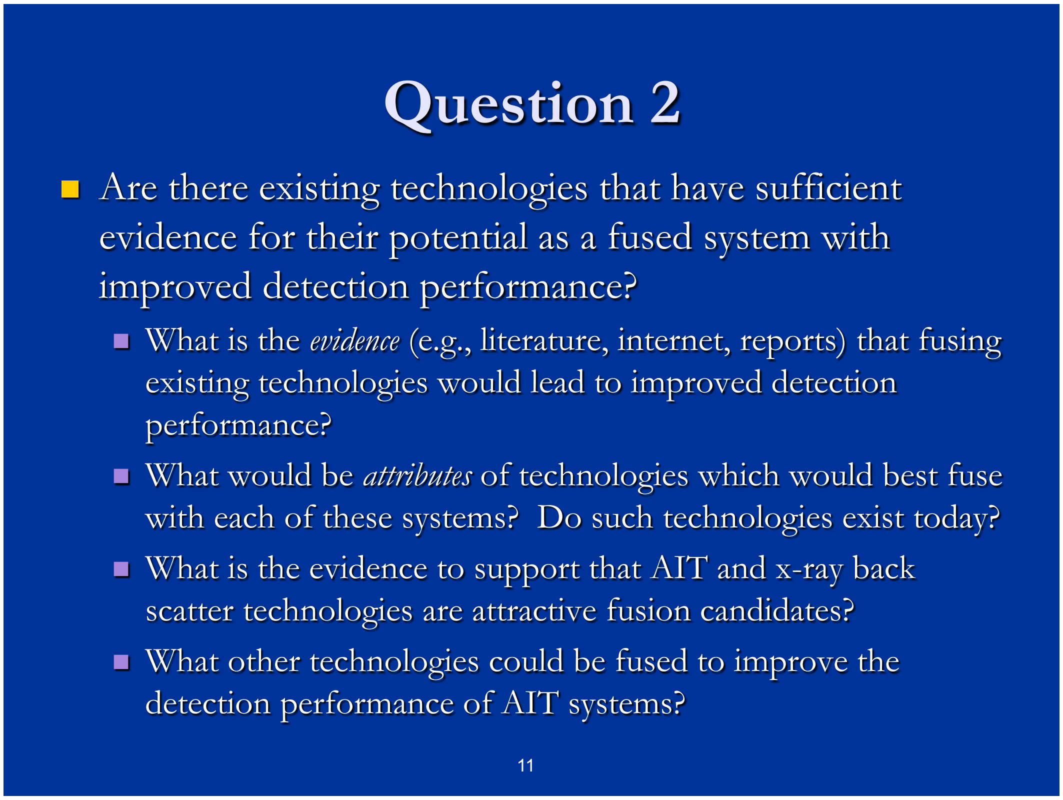


REVIEW OF QUESTIONS



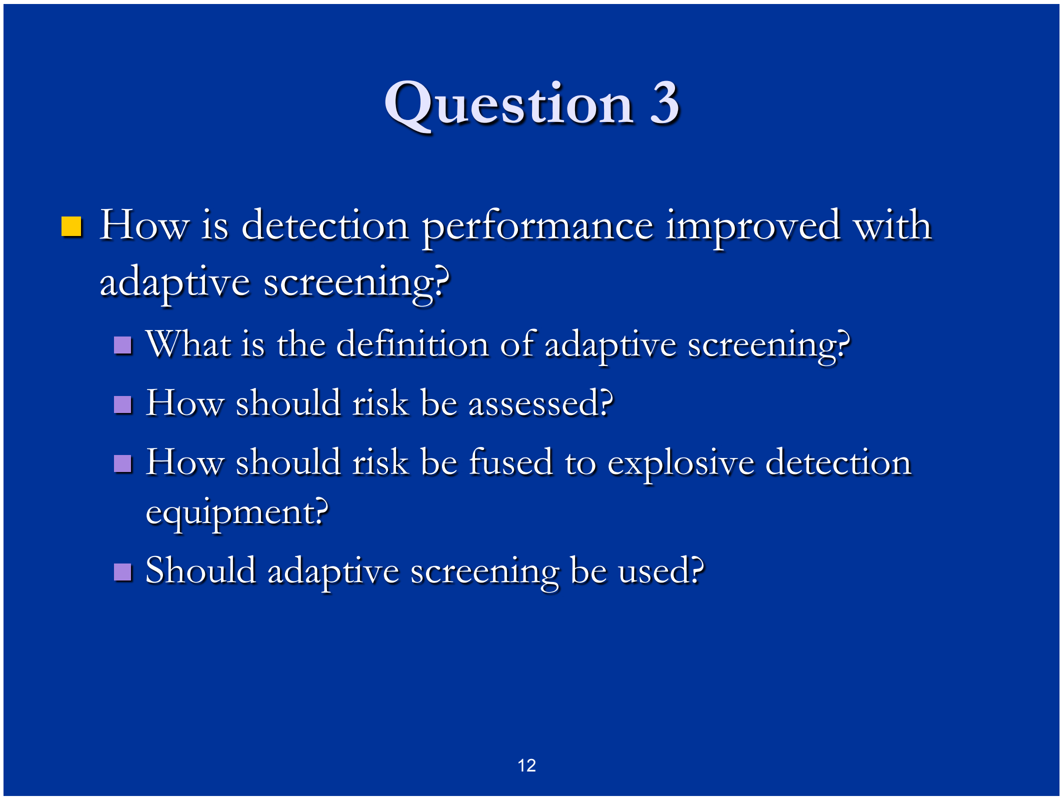
Question 1

- What should the definitions be for *fusion*, *orthogonal* and *technology*?
  - Are *layered* systems (humans plus technology) the same as *fused* systems?
  - Are PET and CT systems *orthogonal*? Are they *fused* in current medical applications for cancer detection?
  - Do systems have to "talk with/guide each other" to be fused?



Question 2

- Are there existing technologies that have sufficient evidence for their potential as a fused system with improved detection performance?
  - What is the *evidence* (e.g., literature, internet, reports) that fusing existing technologies would lead to improved detection performance?
  - What would be *attributes* of technologies which would best fuse with each of these systems? Do such technologies exist today?
  - What is the evidence to support that AIT and x-ray back scatter technologies are attractive fusion candidates?
  - What other technologies could be fused to improve the detection performance of AIT systems?



Question 3

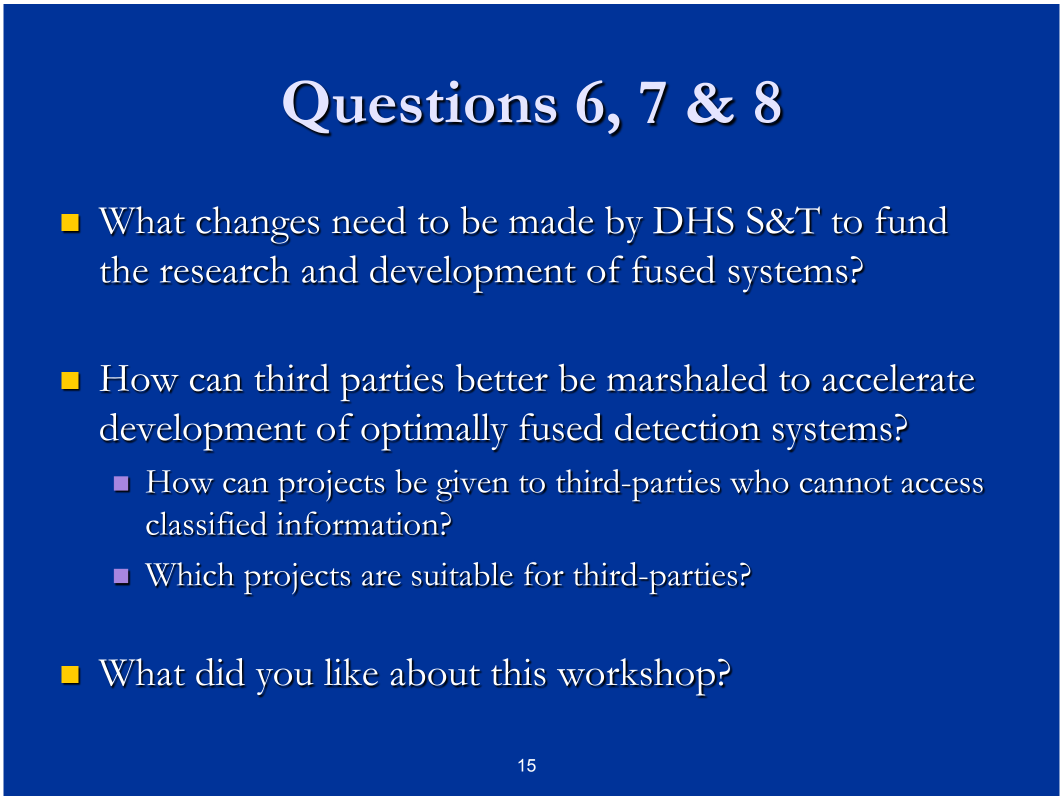
- How is detection performance improved with adaptive screening?
  - What is the definition of adaptive screening?
  - How should risk be assessed?
  - How should risk be fused to explosive detection equipment?
  - Should adaptive screening be used?

Question 4

- Which investment is likely to have the highest rate of return?
    - Fused system identification and performance evaluation
    - Algorithm development (segmentation, reconstruction, artifact reduction)
    - Sensor simulations
    - Integrating systems and then fusing their results

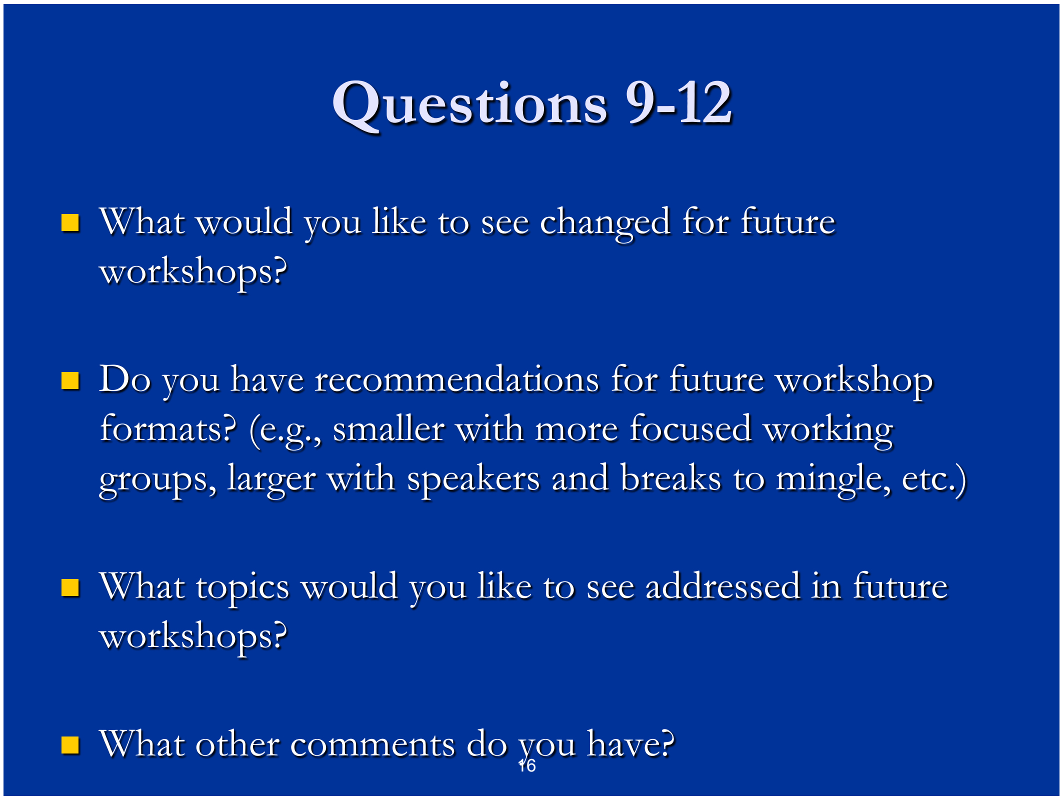
Question 5

- What changes need to be made by the TSA to allow fused systems to be deployed?
    - What are the developmental steps between identification of attractive fused detection systems and acquisition of such systems by TSA? (Describe the research, DT&E, OT&E, and acceptance testing required, necessary resource levels and the timeframe to accomplish it.)
    - What are the implications of fused technologies on the DICOS developmental effort and emphasis?
    - What is needed by traditional vendors to gain their enthusiasm for fused system development? (e.g., IP and patent protections, data on real threats, etc.)



Questions 6, 7 & 8

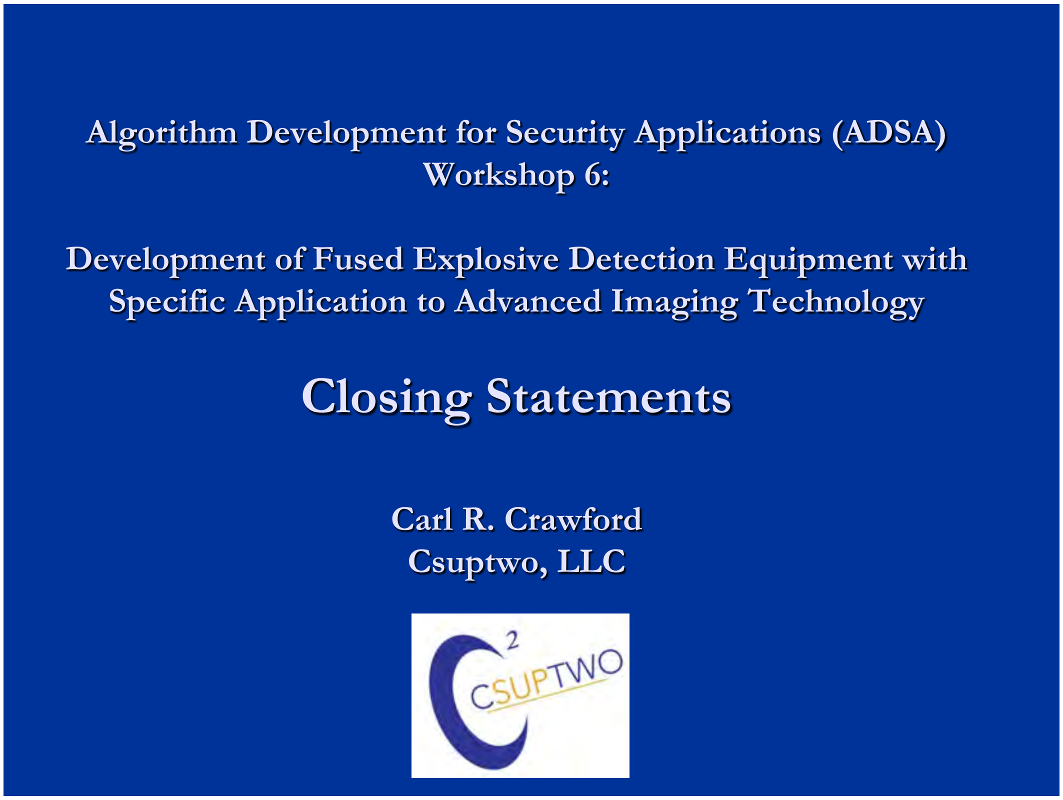
- What changes need to be made by DHS S&T to fund the research and development of fused systems?
- How can third parties better be marshaled to accelerate development of optimally fused detection systems?
  - How can projects be given to third-parties who cannot access classified information?
  - Which projects are suitable for third-parties?
- What did you like about this workshop?



Questions 9-12

- What would you like to see changed for future workshops?
- Do you have recommendations for future workshop formats? (e.g., smaller with more focused working groups, larger with speakers and breaks to mingle, etc.)
- What topics would you like to see addressed in future workshops?
- What other comments do you have?

16.21 Carl Crawford: Closing Statements

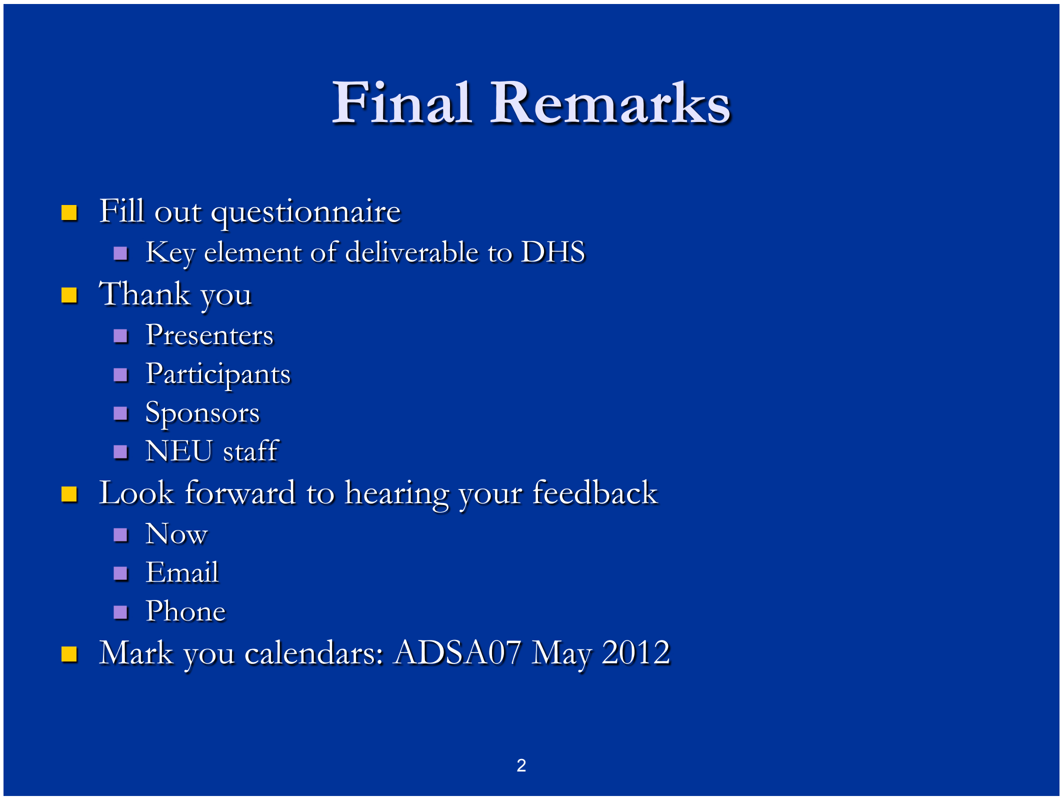


Algorithm Development for Security Applications (ADSA)
Workshop 6:

Development of Fused Explosive Detection Equipment with Specific Application to Advanced Imaging Technology

Closing Statements

Carl R. Crawford
Csuptwo, LLC



Final Remarks

- Fill out questionnaire
  - Key element of deliverable to DHS
- Thank you
  - Presenters
  - Participants
  - Sponsors
  - NEU staff
- Look forward to hearing your feedback
  - Now
  - Email
  - Phone
- Mark you calendars: ADSA07 May 2012