Strategic Study
Workshop Series

Algorithm Development for Security Applications

May 2012 Workshop
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 reconstruction algorithms for CT-based explosion detection systems was held at Northeastern University (NEU) in Boston on May 15-16, 2012. This workshop was the seventh in a series dealing with algorithm development for security applications.

The topic of reconstruction was chosen for the workshop in order to support the Department of Homeland Security's (DHS) objective of improving the detection performance of existing technologies. Detection performance is defined as increased probability of detection, decreased probability of false alarms, lower threat mass and an increased number of types of explosives.

The key topics that were addressed at the workshop are as follows:

- CT reconstruction for few and many-view scanners.
- Pre-processing, post-processing, and model-based methods for artifact reduction.
- Advances in segmentation algorithms for CT-based explosive detection scanners.
- Tools for simulating explosive detection equipment.
- Accelerating the deployment of advances from 3rd parties.
- Review of DHS product acceptance testing and TSA deployment processes.

The workshop was successful in fostering interaction between third parties and vendors, reducing present and future barriers to collaboration. It also directly led to increased third-party involvement in the development of advanced reconstruction algorithms. This conclusion is based on anecdotal evidence of the number of third parties engaging in discussions with vendors during the workshop and the editors' knowledge of third parties consulting for the vendors.

The key findings from the workshop, per the editors of this report, are as follows:

- There are improved reconstruction algorithms available for CT-based explosive detection equipment. In particular, these algorithms may reduce artifacts such as streaks and cupping. Such improved algorithms may lead to improved explosive detection performance. Algorithms, capabilities, characteristics and features that were highlighted as having the potential to provide such gains include:

  - Iterative reconstruction techniques, which are also known as model-based and statistical reconstruction.
  - Improved filtered back-projection.
  - Sinogram processing.
  - Algorithms targeted to reduce CT artifacts, especially artifacts caused by metal, beam hardening and scatter.
  - Reconstruction algorithms that perform dual-energy decomposition simultaneously with reconstruction.
  - Algorithms that perform reconstruction and segmentation simultaneously.
  - Algorithms that exploit prior information, learning, and compressive sensing.

- The following infrastructure should be put in place in order to facilitate and accelerate the development of improved reconstruction algorithms:
  - Public domain computer simulations of security CT scanners, along with the development of standardized simulated objects and simulated packing algorithms.
  - Relevant metrics of image quality instead of actually measuring detection performance. At present, there is no precedent for using image quality metrics to assess the performance of CT-based explosive detection equipment.
  - Projections and meta-data that correspond to scans of standard test objects on a CT scanner.
  - Problem statements describing problems that are of interest to the field that are not classified or sensitive security information.

  - Funding for academic researchers from DHS, TSA and industry.
  - Incentives from the TSA for vendors to deploy equipment with improved detection performance. These incentives will lead to the deployment of advanced reconstruction algorithms.

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 detection 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, all at a constant or increased probability of detection.

One tactic that DHS is pursuing to improve 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 a series of 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)." 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[1]).

The seventh workshop in the ADSA series was held on May 15-16, 2012, at NEU. The workshop addressed reconstruction algorithms for CT-based explosive detection equipment. The topics that were discussed include:

- CT reconstruction for few-view and many-view scanners.

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

- Pre- and post-processing for artifact reduction.
- Advances in segmentation algorithms for CT-based explosive detection scanners.
- Tools for simulating explosive detection equipment.
- Accelerating the deployment of advances from 3rd parties.
- Review of DHS product acceptance testing and TSA deployment processes.

This report discusses what transpired at the workshop and reports a summary of the workshop findings and recommendations.

The workshop was successful in the sense that it fostered interaction between third parties and vendors, reducing barriers to their working together, now and in the future. It also directly led to increased third party involvement in the development of advanced reconstruction algorithms. This conclusion is based on anecdotal evidence of the number of third parties engaging in discussions with vendors during the workshop and the editors' knowledge of third parties consulting for the vendors.

4. Discussion, Findings and Recommendations[2]

Discussion

The objective of the workshop was to facilitate the development of improved reconstruction algorithms for CT-based explosive detection equipment. The issues that were addressed centered on the following list of questions.

1. What problems/issues have to be addressed?
2. How will improvements be measured?
3. What are the characteristics of the CT scanners under consideration?
4. How does the reconstruction step fit with the other blocks/steps in a deployed explosive detection scanner?
5. How are the scanners tested by the TSA?
6. What types of algorithms should be considered?
7. What resources are required?
8. How can the deployment of improved algorithms be accelerated?
9. How to involve third parties?

The purpose of the section is to synthesize the discussion and recommendations in response to these and related questions that surfaced during the discussion.

Scanner Types

In this section, we describe the types of CT scanners that were discussed at the workshop. We use the term *scanner* to describe part of a system that the TSA procures, which is a CT scanner, a computer running advanced threat recognition (ATR) and at least one workstation to resolve alarms from the ATR.

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[2] 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.

1. The scanner may be one of the following types:
    a. Many view (>~ 100 views/rotation)
    b. Few view (<~ 100 views/rotation)
    c. Helical/spiral
    d. Step-and-shoot
    e. Single-detector row
    f. Multi-detector row (cone-beam)
    g. Mechanical rotation
    h. Electron beam
    i. Multi-source
    j. Single-, dual- and multi-energy
    k. Integrating detectors
    l. Photon counting detectors
2. The scanner consists of the following blocks:
    a. X-ray generation at multiple locations
    b. X-ray detection
    c. Conveyance of objects of inspection (luggage)
    d. Reconstruction algorithm
    e. Automated threat recognition (ATR)
    f. Viewing station (workstation) to resolve alarms
3. The reconstruction algorithm may include the following steps:
    a. Correction - converting detector measurements into estimates of line-integrals. The following steps may be present.
        i. Physics
            1. Logarithm of counts to generate approximations to line integrals.
            2. Scatter
            3. Beam hardening
        ii. Electronics
            1. Gain
            2. Offset
            3. Cross-talk
            4. Spectral
            5. Afterglow

      iii. Artifacts
         1. Metal
         2. Missing views
         3. Missing detectors
         4. Rings
   b. Mathematical inversion including helical and cone-beam correction
   c. Post-processing for artifact removal
4. The ATR may include the following steps:
   a. Segmentation including extraction of features such as:
      i. Mass
      ii. Density
      iii. Volume
      iv. Zeff
   b. Correction of segmented objects and their features:
      i. Splitting compensation
      ii. Merging compensation
      iii. Artifact correction for features generated by an ATR
   c. Classification
5. The viewing station may be used to resolve alarms generated by the ATR. Alarms and bag scan images are subject to on-screen review (OSR) for disposition and further investigation where appropriate.
6. The scanner may produce images with the following types of artifacts:
   a. Streaks
   b. Rings
   c. Bands
   d. Low-frequency shading (also known as cupping and dishing)
   e. Noise
   f. Blurring
7. The sources of artifacts include:
   a. Beam hardening
   b. Scatter
   c. Electronic noise
   d. Quantum noise
   e. Sampling/aliasing

    f. Detector gain and offset drift
    g. Finite sized source and detector apertures
    h. Photon starvation
8. The artifacts may be exacerbated by:
    a. Presence of metal
    b. Explosives with varying values of Zeff
    c. Highly attenuating bags
    d. Clutter
9. The artifacts lead to the following problems with ATR:
    a. Segmentation
        i. Merged objects
        ii. Split objects
    b. Feature extraction
        i. Imprecise metrics such as mass, density, volume and texture
    c. Classifier
        i. Lower PD and higher PFA due to imprecise features
10. It appears that most scanners deployed today use either filtered back-projection (FBP) or direct Fourier technique (DFT). The term FBP usually refers to the mathematical inversion step of reconstruction and the steps of correction, post-processing, helical correction and cone-beam correction.
11. Most of the workshop addressed many-view (projections), multi-detector-row, helical CT scanners. Quantum noise is not an issue for such a scanner. The application to few-view scanners was not discussed in sufficient detail.

Scanner Requirements and Testing

1. The scanners are used to find explosives in checked and carry-on luggage.
2. The explosives that have to be detected have the following characteristics:
    a. Minimum mass
    b. Minimum size for certain classes of explosives
    c. May have varying density and atomic number
3. Scanner with the ATR must satisfy the following test:

   a. PD > *x*, where *x* is classified
   b. PFA < *y*, where *y* is classified
   c. Throughput (bags / hour) > z.
4. The testing is known as a certification test.
5. There are no image quality (IQ) requirements for a scanner to pass certification.
6. There are IQ requirements for OSR in order for a TSO to make a decision.

Reconstruction Algorithm Improvements

1. The following types of improvements in reconstruction algorithms should be considered:
   a. Iterative reconstruction techniques (IRT) including statistical reconstruction and model-based iterative reconstruction (MBIR).
   b. Improved filtered back-projection (FBP).
   c. Sinogram processing.
   d. Dictionary-based reconstruction, which is also known as a learning algorithm.
   e. Simultaneous reconstruction and segmentation.
   f. Simultaneous reconstruction and multi-energy decomposition.
   g. Compressive sensing methods for few-view scanners.
   h. Dedicated methods for artifact removal such as:
      i. Metal artifact removal
      ii. Resolution enhancement
      iii. Edge (boundary) enhancement
      iv. Beam hardening correction
      v. Streak removal
      vi. Scatter removal
      vii. Photon starvation
2. The algorithm developers should be cognizant that texture may have to be preserved for certain objects. Image priors used in some reconstruction algorithms may remove texture.
3. There may be combinations of the above algorithms. For example, sinogram processing may be used in combination with IRT or FBP.

4. IRT may include algorithms with many ($N >> 1$) iterations, such as MBIR, or few iterations ($N \sim 2$), such as for second pass iterative bone correction, which is also known as iterative bone correction in the medical imaging field.
5. Reconstruction times and computational expense should not be a consideration at the beginning of the development of new reconstruction algorithms. However, these topics may become a barrier to deployment. Researchers should report reconstruction times and computational expenses after an algorithm is developed.
6. Multiple algorithms may be used to satisfy different situations such as:
    a. Bulk versus thin objects
    b. Homogenous versus textured objects
    c. Uncluttered versus cluttered bags
    d. Concealed versus unconcealed objects
7. Retrospective or targeted reconstruction may be applied after a first pass of an ATR algorithm. That is, regions of interest (ROI) for difficult cases may be reconstructed a second time using a different algorithm.

Test Metrics

The best metric for measuring an improved reconstruction is through detection performance as measured by the area under the ROC as determined through a certification test. This metric cannot be used for the following practical reasons:

- ATRs are known to be tuned to the IQ resulting from a given reconstruction algorithm. In a sense, the ATR is a matched filter. Changing the reconstruction algorithms means modification or replacement of the ATR, which means engineering resources.
- Certification only provides one value each for PD and PFA.
- Performing a certification test requires engineering resources.
- The certification test requires scans of explosives in different configurations including minimum size and mass; this information is classified, which means that many third parties may not be able to participate in the development of new reconstruction algorithms.

- The state-of-the art is controlled by vendors and details are not in the public domain.

Surrogate metrics are therefore required. The following metrics are recommended:

1. Image Quality (IQ)
    a. Modulation transfer function (MTF)
    b. Slice sensitivity profile (SSP)
    c. Signal to noise ratio (SNR)
    d. Contrast to noise ratio (CNR)
    e. Amplitude of streaks
2. Object-based metrics based on using knowledge of location of objects (known as ground truth) to extract voxels associated with an object.
    a. Mean and variance of voxels
    b. Spread of histogram
    c. Amplitude of streaks
    d. Mass
    e. Density
    f. Metrics for assessing texture
3. Connected components labeling (CCL) or one of the methods developed for the Segmentation Initiative could be used to segment the voxels in objects of interest. Additional metrics include:
    a. Volume
    b. Dimensions
4. Simple objects such as water and rubber sheets should be scanned instead of explosives. Recommendations were not provided for textured objects.
5. The simple objects should be scanned with following variations:
    a. Location
    b. Orientation
    c. Containment
    d. Concealment
    e. Clutter
6. Another metric is the spread of feature values (e.g., density and mass) as a function of these variations.

7. The incumbent vendors should be consulted for specific variations that they would like to see tested.
8. The confidence intervals of test results should be considered when assessing improved detection performance (i.e., PD and PFA).

Development Tools

In this section, we describe tools that 3rd parties can use for development of advanced reconstruction algorithms.

1. Standard objects should be supplied to provide a common baseline of objects. Examples include:
    a. The NIST image quality phantom.
    b. A couple of packed suitcases with different types of objects of interest, containment, concealment, orientation and clutter. The characteristics of these suitcases should be disseminated to all of the researchers.
2. Scans of the standard objects on different kinds of CT scanners (e.g., few- and many-view scanners). The following information should be supplied:
    a. Corrected and raw data.
    b. Images reconstructed by the vendor equipment.
    c. File formats
    d. Meta data such as:
        i. Locations of sources and detectors
        ii. Aperture sizes
        iii. Photon counts in air
    e. Description of vendor reconstruction algorithm to understand if which algorithmic steps are required to make acceptable images.
    f. Description of object scans.
    g. Scans of objects of interest in isolation (i.e., without concealment and clutter).
    h. Ground truth (GT) (locations of voxels corresponding to objects of interest).
3. Scanner simulation software.
    a. Simulate a common set of objects.

   b. Accurately simulate standard scanner configurations, including quantity, coverage, SNR of projection data.
   c. Flexible configuration so that different scanners can be simulated.
   d. The code should be extensible so that different types of scanners can be simulated in the future.
   e. The code should be validated using scans of the standard objects on real scanners.
4. Generic ATR (if possible).
5. Simple segmentation algorithm.
6. Defined acceptance criteria and code (e.g., Matlab) for calculating the metrics.

Accelerating Deployment

The following tasks should be performed in order to accelerate the deployment of advanced reconstruction algorithms, especially those developed by third parties.

1. Provide detailed problem statements including:
   a. Short term for vendors and third-party industry
   b. Long term for students
2. Increased incentives from the TSA for vendors to deploy scanners with improved detection performance.
3. Increased incentives for third parties to develop advanced algorithms.
4. Government (DHS/TSA) funding of vendors and third parties.
5. Allowing more people access to classified and SSI information or develop non-classified problems capturing challenges.
6. Developing frameworks for protecting:
   a. Intellectual property
   b. Commercial interests of vendors and third parties
7. Reducing transaction costs of working with third parties.
8. Having third parties reduce computational expense of new reconstruction algorithms. The first of the development of new reconstruction algorithms should not consider computational expense.

9. Giving third parties access to subject matter expert experts in the field of developing and deploying explosive detection equipment.
10. Fund the science of acceptance criteria (metrics).

Future ADSA Workshops

1. The following topics should be addressed in future workshops:
    a. Stand-off detection on personnel and in vehicles
    b. Chemical sensors
    c. DHS detection problems
    d. Cargo
    e. Special nuclear materials (SNM)
    f. AIT (MMW, XBS) – ATR and reconstruction
    g. Video analytics
    h. Executing grand challenges
2. The following changes should be considered for future ADSA workshops:
    a. More/longer breaks
    b. Shorter and fewer presentations
    c. Breakout sessions
    d. Reduce the number of questions in the questionnaire

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.
- Laura Parker, DHS, and Earl Smith, DHS, for coordinating DHS/ALERT activities.
- Greg Struba, DHS, for coordinating the participation of DHS and TSA.
- Northeastern University for hosting the workshop.

The workshop would not have been a success without the participants, the speakers and the students who presented posters. 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
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
Harry Martz, Lawrence Livermore National Laboratory
Rachel Parkin, Northeastern University

The final report was reviewed by:

Clem Karl, Boston University
Doug Pearl, Inzight Consulting
Suriyun Whitehead, Booz Allen Hamilton

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

Rachel Parkin, Northeastern University
Brian Loughlin, Northeastern University
Melanie Smith, 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. 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.
2. 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.
3. Some of the presentations were edited (mainly redacted information) after the workshop.

8. Appendix: Agenda

DAY 1			
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
9:10 AM	Welcoming remarks - DHS	Doug Bauer	DHS
9:15 AM	Welcoming remarks - DHS	Laura Parker	DHS
9:20 AM	Logistics	Rachel Parkin	Northeastern University / ALERT
9:25 AM	Workshop objectives	Carl Crawford	Csuptwo
10:05 AM	Image quality metrics for ATR	Matthew Merzbacher	Morpho Detection
10:15 AM	Image quality metrics for ATR	Richard Bijjani	Robehr Analytics
10:25 AM	Break		
11:00 AM	IRT for few- and many-view CT	Charles Bouman	Purdue
11:25 AM	IRT for few- and many-view CT	Xiaochuan Pan	University of Chicago
11:50 AM	Compressed sensing interative reconstruction	Guang-Hong Chen	University of Wisconsin, Madison
12:15 PM	Lunch		
1:15 PM	Sinogram processing for artifact reduction	Patrick La Riviere	University of Chicago
1:40 PM	Metal artifact removal	Seemeen Karimi	University of California, San Diego
2:05 PM	IRT for polychromatic CT	Johan Nuyts	University of Leuven
2:30 PM	Break		
3:05 PM	CT scanner simulations	Taly Gilat-Schmidt	Marquette University
3:30 PM	Iterative reconstruction at LLNL	Harry Martz	Lawrence Livermore National Laboratory

DAY 1, CONT.			
Time	**Topic**	**Speaker**	**Affiliation**
3:55 PM	Advanced segmentation algorithms	David Wiley	Stratovan Corporation
4:20 PM	Advanced segmentation algorithms	Claus Bahlmann	Siemens Corporate Research
4:45 PM	Reception sponsored by Csuptwo	Carl Crawford	Csuptwo
5:45 PM	Student poster session in reception area	Students	ALERT
5:45 PM	Dinner		
6:10 PM	Student award	Michael Silevitch	Northeastern University / ALERT
6:15 PM	Dinner Speech - Protection of federal buildings	Vincent Eckert	DHS
6:45 PM	Dinner Speech - Video analytics	David Castanon	Boston University
7:15 PM	End Day 1		

DAY 2			
Time	**Topic**	**Speaker**	**Affiliation**
7:30 AM	Continental breakfast		
8:00 AM	Day 2 objectives	Carl Crawford	Csuptwo
8:05 AM	ADSA08 topics	Carl Crawford	Csuptwo
8:15 AM	Combined segmentation/reconstruction	Birsen Yazici	Rensselaer Polytechnic Institute
8:40 AM	Combined segmentation/reconstruction	Willem-Jan Palenstijn	University of Antwerp
9:05 AM	Combined segmentation/reconstruction	Oguz Semerci	Tufts University
9:30 AM	Metrics for segmentation algorithms	Karina Bond	Lawrence Livermore National Laboratory
9:55 AM	Break		
10:30 AM	Dictionary Learning for Few-view Reconstruction	Ge Wang	Virginia Tech
10:55 AM	Artifact reduction for low-dose using IRT	W. Clem Karl	Boston University
11:20 AM	Status of third party involvement	Laura Parker	DHS
11:30 AM	TSA procurement procedures	Matt Cobey	TSA
11:55 AM	3rd involvement in medical imaging & security	Doug Pearl	Inzight Consulting
12:40 PM	Lunch		
1:40 PM	Accelerating 3rd party involvement	Richard Bijjani	Robehr Analytics
1:55 PM	Company introduction and 3rd party support	Joe Paresi	Integrated Defense and Security Solutions
2:05 PM	Next steps	Harry Martz	Lawrence Livermore National Laboratory
2:40 PM	Open discussion	All	All
3:10 PM	Closing remarks - DHS	Laura Parker	DHS
3:15 PM	Closing remarks - DHS	Doug Bauer	DHS
3:20 PM	Closing remarks - ALERT	Michael Silevitch	Northeastern University
3:25 PM	Adjourn	Carl Crawford	Csuptwo

9. Appendix: Previous Workshops

Information about the previous six ADSA workshops, including soft copies of the final reports, can be found at:

www.northeastern.edu/alert/transitioning-technology/strategic-studies

10. Appendix: List of Participants

Name	Organization
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Robert Klueg	Department of Homeland Security
Ronald Krauss	Department of Homeland Security
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Xiaochuan Pan	University of Chicago

Name	Organization
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Edward Solomon	Triple Ring Technologies
Samuel Song	Telesecurity Sciences
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Adam Wunderlich	University of Utah
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Birsen Yazici	Rensselaer Polytechnic Institute
Zhengrong Ying	Zomographic LLC
George Zarur	Department of Homeland Security
Jun Zhang	University of Wisconsin-Milwaukee

11. Appendix: Presenter Biographies

Claus Bahlmann

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

Doug Bauer

Dr. Douglas Bauer is the Explosives Division Program Executive for Basic Research with management responsibility for multiple programs in basic and applied research, homemade explosives (HME) characterization, detection and damage assessment, development of the next generation EDS x-ray technologies, and counter IED basic research in prevention, detection, response and mitigation. Dr. Bauer also has management responsibility for two 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. Following ADSA07, Dr. Bauer has left DHS and is working at the U.S. Patent Office.

Richard Bijjani

Dr. Richard Robehr Bijjani has been a thought leader in security technology for over 20 years. He designed and developed many security products including a dozen different Explosive Detection Systems (EDS) utilizing various technologies. The systems he designed managed to successfully exceed the certification requirements of every known EDS detection standard in the world; a unique achievement.

In 1990, Richard managed R&D during the development of a dynamic signature verification product at Kumahira Inc., one of the very first biometrics products in the industry. In 1994, he joined InVision Technologies as head of the Algorithm and Machine Vision group where he oversaw the development effort that led to the first successful certification by the FAA, a historic event for the then still nascent industry. He went on to design and certify multiple EDS systems for InVision (now Morpho Detection) and later for Vivid (now L3). In 2002, he co-founded Reveal Imaging (now an SAIC company) where he designed and developed the world's highest performing automated explosive detection systems to date, which also happen to be the least expensive and the smallest. In January 2012, Richard founded Robehr Analytics where he plans to develop a suite of low cost sensors that he hopes would revolutionize the way people interact with their environment and help enhance and protect their lives. Dr. Bijjani has a Ph.D. in Electrical Engineering from Rensselaer Polytechnic Institute.

Karina Bond

Karina Bond is a Signal processing engineer at Lawrence Livermore National Laboratory (LLNL) since November of 2009, where she has been developing imaging processing algorithms for CT applications and Gamma–ray imagers. Karina has a decade of algorithm and embedded firmware development experience in wireless communications and imaging applications. Prior to LLNL, Karina worked at Intel, San Jose (July 2007 – July 2008) and before that at GE Medical Systems, Milwaukee (July 2002-July 2007) where she developed wireless communication algorithms in embedded processors for various products. Karina received her Masters' in Electrical Engineering from the University of Wisconsin, Madison in May 2002 and an Electrical Engineering degree from the University of Mumbai in June 2000.

Charles Bouman

Charles A. Bouman is the Michael J. and Katherine R. Birck Professor of Electrical and Computer Engineering at Purdue University where he also holds a courtesy appointment in the School of Biomedical Engineering and serves as a co-director of Purdue’s Magnetic Resonance Imaging Facility. He received his B.S.E.E. degree from the University of Pennsylvania, M.S. degree from the University of California at Berkeley, and Ph.D. from Princeton University in 1989.

Professor Bouman's research focuses on inverse problems, stochastic modeling, and their application in a wide variety of imaging problems including tomographic reconstruction and image processing and rendering. Prof. Bouman is a Fellow of the IEEE, AIMBE, IS&T, and SPIE. He has served as the Editor-in-Chief of the IEEE Transactions on Image Processing, Distinguished Lecturer for the IEEE Signal Processing Society, a member of the IEEE Signal Processing Society’s Board of Governors, and the Vice President of Publications for the IS&T Society. Currently, he is Vice President Elect for Technical Directions of the IEEE Signal Processing Society.

David Castañón

Prof. David Castañón received his B.S. degree in Electrical Engineering from Tulane University in 1971, and his Ph.D. degree in Applied Mathematics from the Massachusetts Institute of Technology in 1976. From 1976 to 1981, he was a research associate with the Laboratory for Information and Decision Systems at the Massachusetts Institute of Technology in Cambridge, MA. From 1982-1990, he was Chief Scientist at Alphatech, Inc. in Burlington, MA. He joined the Department of Electrical and Computer Engineering at Boston University, Boston, MA in 1990, where he is currently professor and Department Chair. Prof. Castañón was Associate Director and Deputy Director of the National Science Foundation Center for Subsurface Sensing and Imaging, co-Director of Boston University's Center for Information and Systems Engineering and served on the Air Force's Scientific Advisory Board from 2007-2010. He is Associate Director of DHS's ALERT Center of Excellence. He has served on the IEEE Control System Society's Board of Governors, and served as President of the IEEE Control Systems in 2008. His research interests include stochastic control, optimization, detection and inverse problems with applications to defense, medical diagnosis and homeland security.

Guang-Hong Chen

University of Wisconsin, Madison

Matt Cobey

James "Matt" Cobey is currently serving as an Evaluator with the Transportation Security Administration (TSA), Office of Security Capabilities (OSC), Test and Evaluation (T&E) Branch. In this capacity Matt is responsible for developing and executing the evaluation strategy of the various transportation security technologies and processes that TSA is seeking to deploy. Matt is a Department of Homeland Security T&E Level III Certified Acquisition Professional. He has served in various T&E positions in TSA and the USAF, to include, TSA OSC Acting Director of T&E, USAF Operational Test Director and TSA Systems Integration Facility (TSIF) Lead Test Engineer. Matt retired from the USAF after 21 years of service in 2007 and after a brief hiatus running a family business returned to T&E joining the TSA T&E team in 2008.

Carl Crawford

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.

Vincent Eckert

Commander Vince Eckert is currently detailed to the Federal Protective Service (FPS) Headquarters as a technical countermeasures expert. Vince was previously assigned to FPS Region 10 in Seattle, WA. He is responsible for developing a design-basis threat (DBT) and associated countermeasures requirements for security at over 9,000 Federal buildings nationwide. Additionally, he is helping FPS develop a formal requirements-based and threat-based acquisition process for security countermeasures, such as checkpoint x-ray, magnetometer, physical access control systems, biometrics, and CBRN (chemical, biological, radiological, nuclear) detectors. In cooperation with Dr. Tom Coty at DHS HQ Science and Technology Directorate (Explosives Division), Vince is assisting with the establishment of a formal working group to design, develop, test, and evaluate future countermeasures technologies for Federal buildings.

Vince was instrumental in getting the Reagan Building, a flagship FPS facility in Washington, DC, designated as the FPS Center of Excellence for the development and deployment of future countermeasures systems. This building will soon host tests of a new modular backscatter x-ray machine, an advanced chemical agent detection system, and a new portable counter-IED (improvised explosives device) jamming device.

Taly Gilat-Schmidt

Taly Gilat Schmidt, Ph. D., is an assistant professor of Biomedical Engineering at Marquette University. Her research interests include medical imaging system design, optimization, and reconstruction. Dr. Schmidt earned an undergraduate degree in Electrical Engineering from the University of Illinois at Urbana Champaign, after which she was employed in the Edison Engineering Program at GE Healthcare. Dr. Schmidt received her M.S. and Ph. D. in Electrical Engineering from Stanford University. She directs the Medical Imaging Systems Laboratory at Marquette University, which is currently conducting research funded by the NIH, DOE, and FDA.

Seemeen Karimi

Seemeen Karimi is a Biomedical Engineer. Her areas of interest are computer vision and image reconstruction. She graduated with an MS degree from the University of North Carolina at Chapel Hill. Subsequently, she worked for Analogic Corporation and NeuroLogica Corporation. Both companies are manufacturers of CT equipment. She developed algorithms for volumetric reconstruction, artifact and noise reduction, automatic image quality, and automatic integration processes. Currently, she is a 3rd-year PhD student in Electrical Engineering at the University of California, San Diego.

W. Clem Karl

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

Patrick La Riviere

Patrick J. La Riviere received the A.B. degree in physics from Harvard University in 1994 and the Ph.D. degree from the Graduate Programs in Medical Physics in the Department of Radiology at the University of Chicago in 2000. In between, he studied the history and philosophy of physics while on the Lionel de Jersey-Harvard scholarship to Cambridge University. He is currently an Assistant Professor in the Department of Radiology at the University of Chicago, where his research interests include algorithm development for tomographic reconstruction in computed tomography, x-ray fluorescence computed tomography, and optoacoustic tomography. In 2005, he received the IEEE Young Investigator Medical Imaging Scientist Award, then given every two years to a young investigator within 6 years of the Ph.D. for significant contributions to medical imaging research. He is an author of more than 30 peer-reviewed articles and peer reviewed conference proceedings and 8 book chapters.

Harry Martz

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

Dr. Merzbacher is manager of the Machine Vision and Innovation group at Quantum Magnetics (part of the SAFRAN group's Morpho Detection). In addition to managing the group, Dr. Merzbacher works on technical projects, such as break-bulk cargo, DICOS, and the detection algorithms for the MDI family of explosives detection systems. He is chair of the NEMA DICOS Threat Detection Working Group, charged with developing a standard for image interchange in security applications. He joined what was, at the time, InVision Technologies in 2003 as a Research Scientist in the Machine Vision group. Dr. Merzbacher has a Ph.D. in Computer Science from UCLA, specializing in data mining. He has several pending patents on image processing for explosives detection.

Johan Nuyts

Johan Nuyts graduated in electronical engineering in 1982, in biomedical engineering in 1983, and in 1991 he received a Ph. D. in Applied Sciences from KU Leuven. Since 1993, he is research professor in the Department of Nuclear Medicine at KU Leuven. He co-authored about 100 scientific journal papers. His research interests include iterative reconstruction in PET, SPECT and CT. Ongoing research projects focus on maximum-a-posteriori reconstruction in emission tomography, iterative reconstruction in CT and tomosynthesis, attenuation correction in PET/CT and PET/MRI and TOF-PET, and motion correction in small animal PET.

Willem Jan Palenstijn

Willem Jan Palenstijn studied mathematics at the Universiteit Leiden, and is now working on image reconstruction in CT and MRI at the IBBT-Vision Lab of the Universiteit Antwerpen, with a focus on GPU acceleration and incorporating prior knowledge in algebraic reconstruction algorithms.

Xiaochuan Pan

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

Joe Paresi

Joseph Paresi is the Founder, Chairman and Chief Executive Officer of IDSS Holdings, Incorporated, operating as Integrated Defense and Security Solutions (IDSS) and Headquartered in Armonk NY with planned operations in Burlington, MA. and Vienna, Va. IDSS is comprised of three sectors: *Government Services* dealing with the Intelligence Community; *Applied Technologies* in the areas of Explosive Detection, Video Surveillance and Cargo Screening; and *Data Management* working in the areas of system integration, data integrity and interoperability, biometric applications, secure credentialing and cyber security. Mr. Paresi brings over three decades of executive management, marketing and sales, and product development experience in worldwide sales of technology, homeland security and defense industry related solutions.

Prior to founding IDSS, Mr. Paresi was the co-founder and Executive Vice President of L-1 Identity Solutions, with a primary focus on Sales and Marketing, Business Operations, and Mergers and Acquisitions. Since its origin in 2005, L-1 Identity Solutions made seventeen acquisitions in the intelligence sector and biometric/credentialing area. L-1 grew revenues from a startup to over $700M in annual revenues and $100M in EBITDA before being sold for $1.5B in a split fashion to BAE Systems and Sagem Morpho, a division of Safran.

Laura Parker

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.

Doug Pearl

Doug Pearl has extensive experience in the biomedical industry and in the commercial applications of medical diagnostics. He has written on the problem of False Positives in the screening of low risk (low prevalence) populations. He has provided strategy and marketing advice to a variety of biomedical clients, including Fortune 500, public biotechnology and development stage start-up companies. He has extensive experience working with clinicians, scientists and customers to determine key drivers of success in the marketplace, and parallel experience working with senior management, marketing, and R&D to transform this information into relevant actions.

Prior to launching Inzight Consulting LLC (formerly Insight Consulting) in 1993, Doug Pearl was Vice President, Business Development for Matritech, Inc., a public biotechnology company in Cambridge, MA. Prior to Matritech, he was a consultant at Bain & Company in Boston. Mr. Pearl has a Masters in Management from the Yale School of Management and an undergraduate degree, *summa cum laude*, from Princeton. He has also worked as a Research Associate at the Harvard School of Public Health.

Oguz Semerci

Oguz Semerci received the B.Sc. and M.Sc. degrees in telecommunication engineering from Istanbul Technical University, Istanbul, Turkey, in 2006 and 2008, respectively. He is currently working toward the Ph.D. degree with the Department of Electrical and Computer Engineering, Tufts University, Medford, MA. His current research interests include physics based signal processing, tomographic iterative image reconstruction, inverse problems, regularization and pattern recognition.

Michael Silevitch

Professor Michael B. Silevitch received the B.S.E.E., M.S.E.E., and Ph. D. 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.

Ge Wang

Ge Wang received his M.S. and Ph. D. in ECE from State University of New York, Buffalo, in 1991 and 1992. He was a faculty member at Mallinckrodt Institute of Radiology, Washington University at St. Louis, 1992-1996; with University of Iowa, 1997-2006; and since then has been the Pritchard professor, the Director of the SBES Division / ICTAS Center for Biomedical Imaging, Virginia Tech. His interests include x-ray computed tomography, optical molecular tomography, and other inverse problems. He authored/co-authored over 300 peer-reviewed articles in journals such as IEEE Trans, Optics Letters, PRL, PNAS, and Nature, including the first paper on spiral/helical cone-beam CT (100-million cone-beam medical CT scans yearly in the world), the first paper on bioluminescence tomography, and the first paper on interior tomography. He with his co-inventors has over 30 patents and disclosures. He is the founding Editor-in-Chief for International Journal of Biomedical Imaging, Associate Editor for IEEE Trans. Medical Imaging and IEEE Trans. Biomedical Engineering, as well as Fellow of IEEE, SPIE, OSA, AIMBE, and AAPM.

Please feel welcome to visit his website: http://www.imaging.sbes.vt.edu, and explore collaborative opportunities.

David Wiley

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

Birsen Yazici

Birsen Yazıcı received B.S. degrees in electrical engineering and mathematics from Bogazici University, Istanbul, Turkey, in 1988, and M.S. and Ph.D. degrees in mathematics and electrical engineering from Purdue University, West Lafayette IN, in 1990 and 1994, respectively. From September 1994 until 2000, she was a research engineer at the General Electric Company Global Research Center, Schenectady, NY. During her tenure in industry, she worked on radar, transportation, industrial, and medical imaging systems. From 1996 until 1999, she was a member of the GE Research, L3 and Analogic team that developed the 3D X-ray CT explosive detection system for airport check-luggage. In 2001 she joined Drexel University as an assistant professor. In 2003, she joined Rensselaer Polytechnic Institute, Troy, NY, where she is currently an Associate Professor in the Department of Electrical, Computer, and Systems Engineering and in the Department of Biomedical Engineering. Her research interests span the areas of statistical signal processing, inverse problems in imaging, biomedical optics, and radar. She holds 11 U.S. patents. Dr. Yazıcı is the recipient of the Rensselaer Polytechnic Institute 2007 School of Engineering Research Excellence Award. Her work on industrial systems received the 2nd best paper award in 1997 given by IEEE Transactions in Industrial Applications.

12. Appendix: Questionnaire

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

1. What opportunities are there for developing *better* reconstruction algorithms?
    - What acceptance criteria should be used to determine if a reconstruction algorithm is *better* than prior methods?
    - Are there differences for few- and many-view scanners?
    - Do you think better reconstruction algorithms can lead to better detection performance? If so:
        - What are the most promising areas in which to look?
        - What are barriers to moving towards real world applications?

2. How can the advances made by third parties be accelerated into fielded systems?
    - What incentives should be put in place for incumbent vendors and 3rd parties?
    - Should 3rd parties be funded by the Government directly?
    - How can projects be given to third-parties who cannot access classified information?
    - Which projects are suitable for third-parties?
    - What differences are there for academic third parties and commercial third parties?

3. What did you like about this workshop?

4. What would you like to see changed for future workshops?

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

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

7. What other comments do you have?

13. Appendix: Questionnaire responses

Question 1. What opportunities are there for developing better reconstruction algorithms?

- *What acceptance criteria should be used to determine if a reconstruction algorithm is better than prior methods?*
- *Are there differences for few- and many-view scanners?*
- *Do you think better reconstruction algorithms can lead to better detection performance? If so:*
    - *What are the most promising areas in which to look?*

What are barriers to moving towards real world applications?

Response A

I firmly believe that the image-quality metric(s) that should be developed for reconstruction (and segmentation, for that matter) ought to be task based. MTF is great for a first pass at comparing imaging systems; given a task, our metric ought to be how well we perform that task. And I believe that we have a huge head start on development of these metrics. - TSA has set the task – you need to find these explosives (or explosives categories), at this size, at this Pd and this PFA. All right, the details cannot be freely shared, but… - Matthew and Richard translated those tasks into three "shareable" ones:

- Keep sheet-like things sheet like
- Keep large, homogeneous things large and homogeneous
- Eliminate streak artifacts (metal artifacts, beam hardening, photon starvation)

And they hinted at a fourth – give up when the problem gets too hard (accept that nuisance alarms will happen). [This could be controlled in a grand challenge / initiative by not getting to that hard problem, but I suspect that to test algorithms one would want to get right up to that edge, which really means crossing it.] And Matthew also hinted at a strategy – a single algorithm does not need to solve for all threats (he said that they did ROI recons using additional information for special cases). I think that this is an important strategy, and consistent with the mantra that there is no silver bullet and multiple technologies will need to be integrated to solve the problem – in this case, multiple reconstruction strategies for multiple threats. (And Richard sort of threw in a wrench with the requirement that there will be a human in the loop for initial alarm resolution. In my opinion, the Grand Challenge Committee (GCC) punts on this requirement. Let the challenge be reconstruction with the intent of ATR; scope needs to be limited, and this seems like a reasonable cutoff, because it allows the GCC to skip question of human-observer performance.) So, how could those metrics be translated into "actionable" metrics? (I think that this is one interpretation of what is meant by the "Cloud Shrinking" metrics.) - the simulated (or experimental) data will need to include sheet-like objects (of different size, density, and thickness) to span threat and benign-object space, and a geometry that covers a couple "corner cases" may need to be included. It will also need to include large uniform stuff in different shapes and artifact-inducing material. "Clutter" will need to be included, too, but I think that these can be two separate object sets (which both need to be collected). Maybe this should be a question – is it fair to say that clutter is a big deal for segmentation, but maybe not for reconstruction? Clutter only affects reconstruction to the extent that it induces artifacts that break up homogeneous objects? - In the perfect challenge, the whole processing chain would be explored, including post-processing, segmentation and ATR, but to develop metrics for judging reconstruction, only segmentation is needed. In the perfect world, the "best" segmentation algorithm from the first challenge would be used for segmentation in the recon challenge. However, even for the first challenge, "ground truth" was defined (by the segmentation monkey?). Can that same ground truth be defined here? With ground truth defined, there is now a region of each image – the truth region – that can be evaluated on criteria that would probably be useful to a segmentation algorithm, which might include:

- Statistics on pixel intensity within the "truth" region; maybe those statistics need to be with respect to reference regions (e.g., the average value in the segment compared to the average of a water sample in the same image)
- Statistics on the streaks through the true region – are they sharp and deep, or smooth and small?
- Statistics of pixels surrounding the truth segment (to get at the phenomena of merging with other objects)

Are there any others? What other info is used by generic segmentation solution? (and here, it may be useful to get one of the segmentation experts (or all of them) to help with what image features are exploited or "break" their methods) the spatially well-defined phantom (see below), it ought to be relatively easy How about defining a phantom to test for sheetiness? Buy a Pelican case filled with foam, metal rods of various diameter and material

(and a hacksaw), a variety pack of Nalgene bottles, and the materials to use as simulants and benign objects, and ask Richard to come by and help develop a couple well defined geometries. (Having someone like Richard assist with the geometries is, in my opinion, critical – they know the space and can nudge the problem toward something interesting, and this fits with his "rules for 3rd parties and vendors". In fact, involving him with the selection of materials for the phantoms should be considered.) If possible, buy one of the explosives-simulant test kits (impossible only if CT data from objects in one of these kits cannot be released). Then collect a test scan (with a hospital system, with the system from the segmentation project?) and see if the data look like they provide the "right" test. Tweak the phantom. Create a couple geometries. The advantage of the Pelican case and well-defined objects is that the simulation / modeling people can describe these objects (the Pelican case has some structural features that may be a hassle, but it is convenient, and could be shipped to a vendor with a scanner that is willing to play). For the "challenge", a small number of geometries of the case should be collected, and multiple orientations of each one should be collected. Additional data in more realistic bags (with the same "threats" and benign objects and additional clutter) will need to be collected, too. QUESTION: does the N42.45 standard include stuff to provide metal artifacts and sheet like and homogeneous stuff? Does it allow for sufficient variation to collect a few geometries? Maybe that standard solves the problem. Shrinking the cloud: what does that mean? Sounds like a great idea (without proof that shrinking the size of the cloud is really helpful), but it is still kind of abstract (at least as it was presented in this meeting; prior ADSA's may have define the cloud better?).
What are the features that form the axis of the cloud? Just consider EDS:

- Density and Zeff are the "classic" features. It may be that they are only available for dual-energy (or multi-energy) CT systems.
- Pixel intensity (proportional to density) is a feature available even to single-energy systems.
- Shape is a feature for sheet
- Size will be a feature for bulk
- Are there others?
- Texture is mentioned – is it really exploited? Is it really a signature?

If those are the only features available, then it seems like some measure of how well those are preserved (in regions of interest) in the reconstructions ought to be the metrics. A couple thoughts on simulated vs. real data and validation:

- How far down the simulation path must you go in order to capture the physics that impacts the corner cases? Do you need to simulate scatter, for instance? Do you risk masking certain effects, or incorrectly compensating for some effects if all of the physics is not in the simulation?
- Do you really need to validate a simulation with a real system? Perhaps that is a subset of the question above, but I am thinking here that an expert can often say pretty quickly that you have it pretty much right, or you are missing some key components. The experts (vendors) are on board with the simulator and challenges, they ought to step up and offer that expertise.

Response B

1. The biggest challenge and opportunity is to build the capability of constructing synthetic images for use by algorithms so that these algorithms can be compared directly.

a. The most important criteria are bound to system effectiveness metrics. That is the performance of the system that uses reconstruction algorithm A is better because: It provides better discrimination (e.g. ROC Curve) - when integrated with the larger system. It provides enhanced performance against some other metric. At a lower level one could define tests - for instance against synthetic test data sets - that measure algorithm performance against criteria like : distinguishes between (some test items) segments a collection of "N" distinct items into "M" distinct items. Estimates of mass and volume for items ...etc.

b. That would have to be tested formally against specific criteria. There may be no difference in terms of a system level (PD PFA) metric. There are obviously differences in terms of human perception of the goodness of a reconstructed image.

c. Yes.

Especially with regards to the ability to reconstruct specific geometries of concern - an algorithm that better segments away clutter would probably permit better detection performance.

- What are the most promising areas in which to look?

Using better forward algorithms is probably the most promising area -this requires details about the internals of the device that made the scan.

- What are barriers to moving towards real world applications?

Data - especially large quantities of data that represent the reality of the luggage screening environment (stacks of 5 bars of soap, multiple toothbrushes are interesting, but rare in practice)

Response C

a. contrast, edge response, noise, artifact content

b. yes- different image characteristics

c. Yes

- What are the most promising areas in which to look?
iterative recon like MBIR

- What are barriers to moving towards real world applications?
For security- biggest barrier is need to certify and/or re-certify scanner systems. Other barrier in EDS for checked baggage is the range of possible "priors"

Response D

1. Speaking from the perspective of a security hardware and algorithm provider, rather than an academic, opportunities tend to be confined to adding specialized paths to support a new thread through the algorithm or a verification step. Recon algs are often implemented early in the development chain and necessarily "frozen" so as to not break a lot of down-stream processing. As COTS computer get more powerful, the opportunity to incrementally add special reconstructions targeting specific configurations becomes more of a reality. Also as products and algorithms mature, the time needed to go back and refine becomes more available.

a. This is tough. It's possible that tiers of criteria are needed. You can't ignore the end goal but to measure that requires a huge amount of downstream logic. You can't focus on a single slice because even if it shows deficiencies, it is possible that simple subsequent steps add so much that the combined result is superior to another approach that may have had a better single slice result. I think the criteria of choice needs to be fidelity in object building, because at the end of the day an ATR is all about getting the object, getting the right mass and drawing a red box (cube). If you put the object together, you can assume a classifier can be written to detect it. I think relying on Pd/Pfa as a metric requires too much additional algorithm work to achieve. Groundtruthing objects in 3D and scoring reconstruction in association with segmentation is the way to go I think.

b. I don't think so if you focus on object identification. You have to find and label the object. If a recon alg can make that happen better, than hooray. Perhaps you need a few canonical "hard" configurations containing a simulated threat object. Score based on the combined recon + seg ability to label the entire object.

c. If they help us find the difficult objects, of course!

- What are the most promising areas in which to look?
The thin stuff in various types of clutter. Consider targeted re-reconstruction informed by what you think you're looking at rather than a one-size fits all super-duper recon that does everything. I don't think that's achievable.

- What are barriers to moving towards real world applications?
All the usual things: time to research and implement, money to research and implement, data-sharing, computational burden, cost of the final product

Response E

1. I think there are MANY opportunities for developing better reconstruction methods. My concern is that those currently developing the algorithms have backgrounds in physics and image processing whereas these methods could benefit greatly by experts having more varied backgrounds in optimization, data analysis, and data approximation. The forward projection models are best suited to experts having computer graphics backgrounds since this is equivalent to raytracing rendering techniques. This also suggests that implementations using video hardware can be utilized to speed up overall

processing, which is also typically out of reach for the standard physicist/image processing engineer.

a. I think the main challenge here is to reduce metal artifacts. I would like to see images that have better contrast, sharper, edges, and more consistent "homogenous" regions. A method that handles metal artifacts better, should improve these characteristics. However, it is difficult to develop software metrics for quantitation of these characteristics. An artificially created phantom can act as the ground truth to provide accurate quantitation, and I think this method should be used in conjunction with real equipment data.

b. Yes. Few-view scanners are similar to stereophotogrammetry and I believe that advanced methods will use techniques developed in that area. Furthermore, since it is more challenging to reconstruct from few-views, concentrated effort in this space should directly improve many-view techniques since more data can be used. For few-view recon, this becomes a data approximation problem which is again beyond the scope of the standard physicist and image processing expert.

c. Yes. Artifacts, noise, poor contrast, etc cause MAJOR issues in the segmentation step that are best fixed at the segmentation stage. Recon problems are so severe, there is no hope for subsequent steps in any workflow. Furthermore, these artifacts introduce intensity shift/offset which affects detection algorithms since they're tuned precisely to look for certain intensity ranges.

- What are the most promising areas in which to look?
Metal artifact reduction, then contrast, then edge sharpening. Constrast is a tricky one since at lower intensities, the data type used to represent intensity plays a major role in quality. If a 12-bit integer is used, then low-intensity materials have severe contrast limitations that can be eliminated if a 32-bit floating point type were used.

- What are barriers to moving towards real world applications?
Implementation. The practical solution will be iteratitive, GPGPU based (run on video hardware), and will significantly improve image quality over existing methods. If these barriers can be overcome, then translation to the real-world will happen.

Response F

1. There are detection opportunities in new domains, for which "better" recon is a definite value. For instance, limited view cargo screening. One might argue that better recon could help on-screen resolution more than it could help automated detection. Yet, not a peep about improved OSR. ATD is already pretty good. Why not go for real improvement?

  a. Measure against known phantoms to start. Create a scaffold pipeline with ALL phases represented. Then let people be creative about fixing parts of the pipe. The overall improvement won't be there (possibly) until several joint improvements are made, but to suggest that "if only we knew what to improve" is a requirement is to require the impossible.

  b. Assuredly.

  c. Yes. Only in concert with detection improvement. But since detection is already so strong, it's a really tough battle to fight.

    - What are the most promising areas in which to look?
    separation of adjoining objects

    - What are barriers to moving towards real world applications?
    data starvation and inability to work on the "big picture" as a group.

Response G

1. There are opportunities for improvement with both analytical and iterative recon algorithms. We should not yet discard analytical algorithms, since there is still much room for improvement with only a little more computation.

  a. Acceptance criteria should be based on overall system performance, including the data acquisition, image reconstruction, segmentation and threat detection steps. We need to approach the problem holistically. Simply optimizing each piece of the chain individually is a wrong-headed approach. For example, if I built a sports car with Porsche brakes, a Ferrari engine, a BMW suspension, and a Maserati gearbox, I would not expect great performance, even though each part is separately excellent. It is the same with threat detection.

Approaching the problem holistically is not difficult. We can develop simulation tools that treat each step in the process as a "black box." In this way, recon can be optimized for particular choices of segmentation and threat detection algorithms, for example.

b. Yes. Few-view scanners have inherent limitations, since they do not collect enough views to characterize many types of objects. Mathematically, one can say that their "null-space" is larger. In common language, this means that certain objects or textures are invisible to the scanner, regardless of the image reconstruction algorithm.

c. Yes. Absolutely, but recon optimization must be done in a holistic manner, taking overall system performance into account.

- What are the most promising areas in which to look?
Analytical algorithms with shift-variant filtering are viable options that have not been adequately explored. Also, iterative sinogram restoration is a promising approach that can be used together with traditional analytical recon algorithms.

- What are barriers to moving towards real world applications?
Computational requirements are still an issue for full iterative reconstruction. At the workshop, many vendors made it clear that there is currently no incentive to increase the cost of scanners with greater computing power.

Response H

1. Quite a lot: a number of algorithms have been presented that will provide better IQ than current algorithms used in EDS. I think it is just a question of finding a good tradeoff between better performance and real time operation.

a. What acceptance criteria should be used to determine if a reconstruction algorithm is better than prior methods?

A combination of cloud performance on threats, as defined by LLNL for example, and performance on the NIST phantoms. The first is more relevant, but the latter reduce the exposure to sensitive configurations.

b. Are there differences for few- and many-view scanners?
Not clear what this means. Of course, the algorithms will need to be optimized for the two cases

c. Do you think better reconstruction algorithms can lead to better detection performance?
Yes. Better algorithms will mostly lead to lower false alarm rates, which can be traded off for better detection. Algorithms that reduce artifacts will reduce the variability that ATR needs to deal with. Algorithms that improve/preserve resolution will provide better segmentation of thin objects and will preserve the true "density" more.

- What are the most promising areas in which to look?
Metal artifact reduction algorithms, as well as iterative reconstruction ones, both for full CT and for limited views or limited angle CT.

- What are barriers to moving towards real world applications?
The incentive to do so. I have no doubt that if detection/false alarm rates were rewarded (from an acquisition point of view, for example), vendors would find very creative ways to get into their systems the ideas that 3rd party vendors and academia are generating.

Response I

1. Opportunities for better reconstruction algorithms are possible only when the manufacturers release sinograms for algorithm developers to use. This is not likely to happen because of (a) various proprietary concerns of the manufacturers, and (b) the algorithm developers who work for manufacturers will do everything possible to shut out other developers. The reason for item "b" is because of the inherent job-insecurity prevalent among the development and research engineers at the manufacturers.

a. NIST should be tasked with developing this criteria. Though the requirements for explosive detection and medical CT are different, it does not hurt to have standard reconstruction algorithms. Currently they are to some extent esoteric and based on various tweaks, many of which do not have a mathematical basis. The best reconstruction algorithm is the one that gives the best image quality.

b. Are there differences for few- and many-view scanners?
Do not wish to answer this question

c. Yes. Given a perfect image, detection algorithms can then focus on extracting the maximum object information possible from these images. Poor reconstruction leads to larger noise content in the image and the detection algorithm will have to thus work with a poorer signal.

- What are barriers to moving towards real world applications?
  1. Computing power available; much has to be done in a very short period of time .
  2. Reluctance of the TSA/DHS to enforce a common imaging format - they seem to be very deferential to manufacturers who continue to use their own unique proprietary format.

Response J

1. Improving the physics model in iterative and possibly in analytical algorithms.

a. It seems difficult to separate segmentation and reconstruction. The ultimate criterion is obviously to have higher or same probability of detection with same or fewer false positives. To see one reconstruction algorithm is better than another one, a dedicated optimal segmentation would be needed for each of them, to ensure that the results of the comparison is fair. I guess this is not feasible. Instead, one could attempt to define a series of objects with key features, together with reasonable metrics to quantify to what extent these key features are preserved in the reconstruction. That would allow quantative comparison of reconstruction algorithms. As discussed in the meeting, a simulator would be very useful for that. Such a public domain simulator would most likely become rapidly popular in the medical CT community as well.

b. I think so. For few-view scanners, the use of a priori knowledge (i.e. constraining, penalties, object models...) is essential to obtain useful images. For many view scanners, one usually needs some noise suppression, but good images can be obtained without other more informative (i.e. more specific) prior knowledge models. More informative models will do more damage when they are not valid, so for few view scanners, the evaluation of this prior knowledge is essential.

c. Yes. I would say a reconstruction algorithm is better when it is more quantitative and/or less prone to artifacts and/or more robust against noise. Such algorithms are expected to make the segmentation more reproducible and more reliable.

- What are the most promising areas in which to look?
    - better modeling of the physics
    - using energy information (dual energy, photon counting detectors...)
    - with iterative reconstruction, the constraints on the scanner geometry are relaxed. One could experiment with unusual geometries to improve the sampling. E.g. redundant sampling would reduce the sensitivity to small dense objects that stop nearly all photons

- What are barriers to moving towards real world applications?
    - detailed information about the scanners is needed if better acquisition models are used during reconstruction.
    - processing times

Response K

1. Plenty - metal artifact removal, beam hardening correction, statistical reconstruction methodology (not necessarily iterative!)

a. Need simulation toolkit and data that mimics typical threats as close as possible - then run the data with different recon algs through the entire image processing chain, including threat detection This is much better than stopping in the middle of the chain with metrics that don't represent the overall task.

b. Of course: the few-view machines will always be missing fundamental object information of some kind, especially since the objects are unpredictable - for a recon comparison, the algorithms need to be evaluated separately.

c. Yes. Of course, we need to be sure we define 'better' correctly.

- What are the most promising areas in which to look?
Refer to question 1

- What are barriers to moving towards real world applications?
Main barrier is to be able to represent the 'typical threats' through simulation - A good simulator can give you a valid comparison, provided we are not too distant from 'actual threats'

Response L

1. Advanced algorithms can help HS applications.

a. Standard datasets.

b. Yes.

c. Yes.

- What are the most promising areas in which to look?
Dictionary learning

- What are barriers to moving towards real world applications?
Funding

Response M

(no response to question 1)

Response N

1. Full-view reconstruction is quite mature nowadays, however, it is still a challenge for limited view scanners

a. speed and resolution

b. Yes, the few view scanners usually have lower resolution

c. The higher the resolution, the better the image segmentation and better classification.

- What are the most promising areas in which to look?
artifacts reduction

- What are barriers to moving towards real world applications?
metal artifacts

Response O

1. There are limited opportunities because of a lack of data. Data sets must be constructed that can be distributed to research groups.

a. Recovered mass and volume of test objects, placed in various orientations, locations, containments and clutter. These should be accurate and precise.

b. Probably. Accuracy may not be possible, but precision may be possible.

c. Yes. Improvements in artifact reduction will be useful. Non-linear processing of the reconstructed images for noise reduction and edge enhancement may be helpful (but I don't know that much about performance of current EDS systems)
- What are the most promising areas in which to look?
Metal artifact reduction seems the most important Scatter compensation Beam hardening compensation

- What are barriers to moving towards real world applications?
I think that vendors are not completely candid about all the issues they face. Maybe they are right not to be, I don't know. But it makes it harder to do a good job when one doesn't know the issues.

Response P

1. There is no "magic bullet" but an engineering problem. Working with real threat data and measuring performance at the system level should lead to identifying good algorithms provide several reconstruction algorithms -

some may be better for segmentation, some for developing features for segmented objects.

a. Pd/Pfa curve for threat classification in the presence of multiple groups of confusers. Have some confuser groups for testing that are not available for training.

b. Don't know.

c. Yes.

- What are the most promising areas in which to look?
No Response

- What are barriers to moving towards real world applications?
Lack of access to threat and unbiased clutter data lack of interest from the vendors as they do not see TSA rewarding them for better performance in the near future.

Response Q

1. There is great potential. Notwithstanding the infuriating lack of common evaluation, quite a few of the talks showed potential.

a. This is a big topic and I cannot understand why it is not addressed fairly and squarely. The ADSA meetings ought to be used to develop such criteria. My own view is that the effect of metallic objects is the over weening problem so it would be useful to generate a defined task based on some of the existing bags. The effect of metal objects is to introduce unwanted striations so a measure of success would be to alter the homogeneity of the underling image. There are many homogeneity measures - entropy being the most obvious but we could think of others. I would certainly enjoy working out the alternatives.

b. Not sure I know enough to answer this question. Obviously I would not wish an evaluation that varies by machine parameters.

c. Yes. It is kind of self referential. By better that is what I mean.

- What are the most promising areas in which to look?
Metal objects.

- What are barriers to moving towards real world applications?
Lack of commonly agreed evaluation

Response R

1. This appears to be a fairly mature technology, with only incremental improvements on the horizon

a. Observable features must be mapped to desired aspects of interest, and the degree to which the reconstruction correctly presents these features is the accurate metric. Determining these features is the hardest challenge.

b. yes

c. Yes. Unless the interpretation only adds noise, better algorithms improve performance.

- What are the most promising areas in which to look?
No Response

- What are barriers to moving towards real world applications?
Inherent inability to define relevant features which are observable.

Question 2. How can the advances made by third parties be accelerated into fielded systems?

- *What incentives should be put in place for incumbent vendors and 3rd parties?*
- *Should 3rd parties be funded by the Government directly?*
- *How can projects be given to third-parties who cannot access classified information?*
- *Which projects are suitable for third-parties?*
- *What differences are there for academic third parties and commercial third parties?*

Response A

I spoke with two “reconstruction” academics (one on “soft” and one on “hard” money) and asked what a PhD student would cost (burdened and including mentoring time), and they both came up with a number on the order of $60-80k. So a 4-year commitment to three students would cost on the order of $1M. Is that on the order of magnitude of what S&T is willing to fund? Could a small program be built around reconstruction (or segmentation or ATR) in which:

- S&T works with the vendors to define a targeted BAA on a problem. Maybe this has mostly already been done in the definition of the segmentation and reconstruction grand challenges; most of the input is there, at least. The BAA call is explicitly for one student and mentor (i.e., the intent is not to fund your whole group) and the project will also involve an (unfunded by DHS) industry mentor, which will encourage the proposers to reach out to vendors at the proposal stage.
- Academics propose against the BAA; S&T (and vendors?) review the proposals
- The projects are linked through an annual ADSA-like event. And maybe other outside parties are invited to these events, so that it is not only the vendors that were included in proposals that reap the benefits, and other 3rd parties can get a hint on direction of current interests.

Response B

2. Third parties who publish their work in open literature should expect that work to make its way into commercial products.

a. Vendors should be incentivized by the acquisition system to be more open to data sharing agreements.

b. Yes, at the basic research level.

c. Synthetic data sets. The ability to generate very large volumes of representative data at various stages of processing is an enormous gap - solving it would lead to advances in the field.

d. Generating large scale realistic representative data sets would be an excellent area for (e.g a university with a lot of compute capability).

e. The business incentives are different. B 2 B relationships are much easier - more flexible. Universities can be difficult to work with - one size does not fit all.

Response C

a. Funding

b. Yes better Govt->OEM->3rd party

c. most recon work can be cleansed into domain

d. feasibility studies, concept development

e. - different motivations, so need
- commercial terms
- IP ownerships/rights.

Should be some incentive for improvement in operational FAR.

Response D

2. Hire them to do just that. Identify a specific need for an incremental improvement and just do it.

   a. The best incentive would come from the government, to somehow allow vendors to be differentiated based on detection and false alarm performance, and to have sales depend on performance. Vendors have to sell machines to survive. The only incentive that makes sense is one that would or could result in sales. The other alternative would be to treat the algorithm performance achievements as a national asset and facilitate its continuous improvement through grants. But for vendors at least there still has to be a link to sales.

   b. Doing so would be a move toward the "national asset" model alluded to above.

   c. Targeted problems using simulants.

   d. This is too vague a question because it depends on the 3rd party. Theoretically any project, no matter how big or small, could be specified, and a 3rd party entity could be established that is able to achieve it.

   e. Many. Most importantly is the answer to the question, "what's in it for them?" Academics have a set of goals that are usually publication-centric. Commercial 3rd parties are more driven by profit. Time is less important (generally) to academics than to commercial entities.

Response E

2. For incumbent vendors, they will need to be willing to change their existing systems. This is a MAJOR hurdle to overcome since change this early stage step has significant impact on every follow-on step: segmentation and detection primarily. However, that also means that improving this step can have a significant POSITIVE improvement to all subsequent stages as well. I think vendors may be willing to outright buy licenses to complete recon algorithms that can be directly incorporated into their systems. Which hardware? How much memory is required? What kind of video hardware requirements? How much time per recon? Etc.

a. This is challenging since you first need a quantitative metric to guage image quality. Then, once a ranking of methods can be established vendors can choose which to incorporate. I think the most practical method to encourage incumbent vendors is to PAY them to include BETTER recon methods into their EXISTING equipment and to include some SUPPORT to insure their CERTIFICATION status is not put at risk. I think this can only come from DHS. Meaning, I think DHS will need to foot the bill for upgrading vendors. Perhaps there can be a list of "approved" recon methods and vendors must choose at least one and DHS will pay for retrofitting existing systems with the algorithm. Thus, DHS would pay the vendors costs for retrofitting and also pay the 3rd party developer who created the new recon method. With this in mind, one could consider employing a certification process not just for the detection step, as it is currently done, but for certifying every key step along the way: recon, segmentation, AND detection. And vendors will need to use certified components (possibly from 3rd parties) for each step.

b. Everyone is in a safe "holding pattern" right now waiting to see what DHS/TSA are going to do. No incumbent vendors are willing to risk their current market share by changing their existing systems. Thus, the only practical mechanism for 3rd parties is to be directly funded by DHS.

c. Collect exemplar data in a non-classified manner, similar to how the CT segmentation project was done. Or, give promising 3rd party vendors limited clearance to be able to work on this data. They don't need to be fully privy to the details, just enough to get the work done.

d. All.

e. Academic third parties have major limitations in developing practical commercial-quality "modules" that can be incorporated into vendor systems. They may be able to develop a fancy new algorithm, but it takes professional software developers to build implementations that can be used in commercial systems. I don't think licensing issues are insurmountable in either case.

Response F

2. Prove that they are, in fact, advances. I've heard many claims, but the segmentation workshop algorithms were relatively inconsequential in terms of improvements (if it had any at all). I suggest working on an unsolved problem, rather than trying to "improve" one that already exists. This whole workshop pre-supposes that ATD is not already a solved problem. I think that's not a valid pre-supposition.

   a. The opposite of today's environment, where there is 100% risk and no value.

   b. Yes. However, the gov't needs to get its IP rights less stringent.

   c. Classified isn't the problem. Export control (and SSI) are. So, create non-SSI requirements.

   d. Directed ones. Open research doesn't seem to work here, because there cannot be open discourse about what's already been done.

   e. No Response

Response G

2. DHS and TSA need to develop comprehensive funding mechanisms that encourage vendors and third parties to collaborate. At present, the vendors do not have resources for funding third parties. Moreover, they are overly protective of their intellectual property.

   a. To reiterate, DHS and TSA need to develop comprehensive funding mechanisms that encourage vendors and third parties to collaborate. The current system is not broadly known and it is much too limited.

   b. Absolutely. The vendors do not currently have enough money to foster collaborations with third parties on their own. The companies are simply too small to allocate money to R&D that might not pay off immediately.

   c. Much can be done without classified information. We can develop sets of phantoms that display common problems and weak points that are already in the public domain.

d. Development of simulation tools and algorithms. Hardware development is best left to the vendors.
e. Academic third parties can often operate more cheaply than commercial third parties. However, academic third parties generally seek a larger time-commitment, whereas commercial third parties can deliver results quickly.

Response H

2. See my previous answer: incentives for vendors that reward better detection performance. Today acquisition decisions are made with no consideration for detection (once a system passes certification), as we were told during a contract debrief.

a. The incentives can be of two types: 1. Funding of research: this would be especially beneficial for academia and 3rd parties but it would not necessarily needed for vendors (2nd parties) if the next incentive is in place 2. An acquisition system that rewards better performance (detection/false alarm) through a tiered pricing structure.

b. Yes. It is important for the government to have something at stake in this process, and it is important to fund research for academia and smaller businesses.

c. One possibility is to couple the third party with an institution (a vendor or a national lab for example) that has access to the classified information. In this way, this institution can act as a buffer and filter (the details would depend on the specific task/project) For example, take the development of a new reconstruction. The third party would have access to, for example, the image of the CT NIST phantom, and would be told to optimize the algorithm for the metrics measured by that phantom. At the same time the institution would have a set of critical bags where the algorithm would be measured. Once the institution receives the optimized algorithm, would evaluate the performance on the critical bags and provide feedback to the 3rd party (for example: decrease a bit the resolution to improve noise...or something like that). 2 The method described above can work, but it is not the most efficient to get progress. Alternatively, the government should consider more to allow limited clearances to individuals working in this field.

d. Pretty much all of them

e. Commercial third parties eventually want to make money. As such, funding is an incentive but it is not sufficient. The government should make sure that that there is a plan/strategy in place for commercial third parties to transition their technology/products to vendors.

Response I

2. 1. With the current organizational and political set up there is no way that third party advances can be put into fielded systems without a manufacturer buying the third party. 2. The whole DHS/TSA-Industry liaison is geared to preventing small third parties from doing business with either. DHS/TSA has made it very hard for small companies to get any contract from them, unless it is in the form of a subcontract to a larger company. Furthermore, SSI requirements makes it impossible for small business to get the required information for them to advance the technology.

a. 1. Force manufacturers to spend 20% of their R&D budget subcontracting to small companies. By small companies I mean businesses with less than one million dollar per year revenues. 2. TSA should remove all this Dun & Bradstreet requirements. Registering with D&B is mandatory. Why should it be? All it does is make start up companies look financially non-viable. The government should not be making registering with a private organization like D&B mandatory. If they are interested in the financial status of the company they can ask for income tax returns.

b. Yes. The current system forces small companies to be totally subservient to large companies. During ADSA07 it was apparent that even the Northeastern University researchers and staff were only interested in talking to large companies. They were not interested in talking to small companies. Closer collaboration between universities and small companies would result if the Government funded small companies directly.

c. The Government should provide a methodology for this. It is always the individuals that protect the classified information, not the company. Furthermore, most of what passes off as classified information is widely available on the internet and it makes no sense to classify either detection or reconstruction algorithms as secret etc.

d. 1. Systems engineering 2. Generation of specificiations for systems, detection, reconstruction and image quality 3. Graphical user interfaces 4. Algorithm development

e. Please see answers above.

Response J

2. (I am from the medical community, I have no experience with systems for HS) For evaluating new reconstruction algorithms on real data, one needs to have detailed information on the system. In the medical community, not all manufacturers are willing to share those, even under non-disclosure agreements. I guess this problem will even be larger in security applications.

a. No response.

b. For the medical community I would definitely say yes, because otherwise longer term (more fundamental) research may not get financed. I don't know if this also holds for HS.

c. Depends on the problem that must be solved. I guess this problem will be hard to solve for something like the detection of a new and particular type of threat or so. For reconstruction, I guess this is not a major problem. The design of CT scanners may be a company secret, but would probably not be classified information. A reconstruction algorithm that works really well for one scanner would probably also work well for another slightly different one. We work on CT and microCT obtaining similar results, and same for our research in emission tomography (different type of PET and SPECT systems). So I think useful reconstruction research is possible without the need for revealing very sensitive information. Therefore, useful CT reconstruction can be done without the need for revealing all details.

d. see above.

e. I am academic. If the project would fit in my ongoing research projects, and if at least some of the results can be published, I might need less money to do it, because part of the project could then be done by already available researchers. If publication is not possible at all, the work would have to be done by someone who would then not be working on a PhD. It would be a bit harder to find such candidates, and it would be impossible to find additional money outside the project. As mentioned in the workshop, academic partners probably tend to be better for longer term research.

Response K

2. Get the funding from DHS to allow third parties with advanced experience to work with the vendors directly, applying their advances to fielded systems, sharing and/or licensing IP as appropriate

a. As stated above, make sure funding and fair and appropriate assignment of IP is provided For academia, insure publication can be supported by appropriate substitution of 'real' threat material and assigning IP appropriately as stated above

b. Yes. Depending on the project, this could be very appropriate. For example, generating a common base of evaluation tools and data, including simulation software to define and generate threat phantoms would be a very important project that might be best funded by the Government

c. 1) Work with the vendors who have access to the classified information, but can work with the third party 2) In general, 'actual' threats substituted by 'equivalent' threats should allow third parties to work on the recon and image processing issues without being privy to the classified information

d. By performing the above, a rather broad set of projects should be suitable for third parties, including system design (working in collaboration with a vendor or an SBIR funded effort as a start-up), reconstruction, image processing, threat algorithms, and simulation and evaluation tools.

e. Academic parties need to have their IP negotiated and handled by their technology office which likely is quite different than working with commercial parties Journal publications are of higher priority for academic parties Grant monies may be easier to acquire through a joint academic effort than a joint commercial effort. An academic third party's contract would be negotiated by an office of special projects rather than directly with a consulting team or commercial third party, which is probably a simpler process and can be focused better to a specific project need.

Response L

2. Funding

a. Funding

b. Yes.

c. Simulated datasets.

d. Recon.

e. Academic 3rd parties need funding more urgently.

Response M

No response.

Response N

2. IP protected alliance between a third party with a vendor.

a. IP protection and profit sharing

b. No. This will turn vendors away, vendors don't want to be pure hardware suppliers.

c. The third party should get clearance, perhaps with the help from the Government.

d. Reconstruction and generic segmentation

e. academic third parties should be converted into commercial third parties.

Response O

2. No Response

    a. No Response

    b. No Response

    c. Maybe it is possible to create similar problems (eg simulations/medical). If third parties want to publish, I dont see how the issues (eg image quality problems) can be kept undisclosed unless they are applied to another domain, and no mention of luggage is made.

    d. Projects that can be disguised as other projects that they can publish. For every security CT problem, create a problem in another domain (medical CT, optical imaging, photography) that the project can be applied to, so they can publish it.

    e. No Response

Response P

2. provide datasets at SSI level

    a. forecast future acquisition and requirements. Provide clear explanation how performance quality and cost will be weighted

    b. Yes. Provide competitive environment by having separate RFPs for exploitation systems.

    c. match performers so that algorithm developers work jointly with companies who can test in classified environment

    d. most decoupled from the hardware - classification, segmentation,

    e. commercial 3rd parties need different type of contracting and incentives. Current grand challenges require for a lot of upfront labor for no apparent benefits. this works for grad students but not for businesses contracting: SBIR topics, for example, on CT classification. Consider "rapid innovation fund" RIF, a recent program focused on transitions incentives; provide future acquisition opportunities where DHS buys exploitation systems from 3rd parties or at least promotes integration of 3rd parties with vendors. These incentives need to be known in advance to motivate 3rd parties to participate.

Response Q

2. It will happen. You need multiple researchers, multiple vendors and a competition for quality. I have spoken to some vendors who believe that quality is not properly incentivized by the TSA. If so, there is a potential problem.

a. Well I work in a university. I attended this meeting, despite rather discouraging discussions with a vendor previously, to see if it was worth carrying on with work in this field. The answer is no. There is no funding on the table, and right now, the vendors are not really interested. So that leaves us with the academic gains - what publications could result? Not many because the data are not in the public domain, there is restricted competition from other universities. So the field is academically dead.

b. Yes. Actually I do not care who funds us. But I think lack of funding is a problem.

c. You either have to develop surrogate problems. Or, as in the UK, you have to work with a subset of trusted partners.

d. All.

e. Academics want peer acclaim and publication. The current format does not really provide that.

Response R

2. No Response

a. No Response

b. Yes. To ensure leaps in technology development, new work must not be encumbered with short-term, product-based, IP-restricted funding to third parties.

c. Cleanse the information of its classified aspects so that uncleared investigators can work on fundamental research. This is acceptable to both those who specify the large technological problems, and those who solve them

d. Basic research, fundamental science, new modalities, new algorithms, computational experiments, parameter studies.

e. Academics can work on higher risk projects, and they publish their results. Thus, academics boost the technology for all involved in the technology development.

Question 3. What did you like about this workshop?

Response A

The themes of morning to afternoon to next day were pretty clear this time. Not that they have not been in the past, but this time the themes were really clear. Doug's talk was great – this seems like work that was overdue; it could have been the preamble to the first workshop.

Response B

This is a rich and dense workshop. We cover a great deal of ground in a short period of time. Many views are represented.

Response C

Focus of presentations on recon w'examples of improvement.

Response D

Networking with so many key people in the security industry - great coming together of government, academia and industry.

Response E

Everything. Good discussion. Good links between recon problems and how they cause problems in follow-on steps such as segmentation. And I also liked the candid discussion about involving 3rd parties.

Response F

Better openness about the discussions.

Response G

The overall program was much better than ADSA 4. The organizers did a great job by including speakers on the topics of image quality and segmentation.

Response H

The interactions.

Response I

It gave me a chance to meet a few people in the field.

Response J

Relaxed atmosphere with many discussions. The group stays together for lunch and dinner, which is good for discussions and contacts.

Response K

The networking and more open sharing of technology and requirements.

Response L

Discussions.

Response M

Open interaction format, Government perspectives.

Response N

Networking opportunities.

Response O

It was organized well. People were supportive of each other, and the criticisms were constructive. I don't think this was always the case in ADSA workshops, maybe this time there were fewer vendors…

Response P

No Response.

Response Q

I really commend the compressed format. Northeastern are very hospitable and Boston is an excellent location. And I particularly enjoyed the talks from the vendors and from Vincent Eckert - it's really nice to hear about problems from the horse's mouth.

Response R

Open exchange of ideas.

Question 4. What would you like to see changed for future workshops?

Response A

One of the problems with brainstorming – maybe a better term would be free-form suggestion – is that you get a lot of "wouldn't it be great if we could do this, and then that would happen, and …" and there is not a lot of concrete (or "action items") at the end. I do not think that the free-form discussion should end; it seems valuable. But it is frustrating to hear again (from the same people) that we ought to build phantoms, or that we need system details (or that we ought to define image quality on a task basis!!). Maybe these things get catalogued, acknowledged in some way so that we move on quickly.

Response B

I would like to see a workshop at which DNDO provides a comprehensive overview of the direction this field is headed, something like a "concepts development" or "deep futures" workshop.

Response C

Nothing - these are extremely well organized and run.

Response D

Can't think of anything, thought it was great.

Response E

Everything. Good discussion. Good links between recon problems and how they cause problems in follow-on steps such as segmentation. And I also liked the candid discussion about involving 3rd parties.

Response F

Don't have Harry & Carl tell us what we've proposed going forward, when it's clear that's not what we said. Have a few break-out sessions. Smaller is better for progress.

Response G

I would like to see more leadership from DHS on the subject of supporting third-party involvement. Also, more talks on segmentation and threat detection algorithms would be nice.

Response H

No response.

Response I

1. I was surprised to see people marketing their firms on this workshop on the second day. This should not be done. 2. The DHS/TSA representatives should be made to make specific comments about how they can help. Currently they just mouth platitudes and broad generalities. 3. The DHS/TSA and Northeastern staff should be accessible for discussions with small companies. They seem to be only interested in talking to large companies.

Response J

A disadvantage of starting with the conclusions is that the speaker then gets questions that would be answered by the presentation anyway. I think this results in a somewhat inefficient use of the presentation time. In the list of attendees, I would add the e-mail addresses (I guess almost everyone would be happy to have their e-mail in that list). That could encourage post-workshop e-mail discussions.

Response K

Perhaps use the workshop to define individuals or teams that can lead common efforts and how these efforts should be funded - right now, it is not clear who should take up the lead in a common effort: e.g. if we are to have a common simulation and evaluation capability, who will lead, manage, and take ownership of this so that it can be properly funded, maintained, and executed?

Response L

Discussions.

Response M

Questions (including this survey) tend to be competition sensitive, which limits contributions from established industry to open discussions.

Response N

More commercial third parties involvement, more product based solutions.

Response O

Introductory speeches should be shorter. (People can lose focus in the technical presentations if they have been sitting too long).

Response P

Focus on classifiers, fusion, results on real data. Separate workshop in SSI environment.

Response Q

It should be mandatory to have a talk on evaluation.

Response R

No Response.

Question 5. Do you have recommendations for future workshop formats?

Response A

There were a number of topics mentioned (but I only wrote down comments on a few):

How would the "body bombs" topic differ from ATR for AIT systems? Are you considering detection modalities (IR imaging, ultrasonics) that would not otherwise be considered in another AIT workshop? It is not clear to me that the body bomb would have different signatures than you would have for other AIT detection tasks. Perhaps a BB discussion (part of a day) at an AIT workshop would be warranted, but it does not seem to deserve a whole workshop (unless I am really missing some portion of the detection space). - Video analytics would expand the group, especially on the vendor side. There are groups at PNNL that have video analytic projects (for JIEDDO, DHS) that would be very interested in this topic, but dilution of ADSA energy with another topic may result in loss of momentum from current topics (CT, AIT, data fusion).

Cargo – so the deal with cargo is that the package is bigger, but the threat size does not change dramatically, which makes the problem much harder. It also gets people thinking of probing with other particles (mostly neutrons, but the muon people show up, too). And it turns out that most of the photon and neutron signatures have been explored by the FAA / TSA going back to the 80's if not earlier. If ADSA goes down that route, I would suggest coaxing someone like Lyle Malotky to give a brief history of the types of systems explored, or the physics exploited, by the FAA in the past.

SNM – different set of signatures. Still have (really-high) density and (really-high) Z, but you also get the spontaneous- and induced-emission signatures. I think that this would have to be coordinated with DNDO or NNSA to be done efficiently.

Next-generation checkpoint – sort of a superset of the fusion problem – how can we coordinate all of the information gathered at the checkpoint and use it efficiently? Perhaps this was covered at the last two fusion meetings, or perhaps this is part of the video-analytics topic area. I think that many of the usual ADSA suspects would be interested, but there should be some new people as well.

How about a meeting to launch the reconstruction challenge? Realistically, it is going to take a few months for a small group to come to consensus on things like phantoms, preliminary metrics, scanner, simulation criteria – all the details necessary for the recon challenge. What if the first pass at all that was complete in time for the next meeting – including a couple of data sets that could be discussed, maybe even downloaded to everyone's laptop – and the rules (and reasoning) were to be discussed with the possibility of change? (So a small group makes the preliminary definitions, rules, etc., but then the larger group can weigh in, rather than a large-room-free-for-all rule-making session.) The deadline for proposals could be a few weeks after the meeting, time enough to get the data and proposal rules out to outsiders as well. (Hmmm, of the 5 groups that were funded last time, how many had no previous connection with ADSA?)

Response B

I really believe the format is well balanced - nearly ideal.

Response C

The student poster session before dinner was excellent! Continue.

Response D

Shorter survey!! This is taking me a long time ... Really, the workshop format was perfect.

Response E

I think it's structured fine.

Response F

Fewer speakers.

Response G

The overall program was much better than ADSA 4. The organizers did a great job by including speakers on the topics of image quality and segmentation.

Response H

No response.

Response I

- More breaks
- Fewer speakers
- More planning is needed that we all feel we are participating. Small businesses and consultants feel left out. Presentations should have more content - this year presentations were really thin in content.

Response J

Relaxed atmosphere with many discussions. The group stays together for lunch and dinner, which is good for discussions and contacts.

Response K

Workshop is of about the proper size and the number of speakers is ok - however, it would be great if there would be a way to have 'breakout groups' identified in the course of the workshop such that, e.g., third parties can discuss potential collaborations directly with vendors more formally, rather than by 'serendipity' in the course of the refreshment and dinner breaks.

Response L

- Smaller size
- Focused working groups

Response M

No response.

Response N

- More breaks
- Focused working groups

Response O

- Focused working groups
- Keep the introductions short.

Response P

- Focused working groups
- tables in front of some chairs

Response Q

Focused working groups.

Response R

No response.

Question 6. What topics would you like to see addressed in future workshops?

Response A

No response.

Response B

- DICOS
- Synthetic data and test data sets

Response C

DHS S&T scatter imaging initiative discussion.

Response D

- Cargo
- Stand-off - personnel
- Third party - development and deployment
- Body bombs
- AIT (MMW, XBS) reconstruction
- security checkpoints, especially aviation - whole solutions; data mining and apps to security

Response E

- Cargo
- Third party - development and deployment
- DICOS
- AIT (MMW, XBS) reconstruction

Response F

- Special nuclear materials
- Cargo

Response G

Third party - development and deployment.

Response H

- Special nuclear materials
- Cargo

Response I

- Third party - development and deployment
- DICOS

Response J

No response.

Response K

- Third party - development and deployment
- Identification of 'breakout groups' as discussed in the previous question

Response L

- Cargo
- Stand-off - vehicle
- infrastructural imaging

Response M

No response.

Response N

- Special nuclear materials
- Cargo
- Third party - development and deployment

Response O

- Cargo
- Body bombs
- AIT (MMW, XBS) reconstruction

Response P

- Stand-off - personnel
- Stand-off - vehicle
- Video Analytics
- Third party - development and deployment

Response Q

Video Analytics

Response R

- Stand-off - personnel
- Stand-off - vehicle
- Body bombs
- AIT (MMW, XBS) reconstruction

Question 7. What other comments do you have?

Response A
I think that you have read enough.

Response B

Thanks for another excellent workshop.

Response C
Discussion from Matt Cobey did not agree with any near-term practice at TSA. More like what they wish it were? Or their perception of reality.

Response D
Thanks for a great workshop. Please make a shorter survey next time :)

Response E

It's one thing to have a workshop to discuss change. It's another to actually have change.

Response F
Amazingly, when you get a room full of reconstruction experts, they think that recon is the problem that needs to be solved. How about adding expertise from further afield?

Response G

No response.

Response H
We are at the 7th workshop, and the incentives are still missing...soon people will start to ask themselves why they should invest their time in these workshops.

Response I
1. The goal of the organizers is commendable. 2. Small organizations should also be consulted during the planning of ADSA08.

Response J
No response.

Response K

Looking forward to the recon challenge - This is where simulation and phantom development would be very helpful as discussed earlier in the questionnaire. By learning from the effectiveness of previous workshops, another iteration through these topics should greatly benefit the generation of real, effective collaborations.

Response L

Funding mechanisms to make real progress.

Response M

No response.

Response N

No response.

Response O

It will be nice if the proceedings can be available soon.

Response P

No response.

Response Q

No response.

Response R

No response.

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
ADSA07	Seventh ADSA workshop held in May 2012 on reconstruction algorithms for CT-based explosive detection equipment
ADSA08	Eighth ADSA workshop to be held in October 2012 on automated target recognition (ATR) algorithms
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
BHS	Baggage handling system
BIR	Baggage inspection room
BLS	Bottle Liquids Scanners
CAT	Credential Authentication Technology

Term	Definition
CCL	Connected components labeling
CERT	Certification testing at the TSL
CNR	Contrast to noise ratio
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
DFT	Direct Fourier Technique
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.
EDS	Explosive detection scanner that passes TSL's CERT.
ETD	Explosive trace detection
EXD	Explosive detection directorate of DHS
FA	False alarm
FAT	Factory acceptance testing
FBI	Federal Bureau of Intelligence
FBP	Filtered back-projection
FDA	Food and Drug Administration
Gordon-CenSSIS	Center for Subsurface Sensing and Imaging Systems, a National Science Foundation Engineering Research Center at NEU
GT	Ground truth
HME	Homemade explosive
IED	Improvised explosive device
IMS	Ion mobility spectrometry
IQ	Image quality
IRT	Iterative reconstruction
LAC	Linear Attenuation Coefficient
LLNL	Lawrence Livermore National Laboratory
MBIR	Model based iterative reconstruction

Term	Definition
MMW	Millimeter wave
MTF	Modulation transfer function
NDA	Non-disclosure agreement
NDE	Non-destructive evaluation
NEMA	National Electrical Manufacturers Association
NEU	Northeastern University
NIST	National Institute of Standards and Technology
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
QPL	Qualified products list
QR	Quadruple resonance
RFI	Request for information
ROC	Receiver operator characteristic
ROI	Return on investment or region of interest
SAT	Site acceptance testing
SNM	Special nuclear materials
SNR	Signal to noise ratio
SOC	Stream of commerce
SOP	Standard operating procedure
SSI	Sensitive security information
SSP	Slice sensitivity profile
TBD	To be determined
TRX	TIP-ready x-ray line scanners
TSA	Transportation Security Administration
TSIF	TSA Systems Integration Facility
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
Zeff	Effective atomic number

15. Appendix: Minutes[3]

Minutes: Day 1: May 15, 2012

Carl Crawford: Good morning, and welcome to ADSA07.

(Call to Order slides)

Carey Rappaport: Unfortunately, Michael Silevitch is feeling so poorly that for the first time in 13 years, he is unable to attend this ALERT event. Hopefully he will be back tomorrow.

Doug Bauer: I'd like to add my welcome to each and every one of you who is here. We are very pleased by the communities that you represent and we hope that you will make individual partnerships, make connections with students during the coffee breaks and elsewhere. What makes this seventh workshop very important is that as we discuss issues like reconstruction as it relates to CT-based technology, we come face-to-face with something that we have punted on in the past and need to punt on no longer. How do we gain access to the data in security applications to help safeguard against real threats, including the family of homemade explosives that we have only barely begun to deal with? In order to get access to that data, we need a trust between the government, third parties and vendors. How in the process of looking at real problems with real threat data with real machines that are deployed, can we concurrently protect the nation's security (used in a broad sense) and make progress with respect to introducing the innovation that we can bring in through careful negotiation and agreements. We can lift the curtain so that security applications, as in the medical applications that we use each day, we make substantial progress on higher detection, lower false alarm rates, and keeping throughput the same if not higher.

Laura Parker: I work with Doug and ALERT, we're at the explosives division at DHS S&T. Doug and I are trying to marry more students with vendors. It happens naturally with ALERT, we also want to help foster more

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[3] Inaudible or missing portions of the minutes will be indicated in parentheses as (???).

postdoc and graduate internships. Please come see me during this event if you have things and opportunities you can bring up to us.

Richard Bijjani: When you say this is an area of interest for DHS, what does that mean? Does that mean it's sort of a matchmaking thing?

Laura Parker: That's a very good question, it won't be immediate, but we're definitely trying to explore DHS S&T fellowship programs which are open to industry also.

Carl Crawford: LLNL is hiring.

Matthew Merzbacher: We're hiring, summer and permanent (Morpho).

Doug Bauer: I have resumes to hand out too.

Carl Crawford – workshop objectives

CC: So the question essentially is, how do we make these images better? In the past we've talked about doing reconstruction. We moved on with segmentation first. (Explains reduce cluster size diagram)

Harry Martz: We're going to talk about recon today and how to score recon and segmentation. It's very difficult, everyone has their own metrics. What will be very useful is to figure out how to do it independent of those others. We did it right the first time but we did it after the fact. If we do it up front, how do we start it? So what are the features? Which features do we use? So we can do a scoring without going through the whole process. And that's the key, figuring out how to do that.

Simon Streltsov: I think you always need to think about scoring in the context of the overall problem. Depending on how you do the next step, your reconstruction, perhaps you want several reconstructions at the same time. You have to consider your overall goal. Do you have to segment in parts? It depends on what's your final thing, what's your false alarm?

CC: We're talking about computational intent here, not how long it takes. And Simon brings up a good point that different algorithms could be optimal for different situations.

AF: One thing vendors have to be very aware of is that when we take data sets, the physics features are very consistent with what they're going to be tested on and there has to be a lot of care in whether you use.

HM: It's difficult but important to have that discussion. I don't know how many times we've done reconstructions, and you give it to a person who's going to segment that, and they smooth it. So if you have x reconstruction processes, y ATDs, that gives a very complex space. So maybe you iterate back and see what those metrics would be.

RB: One of the main issues that seems to be in wide agreement is that you choose what recon you're going to do, then you do segmentation on it on the ATR and so on, and then it's going to drop because you are losing the image that everything is trained on. The original question is how do you quantify the recon? You have a great recon with high contrast and so on… it's true if you're looking for a cow but not if you're looking for a sheep. So vendors come up with a compromise and look for everything. So if we can agree our problem is metal artifact reduction … we're never going to find something that works for everything. But if we can agree what to narrow it down, target applications, it could move the process forward a little faster.

XP: This touches on the core of the issue. There has to be task-specific guidance on reconstruction. The endpoint has to be something based upon design.

CC: In security everything is traditionally controlled by one vendor. In medical imaging bits and pieces are produced by different vendors. So how do we break this up? We had another underwear bomber attempt this week. They're still trying. The bottom line is that progress is being made. (Progress with Tactics slide)

Frederick Noo: We are hosting a CT conference this June 24-27. There will be 97 presentations covering all aspects of CT and there will be a special session on DHS.

CC: Just Google "Noo" and "CT". Unfortunately, there's still not enough money, the vernacular is difficult, and classification is an issue. I think that all the feedback I've received, the #1 purpose is the hallway conversations, the meet and greet, and I believe that.

(Discusses ADSA reports and CT segmentation reports)

Jeff Stillson: Who won?

CC: I think industry won because 5 groups developed very clever algorithms.

JB: We all ended up profiting from the experience.

CC: Who was the best? We're going to sidestep that. We talked about that, but each one had strengths and weaknesses.

HM: It may not be that each one is a different threat. It may be the same threat that has a variance from homogeneous to heterogeneous.

CC: Please note that this is a public meeting, no SSI or classified material. (Tells Man from Milwaukee story.) The point is that you have to raise your hand and ask for help and you'll get it. We don't want to have to strip search everyone!

JB: The segmentation workshop, which was birthed out of ADSA01, took place because a vendor had the wherewithal to give us the data that allowed the segmentation information to be provided. I find myself in the same position again. We need data for the reconstruction effort. You can't apply your trade without this data. I need these data and I need the corresponding projection data so that we can improve the quality of the results in the reconstruction area. Don't be surprised when I approach you and ask you to help. We'll provide the protections that you want so that this community can improve our overall performance.

RB: A lot of the HMEs we're worried about right now are also difficult. There are more aspects than just resolution.

AF: The way I think about it is what false alarm rate do you incur for detecting something? That has to do with the overlap and a lot of these HMEs are more likely to fall into that category.

CC: Every time you add a threat to the threat list the difficulty goes up. So as more threats are created we need to increase our abilities and the capacities of our machines.

KB: One of the technical things I've seen is that operationally, false alarm rates in Asia, etc. are double what they are here. I think that the false alarm part is a significant topic.

CC: When I'm talking about detection I'm also talking about false alarms. You can't talk about one without the other.

KB: Even though they have the same scanners, it seems like the false alarms internationally are much higher.

SS: What is the reason for this false alarm rate?

KB: I think bag contents are a lot different than what you see here. I think a lot of these algorithms are based on luggage carried here but a lot of the threat is coming from overseas.

CC: So we're beginning with talks about what does it mean to make a better image?

<u>Matthew Merzbacher</u>

MM: Improved any of the several parts of the ATR. We don't need the world's most beautiful false alarms. As long as the viewer can see that it is an 'orange' it's fine.

Both objects need consistency.

??: Do you need an image at all?

MM: You do for a screening process. It's a multi-tiered process. In the U.S the process is scan a bag through a CT device, if the alarm goes off, then the bag goes to a baggage inspection room. In other countries, it might be a five step process, with a projection x-ray, operators at level 2 can't, it goes to the CT. etc...

MM: CTX 9800 or CTX 5800, which is safe (from presentation)

??: Does red mean alarm?

MM: Red means something in the threat area.

MM: I would like to tell you about ATR and what we'd like to do. This is at a glance, high CT stuff, we deal with separately. We then clean up our objects, and we calculate features. We start with our objects, and after the cleanup we get a block of an explosive, and then break the objects down, using Histogram techniques. You might take two objects which are connected together, and break them into two. We end up with one object, and we clean up the pieces that are left over. The point of reconstruction is to prove that this is possible. The error is that these need cleaning around the boarders. A few are listed.

If we want to improve ATR we need to improve these steps …

??: How do you fix it?

MM: If we can't do good sheet reconstruction, we have to go fix our sheets.

??: It's important to note that if you fix or improve one step, it directly impacts the other steps.

MM: Exactly. It might help to have beautiful false alarms, but it's not necessary.

Things that are touching need to look different, and can't cross-contaminate each other. Containment creates problems.

??: What do you mean by that?

MM: Both objects need consistency, if you want to detect a sheet; thin objects need to be separated from the bulk objects.

??: Any thought about what the thin object looks like?

MM: If they're thin objects, they need to be distinguishable; we need to re-reconstruct that area to solve that problem.

Mike Litchfield: What would you do differently?

MM: We do scatter correction, and we do correction we could not normally do for computational reasons.

??: What metrics would you want to apply to them?

MM: I don't know. We do it by taking data collections, and taking a thousand difficult models and some of them we give up on. We can or can't fix it.

Suriyun Whitehead: You do some things that you cannot do because they are computationally expensive, could you throw more hardware at it?

MM: It might not be worth the cost of the hardware. You have a time and money budgets. You are not going for 100% detection, and you have to trade off. At 3.6 seconds per bag you can commit to each bag. Let's say 6 sec per bag, a process that takes 2 hours, is not worth it.

Piero Landolfi: It becomes not practical from a TSA perspective.

??: What do you mean by you don't need the most beautiful false alarm?

MM: If you don't alarm on false alarms, a lot of people want to 'see the dimples on the golf ball' but that's not that important.

PL: It has no impact on the detection.

MM: You want to solve the ones that matter. Maybe the ones that get discarded for medicine, say, would be very helpful for security.

??: You really need to have knowledge of fixing one of them?

MM: That's only way to make improvement.

??: Don't you think for the future you want to be able to tell for the HME's for texture?

MM: We have maybe 50 different kinds of HMEs.

??: Which of the steps give you the most improvement?

MM: Start at the end and fix something, you know that it isn't broken at the beginning.

??: To what extent is a bomb considered a precisely defined thing, with the small detonator, etc?

MM: Is it a question about primary, secondary charge, it gets messy. I wouldn't dismiss it,

RM: Do you get any trouble with hyper-tuning?

MM: There are whole bunches of techniques, and use approaches to *fuzzify* my features, so yes.

??: To what extent does the bag itself cause a false alarm?

MM: The roller bags, with the metal bars have to be dealt with in special ways. The zipper isn't a problem. By the way, we are hiring for the summer.

CC: Raise your hand, students.

MM: Contact me if you have questions.

CR: It seems like shape is a big deal for homemade explosives, does it mess everything up if it is in the shape of a banana?

MM: The best classifier we ever built, we put in all the features, with 99% high detection, and false alarms went down to zero. And we looked, and it turned out the classifier was the mass of the object. Typically our data was at the smallest mass. You can create very clever features, and if you're not careful, all you've found is that you (???)

??: But that's an artifact.

MM: But it's surface area, very quickly that will trickle down to some component that means mass. If it's above, it doesn't matter how much above it is.

<u>Richard Bijjani</u>

RB: I think Matthew covered everything. What is image quality? There are two aspects, automated threat detection and the second thing is what you do when you find explosives. When you find explosives, there is a procedure

OSAR, it's classified, but there's a problem here. What you need to find explosives, as we add more and more HMEs more false alarms are going to occur. Operators are used to looking at the same false alarms. But that's a particular false alarm that they are used to seeing. But now we have new explosives, there is more training necessary. This looks like shampoo, but it's not. We need two sets of image quality. They are contradictory. When we started, we had very limited computing power. Later on of course, pending patents, a lot of people in the industry are looking at a generic reconstruction, now we have more computing power.

For the alarm resolution, we need new things. Eventually we will move away from this reconstruction. If you cannot get down to the tech company, you do not have anything to sell. Is an image necessary? Of course! You are going to have false alarms. Is this better than an image than a false alarm that has a 10% rate? It takes longer and costs more than something with a 90% false alarm rate. You do need an image. The better they look, the more likely we can move forward.

The first detection system ever, (slide) as you can see the guy holding a bag. I bet you this is a better image than anything we look at today. We need to see what is in the bag, with a nice clean image. This is not a new problem.

Slide, which is better resolution? AS+E images… which image is better? Depends on what you are trying to do. This is backscatter images, you have a gun, explosives, in a sense, if you look objectively, and you look at the list and score it, it seems like the other image is better. But the (black and white) image here is actually better.

I am not advocating any technology, and am not selling anything. But we have to be careful to not talk about metrics.

??: So how do you guys do this?

RB: I personally believe that we have to use metrics in, and this is the problem that everyone encounters in the CT world. You need to be able to correct for missing data. You can clearly see here a sheet, but this other one clearly has better resolution. There is fuzziness here. What's the metric?

What are we trying to accomplish here? It's information not resolution that we are concerned about. I will give you another example.

(Maps) Which of these two are better? What's my objective? This one has a map of the trains, so it's better for me to get home. It has a worse resolution, but better information.

What is resolution? What matters? I think the consensus is that the constancy of the metrics matters, but the metrics themselves don't.

I sell module number 1, do I certify it if it is the same as module number 2?

It's all about mass, they way you measure mass includes how it is moving. A piece of sheet here, what happens as the sheet gets bigger? What is the noise? CT uniformity? Is it a different material?

These are the metrics that the industry has agreed are important. All standards need to be reviewed now and then. For OSARP, however, for the x-ray machines at check-points have whole different standards. Why? They have operators have to do something after looking at an image. They have different tests. It gives you an idea of what's important.

If you are able to see these wires behind the aluminum, and you put this through a CT, no one can see this resolution, and this 3000 dollar machine at the airport, you don't have the ability to measure mass, and density. If you need resolution, it's a really good system.

Questions:

LU: I like the way you talk about it, you mention that we may want to revise some metrics. You have differently levels of technical efficacy, and I believe that you have to be test specific. Even if you have different levels, you will probably see a difference.

RB: There is a big range of resolution, and some of the lowest resolutions of machines have the lowest false alarm rate.

Ken Sauer: You have something in there about organic discrimination; can you tell me more about that?

RB: You have high x-ray beam and low x-ray beam, if water is around 7.4, and graphite is around 6, and there is a range between 6 and 13, and it is called organic, and we have to operate and pay attention to it. The low energy is more sensitive, and the high is less sensitive, and the ratios can tell you how to discriminate between organic and non-organic.

KS: You are speaking with the assumption of duel energy.

RB: Yes.

BREAK.

Charles Bouman

CB: "Overview of Talk" slide, a quick review of MBIR and ALERT data.

Quality metrics: what are they right metrics? Some are accuracy of artifacts, and we are looking at ASSR, and we are doing reconstruction, and the few-view reconstruction has become very important, and segmentation.

??: The very first sub-bullet, you define better image quality; will result in low Pfa and Pd. Can define what's better?

CB: You want different reconstructions for different tasks, so that's one issue. I think better image quality for medical and image quality for security are very different. In security, you are much more interested in high contrast objects. Which is favorable?

??: The first time you showed MBIR, was it accepted?

CB: At least some subjective measures of performance are.

It's a whole new starting point, and the quality issues are very great.

Fred Noo: For decades, the reconstruction had to be done in 1 minute. And now suddenly, it is 1 hour. But it is important, if we can do it [FBP] in 10 minutes instead of 1 minute. There are a lot of improvements that can be made. In the context of medical CT, you can shift with FFT, you can say according to the measurement,

CB: You can have a non-linear measurement.

??: Different pixels, can be done at the computation, one result is you can have it filtered for every pixel, and compute this.

Carl: How much of the gain of the reconstruction is there?

CB: The question is imprecise and the answer is imprecise, is that it's kind of a 50/50 split.

The broader point is next generation of views. This is one way of going about it, and they have a lot of promise.

HM: The one on the left seems like there is less mass.

CB: My sense is the variation is that artifact changes but I would have to go back.

KS: It is preliminary in that respect.

RB: Even if the lower part was more homogeneous you are going to get more mass. It adds a lot of false alarms.

HM: Which looks more true the image on the left or right?

RM: It is very hard to draw conclusions. The right handed image is more detailed.

BY: How much of the (???)

CB: I'm not sure I agree with your statement Birsen.

(???)

ELM: The devil is in the details whoever implements a spatial algorithm you are going to essentially get two different images.

CB: A lot of streaking could be reduced by a better forward model. We don't know how to handle the (???). Birsen, let me just say that the word iterative is a bit misleading.

CC: You are showing that you are changing what the images look like. Do all the processes make the images look differently? It's important for the reconstruction people and (???) to get together to figure this out.

JB: I have a comment because in order to achieve image quality has a lot to do with the communication between Charlie and the vendor. There is some real speculation that the left image is not as good as the image on the right so we don't have all the information we need. The communication between the user and the developer has to be very high and iterative.

Xiaochuan Pan

??: So these aren't fully 3D?

XP: I have no idea. No matter what you do the data you have won't match perfectly to your model.

CC: So you are talking about approximation?

??: Yes.

(University of Utah): Something we need to remember is you concerned about (???)

XP: It has to be task specific.

CC: Can you use the methods on the right of the photo to improve the images on the left?

XP: That's a great question.

Guang-Hong Chen

CC: How much can the noise be reduced?

GHC: (???)

Patrick La Riviere

PR: All CT data is sort of massaged into place. We've been trying to formalize and formulate that process into a potentially iterative process. There are limitations. You can't do everything in the sinogram domain.

We've been talking all morning about what better means and I don't think any of us know. I think potentially this could get you part of the way there with less cost and the potential to model some of these nonlinearities. FBP is usually assuming something very specific. In practice the real data you measure is very messy. (Deviations from model slide). It's all very subtle because especially in the medical world, you're usually looking for a ~1% contrast.

HM: The model you talk about there is your FBP model?

PR: These are the deviations from the simplistic FBP model. As far as I know most of the (???) models people already looking at these days start with data that's already been corrected by the manufacturer.

We worked on this a little bit with Phillips R&D in Hamburg.

CC: Did they give you corrected data?

PR: They did this implementation of my algorithm in-house. Every scanner has tradeoffs, even though they're all reasonable choices.

(Imaging model slide)

FN: This is particularly important if we have metals, right?

PR: Yes, that becomes a worse approximation. In a soft tissue context, it's actually not that bad. The error you get is linearizing that's not very hard. It could be another way forward with metal artifacts.

Charlie Bouman: This might be valuable in the context of the hardware and the algorithm. Any sense about how that increases the design envelope?

PR: We haven't thought specifically in that direction, but it does give you that ability.

CB: You could have really big detectors and still do reconstruction.

PR: Angle, etc. become really big issues in micro CT, like if you're working with small animals and want really high resolution. It's a bigger spot size and try to model these spot size effects.

CC: If someone gave you corrected data, how long would it take you to fine-tune your algorithms?

PR: We actually want uncorrected. It depends. We may want to correct for detector effects that some people may be unwilling to reveal.

Seemeen Karimi

SK: I'm a graduate student and I had ideas that were more sensible to apply to the medical domain. The shadows are what are challenging to remove. (Origin of metal artifacts slide) So our goal is to generate an image that contains as much anatomical structure as we can. We treat the differences on positive and negative polarities separately. I have a region that contains both artifacts and anatomy. I want to classify the voxels that are more likely to belong to anatomy and the voxels that are more likely to belong to artifacts. (Explains discriminant curves slide)

CC: At the CTSeg initiative in December, Siemens … Is your work applicable to that?

SK: When you re-project something your contamination goes there. The set of projections you generate now are perfectly consistent.

CC: Essentially what you're doing now is instead of segmenting threats; you're segmenting (???). Can you segment other (???)

??: You initially had to segment the metal and you did that in an automatic way. Didn't the streaks make that difficult?

SK: Say that streaks are about 4000-5000 and teeth are 3000, so…

??: So it's above enough.

Andrew Foland: There is a scale here that you have to pick out, and depending on which way you slice a sheet it's going to look a lot like a streak. Does this also get rid of the sheet-like threats you're looking for?

SK: Yes it will. If you delete something it's not like it's lost in a final image because it's still a prior. It's looking for structure. The chances are that you create some secondary artifacts from missing anything. That's it.

Johan Nuyts

JN: I'm a medical imaging guy, I don't know much about the applications to safety, but I assume that reduced artifacts and improved quantification will be useful.

(Models for iterative reconstruction –technical explanation)

It is not reliable, but you will find that if we use a combination it will not be too bad. The other thing we use is Local Models. The full energy model is complex but slow. The MLTR and MLTR_C are simpler and faster. One advantage is that that they are boasted dramatically, and you can define patches. The result is there are low contrast materials. The result is the correction completion; in PC NMAR is much better resolution. (Slide) the difference between IMPACT and IMPACT Patch is there are less of these large patches.

(Slide) Technical explanation of slide 14.

Slide 15, this is very similar to the biomedical gauge. Soft tissue and cartilage, and you can see that the IMPACT image has a much better image of the titanium.

Side 16, People want to see how the blood supply evolves. They use the blood of the animals to follow the evolution. Technical explanation of slide images.

Slide 17, people typically select both Post reconstruction and IMACT decomposition.

Slide 18, conclusion again, we are not sure about the remaining parts, but we are still investigating. I don't really know how useful this will be. We need a lot of insight to this data, but I would like to …

??: Can we go back to the slide of Body Shaped Phantom? Have you investigated the accuracy of the (???)

JN: We only used data construction, but there is a potential advantage.

??: In luggage you get enough metal that you have to stop, I wonder if you have too much to be effective, and if you have to stop trying. Is there a way to have a measure of your confidence of your result?

JN: In that case, it will get better and better, and that's all we know.

??: I would rather do a good job for us for fewer problems, and not give up.

JN: If you do a test, it might still be useful to you, so it might still be an advantage.

??: How much do you rely on materials?

JN: We should put all elements there and see, but we have never done that. So I have no idea if it would survive that.

PD: If you have to submit different materials, how difficult is that? Can you just create materials, like something between water and alcohol?

JN: I suppose that would still be helpful …. (???)

??: The last thing we want to do is get over confident in the result.

JN: It is still possible to reconstruct this, because most artifacts like to go negative, but we don't allow that.

??: Going back between distinguishing the material, to identify sheets. You get a lot of partial volume, and the continuation does not necessarily detect the material, is there a way to get around that?

JN: We can decrease the pixel size, and that should accommodate the difference between partial metals, and change the resolution. If your pixels are smaller you may get what you are looking for.

CB: Model based reconstruction? And I have worked on this and not focused on artifact reconstruction. How does it compare to this technique, it's hard to say. How would the poly-energetic CT compare to this? There are some trade-offs between richness of the model.

??: You can incorporate all of this into the model, but at what cost?

CB: There is a price to be paid for this.

JN: You really need to be careful, because every time you model something, it gets more… (???)

Carl: You have modeled something like this before, how has that worked for you?

JN: Technical explanation with slide 9.

Break

Harry Martz

Jeff couldn't be here, and I was thinking about what I have seen so far today. And I want to talk about methods of how to reduce artifacts, and we have few metrics and objects, and we need to compare these.

The last time Jeff was here for ADSA 05, he spoke about the conjugated method of gradient algorithm.

Now we are looking at power of ray transmission. We are determining the methods of determining appropriate limits, but that's not working very well.

Jeff and I struggled to do this and tried to put this into perspective, and put them on the same scale. Like Matthew said, we can use the shield, so we are trying to do this for our own application, when we take a material, and do a cross section, you get a deviation, and you rotate it, and you can see more, and it gets bigger. But if you reduce that space, in theory, your performance should be better.

The projection difference error is here (slide) and the error yields are shown in this equation here (slide).

There are two different methods, which is ray weighting by transmission to a power, and then by (???) (slide)

We are using a steel bar, thick steel bar, with jelly, and you can see with in this, these artifacts, slide explanation.

We are showing this is a function of a different algorithm. The windows to see what's inside the steel, you can see basically that there are improvements, especially with Ray Weighting, and you can get better results.

HM: You can weight that less. You are basically looking at the weight transition. This is the other function, so you can weight these less, and weight these more. And basically, these are showing for a power of 2.5, but in these slides, you can see the mean value. Then we scanned the jelly without the bar, and you can see the standard deviation, and you look at this image here, and deconstruct it. This is a measure of how to quantify this stuff. There are a lot of features, but there are two key features.

??: How did you decide which the bar is and which is the Jelly?

HM: We know, because we did the test. This is a simple test. How do you define a shield alarm, and we did an example of how to see this.

??: What's happening physically?

HM: I think what he's doing is throwing away a lot of the photons here, and he is using the rays, which rates it less here, and more here. (slide photo). You are throwing away the photons. That is our interpretation.

??: That is interesting to look at.

HM: As he weights it here, as we go, here is the same thing, and he highlights these different regions.

Here is the one where looking at the steel bar, you can see how it cleans up the result of the steel bar as well. One of the things is this jump here, is that important or not? Maybe for medical, but not security.

??: Where is the weight going?

HM: In the air function.

??: If you do that, how can you guarantee convergence?

HM: I don't know; that would be a question for Jeff. Anytime you are doing this you could be ill composed. We are working with very limited data. This is very simple. We have to find out what metrics we want to use.

JN: Are you not forcing these results?

HM: Maybe or maybe not. It's possible.

Here, he is using point B, and here it's not doing too well, as you can see. And the standard deviation is pretty poor. And at 0.5 this doesn't make any sense.

I want to come back to this (slide) how can these be reduced, and what features should be used. You can use mass, you can use other features, and decide what that space look like, and in doing this, and we still need segmentation. So think about it until tomorrow.

JN: I would say if you change the weight, maybe it can infuse convergence?

HM: Depending on when you stop the iteration.

JN: How would you decide?

HM: Usually they will take the data without being compared. We did other studies like this.

??: What if your metal bar is a circle, or annular?

HM: That's a different problem. I think we have some data of putting a jelly bar in a steel pipe, and we have a lot of different data sets where we look at options.

It depends where you are in the transition curve. You should say that I can't measure anything inside this steel pipe.

Taly Gilat-Schmidt

My background is in medical imaging. I will start with my conclusions. (Slide) it is challenging to access the raw data. The medical imaging community uses these common sources of data for algorithm, and to increase access to simulation security applications.

Why simulations, assuming you have good software, it is accessible, and inexpensive.

It's very easy to model things and change them. It enables you to affect their performance without having to change the hardware.

What's the discussion about the ground truth, and this gives us a way to compare the literature, so it might be easier to compare these.

If you change one knob in the software,

??: How hard it is to change this simulation?

TG: A lot of this is already out there.

JN: This sounds very difficult

TG: Right, it is very challenging depending on shapes, etc. We can't exactly model everything about the scanner. In the end, when you are designing it, you are eventually going to have to experiment. But this will help.

Our goal is to define the standard test bags and objects, and we develop objects to randomly place them. As far as these algorithms, they are already out there, it's just a matter of tweaking them.

The first step is defining standard objects. This is already known, and has been developed, for these objects you need a material density, defined for each object. In this image, there is a shoe, magazine, water bottle. This shows us that this is feasible.

This is the image of the object itself. The next step would be to have a packing program, and they would randomly select objects from this list. We would need to adjust the position to prevent overlap, so this could be simulated by other people. Finally we would like it to be something in the public domain. We would like to adjust for different geometry, and of course, this would have to be validated. So these are our goals.

What has already been done, for those of you who aren't familiar with this. What we can learn from the medical imaging community. We have these phantoms, called FORBILD phantoms, and here are the slices of thorax, these were made at U. of Erlangen. There are more of these artifact types at this website.

To give you an idea of how prevalent this is, you can Google this and see how commonly used these phantoms are.

??: How easy to use is this?

TG: They are easy to use, but they are defined by the position, and primitive shapes and you could make a phantom from this with your software, and if you go to the website, you can see this.

??: Are you familiar with BRL cats? They came out the army.

TG: No I am not familiar with that.

Frank Sprenger: It is important to keep in mind, one way is simple addition, but these are not using addition, they are using the painter, and there is an order of the object, and if object 10 overlaps number 9, it is part of that. A lot of the software will not be useful, because of that effect.

??: Do you believe this is an easier way?

FS: Do I believe that you can make a fancier phantom? I have spent many hours trying, but I suppose you have a lot of flexibility. But there is software may not work for these phantoms.

TG: Again, this is what we have done in the medical image community. How can we make these models? Let's look at a simulation example. If we shoot a number of photons here, and we measure how many come out. If you had this simple object, all you would need is this equation.

We need to know how many photons are coming in with this energy. You can use IPEM Report 78; a lot of these effects can be estimated.

This is our model, but we can still get out how many photons get out. There are two effects, (slide) we can use this as our main value, and we can use this as our simulated value.

There are many non-ideal effects (slide) detector aperture, you can model these effects.

All these things can be included into this model.

But with a more complicated object, you can use these values, and we need to calculate line integral through this distribution. One method is this analytical calculation of line integrals, voxelized forward projection or Monte Carlo methods.

But the first one gives us a starting point. In these various 3D object, and those phantoms built from primitive shapes, with the analytical intersection.

There are simpler thorax phantoms (slide photo) if you look here, you can see that streaky result. There are other options for modeling these complex objects, is using each little cube is one u.

Charlie Bowman showed a voxelized phantom like this. Now if we want to model texture, we will have to use methods like this. There are fast algorithms for this projection.

JN: since we are dividing these into two parts, would that be an option?

TG: Yes, that’s right.

??: Are we able to talk about validation?

TG: I do have a slide where I can mention it briefly.

What are the relevant objects that we want to model?

How is the validation done in the medical community?

TG: I haven't seen that. Someone would make some simple objects like them do it.

TG: Another question is, are we modeling enough of the non-ideal effects?

ELM: Many years ago worked at Analogic and they told me to look at MCMP, what is the difference between MCMP and (???)

TG: From each photon it draws from random numbers, in order to get a simulated set up it is expensive and difficult to model this many photons in Monte Carlo. Another problem with the Monte Carlo is it doesn't model the stochastic generation of the photons.

ELM: I was referred by a security person to look at Monte Carlo.

TG: I wouldn't have suggested that. I guess it depends on the situation.

??: Have you validated with Monte Carlo?

TG: I have, it takes about a day.

<u>David Wiley</u>

Automatic Object Delineation from Checked Airport Baggage CT Scans

CC: How did you determine where the marble started?

DW: We looked at every voxel. We got every boundary. I guess it's just our opinion that it was done well.

MM: When do you stop merging?

DW: We spent only a couple of days on merging and it worked very well. I was impressed by Siemens's work in this area and if we could borrow this we would do well.

??: How long?

DW: About 30 minutes. We are in the process of porting over to GPUs but we don't have any funding for it.

JB: How many bags did you use out of 150?

DW: All of them.

??: Does the noise texture play into this at all?

DW: It can but you can pick your parameters if it's mostly uniform and ignore it. But if you're using a jar of rice it's different. It also depends on the granularity of the object being scanned.

CC: How hard would it be to convert to 2D?

CB: It's a very good question and I think the answer is roughly that you want to work in 3D. There is a tradeoff in terms of complexity and quality. Segmentation I think you would want in 3D but it depends a lot on the application.

<u>Claus Bahlmann</u>

Luggage Segmentation Challenge

??: How sensitive are you to noise?

CB: What type of noise? Some of the artifacts we couldn't remove. Some Gaussian noise and the merging itself was on the sample itself.

Minutes: Day 2: May 16, 2012

Carl Crawford

CC: We are shooting for November for ADSA 8. What should we talk about? (see slide) Any thoughts?

MBS: Say we talk about body bombs, how feasible is it to stay on the unclassified portion of that topic?

CC: My intuition is we aren't going to speak about the specifics of that topic; so essentially it is a medical imaging situation.

MBS: If we could have a forum on that it would be very interesting.

CC: When we did a topic on video analytics we almost had a complete turnover in attendees.

??: I continue to be stimulated by the ideas that could be constructed and pursued. They would be standard types of problems. The team would then make a breakthrough. The two days could synthesize what the problems are. The problems would be maintained by ALERT. For example, we are going to talk about bags. We are going to put together phantoms and we are going to want to do them fast. Almost like the kind of problems you have in graduate school.

CC: I went to an IEEE conference that did something similar.

MBS: (???)

John Bush: The problem statements should be hard, something worthwhile. Worthy challenges, it's not a homework assignment. Something if we made progress on that would grab peoples' attention.

MM: If we had a grand challenge spanning reconstruction and detection you could discuss everyone's vision. We could then hammer through the legal parts where we got hung up last time. I don't know if it's worth it.

John Bush: I think I just heard Matthew say he likes the idea. I think the grand challenge would be security focused.

MM: I would be interested in hearing from the academic side if this would drive innovation and discussion or would the grand challenge approach just distract from real topic. This would be of interest to me.

CC: Could someone from academia answer Matthew's idea?

PH: I thoroughly agree with you that it would be of value. It would plant a flag for academia and tell them what is of interest to them.

MBS: The real question is if you want to get more detailed datasets you have to deal with the secret sauce each vendor is dealing with. This is the difficult part to navigate around. It is not easy.

MM: That is exactly my point I have a lot of ideas of how to get around that rock but now is not the time. Rather than worrying about how to get around the rock there have got to be other ideas for how to approach and get around the rock.

CC: If we are going to do this don't we have a specific problem to discuss?

MM: I am an end to end guy. If Jan Nuyts creates a beautiful recon but my hardware isn't ready for it, it doesn't mean that it isn't good recon. Any improvement in one piece doesn't help but once you glue all the pieces together you improve the process, drive down false positives, etc. From a detection server I would love to have the same bag reconstructed 18 times. You could then do the pairing and the end to end. For me the real question is you need to know how to set this up and how to contribute. Maybe a smaller group.

KB: Would it be important for people to know what the test is and how it is run?

Birsen Yazici

Combined Segmentation/Reconstruction
CC: Tell us in words how you got these images.

BY: I enhanced the images with a filter and I enhanced only the high frequency and left the low frequency alone. We can do a variation of this.

Willem-Jan Palenstijn

Good morning, I am from the University of Antwerp. Starting with Conclusions, I am talking about combining segmentation and reconstruction, as this is a starting point for segmentation. A key point is homogeneous regions. We have developed a range of algorithms for this, and general segmentation methods.

I am part of Antwerp ASTRA group. Use micro CT on the micrometer scale. The standard workflow is data acquisition, data preprocessing, reconstruction segmentation, and analysis.

Either reusing process data to segment data

Suppose you want to find the density (???)

A couple of plausible segmentation details to find the threshold. Go back to projection data, and then reconstruction, then segmentation.

??: It seems like if you are allowing the threshold to flow, you have problems allowing multiple tissues, or different materials, you would get lost?

WJ: We have tested it with multiple materials, 4 or 5, but if you had more it is not necessarily difficult.

??: Do you have to do it per threshold?

WJ: If you select thresholds, you can have 3D.

The field of tomography, discrete tomography, we are collaborating with partners to develop a set of well-known semiconducting materials. We have developed an algorithm for DARTS. This works in a variety of settings, CT, computation

The key ultrication (???) for DART algorithm is generally okay, but the boundary is a major issue. Here you can see the underlying DART method, and vertical resolution. Again, we start with reconstruction, and do segmentation using the grey value. There are close to 10,000 error pixels in this case. The complication is the boundary, so if we separate this into parts, and there are parts that we are not sure of, we can look at those, we can project pixels, and do a new reconstruction, and only updating the pixels from this. Up to 50 iterations the error pixels becomes 233. With each iteration, it improves with each segmentation.

There are a couple of details that make this work. One is to make the smattering of noise over these pixels, and the initial segmentation is wrong, and there are different grey values that you need to fix. Instead of fixing the entire area, we get the set of pixels to create new gaps and holes.

The second thing is blurring them, as if you reconstruct them you might end up with over shooting or under shooting,

??: Do you only have to find out the boundary with homogeneous?

WJ: But there are maybe holes in there, or inclusions from other materials, so you have to do more than reconstruct the boundary.

This here is a carbon image, with more inclusions in there. What is the exact shape of this? But here it is very noisy, and if you apply DARTs to this, it is sufficiently sharp.

CC: How do you know this is right?

WJ: We have talked to experts, and we do extensive research on this.

MBS: With a microscope, you can see how well the actual construction is to what you can do?

WJ: It is very hard to evenly reconstruct at this resolution. We also have CT data. This shows the flip side of data, and we can increase the resolution to see fine details. By increasing the resolution with the DART, we can nicely see the results here.

So the last algorithm I will go over, is the practical techniques in these homogenous regions, this is a situation here that does not apply. These lead particles have background that is not homogenous.

??: What is the size of this object?

WJ: it is 100 nanometers in size (???)

We have segmented out the densest particles, where we are removing variables. So this is ongoing research, where we are combining this detection method with the reconstruction technique, so we can integrate these.

Combining segmentation with reconstruction is essential; it is a key property for this link.

??: How would you apply this to security?

WJ: That would be quite a challenge, but things in terms of these practical discrete techniques may apply. Once you can update boundaries, you can improve with ongoing collaboration. We imagine working in this direction with research.

??: Are you thinking about regularizing your boundaries of objects at all?

WJ: We have not tried that, but we do have a new blurring set, which does have some regularization.

??: Computationally, if you are trying to search that space, do you have to do a forward projection?

WJ: Yes.

??: In the case that you had many views, did you do that?

WJ: It is part of our plans to selectively increase resolution. We knew that there were going to be very fine details.

??: You may still be able to see these, but doing normal segmentation, to see if you can recover some information about (???)

<u>Oguz Semerci</u>

I am working on dual energy at Tufts University as a PhD. We are simultaneously segmenting objects of interest from projection data, and also renovating the algorithm on Monte Carlo data.

We are looking for industry partners to carry the work forward.

For the multi-energy computed tech, we are trying to enable an algorithm (???)

This shape here is an object of interest, the idea is to reconstruct its boundary very well, and reconstruct its background reasonably. The reconstruction here we expect, as you see here the results. For every measurement point, it is reasonably solved with little back ground noise. The first and second image here, with that type of regularization, you can see the counter image, where the object boundary is captured very well.

The contribution of detection is very low, especially for low images. This is a very simple background image, but if everything is equal for both (???)

It can do some noise reduction, but it doesn't make much here.

I will talk briefly about what's going on. Here is a model, where you can see the computations, and the background noise comes from the detectors. You can add the scatter to this equation, but we have not tried that yet. This is the entire reconstruction algorithm. You can see the regular data transfer here.

The energy bases are known, and you can reconstruct the space so we can get the idea of what's going on inside. An object here, of interest, the idea is to focus on the image, except that it is the smooth version of the background. To define the 2D boundary of the 3D function. To sample a distance function, to find the value, this is not a good idea to find this; there are too many unknowns and issues to deal with to find it. The function is lowering the basis expansion.

As the high dimension of function changes, as you see here, it will eventually give us what we want.

We have a regularization term; the idea here is that the background should look similar to the image here. You want to see that the boundary is not similar; you have to normalize the gradient images, the large penalty here.

The other knowledge taken is that we assume that the objects parameters come from this region. I can enforce the constraints in the algorithm, so that the objects will be from this region, so it gives us two sets of contracts.

??: Why are you using these images?

OS: Because this is related to both, this is a hybrid shape, with a pixel method, for the background we (???)

??: How accurate is this, simulation?

OS: You want to see the value, or you want to see the pixels? I think this is sure data, where you can see these are normalized, it is much better than the background noise.

We also look at this recent work on development of energy, and we determine the series of problems, and we wanted to look at solving these individually, but we would rather solve them simultaneously.

These images are different energies, and the problem is defined as looking at a very energy characterized case.

The idea here is that they regularize the problem, that in this energy dilation, this needs to be lower, and if this tensor is a 3 way tensor, is low ranking as it is, is composed of spectral images with similarities. If this is low, it unfolds, and impose the low rank reconstruction you can get these to be normal. We design these nuclear to regularize for multi energy CT problems.

We can solve these multi energy CT problems with various ways, (???)

The results are promising, initially, but the background here is noisy, but if I get rid of the nuclear (???)

This is a result using only regularizing, and this is obtained by a quadratic problem, so if the problem is small enough, you can make it a little less noisy. It's better than the total variation.

The results are good in terms of accuracy and applicability, but how do we incorporate information and interest? (???)

??: Oguz, when do you graduate?

OS: Hopefully this summer.

??: I would suggest you read our work, as we have already come up with ways to solve some of this.

OS: Okay. I will.

Karina Bond

I work for Lawrence Livermore National Lab. One way that we might assess reconstruction performance, is to measure how well the results can be segmented. It turns out that we have not a trivial task.

Based on the study that we did, we came up with a classification of evaluation methods. It is to find the quality of system level metrics.

You evaluate single energy systems, how well can you estimate the objects, volume. But in the direct methods, you can measure analytical or empirical methods.

Supervised methods where you use your algorithm to find a whole set of segmentation results.

There are methods that we have found that are based on the results of the segmentation algorithms.

The F-Measure as based on well-known concepts.

Define a fragment, which is the intersection of n object with a segment. (???).

For a simple object, D1, being the size of the fragment, should be equal to the size of the object and equal to the size of the segment. If you split this, then the size of your fragment is smaller, but the size of your fragment is equal to the size of your segment. If this size of your fragment is much smaller than the size of your segment. If you split and merge, with another object, in which case you have imperfect precision.

If you split it too much, then all your fragments will fall to the top right corner, but if you split too little it falls to the bottom right.

Your segmentation algorithm is in 3 segments; it would result in a 3x3, and would result in 4 non-zero fragments. I am plotting the position, and the scheme I am using is a safe model.

??: Are you not including the background?

KB: No I am not. The background score is not considered. You are right that you can plot the back ground, but you can't use it to find the overall score.

So the ground truth segment is basically sliding down to the bottom to the right. Ground truth object 2 (slide).

This will give us two to measure, but we want 1 to measure. We lean on another well-known concept; it is the F1 score, or measure, combines this to measure every fragment. We really want a way to combine all these measures. We chose to do this with Fg, which is a weighted sum of the maximum measure, for larger ground truth objects to give us the same score. GT object 1 had two fragments, and the top score is 0-9 on a scale of 0-1. Here I am plotting the position for each of the five results for bag 3, and I am not plotting really small fragments, because it gets messy. Researcher 1 has a lot of points in the top left corner; researcher 5 has a lot of points in the bottom left. Researcher 4 has points on the one 0 position. That's because they lodged a lot of those objects with the background. They consider it on an object by object basis. But if you look at all of the researchers, they are all in the same shape.

There are 3 bars of soap, but they are considered 1 object. All of the researchers chose to split them as 3 separate bars of soap. Researcher 2 has 1 fragment for blue cross, so it's near where they want to be, so that's good. But researchers 4 and 3 and 1 kind of split more. So you can tell different things, and this is valuable, but it's hard to look at these slots. But this is a combined measure called the F measure.

??: The fact that there are no 00s, you're talking about how an object that merges with the background counts as one zero, that doesn't make a lot of sense to me.

KB: I don't think they completely merged it with the background. There was probably a really small segment that overlapped with something else.

??: I don't see any 00s at all. So nothing fully merged into the background?

MC: I don't think there is a background. The background is an object.

??: That's the problem; I don't think you'd want to do that.

KB: But I think you'd want to know you merged it into something.

RH: If the background was an object, would these results change dramatically? Have you tried it?

KB: I have tried it and they don't change.

CC: You should mention that there's this concept called *object philosophy* and that could part of the reason the bars are moving up and down.

KB: A lot of people have not included ground truth; they have just included different consistency algorithms. (Summary of Scores slide) I think it's important to tie this metric back to system level, irrespective to system, otherwise what's the point? The bottom line is that this does correlate very well with system performance.

Frederick Noo: I feel like we should really stick to the task to generate a family of challenging phantoms. The task is the most important thing to keep up front and whenever we go along this path we end up with non-meaningful research.

JStillson: Except I think there's a framework here, you can take the task you want and work backwards.

KB: The reason that this metric fails is that we're aligning one segment to the others. In that simple example I showed, the fragment that squeezes into object 1 is contributing to the score for ground truth 1 and ground truth 2. If we were able to solve an assignment problem, where we assign a segment to a ground truth object, we'd get a much more meaningful metric.

MM: The point that's missing is the classification, and without the classification it doesn't mean anything. I care about the precision and recall measures for two or three objects in this bag.

KB: I chose based on size and you're choosing based on importance to the task at hand.

MM: Once you're out of the top right quadrant, it doesn't really matter how far out of the top right quadrant you are, it's still wrong.

HM: So where is the box?

MM: You have to look at the measure a little bit, but you have to be above about 80% precision and 80% recall. Once you've crossed that border, it may as well have been zero.

SS: I think it's easy to move this to what you're looking for, Matt, by moving the threshold.

MM: The segmentation results were what was interesting to me, not how did you do overall, but wow, you found this difficult one really well.

KB: So I was in this mindset of what's the best reconstruction algorithm, but you don't necessarily want to use the best segment. You want to use a basic segment to highlight differences across reconstruction. Sometimes it was like you're saying, you fix your pipeline and you tweak something and you try to solve a particular problem you've seen in segmentation before. I don't think that we need segmentation to assess… reconstruction should be the only way to go. It could be image.

DLieblich: I think it would be useful to know outside the segmentation philosophy, how the algorithm is different. Once you know that, maybe they're all good and they're all possible. Then it would be interesting to know that because you'd know the object philosophy.

KB: If you took the rubber sheet, for example, it has no object philosophy. If you meticulously went through the list of objects and assessed only ones that have no object philosophy, you could segment those to show the process.

Ge Wang

GW: CS = Compressive Sensing, Correlation Sparsity. These two problems are very synergistic. I've been working on sparsity to transform since 1987. The total variation is one way to capture sparsity. The interior problem (???). So we have given ways to extract sparsity.

PRISM = Prior Rank, Image and Sparsity Model

CC: Where are you getting the dictionary from?

GW: From the image, from my friend at the University of Iowa. We have used the dictionary learning measure to remove artifacts. Oversamples and undersamples. (???)

CC: How many views do you think you can go down to?

GW: I think it's application-specific.

CC: For baggage scanning, anything can be in a suitcase, so how do you do that?

GW: We make some assumptions, scan a bunch of images and keep going. We look for pattern recognition. There are some very risky images.

CC: If someone gave you 50 images, how long would it take?

GW: It depends on the computing power. There are too many variables. (Rank of a Tensor slide)

CC: Tomosynthesis for backscatter using two dimensional detection.

GW: Overlap the data, that's different.

CC: Why do you want to overlap?

GW: That's a good question. (technical explanation) It's just an idea. I don't have a solid answer.

JB: There's a small company called Digitone that did your experiment. Seven different sources on a linear detector. That has been around for about seven years that I am aware of.

GW: (???)

JB: I don't know.

Harry Martz: We had a paper that says that if you're going to be equal dose (???) Norbert Pelc.

GW: (???)

HM: What about if there was no dose required, if you could double the dose?

GW: (???)

Clem Karl

CK: We were motivated by low dose, but we were also interested in trying to find challenging problems in data inversion, particularly in the area of prior models. A lot of the prior models are very simplistic and generic. We're trying to figure out ways of building in prior information that is more sophisticated and looking for challenges in terms of texture modeling. These dictionary methods have shown a lot of potential in image processing. We wanted to bring that same modeling idea into the tomographic realm. Initially this was painful, as the corruption is distributed and you only get access to these non-local measurements. Trying to tweak pixels is once-removed from where the data is which makes more challenging problem.

The dictionary thing brought in textures and the sinogram stabilized this local/non-local issue. (Low Dose Computed Tomography slide) You can certainly reduce dose by reducing views, but that isn't what we were focusing on.

CC: People are trying to build explosive detection equipment with fewer views. So lower dose and fewer views are equivalent.

CK: I don't know how this would go with dropping views for a variety of reasons, and I don't' want to claim that space. Prior modeling can play a role in both of those situations. (New Joint Sinogram and Dictionary Formulation slide) Our choice is to smooth more between angles than within the projection. If the views are close together, there isn't much change between projections to projection.

CC: How big should the dictionary be?

CK: It is a design parameter. You don't want it too large or too small for various reasons. At the end of the day what pops out is the learned dictionary. Each patch is a little behavior. Some of them are more edge oriented.

CK: (Shows an example of dictionary/sinogram approach.) We can discuss which approach is better? (Now shows a comparison slide.) When we were only using the dictionary approach it was messing up the texture. All these methods do well with high concentration; the problem is texture. The idea is to build better, more sophisticated priors.

??: Would it be easier to extend it to (???)

CK: Conceptually yes.

CB: Can formulate that as a constraint and stick another variable in it?

CK: I don't see why not.

??: Is that sinogram smoothing stationary?

CK: Yes.

MC: (???)

CK: We are essentially assembling it into a patched dictionary and then normalizing it. You are reassembling all the patches into a global image. The local patch has a sparsity constraint.

MC: How does that affect noise reduction?

CK: (???)

XP: Use this kind of scheme to make an image. Can we use this scheme to create an image with very little data from a patient?

CK: I don't buy that. Some of these things are very subtle. I would claim the radiologists aren't jumping up and down about this.

??: How you build a dictionary is very important.

CK: For this problem 8x8 seems to be the best.

ELM: Can you enforce continuity over the dictionary?

CK: No.

CC: Can you discuss the texture problem?

CK: A lot of the stuff I've seen is with higher contrast. IF you wanted to use this for luggage you would have to think about the issues.

<u>Laura Parker</u>

LP: I'm going to give you the program management viewpoint. I think we are all in agreement is that there are still terrorists trying to get bombs on planes. The security screening we have is quite challenging and we need bright people to help us with this. Our mission is we try to find ways to mitigate this. We have shorter and longer term projects to deal with this. My management is very interested in how we are going to transition these technologies. We look at COEs as ways to reach out to the community. We've been running ADSA workshops for three years. We are looking at doing a reconstruction initiative. We are looking at ways of working/collaborating on data sets. The third initiative is ATR. If you look around the room and during the breaks people are really networking. These are leading to team, consulting, and working with getting students involved. We need help from all kinds of people who dealt with similar problems but didn't understand the security field. I am going to get down to the bare bones. We have funded some COEs. There is a movement towards targeted BAAs so I encourage you to keep looking. I can't give you a timeline.

CC: Can you explain a targeted BAA?

LP: You can submit a white paper, sometimes a full proposal. They are vetted through a technical group and you are notified. It can take several months. For small companies there are SBIRs. You have to be a small business, less than 500 employees. We might have more work in the area of algorithm development. Also there will be funding for students to work in labs. Doug Bauer and I are always looking for ways to outreach. We have to look for ideas to get better ideas out into the field.

David: I've been watching the Voice on TV and at the end they are guaranteed they will get a contract. There is no thing for us. It is very challenging for us.

LP: I understand your point of view. We are trying to formulate ideas to deal with this. The problem with forced marriages is they end in divorce.

MBS: We are trying to create a community where small businesses can interact with DHS to penetrate a pretty impenetrable environment.

JB: I come from a DOE/DOD environment and there is no comparable approach. What is unique about this is we've created a community of industry and government. It doesn't make it easier or harder. The uniqueness is the experience. I think it keeps all elements of the community involved.

RB: For the SBIR you mentioned, what is the topic? It is on ATR but I forget the topic. I'll send it out to you.

??: It is from TSA and the ATR is point two. There are five topics total.

CC: There is a topic 3 dealing with image quality.

<u>Doug Pearl</u>

DP: I am from Inzight Consulting. We've talked about 3rd party research. It is reasonable to discuss whether that pays off. My work is funded by DHS and this is what I am looking at. I look at the implications of the research. Most of my interviews are by phone and they last for over one hour. I want to thank everyone who participated. The next step is to begin to talk with security vendors. I am just starting this. I am looking for feedback from the audience. I am not an employee of DHS so I do not speak for them.

CC: Can you describe what a proprietary role is?

DP: Before DICOM the hospitals were locked into one vendor. There were no standards connecting systems. Now a vendor brings a product to market it is going to be a DICOM product. They will work together well enough to keep the customer happy.

MM: What drove DICOM?

DP: I think interoperability drove DICOM both clinical and research interoperability.

I'm going to walk down the hall, and put it in front of them, and they can tell you what they want.

This is the homepage of a radiology group in NJ. The third parties involved, are here in the room. On the left side they talk about human mammography. If you are patient, we might ask you for a higher fee, because they payers won't pay more.

We have full market growth. It will lead to a faster upgrade cycle, which means growth. Third parties played a role on the right and on the left. CAD was also developed, in part from dot-com. In Detroit a company called R2 was acquired for millions of dollars.

Rule number one, (???)

??: Why MRI is more successful than CT?

DP: I will get to that. It's a good question.

??: Is the relative roll of FDA approval relative to certification approval?

DP: I don't spend a lot of time looking at FDA approval process. But certification process plays a roll on it.

??: It is a disincentive to innovate, FDA approval.

??: In the FDA regulatory space, if you make a change, do you have to go through the whole process of getting approval?

??: The first time it's not that difficult, and the cost can vary widely. It's about a billion dollars. For a DICOM viewing station, it's a qualified device; it's just about 6 months. In terms of doing a diagnostic system, as you go through iterations of software, FDA defines procedures. So you have to track every patient relative to the software, and as you change your process, to find if your results are the same. If they are, you don't have to get FDA approval again.

??: To be approved for a new product, it shouldn't cost you as much if you've already done it.

??: It depends on where you've changed things. If you fulfill all of the requirements.

??: I don't know how it works.

??: You have no real benefit in improving, because there is a limit, a threshold, you don't get paid much more.

DP: There is no benefit of that?

John Beaty: You change to approve, you have to go through it, and you're not rewarded for the improvement, you pay to improve. If you look at all of the manufacturers here today, than years ago, it is diminished. In medical, many sell to hospital, so it would be like selling to the airports, and you would have a market place that has many buyers, and they would compete. But in this market place there is only 1 buyer, and everyone competes for 1 sale. And the sale is only periodic. It's not a market place that makes companies want to gravitate.

PD: I had someone saying that they couldn't afford to sell to TSA. It's so much investment and it's only the big ones can really do it.

CC: but aren't you funded?

PD: But there's not profit in this funding. You have to choose from doing this work, or doing something creative in this area, and you block your capacities in this process. But the goal is continuously changing, and there are requirements that you have to fulfill, and you have to go over your work over and over, and only few can afford it.

JB: Companies decide if they are only engineering or many companies. The rewards you get of funding to provide hardware, so if I spend my time as an engineer, I get multiple returns on my research. It's only a researcher's imposition. If you are building hardware, you need returns. From a bunch of perspectives, it's not healthy.

MBS: Maybe that good, but however, it's against what we are shooting for. What we want is How do we create a momentum where third parties and vendors and TSA can get over this problem, it is important that we recognize this, but we can't just give in.

??: On the medical side, what you said about approval burden is only turn for devices, but once you have innovation, the approval is very high. But on the other end, you have a small company, however once you change and add new innovation, you either need to improve your device, and make small changes, you can get approval. But there are not a lot of buyers for medical. You have an equivalent to security sides. For the security side, TSA is not the only customer. You have other markets overseas. We are going to China, so we are looking at it a single buyer situation is misleading.

JP: You don't have to go to FDA for what you ask for in advance. It can be innovation. It can be from the market.

??: But you need to educate the FDA to make them comfortable.

??: One of my colleagues, she brought it to Congress to get the code for CT to have hospitals build.

??: There are multiple TSA tests, we heard about them yesterday and at dinner. Federal protection services, it will become more like that. I used to work for a medical device many and I know that getting approval is very difficult and there is a sense of burden. Clinical trials are a lot of work, looking at approval from the inside; it's probably not as bad as if it was FDA. Yes we have fewer customers in security than medical, but certification is less burdensome.

??: But the buyer is really dangerous on their side.

??: I disagree, because most international customers, you past the test, they buy based on speed, and cost. They don't buy based on tests. There are a few who look at detection capability, but from an industrial research, that would be the direct value to us.

JP: Can you tell us what the incentive is?

PL: It's kind of a base price, but however, but currently, we are struggling, because it's competitive.

??: I know when DHS started, they have many examples of what we are doing out here. No one has the money to develop the multiplicity to get to those advanced systems, because of free market. There has to be financial stimulation.

??: It's a very high variable, and it's costly, but one thing I want to remind everyone, it this industry was started by small companies. (Directed to Richard Bijjani) It can be done, don't give up. But as far as incentive, there are two aspects; a lot of us are in this industry because you want to do the right thing. But from a financial incentive, companies need to position themselves in such a way that they can change the specs, you have to get ready to improve the system, and you have to improve your improvement. Even if TSA is not telling you to improve your development, so your incentive is to stay in the business.

JP: Can you say more about that?

Matthew, it is a challenge for TSA and vendor perspective, to have single supplier, they need two.

CC: So you don't have incentive to be first.

??: The first one gets beat up, and the second guy follows the same path.

Matthew, you have advantages of being the first, but you need the second.

CC: But we heard that there is no difference in performance.

??: I agree that we need to get over that kind of thinking. Anyone who exceeds the minimum threshold, we need to get over that. There is incentive to be the best, not just in the class. To make it less painful and costly. Even just from the mechanics of it. Those are takeaways.

David Legal: Market is a regulatory driven one, so there is risk in going first. And project where you think it will go, and what requirements will go, cause as we have seen in the US and the EU, the regulatory requirements, the procurements have been delayed. When you have investments that are made by manufacturer, you are planning on return in a reasonable amount of time. And if it's delayed, it's not incentive. You need to do it ahead of requirements.

MBS: We have been grappling with this same topic since the beginning, but how do you create the vehicles like the data sets, to encourage pathways for third parties to demonstrate without having to go through this process, with real innovation, without a particular third party invention, when I say the Livermore presentation on metrics, it shows the power of what we can do. It is a way for assessing the performance of the algorithms that we are developing; but we still get the attention of the main line vendors to get third parties. I don't know if it could be better or none.

CC: Some of these people say there is no way to go to security.

MBS: but it's the same thing, which would give quantitative path.

EM: I have been working on support with grad students and post docs, as a faculty member, that's a preferable mode of operation, NSF, 3 year and 5 year programs which are competitive, which expect response, and there are government agencies that support this.

JP: That's my 4th category here.

??: One of the things I believe I have captured over the years, the idea is that people look over at medical, and see technology to apply to security, but hopefully with ADSA and other workshops, we are reinforcing that the reality is that it is different. There are different needs. The goals are changing because the threats keep getting added too. This unique set of our own needs. There are a lot of other federal governments working for that.

JP: Ask us to remember that there are different kinds of third parties. Between commercial third parties, whether you are working with a vendor or not, or are funded or not.

There are at least 4 subsets. 3 are funded by a vendor. 1 is not funded by a vendor. You can hire academics to solve these problems, if you hire smart people

<u>Break</u>

<u>Matt Cobey</u>

From TSA office of security capabilities, I am an evaluator, I am here to talk about this TSA process. I focus on the developmental testing, from research and development, anything that is not done in the airport. Developmental testing is designed to verify technical requirements meet the requirements. In operational testing, we take the system and put it in the airport and give it to the users, and have them operate like any other system; we are looking to see if the system has enabled TSA to get the job done.

DHS acquisition, DOD has a bunch of robust processes in place, basically if you follow this through, you will know how to get the requirements. DHS is still defining themselves as an entity of how to acquire systems. These diamonds are decision points for DHS. Under the new laws, we cannot buy a system without approval from the secretary. Someone from TSA says we have to keep bombs off of airplanes, so the decision makers have decided that is a good idea. They decide that there has to be research done, so a lot of these are satisfied, but then there are these boxes, this is where money gets applied. At 2A, they say okay, you have a valid need, so we are going to give you funding. 2B, is where we say that your strategy is acceptable. On 3, this is where I come in. The secretary of management says, “Are these systems viable?” They look at the source selection team results, and they evaluate all of your proposals. What machine performs the best? And if the secretary thinks you have a winner, or more than one, he will approve the acquisition, so we all work to make this decision.

Who is the we? The user community is the most important one. The parts are the leadership, who says I need to fit this here, and process 4000 bags, the TSO, the transport officer, or the guy doing the hand search of the bags, and the passenger. In the case of an imaging system, or anything in the check point environment, they are the user, and then the taxpayer.

The next group of people we deal with. The contracting officers, acquisition managers, anyone who decides if we are going to use this system. Then there are the maintenance folks, who develop a maintenance strategy. Then my team, the testers, we are made of a several different folks, we also have oversight. DHS has an entity, has a director of test evaluation, and they look at everything we do for testing, and the look for integrity etc.

For the system evaluation team, where I come from, we (???) TSL lab, who certify the systems the detection piece and safely. Then there is the office of TSA integration facility, then there are operational test evaluation. The bottom line is we give a system evolution report that has all of these entities, and we provide that to DHS.

You are probably familiar with the TSL; Robert in the back can fill you in on that. The TSA warehouse transition from the environment that emulates the setting to reduce the risk and cost. We bring TSO on the floor to operate the systems. The bottom line is the final exam for your technology is to see what your research is like in the real world. This is where your detection comes in, and we see if it can be interoperable with TSA's process. How important is that image for the user? In the airport, all of this comes to real life. An image goes to an image operator system, and the TSO has to look at that bag and say if it is a bomb or peanut butter. And if he thinks that there is a problem in that bag, he sends to get hand searched. The challenge is that there are not a whole lot of requirements, and performance requirements with the hand search. And how do I really test that. So we have to create simulated threats. We have to create simulants into artfully concealed explosives devices. We have a very creative shop, where we don't just put a clock with dynamite into a bag.

We will run it out to the airport and put it into commerce, and we have to make a visual explosive system. How long does it take the TSO to clear this?

Then we look at availability, and you guys build something that only works one hours of the day that's not helpful.

We noticed one system in the lab that if you put it in the lab, is it better to put it in a truck that has an open trailer. Human system integration, because there is a human in the loop, we have to find out if the colors or the grade are good for the TSO. Information insurance has a component for image stations that work for the TSA. At the end of the day we evaluate all of this, and see if these systems work for the TSA and if we have a provable

??: There was a change in the process; is their result of this going to be streamlined?

MC: I think so. We have had experience of how things have gone over the last several years; we have found a few things that impact something else down the stream. Like airport costs. What we want to do is conduct tests in a logical methodology, as I don't want my team involved until it is certified. Then we want to bring it into the TSA Systems Integration Facility (TSIF), and we want to reduce the number of times we bring the TSA into the process.

From the developments side, we would like to see commercially available test resources, so you can do your work, and it only has to go through us one time. That is our goal, to increase the efficiency and reduce the cost. It's expensive for us too.

??: What actually was the important thing to be tested on, so if you have requirements, but say you had one hour, it's not important to know.

MC: That's a big challenge. I can't get into the specifics. There are two types of tests, there are tests that support he development. But when you are competitive procurement mode, the rules have to change. The rules change on how we are going to test and evaluate. We need to do this upfront, being the vendor and being more clear, and in the case of this type of procurement, how do they make that trade off. It's a struggle, so there are evolutions.

??: Sounds like the cert testing is different from the procurement testing.

MC: Cert testing is one element of the procurement testing. If you don't certify, you're never going to get the (???). We are not buying the systems for anything other than to detect.

That's not the only test, and it's not the end result. It's a gate, or threshold, you have to be certified.

??: The test criteria are different during development than procurement, Developmental happens first.

MC: Certification is the final exam for that algorithm.

CC: What is the third party certifying?

MC: Any improvement, third party work station, or any change to the tech, anything will be accepted into a formal test, and any change are received there, and on detection attributes. It's examined, and if it's something that is not going to affect the quality, then we don't have to go through the cert process again. But if you change the image quality in a way that a TSO interprets it differ (???)

CC: But if he comes to a vendor, and says I want to sell you a common work station, is there a way for that to work?

MC: One of the goals is that there is a common element of architecture in that case, we would test it, and run evaluation, but how you get that workstation into the front door, is going to be based on if they decide (???)

CC: I have a device that has 99% detection, and walk in the door, will you buy it?

MC: I will test it, but if you have something like that, there is an open agency announcement if you have ideas you can submit them.

JP: Where is it in your diagram?

MC: Here, in this area, TSA will continue to use this qualifying product list, at the end of the day, with a successful OT (???), it is based on a qualified product list (QPL). I have to be careful to describe it to you, because QPL doesn't take into account anything but technical. TSA tests a bunch of systems and if they qualify, they can buy QPL. Foreign countries use our QPL.

I know it's quick, but if you have more questions, please contact me at my email.

Doug Pearl

DP: (Medical Vendors Engage Academic 3rd Parties slide) the further we move to the right of this slide, the less predictable things become. The less predictable things are, the more potential for a big advance, or nothing at all with no direct application in the foreseeable future. Do vendors make money from these things? I think so, yes.

FN: There might not be the problem solved, but the return on investment can come in the form of having created an expert for the company. (on vendors hiring academics)

DP: Charlie, how long did you work with GE before they saw a product out of it?

CB: About 10 years. I have worked on the problem for at least 20 years. But I don't want to discourage anyone from making investments. In the future, it will be really fast!

DP: It's a trivial, yet important observation that the less predictable things become, the more opportunity there is for a major investment. Eric's example, NIH, the role of government funding is more significant. What I've begun to hear is that security vendors may be doing less "find smart people, give them money and see what happens," that may be more likely to be funded by government.

Andrew Foland: One thing that's not obvious is that the medical market is much larger than the security market, just in raw dollars, so there's more room to throw some money in that department.

DP: And of course size is related to growth.

DLieblich: So what you have circled is a situation where nobody has a competitive advantage.

DP: But the market could nevertheless grow. For instance, if there is a faster upgrade cycle. In medical imaging there's also broad cross-licensing, that's the way the world works there.

??: In the next generation of air transportation systems, they are saying there are 3x as many people going to be flying 25 years from now. We're going to see turnover in imaging equipment just because we're going to have to handle more people, since cities are more likely to get use out of existing airports than build secondary ones.

(MRI vs. CT slide)

DP: Medical vendors say: Why don't you share your data for CT? It takes a huge amount of time and handholding. So to justify those barriers there also need to be some increased incentives.

DKim: Do you make a distinction in 3rd parties between academic institutions and small companies? Did you address those differences in your slides?

DP: Yes (goes through slides) I do think it's important to draw those distinctions.

DK: Do you plan to do a similar kind of analysis that result in the same observations for small companies?

DP: I didn't but the situation is analogous (goes through slides).

MM: But I don't think a left column exists in terms of innovation. It could, but it doesn't.

AF: I disagree a bit, I think there is room in that first column early on in that feasibility study where you can define a piece of a feasibility study very well to farm out to someone as part of the innovation process. That I have seen. But in general, I agree.

??: We're a small company and usually we do our work in the left-most column, but we've also been doing work in the right-most column. The issues that I see on the left side, us fitting into an existing (???) it's a big risk for them to take to have someone new come in and start mucking around with things. It also limits our ability to do better work and I think it's very restrictive. It may solve the vendor problem but it didn't solve the underlying TSA problem. There are just too many risks on the right-hand side in the security industry. If it's doing something you know TSA wants, meet the certification requirement, I would like to think that TSA would buy the right system. So I think that would remove the unpredictability of it.

DP: A reminder, DICOM is a standard for formatting and transmitting images in medical CT. DICOM begins where the image begins and once you've got DICOM, you've got interoperability. If you think not just about deployment but about the R&D and the development of that… in contrast, there's little access to the data and there is no plug and play reconstruction. Where it gets tricky is DICOS to ATR, if you're strictly analogous to medical. It's a little more complicated because ATR is such an integral part of the system.

JParisi: The ATR part isn't necessarily where you're going to touch anyway. You're going to do on the back end. That provides consistency and interoperability to TSA, but there's a cost because you now have to enable it to handle more than what a simple unit would normally handle. The cost of adaptation to that model is a transitional cost that's going to happen, but once it's done, it's to the benefit of TSA. Still, TSA will have to pay for it.

??: The problem is in doing the (???) imaging. Doing (???) is where it's difficult.

MM: Be a little careful about CAD/ATR equivalence where you could have it at the end, for instance, contraband detection. I could easily see starting a company where you just took images and found artifacts and sold it to say, Thailand. DICOS might be more useful there, for example. If DICOS is implemented, you can't just say gee, all these parts perform to the DICOS standard. Private tags do exist in medical DICOM. There's a pro and con – interoperability vs. innovation.

Richard Bijjani

RB: We pretty much covered everything through the discussions about how to get 3rd parties involved. There's not much involved. I see common vendor-specific and 3rd party-specific obstacles. Every company has its own culture and believes that they do things best. The fact is that this is a tough industry and it's a tough thing to do. Yes, the vendors are right to be arrogant and feel that it's unique to them, but there are still things to learn. Don't just talk, do the research. Arrogance comes from the fact that I took one image, I ran it, and it looks good. But it takes a lot more than one image, right? It's a lot more complex. So there's a mismatch of expectations. What does the vendor want vs. what does the 3rd party want, and they're not the same?

Be open and accept new ideas. Not all new ideas are good. But there are good new ideas. Like "oh, I can't share my data, my data's so good." Give me a break guys, it's a CT machine. What's so great about your CT machine? Let them learn, guide, mentor. Don't expect the academic who comes over and hands you the code, it will work right away. It won't. You'll have to work on it, invest in it, and improve it the same as your own code. Nobody here has a problem finding a simple bomb in a bag. So academics, don't work on that. Come ask so you know what the problem is and then we will take you seriously.

If somebody comes up to me now and asks a question, we can go to the side and perhaps talk a little more freely, but if Doug says Richard, why don't you go talk to this guy, it's a known quantity. It's easy to research these problems and you can research them academically. Google "explosives on airplanes" and you'll figure out what the threat is.

CC: You say that it's not hard for vendors to find bulk explosives, but you also have to meet PFA.

RB: I was talking generically, when someone comes into a vendor and says, "I have this new device that can do great things." But it doesn't actually solve any problems. Stop solving problems that don't need to be solved. (Template from duatre.com: Imagine meaning)

Eli Lilly and Company introduced InnoCentive.com (grand challenge) for something that their engineers couldn't solve. It worked, the website is still alive 10 years later. Outsiders do solve difficult problems that stump experts. This is a known fact, it happens across every industry. Outsiders are people working on the margins of their field, boundaries of their disciplines, not traditional experts. They aren't as likely to be stymied just because they've been to 100 conferences and talked about this insoluble problem. The best outsiders are the young people who have not yet learned it's impossible.

??: Dos and don'ts for the government?

RB: Dos? Introduce people. Act as an honest broker. When I was at Reveal, I would be happy to give images to any researcher as long as they are vetted by the government, as long as Doug sends me an email saying "trust this person". Articulate long-term goals. Say what's happening in 5 years. If designing a new system, what should it do?

Joe Parisi

JP: Richard's presentation just now was fantastic; he captured a lot of what people don't know about this business and how it works. It's one thing to think you have something good; it's another thing to tie technology to operational requirements. Where the government puts in not what they need, but tells you how to do it. One of the first rules of buying something is to tell people what problem you're trying to solve.

I was at L3 and got kind of bored with that, started L1, grew a company that went from 0 to $700M, sold it for 1.5B, decided to retire, got bored, and started a new company. So I am starting new ideas and want to enable people to achieve those. (Shows Professional Background slide) I've got a great group of people that are working. The real need going forward is checkpoints. My company has three areas: government services, applied technologies, and data management. Applied technologies includes checkpoints, thousands will be bought in the next several years. TSA needs to wake up to the need for an automated checkpoint. Data management, this area is usually stove pipe solutions. How do you take all the information at an airport and get a better overall view with it? The reason I am giving you this view is I am the first tenant of the new Northeastern University technology center. Universities are great at big research but are terrible at manufacturing. This center will bring the customer and vendors together. I look forward to this and the opportunity to transfer their research to the fields.

Harry Martz:

HM: Can we do something different when we improve this or not?

CC: Create boundaries?

CR: There should be openings for other metrics as they show up.

HM: We did have some of this discussion; John was saying sometimes it isn't clear. Let's start to make this general and see what we do. "We did it this way in industry; this is what we should do." No, let's open it up. Let's woo young people. We want to compare and we didn't have the runtime segmentation. Is it worth the cost?

CC: If you lower half the cost on false positives…

PH: In the segmentation challenge everyone was asked what their run time was.

??: I think Jeff's comment is correct, if you have runtime it doesn't tell you what you need to know. You need to know complexity.

HM: There might be ways of using the information differently. I think the other problem is if you are looking for specific items you will miss other things. There are holes in the algorithms. Recon Steps Forwards slide.

??: If you could do a lot more sophisticated algorithms, even if they aren't fast, is of great use.

JB: I see us creating a pathway for going forward. A good simulator would endure and it would teach a body of people a piece of technology outside of this room.

John Bush: Wouldn't it be interesting if the leading EDS manufacturers were put together?

MBS: In the same set as the dataset was gathered for the data challenge, the simulator could be a *simulatable* piece which others could emulate or improve on the results. It would create the mass needed just as it is in the medical community. It would be a piece of the arsenal in the security community.

MM: Open architecture, recon is the following five or six steps as well as EDS. Have architecture will run all these steps with closed modules.

HM: Just run it?

MM: Yes this sits on a LLNL server and a researcher can run new parameters but that is all they will see. Someone at a higher level can look at the new results. You basically have proprietary module with an open architecture. The point is you can have an end to end evaluation.

CR: This is one of the reasons a good model is needed. There are a couple of other aspects of modeling. First off a good model is you know what good/bad results. As Dave said the next step in reconstruction, if you put in physics you will make the next leap.

ELM: You could make an open source simulator and if someone for Morpho wanted to then use this and modify it is doable and useful.

JB: You have to have one good tool.

CR: Carl, there is your next workshop.

JP: I am very skeptical.

CC: I have to go to the next step, but we have to go.

HM: Codes exist that you can use for that. We do want to have some data to compare to that. It is a big deal to generate ground truth, and distribute simulation. We want to make sure we can simulate what we acquire. We do this in the md world as well. Sometimes we misinterpret the data. So I put this data into this, we have recon, post processing, but we need to focus on recon, do we want to use sub-system metrics, or do we want to sue system performance. That doesn't necessarily correlate. If we can reduce the effects was can make the cloud smaller. Simulated vs. experimental data.

??: So I want to make a comment about living in sub system metrics, is that if they are well adapted to CT systems, they may not do well in predicting how a scanner works at the end of the day.

HM: If it generates a smaller cloud, who knows? Maybe that would give you better performance. A lot of people are talking about segmentation, eventually you can get into here. Now if we make it subset, based on what we used here.

??: The MTF does not exist anymore, we cannot hope to quantify advance algorithms, and we have to understand that. I get that you are worried about this pd/pfa system, we have to realize that augment system is not going to do that.

HM: The question is, what about the reduction?

But if I use this algorithm, I end up having a cloud that 'this' big. This is what I did, and I reduced this, but I don't know what others think, but what happens here, what if we went to pd & pfa, and I give them a banana, and I got great pd, but you know what that's going to say, nothing. It is an unrealistic problem. Some people want to publish, but you can't publish unless you set up metrics. You have to go to the dark side, so that people can be set up so that they can see what you're doing.

John Beaty: The issue out of this is to get all of the elements the whole target the entire algorithmic package, and deliver it back to this group. And to the people in and not in this room, so that they have the access to the simulator.

HM: Recommendations here, recon, metrics to be determined. This isn't going to be any easier. The cloud metrics, I think it's simple, and what you have this big space, you have to figure out how to reduce it. Maybe it's limited and won't work. Security light scanner, but maybe it won't be specific. How close can you get, maybe there aren't security issues. Perhaps we talk to a lot of people, and mainly focus on 2D, and maybe focus on 3D. So acquire full data sets, but you can reduce these. Maybe you will be able to look at other people's technologies. Use researcher's segmentation. If they are willing to supply their code, so we can see if this is useful to us. Maybe you pick one, or maybe you run all five, and see what the results are. Maybe it's sensitive. Apply and adapt IR and Analytic Algorithms. Someday, if you want to solve a problem, come to the dark side. At the national lab, we will get people the clearance necessary, if there is a problem we want to solve., If you want to solve this, let's not talk about solving, lets solve it.

??: The university is going through the process to get certified.

MM: Can you provide a reference for reconstruction baseline?

HM: Yes, we can.

MM: Even a trivial one.

HM: Yes.

<u>Closing remarks:</u>

LP: Thank you for coming. Michael has sent an email to the group, and I have read all of the emails, and if anyone has comments that they want to send me, please do.

I want to thank Carl and Carey and Jack, you have done a lot.

MBS: I want to thank the audience. The commitment to come, and struggle with this problem, with parameters and barriers, and with 7 workshops, we have made progress. I am very grateful, and I want to thank you for your participation, and I hope you continue on with us as we take this path. We are a community.

CC: Thank you to everyone. Please fill out this questionnaire, as it is very important to us.

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. Some of the presentation slides have been redacted to ensure their suitability for public distribution.

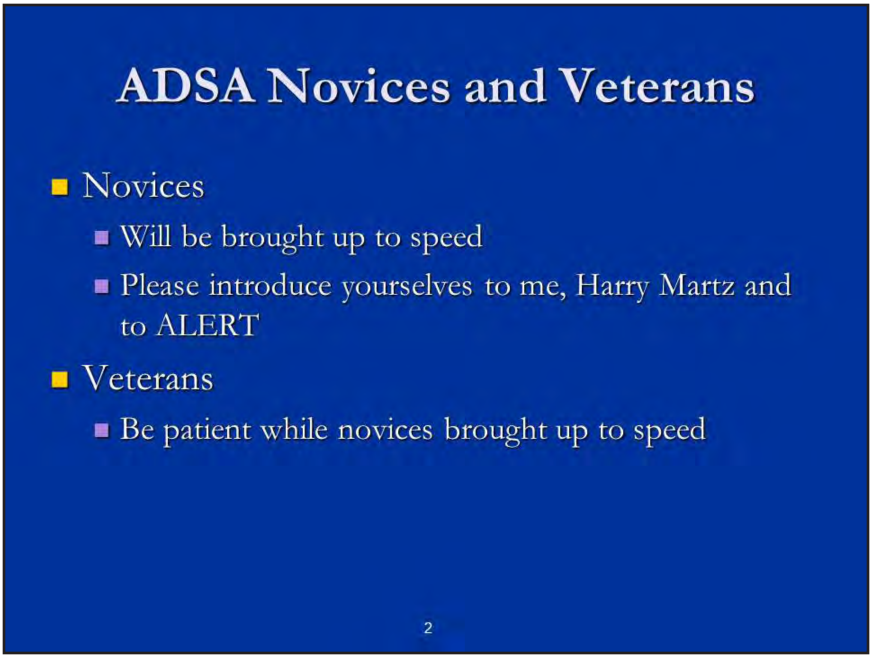
16.1 Carl Crawford: Call to Order

Algorithm Development for Security Applications (ADSA)
Workshop 7:

CT-Based Explosive Detection Equipment: Improved Reconstruction and Accelerated Deployment

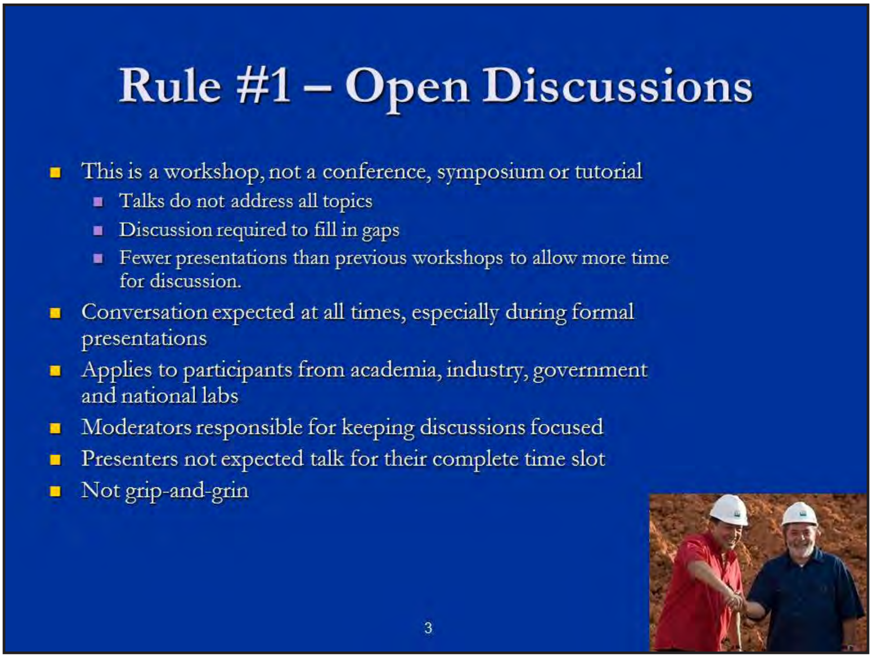
Call To Order
Day 1

Carl R. Crawford
Csuptwo, LLC



ADSA Novices and Veterans

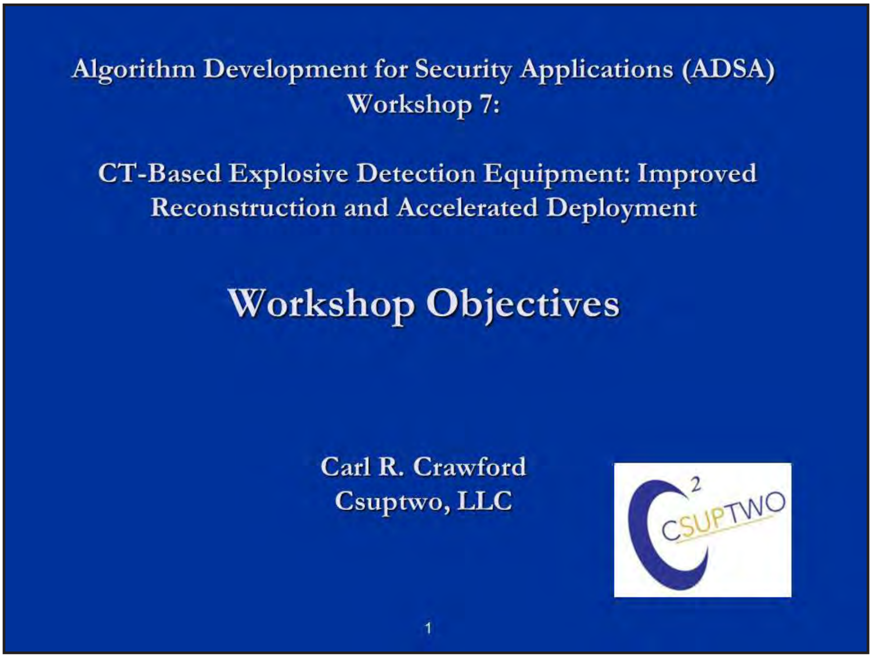
- Novices
  - Will be brought up to speed
  - Please introduce yourselves to me, Harry Martz and to ALERT
- Veterans
  - Be patient while novices brought up to speed



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
- Presenters not expected talk for their complete time slot
- Not grip-and-grin

16.2 Carl Crawford: Workshop Objectives

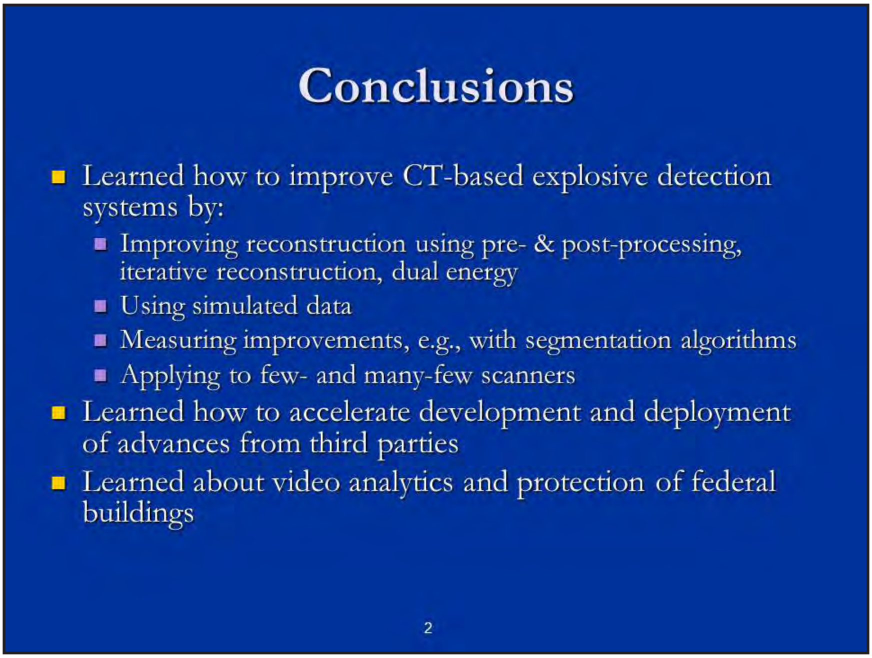


Algorithm Development for Security Applications (ADSA)
Workshop 7:

CT-Based Explosive Detection Equipment: Improved Reconstruction and Accelerated Deployment

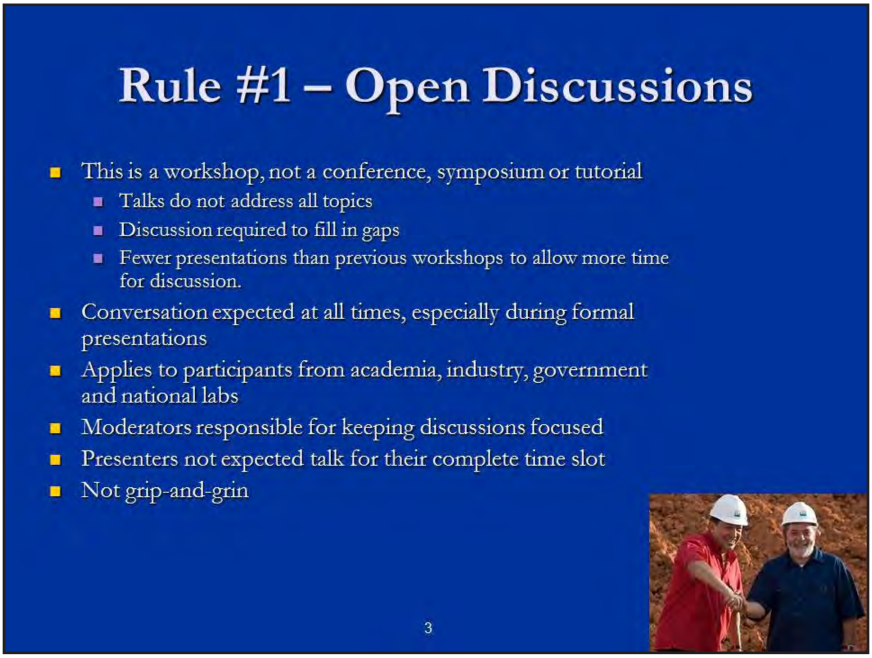
Workshop Objectives

Carl R. Crawford
Csuptwo, LLC



Conclusions

- Learned how to improve CT-based explosive detection systems by:
  - Improving reconstruction using pre- & post-processing, iterative reconstruction, dual energy
  - Using simulated data
  - Measuring improvements, e.g., with segmentation algorithms
  - Applying to few- and many-few scanners
- Learned how to accelerate development and deployment of advances from third parties
- Learned about video analytics and protection of federal buildings



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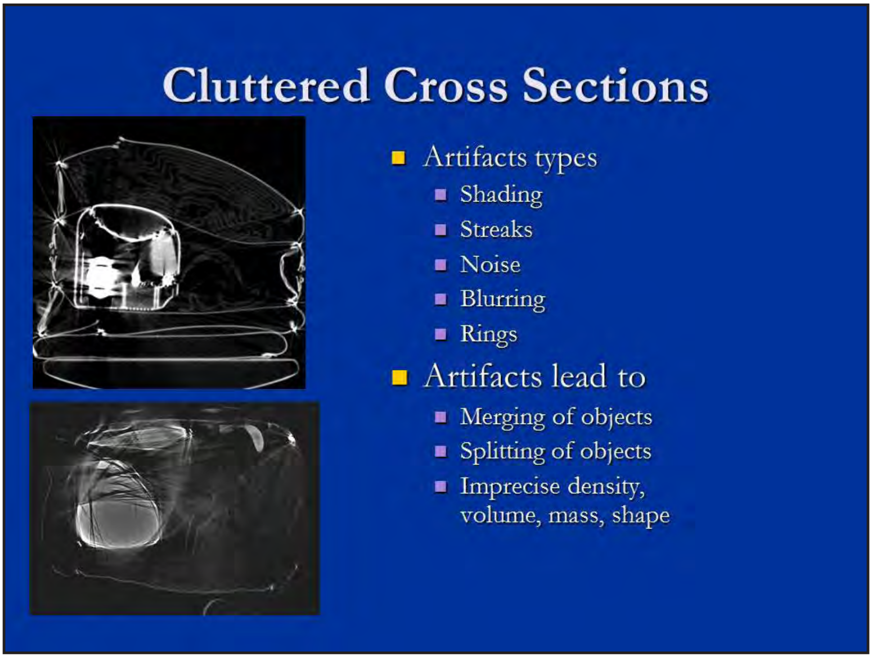
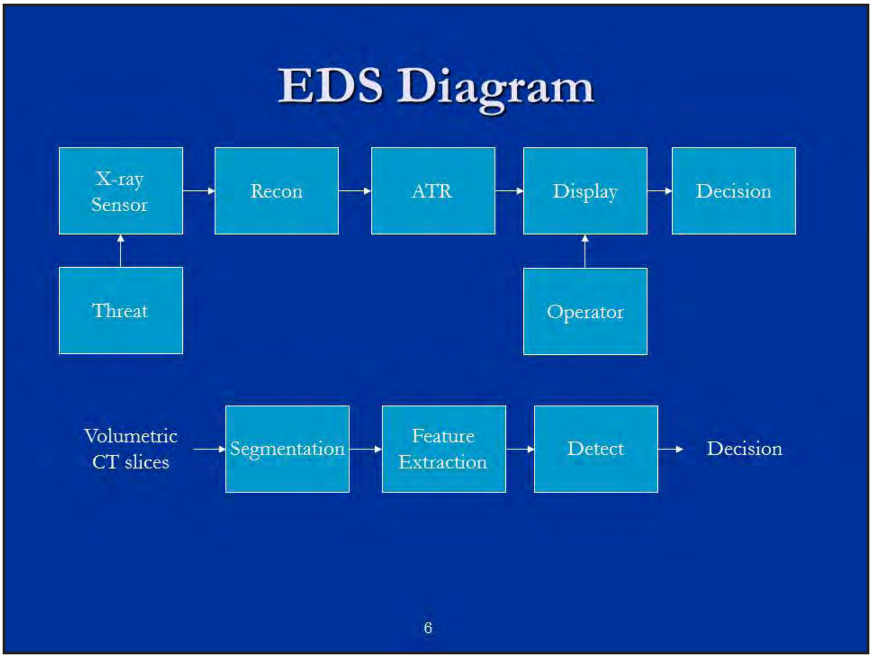
Deployed Scanners

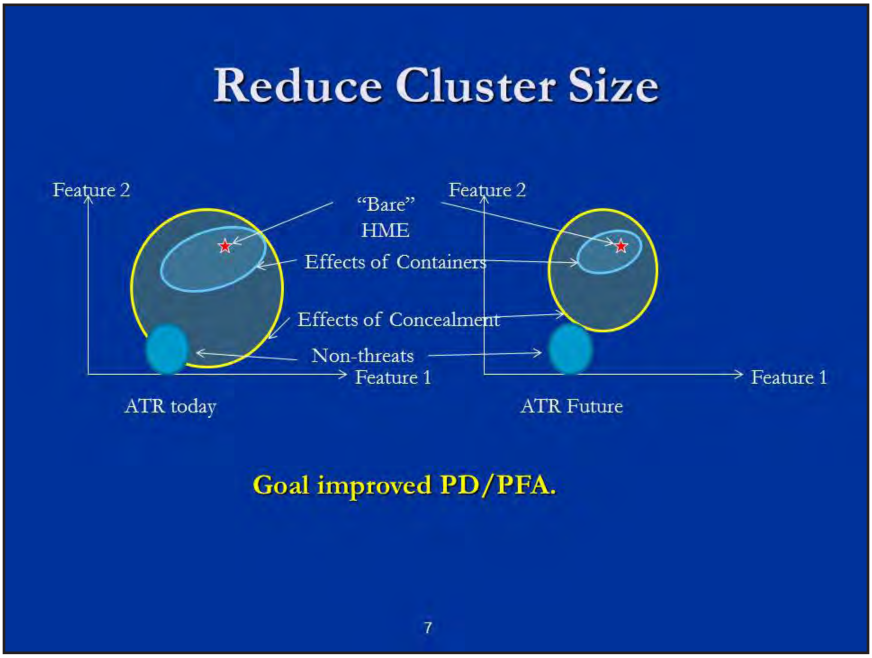


Cluttered Cross Sections

- Artifacts types
  - Shading
  - Streaks
  - Noise
  - Blurring
  - Rings
- Artifacts lead to
  - Merging of objects
  - Splitting of objects
  - Imprecise density, volume, mass, shape



EDS Diagram



Reduce Cluster Size

Feature 2

"Bare"
HME

Feature 2

Effects of Containers

Effects of Concealment

Non-threats

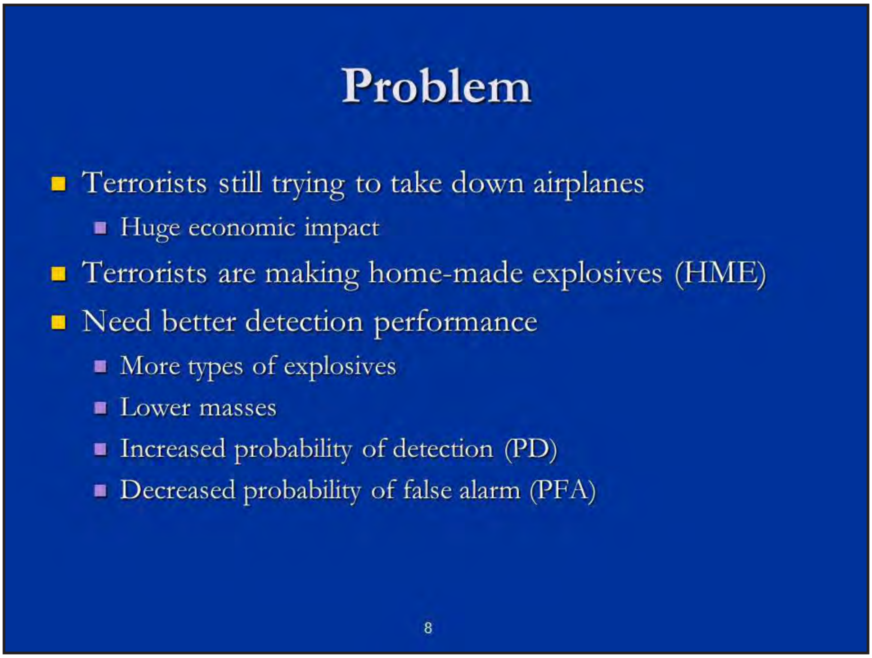
Feature 1

Feature 1

ATR today

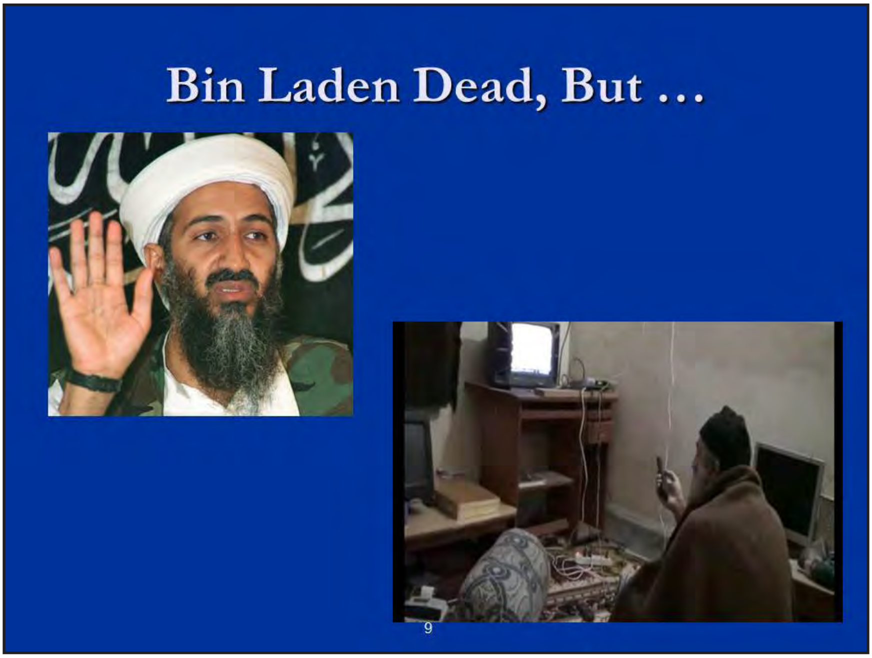
ATR Future

Goal improved PD/PFA.



Problem

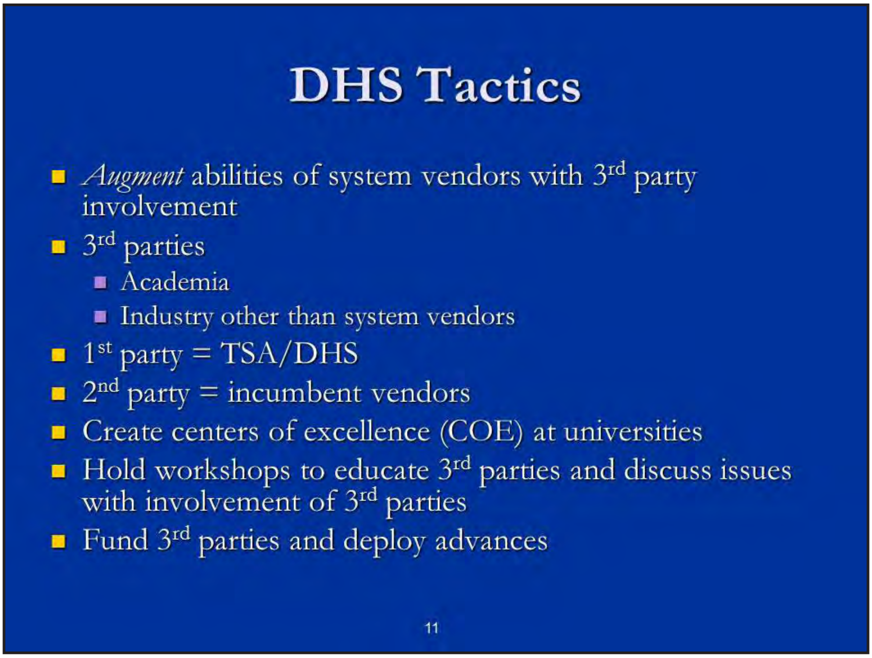
- Terrorists still trying to take down airplanes
  - Huge economic impact
- Terrorists are making home-made explosives (HME)
- Need better detection performance
  - More types of explosives
  - Lower masses
  - Increased probability of detection (PD)
  - Decreased probability of false alarm (PFA)



Bin Laden Dead, But …

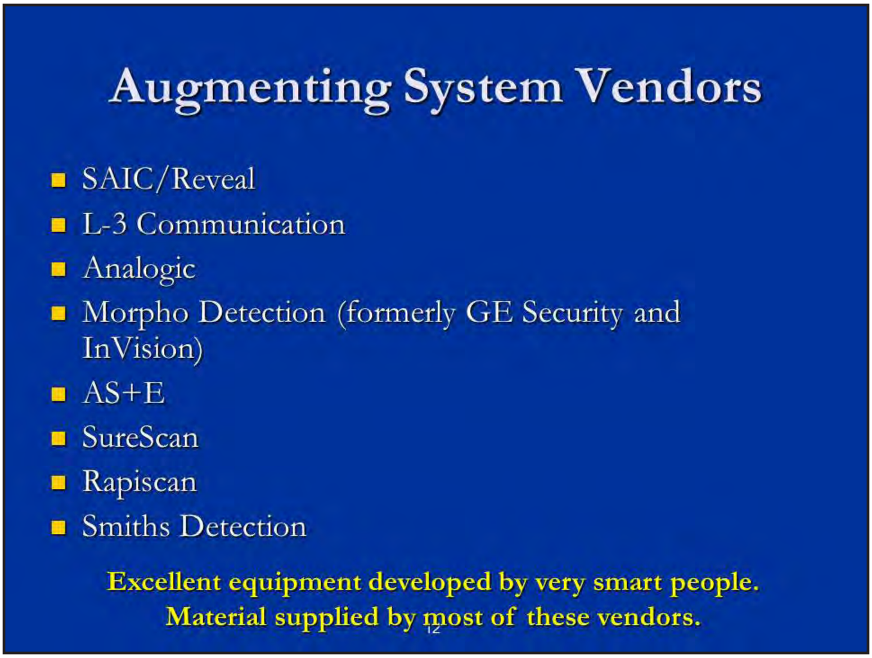
His Followers Are Still There

- Plot to bomb airliner foiled, officials say
- A nonmetallic explosive device was recovered that had similarities to the one used in the failed attempt to bomb a Detroit-bound jet in 2009, a U.S. official said.



DHS Tactics

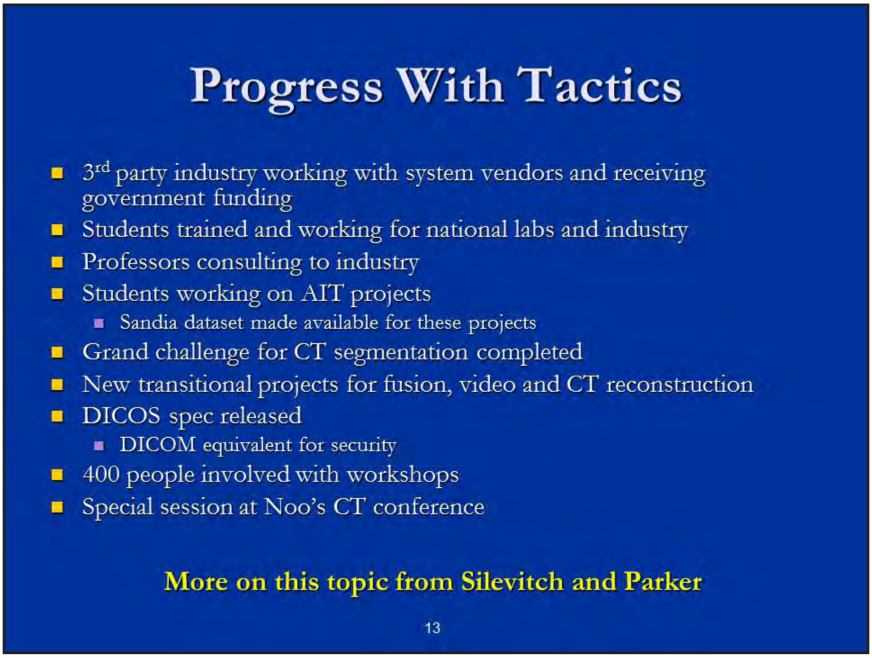
- *Augment* abilities of system vendors with 3rd party involvement
- 3rd parties
  - Academia
  - Industry other than system vendors
- 1st party = TSA/DHS
- 2nd party = incumbent vendors
- Create centers of excellence (COE) at universities
- Hold workshops to educate 3rd parties and discuss issues with involvement of 3rd parties
- Fund 3rd parties and deploy advances



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.



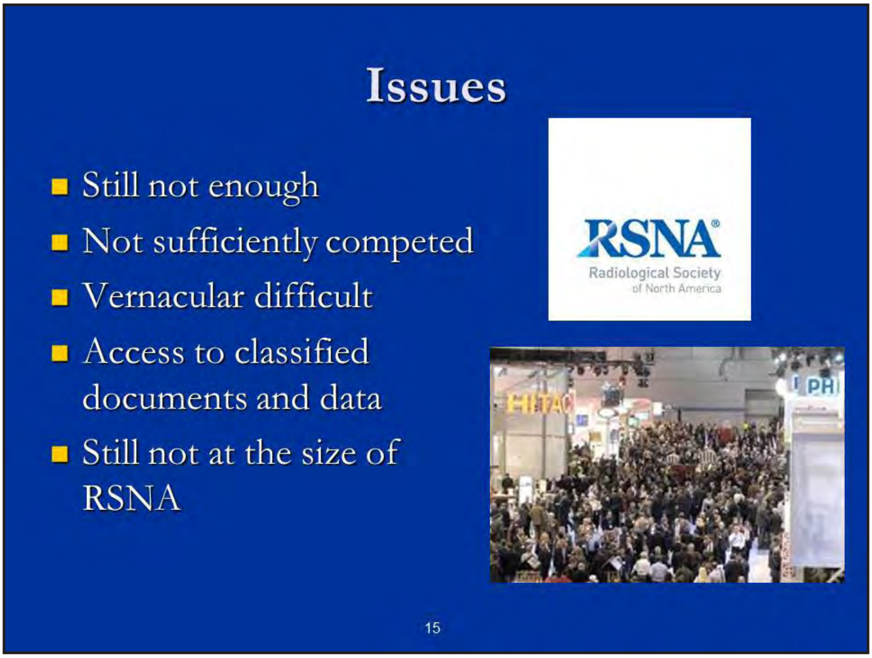
Progress With Tactics

- 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 completed
- New transitional projects for fusion, video and CT reconstruction
- DICOS spec released
  - DICOM equivalent for security
- 400 people involved with workshops
- Special session at Noo's CT conference

More on this topic from Silevitch and Parker

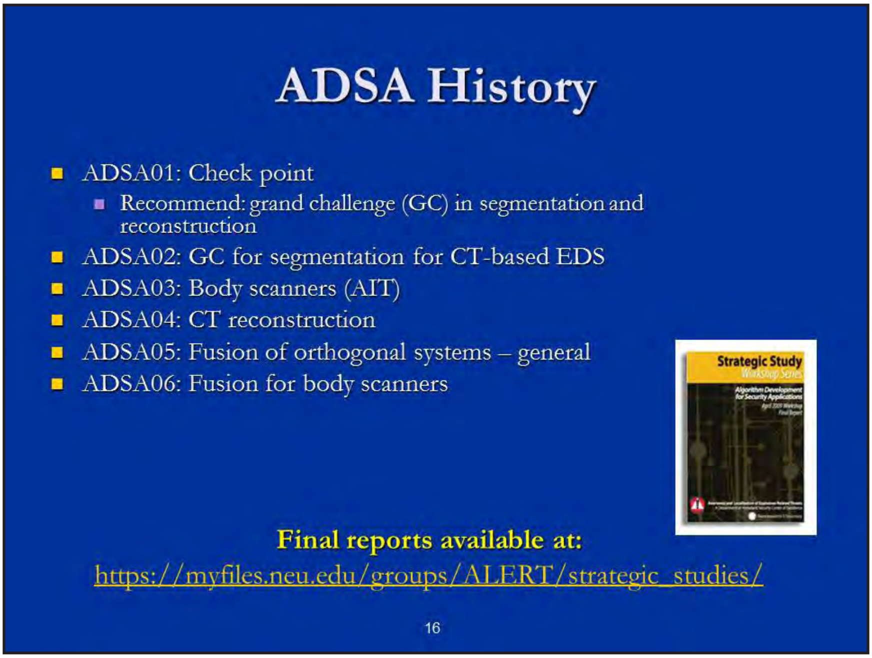
Funding Opportunities

- Industry consulting
- DHS & TSA request for proposals
  - Broad area announcements
  - Targeted announcements
  - SBIR (DICOS-based ATR) and image quality assessment
- Sub-contracts via ALERT
- Summer and post-doc positions with LLNL, PNNL, TSL



Issues

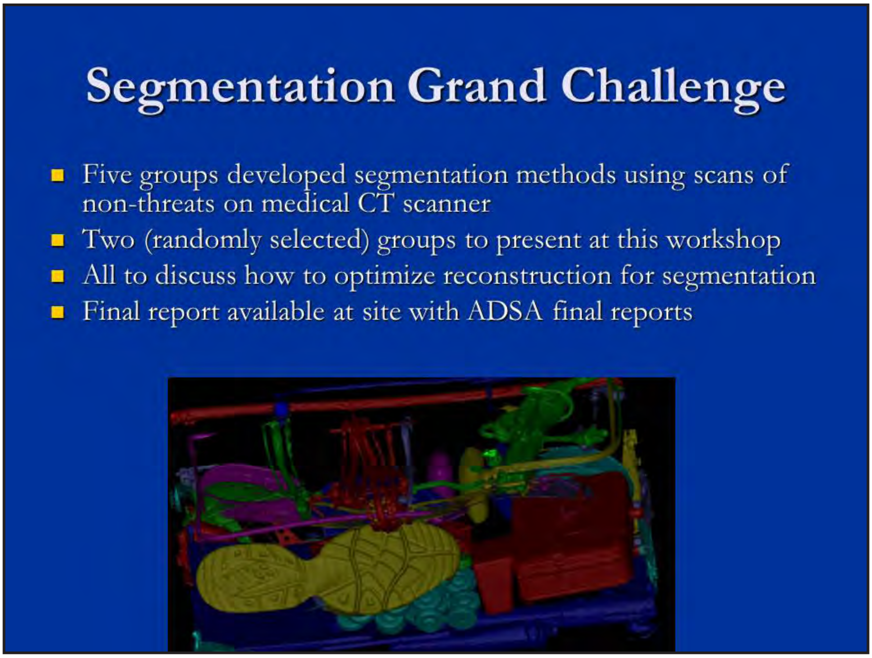
- Still not enough
- Not sufficiently competed
- Vernacular difficult
- Access to classified documents and data
- Still not at the size of RSNA



ADSA History

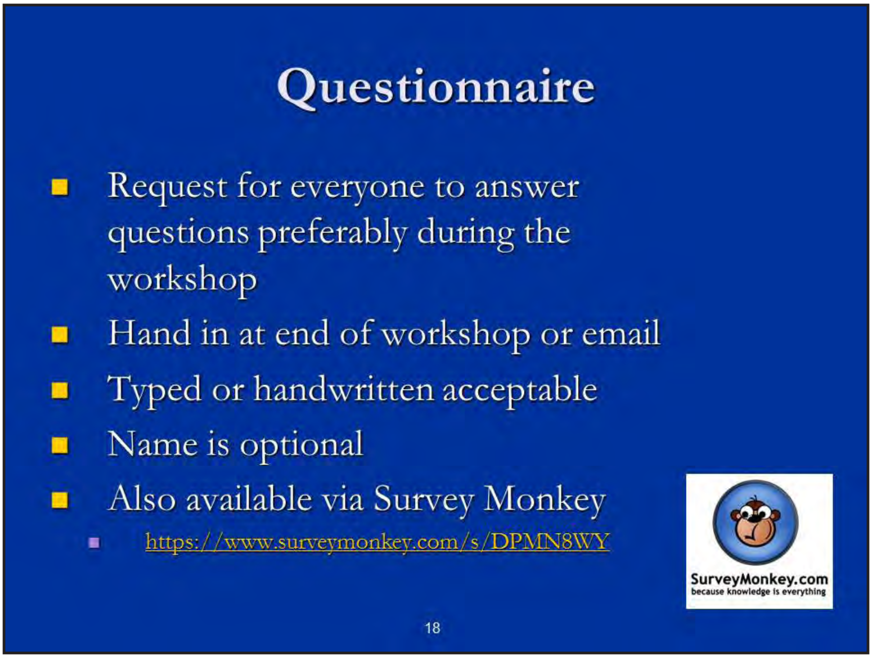
- ADSA01: Check point
    - Recommend: grand challenge (GC) in segmentation and reconstruction
- ADSA02: GC for segmentation for CT-based EDS
- ADSA03: Body scanners (AIT)
- ADSA04: CT reconstruction
- ADSA05: Fusion of orthogonal systems – general
- ADSA06: Fusion for body scanners

Final reports available at:
https://myfiles.neu.edu/groups/ALERT/strategic_studies/



Segmentation Grand Challenge

- Five groups developed segmentation methods using scans of non-threats on medical CT scanner
- Two (randomly selected) groups to present at this workshop
- All to discuss how to optimize reconstruction for segmentation
- Final report available at site with ADSA final reports



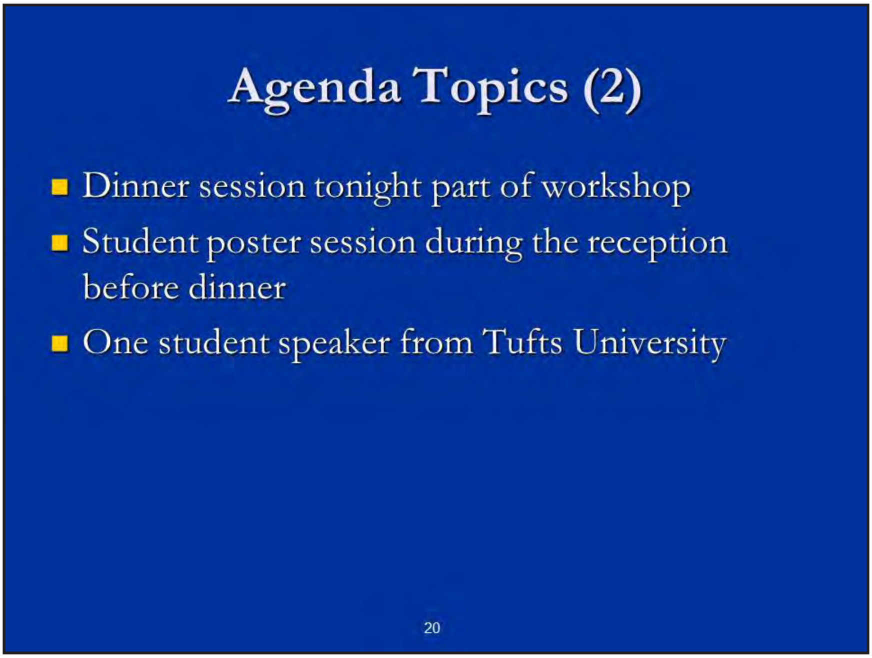
Questionnaire

- 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
- Also available via Survey Monkey
  - https://www.surveymonkey.com/s/DPMN8WY

SurveyMonkey.com
because knowledge is everything

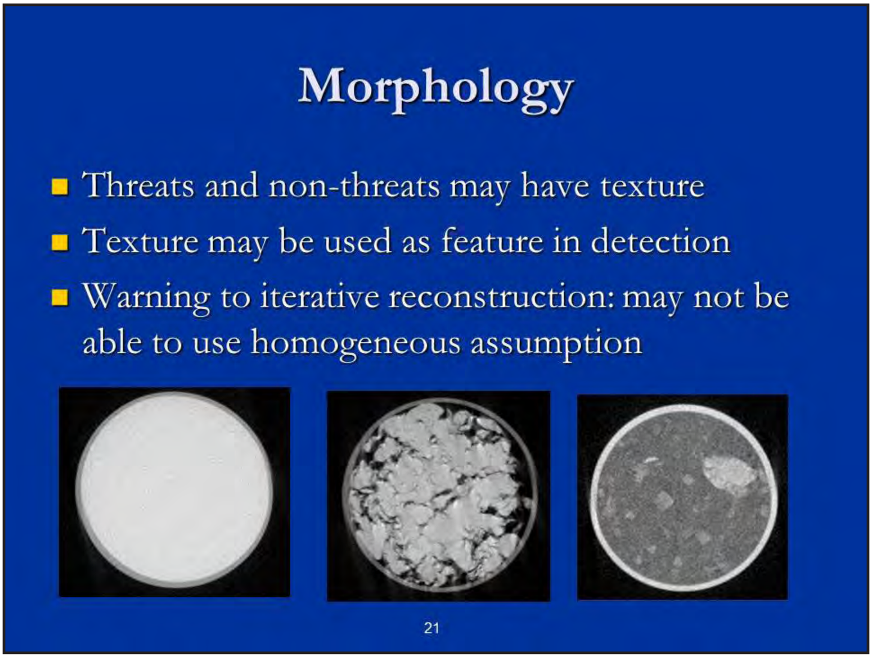
Agenda Topics

- CT reconstruction for few- and many-view CT scanners
  - Pre- and post-processing algorithms
  - Iterative reconstruction
  - Measuring reconstruction improvements
  - Computer simulations
- Accelerating third party advancements and deployments
- Introductions to video analytics and protection of federal buildings



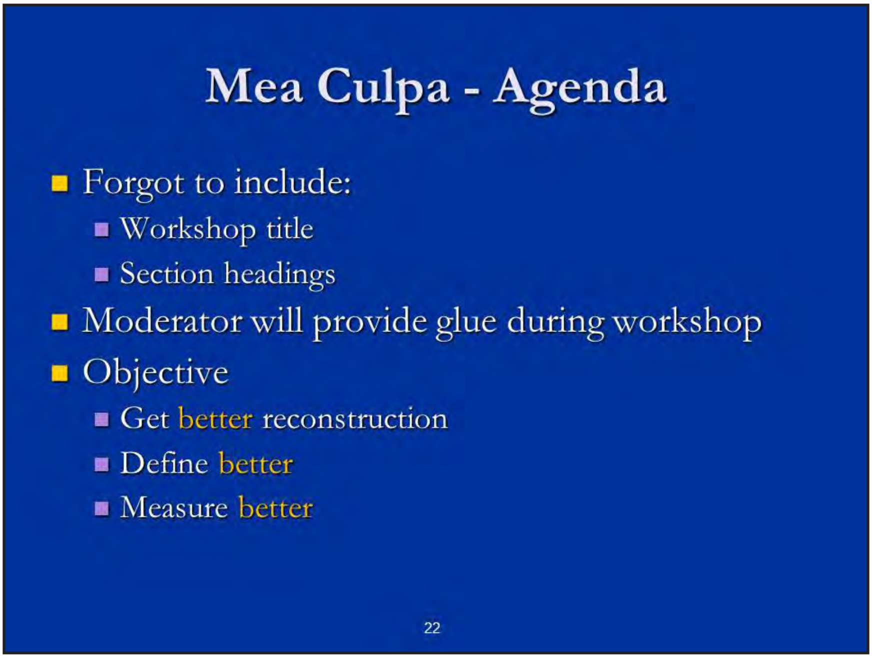
Agenda Topics (2)

- Dinner session tonight part of workshop
- Student poster session during the reception before dinner
- One student speaker from Tufts University



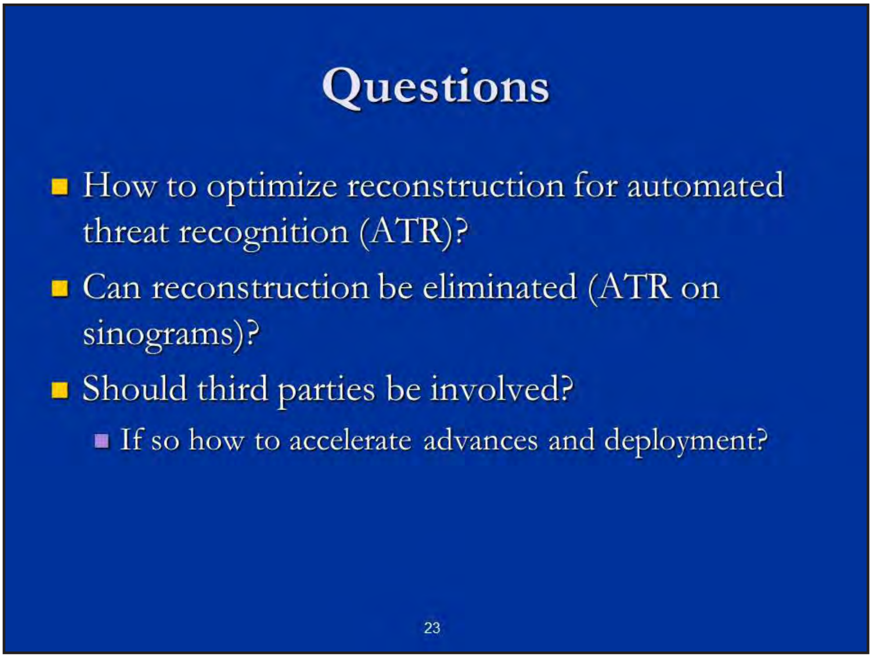
Morphology

- Threats and non-threats may have texture
- Texture may be used as feature in detection
- Warning to iterative reconstruction: may not be able to use homogeneous assumption



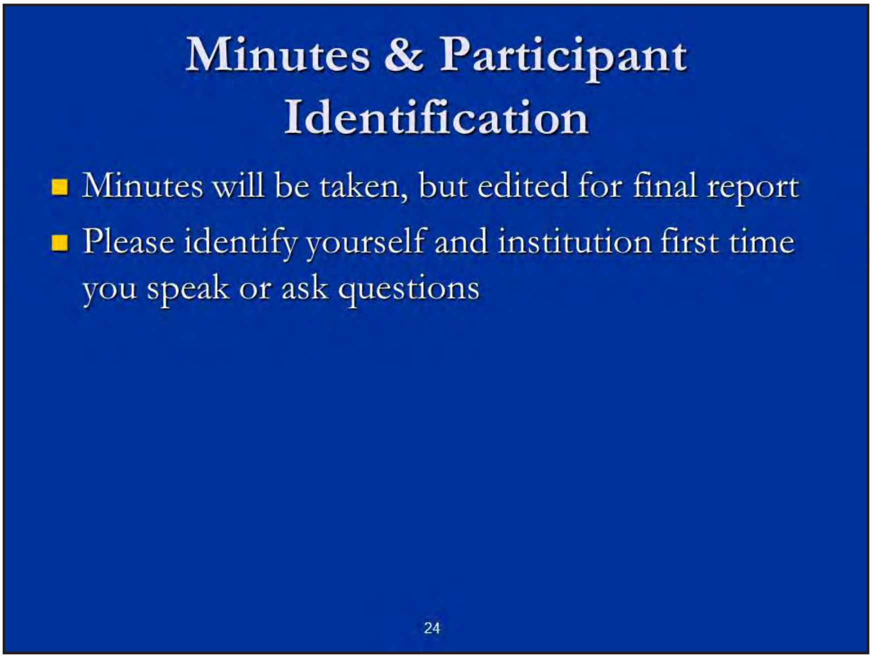
Mea Culpa - Agenda

- Forgot to include:
  - Workshop title
  - Section headings
- Moderator will provide glue during workshop
- Objective
  - Get better reconstruction
  - Define better
  - Measure better



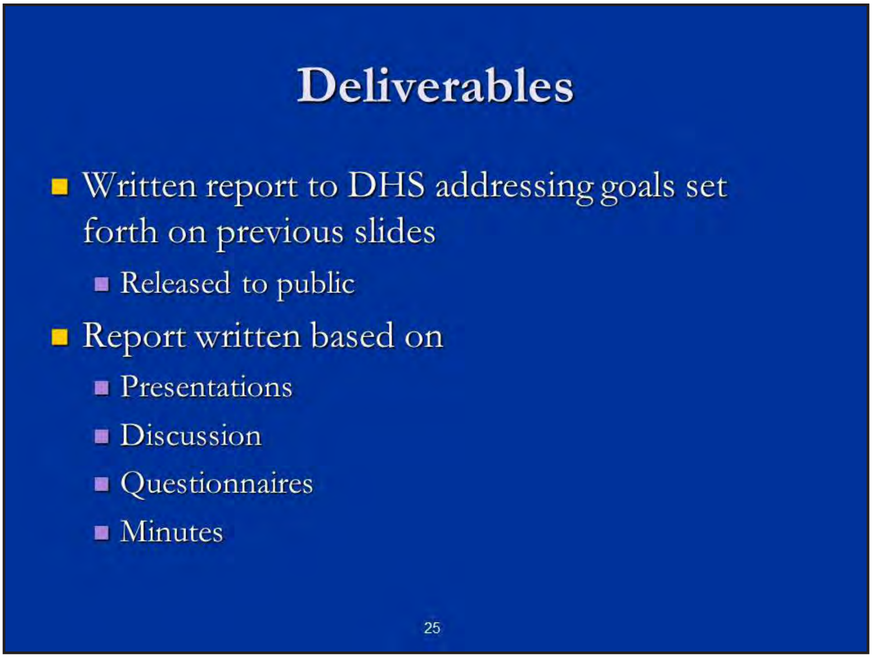
Questions

- How to optimize reconstruction for automated threat recognition (ATR)?
- Can reconstruction be eliminated (ATR on sinograms)?
- Should third parties be involved?
  - If so how to accelerate advances and deployment?



Minutes & Participant Identification

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

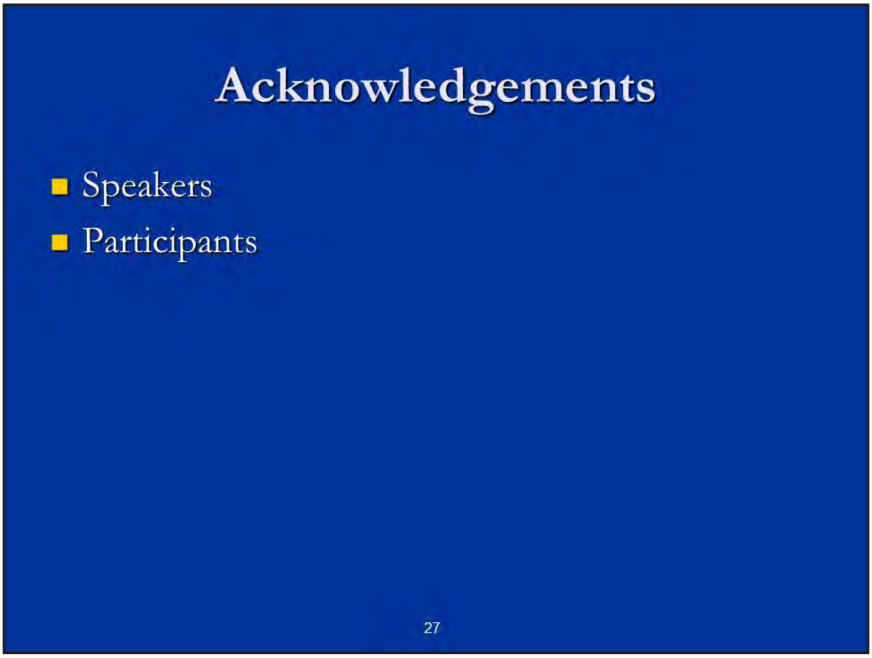


Deliverables

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

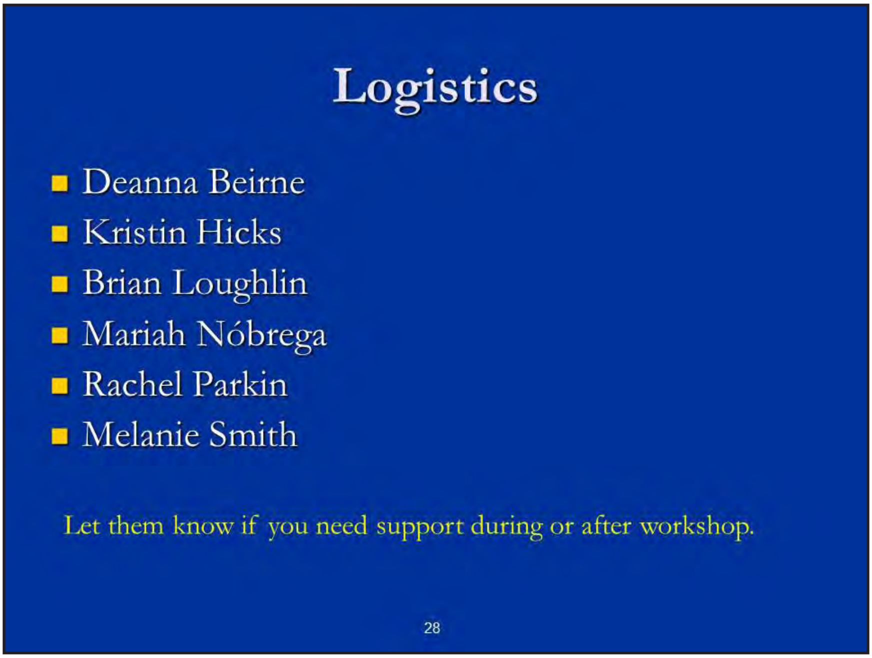
Acknowledgements

- 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



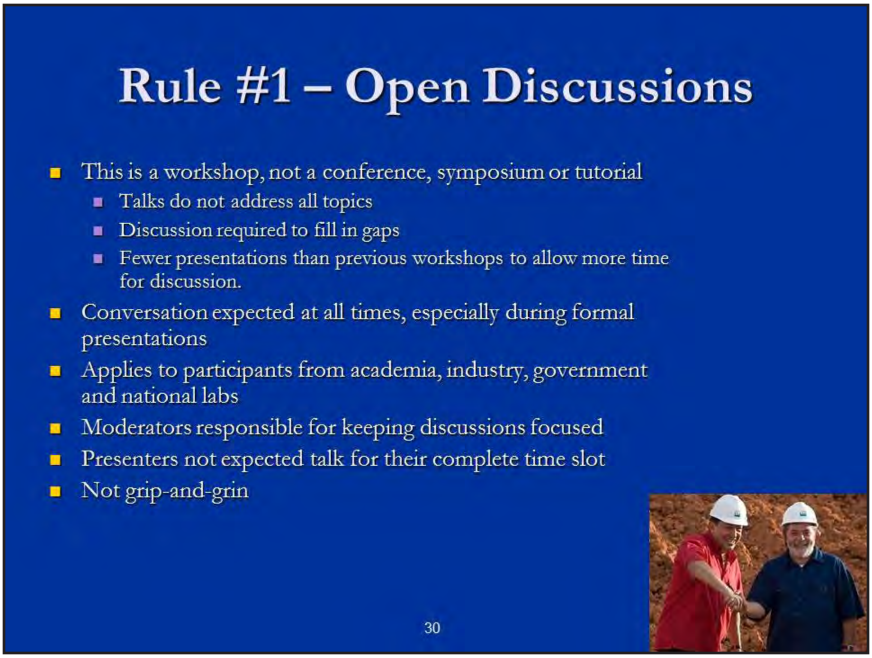
Logistics

- Deanna Beirne
- Kristin Hicks
- Brian Loughlin
- Mariah Nóbrega
- Rachel Parkin
- Melanie Smith

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

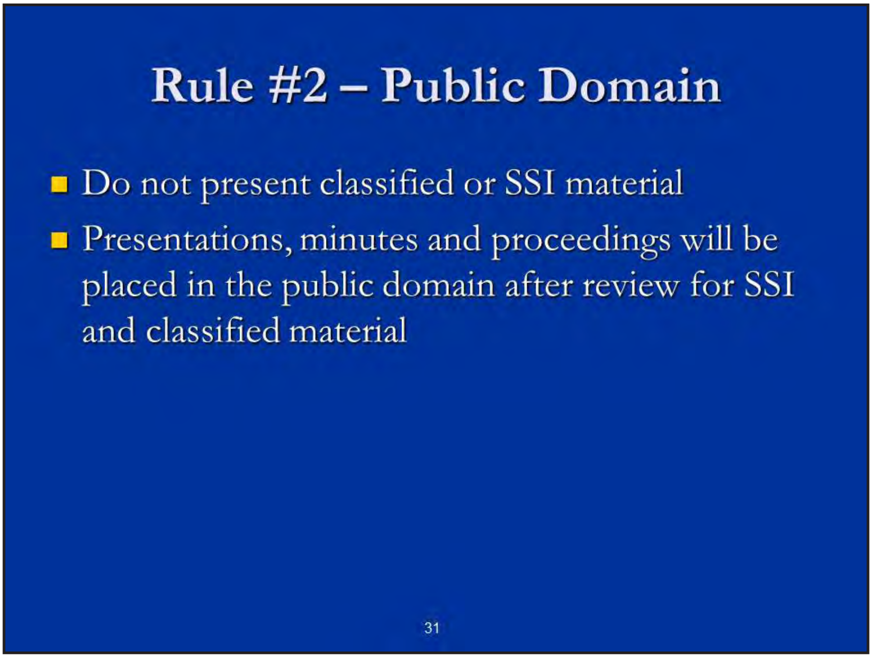
Mariah Nóbrega

- Personal thank you for everything you have done to support the ADSA workshops and other work I have done with ALERT.
- Good luck with your new position.
- I look forward to working with you in your new position.



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
- Presenters not expected talk for their complete time slot
- 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

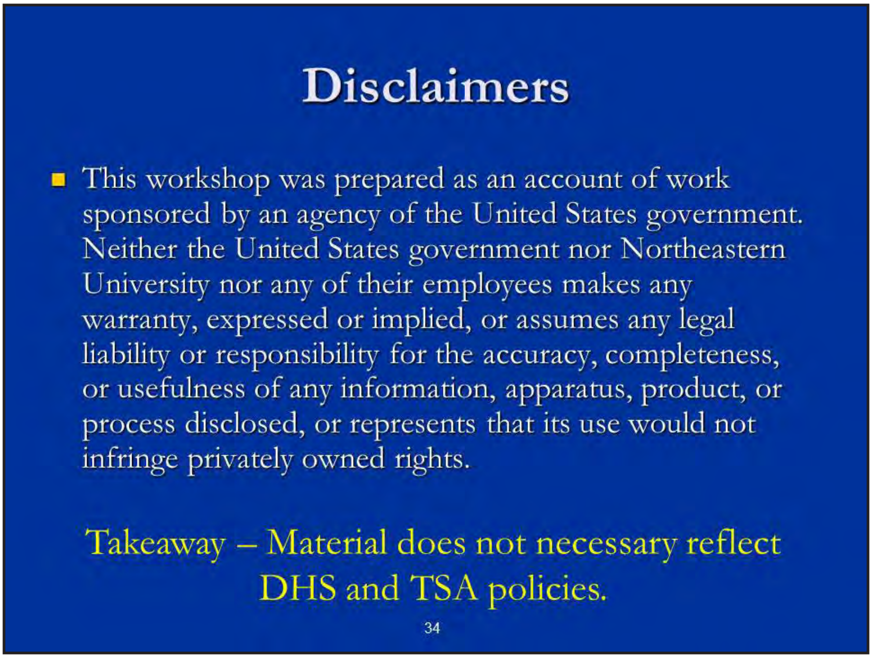
Rule #3 – Speaker Instructions

- 2nd slide has to be conclusions
- Expect discussion during presentation
- Allocate 50% of time slot for discussion
- Do not repeat material from prior speakers
- Provide presentations in advance of your session to ALERT staff
- Delete slides now if necessary
- Put presentation on ALERT laptop in advance.

Beware of Moderator!

Logitech R800

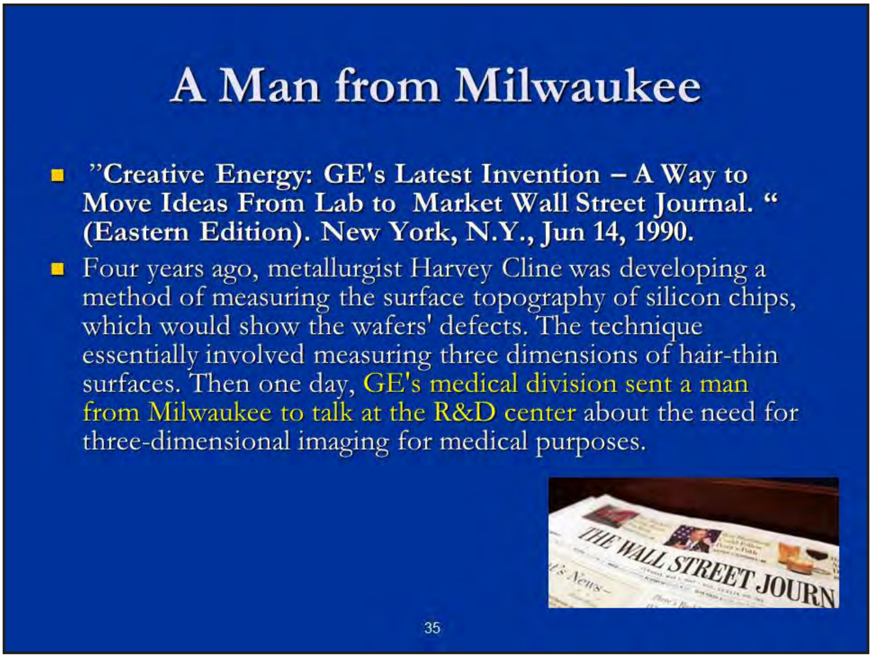
- Slide advancer
- Laser pointer
- Count-down timer
  - Vibrate at 5, 2, 0 minutes left
- Explodes if 1 minute late!!



Disclaimers

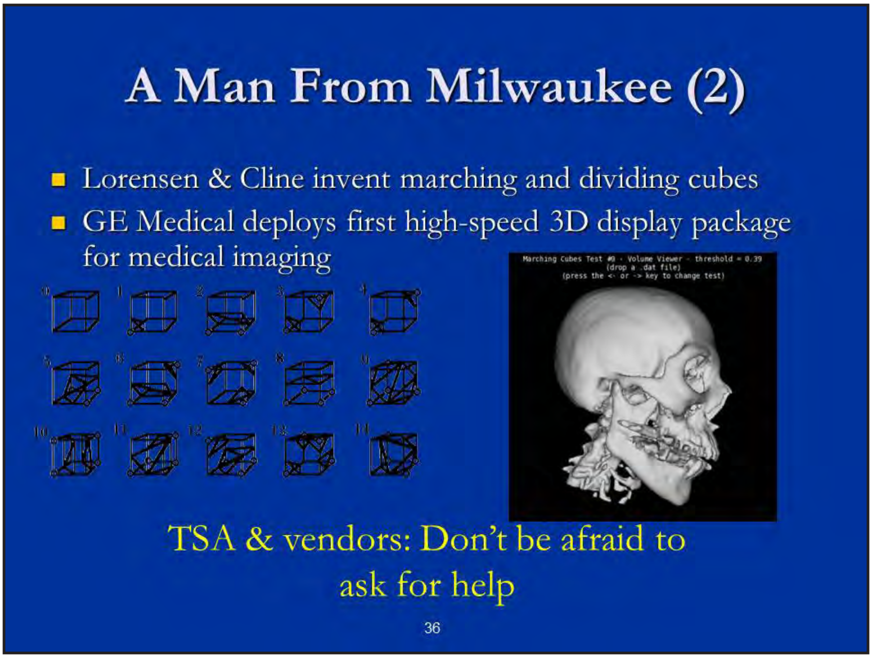
- This workshop was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Northeastern University nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, 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.



A Man from Milwaukee

- **”Creative Energy: GE's Latest Invention – A Way to Move Ideas From Lab to Market Wall Street Journal. “ (Eastern Edition). New York, N.Y., Jun 14, 1990.**
- Four years ago, metallurgist Harvey Cline was developing a method of measuring the surface topography of silicon chips, which would show the wafers' defects. The technique essentially involved measuring three dimensions of hair-thin surfaces. Then one day, GE's medical division sent a man from Milwaukee to talk at the R&D center about the need for three-dimensional imaging for medical purposes.

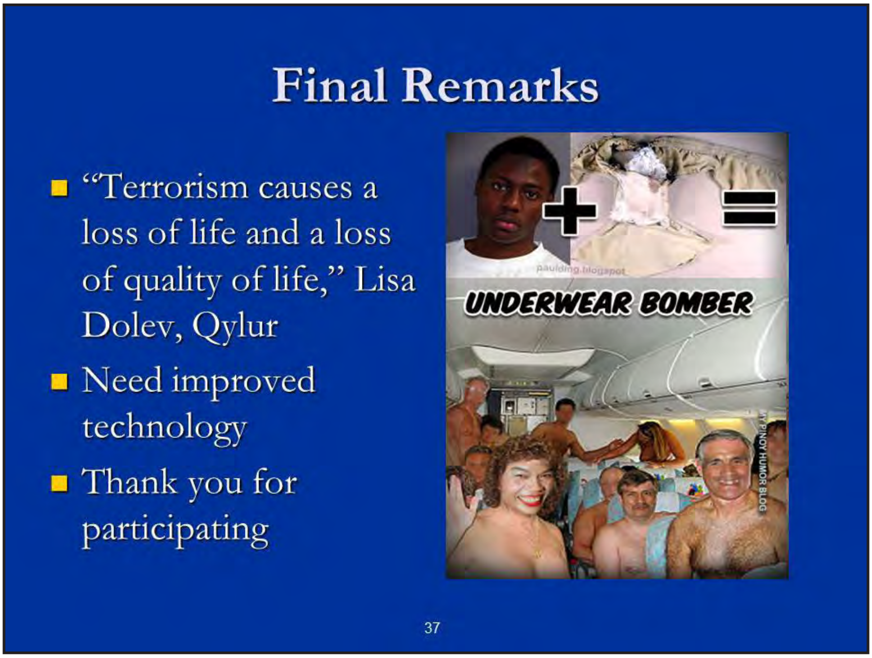


A Man From Milwaukee (2)

- Lorensen & Cline invent marching and dividing cubes
- GE Medical deploys first high-speed 3D display package for medical imaging

Marching Cubes Test #0 - Volume Viewer - threshold = 0.39
(drop a .dat file)
(press the <- or -> key to change test)

TSA & vendors: Don’t be afraid to ask for help



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

Not A Joke

16.3 Matthew Merzbacher: Image Quality Metrics for Improving ATR

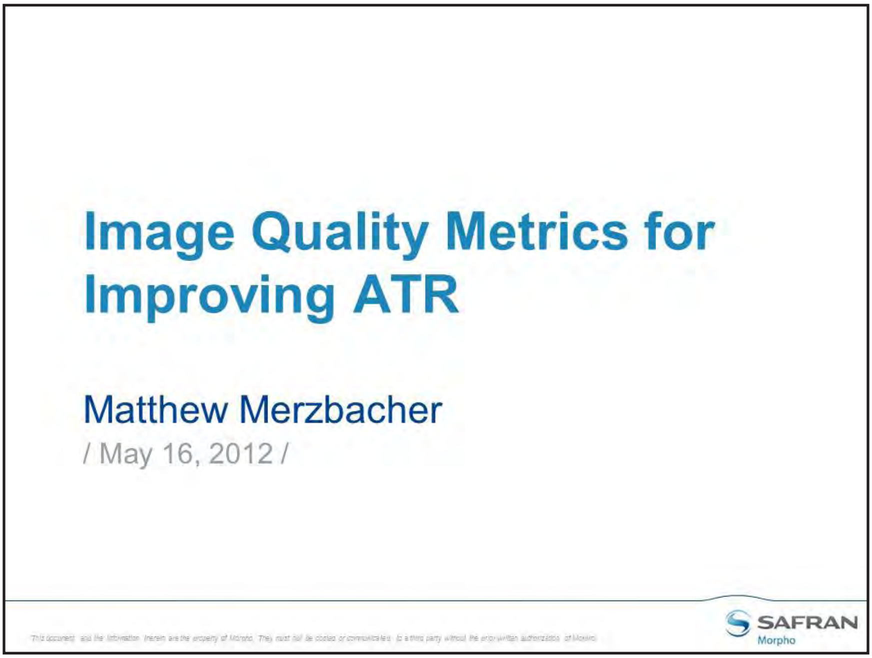
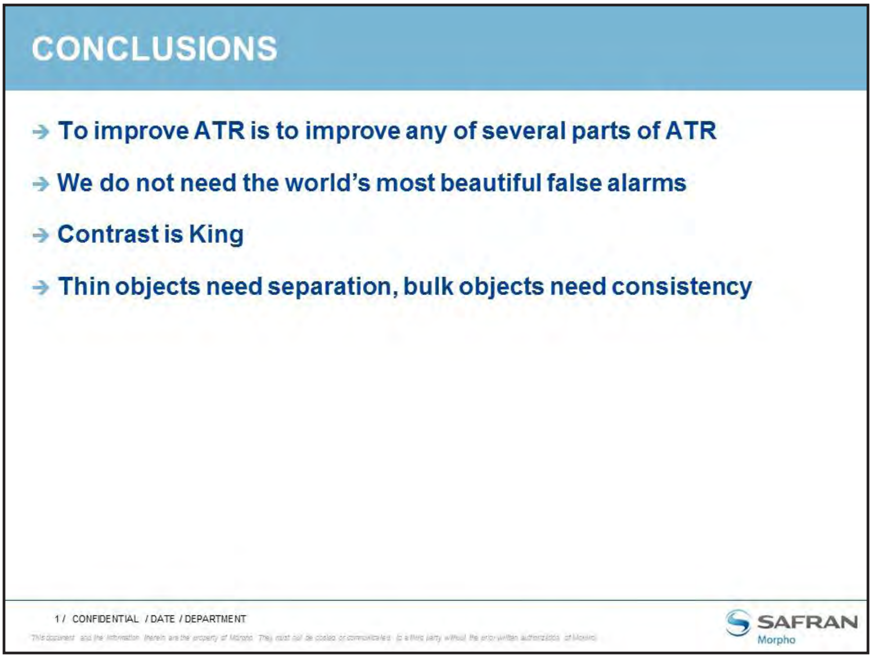


Image Quality Metrics for Improving ATR

Matthew Merzbacher

/ May 16, 2012 /



CONCLUSIONS

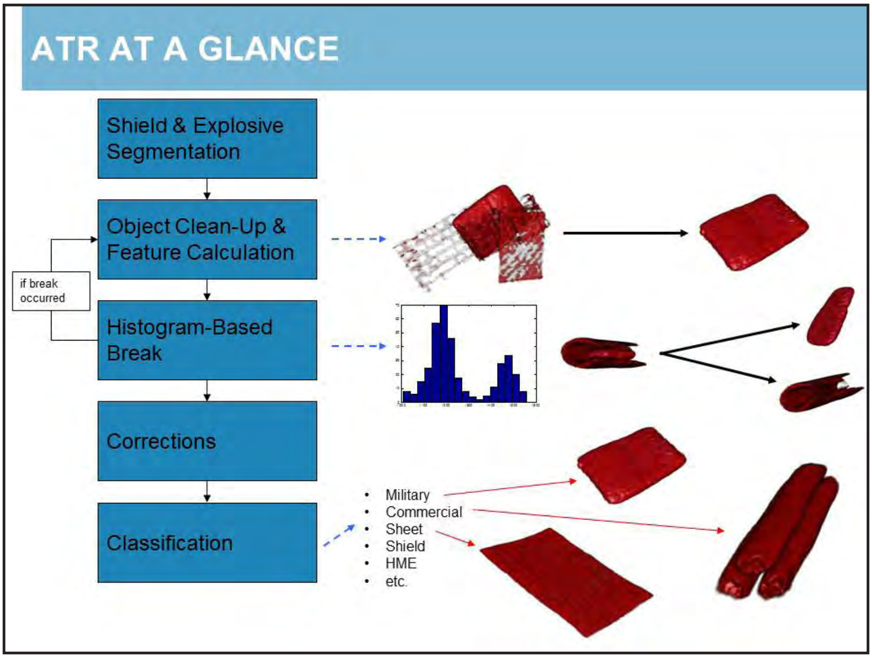
- To improve ATR is to improve any of several parts of ATR
- We do not need the world's most beautiful false alarms
- Contrast is King
- Thin objects need separation, bulk objects need consistency

CHALLENGE: WHICH OF THESE IS SAFE?

Images taken on MDI CTX 9800 or CTX 5800

2 /

SAFRAN
Morpho



ATR AT A GLANCE

Shield & Explosive Segmentation

Object Clean-Up & Feature Calculation

Histogram-Based Break

Corrections

Classification

if break occurred

- Military
- Commercial
- Sheet
- Shield
- HME
- etc.

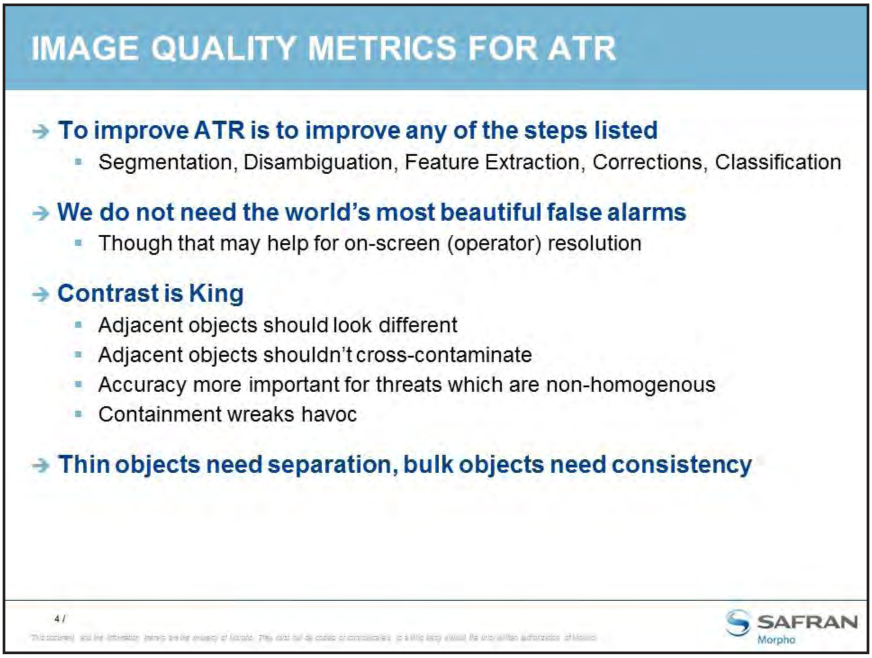


IMAGE QUALITY METRICS FOR ATR

- **To improve ATR is to improve any of the steps listed**
  - Segmentation, Disambiguation, Feature Extraction, Corrections, Classification
- **We do not need the world's most beautiful false alarms**
  - Though that may help for on-screen (operator) resolution
- **Contrast is King**
  - Adjacent objects should look different
  - Adjacent objects shouldn't cross-contaminate
  - Accuracy more important for threats which are non-homogenous
  - Containment wreaks havoc
- **Thin objects need separation, bulk objects need consistency**

SAFRAN
Morpho

16.4 Richard Bijjani: Image Quality Metrics

ROBEHR ANALYTICS

Richard Robehr Bijjani, Ph.D.
rbijjani@robehr.com

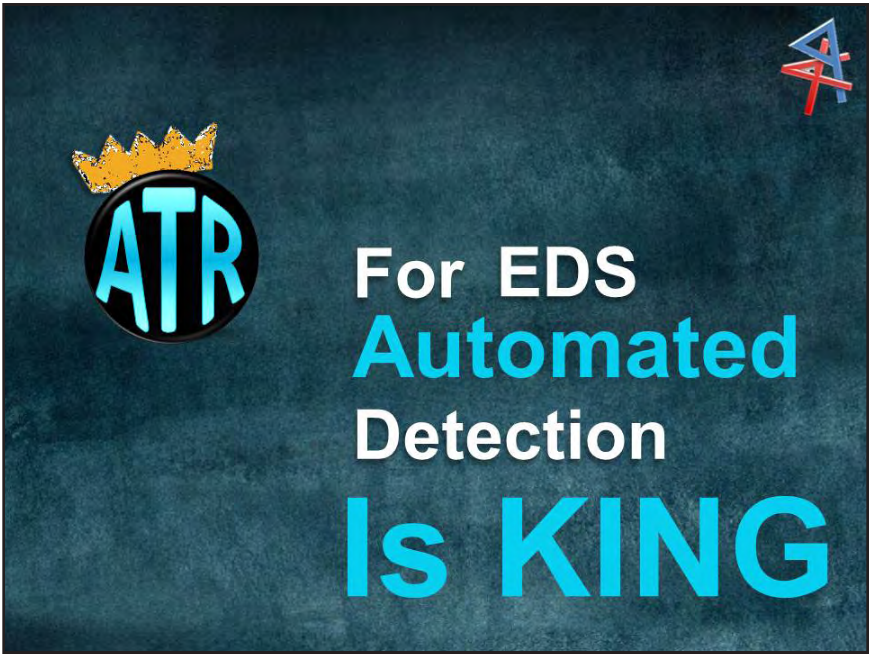
IMAGE QUALITY METRICS

INTRO-CONCLUSION

Image Quality

Automated Detection

Alarm Resolution

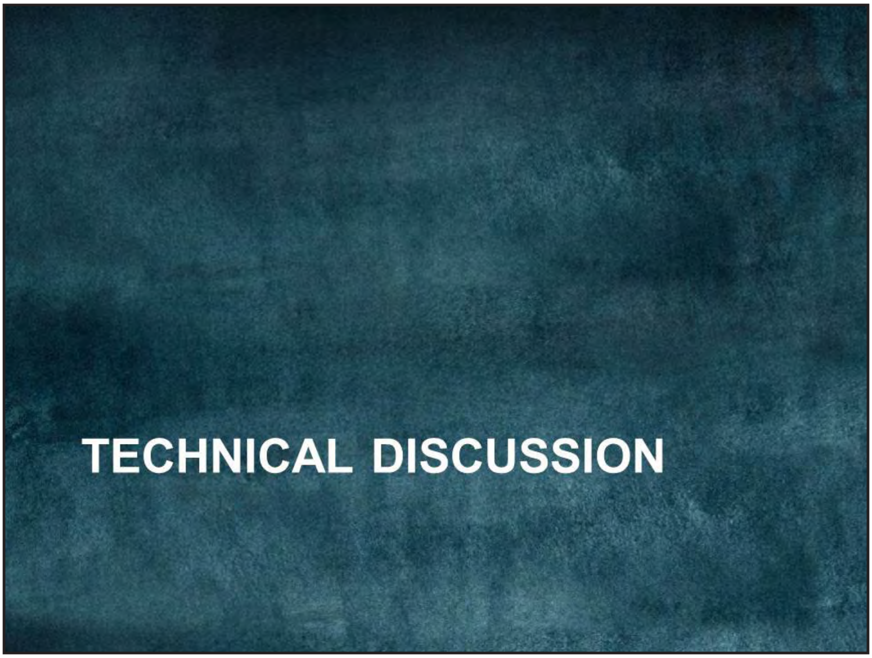


ATR

For EDS
Automated
Detection
Is KING

OSARP

Resolve
Alarms
OR
Find Another Job



TECHNICAL DISCUSSION

ANOTHER
MEETING

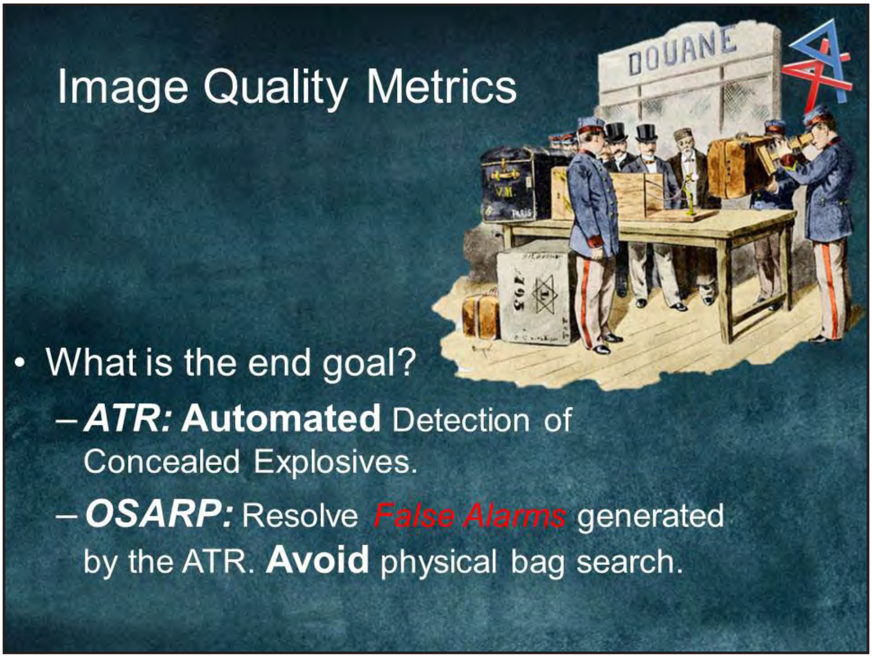


Image Quality Metrics

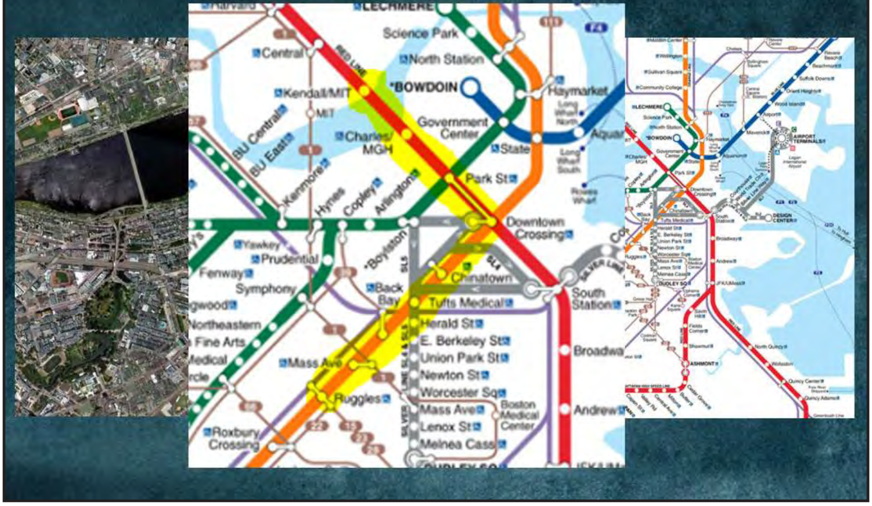
- What is the end goal?
  - ***ATR:* Automated** Detection of Concealed Explosives.
  - ***OSARP:*** Resolve *False Alarms* generated by the ATR. **Avoid** physical bag search.

Which has better resolution?

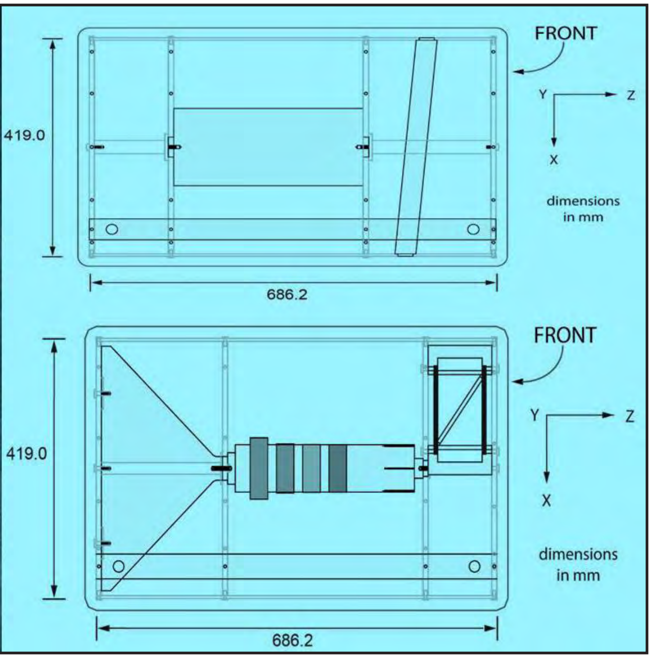
It's about information content, not resolution!

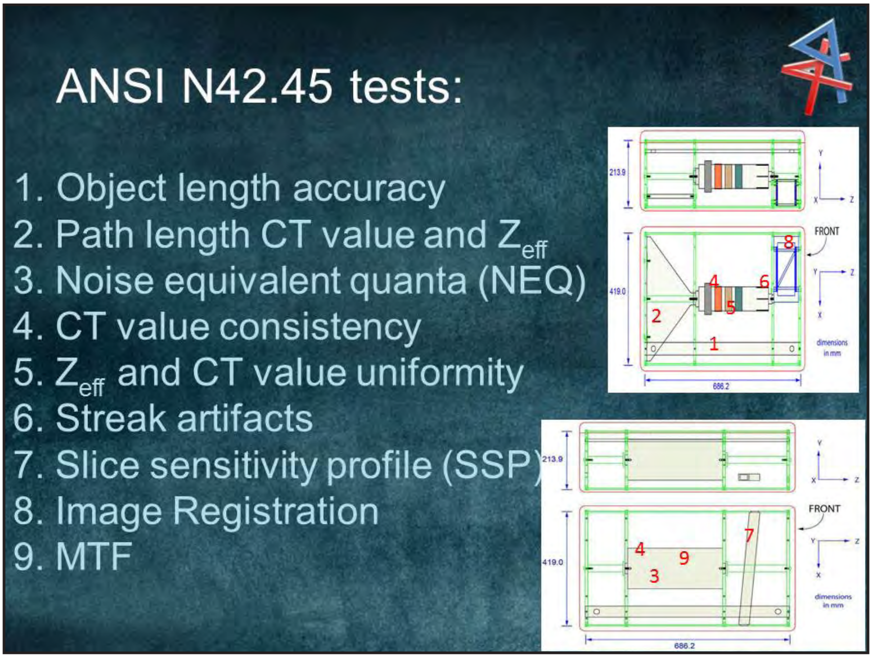
Courtesy of Google

Information Content



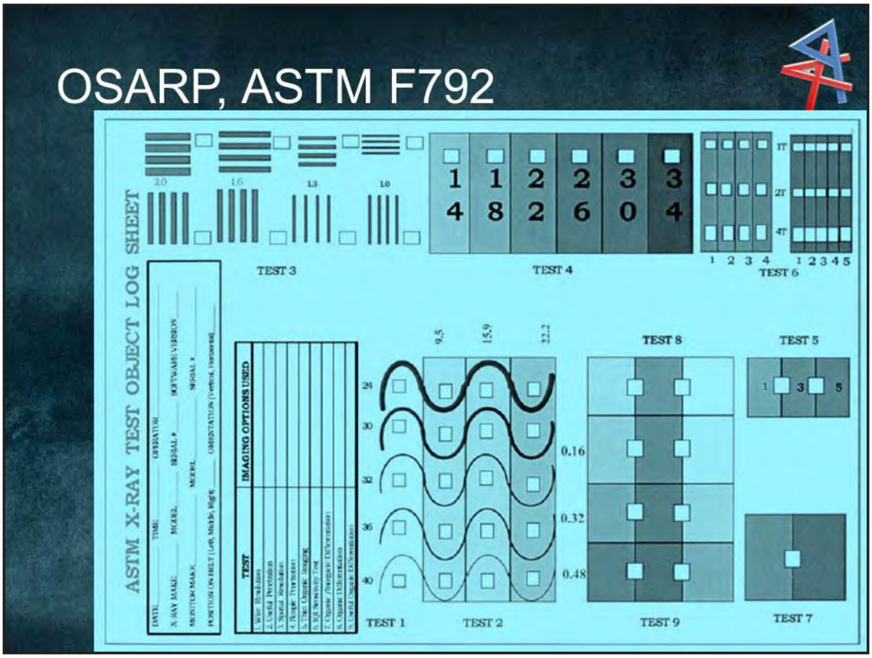
For ATR: ANSI N42.45



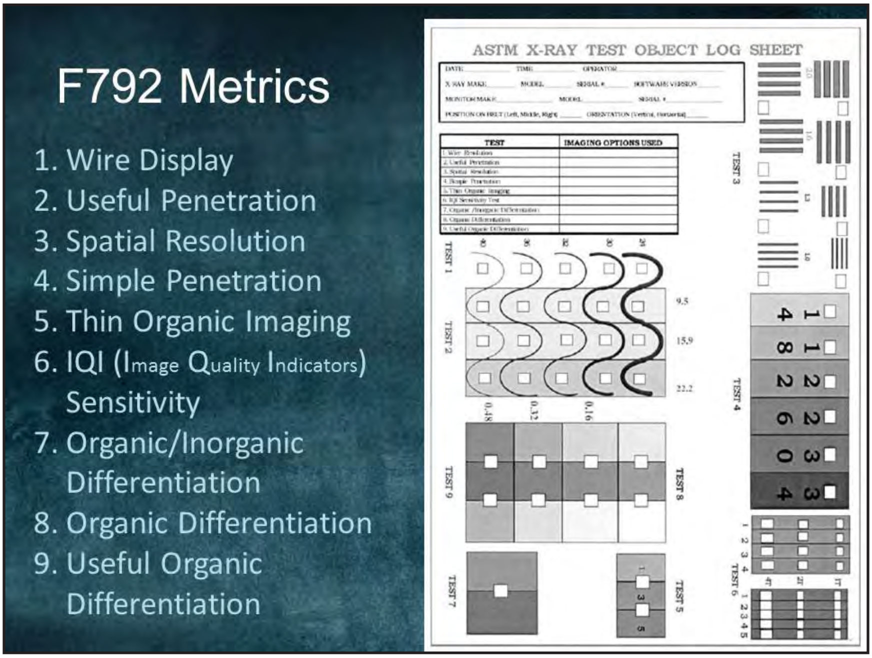


ANSI N42.45 tests:

1. Object length accuracy
2. Path length CT value and Z_{eff}
3. Noise equivalent quanta (NEQ)
4. CT value consistency
5. Z_{eff} and CT value uniformity
6. Streak artifacts
7. Slice sensitivity profile (SSP)
8. Image Registration
9. MTF



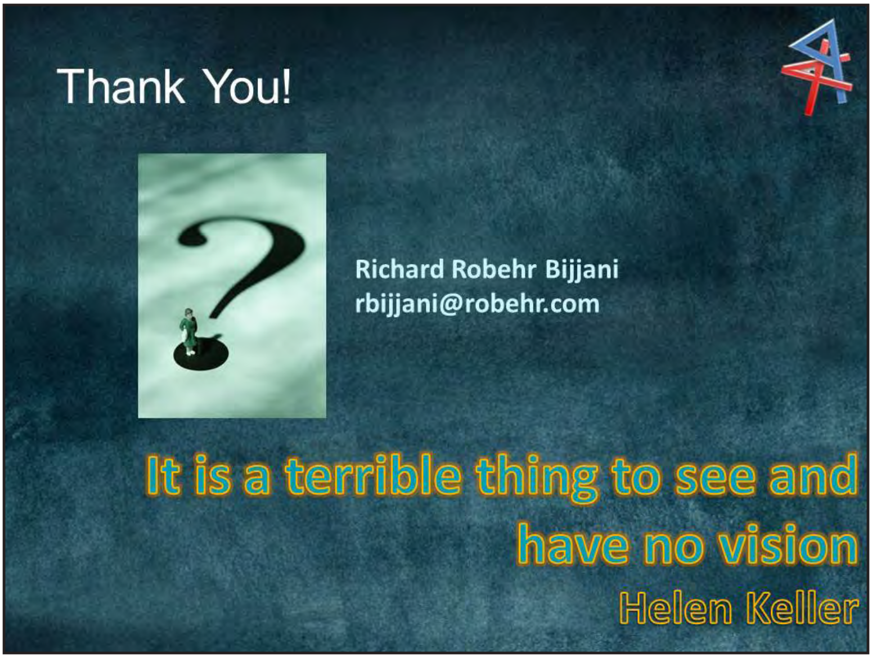
OSARP, ASTM F792



F792 Metrics

1. Wire Display
2. Useful Penetration
3. Spatial Resolution
4. Simple Penetration
5. Thin Organic Imaging
6. IQI (Image Quality Indicators) Sensitivity
7. Organic/Inorganic Differentiation
8. Organic Differentiation
9. Useful Organic Differentiation

ASTM X-RAY TEST OBJECT LOG SHEET



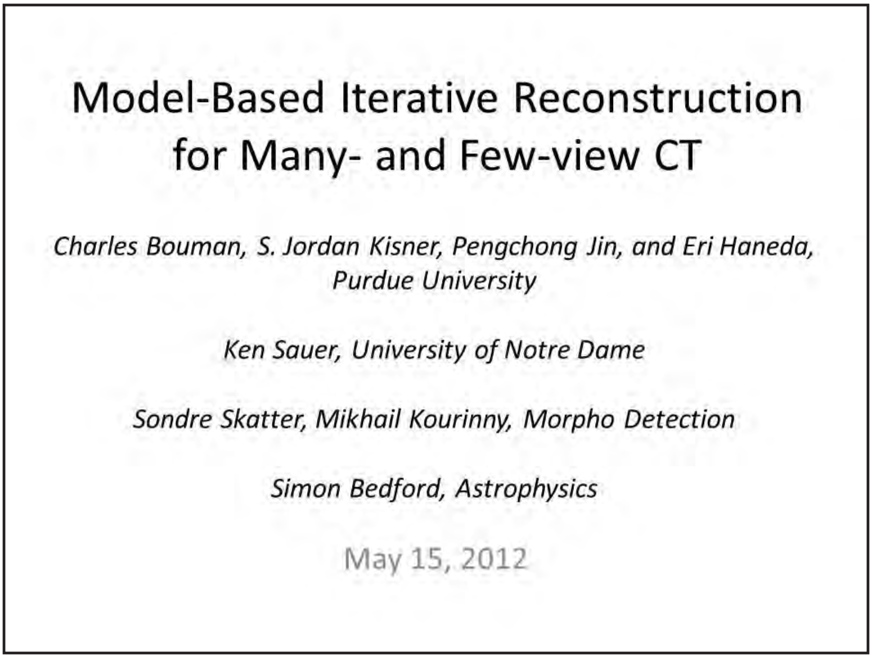
Thank You!

Richard Robehr Bijjani
rbijjani@robehr.com

It is a terrible thing to see and have no vision

Helen Keller

16.5 Charles Bouman: Model-Based Iterative Reconstruction for Many- and Few-view CT



Model-Based Iterative Reconstruction for Many- and Few-view CT

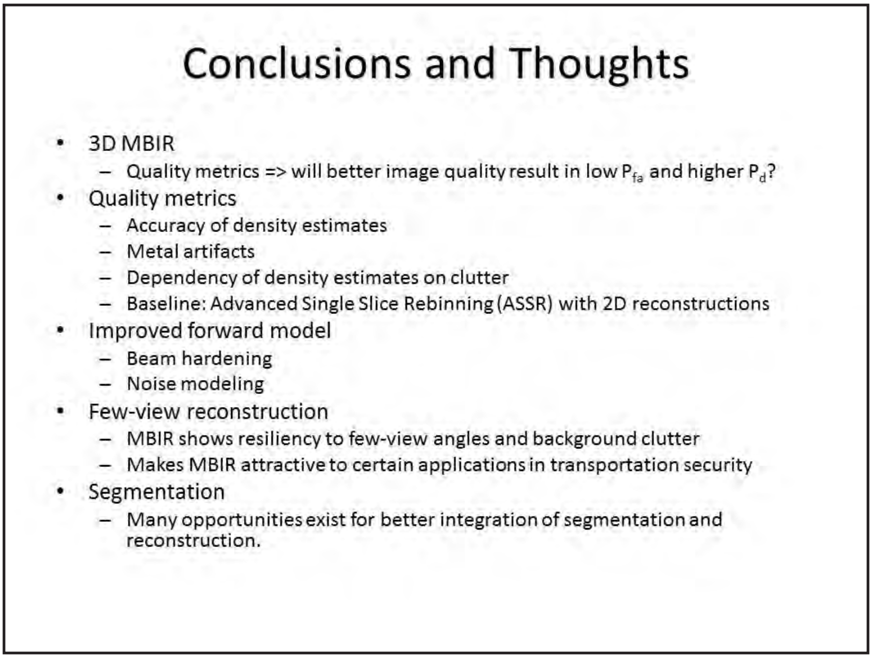
Charles Bouman, S. Jordan Kisner, Pengchong Jin, and Eri Haneda,
Purdue University

Ken Sauer, University of Notre Dame

Sondre Skatter, Mikhail Kourinny, Morpho Detection

Simon Bedford, Astrophysics

May 15, 2012



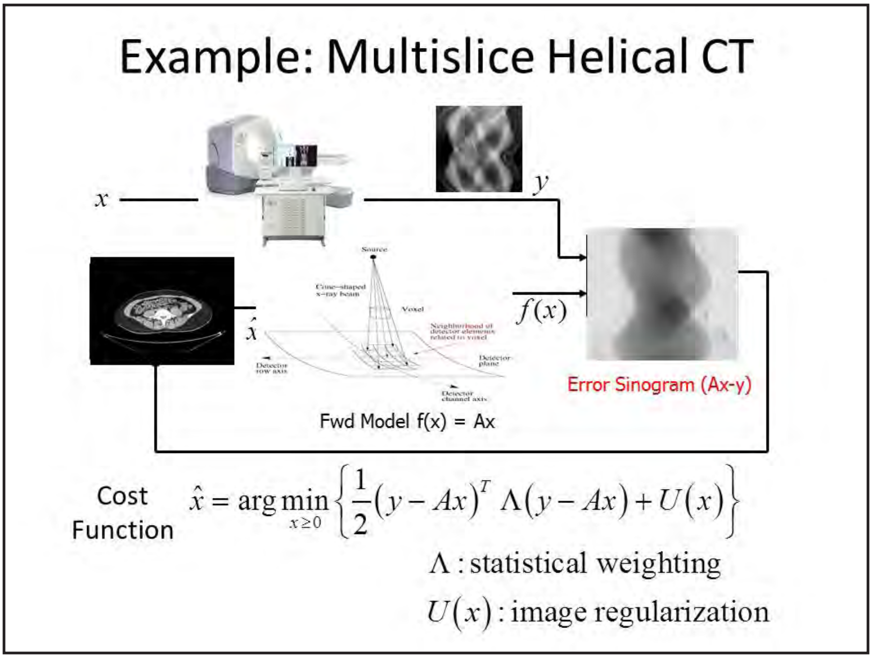
Conclusions and Thoughts

- 3D MBIR
  - Quality metrics => will better image quality result in low P_{fa} and higher P_d?
- Quality metrics
  - Accuracy of density estimates
  - Metal artifacts
  - Dependency of density estimates on clutter
  - Baseline: Advanced Single Slice Rebinning (ASSR) with 2D reconstructions
- Improved forward model
  - Beam hardening
  - Noise modeling
- Few-view reconstruction
  - MBIR shows resiliency to few-view angles and background clutter
  - Makes MBIR attractive to certain applications in transportation security
- Segmentation
  - Many opportunities exist for better integration of segmentation and reconstruction.

Overview of Talk

- Quick review of MBIR
- 3D MBIR for ALERT data
  - *Pengchong Jin and Eri Haneda*
- Few-view reconstruction
  - *Jordan Kisner, Sondre Skatter, Mikhail Kourinny, and Simon Bedford*
- Thoughts about Segmentation-based MBIR

Example: Multislice Helical CT

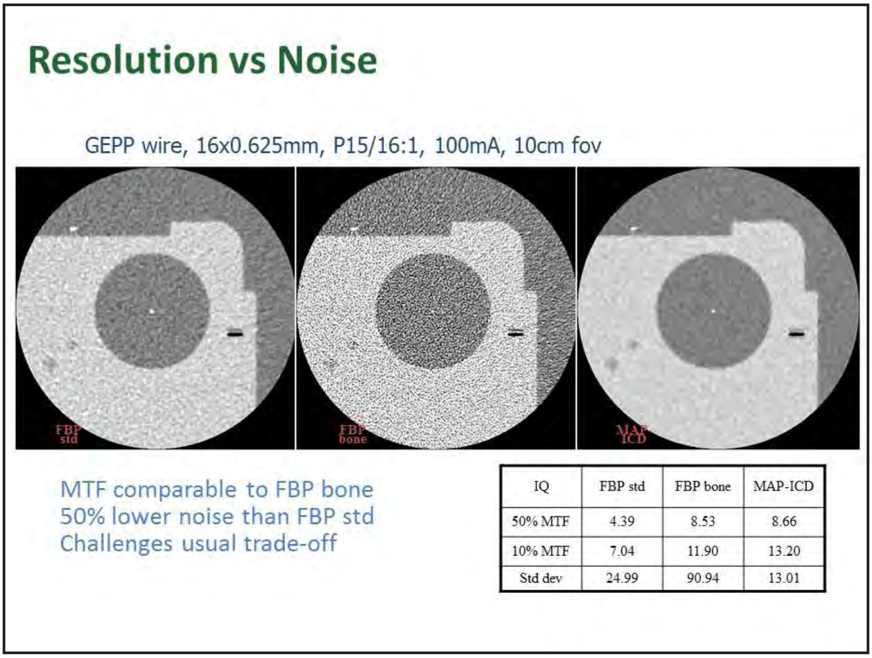


Cost Function

$$\hat{x} = \arg\min_{x \geq 0} \left\{ \frac{1}{2}(y - Ax)^T \Lambda (y - Ax) + U(x) \right\}$$

Λ : statistical weighting

$U(x)$: image regularization

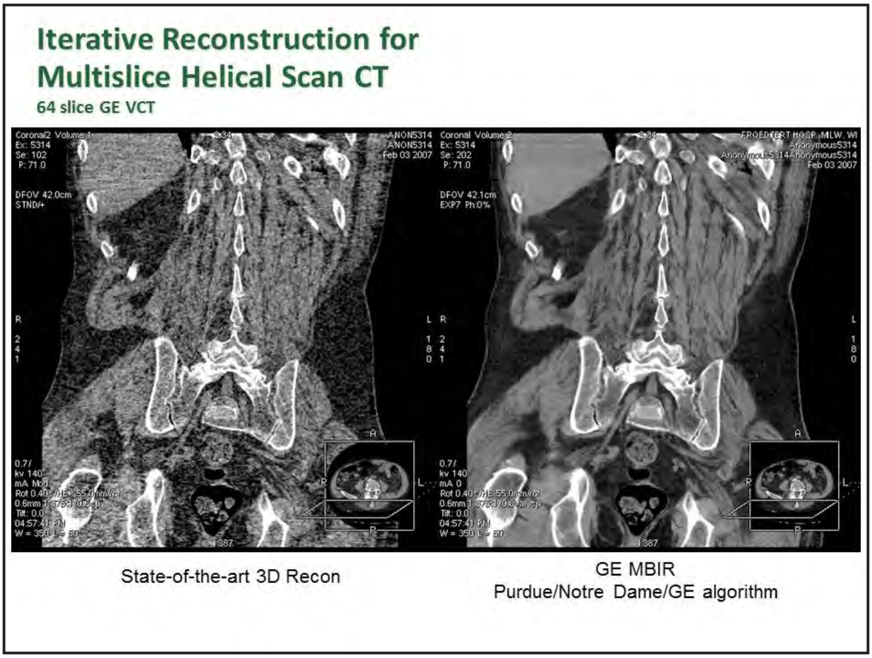


Resolution vs Noise

GEPP wire, 16x0.625mm, P15/16:1, 100mA, 10cm fov

MTF comparable to FBP bone
50% lower noise than FBP std
Challenges usual trade-off

IQ	FBP std	FBP bone	MAP-ICD
50% MTF	4.39	8.53	8.66
10% MTF	7.04	11.90	13.20
Std dev	24.99	90.94	13.01

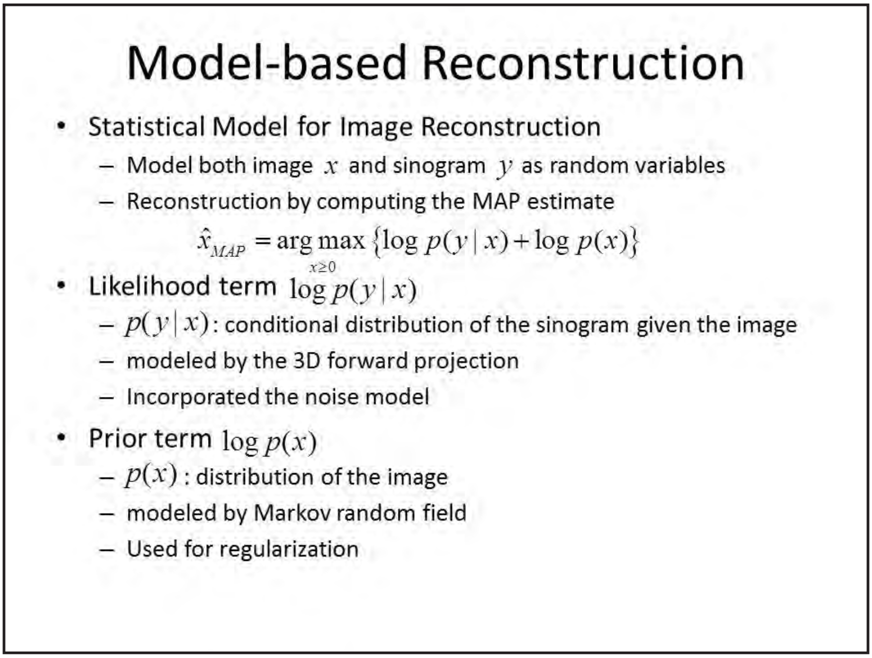


Iterative Reconstruction for Multislice Helical Scan CT

64 slice GE VCT

State-of-the-art 3D Recon

GE MBIR
Purdue/Notre Dame/GE algorithm

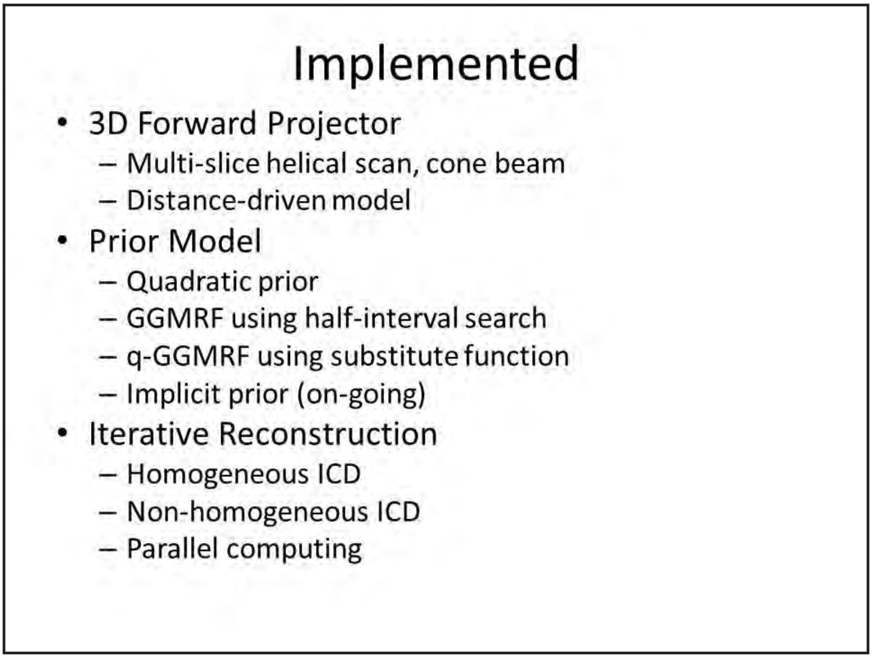


Model-based Reconstruction

- Statistical Model for Image Reconstruction
  - Model both image x and sinogram y as random variables
  - Reconstruction by computing the MAP estimate

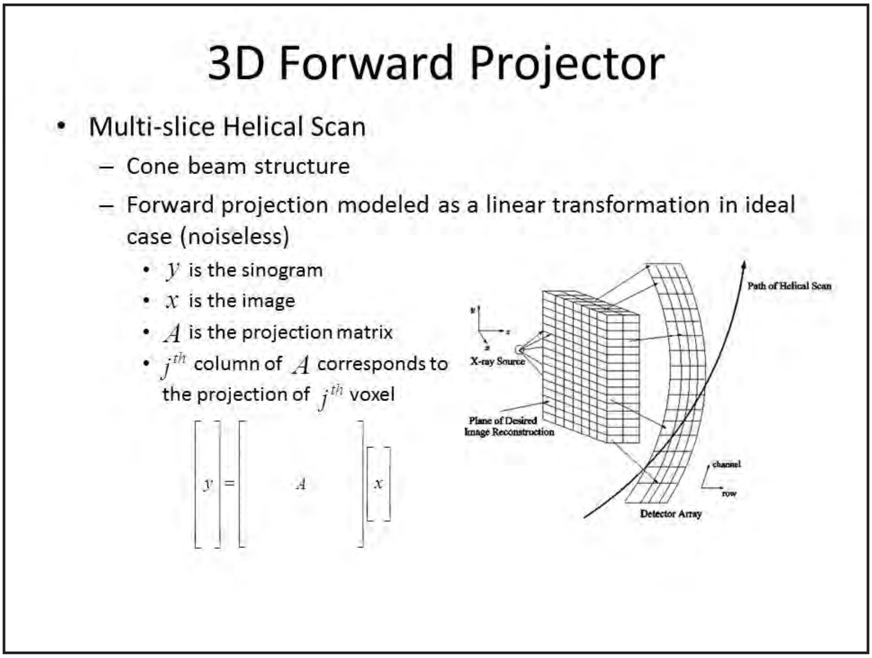
$$\hat{x}_{MAP} = \arg\max_{x \geq 0} \{\log p(y \mid x) + \log p(x)\}$$

- Likelihood term $\log p(y \mid x)$
  - $p(y \mid x)$: conditional distribution of the sinogram given the image
  - modeled by the 3D forward projection
  - Incorporated the noise model
- Prior term $\log p(x)$
  - $p(x)$: distribution of the image
  - modeled by Markov random field
  - Used for regularization



Implemented

- 3D Forward Projector
  - Multi-slice helical scan, cone beam
  - Distance-driven model
- Prior Model
  - Quadratic prior
  - GGMRF using half-interval search
  - q-GGMRF using substitute function
  - Implicit prior (on-going)
- Iterative Reconstruction
  - Homogeneous ICD
  - Non-homogeneous ICD
  - Parallel computing



3D Forward Projector

- Multi-slice Helical Scan
  - Cone beam structure
  - Forward projection modeled as a linear transformation in ideal case (noiseless)
    - y is the sinogram
    - x is the image
    - A is the projection matrix
    - j^{th} column of A corresponds to the projection of j^{th} voxel

$$\begin{bmatrix} \\ y \\ \\ \end{bmatrix} = \begin{bmatrix} & & \\ & A & \\ & & \end{bmatrix} \begin{bmatrix} x \end{bmatrix}$$

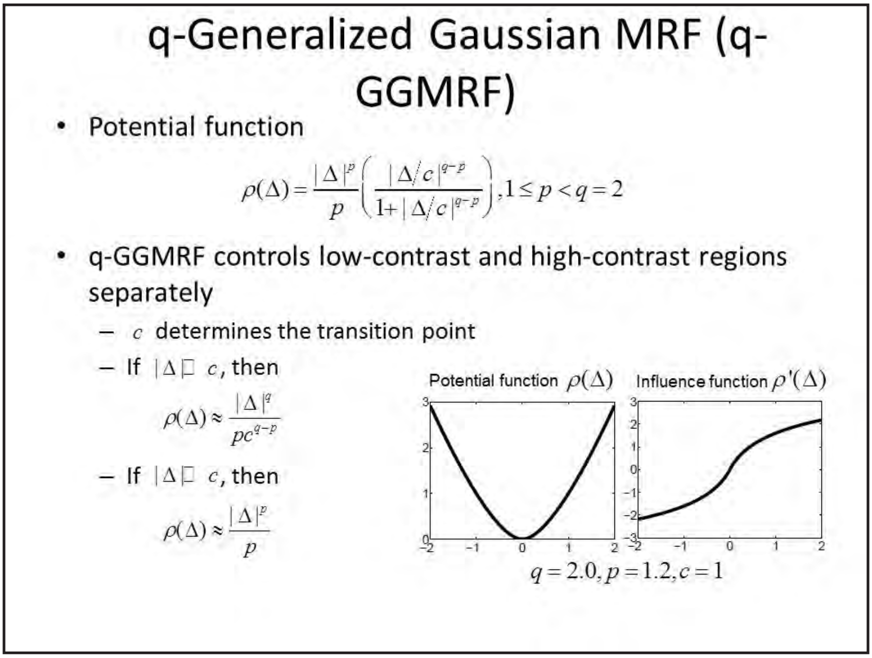
Prior Model

- Markov random field

$$p(x) = \frac{1}{Z}\exp\left\{ -\sum_{\{s,r\}\in C} b_{s,r}\,\rho\left(\frac{x_s - x_r}{\sigma_x}\right)\right\}$$

  - σ_x is the scaling constant used to balance the prior and likelihood
  - ρ is the potential function of difference of neighborhood pixels
  - $b_{s,r}$ are weights for neighbors
  - C is the set of all pairwise cliques
  - Z is the normalized constant, partition function
  - Choices of potential function $\rho(\Delta)$
    - Quadratic (GMRF): $\rho(\Delta) = \frac{\Delta^2}{2}$
    - Generalized Gaussian: $\rho(\Delta) = \frac{|\Delta|^p}{p}, 1 \le p \le 2$
    - q-Generalized Gaussian:

$$\rho(\Delta) = \frac{|\Delta|^p}{p}\left(\frac{|\Delta/c|^{q-p}}{1+|\Delta/c|^{q-p}}\right), 1 \le p < q = 2$$



q-Generalized Gaussian MRF (q-GGMRF)

- Potential function

$$\rho(\Delta)=\frac{|\Delta|^p}{p}\left(\frac{|\Delta/c|^{q-p}}{1+|\Delta/c|^{q-p}}\right),1\le p<q=2$$

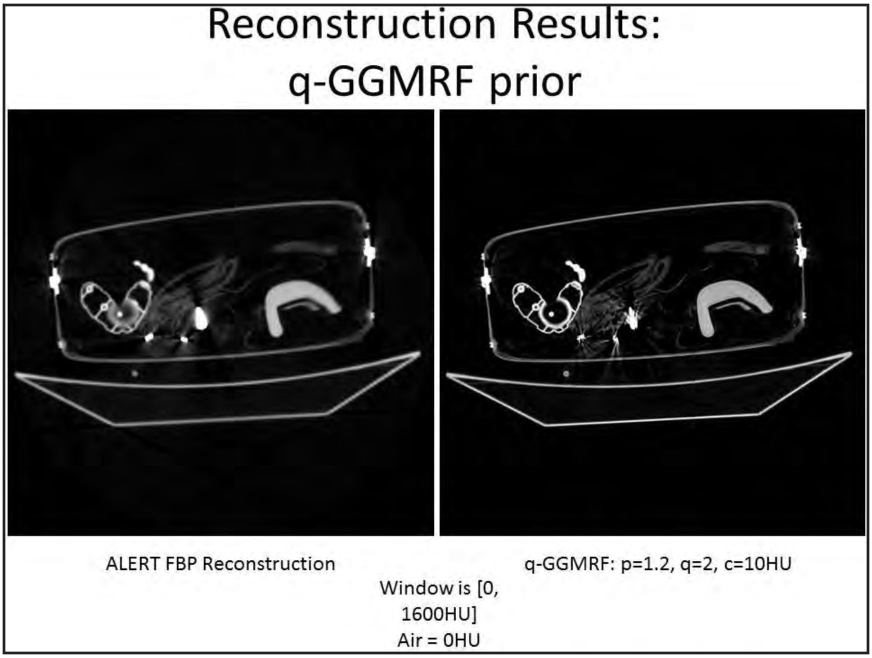
- q-GGMRF controls low-contrast and high-contrast regions separately
  - c determines the transition point
  - If $|\Delta\square\ c$, then

$$\rho(\Delta)\approx\frac{|\Delta|^q}{pc^{q-p}}$$

  - If $|\Delta\square\ c$, then

$$\rho(\Delta)\approx\frac{|\Delta|^p}{p}$$

$q=2.0, p=1.2, c=1$

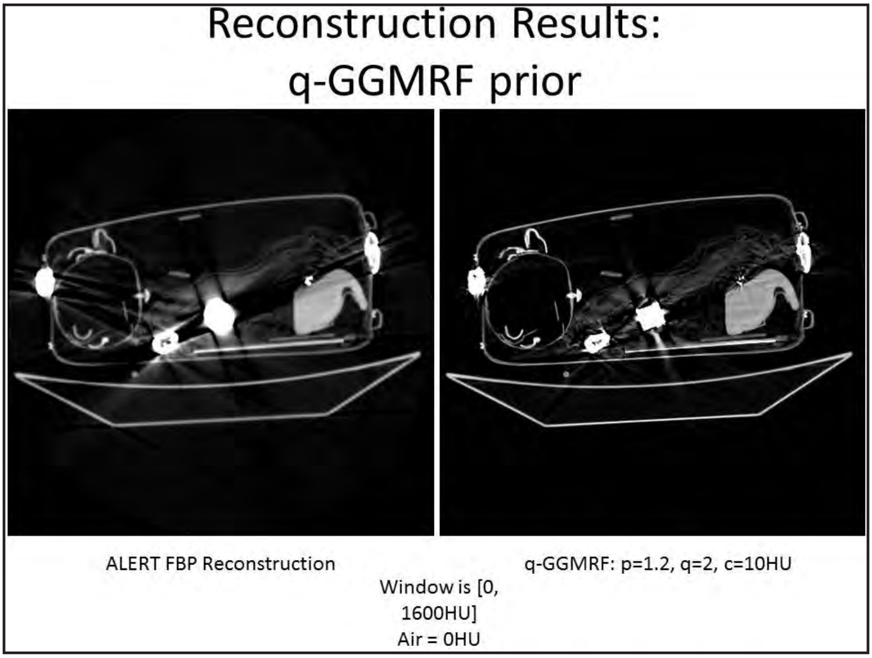


Reconstruction Results: q-GGMRF prior

ALERT FBP Reconstruction

q-GGMRF: p=1.2, q=2, c=10HU

Window is [0, 1600HU]
Air = 0HU

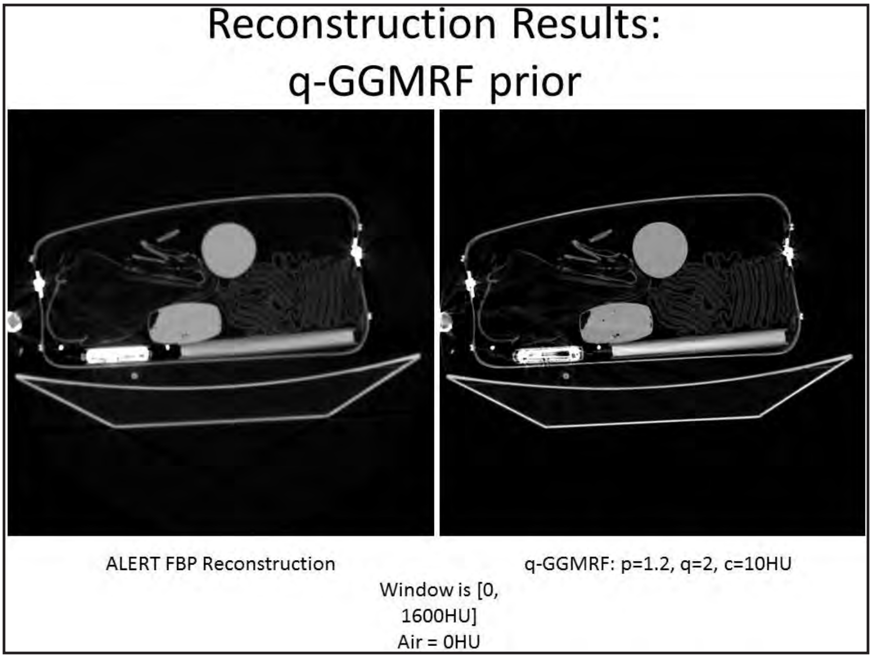


Reconstruction Results:
q-GGMRF prior

ALERT FBP Reconstruction

q-GGMRF: p=1.2, q=2, c=10HU

Window is [0,
1600HU]
Air = 0HU

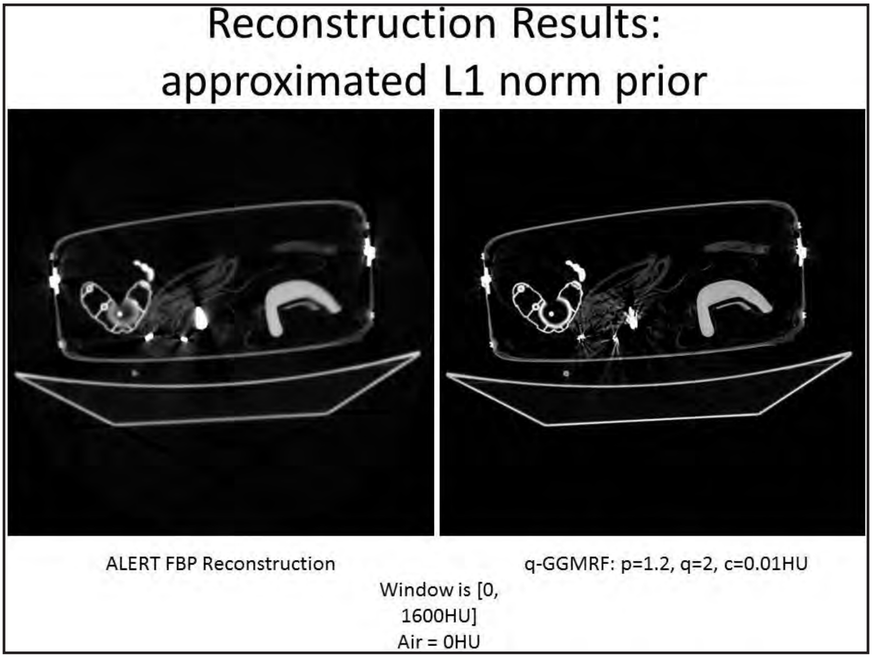


Reconstruction Results:
q-GGMRF prior

ALERT FBP Reconstruction

q-GGMRF: p=1.2, q=2, c=10HU

Window is [0,
1600HU]
Air = 0HU

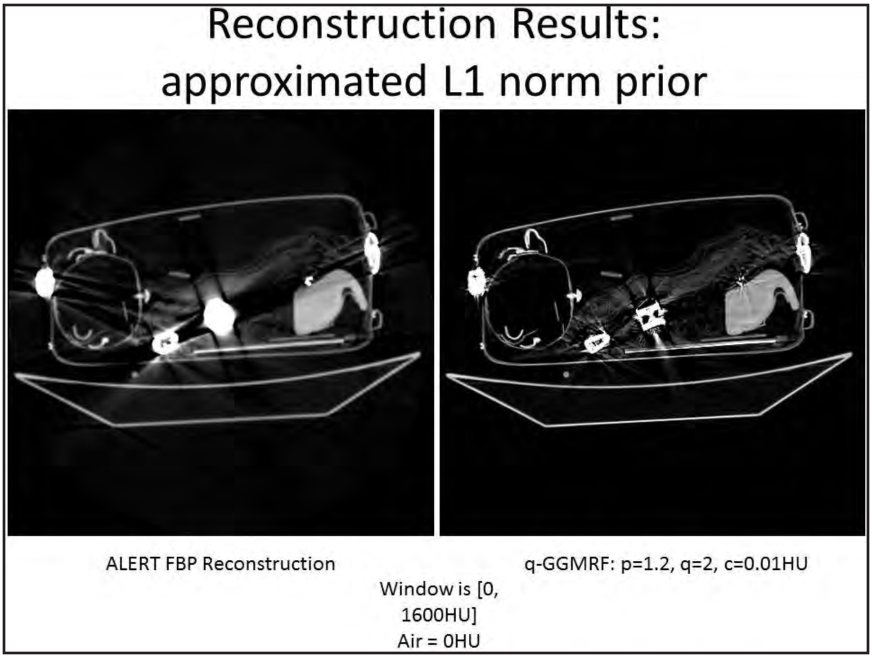


Reconstruction Results:
approximated L1 norm prior

ALERT FBP Reconstruction

q-GGMRF: p=1.2, q=2, c=0.01HU

Window is [0,
1600HU]
Air = 0HU

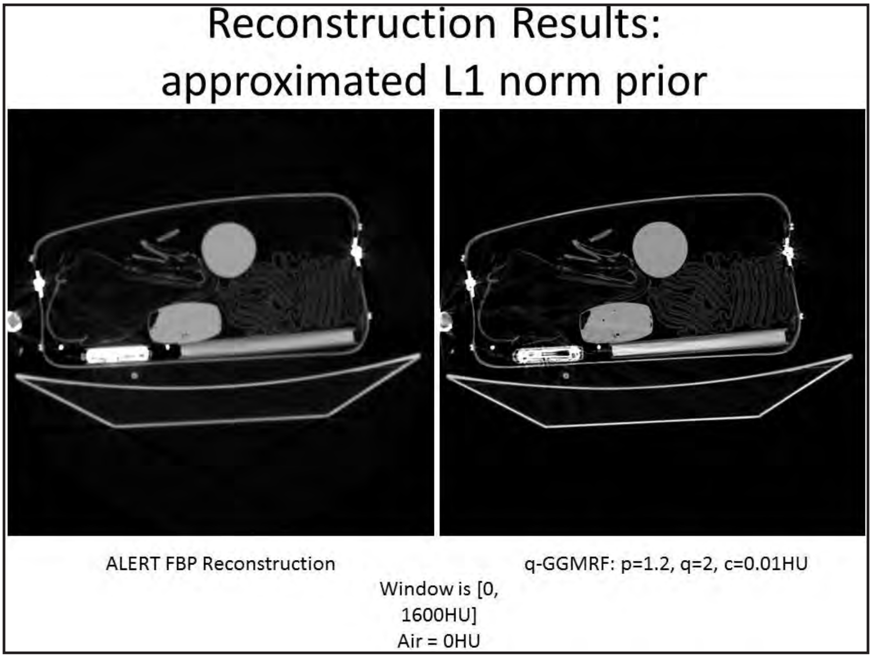


Reconstruction Results:
approximated L1 norm prior

ALERT FBP Reconstruction

q-GGMRF: p=1.2, q=2, c=0.01HU

Window is [0,
1600HU]
Air = 0HU

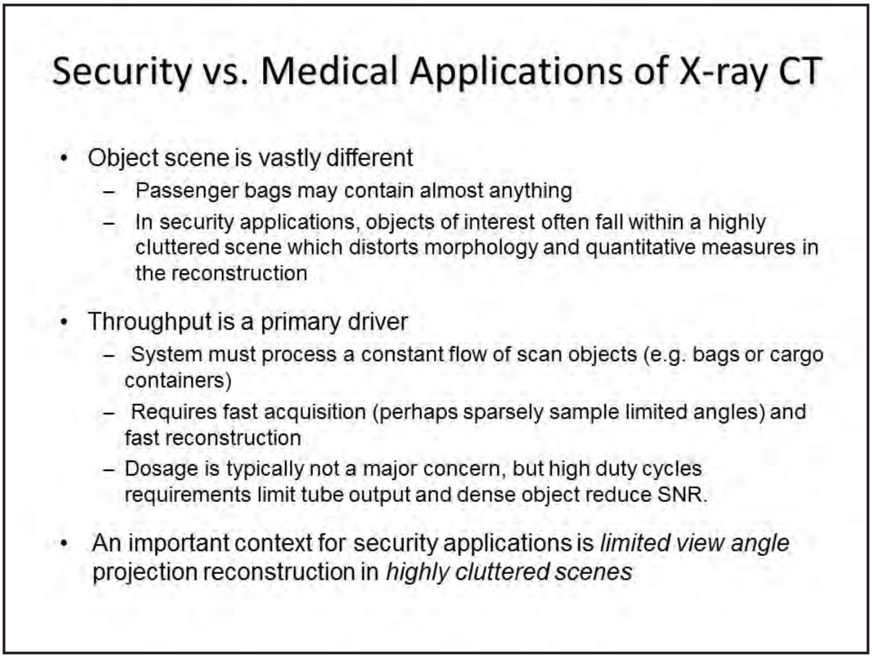


Reconstruction Results: approximated L1 norm prior

ALERT FBP Reconstruction

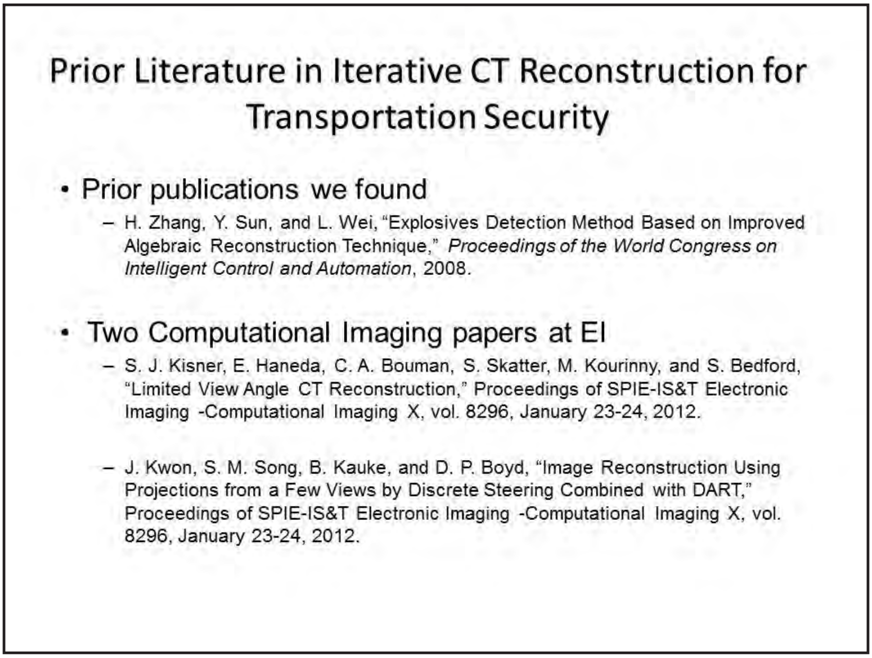
q-GGMRF: p=1.2, q=2, c=0.01HU

Window is [0, 1600HU]
Air = 0HU



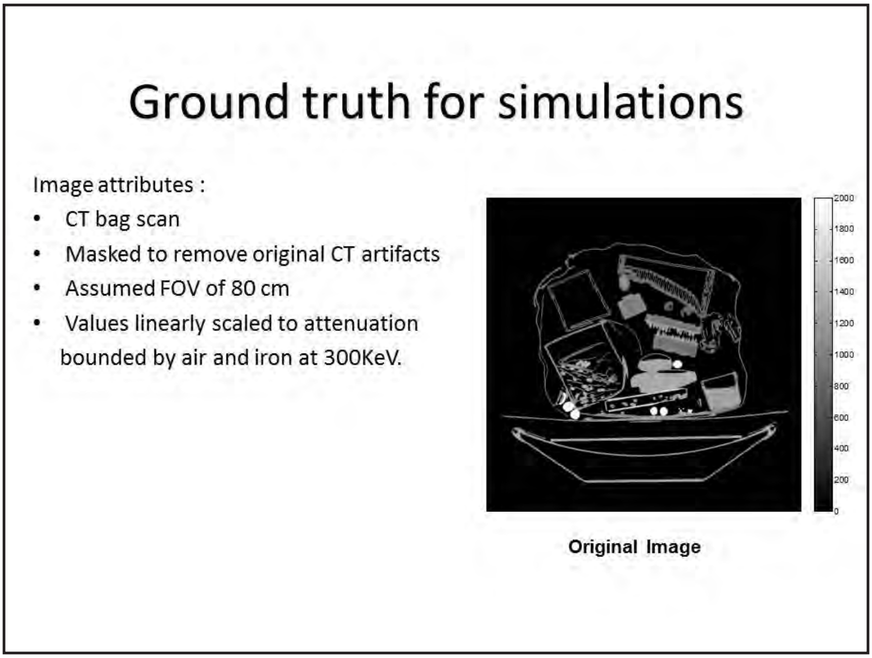
Security vs. Medical Applications of X-ray CT

- Object scene is vastly different
  - Passenger bags may contain almost anything
  - In security applications, objects of interest often fall within a highly cluttered scene which distorts morphology and quantitative measures in the reconstruction
- Throughput is a primary driver
  - System must process a constant flow of scan objects (e.g. bags or cargo containers)
  - Requires fast acquisition (perhaps sparsely sample limited angles) and fast reconstruction
  - Dosage is typically not a major concern, but high duty cycles requirements limit tube output and dense object reduce SNR.
- An important context for security applications is *limited view angle* projection reconstruction in *highly cluttered scenes*



Prior Literature in Iterative CT Reconstruction for Transportation Security

- Prior publications we found
  - H. Zhang, Y. Sun, and L. Wei, "Explosives Detection Method Based on Improved Algebraic Reconstruction Technique," *Proceedings of the World Congress on Intelligent Control and Automation*, 2008.
- Two Computational Imaging papers at EI
  - S. J. Kisner, E. Haneda, C. A. Bouman, S. Skatter, M. Kourinny, and S. Bedford, "Limited View Angle CT Reconstruction," Proceedings of SPIE-IS&T Electronic Imaging -Computational Imaging X, vol. 8296, January 23-24, 2012.
  - J. Kwon, S. M. Song, B. Kauke, and D. P. Boyd, "Image Reconstruction Using Projections from a Few Views by Discrete Steering Combined with DART," Proceedings of SPIE-IS&T Electronic Imaging -Computational Imaging X, vol. 8296, January 23-24, 2012.

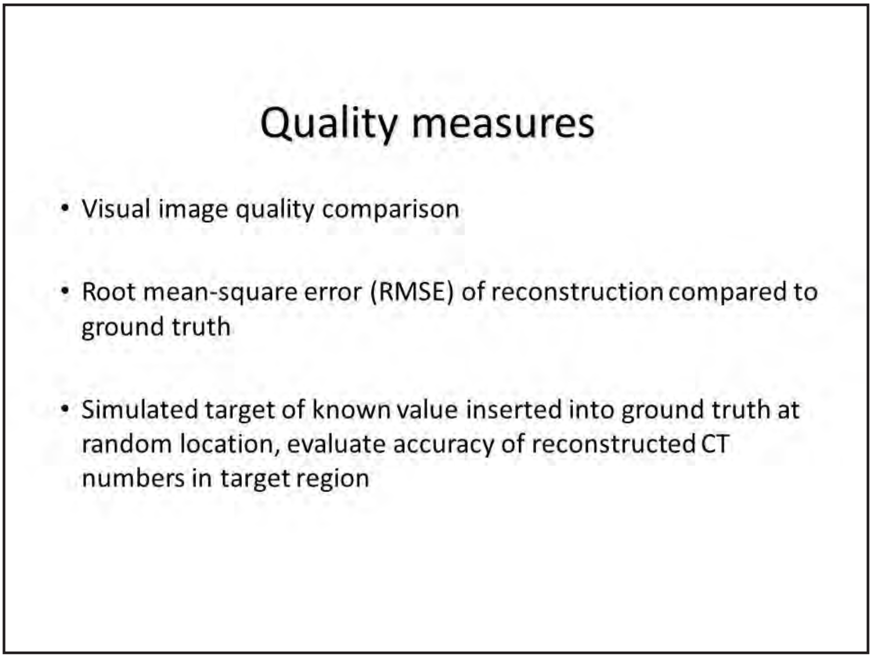


Ground truth for simulations

Image attributes :

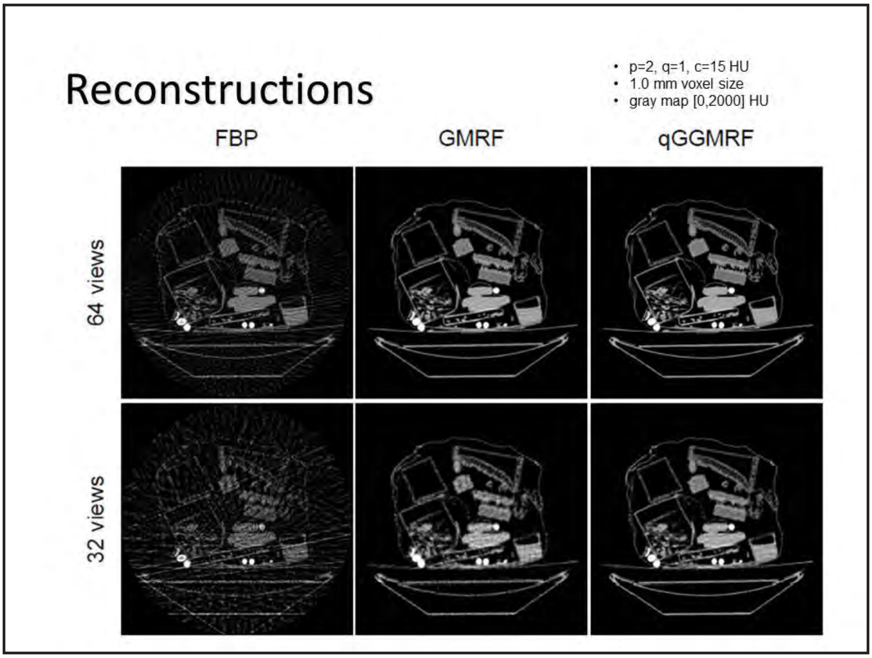
- CT bag scan
- Masked to remove original CT artifacts
- Assumed FOV of 80 cm
- Values linearly scaled to attenuation bounded by air and iron at 300KeV.

Original Image



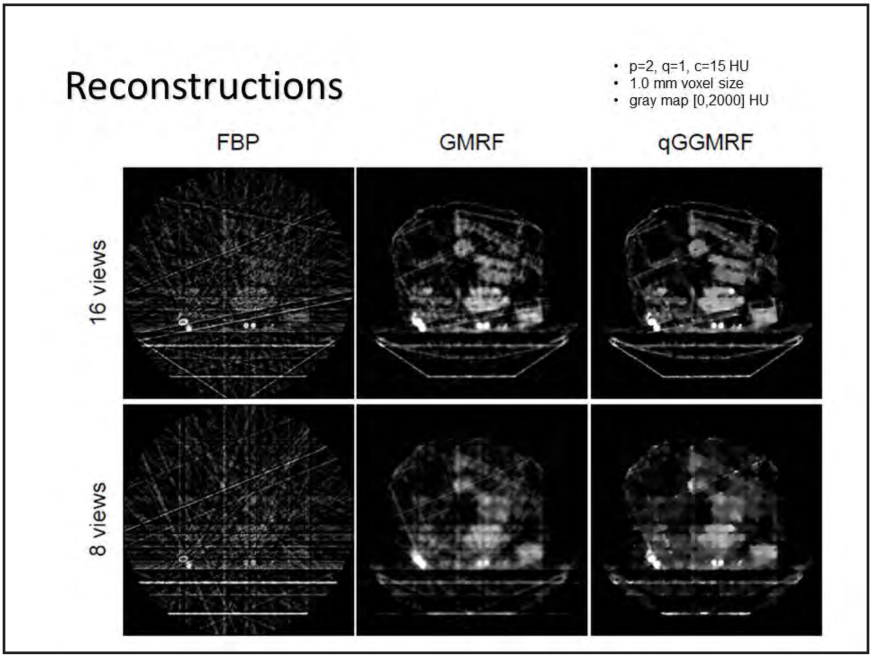
Quality measures

- Visual image quality comparison
- Root mean-square error (RMSE) of reconstruction compared to ground truth
- Simulated target of known value inserted into ground truth at random location, evaluate accuracy of reconstructed CT numbers in target region



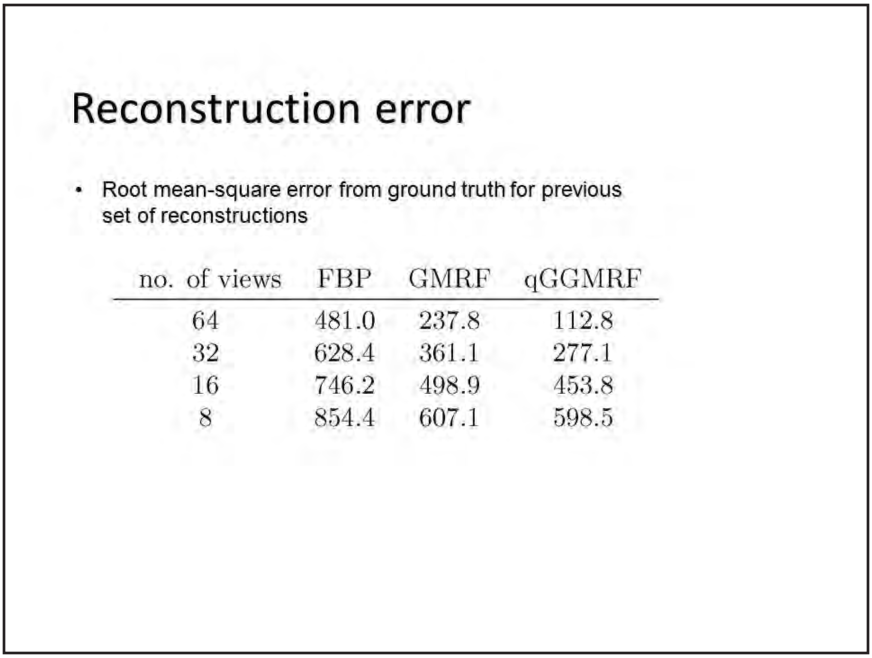
Reconstructions

- p=2, q=1, c=15 HU
- 1.0 mm voxel size
- gray map [0,2000] HU



Reconstructions

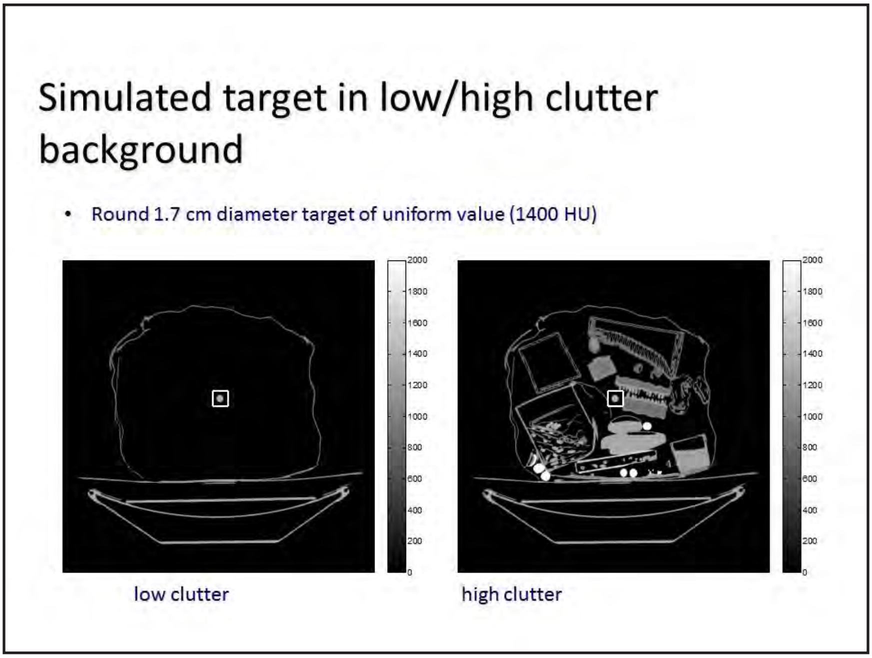
- p=2, q=1, c=15 HU
- 1.0 mm voxel size
- gray map [0,2000] HU



Reconstruction error

- Root mean-square error from ground truth for previous set of reconstructions

no. of views	FBP	GMRF	qGGMRF
64	481.0	237.8	112.8
32	628.4	361.1	277.1
16	746.2	498.9	453.8
8	854.4	607.1	598.5

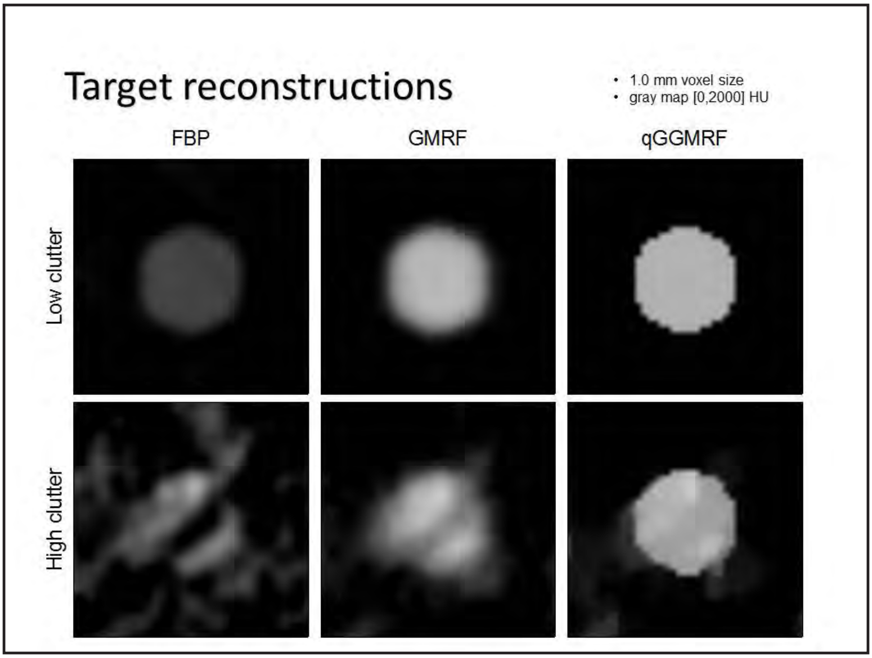


Simulated target in low/high clutter background

- Round 1.7 cm diameter target of uniform value (1400 HU)

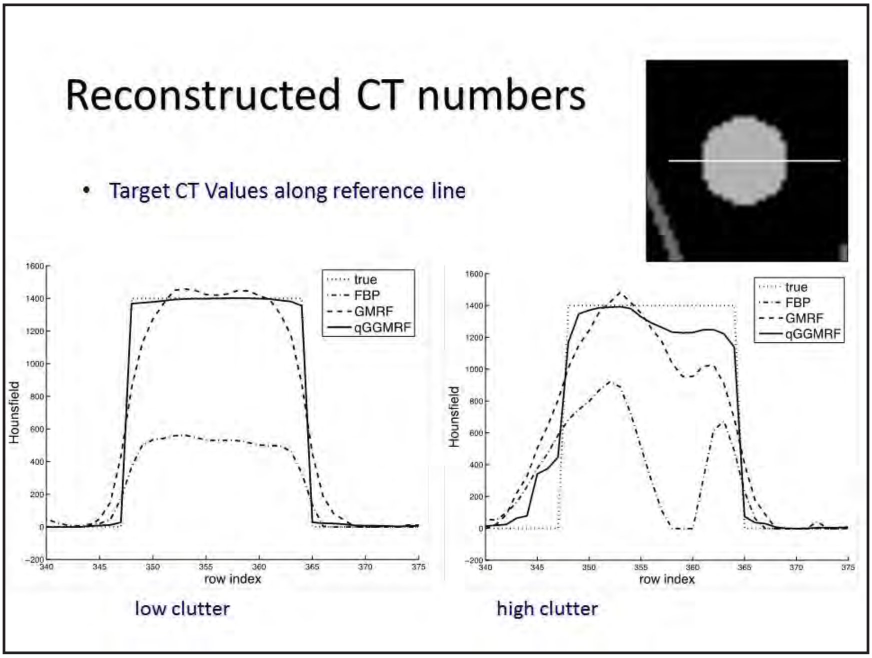
low clutter

high clutter



Target reconstructions

- 1.0 mm voxel size
- gray map [0,2000] HU

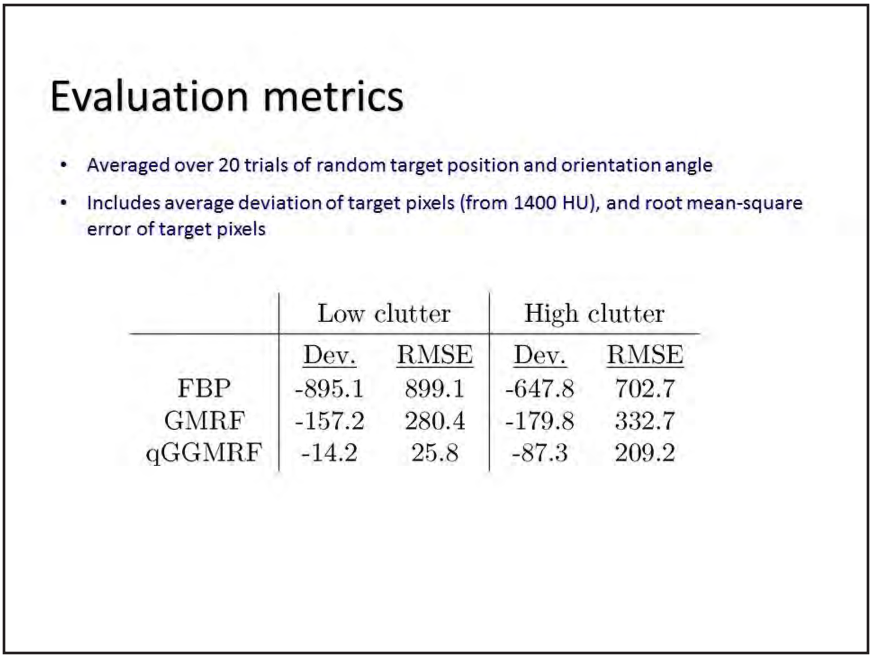


Reconstructed CT numbers

- Target CT Values along reference line

low clutter

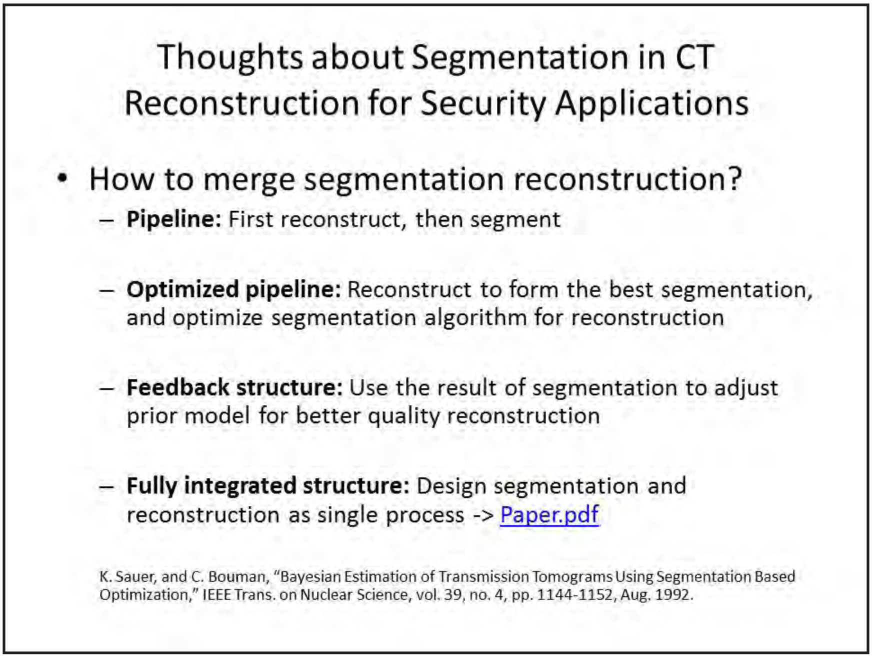
high clutter



Evaluation metrics

- Averaged over 20 trials of random target position and orientation angle
- Includes average deviation of target pixels (from 1400 HU), and root mean-square error of target pixels

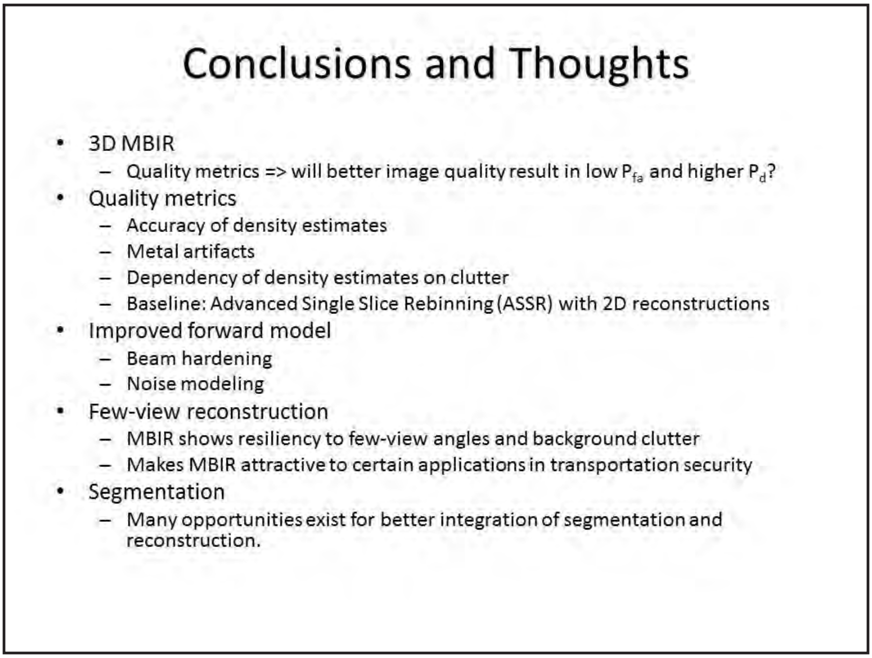
	Low clutter		High clutter	
	Dev.	RMSE	Dev.	RMSE
FBP	-895.1	899.1	-647.8	702.7
GMRF	-157.2	280.4	-179.8	332.7
qGGMRF	-14.2	25.8	-87.3	209.2



Thoughts about Segmentation in CT Reconstruction for Security Applications

- How to merge segmentation reconstruction?
  - **Pipeline:** First reconstruct, then segment
  - **Optimized pipeline:** Reconstruct to form the best segmentation, and optimize segmentation algorithm for reconstruction
  - **Feedback structure:** Use the result of segmentation to adjust prior model for better quality reconstruction
  - **Fully integrated structure:** Design segmentation and reconstruction as single process -> Paper.pdf

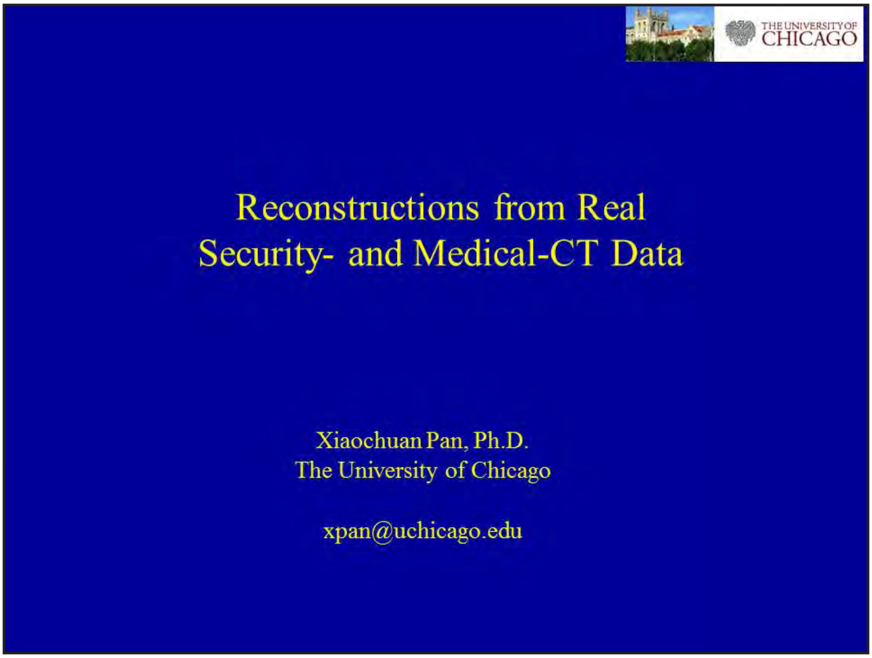
K. Sauer, and C. Bouman, "Bayesian Estimation of Transmission Tomograms Using Segmentation Based Optimization," IEEE Trans. on Nuclear Science, vol. 39, no. 4, pp. 1144-1152, Aug. 1992.



Conclusions and Thoughts

- 3D MBIR
  - Quality metrics => will better image quality result in low P_{fa} and higher P_d?
- Quality metrics
  - Accuracy of density estimates
  - Metal artifacts
  - Dependency of density estimates on clutter
  - Baseline: Advanced Single Slice Rebinning (ASSR) with 2D reconstructions
- Improved forward model
  - Beam hardening
  - Noise modeling
- Few-view reconstruction
  - MBIR shows resiliency to few-view angles and background clutter
  - Makes MBIR attractive to certain applications in transportation security
- Segmentation
  - Many opportunities exist for better integration of segmentation and reconstruction.

16.6 Xiaochuan Pan: Reconstructions from Real Security- and Medical-CT Data



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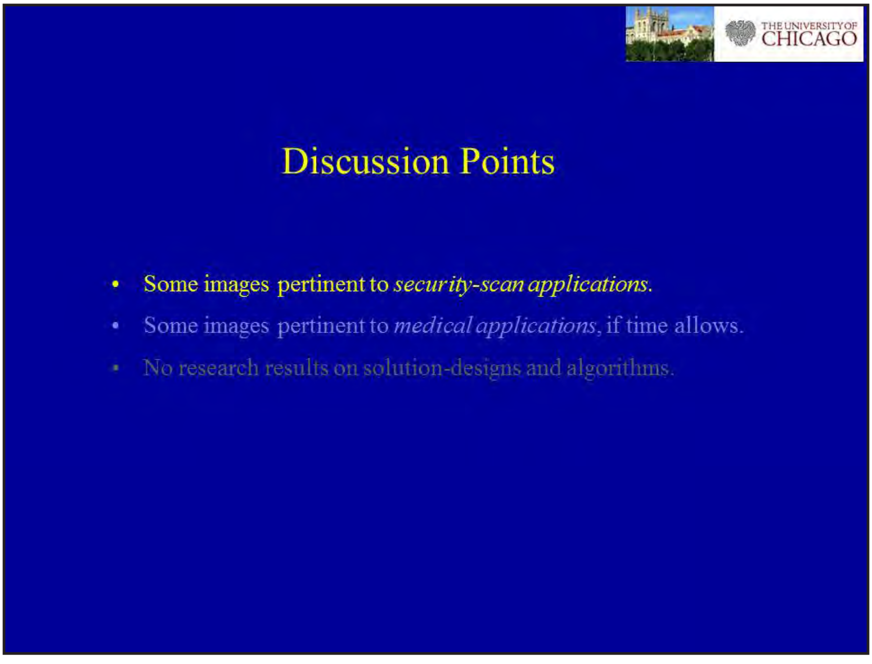
Reconstructions from Real
Security- and Medical-CT Data

Xiaochuan Pan, Ph.D.
The University of Chicago

xpan@uchicago.edu



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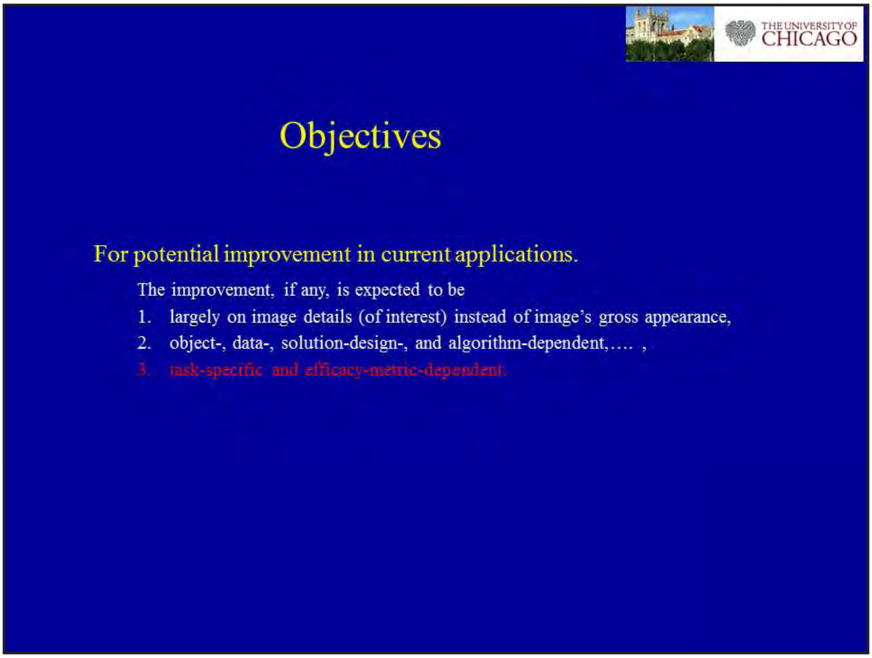
Discussion Points

- Some images pertinent to *security-scan applications*.
- Some images pertinent to *medical applications*, if time allows.
- No research results on solution-designs and algorithms.

Motivations for the Discussion Points

- Many algorithms have already been developed.
- Which one to use for which tasks ?

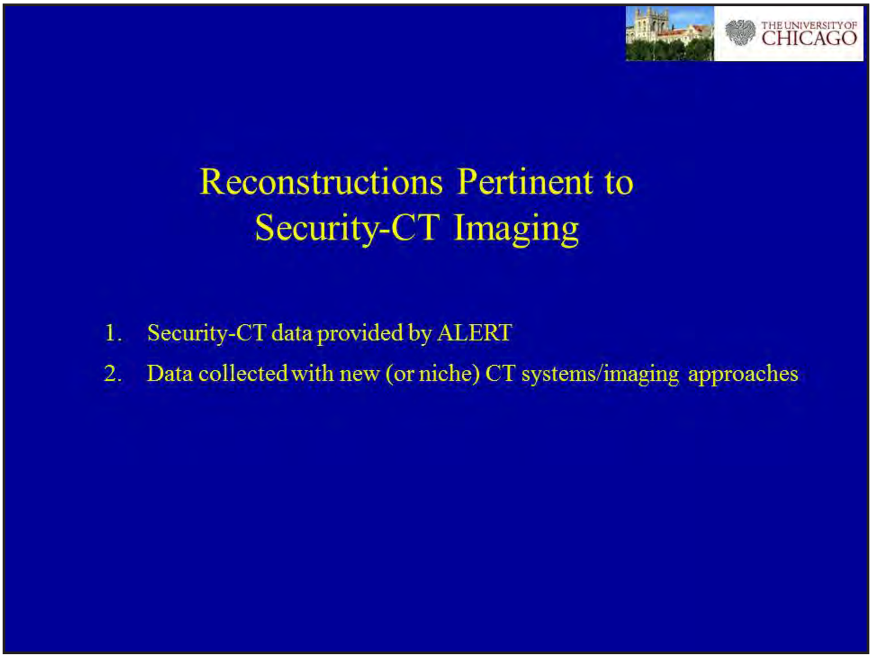


Objectives

For potential improvement in current applications.

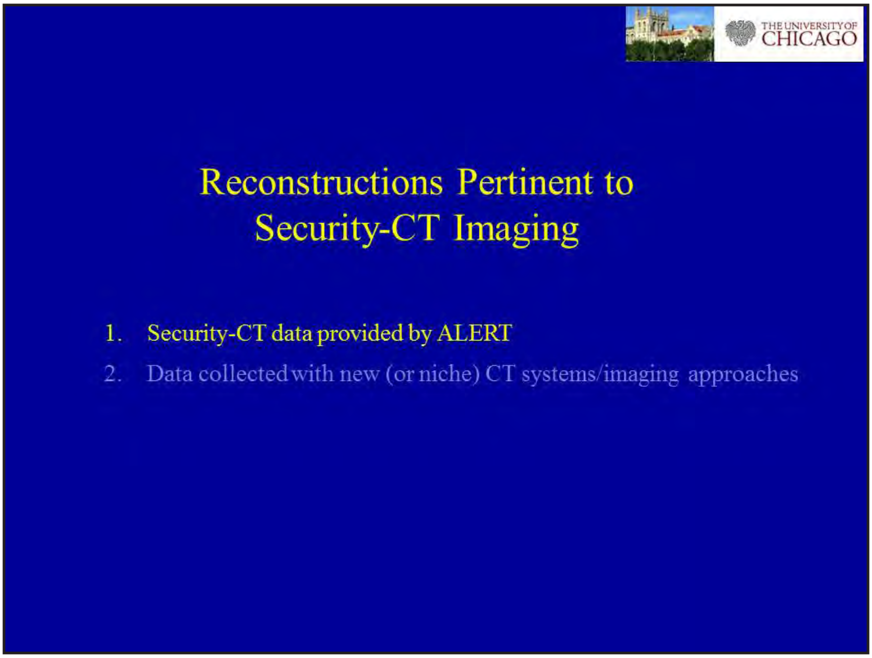
The improvement, if any, is expected to be

1. largely on image details (of interest) instead of image's gross appearance,
2. object-, data-, solution-design-, and algorithm-dependent,…. ,
3. task-specific and efficacy-metric-dependent.



Reconstructions Pertinent to Security-CT Imaging

1. Security-CT data provided by ALERT
2. Data collected with new (or niche) CT systems/imaging approaches



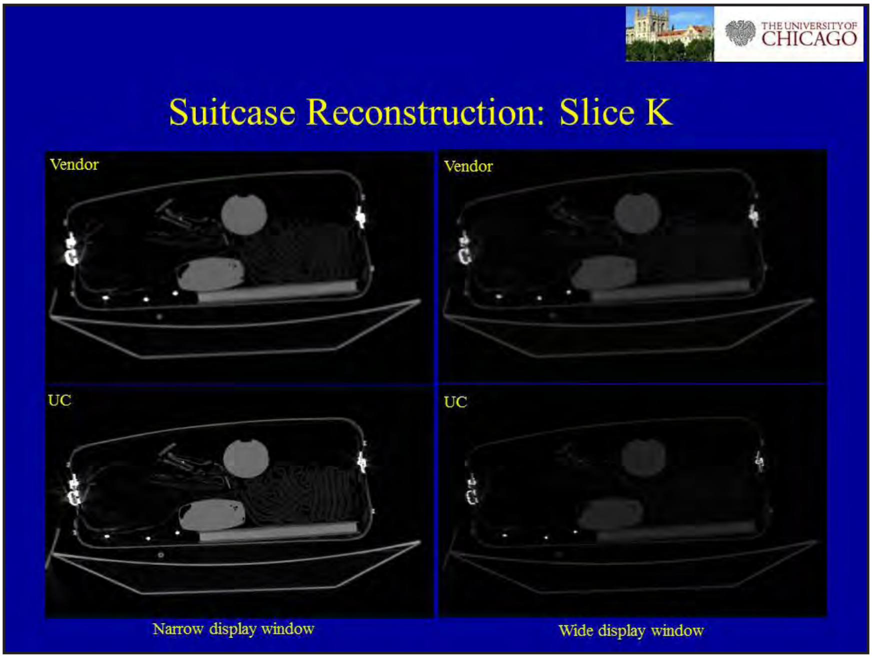
Reconstructions Pertinent to Security-CT Imaging

1. Security-CT data provided by ALERT
2. Data collected with new (or niche) CT systems/imaging approaches

UC Reconstructions from ALERT Data: Timeline and Current Status

Timeline

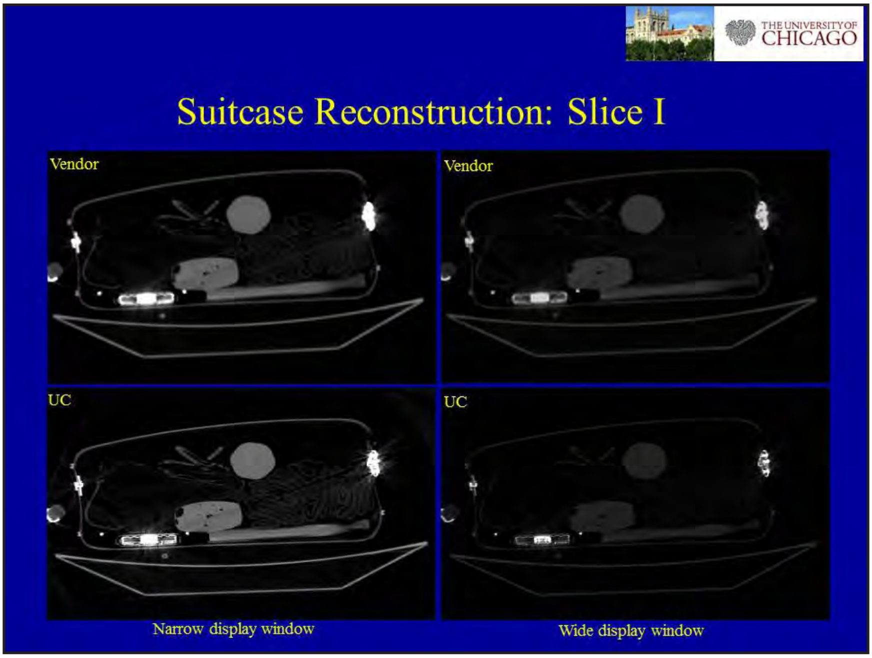
- ALERT data were received on June 7, 2011.
- Our own resource was allocated to support the work on the data.
- It took some time (from June 9 to July 22, 2011) to receive additional information about the data.
- Initial reconstruction was carried out in Aug., 2011.
- Some reconstruction results were sent out to ALERT on Sept. 14, 2011.



Suitcase Reconstruction: Slice K

Narrow display window

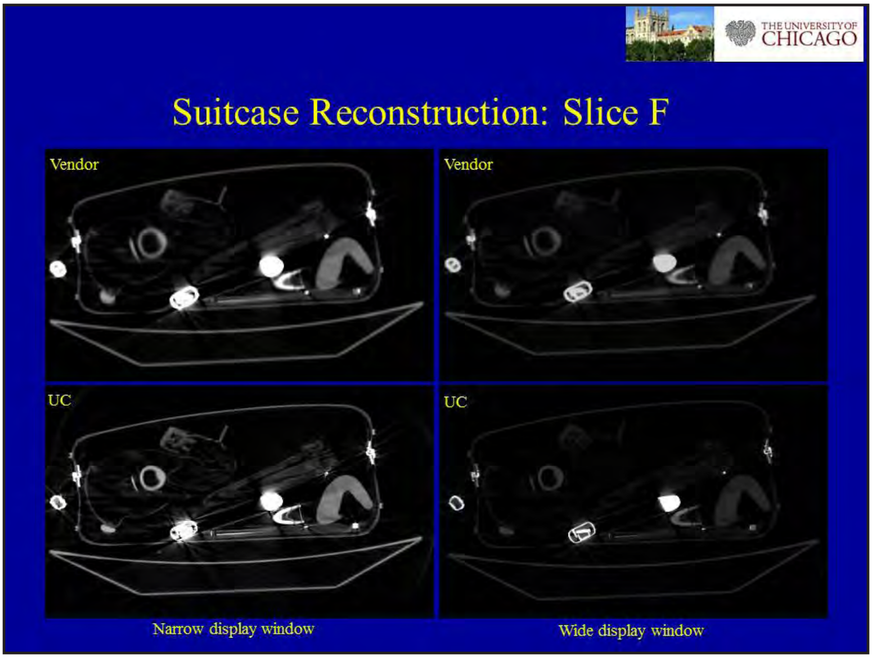
Wide display window



Suitcase Reconstruction: Slice I

Narrow display window

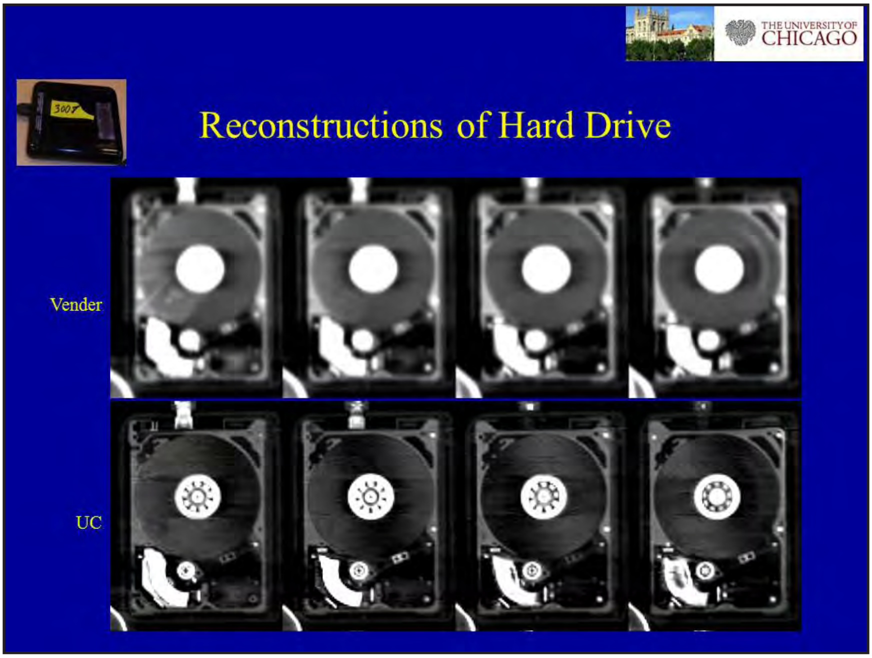
Wide display window



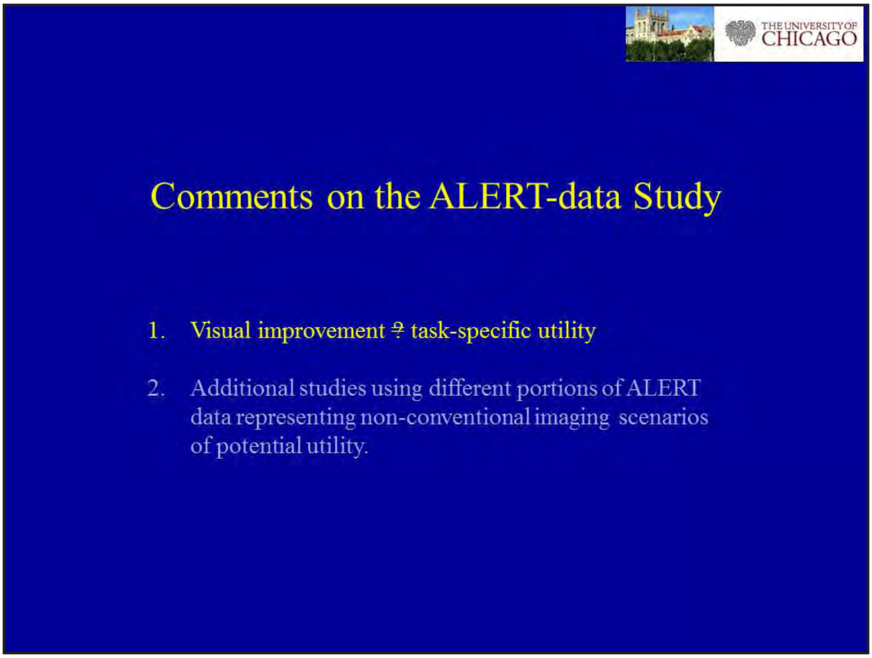
Suitcase Reconstruction: Slice F

Narrow display window

Wide display window

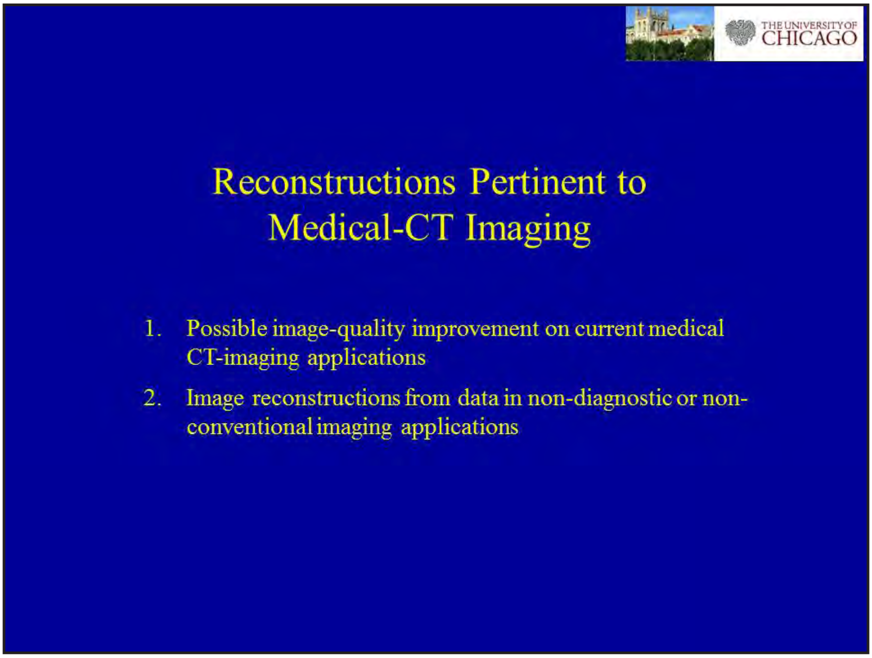


Reconstructions of Hard Drive



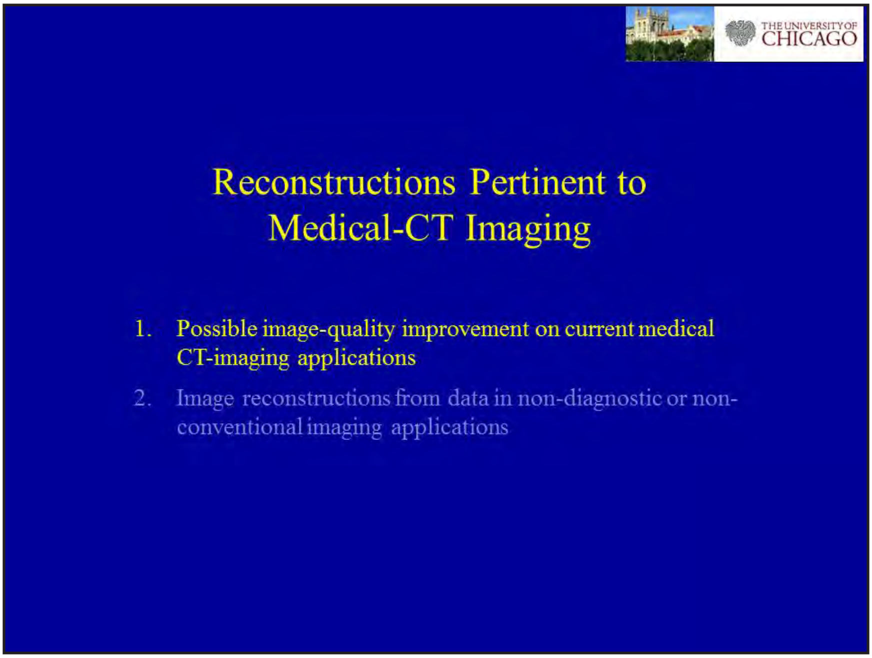
Comments on the ALERT-data Study

1. Visual improvement ≟ task-specific utility
2. Additional studies using different portions of ALERT data representing non-conventional imaging scenarios of potential utility.



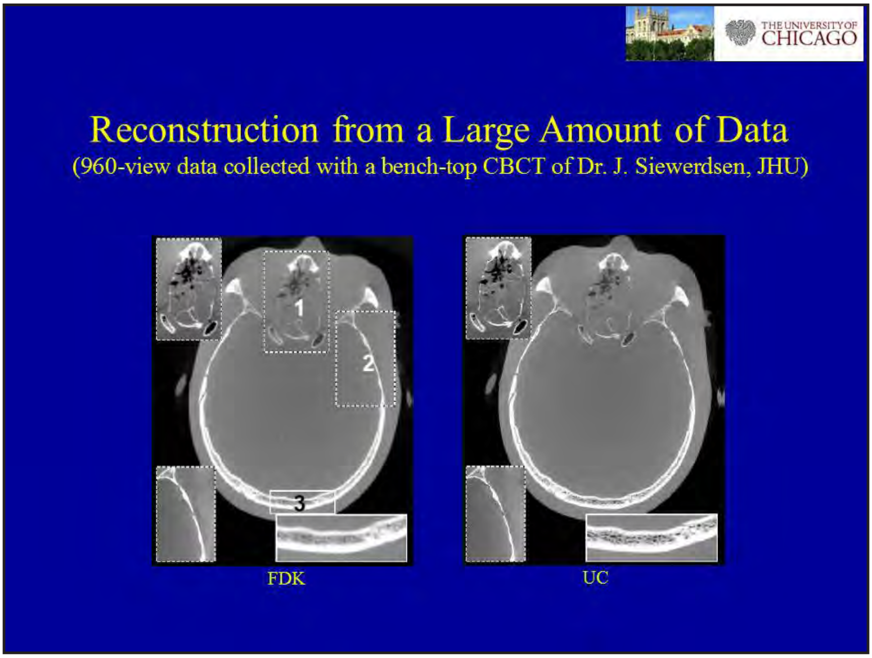
Reconstructions Pertinent to Medical-CT Imaging

1. Possible image-quality improvement on current medical CT-imaging applications
2. Image reconstructions from data in non-diagnostic or non-conventional imaging applications



Reconstructions Pertinent to Medical-CT Imaging

1. Possible image-quality improvement on current medical CT-imaging applications
2. Image reconstructions from data in non-diagnostic or non-conventional imaging applications

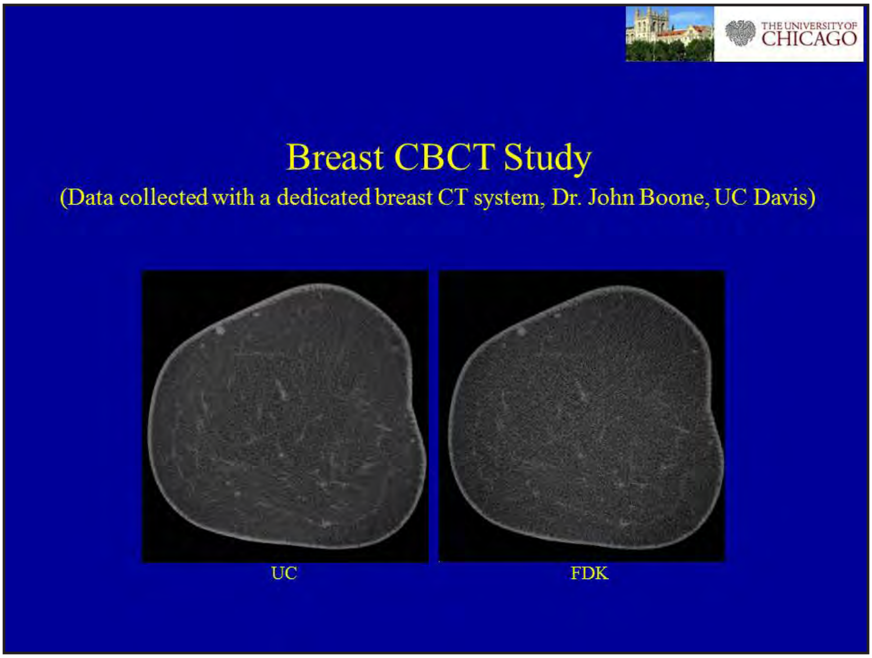


Reconstruction from a Large Amount of Data

(960-view data collected with a bench-top CBCT of Dr. J. Siewerdsen, JHU)

FDK

UC

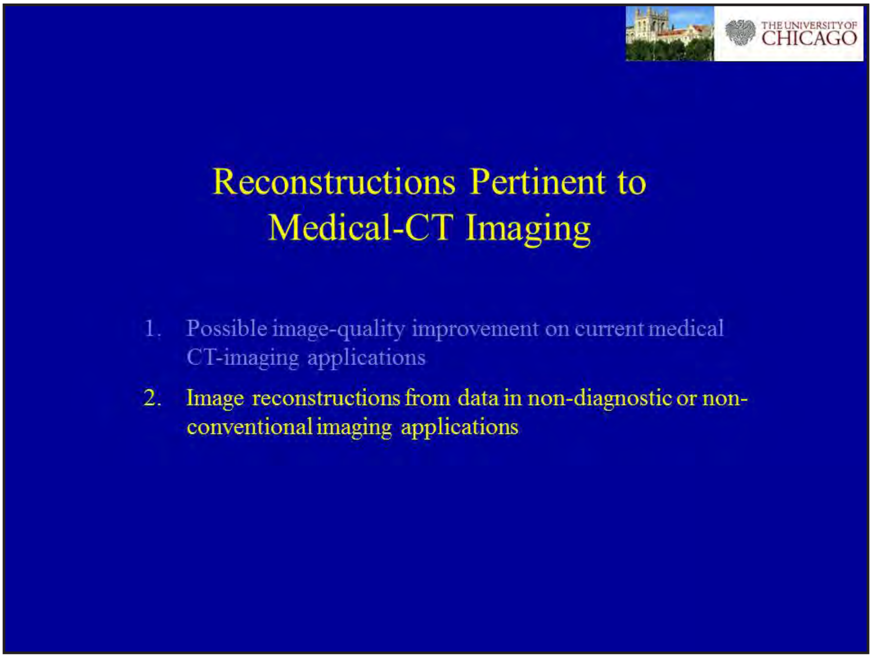


Breast CBCT Study

(Data collected with a dedicated breast CT system, Dr. John Boone, UC Davis)

UC

FDK



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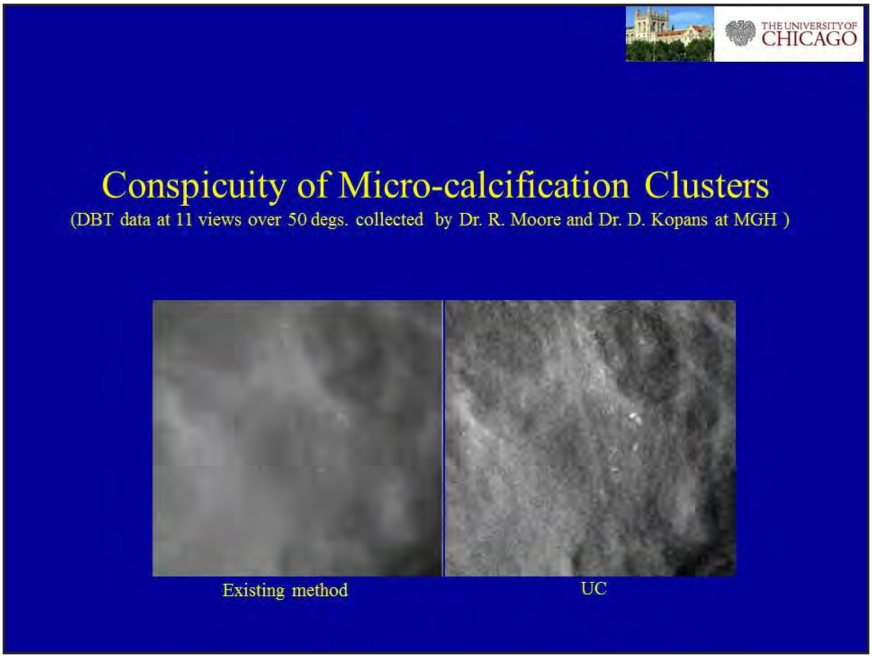
Reconstructions Pertinent to Medical-CT Imaging

1. Possible image-quality improvement on current medical CT-imaging applications
2. Image reconstructions from data in non-diagnostic or non-conventional imaging applications



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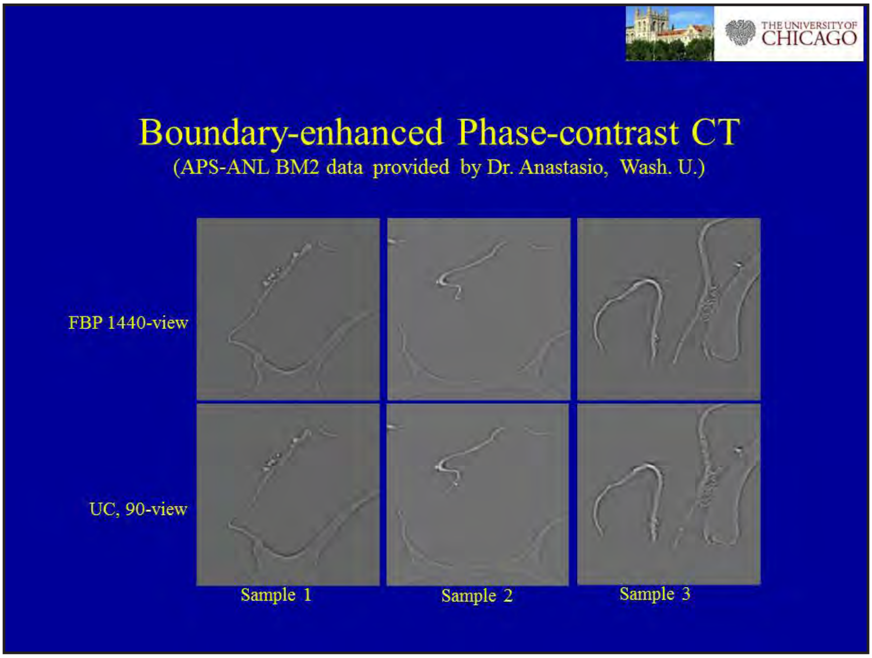
Conspicuity of Micro-calcification Clusters

(DBT data at 11 views over 50 degs. collected by Dr. R. Moore and Dr. D. Kopans at MGH)

Existing method

UC



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Boundary-enhanced Phase-contrast CT

(APS-ANL BM2 data provided by Dr. Anastasio, Wash. U.)

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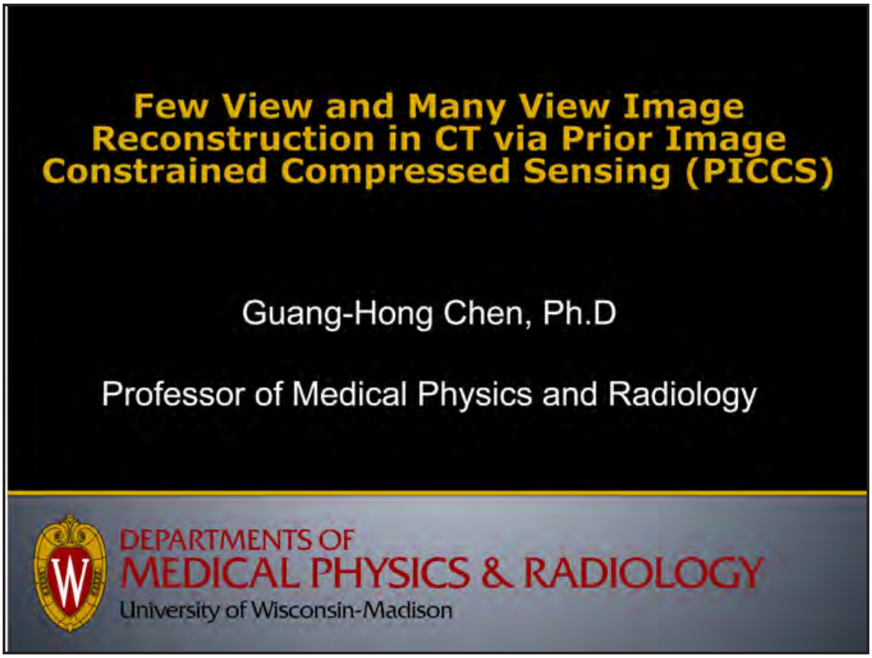
Thank You.

16.7 Guang-Hong Chen: Few View and Many View Image Reconstruction in CT via PICCS

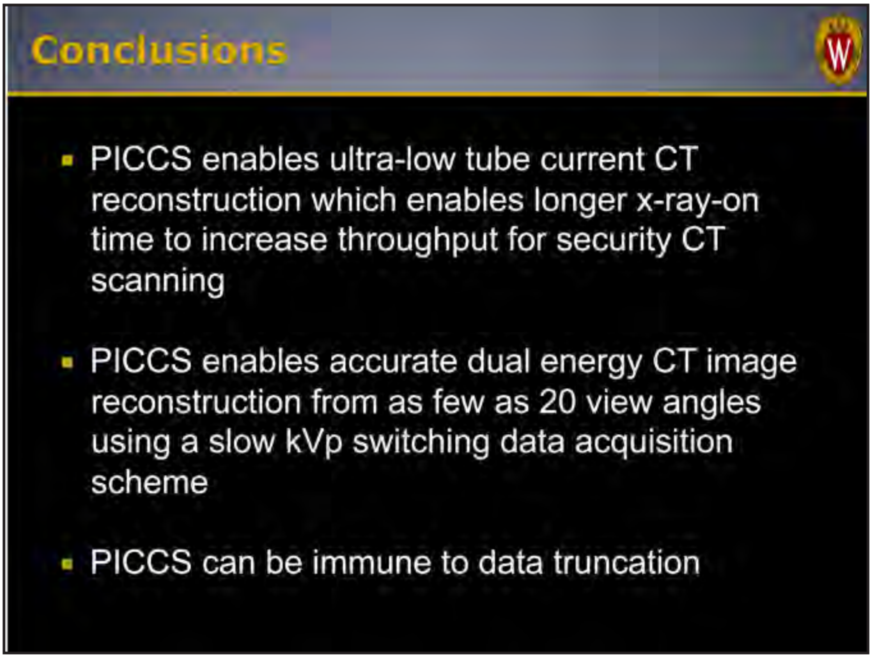


Few View and Many View Image Reconstruction in CT via Prior Image Constrained Compressed Sensing (PICCS)

Guang-Hong Chen, Ph.D

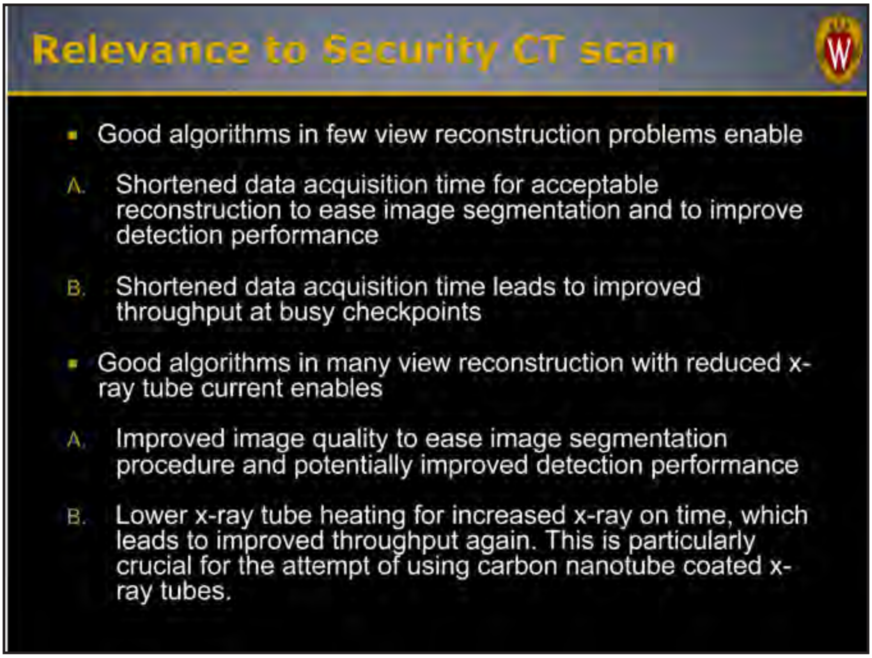
Professor of Medical Physics and Radiology

DEPARTMENTS OF
MEDICAL PHYSICS & RADIOLOGY
University of Wisconsin-Madison



Conclusions

- PICCS enables ultra-low tube current CT reconstruction which enables longer x-ray-on time to increase throughput for security CT scanning
- PICCS enables accurate dual energy CT image reconstruction from as few as 20 view angles using a slow kVp switching data acquisition scheme
- PICCS can be immune to data truncation



Relevance to Security CT scan

- Good algorithms in few view reconstruction problems enable

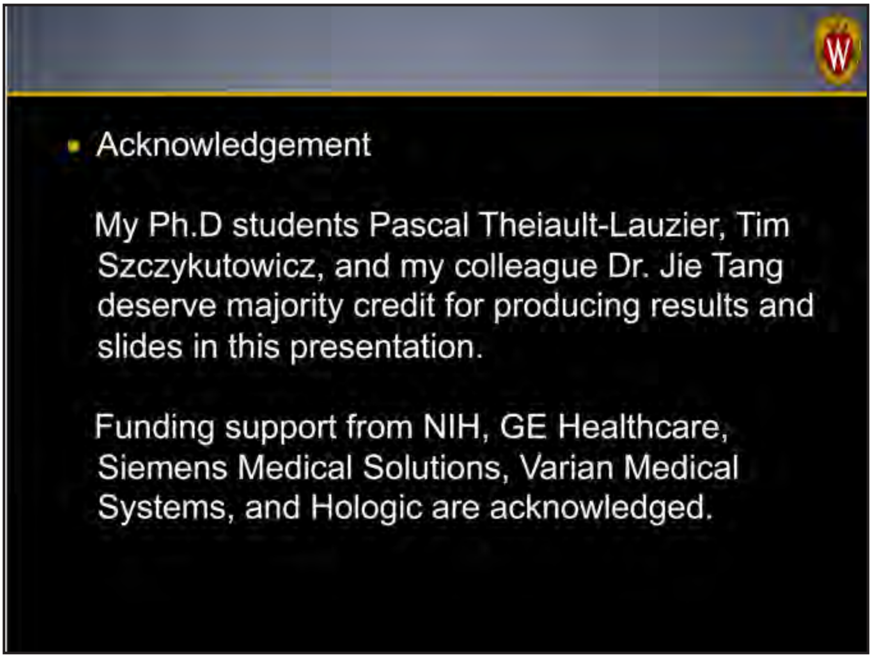
A. Shortened data acquisition time for acceptable reconstruction to ease image segmentation and to improve detection performance

B. Shortened data acquisition time leads to improved throughput at busy checkpoints

- Good algorithms in many view reconstruction with reduced x-ray tube current enables

A. Improved image quality to ease image segmentation procedure and potentially improved detection performance

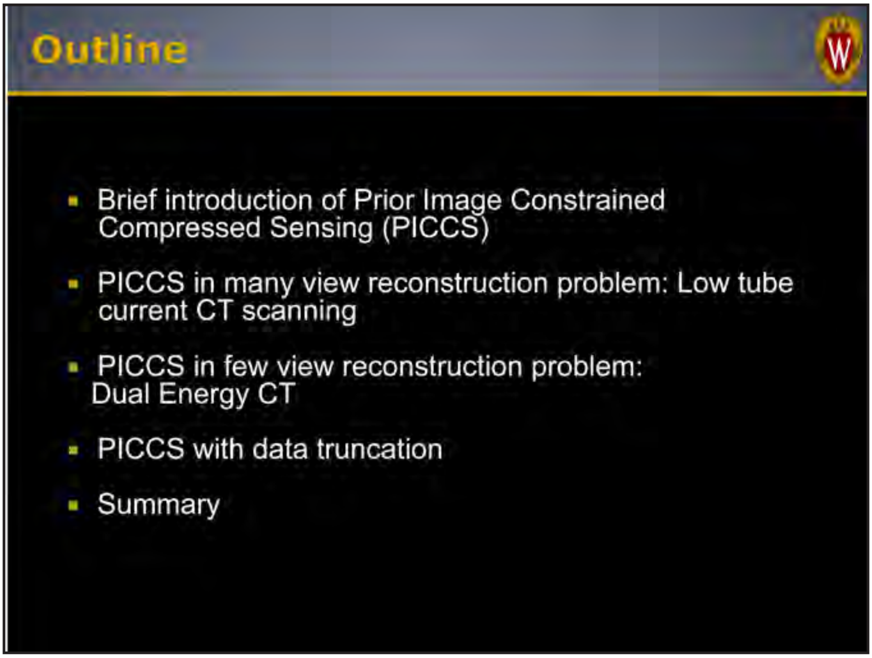
B. Lower x-ray tube heating for increased x-ray on time, which leads to improved throughput again. This is particularly crucial for the attempt of using carbon nanotube coated x-ray tubes.



- Acknowledgement

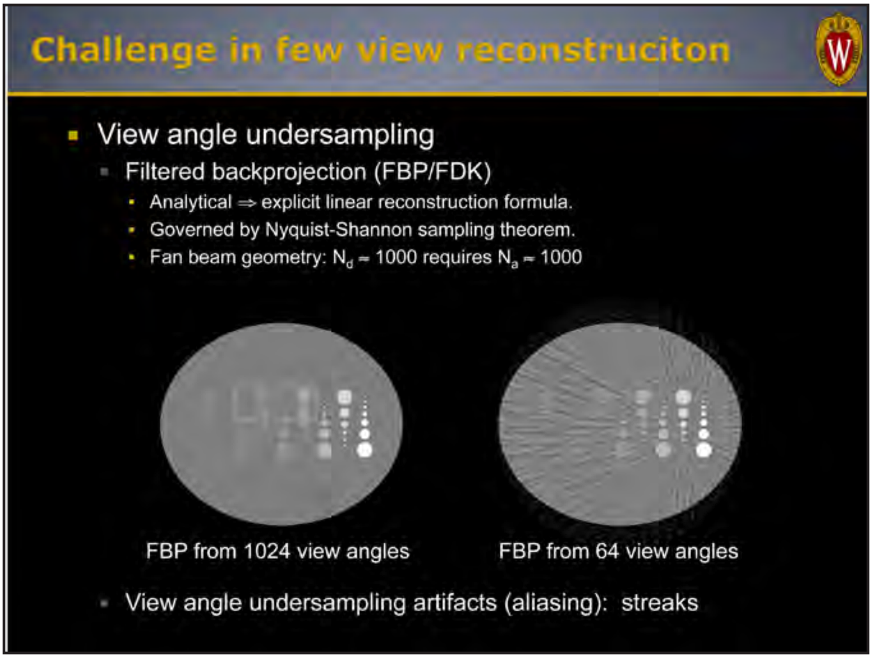
My Ph.D students Pascal Theiault-Lauzier, Tim Szczykutowicz, and my colleague Dr. Jie Tang deserve majority credit for producing results and slides in this presentation.

Funding support from NIH, GE Healthcare, Siemens Medical Solutions, Varian Medical Systems, and Hologic are acknowledged.



Outline

- Brief introduction of Prior Image Constrained Compressed Sensing (PICCS)
- PICCS in many view reconstruction problem: Low tube current CT scanning
- PICCS in few view reconstruction problem: Dual Energy CT
- PICCS with data truncation
- Summary



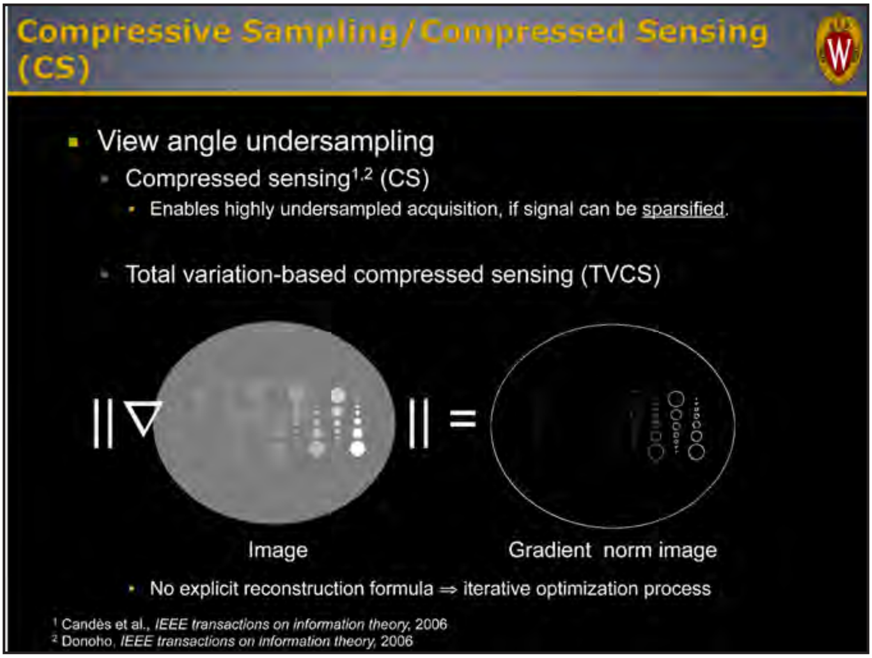
Challenge in few view reconstruciton

- View angle undersampling
  - Filtered backprojection (FBP/FDK)
    - Analytical ⇒ explicit linear reconstruction formula.
    - Governed by Nyquist-Shannon sampling theorem.
    - Fan beam geometry: $N_d = 1000$ requires $N_a = 1000$

FBP from 1024 view angles

FBP from 64 view angles

  - View angle undersampling artifacts (aliasing): streaks



Compressive Sampling / Compressed Sensing (CS)

- View angle undersampling
  - Compressed sensing[1,2] (CS)
    - Enables highly undersampled acquisition, if signal can be sparsified.
  - Total variation-based compressed sensing (TVCS)

$\|\nabla$ Image $\|$ = Gradient norm image

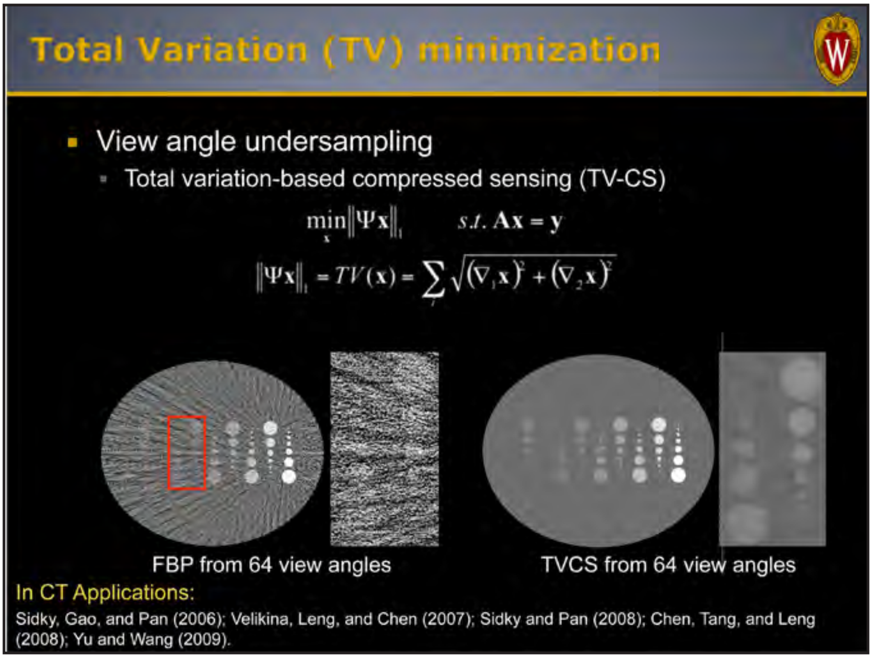
Image

Gradient norm image

- No explicit reconstruction formula ⇒ iterative optimization process

[1] Candès et al., *IEEE transactions on information theory*, 2006

[2] Donoho, *IEEE transactions on information theory*, 2006



Total Variation (TV) minimization

- View angle undersampling
  - Total variation-based compressed sensing (TV-CS)

$$\min_{x} \|\Psi \mathbf{x}\|_1 \qquad s.t.\ \mathbf{Ax} = \mathbf{y}$$

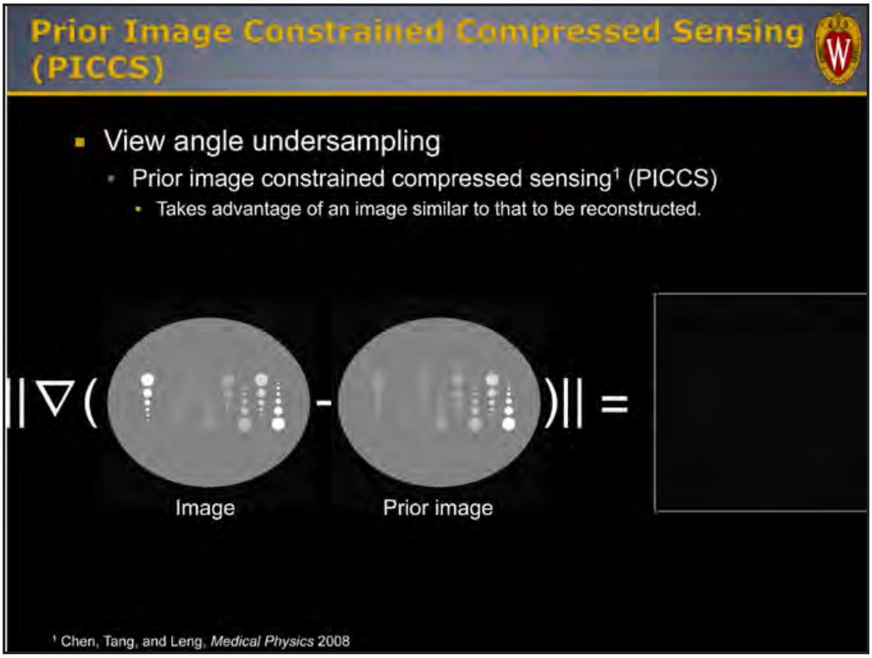
$$\|\Psi \mathbf{x}\|_1 = TV(\mathbf{x}) = \sum_i \sqrt{(\nabla_1 \mathbf{x})^2 + (\nabla_2 \mathbf{x})^2}$$

FBP from 64 view angles

TVCS from 64 view angles

In CT Applications:

Sidky, Gao, and Pan (2006); Velikina, Leng, and Chen (2007); Sidky and Pan (2008); Chen, Tang, and Leng (2008); Yu and Wang (2009).

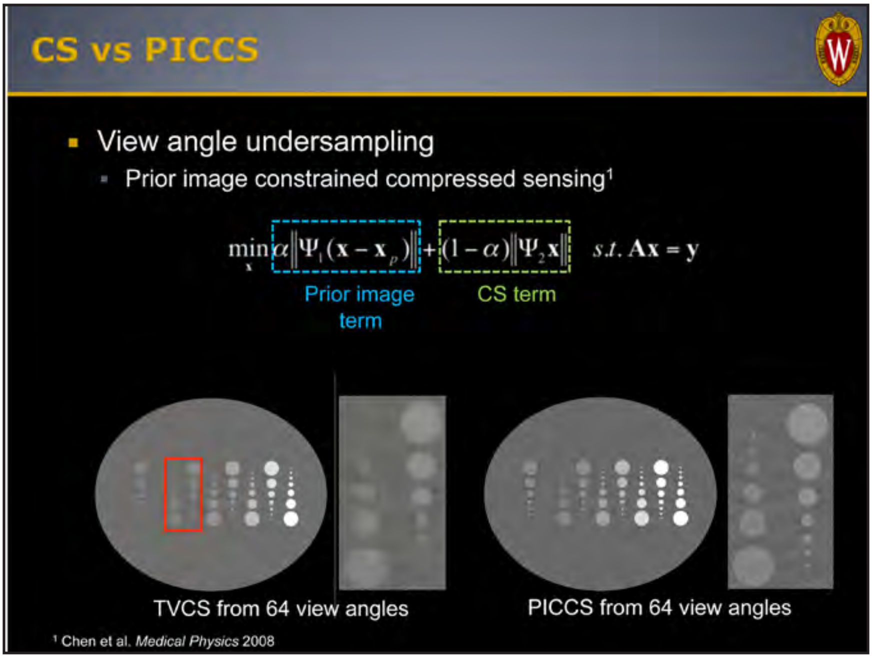


Prior Image Constrained Compressed Sensing (PICCS)

- View angle undersampling
  - Prior image constrained compressed sensing[1] (PICCS)
    - Takes advantage of an image similar to that to be reconstructed.

$\|\nabla($ Image $-$ Prior image $)\| =$

[1] Chen, Tang, and Leng, *Medical Physics* 2008



CS vs PICCS

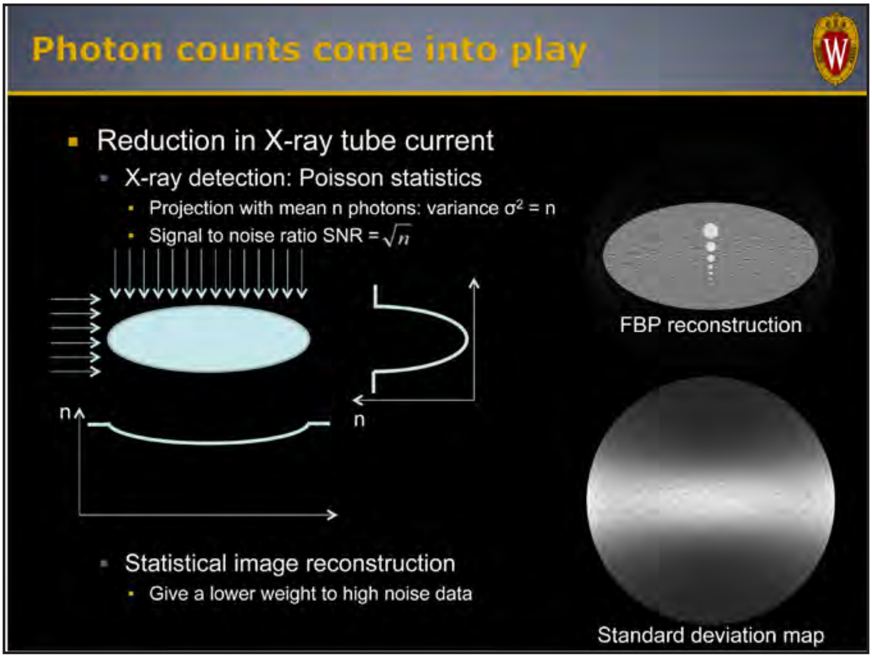
- View angle undersampling
  - Prior image constrained compressed sensing[1]

$$\min_{\mathbf{x}} \underbrace{\alpha\|\Psi_1(\mathbf{x}-\mathbf{x}_p)\|_1}_{\text{Prior image term}} + \underbrace{(1-\alpha)\|\Psi_2\mathbf{x}\|_1}_{\text{CS term}} \quad s.t.\ \mathbf{Ax}=\mathbf{y}$$

TVCS from 64 view angles

PICCS from 64 view angles

[1] Chen et al. *Medical Physics* 2008



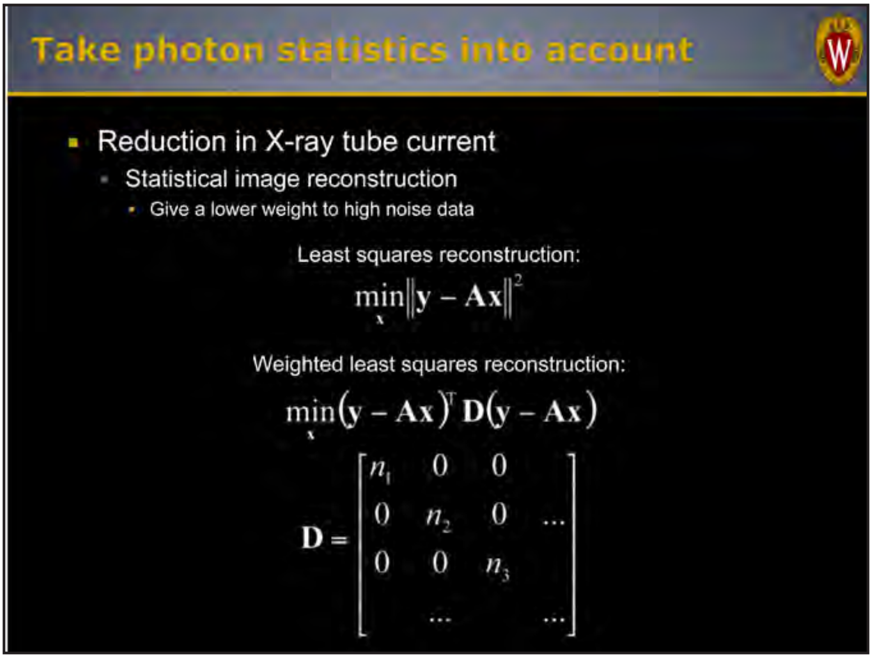
Photon counts come into play

- Reduction in X-ray tube current
  - X-ray detection: Poisson statistics
    - Projection with mean n photons: variance $\sigma^2 = n$
    - Signal to noise ratio SNR = $\sqrt{n}$

FBP reconstruction

Standard deviation map

  - Statistical image reconstruction
    - Give a lower weight to high noise data



Take photon statistics into account

- Reduction in X-ray tube current
  - Statistical image reconstruction
    - Give a lower weight to high noise data

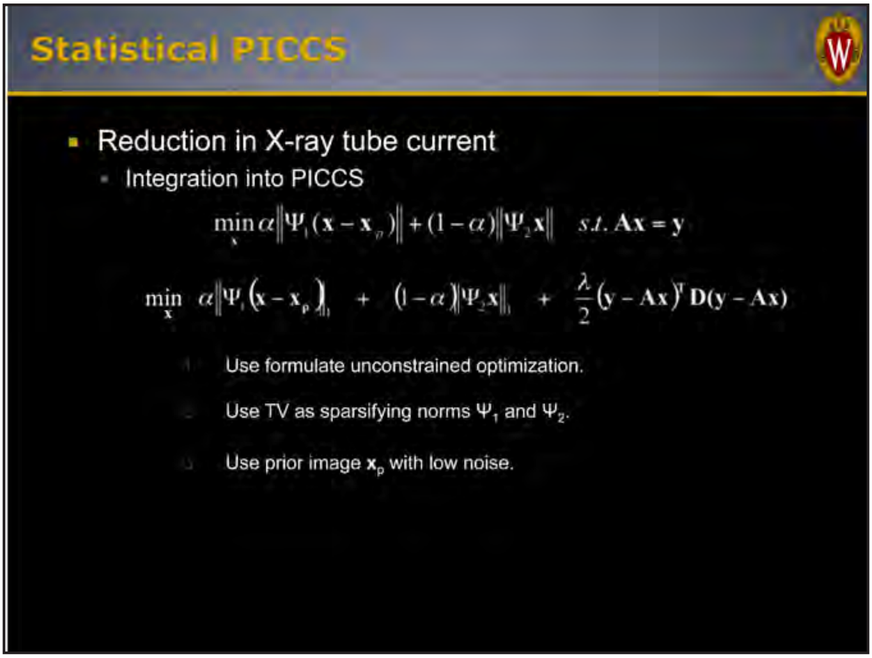
Least squares reconstruction:

$$\min_{\mathbf{x}} \left\| \mathbf{y} - \mathbf{A}\mathbf{x} \right\|^2$$

Weighted least squares reconstruction:

$$\min_{\mathbf{x}} (\mathbf{y} - \mathbf{A}\mathbf{x})^T \mathbf{D} (\mathbf{y} - \mathbf{A}\mathbf{x})$$

$$\mathbf{D} = \begin{bmatrix} n_1 & 0 & 0 & \\ 0 & n_2 & 0 & \dots \\ 0 & 0 & n_3 & \\ & \dots & & \dots \end{bmatrix}$$



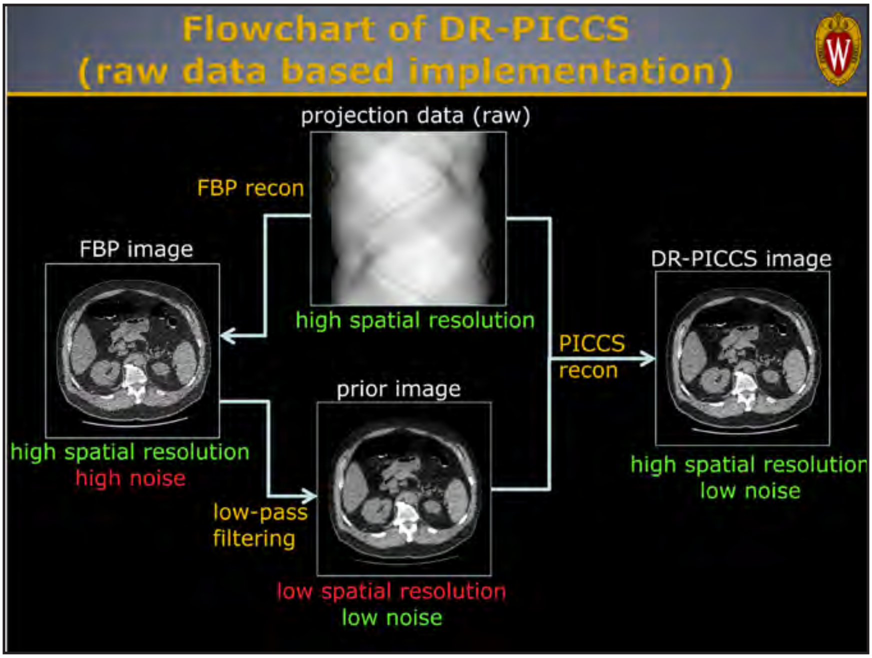
Statistical PICCS

- Reduction in X-ray tube current
  - Integration into PICCS

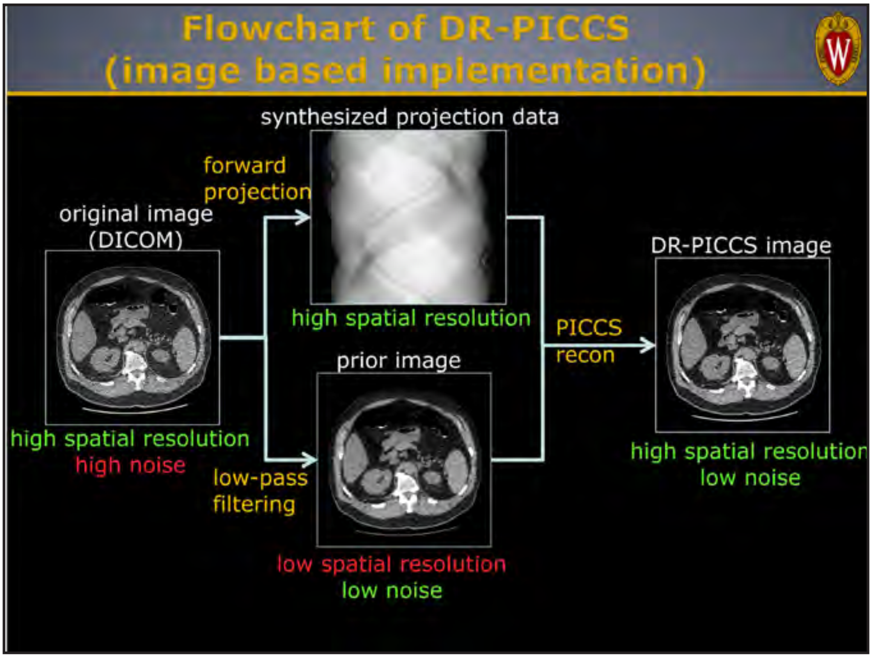
$$\min_{x} \alpha\left\|\Psi_1(x - x_p)\right\| + (1-\alpha)\left\|\Psi_2 x\right\| \quad s.t.\ Ax = y$$

$$\min_{x} \ \alpha\left\|\Psi_1(x - x_p)\right\|_1 + (1-\alpha)\left\|\Psi_2 x\right\|_1 + \frac{\lambda}{2}(y - Ax)^T D(y - Ax)$$

1. Use formulate unconstrained optimization.
2. Use TV as sparsifying norms Ψ_1 and Ψ_2.
3. Use prior image x_p with low noise.



Flowchart of DR-PICCS (raw data based implementation)



Flowchart of DR-PICCS (image based implementation)

synthesized projection data

forward projection

original image (DICOM)

high spatial resolution
high noise

high spatial resolution

low-pass filtering

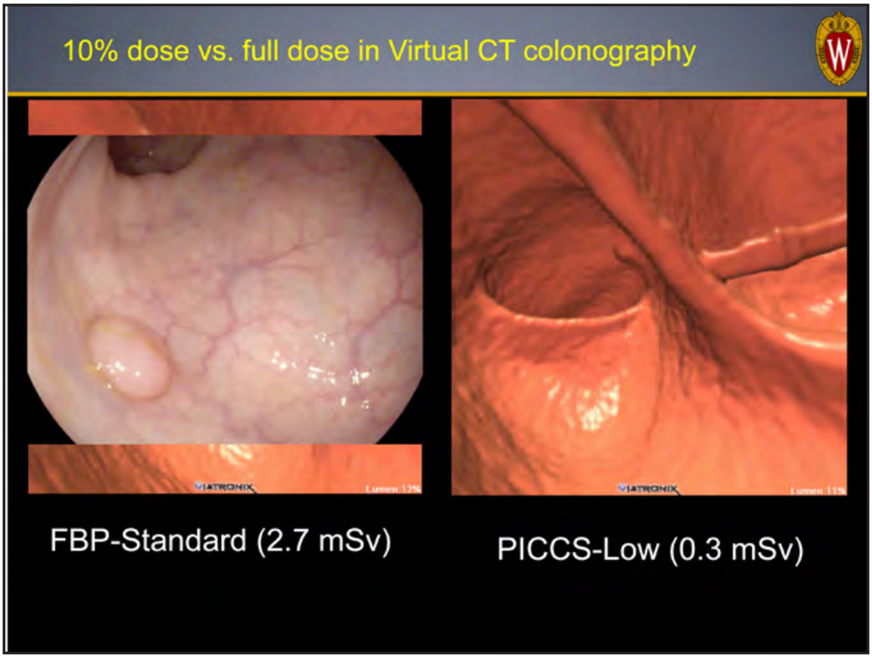
prior image

low spatial resolution
low noise

PICCS recon

DR-PICCS image

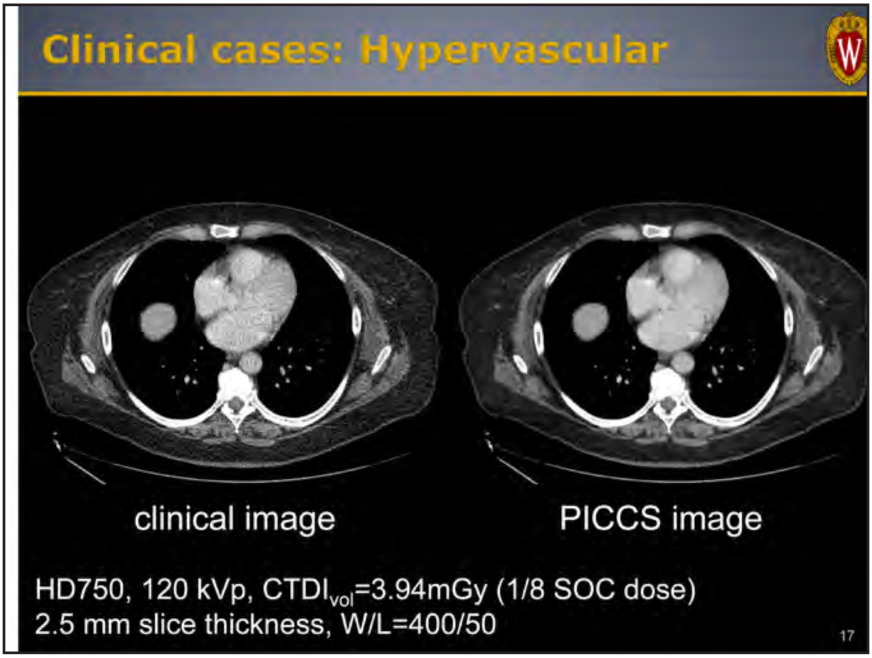
high spatial resolution
low noise



10% dose vs. full dose in Virtual CT colonography

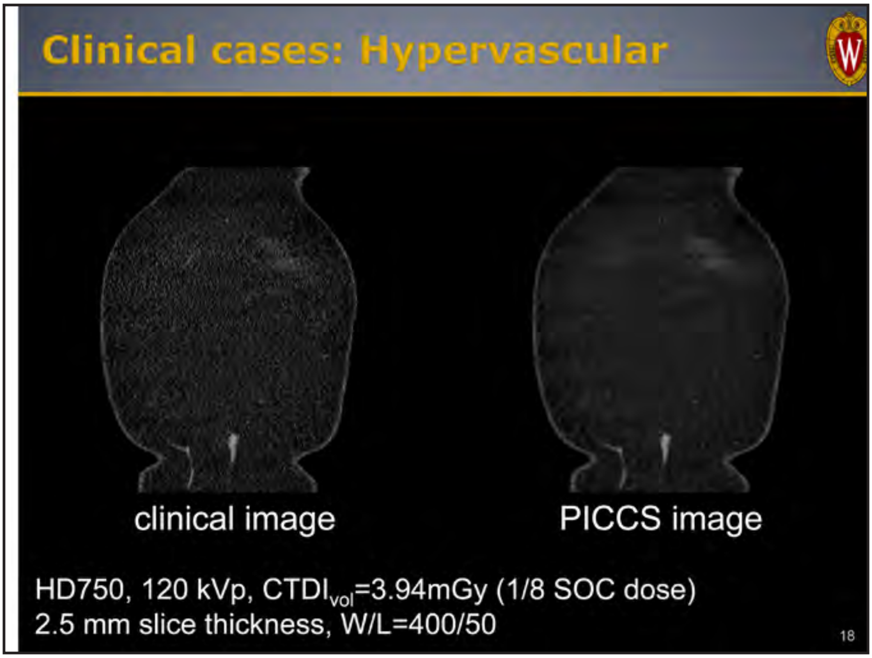
FBP-Standard (2.7 mSv)

PICCS-Low (0.3 mSv)



Clinical cases: Hypervascular

HD750, 120 kVp, CTDI$_{\text{vol}}$=3.94mGy (1/8 SOC dose)
2.5 mm slice thickness, W/L=400/50



Clinical cases: Hypervascular

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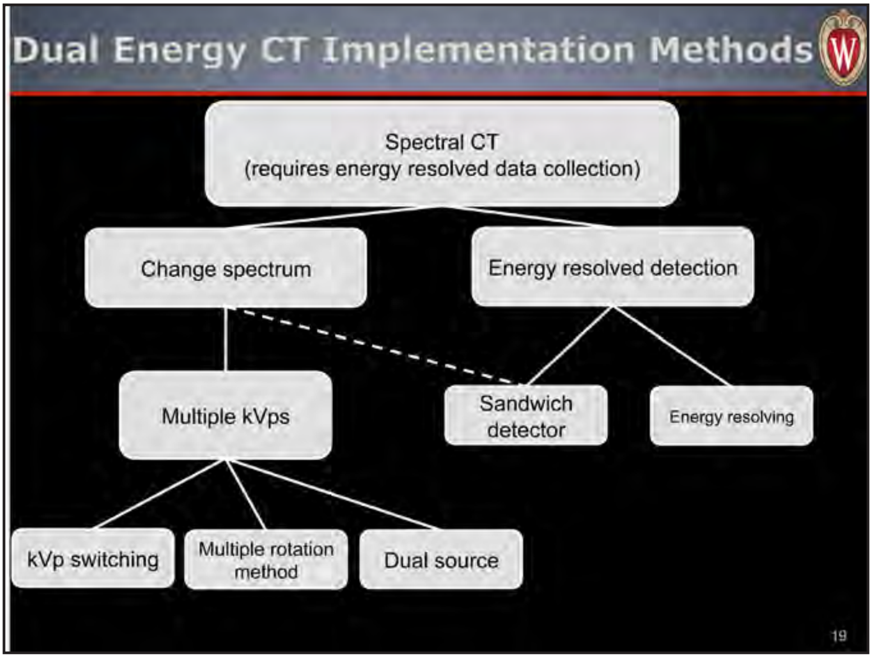


Dual Energy CT Implementation Methods

Spectral CT
(requires energy resolved data collection)

Change spectrum

Energy resolved detection

Multiple kVps

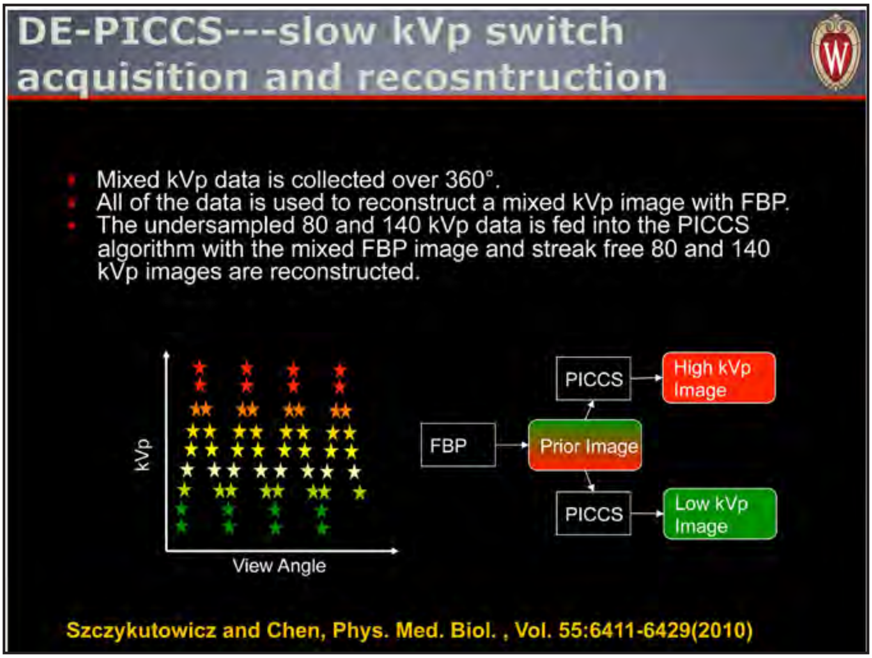
Sandwich detector

Energy resolving

kVp switching

Multiple rotation method

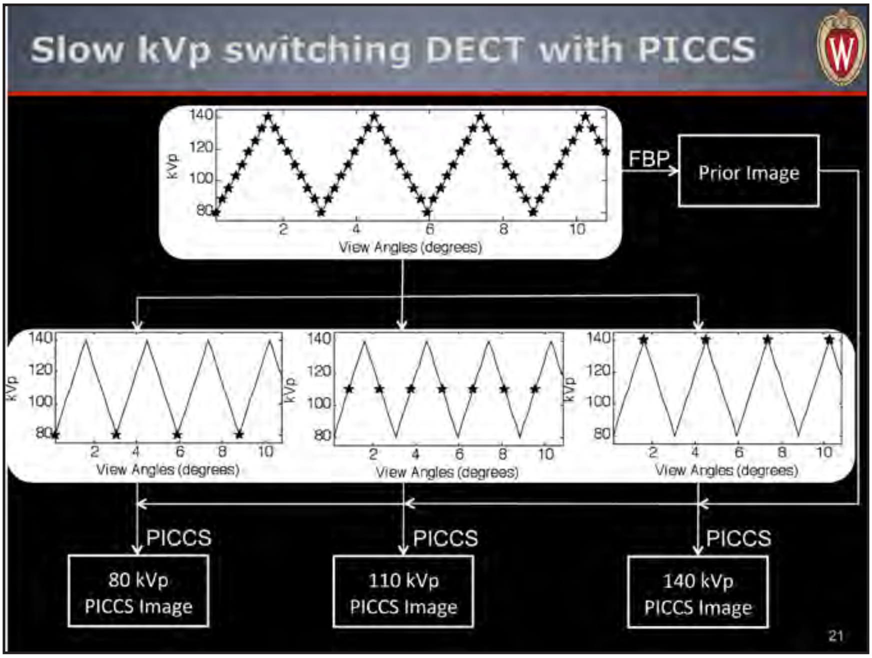
Dual source



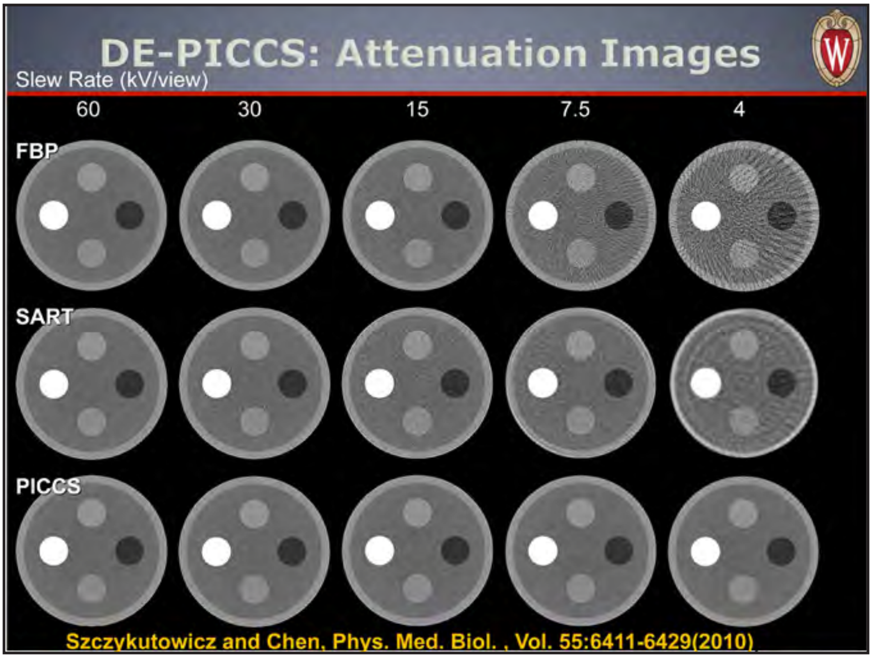
DE-PICCS---slow kVp switch acquisition and recosntruction

- Mixed kVp data is collected over 360°.
- All of the data is used to reconstruct a mixed kVp image with FBP.
- The undersampled 80 and 140 kVp data is fed into the PICCS algorithm with the mixed FBP image and streak free 80 and 140 kVp images are reconstructed.

Szczykutowicz and Chen, Phys. Med. Biol. , Vol. 55:6411-6429(2010)

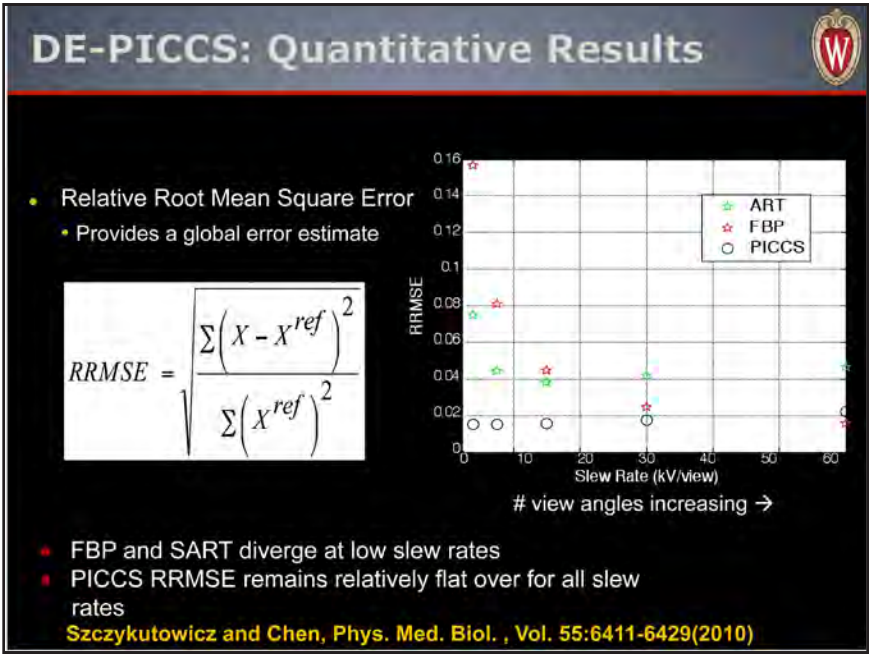


Slow kVp switching DECT with PICCS



DE-PICCS: Attenuation Images

Szczykutowicz and Chen, Phys. Med. Biol. , Vol. 55:6411-6429(2010)



DE-PICCS: Quantitative Results

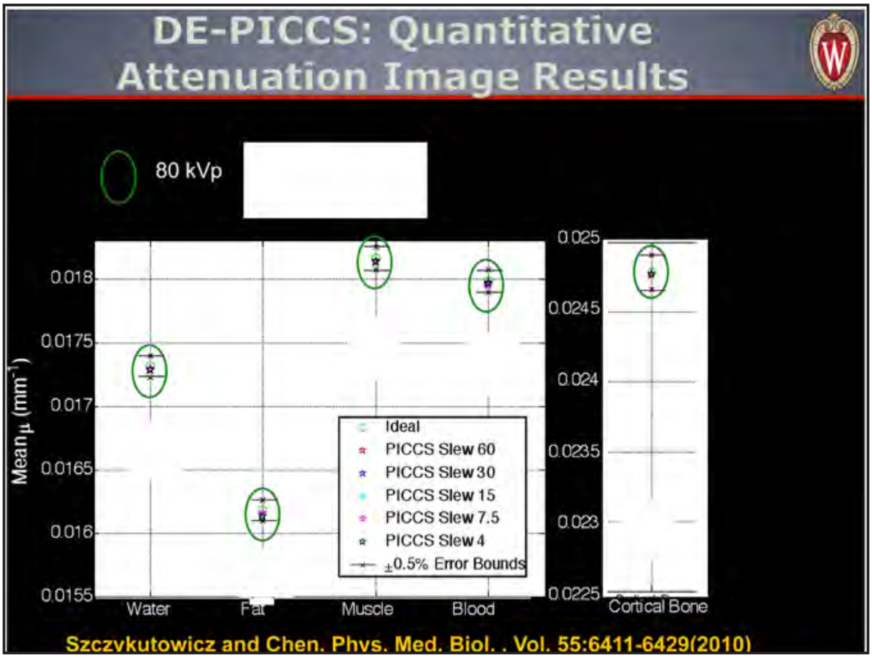
- Relative Root Mean Square Error
  - Provides a global error estimate

$$RRMSE = \sqrt{\frac{\sum\left(X - X^{ref}\right)^2}{\sum\left(X^{ref}\right)^2}}$$

\# view angles increasing →

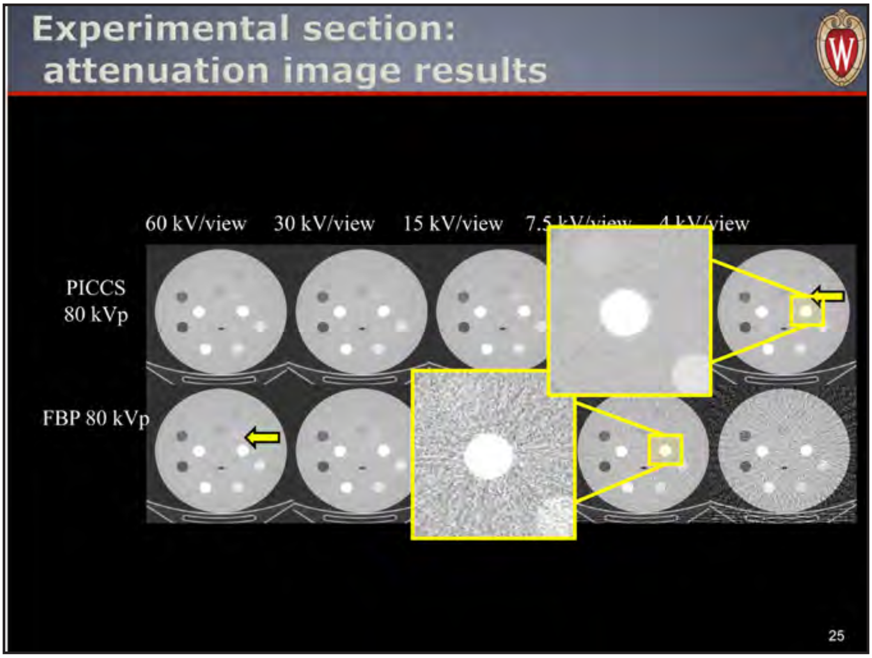
- FBP and SART diverge at low slew rates
- PICCS RRMSE remains relatively flat over for all slew rates

Szczykutowicz and Chen, Phys. Med. Biol. , Vol. 55:6411-6429(2010)



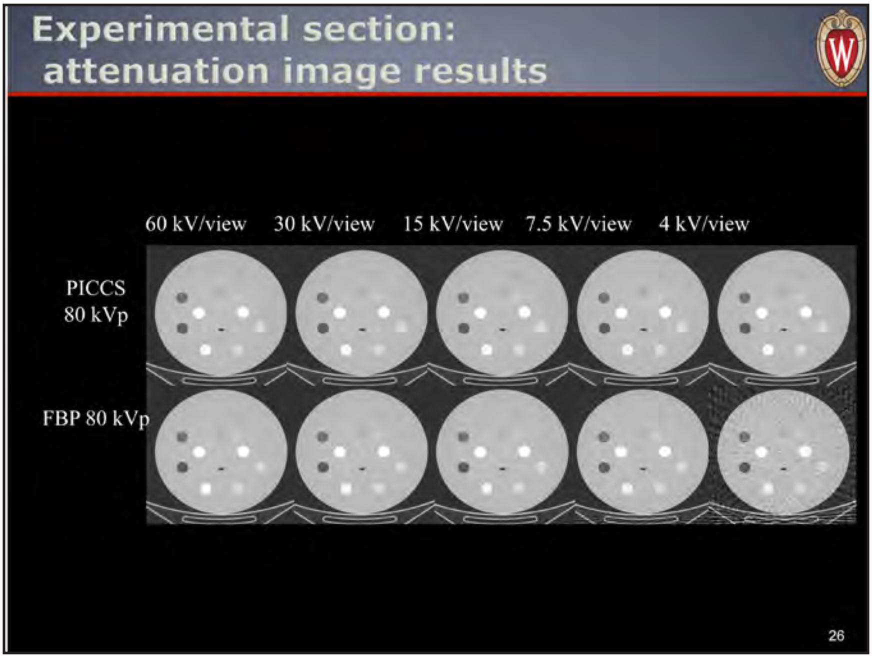
DE-PICCS: Quantitative Attenuation Image Results

Szczykutowicz and Chen, Phys. Med. Biol. , Vol. 55:6411-6429(2010)



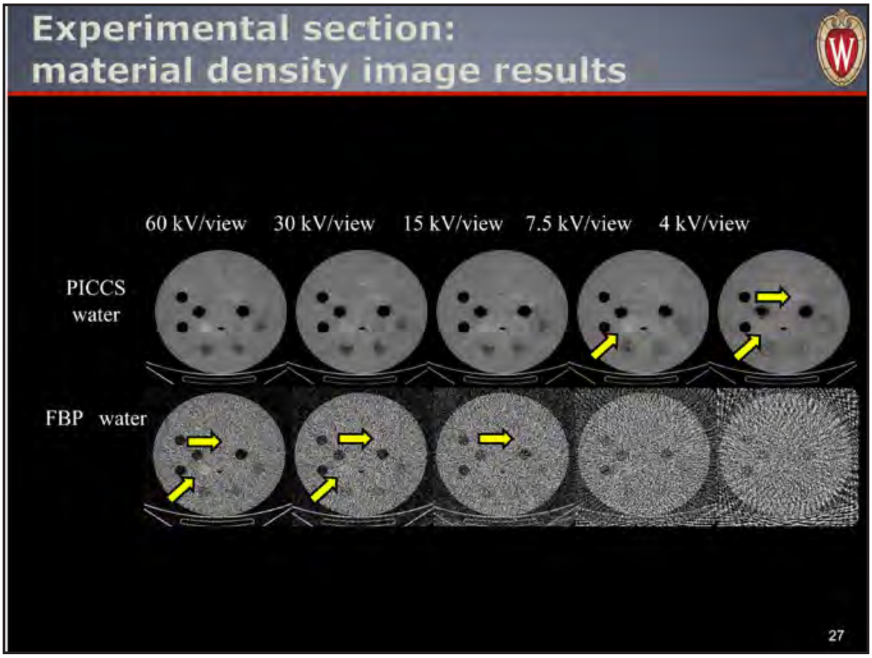
Experimental section: attenuation image results

25



Experimental section: attenuation image results

26

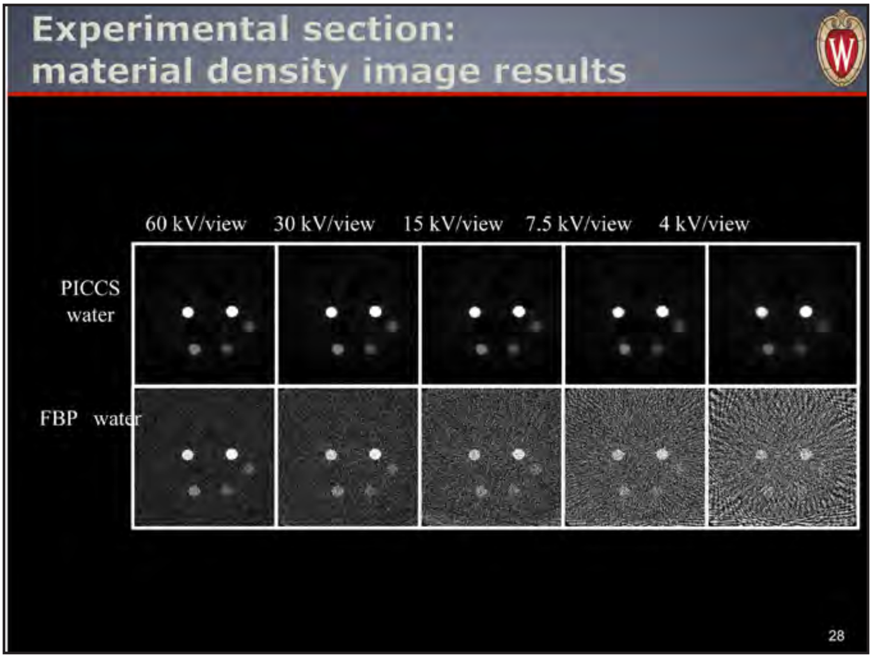


Experimental section: material density image results

60 kV/view 30 kV/view 15 kV/view 7.5 kV/view 4 kV/view

PICCS water

FBP water

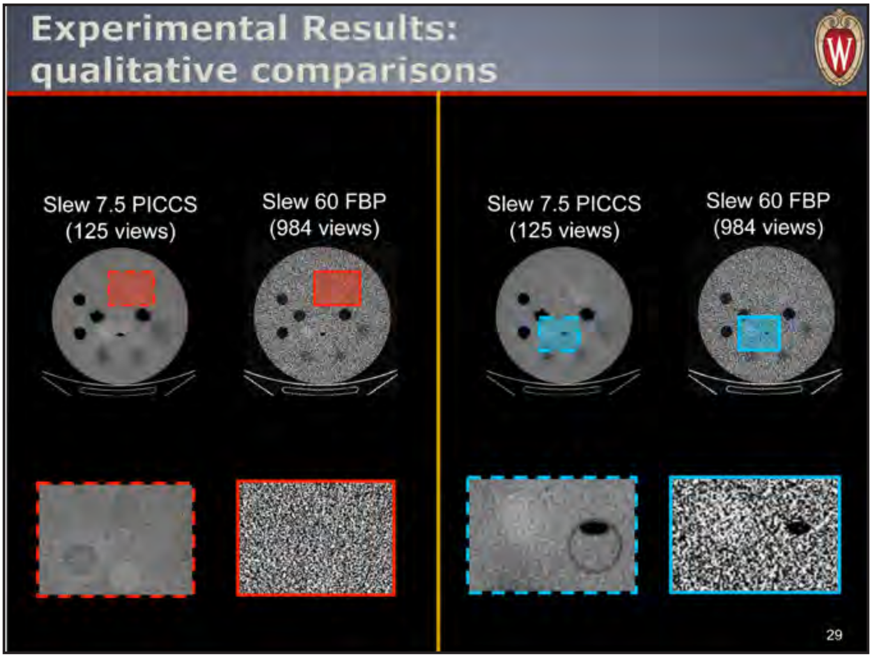


Experimental section: material density image results

60 kV/view 30 kV/view 15 kV/view 7.5 kV/view 4 kV/view

PICCS water

FBP water



Experimental Results: qualitative comparisons

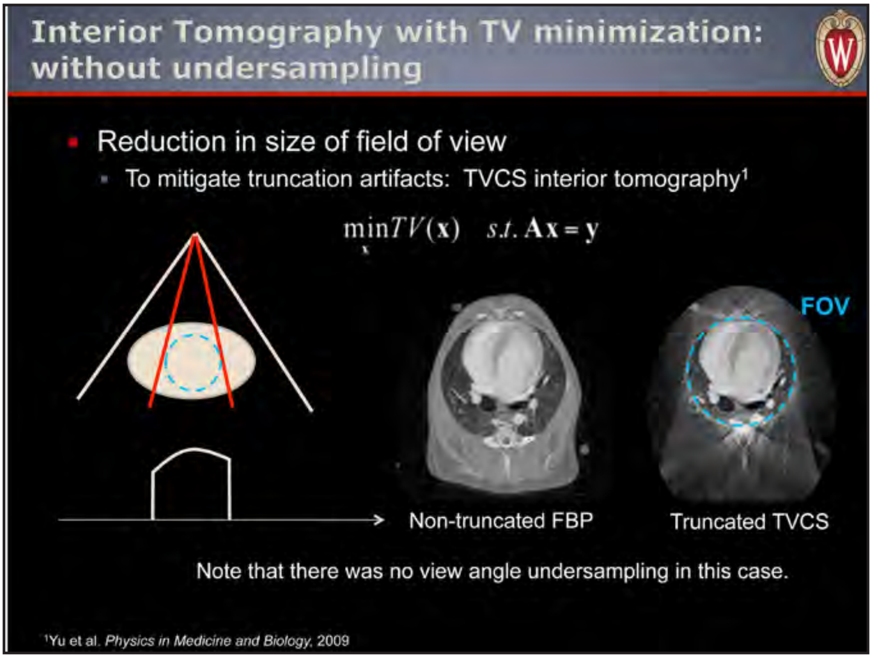
Slew 7.5 PICCS
(125 views)

Slew 60 FBP
(984 views)

Slew 7.5 PICCS
(125 views)

Slew 60 FBP
(984 views)

29



Interior Tomography with TV minimization: without undersampling

- Reduction in size of field of view
  - To mitigate truncation artifacts: TVCS interior tomography[1]

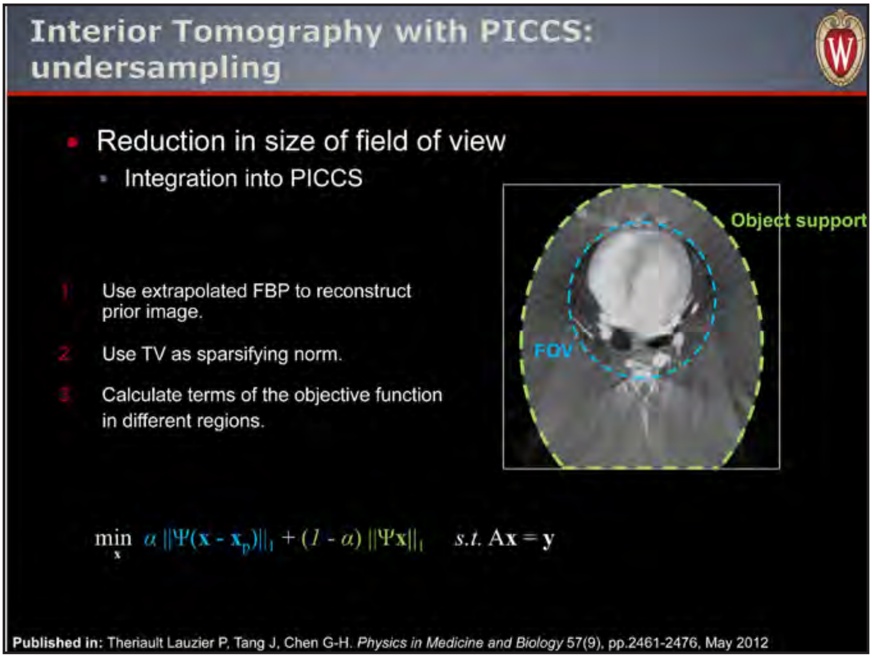
$$\min_{\mathbf{x}} TV(\mathbf{x}) \quad s.t.\ \mathbf{Ax} = \mathbf{y}$$

Non-truncated FBP

Truncated TVCS

Note that there was no view angle undersampling in this case.

[1] Yu et al. *Physics in Medicine and Biology*, 2009



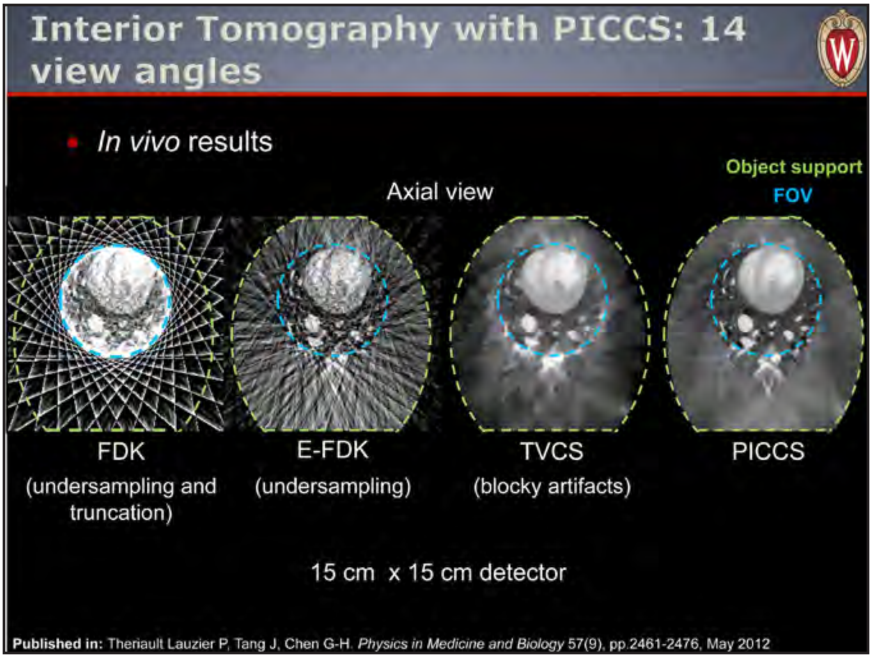
Interior Tomography with PICCS: undersampling

- Reduction in size of field of view
  - Integration into PICCS

1. Use extrapolated FBP to reconstruct prior image.
2. Use TV as sparsifying norm.
3. Calculate terms of the objective function in different regions.

$$\min_{\mathbf{x}} \ \alpha \, \|\Psi(\mathbf{x} - \mathbf{x}_p)\|_1 + (1 - \alpha) \, \|\Psi\mathbf{x}\|_1 \qquad s.t.\ \mathbf{A}\mathbf{x} = \mathbf{y}$$

Published in: Theriault Lauzier P, Tang J, Chen G-H. *Physics in Medicine and Biology* 57(9), pp.2461-2476, May 2012



Interior Tomography with PICCS: 14 view angles

- *In vivo* results

Axial view

FDK (undersampling and truncation)

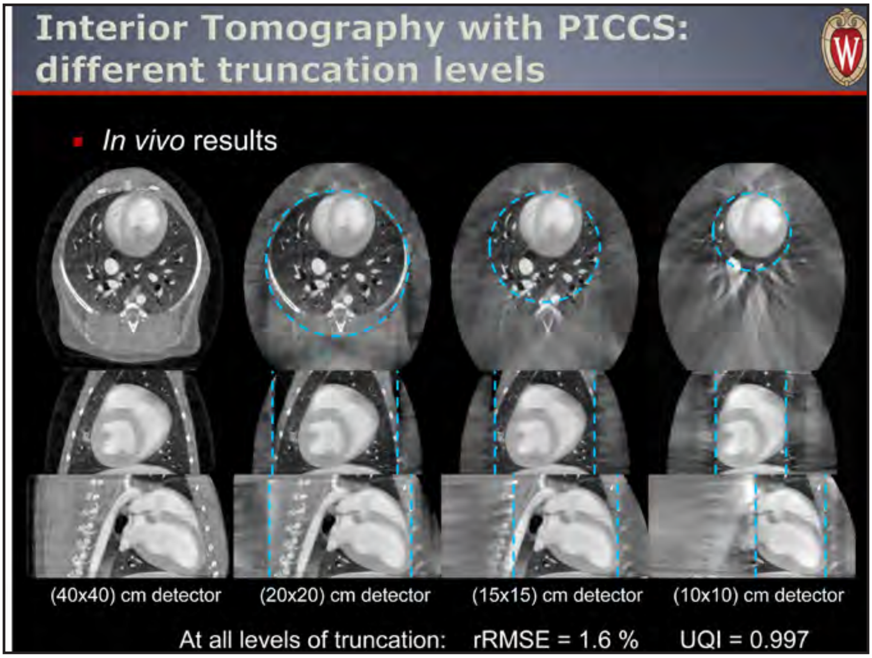
E-FDK (undersampling)

TVCS (blocky artifacts)

PICCS

15 cm x 15 cm detector

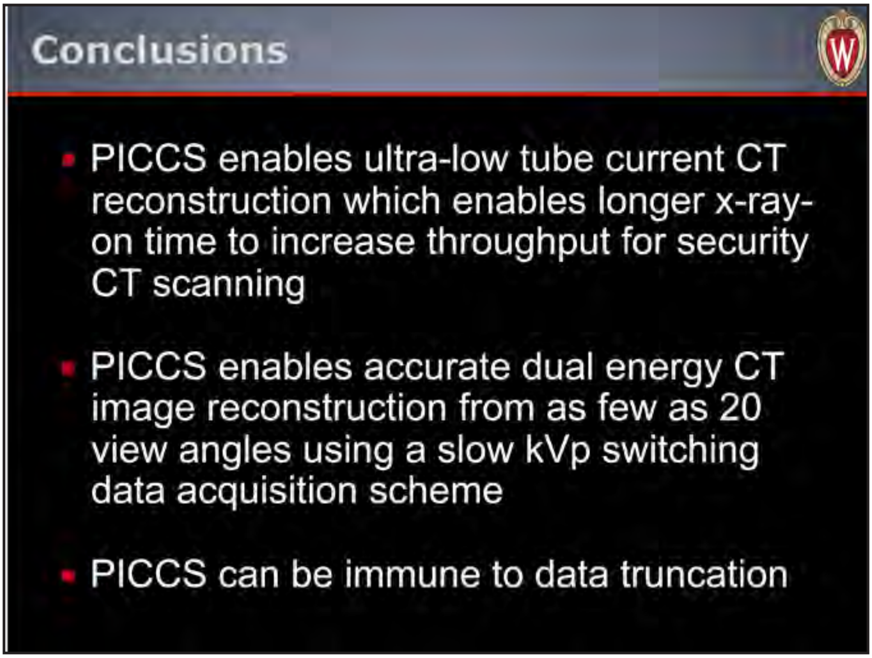
Published in: Theriault Lauzier P, Tang J, Chen G-H. *Physics in Medicine and Biology* 57(9), pp.2461-2476, May 2012



Interior Tomography with PICCS: different truncation levels

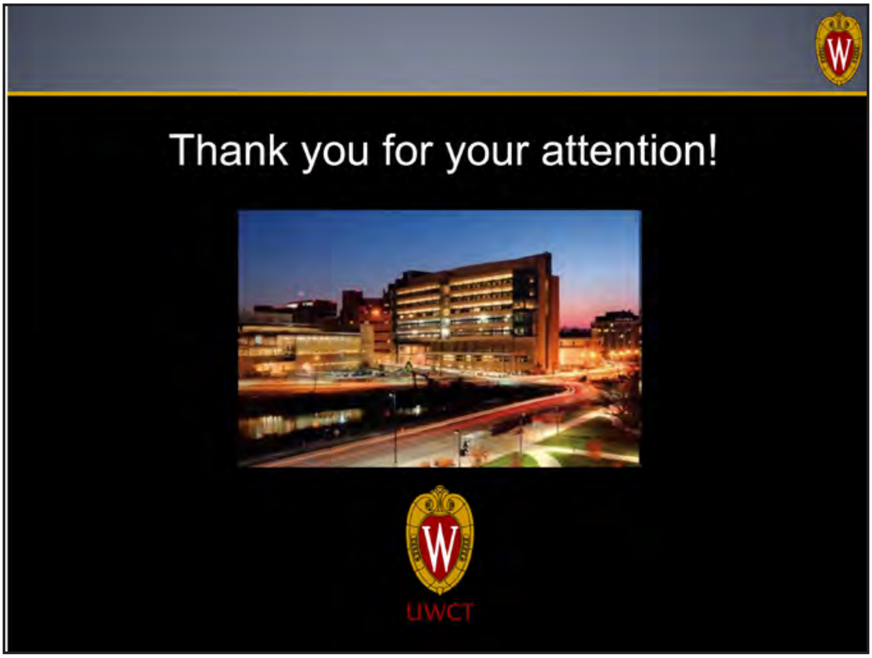
- *In vivo* results

At all levels of truncation: rRMSE = 1.6 % UQI = 0.997



Conclusions

- PICCS enables ultra-low tube current CT reconstruction which enables longer x-ray-on time to increase throughput for security CT scanning
- PICCS enables accurate dual energy CT image reconstruction from as few as 20 view angles using a slow kVp switching data acquisition scheme
- PICCS can be immune to data truncation



Thank you for your attention!

UWCT

16.8 Patrick La Riviere: Sinogram restoration for computed tomography

Sinogram restoration for computed tomography

ADSA07 Workshop
Boston, MA
May 15, 2012

Patrick La Rivière, Ph.D.
Associate Professor
Department of Radiology
The University of Chicago

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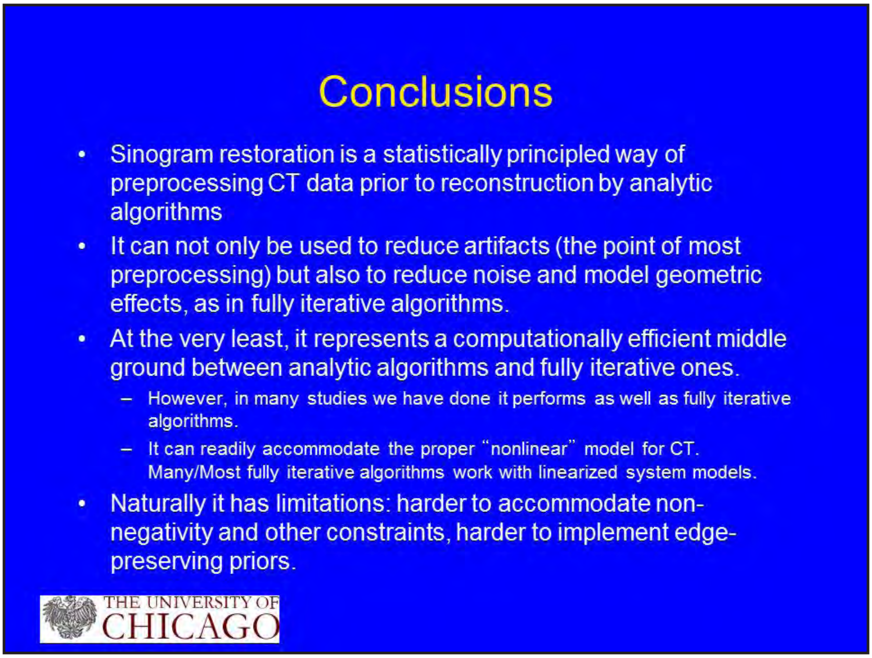
Supported by
NIH R01CA134680



Conclusions

- Sinogram restoration is a statistically principled way of preprocessing CT data prior to reconstruction by analytic algorithms
- It can not only be used to reduce artifacts (the point of most preprocessing) but also to reduce noise and model geometric effects, as in fully iterative algorithms.
- At the very least, it represents a computationally efficient middle ground between analytic algorithms and fully iterative ones.
    - However, in many studies we have done it performs as well as fully iterative algorithms.
    - It can readily accommodate the proper "nonlinear" model for CT. Many/Most fully iterative algorithms work with linearized system models.
- Naturally it has limitations: harder to accommodate non-negativity and other constraints, harder to implement edge-preserving priors.

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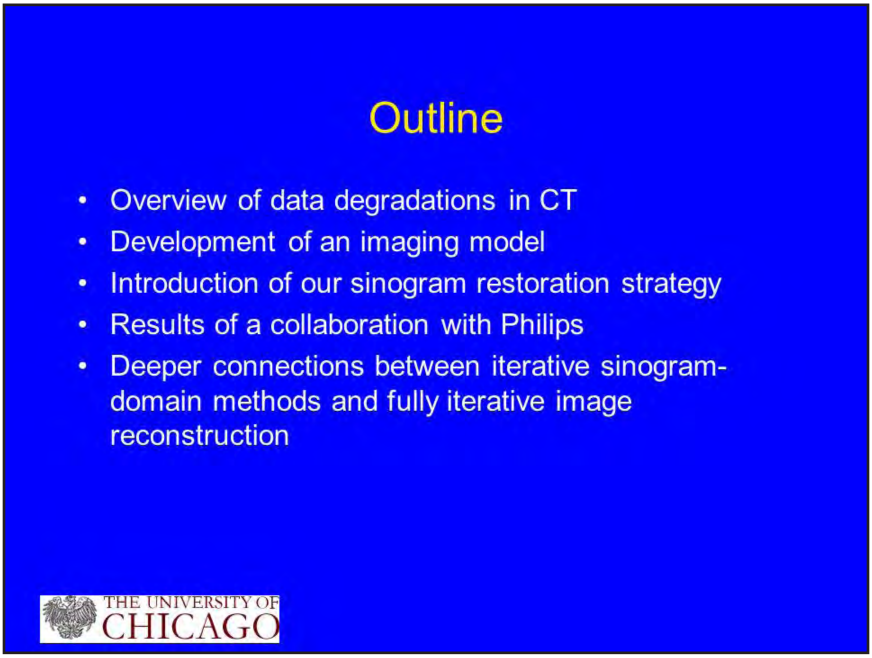

Outline

- Overview of data degradations in CT
- Development of an imaging model
- Introduction of our sinogram restoration strategy
- Results of a collaboration with Philips
- Deeper connections between iterative sinogram-domain methods and fully iterative image reconstruction

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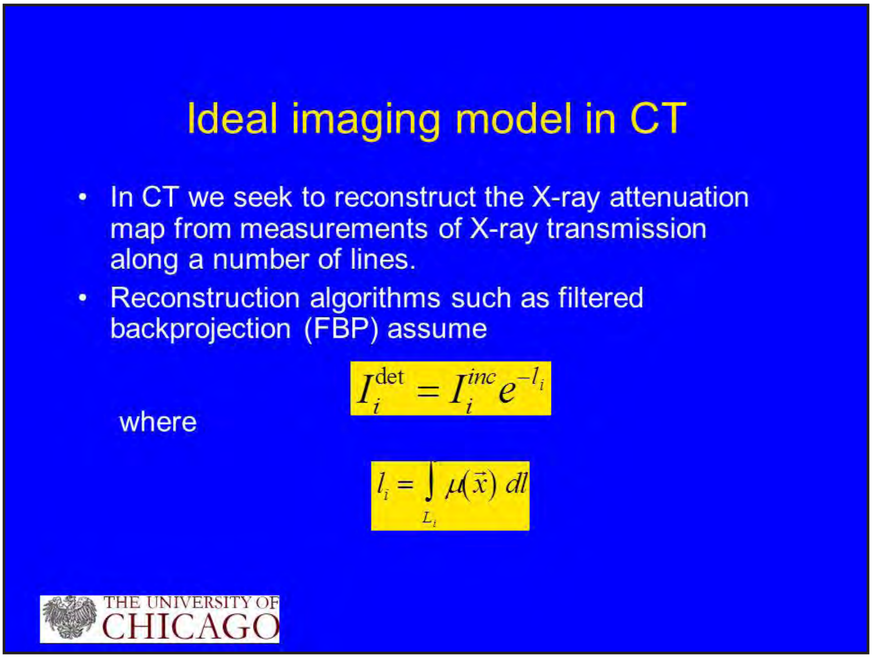

Ideal imaging model in CT

- In CT we seek to reconstruct the X-ray attenuation map from measurements of X-ray transmission along a number of lines.
- Reconstruction algorithms such as filtered backprojection (FBP) assume

$$I_i^{\det} = I_i^{inc} e^{-l_i}$$

where

$$l_i = \int_{L_i} \mu(\vec{x})\, dl$$

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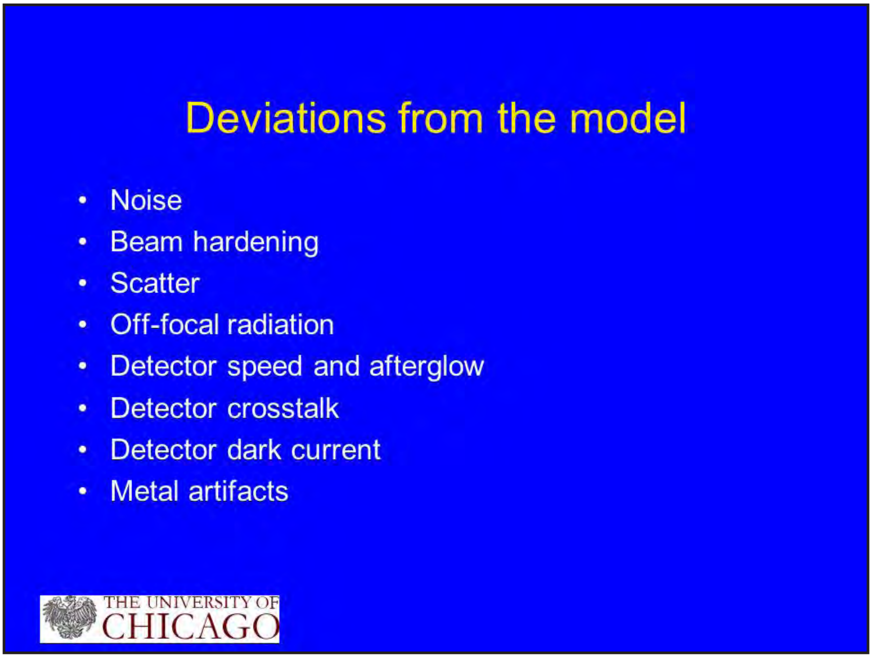

Deviations from the model

- Noise
- Beam hardening
- Scatter
- Off-focal radiation
- Detector speed and afterglow
- Detector crosstalk
- Detector dark current
- Metal artifacts

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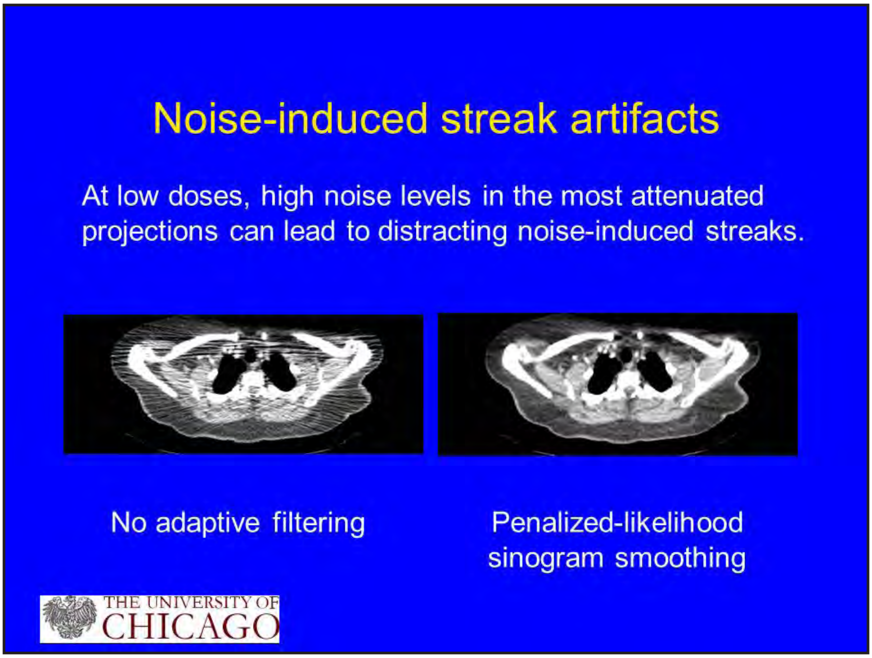

Noise-induced streak artifacts

At low doses, high noise levels in the most attenuated projections can lead to distracting noise-induced streaks.

No adaptive filtering

Penalized-likelihood sinogram smoothing

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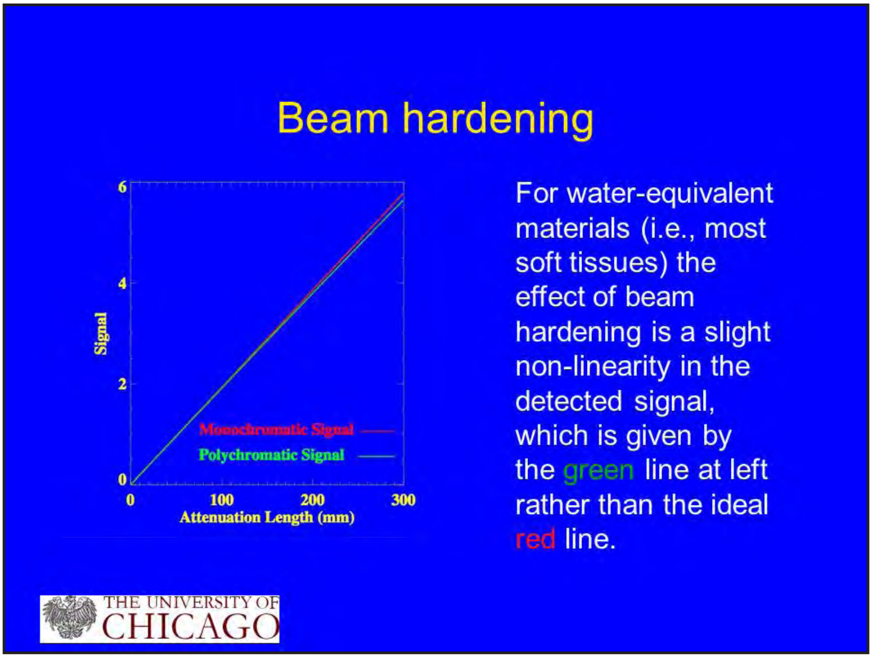
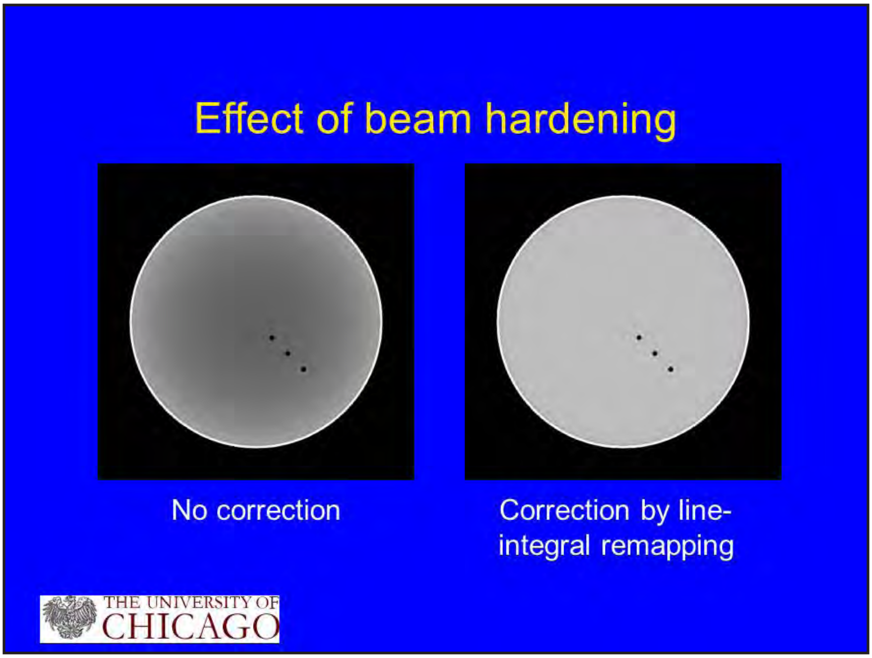


Beam hardening

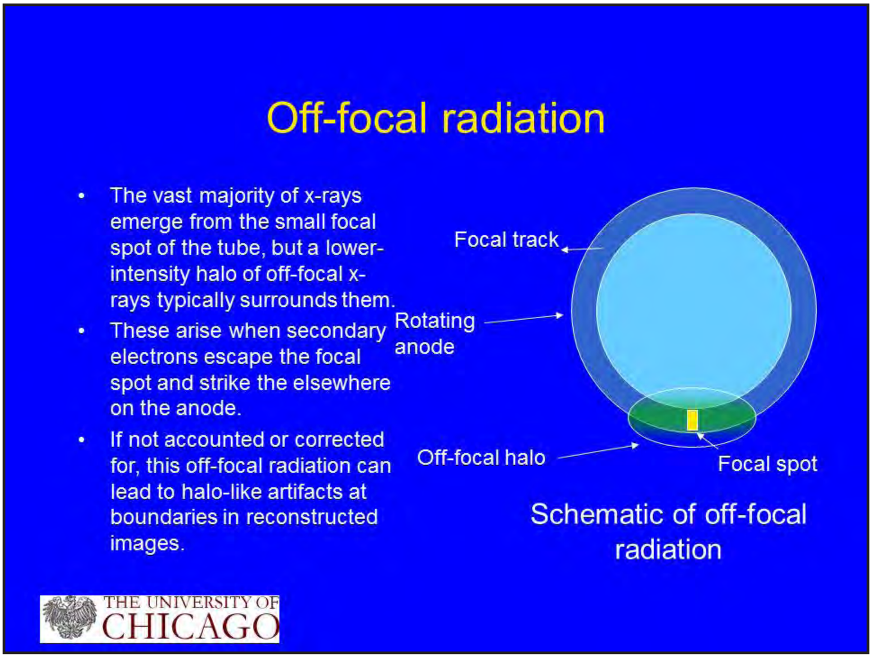
For water-equivalent materials (i.e., most soft tissues) the effect of beam hardening is a slight non-linearity in the detected signal, which is given by the green line at left rather than the ideal red line.



Effect of beam hardening

No correction

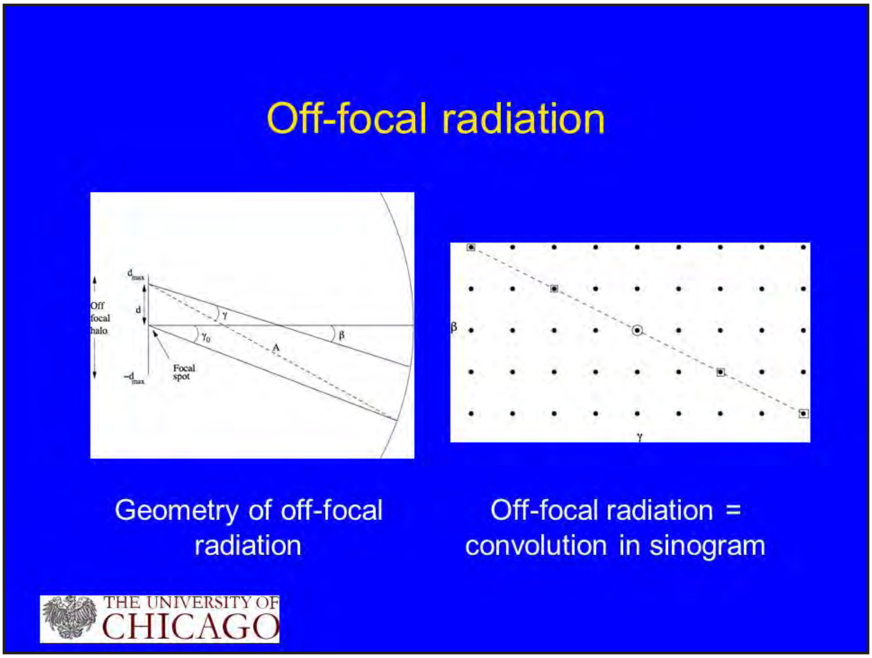
Correction by line-integral remapping



Off-focal radiation

- The vast majority of x-rays emerge from the small focal spot of the tube, but a lower-intensity halo of off-focal x-rays typically surrounds them.
- These arise when secondary electrons escape the focal spot and strike the elsewhere on the anode.
- If not accounted or corrected for, this off-focal radiation can lead to halo-like artifacts at boundaries in reconstructed images.

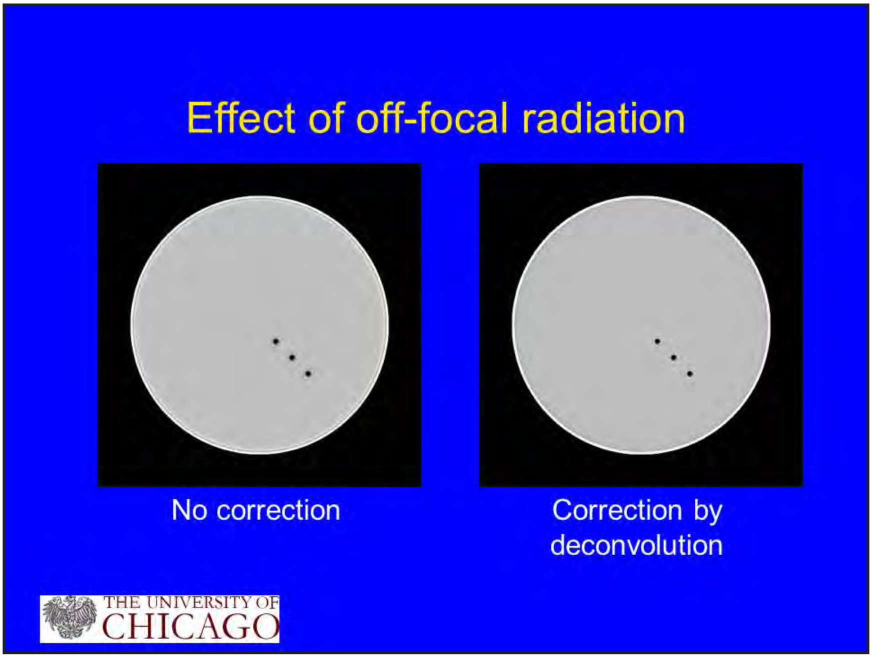
Schematic of off-focal radiation



Off-focal radiation

Geometry of off-focal radiation

Off-focal radiation = convolution in sinogram



Effect of off-focal radiation

No correction

Correction by deconvolution

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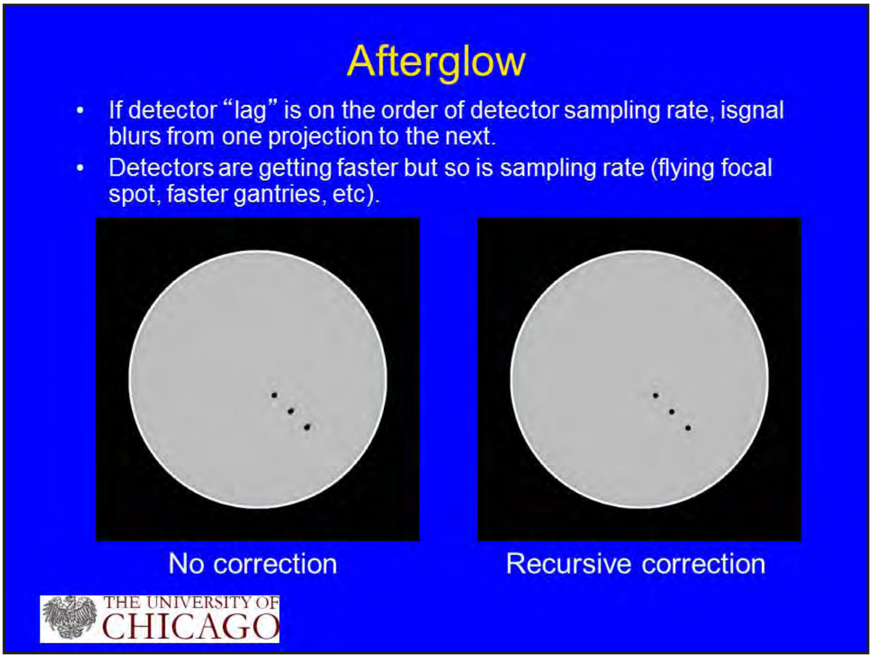

Afterglow

- If detector “lag” is on the order of detector sampling rate, isgnal blurs from one projection to the next.
- Detectors are getting faster but so is sampling rate (flying focal spot, faster gantries, etc).

No correction

Recursive correction

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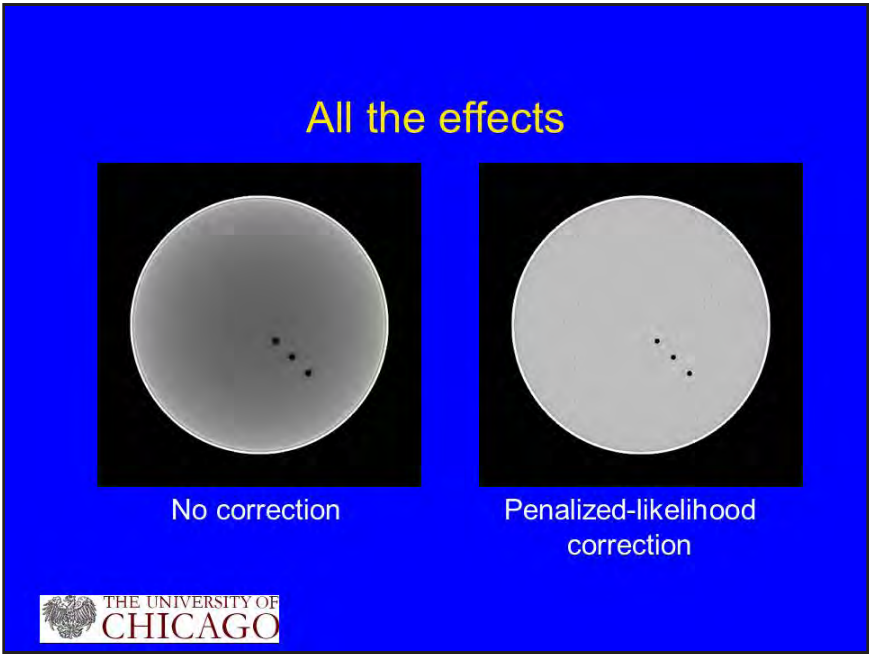

All the effects

No correction

Penalized-likelihood correction

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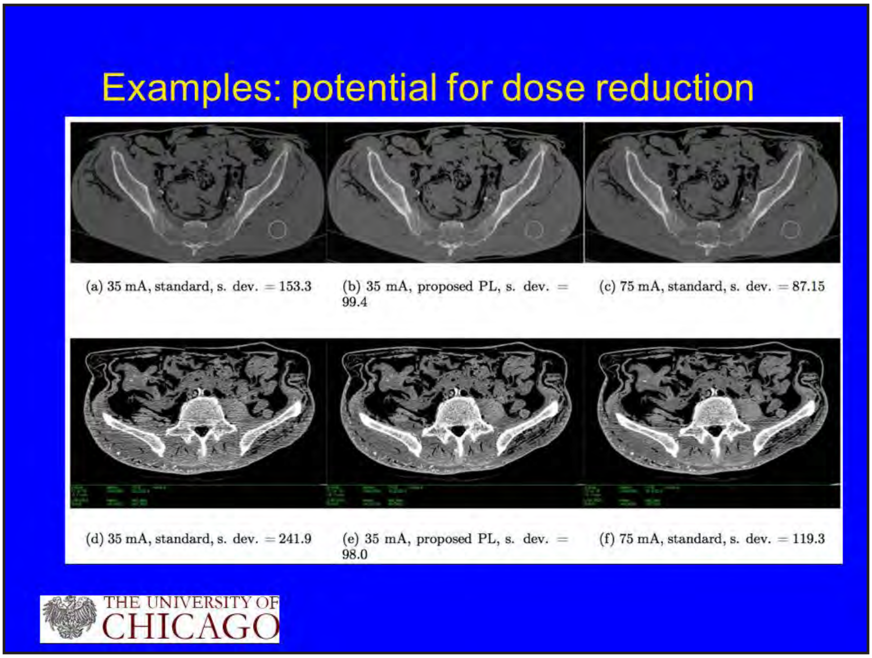

Examples: potential for dose reduction

(a) 35 mA, standard, s. dev. = 153.3

(b) 35 mA, proposed PL, s. dev. = 99.4

(c) 75 mA, standard, s. dev. = 87.15

(d) 35 mA, standard, s. dev. = 241.9

(e) 35 mA, proposed PL, s. dev. = 98.0

(f) 75 mA, standard, s. dev. = 119.3

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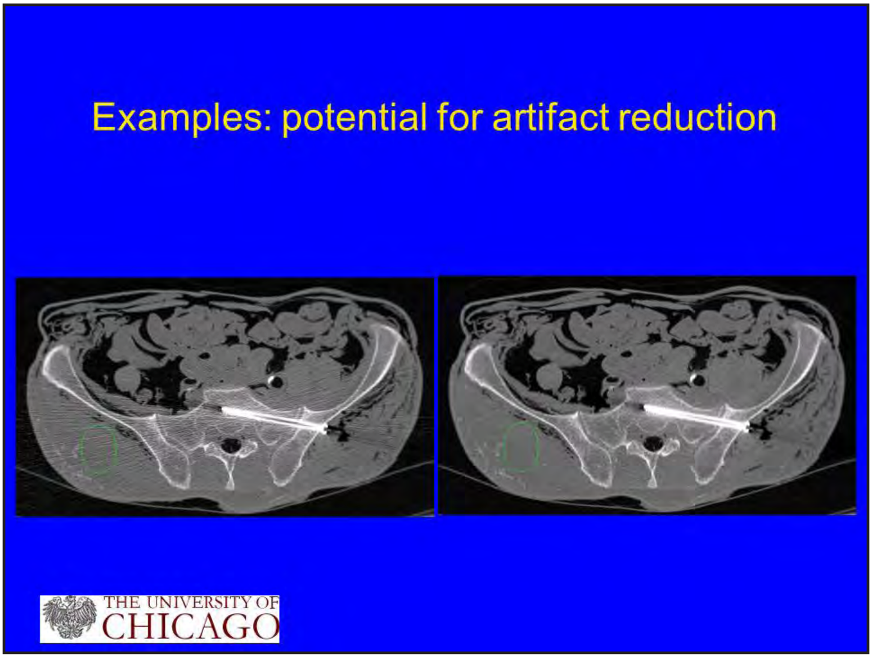
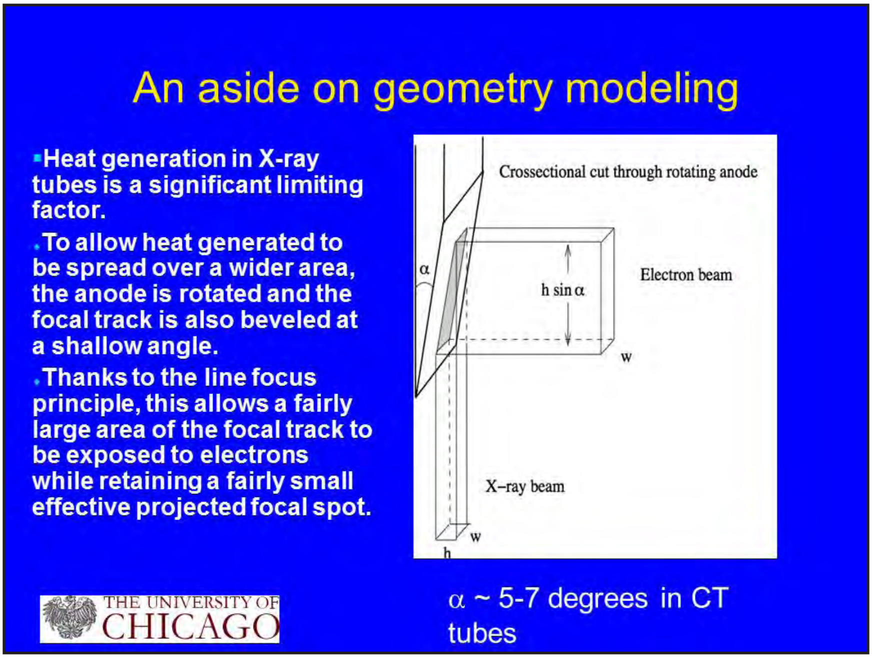


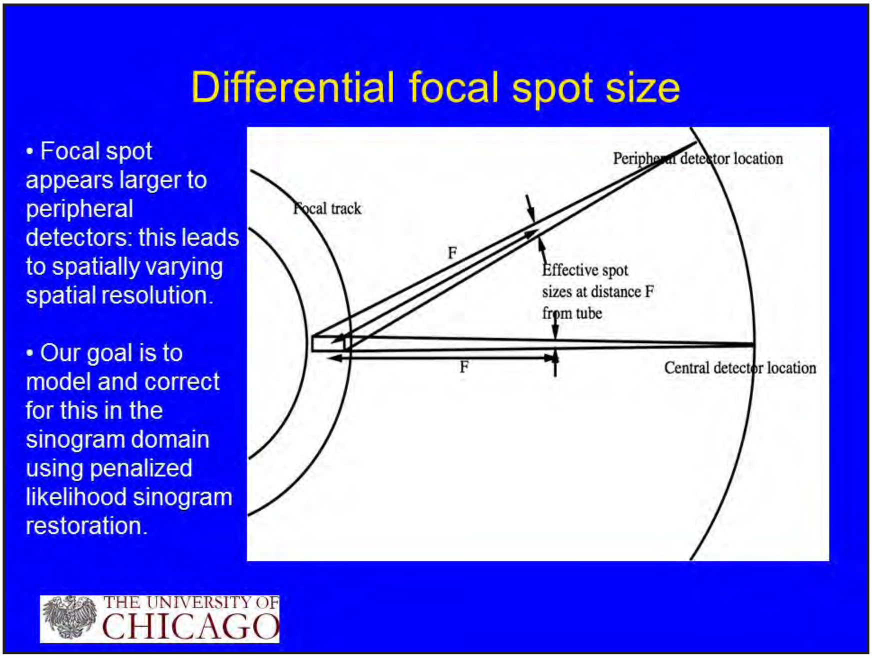
Examples: potential for artifact reduction



An aside on geometry modeling

- Heat generation in X-ray tubes is a significant limiting factor.
- To allow heat generated to be spread over a wider area, the anode is rotated and the focal track is also beveled at a shallow angle.
- Thanks to the line focus principle, this allows a fairly large area of the focal track to be exposed to electrons while retaining a fairly small effective projected focal spot.

α ~ 5-7 degrees in CT tubes



Differential focal spot size

- Focal spot appears larger to peripheral detectors: this leads to spatially varying spatial resolution.
- Our goal is to model and correct for this in the sinogram domain using penalized likelihood sinogram restoration.

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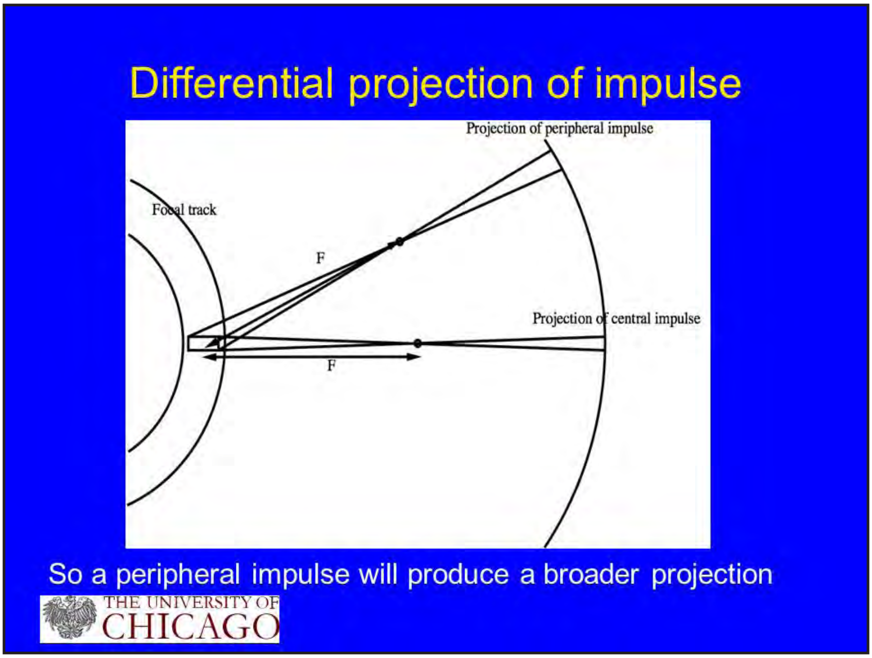

Differential projection of impulse

So a peripheral impulse will produce a broader projection

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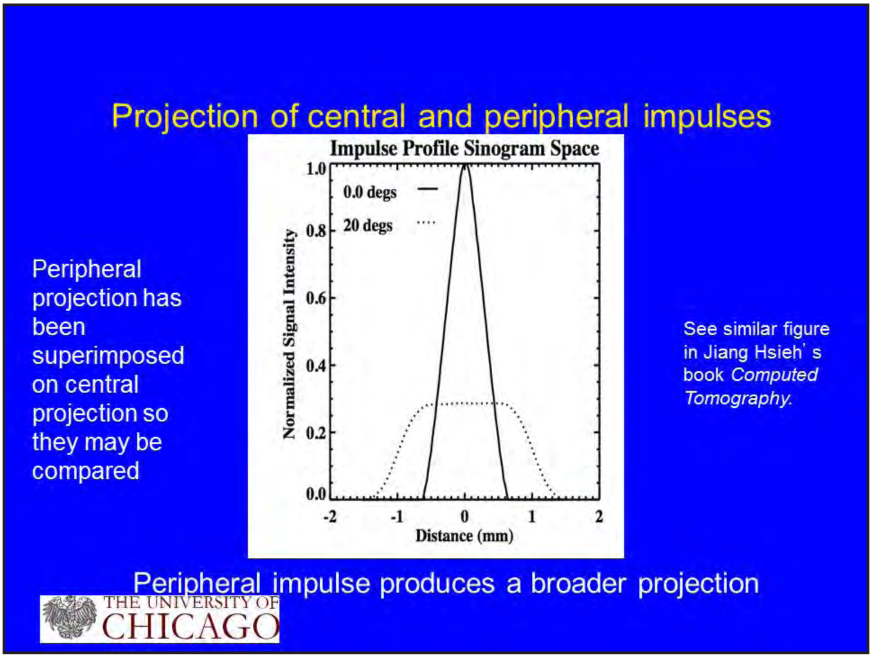

Projection of central and peripheral impulses

Peripheral projection has been superimposed on central projection so they may be compared

See similar figure in Jiang Hsieh's book *Computed Tomography.*

Peripheral impulse produces a broader projection

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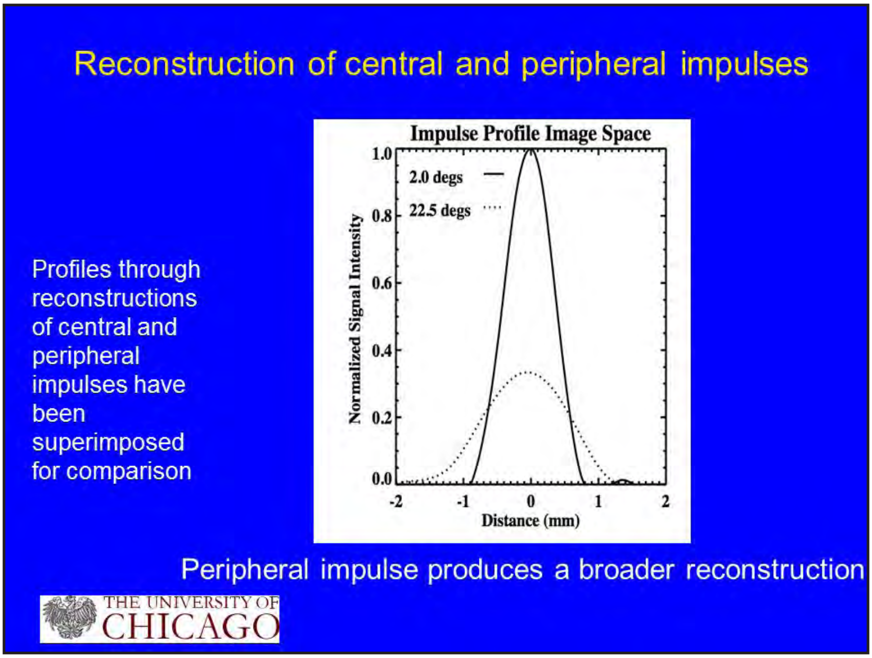

Reconstruction of central and peripheral impulses

Profiles through reconstructions of central and peripheral impulses have been superimposed for comparison

Peripheral impulse produces a broader reconstruction

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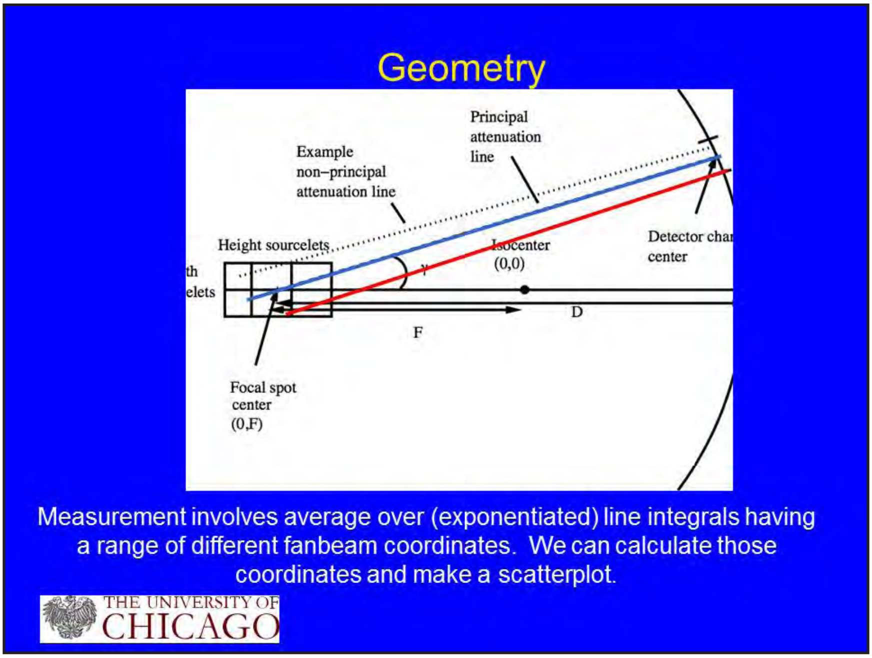

Geometry

Measurement involves average over (exponentiated) line integrals having a range of different fanbeam coordinates. We can calculate those coordinates and make a scatterplot.

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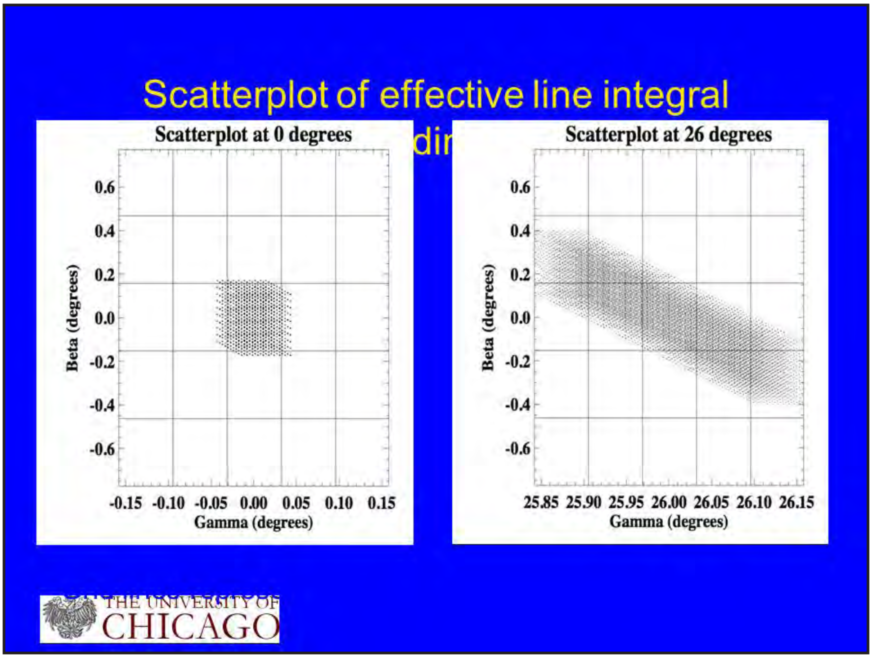

Scatterplot of effective line integral dir

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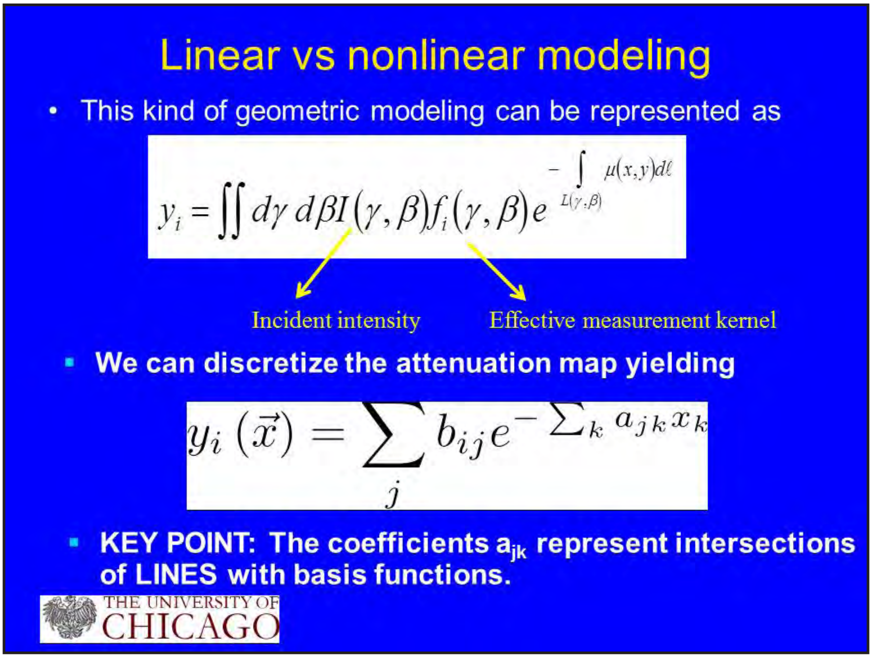

Linear vs nonlinear modeling

- This kind of geometric modeling can be represented as

$$y_i = \iint d\gamma \, d\beta I(\gamma,\beta) f_i(\gamma,\beta) e^{-\int_{L(\gamma,\beta)} \mu(x,y) d\ell}$$

Incident intensity

Effective measurement kernel

- **We can discretize the attenuation map yielding**

$$y_i(\vec{x}) = \sum_j b_{ij} e^{-\sum_k a_{jk} x_k}$$

- **KEY POINT: The coefficients a_{jk} represent intersections of LINES with basis functions.**

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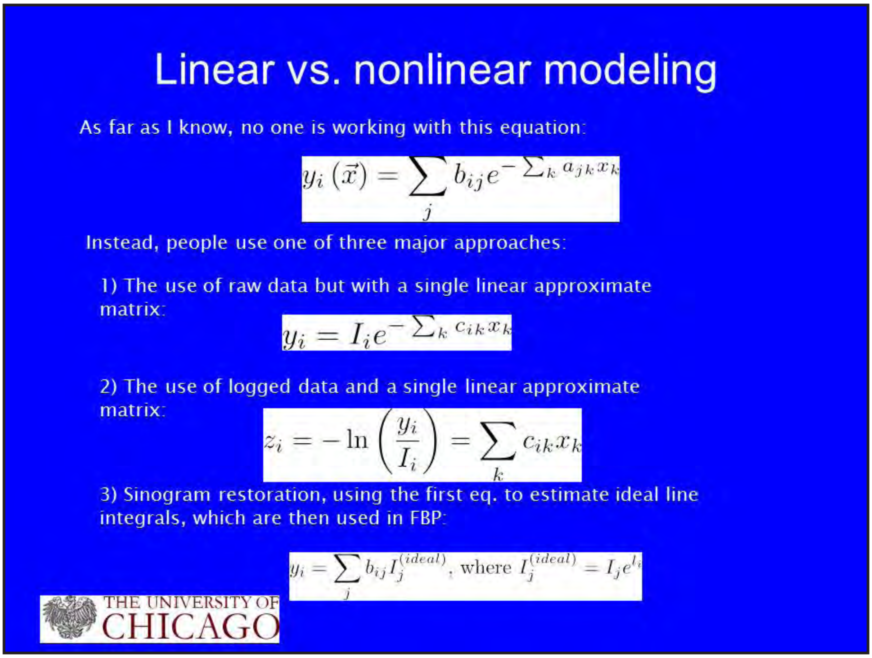

Linear vs. nonlinear modeling

As far as I know, no one is working with this equation:

$$y_i(\vec{x}) = \sum_j b_{ij} e^{-\sum_k a_{jk} x_k}$$

Instead, people use one of three major approaches:

1) The use of raw data but with a single linear approximate matrix:

$$y_i = I_i e^{-\sum_k c_{ik} x_k}$$

2) The use of logged data and a single linear approximate matrix:

$$z_i = -\ln\left(\frac{y_i}{I_i}\right) = \sum_k c_{ik} x_k$$

3) Sinogram restoration, using the first eq. to estimate ideal line integrals, which are then used in FBP:

$$y_i = \sum_j b_{ij} I_j^{(ideal)}, \text{ where } I_j^{(ideal)} = I_j e^{l_i}$$

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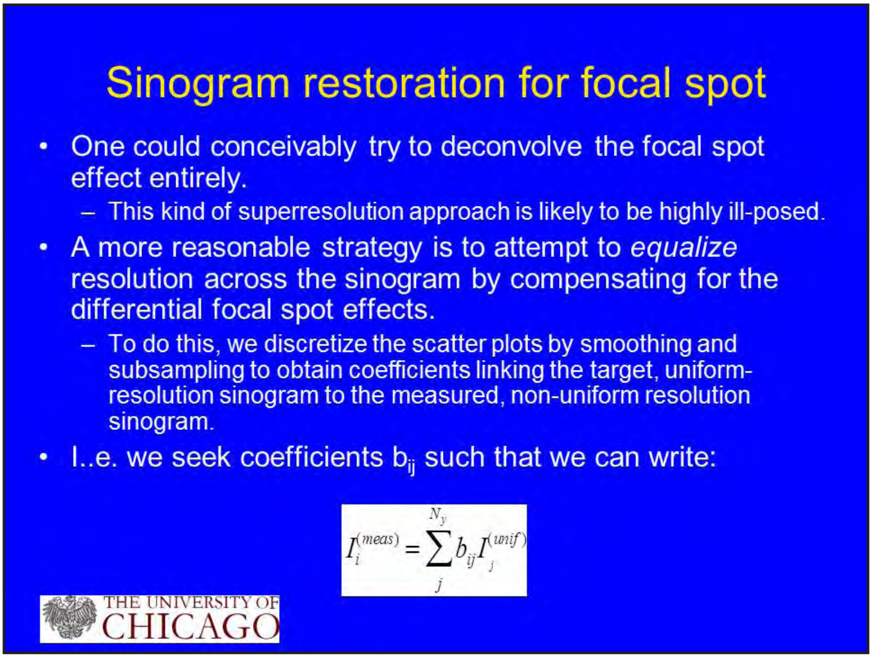

Sinogram restoration for focal spot

- One could conceivably try to deconvolve the focal spot effect entirely.
  - This kind of superresolution approach is likely to be highly ill-posed.
- A more reasonable strategy is to attempt to *equalize* resolution across the sinogram by compensating for the differential focal spot effects.
  - To do this, we discretize the scatter plots by smoothing and subsampling to obtain coefficients linking the target, uniform-resolution sinogram to the measured, non-uniform resolution sinogram.
- I..e. we seek coefficients b_{ij} such that we can write:

$$I_i^{(meas)} = \sum_j^{N_y} b_{ij} I_j^{(unif)}$$

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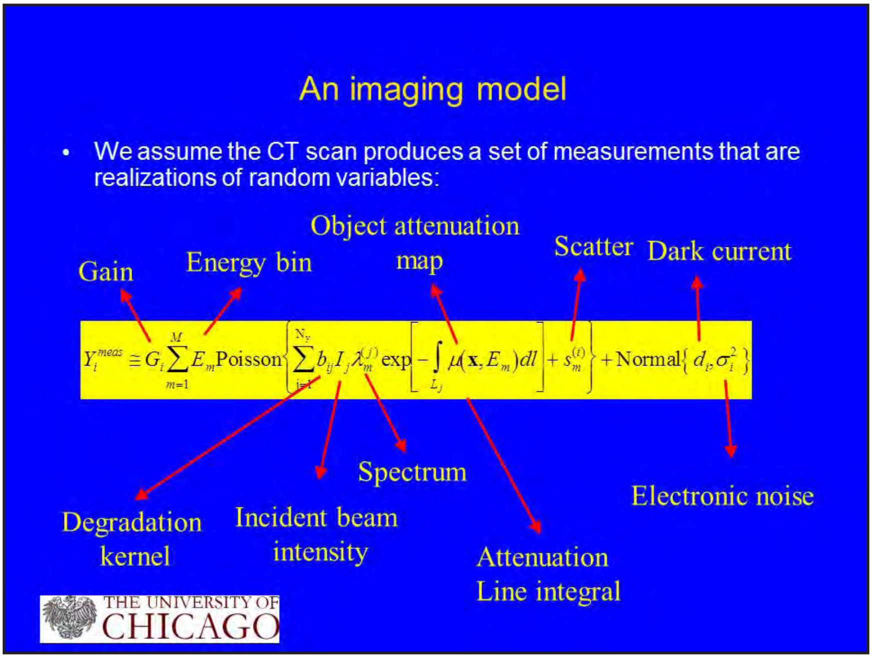

An imaging model

- We assume the CT scan produces a set of measurements that are realizations of random variables:

$$Y_i^{meas} \cong G_i \sum_{m=1}^{M} E_m \text{Poisson}\left\{ \sum_{j=1}^{N_y} b_{ij} I_j \lambda_m^{(j)} \exp\left[-\int_{L_j} \mu(\mathbf{x}, E_m) dl \right] + s_m^{(i)} \right\} + \text{Normal}\{ d_i, \sigma_i^2 \}$$

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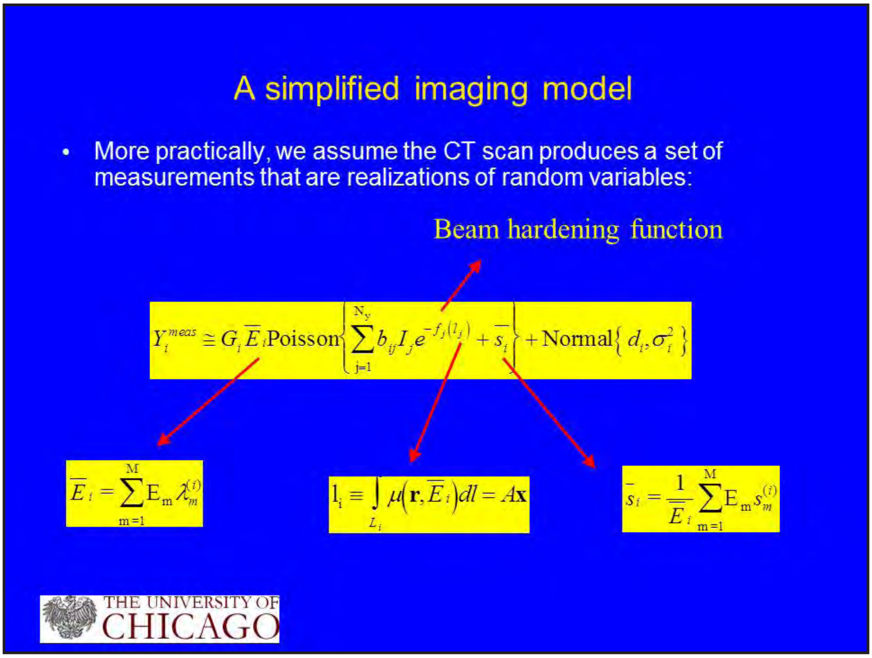

A simplified imaging model

- More practically, we assume the CT scan produces a set of measurements that are realizations of random variables:

Beam hardening function

$$Y_i^{meas} \cong G_i \overline{E}_i \text{Poisson}\left\{ \sum_{j=1}^{N_y} b_{ij} I_j e^{-f_j(l_j)} + \overline{s}_i \right\} + \text{Normal}\left\{ d_i, \sigma_i^2 \right\}$$

$$\overline{E}_i = \sum_{m=1}^{M} \text{E}_m \lambda_m^{(i)}$$

$$\text{l}_i \equiv \int_{L_i} \mu(\mathbf{r}, \overline{E}_i) dl = A\mathbf{x}$$

$$\overline{s}_i = \frac{1}{\overline{E}_i} \sum_{m=1}^{M} \text{E}_m s_m^{(i)}$$

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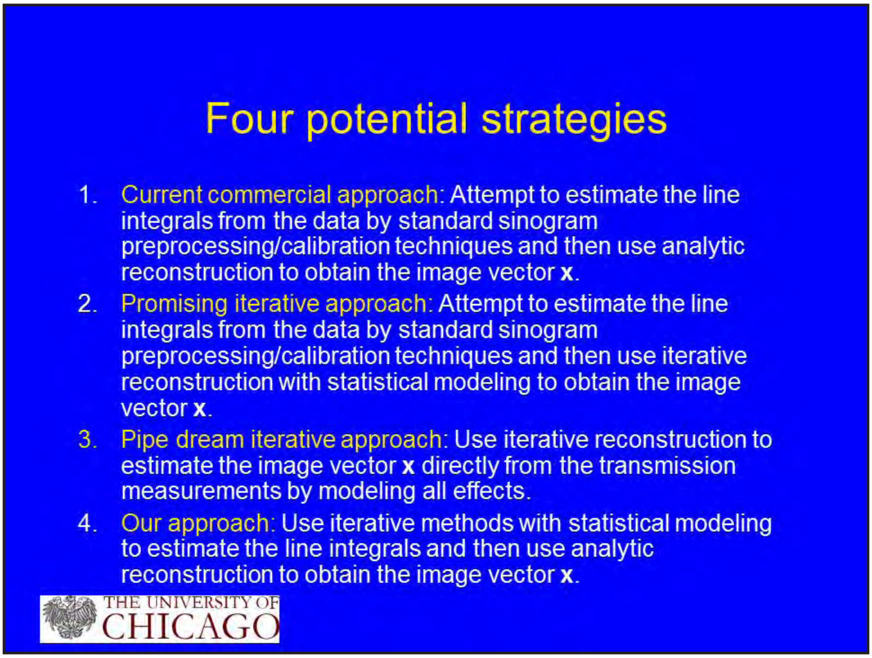

Four potential strategies

1. Current commercial approach: Attempt to estimate the line integrals from the data by standard sinogram preprocessing/calibration techniques and then use analytic reconstruction to obtain the image vector **x**.
2. Promising iterative approach: Attempt to estimate the line integrals from the data by standard sinogram preprocessing/calibration techniques and then use iterative reconstruction with statistical modeling to obtain the image vector **x**.
3. Pipe dream iterative approach: Use iterative reconstruction to estimate the image vector **x** directly from the transmission measurements by modeling all effects.
4. Our approach: Use iterative methods with statistical modeling to estimate the line integrals and then use analytic reconstruction to obtain the image vector **x**.

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Our approach to sinogram processing

- We have formulated CT sinogram preprocessing as a statistical restoration problem.
  - The goal is to estimate as accurately as possible the attenuation line integrals needed for reconstruction from the set of noisy, degraded measurements.
  - We do so by maximizing a penalized-likelihood objective function.
  - Reconstruction is then done by use of existing methods.
- The hope is that one could achieve reduced noise and artifact levels relative to existing approaches, especially in low-dose and non-contrast scans.

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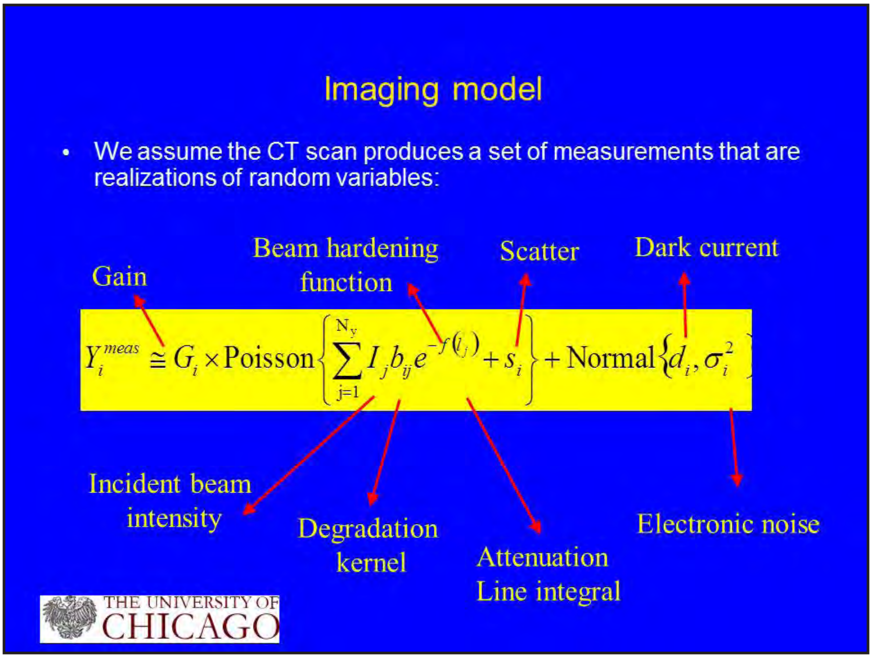

Imaging model

- We assume the CT scan produces a set of measurements that are realizations of random variables:

$$Y_i^{meas} \cong G_i \times \text{Poisson}\left\{\sum_{j=1}^{N_y} I_j b_{ij} e^{-f(l_j)} + s_i\right\} + \text{Normal}\left\{d_i, \sigma_i^2\right\}$$

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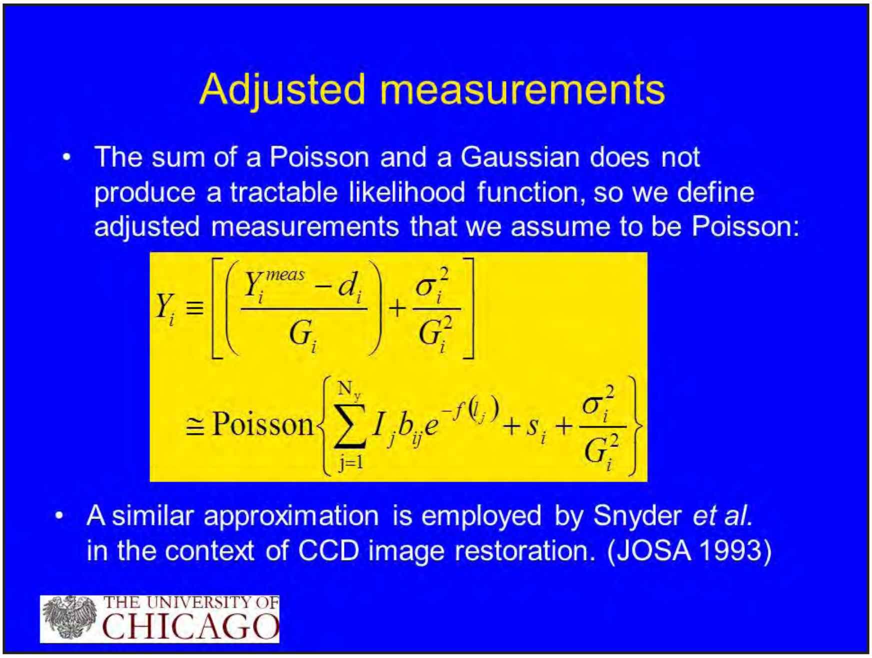

Adjusted measurements

- The sum of a Poisson and a Gaussian does not produce a tractable likelihood function, so we define adjusted measurements that we assume to be Poisson:

$$Y_i \equiv \left[\left(\frac{Y_i^{meas} - d_i}{G_i}\right) + \frac{\sigma_i^2}{G_i^2}\right]$$

$$\cong \text{Poisson}\left\{\sum_{j=1}^{N_y} I_j b_{ij} e^{-f(l_j)} + s_i + \frac{\sigma_i^2}{G_i^2}\right\}$$

- A similar approximation is employed by Snyder *et al.* in the context of CCD image restoration. (JOSA 1993)

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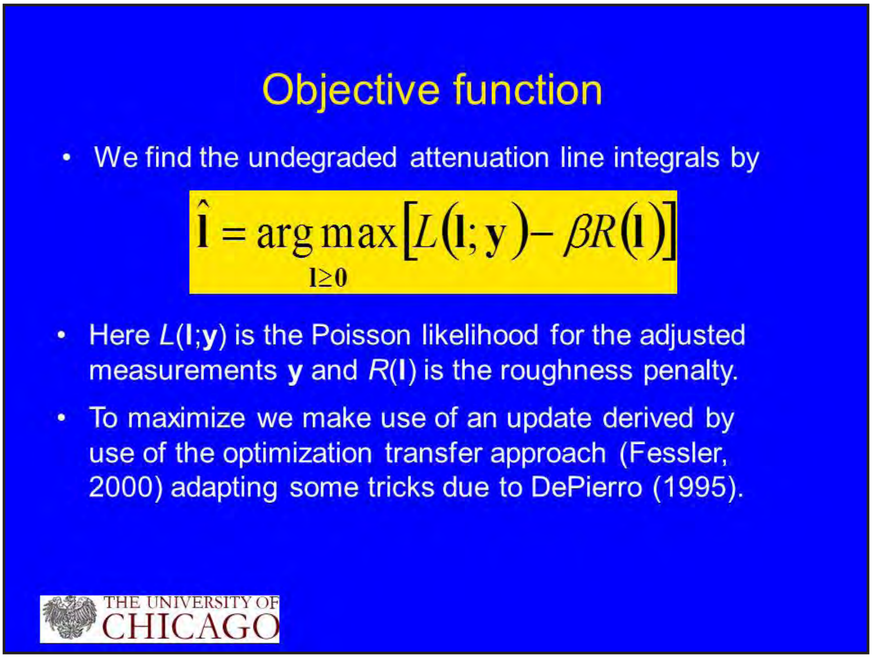

Objective function

- We find the undegraded attenuation line integrals by

$$\hat{\mathbf{l}} = \arg\max_{\mathbf{l} \geq 0} \left[L(\mathbf{l}; \mathbf{y}) - \beta R(\mathbf{l})\right]$$

- Here $L(\mathbf{l};\mathbf{y})$ is the Poisson likelihood for the adjusted measurements **y** and $R(\mathbf{l})$ is the roughness penalty.
- To maximize we make use of an update derived by use of the optimization transfer approach (Fessler, 2000) adapting some tricks due to DePierro (1995).

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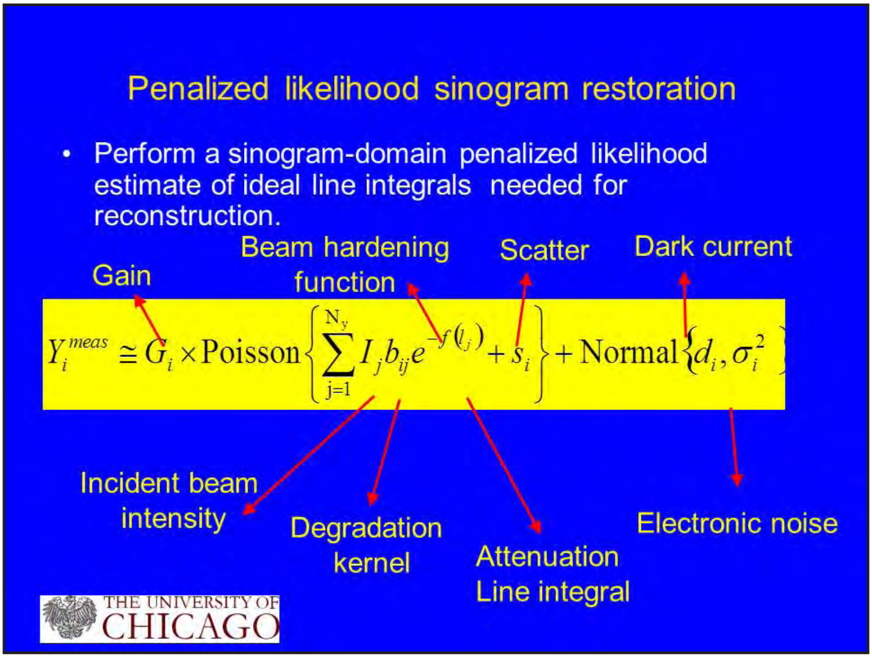

Penalized likelihood sinogram restoration

- Perform a sinogram-domain penalized likelihood estimate of ideal line integrals needed for reconstruction.

Gain

Beam hardening function

Scatter

Dark current

$$Y_i^{meas} \cong G_i \times \text{Poisson}\left\{\sum_{j=1}^{N_y} I_j b_{ij} e^{-f(l_j)} + s_i\right\} + \text{Normal}\left\{d_i, \sigma_i^2\right\}$$

Incident beam intensity

Degradation kernel

Attenuation Line integral

Electronic noise

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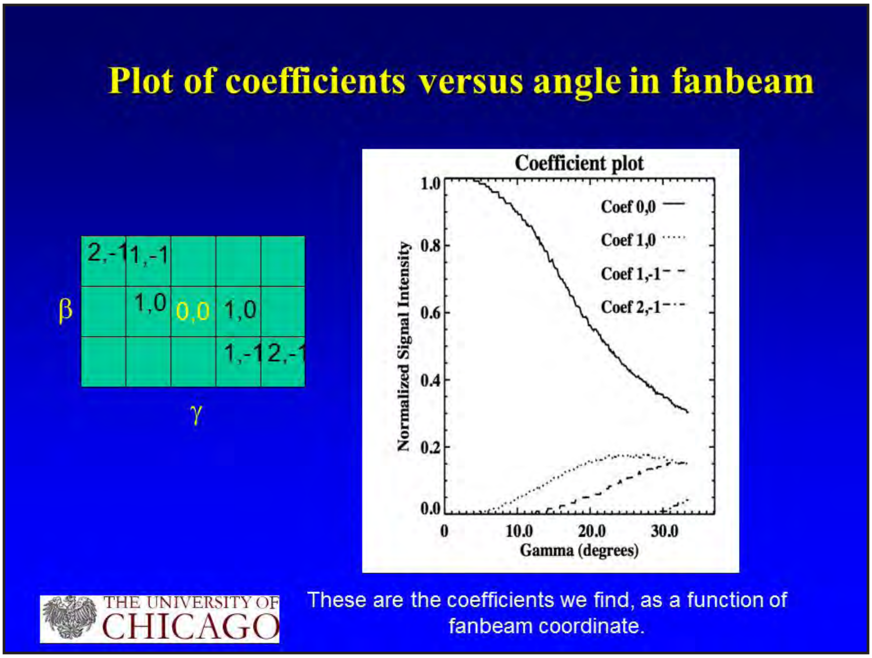

Plot of coefficients versus angle in fanbeam

β				
2,-1	1,-1			
	1,0	0,0	1,0	
			1,-1	2,-1

γ

These are the coefficients we find, as a function of fanbeam coordinate.

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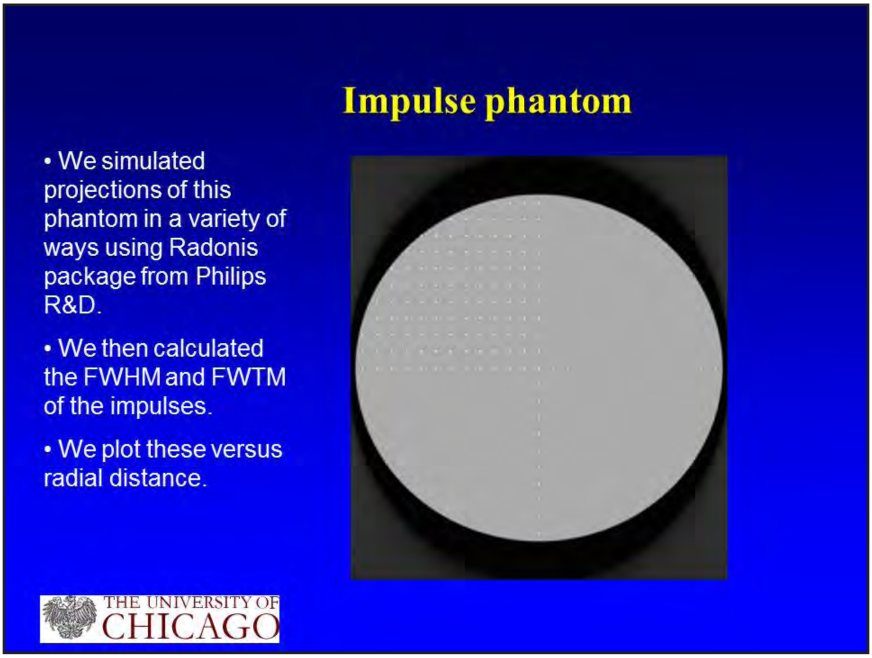
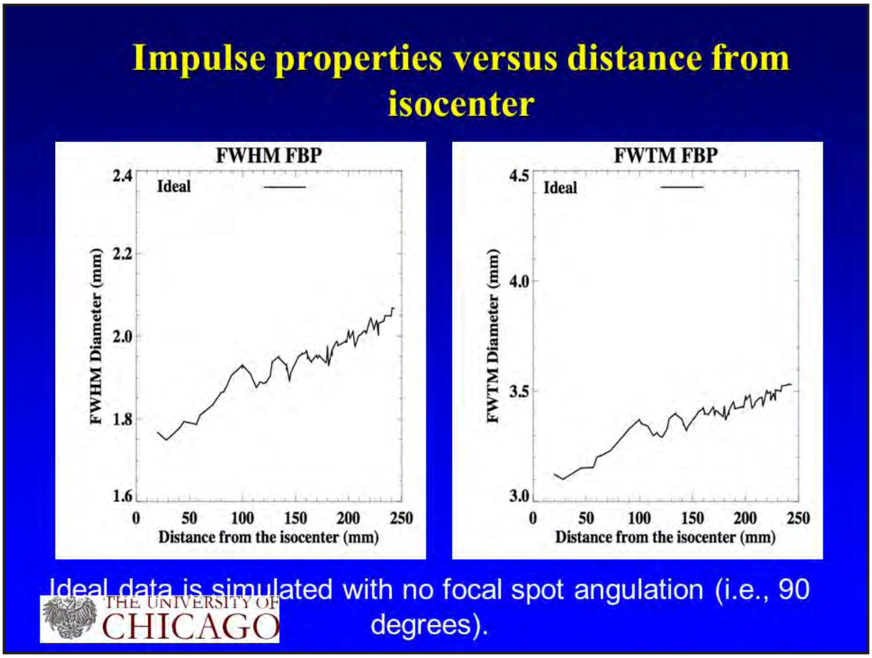


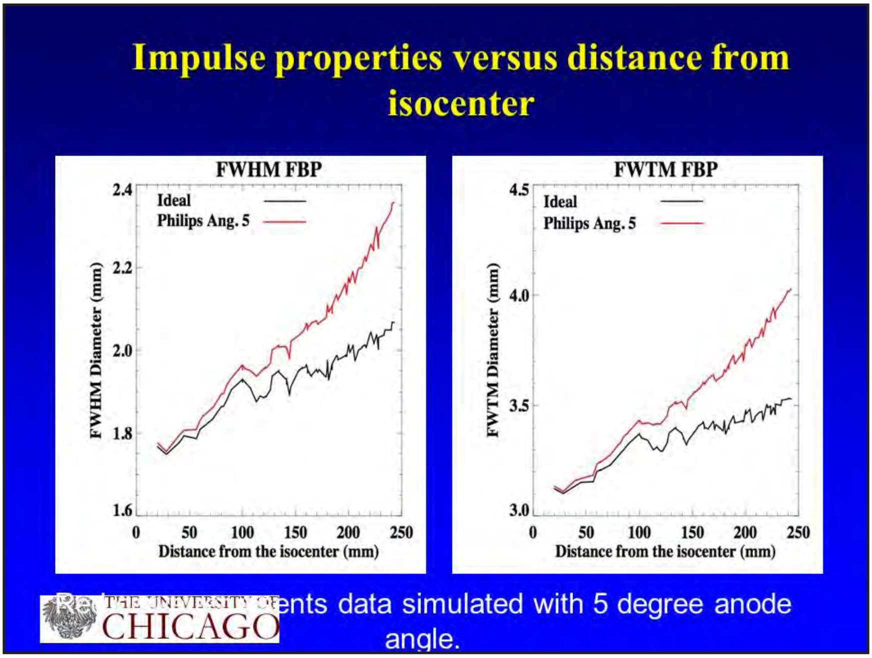
Impulse phantom

- We simulated projections of this phantom in a variety of ways using Radonis package from Philips R&D.
- We then calculated the FWHM and FWTM of the impulses.
- We plot these versus radial distance.



Impulse properties versus distance from isocenter

Ideal data is simulated with no focal spot angulation (i.e., 90 degrees).



Impulse properties versus distance from isocenter

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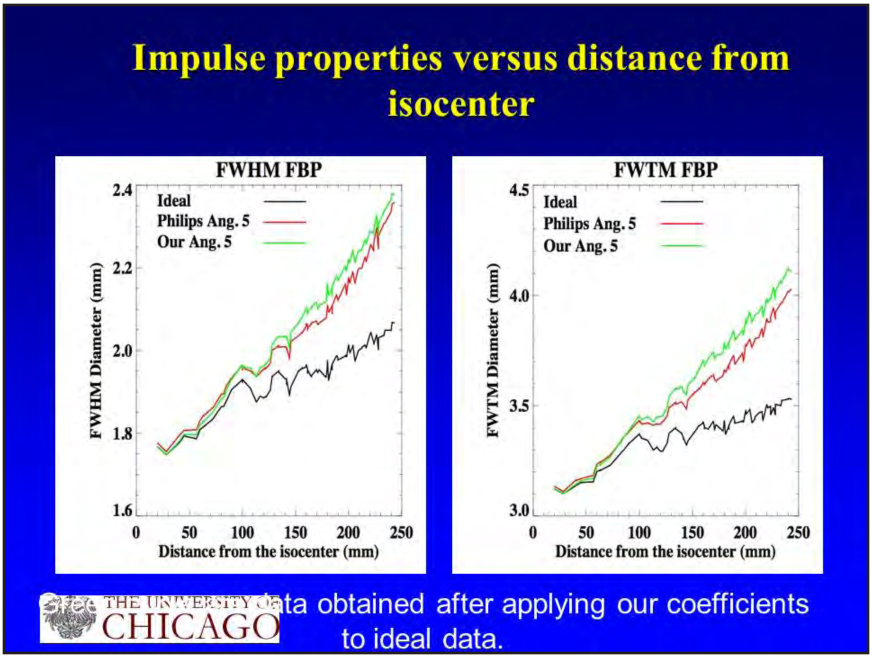
Re ents data simulated with 5 degree anode angle.



Impulse properties versus distance from isocenter

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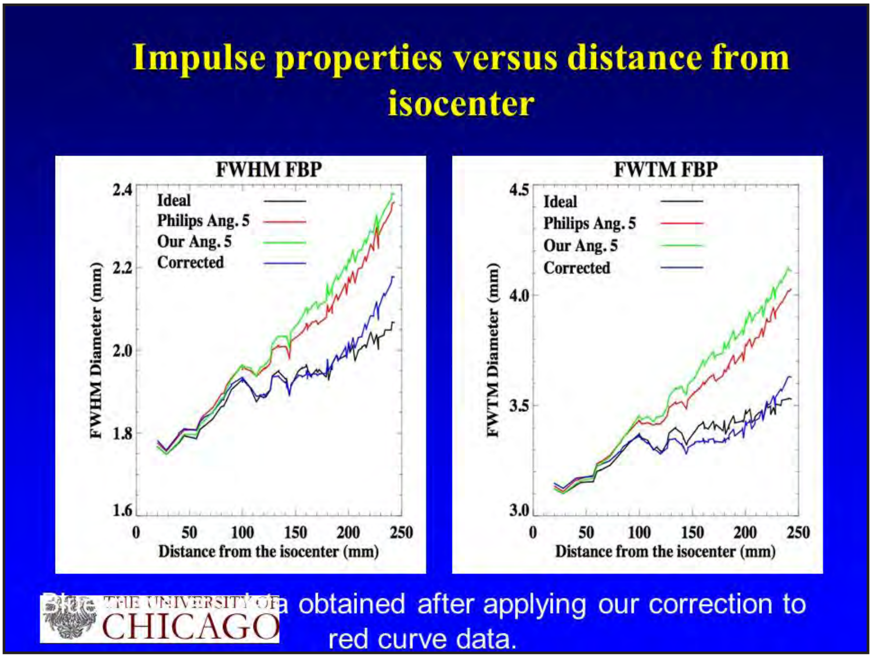
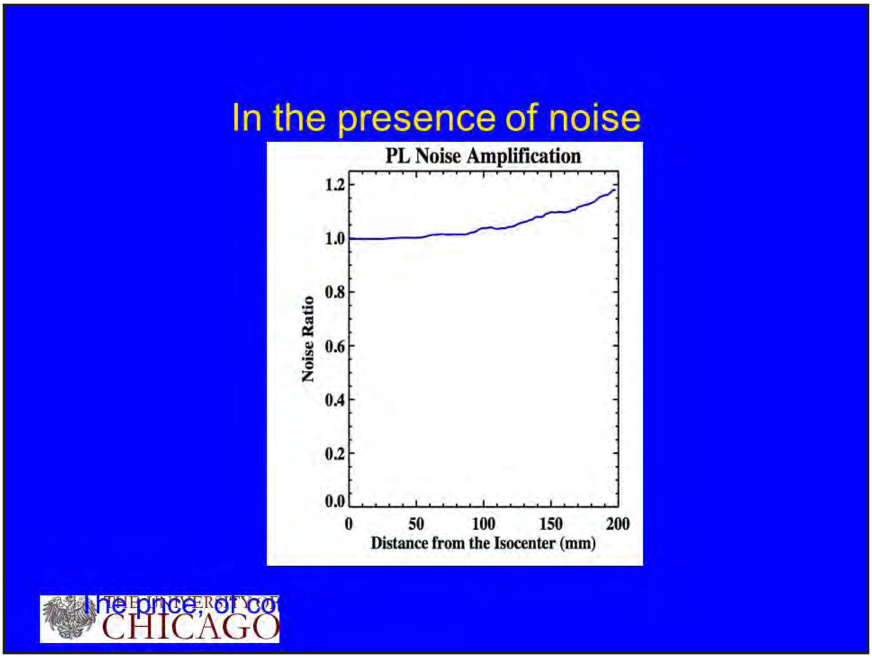
Gre ta obtained after applying our coefficients to ideal data.



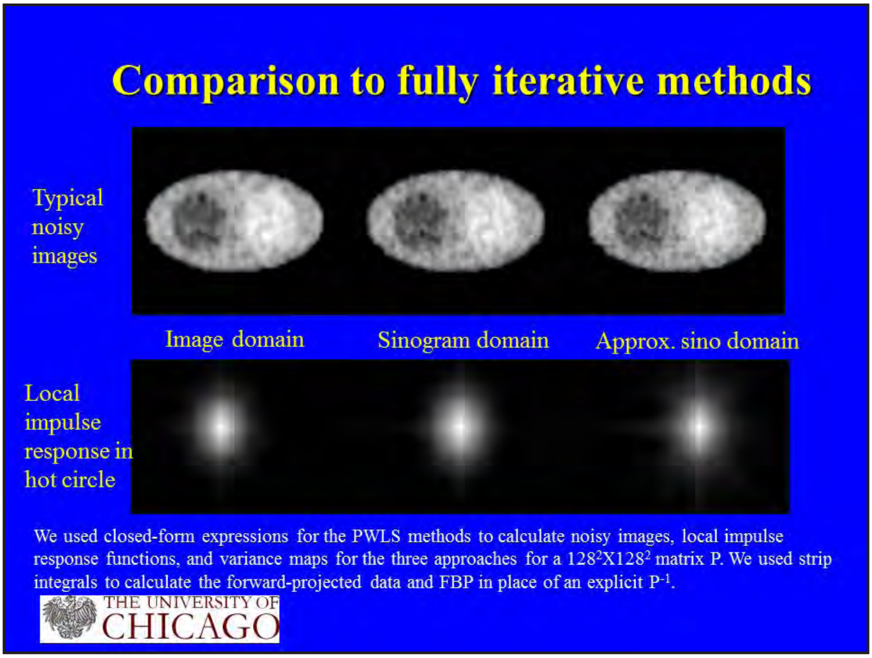
Impulse properties versus distance from isocenter

Blue [illegible]a obtained after applying our correction to red curve data.



In the presence of noise

he price, of co



Comparison to fully iterative methods

Typical noisy images

Image domain

Sinogram domain

Approx. sino domain

Local impulse response in hot circle

We used closed-form expressions for the PWLS methods to calculate noisy images, local impulse response functions, and variance maps for the three approaches for a 128^2X128^2 matrix P. We used strip integrals to calculate the forward-projected data and FBP in place of an explicit P^{-1}.

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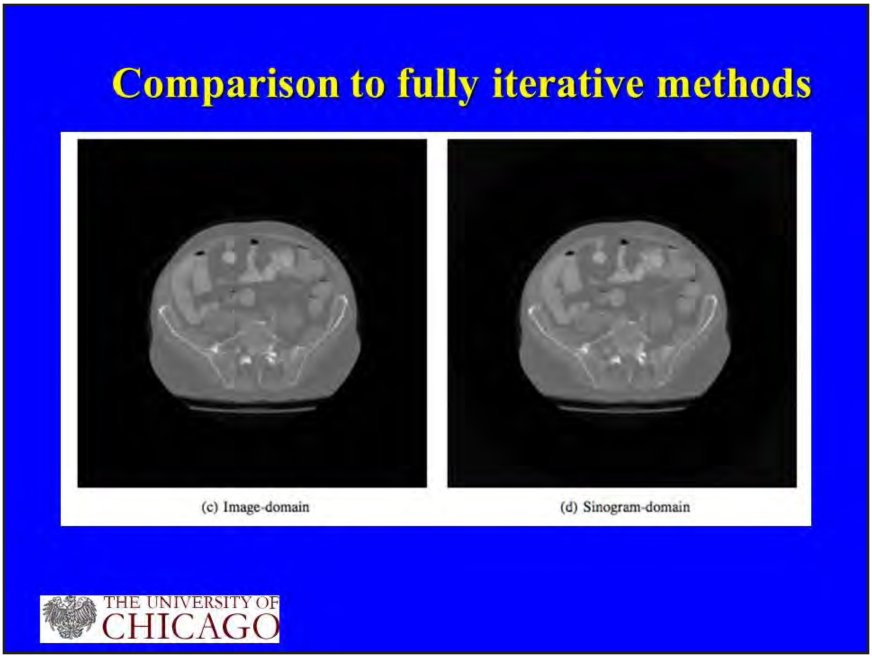

Comparison to fully iterative methods

(c) Image-domain

(d) Sinogram-domain

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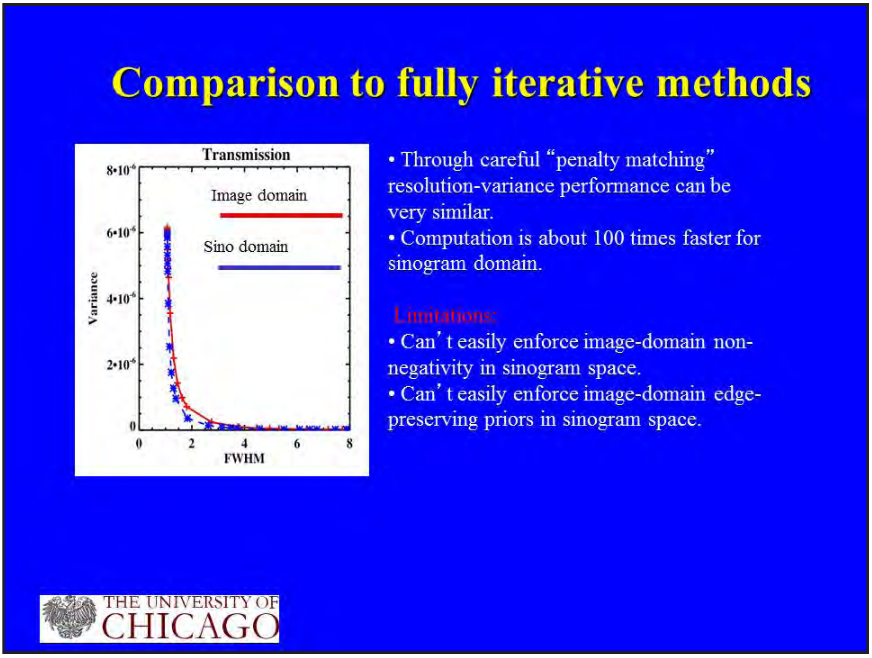

Comparison to fully iterative methods

- Through careful "penalty matching" resolution-variance performance can be very similar.
- Computation is about 100 times faster for sinogram domain.

Limitations:

- Can't easily enforce image-domain non-negativity in sinogram space.
- Can't easily enforce image-domain edge-preserving priors in sinogram space.

Conclusions

- **Sinogram restoration is a statistically principled way of preprocessing CT data prior to reconstruction by analytic algorithms**
- **It can not only be used to reduce artifacts (the point of most preprocessing) but also to reduce noise and model geometric effects, as in fully iterative algorithms.**
- **At the very least, it represents a computationally efficient middle ground between analytic algorithms and fully iterative ones.**
  - **However, in many studies we have done it performs as well as fully iterative algorithms.**
  - **It can readily accommodate the proper "nonlinear" model for CT. Many/Most fully iterative algorithms work with linearized system models.**
- **Naturally it has limitations: harder to accommodate non-negativity and other constraints, harder to implement edge-preserving priors.**

16.9 Seemeen Karimi: Tissue Segmentation in CT Metal Artifact Reduction

TISSUE SEGMENTATION IN CT METAL ARTIFACT REDUCTION

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Harry Martz, Lawrence Livermore National Laboratories
Christoph Wald, Lahey Clinic

April 23, 2012

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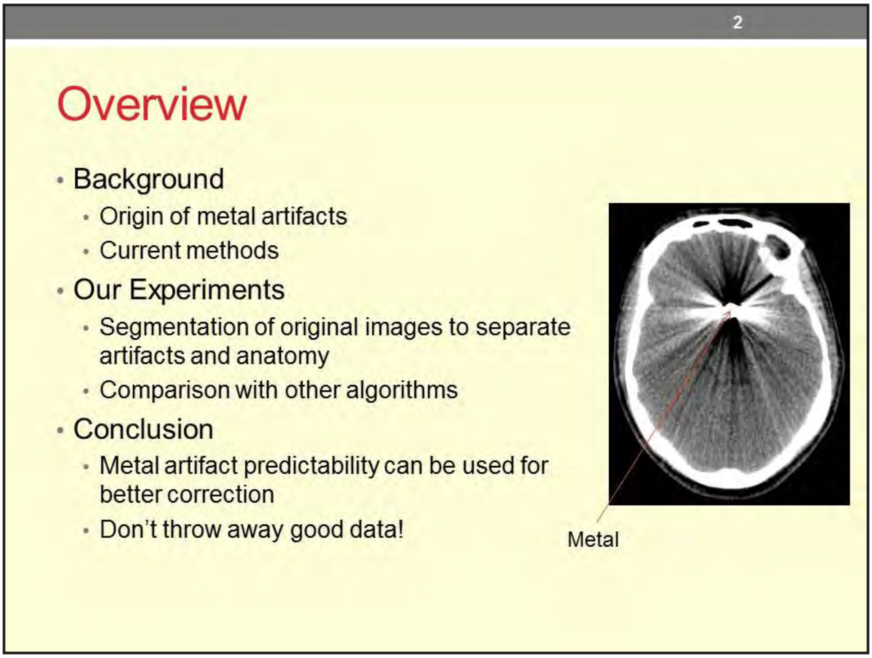
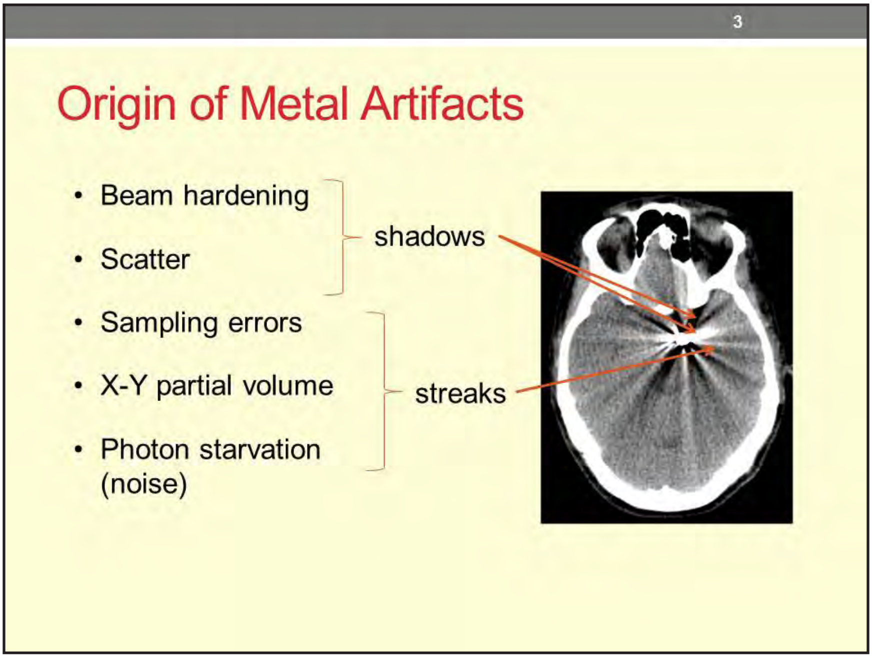
Thanks to Dr. Xiaoqian Jiang (UCSD) for discussions



Overview

- Background
  - Origin of metal artifacts
  - Current methods
- Our Experiments
  - Segmentation of original images to separate artifacts and anatomy
  - Comparison with other algorithms
- Conclusion
  - Metal artifact predictability can be used for better correction
  - Don't throw away good data!

Metal



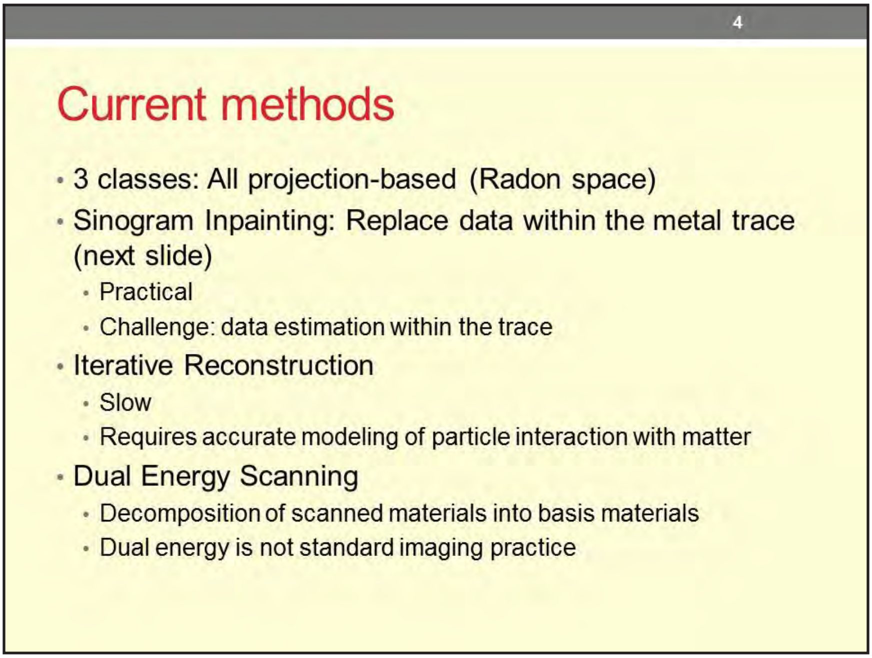
Origin of Metal Artifacts

- Beam hardening
- Scatter

shadows

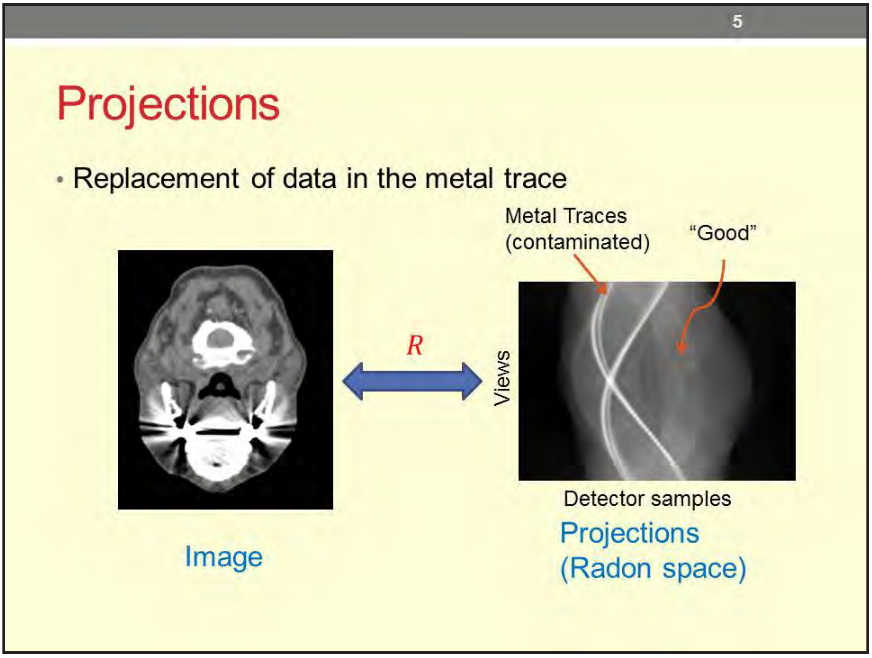
- Sampling errors
- X-Y partial volume
- Photon starvation (noise)

streaks



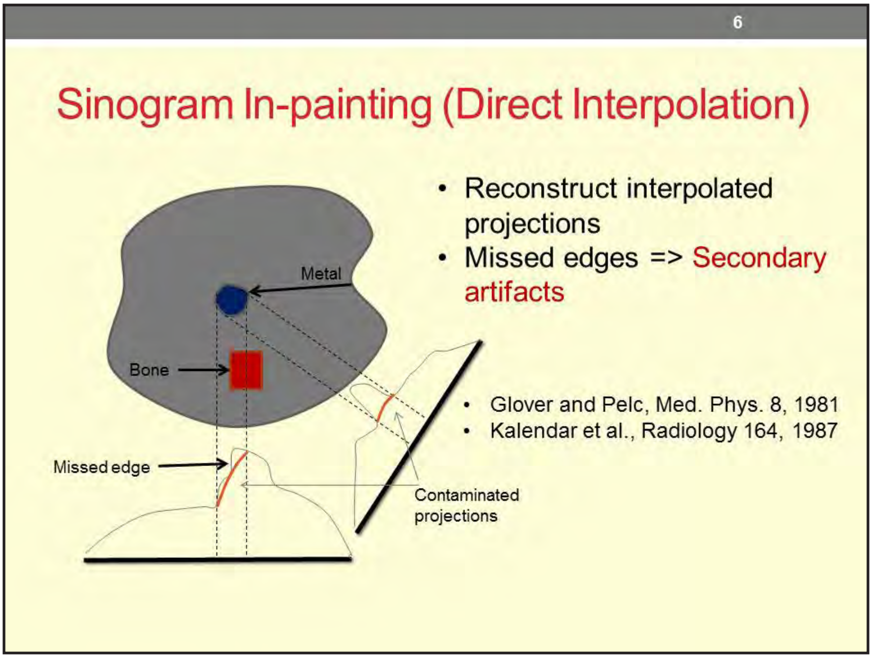
Current methods

- 3 classes: All projection-based (Radon space)
- Sinogram Inpainting: Replace data within the metal trace (next slide)
  - Practical
  - Challenge: data estimation within the trace
- Iterative Reconstruction
  - Slow
  - Requires accurate modeling of particle interaction with matter
- Dual Energy Scanning
  - Decomposition of scanned materials into basis materials
  - Dual energy is not standard imaging practice



Projections

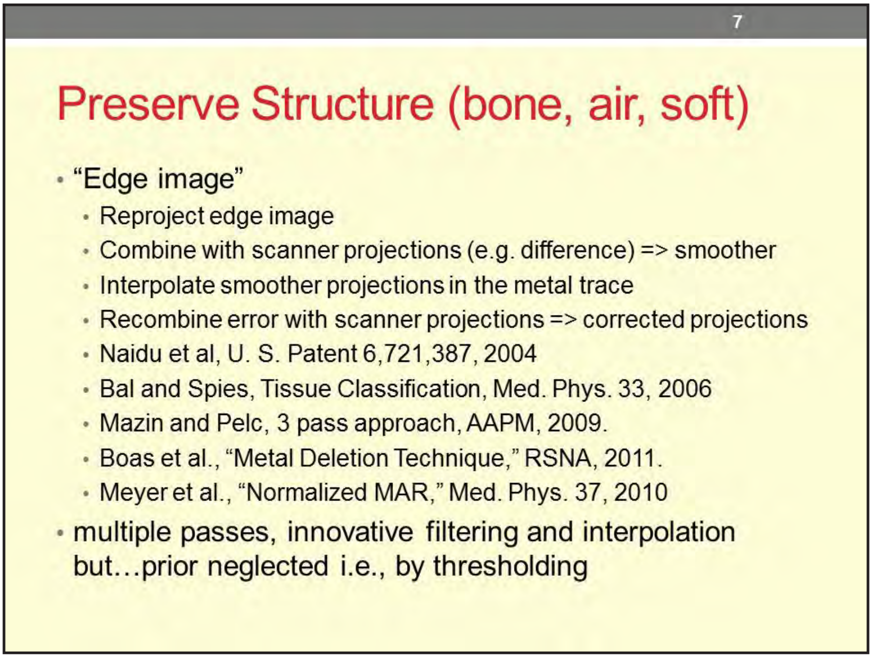
- Replacement of data in the metal trace



Sinogram In-painting (Direct Interpolation)

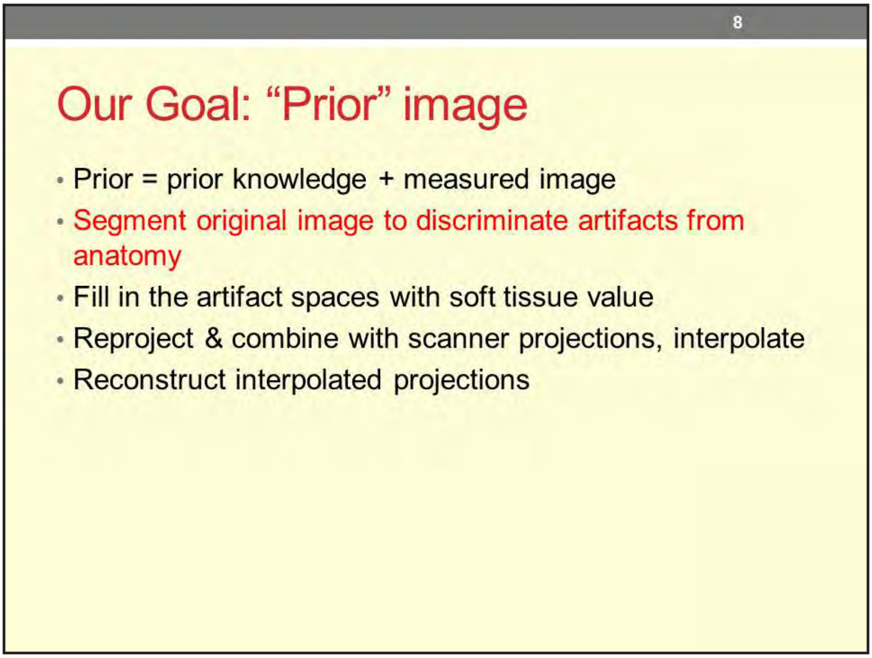
- Reconstruct interpolated projections
- Missed edges => Secondary artifacts

- Glover and Pelc, Med. Phys. 8, 1981
- Kalendar et al., Radiology 164, 1987



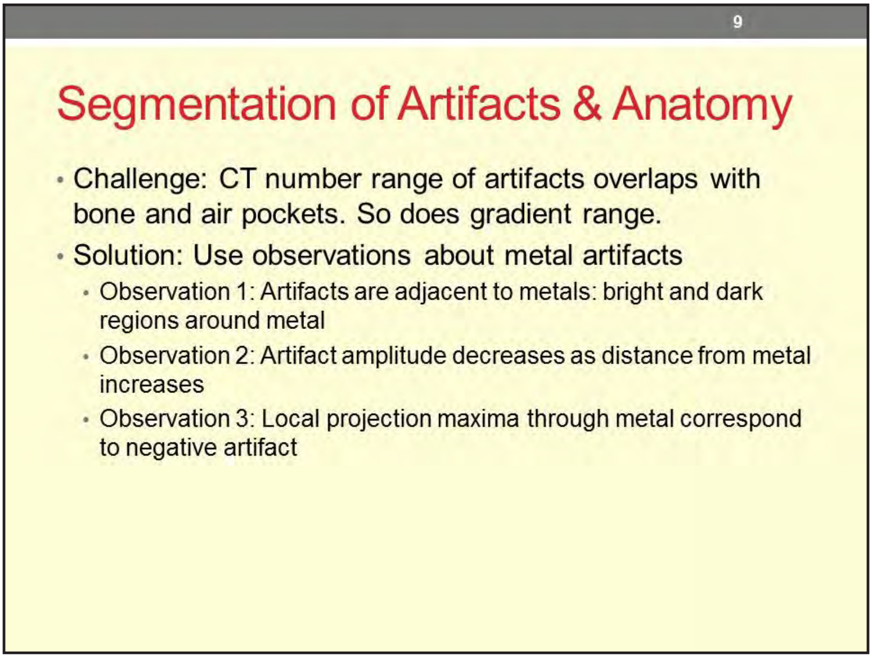
Preserve Structure (bone, air, soft)

- "Edge image"
  - Reproject edge image
  - Combine with scanner projections (e.g. difference) => smoother
  - Interpolate smoother projections in the metal trace
  - Recombine error with scanner projections => corrected projections
  - Naidu et al, U. S. Patent 6,721,387, 2004
  - Bal and Spies, Tissue Classification, Med. Phys. 33, 2006
  - Mazin and Pelc, 3 pass approach, AAPM, 2009.
  - Boas et al., "Metal Deletion Technique," RSNA, 2011.
  - Meyer et al., "Normalized MAR," Med. Phys. 37, 2010
- multiple passes, innovative filtering and interpolation but…prior neglected i.e., by thresholding



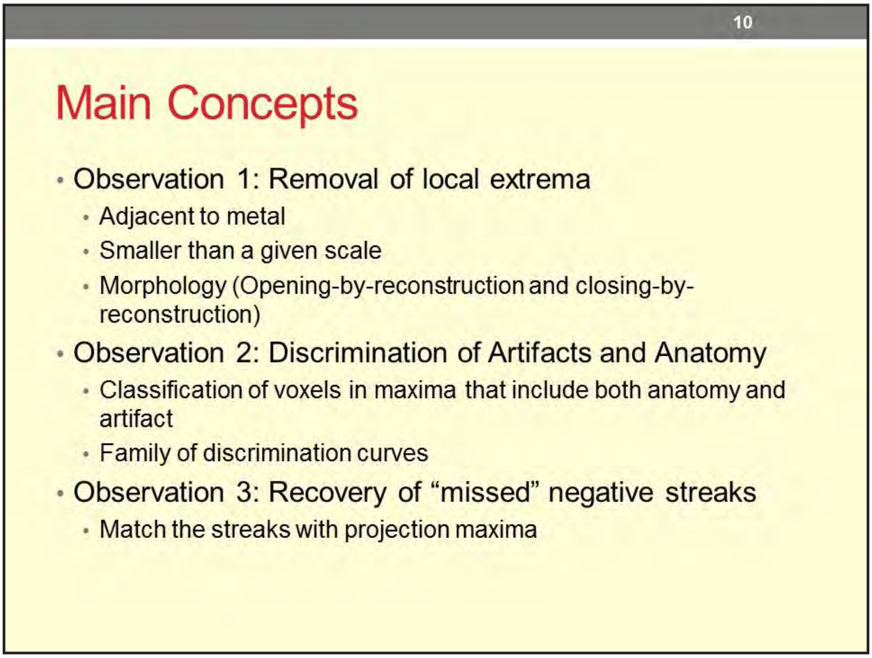
Our Goal: "Prior" image

- Prior = prior knowledge + measured image
- Segment original image to discriminate artifacts from anatomy
- Fill in the artifact spaces with soft tissue value
- Reproject & combine with scanner projections, interpolate
- Reconstruct interpolated projections



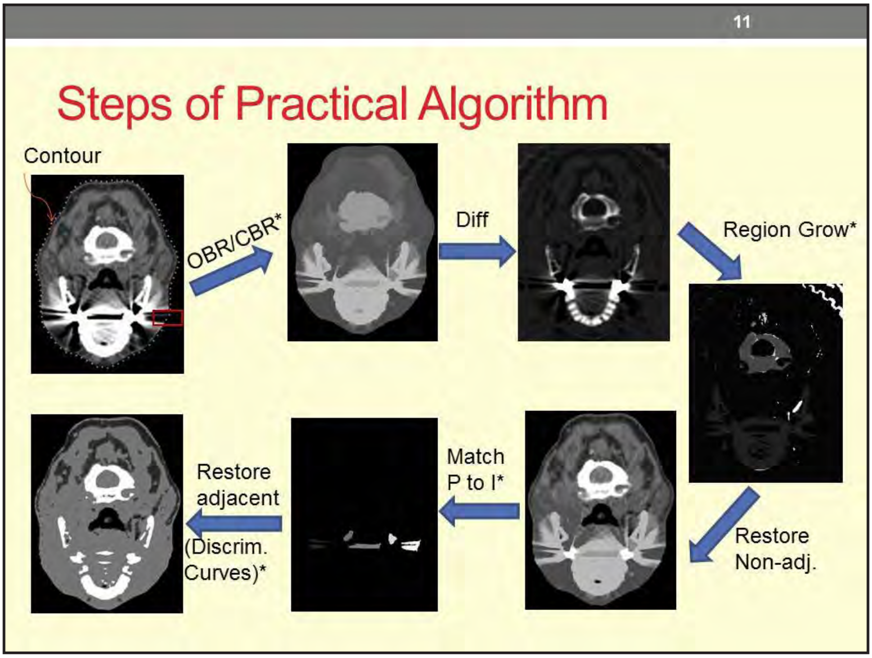
Segmentation of Artifacts & Anatomy

- Challenge: CT number range of artifacts overlaps with bone and air pockets. So does gradient range.
- Solution: Use observations about metal artifacts
  - Observation 1: Artifacts are adjacent to metals: bright and dark regions around metal
  - Observation 2: Artifact amplitude decreases as distance from metal increases
  - Observation 3: Local projection maxima through metal correspond to negative artifact



Main Concepts

- Observation 1: Removal of local extrema
  - Adjacent to metal
  - Smaller than a given scale
  - Morphology (Opening-by-reconstruction and closing-by-reconstruction)
- Observation 2: Discrimination of Artifacts and Anatomy
  - Classification of voxels in maxima that include both anatomy and artifact
  - Family of discrimination curves
- Observation 3: Recovery of “missed” negative streaks
  - Match the streaks with projection maxima



Steps of Practical Algorithm

Contour

OBR/CBR*

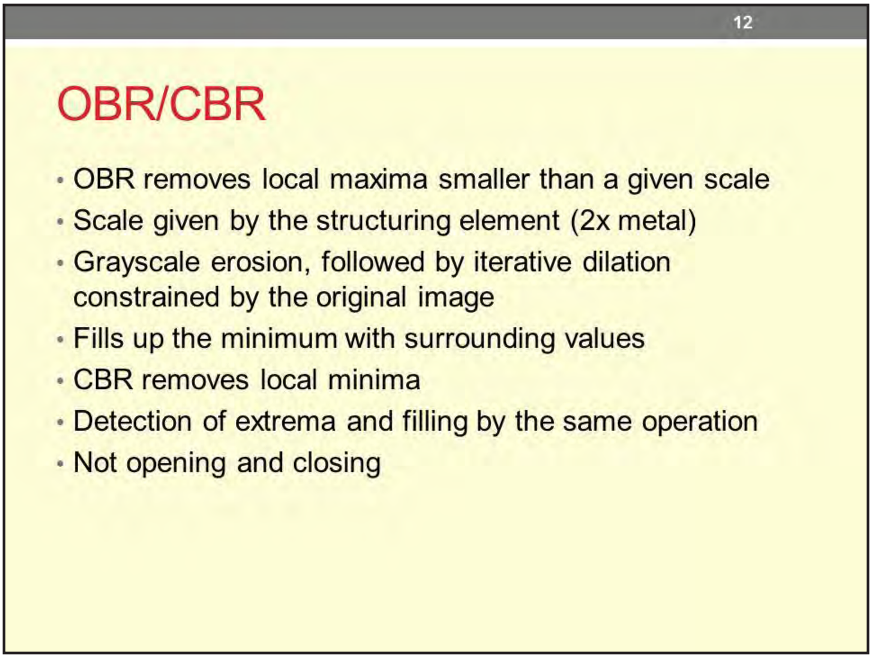
Diff

Region Grow*

Restore Non-adj.

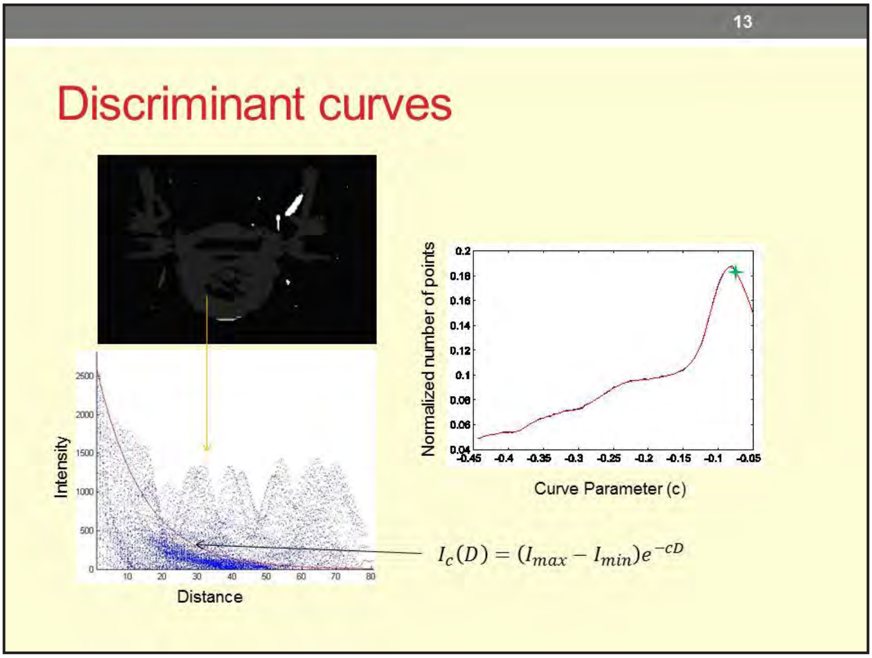
Match P to I*

Restore adjacent (Discrim. Curves)*



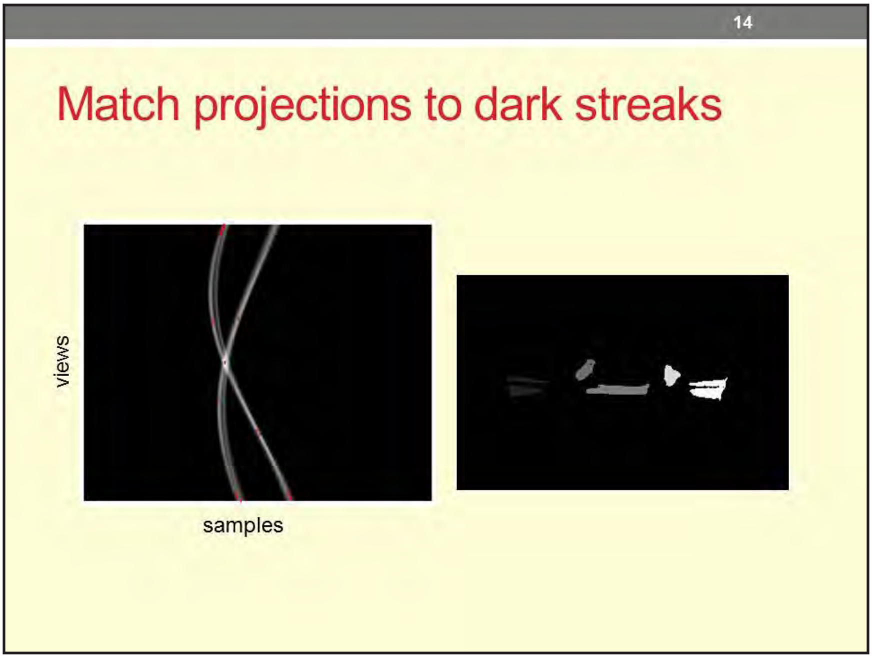
OBR/CBR

- OBR removes local maxima smaller than a given scale
- Scale given by the structuring element (2x metal)
- Grayscale erosion, followed by iterative dilation constrained by the original image
- Fills up the minimum with surrounding values
- CBR removes local minima
- Detection of extrema and filling by the same operation
- Not opening and closing

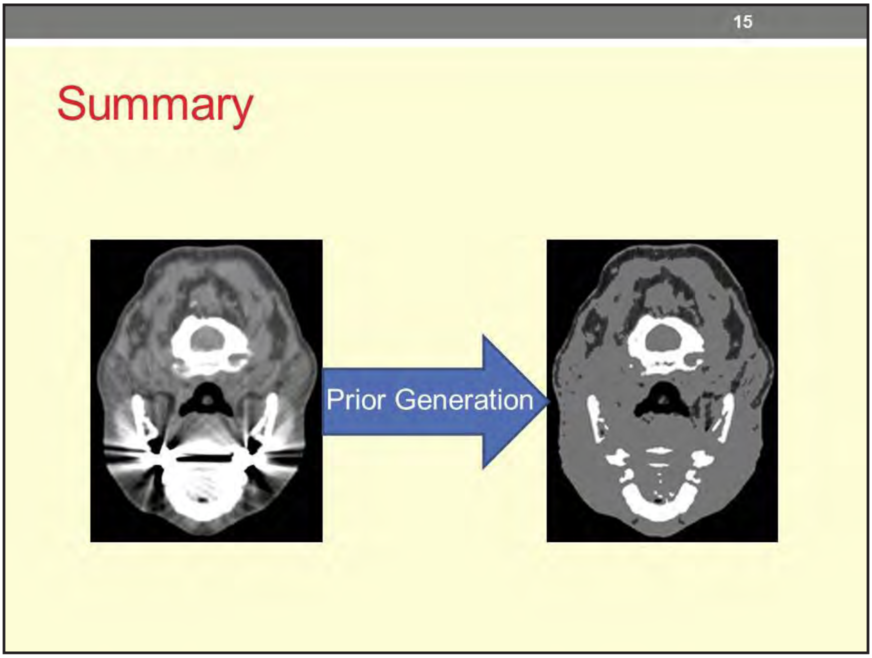


Discriminant curves

$$I_c(D) = (I_{max} - I_{min})e^{-cD}$$

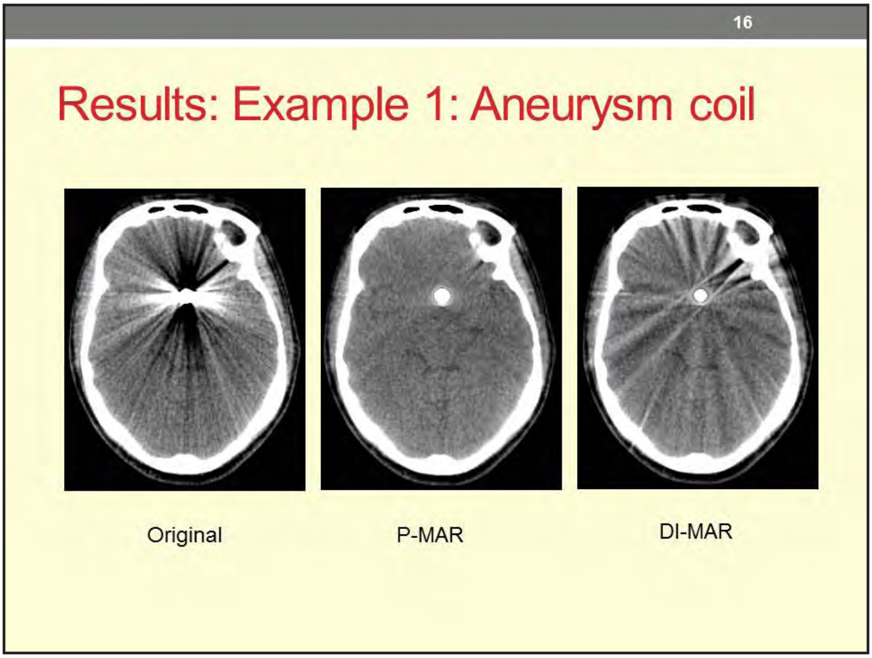


Match projections to dark streaks



Summary

Prior Generation

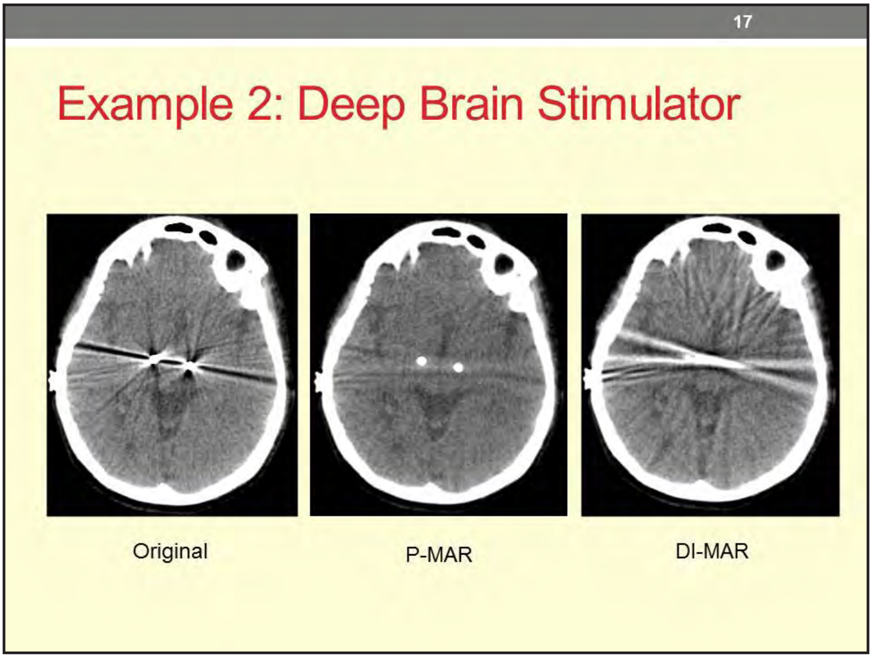


Results: Example 1: Aneurysm coil

Original

P-MAR

DI-MAR

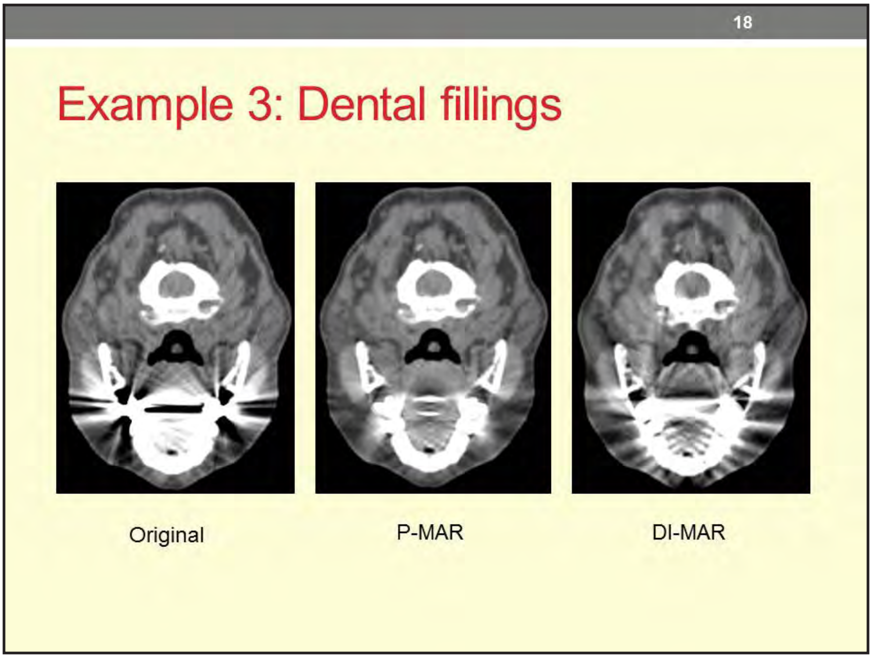


Example 2: Deep Brain Stimulator

Original

P-MAR

DI-MAR

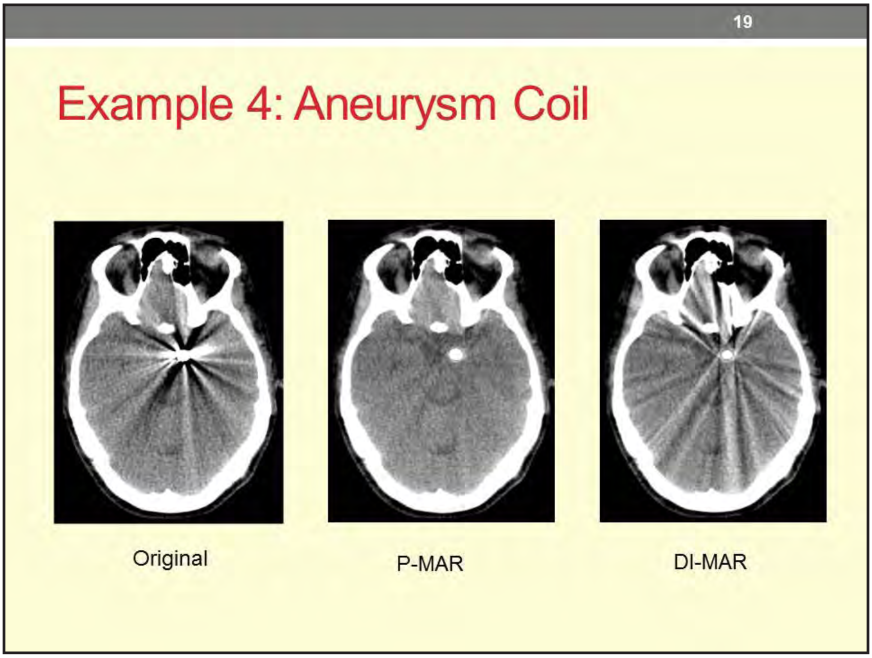


Example 3: Dental fillings

Original

P-MAR

DI-MAR

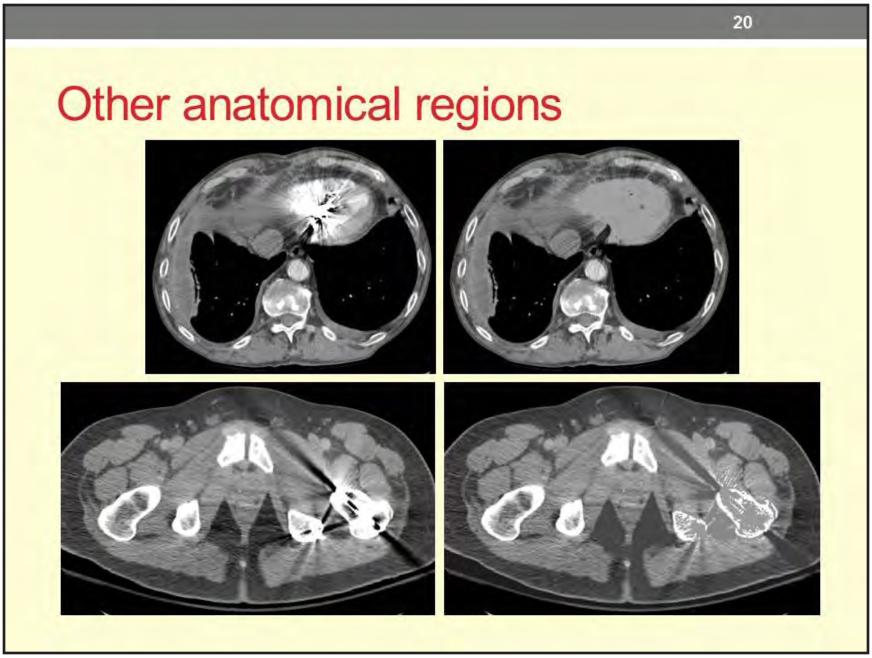


Example 4: Aneurysm Coil

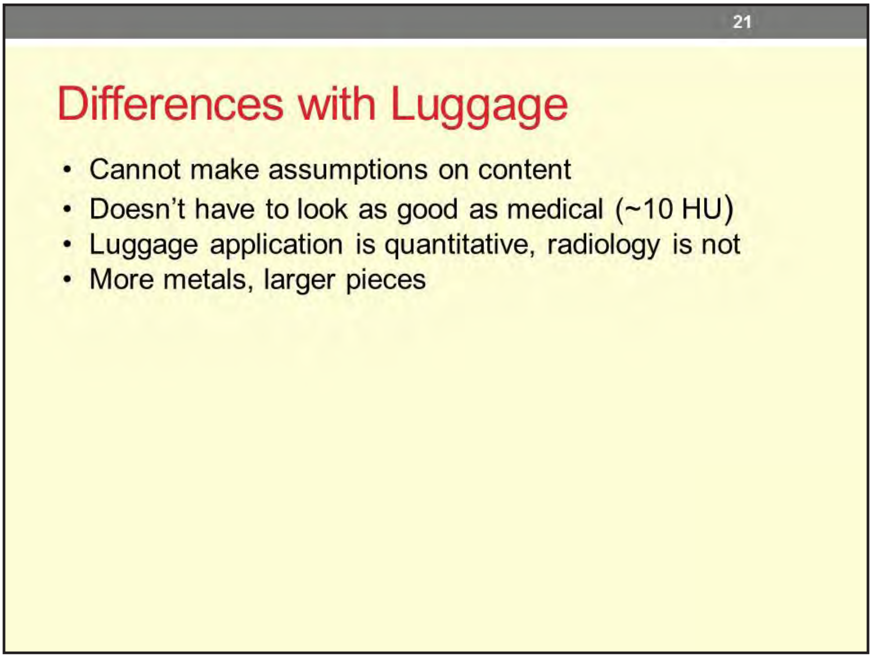
Original

P-MAR

DI-MAR

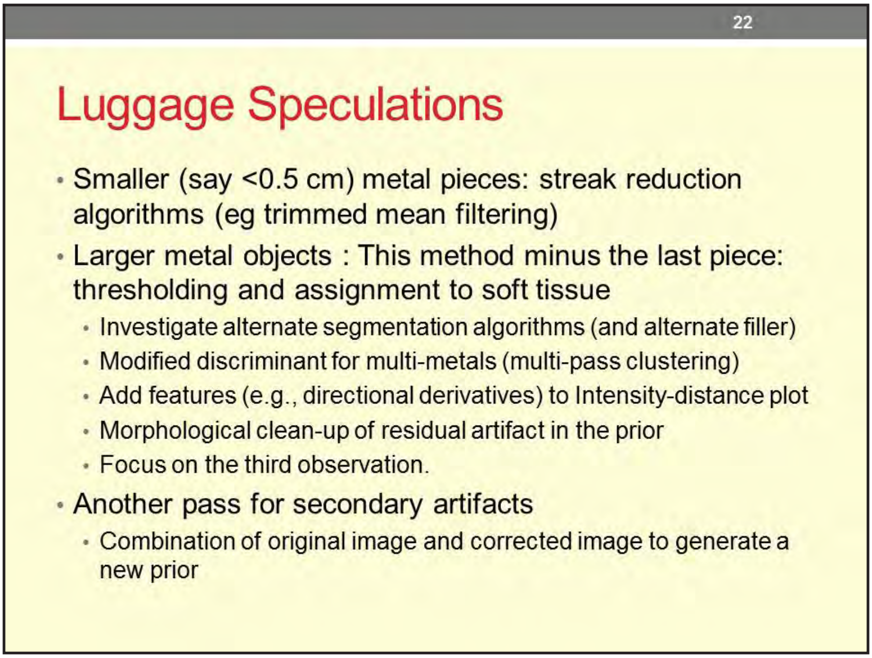


Other anatomical regions



Differences with Luggage

- Cannot make assumptions on content
- Doesn't have to look as good as medical (~10 HU)
- Luggage application is quantitative, radiology is not
- More metals, larger pieces



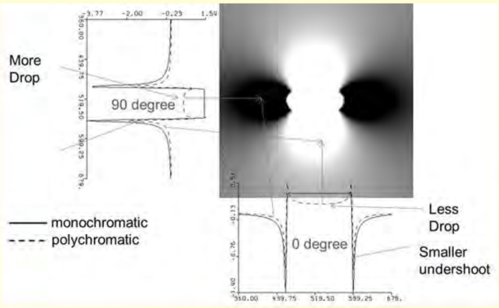
Luggage Speculations

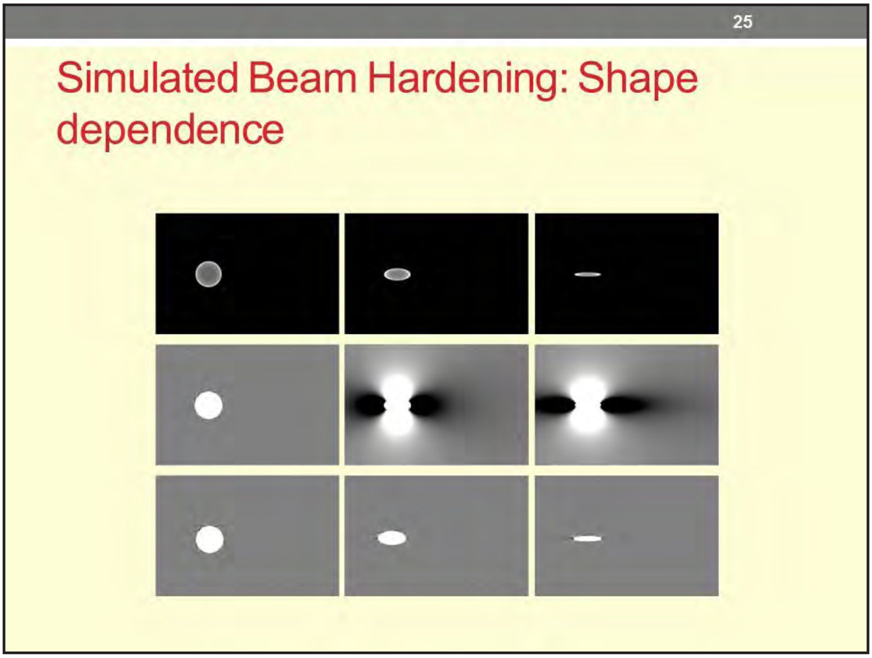
- Smaller (say <0.5 cm) metal pieces: streak reduction algorithms (eg trimmed mean filtering)
- Larger metal objects : This method minus the last piece: thresholding and assignment to soft tissue
  - Investigate alternate segmentation algorithms (and alternate filler)
  - Modified discriminant for multi-metals (multi-pass clustering)
  - Add features (e.g., directional derivatives) to Intensity-distance plot
  - Morphological clean-up of residual artifact in the prior
  - Focus on the third observation.
- Another pass for secondary artifacts
  - Combination of original image and corrected image to generate a new prior

Thank you

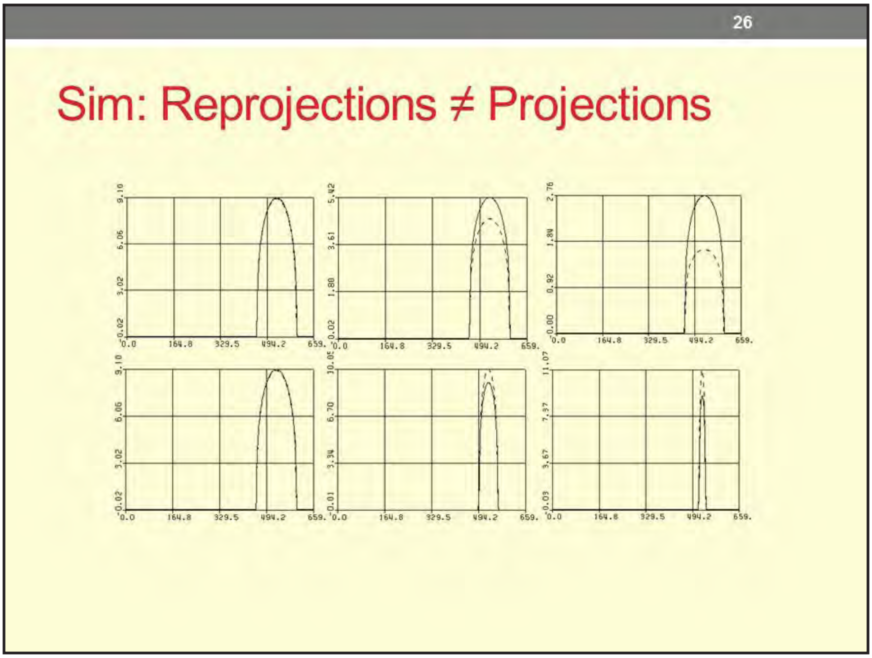
- Suggestions are welcome

Beam Hardening Simulation



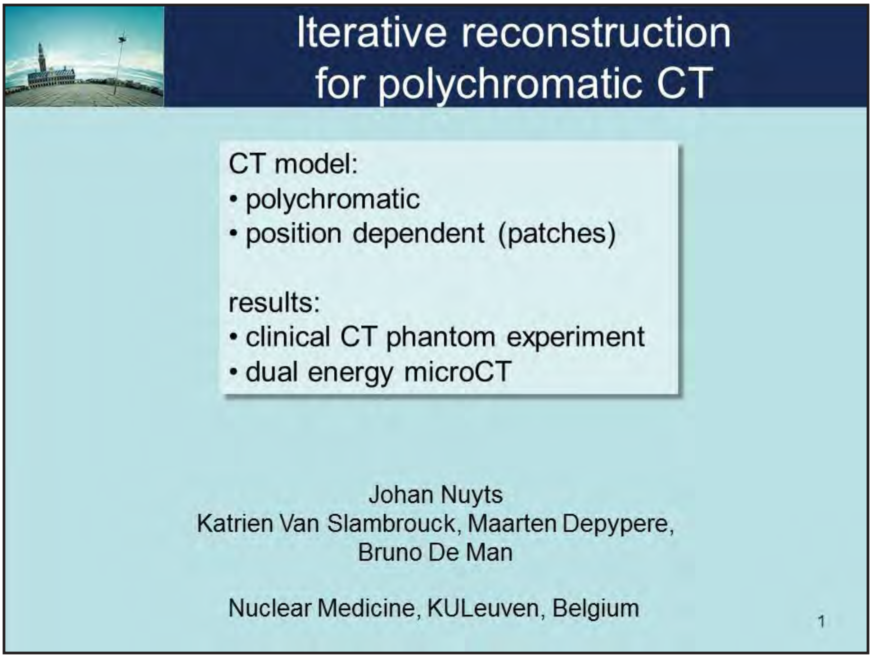


Simulated Beam Hardening: Shape dependence



Sim: Reprojections ≠ Projections

16.10 Johan Nuyts: Iterative reconstruction for polychromatic CT



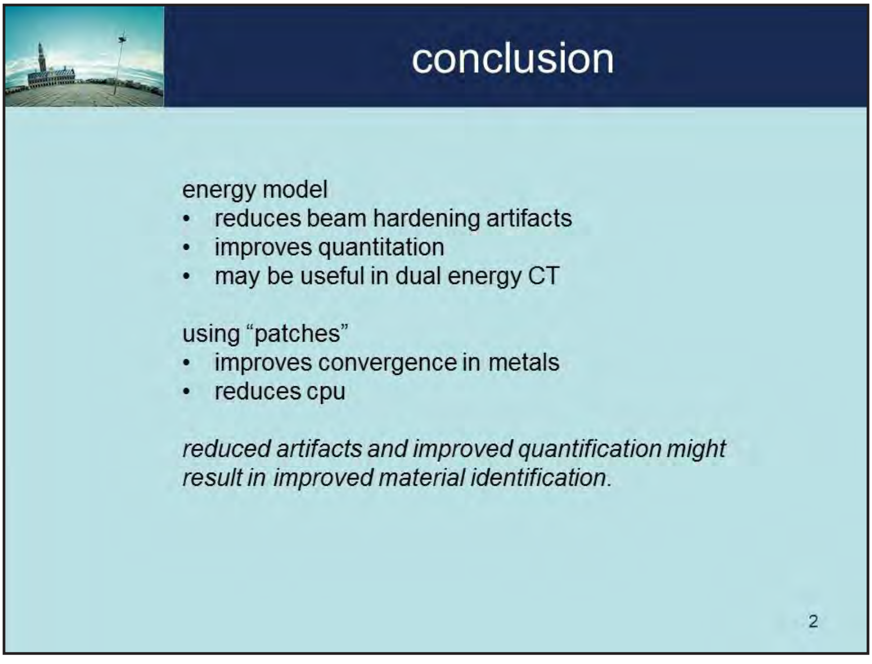
Iterative reconstruction for polychromatic CT

CT model:
- polychromatic
- position dependent (patches)

results:
- clinical CT phantom experiment
- dual energy microCT

Johan Nuyts
Katrien Van Slambrouck, Maarten Depypere,
Bruno De Man

Nuclear Medicine, KULeuven, Belgium

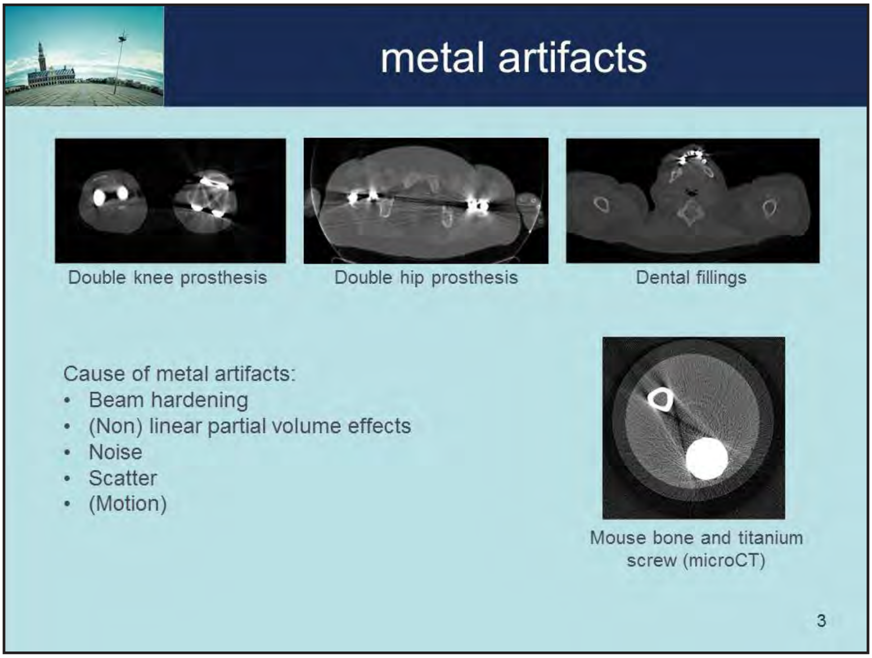


conclusion

energy model
- reduces beam hardening artifacts
- improves quantitation
- may be useful in dual energy CT

using “patches”
- improves convergence in metals
- reduces cpu

reduced artifacts and improved quantification might result in improved material identification.



metal artifacts

Double knee prosthesis

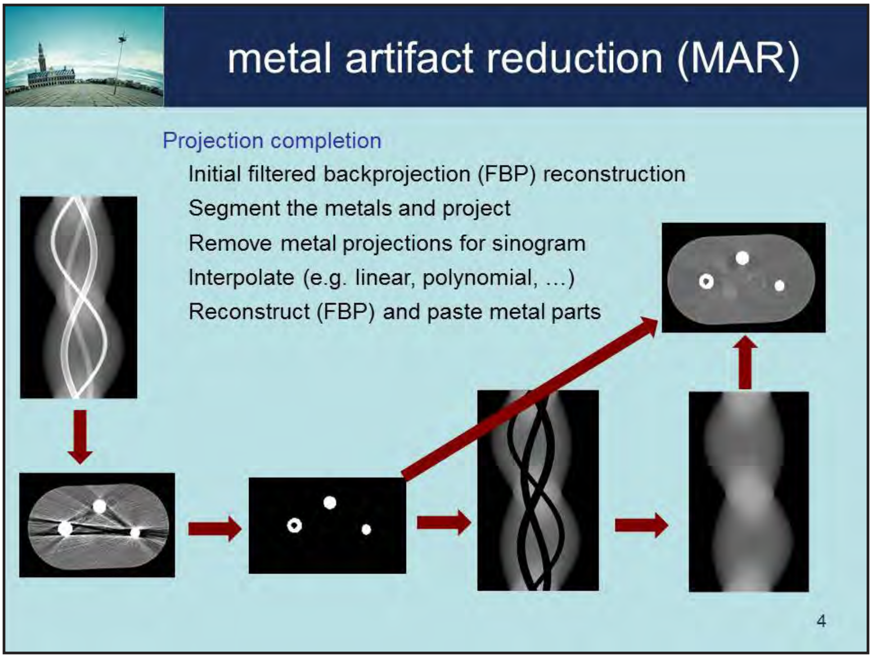
Double hip prosthesis

Dental fillings

Cause of metal artifacts:

- Beam hardening
- (Non) linear partial volume effects
- Noise
- Scatter
- (Motion)

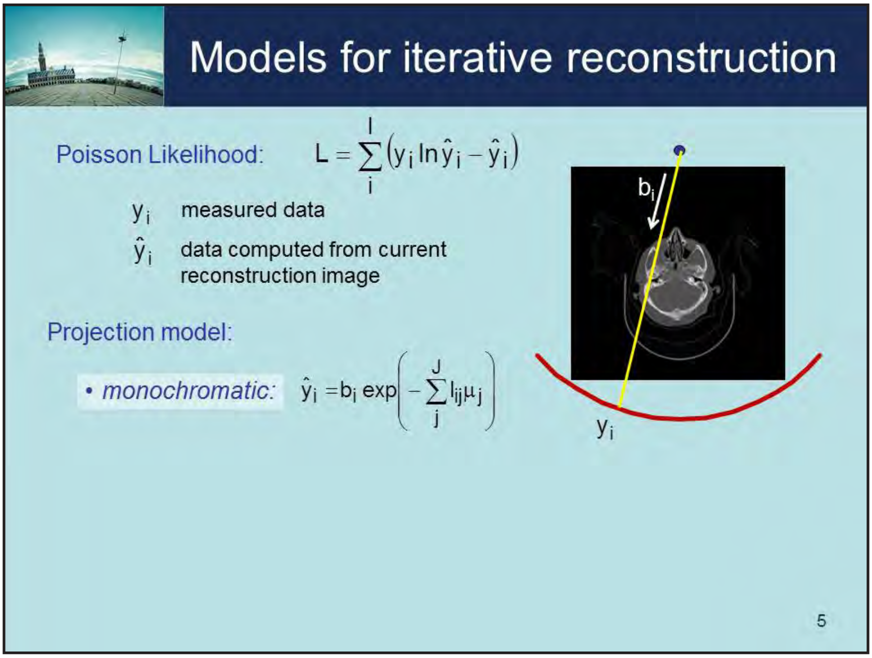
Mouse bone and titanium screw (microCT)



metal artifact reduction (MAR)

Projection completion

Initial filtered backprojection (FBP) reconstruction
Segment the metals and project
Remove metal projections for sinogram
Interpolate (e.g. linear, polynomial, …)
Reconstruct (FBP) and paste metal parts



Models for iterative reconstruction

Poisson Likelihood: $L = \sum_{i}^{I} \left(y_i \ln \hat{y}_i - \hat{y}_i \right)$

y_i measured data

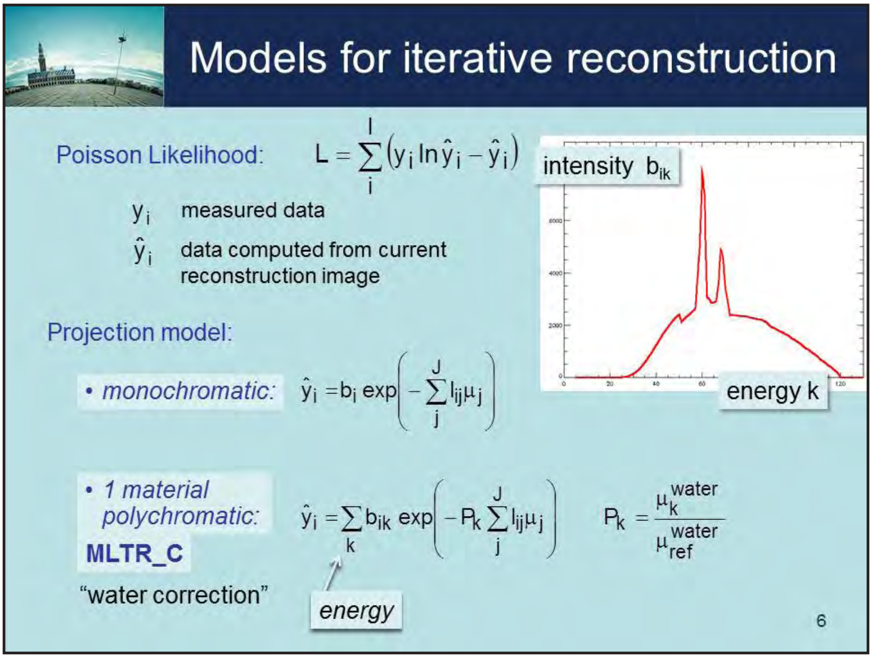
$\hat{y}_i$ data computed from current reconstruction image

Projection model:

- *monochromatic:* $\hat{y}_i = b_i \exp\left(- \sum_{j}^{J} l_{ij} \mu_j \right)$

b_i

y_i



Models for iterative reconstruction

Poisson Likelihood: $L = \sum_{i}^{I} \left(y_i \ln \hat{y}_i - \hat{y}_i \right)$

y_i measured data

$\hat{y}_i$ data computed from current reconstruction image

Projection model:

- *monochromatic:* $\hat{y}_i = b_i \exp\left(- \sum_{j}^{J} l_{ij} \mu_j \right)$
- *1 material polychromatic:* $\hat{y}_i = \sum_{k} b_{ik} \exp\left(- P_k \sum_{j}^{J} l_{ij} \mu_j \right)$ $P_k = \frac{\mu_k^{water}}{\mu_{ref}^{water}}$

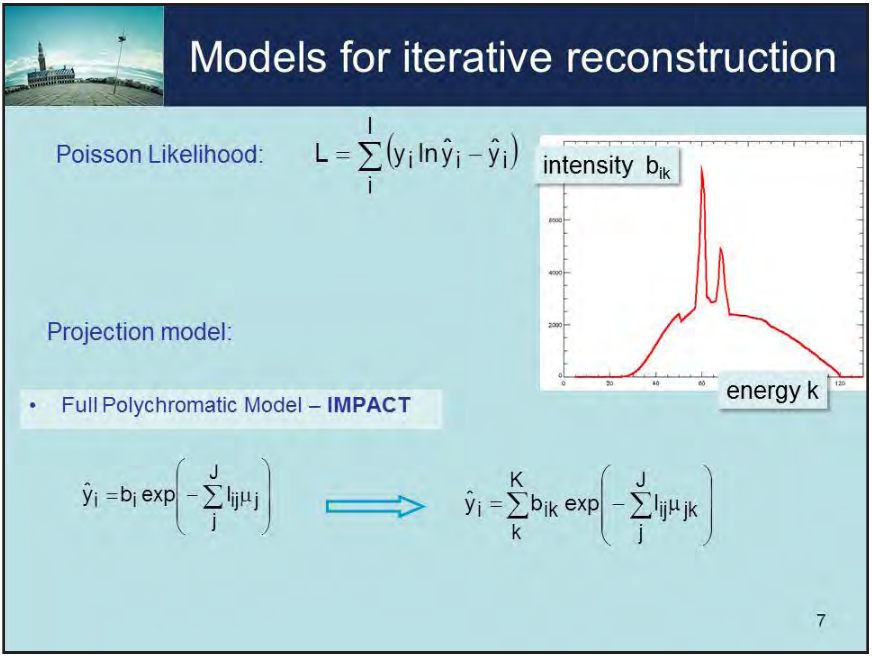
MLTR_C

"water correction"

energy

intensity b_{ik}

energy k



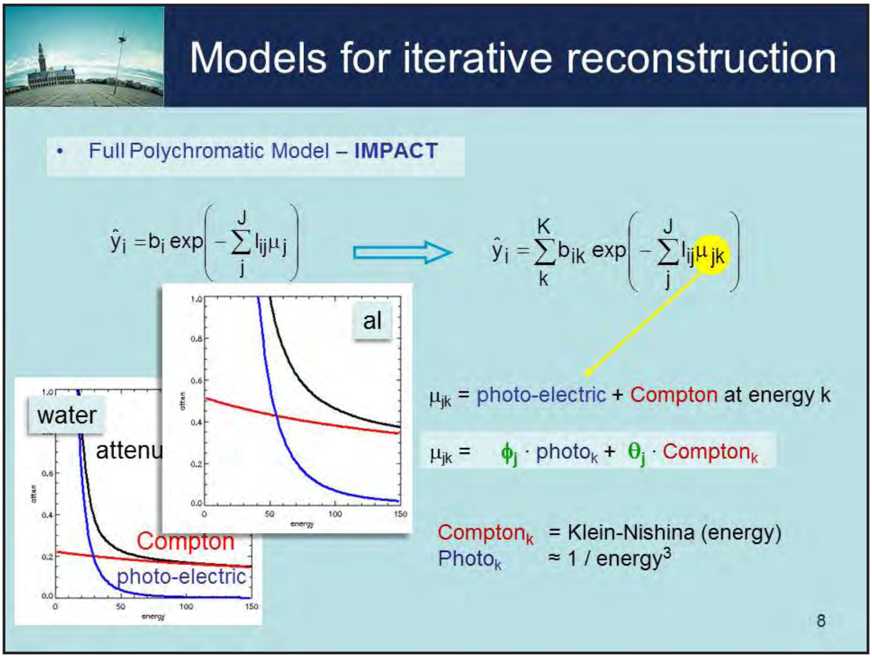
Models for iterative reconstruction

Poisson Likelihood: $L = \sum_{i}^{I} \left(y_i \ln \hat{y}_i - \hat{y}_i \right)$

Projection model:

- Full Polychromatic Model – **IMPACT**

$$\hat{y}_i = b_i \exp\left(- \sum_{j}^{J} l_{ij} \mu_j \right) \Longrightarrow \hat{y}_i = \sum_{k}^{K} b_{ik} \exp\left(- \sum_{j}^{J} l_{ij} \mu_{jk} \right)$$



Models for iterative reconstruction

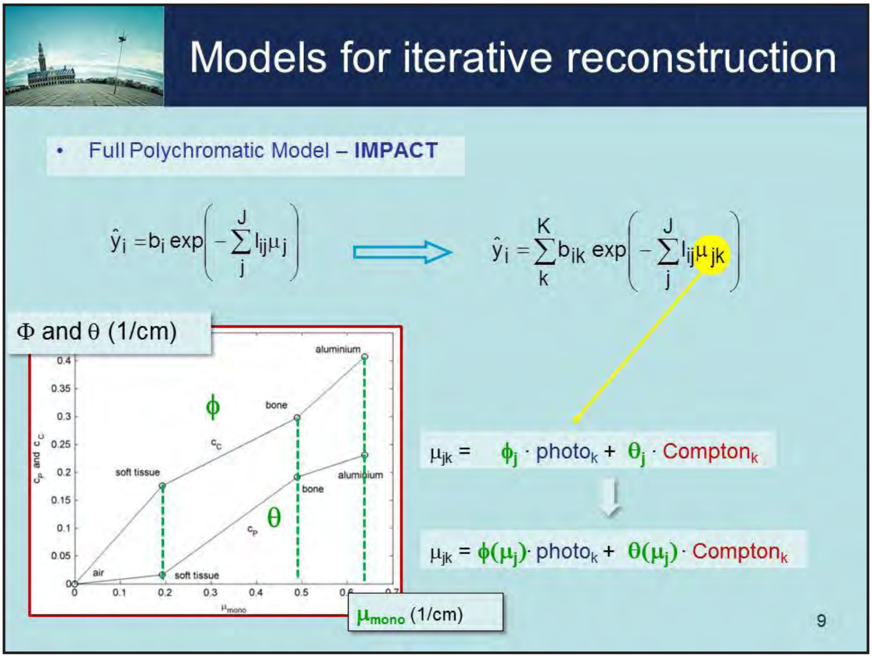
- Full Polychromatic Model – **IMPACT**

$$\hat{y}_i = b_i \exp\left(- \sum_{j}^{J} l_{ij} \mu_j \right) \Longrightarrow \hat{y}_i = \sum_{k}^{K} b_{ik} \exp\left(- \sum_{j}^{J} l_{ij} \mu_{jk} \right)$$

μ_{jk} = photo-electric + Compton at energy k

$\mu_{jk} = \phi_j \cdot \text{photo}_k + \theta_j \cdot \text{Compton}_k$

Compton_k = Klein-Nishina (energy)
Photo_k ≈ 1 / energy^3



Models for iterative reconstruction

- Full Polychromatic Model – **IMPACT**

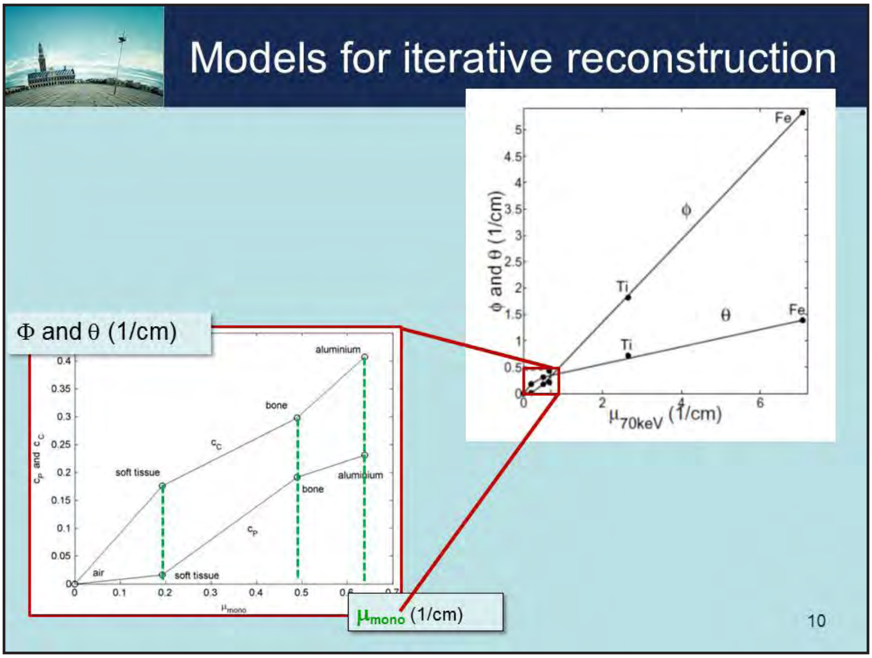
$$\hat{y}_i = b_i \exp\left(-\sum_j^J l_{ij}\mu_j\right) \Rightarrow \hat{y}_i = \sum_k^K b_{ik} \exp\left(-\sum_j^J l_{ij}\mu_{jk}\right)$$

Φ and θ (1/cm)

$\mu_{jk} = \phi_j \cdot photo_k + \theta_j \cdot Compton_k$

$\mu_{jk} = \phi(\mu_j) \cdot photo_k + \theta(\mu_j) \cdot Compton_k$

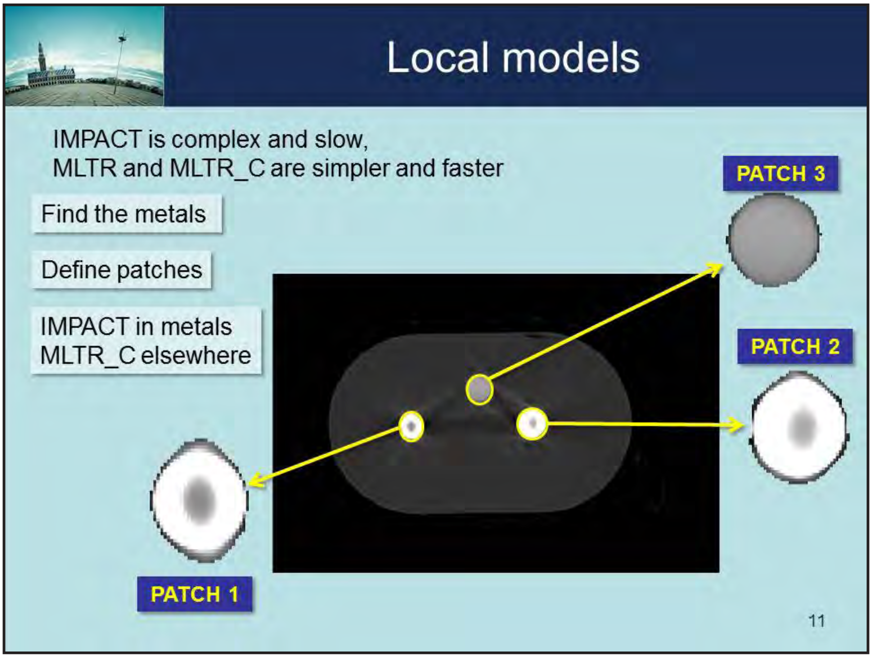
μ_{mono} (1/cm)



Models for iterative reconstruction

Φ and θ (1/cm)

μ_{mono} (1/cm)



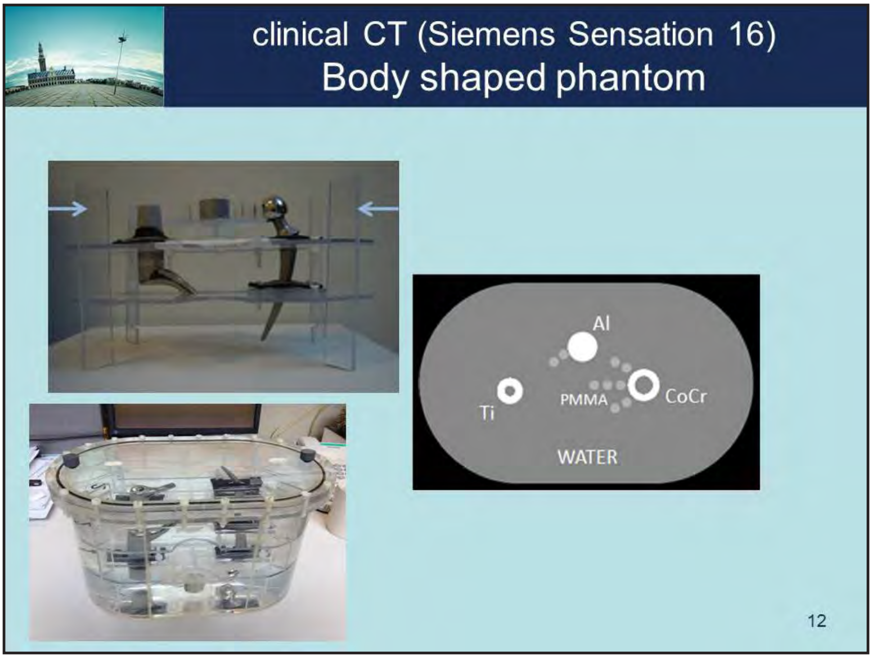
Local models

IMPACT is complex and slow,
MLTR and MLTR_C are simpler and faster

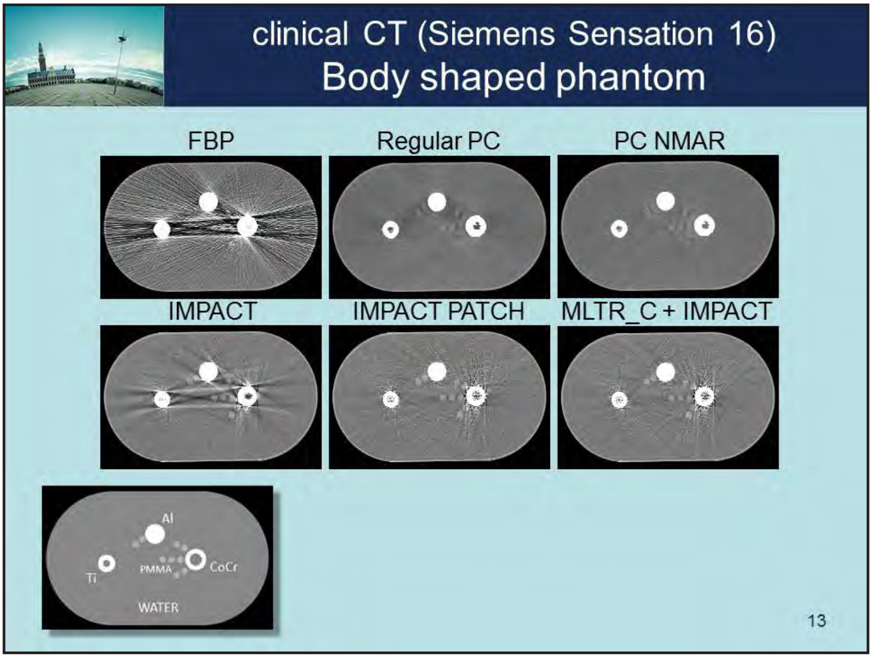
Find the metals

Define patches

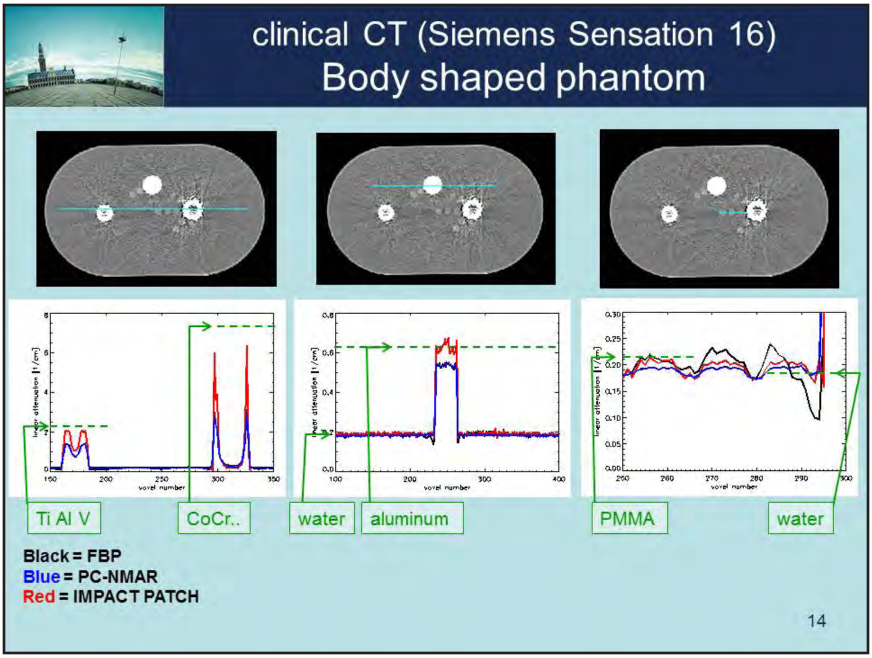
IMPACT in metals
MLTR_C elsewhere



clinical CT (Siemens Sensation 16)
Body shaped phantom

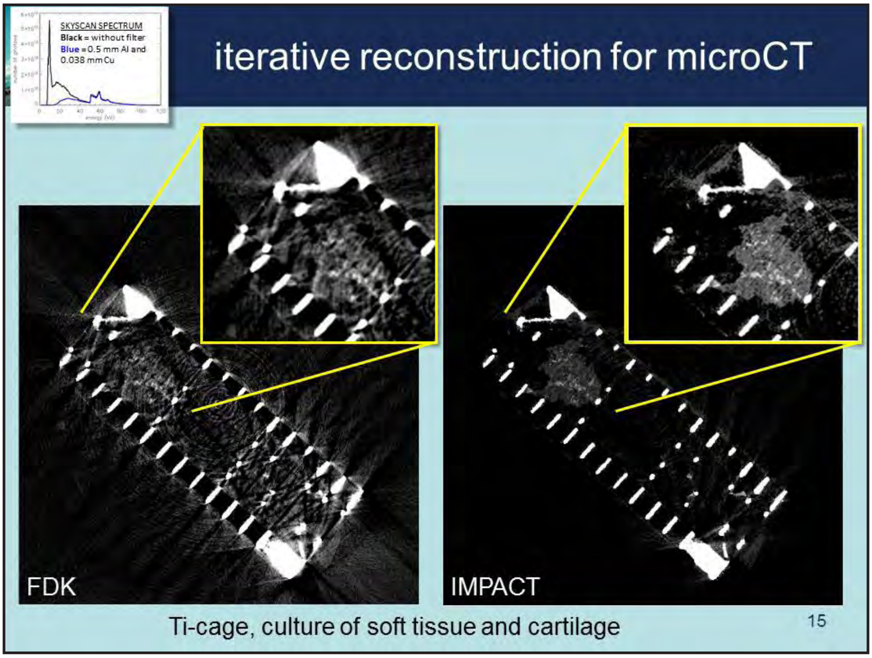


clinical CT (Siemens Sensation 16)
Body shaped phantom



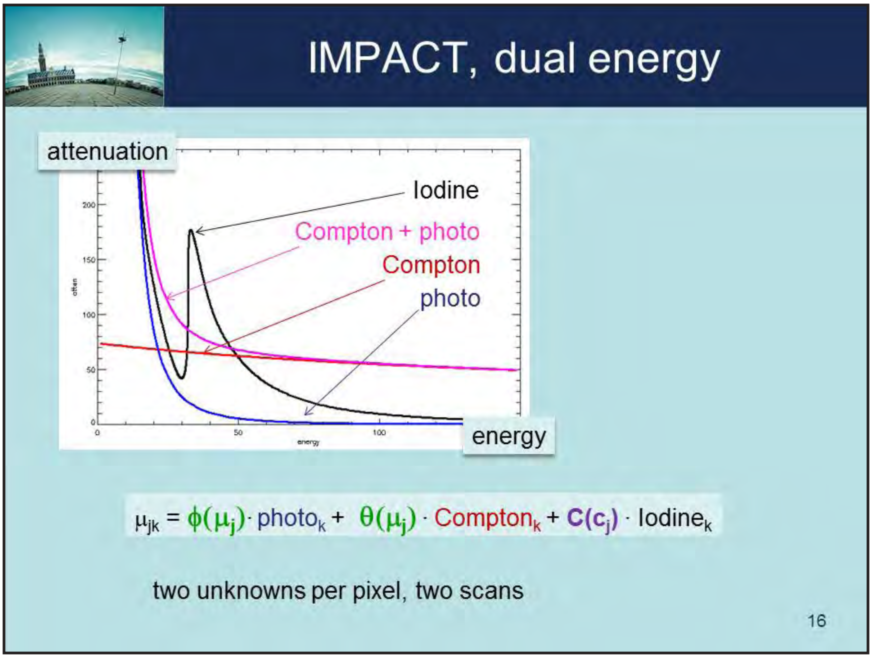
clinical CT (Siemens Sensation 16)
Body shaped phantom

Black = **FBP**
Blue = **PC-NMAR**
Red = **IMPACT PATCH**



iterative reconstruction for microCT

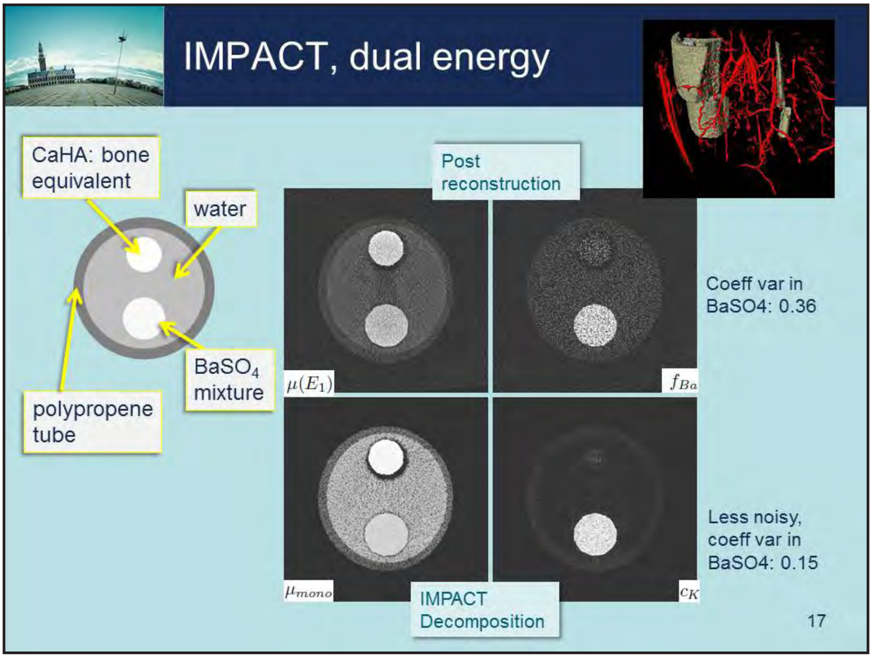
Ti-cage, culture of soft tissue and cartilage



IMPACT, dual energy

$$\mu_{jk} = \phi(\mu_j)\cdot \text{photo}_k + \theta(\mu_j)\cdot \text{Compton}_k + C(c_j)\cdot \text{Iodine}_k$$

two unknowns per pixel, two scans



IMPACT, dual energy

CaHA: bone equivalent

water

BaSO$_4$ mixture

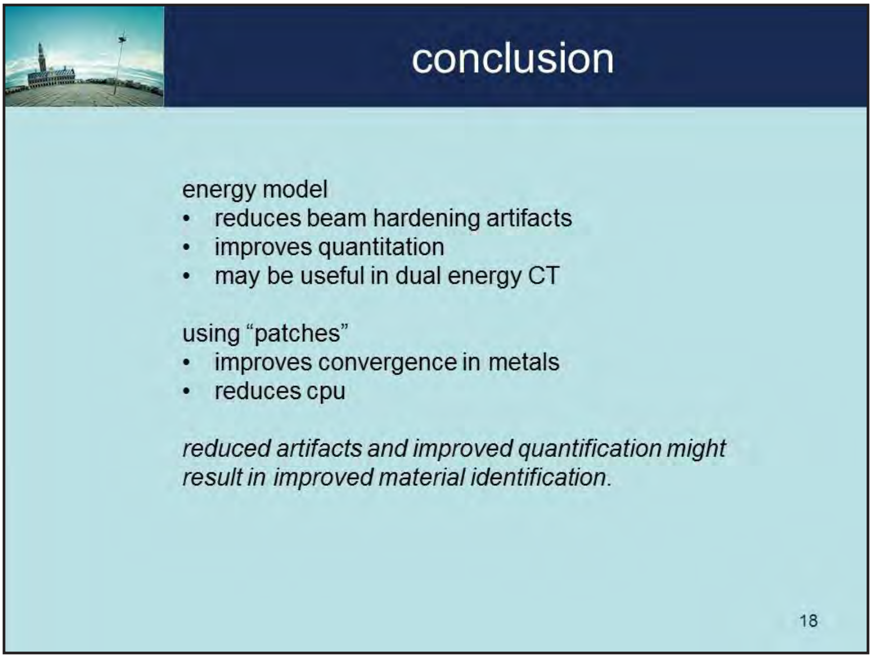
polypropene tube

Post reconstruction

Coeff var in BaSO4: 0.36

IMPACT Decomposition

Less noisy, coeff var in BaSO4: 0.15



conclusion

energy model
- reduces beam hardening artifacts
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- may be useful in dual energy CT

using "patches"
- improves convergence in metals
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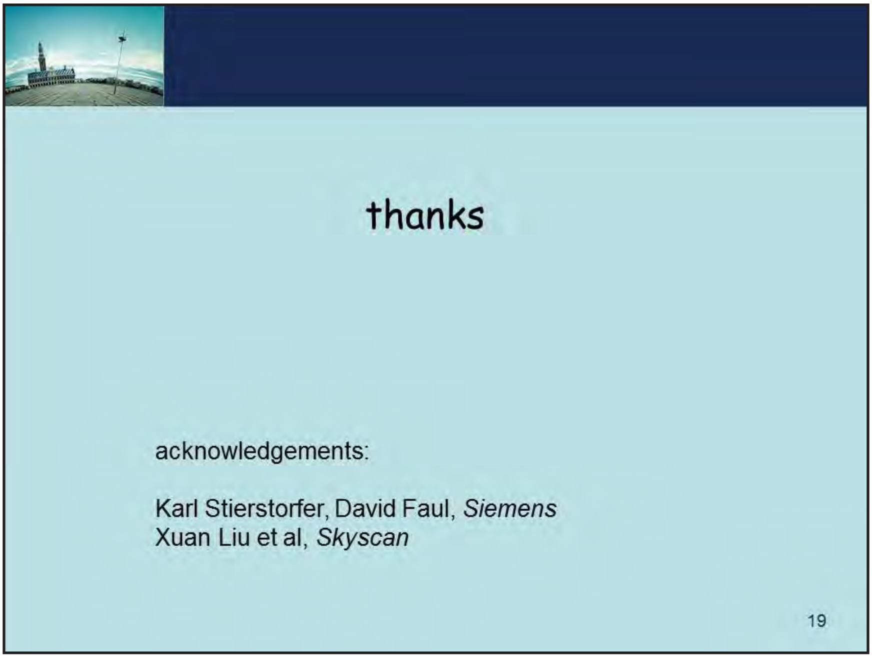
reduced artifacts and improved quantification might result in improved material identification.

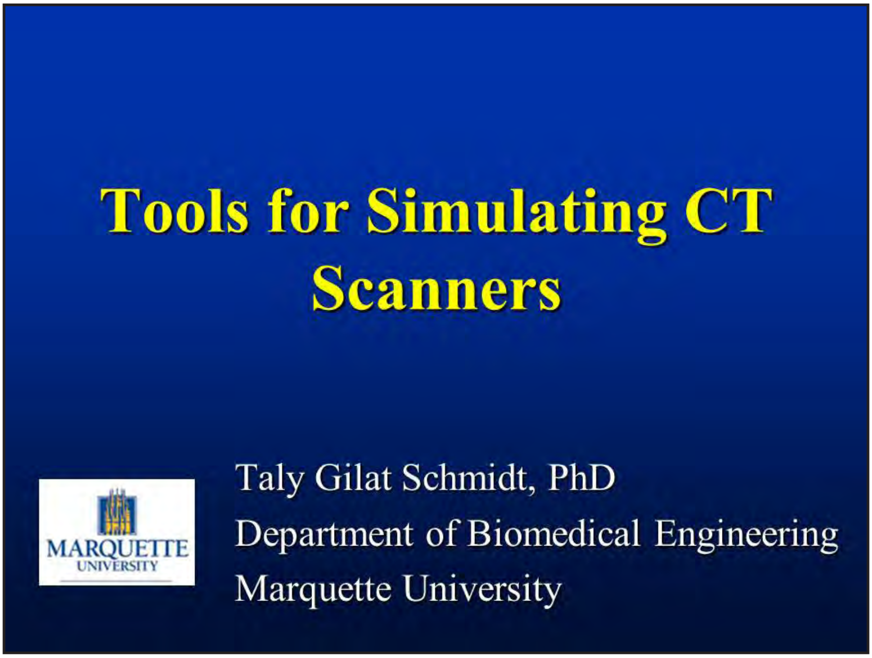


thanks

acknowledgements:

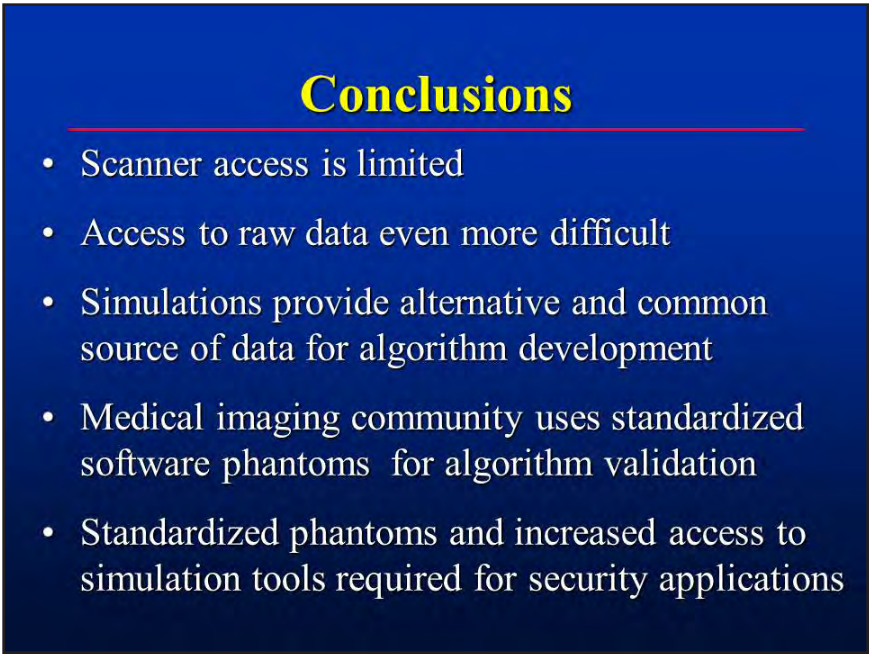
Karl Stierstorfer, David Faul, *Siemens*
Xuan Liu et al, *Skyscan*

16.11 Taly Gilat Schmidt: Tools for Simulating CT Scanners



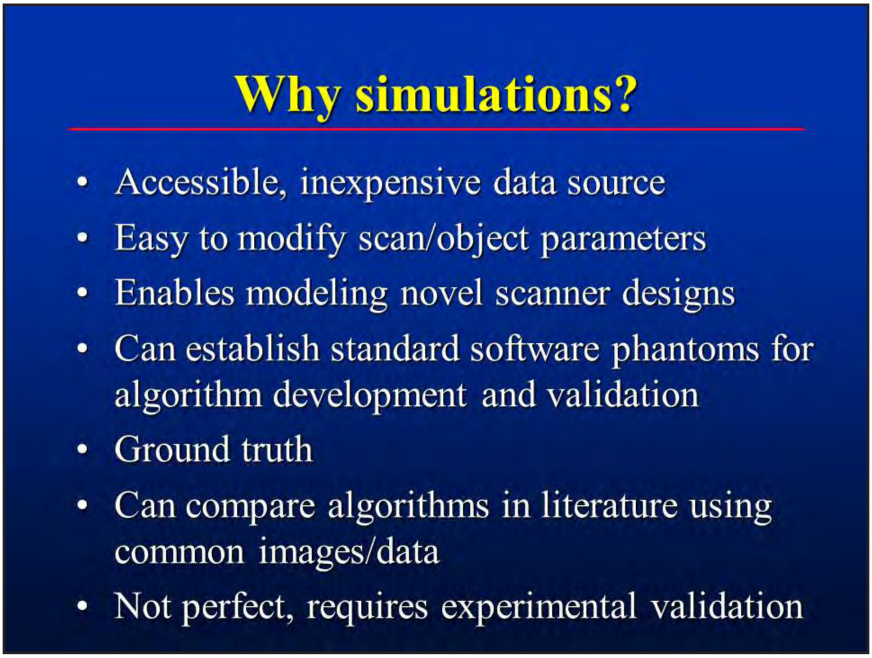
Tools for Simulating CT Scanners

Taly Gilat Schmidt, PhD
Department of Biomedical Engineering
Marquette University



Conclusions

- Scanner access is limited
- Access to raw data even more difficult
- Simulations provide alternative and common source of data for algorithm development
- Medical imaging community uses standardized software phantoms for algorithm validation
- Standardized phantoms and increased access to simulation tools required for security applications

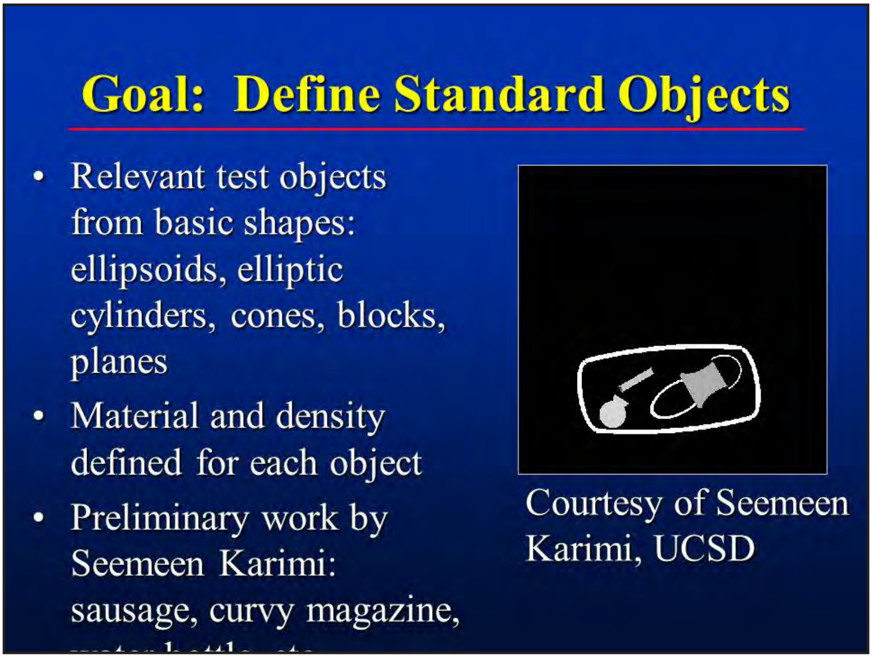


Why simulations?

- Accessible, inexpensive data source
- Easy to modify scan/object parameters
- Enables modeling novel scanner designs
- Can establish standard software phantoms for algorithm development and validation
- Ground truth
- Can compare algorithms in literature using common images/data
- Not perfect, requires experimental validation

Goal for security research

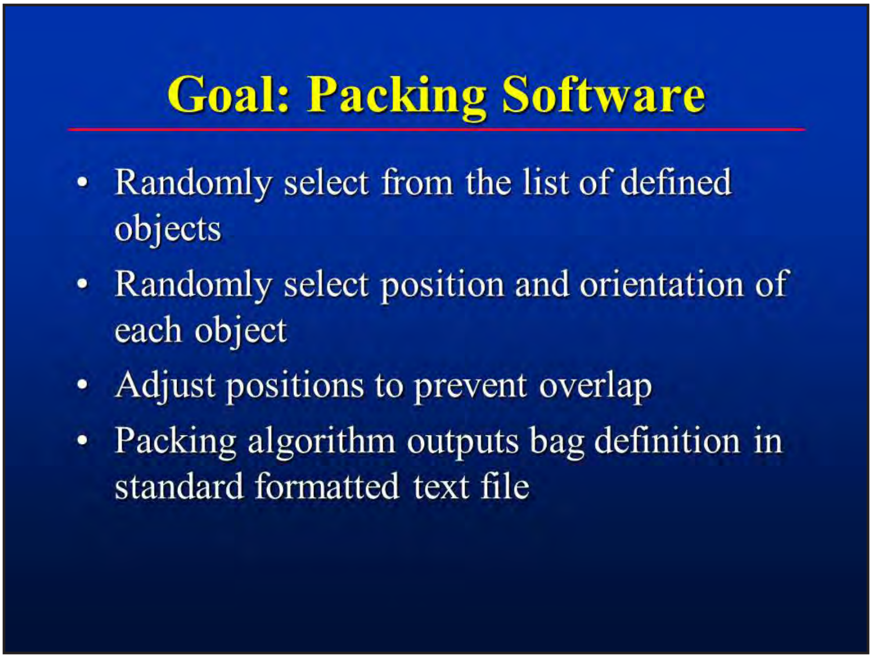
- Define standard test bags and objects
  - repeatable across groups and sites
- Develop packing software
- Develop simulation software that models realistic scanner effects



Goal: Define Standard Objects

- Relevant test objects from basic shapes: ellipsoids, elliptic cylinders, cones, blocks, planes
- Material and density defined for each object
- Preliminary work by Seemeen Karimi: sausage, curvy magazine,

Courtesy of Seemeen Karimi, UCSD



Goal: Packing Software

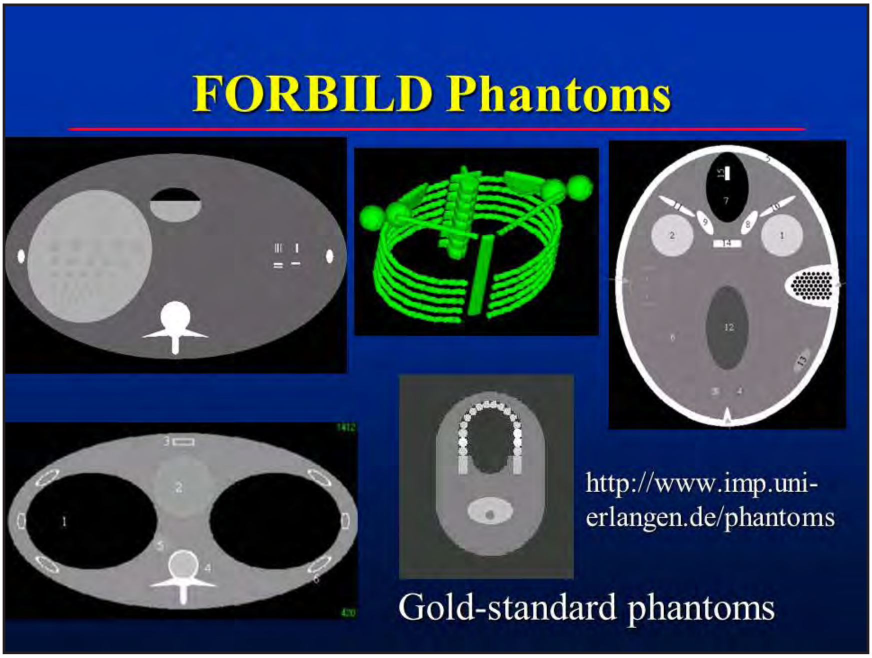
- Randomly select from the list of defined objects
- Randomly select position and orientation of each object
- Adjust positions to prevent overlap
- Packing algorithm outputs bag definition in standard formatted text file

Goal: Simulation Software

- Public Domain
- Easy to use
- Flexible scanner configuration
- Realistic scanner effects
- Validated

Outline

- What we can learn from the medical imaging community
- Simulation methods and tools



FORBILD Phantoms

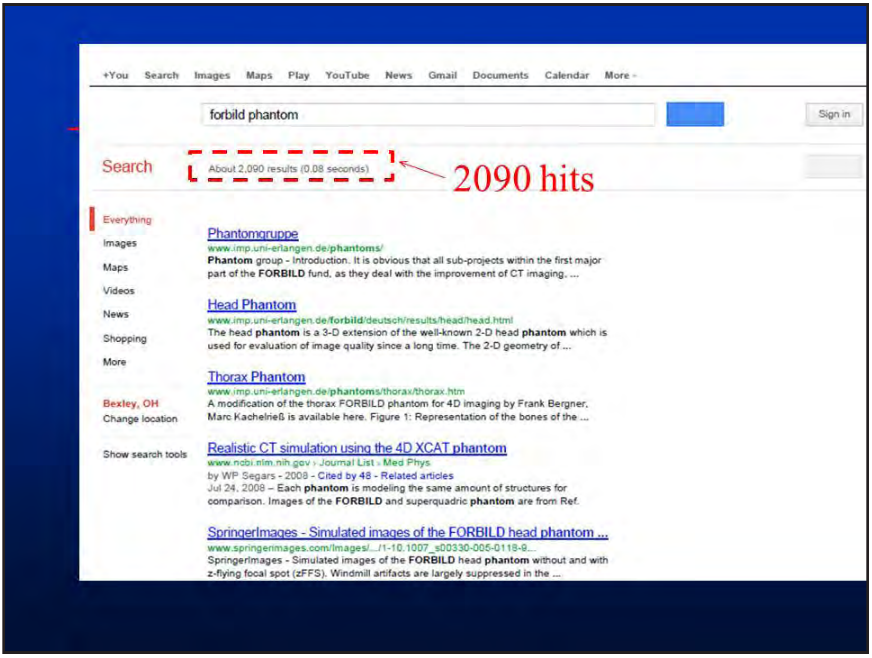
http://www.imp.uni-erlangen.de/phantoms

Gold-standard phantoms

FORBILD Phantoms

- Collaboration between the University of Erlangen and Siemens Medical Solutions
- Gold standard 3D phantom definitions for specific applications
  - abdomen, head, hip, jaw, lung, thorax
  - artifact, high-contrast, low-contrast

http://www.imp.uni-erlangen.de/phantoms



forbild phantom

About 2,090 results (0.08 seconds)

2090 hits

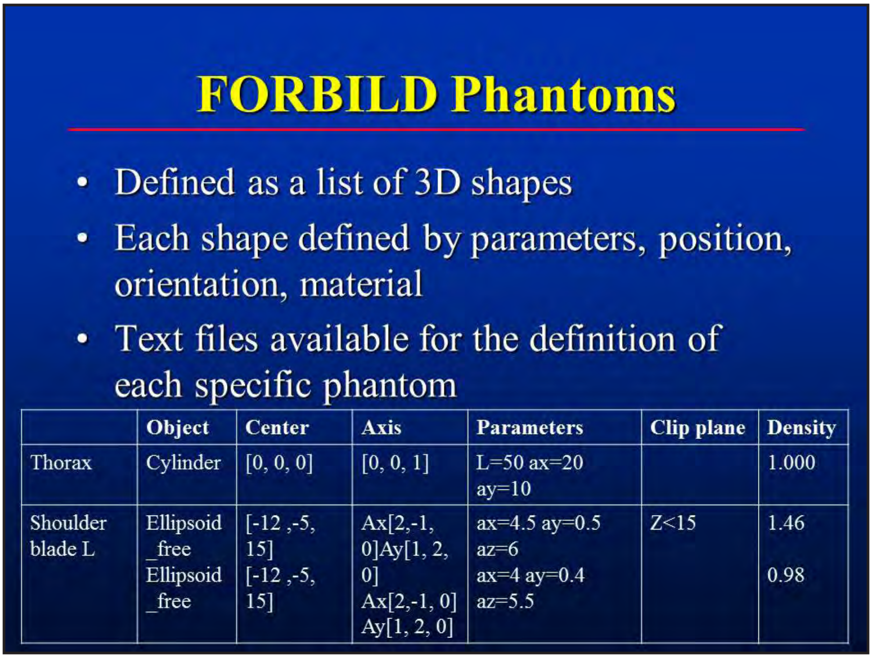
Phantomgruppe
www.imp.uni-erlangen.de/**phantoms**/
Phantom group - Introduction. It is obvious that all sub-projects within the first major part of the **FORBILD** fund, as they deal with the improvement of CT imaging. ...

Head Phantom
www.imp.uni-erlangen.de/**forbild**/deutsch/results/head/head.html
The head **phantom** is a 3-D extension of the well-known 2-D head **phantom** which is used for evaluation of image quality since a long time. The 2-D geometry of ...

Thorax Phantom
www.imp.uni-erlangen.de/**phantoms**/thorax/thorax.htm
A modification of the thorax FORBILD phantom for 4D imaging by Frank Bergner, Marc Kachelrieß is available here. Figure 1: Representation of the bones of the ...

Realistic CT simulation using the 4D XCAT phantom
www.ncbi.nlm.nih.gov › Journal List › Med Phys
by WP Segars - 2008 - Cited by 48 - Related articles
Jul 24, 2008 – Each **phantom** is modeling the same amount of structures for comparison. Images of the **FORBILD** and superquadric **phantom** are from Ref.

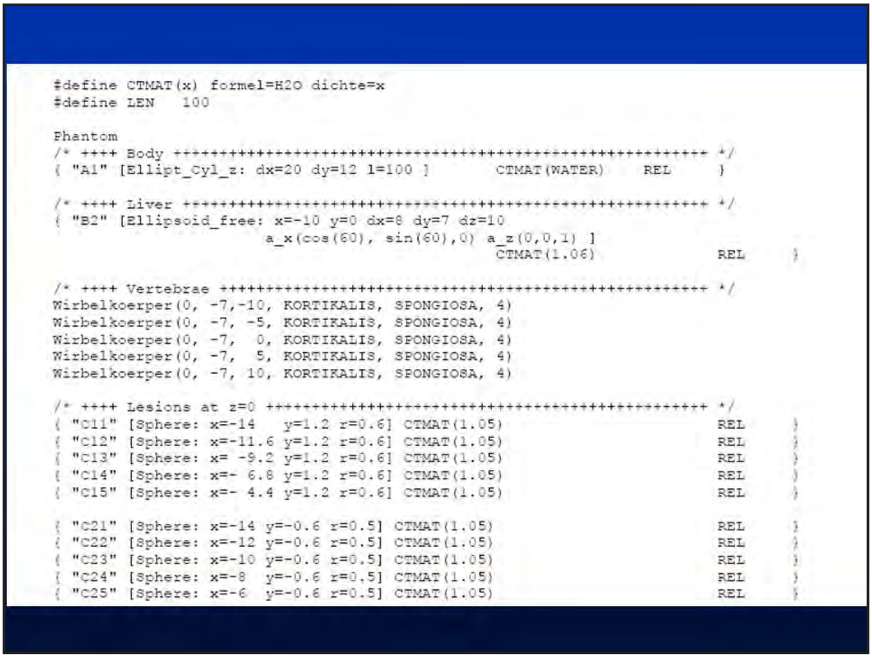
SpringerImages - Simulated images of the FORBILD head phantom ...
www.springerimages.com/Images/.../1-10.1007_s00330-005-0118-9...
SpringerImages - Simulated images of the **FORBILD** head **phantom** without and with z-flying focal spot (zFFS). Windmill artifacts are largely suppressed in the ...



FORBILD Phantoms

- Defined as a list of 3D shapes
- Each shape defined by parameters, position, orientation, material
- Text files available for the definition of each specific phantom

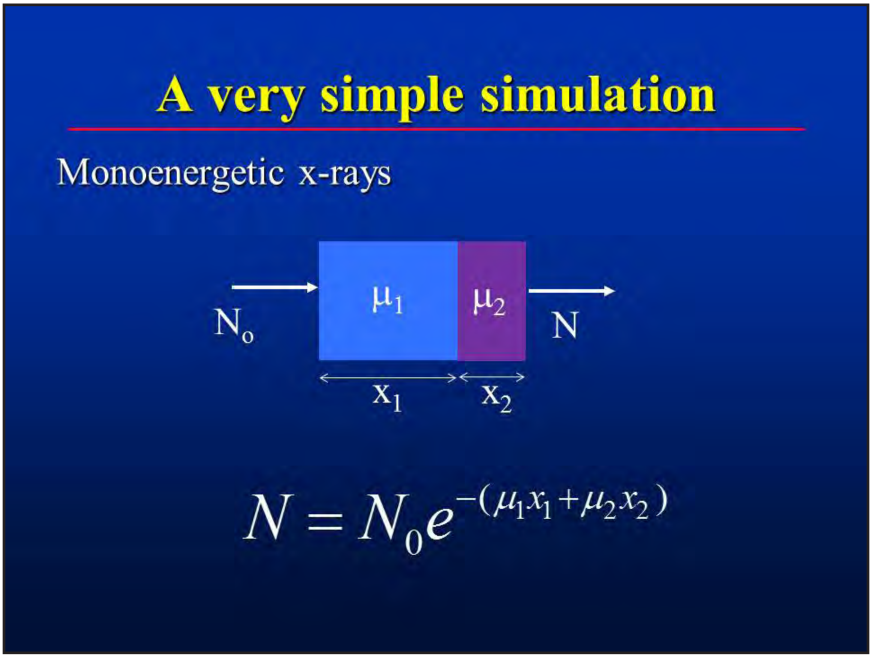
	Object	Center	Axis	Parameters	Clip plane	Density
Thorax	Cylinder	[0, 0, 0]	[0, 0, 1]	L=50 ax=20 ay=10		1.000
Shoulder blade L	Ellipsoid _free Ellipsoid _free	[-12 ,-5, 15] [-12 ,-5, 15]	Ax[2,-1, 0]Ay[1, 2, 0] Ax[2,-1, 0] Ay[1, 2, 0]	ax=4.5 ay=0.5 az=6 ax=4 ay=0.4 az=5.5	Z<15	1.46 0.98



```
#define CTMAT(x) formel=H2O dichte=x
#define LEN   100

Phantom
/* ++++ Body ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ */
{ "A1" [Ellipt_Cyl_z: dx=20 dy=12 l=100 ]       CTMAT(WATER)    REL     }

/* ++++ Liver +++++++++++++++++++++++++++++++++++++++++++++++++++++++++ */
{ "B2" [Ellipsoid_free: x=-10 y=0 dx=8 dy=7 dz=10
                       a_x(cos(60), sin(60),0) a_z(0,0,1) ]
                                                CTMAT(1.06)             REL     }

/* ++++ Vertebrae +++++++++++++++++++++++++++++++++++++++++++++++++++++ */
Wirbelkoerper(0, -7,-10, KORTIKALIS, SPONGIOSA, 4)
Wirbelkoerper(0, -7, -5, KORTIKALIS, SPONGIOSA, 4)
Wirbelkoerper(0, -7,  0, KORTIKALIS, SPONGIOSA, 4)
Wirbelkoerper(0, -7,  5, KORTIKALIS, SPONGIOSA, 4)
Wirbelkoerper(0, -7, 10, KORTIKALIS, SPONGIOSA, 4)

/* ++++ Lesions at z=0 ++++++++++++++++++++++++++++++++++++++++++++++++ */
{ "C11" [Sphere: x=-14   y=1.2 r=0.6] CTMAT(1.05)                      REL     }
{ "C12" [Sphere: x=-11.6 y=1.2 r=0.6] CTMAT(1.05)                      REL     }
{ "C13" [Sphere: x= -9.2 y=1.2 r=0.6] CTMAT(1.05)                      REL     }
{ "C14" [Sphere: x=- 6.8 y=1.2 r=0.6] CTMAT(1.05)                      REL     }
{ "C15" [Sphere: x=- 4.4 y=1.2 r=0.6] CTMAT(1.05)                      REL     }

{ "C21" [Sphere: x=-14 y=-0.6 r=0.5] CTMAT(1.05)                       REL     }
{ "C22" [Sphere: x=-12 y=-0.6 r=0.5] CTMAT(1.05)                       REL     }
{ "C23" [Sphere: x=-10 y=-0.6 r=0.5] CTMAT(1.05)                       REL     }
{ "C24" [Sphere: x=-8  y=-0.6 r=0.5] CTMAT(1.05)                       REL     }
{ "C25" [Sphere: x=-6  y=-0.6 r=0.5] CTMAT(1.05)                       REL     }
```

Outline

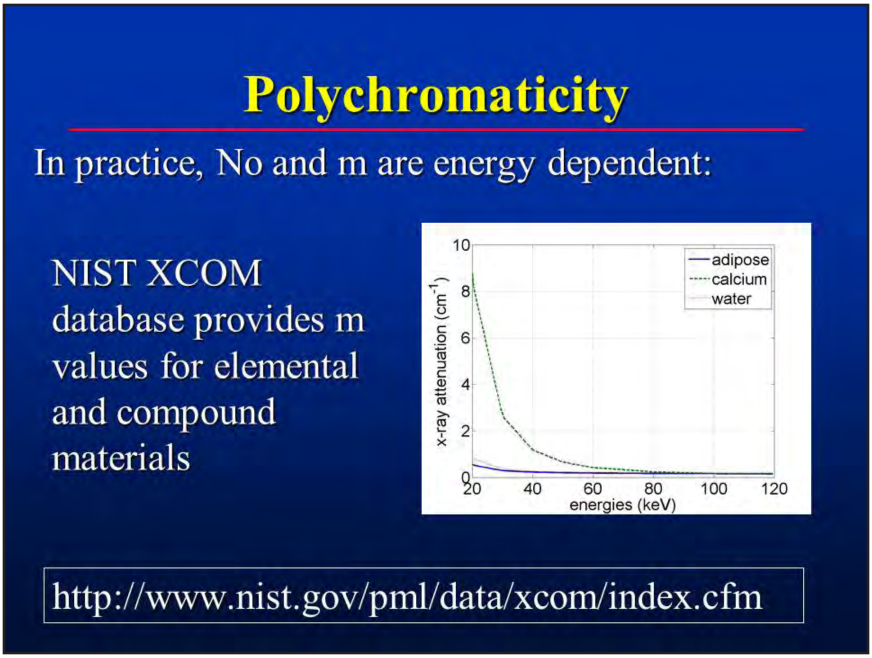
- What we can learn from the medical imaging community
- Simulation methods and tools



A very simple simulation

Monoenergetic x-rays

$$N = N_0 e^{-(\mu_1 x_1 + \mu_2 x_2)}$$

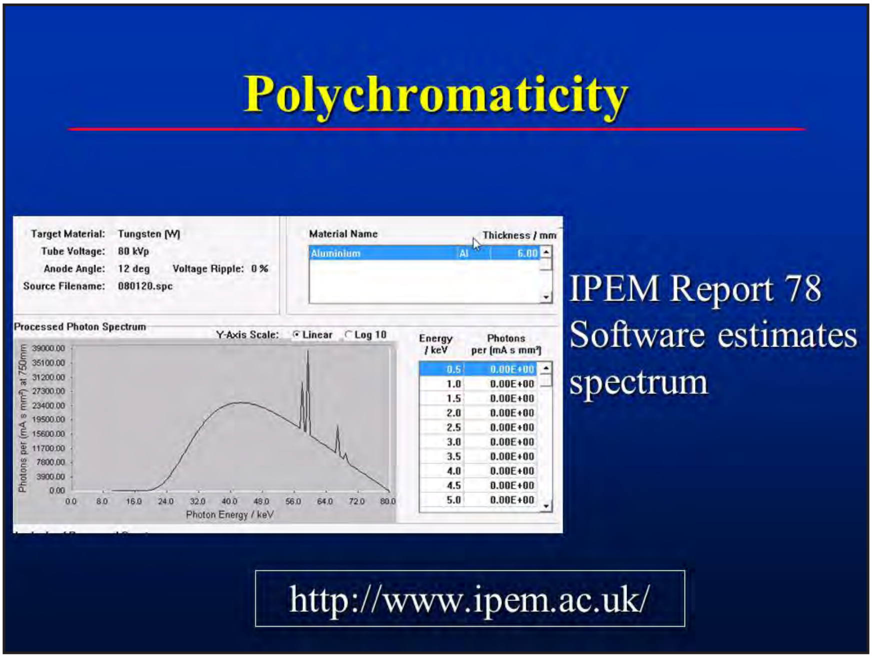


Polychromaticity

In practice, No and m are energy dependent:

NIST XCOM database provides m values for elemental and compound materials

http://www.nist.gov/pml/data/xcom/index.cfm



Polychromaticity

Target Material: Tungsten (W)
Tube Voltage: 80 kVp
Anode Angle: 12 deg
Voltage Ripple: 0 %
Source Filename: 080120.spc

Material Name		Thickness / mm
Aluminium	Al	6.00

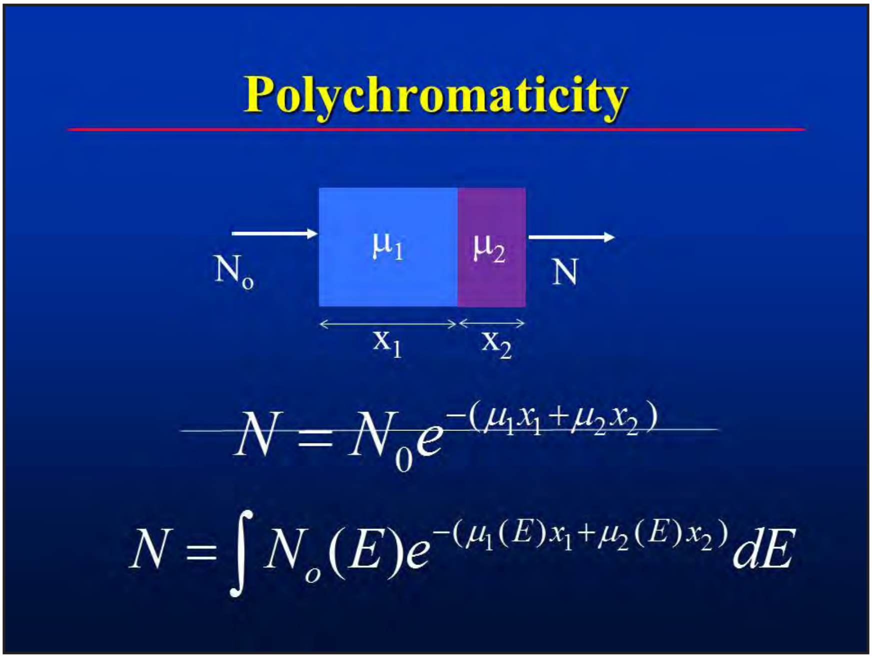
Processed Photon Spectrum

Y-Axis Scale: ● Linear ○ Log 10

Energy / keV	Photons per (mA s mm²)
0.5	0.00E+00
1.0	0.00E+00
1.5	0.00E+00
2.0	0.00E+00
2.5	0.00E+00
3.0	0.00E+00
3.5	0.00E+00
4.0	0.00E+00
4.5	0.00E+00
5.0	0.00E+00

IPEM Report 78
Software estimates spectrum

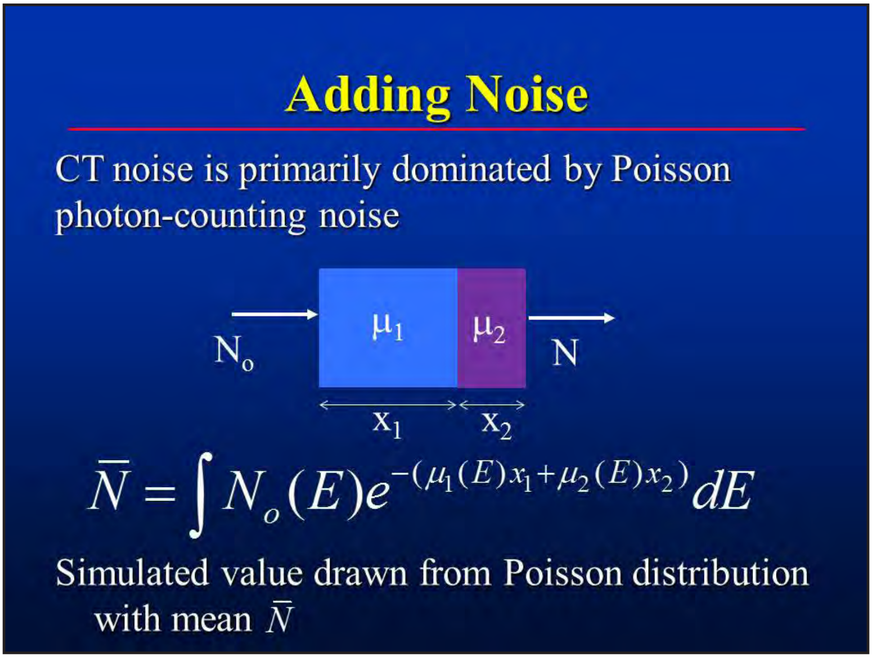
http://www.ipem.ac.uk/



Polychromaticity

$$\cancel{N = N_0 e^{-(\mu_1 x_1 + \mu_2 x_2)}}$$

$$N = \int N_o(E) e^{-(\mu_1(E) x_1 + \mu_2(E) x_2)} dE$$

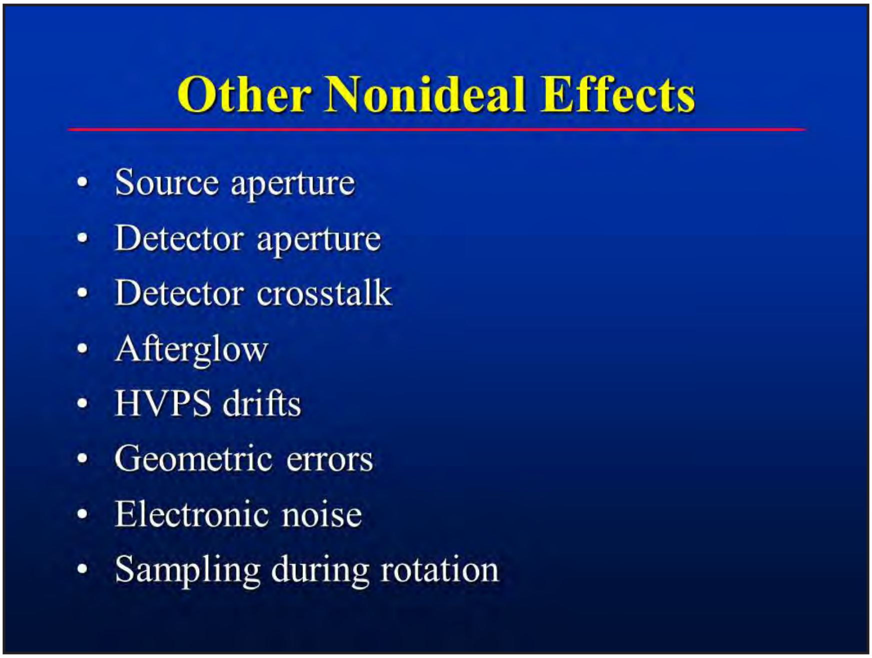


Adding Noise

CT noise is primarily dominated by Poisson photon-counting noise

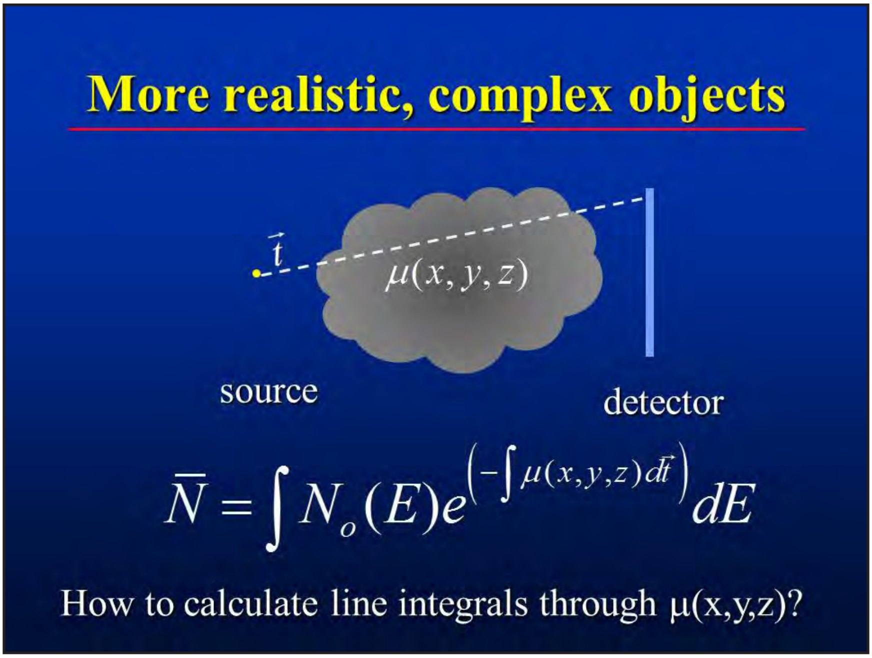
$$\bar{N} = \int N_o(E) e^{-(\mu_1(E)x_1 + \mu_2(E)x_2)} dE$$

Simulated value drawn from Poisson distribution with mean $\bar{N}$



Other Nonideal Effects

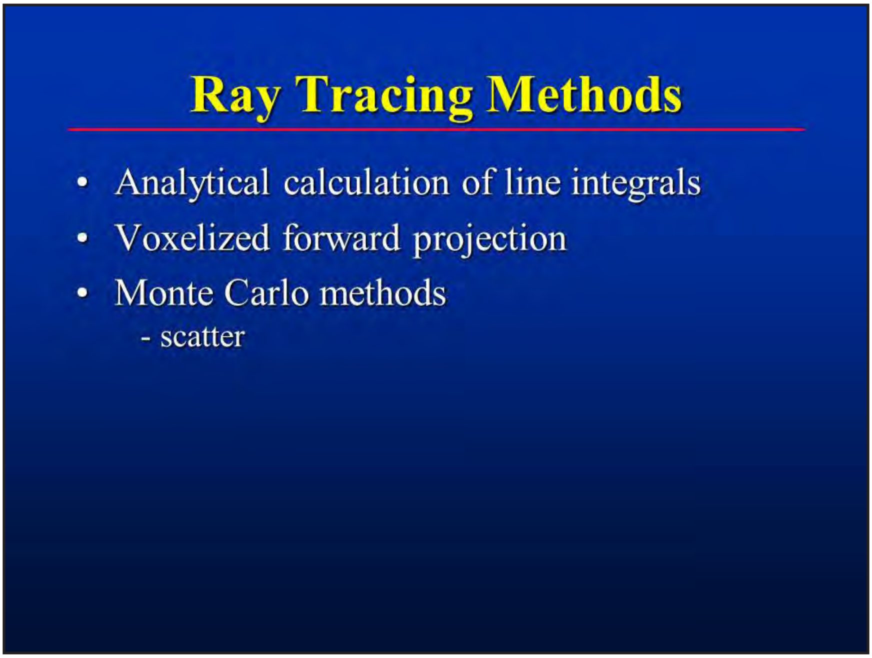
- Source aperture
- Detector aperture
- Detector crosstalk
- Afterglow
- HVPS drifts
- Geometric errors
- Electronic noise
- Sampling during rotation



More realistic, complex objects

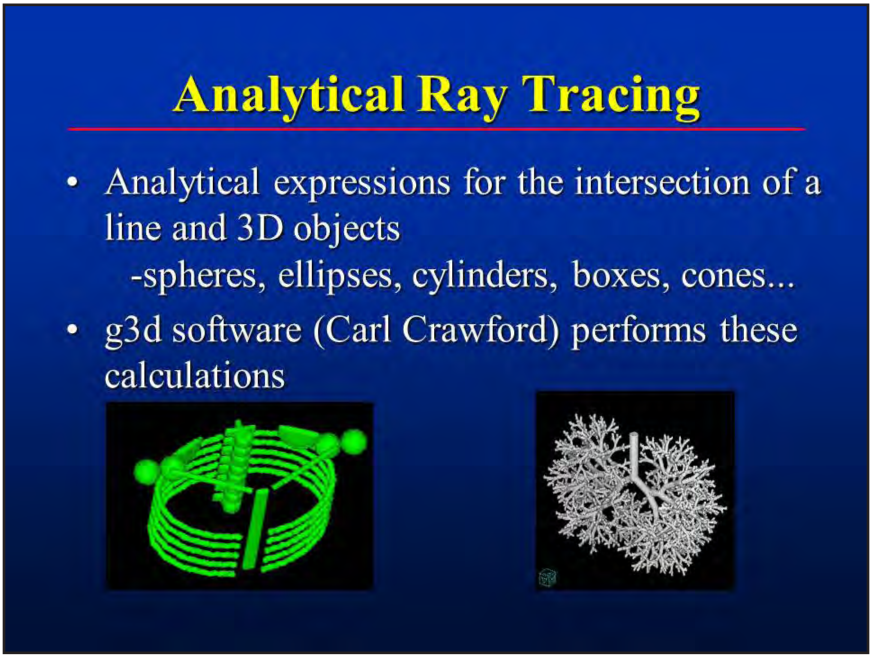
$$\bar{N} = \int N_o(E) e^{\left(-\int \mu(x,y,z)\, d\vec{t}\right)} dE$$

How to calculate line integrals through μ(x,y,z)?



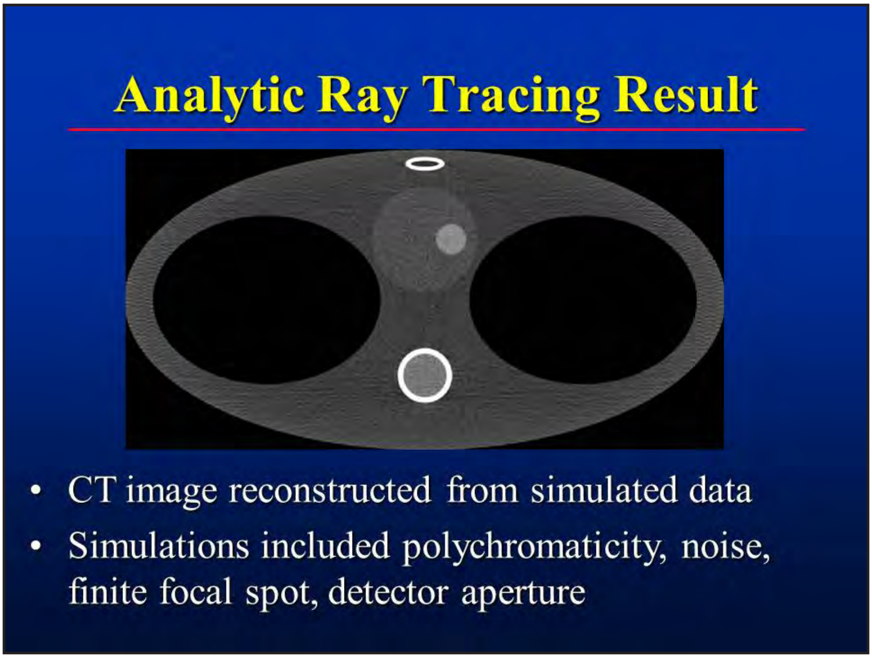
Ray Tracing Methods

- Analytical calculation of line integrals
- Voxelized forward projection
- Monte Carlo methods
  - scatter



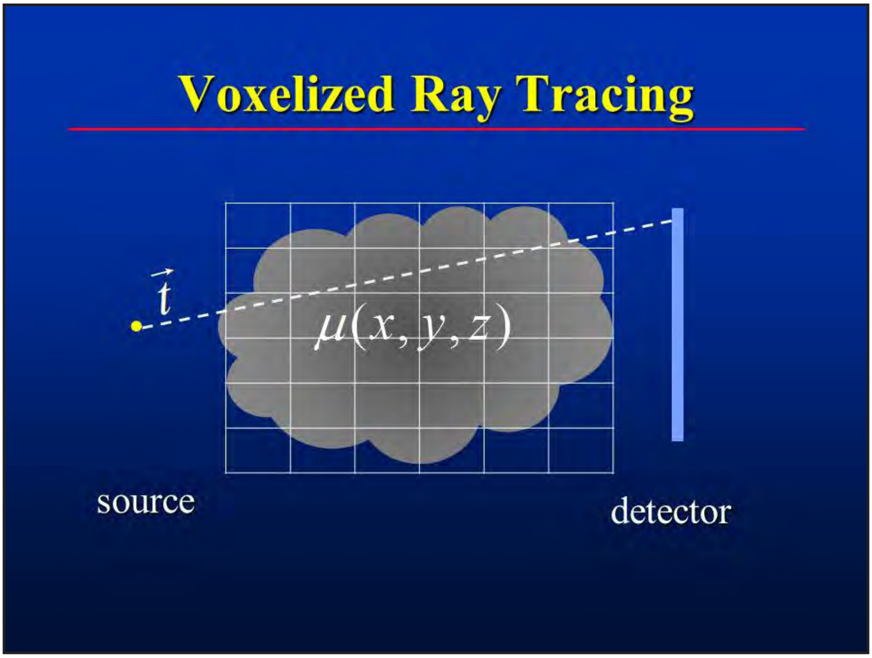
Analytical Ray Tracing

- Analytical expressions for the intersection of a line and 3D objects
  - -spheres, ellipses, cylinders, boxes, cones...
- g3d software (Carl Crawford) performs these calculations

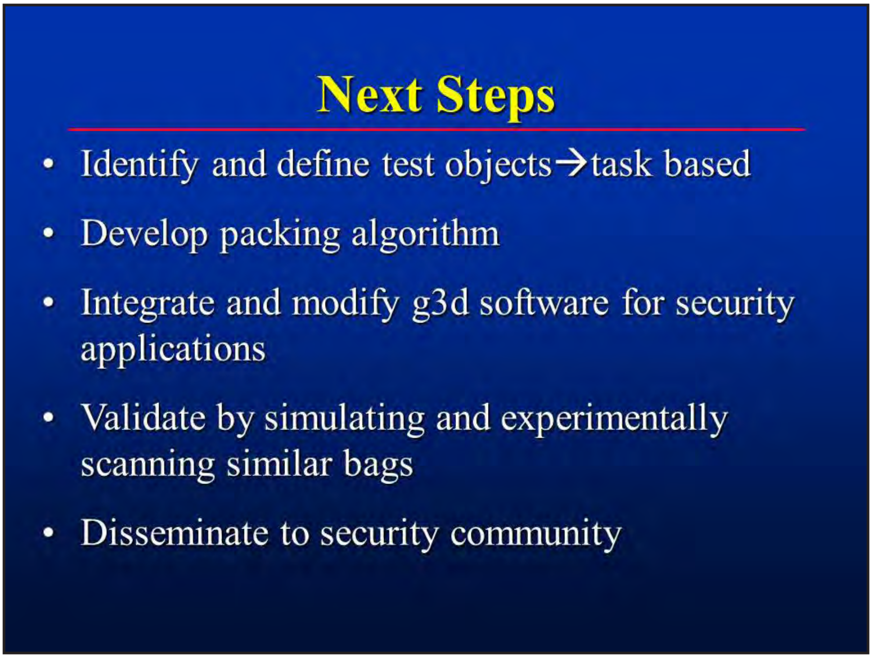


Analytic Ray Tracing Result

- CT image reconstructed from simulated data
- Simulations included polychromaticity, noise, finite focal spot, detector aperture

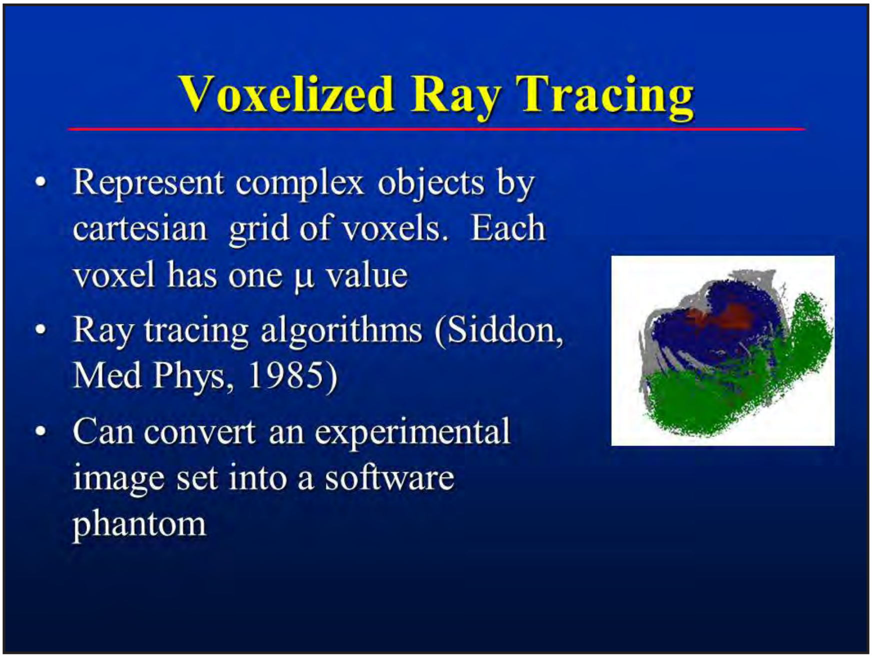


Voxelized Ray Tracing



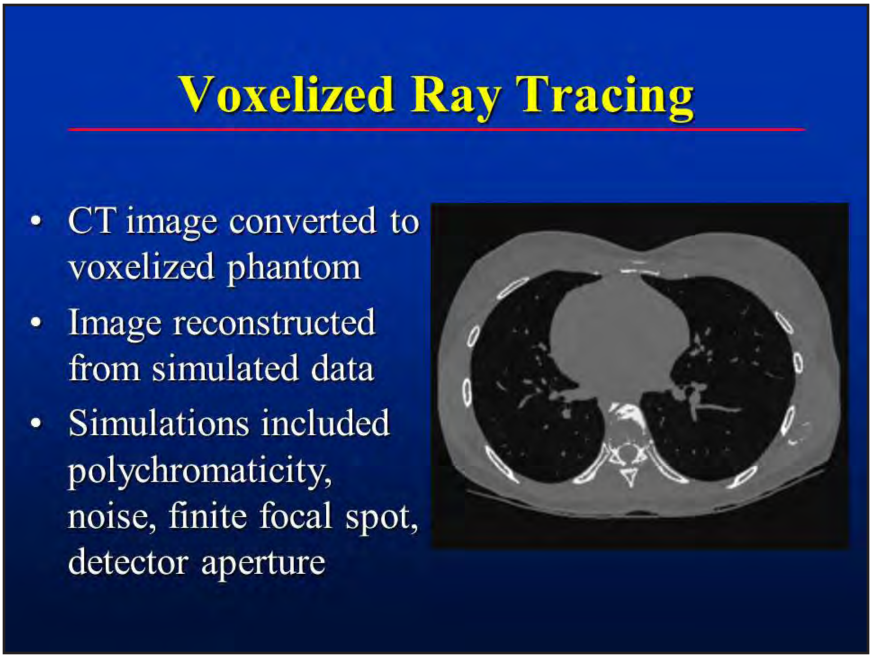
Next Steps

- Identify and define test objects→task based
- Develop packing algorithm
- Integrate and modify g3d software for security applications
- Validate by simulating and experimentally scanning similar bags
- Disseminate to security community



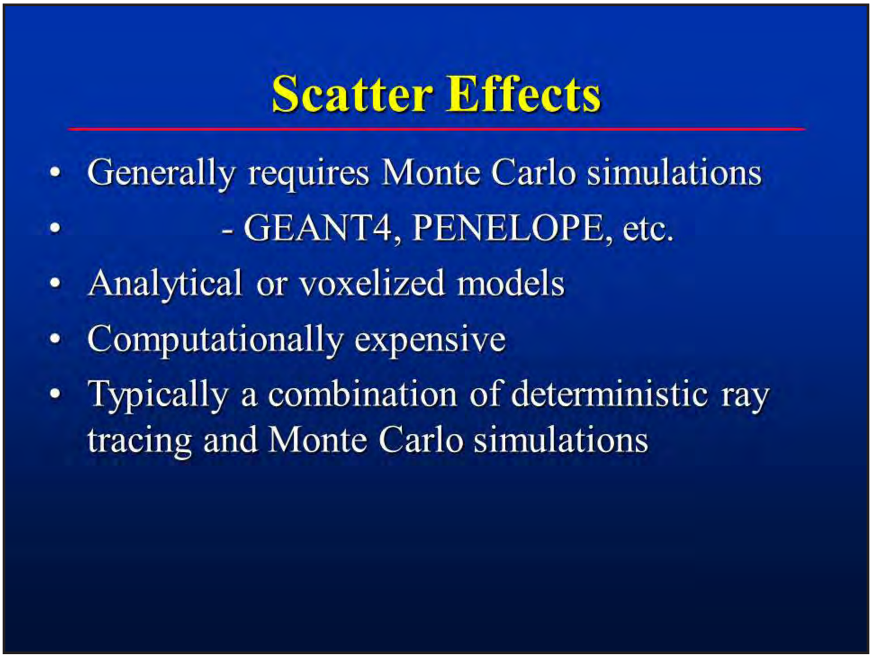
Voxelized Ray Tracing

- Represent complex objects by cartesian grid of voxels. Each voxel has one μ value
- Ray tracing algorithms (Siddon, Med Phys, 1985)
- Can convert an experimental image set into a software phantom



Voxelized Ray Tracing

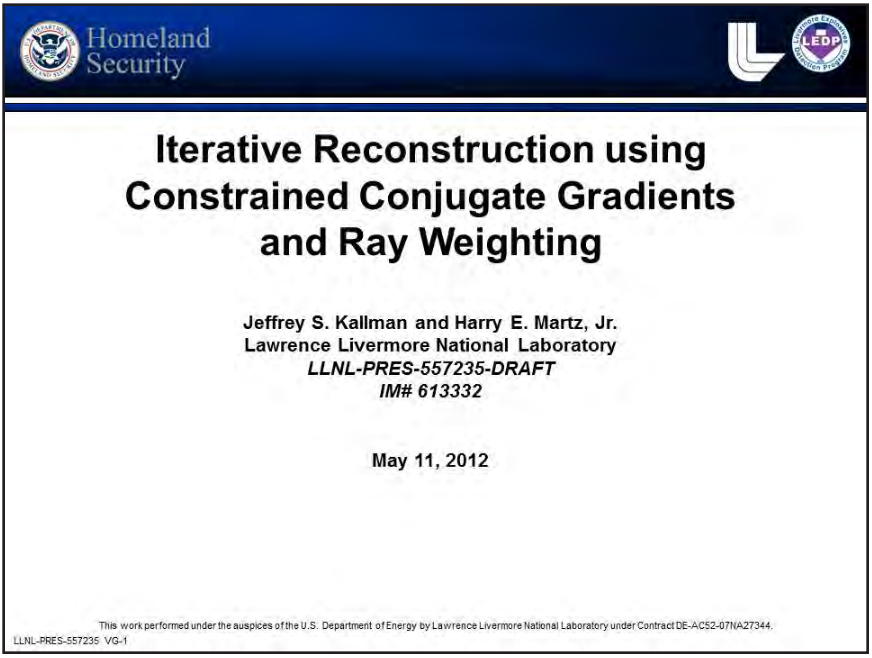
- CT image converted to voxelized phantom
- Image reconstructed from simulated data
- Simulations included polychromaticity, noise, finite focal spot, detector aperture



Scatter Effects

- Generally requires Monte Carlo simulations
- - GEANT4, PENELOPE, etc.
- Analytical or voxelized models
- Computationally expensive
- Typically a combination of deterministic ray tracing and Monte Carlo simulations

16.12 Harry Martz: Iterative Reconstruction using Constrained Conjugate Gradients and Ray Weighting



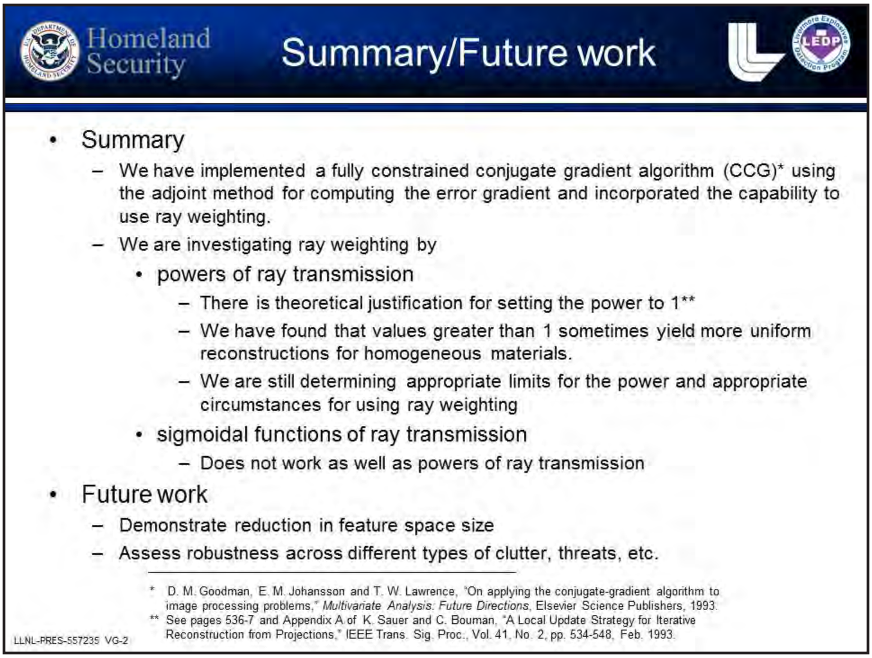
Iterative Reconstruction using Constrained Conjugate Gradients and Ray Weighting

Jeffrey S. Kallman and Harry E. Martz, Jr.
Lawrence Livermore National Laboratory
LLNL-PRES-557235-DRAFT
IM# 613332

May 11, 2012

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

LLNL-PRES-557235 VG-1



Summary/Future work

- Summary
  - We have implemented a fully constrained conjugate gradient algorithm (CCG)* using the adjoint method for computing the error gradient and incorporated the capability to use ray weighting.
  - We are investigating ray weighting by
    - powers of ray transmission
      - There is theoretical justification for setting the power to 1**
      - We have found that values greater than 1 sometimes yield more uniform reconstructions for homogeneous materials.
      - We are still determining appropriate limits for the power and appropriate circumstances for using ray weighting
    - sigmoidal functions of ray transmission
      - Does not work as well as powers of ray transmission
- Future work
  - Demonstrate reduction in feature space size
  - Assess robustness across different types of clutter, threats, etc.

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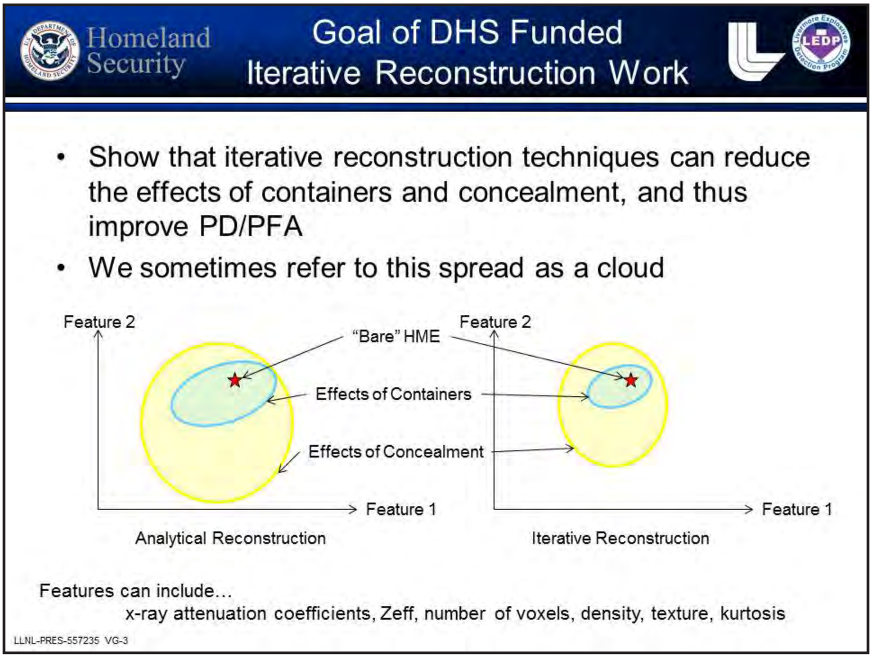
* D. M. Goodman, E. M. Johansson and T. W. Lawrence, "On applying the conjugate-gradient algorithm to image processing problems," *Multivariate Analysis: Future Directions*, Elsevier Science Publishers, 1993.

** See pages 536-7 and Appendix A of K. Sauer and C. Bouman, "A Local Update Strategy for Iterative Reconstruction from Projections," IEEE Trans. Sig. Proc., Vol. 41, No. 2, pp. 534-548, Feb. 1993.

LLNL-PRES-557235 VG-2

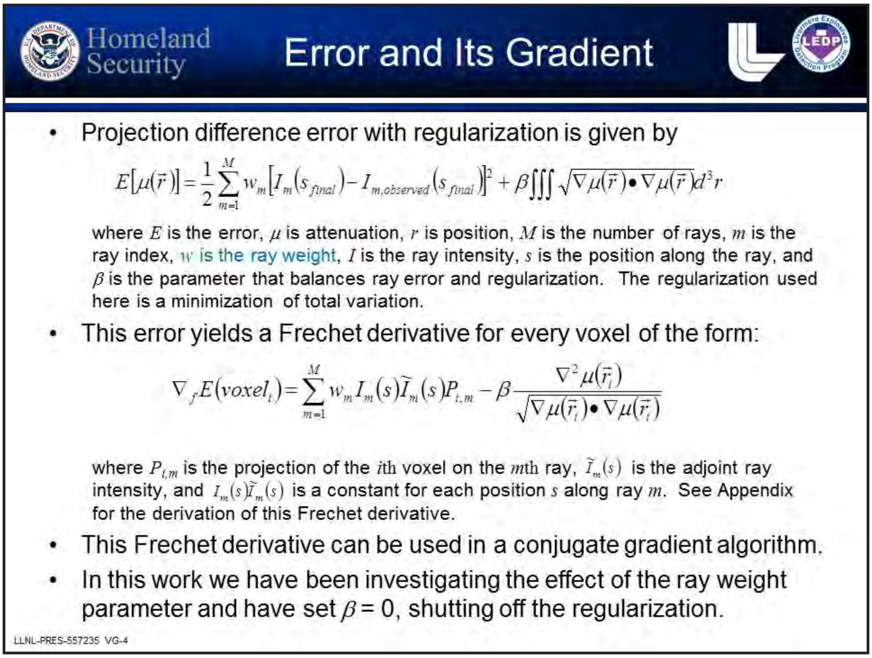


Goal of DHS Funded Iterative Reconstruction Work

- Show that iterative reconstruction techniques can reduce the effects of containers and concealment, and thus improve PD/PFA
- We sometimes refer to this spread as a cloud

Features can include…
x-ray attenuation coefficients, Zeff, number of voxels, density, texture, kurtosis

LLNL-PRES-557235 VG-3



Error and Its Gradient

- Projection difference error with regularization is given by

$$E[\mu(\vec{r})]=\frac{1}{2}\sum_{m=1}^{M}w_m\left[I_m(s_{final})-I_{m,observed}(s_{final})\right]^2+\beta\iiint\sqrt{\nabla\mu(\vec{r})\bullet\nabla\mu(\vec{r})}d^3r$$

where E is the error, μ is attenuation, r is position, M is the number of rays, m is the ray index, w is the ray weight, I is the ray intensity, s is the position along the ray, and β is the parameter that balances ray error and regularization. The regularization used here is a minimization of total variation.

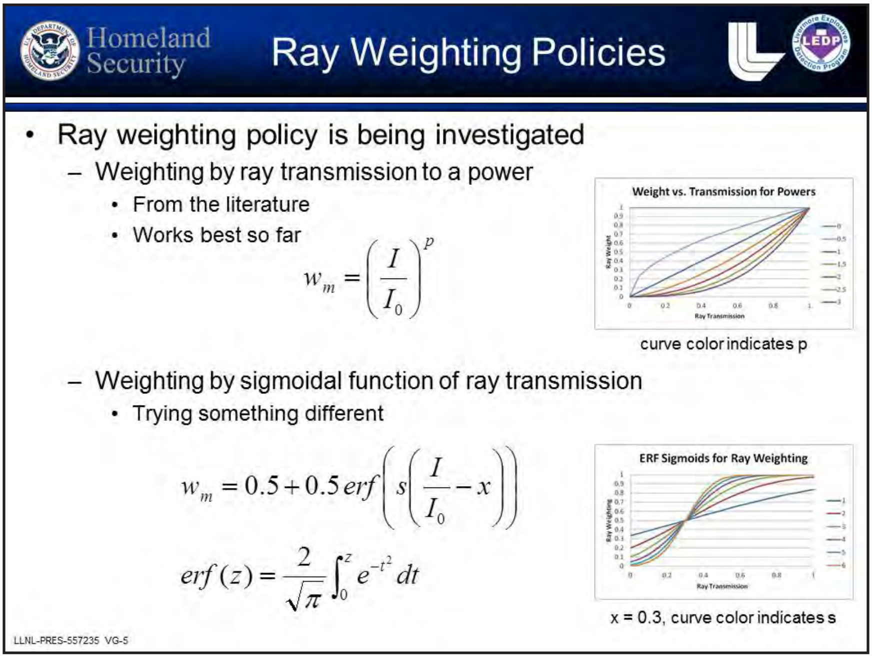
- This error yields a Frechet derivative for every voxel of the form:

$$\nabla_f E(voxel_i)=\sum_{m=1}^{M}w_m I_m(s)\tilde{I}_m(s)P_{i,m}-\beta\frac{\nabla^2\mu(\vec{r}_i)}{\sqrt{\nabla\mu(\vec{r}_i)\bullet\nabla\mu(\vec{r}_i)}}$$

where $P_{i,m}$ is the projection of the ith voxel on the mth ray, $\tilde{I}_m(s)$ is the adjoint ray intensity, and $I_m(s)\tilde{I}_m(s)$ is a constant for each position s along ray m. See Appendix for the derivation of this Frechet derivative.

- This Frechet derivative can be used in a conjugate gradient algorithm.
- In this work we have been investigating the effect of the ray weight parameter and have set $\beta = 0$, shutting off the regularization.

LLNL-PRES-557235 VG-4



Homeland Security

Ray Weighting Policies

- Ray weighting policy is being investigated
  - Weighting by ray transmission to a power
    - From the literature
    - Works best so far

$$w_m = \left(\frac{I}{I_0}\right)^p$$

curve color indicates p

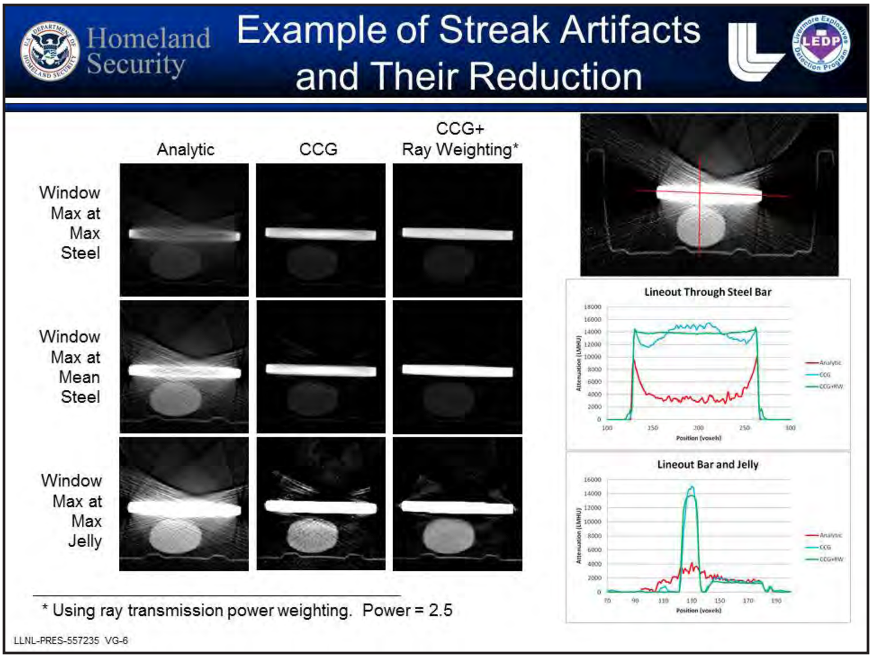
  - Weighting by sigmoidal function of ray transmission
    - Trying something different

$$w_m = 0.5 + 0.5\,erf\left(s\left(\frac{I}{I_0} - x\right)\right)$$

$$erf(z) = \frac{2}{\sqrt{\pi}}\int_0^z e^{-t^2}\,dt$$

x = 0.3, curve color indicates s

LLNL-PRES-557235 VG-5

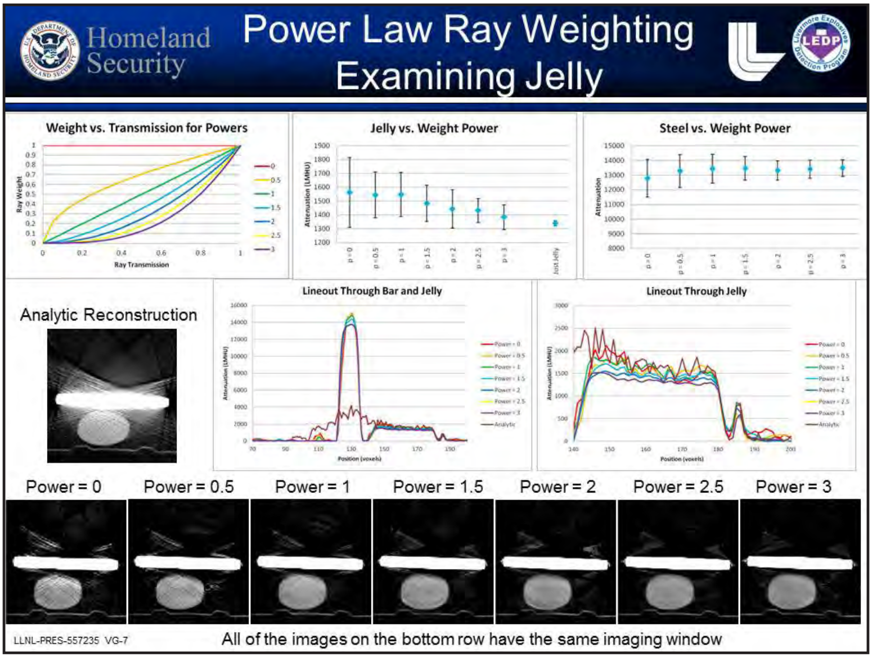


Homeland Security

Example of Streak Artifacts and Their Reduction

* Using ray transmission power weighting. Power = 2.5

LLNL-PRES-557235 VG-6



Homeland Security

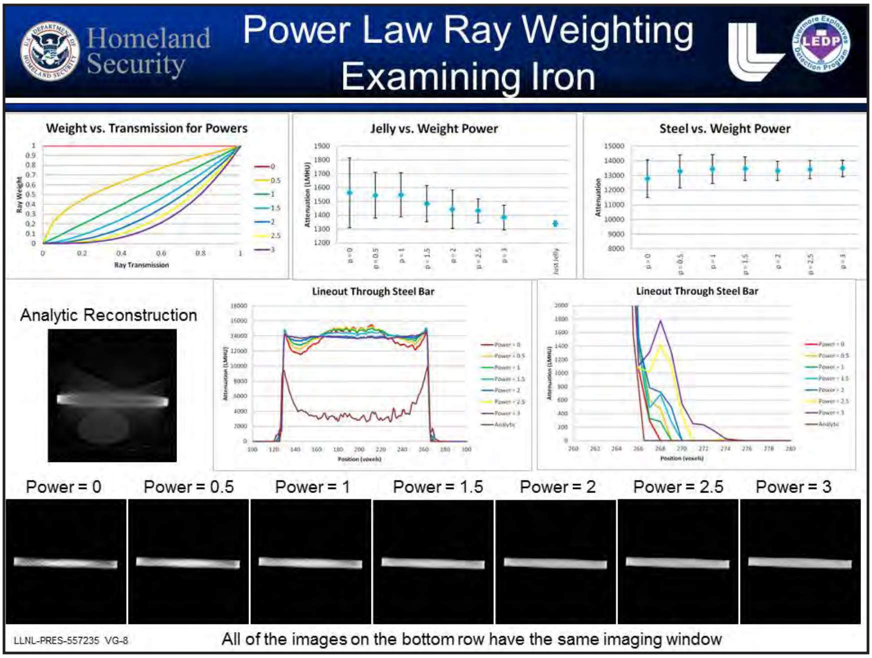
Power Law Ray Weighting Examining Jelly

Analytic Reconstruction

Power = 0 Power = 0.5 Power = 1 Power = 1.5 Power = 2 Power = 2.5 Power = 3

LLNL-PRES-557235 VG-7

All of the images on the bottom row have the same imaging window



Homeland Security

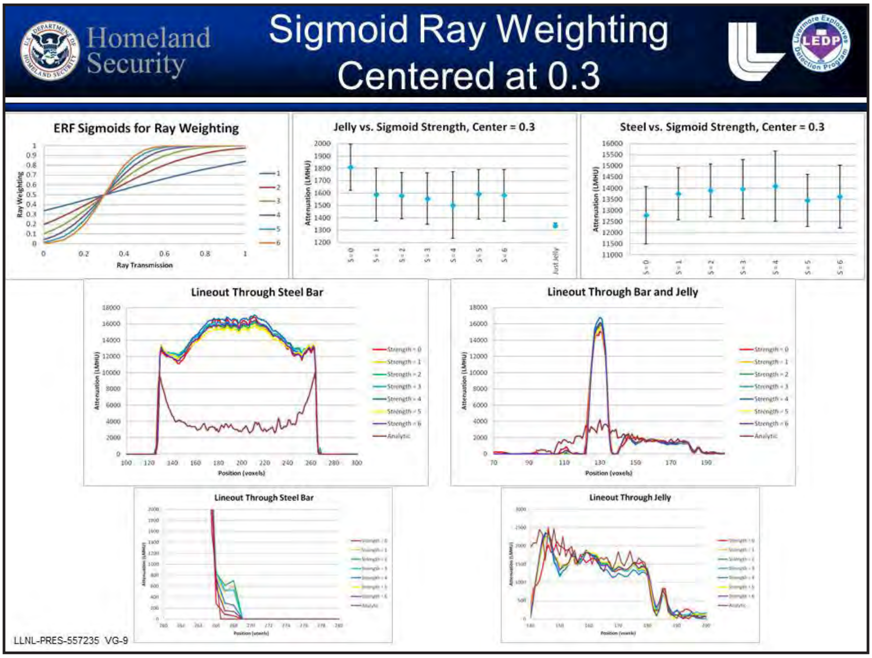
Power Law Ray Weighting Examining Iron

Analytic Reconstruction

Power = 0 Power = 0.5 Power = 1 Power = 1.5 Power = 2 Power = 2.5 Power = 3

LLNL-PRES-557235 VG-8

All of the images on the bottom row have the same imaging window



Homeland Security

Sigmoid Ray Weighting Centered at 0.3

LEDP Livermore Explosives Detection Program

ERF Sigmoids for Ray Weighting

Jelly vs. Sigmoid Strength, Center = 0.3

Steel vs. Sigmoid Strength, Center = 0.3

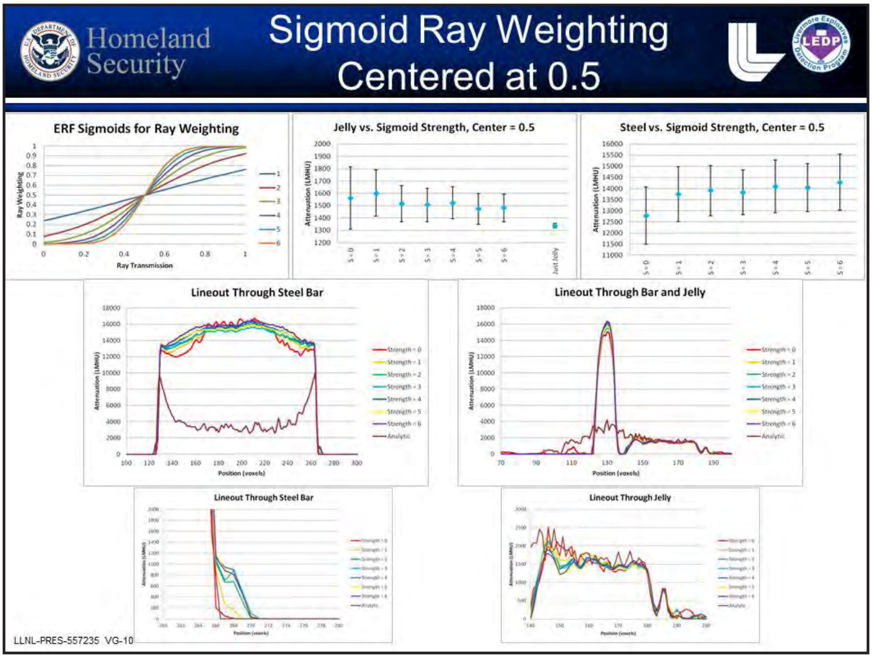
Lineout Through Steel Bar

Lineout Through Bar and Jelly

Lineout Through Steel Bar

Lineout Through Jelly

LLNL-PRES-557235 VG-9



Homeland Security

Sigmoid Ray Weighting Centered at 0.5

LEDP Livermore Explosives Detection Program

ERF Sigmoids for Ray Weighting

Jelly vs. Sigmoid Strength, Center = 0.5

Steel vs. Sigmoid Strength, Center = 0.5

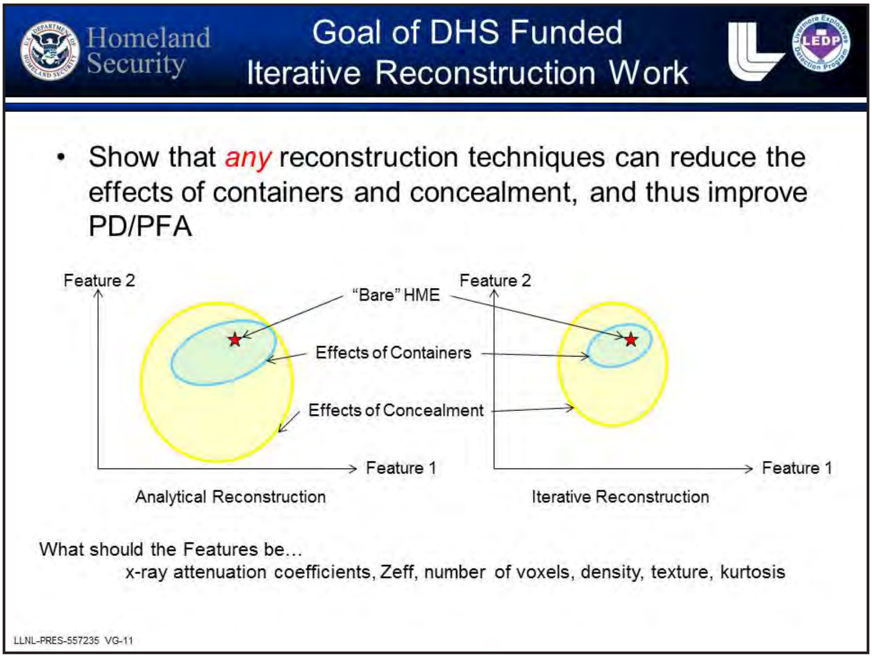
Lineout Through Steel Bar

Lineout Through Bar and Jelly

Lineout Through Steel Bar

Lineout Through Jelly

LLNL-PRES-557235 VG-10



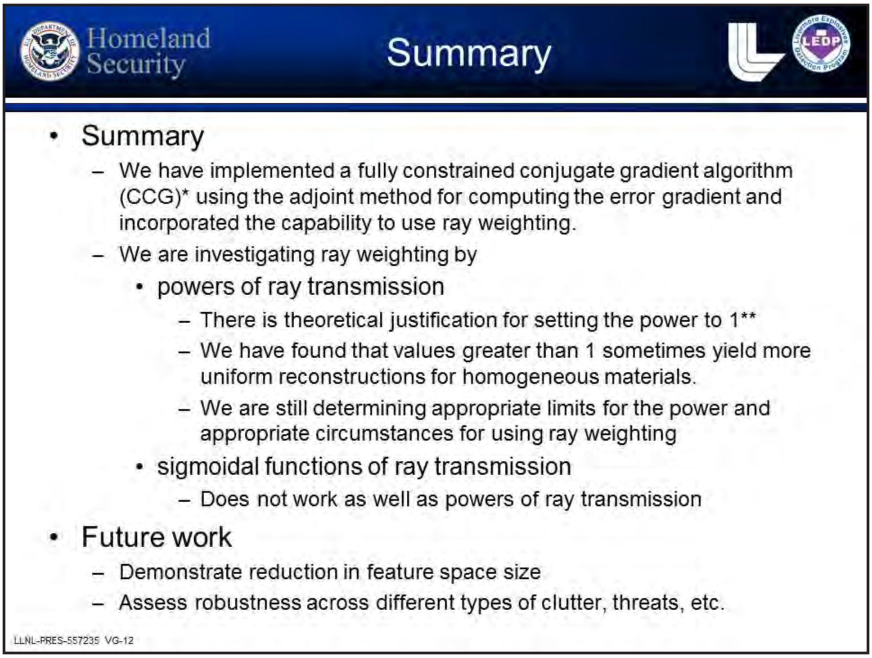
Goal of DHS Funded Iterative Reconstruction Work

- Show that *any* reconstruction techniques can reduce the effects of containers and concealment, and thus improve PD/PFA

What should the Features be…

x-ray attenuation coefficients, Zeff, number of voxels, density, texture, kurtosis

LLNL-PRES-557235 VG-11



Summary

- Summary
  - We have implemented a fully constrained conjugate gradient algorithm (CCG)* using the adjoint method for computing the error gradient and incorporated the capability to use ray weighting.
  - We are investigating ray weighting by
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      - There is theoretical justification for setting the power to 1**
      - We have found that values greater than 1 sometimes yield more uniform reconstructions for homogeneous materials.
      - We are still determining appropriate limits for the power and appropriate circumstances for using ray weighting
    - sigmoidal functions of ray transmission
      - Does not work as well as powers of ray transmission
- Future work
  - Demonstrate reduction in feature space size
  - Assess robustness across different types of clutter, threats, etc.

LLNL-PRES-557235 VG-12

Appendix: Derivation of Error Gradient

Outline

- One Dimensional Ray Equation
- Frechet Derivative and Variations
- Adjoint Ray Equation
- Manipulations to get Frechet Derivative
- Evaluation of Frechet Derivative
- Finite dimensional cases

One Dimensional Ray Equation

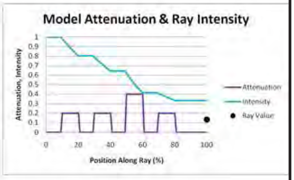
- Position along the ray is represented by *s*.
- Intensity at any point along the ray is represented by $I(s)$.
- Attenuation at any point along the ray is represented by $\mu(s)$.
- Initial Intensity $I(0) = I_0$.
- One dimensional ray equation is:

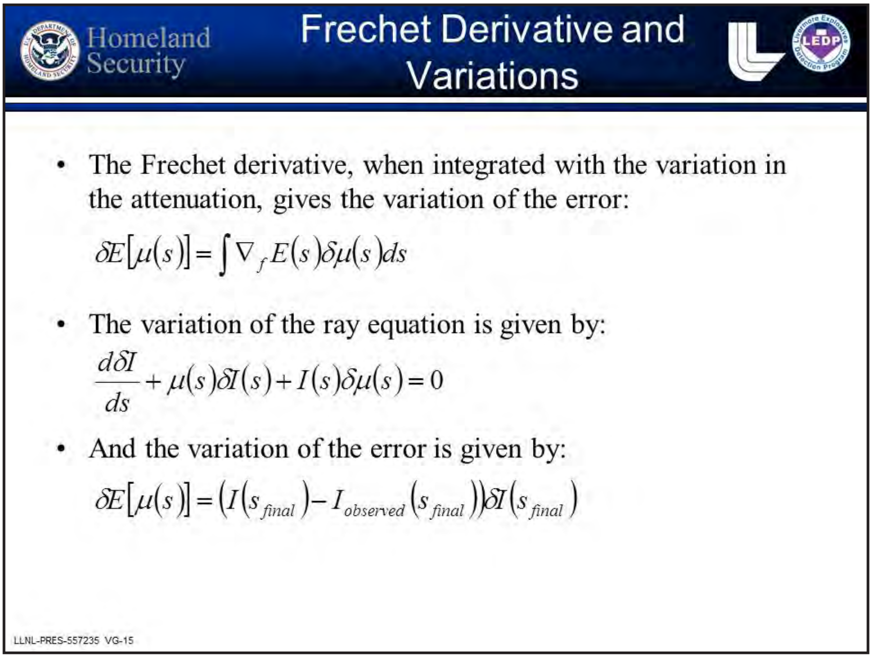
$$\frac{dI}{ds} + \mu(s)I(s) = -I_0\delta(s)$$

- Define the Error as:

$$E[\mu(s)] = \frac{1}{2}\left(I\left(s_{final}\right) - I_{observed}\left(s_{final}\right)\right)^2$$

- What we really want is the gradient of the error with respect to the attenuation distribution, the Frechet derivative.





Frechet Derivative and Variations

- The Frechet derivative, when integrated with the variation in the attenuation, gives the variation of the error:

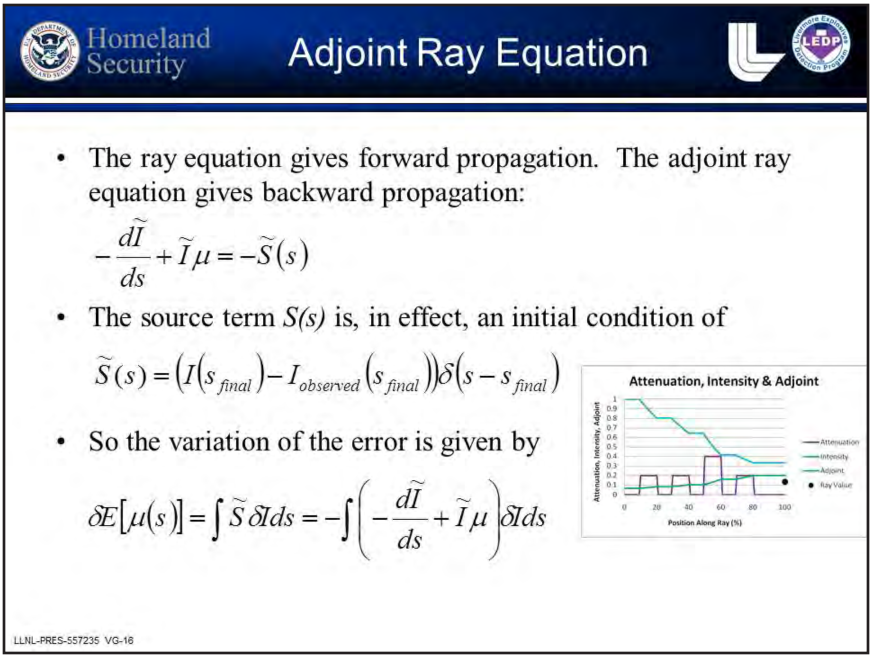
$$\delta E[\mu(s)] = \int \nabla_f E(s) \delta\mu(s) ds$$

- The variation of the ray equation is given by:

$$\frac{d\delta I}{ds} + \mu(s)\delta I(s) + I(s)\delta\mu(s) = 0$$

- And the variation of the error is given by:

$$\delta E[\mu(s)] = \left(I\left(s_{final}\right) - I_{observed}\left(s_{final}\right)\right)\delta I\left(s_{final}\right)$$



Adjoint Ray Equation

- The ray equation gives forward propagation. The adjoint ray equation gives backward propagation:

$$-\frac{d\tilde{I}}{ds} + \tilde{I}\mu = -\tilde{S}(s)$$

- The source term *S(s)* is, in effect, an initial condition of

$$\tilde{S}(s) = \left(I\left(s_{final}\right) - I_{observed}\left(s_{final}\right)\right)\delta\left(s - s_{final}\right)$$

- So the variation of the error is given by

$$\delta E[\mu(s)] = \int \tilde{S}\,\delta I ds = -\int \left(-\frac{d\tilde{I}}{ds} + \tilde{I}\mu\right)\delta I ds$$

Manipulations to get Frechet Derivative

- We use the identity:

$$\delta I \frac{d\tilde{I}}{ds} = -\tilde{I}\frac{d\delta I}{ds} + \frac{d}{ds}\left(\tilde{I}\,\delta I\right)$$

- Realizing we can disregard the right hand term of the identity because it is zero at the endpoints we find the variation of the error:

$$\delta E = -\int\left(\frac{d\delta I}{ds} + \delta I \mu\right)\tilde{I}\,ds$$

- Substituting from the variation of the ray equation we find the variation of the error is now in a form from which we can easily extract the Frechet derivative:

$$\delta E[\mu(s)] = \int I(s)\tilde{I}(s)\delta\mu(s)ds = \int \nabla_f E(s)\delta\mu(s)ds$$

- The Frechet Derivative is thus:

$$\nabla_f E(s) = I(s)\tilde{I}(s)$$

How Can We Evaluate The Frechet Derivative?

- For simplicity consider a uniform attenuation distribution. Over the course of the forward propagation the intensity at any position is:

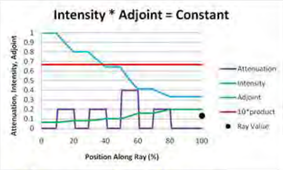
$$I(s) = I_0 e^{-\mu s}$$

- Suppose the result of the forward propagation is not the same as the observed intensity. The difference is the initial condition on the back propagation.
- Over the course of back propagation the intensity at any position is

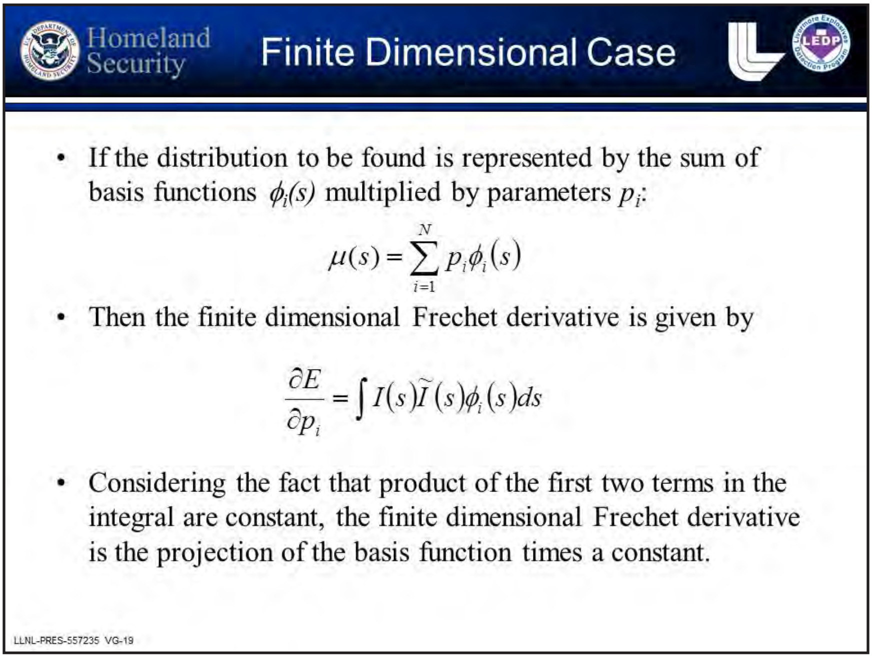
$$\tilde{I}(s) = \left(I\left(s_{final}\right) - I_{observed}\left(s_{final}\right)\right)e^{-\mu\left(s_{final}-s\right)}$$

- The resultant product at any position is constant:

$$I(s)\tilde{I}(s) = \left(I\left(s_{final}\right) - I_{observed}\left(s_{final}\right)\right)I\left(s_{final}\right)$$



- This works for **ANY** distribution of attenuation along the ray. And there is no need to actually do the back propagation.



Finite Dimensional Case

- If the distribution to be found is represented by the sum of basis functions $\phi_i(s)$ multiplied by parameters p_i:

$$\mu(s) = \sum_{i=1}^{N} p_i \phi_i(s)$$

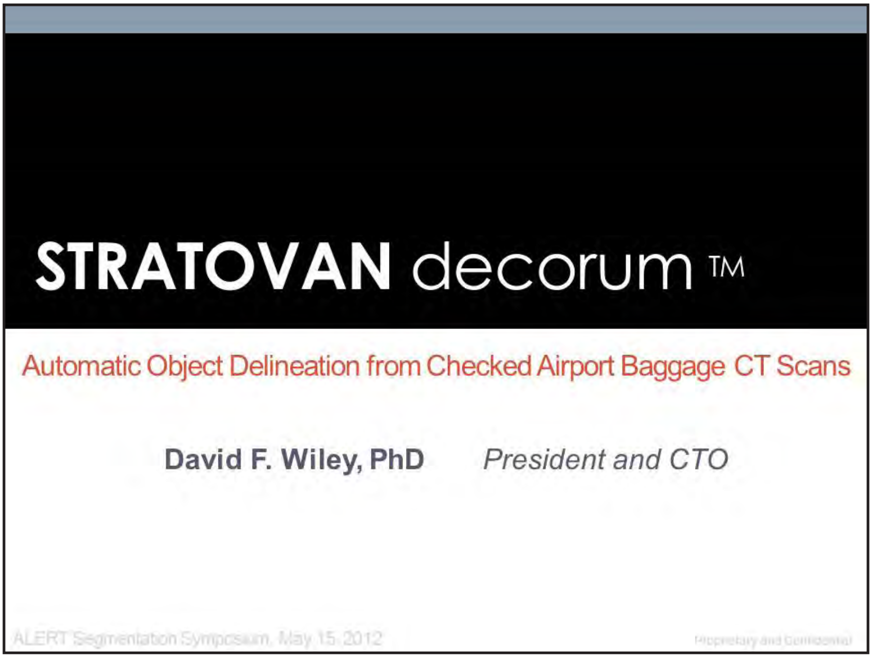
- Then the finite dimensional Frechet derivative is given by

$$\frac{\partial E}{\partial p_i} = \int I(s)\tilde{I}(s)\phi_i(s)ds$$

- Considering the fact that product of the first two terms in the integral are constant, the finite dimensional Frechet derivative is the projection of the basis function times a constant.

LLNL-PRES-557235 VG-19

16.13 David Wiley: Advanced segmentation algorithms

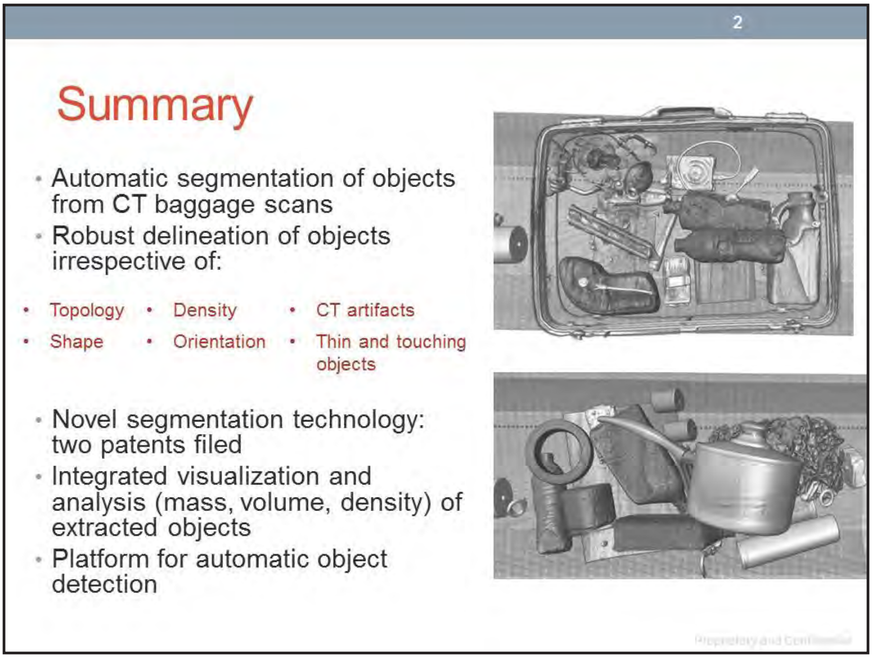


STRATOVAN decorum ™

Automatic Object Delineation from Checked Airport Baggage CT Scans

David F. Wiley, PhD *President and CTO*

ALERT Segmentation Symposium, May 15, 2012



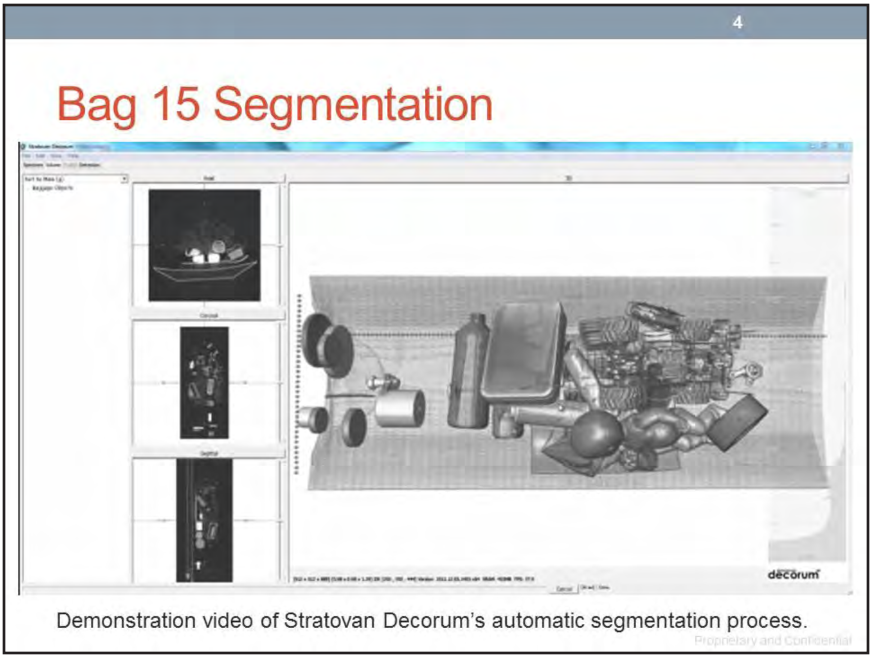
Summary

- Automatic segmentation of objects from CT baggage scans
- Robust delineation of objects irrespective of:
  - Topology
  - Shape
  - Density
  - Orientation
  - CT artifacts
  - Thin and touching objects
- Novel segmentation technology: two patents filed
- Integrated visualization and analysis (mass, volume, density) of extracted objects
- Platform for automatic object detection

STRATOVAN Background

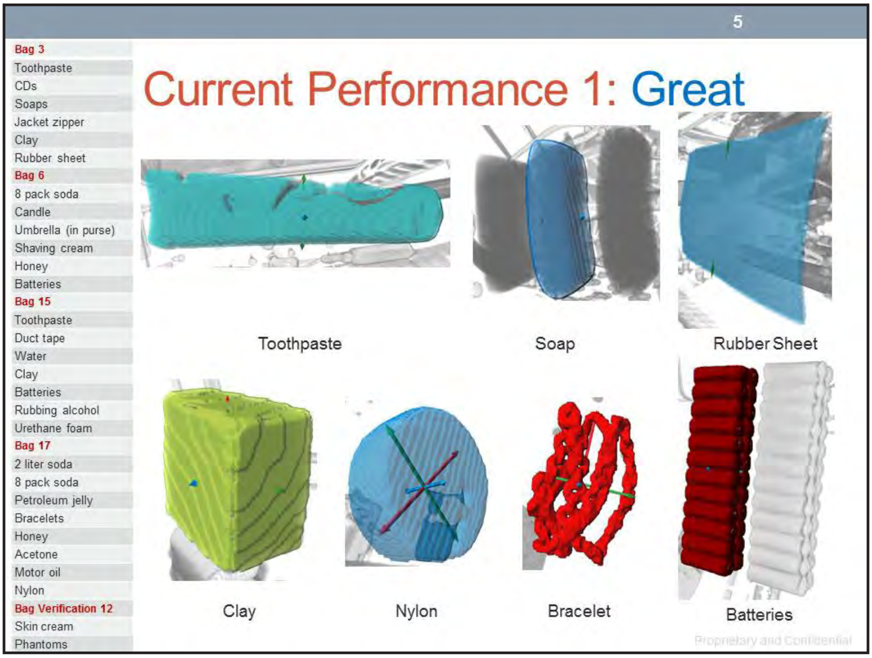
- **David F. Wiley, PhD**
  President and CTO
  - 20+ years in software
  - Medical imaging, user interfaces, software platforms, image processing
- **Jim Olson, MBA** *CEO*
  - 30+ years in the Silicon Valley
  - Former CEO of SkyStream
- **Bernd Hamann, PhD** *Director*
  - Leading visualization scientist
  - UC Davis Assoc. Vice Chancellor
- **Deb Ghosh, PhD**
  Software Engineer
- **Christian Woodhouse, BS**
  Application Developer

- Startup (since 2005) from the Institute for Data Analysis and Visualization (IDAV) at University of California, Davis.
- 3D medical imaging, surgical planning, and treatment planning software.
- Products in orthopedic, craniofacial, neuroimaging, etc.
- Proprietary imaging platform called Encircle.



Bag 15 Segmentation

Demonstration video of Stratovan Decorum's automatic segmentation process.



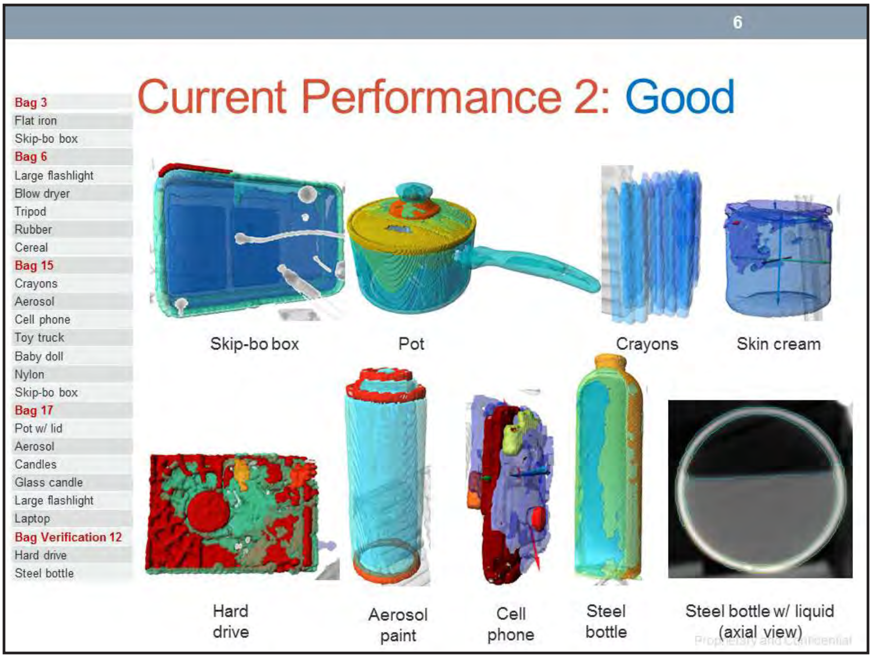
5

Bag 3
Toothpaste
CDs
Soaps
Jacket zipper
Clay
Rubber sheet
Bag 6
8 pack soda
Candle
Umbrella (in purse)
Shaving cream
Honey
Batteries
Bag 15
Toothpaste
Duct tape
Water
Clay
Batteries
Rubbing alcohol
Urethane foam
Bag 17
2 liter soda
8 pack soda
Petroleum jelly
Bracelets
Honey
Acetone
Motor oil
Nylon
Bag Verification 12
Skin cream
Phantoms

Current Performance 1: Great

Toothpaste
Soap
Rubber Sheet
Clay
Nylon
Bracelet
Batteries

Proprietary and Confidential



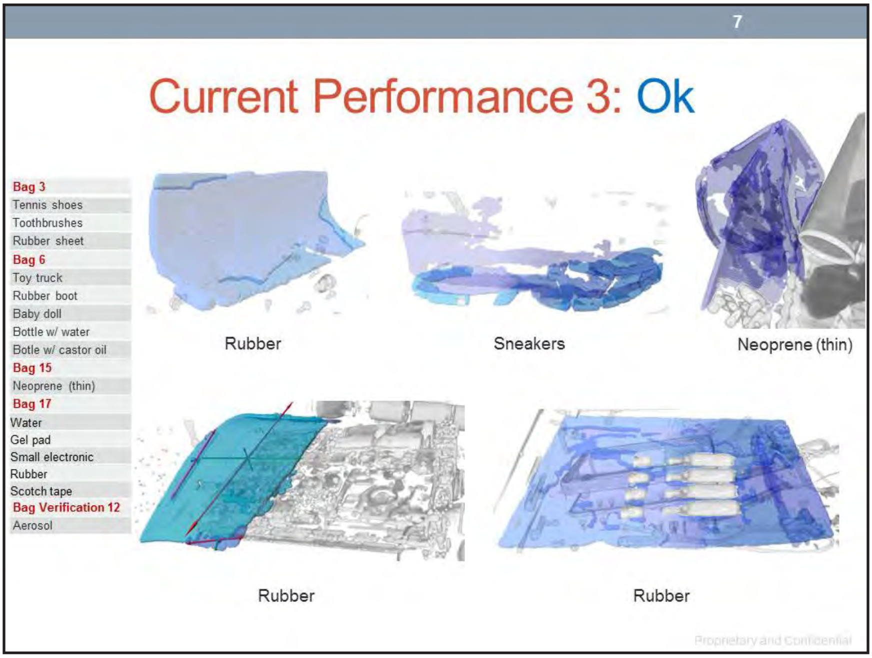
6

Bag 3
Flat iron
Skip-bo box
Bag 6
Large flashlight
Blow dryer
Tripod
Rubber
Cereal
Bag 15
Crayons
Aerosol
Cell phone
Toy truck
Baby doll
Nylon
Skip-bo box
Bag 17
Pot w/ lid
Aerosol
Candles
Glass candle
Large flashlight
Laptop
Bag Verification 12
Hard drive
Steel bottle

Current Performance 2: Good

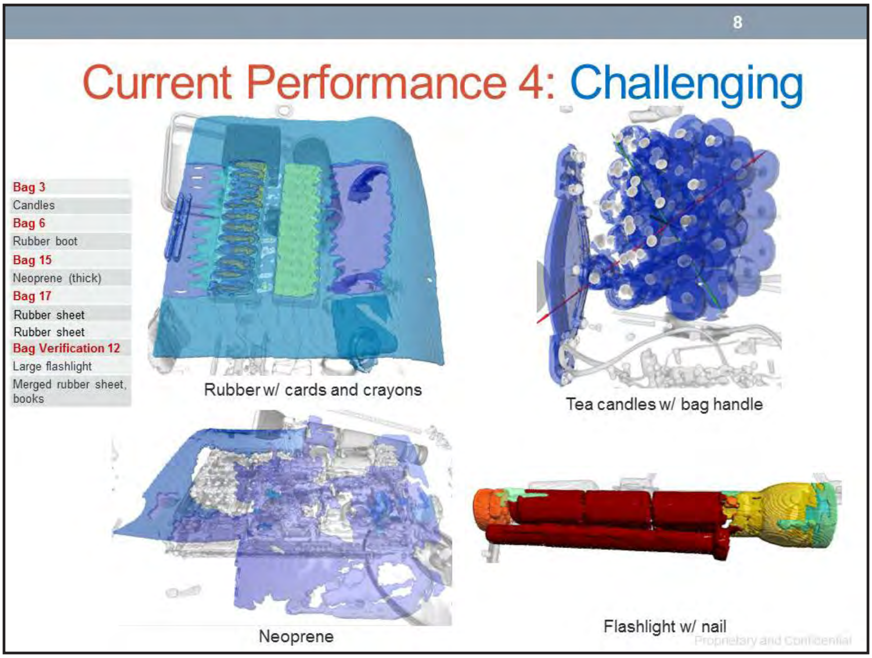
Skip-bo box
Pot
Crayons
Skin cream
Hard drive
Aerosol paint
Cell phone
Steel bottle
Steel bottle w/ liquid (axial view)

Proprietary and Confidential



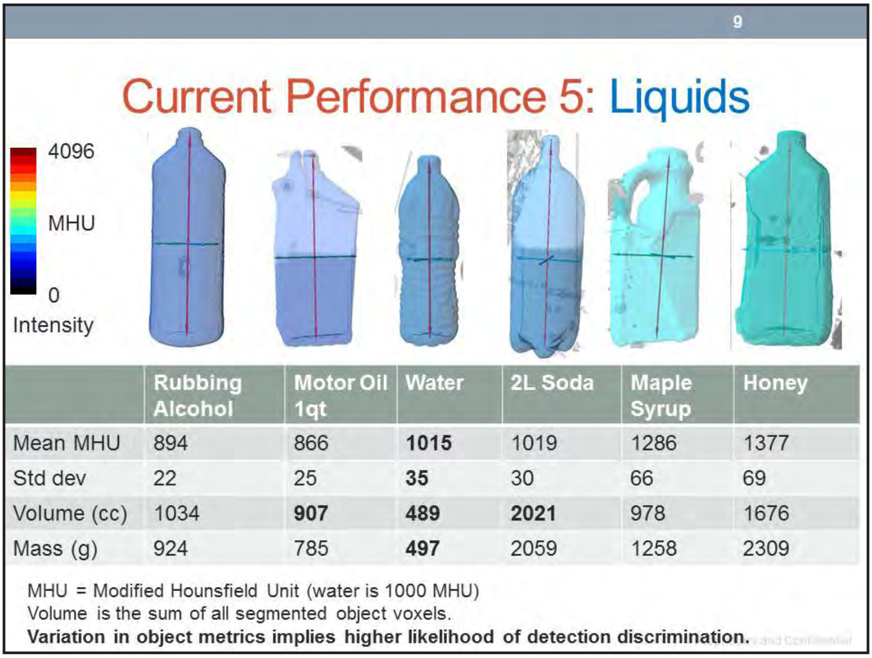
Current Performance 3: Ok

Bag 3
Tennis shoes
Toothbrushes
Rubber sheet
Bag 6
Toy truck
Rubber boot
Baby doll
Bottle w/ water
Botle w/ castor oil
Bag 15
Neoprene (thin)
Bag 17
Water
Gel pad
Small electronic
Rubber
Scotch tape
Bag Verification 12
Aerosol



Current Performance 4: Challenging

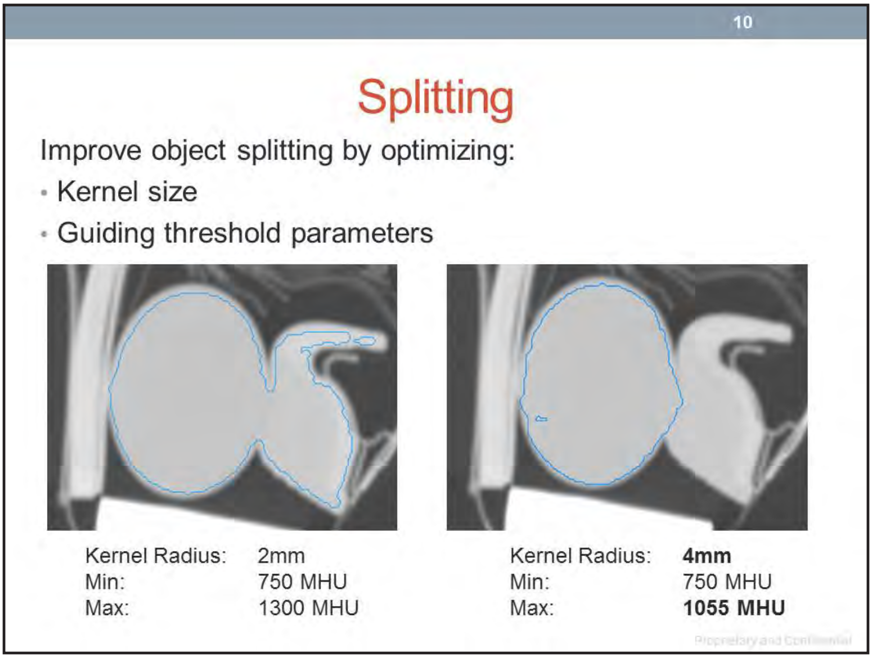
Bag 3
Candles
Bag 6
Rubber boot
Bag 15
Neoprene (thick)
Bag 17
Rubber sheet
Rubber sheet
Bag Verification 12
Large flashlight
Merged rubber sheet, books



Current Performance 5: Liquids

	Rubbing Alcohol	Motor Oil 1qt	Water	2L Soda	Maple Syrup	Honey
Mean MHU	894	866	**1015**	1019	1286	1377
Std dev	22	25	**35**	30	66	69
Volume (cc)	1034	**907**	**489**	**2021**	978	1676
Mass (g)	924	785	**497**	2059	1258	2309

MHU = Modified Hounsfield Unit (water is 1000 MHU)
Volume is the sum of all segmented object voxels.
Variation in object metrics implies higher likelihood of detection discrimination.



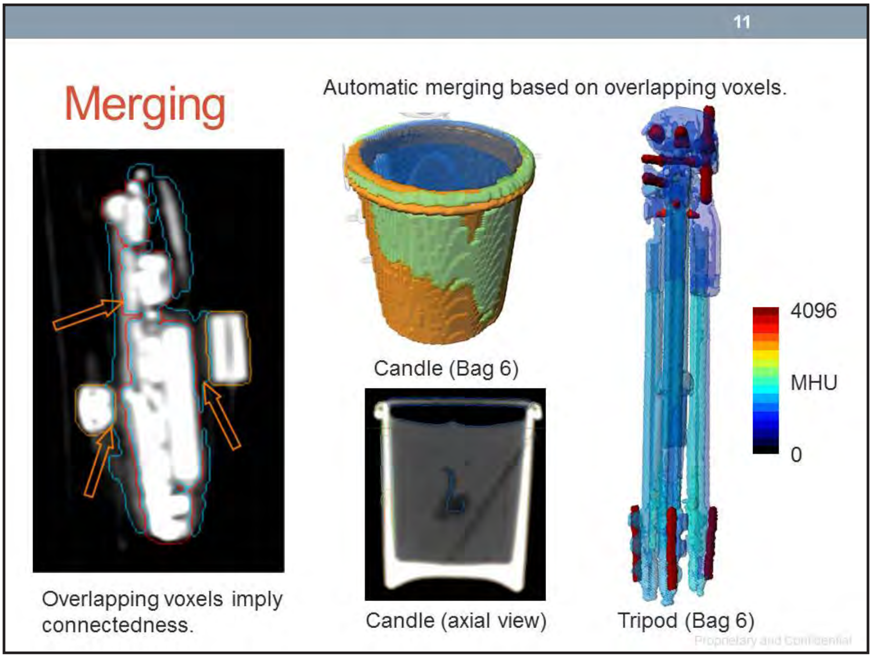
Splitting

Improve object splitting by optimizing:

- Kernel size
- Guiding threshold parameters

Kernel Radius:	2mm
Min:	750 MHU
Max:	1300 MHU

Kernel Radius:	**4mm**
Min:	750 MHU
Max:	**1055 MHU**



Merging

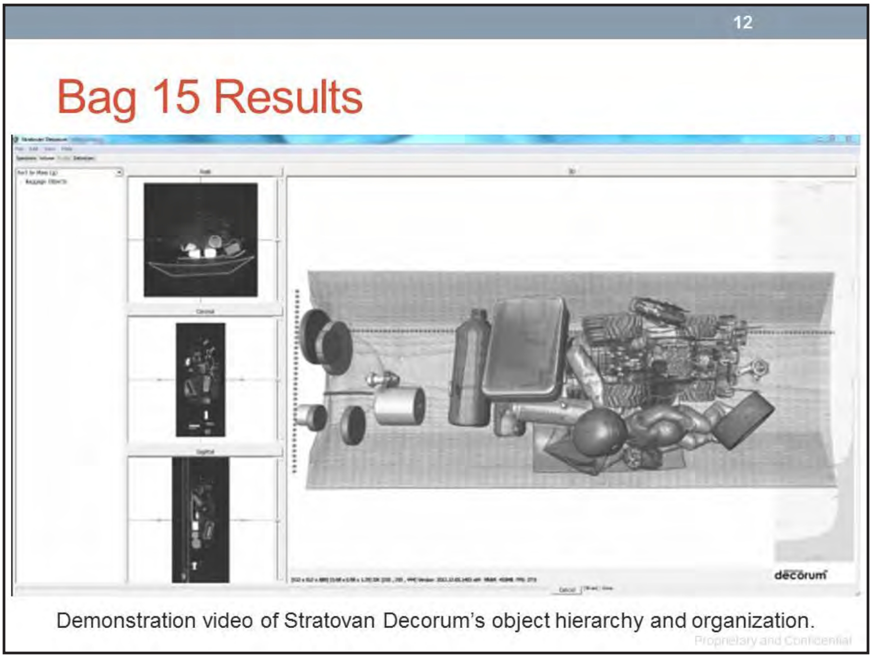
Automatic merging based on overlapping voxels.

Overlapping voxels imply connectedness.

Candle (Bag 6)

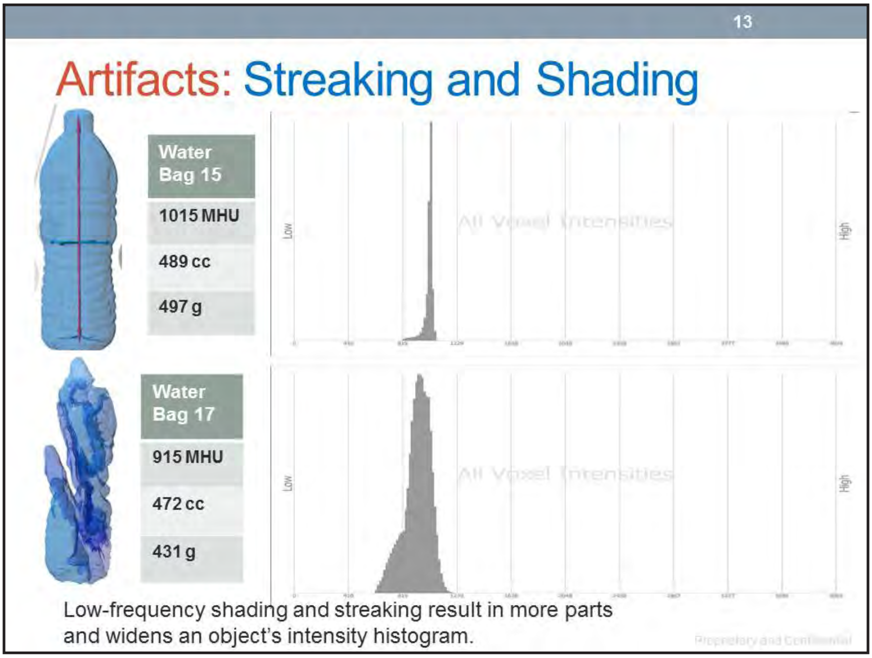
Candle (axial view)

Tripod (Bag 6)



Bag 15 Results

Demonstration video of Stratovan Decorum's object hierarchy and organization.

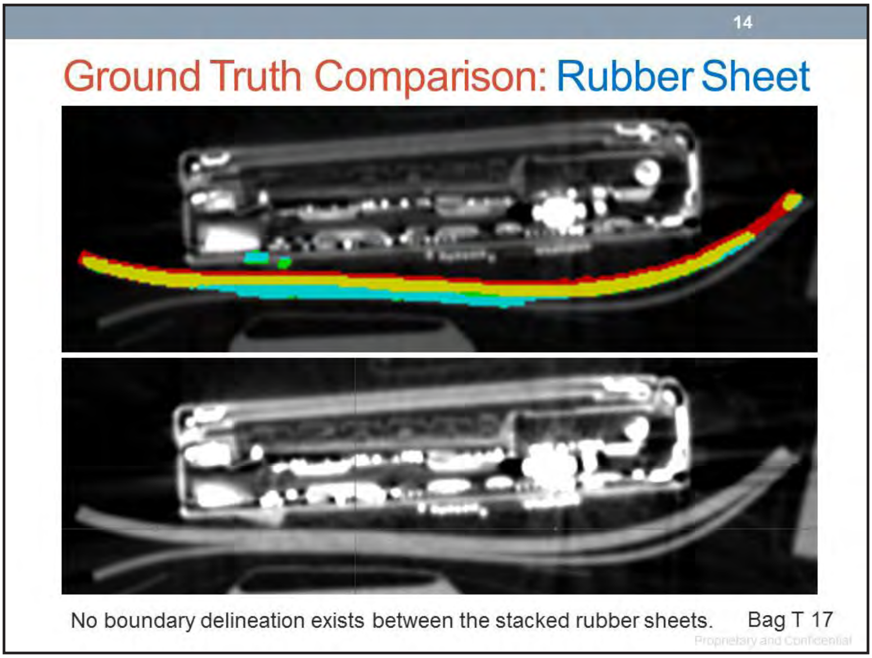


Artifacts: Streaking and Shading

Water Bag 15
1015 MHU
489 cc
497 g

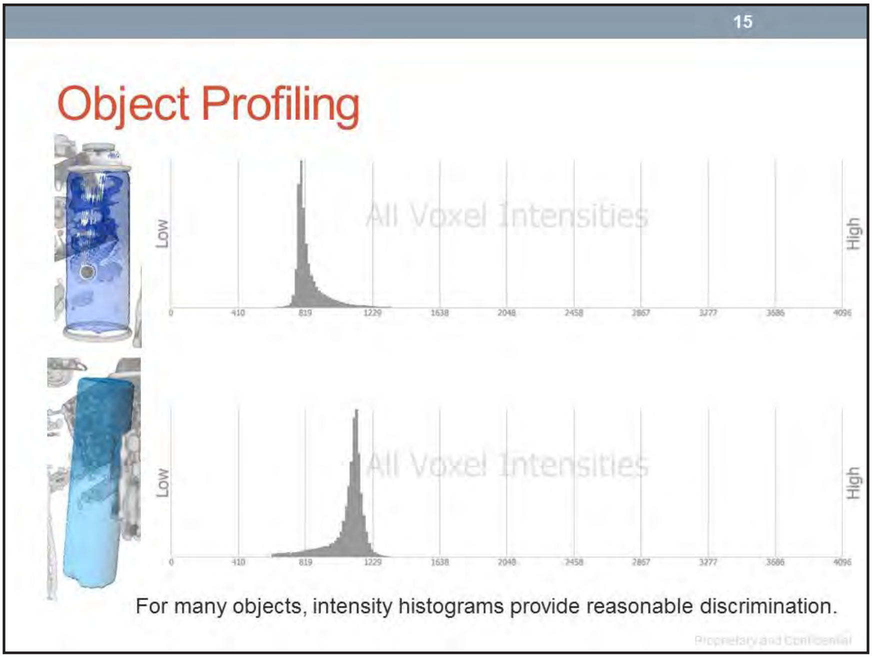
Water Bag 17
915 MHU
472 cc
431 g

Low-frequency shading and streaking result in more parts and widens an object's intensity histogram.



Ground Truth Comparison: Rubber Sheet

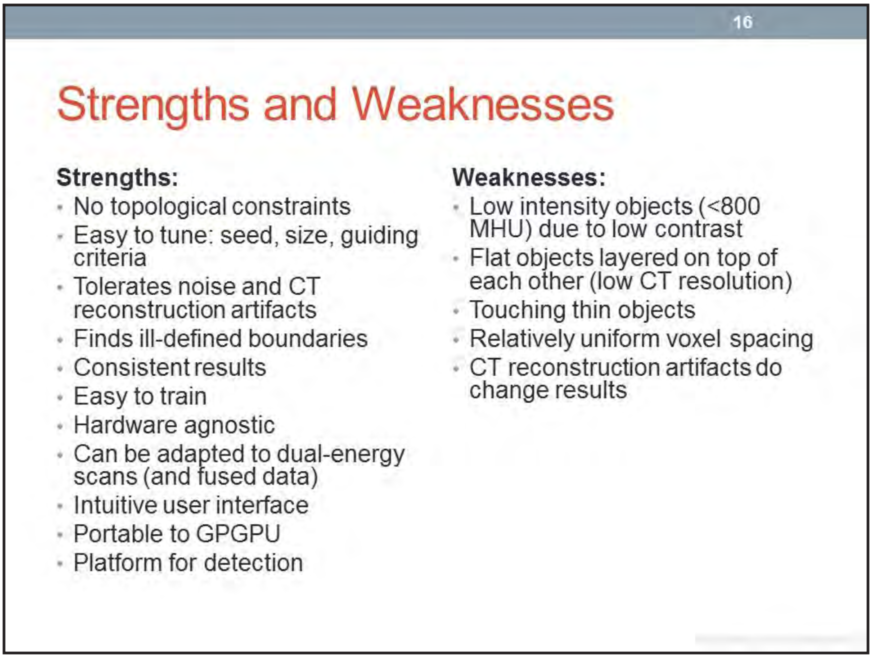
No boundary delineation exists between the stacked rubber sheets. Bag T 17



Object Profiling

For many objects, intensity histograms provide reasonable discrimination.

Proprietary and Confidential



Strengths and Weaknesses

Strengths:

- No topological constraints
- Easy to tune: seed, size, guiding criteria
- Tolerates noise and CT reconstruction artifacts
- Finds ill-defined boundaries
- Consistent results
- Easy to train
- Hardware agnostic
- Can be adapted to dual-energy scans (and fused data)
- Intuitive user interface
- Portable to GPGPU
- Platform for detection

Weaknesses:

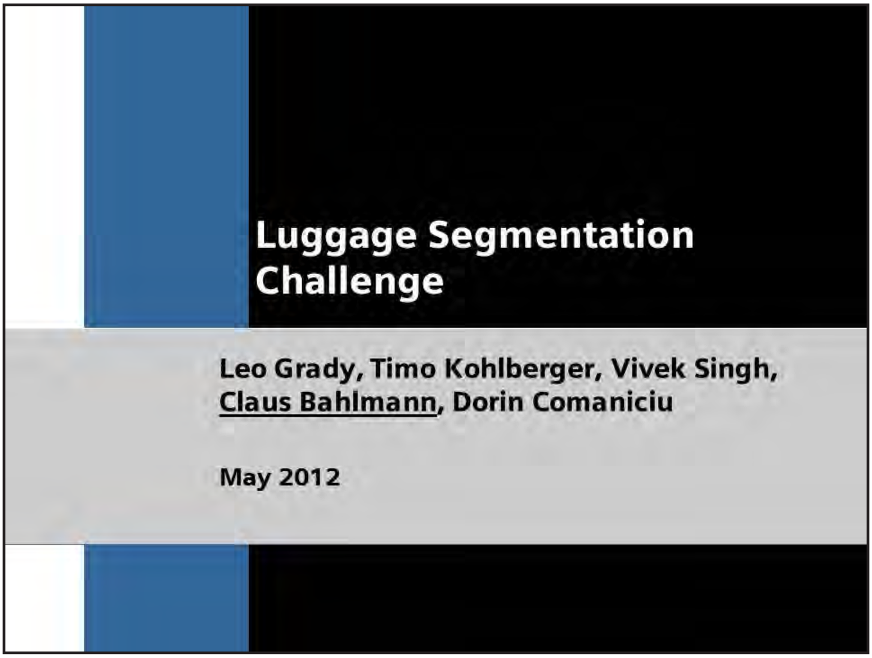
- Low intensity objects (<800 MHU) due to low contrast
- Flat objects layered on top of each other (low CT resolution)
- Touching thin objects
- Relatively uniform voxel spacing
- CT reconstruction artifacts do change results

Future Work

- Improve training to cover parameter space
- Improve aggregation to group object parts reliably
- Improve matching/detection system to perform "bottom-up" matching reliably
- Evaluate on scans from multiple equipment vendors
- Port to GPGPU
- Detection knowledge-base

Contact:	**www.stratovan.com**	
David F. Wiley	wiley@stratovan.com	916-813-7233
Jim Olson	olson@stratovan.com	650-400-4046

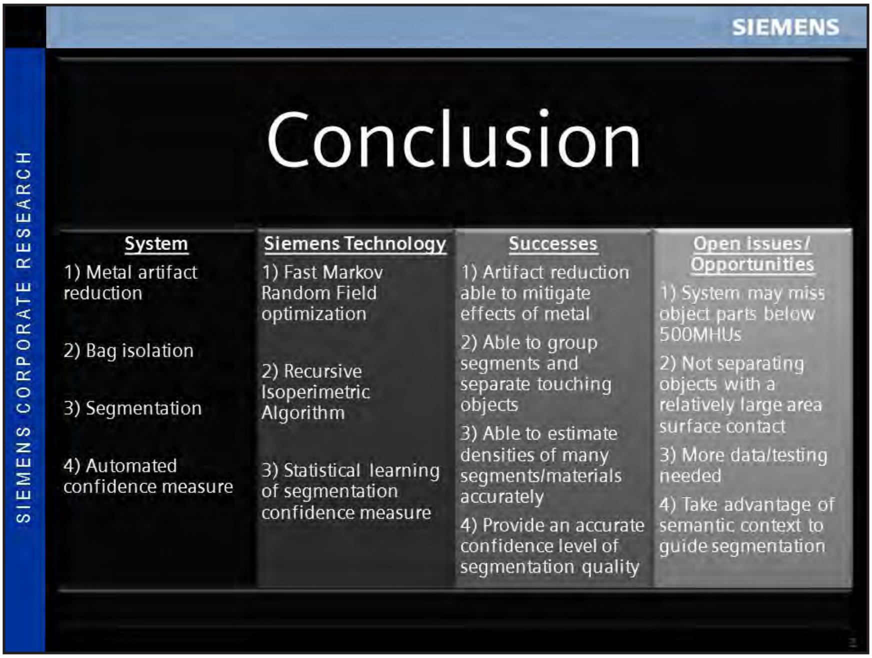
16.14 Claus Bahlmann: Luggage Segmentation Challenge



Luggage Segmentation Challenge

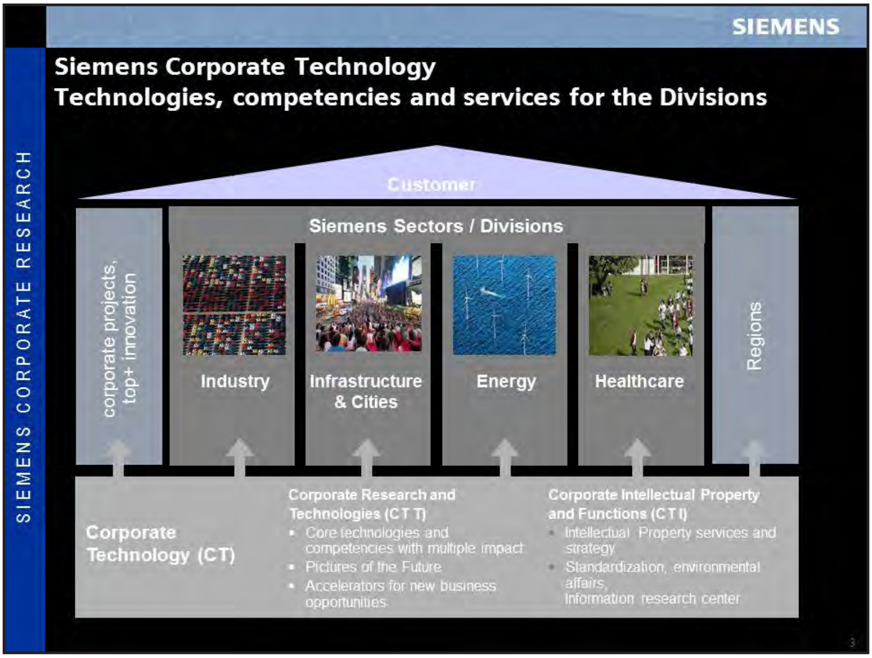
Leo Grady, Timo Kohlberger, Vivek Singh,
Claus Bahlmann, Dorin Comaniciu

May 2012



Conclusion

System	Siemens Technology	Successes	Open issues/ Opportunities
1) Metal artifact reduction	1) Fast Markov Random Field optimization	1) Artifact reduction able to mitigate effects of metal	1) System may miss object parts below 500MHUs
2) Bag isolation	2) Recursive Isoperimetric Algorithm	2) Able to group segments and separate touching objects	2) Not separating objects with a relatively large area surface contact
3) Segmentation	3) Statistical learning of segmentation confidence measure	3) Able to estimate densities of many segments/materials accurately	3) More data/testing needed
4) Automated confidence measure		4) Provide an accurate confidence level of segmentation quality	4) Take advantage of semantic context to guide segmentation



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Siemens Corporate Technology
Technologies, competencies and services for the Divisions

Corporate Research and Technologies (CT T)
- Core technologies and competencies with multiple impact
- Pictures of the Future
- Accelerators for new business opportunities

Corporate Intellectual Property and Functions (CT I)
- Intellectual Property services and strategy
- Standardization, environmental affairs, Information research center

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Siemens Corporate Research

- ~140 PhD-level people working on computer vision & imaging algorithms and software

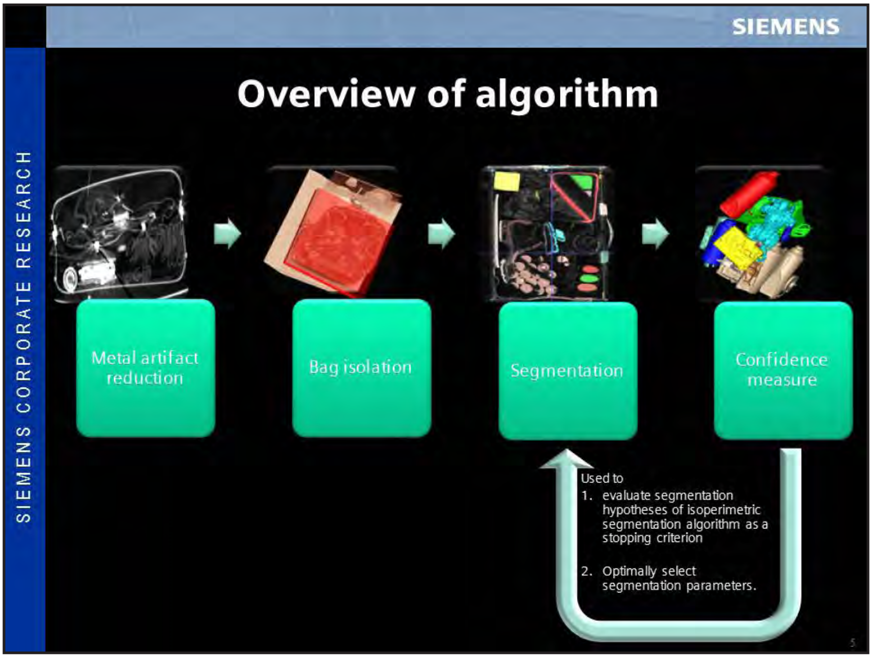
Princeton, USA

Internationally recognized team

Winner of 2010 Longuet-Higgens Prize for fundamental contributions in Computer Vision

Winner of segmentation challenge in 2009 and 2011

Winner of young scientist award for 2011, 2010, 2007 - runner-up 2008



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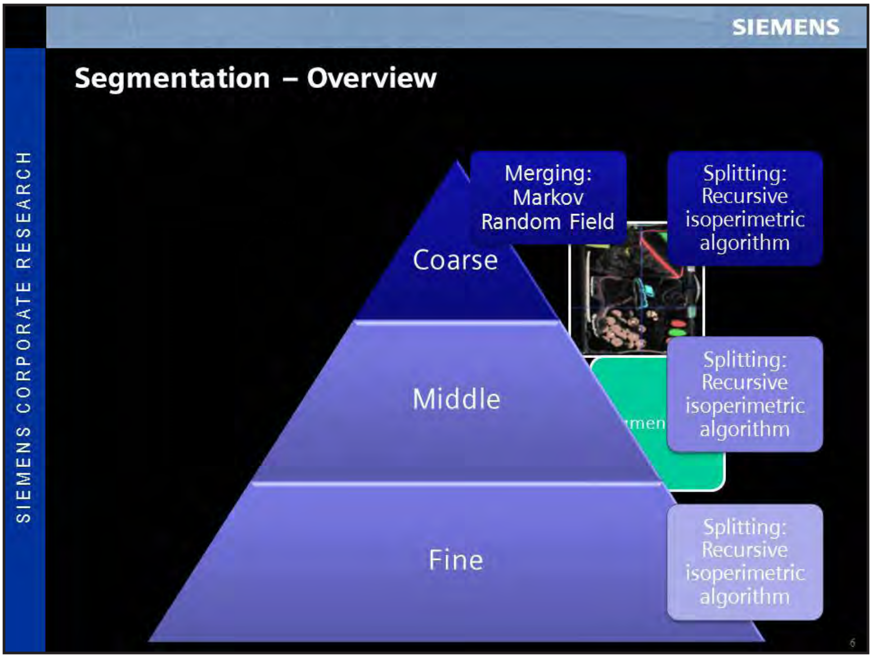
Overview of algorithm

Used to
1. evaluate segmentation hypotheses of isoperimetric segmentation algorithm as a stopping criterion
2. Optimally select segmentation parameters.



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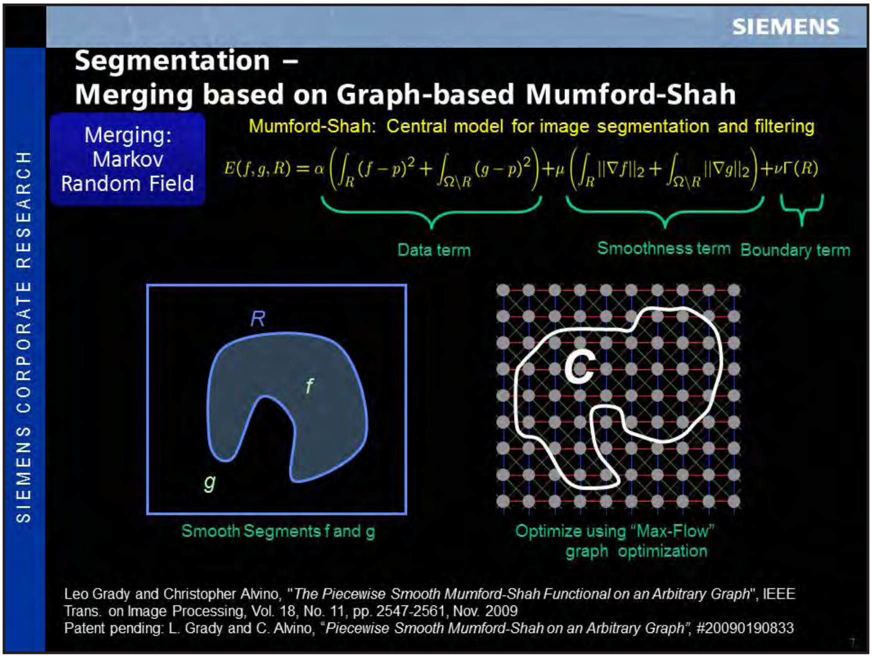
Segmentation – Overview



Segmentation – Merging based on Graph-based Mumford-Shah

Merging: Markov Random Field

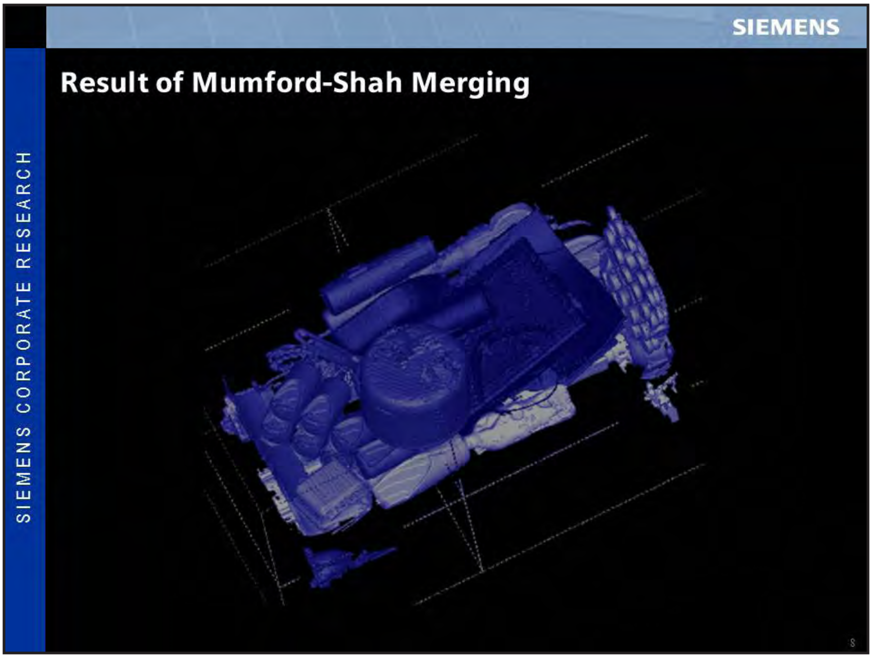
Mumford-Shah: Central model for image segmentation and filtering

$$E(f,g,R)=\underbrace{\alpha\left(\int_R (f-p)^2+\int_{\Omega\setminus R}(g-p)^2\right)}_{\text{Data term}}+\underbrace{\mu\left(\int_R \|\nabla f\|_2+\int_{\Omega\setminus R}\|\nabla g\|_2\right)}_{\text{Smoothness term}}+\underbrace{\nu\Gamma(R)}_{\text{Boundary term}}$$

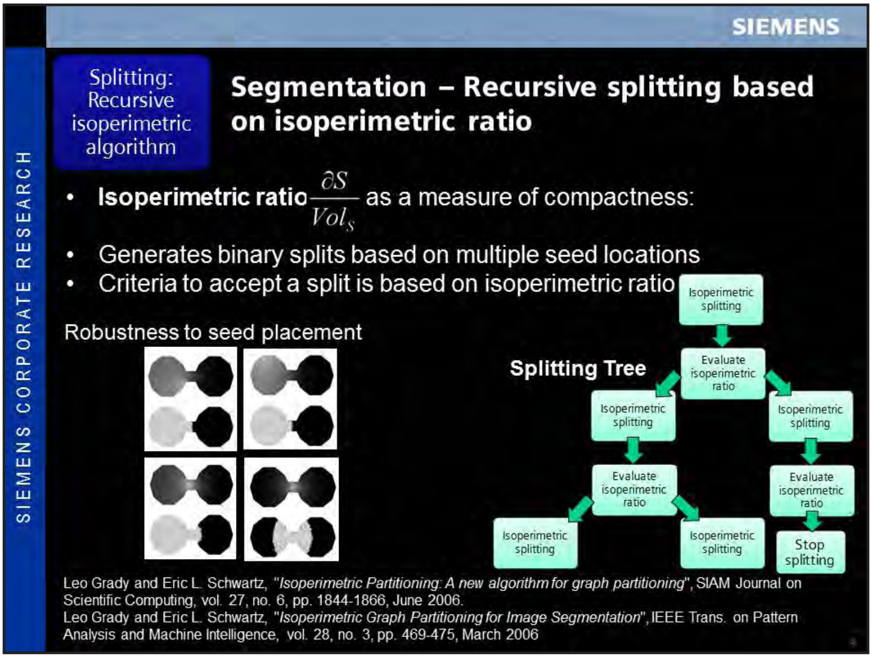
Smooth Segments f and g

Optimize using "Max-Flow" graph optimization

Leo Grady and Christopher Alvino, "*The Piecewise Smooth Mumford-Shah Functional on an Arbitrary Graph*", IEEE Trans. on Image Processing, Vol. 18, No. 11, pp. 2547-2561, Nov. 2009
Patent pending: L. Grady and C. Alvino, "*Piecewise Smooth Mumford-Shah on an Arbitrary Graph*", #20090190833



Result of Mumford-Shah Merging

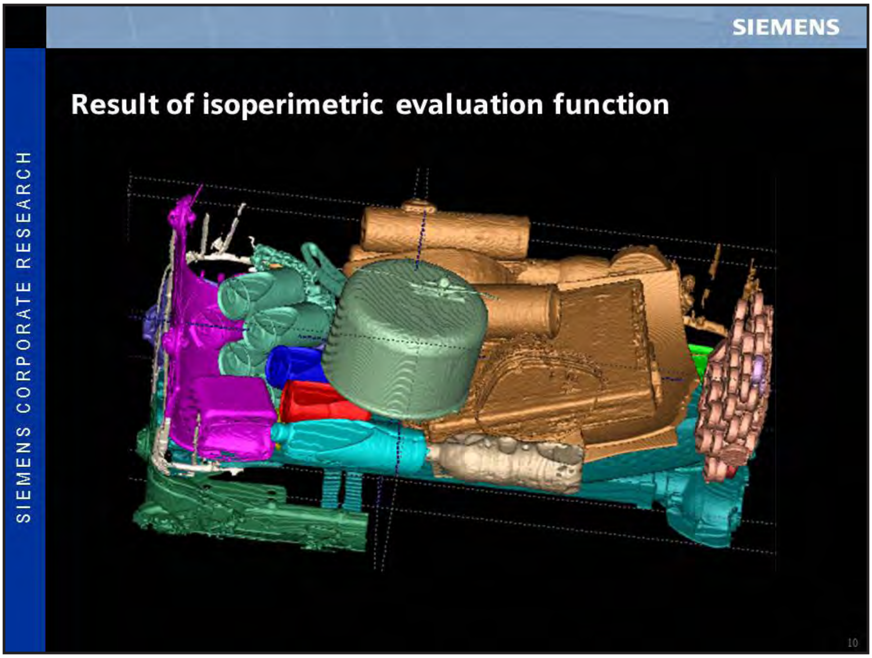


Segmentation – Recursive splitting based on isoperimetric ratio

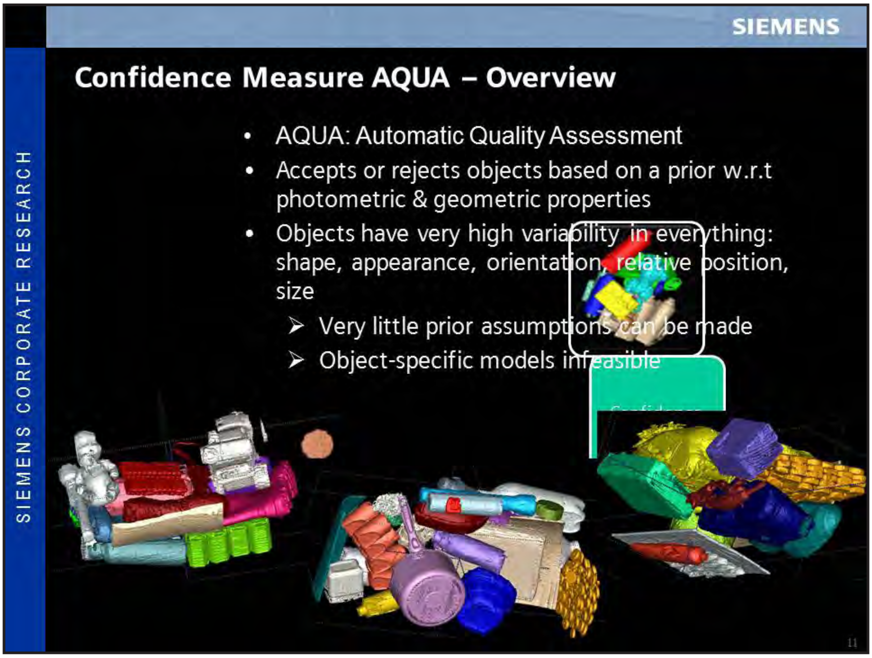
- **Isoperimetric ratio** $\frac{\partial S}{Vol_S}$ as a measure of compactness:
- Generates binary splits based on multiple seed locations
- Criteria to accept a split is based on isoperimetric ratio

Robustness to seed placement

Leo Grady and Eric L. Schwartz, "*Isoperimetric Partitioning: A new algorithm for graph partitioning*", SIAM Journal on Scientific Computing, vol. 27, no. 6, pp. 1844-1866, June 2006.
Leo Grady and Eric L. Schwartz, "*Isoperimetric Graph Partitioning for Image Segmentation*", IEEE Trans. on Pattern Analysis and Machine Intelligence, vol. 28, no. 3, pp. 469-475, March 2006

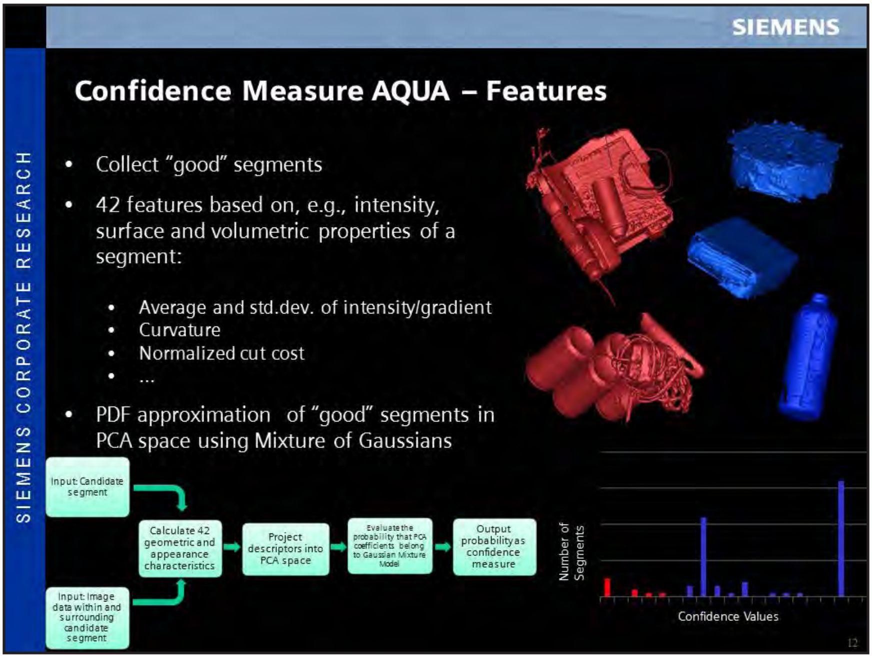


Result of isoperimetric evaluation function



Confidence Measure AQUA – Overview

- AQUA: Automatic Quality Assessment
- Accepts or rejects objects based on a prior w.r.t photometric & geometric properties
- Objects have very high variability in everything: shape, appearance, orientation, relative position, size
  - ➢ Very little prior assumptions can be made
  - ➢ Object-specific models infeasible



Confidence Measure AQUA – Features

- Collect “good” segments
- 42 features based on, e.g., intensity, surface and volumetric properties of a segment:
  - Average and std.dev. of intensity/gradient
  - Curvature
  - Normalized cut cost
  - …
- PDF approximation of “good” segments in PCA space using Mixture of Gaussians

Input: Candidate segment

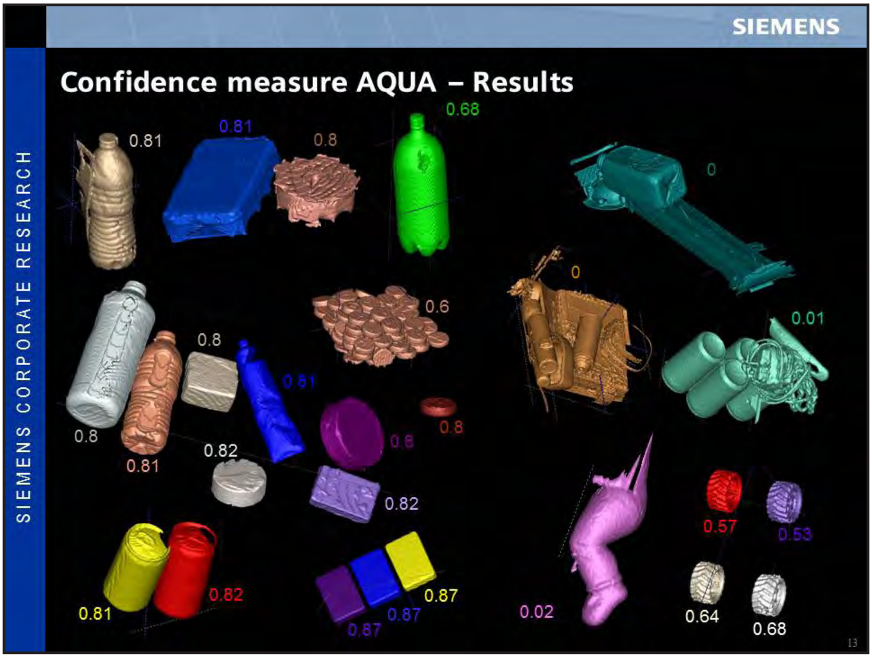
Input: Image data within and surrounding candidate segment

Calculate 42 geometric and appearance characteristics

Project descriptors into PCA space

Evaluate the probability that PCA coefficients belong to Gaussian Mixture Model

Output probability as confidence measure



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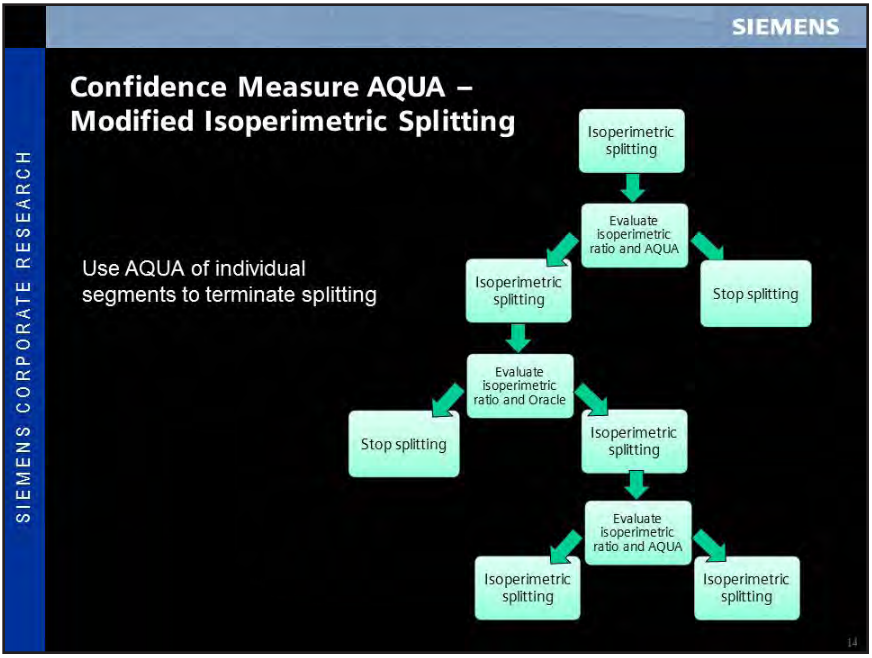
Confidence measure AQUA – Results



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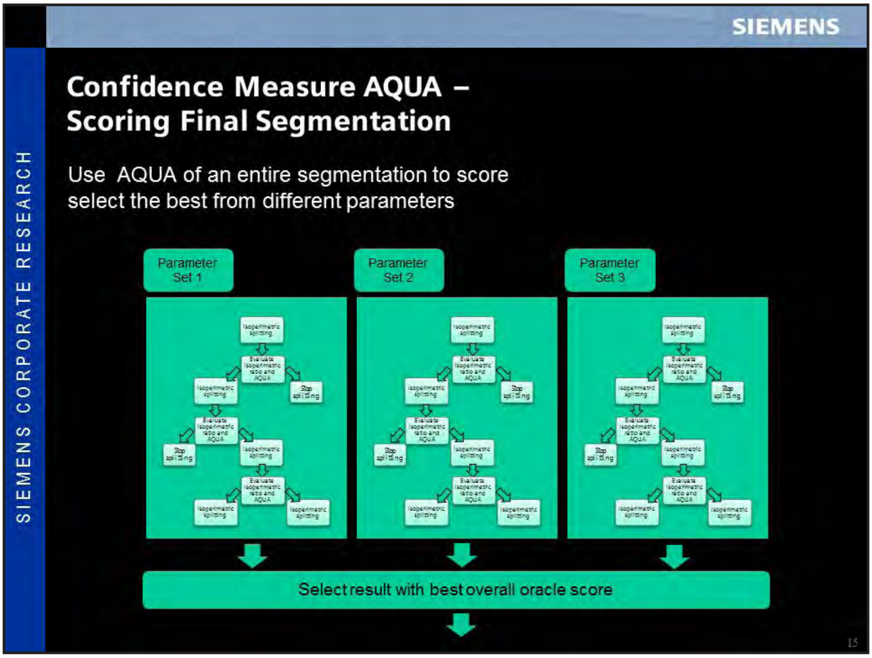
Confidence Measure AQUA – Modified Isoperimetric Splitting

Use AQUA of individual segments to terminate splitting

- Isoperimetric splitting
- Evaluate isoperimetric ratio and AQUA
- Isoperimetric splitting
- Stop splitting
- Evaluate isoperimetric ratio and Oracle
- Stop splitting
- Isoperimetric splitting
- Evaluate isoperimetric ratio and AQUA
- Isoperimetric splitting
- Isoperimetric splitting



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Confidence Measure AQUA – Scoring Final Segmentation

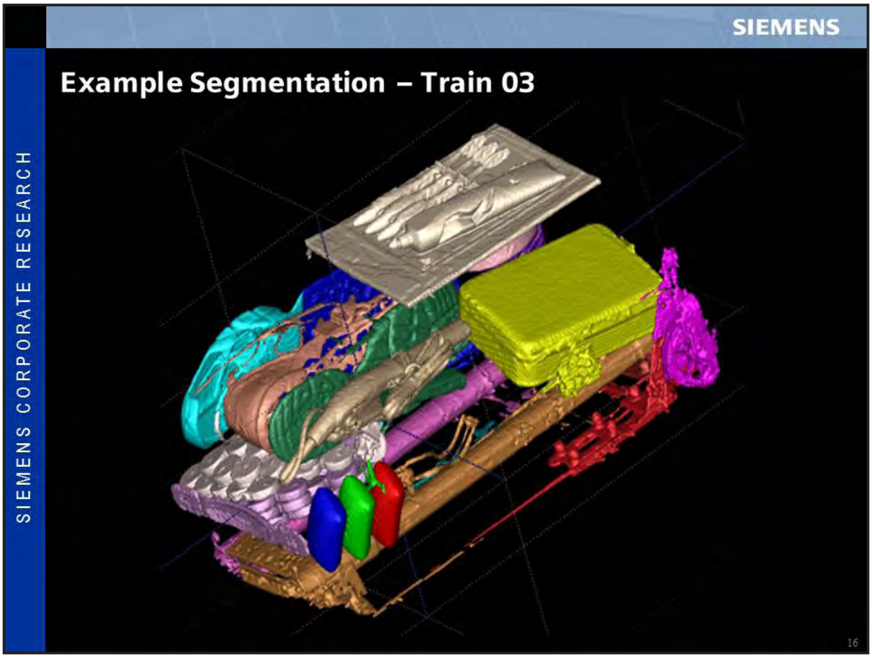
Use AQUA of an entire segmentation to score select the best from different parameters

Parameter Set 1

Parameter Set 2

Parameter Set 3

Select result with best overall oracle score



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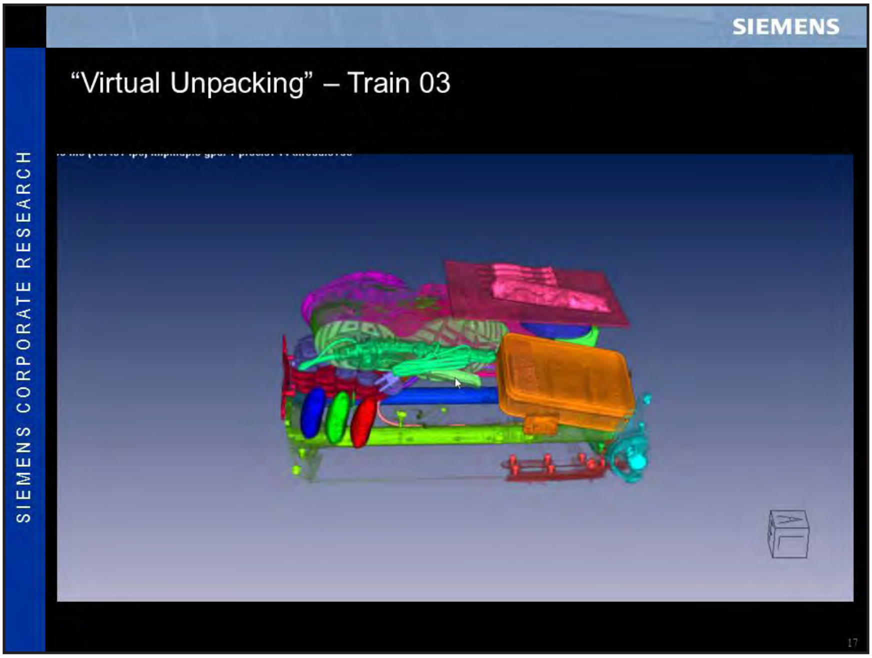
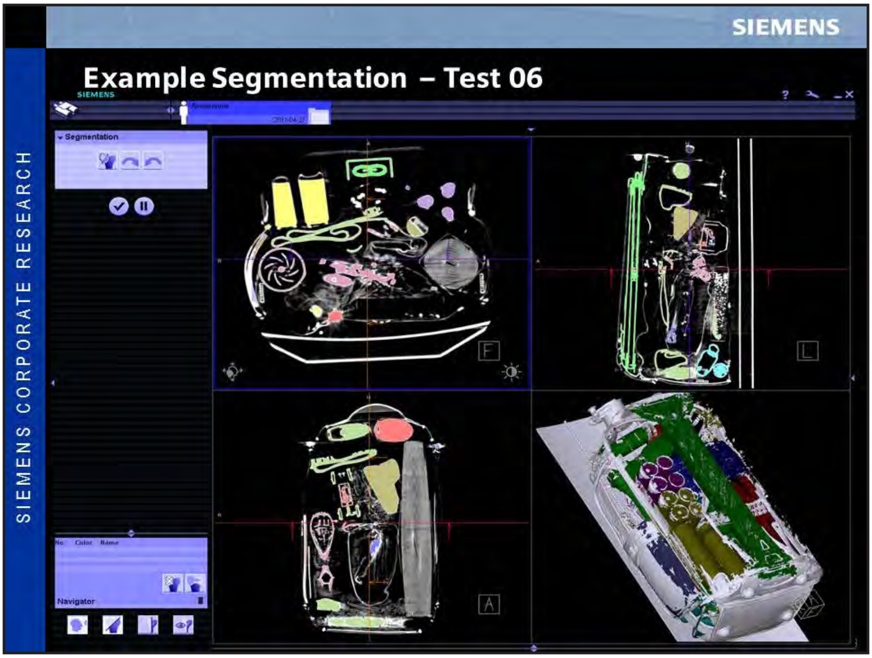
Example Segmentation – Train 03

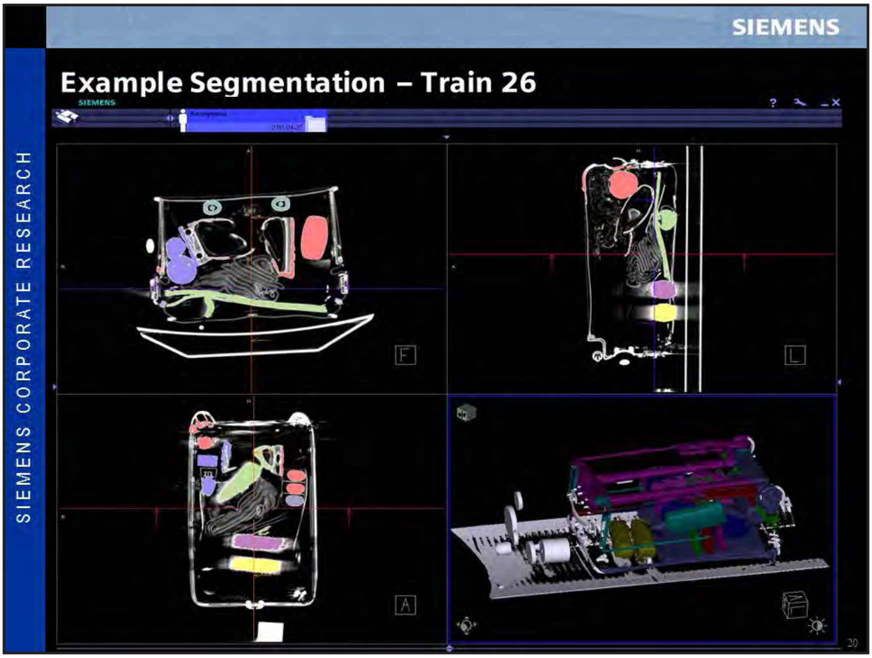


“Virtual Unpacking” – Train 03

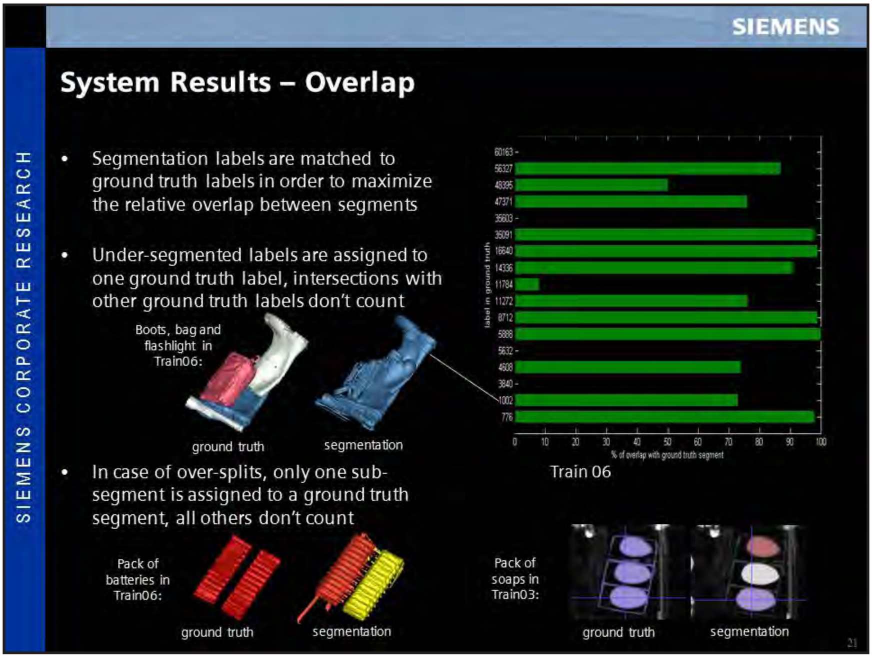


Example Segmentation – Test 06

Example Segmentation – Train 09

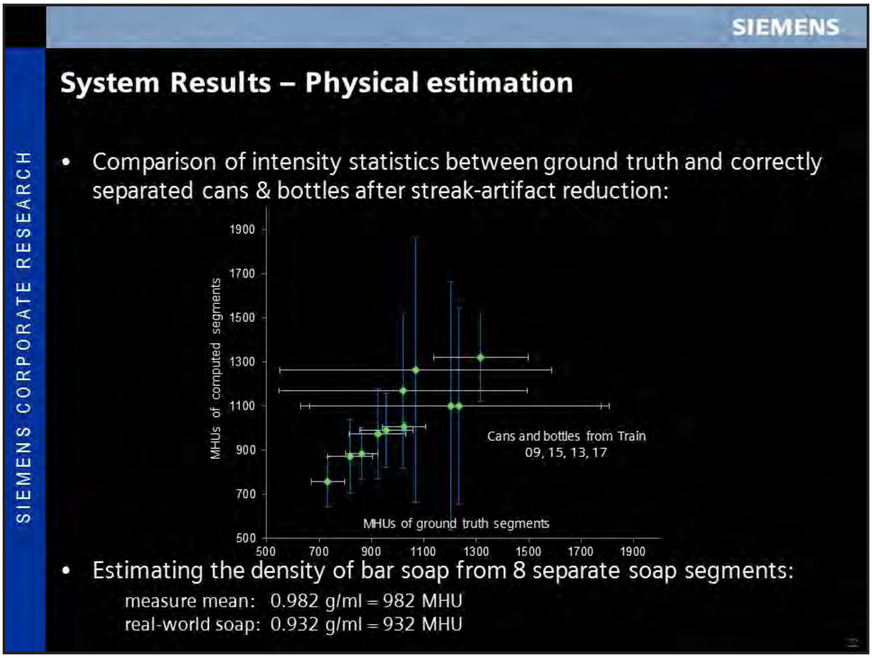


Example Segmentation – Train 26



System Results – Overlap

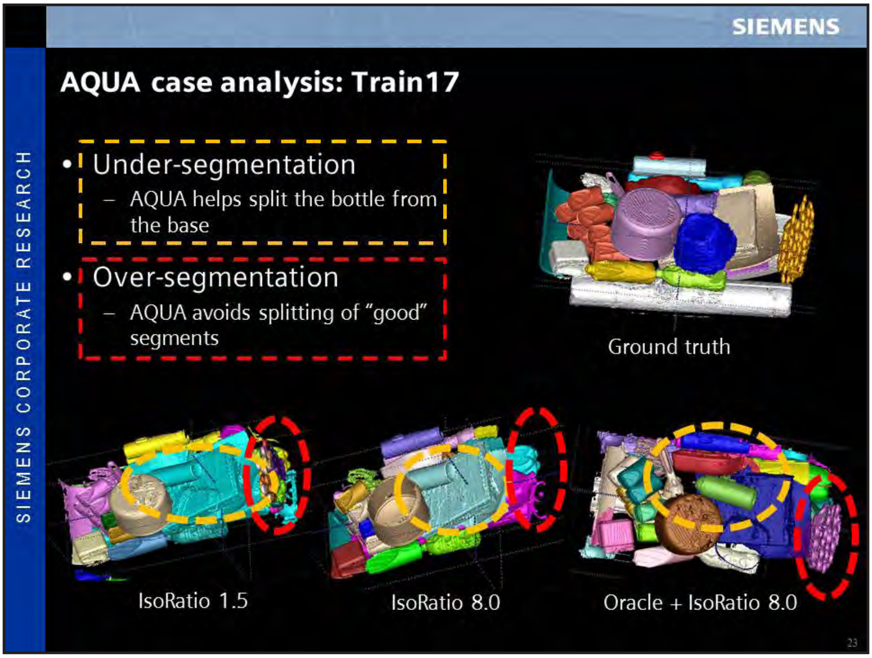
- Segmentation labels are matched to ground truth labels in order to maximize the relative overlap between segments
- Under-segmented labels are assigned to one ground truth label, intersections with other ground truth labels don't count
- In case of over-splits, only one sub-segment is assigned to a ground truth segment, all others don't count



System Results – Physical estimation

- Comparison of intensity statistics between ground truth and correctly separated cans & bottles after streak-artifact reduction:

- Estimating the density of bar soap from 8 separate soap segments:
  - measure mean: 0.982 g/ml = 982 MHU
  - real-world soap: 0.932 g/ml = 932 MHU



AQUA case analysis: Train17

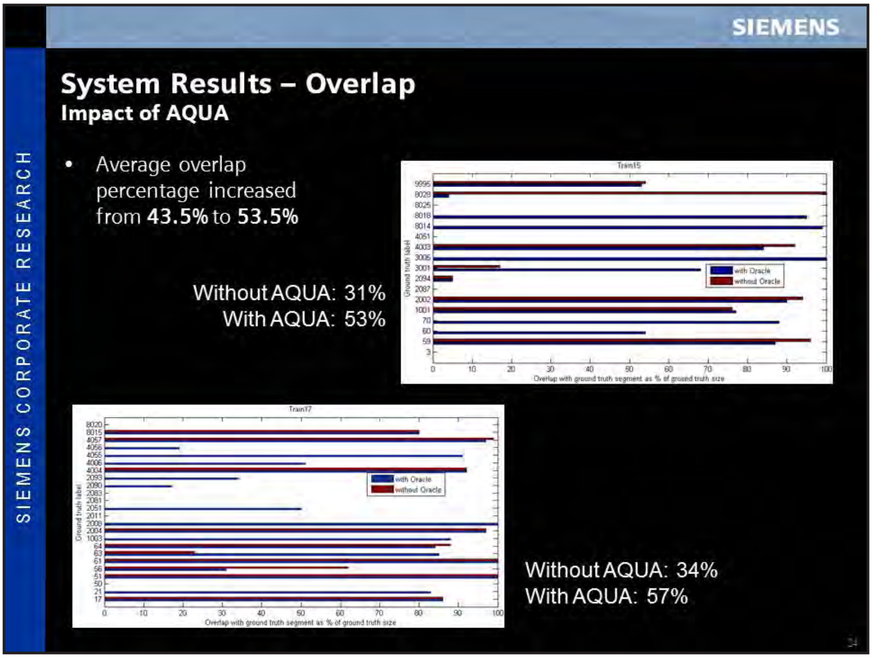
- Under-segmentation
  - AQUA helps split the bottle from the base
- Over-segmentation
  - AQUA avoids splitting of "good" segments

Ground truth

IsoRatio 1.5

IsoRatio 8.0

Oracle + IsoRatio 8.0



System Results – Overlap

Impact of AQUA

- Average overlap percentage increased from **43.5%** to **53.5%**

Without AQUA: 31%
With AQUA: 53%

Without AQUA: 34%
With AQUA: 57%

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Thank you for your attention!

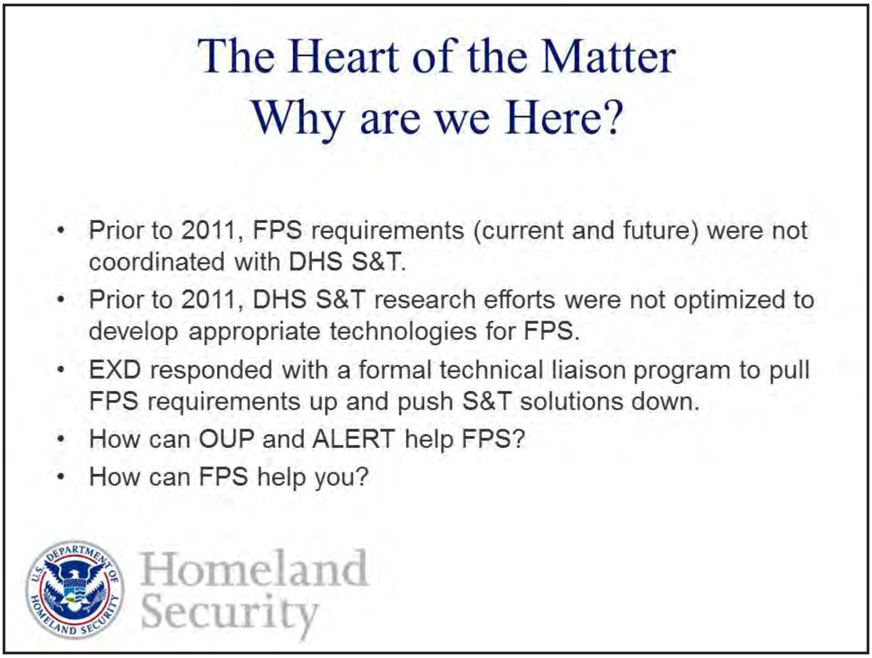
16.15 Vincent Eckert: DHS S&T Support to the Federal Protective Service

DHS S&T Support to the Federal Protective Service

Countermeasures for Federal Buildings

Homeland Security

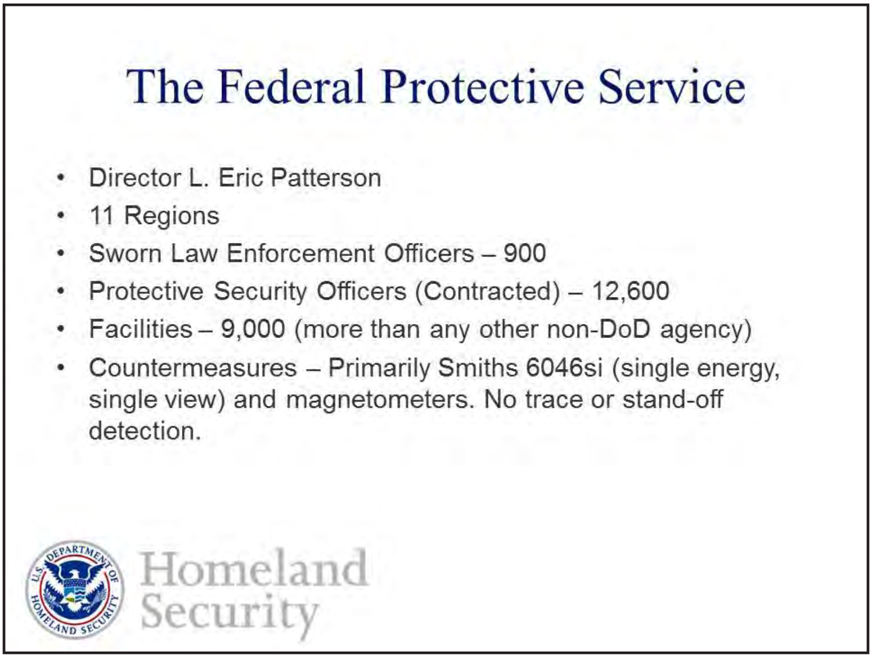
Vince Eckert



The Heart of the Matter
Why are we Here?

- Prior to 2011, FPS requirements (current and future) were not coordinated with DHS S&T.
- Prior to 2011, DHS S&T research efforts were not optimized to develop appropriate technologies for FPS.
- EXD responded with a formal technical liaison program to pull FPS requirements up and push S&T solutions down.
- How can OUP and ALERT help FPS?
- How can FPS help you?

Homeland Security



The Federal Protective Service

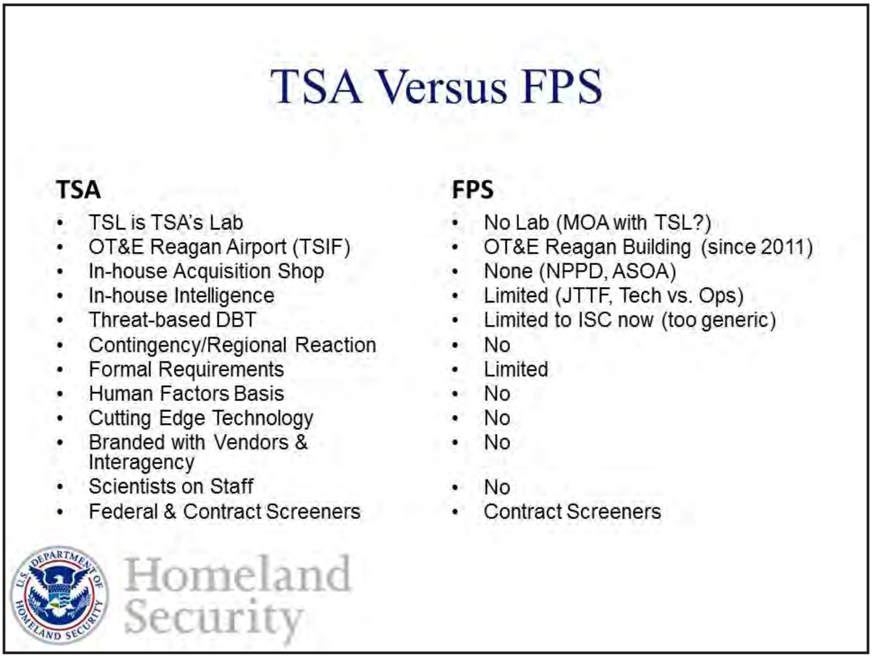
- Director L. Eric Patterson
- 11 Regions
- Sworn Law Enforcement Officers – 900
- Protective Security Officers (Contracted) – 12,600
- Facilities – 9,000 (more than any other non-DoD agency)
- Countermeasures – Primarily Smiths 6046si (single energy, single view) and magnetometers. No trace or stand-off detection.

Homeland
Security

Countermeasure Process

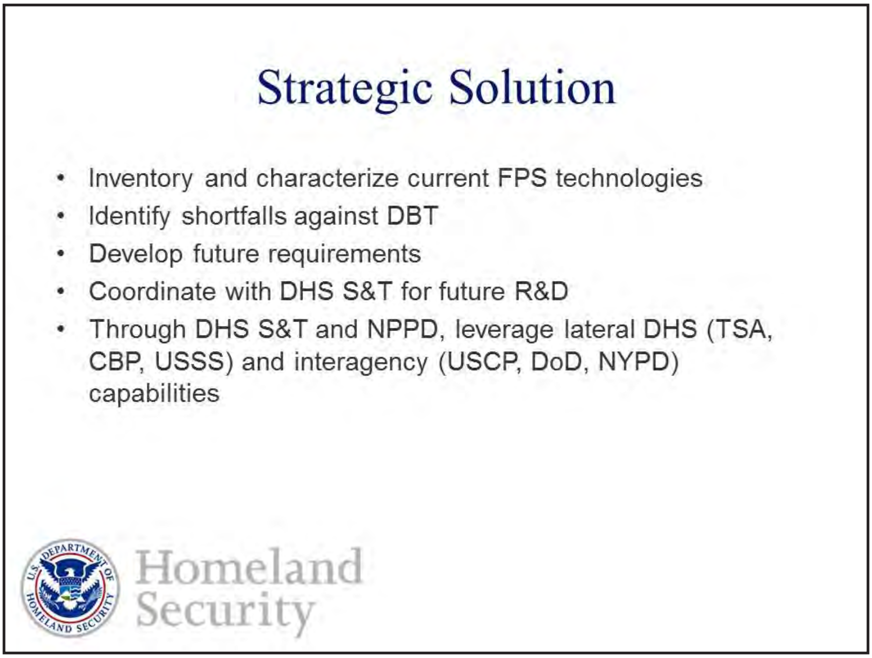
- Design-Basis Threat (DBT)
  - Interagency Security Committee (ISC)
  - FPS Supplement
- Risk Assessment (ISC prescribed)
- Facility Security Level (FSL) Determination
- Local Facility Security Committee Authority
- Funding Issues
- General Services Administration

Homeland
Security



TSA Versus FPS

TSA	FPS
TSL is TSA's Lab	No Lab (MOA with TSL?)
OT&E Reagan Airport (TSIF)	OT&E Reagan Building (since 2011)
In-house Acquisition Shop	None (NPPD, ASOA)
In-house Intelligence	Limited (JTTF, Tech vs. Ops)
Threat-based DBT	Limited to ISC now (too generic)
Contingency/Regional Reaction	No
Formal Requirements	Limited
Human Factors Basis	No
Cutting Edge Technology	No
Branded with Vendors & Interagency	No
Scientists on Staff	No
Federal & Contract Screeners	Contract Screeners



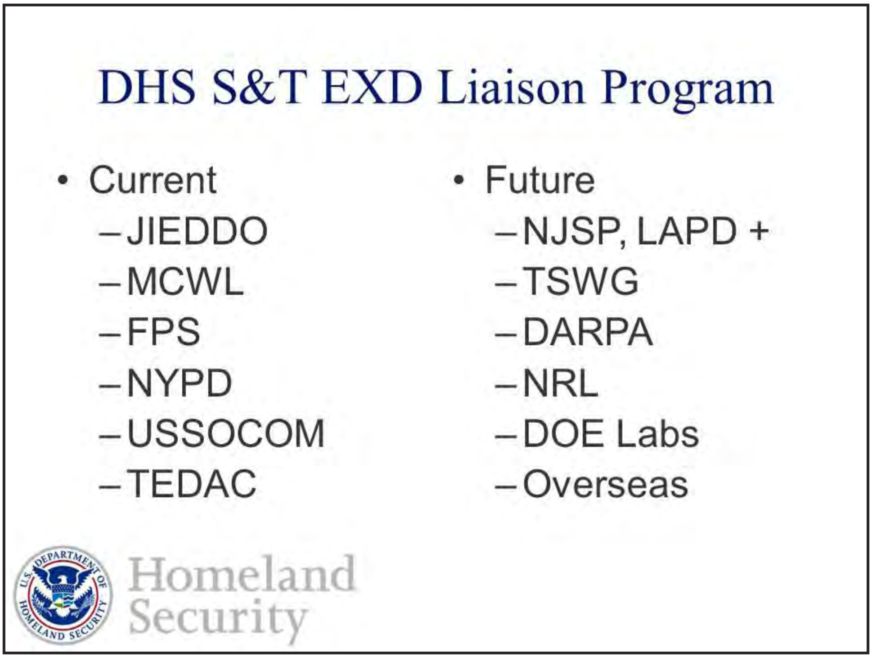
Strategic Solution

- Inventory and characterize current FPS technologies
- Identify shortfalls against DBT
- Develop future requirements
- Coordinate with DHS S&T for future R&D
- Through DHS S&T and NPPD, leverage lateral DHS (TSA, CBP, USSS) and interagency (USCP, DoD, NYPD) capabilities

Progress to Date

- DHS S&T EXD Liaison Office (LNO) Program
- FINS (FPS Initiatives with S&T), Dr. Houser controls distribution
- FPS DBT Supplement (Intelligence/Threat-Based)
- Dedicated FPS Countermeasures POC (Commander Eckert)
- Acquisition Support (S&T ASOA, NPPD CAE, in-house)
- COE Reagan (ModBX, ARFCAM, REBUS, etc.)
- Beyond EXD to HFD, CBD, OBP, JIEDDO, FBI, TSA, TSL +
- NIST and DHS S&T Standards Office
- New IPT "Checkpoint 2020"
- Direct Support to Regions (e.g. Region 1, Boston Moakley)

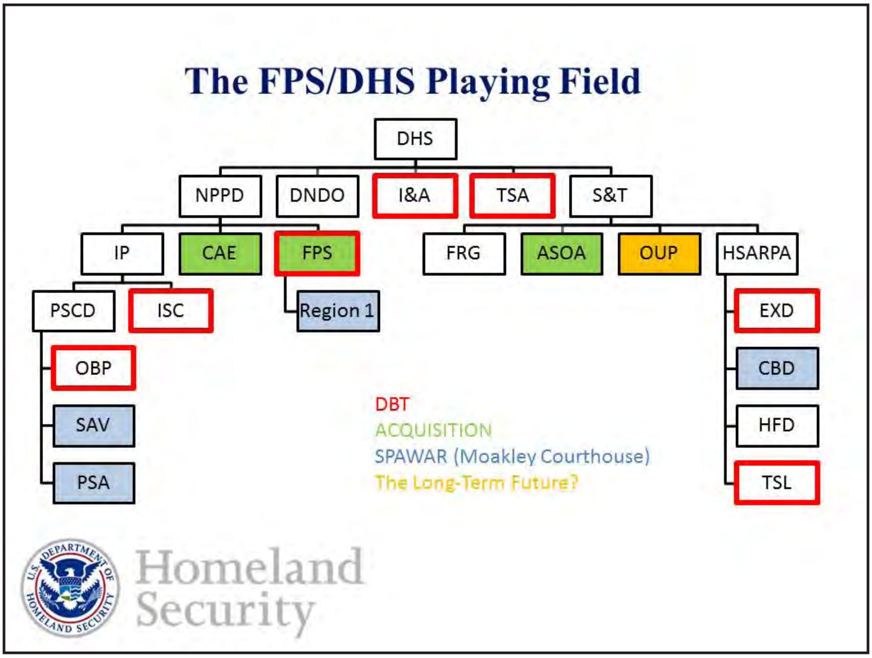
Homeland
Security



DHS S&T EXD Liaison Program

- Current
  - JIEDDO
  - MCWL
  - FPS
  - NYPD
  - USSOCOM
  - TEDAC
- Future
  - NJSP, LAPD +
  - TSWG
  - DARPA
  - NRL
  - DOE Labs
  - Overseas

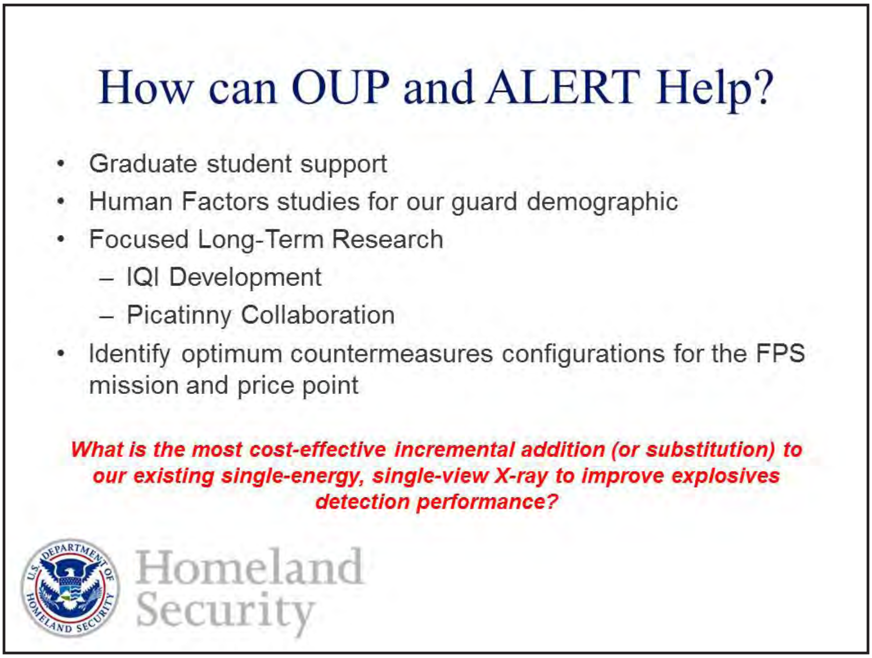
Homeland
Security



The FPS/DHS Playing Field

- DHS
  - NPPD
    - IP
      - PSCD
        - OBP
        - SAV
        - PSA
      - ISC
    - CAE
    - FPS
      - Region 1
  - DNDO
  - I&A
  - TSA
  - S&T
    - FRG
    - ASOA
    - OUP
    - HSARPA
      - EXD
      - CBD
      - HFD
      - TSL

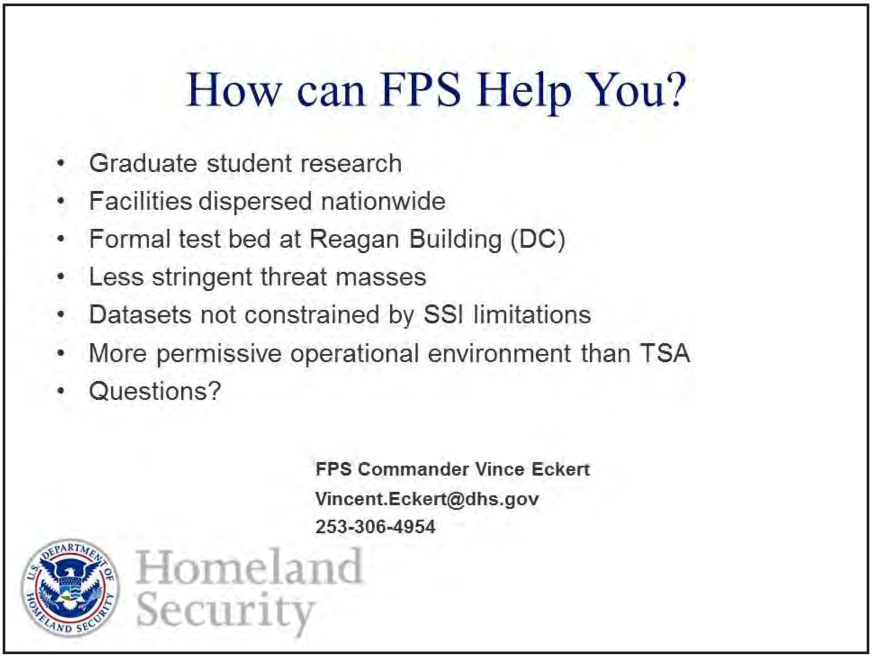
DBT
ACQUISITION
SPAWAR (Moakley Courthouse)
The Long-Term Future?



How can OUP and ALERT Help?

- Graduate student support
- Human Factors studies for our guard demographic
- Focused Long-Term Research
  - IQI Development
  - Picatinny Collaboration
- Identify optimum countermeasures configurations for the FPS mission and price point

What is the most cost-effective incremental addition (or substitution) to our existing single-energy, single-view X-ray to improve explosives detection performance?



How can FPS Help You?

- Graduate student research
- Facilities dispersed nationwide
- Formal test bed at Reagan Building (DC)
- Less stringent threat masses
- Datasets not constrained by SSI limitations
- More permissive operational environment than TSA
- Questions?

FPS Commander Vince Eckert
Vincent.Eckert@dhs.gov
253-306-4954

Homeland
Security

Homeland
Security

Homeland
Security

16.16 David Castañón: Video Analytics (and Homeland Security)

Video Analytics

(and Homeland Security)

David A. Castañón

Boston University

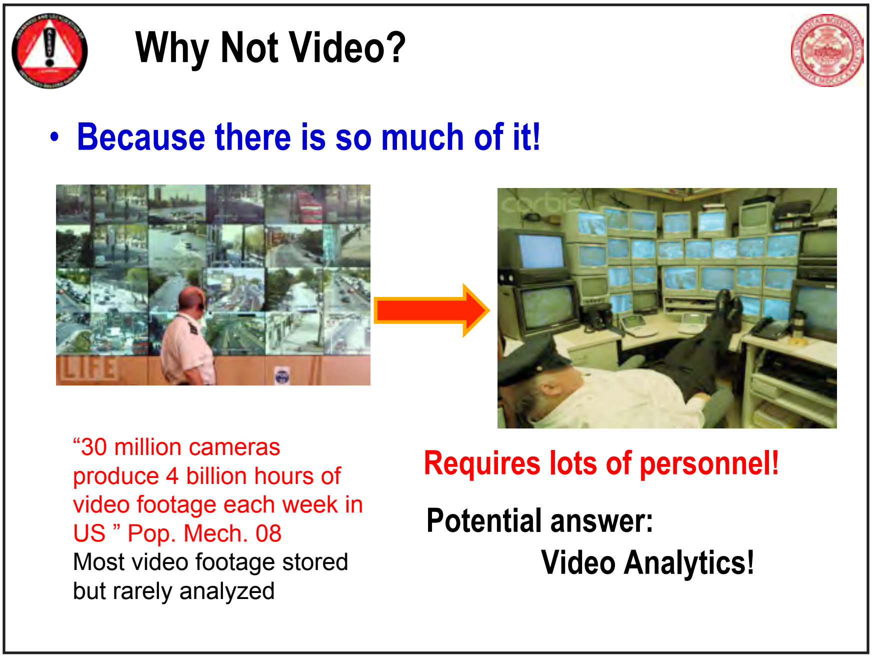
With contributions from V. Saligrama, J. Konrad,
P. Ishwar, M. Sznaier, O. Camps, R. Radke et al.

Why Video?

- **Because it is there, and it is cheap**

Networked Cameras are Everywhere

- **And there is much technology in development that may transfer to DHS**



Why Not Video?

- Because there is so much of it!

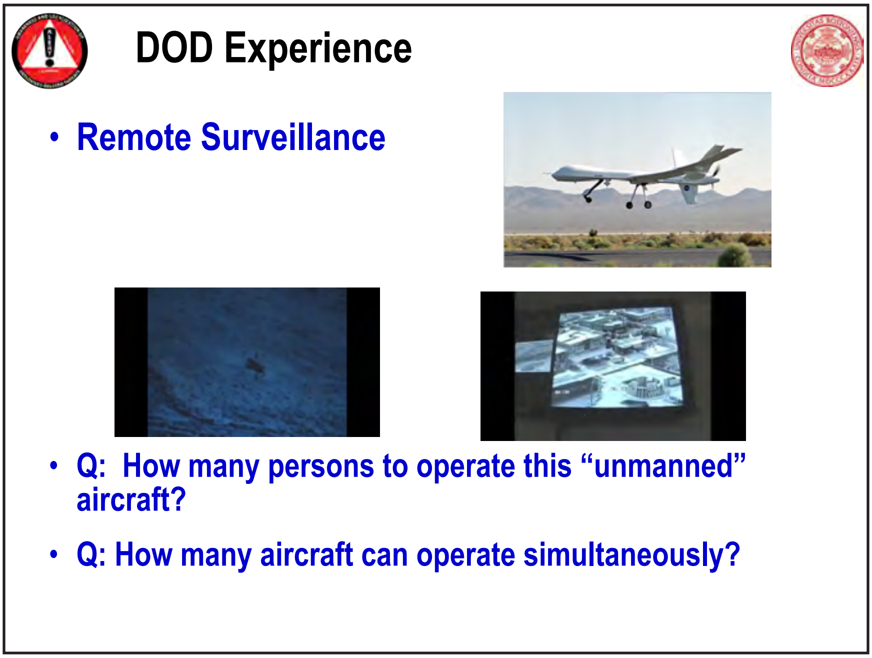
"30 million cameras produce 4 billion hours of video footage each week in US " Pop. Mech. 08

Most video footage stored but rarely analyzed

Requires lots of personnel!

Potential answer:

Video Analytics!



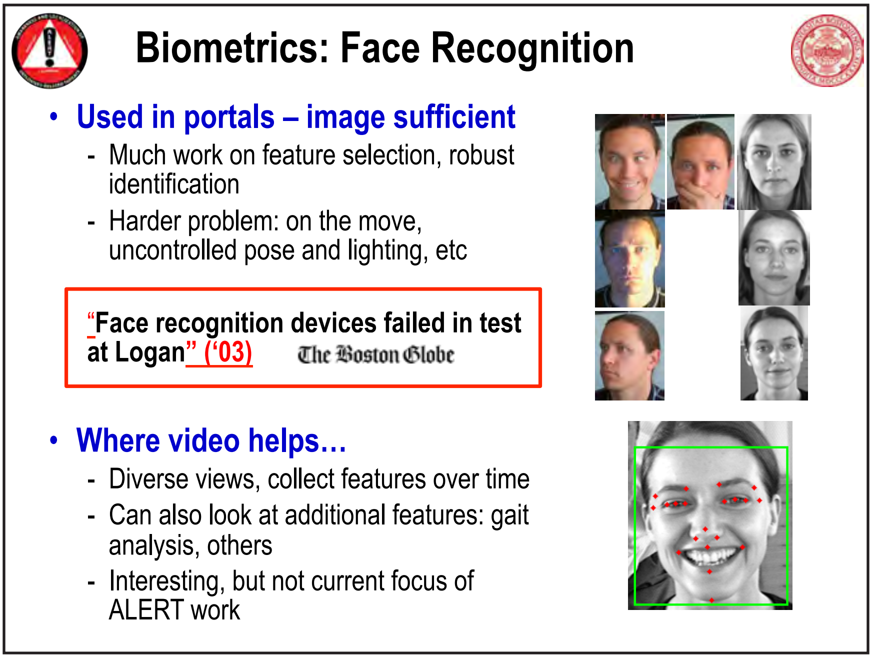
DOD Experience

- Remote Surveillance

- Q: How many persons to operate this "unmanned" aircraft?
- Q: How many aircraft can operate simultaneously?

Some DHS Potential Applications

- **Biometrics: Who is there**
  - Automatically recognize individuals in watch lists, …
- **Anomaly Detection: Something unusual**
  - Activities that raise concerns
- **Tracking: Maintain continuity of ID, fuse temporal information**
  - Associate activities, data over time
- **Forensics: find past activities by person or type**
  - Review old video with new perspective



Biometrics: Face Recognition

- **Used in portals – image sufficient**
  - Much work on feature selection, robust identification
  - Harder problem: on the move, uncontrolled pose and lighting, etc

"Face recognition devices failed in test at Logan" ('03) The Boston Globe

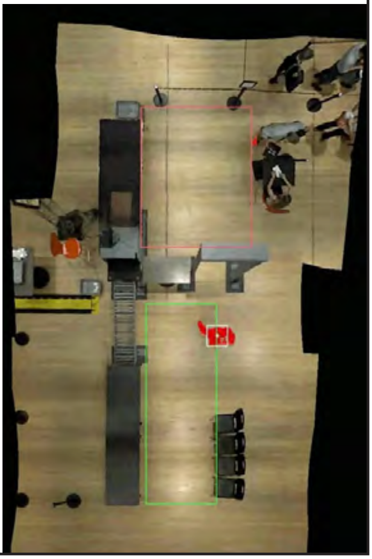
- **Where video helps…**
  - Diverse views, collect features over time
  - Can also look at additional features: gait analysis, others
  - Interesting, but not current focus of ALERT work

Interesting Problem: Storage

- **Most video has little of interest**
  - Should we store it?
  - Approach: video condensation – lossless compression

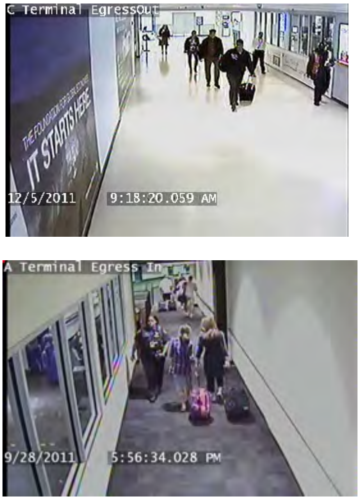
Anomaly Detection: Security Lane

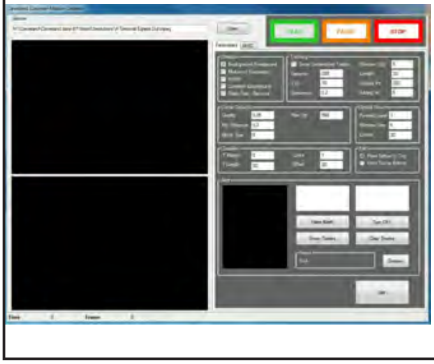
- **Maintain relationship between luggage and persons, groups, others…**
  - Similar to Logan overhead cameras, Terminal C
  - Anomalies: change of bag/ person association



Anomaly Detection: Exit Lane

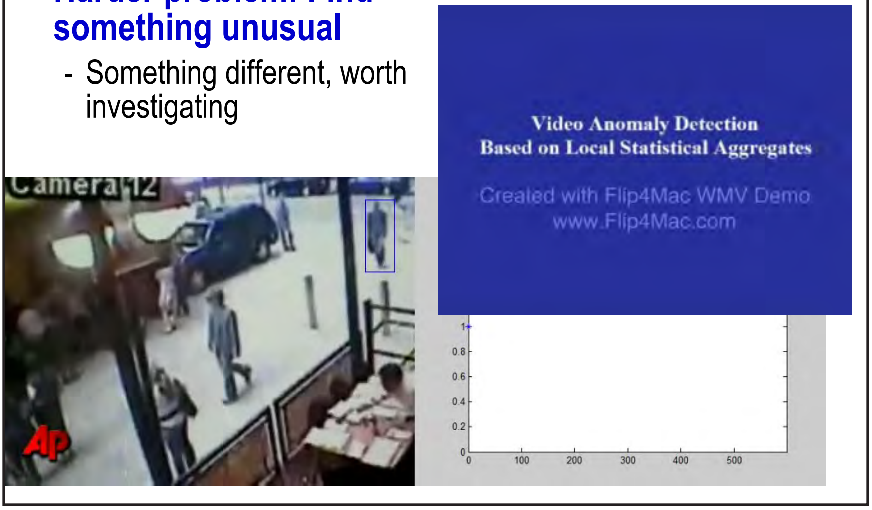
- **Look for individuals moving against normal flow**
  - Known type of anomaly





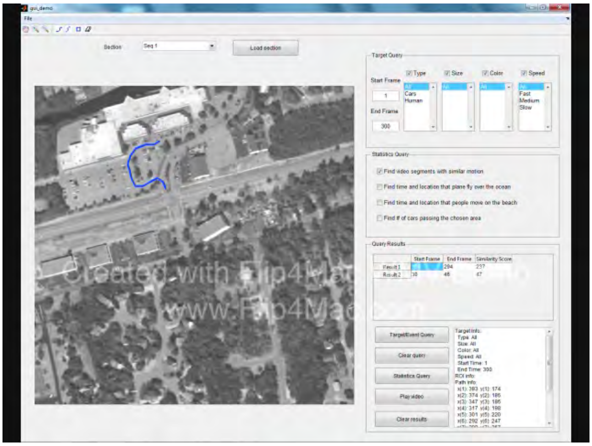
Anomaly Detection: Unknown Anomalies?

- **Harder problem: Find something unusual**
  - Something different, worth investigating



Forensic Search

- Detecting motion patterns in stored video



Section: Seq 1

Target Query

Start Frame: 1

End Frame: 300

☑ Type: All, Cars, Human

☑ Size: All

☑ Color: All

☑ Speed: All, Fast, Medium, Slow

Statistics Query

☑ Find video segments with similar motion

☐ Find time and location that plane fly over the ocean

☐ Find time and location that people move on the beach

☐ Find # of cars passing the chosen area

Query Results

	Start Frame	End Frame	Similarity Score
Result 1	[illegible]	294	237
Result 2	30	46	47

Target Info:
Type: All
Size: All
Color: All
Speed: All
Start Time: 1
End Time: 300
ROI Info:
Path Info:
x(1): 393 y(1): 174
x(2): 374 y(2): 186
x(3): 347 y(3): 186
x(4): 317 y(4): 198
x(5): 301 y(5): 220
x(6): 292 y(6): 247

4 hours processed in 12 seconds!

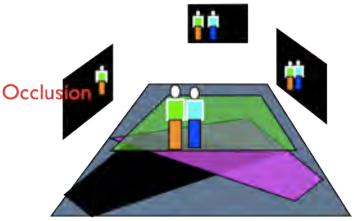
Tag and Track

Tracking: Geometry Matters

- Many tracking algorithms exploit good vantage points
  - Minimizes obscuration, facilitates coverage
  - See external video

Multiple Cameras Assist Tracking

- If target is occluded in one view, the system should recover using the other cameras.
- Exploit geometrical and dynamical constraints

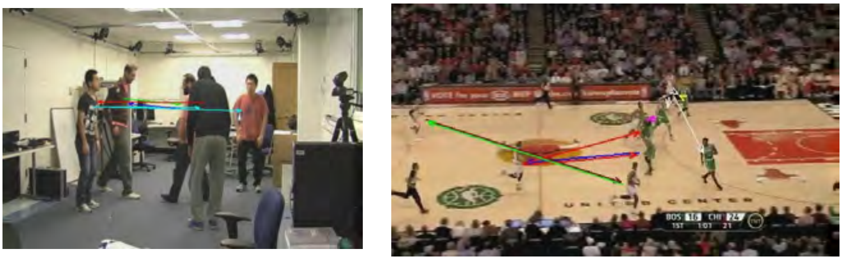


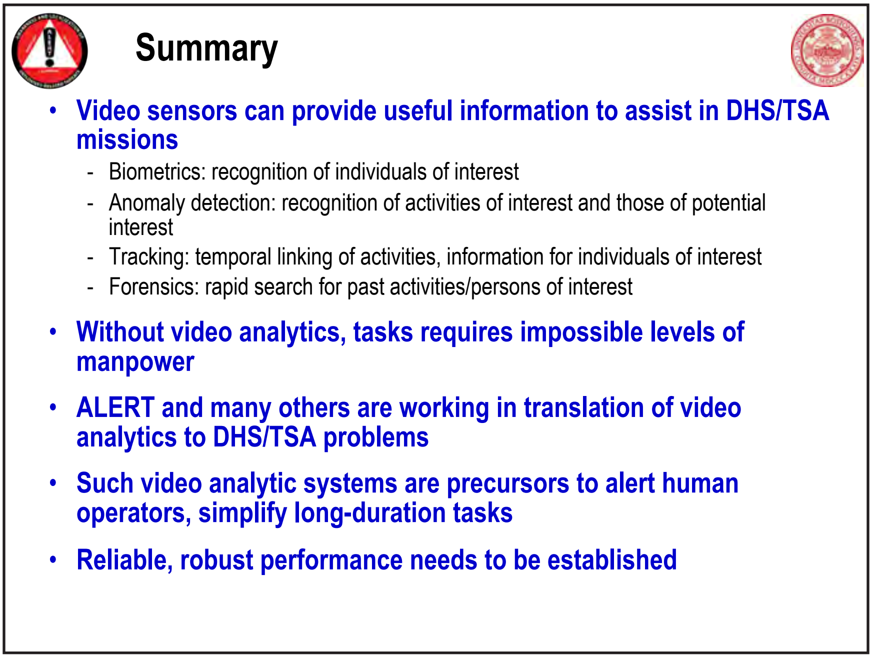
Tag and Track Made Easy…

- **What $300 hardware + clever algorithms do…**

Detection of Team Behavior

- **Multiple agents acting in coherent fashion, potentially in crowds**
  - Look for time series of actions that have spatial correlation

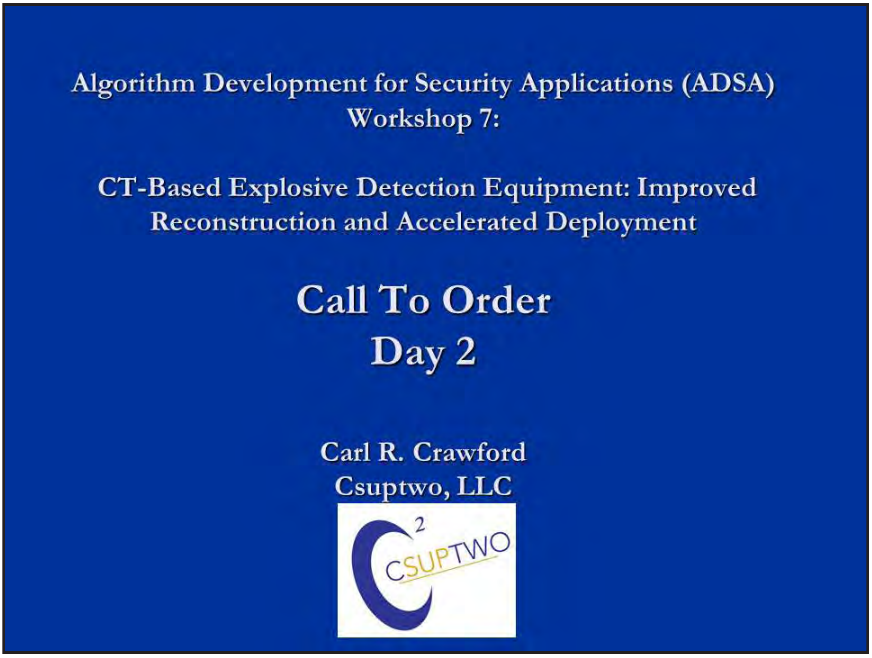




Summary

- **Video sensors can provide useful information to assist in DHS/TSA missions**
  - Biometrics: recognition of individuals of interest
  - Anomaly detection: recognition of activities of interest and those of potential interest
  - Tracking: temporal linking of activities, information for individuals of interest
  - Forensics: rapid search for past activities/persons of interest
- **Without video analytics, tasks requires impossible levels of manpower**
- **ALERT and many others are working in translation of video analytics to DHS/TSA problems**
- **Such video analytic systems are precursors to alert human operators, simplify long-duration tasks**
- **Reliable, robust performance needs to be established**

16.17 Carl Crawford: Call to Order Day 2

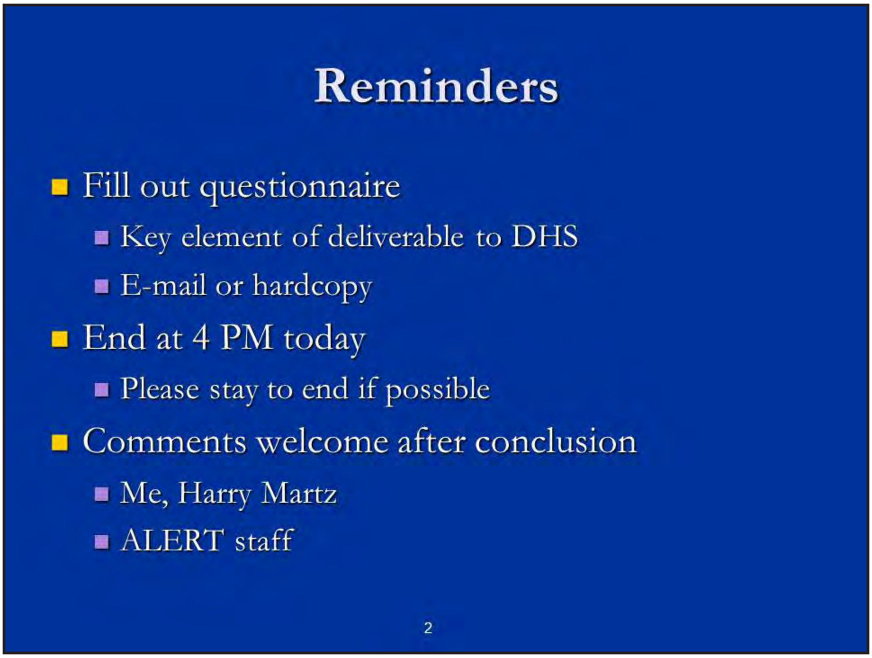


Algorithm Development for Security Applications (ADSA)
Workshop 7:

CT-Based Explosive Detection Equipment: Improved
Reconstruction and Accelerated Deployment

Call To Order
Day 2

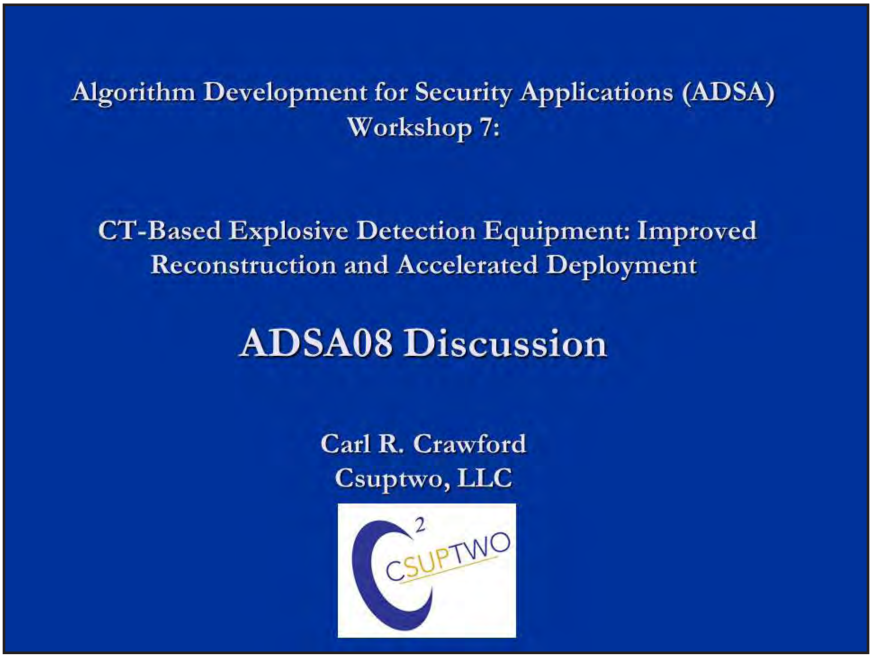
Carl R. Crawford
Csuptwo, LLC



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

16.18 Carl Crawford: ADSA08 Discussion

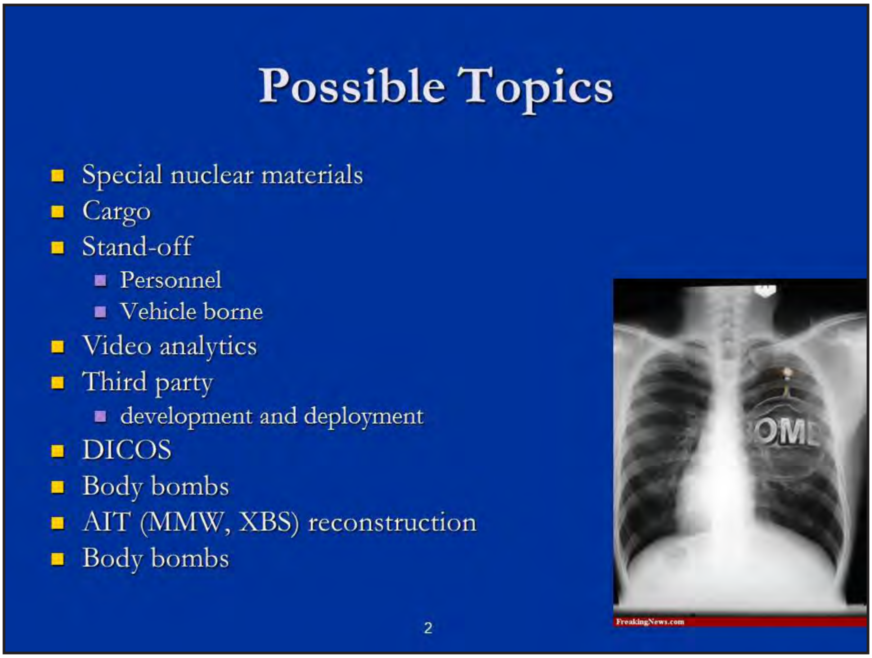


Algorithm Development for Security Applications (ADSA)
Workshop 7:

CT-Based Explosive Detection Equipment: Improved Reconstruction and Accelerated Deployment

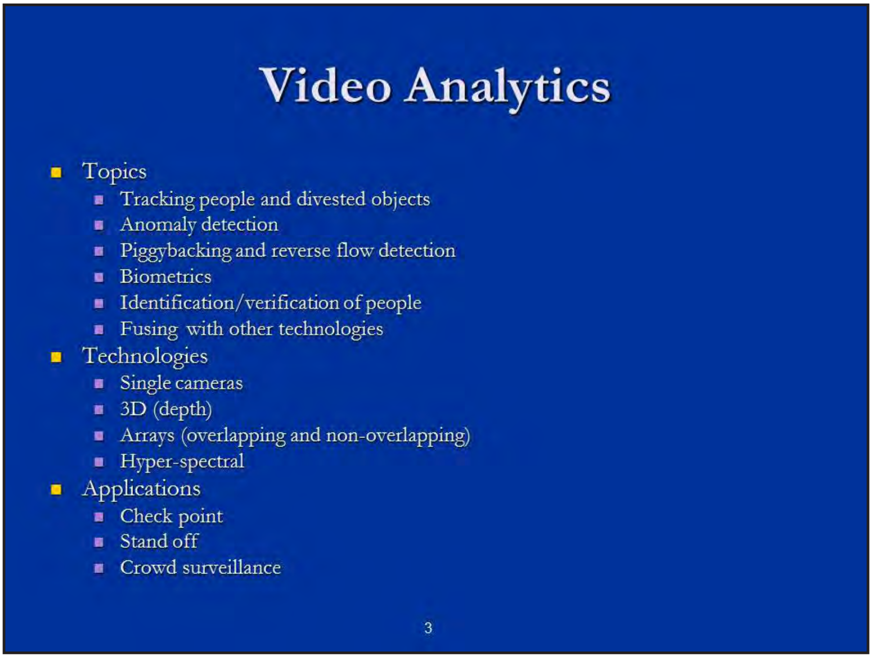
ADSA08 Discussion

Carl R. Crawford
Csuptwo, LLC



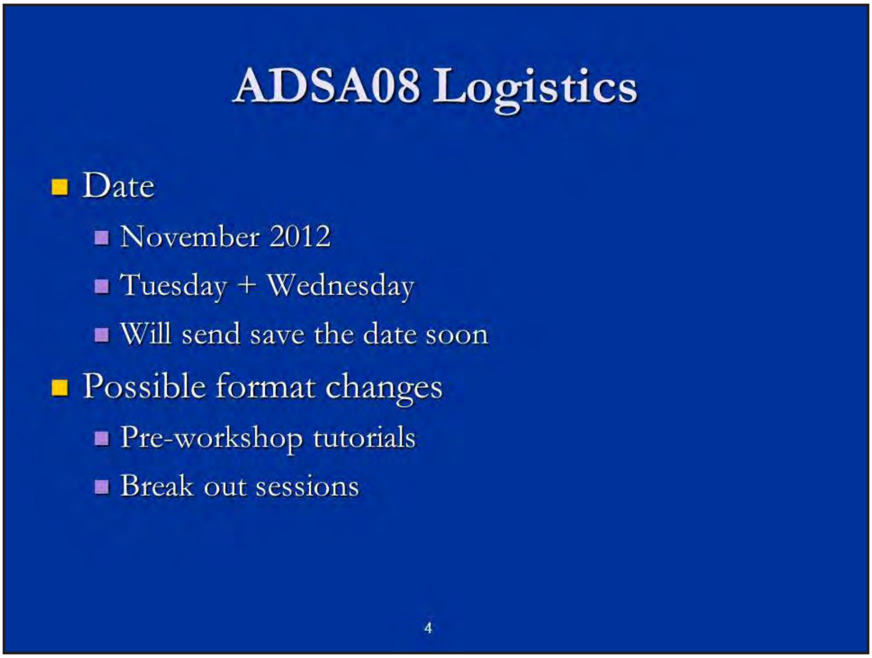
Possible Topics

- Special nuclear materials
- Cargo
- Stand-off
  - Personnel
  - Vehicle borne
- Video analytics
- Third party
  - development and deployment
- DICOS
- Body bombs
- AIT (MMW, XBS) reconstruction
- Body bombs



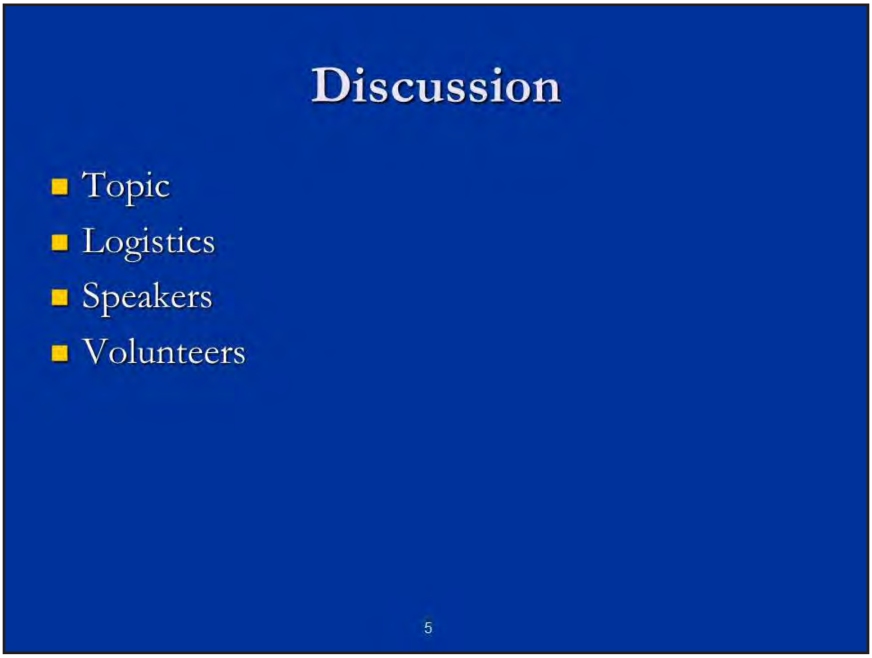
Video Analytics

- 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



ADSA08 Logistics

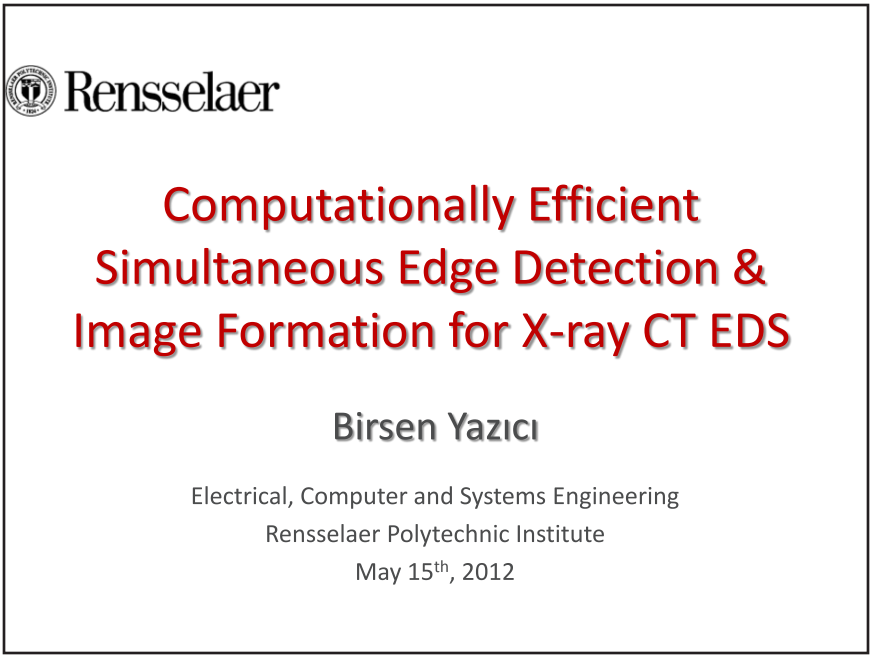
- Date
  - November 2012
  - Tuesday + Wednesday
  - Will send save the date soon
- Possible format changes
  - Pre-workshop tutorials
  - Break out sessions



Discussion

- Topic
- Logistics
- Speakers
- Volunteers

16.19 Birsen Yazici: Computationally Efficient Simultaneous Edge Detection Image Formation for X-ray CT

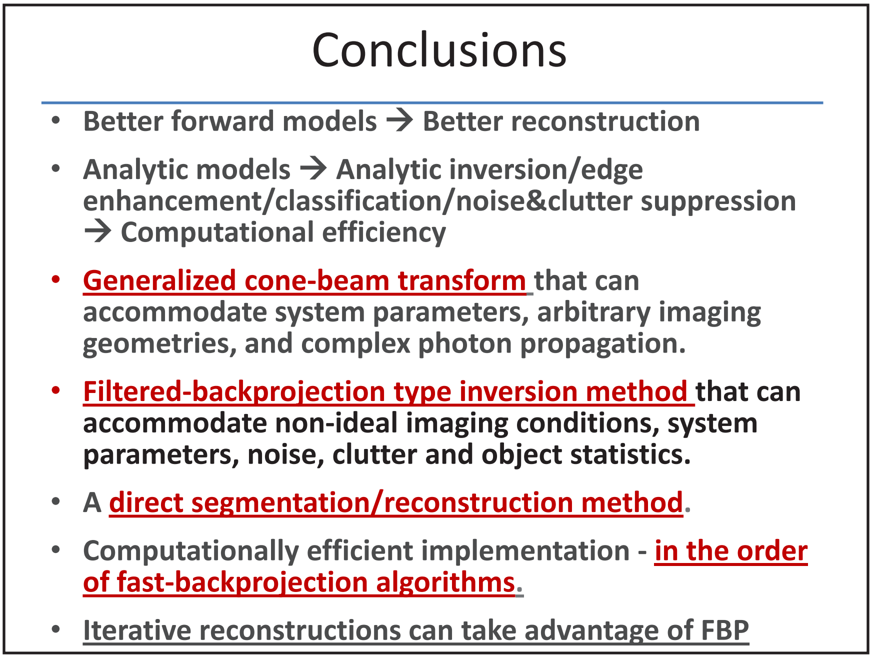


Rensselaer

Computationally Efficient Simultaneous Edge Detection & Image Formation for X-ray CT EDS

Birsen Yazıcı

Electrical, Computer and Systems Engineering
Rensselaer Polytechnic Institute
May 15th, 2012



Conclusions

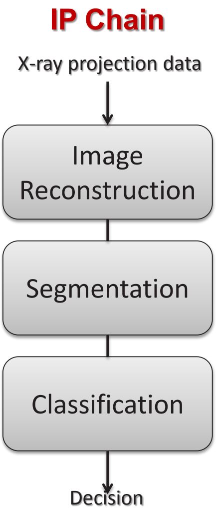
- Better forward models → Better reconstruction
- Analytic models → Analytic inversion/edge enhancement/classification/noise&clutter suppression → Computational efficiency
- Generalized cone-beam transform that can accommodate system parameters, arbitrary imaging geometries, and complex photon propagation.
- Filtered-backprojection type inversion method that can accommodate non-ideal imaging conditions, system parameters, noise, clutter and object statistics.
- A direct segmentation/reconstruction method.
- Computationally efficient implementation - in the order of fast-backprojection algorithms.
- Iterative reconstructions can take advantage of FBP

Outline

- Motivations/relevance
- Objectives
- Generalized cone-beam transform
- FBP inversion
- Simultaneous edge detection and reconstruction
- Numerical simulations
- Conclusion

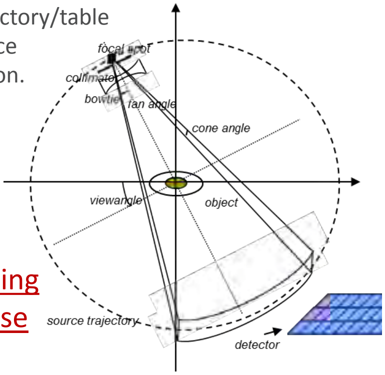
Motivations - 1

- The image processing (IP) chain in X-ray CT EDS systems includes the steps of
  - image reconstruction,
  - segmentation and
  - classification.
- In existing EDS systems these steps are implemented in a decoupled fashion using all purpose algorithms.
- Segmentation is one of the most computationally intense steps in the EDS IP chain.

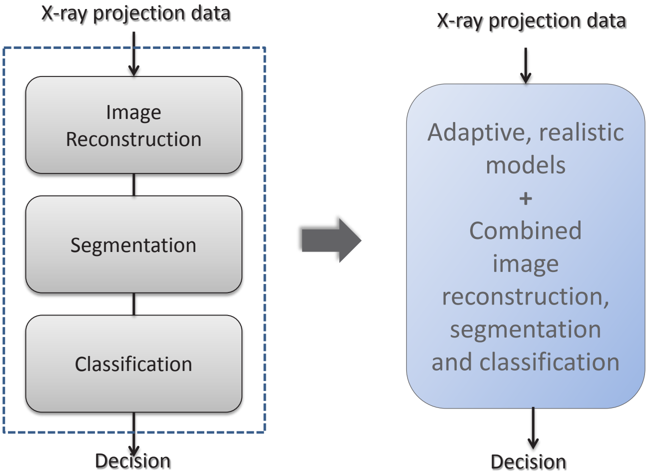


Motivations - 2

- Optimal IP chain algorithms largely depend on system parameters and imaging geometry
  - Detector size and shape, source trajectory/table speed, focal spot size, detector surface topography, detector plane orientation.
- X-ray CT EDS parameters are different for different vendors
- Photon propagation in luggage: more complex than in human tissue – multiple scattering + quantum mottle and elec. noise
- Use of a priori information



Objectives



X-ray projection data

Image Reconstruction

Segmentation

Classification

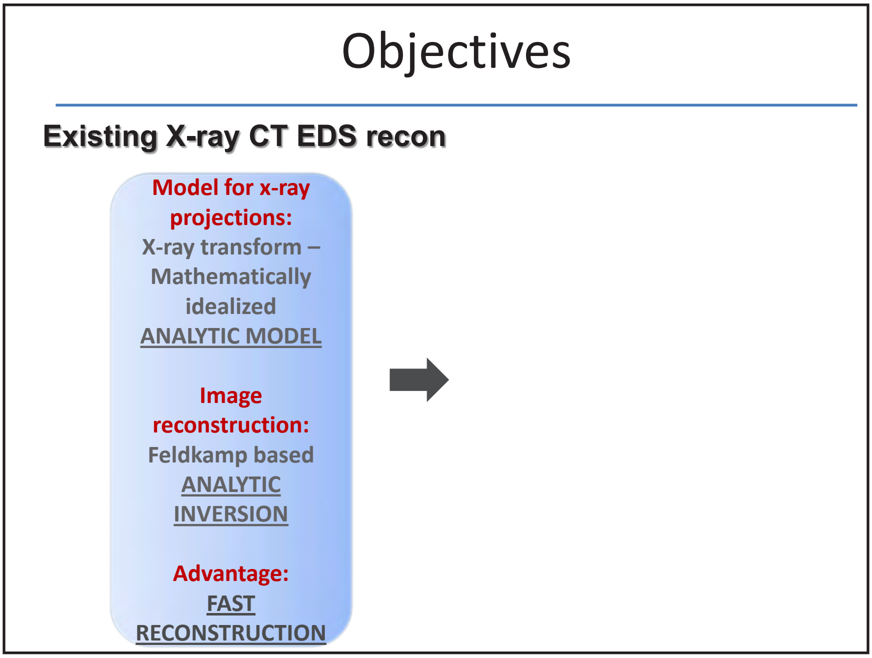
Decision

X-ray projection data

Adaptive, realistic models
+
Combined image reconstruction, segmentation and classification

Decision

Reduced computational complexity + better performance



Objectives

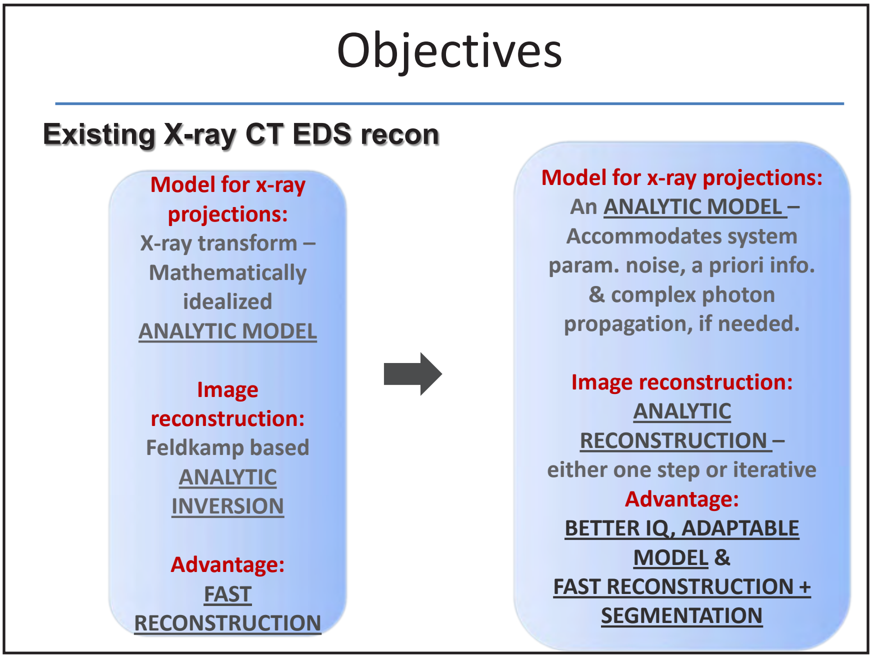
Existing X-ray CT EDS recon

Model for x-ray projections:
X-ray transform – Mathematically idealized
ANALYTIC MODEL

Image reconstruction:
Feldkamp based
ANALYTIC INVERSION

Advantage:
FAST RECONSTRUCTION

→



Objectives

Existing X-ray CT EDS recon

Model for x-ray projections:
X-ray transform – Mathematically idealized
ANALYTIC MODEL

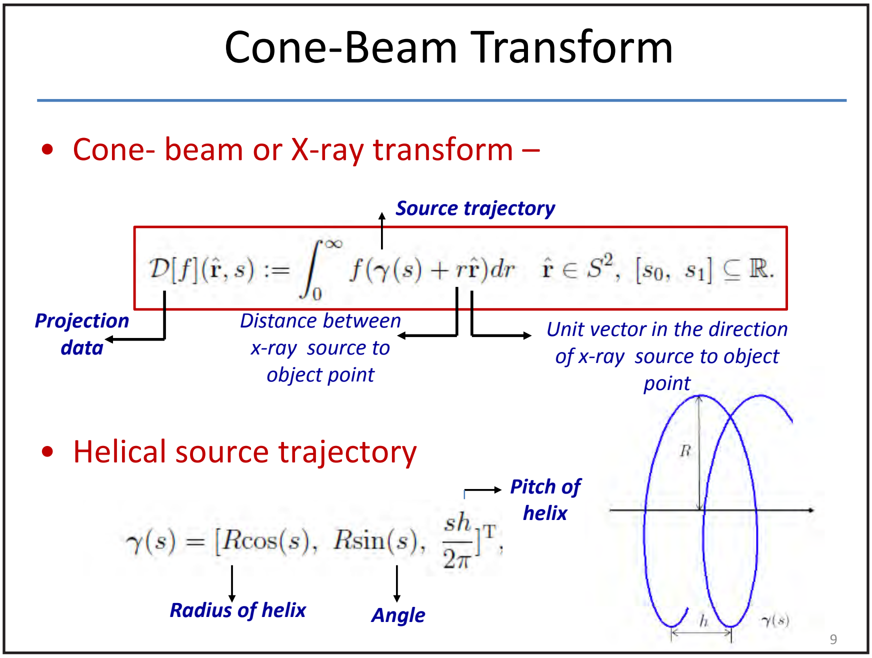
Image reconstruction:
Feldkamp based
ANALYTIC INVERSION

Advantage:
FAST RECONSTRUCTION

→

Model for x-ray projections:
An **ANALYTIC MODEL** – Accommodates system param. noise, a priori info. & complex photon propagation, if needed.

Image reconstruction:
ANALYTIC RECONSTRUCTION – either one step or iterative
Advantage:
BETTER IQ, ADAPTABLE MODEL &
FAST RECONSTRUCTION + SEGMENTATION



Cone-Beam Transform

- Cone- beam or X-ray transform –

Source trajectory

$$\mathcal{D}[f](\hat{\mathbf{r}}, s) := \int_0^\infty f(\gamma(s) + r\hat{\mathbf{r}})dr \quad \hat{\mathbf{r}} \in S^2, \; [s_0, \; s_1] \subseteq \mathbb{R}.$$

Projection data

Distance between x-ray source to object point

Unit vector in the direction of x-ray source to object point

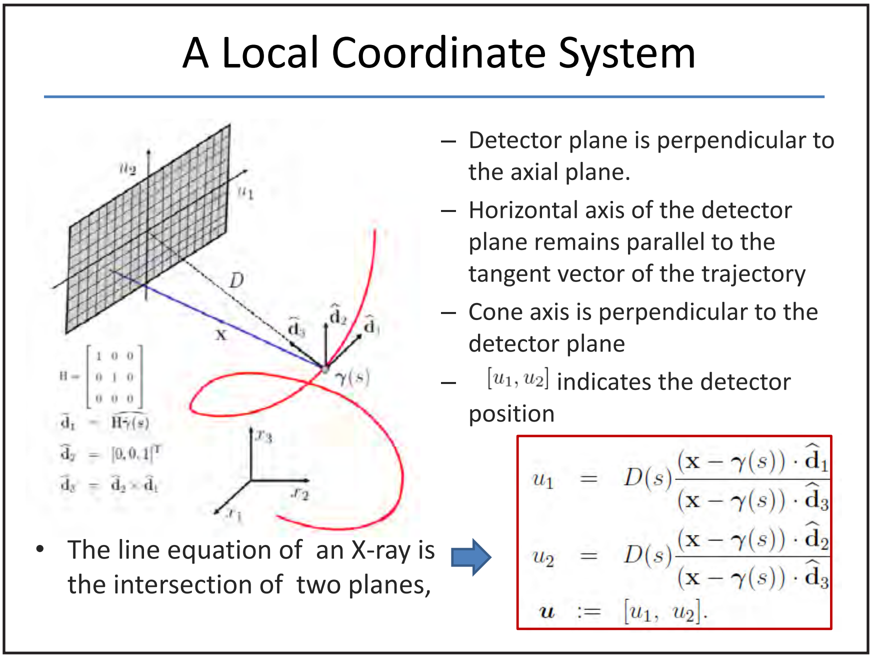
- Helical source trajectory

$$\gamma(s) = [R\cos(s), \; R\sin(s), \; \frac{sh}{2\pi}]^{\mathrm{T}},$$

Pitch of helix

Radius of helix

Angle



A Local Coordinate System

$$H = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\hat{\mathbf{d}}_1 = \widehat{H\gamma(s)}$$

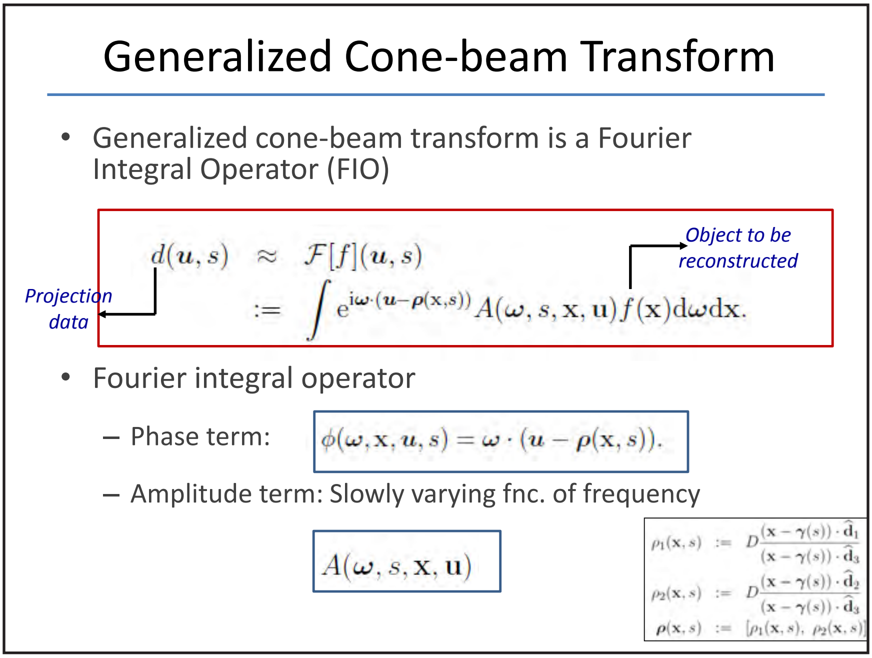
$$\hat{\mathbf{d}}_2 = [0, 0, 1]^{\mathrm{T}}$$

$$\hat{\mathbf{d}}_3 = \hat{\mathbf{d}}_2 \times \hat{\mathbf{d}}_1$$

- Detector plane is perpendicular to the axial plane.
- Horizontal axis of the detector plane remains parallel to the tangent vector of the trajectory
- Cone axis is perpendicular to the detector plane
- $[u_1, u_2]$ indicates the detector position

- The line equation of an X-ray is the intersection of two planes,

$$\begin{aligned} u_1 &= D(s)\frac{(\mathbf{x} - \gamma(s)) \cdot \widehat{\mathbf{d}}_1}{(\mathbf{x} - \gamma(s)) \cdot \widehat{\mathbf{d}}_3} \\ u_2 &= D(s)\frac{(\mathbf{x} - \gamma(s)) \cdot \widehat{\mathbf{d}}_2}{(\mathbf{x} - \gamma(s)) \cdot \widehat{\mathbf{d}}_3} \\ \boldsymbol{u} &:= [u_1, \; u_2]. \end{aligned}$$



Generalized Cone-beam Transform

- Generalized cone-beam transform is a Fourier Integral Operator (FIO)

$$\begin{aligned} d(\boldsymbol{u},s) &\approx \mathcal{F}[f](\boldsymbol{u},s) \\ &:= \int e^{i\boldsymbol{\omega}\cdot(\boldsymbol{u}-\boldsymbol{\rho}(\mathrm{x},s))} A(\boldsymbol{\omega},s,\mathrm{x},\mathrm{u}) f(\mathrm{x}) \mathrm{d}\boldsymbol{\omega}\mathrm{d}\mathrm{x}. \end{aligned}$$

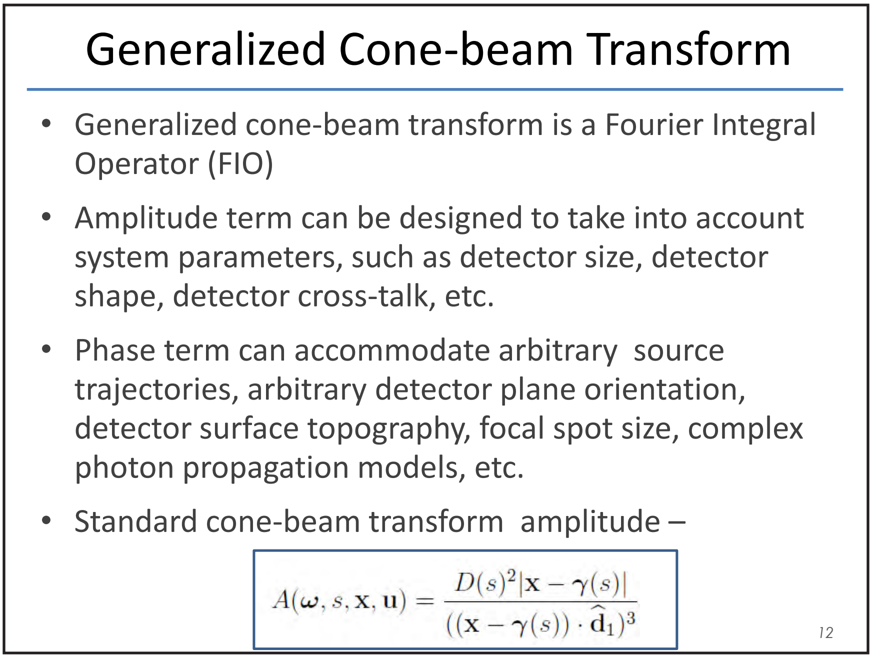
Projection data

Object to be reconstructed

- Fourier integral operator
  - Phase term: $\phi(\boldsymbol{\omega},\mathrm{x},\boldsymbol{u},s) = \boldsymbol{\omega}\cdot(\boldsymbol{u}-\boldsymbol{\rho}(\mathrm{x},s)).$
  - Amplitude term: Slowly varying fnc. of frequency

$$A(\boldsymbol{\omega},s,\mathrm{x},\mathrm{u})$$

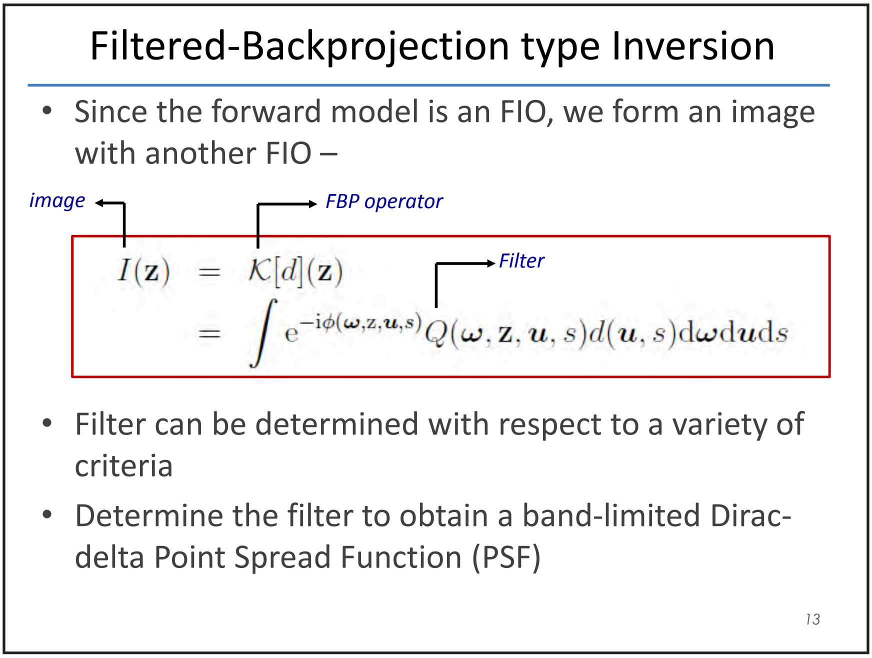
$$\begin{aligned} \rho_1(\mathrm{x},s) &:= D\frac{(\mathrm{x}-\boldsymbol{\gamma}(s))\cdot\widehat{\mathrm{d}}_1}{(\mathrm{x}-\boldsymbol{\gamma}(s))\cdot\widehat{\mathrm{d}}_3} \\ \rho_2(\mathrm{x},s) &:= D\frac{(\mathrm{x}-\boldsymbol{\gamma}(s))\cdot\widehat{\mathrm{d}}_2}{(\mathrm{x}-\boldsymbol{\gamma}(s))\cdot\widehat{\mathrm{d}}_3} \\ \boldsymbol{\rho}(\mathrm{x},s) &:= [\rho_1(\mathrm{x},s),\ \rho_2(\mathrm{x},s)] \end{aligned}$$



Generalized Cone-beam Transform

- Generalized cone-beam transform is a Fourier Integral Operator (FIO)
- Amplitude term can be designed to take into account system parameters, such as detector size, detector shape, detector cross-talk, etc.
- Phase term can accommodate arbitrary source trajectories, arbitrary detector plane orientation, detector surface topography, focal spot size, complex photon propagation models, etc.
- Standard cone-beam transform amplitude –

$$A(\boldsymbol{\omega},s,\mathrm{x},\mathrm{u}) = \frac{D(s)^2|\mathrm{x}-\boldsymbol{\gamma}(s)|}{((\mathrm{x}-\boldsymbol{\gamma}(s))\cdot\widehat{\mathrm{d}}_1)^3}$$



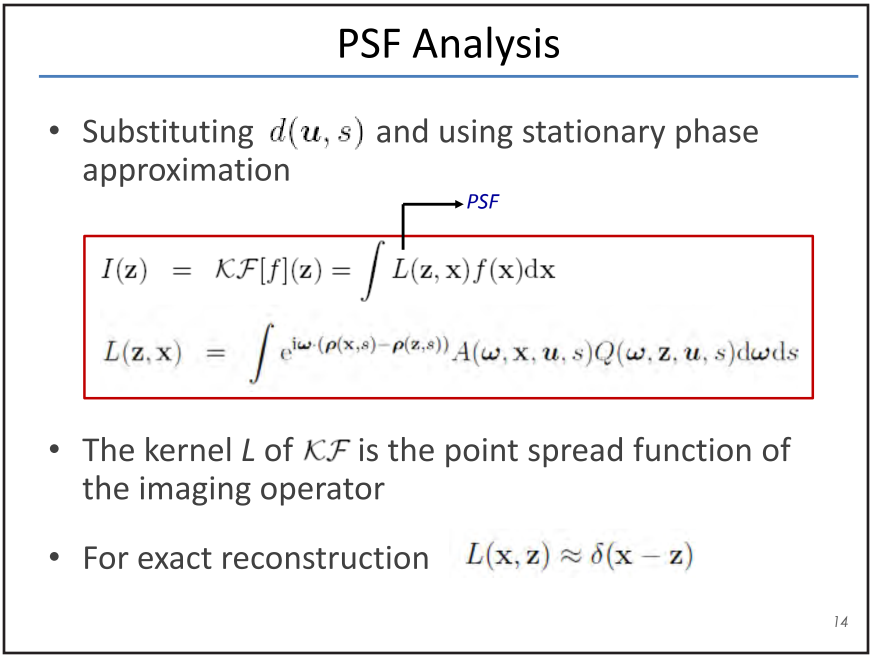
Filtered-Backprojection type Inversion

- Since the forward model is an FIO, we form an image with another FIO –

image *FBP operator* *Filter*

$$\begin{aligned} I(\mathbf{z}) &= \mathcal{K}[d](\mathbf{z}) \\ &= \int \mathrm{e}^{-\mathrm{i}\phi(\boldsymbol{\omega},\mathbf{z},\boldsymbol{u},s)} Q(\boldsymbol{\omega},\mathbf{z},\boldsymbol{u},s) d(\boldsymbol{u},s) \mathrm{d}\boldsymbol{\omega} \mathrm{d}\boldsymbol{u} \mathrm{d}s \end{aligned}$$

- Filter can be determined with respect to a variety of criteria
- Determine the filter to obtain a band-limited Dirac-delta Point Spread Function (PSF)



PSF Analysis

- Substituting $d(\boldsymbol{u},s)$ and using stationary phase approximation

PSF

$$\begin{aligned} I(\mathrm{z}) &= \mathcal{K}\mathcal{F}[f](\mathrm{z}) = \int L(\mathrm{z},\mathrm{x}) f(\mathrm{x}) \mathrm{d}\mathrm{x} \\ L(\mathrm{z},\mathrm{x}) &= \int \mathrm{e}^{\mathrm{i}\boldsymbol{\omega}\cdot(\boldsymbol{\rho}(\mathrm{x},s)-\boldsymbol{\rho}(\mathrm{z},s))} A(\boldsymbol{\omega},\mathrm{x},\boldsymbol{u},s) Q(\boldsymbol{\omega},\mathrm{z},\boldsymbol{u},s) \mathrm{d}\boldsymbol{\omega} \mathrm{d}s \end{aligned}$$

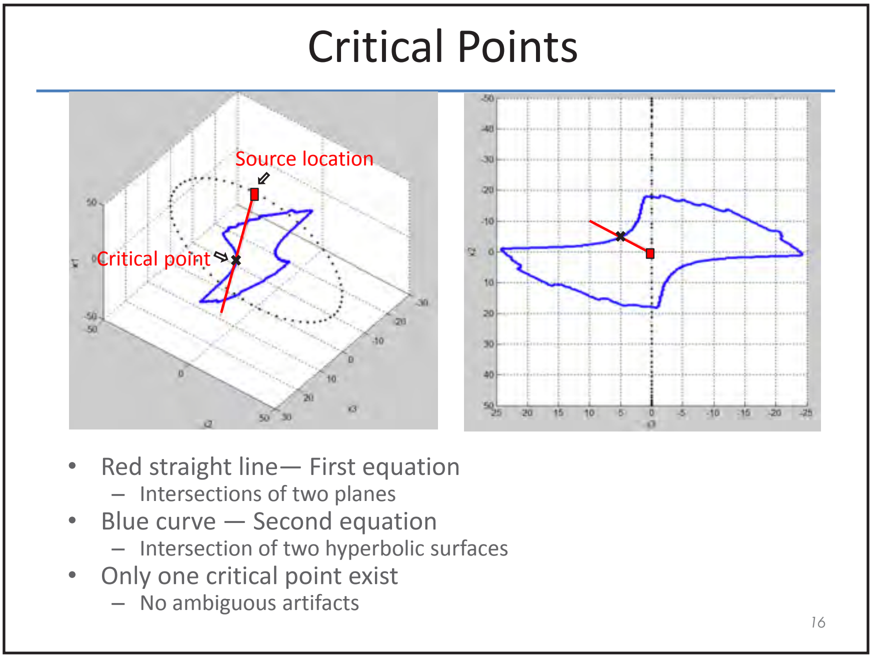
- The kernel *L* of $\mathcal{K}\mathcal{F}$ is the point spread function of the imaging operator
- For exact reconstruction $L(\mathrm{x},\mathrm{z}) \approx \delta(\mathrm{x}-\mathrm{z})$

Leading Order Contributions to PSF

- The main contribution to *L* come from the critical points of the phase of $\mathcal{KF} \Leftarrow \boxed{\varphi(\mathbf{z},\mathbf{x},\boldsymbol{\omega},s) = \boldsymbol{\omega}\cdot\left(\boldsymbol{\rho}(\mathbf{x},s)-\boldsymbol{\rho}(\mathbf{z},s)\right).}$

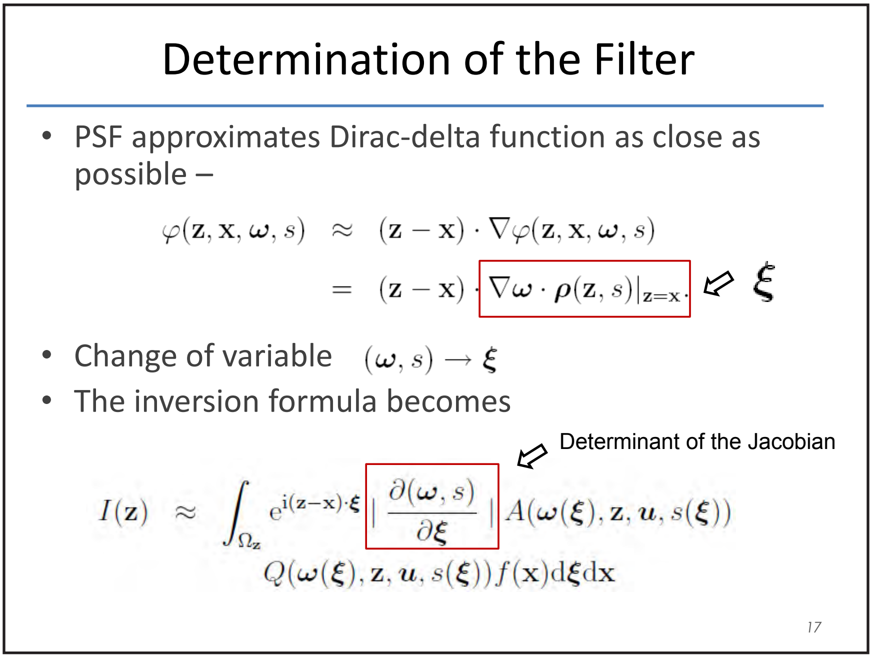
$$\boxed{\begin{aligned} \frac{\partial\varphi}{\partial\boldsymbol{\omega}} &= 0 &\Rightarrow&\quad \boldsymbol{\rho}(\mathbf{x},s)=\boldsymbol{\rho}(\mathbf{z},s) \\ \frac{\partial\varphi}{\partial s} &= 0 &\Rightarrow&\quad \partial_s\boldsymbol{\rho}(\mathbf{x},s)=\partial_s\boldsymbol{\rho}(\mathbf{z},s). \end{aligned}}$$

- We recover the singularities at the intersection of the two 3D manifolds defined above
- Expected contributions z = x, other solutions → artifacts



Critical Points

- Red straight line— First equation
  - Intersections of two planes
- Blue curve — Second equation
  - Intersection of two hyperbolic surfaces
- Only one critical point exist
  - No ambiguous artifacts



Determination of the Filter

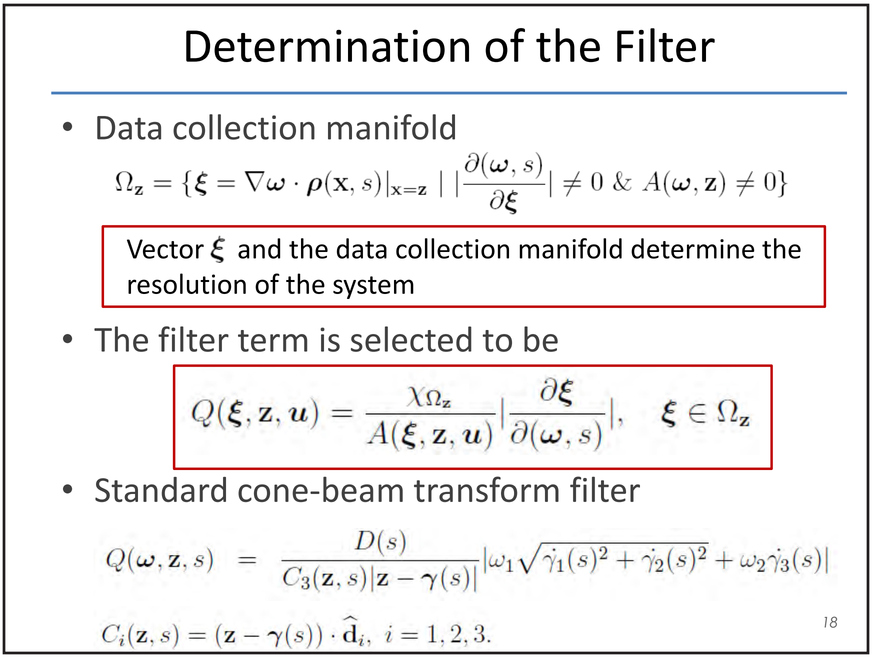
- PSF approximates Dirac-delta function as close as possible –

$$\begin{aligned}\varphi(\mathbf{z},\mathbf{x},\boldsymbol{\omega},s) &\approx (\mathbf{z}-\mathbf{x})\cdot\nabla\varphi(\mathbf{z},\mathbf{x},\boldsymbol{\omega},s)\\ &= (\mathbf{z}-\mathbf{x})\cdot\boxed{\nabla\omega\cdot\boldsymbol{\rho}(\mathbf{z},s)|_{\mathbf{z}=\mathbf{x}}} \Leftarrow \ \boldsymbol{\xi}\end{aligned}$$

- Change of variable $(\boldsymbol{\omega},s)\rightarrow\boldsymbol{\xi}$
- The inversion formula becomes

Determinant of the Jacobian

$$I(\mathbf{z}) \approx \int_{\Omega_{\mathbf{z}}} \mathrm{e}^{\mathrm{i}(\mathbf{z}-\mathbf{x})\cdot\boldsymbol{\xi}} \boxed{\left|\frac{\partial(\boldsymbol{\omega},s)}{\partial\boldsymbol{\xi}}\right|} A(\boldsymbol{\omega}(\boldsymbol{\xi}),\mathbf{z},\boldsymbol{u},s(\boldsymbol{\xi})) \\ Q(\boldsymbol{\omega}(\boldsymbol{\xi}),\mathbf{z},\boldsymbol{u},s(\boldsymbol{\xi}))f(\mathbf{x})\mathrm{d}\boldsymbol{\xi}\mathrm{d}\mathbf{x}$$



Determination of the Filter

- Data collection manifold

$$\Omega_{\mathbf{z}} = \{\boldsymbol{\xi} = \nabla\omega\cdot\boldsymbol{\rho}(\mathbf{x},s)|_{\mathbf{x}=\mathbf{z}} \mid |\frac{\partial(\boldsymbol{\omega},s)}{\partial\boldsymbol{\xi}}| \neq 0 \ \& \ A(\boldsymbol{\omega},\mathbf{z}) \neq 0\}$$

Vector $\boldsymbol{\xi}$ and the data collection manifold determine the resolution of the system

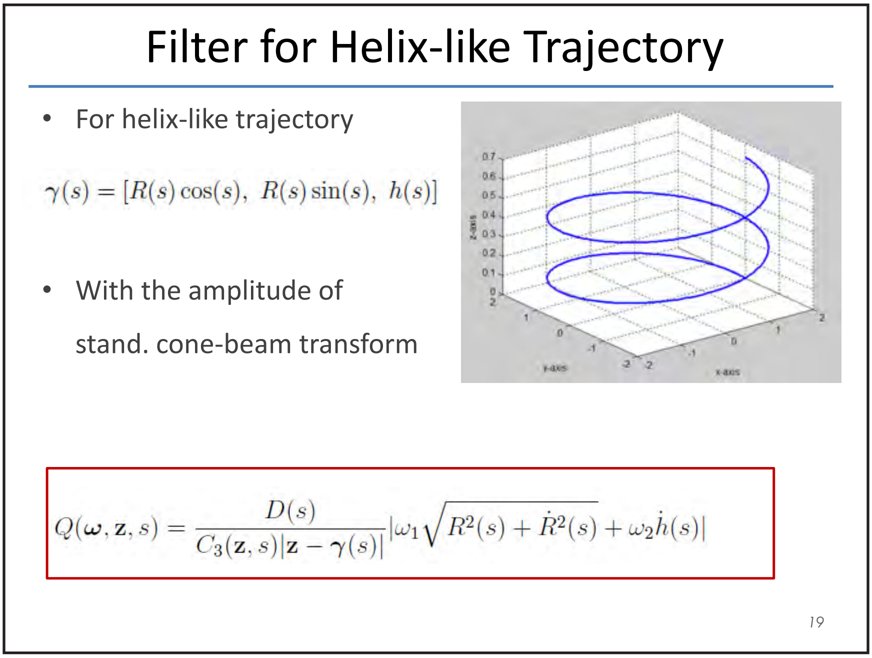
- The filter term is selected to be

$$\boxed{Q(\boldsymbol{\xi},\mathbf{z},\boldsymbol{u}) = \frac{\chi_{\Omega_{\mathbf{z}}}}{A(\boldsymbol{\xi},\mathbf{z},\boldsymbol{u})}\left|\frac{\partial\boldsymbol{\xi}}{\partial(\boldsymbol{\omega},s)}\right|, \quad \boldsymbol{\xi}\in\Omega_{\mathbf{z}}}$$

- Standard cone-beam transform filter

$$Q(\boldsymbol{\omega},\mathbf{z},s) = \frac{D(s)}{C_3(\mathbf{z},s)|\mathbf{z}-\boldsymbol{\gamma}(s)|}|\omega_1\sqrt{\dot\gamma_1(s)^2+\dot\gamma_2(s)^2}+\omega_2\dot\gamma_3(s)|$$

$$C_i(\mathbf{z},s) = (\mathbf{z}-\boldsymbol{\gamma}(s))\cdot\widehat{\mathbf{d}}_i, \ i=1,2,3.$$



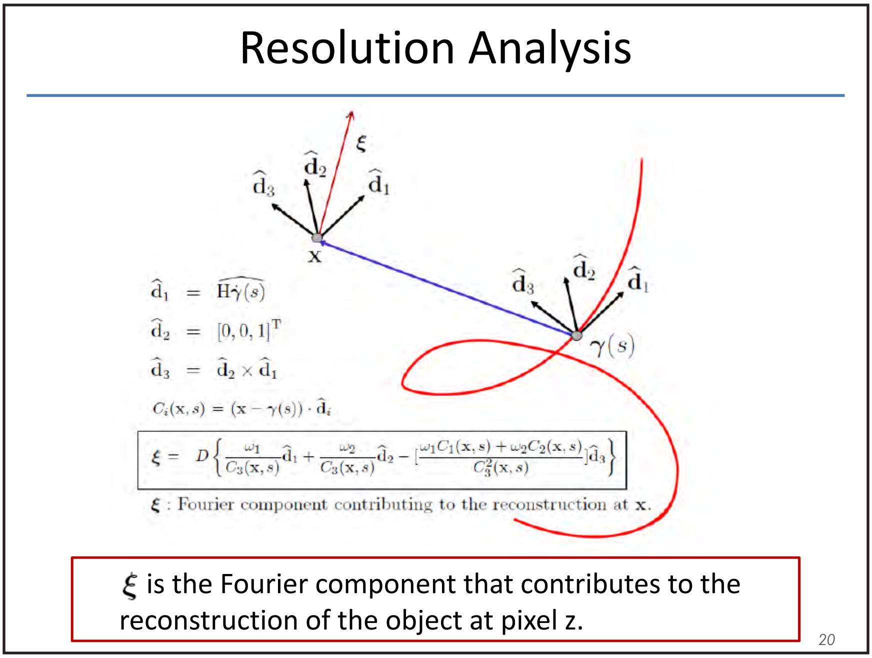
Filter for Helix-like Trajectory

- For helix-like trajectory

$$\gamma(s) = [R(s)\cos(s),\ R(s)\sin(s),\ h(s)]$$

- With the amplitude of stand. cone-beam transform

$$Q(\boldsymbol{\omega}, \mathbf{z}, s) = \frac{D(s)}{C_3(\mathbf{z}, s)|\mathbf{z} - \boldsymbol{\gamma}(s)|}|\omega_1\sqrt{R^2(s) + \dot{R}^2(s)} + \omega_2\dot{h}(s)|$$



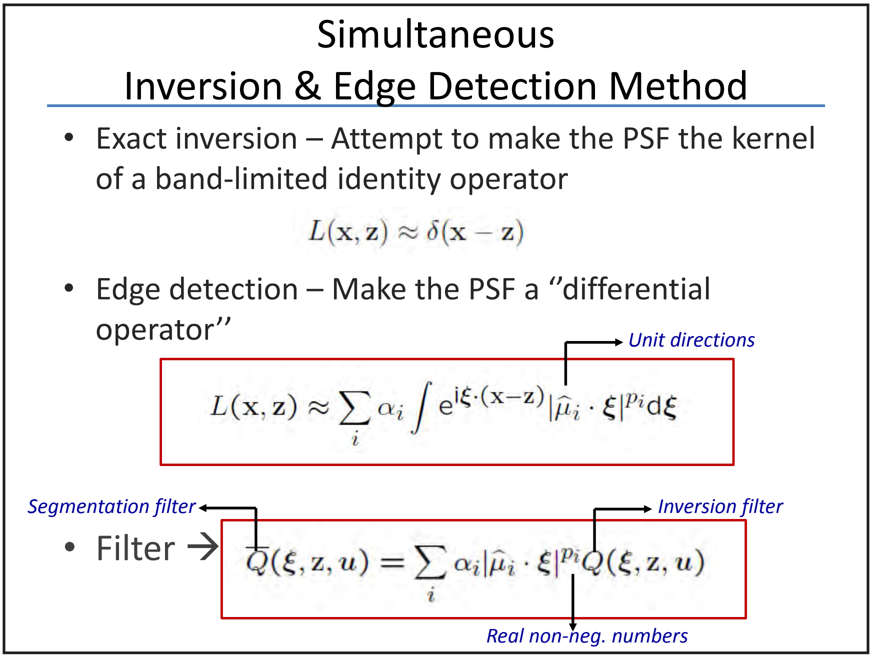
Resolution Analysis

$$\widehat{\mathbf{d}}_1 = \widehat{\mathrm{H}\dot{\gamma}(s)}$$
$$\widehat{\mathbf{d}}_2 = [0, 0, 1]^{\mathrm{T}}$$
$$\widehat{\mathbf{d}}_3 = \widehat{\mathbf{d}}_2 \times \widehat{\mathbf{d}}_1$$
$$C_i(\mathbf{x}, s) = (\mathbf{x} - \gamma(s)) \cdot \widehat{\mathbf{d}}_i$$

$$\boxed{\boldsymbol{\xi} = D\left\{\frac{\omega_1}{C_3(\mathbf{x}, s)}\widehat{\mathbf{d}}_1 + \frac{\omega_2}{C_3(\mathbf{x}, s)}\widehat{\mathbf{d}}_2 - [\frac{\omega_1 C_1(\mathbf{x}, s) + \omega_2 C_2(\mathbf{x}, s)}{C_3^2(\mathbf{x}, s)}]\widehat{\mathbf{d}}_3\right\}}$$

$\boldsymbol{\xi}$: Fourier component contributing to the reconstruction at $\mathbf{x}$.

ξ is the Fourier component that contributes to the reconstruction of the object at pixel z.



Simultaneous Inversion & Edge Detection Method

- Exact inversion – Attempt to make the PSF the kernel of a band-limited identity operator

$$L(\mathrm{x},\mathrm{z}) \approx \delta(\mathrm{x}-\mathrm{z})$$

- Edge detection – Make the PSF a ‘’differential operator’’

Unit directions

$$\boxed{L(\mathrm{x},\mathrm{z}) \approx \sum_i \alpha_i \int \mathrm{e}^{\mathrm{i}\xi\cdot(\mathrm{x}-\mathrm{z})} |\widehat{\mu}_i \cdot \xi|^{p_i} \mathrm{d}\xi}$$

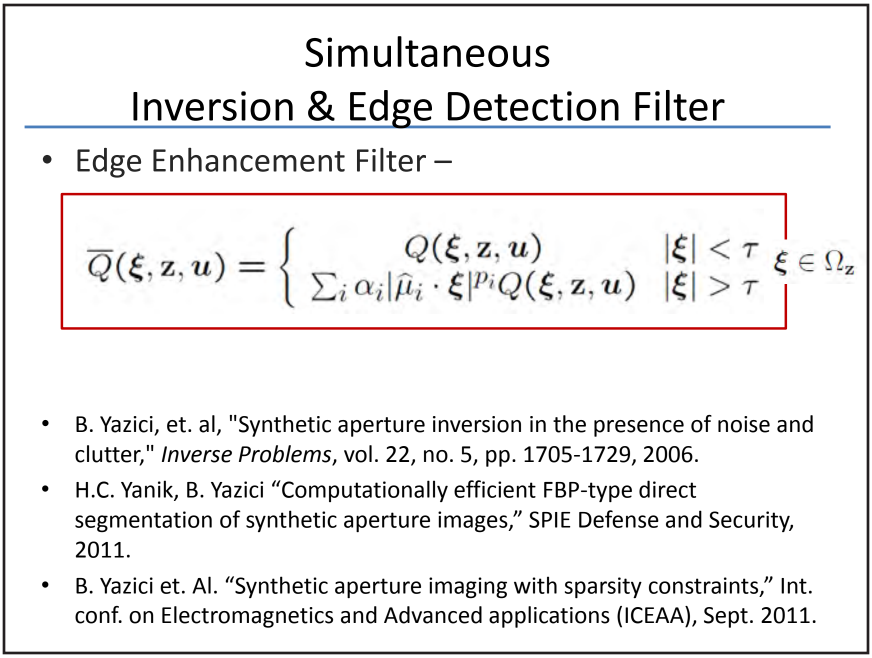
Segmentation filter

Inversion filter

- Filter →

$$\boxed{\overline{Q}(\xi,\mathrm{z},u) = \sum_i \alpha_i |\widehat{\mu}_i \cdot \xi|^{p_i} Q(\xi,\mathrm{z},u)}$$

Real non-neg. numbers



Simultaneous Inversion & Edge Detection Filter

- Edge Enhancement Filter –

$$\boxed{\overline{Q}(\xi,\mathrm{z},u) = \begin{cases} Q(\xi,\mathrm{z},u) & |\xi| < \tau \\ \sum_i \alpha_i |\widehat{\mu}_i \cdot \xi|^{p_i} Q(\xi,\mathrm{z},u) & |\xi| > \tau \end{cases}} \quad \xi \in \Omega_\mathrm{z}$$

- B. Yazici, et. al, "Synthetic aperture inversion in the presence of noise and clutter," *Inverse Problems*, vol. 22, no. 5, pp. 1705-1729, 2006.
- H.C. Yanik, B. Yazici “Computationally efficient FBP-type direct segmentation of synthetic aperture images,” SPIE Defense and Security, 2011.
- B. Yazici et. Al. “Synthetic aperture imaging with sparsity constraints,” Int. conf. on Electromagnetics and Advanced applications (ICEAA), Sept. 2011.

Inversion/Edge Detection Method

- Applicable to arbitrary imaging geometries, can accommodate system related parameters, such as dose modulations, system bandwidth, bow-tie filter etc.
- Can be coupled with classification task
- Method can be analyzed using microlocal analysis
- Can be implemented efficiently using the fast FIO calculations* in the order of fast-backprojection algorithms.

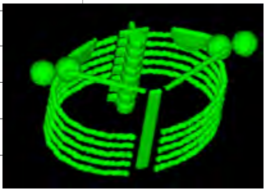
*E. Candes, L. Demanet, L. Ying, *Fast Computation of Fourier Integral Operators*, *SIAM J. Sci. Comput.* 29-6 (2007) 2464-2493

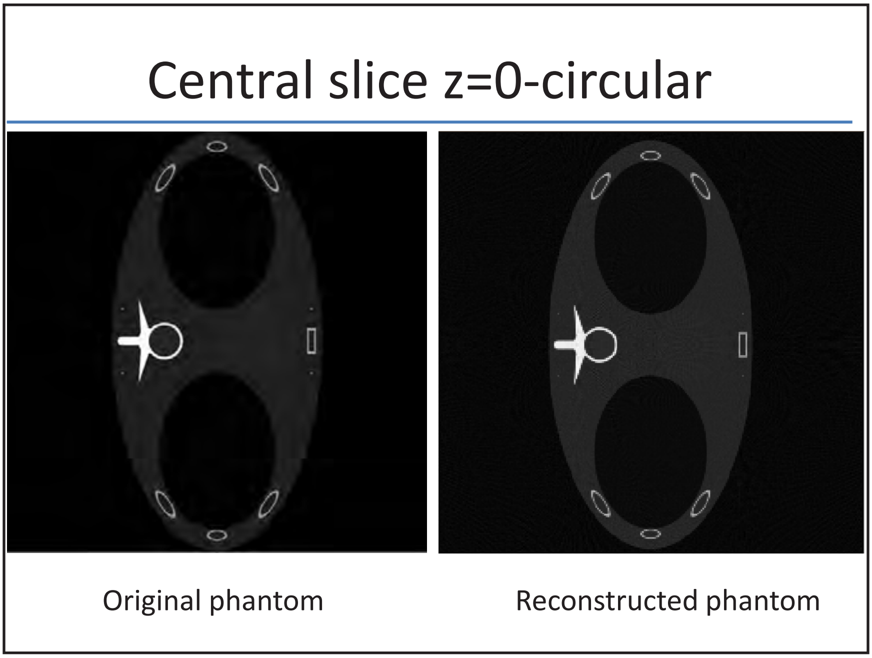
Simulation Study

- Data simulated using GE's proprietary X-ray CT simulation platform CatSim

Parameters	CT scanner
Source to detector distance	949 mm
Origin to detector distance	541 mm
Noise level	0
Number of views	984
Detector column size	1.0239 mm
Detector row size	1.0915 mm
Columns count	888
Rows count	16
Slice sickness	1 mm
Reconstruction size	512*512

3D Thorax phantom

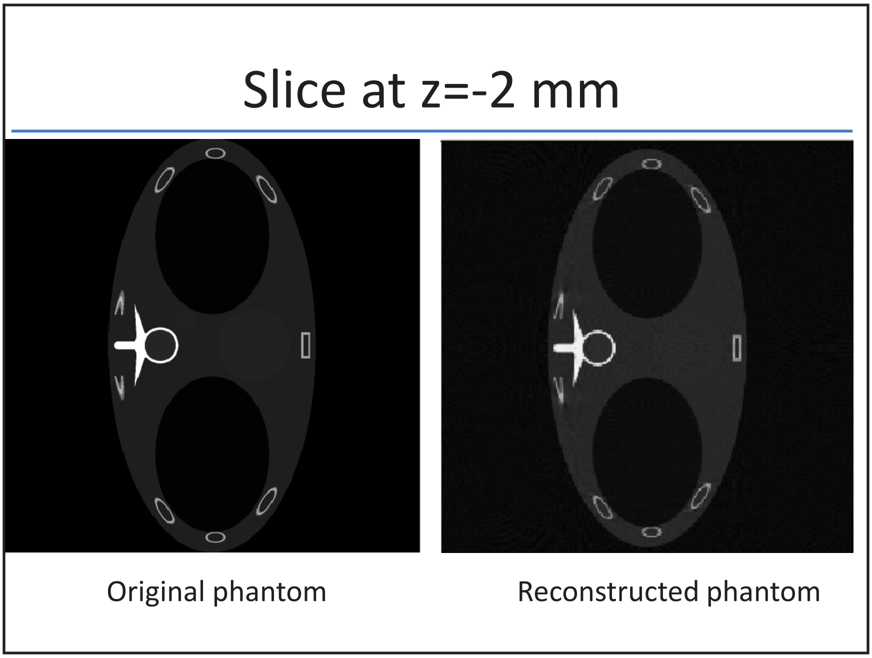




Central slice z=0-circular

Original phantom

Reconstructed phantom



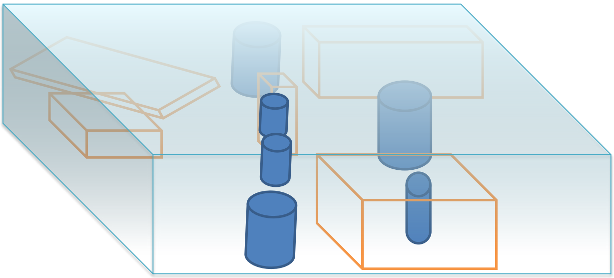
Slice at z=-2 mm

Original phantom

Reconstructed phantom

Edge Detection Simulation Study

- Luggage phantom

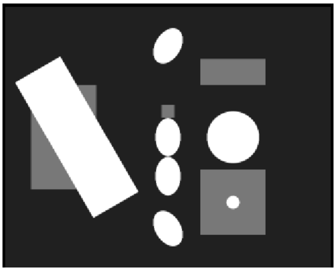


- Several different objects in the bag
  - Dark blue objects (ellipsoids, cylinders, etc.) - high CT number (explosives, weapons etc.)
  - Light blue objects - low CT numbers (clothes, books etc.)

Reconstruction Parameters

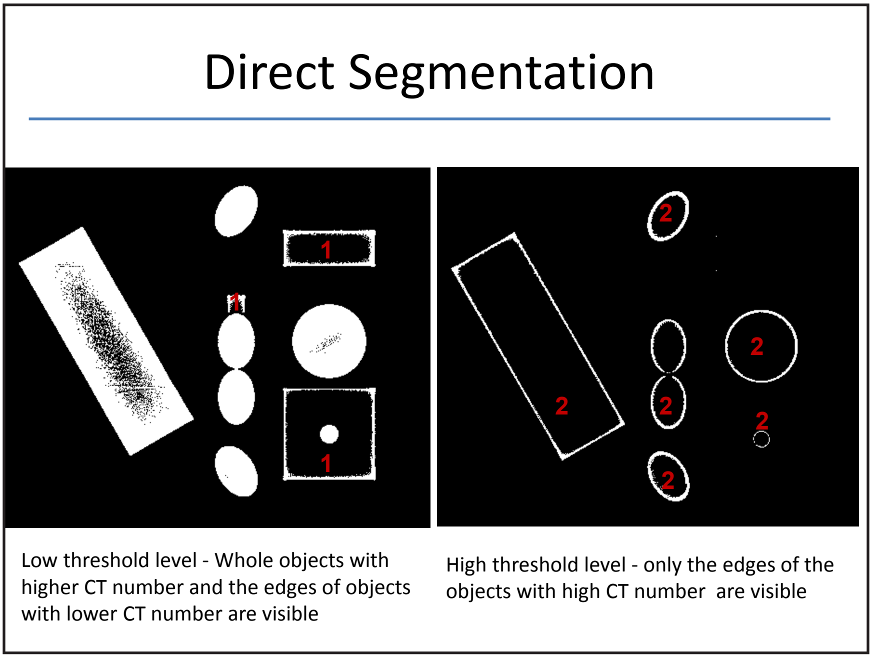
- Helical source trajectory

Parameter	CT scanner
Source to detector distance	949 mm
Origin to detector distance	541 mm
Noise level	0
Number of views	984
Detector column size	1.0239 mm
Detector row size	1.0915 mm
Columns count	888
Rows count	16
Slice sickness	1 mm
Reconstruction size	512*512



•Rotation period=0.5s

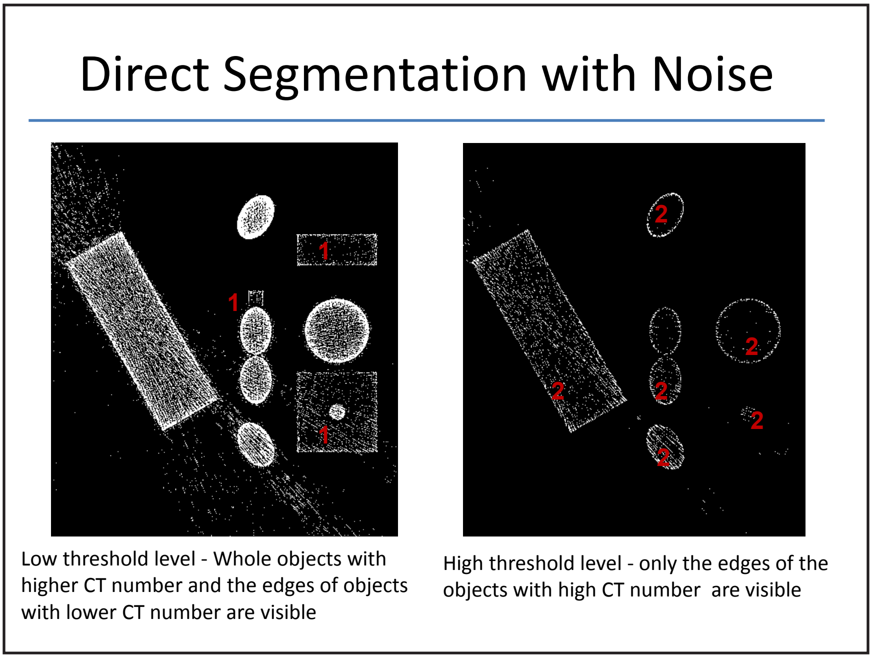
•Table speed=10mm/s



Direct Segmentation

Low threshold level - Whole objects with higher CT number and the edges of objects with lower CT number are visible

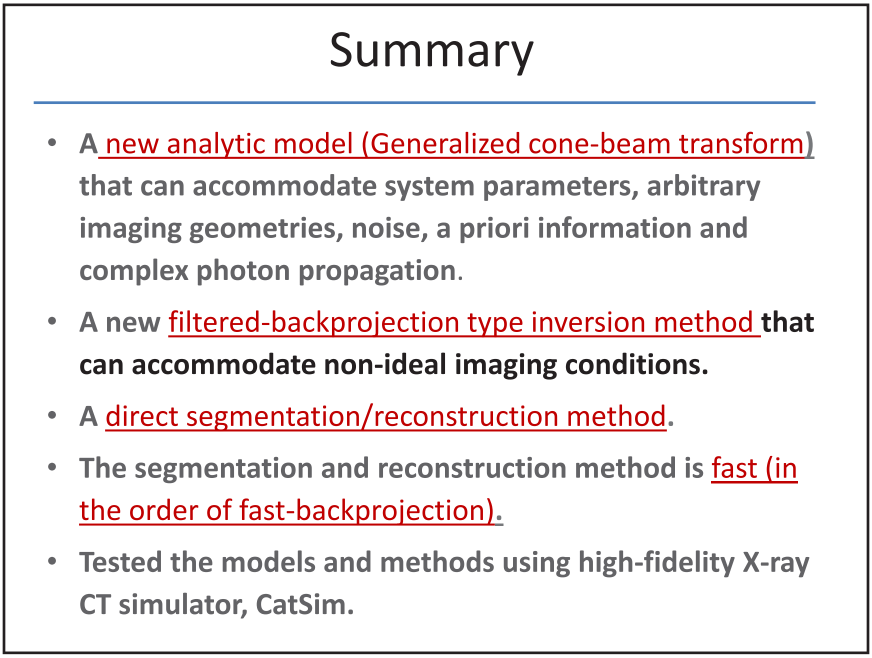
High threshold level - only the edges of the objects with high CT number are visible



Direct Segmentation with Noise

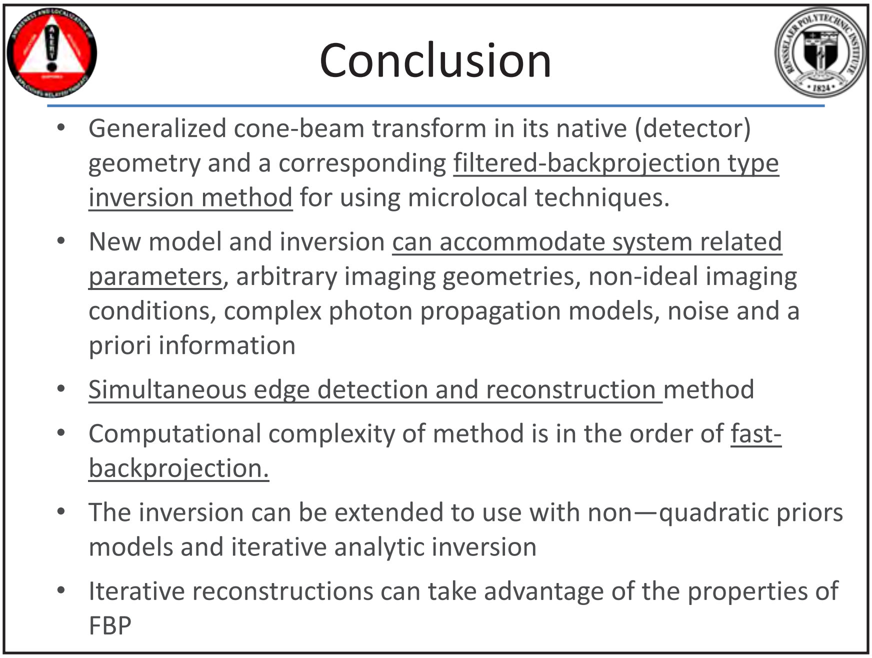
Low threshold level - Whole objects with higher CT number and the edges of objects with lower CT number are visible

High threshold level - only the edges of the objects with high CT number are visible



Summary

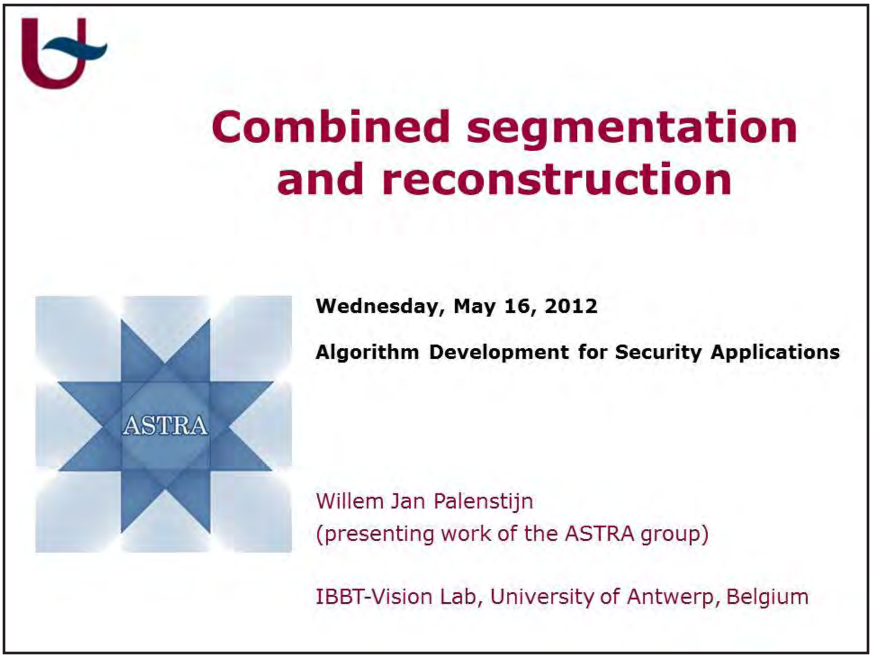
- **A new analytic model (Generalized cone-beam transform) that can accommodate system parameters, arbitrary imaging geometries, noise, a priori information and complex photon propagation.**
- **A new filtered-backprojection type inversion method that can accommodate non-ideal imaging conditions.**
- **A direct segmentation/reconstruction method.**
- **The segmentation and reconstruction method is fast (in the order of fast-backprojection).**
- **Tested the models and methods using high-fidelity X-ray CT simulator, CatSim.**



Conclusion

- Generalized cone-beam transform in its native (detector) geometry and a corresponding filtered-backprojection type inversion method for using microlocal techniques.
- New model and inversion can accommodate system related parameters, arbitrary imaging geometries, non-ideal imaging conditions, complex photon propagation models, noise and a priori information
- Simultaneous edge detection and reconstruction method
- Computational complexity of method is in the order of fast-backprojection.
- The inversion can be extended to use with non—quadratic priors models and iterative analytic inversion
- Iterative reconstructions can take advantage of the properties of FBP

16.20 Willem Jan Palenstijn: Combined segmentation and reconstruction



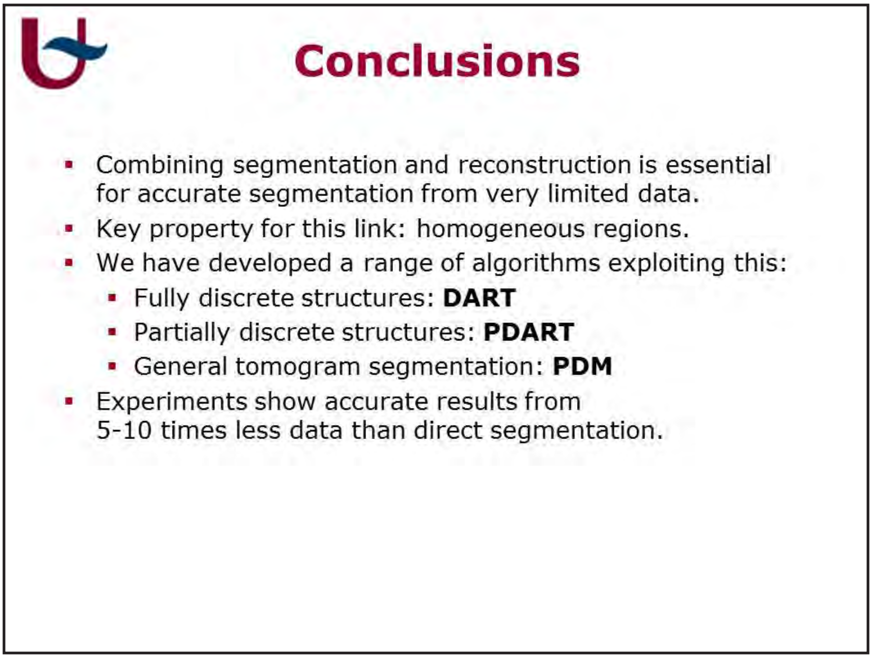
Combined segmentation and reconstruction

Wednesday, May 16, 2012

Algorithm Development for Security Applications

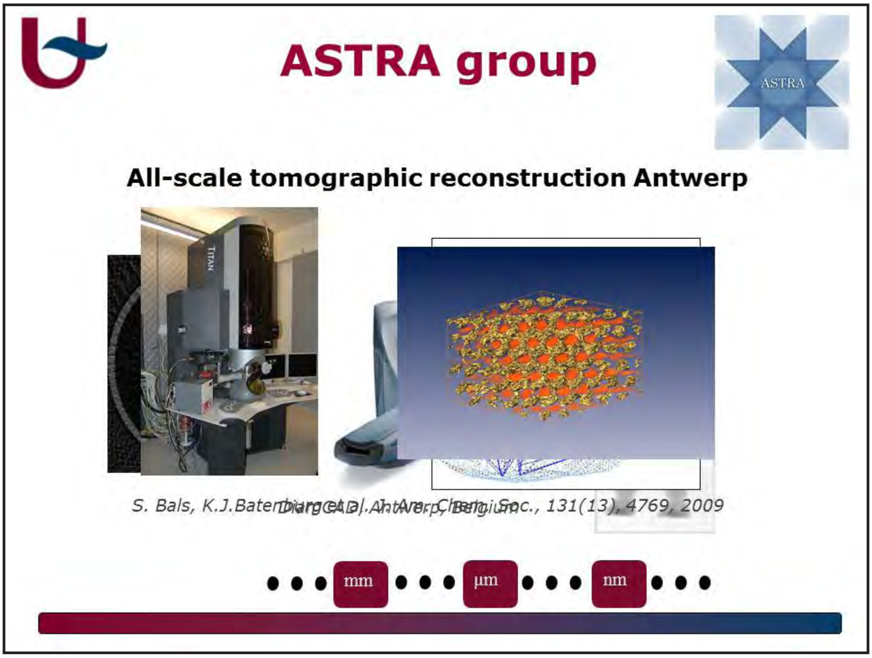
Willem Jan Palenstijn
(presenting work of the ASTRA group)

IBBT-Vision Lab, University of Antwerp, Belgium



Conclusions

- Combining segmentation and reconstruction is essential for accurate segmentation from very limited data.
- Key property for this link: homogeneous regions.
- We have developed a range of algorithms exploiting this:
  - Fully discrete structures: **DART**
  - Partially discrete structures: **PDART**
  - General tomogram segmentation: **PDM**
- Experiments show accurate results from 5-10 times less data than direct segmentation.

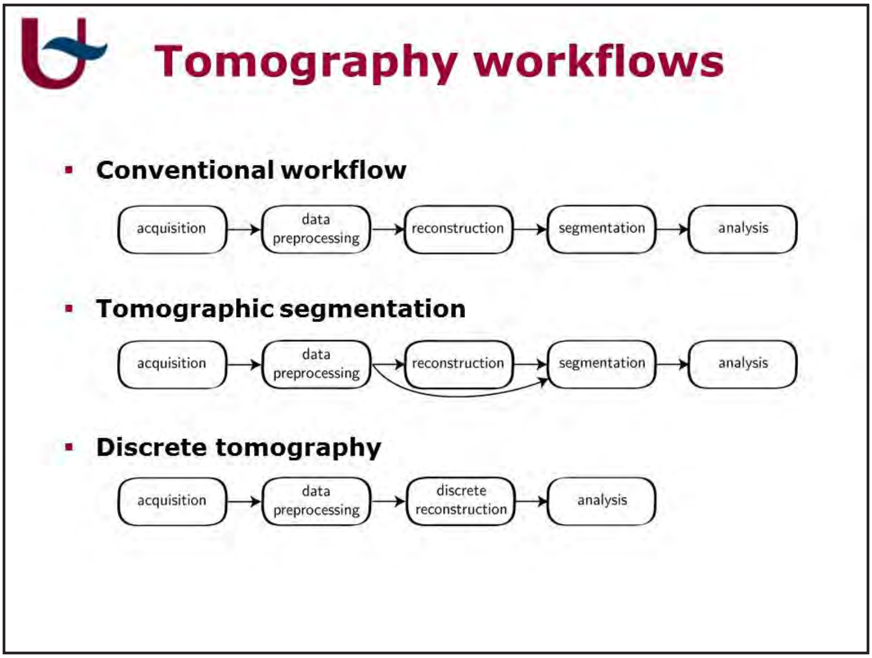


ASTRA group

All-scale tomographic reconstruction Antwerp

S. Bals, K.J.Batenburg et al. J. Am. Chem. Soc., 131(13), 4769, 2009

DiamCAD, Antwerp, Belgium

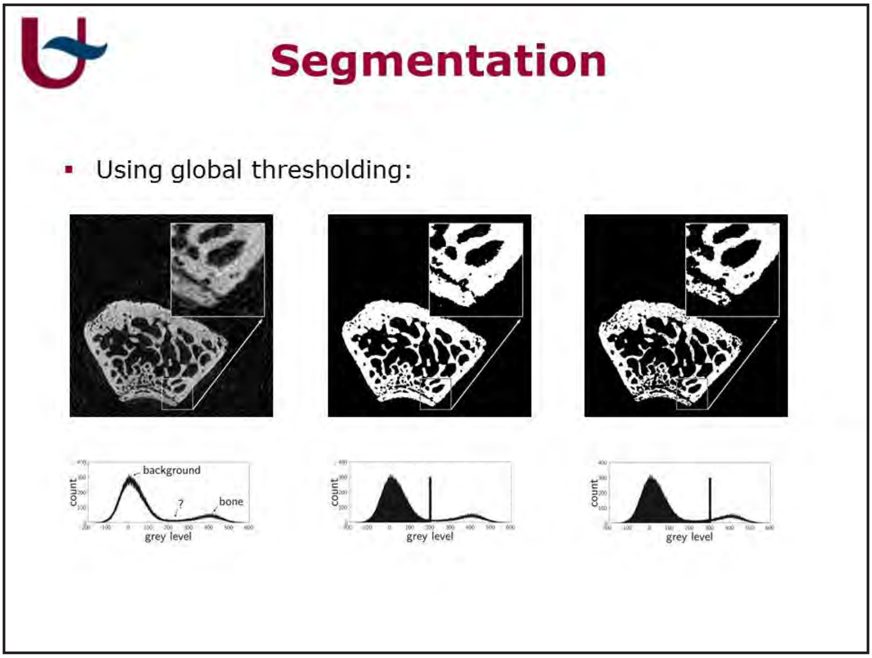


Tomography workflows

- **Conventional workflow**

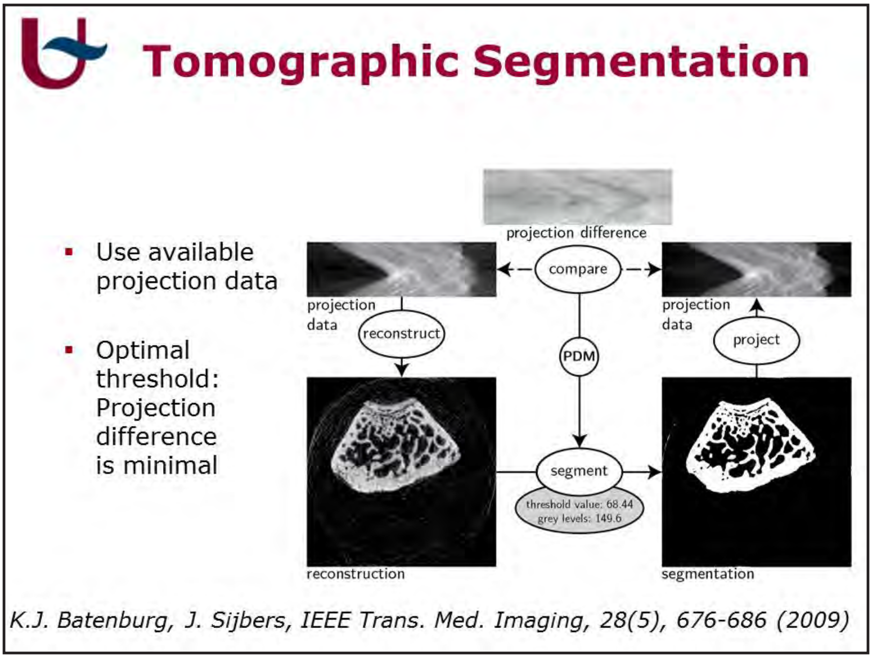
- **Tomographic segmentation**

- **Discrete tomography**



Segmentation

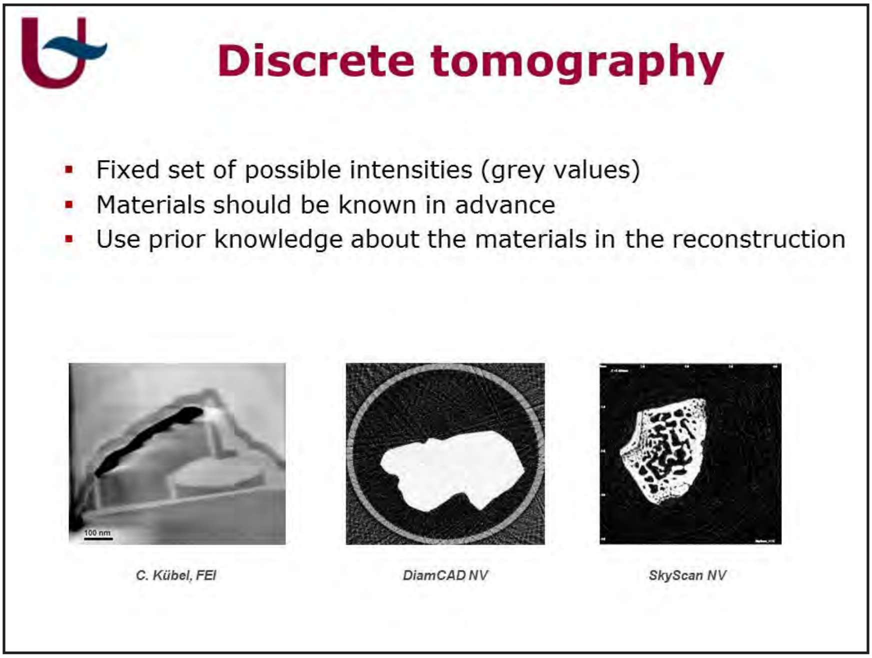
- Using global thresholding:



Tomographic Segmentation

- Use available projection data
- Optimal threshold: Projection difference is minimal

K.J. Batenburg, J. Sijbers, IEEE Trans. Med. Imaging, 28(5), 676-686 (2009)



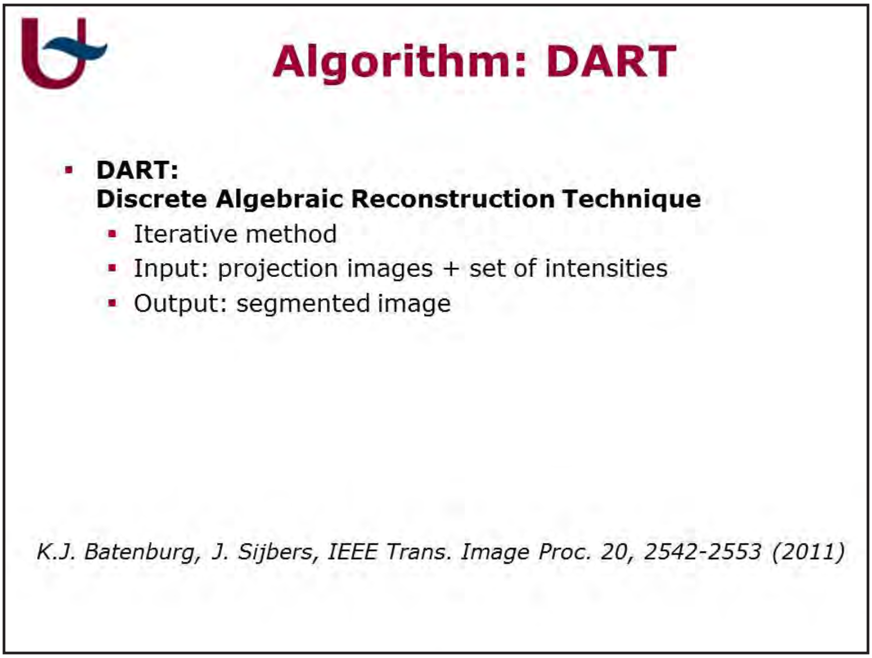
Discrete tomography

- Fixed set of possible intensities (grey values)
- Materials should be known in advance
- Use prior knowledge about the materials in the reconstruction

C. Kübel, FEI

DiamCAD NV

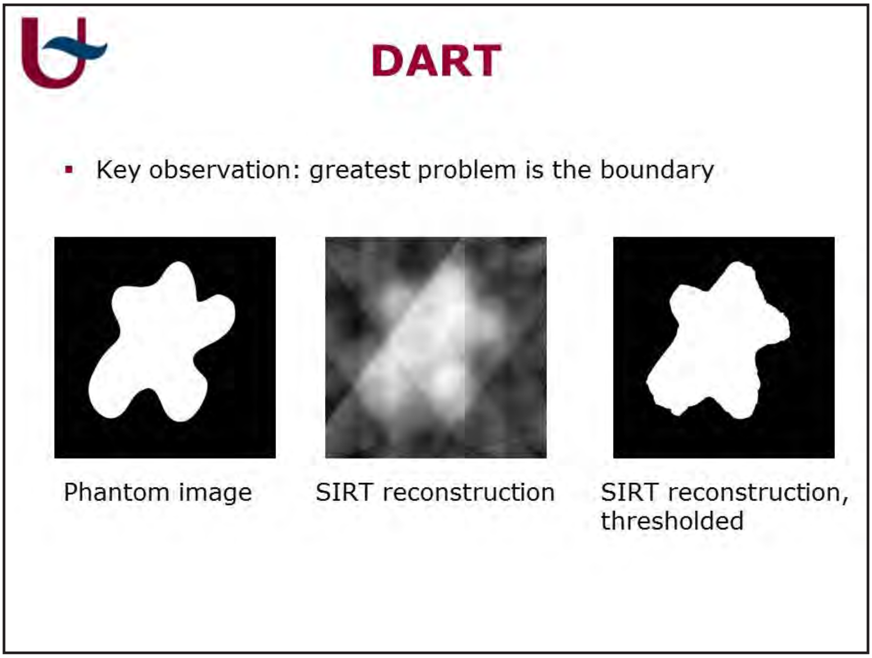
SkyScan NV



Algorithm: DART

- **DART:**
  Discrete Algebraic Reconstruction Technique
  - Iterative method
  - Input: projection images + set of intensities
  - Output: segmented image

K.J. Batenburg, J. Sijbers, IEEE Trans. Image Proc. 20, 2542-2553 (2011)



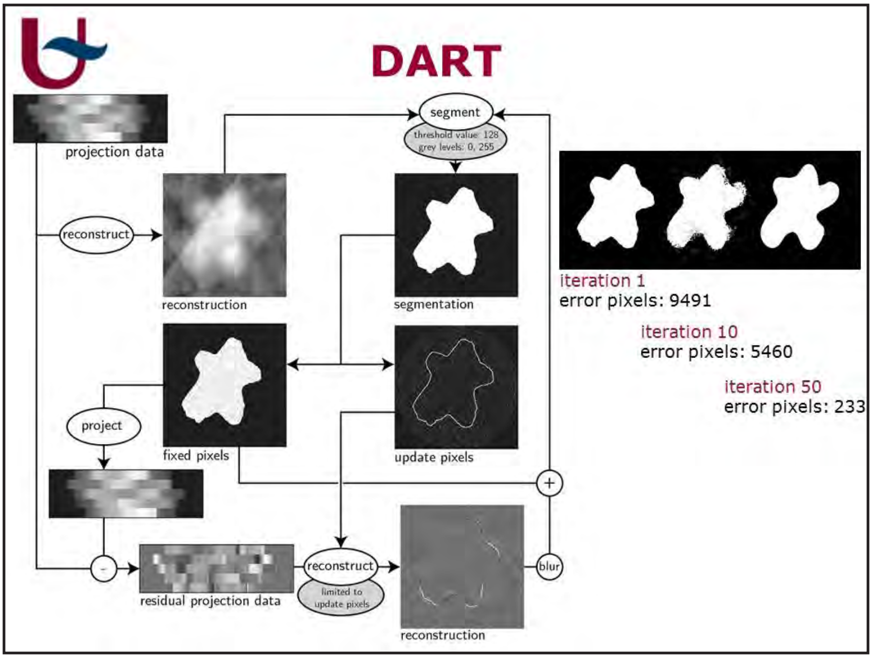
DART

- Key observation: greatest problem is the boundary

Phantom image

SIRT reconstruction

SIRT reconstruction, thresholded

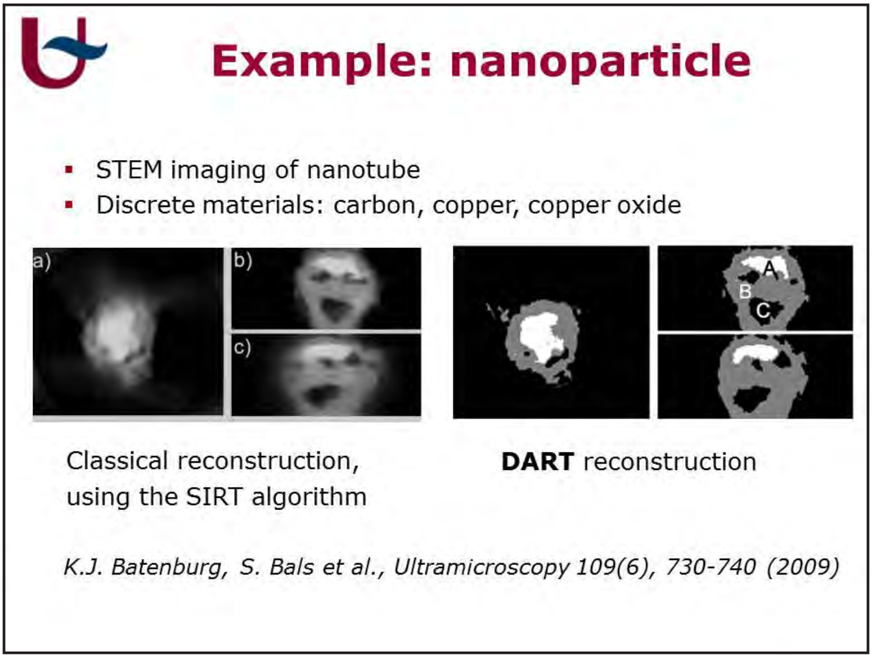


DART

iteration 1
error pixels: 9491

iteration 10
error pixels: 5460

iteration 50
error pixels: 233



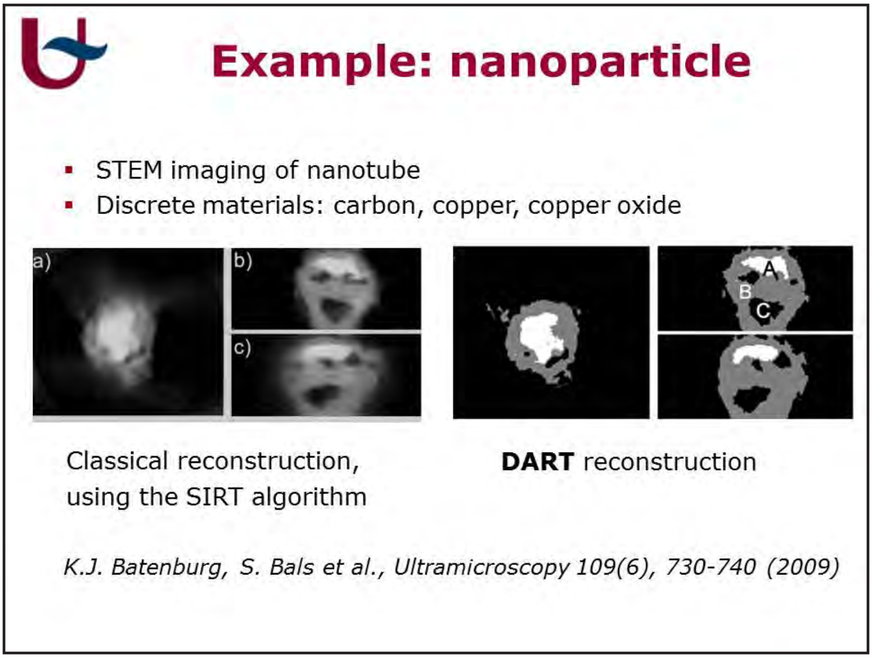
Example: nanoparticle

- STEM imaging of nanotube
- Discrete materials: carbon, copper, copper oxide

Classical reconstruction, using the SIRT algorithm

DART reconstruction

K.J. Batenburg, S. Bals et al., Ultramicroscopy 109(6), 730-740 (2009)



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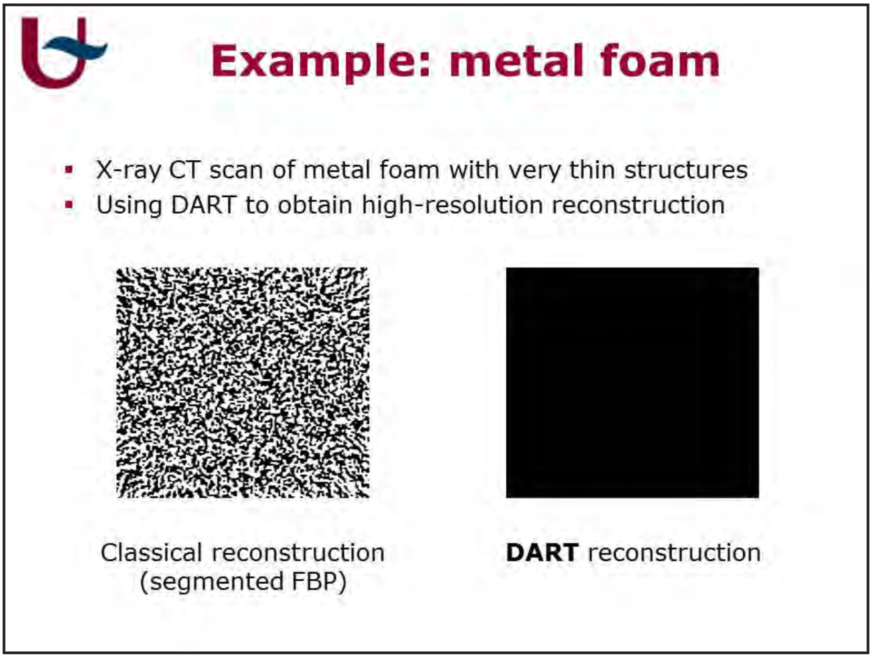
K.J. Batenburg, S. Bals et al., Ultramicroscopy 109(6), 730-740 (2009)

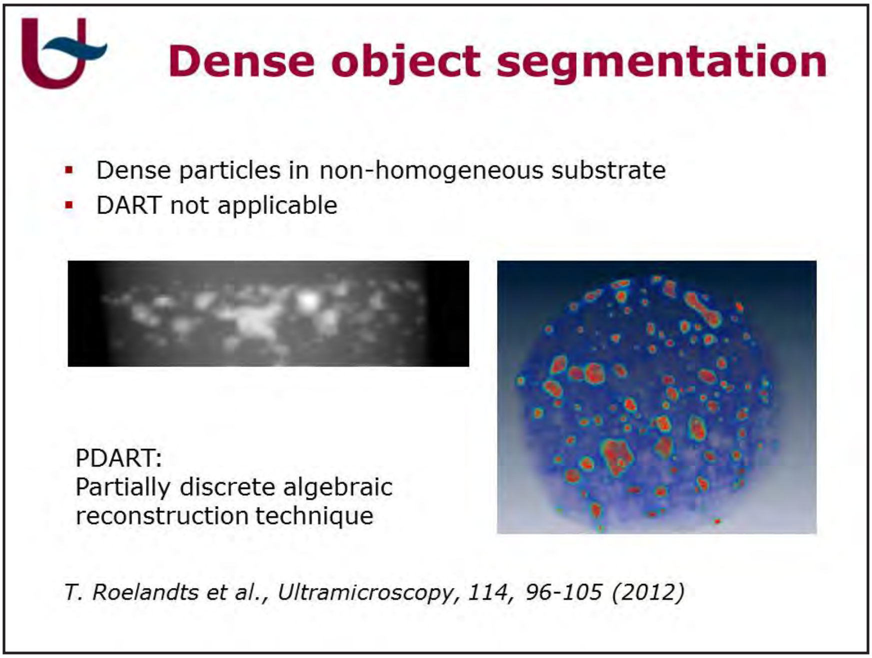


Example: metal foam

- X-ray CT scan of metal foam with very thin structures
- Using DART to obtain high-resolution reconstruction

Classical reconstruction
(segmented FBP)

DART reconstruction

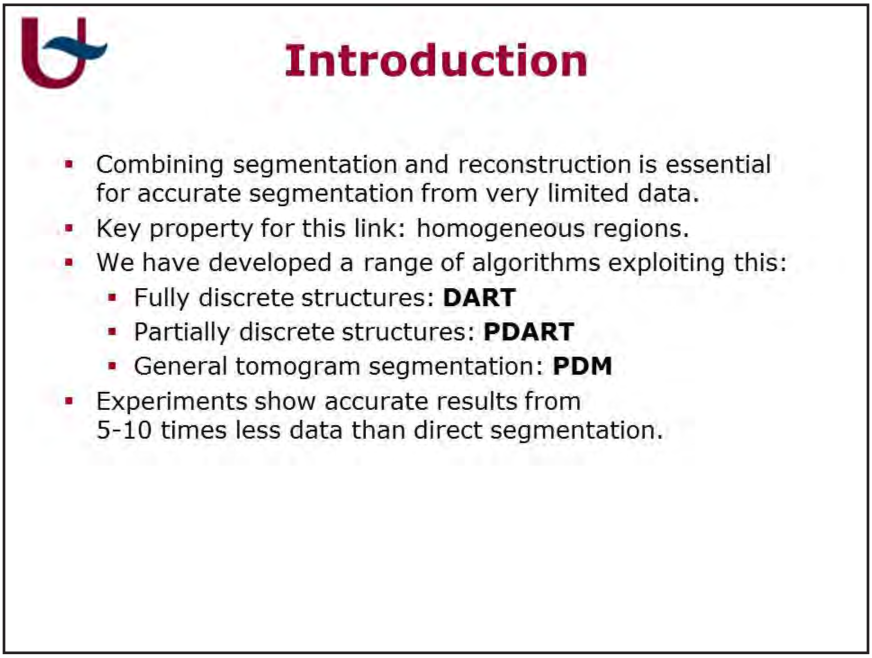


Dense object segmentation

- Dense particles in non-homogeneous substrate
- DART not applicable

PDART:
Partially discrete algebraic
reconstruction technique

T. Roelandts et al., Ultramicroscopy, 114, 96-105 (2012)



Introduction

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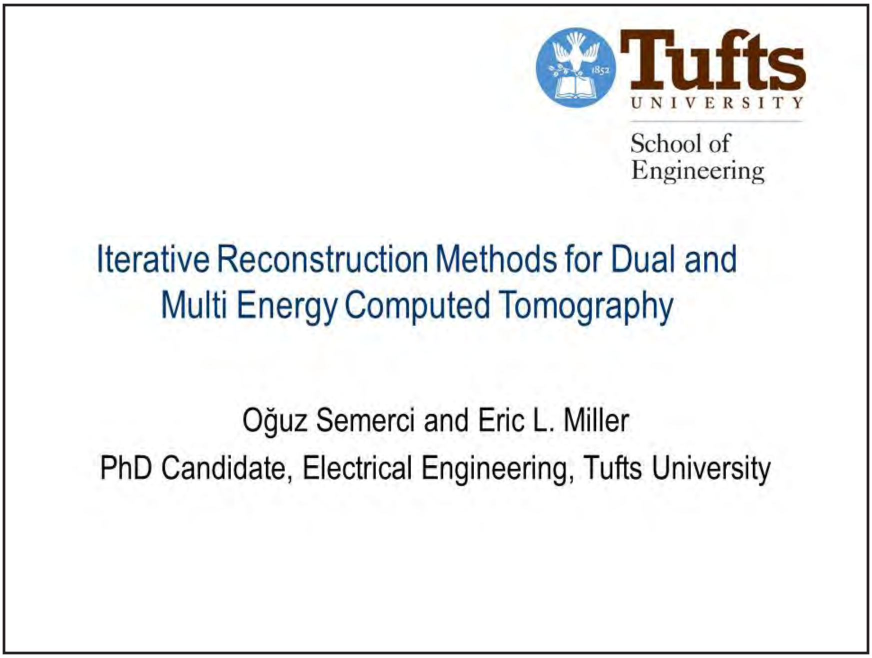
  - Partially discrete structures: **PDART**
  - General tomogram segmentation: **PDM**
- Experiments show accurate results from 5-10 times less data than direct segmentation.

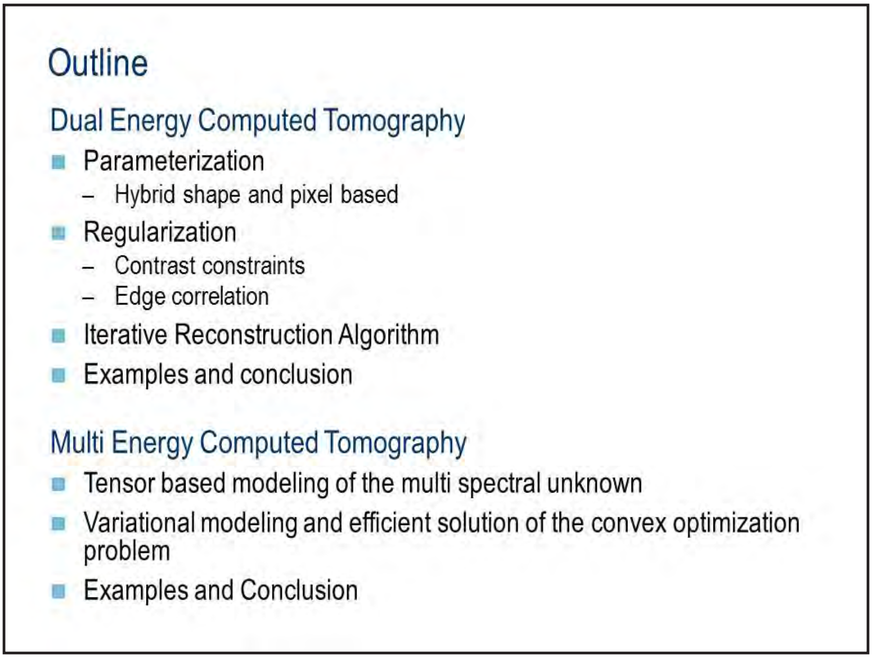
16.21 Oguz Semerci: Iterative Reconstruction Methods for Dual and Multi Energy Computed Tomography



Tufts UNIVERSITY
School of Engineering

Iterative Reconstruction Methods for Dual and Multi Energy Computed Tomography

Oğuz Semerci and Eric L. Miller
PhD Candidate, Electrical Engineering, Tufts University



Outline

Dual Energy Computed Tomography
- Parameterization
  - Hybrid shape and pixel based
- Regularization
  - Contrast constraints
  - Edge correlation
- Iterative Reconstruction Algorithm
- Examples and conclusion

Multi Energy Computed Tomography
- Tensor based modeling of the multi spectral unknown
- Variational modeling and efficient solution of the convex optimization problem
- Examples and Conclusion

Take Away Messages

Dual Energy Computed Tomography

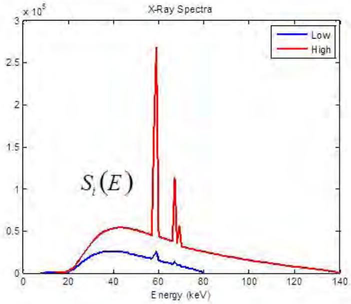
- Model based iterative reconstruction for Compton and Photoelectric images
- Direct identification of objects of interest from projection data
- Validated on Monte Carlo data
- Looking for industrial partner to carry the work forward
- For more details see: Semerci O. & Miller E.L., IEEE TIP, vol:21, issue:5. 2012

Multi Energy Computed Tomography

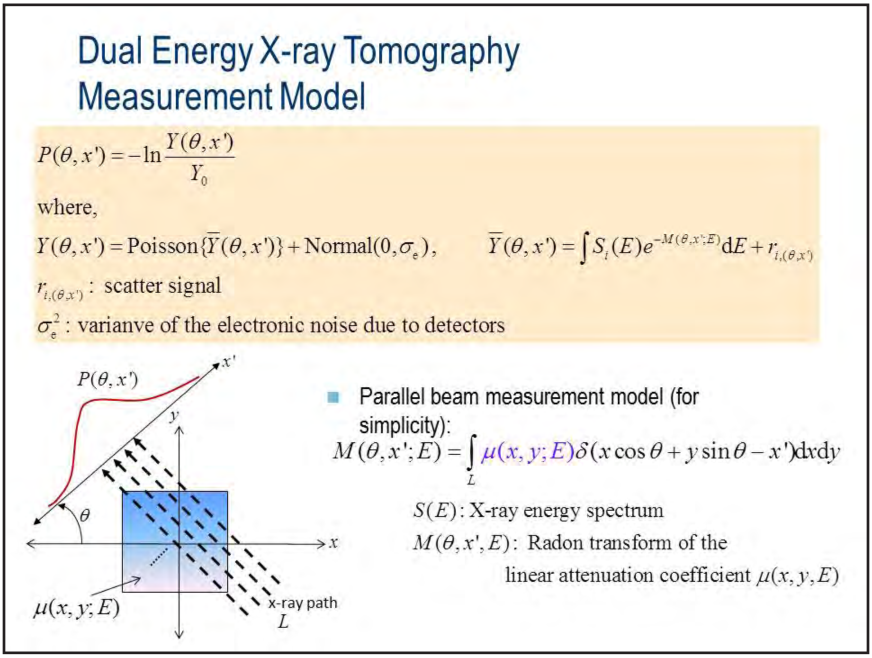
- Convex optimization approach for binned detector systems
- Enabling algorithmic technology for hyperspectral X-ray CT

Polychromatic Dual Energy

- Ability for material characterization (Quantitative CT)
- Incorporation of the non-linear character of X-ray interactions
- Energy dependency of attenuation is considered:



- Wide range of applications due to quantitative nature of the modality
- Luggage Screening (Aviation Security) – Addressed in this work
- Diagnostic Medical Imaging
- Non-destructive testing



Dual Energy X-ray Tomography Measurement Model

$$P(\theta,x') = -\ln\frac{Y(\theta,x')}{Y_0}$$

where,

$Y(\theta,x') = \text{Poisson}\{\overline{Y}(\theta,x')\} + \text{Normal}(0,\sigma_e)$, $\overline{Y}(\theta,x') = \int S_i(E)e^{-M(\theta,x';E)}\text{d}E + r_{i,(\theta,x')}$

$r_{i,(\theta,x')}$: scatter signal

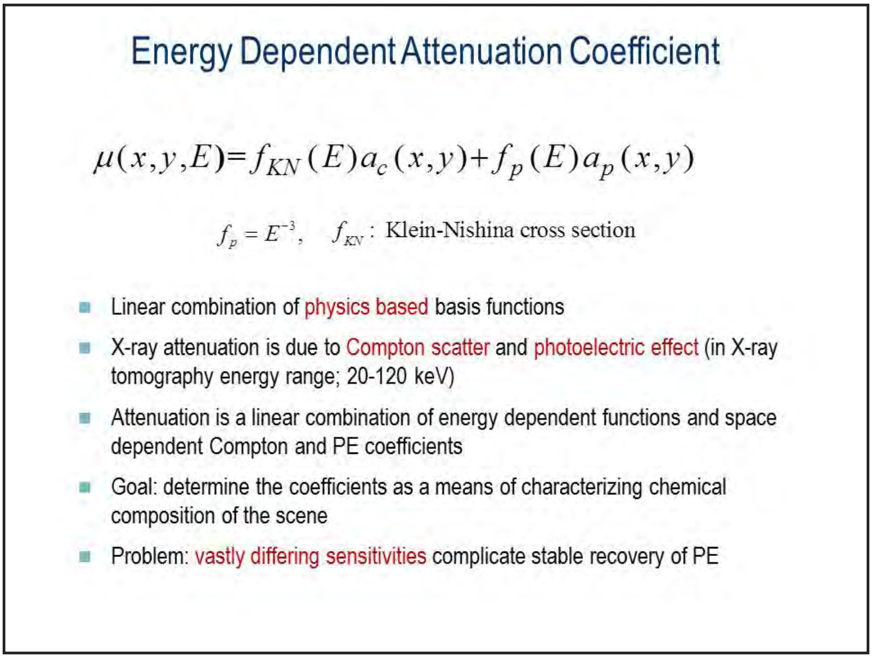
σ_e^2 : varianve of the electronic noise due to detectors

- Parallel beam measurement model (for simplicity):

$$M(\theta,x';E) = \int_L \mu(x,y;E)\delta(x\cos\theta + y\sin\theta - x')\text{d}x\text{d}y$$

$S(E)$: X-ray energy spectrum

$M(\theta,x',E)$: Radon transform of the linear attenuation coefficient $\mu(x,y,E)$

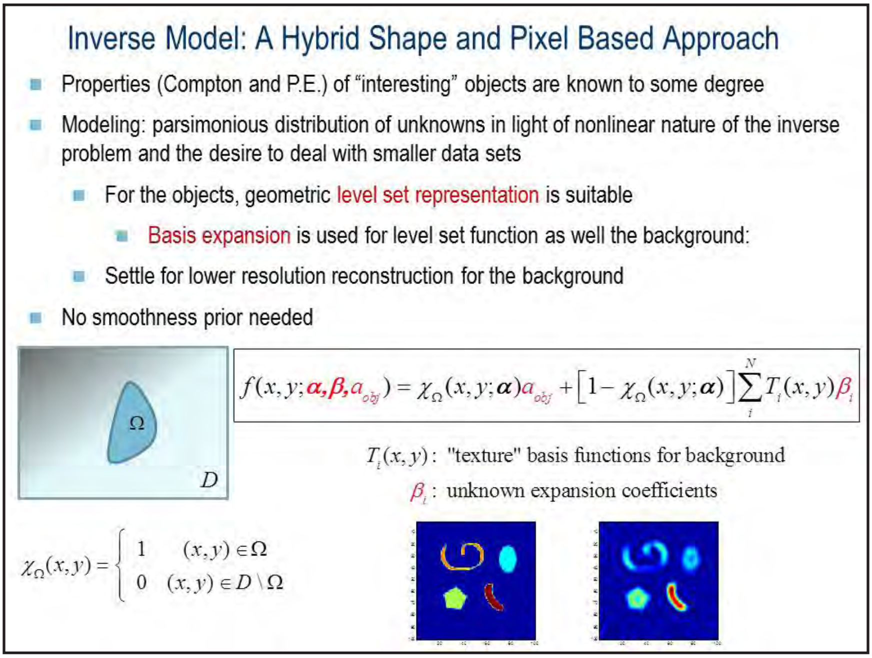


Energy Dependent Attenuation Coefficient

$$\mu(x,y,E) = f_{KN}(E)a_c(x,y) + f_p(E)a_p(x,y)$$

$f_p = E^{-3}$, f_{KN}: Klein-Nishina cross section

- Linear combination of physics based basis functions
- X-ray attenuation is due to Compton scatter and photoelectric effect (in X-ray tomography energy range; 20-120 keV)
- Attenuation is a linear combination of energy dependent functions and space dependent Compton and PE coefficients
- Goal: determine the coefficients as a means of characterizing chemical composition of the scene
- Problem: vastly differing sensitivities complicate stable recovery of PE



Inverse Model: A Hybrid Shape and Pixel Based Approach

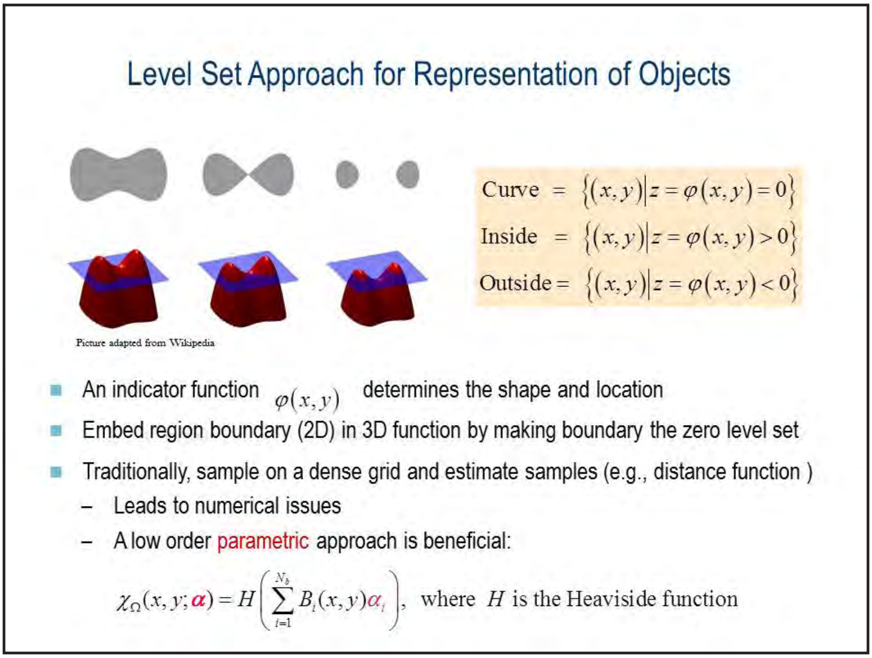
- Properties (Compton and P.E.) of "interesting" objects are known to some degree
- Modeling: parsimonious distribution of unknowns in light of nonlinear nature of the inverse problem and the desire to deal with smaller data sets
    - For the objects, geometric level set representation is suitable
        - Basis expansion is used for level set function as well the background:
    - Settle for lower resolution reconstruction for the background
- No smoothness prior needed

$$f(x,y;\boldsymbol{\alpha},\boldsymbol{\beta},a_{obj}) = \chi_\Omega(x,y;\boldsymbol{\alpha})a_{obj} + \left[1-\chi_\Omega(x,y;\boldsymbol{\alpha})\right]\sum_i^N T_i(x,y)\beta_i$$

$T_i(x,y)$: "texture" basis functions for background

β_i: unknown expansion coefficients

$$\chi_\Omega(x,y) = \begin{cases} 1 & (x,y) \in \Omega \\ 0 & (x,y) \in D \setminus \Omega \end{cases}$$



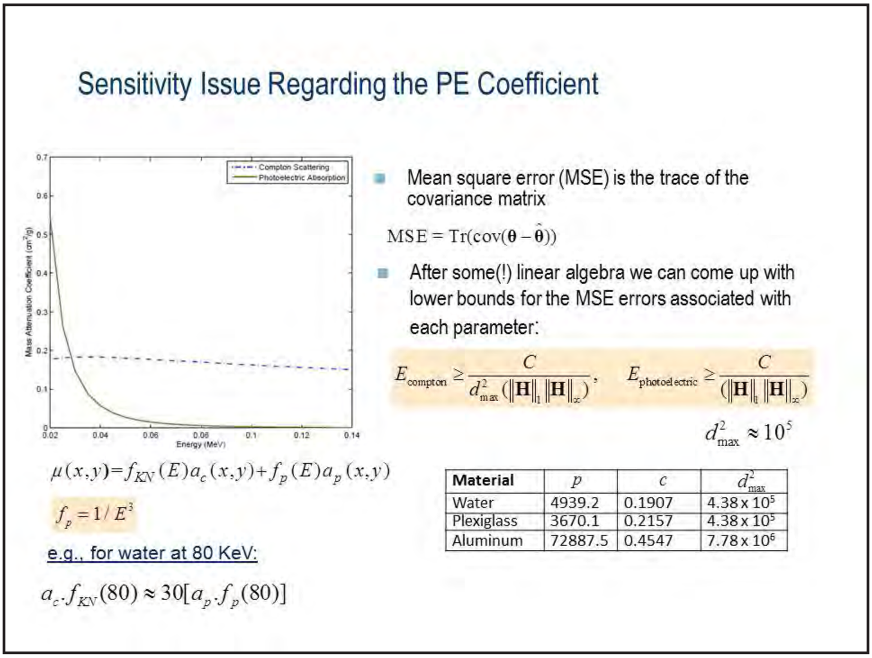
Level Set Approach for Representation of Objects

Picture adapted from Wikipedia

$$\begin{aligned} \text{Curve} &= \{(x,y) \mid z = \varphi(x,y) = 0\} \\ \text{Inside} &= \{(x,y) \mid z = \varphi(x,y) > 0\} \\ \text{Outside} &= \{(x,y) \mid z = \varphi(x,y) < 0\} \end{aligned}$$

- An indicator function $\varphi(x,y)$ determines the shape and location
- Embed region boundary (2D) in 3D function by making boundary the zero level set
- Traditionally, sample on a dense grid and estimate samples (e.g., distance function)
    - Leads to numerical issues
    - A low order parametric approach is beneficial:

$$\chi_\Omega(x,y;\boldsymbol{\alpha}) = H\left(\sum_{i=1}^{N_b} B_i(x,y)\alpha_i\right), \quad \text{where } H \text{ is the Heaviside function}$$



Sensitivity Issue Regarding the PE Coefficient

$$\mu(x,y)=f_{KN}(E)a_c(x,y)+f_p(E)a_p(x,y)$$

$$f_p=1/E^3$$

e.g., for water at 80 KeV:

$$a_c{\cdot}f_{KN}(80)\approx 30[a_p{\cdot}f_p(80)]$$

- Mean square error (MSE) is the trace of the covariance matrix

$$\mathrm{MSE}=\mathrm{Tr}(\mathrm{cov}(\boldsymbol{\theta}-\hat{\boldsymbol{\theta}}))$$

- After some(!) linear algebra we can come up with lower bounds for the MSE errors associated with each parameter:

$$E_{\text{compton}}\geq\frac{C}{d_{\max}^2(\|\mathbf{H}\|_1\|\mathbf{H}\|_\infty)},\qquad E_{\text{photoelectric}}\geq\frac{C}{(\|\mathbf{H}\|_1\|\mathbf{H}\|_\infty)}$$

$$d_{\max}^2\approx 10^5$$

Material	p	c	$d_{\max}^2$
Water	4939.2	0.1907	4.38×10^5
Plexiglass	3670.1	0.2157	4.38×10^5
Aluminum	72887.5	0.4547	7.78×10^6

Regularization (addressing the sensitivity issue)

Must address sensitivity issue

- Important for background reconstructions since object model is pretty well constrained

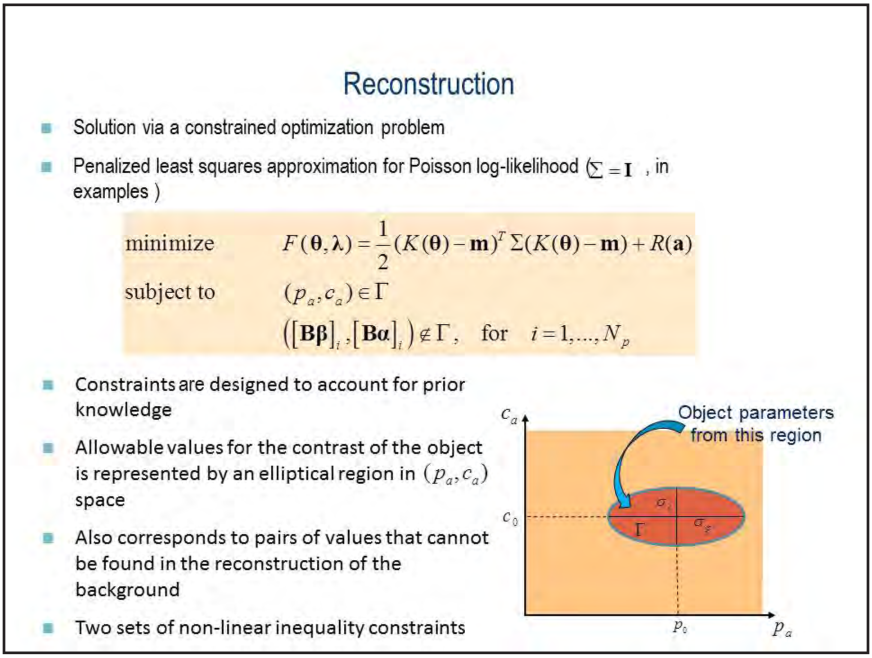
Intuition: Background should “look” similar

- For baggage screening application, background is associated with nominal objects in a piece of luggage
- Boundaries will be the same in Compton and PE images (an iPod in one image is an iPod in the other)

Mathematics

- Gradients of the two images should be highly correlated
- Small penalty if correlation coefficient between gradients is close to ±1
- Large penalty if correlation coefficient between gradients is close to 0

$$R_3(\boldsymbol{\beta})=\lambda_2\left[\frac{\|\nabla(\mathbf{B}\beta_C)\|_2^2\,\|\nabla(\mathbf{B}\beta_P)\|_2^2}{\left[\nabla(\mathbf{B}\beta_C)^T\nabla(\mathbf{B}\beta_P)\right]^2}-1\right]$$



Reconstruction

- Solution via a constrained optimization problem
- Penalized least squares approximation for Poisson log-likelihood ($\Sigma = \mathbf{I}$, in examples)

$$
\begin{array}{ll}
\text{minimize} & F(\boldsymbol{\theta},\boldsymbol{\lambda}) = \frac{1}{2}(K(\boldsymbol{\theta}) - \mathbf{m})^T \Sigma (K(\boldsymbol{\theta}) - \mathbf{m}) + R(\mathbf{a}) \\
\text{subject to} & (p_a, c_a) \in \Gamma \\
 & \left([\mathbf{B}\boldsymbol{\beta}]_i, [\mathbf{B}\boldsymbol{\alpha}]_i\right) \notin \Gamma, \quad \text{for} \quad i = 1, \ldots, N_p
\end{array}
$$

- Constraints are designed to account for prior knowledge
- Allowable values for the contrast of the object is represented by an elliptical region in (p_a, c_a) space
- Also corresponds to pairs of values that cannot be found in the reconstruction of the background
- Two sets of non-linear inequality constraints

Dual Energy Filtered Back Projection

- Reminder - The measurement model:

$$P(\theta, x') = -\ln \frac{Y(\theta, x')}{Y_0}$$

where,

$$Y(\theta, x') = \text{Poisson}\{\overline{Y}(\theta, x')\} + \text{Normal}(0, \sigma_e), \qquad \overline{Y}_{\text{L,H}}(\theta, x') = \int S_{\text{L,H}}(E) e^{-M_{\text{L,H}}(\theta, x')} \text{d}E$$

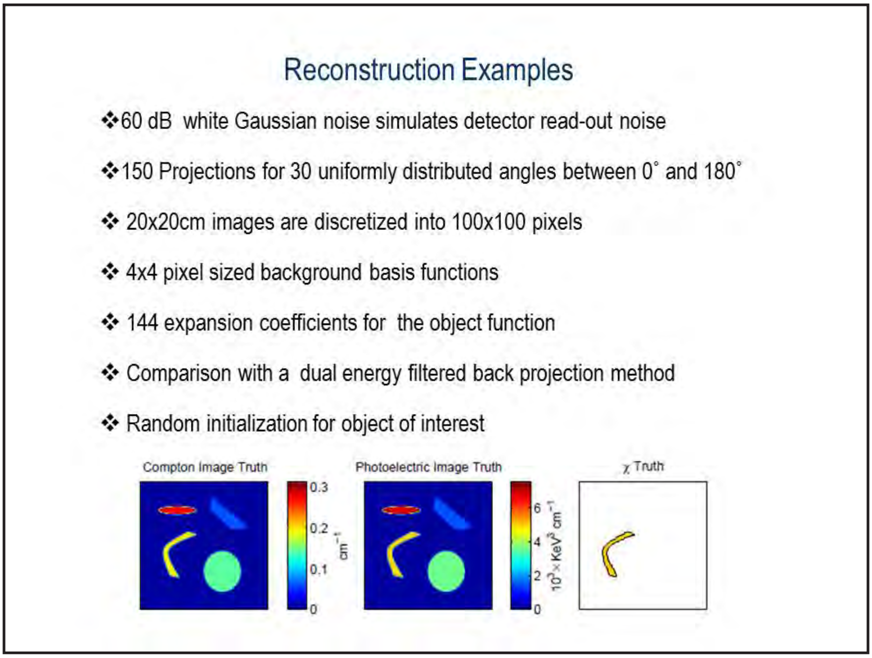
- For every measurement point estimate Radon transform of Compton and photoelectric coefficients using

$$M_{\text{L,H}}(\theta, x') = f_{KN_{\{\text{L,H}\}}} M_{\text{Compton}_{\{\text{L,H}\}}}(\theta, x') + f_{P_{\{\text{L,H}\}}} M_{\text{photoelectric}_{\{\text{L,H}\}}}(\theta, x')$$

since,

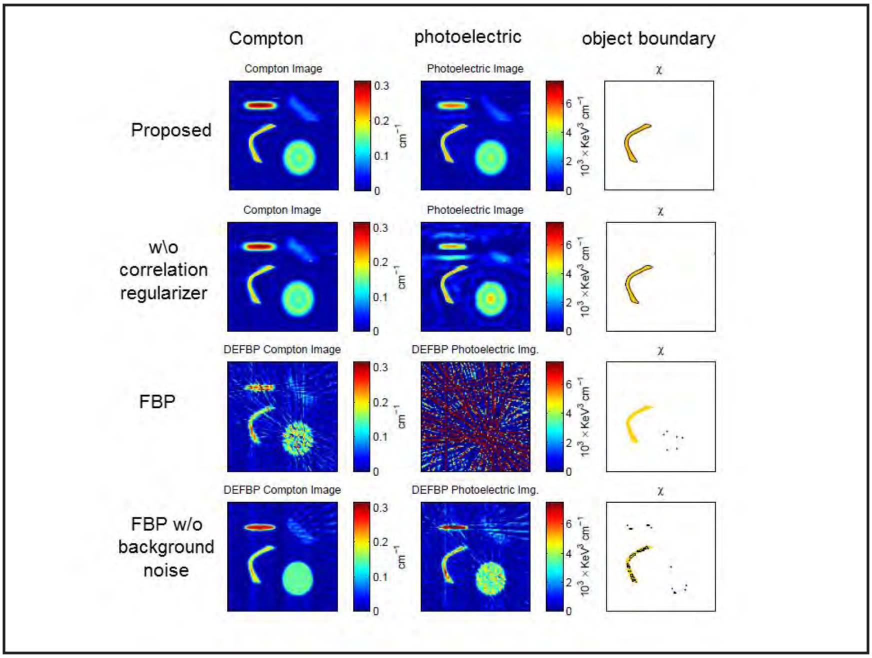
$$\mu(x, y, E) = f_{KN}(E) a_c(x, y) + f_P(E) a_p(x, y)$$

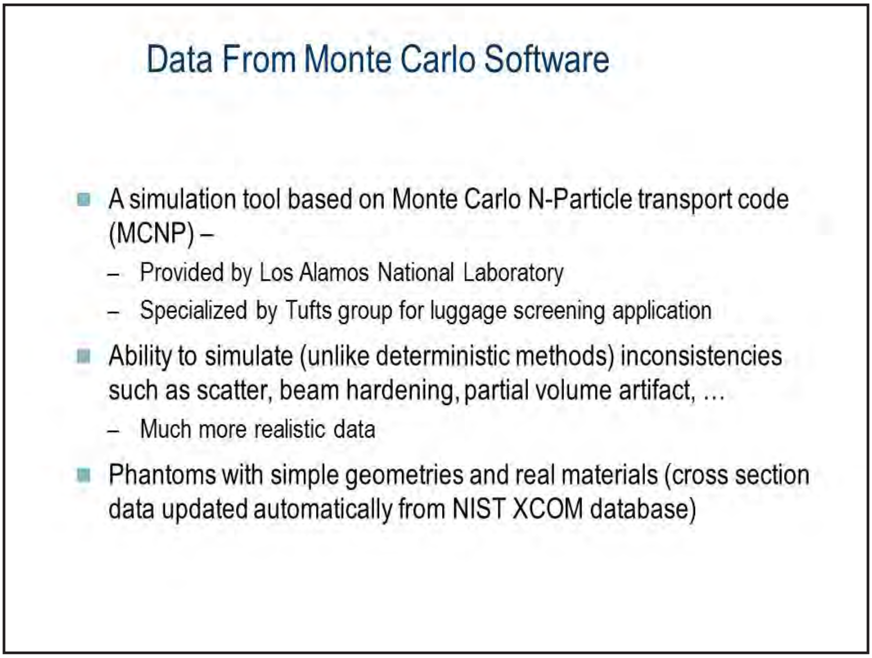
- Apply FBP to reconstruct Compton and photoelectric images.



Reconstruction Examples

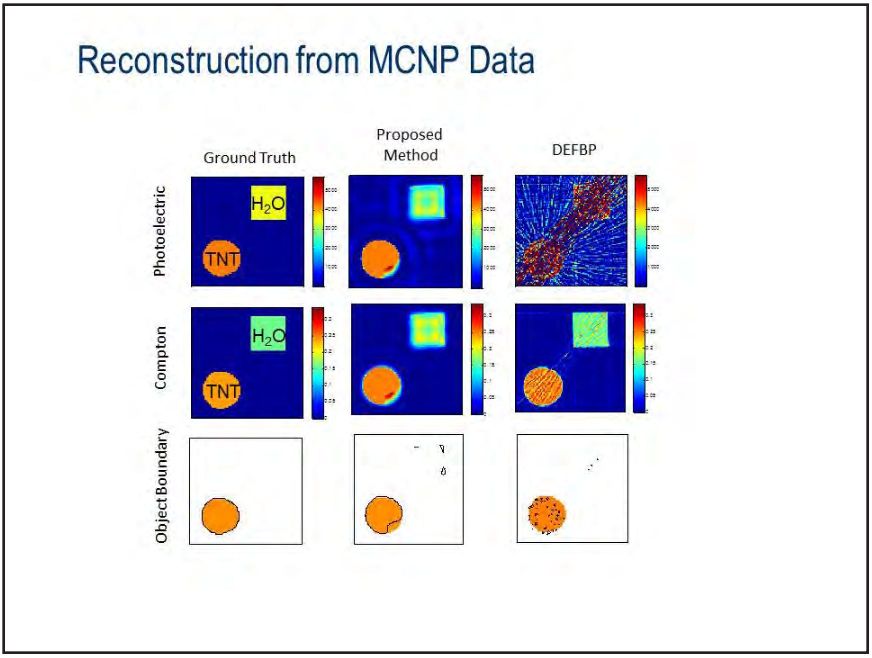
- 60 dB white Gaussian noise simulates detector read-out noise
- 150 Projections for 30 uniformly distributed angles between 0° and 180°
- 20x20cm images are discretized into 100x100 pixels
- 4x4 pixel sized background basis functions
- 144 expansion coefficients for the object function
- Comparison with a dual energy filtered back projection method
- Random initialization for object of interest



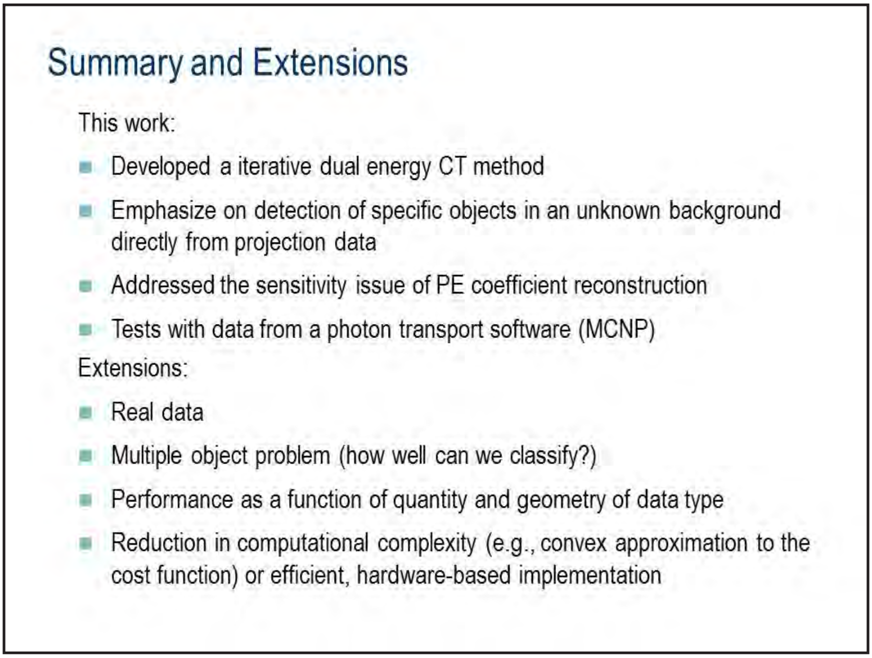


Data From Monte Carlo Software

- A simulation tool based on Monte Carlo N-Particle transport code (MCNP) –
  - Provided by Los Alamos National Laboratory
  - Specialized by Tufts group for luggage screening application
- Ability to simulate (unlike deterministic methods) inconsistencies such as scatter, beam hardening, partial volume artifact, …
  - Much more realistic data
- Phantoms with simple geometries and real materials (cross section data updated automatically from NIST XCOM database)



Reconstruction from MCNP Data



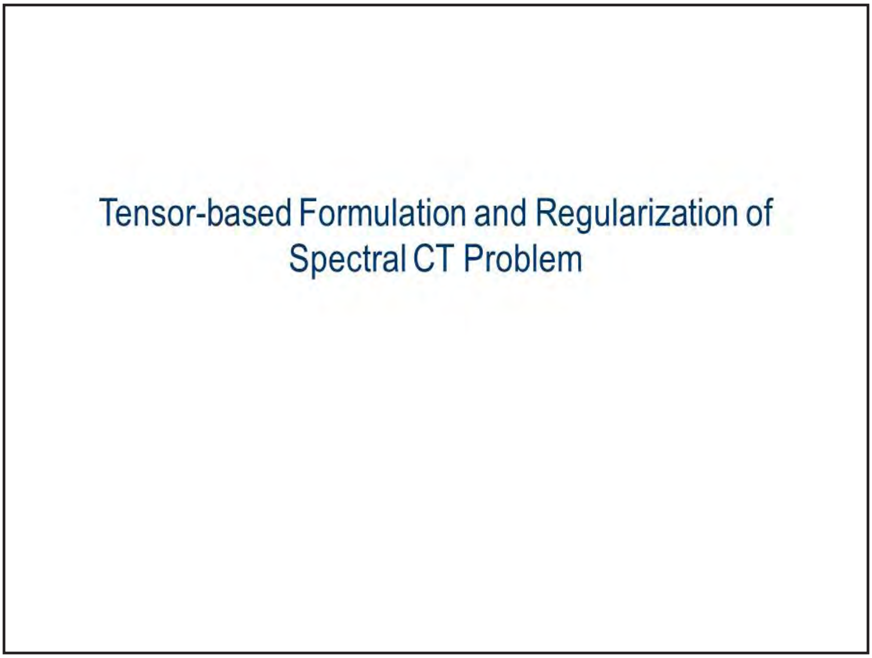
Summary and Extensions

This work:

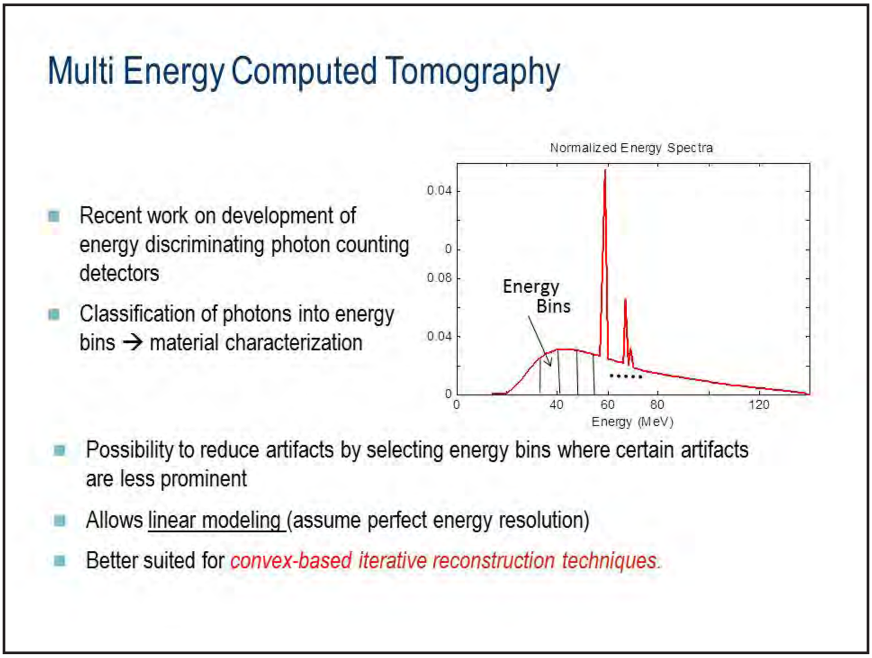
- Developed a iterative dual energy CT method
- Emphasize on detection of specific objects in an unknown background directly from projection data
- Addressed the sensitivity issue of PE coefficient reconstruction
- Tests with data from a photon transport software (MCNP)

Extensions:

- Real data
- Multiple object problem (how well can we classify?)
- Performance as a function of quantity and geometry of data type
- Reduction in computational complexity (e.g., convex approximation to the cost function) or efficient, hardware-based implementation



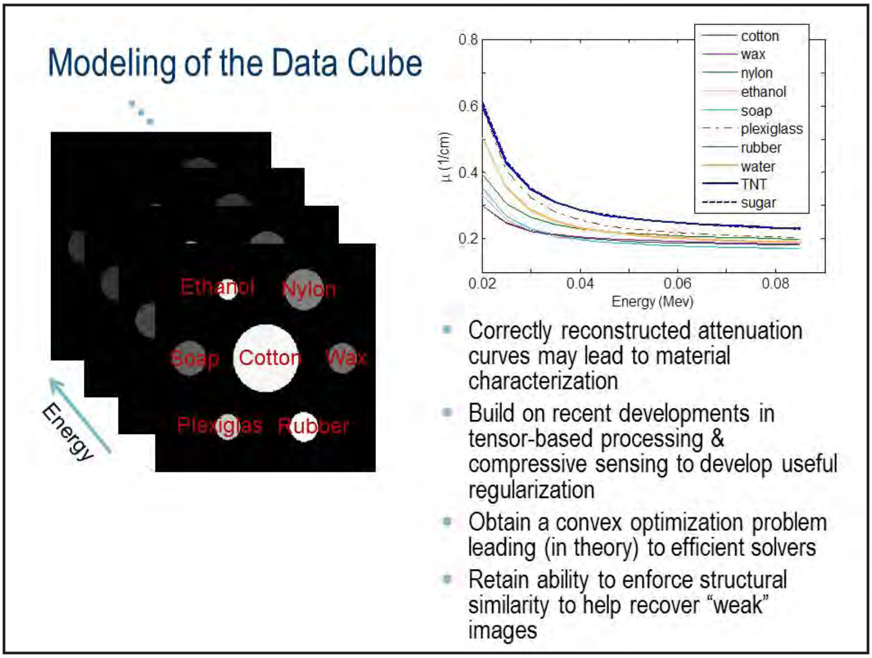
Tensor-based Formulation and Regularization of Spectral CT Problem



Multi Energy Computed Tomography

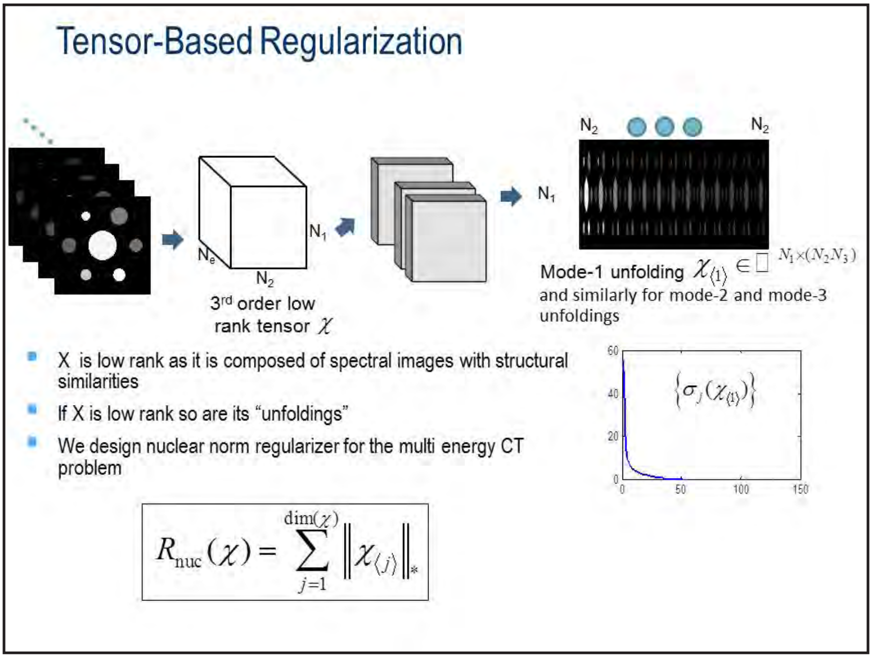
- Recent work on development of energy discriminating photon counting detectors
- Classification of photons into energy bins → material characterization

- Possibility to reduce artifacts by selecting energy bins where certain artifacts are less prominent
- Allows linear modeling (assume perfect energy resolution)
- Better suited for *convex-based iterative reconstruction techniques.*



Modeling of the Data Cube

- Correctly reconstructed attenuation curves may lead to material characterization
- Build on recent developments in tensor-based processing & compressive sensing to develop useful regularization
- Obtain a convex optimization problem leading (in theory) to efficient solvers
- Retain ability to enforce structural similarity to help recover "weak" images



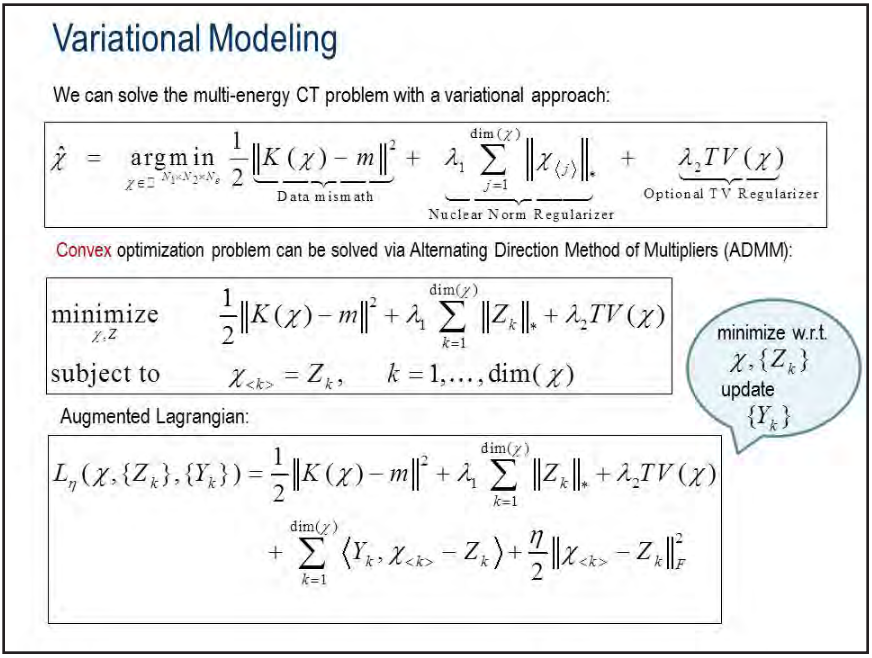
Tensor-Based Regularization

3rd order low rank tensor χ

Mode-1 unfolding $\chi_{\langle 1\rangle} \in \square^{N_1\times(N_2N_3)}$ and similarly for mode-2 and mode-3 unfoldings

- X is low rank as it is composed of spectral images with structural similarities
- If X is low rank so are its "unfoldings"
- We design nuclear norm regularizer for the multi energy CT problem

$$R_{\mathrm{nuc}}(\chi) = \sum_{j=1}^{\dim(\chi)} \left\|\chi_{\langle j\rangle}\right\|_*$$



Variational Modeling

We can solve the multi-energy CT problem with a variational approach:

$$\hat{\chi} = \underset{\chi\in\square^{N_1\times N_2\times N_e}}{\arg\min}\ \frac{1}{2}\underbrace{\left\|K(\chi)-m\right\|^2}_{\text{Data mismath}} + \underbrace{\lambda_1\sum_{j=1}^{\dim(\chi)}\left\|\chi_{\langle j\rangle}\right\|_*}_{\text{Nuclear Norm Regularizer}} + \underbrace{\lambda_2 TV(\chi)}_{\text{Optional TV Regularizer}}$$

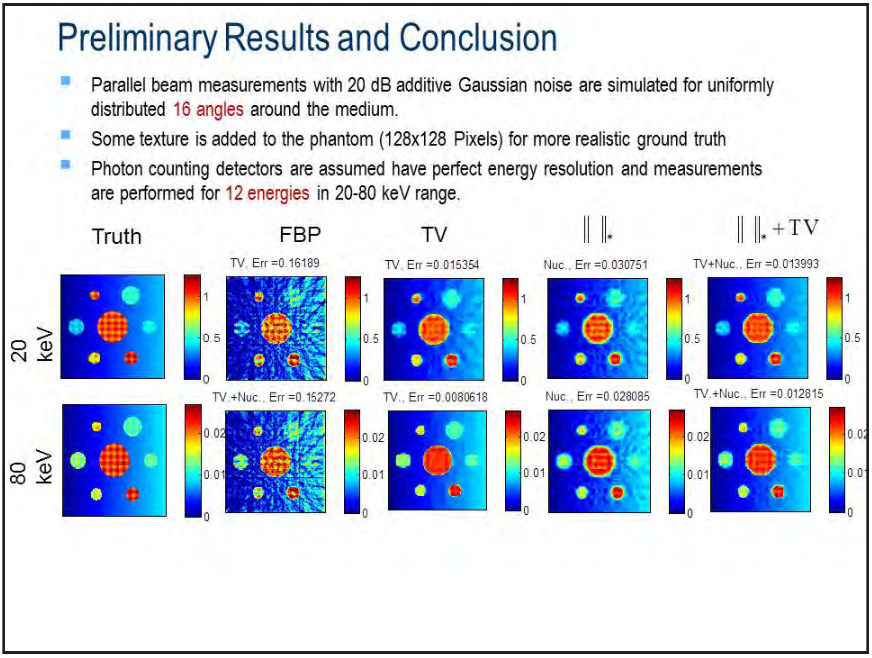
Convex optimization problem can be solved via Alternating Direction Method of Multipliers (ADMM):

$$\begin{aligned}&\underset{\chi,Z}{\text{minimize}} && \frac{1}{2}\left\|K(\chi)-m\right\|^2 + \lambda_1\sum_{k=1}^{\dim(\chi)}\left\|Z_k\right\|_* + \lambda_2 TV(\chi)\\ &\text{subject to} && \chi_{<k>} = Z_k, \quad k = 1,\ldots,\dim(\chi)\end{aligned}$$

minimize w.r.t. $\chi, \{Z_k\}$
update $\{Y_k\}$

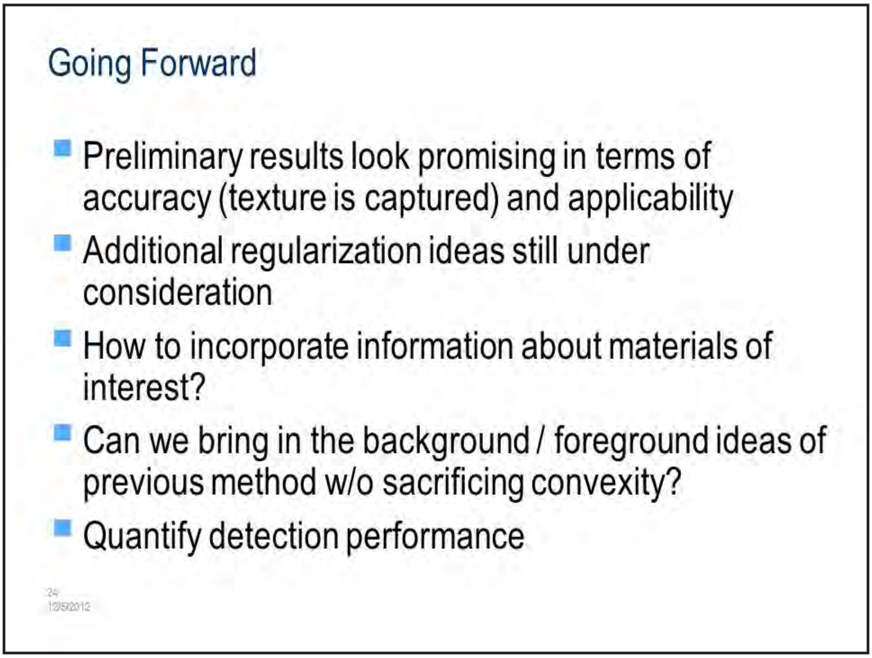
Augmented Lagrangian:

$$\begin{aligned}L_\eta(\chi,\{Z_k\},\{Y_k\}) &= \frac{1}{2}\left\|K(\chi)-m\right\|^2 + \lambda_1\sum_{k=1}^{\dim(\chi)}\left\|Z_k\right\|_* + \lambda_2 TV(\chi)\\ &+ \sum_{k=1}^{\dim(\chi)}\left\langle Y_k, \chi_{<k>} - Z_k\right\rangle + \frac{\eta}{2}\left\|\chi_{<k>} - Z_k\right\|_F^2\end{aligned}$$



Preliminary Results and Conclusion

- Parallel beam measurements with 20 dB additive Gaussian noise are simulated for uniformly distributed 16 angles around the medium.
- Some texture is added to the phantom (128x128 Pixels) for more realistic ground truth
- Photon counting detectors are assumed have perfect energy resolution and measurements are performed for 12 energies in 20-80 keV range.



Going Forward

- Preliminary results look promising in terms of accuracy (texture is captured) and applicability
- Additional regularization ideas still under consideration
- How to incorporate information about materials of interest?
- Can we bring in the background / foreground ideas of previous method w/o sacrificing convexity?
- Quantify detection performance

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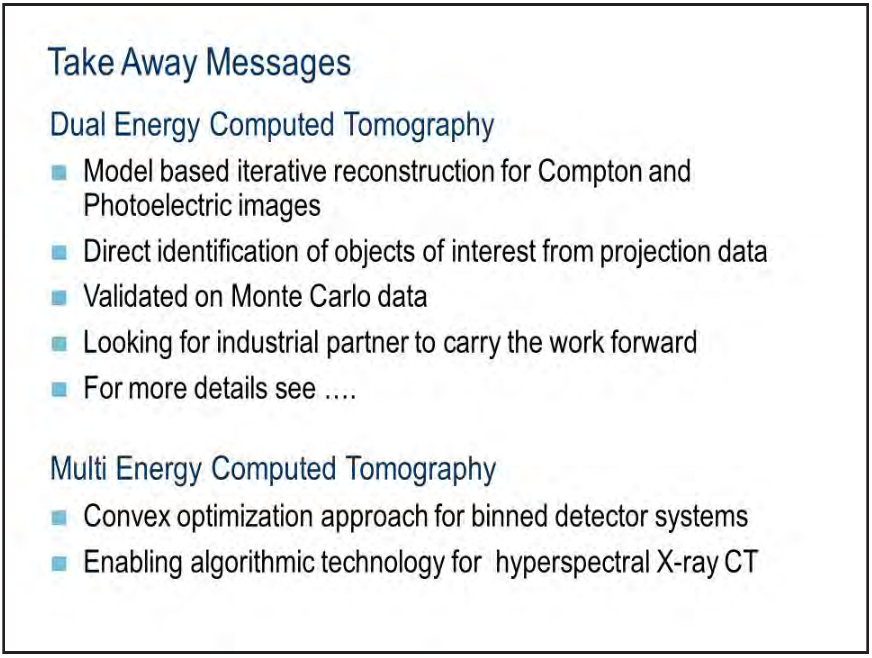
12/5/2012



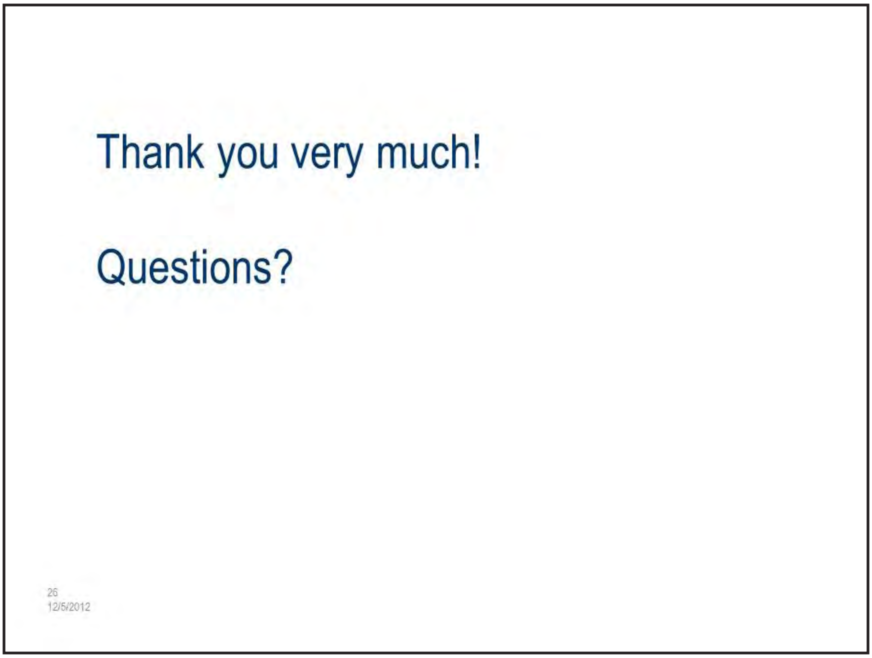
Take Away Messages

Dual Energy Computed Tomography

- Model based iterative reconstruction for Compton and Photoelectric images
- Direct identification of objects of interest from projection data
- Validated on Monte Carlo data
- Looking for industrial partner to carry the work forward
- For more details see ….

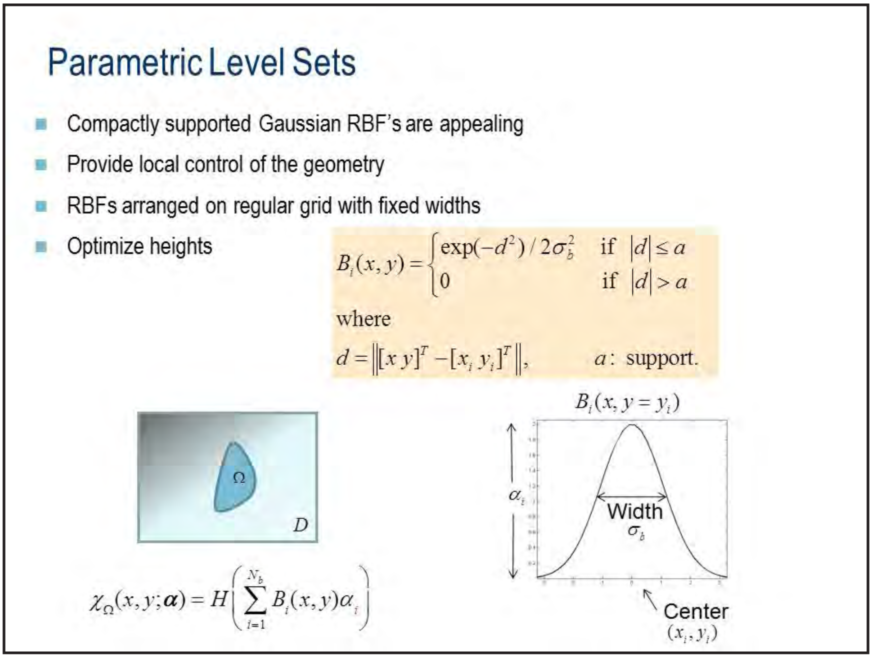
Multi Energy Computed Tomography

- Convex optimization approach for binned detector systems
- Enabling algorithmic technology for hyperspectral X-ray CT



Thank you very much!

Questions?



Parametric Level Sets

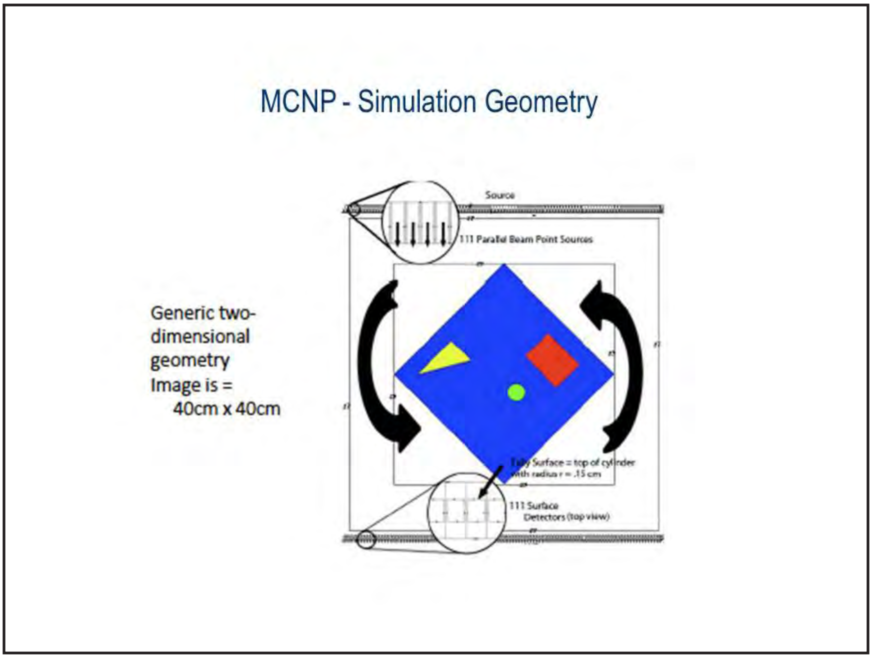
- Compactly supported Gaussian RBF's are appealing
- Provide local control of the geometry
- RBFs arranged on regular grid with fixed widths
- Optimize heights

$$B_i(x,y)=\begin{cases}\exp(-d^2)/2\sigma_b^2 & \text{if } |d|\le a\\ 0 & \text{if } |d|>a\end{cases}$$

where

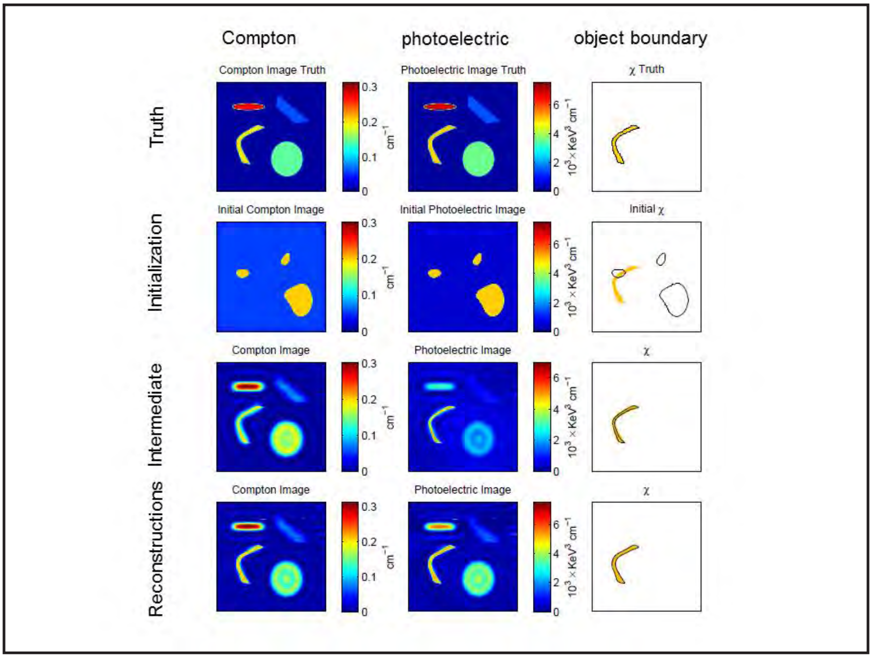
$$d=\left\|[x\ y]^T-[x_i\ y_i]^T\right\|, \qquad a:\ \text{support}.$$

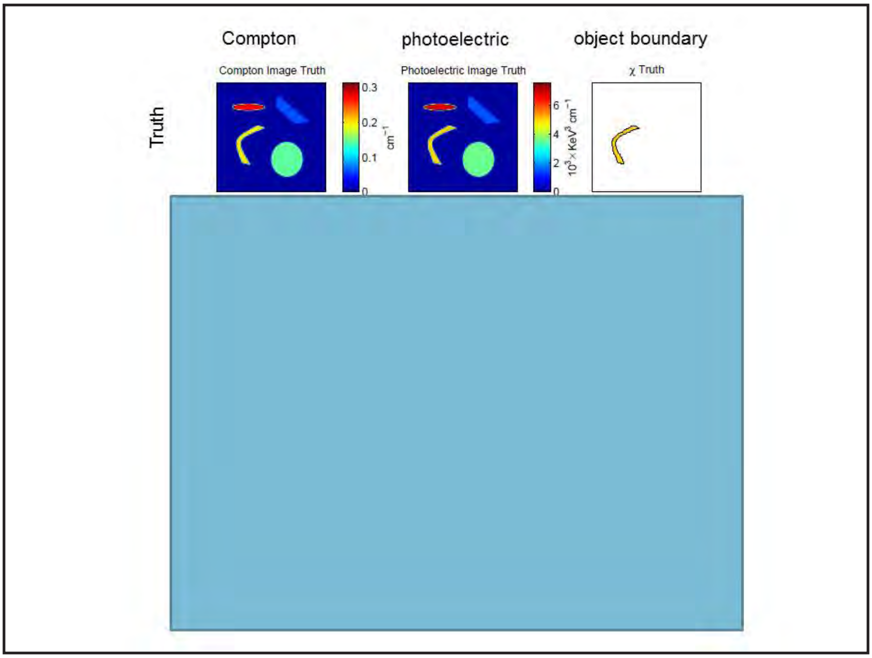
$$\chi_\Omega(x,y;\boldsymbol{\alpha})=H\left(\sum_{i=1}^{N_b}B_i(x,y)\alpha_i\right)$$



MCNP - Simulation Geometry

Generic two-dimensional geometry
Image is =
40cm x 40cm


Compton
photoelectric
object boundary
Truth
Compton Image Truth
Photoelectric Image Truth
χ Truth
Initialization
Initial Compton Image
Initial Photoelectric Image
Initial χ
Intermediate
Compton Image
Photoelectric Image
χ
Reconstructions
Compton Image
Photoelectric Image
χ
0.3
0.2
0.1
0
cm⁻¹
6
4
2
0
10³ × KeV³ cm⁻¹


Compton
photoelectric
object boundary
Truth
Compton Image Truth
Photoelectric Image Truth
χ Truth
0.3
0.2
0.1
0
cm⁻¹
6
4
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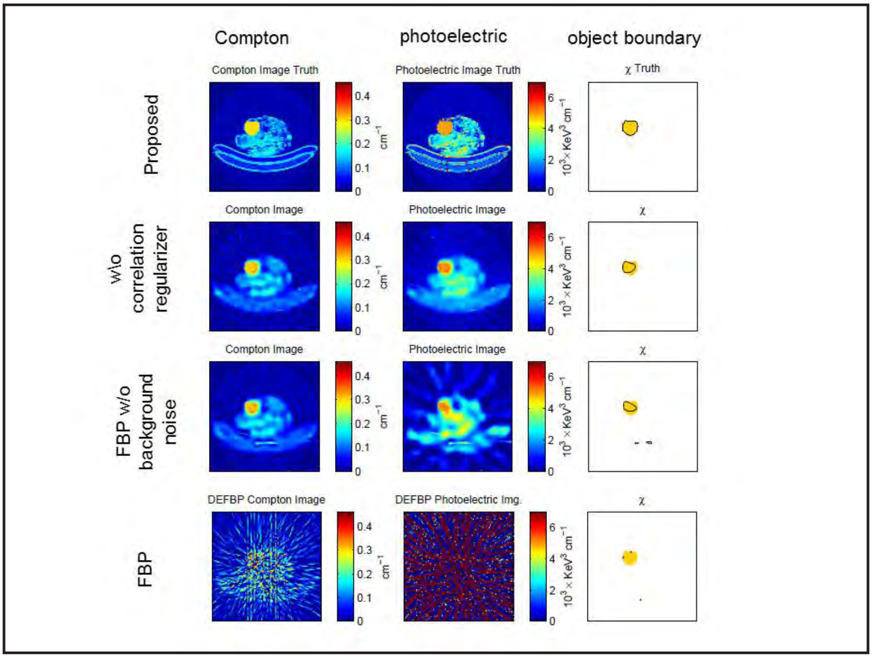
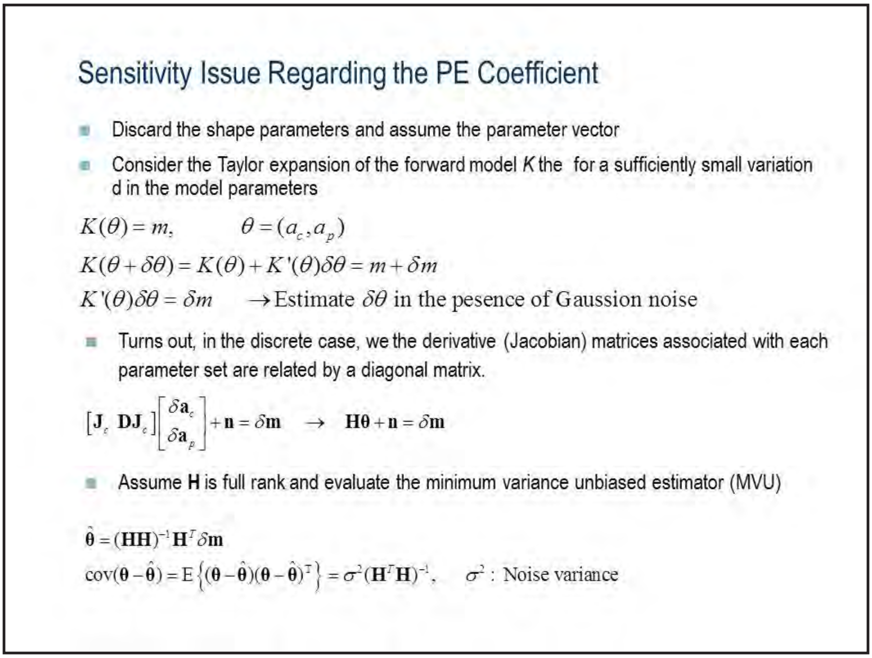
10³ × KeV³ cm⁻¹





Sensitivity Issue Regarding the PE Coefficient

- Discard the shape parameters and assume the parameter vector
- Consider the Taylor expansion of the forward model *K* the for a sufficiently small variation d in the model parameters

$$K(\theta) = m, \qquad \theta = (a_c, a_p)$$

$$K(\theta + \delta\theta) = K(\theta) + K'(\theta)\delta\theta = m + \delta m$$

$$K'(\theta)\delta\theta = \delta m \qquad \rightarrow \text{Estimate } \delta\theta \text{ in the pesence of Gaussion noise}$$

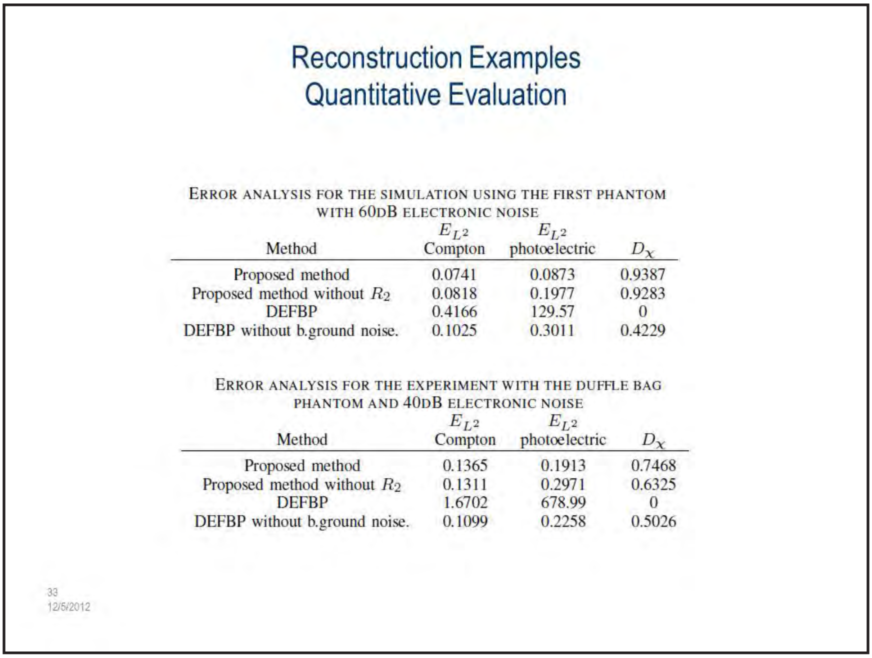
- Turns out, in the discrete case, we the derivative (Jacobian) matrices associated with each parameter set are related by a diagonal matrix.

$$[\mathbf{J}_c \;\; \mathbf{D}\mathbf{J}_c]\begin{bmatrix} \delta\mathbf{a}_c \\ \delta\mathbf{a}_p \end{bmatrix} + \mathbf{n} = \delta\mathbf{m} \quad \rightarrow \quad \mathbf{H}\boldsymbol{\theta} + \mathbf{n} = \delta\mathbf{m}$$

- Assume **H** is full rank and evaluate the minimum variance unbiased estimator (MVU)

$$\hat{\boldsymbol{\theta}} = (\mathbf{H}\mathbf{H})^{-1}\mathbf{H}^T\delta\mathbf{m}$$

$$\mathrm{cov}(\boldsymbol{\theta} - \hat{\boldsymbol{\theta}}) = \mathrm{E}\left\{(\boldsymbol{\theta} - \hat{\boldsymbol{\theta}})(\boldsymbol{\theta} - \hat{\boldsymbol{\theta}})^T\right\} = \sigma^2(\mathbf{H}^T\mathbf{H})^{-1}, \qquad \sigma^2 : \text{ Noise variance}$$



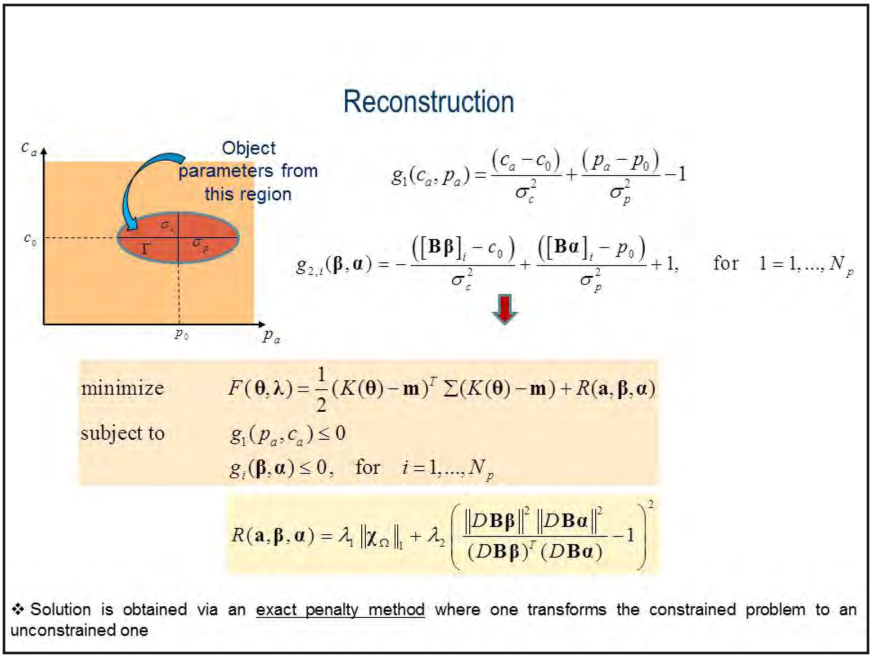
Reconstruction Examples
Quantitative Evaluation

ERROR ANALYSIS FOR THE SIMULATION USING THE FIRST PHANTOM WITH 60DB ELECTRONIC NOISE

Method	E_{L^2} Compton	E_{L^2} photoelectric	D_χ
Proposed method	0.0741	0.0873	0.9387
Proposed method without R_2	0.0818	0.1977	0.9283
DEFBP	0.4166	129.57	0
DEFBP without b.ground noise.	0.1025	0.3011	0.4229

ERROR ANALYSIS FOR THE EXPERIMENT WITH THE DUFFLE BAG PHANTOM AND 40DB ELECTRONIC NOISE

Method	E_{L^2} Compton	E_{L^2} photoelectric	D_χ
Proposed method	0.1365	0.1913	0.7468
Proposed method without R_2	0.1311	0.2971	0.6325
DEFBP	1.6702	678.99	0
DEFBP without b.ground noise.	0.1099	0.2258	0.5026



Reconstruction

Object parameters from this region

$$g_1(c_a, p_a) = \frac{(c_a - c_0)}{\sigma_c^2} + \frac{(p_a - p_0)}{\sigma_p^2} - 1$$

$$g_{2,i}(\boldsymbol{\beta}, \boldsymbol{\alpha}) = -\frac{([\mathbf{B}\boldsymbol{\beta}]_i - c_0)}{\sigma_c^2} + \frac{([\mathbf{B}\boldsymbol{\alpha}]_i - p_0)}{\sigma_p^2} + 1, \quad \text{for} \quad 1 = 1, \dots, N_p$$

$$\Downarrow$$

minimize $\quad F(\boldsymbol{\theta}, \boldsymbol{\lambda}) = \frac{1}{2}(K(\boldsymbol{\theta}) - \mathbf{m})^T \Sigma (K(\boldsymbol{\theta}) - \mathbf{m}) + R(\mathbf{a}, \boldsymbol{\beta}, \boldsymbol{\alpha})$

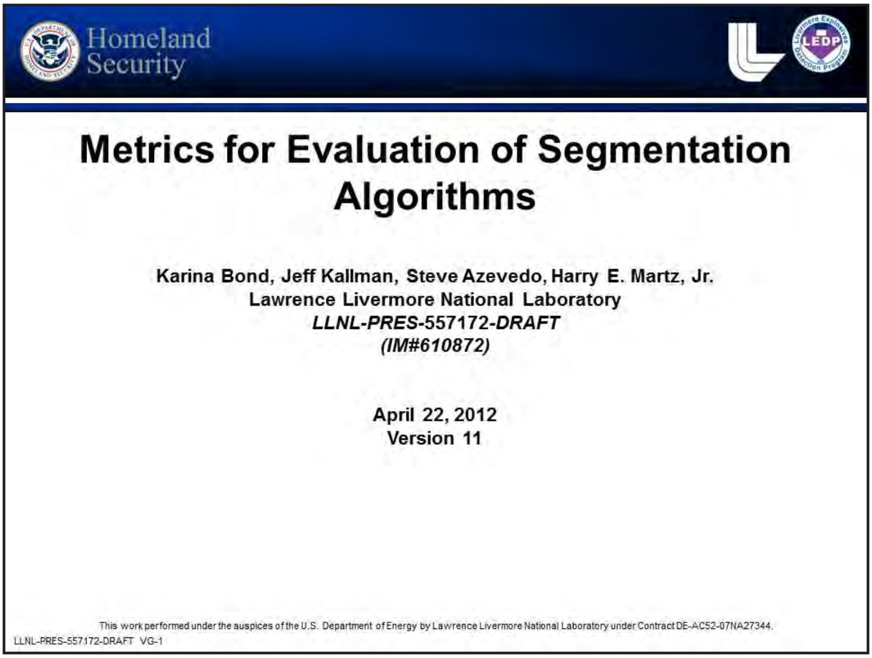
subject to $\quad g_1(p_a, c_a) \le 0$

$\quad g_i(\boldsymbol{\beta}, \boldsymbol{\alpha}) \le 0, \quad \text{for} \quad i = 1, \dots, N_p$

$$R(\mathbf{a}, \boldsymbol{\beta}, \boldsymbol{\alpha}) = \lambda_1 \|\chi_\Omega\|_1 + \lambda_2 \left(\frac{\|D\mathbf{B}\boldsymbol{\beta}\|^2 \|D\mathbf{B}\boldsymbol{\alpha}\|^2}{(D\mathbf{B}\boldsymbol{\beta})^T (D\mathbf{B}\boldsymbol{\alpha})} - 1 \right)^2$$

❖ Solution is obtained via an <u>exact penalty method</u> where one transforms the constrained problem to an unconstrained one

16.22 Karina Bond: Metrics for Evaluation of Segmentation Algorithms



Homeland Security

Metrics for Evaluation of Segmentation Algorithms

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Lawrence Livermore National Laboratory
LLNL-PRES-557172-DRAFT
(IM#610872)

April 22, 2012
Version 11

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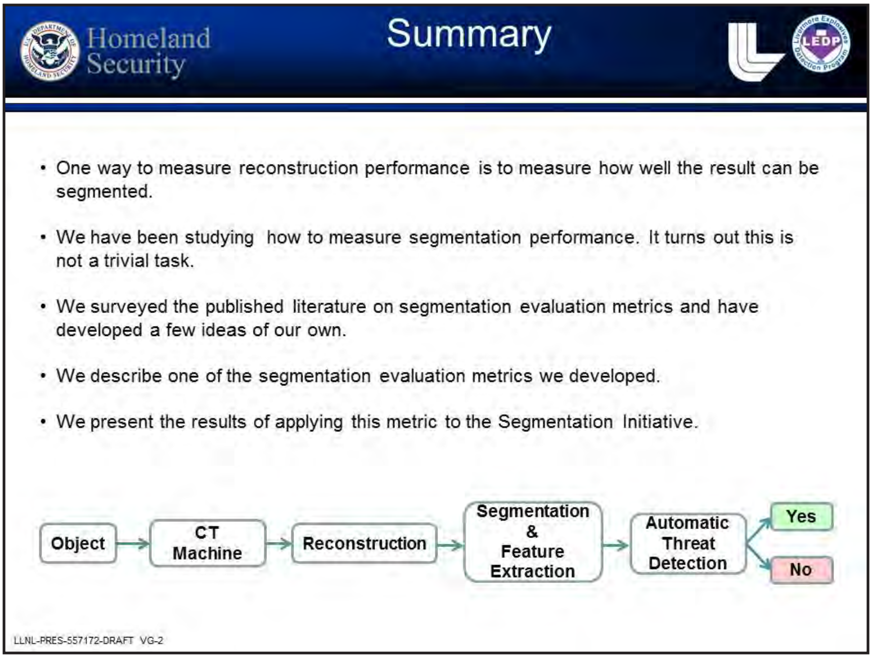
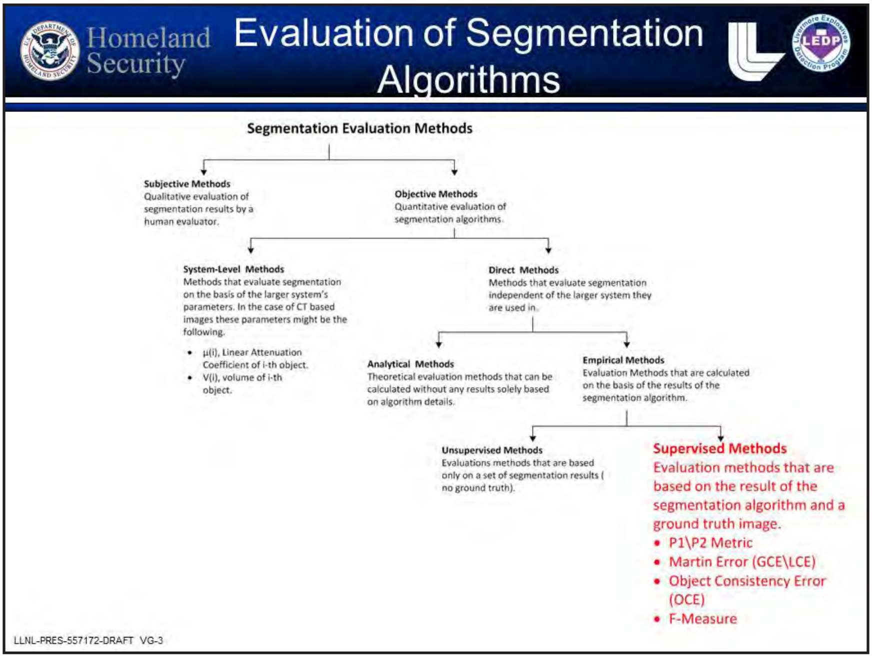


Homeland Security

Summary

- One way to measure reconstruction performance is to measure how well the result can be segmented.
- We have been studying how to measure segmentation performance. It turns out this is not a trivial task.
- We surveyed the published literature on segmentation evaluation metrics and have developed a few ideas of our own.
- We describe one of the segmentation evaluation metrics we developed.
- We present the results of applying this metric to the Segmentation Initiative.



Evaluation of Segmentation Algorithms

Segmentation Evaluation Methods

Subjective Methods
Qualitative evaluation of segmentation results by a human evaluator.

Objective Methods
Quantitative evaluation of segmentation algorithms.

System-Level Methods
Methods that evaluate segmentation on the basis of the larger system's parameters. In the case of CT based images these parameters might be the following.

- μ(i), Linear Attenuation Coefficient of i-th object.
- V(i), volume of i-th object.

Direct Methods
Methods that evaluate segmentation independent of the larger system they are used in.

Analytical Methods
Theoretical evaluation methods that can be calculated without any results solely based on algorithm details.

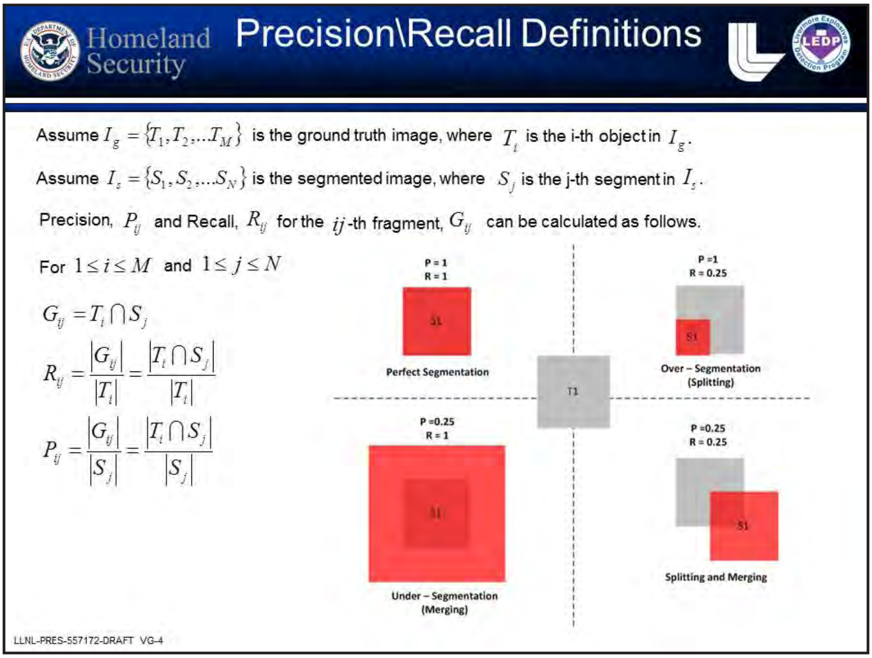
Empirical Methods
Evaluation Methods that are calculated on the basis of the results of the segmentation algorithm.

Unsupervised Methods
Evaluations methods that are based only on a set of segmentation results (no ground truth).

Supervised Methods
Evaluation methods that are based on the result of the segmentation algorithm and a ground truth image.

- P1\P2 Metric
- Martin Error (GCE\LCE)
- Object Consistency Error (OCE)
- F-Measure

LLNL-PRES-557172-DRAFT VG-3



Precision\Recall Definitions

Assume $I_g = \{T_1, T_2, \ldots T_M\}$ is the ground truth image, where T_i is the i-th object in I_g.

Assume $I_s = \{S_1, S_2, \ldots S_N\}$ is the segmented image, where S_j is the j-th segment in I_s.

Precision, P_{ij} and Recall, R_{ij} for the ij-th fragment, G_{ij} can be calculated as follows.

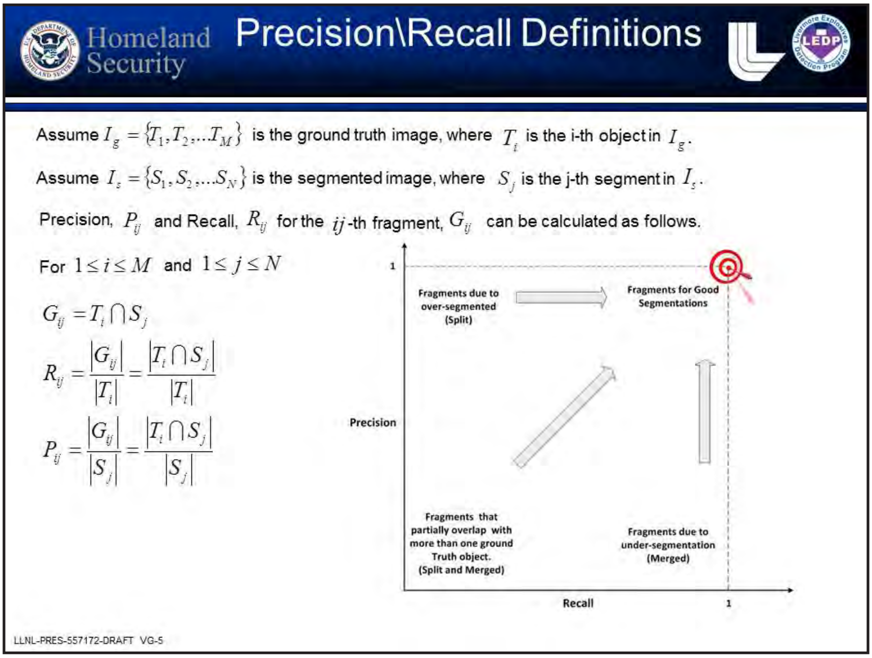
For $1 \le i \le M$ and $1 \le j \le N$

$$G_{ij} = T_i \cap S_j$$

$$R_{ij} = \frac{|G_{ij}|}{|T_i|} = \frac{|T_i \cap S_j|}{|T_i|}$$

$$P_{ij} = \frac{|G_{ij}|}{|S_j|} = \frac{|T_i \cap S_j|}{|S_j|}$$

LLNL-PRES-557172-DRAFT VG-4



Precision\Recall Definitions

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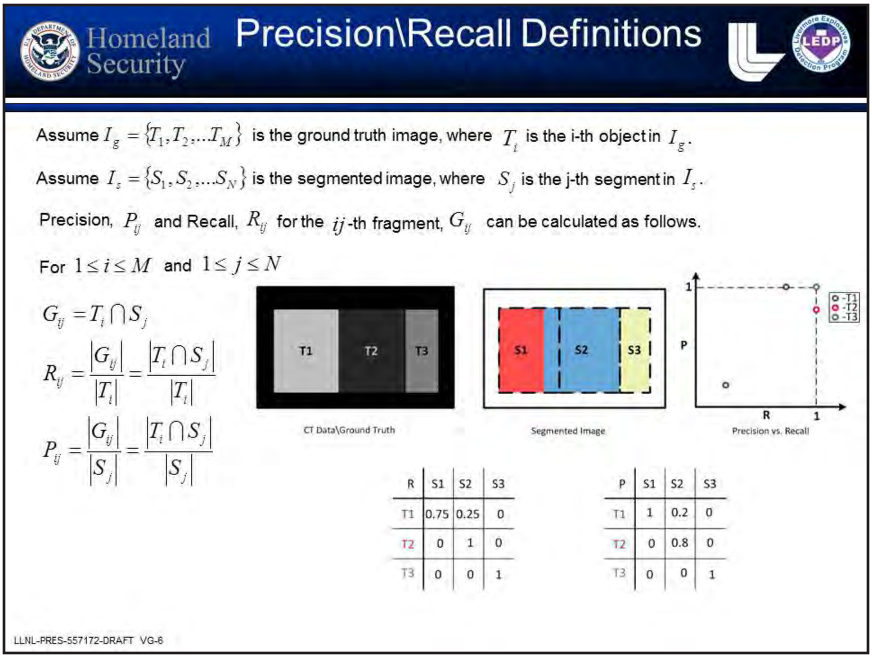
$$R_{ij} = \frac{|G_{ij}|}{|T_i|} = \frac{|T_i \cap S_j|}{|T_i|}$$

$$P_{ij} = \frac{|G_{ij}|}{|S_j|} = \frac{|T_i \cap S_j|}{|S_j|}$$



Precision\Recall Definitions

Assume $I_g = \{T_1, T_2, ... T_M\}$ is the ground truth image, where T_i is the i-th object in I_g.

Assume $I_s = \{S_1, S_2, ... S_N\}$ is the segmented image, where S_j is the j-th segment in I_s.

Precision, P_{ij} and Recall, R_{ij} for the ij-th fragment, G_{ij} can be calculated as follows.

For $1 \leq i \leq M$ and $1 \leq j \leq N$

$$G_{ij} = T_i \cap S_j$$

$$R_{ij} = \frac{|G_{ij}|}{|T_i|} = \frac{|T_i \cap S_j|}{|T_i|}$$

$$P_{ij} = \frac{|G_{ij}|}{|S_j|} = \frac{|T_i \cap S_j|}{|S_j|}$$

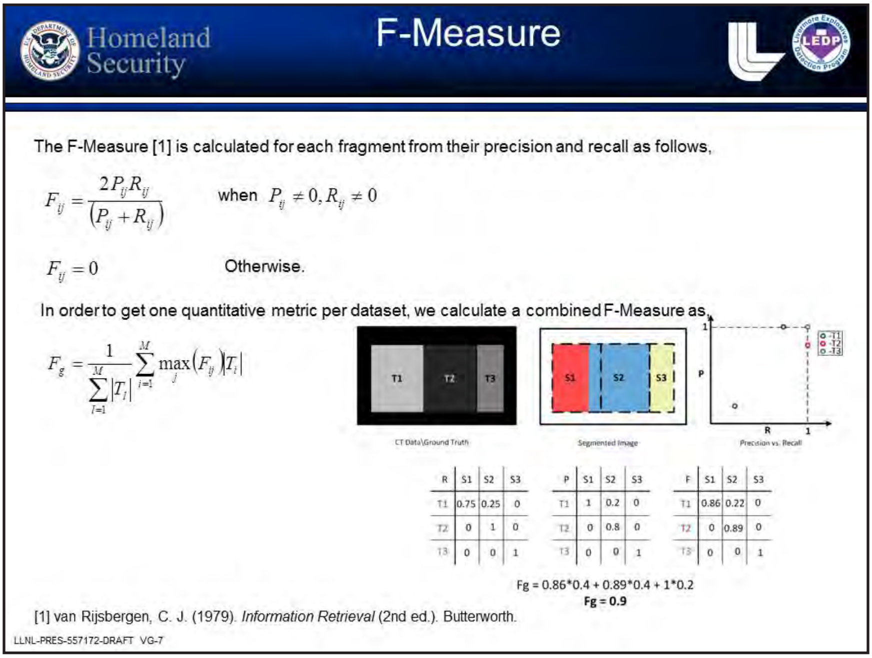
CT Data\Ground Truth

Segmented Image

Precision vs. Recall

R	S1	S2	S3
T1	0.75	0.25	0
T2	0	1	0
T3	0	0	1

P	S1	S2	S3
T1	1	0.2	0
T2	0	0.8	0
T3	0	0	1



F-Measure

The F-Measure [1] is calculated for each fragment from their precision and recall as follows,

$$F_{ij} = \frac{2P_{ij}R_{ij}}{(P_{ij}+R_{ij})} \qquad \text{when } P_{ij} \neq 0, R_{ij} \neq 0$$

$$F_{ij} = 0 \qquad \text{Otherwise.}$$

In order to get one quantitative metric per dataset, we calculate a combined F-Measure as,

$$F_g = \frac{1}{\sum_{l=1}^{M} |T_l|} \sum_{i=1}^{M} \max_j (F_{ij}) |T_i|$$

R	S1	S2	S3
T1	0.75	0.25	0
T2	0	1	0
T3	0	0	1

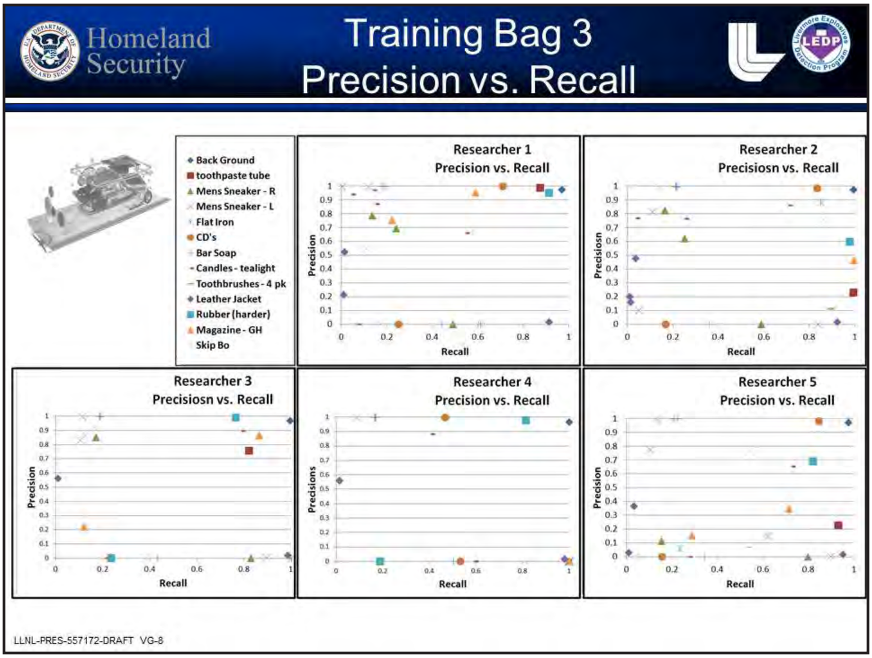
P	S1	S2	S3
T1	1	0.2	0
T2	0	0.8	0
T3	0	0	1

F	S1	S2	S3
T1	0.86	0.22	0
T2	0	0.89	0
T3	0	0	1

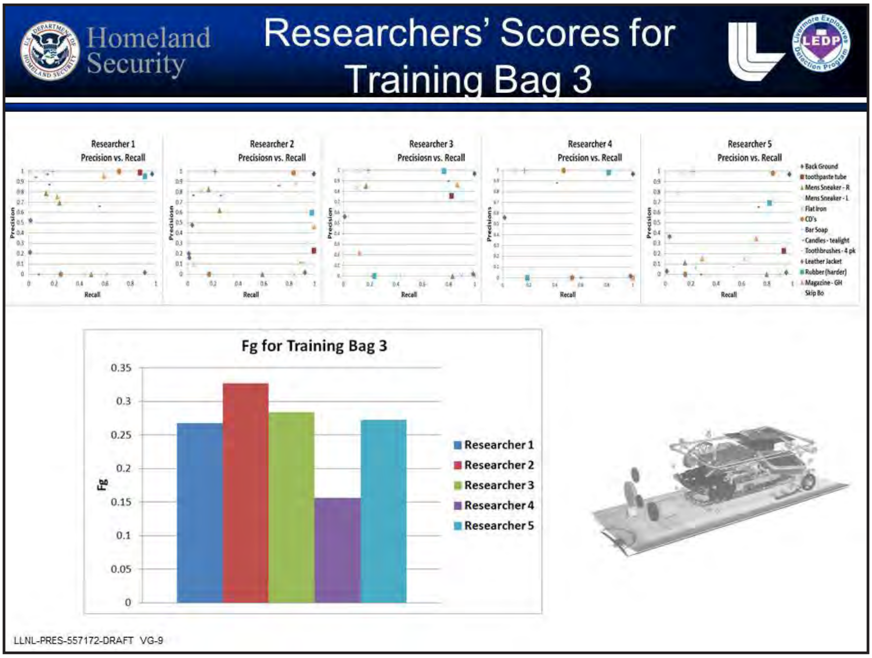
Fg = 0.86*0.4 + 0.89*0.4 + 1*0.2

Fg = 0.9

[1] van Rijsbergen, C. J. (1979). *Information Retrieval* (2nd ed.). Butterworth.



Training Bag 3 Precision vs. Recall



Researchers' Scores for Training Bag 3

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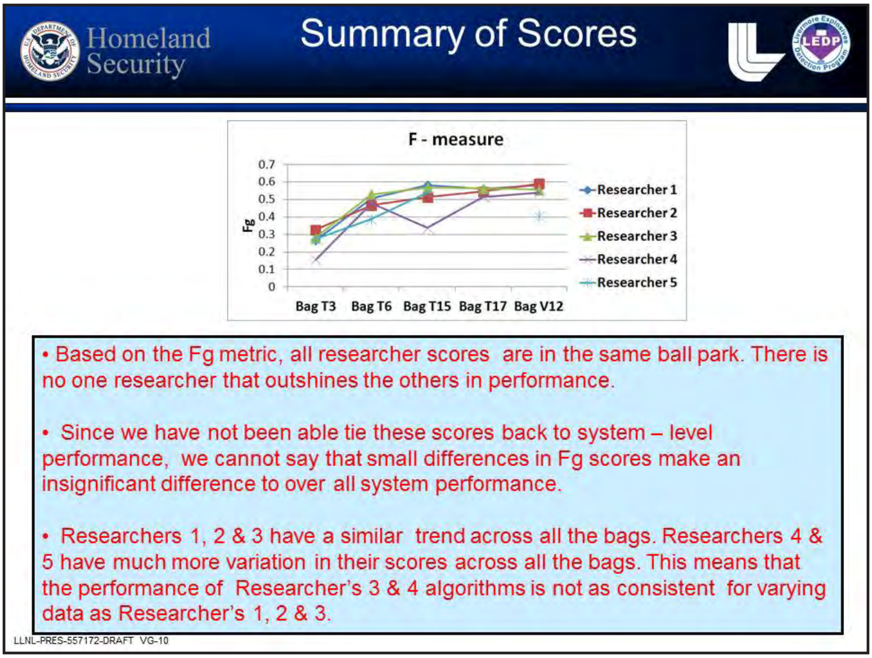

Summary of Scores

- Based on the Fg metric, all researcher scores are in the same ball park. There is no one researcher that outshines the others in performance.
- Since we have not been able tie these scores back to system – level performance, we cannot say that small differences in Fg scores make an insignificant difference to over all system performance.
- Researchers 1, 2 & 3 have a similar trend across all the bags. Researchers 4 & 5 have much more variation in their scores across all the bags. This means that the performance of Researcher's 3 & 4 algorithms is not as consistent for varying data as Researcher's 1, 2 & 3.

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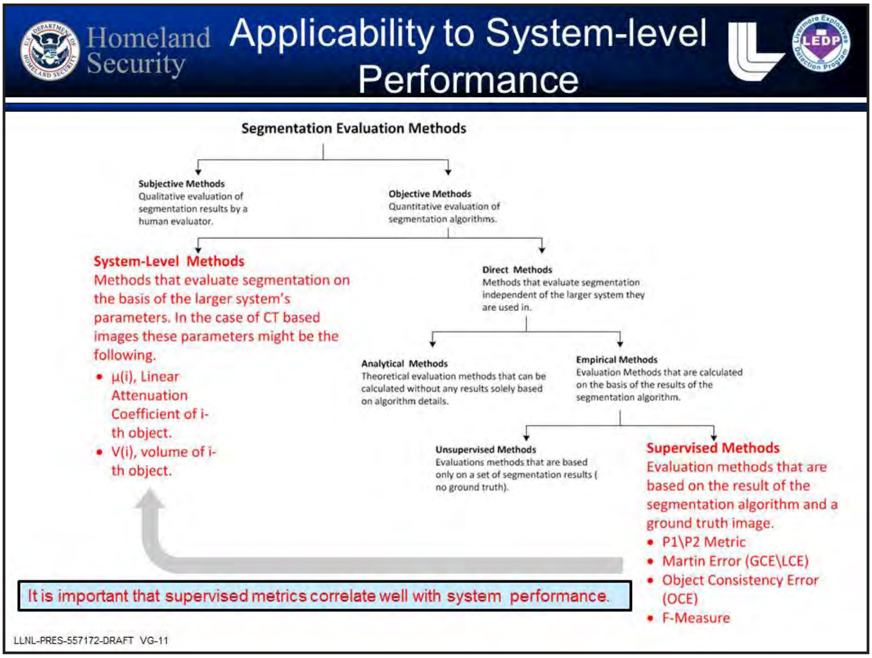


Applicability to System-level Performance

Segmentation Evaluation Methods

Subjective Methods
Qualitative evaluation of segmentation results by a human evaluator.

Objective Methods
Quantitative evaluation of segmentation algorithms.

System-Level Methods
Methods that evaluate segmentation on the basis of the larger system's parameters. In the case of CT based images these parameters might be the following.

- μ(i), Linear Attenuation Coefficient of i-th object.
- V(i), volume of i-th object.

Direct Methods
Methods that evaluate segmentation independent of the larger system they are used in.

Analytical Methods
Theoretical evaluation methods that can be calculated without any results solely based on algorithm details.

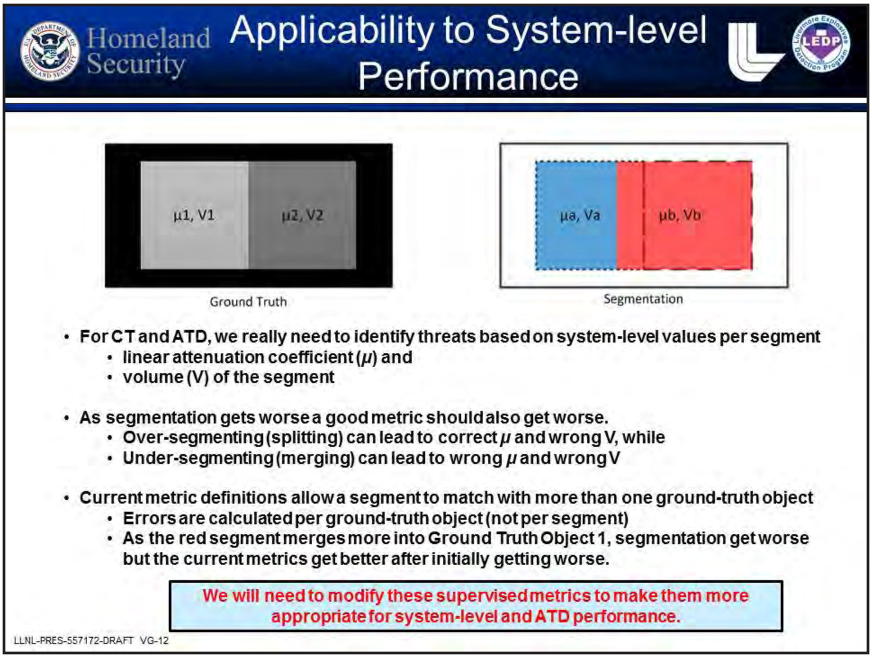
Empirical Methods
Evaluation Methods that are calculated on the basis of the results of the segmentation algorithm.

Unsupervised Methods
Evaluations methods that are based only on a set of segmentation results (no ground truth).

Supervised Methods
Evaluation methods that are based on the result of the segmentation algorithm and a ground truth image.

- P1\P2 Metric
- Martin Error (GCE\LCE)
- Object Consistency Error (OCE)
- F-Measure

It is important that supervised metrics correlate well with system performance.



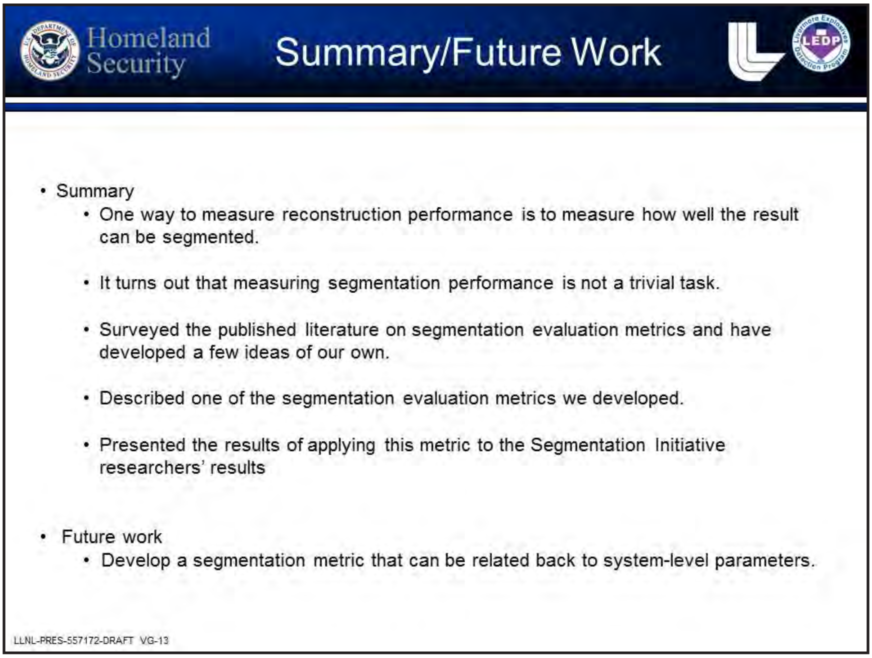
Applicability to System-level Performance

Ground Truth

Segmentation

- For CT and ATD, we really need to identify threats based on system-level values per segment
  - linear attenuation coefficient (μ) and
  - volume (V) of the segment
- As segmentation gets worse a good metric should also get worse.
  - Over-segmenting (splitting) can lead to correct μ and wrong V, while
  - Under-segmenting (merging) can lead to wrong μ and wrong V
- Current metric definitions allow a segment to match with more than one ground-truth object
  - Errors are calculated per ground-truth object (not per segment)
  - As the red segment merges more into Ground Truth Object 1, segmentation get worse but the current metrics get better after initially getting worse.

We will need to modify these supervised metrics to make them more appropriate for system-level and ATD performance.



Homeland Security

Summary/Future Work

- Summary
  - One way to measure reconstruction performance is to measure how well the result can be segmented.
  - It turns out that measuring segmentation performance is not a trivial task.
  - Surveyed the published literature on segmentation evaluation metrics and have developed a few ideas of our own.
  - Described one of the segmentation evaluation metrics we developed.
  - Presented the results of applying this metric to the Segmentation Initiative researchers' results
- Future work
  - Develop a segmentation metric that can be related back to system-level parameters.

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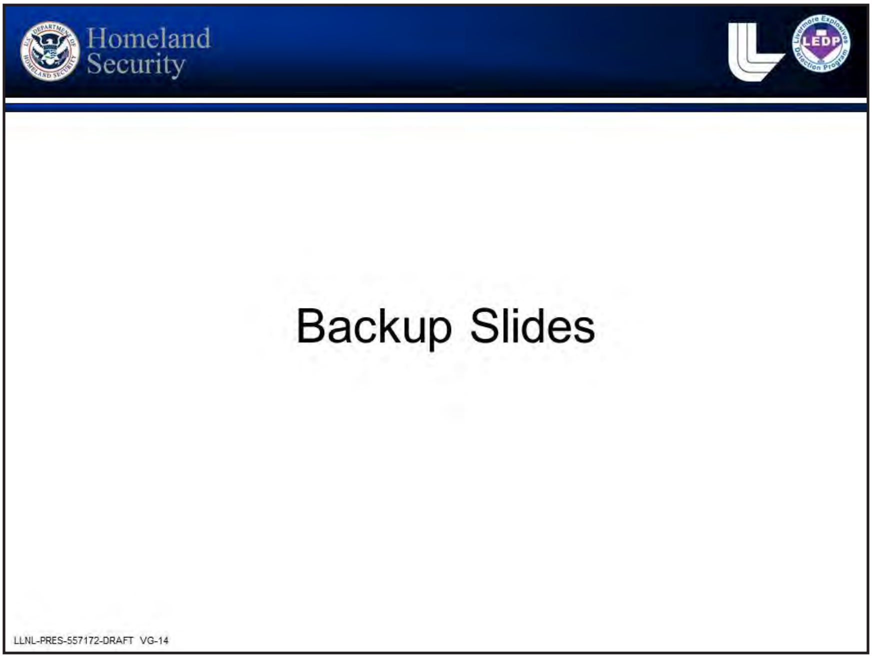

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Backup Slides

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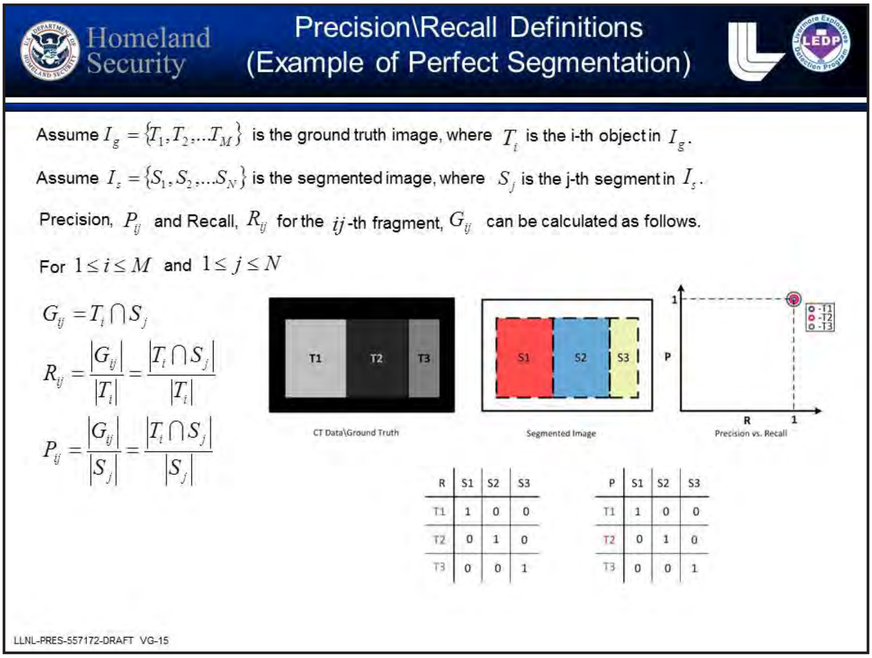

Precision\Recall Definitions (Example of Perfect Segmentation)

Assume $I_g = \{T_1, T_2, \ldots T_M\}$ is the ground truth image, where T_i is the i-th object in I_g.

Assume $I_s = \{S_1, S_2, \ldots S_N\}$ is the segmented image, where S_j is the j-th segment in I_s.

Precision, P_{ij} and Recall, R_{ij} for the ij-th fragment, G_{ij} can be calculated as follows.

For $1 \le i \le M$ and $1 \le j \le N$

$$G_{ij} = T_i \cap S_j$$

$$R_{ij} = \frac{|G_{ij}|}{|T_i|} = \frac{|T_i \cap S_j|}{|T_i|}$$

$$P_{ij} = \frac{|G_{ij}|}{|S_j|} = \frac{|T_i \cap S_j|}{|S_j|}$$

CT Data\Ground Truth

Segmented Image

Precision vs. Recall

R	S1	S2	S3
T1	1	0	0
T2	0	1	0
T3	0	0	1

P	S1	S2	S3
T1	1	0	0
T2	0	1	0
T3	0	0	1

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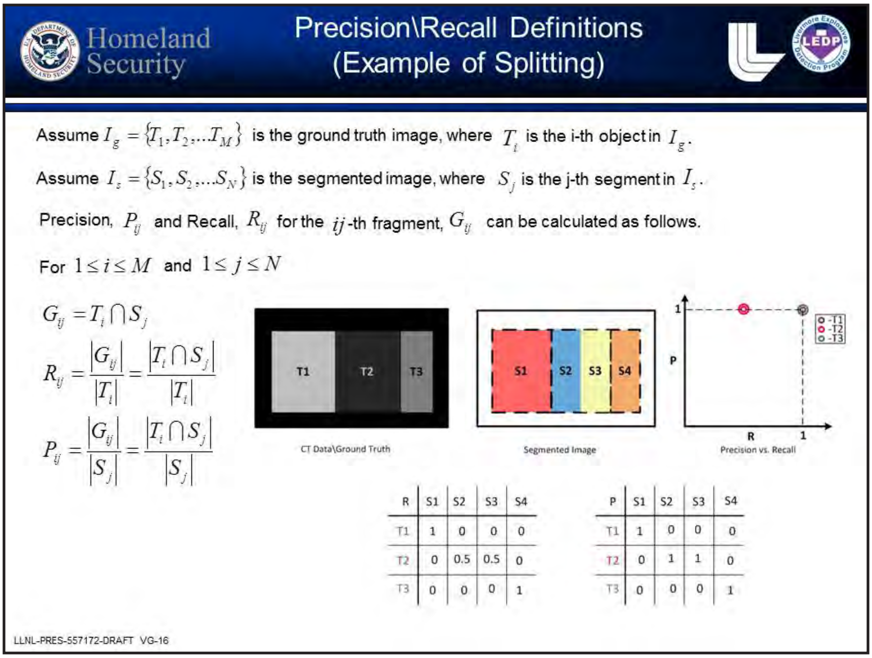

Precision\Recall Definitions (Example of Splitting)

Assume $I_g = \{T_1, T_2, \ldots T_M\}$ is the ground truth image, where T_i is the i-th object in I_g.

Assume $I_s = \{S_1, S_2, \ldots S_N\}$ is the segmented image, where S_j is the j-th segment in I_s.

Precision, P_{ij} and Recall, R_{ij} for the ij-th fragment, G_{ij} can be calculated as follows.

For $1 \le i \le M$ and $1 \le j \le N$

$$G_{ij} = T_i \cap S_j$$

$$R_{ij} = \frac{|G_{ij}|}{|T_i|} = \frac{|T_i \cap S_j|}{|T_i|}$$

$$P_{ij} = \frac{|G_{ij}|}{|S_j|} = \frac{|T_i \cap S_j|}{|S_j|}$$

CT Data\Ground Truth

Segmented Image

Precision vs. Recall

R	S1	S2	S3	S4
T1	1	0	0	0
T2	0	0.5	0.5	0
T3	0	0	0	1

P	S1	S2	S3	S4
T1	1	0	0	0
T2	0	1	1	0
T3	0	0	0	1

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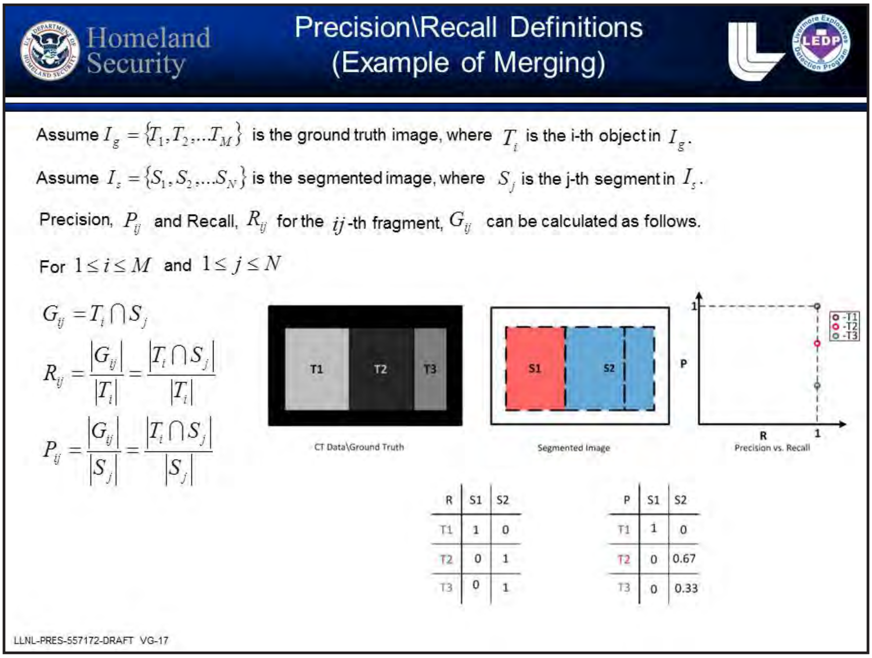

Precision\Recall Definitions (Example of Merging)

Assume $I_g = \{T_1, T_2, \ldots T_M\}$ is the ground truth image, where T_i is the i-th object in I_g.

Assume $I_s = \{S_1, S_2, \ldots S_N\}$ is the segmented image, where S_j is the j-th segment in I_s.

Precision, P_{ij} and Recall, R_{ij} for the ij-th fragment, G_{ij} can be calculated as follows.

For $1 \le i \le M$ and $1 \le j \le N$

$$G_{ij} = T_i \cap S_j$$

$$R_{ij} = \frac{|G_{ij}|}{|T_i|} = \frac{|T_i \cap S_j|}{|T_i|}$$

$$P_{ij} = \frac{|G_{ij}|}{|S_j|} = \frac{|T_i \cap S_j|}{|S_j|}$$

CT Data\Ground Truth

Segmented Image

Precision vs. Recall

R	S1	S2
T1	1	0
T2	0	1
T3	0	1

P	S1	S2
T1	1	0
T2	0	0.67
T3	0	0.33

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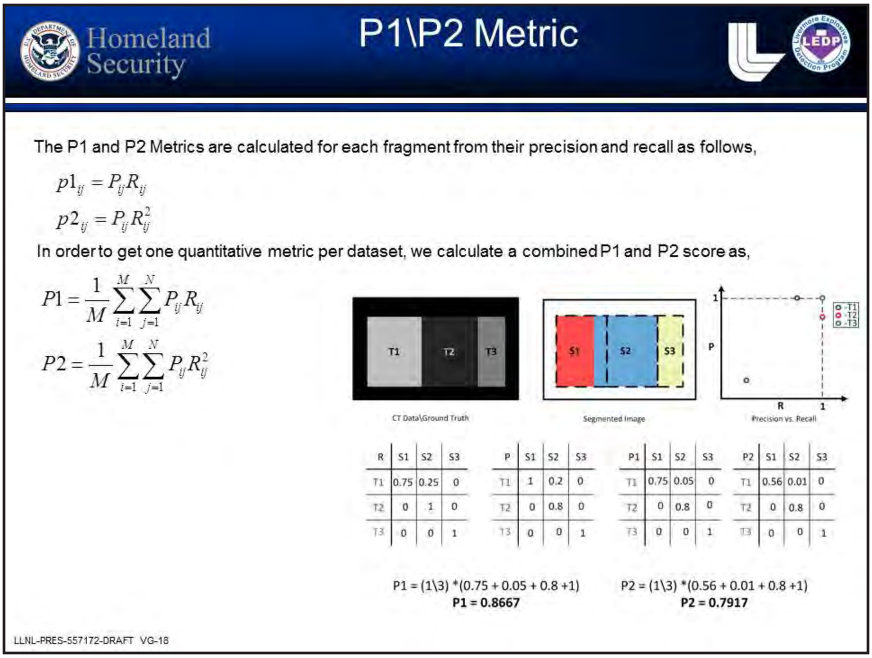

P1\P2 Metric

The P1 and P2 Metrics are calculated for each fragment from their precision and recall as follows,

$$p1_{ij} = P_{ij} R_{ij}$$

$$p2_{ij} = P_{ij} R_{ij}^2$$

In order to get one quantitative metric per dataset, we calculate a combined P1 and P2 score as,

$$P1 = \frac{1}{M} \sum_{i=1}^{M} \sum_{j=1}^{N} P_{ij} R_{ij}$$

$$P2 = \frac{1}{M} \sum_{i=1}^{M} \sum_{j=1}^{N} P_{ij} R_{ij}^2$$

CT Data\Ground Truth

Segmented Image

Precision vs. Recall

R	S1	S2	S3
T1	0.75	0.25	0
T2	0	1	0
T3	0	0	1

P	S1	S2	S3
T1	1	0.2	0
T2	0	0.8	0
T3	0	0	1

P1	S1	S2	S3
T1	0.75	0.05	0
T2	0	0.8	0
T3	0	0	1

P2	S1	S2	S3
T1	0.56	0.01	0
T2	0	0.8	0
T3	0	0	1

P1 = (1\3) *(0.75 + 0.05 + 0.8 +1)
P1 = 0.8667

P2 = (1\3) *(0.56 + 0.01 + 0.8 +1)
P2 = 0.7917

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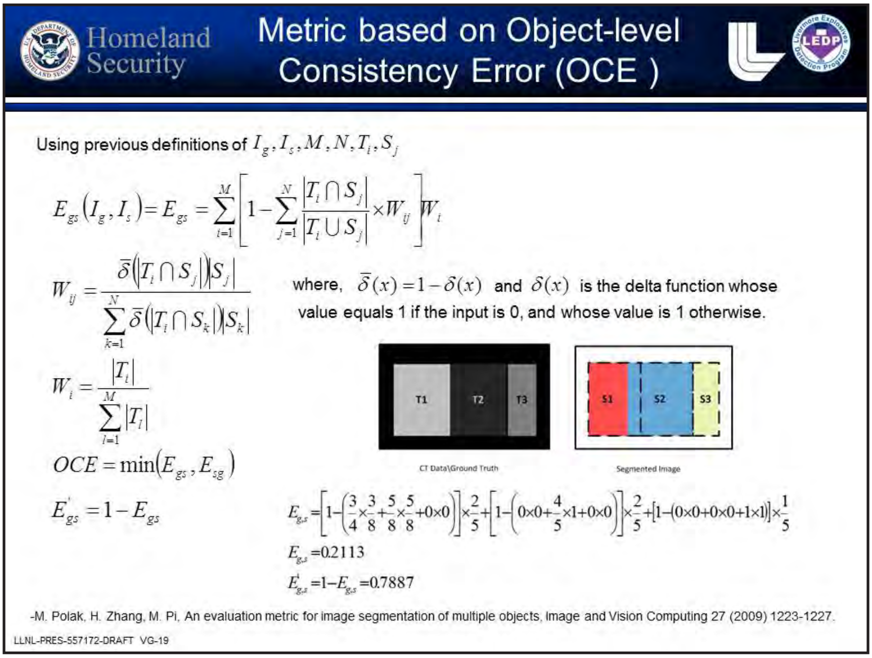

Metric based on Object-level Consistency Error (OCE)

Using previous definitions of I_g, I_s, M, N, T_i, S_j

$$E_{gs}(I_g, I_s) = E_{gs} = \sum_{i=1}^{M}\left[1 - \sum_{j=1}^{N}\frac{|T_i \cap S_j|}{|T_i \cup S_j|} \times W_{ij}\right] W_i$$

$$W_{ij} = \frac{\bar{\delta}(|T_i \cap S_j|)|S_j|}{\sum_{k=1}^{N}\bar{\delta}(|T_i \cap S_k|)|S_k|}$$

where, $\bar{\delta}(x) = 1 - \delta(x)$ and $\delta(x)$ is the delta function whose value equals 1 if the input is 0, and whose value is 1 otherwise.

$$W_i = \frac{|T_i|}{\sum_{l=1}^{M}|T_l|}$$

$$OCE = \min(E_{gs}, E_{sg})$$

$$E'_{gs} = 1 - E_{gs}$$

CT Data\Ground Truth

Segmented Image

$$E_{g,s} = \left[1 - \left(\frac{3}{4}\times\frac{3}{8} + \frac{5}{8}\times\frac{5}{8} + 0\times0\right)\right]\times\frac{2}{5} + \left[1 - \left(0\times0 + \frac{4}{5}\times1 + 0\times0\right)\right]\times\frac{2}{5} + [1 - (0\times0 + 0\times0 + 1\times1)]\times\frac{1}{5}$$

$$E_{g,s} = 0.2113$$

$$E'_{g,s} = 1 - E_{g,s} = 0.7887$$

-M. Polak, H. Zhang, M. Pi, An evaluation metric for image segmentation of multiple objects, Image and Vision Computing 27 (2009) 1223-1227.

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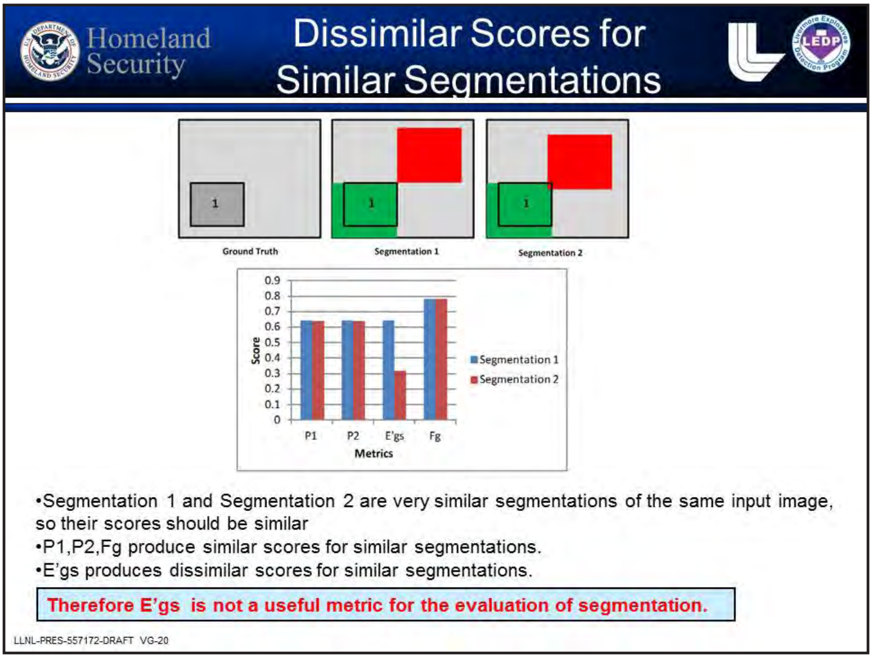

Dissimilar Scores for Similar Segmentations

Ground Truth

Segmentation 1

Segmentation 2

- Segmentation 1 and Segmentation 2 are very similar segmentations of the same input image, so their scores should be similar
- P1,P2,Fg produce similar scores for similar segmentations.
- E'gs produces dissimilar scores for similar segmentations.

Therefore E'gs is not a useful metric for the evaluation of segmentation.

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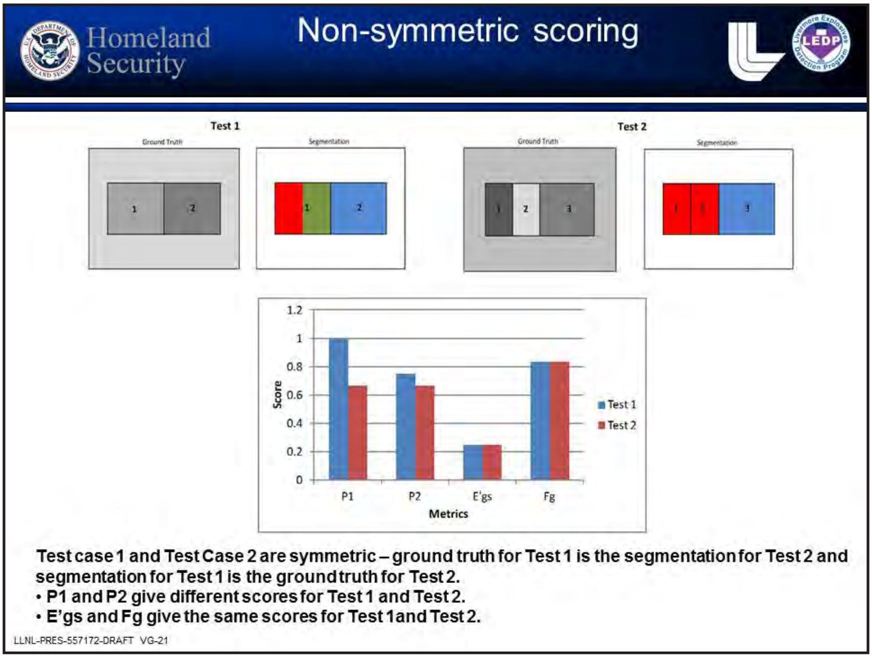

Non-symmetric scoring

Test case 1 and Test Case 2 are symmetric – ground truth for Test 1 is the segmentation for Test 2 and segmentation for Test 1 is the ground truth for Test 2.

- P1 and P2 give different scores for Test 1 and Test 2.
- E'gs and Fg give the same scores for Test 1 and Test 2.

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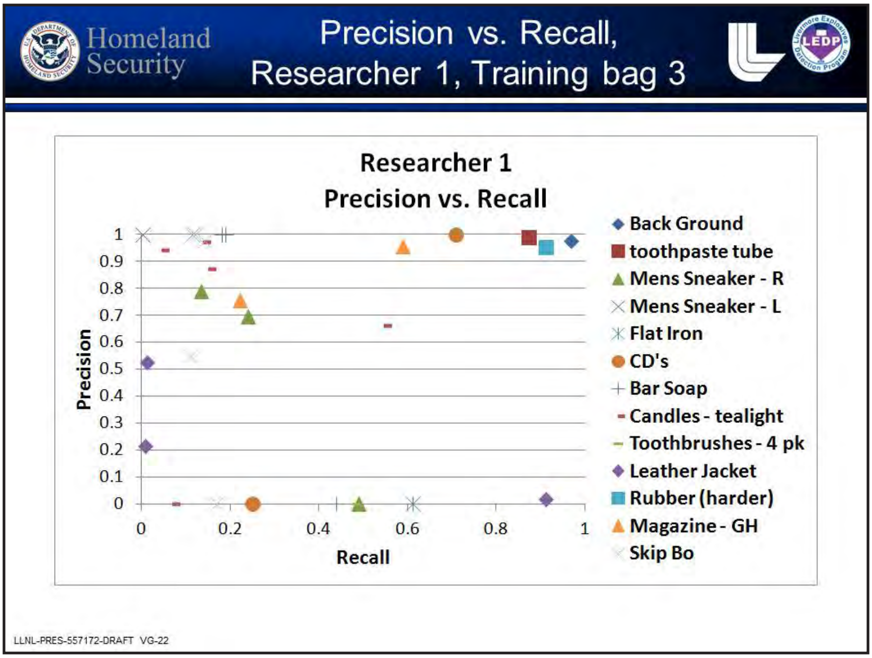

Precision vs. Recall, Researcher 1, Training bag 3

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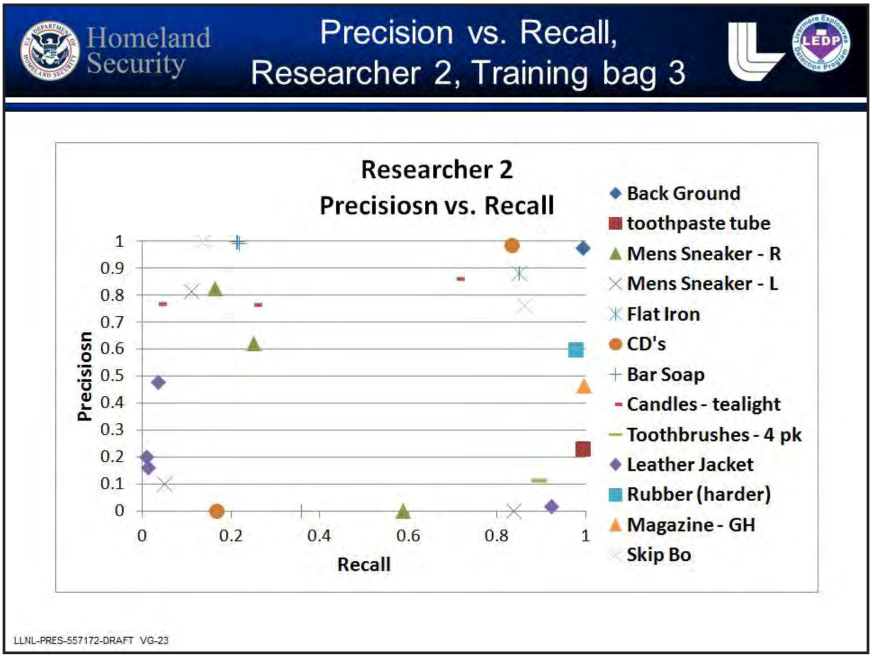

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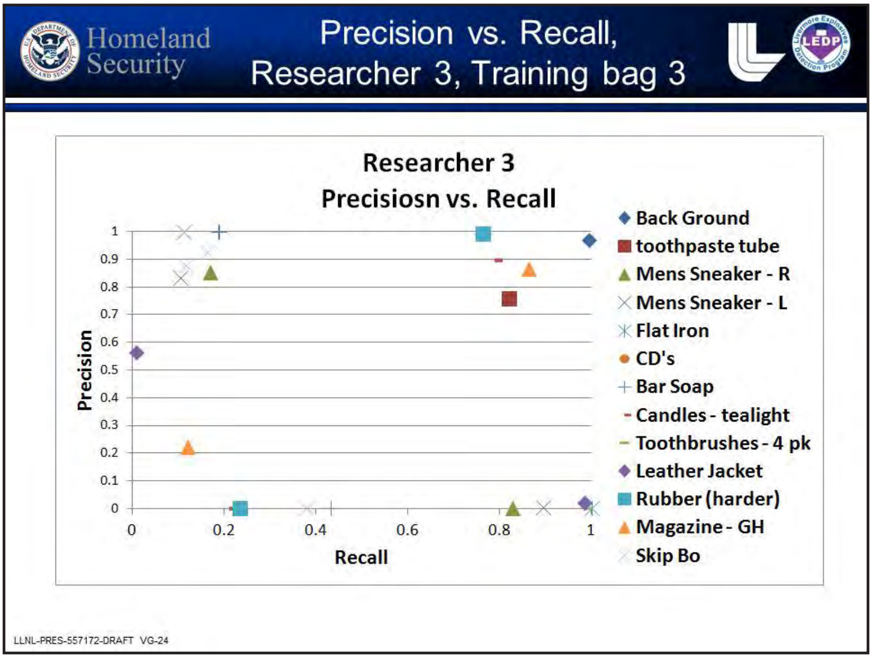
Precision vs. Recall,
Researcher 2, Training bag 3

LLNL-PRES-557172-DRAFT VG-23



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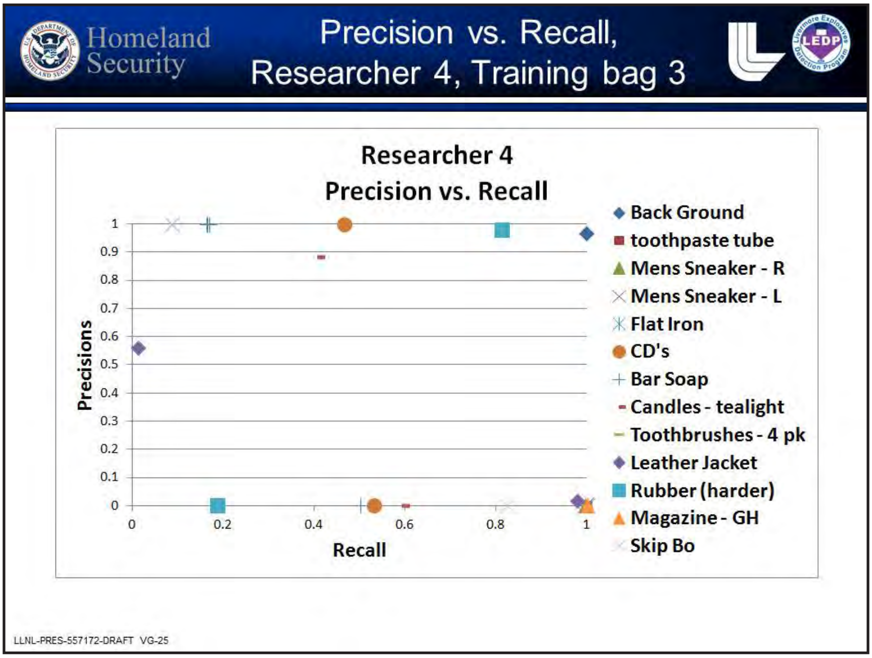
Precision vs. Recall,
Researcher 3, Training bag 3

LLNL-PRES-557172-DRAFT VG-24



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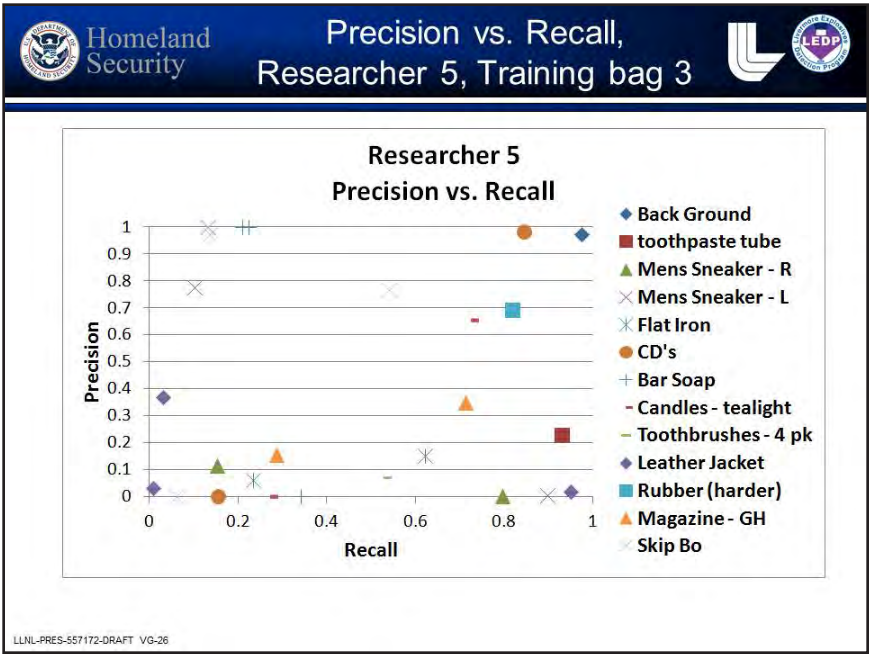
Precision vs. Recall, Researcher 4, Training bag 3

LLNL-PRES-557172-DRAFT VG-25



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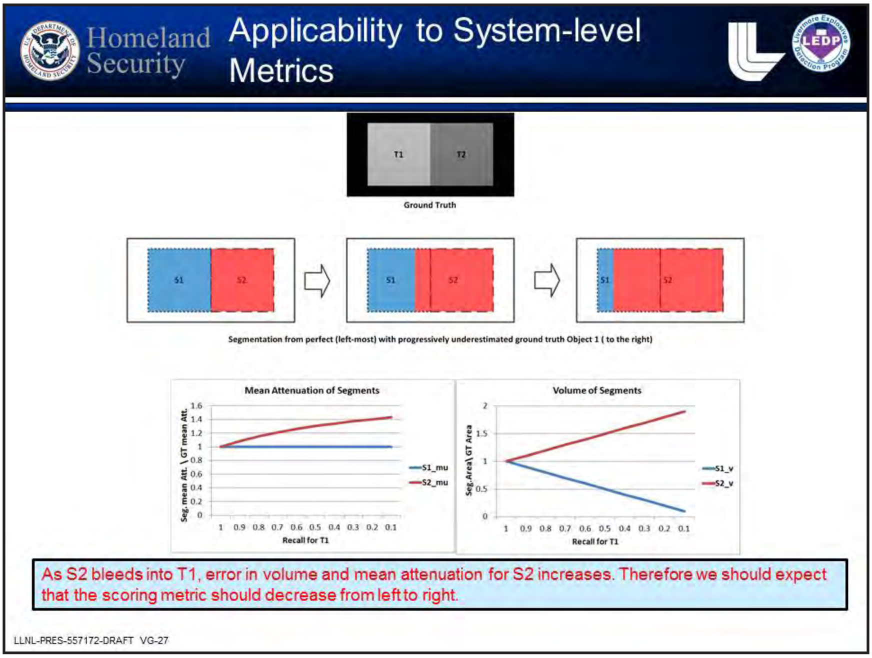
Precision vs. Recall, Researcher 5, Training bag 3

LLNL-PRES-557172-DRAFT VG-26



Applicability to System-level Metrics

Ground Truth

Segmentation from perfect (left-most) with progressively underestimated ground truth Object 1 (to the right)

As S2 bleeds into T1, error in volume and mean attenuation for S2 increases. Therefore we should expect that the scoring metric should decrease from left to right.

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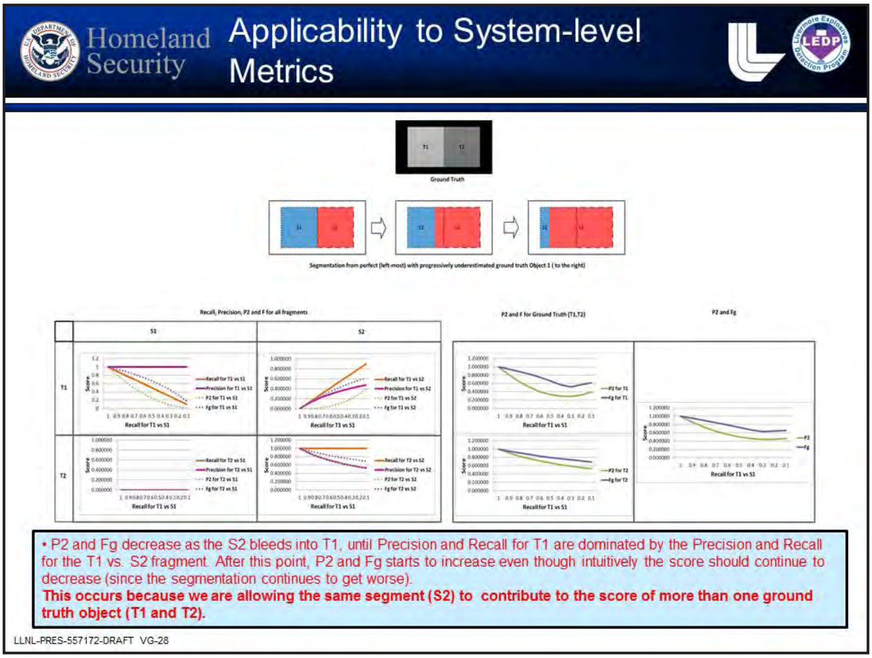

Applicability to System-level Metrics

Ground Truth

Segmentation from perfect (left-most) with progressively underestimated ground truth Object 1 (to the right)

- P2 and Fg decrease as the S2 bleeds into T1, until Precision and Recall for T1 are dominated by the Precision and Recall for the T1 vs. S2 fragment. After this point, P2 and Fg starts to increase even though intuitively the score should continue to decrease (since the segmentation continues to get worse).

This occurs because we are allowing the same segment (S2) to contribute to the score of more than one ground truth object (T1 and T2).

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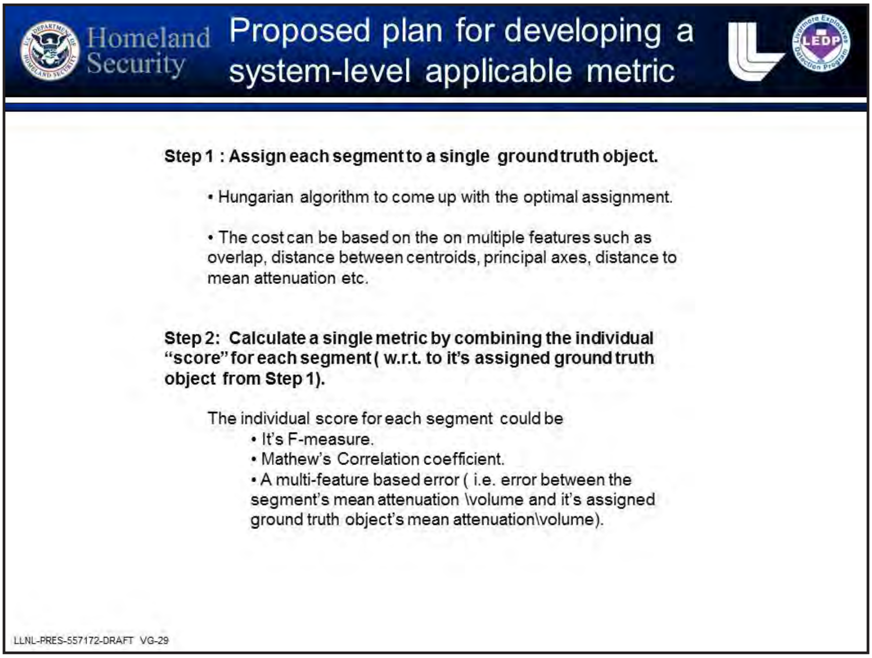

Proposed plan for developing a system-level applicable metric

Step 1 : Assign each segment to a single ground truth object.

- Hungarian algorithm to come up with the optimal assignment.
- The cost can be based on the on multiple features such as overlap, distance between centroids, principal axes, distance to mean attenuation etc.

Step 2: Calculate a single metric by combining the individual "score" for each segment (w.r.t. to it's assigned ground truth object from Step 1).

The individual score for each segment could be

- It's F-measure.
- Mathew's Correlation coefficient.
- A multi-feature based error (i.e. error between the segment's mean attenuation \volume and it's assigned ground truth object's mean attenuation\volume).

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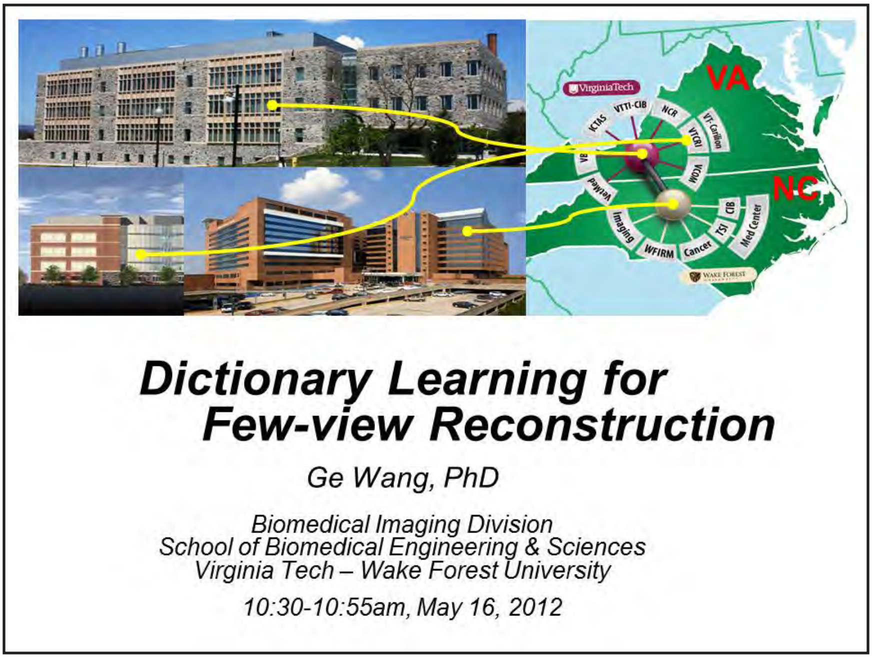
16.23 Ge Wang: Dictionary Learning for Few-view Reconstruction

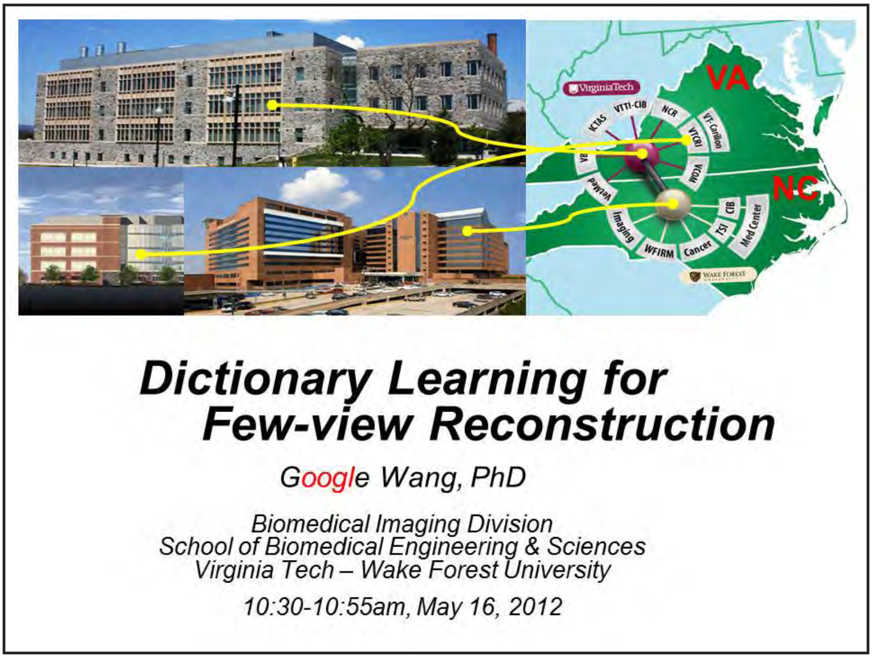


Dictionary Learning for
Few-view Reconstruction

Ge Wang, PhD

Biomedical Imaging Division
School of Biomedical Engineering & Sciences
Virginia Tech – Wake Forest University

10:30-10:55am, May 16, 2012

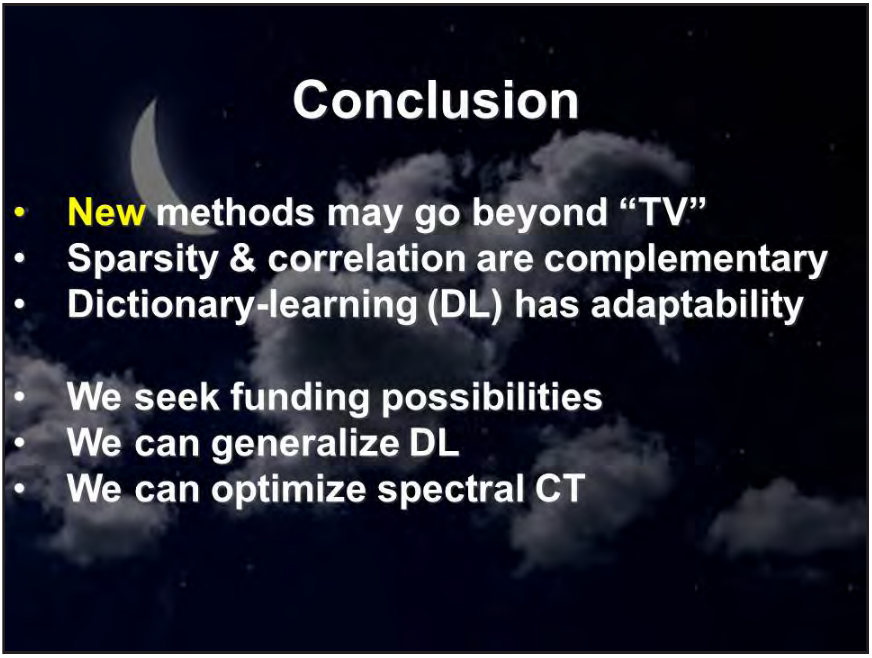


Dictionary Learning for
Few-view Reconstruction

Google Wang, PhD

Biomedical Imaging Division
School of Biomedical Engineering & Sciences
Virginia Tech – Wake Forest University

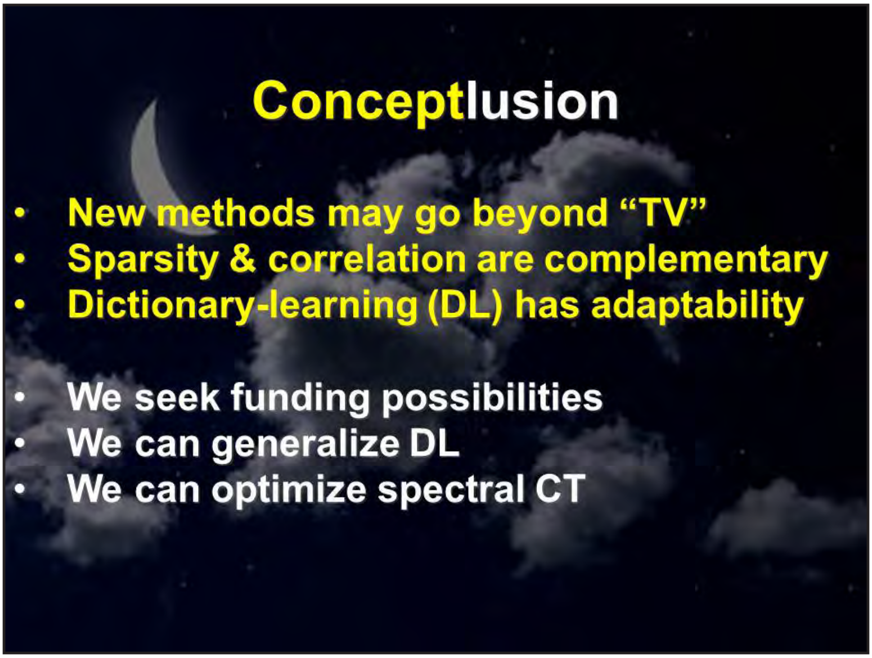
10:30-10:55am, May 16, 2012



Conclusion

- New methods may go beyond "TV"
- Sparsity & correlation are complementary
- Dictionary-learning (DL) has adaptability

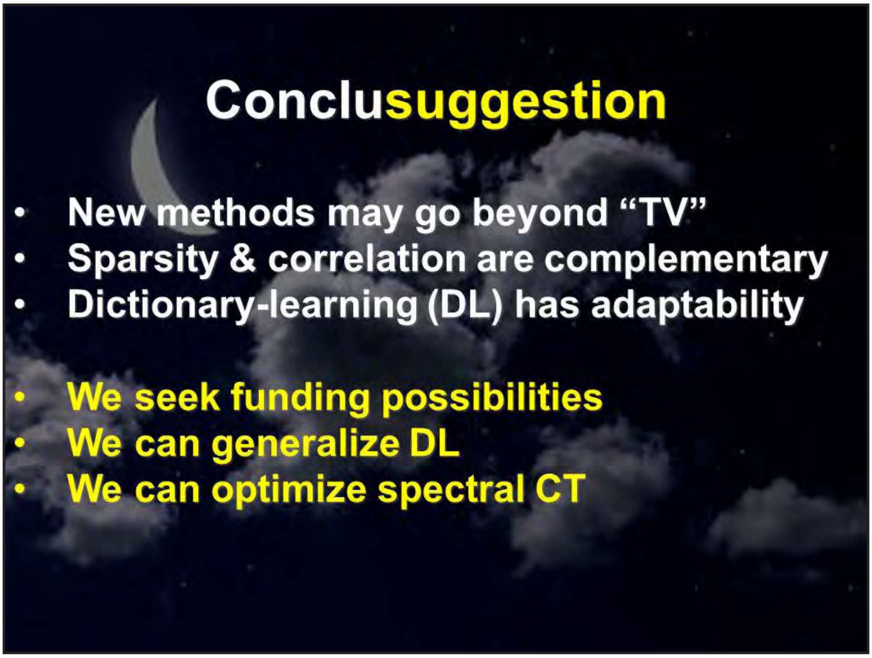
- We seek funding possibilities
- We can generalize DL
- We can optimize spectral CT



Conceptlusion

- New methods may go beyond "TV"
- Sparsity & correlation are complementary
- Dictionary-learning (DL) has adaptability

- We seek funding possibilities
- We can generalize DL
- We can optimize spectral CT



Conclusuggestion

- New methods may go beyond “TV”
- Sparsity & correlation are complementary
- Dictionary-learning (DL) has adaptability

- We seek funding possibilities
- We can generalize DL
- We can optimize spectral CT

CS=?

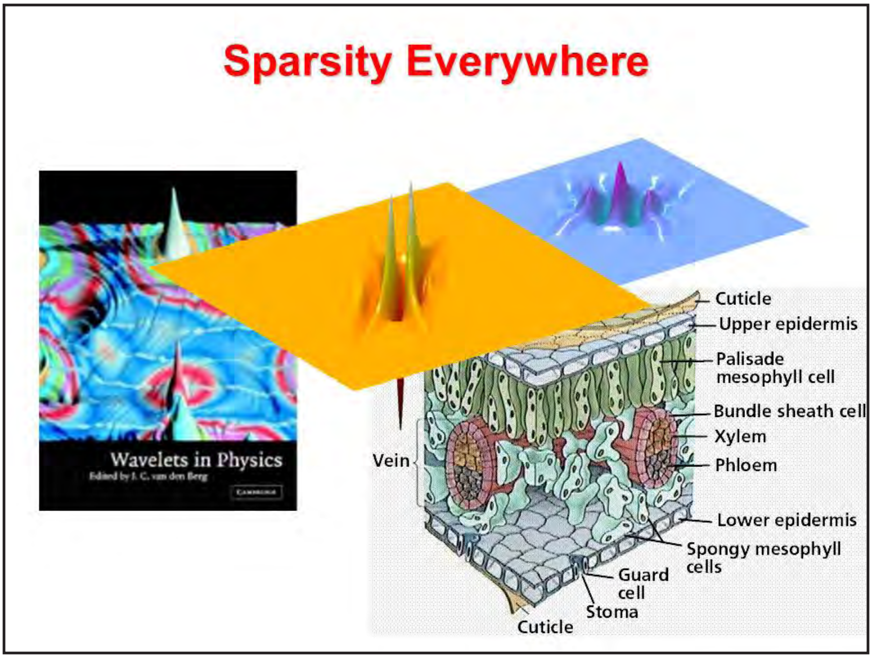
Compressive
Sensing

Compression + Inversion

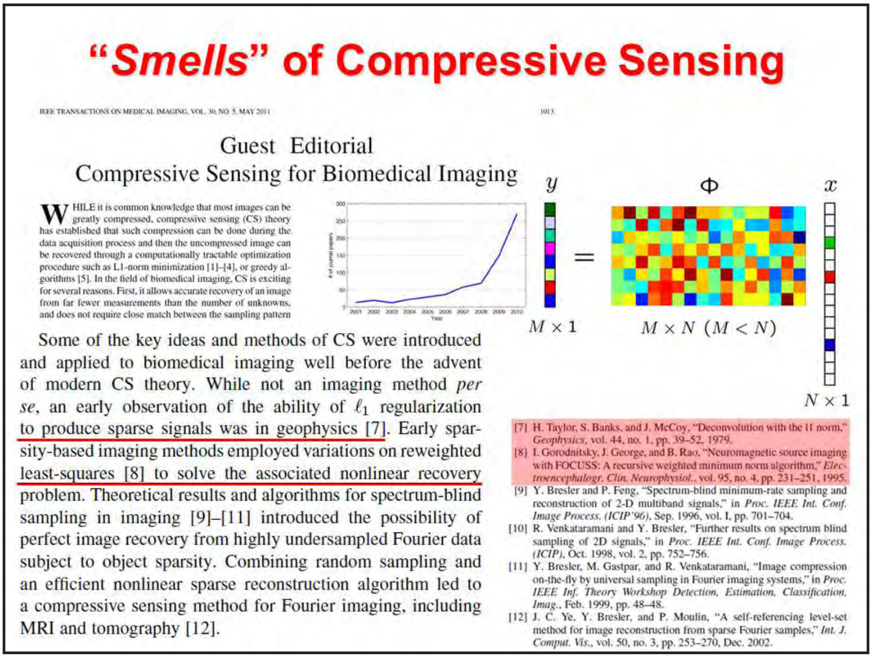
Correlation
Sparsity

Correlation

Sparsity



Sparsity Everywhere



"*Smells*" of Compressive Sensing

IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 30, NO. 5, MAY 2011 1013

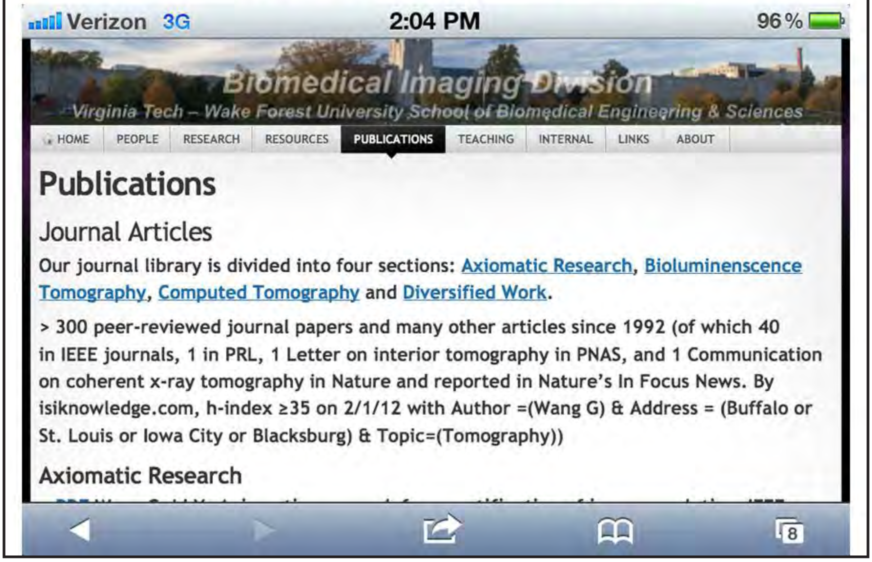
Guest Editorial
Compressive Sensing for Biomedical Imaging

WHILE it is common knowledge that most images can be greatly compressed, compressive sensing (CS) theory has established that such compression can be done during the data acquisition process and then the uncompressed image can be recovered through a computationally tractable optimization procedure such as L1-norm minimization [1]–[4], or greedy algorithms [5]. In the field of biomedical imaging, CS is exciting for several reasons. First, it allows accurate recovery of an image from far fewer measurements than the number of unknowns, and does not require close match between the sampling pattern

Some of the key ideas and methods of CS were introduced and applied to biomedical imaging well before the advent of modern CS theory. While not an imaging method *per se*, an early observation of the ability of ℓ_1 regularization to produce sparse signals was in geophysics [7]. Early sparsity-based imaging methods employed variations on reweighted least-squares [8] to solve the associated nonlinear recovery problem. Theoretical results and algorithms for spectrum-blind sampling in imaging [9]–[11] introduced the possibility of perfect image recovery from highly undersampled Fourier data subject to object sparsity. Combining random sampling and an efficient nonlinear sparse reconstruction algorithm led to a compressive sensing method for Fourier imaging, including MRI and tomography [12].

[7] H. Taylor, S. Banks, and J. McCoy, "Deconvolution with the l1 norm," *Geophysics*, vol. 44, no. 1, pp. 39–52, 1979.
[8] I. Gorodnitsky, J. George, and B. Rao, "Neuromagnetic source imaging with FOCUSS: A recursive weighted minimum norm algorithm," *Electroencephalogr. Clin. Neurophysiol.*, vol. 95, no. 4, pp. 231–251, 1995.
[9] Y. Bresler and P. Feng, "Spectrum-blind minimum-rate sampling and reconstruction of 2-D multiband signals," in *Proc. IEEE Int. Conf. Image Process. (ICIP'96)*, Sep. 1996, vol. I, pp. 701–704.
[10] R. Venkataramani and Y. Bresler, "Further results on spectrum blind sampling of 2D signals," in *Proc. IEEE Int. Conf. Image Process. (ICIP)*, Oct. 1998, vol. 2, pp. 752–756.
[11] Y. Bresler, M. Gastpar, and R. Venkataramani, "Image compression on-the-fly by universal sampling in Fourier imaging systems," in *Proc. IEEE Inf. Theory Workshop Detection, Estimation, Classification, Imag.*, Feb. 1999, pp. 48–48.
[12] J. C. Ye, Y. Bresler, and P. Moulin, "A self-referencing level-set method for image reconstruction from sparse Fourier samples," *Int. J. Comput. Vis.*, vol. 50, no. 3, pp. 253–270, Dec. 2002.

Publications in A, B, C, & D



Publications

Journal Articles

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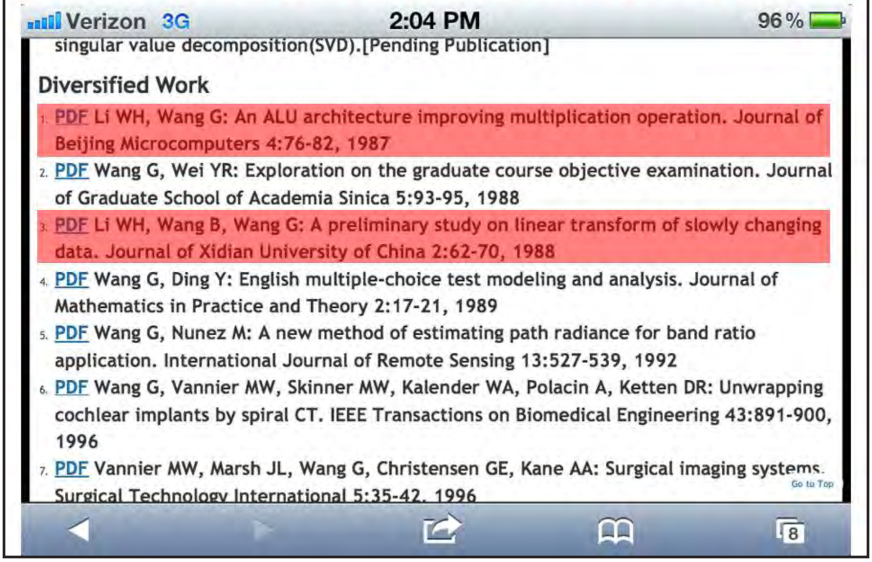
> 300 peer-reviewed journal papers and many other articles since 1992 (of which 40 in IEEE journals, 1 in PRL, 1 Letter on interior tomography in PNAS, and 1 Communication on coherent x-ray tomography in Nature and reported in Nature's In Focus News. By isiknowledge.com, h-index ≥35 on 2/1/12 with Author =(Wang G) & Address = (Buffalo or St. Louis or Iowa City or Blacksburg) & Topic=(Tomography))

Axiomatic Research

Sparsity for Transform (1987)

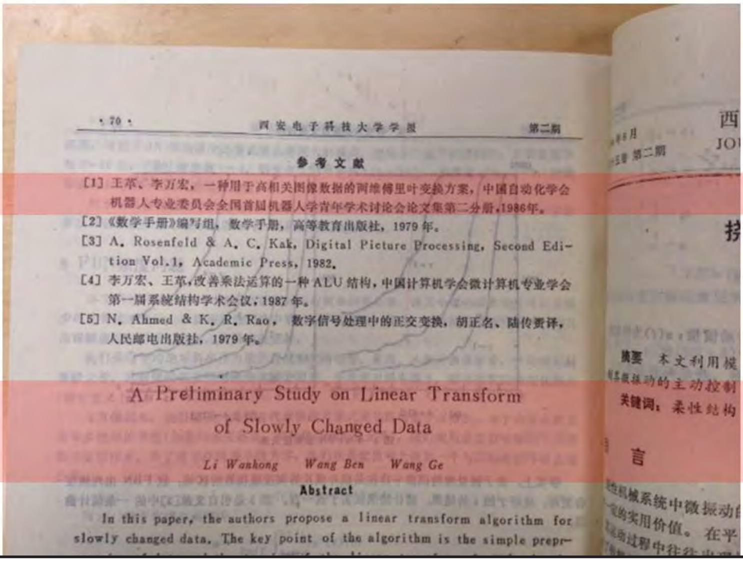


singular value decomposition(SVD).[Pending Publication]

Diversified Work

1. PDF Li WH, Wang G: An ALU architecture improving multiplication operation. Journal of Beijing Microcomputers 4:76-82, 1987
2. PDF Wang G, Wei YR: Exploration on the graduate course objective examination. Journal of Graduate School of Academia Sinica 5:93-95, 1988
3. PDF Li WH, Wang B, Wang G: A preliminary study on linear transform of slowly changing data. Journal of Xidian University of China 2:62-70, 1988
4. PDF Wang G, Ding Y: English multiple-choice test modeling and analysis. Journal of Mathematics in Practice and Theory 2:17-21, 1989
5. PDF Wang G, Nunez M: A new method of estimating path radiance for band ratio application. International Journal of Remote Sensing 13:527-539, 1992
6. PDF Wang G, Vannier MW, Skinner MW, Kalender WA, Polacin A, Ketten DR: Unwrapping cochlear implants by spiral CT. IEEE Transactions on Biomedical Engineering 43:891-900, 1996
7. PDF Vannier MW, Marsh JL, Wang G, Christensen GE, Kane AA: Surgical imaging systems. Surgical Technology International 5:35-42, 1996

Linear Transform of Slow Data



· 70 ·　西安电子科技大学学报　第二期

参考文献

[1] 王苯、李万宏，一种用于高相关图像数据的两维傅里叶变换方案，中国自动化学会机器人专业委员会全国首届机器人学青年学术讨论会论文集第二分册，1986年。

[2] 《数学手册》编写组，数学手册，高等教育出版社，1979 年。

[3] A. Rosenfeld & A. C. Kak, Digital Picture Processing, Second Edition Vol.1, Academic Press, 1982.

[4] 李万宏、王苯，改善乘法运算的一种 ALU 结构，中国计算机学会微计算机专业学会第一届系统结构学术会议，1987 年。

[5] N. Ahmed & K. R. Rao, 数学信号处理中的正交变换，胡正名、陆传赉译，人民邮电出版社，1979 年。

A Preliminary Study on Linear Transform
of Slowly Changed Data

Li Wanhong　Wang Ben　Wang Ge

Abstract

In this paper, the authors propose a linear transform algorithm for slowly changed data. The key point of the algorithm is the simple prepr-

摘要　本文利用模

关键词：柔性结构

言

Absolute Difference for Sparsity (1988)

· 64 ·　西安电子科技大学学报　第二期

为 D 矩阵。D 中的每一个元素 $d(i,j)$ 满足

$$d(i,j)=\begin{cases}1 & i=j \quad j=1,2,\cdots N\\ -1 & i=j+1 \quad j=1,2,\cdots N-1\\ 0 & \text{其它}\end{cases}$$

2.5. 定理（D的逆阵）

D 矩阵是满秩的，其逆阵 D^{-1} 为一主对角线及其以下所有元素值均为 1 的下三角形矩阵。即：

$$D^{-1}=\begin{pmatrix}1 & 0 & 0 & \cdots\cdots & 0\\ 1 & 1 & 0 & \cdots\cdots & 0\\ 1 & 1 & 1 & \cdots\cdots & 0\\ \vdots & \vdots & \vdots & \ddots & \vdots\\ 1 & 1 & 1 & \cdots\cdots & 1\end{pmatrix}$$

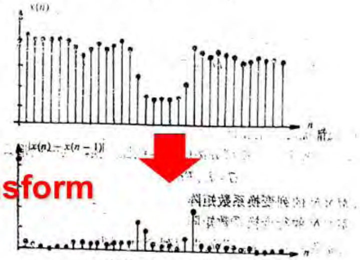
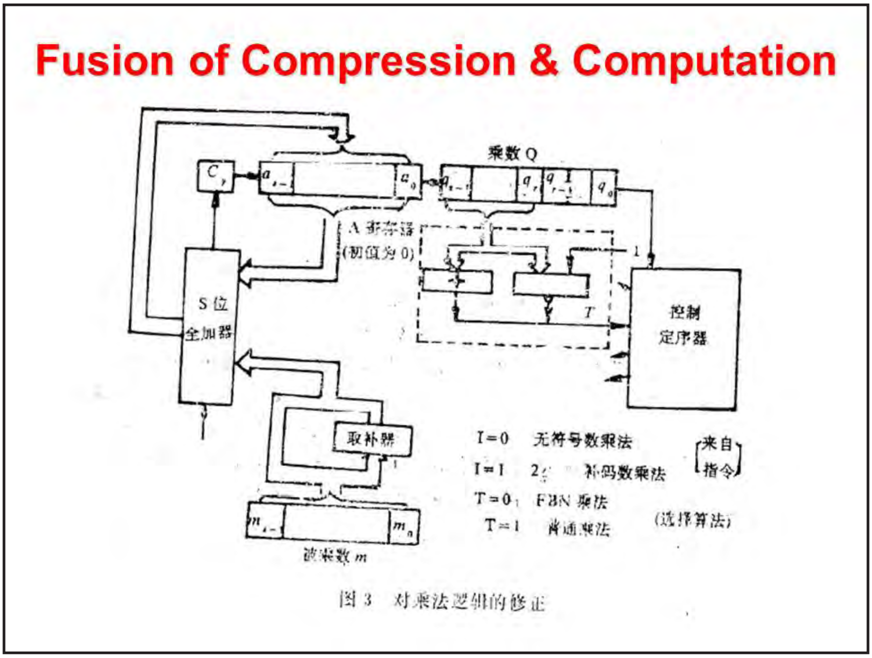


图 1　慢变过程的一次采样

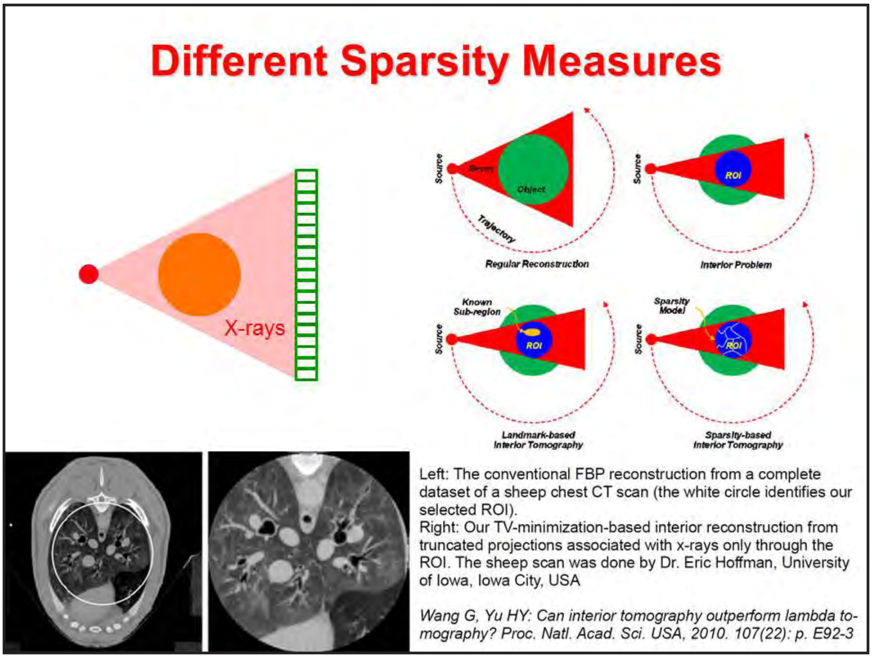
Total Variation Transform

$$E\left\{\frac{\frac{1}{N}\sum_{i=1}^{N}|Y(i)-Y(i-1)|}{\frac{1}{N+1}\sum_{i=0}^{N}|Y(i)|}\right\}<<1$$



Fusion of Compression & Computation

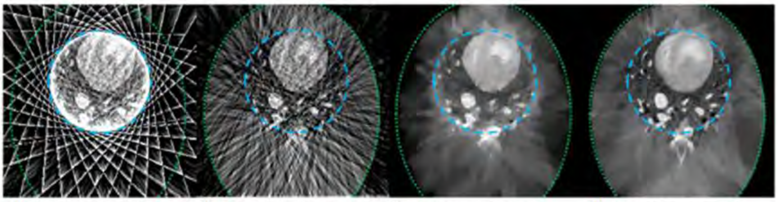
图 3　对乘法逻辑的修正



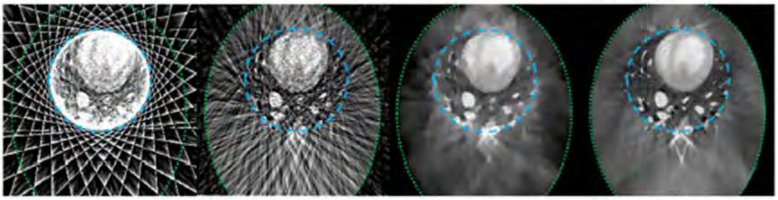
Different Sparsity Measures

Left: The conventional FBP reconstruction from a complete dataset of a sheep chest CT scan (the white circle identifies our selected ROI).
Right: Our TV-minimization-based interior reconstruction from truncated projections associated with x-rays only through the ROI. The sheep scan was done by Dr. Eric Hoffman, University of Iowa, Iowa City, USA

Wang G, Yu HY: Can interior tomography outperform lambda tomography? Proc. Natl. Acad. Sci. USA, 2010. 107(22): p. E92-3



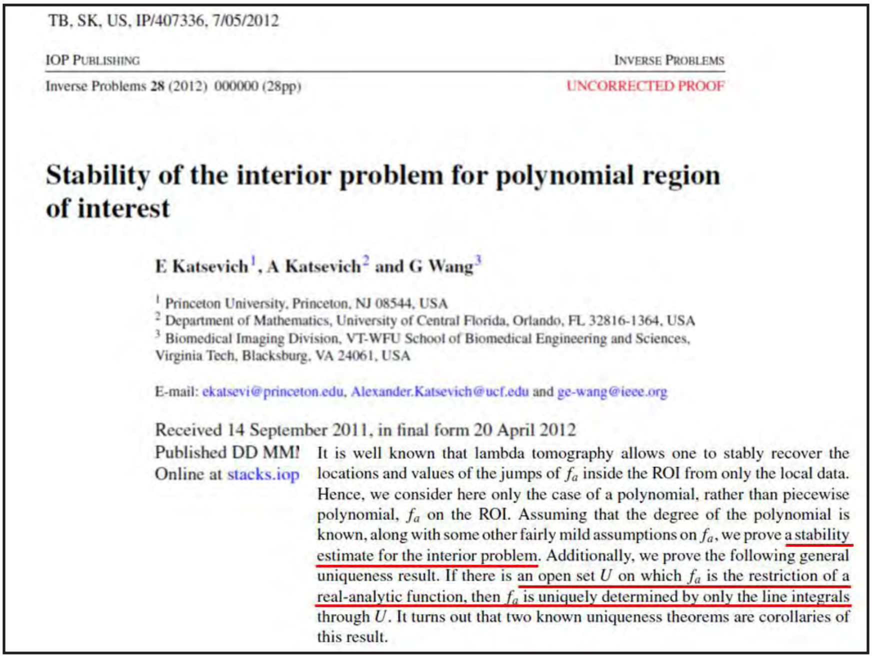
(a) FDK time frame 8 (b) E-FDK time frame 8 (c) TVCS time frame 8 (d) PICCS time frame 8



(e) FDK time frame 17 (f) E-FDK time frame 17 (g) TVCS time frame 17 (h) PICCS time frame 17

Figure 6. Axial slice through the reconstructions from truncated projection dataset simulating a (15×15) cm^2 detector size for the four reconstruction algorithms studied. Time frame 8 is at the end of the systole and time frame 17 is at the end of the diastole. The long-dashed line encircles region F and the short-dashed line encircles region S.

Lauzier PT, Tang J, Chen GH: Time-resolved cardiac interventional cone-beam CT reconstruction from fully truncated projections using the prior image constrained compressed sensing (PICCS) algorithm. Phys. Med. Biol. 57:2461–2476, 2012



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IOP PUBLISHING INVERSE PROBLEMS

Inverse Problems **28** (2012) 000000 (28pp) UNCORRECTED PROOF

Stability of the interior problem for polynomial region of interest

E Katsevich[1], **A Katsevich**[2] **and G Wang**[3]

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[3] Biomedical Imaging Division, VT-WFU School of Biomedical Engineering and Sciences, Virginia Tech, Blacksburg, VA 24061, USA

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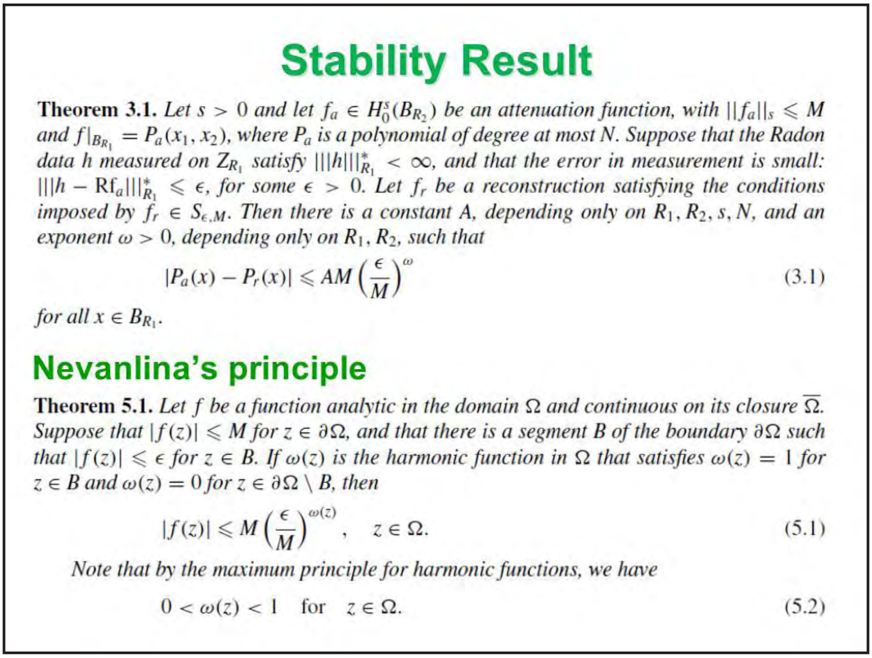
It is well known that lambda tomography allows one to stably recover the locations and values of the jumps of f_a inside the ROI from only the local data. Hence, we consider here only the case of a polynomial, rather than piecewise polynomial, f_a on the ROI. Assuming that the degree of the polynomial is known, along with some other fairly mild assumptions on f_a, we prove a stability estimate for the interior problem. Additionally, we prove the following general uniqueness result. If there is an open set U on which f_a is the restriction of a real-analytic function, then f_a is uniquely determined by only the line integrals through U. It turns out that two known uniqueness theorems are corollaries of this result.



Stability Result

Theorem 3.1. *Let $s > 0$ and let $f_a \in H_0^s(B_{R_2})$ be an attenuation function, with $||f_a||_s \leqslant M$ and $f|_{B_{R_1}} = P_a(x_1, x_2)$, where P_a is a polynomial of degree at most N. Suppose that the Radon data h measured on Z_{R_1} satisfy $|||h|||^*_{R_1} < \infty$, and that the error in measurement is small: $|||h - \mathrm{Rf}_a|||^*_{R_1} \leqslant \epsilon$, for some $\epsilon > 0$. Let f_r be a reconstruction satisfying the conditions imposed by $f_r \in S_{\epsilon,M}$. Then there is a constant A, depending only on R_1, R_2, s, N, and an exponent $\omega > 0$, depending only on R_1, R_2, such that*

$$|P_a(x) - P_r(x)| \leqslant AM \left(\frac{\epsilon}{M}\right)^{\omega} \qquad (3.1)$$

for all $x \in B_{R_1}$.

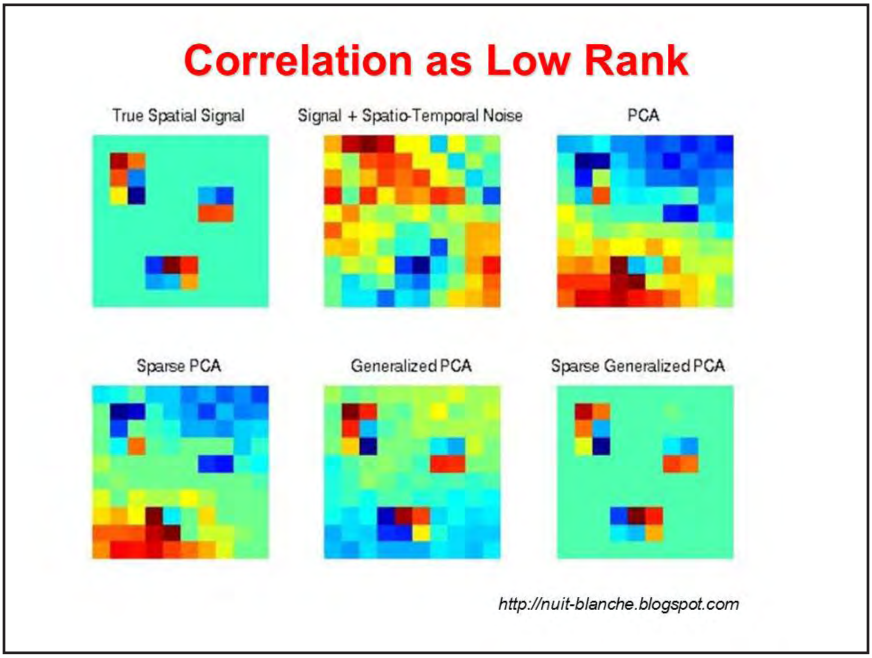
Nevanlina's principle

Theorem 5.1. *Let f be a function analytic in the domain Ω and continuous on its closure $\overline{\Omega}$. Suppose that $|f(z)| \leqslant M$ for $z \in \partial\Omega$, and that there is a segment B of the boundary $\partial\Omega$ such that $|f(z)| \leqslant \epsilon$ for $z \in B$. If $\omega(z)$ is the harmonic function in Ω that satisfies $\omega(z) = 1$ for $z \in B$ and $\omega(z) = 0$ for $z \in \partial\Omega \setminus B$, then*

$$|f(z)| \leqslant M \left(\frac{\epsilon}{M}\right)^{\omega(z)}, \quad z \in \Omega. \qquad (5.1)$$

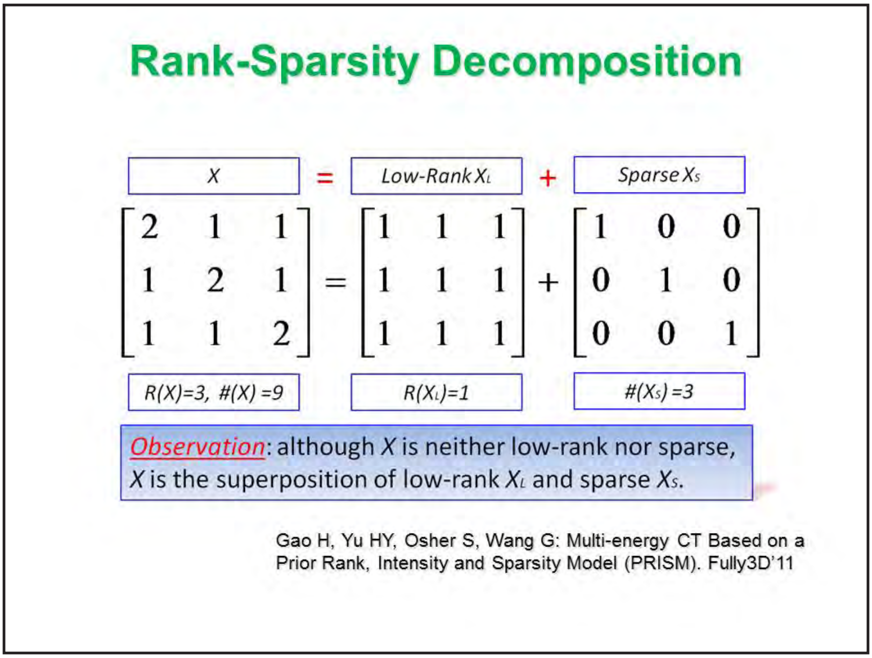
Note that by the maximum principle for harmonic functions, we have

$$0 < \omega(z) < 1 \quad \text{for} \quad z \in \Omega. \qquad (5.2)$$



Correlation as Low Rank

http://nuit-blanche.blogspot.com



Rank-Sparsity Decomposition

X = *Low-Rank* X_L + *Sparse* X_S

$$\begin{bmatrix} 2 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 2 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

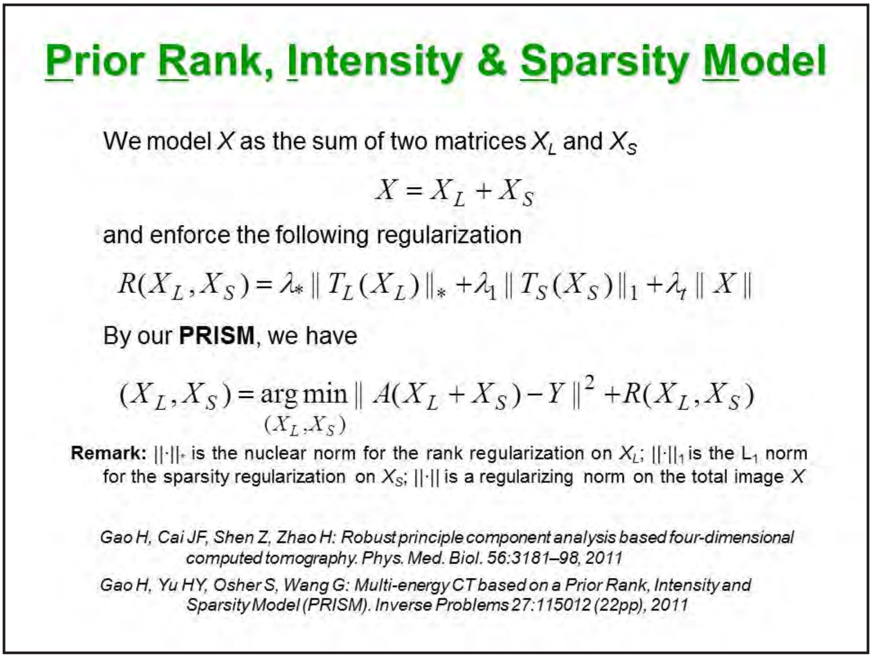
$R(X)=3,\ \#(X)=9$

$R(X_L)=1$

$\#(X_S)=3$

Observation: although *X* is neither low-rank nor sparse, *X* is the superposition of low-rank X_L and sparse X_S.

Gao H, Yu HY, Osher S, Wang G: Multi-energy CT Based on a Prior Rank, Intensity and Sparsity Model (PRISM). Fully3D'11



Prior Rank, Intensity & Sparsity Model

We model X as the sum of two matrices X_L and X_S

$$X = X_L + X_S$$

and enforce the following regularization

$$R(X_L, X_S) = \lambda_* \| T_L(X_L) \|_* + \lambda_1 \| T_S(X_S) \|_1 + \lambda_t \| X \|$$

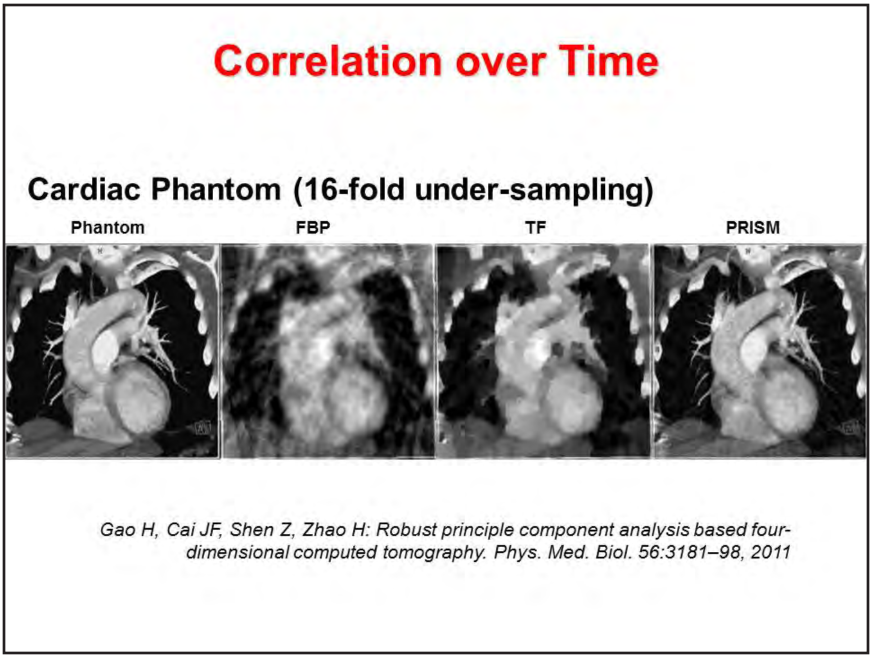
By our **PRISM**, we have

$$(X_L, X_S) = \underset{(X_L, X_S)}{\arg\min} \| A(X_L + X_S) - Y \|^2 + R(X_L, X_S)$$

Remark: $\|\cdot\|_*$ is the nuclear norm for the rank regularization on X_L; $\|\cdot\|_1$ is the L_1 norm for the sparsity regularization on X_S; $\|\cdot\|$ is a regularizing norm on the total image X

Gao H, Cai JF, Shen Z, Zhao H: Robust principle component analysis based four-dimensional computed tomography. Phys. Med. Biol. 56:3181–98, 2011

Gao H, Yu HY, Osher S, Wang G: Multi-energy CT based on a Prior Rank, Intensity and Sparsity Model (PRISM). Inverse Problems 27:115012 (22pp), 2011

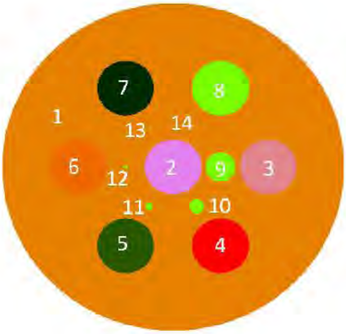


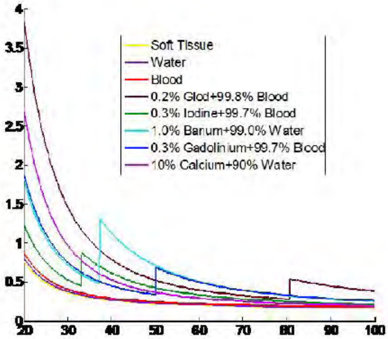
Correlation over Time

Cardiac Phantom (16-fold under-sampling)

Gao H, Cai JF, Shen Z, Zhao H: Robust principle component analysis based four-dimensional computed tomography. Phys. Med. Biol. 56:3181–98, 2011

Correlation among Spectrum

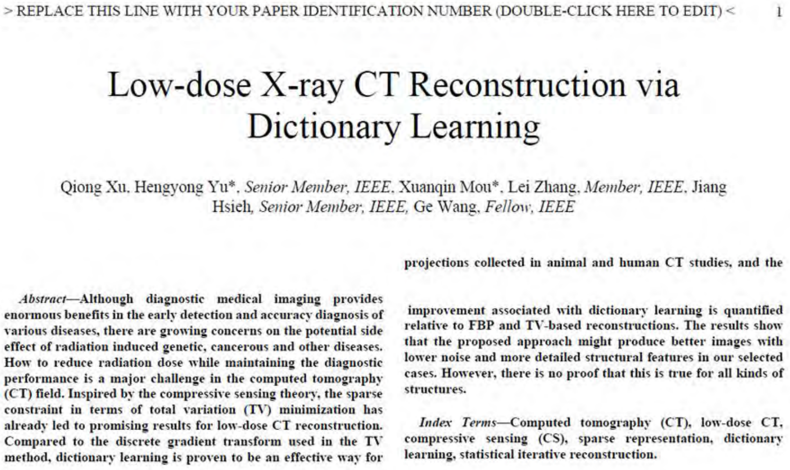




Gao H, Yu HY, Osher S, Wang G: Multi-energy CT based on a Prior Rank, Intensity and Sparsity Model (PRISM). Inverse Problems 27:115012 (22pp), 2011

Xu Q, Yu HY, Bennett J, He P, Zianon R, Doesburg R, Opie A, Walsh M, Butler A, Butler P, Shen HO, Mou X, Wang G: Image reconstruction for a hybrid true-color micro-CT system. To appear in IEEE Trans. Biomedical Engineering, 2012

"CS" Application



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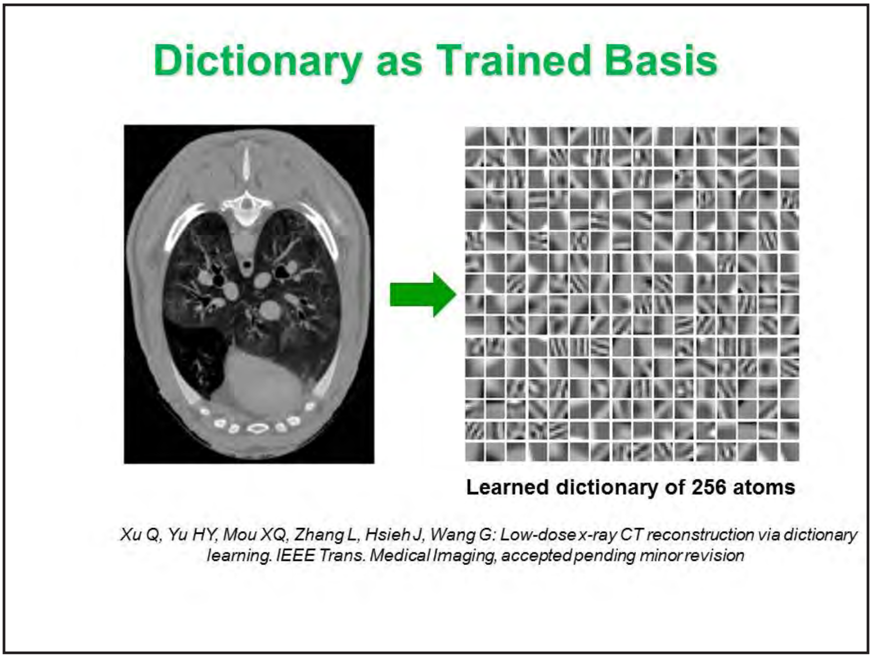
Low-dose X-ray CT Reconstruction via Dictionary Learning

Qiong Xu, Hengyong Yu*, *Senior Member, IEEE*, Xuanqin Mou*, Lei Zhang, *Member, IEEE*, Jiang Hsieh, *Senior Member, IEEE*, Ge Wang, *Fellow, IEEE*

Abstract—Although diagnostic medical imaging provides enormous benefits in the early detection and accuracy diagnosis of various diseases, there are growing concerns on the potential side effect of radiation induced genetic, cancerous and other diseases. How to reduce radiation dose while maintaining the diagnostic performance is a major challenge in the computed tomography (CT) field. Inspired by the compressive sensing theory, the sparse constraint in terms of total variation (TV) minimization has already led to promising results for low-dose CT reconstruction. Compared to the discrete gradient transform used in the TV method, dictionary learning is proven to be an effective way for projections collected in animal and human CT studies, and the improvement associated with dictionary learning is quantified relative to FBP and TV-based reconstructions. The results show that the proposed approach might produce better images with lower noise and more detailed structural features in our selected cases. However, there is no proof that this is true for all kinds of structures.

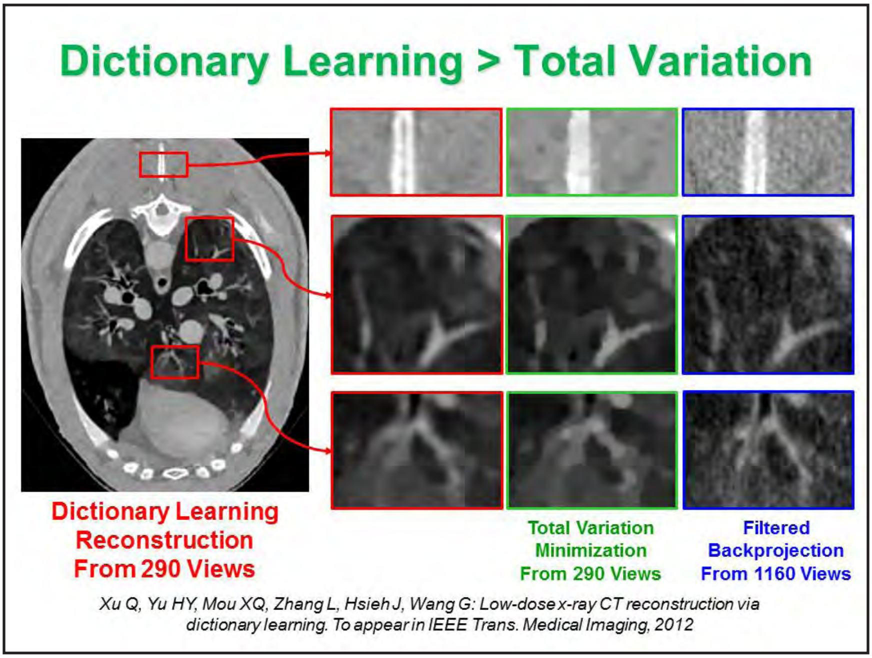
***Index Terms*—Computed tomography (CT), low-dose CT, compressive sensing (CS), sparse representation, dictionary learning, statistical iterative reconstruction.**



Dictionary as Trained Basis

Learned dictionary of 256 atoms

Xu Q, Yu HY, Mou XQ, Zhang L, Hsieh J, Wang G: Low-dose x-ray CT reconstruction via dictionary learning. IEEE Trans. Medical Imaging, accepted pending minor revision



Dictionary Learning > Total Variation

Dictionary Learning Reconstruction From 290 Views

Total Variation Minimization From 290 Views

Filtered Backprojection From 1160 Views

Xu Q, Yu HY, Mou XQ, Zhang L, Hsieh J, Wang G: Low-dose x-ray CT reconstruction via dictionary learning. To appear in IEEE Trans. Medical Imaging, 2012

"CS"-based Artifact Reduction

IOP PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **57** (2012) 173–189 doi:10.1088/0031-9155/57/1/173

Few-view image reconstruction with dual dictionaries

Yang Lu[1], **Jun Zhao**[1,3] **and Ge Wang**[2]

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[2] Biomedical Imaging Division, VT-WFU School of Biomedical Engineering and Science, Virginia Tech, Blacksburg, VA 24061, USA

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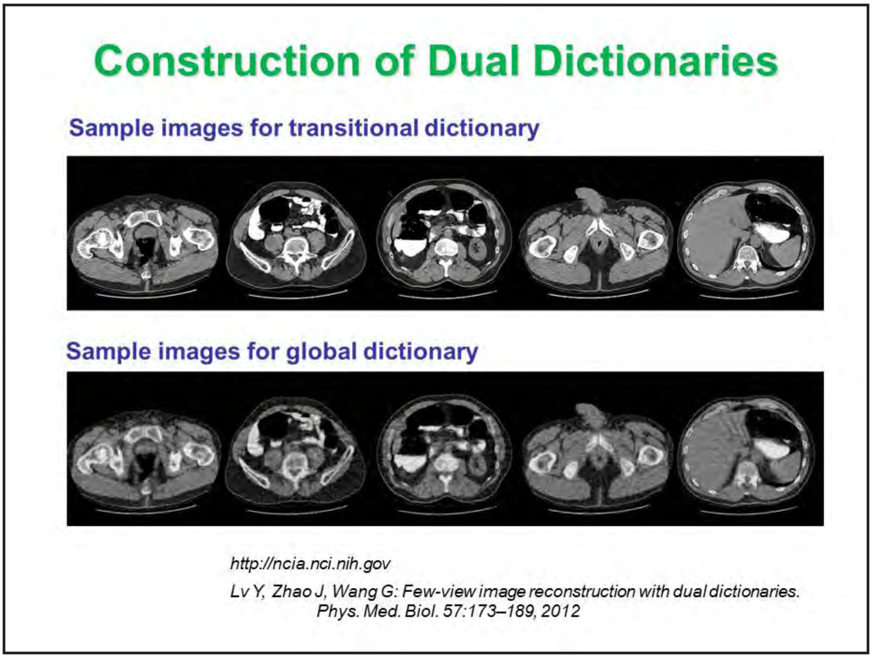
Online at stacks.iop.org/PMB/57/173

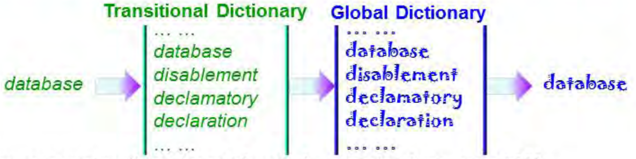


Construction of Dual Dictionaries

http://ncia.nci.nih.gov

Lv Y, Zhao J, Wang G: Few-view image reconstruction with dual dictionaries. Phys. Med. Biol. 57:173–189, 2012

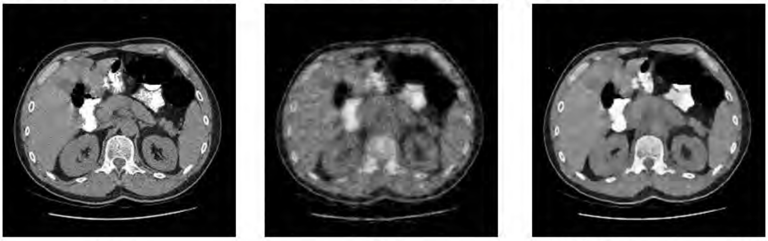
Dual Dictionaries Help Few-view CT



Transitional Dictionary **Global Dictionary**

database → … … database disablement declamatory declaration … … → … … database disablement declamatory declaration … … → database

Few-view reconstructions from 30 noiseless projections over 360°

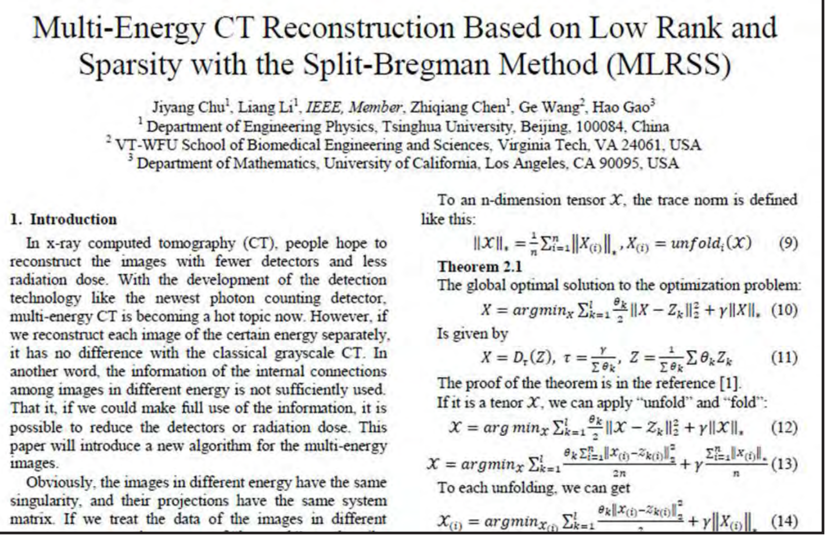


Truth **SART** **Dual Dictionaries + TV**

Lv Y, Zhao J, Wang G: Few-view image reconstruction with dual dictionaries. Phys. Med. Biol. 57:173–189, 2012

Wang G, Snyder DL, O'Sullivan JA, Vannier MW: Iterative deblurring for metal artifact reduction. IEEE Trans. on Med. Imaging 15:657-664, 1996

Rank of a Tensor?



Multi-Energy CT Reconstruction Based on Low Rank and Sparsity with the Split-Bregman Method (MLRSS)

Jiyang Chu[1], Liang Li[1], *IEEE, Member*, Zhiqiang Chen[1], Ge Wang[2], Hao Gao[3]
[1] Department of Engineering Physics, Tsinghua University, Beijing, 100084, China
[2] VT-WFU School of Biomedical Engineering and Sciences, Virginia Tech, VA 24061, USA
[3] Department of Mathematics, University of California, Los Angeles, CA 90095, USA

1. Introduction

In x-ray computed tomography (CT), people hope to reconstruct the images with fewer detectors and less radiation dose. With the development of the detection technology like the newest photon counting detector, multi-energy CT is becoming a hot topic now. However, if we reconstruct each image of the certain energy separately, it has no difference with the classical grayscale CT. In another word, the information of the internal connections among images in different energy is not sufficiently used. That it, if we could make full use of the information, it is possible to reduce the detectors or radiation dose. This paper will introduce a new algorithm for the multi-energy images.

Obviously, the images in different energy have the same singularity, and their projections have the same system matrix. If we treat the data of the images in different

To an n-dimension tensor $\mathcal{X}$, the trace norm is defined like this:

$$\|\mathcal{X}\|_* = \frac{1}{n}\sum_{i=1}^{n}\left\|X_{(i)}\right\|_*, X_{(i)} = unfold_i(\mathcal{X}) \quad (9)$$

Theorem 2.1

The global optimal solution to the optimization problem:

$$X = argmin_X \sum_{k=1}^{l}\frac{\theta_k}{2}\|X - Z_k\|_2^2 + \gamma\|X\|_* \quad (10)$$

Is given by

$$X = D_\tau(Z),\ \tau = \frac{\gamma}{\sum\theta_k},\ Z = \frac{1}{\sum\theta_k}\sum\theta_k Z_k \quad (11)$$

The proof of the theorem is in the reference [1].

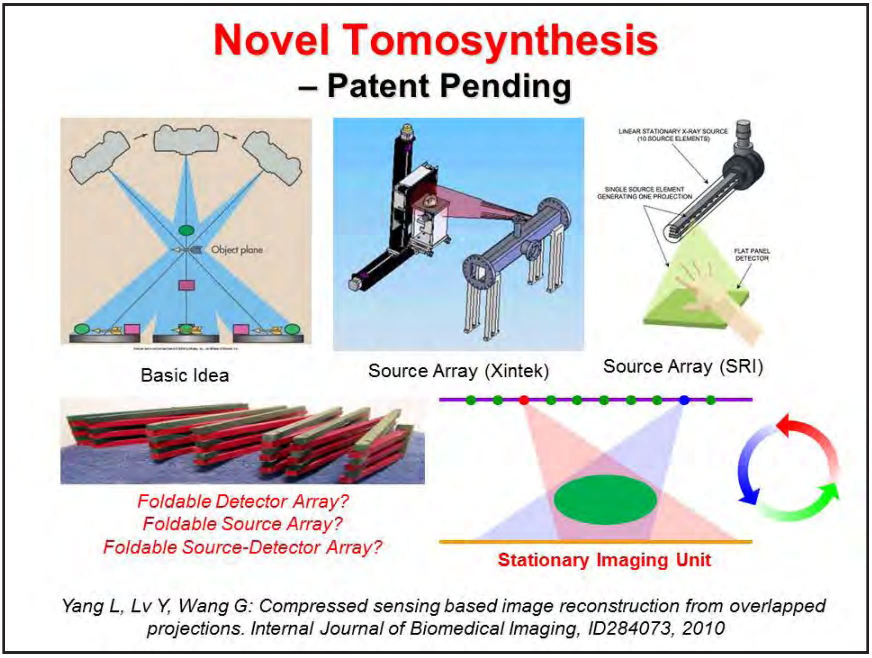
If it is a tenor $\mathcal{X}$, we can apply "unfold" and "fold":

$$\mathcal{X} = arg\,min_{\mathcal{X}} \sum_{k=1}^{l}\frac{\theta_k}{2}\|\mathcal{X} - \mathcal{Z}_k\|_2^2 + \gamma\|\mathcal{X}\|_* \quad (12)$$

$$\mathcal{X} = argmin_{\mathcal{X}} \sum_{k=1}^{l}\frac{\theta_k\sum_{i=1}^{n}\|\mathcal{X}_{(i)} - \mathcal{Z}_{k(i)}\|_2^2}{2n} + \gamma\frac{\sum_{i=1}^{n}\|\mathcal{X}_{(i)}\|_*}{n} \quad (13)$$

To each unfolding, we can get

$$\mathcal{X}_{(i)} = argmin_{\mathcal{X}_{(i)}} \sum_{k=1}^{l}\frac{\theta_k\|\mathcal{X}_{(i)} - \mathcal{Z}_{k(i)}\|_2^2}{2} + \gamma\left\|X_{(i)}\right\|_* \quad (14)$$



Novel Tomosynthesis
– Patent Pending

Basic Idea

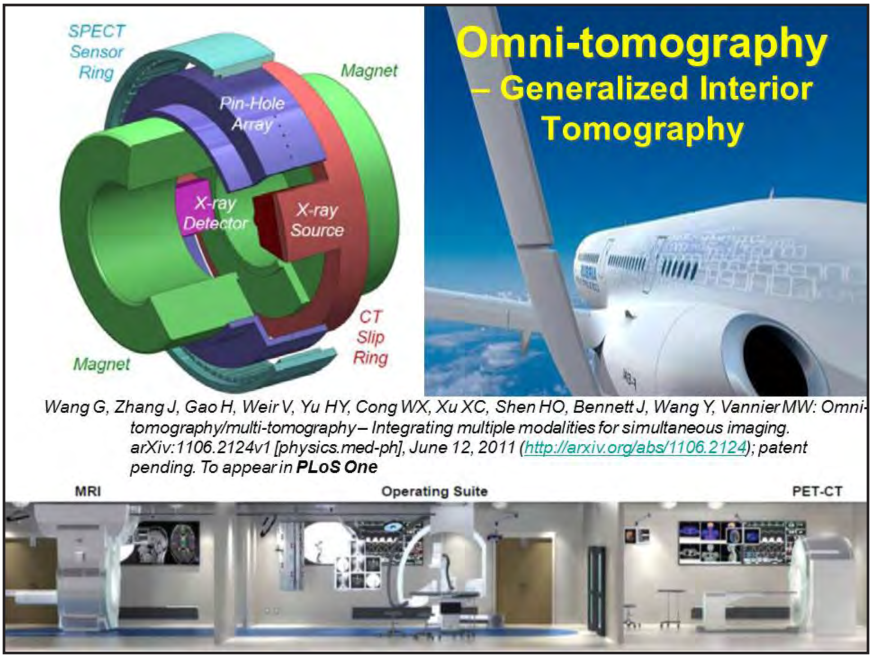
Source Array (Xintek)

Source Array (SRI)

Foldable Detector Array?
Foldable Source Array?
Foldable Source-Detector Array?

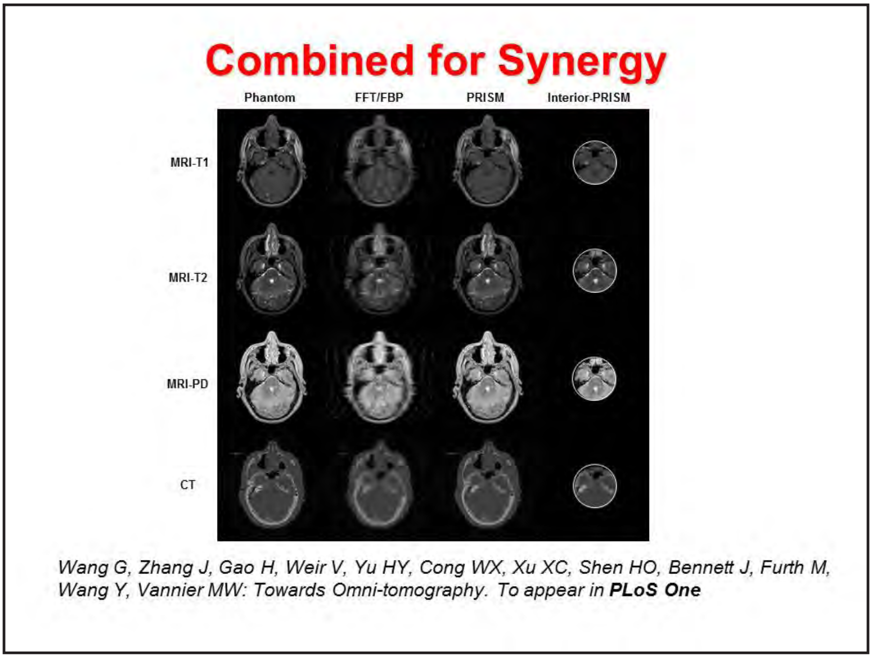
Stationary Imaging Unit

Yang L, Lv Y, Wang G: Compressed sensing based image reconstruction from overlapped projections. Internal Journal of Biomedical Imaging, ID284073, 2010



Omni-tomography
– Generalized Interior Tomography

*Wang G, Zhang J, Gao H, Weir V, Yu HY, Cong WX, Xu XC, Shen HO, Bennett J, Wang Y, Vannier MW: Omni-tomography/multi-tomography – Integrating multiple modalities for simultaneous imaging. arXiv:1106.2124v1 [physics.med-ph], June 12, 2011 (http://arxiv.org/abs/1106.2124); patent pending. To appear in **PLoS One***

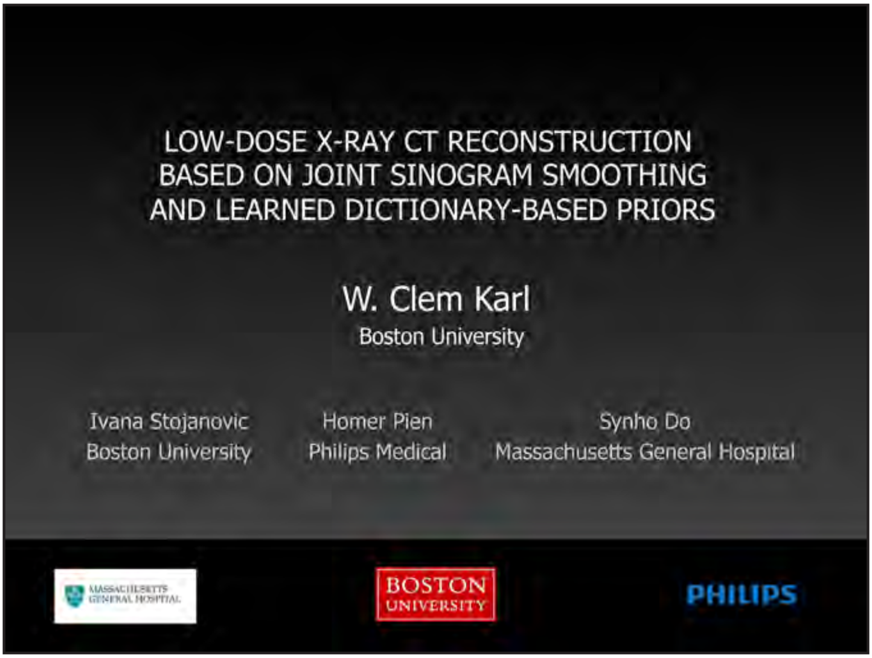


Combined for Synergy

Wang G, Zhang J, Gao H, Weir V, Yu HY, Cong WX, Xu XC, Shen HO, Bennett J, Furth M, Wang Y, Vannier MW: Towards Omni-tomography. To appear in ***PLoS One***

THANK YOU

16.24 W. Clem Karl: Low-Dose X-Ray CT Reconstruction Based on Joint Sinogram Smoothing and Learned Dictionary-Based Priors



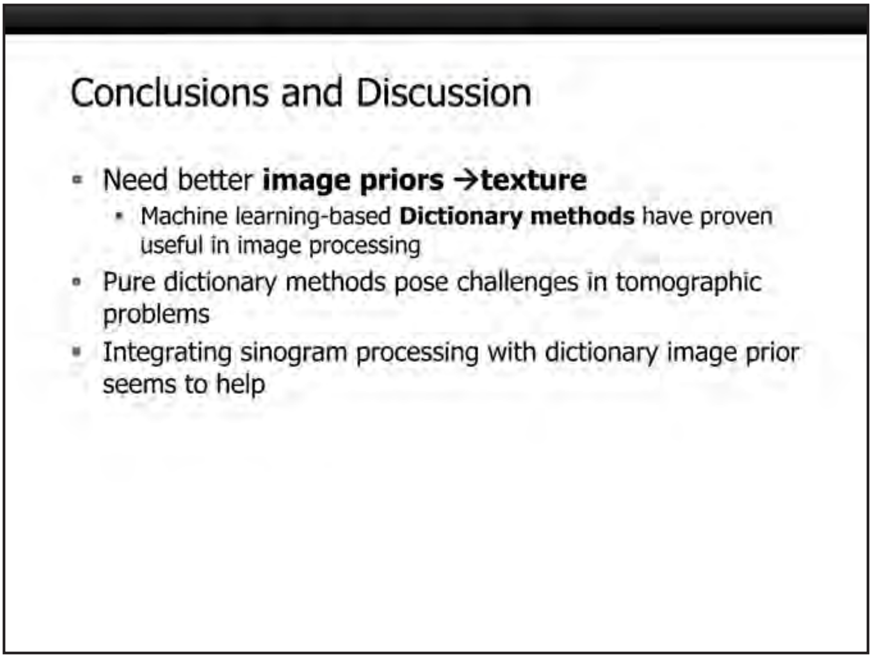
LOW-DOSE X-RAY CT RECONSTRUCTION BASED ON JOINT SINOGRAM SMOOTHING AND LEARNED DICTIONARY-BASED PRIORS

W. Clem Karl
Boston University

Ivana Stojanovic
Boston University

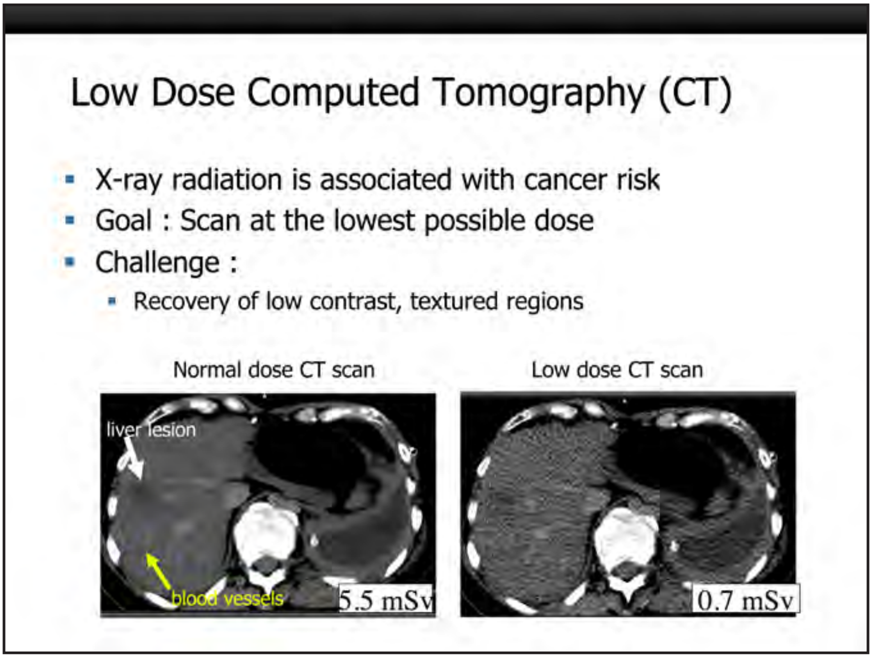
Homer Pien
Philips Medical

Synho Do
Massachusetts General Hospital



Conclusions and Discussion

- Need better **image priors →texture**
  - Machine learning-based **Dictionary methods** have proven useful in image processing
- Pure dictionary methods pose challenges in tomographic problems
- Integrating sinogram processing with dictionary image prior seems to help

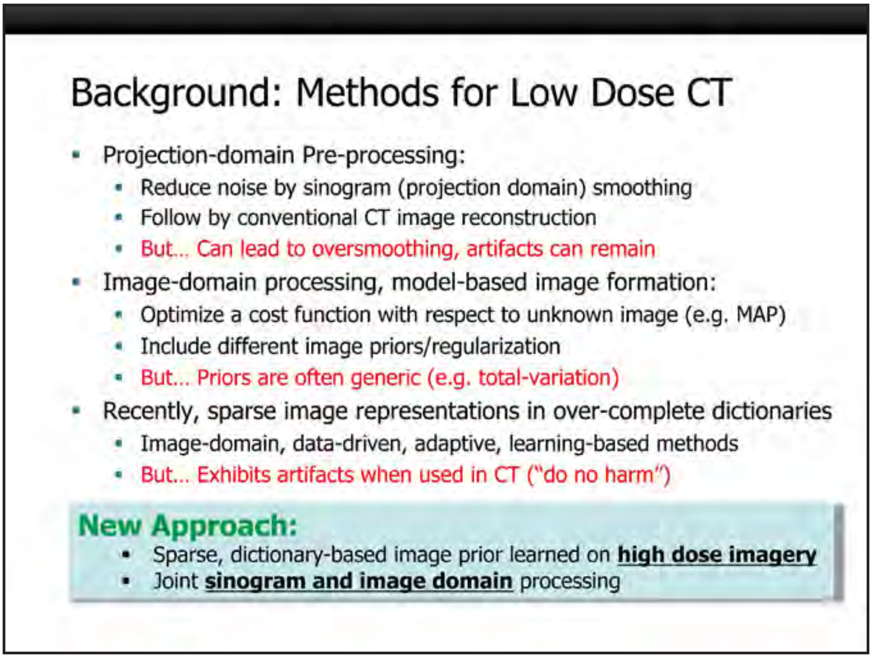


Low Dose Computed Tomography (CT)

- X-ray radiation is associated with cancer risk
- Goal : Scan at the lowest possible dose
- Challenge :
  - Recovery of low contrast, textured regions

Normal dose CT scan

Low dose CT scan

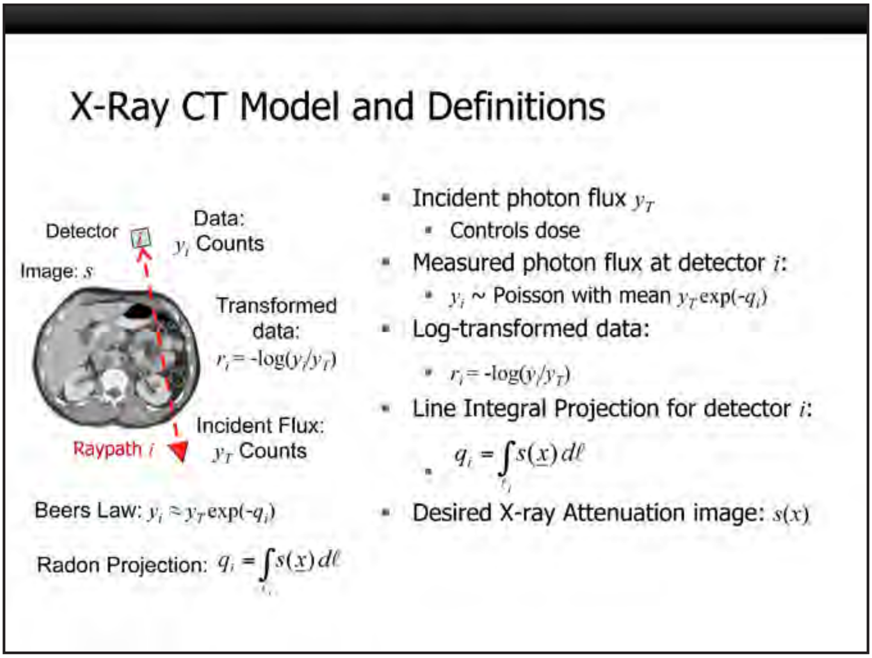


Background: Methods for Low Dose CT

- Projection-domain Pre-processing:
  - Reduce noise by sinogram (projection domain) smoothing
  - Follow by conventional CT image reconstruction
  - But... Can lead to oversmoothing, artifacts can remain
- Image-domain processing, model-based image formation:
  - Optimize a cost function with respect to unknown image (e.g. MAP)
  - Include different image priors/regularization
  - But... Priors are often generic (e.g. total-variation)
- Recently, sparse image representations in over-complete dictionaries
  - Image-domain, data-driven, adaptive, learning-based methods
  - But... Exhibits artifacts when used in CT ("do no harm")

New Approach:

- Sparse, dictionary-based image prior learned on **high dose imagery**
- Joint **sinogram and image domain** processing



X-Ray CT Model and Definitions

Detector i

Image: s

Data: y_i Counts

Transformed data: $r_i = -\log(y_i/y_T)$

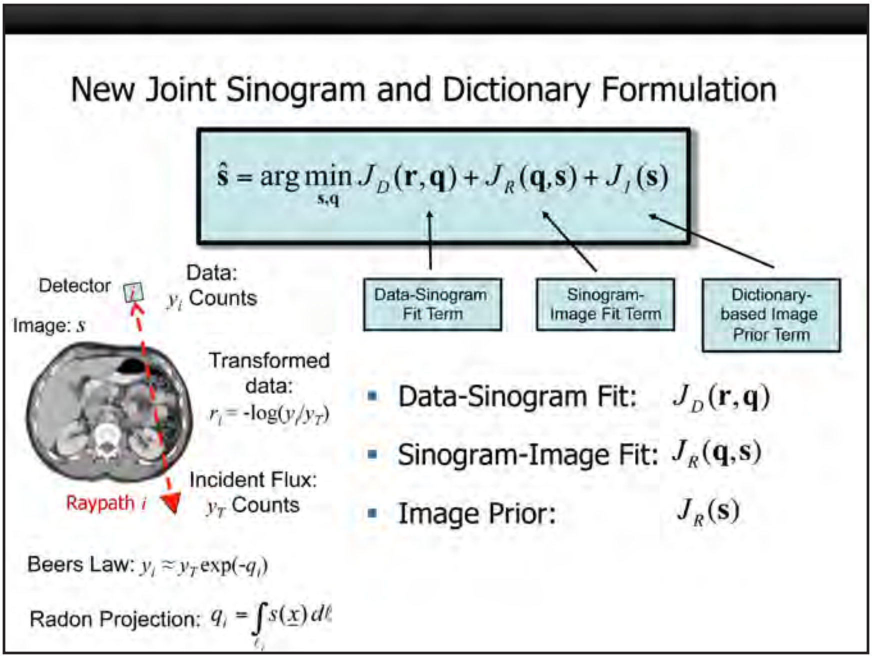
Incident Flux: y_T Counts

Raypath i

Beers Law: $y_i \approx y_T \exp(-q_i)$

Radon Projection: $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$

- Incident photon flux y_T
  - Controls dose
- Measured photon flux at detector i:
  - y_i ~ Poisson with mean $y_T \exp(-q_i)$
- Log-transformed data:
  - $r_i = -\log(y_i/y_T)$
- Line Integral Projection for detector i:
  - $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$
- Desired X-ray Attenuation image: $s(x)$



New Joint Sinogram and Dictionary Formulation

$$\hat{\mathbf{s}} = \arg\min_{\mathbf{s},\mathbf{q}} J_D(\mathbf{r},\mathbf{q}) + J_R(\mathbf{q},\mathbf{s}) + J_I(\mathbf{s})$$

Data-Sinogram Fit Term

Sinogram-Image Fit Term

Dictionary-based Image Prior Term

Detector i

Image: s

Data: y_i Counts

Transformed data: $r_i = -\log(y_i/y_T)$

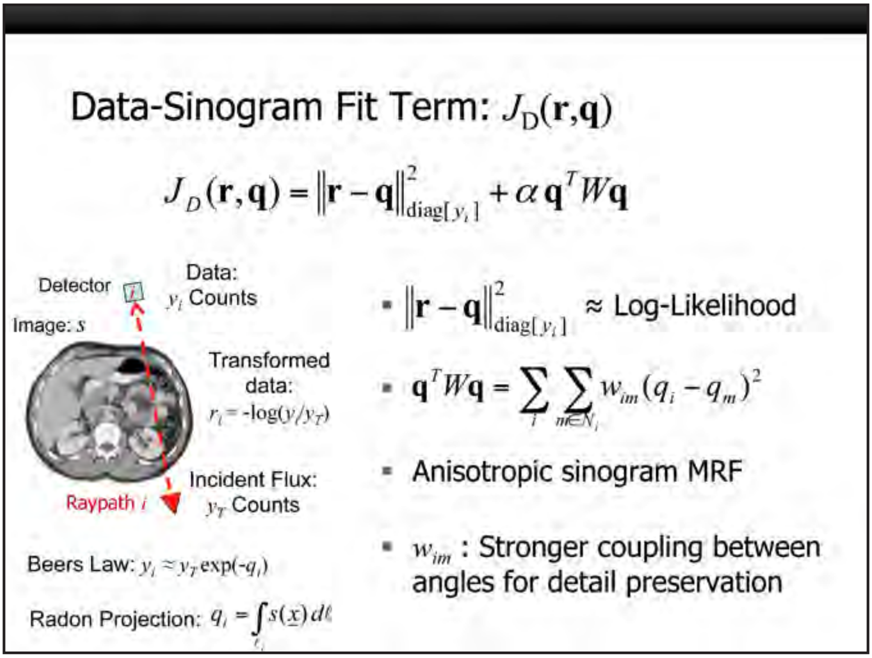
Incident Flux: y_T Counts

Raypath i

Beers Law: $y_i \approx y_T \exp(-q_i)$

Radon Projection: $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$

- Data-Sinogram Fit: $J_D(\mathbf{r},\mathbf{q})$
- Sinogram-Image Fit: $J_R(\mathbf{q},\mathbf{s})$
- Image Prior: $J_R(\mathbf{s})$



Data-Sinogram Fit Term: $J_{\mathrm{D}}(\mathbf{r},\mathbf{q})$

$$J_D(\mathbf{r},\mathbf{q}) = \|\mathbf{r}-\mathbf{q}\|^2_{\mathrm{diag}[y_i]} + \alpha\, \mathbf{q}^T W \mathbf{q}$$

Detector i

Data: y_i Counts

Image: s

Transformed data: $r_i = -\log(y_i/y_T)$

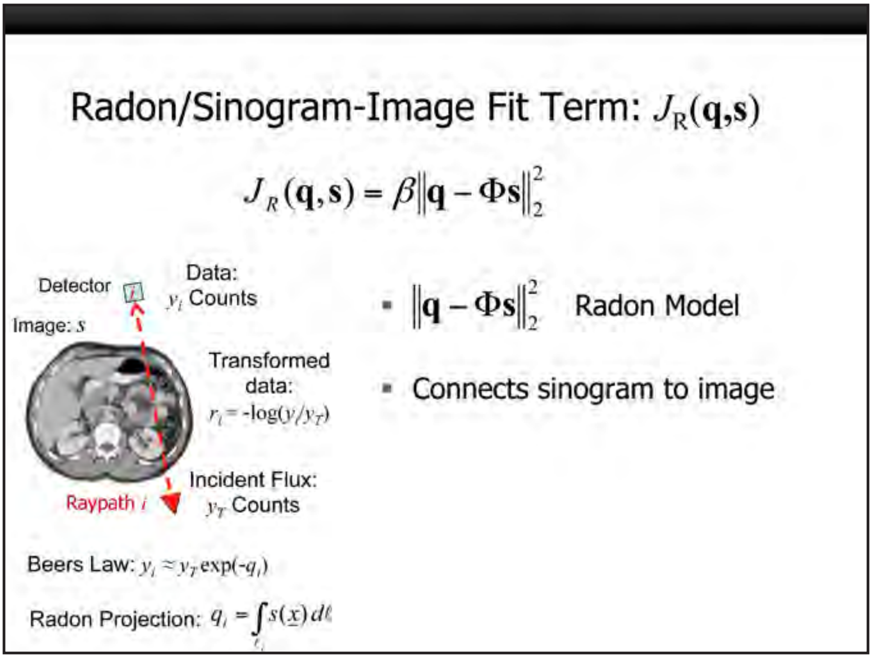
Incident Flux: y_T Counts

Raypath i

Beers Law: $y_i \approx y_T \exp(-q_i)$

Radon Projection: $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$

- $\|\mathbf{r}-\mathbf{q}\|^2_{\mathrm{diag}[y_i]}$ ≈ Log-Likelihood
- $\mathbf{q}^T W \mathbf{q} = \sum_i \sum_{m \in N_i} w_{im} (q_i - q_m)^2$
- Anisotropic sinogram MRF
- w_{im} : Stronger coupling between angles for detail preservation



Radon/Sinogram-Image Fit Term: $J_{\mathrm{R}}(\mathbf{q},\mathbf{s})$

$$J_R(\mathbf{q},\mathbf{s}) = \beta \|\mathbf{q}-\Phi\mathbf{s}\|_2^2$$

Detector i

Data: y_i Counts

Image: s

Transformed data: $r_i = -\log(y_i/y_T)$

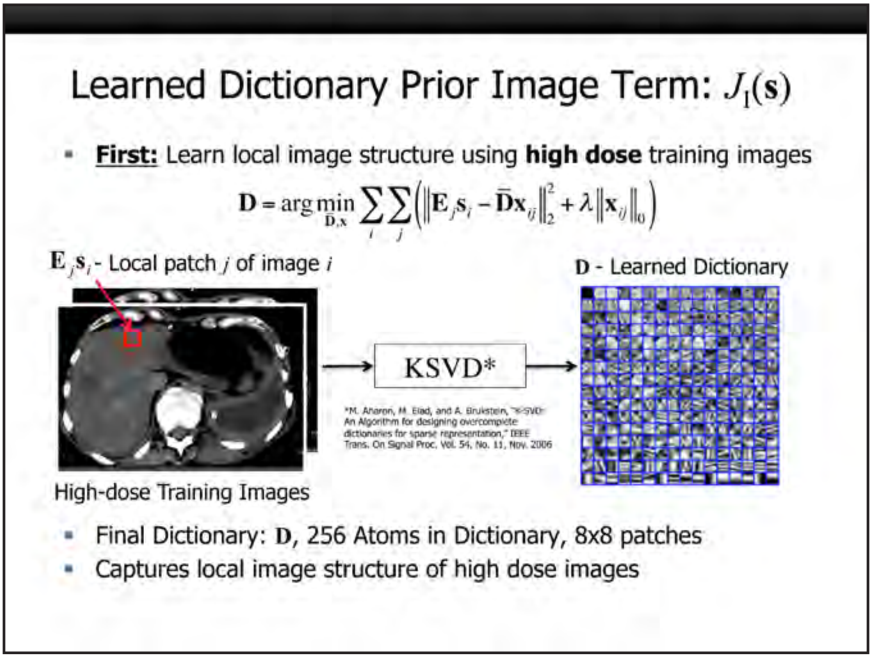
Incident Flux: y_T Counts

Raypath i

Beers Law: $y_i \approx y_T \exp(-q_i)$

Radon Projection: $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$

- $\|\mathbf{q}-\Phi\mathbf{s}\|_2^2$ Radon Model
- Connects sinogram to image



Learned Dictionary Prior Image Term: $J_I(\mathbf{s})$

- **First:** Learn local image structure using **high dose** training images

$$\mathbf{D} = \arg\min_{\bar{\mathbf{D}},\mathbf{x}} \sum_i \sum_j \left(\left\| \mathbf{E}_j \mathbf{s}_i - \bar{\mathbf{D}} \mathbf{x}_{ij} \right\|_2^2 + \lambda \left\| \mathbf{x}_{ij} \right\|_0 \right)$$

$\mathbf{E}_j\mathbf{s}_i$ - Local patch j of image i

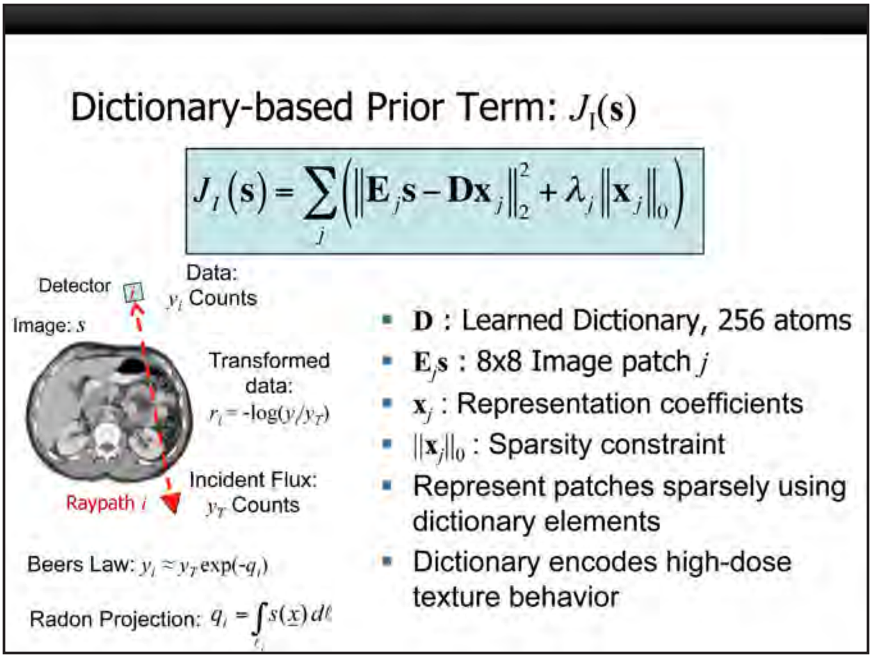
$\mathbf{D}$ - Learned Dictionary

KSVD*

*M. Aharon, M. Elad, and A. Brukstein, "K-SVD: An Algorithm for designing overcomplete dictionaries for sparse representation," IEEE Trans. On Signal Proc. Vol. 54, No. 11, Nov. 2006

High-dose Training Images

- Final Dictionary: $\mathbf{D}$, 256 Atoms in Dictionary, 8x8 patches
- Captures local image structure of high dose images



Dictionary-based Prior Term: $J_I(\mathbf{s})$

$$J_I(\mathbf{s}) = \sum_j \left(\left\| \mathbf{E}_j \mathbf{s} - \mathbf{D}\mathbf{x}_j \right\|_2^2 + \lambda_j \left\| \mathbf{x}_j \right\|_0 \right)$$

Detector i

Data: y_i Counts

Image: s

Transformed data: $r_i = -\log(y_i/y_T)$

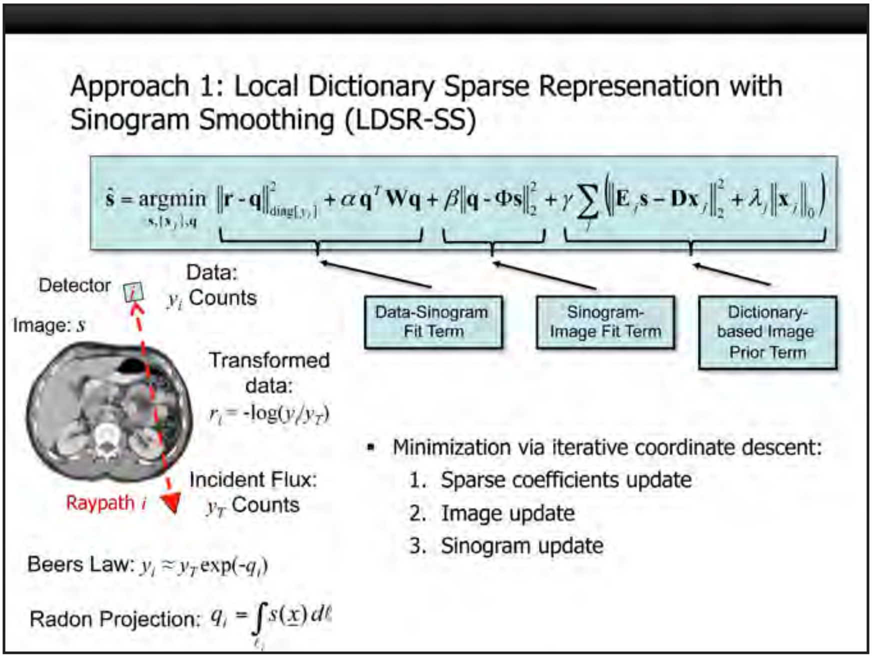
Raypath i

Incident Flux: y_T Counts

Beers Law: $y_i \approx y_T \exp(-q_i)$

Radon Projection: $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$

- $\mathbf{D}$: Learned Dictionary, 256 atoms
- $\mathbf{E}_j\mathbf{s}$: 8x8 Image patch j
- $\mathbf{x}_j$: Representation coefficients
- $\|\mathbf{x}_j\|_0$: Sparsity constraint
- Represent patches sparsely using dictionary elements
- Dictionary encodes high-dose texture behavior



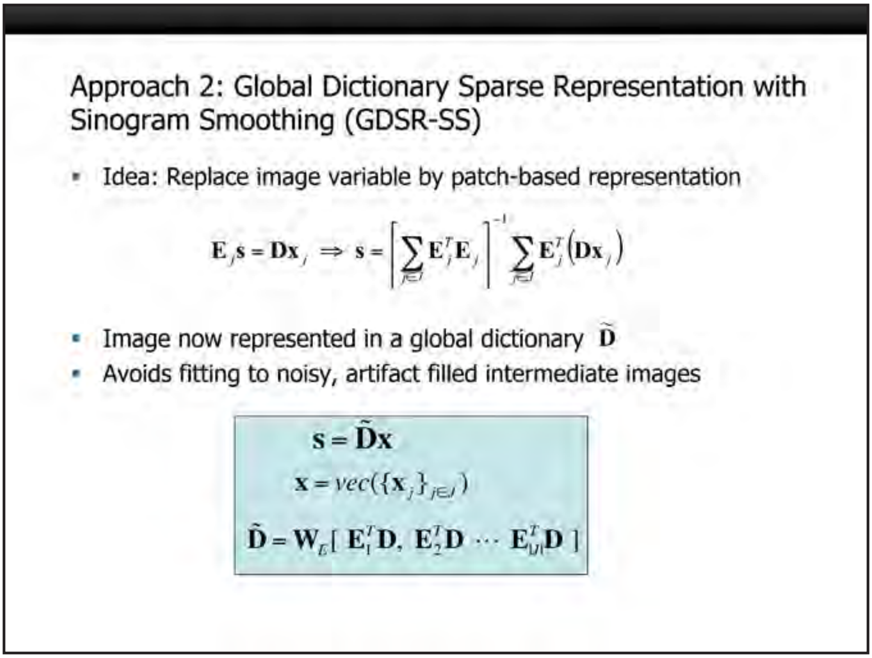
Approach 1: Local Dictionary Sparse Represenation with Sinogram Smoothing (LDSR-SS)

$$\hat{\mathbf{s}} = \underset{\mathbf{s},\{\mathbf{x}_j\},\mathbf{q}}{\operatorname{argmin}} \underbrace{\|\mathbf{r}-\mathbf{q}\|^2_{\mathrm{diag}[y_i]} + \alpha \mathbf{q}^T \mathbf{W}\mathbf{q}}_{\text{Data-Sinogram Fit Term}} + \underbrace{\beta\|\mathbf{q}-\Phi\mathbf{s}\|_2^2}_{\text{Sinogram-Image Fit Term}} + \underbrace{\gamma\sum_j \left(\|\mathbf{E}_j\mathbf{s}-\mathbf{D}\mathbf{x}_j\|_2^2 + \lambda_j\|\mathbf{x}_j\|_0\right)}_{\text{Dictionary-based Image Prior Term}}$$

Beers Law: $y_i \approx y_T \exp(-q_i)$

Radon Projection: $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$

- Minimization via iterative coordinate descent:
  1. Sparse coefficients update
  2. Image update
  3. Sinogram update



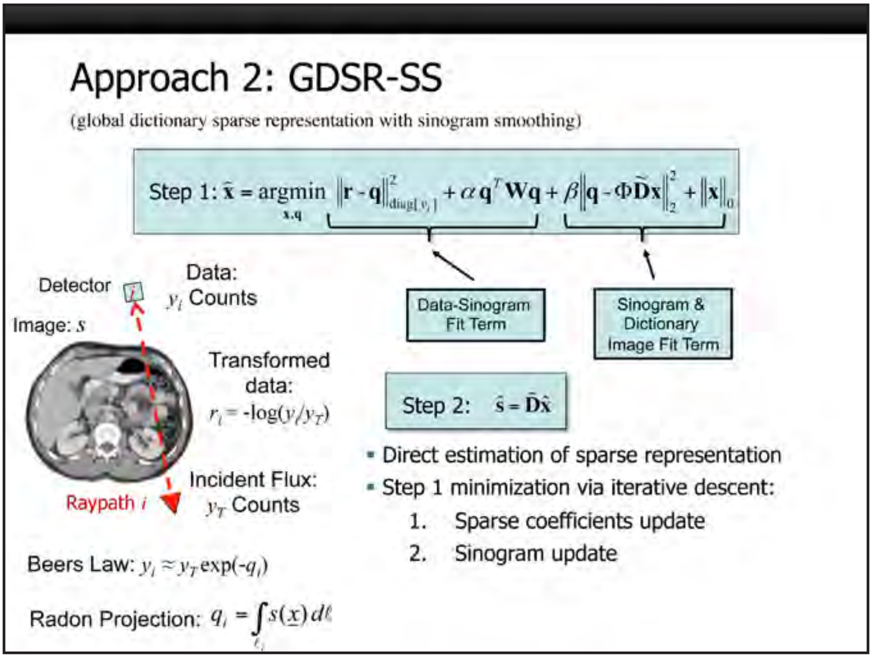
Approach 2: Global Dictionary Sparse Representation with Sinogram Smoothing (GDSR-SS)

- Idea: Replace image variable by patch-based representation

$$\mathbf{E}_j\mathbf{s} = \mathbf{D}\mathbf{x}_j \;\Rightarrow\; \mathbf{s} = \left[\sum_{j\in J}\mathbf{E}_j^T\mathbf{E}_j\right]^{-1}\sum_{j\in J}\mathbf{E}_j^T(\mathbf{D}\mathbf{x}_j)$$

- Image now represented in a global dictionary $\tilde{\mathbf{D}}$
- Avoids fitting to noisy, artifact filled intermediate images

$$\mathbf{s} = \tilde{\mathbf{D}}\mathbf{x}$$
$$\mathbf{x} = vec(\{\mathbf{x}_j\}_{j\in J})$$
$$\tilde{\mathbf{D}} = \mathbf{W}_E[\ \mathbf{E}_1^T\mathbf{D},\ \mathbf{E}_2^T\mathbf{D}\ \cdots\ \mathbf{E}_{|J|}^T\mathbf{D}\ ]$$



Approach 2: GDSR-SS

(global dictionary sparse representation with sinogram smoothing)

Step 1: $\hat{\mathbf{x}} = \underset{\mathbf{x},\mathbf{q}}{\operatorname{argmin}} \underbrace{\|\mathbf{r}-\mathbf{q}\|^2_{\mathrm{diag}[y_i]} + \alpha\,\mathbf{q}^T\mathbf{W}\mathbf{q}} + \underbrace{\beta\|\mathbf{q}-\Phi\tilde{\mathbf{D}}\mathbf{x}\|_2^2 + \|\mathbf{x}\|_0}$

Data-Sinogram Fit Term

Sinogram & Dictionary Image Fit Term

Detector

Data:
y_i Counts

Image: s

Transformed data:
$r_i = -\log(y_i/y_T)$

Incident Flux:
y_T Counts

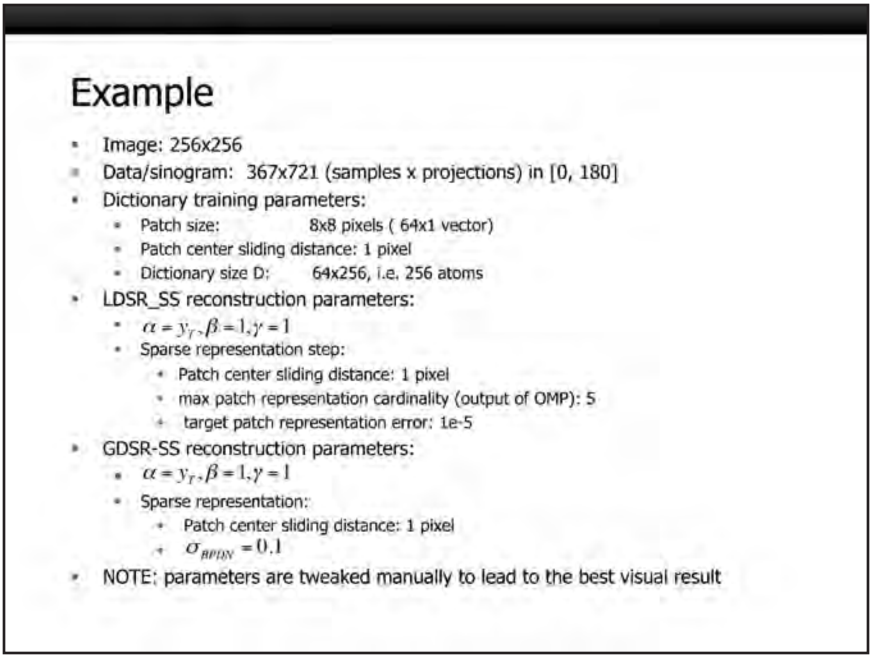
Raypath i

Beers Law: $y_i \approx y_T \exp(-q_i)$

Radon Projection: $q_i = \int_{\ell_i} s(\underline{x})\, d\ell$

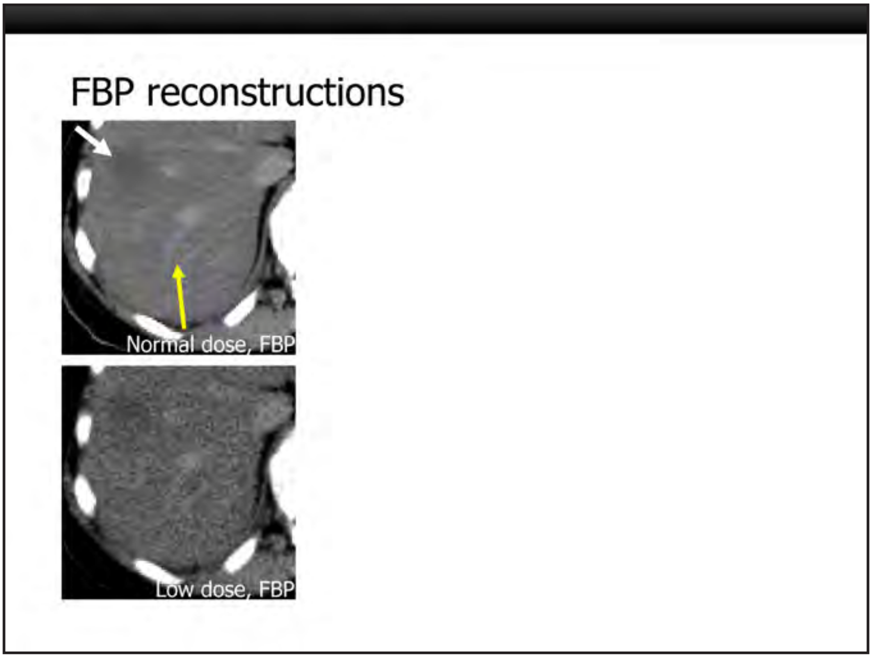
Step 2: $\hat{\mathbf{s}} = \tilde{\mathbf{D}}\hat{\mathbf{x}}$

- Direct estimation of sparse representation
- Step 1 minimization via iterative descent:
  1. Sparse coefficients update
  2. Sinogram update



Example

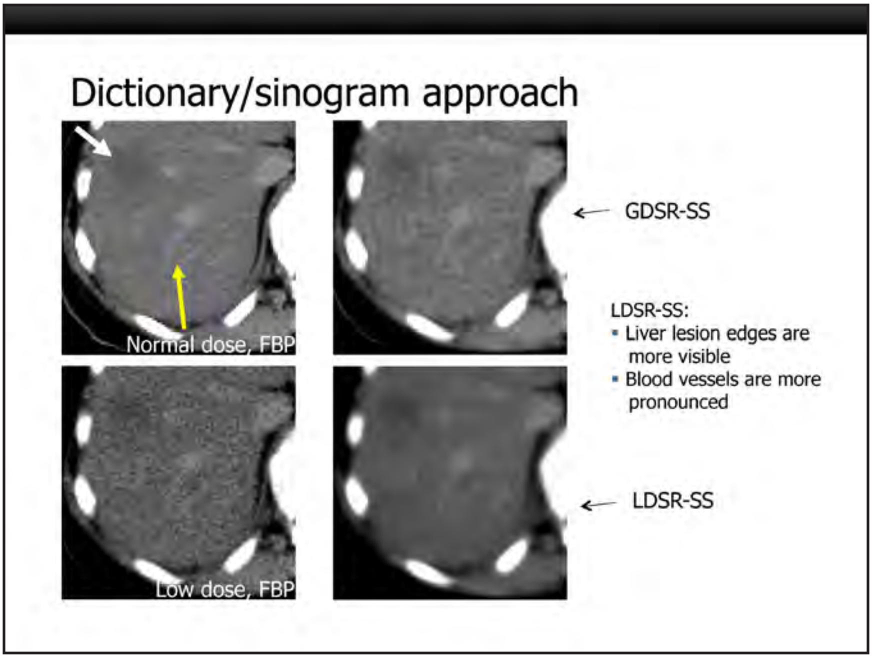
- Image: 256x256
- Data/sinogram: 367x721 (samples x projections) in [0, 180]
- Dictionary training parameters:
  - Patch size: 8x8 pixels (64x1 vector)
  - Patch center sliding distance: 1 pixel
  - Dictionary size D: 64x256, i.e. 256 atoms
- LDSR_SS reconstruction parameters:
  - $\alpha = y_T, \beta = 1, \gamma = 1$
  - Sparse representation step:
    - Patch center sliding distance: 1 pixel
    - max patch representation cardinality (output of OMP): 5
    - target patch representation error: 1e-5
- GDSR-SS reconstruction parameters:
  - $\alpha = y_T, \beta = 1, \gamma = 1$
  - Sparse representation:
    - Patch center sliding distance: 1 pixel
    - $\sigma_{BPDN} = 0.1$
- NOTE: parameters are tweaked manually to lead to the best visual result



FBP reconstructions

Normal dose, FBP

Low dose, FBP



Dictionary/sinogram approach

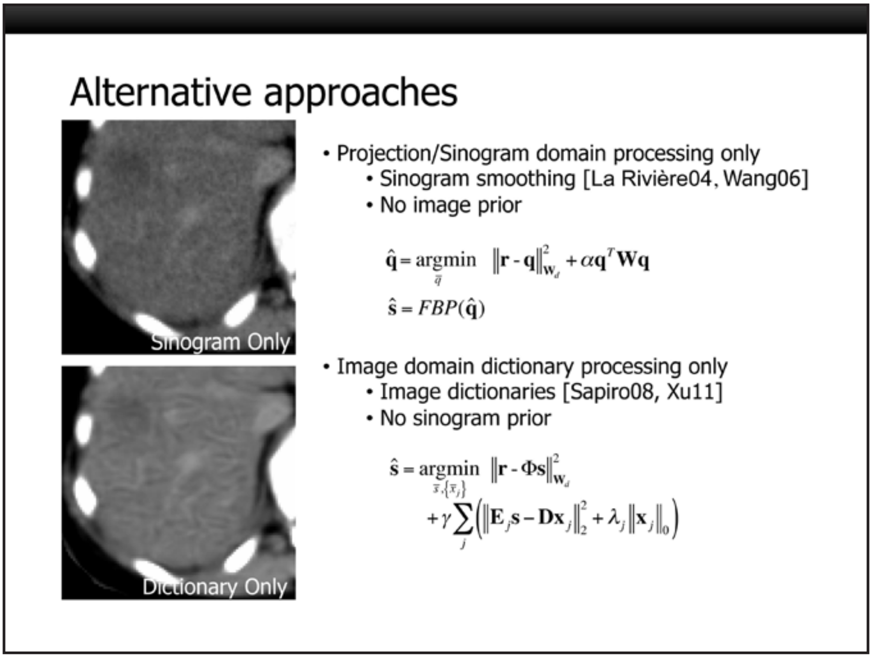
Normal dose, FBP

Low dose, FBP

← GDSR-SS

LDSR-SS:
- Liver lesion edges are more visible
- Blood vessels are more pronounced

← LDSR-SS



Alternative approaches

Sinogram Only

Dictionary Only

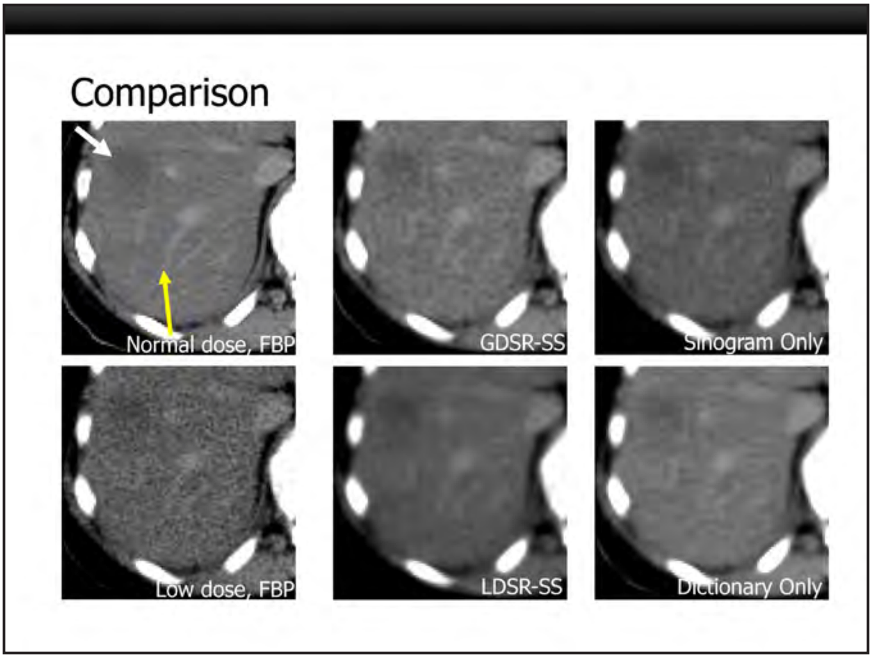
- Projection/Sinogram domain processing only
  - Sinogram smoothing [La Rivière04, Wang06]
  - No image prior

$$\hat{\mathbf{q}} = \underset{\bar{q}}{\text{argmin}} \ \|\mathbf{r} - \mathbf{q}\|^2_{\mathbf{W}_d} + \alpha \mathbf{q}^T \mathbf{W} \mathbf{q}$$

$$\hat{\mathbf{s}} = FBP(\hat{\mathbf{q}})$$

- Image domain dictionary processing only
  - Image dictionaries [Sapiro08, Xu11]
  - No sinogram prior

$$\hat{\mathbf{s}} = \underset{\bar{s},\{\bar{x}_j\}}{\text{argmin}} \ \|\mathbf{r} - \Phi \mathbf{s}\|^2_{\mathbf{W}_d} + \gamma \sum_j \left(\|\mathbf{E}_j \mathbf{s} - \mathbf{D}\mathbf{x}_j\|_2^2 + \lambda_j \|\mathbf{x}_j\|_0 \right)$$



Comparison

Normal dose, FBP

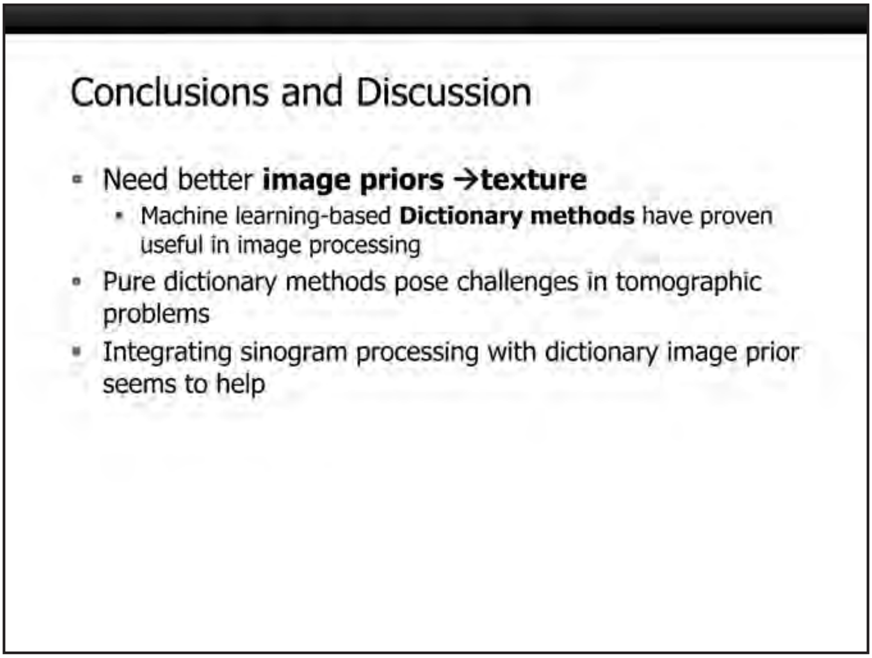
GDSR-SS

Sinogram Only

Low dose, FBP

LDSR-SS

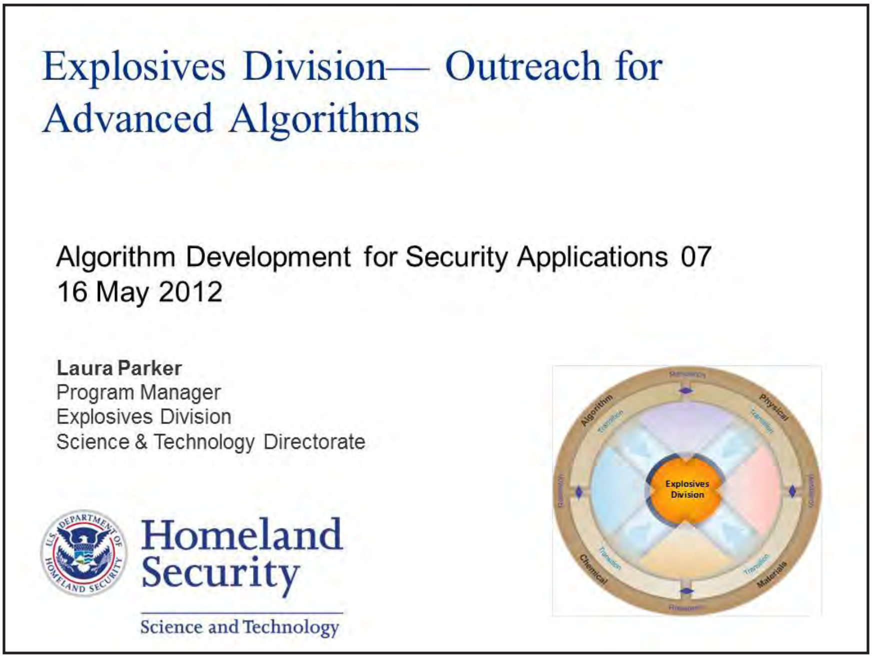
Dictionary Only



Conclusions and Discussion

- Need better **image priors →texture**
  - Machine learning-based **Dictionary methods** have proven useful in image processing
- Pure dictionary methods pose challenges in tomographic problems
- Integrating sinogram processing with dictionary image prior seems to help

16.25 Laura Parker: Explosives Division — Outreach for Advanced Algorithms

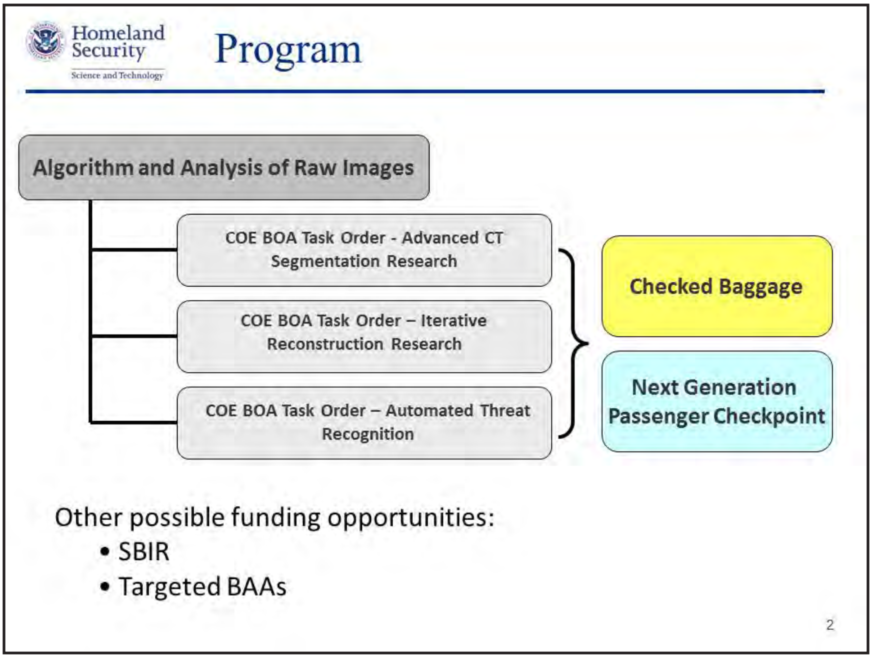


Explosives Division— Outreach for Advanced Algorithms

Algorithm Development for Security Applications 07
16 May 2012

Laura Parker
Program Manager
Explosives Division
Science & Technology Directorate

Homeland Security
Science and Technology



Program

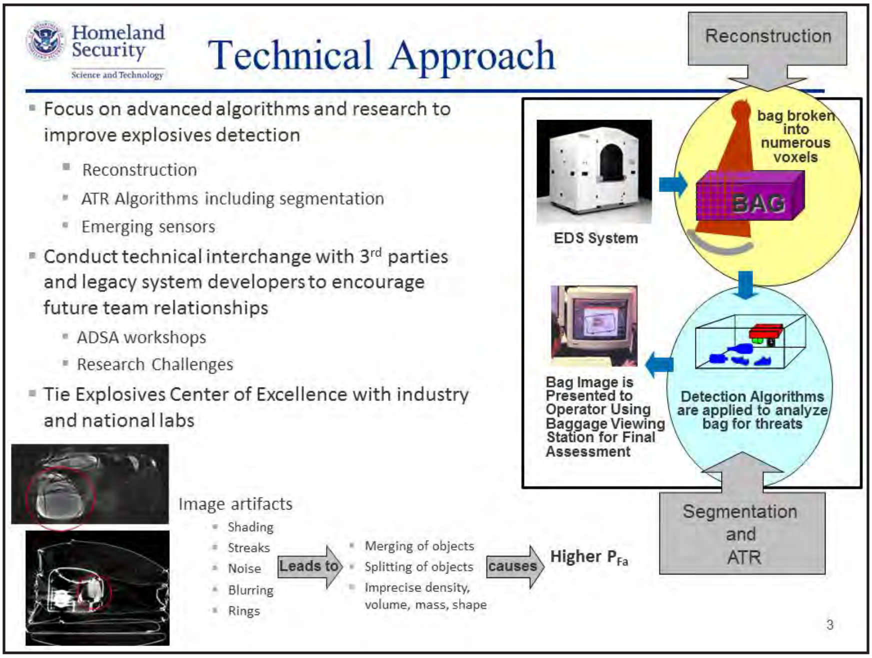
Algorithm and Analysis of Raw Images

- COE BOA Task Order - Advanced CT Segmentation Research
- COE BOA Task Order – Iterative Reconstruction Research
- COE BOA Task Order – Automated Threat Recognition

Checked Baggage

Next Generation Passenger Checkpoint

Other possible funding opportunities:
- SBIR
- Targeted BAAs



Technical Approach

- Focus on advanced algorithms and research to improve explosives detection
  - Reconstruction
  - ATR Algorithms including segmentation
  - Emerging sensors
- Conduct technical interchange with 3rd parties and legacy system developers to encourage future team relationships
  - ADSA workshops
  - Research Challenges
- Tie Explosives Center of Excellence with industry and national labs

Reconstruction

EDS System

bag broken into numerous voxels

BAG

Detection Algorithms are applied to analyze bag for threats

Bag Image is Presented to Operator Using Baggage Viewing Station for Final Assessment

Segmentation and ATR

Image artifacts
- Shading
- Streaks
- Noise
- Blurring
- Rings

Leads to

- Merging of objects
- Splitting of objects
- Imprecise density, volume, mass, shape

causes

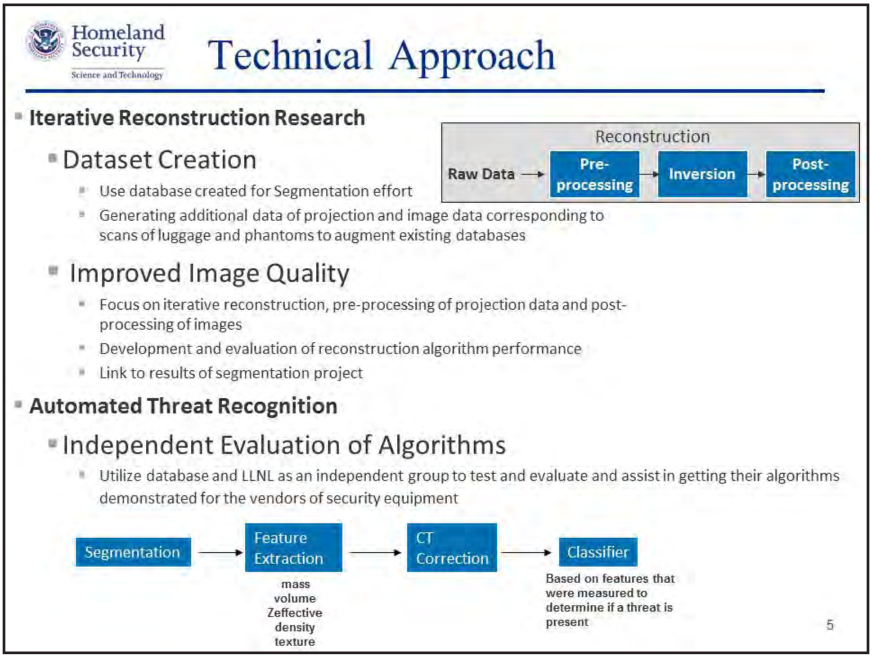
Higher P_{Fa}

Technical Approach

Advanced CT Segmentation Research

- Dataset Creation
  - Nonthreats scanned on medical CT scanner to create reuseable datasets
  - Common datasets for analysis by researchers
- Research Challenge
  - Five performers from academia and industry provided innovative segmentation approaches
- Mentors for Third Party Performers
  - Subject Matter Experts acting as mentors
- Open technical interchange with all performers
  - Held joint symposium with TSA in December 2011 to showcase outcomes
  - Legacy system vendors encouraged to establish information/results exchange
- Outcomes
  - Paper submission to the 2012 European Conference on Computer Vision by performer Siemens, "Automatic Segmentation of Unknown Objects in 3D CT Images, with Application to Baggage Security"
  - Exchanges between performer Stratovan Corp. and Telesecurity Sciences, Inc. and vendors

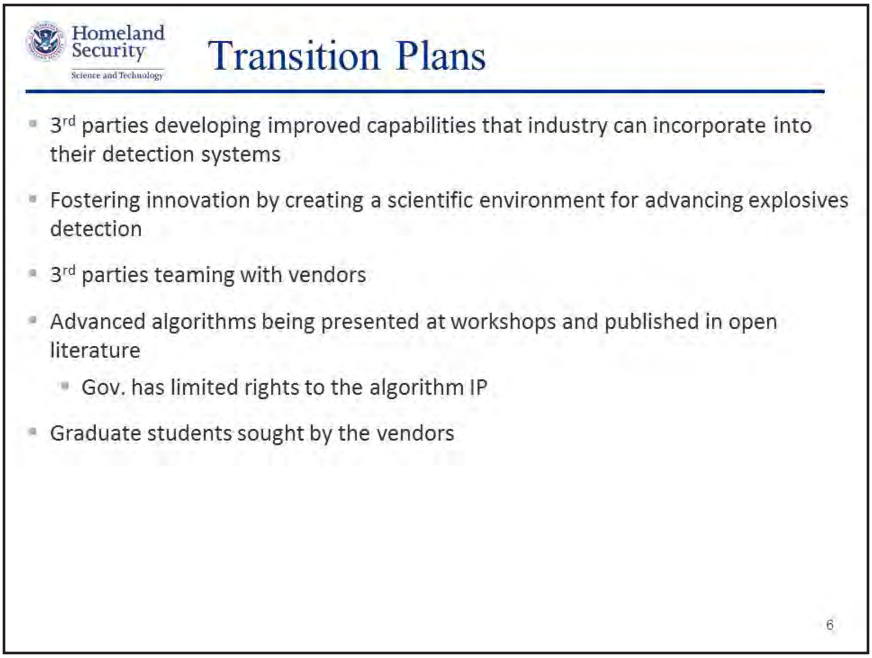
Properties	Value
No. of voxels	175,675
Mass-CT	270.51g
Volume	216.77cm^3
Density-CT	1.248g/cc



Homeland Security
Science and Technology

Technical Approach

- **Iterative Reconstruction Research**
  - Dataset Creation
    - Use database created for Segmentation effort
    - Generating additional data of projection and image data corresponding to scans of luggage and phantoms to augment existing databases
  - Improved Image Quality
    - Focus on iterative reconstruction, pre-processing of projection data and post-processing of images
    - Development and evaluation of reconstruction algorithm performance
    - Link to results of segmentation project
- **Automated Threat Recognition**
  - Independent Evaluation of Algorithms
    - Utilize database and LLNL as an independent group to test and evaluate and assist in getting their algorithms demonstrated for the vendors of security equipment



Homeland Security
Science and Technology

Transition Plans

- 3rd parties developing improved capabilities that industry can incorporate into their detection systems
- Fostering innovation by creating a scientific environment for advancing explosives detection
- 3rd parties teaming with vendors
- Advanced algorithms being presented at workshops and published in open literature
  - Gov. has limited rights to the algorithm IP
- Graduate students sought by the vendors

Homeland
Security

Science and Technology

16.26 Matt Cobey: TSA Office of Security Capabilities (OSC) Testing within an Acquisition Program

TSA Office of Security Capabilities (OSC)
Testing within an Acquisition Program

Transportation
Security
Administration

OSC Testing within an Acquisition Program

Two Types of Testing within an Acquisition Program: Developmental (DT) and Operational (OT).

DT:

Testing at the Transportation Security Lab (TSL)/TSA Systems Integration Facility (TSIF) is categorized as DT. This testing is primarily oriented toward conformance with technical requirements and is conducted under controlled conditions in laboratory or a simulated operational environment.

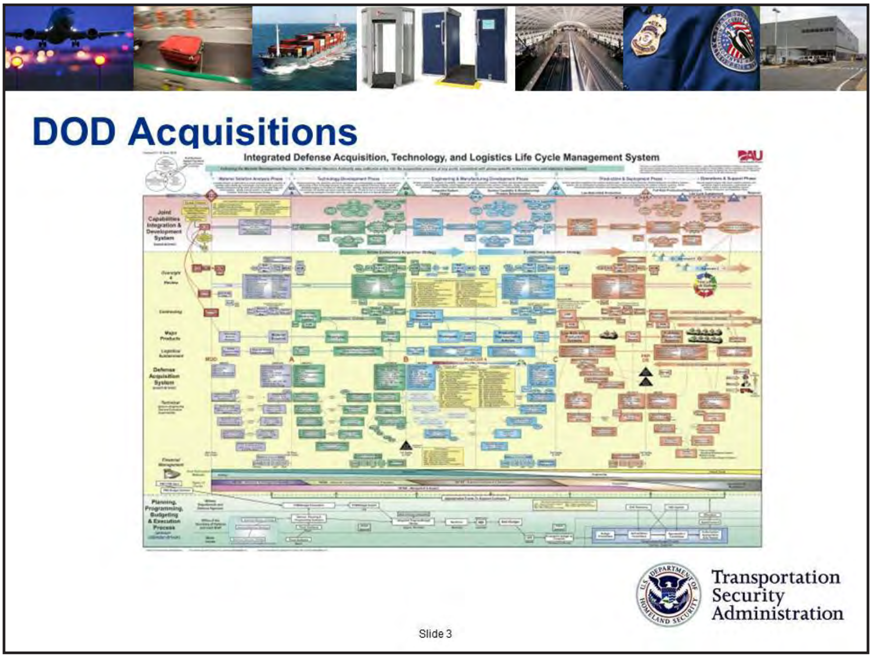
Typically, DT verification is based on requirements documented in the Procurement Specification or Functional Requirements Document (FRD).

OT:

OT is conducted in the operational environment, the airport, with typically trained users (TSOs) operating under an approved Concept of Operations (CONOPS) and Standard Operating Procedures SOP.

OT validates the system against the Operational Requirements Document (ORD) and that the system enables TSA to complete the mission of safeguarding the aviation transportation system.

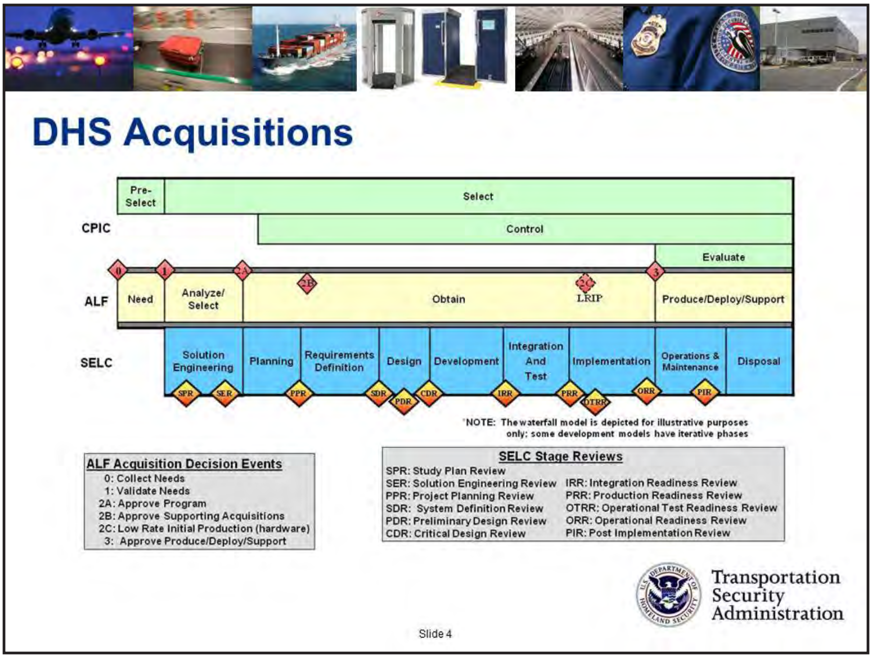
Transportation
Security
Administration



DOD Acquisitions

Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System

Transportation Security Administration



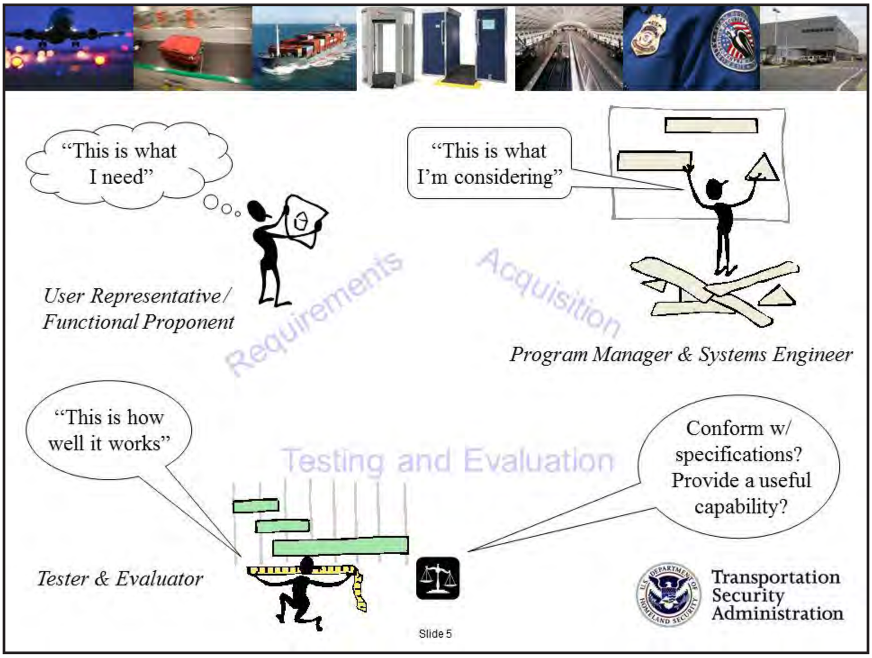
DHS Acquisitions

*NOTE: The waterfall model is depicted for illustrative purposes only; some development models have iterative phases

ALF Acquisition Decision Events
0: Collect Needs
1: Validate Needs
2A: Approve Program
2B: Approve Supporting Acquisitions
2C: Low Rate Initial Production (hardware)
3: Approve Produce/Deploy/Support

SELC Stage Reviews
SPR: Study Plan Review
SER: Solution Engineering Review
PPR: Project Planning Review
SDR: System Definition Review
PDR: Preliminary Design Review
CDR: Critical Design Review
IRR: Integration Readiness Review
PRR: Production Readiness Review
OTRR: Operational Test Readiness Review
ORR: Operational Readiness Review
PIR: Post Implementation Review

Transportation Security Administration



"This is what
I need"

User Representative/
Functional Proponent

Requirements

"This is what
I'm considering"

Acquisition

Program Manager & Systems Engineer

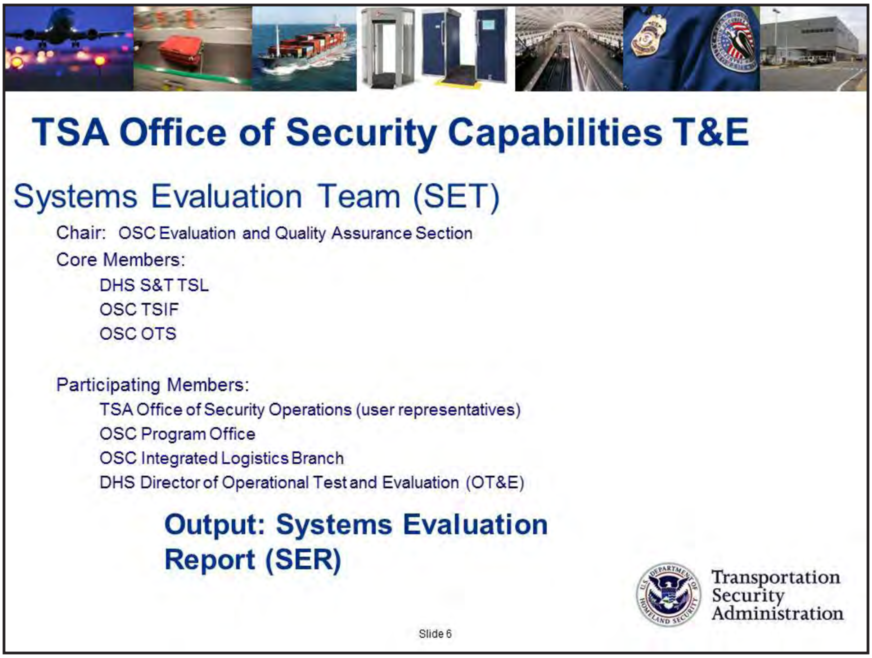
"This is how
well it works"

Testing and Evaluation

Conform w/
specifications?
Provide a useful
capability?

Tester & Evaluator

Transportation
Security
Administration



TSA Office of Security Capabilities T&E

Systems Evaluation Team (SET)

Chair: OSC Evaluation and Quality Assurance Section

Core Members:
- DHS S&T TSL
- OSC TSIF
- OSC OTS

Participating Members:
- TSA Office of Security Operations (user representatives)
- OSC Program Office
- OSC Integrated Logistics Branch
- DHS Director of Operational Test and Evaluation (OT&E)

Output: Systems Evaluation Report (SER)

Transportation
Security
Administration

Transportation Security Laboratory

Testing facility that support a wide variety research and development activites in addition to EDS certification testing

Explosive Effects Lab

Bulk Explosives Research Lab

Electromagnetic Studies of Explosives

Simulant Development Lab

Human Factors Lab

Trace Explosives Detection Lab

Certification Testing includes a comprehensive review of vendor qualification data packages and safety conformance in addition to detection and false alarm data collection.

Transportation
Security
Administration

Slide 7

TSA Systems Integration Facility (TSIF)

- Testing facility that emulates a field environment for pre-deployment integration and evaluation

- Facilitates the evaluation of concepts, systems, and technologies prior to key acquisition and deployment decisions

- Allows for Concepts of Operations (CONOPS), Standard Operating Procedures (SOP), and training development

Transportation
Security
Administration

Slide 8

TSIF Baggage Handling System Test Area

Transportation
Security
Administration

Slide 9

Operational Testing

Tests Systems against Critical Operational Issues (COI) and Additional Issues (AI)

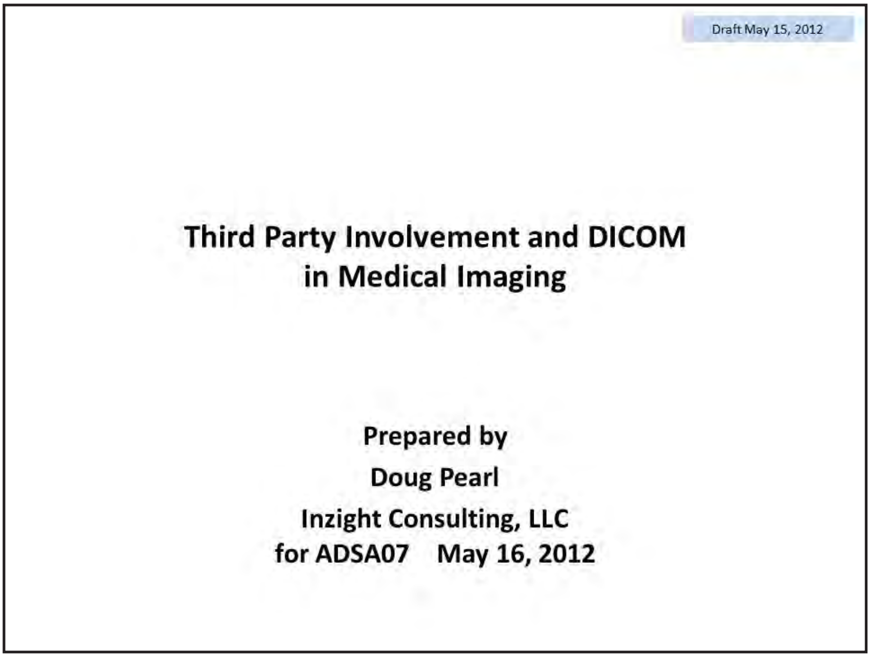
COI 1 - Mission Performance
COI 2 – Interoperability
COI 3 – Availability
AI 4 – Logistics Supportability
AI 5 – Human-Systems Integration (HSI)
AI 6 – Information Assurance

Bottomline: Do the systems enable TSA to prevent this

Transportation
Security
Administration

Slide 10

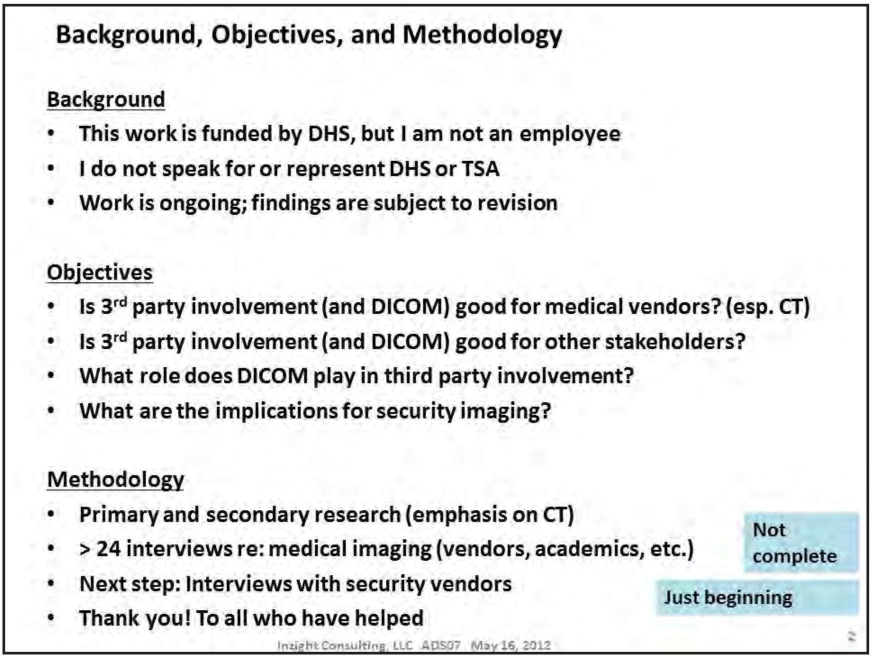
16.27 Doug Pearl: Third Party Involvement and DICOM in Medical Imaging



Draft May 15, 2012

Third Party Involvement and DICOM in Medical Imaging

Prepared by
Doug Pearl
Inzight Consulting, LLC
for ADSA07 May 16, 2012



Background, Objectives, and Methodology

Background

- This work is funded by DHS, but I am not an employee
- I do not speak for or represent DHS or TSA
- Work is ongoing; findings are subject to revision

Objectives

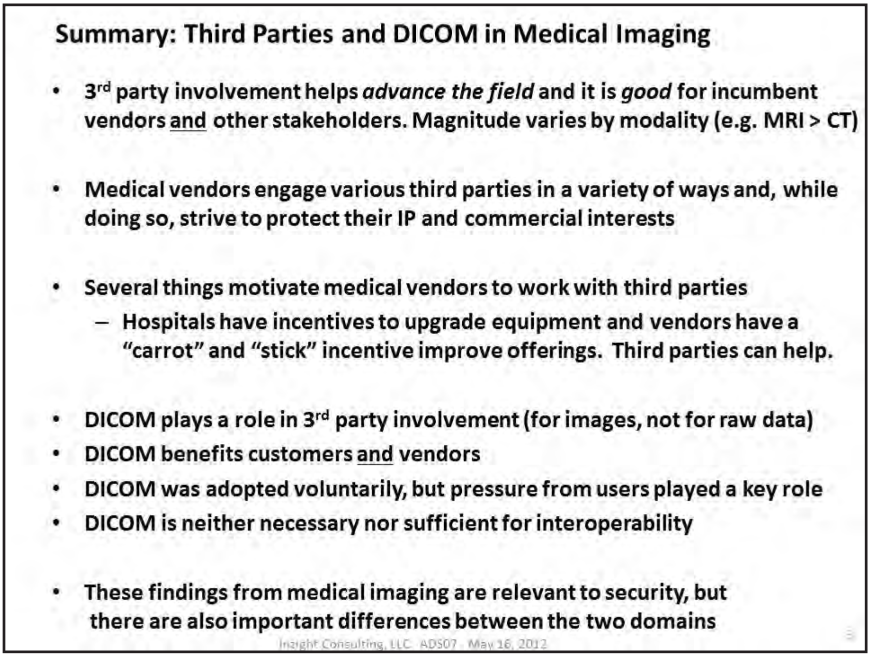
- Is 3rd party involvement (and DICOM) good for medical vendors? (esp. CT)
- Is 3rd party involvement (and DICOM) good for other stakeholders?
- What role does DICOM play in third party involvement?
- What are the implications for security imaging?

Methodology

- Primary and secondary research (emphasis on CT)
- > 24 interviews re: medical imaging (vendors, academics, etc.)
- Next step: Interviews with security vendors
- Thank you! To all who have helped

Not complete

Just beginning



Summary: Third Parties and DICOM in Medical Imaging

- 3rd party involvement helps *advance the field* and it is *good* for incumbent vendors and other stakeholders. Magnitude varies by modality (e.g. MRI > CT)
- Medical vendors engage various third parties in a variety of ways and, while doing so, strive to protect their IP and commercial interests
- Several things motivate medical vendors to work with third parties
  - Hospitals have incentives to upgrade equipment and vendors have a "carrot" and "stick" incentive improve offerings. Third parties can help.
- DICOM plays a role in 3rd party involvement (for images, not for raw data)
- DICOM benefits customers and vendors
- DICOM was adopted voluntarily, but pressure from users played a key role
- DICOM is neither necessary nor sufficient for interoperability
- These findings from medical imaging are relevant to security, but there are also important differences between the two domains

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Medical Market Characteristics (Possible Differences vs. Security)

- Large vibrant ecosystem of MD, PhD, Vendors (e.g. RSNA)
- Large and growing market, with proven ability to absorb new advances
- Thousands of customers: different niches, buying criteria, and timelines
- Potential for serendipity→innovation→new applications and markets
- Third Parties in medical imaging have
  - Common understanding of goals and close relationships with vendors
  - Access to MDs, images, cutting-edge problems, and feedback loops

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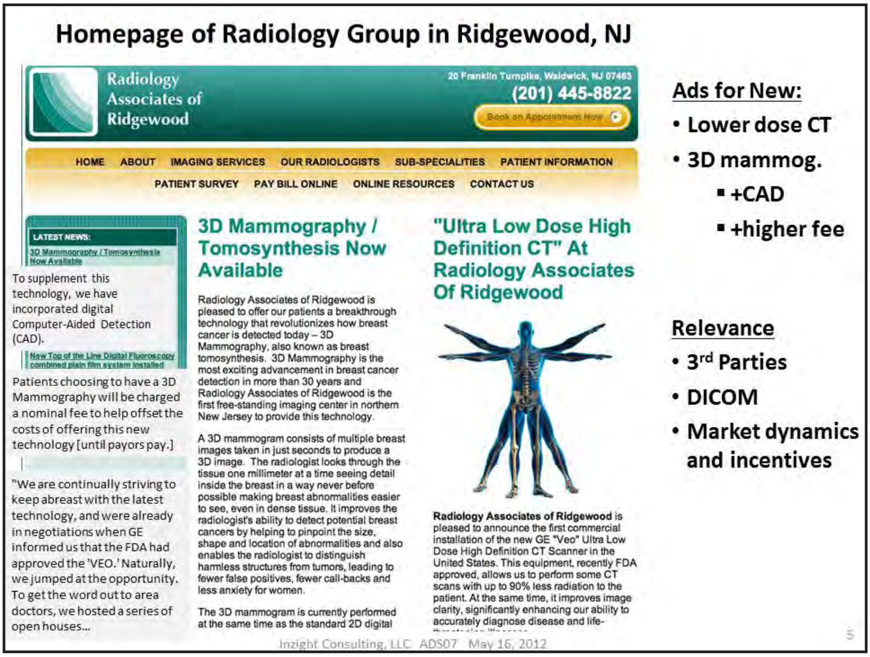

Homepage of Radiology Group in Ridgewood, NJ

Radiology
Associates of
Ridgewood

20 Franklin Turnpike, Waldwick, NJ 07463
(201) 445-8822

LATEST NEWS:

3D Mammography / Tomosynthesis Now Available

To supplement this technology, we have incorporated digital Computer-Aided Detection (CAD).

New Top of the Line Digital Fluoroscopy combined plain film system installed

Patients choosing to have a 3D Mammography will be charged a nominal fee to help offset the costs of offering this new technology [until payors pay.]

"We are continually striving to keep abreast with the latest technology, and were already in negotiations when GE informed us that the FDA had approved the 'VEO.' Naturally, we jumped at the opportunity. To get the word out to area doctors, we hosted a series of open houses...

3D Mammography / Tomosynthesis Now Available

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A 3D mammogram consists of multiple breast images taken in just seconds to produce a 3D image. The radiologist looks through the tissue one millimeter at a time seeing detail inside the breast in a way never before possible making breast abnormalities easier to see, even in dense tissue. It improves the radiologist's ability to detect potential breast cancers by helping to pinpoint the size, shape and location of abnormalities and also enables the radiologist to distinguish harmless structures from tumors, leading to fewer false positives, fewer call-backs and less anxiety for women.

The 3D mammogram is currently performed at the same time as the standard 2D digital

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Ads for New:

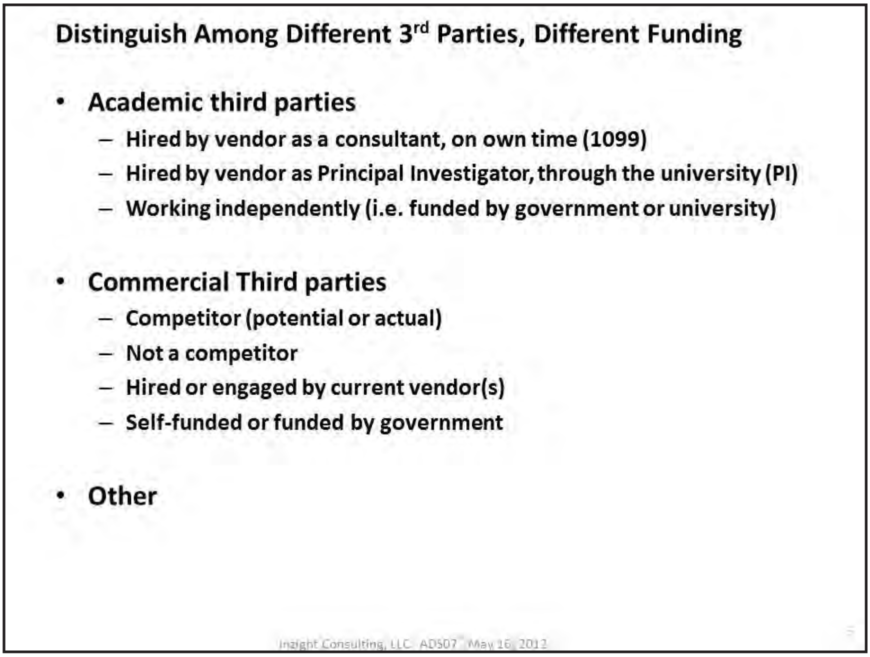
- Lower dose CT
- 3D mammog.
  - +CAD
  - +higher fee

Relevance

- 3rd Parties
- DICOM
- Market dynamics and incentives

Agenda/Contents

- Background, Objectives and Methodology
- Caveats
- Summary
- Medical Market Characteristics
- → Types of third parties; types of involvement
- → Is 3rd party involvement good for vendors? Other stakeholders?
- How do vendors protect their interests?
- MRI versus CT
- Government role in third party funding
- Role of DICOM in medical imaging and third party involvement
- Summary



Distinguish Among Different 3rd Parties, Different Funding

- Academic third parties
  - Hired by vendor as a consultant, on own time (1099)
  - Hired by vendor as Principal Investigator, through the university (PI)
  - Working independently (i.e. funded by government or university)
- Commercial Third parties
  - Competitor (potential or actual)
  - Not a competitor
  - Hired or engaged by current vendor(s)
  - Self-funded or funded by government
- Other

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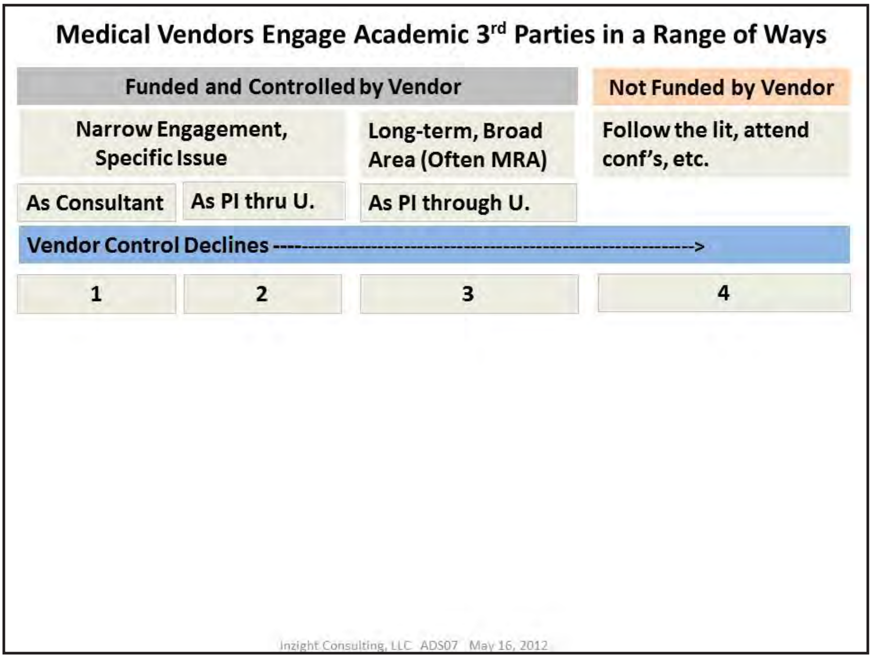

Medical Vendors Engage Academic 3rd Parties in a Range of Ways

Funded and Controlled by Vendor			Not Funded by Vendor
Narrow Engagement, Specific Issue		Long-term, Broad Area (Often MRA)	Follow the lit, attend conf's, etc.
As Consultant	As PI thru U.	As PI through U.	
Vendor Control Declines -->			
1	2	3	4

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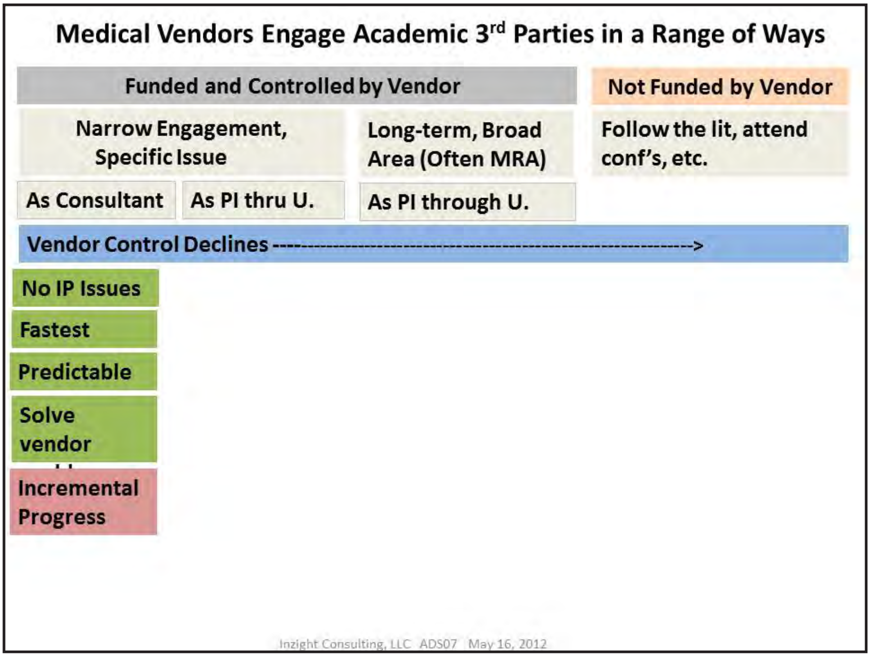

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Vendor Control Declines -->

- No IP Issues
- Fastest
- Predictable
- Solve vendor
- Incremental Progress

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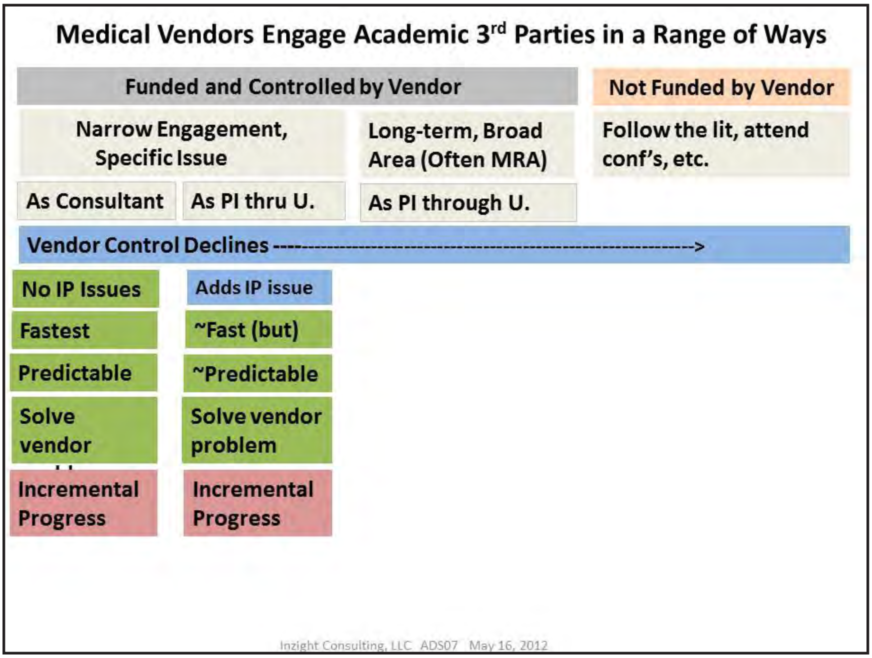

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Vendor Control Declines -->

No IP Issues	Adds IP issue
Fastest	~Fast (but)
Predictable	~Predictable
Solve vendor	Solve vendor problem
Incremental Progress	Incremental Progress

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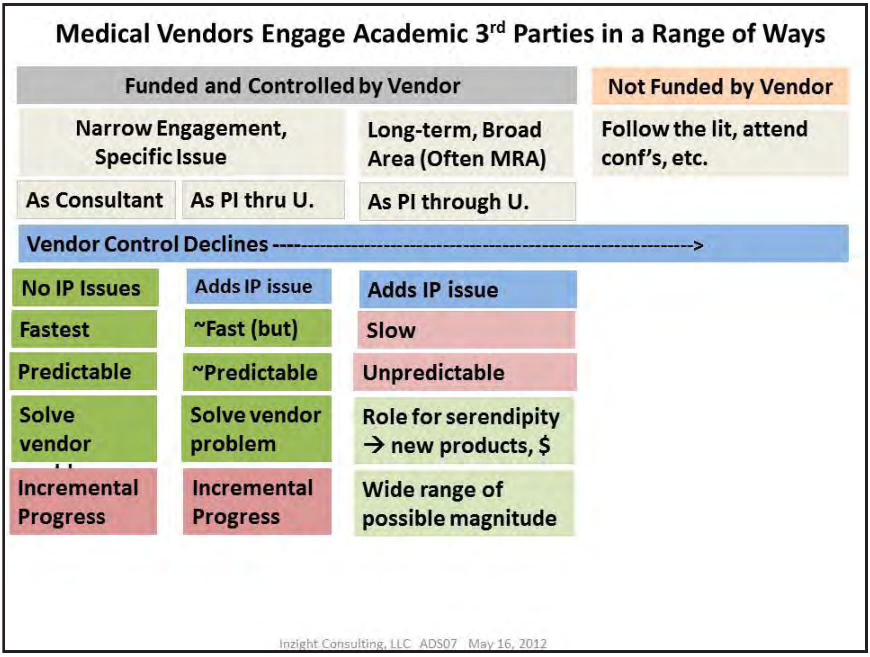

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Vendor Control Declines -->			
No IP Issues	Adds IP issue	Adds IP issue	
Fastest	~Fast (but)	Slow	
Predictable	~Predictable	Unpredictable	
Solve vendor	Solve vendor problem	Role for serendipity → new products, $	
Incremental Progress	Incremental Progress	Wide range of possible magnitude	

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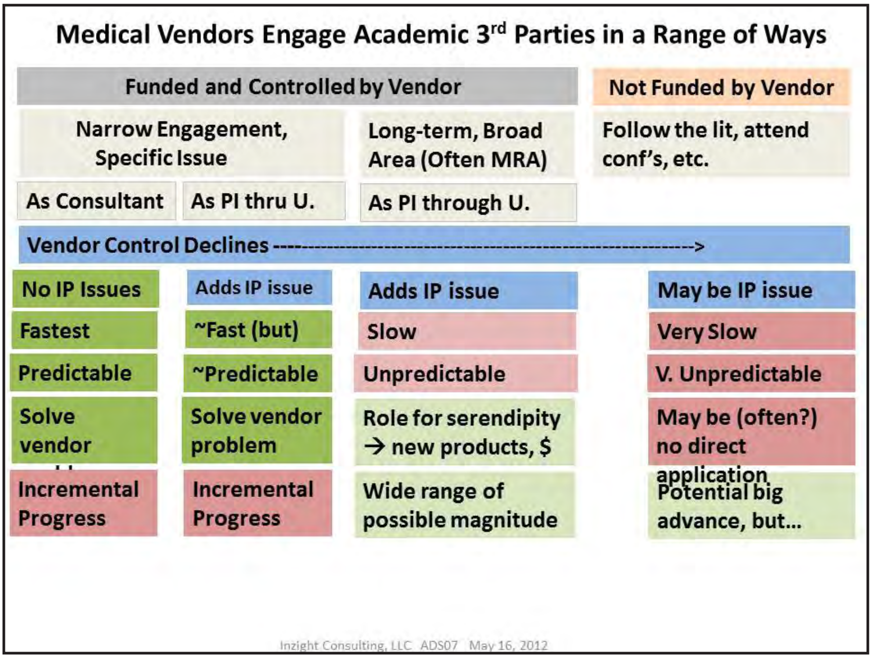

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Narrow Engagement, Specific Issue		Long-term, Broad Area (Often MRA)	Follow the lit, attend conf's, etc.
As Consultant	As PI thru U.	As PI through U.	
Vendor Control Declines -->			
No IP Issues	Adds IP issue	Adds IP issue	May be IP issue
Fastest	~Fast (but)	Slow	Very Slow
Predictable	~Predictable	Unpredictable	V. Unpredictable
Solve vendor	Solve vendor problem	Role for serendipity → new products, $	May be (often?) no direct application
Incremental Progress	Incremental Progress	Wide range of possible magnitude	Potential big advance, but…

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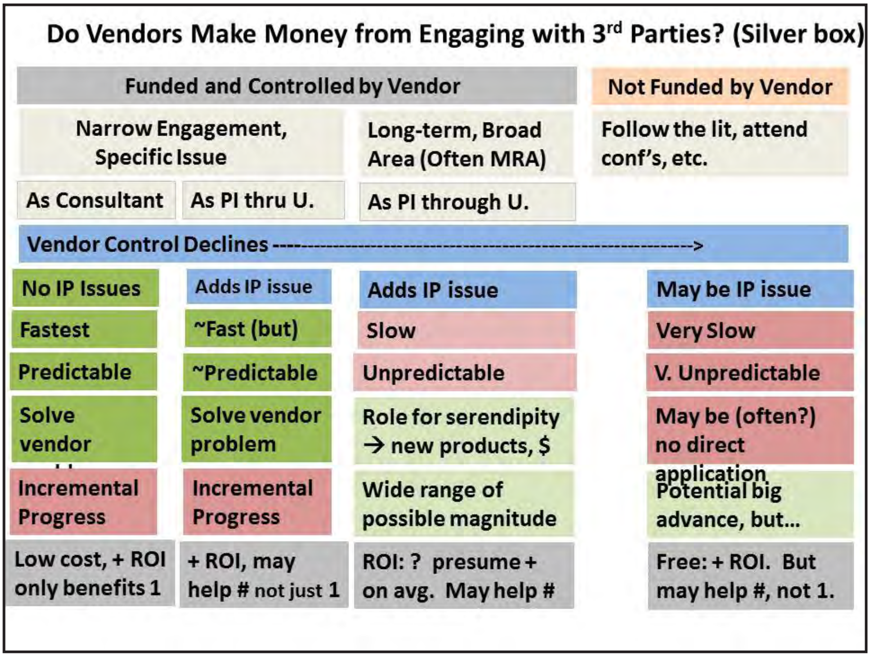
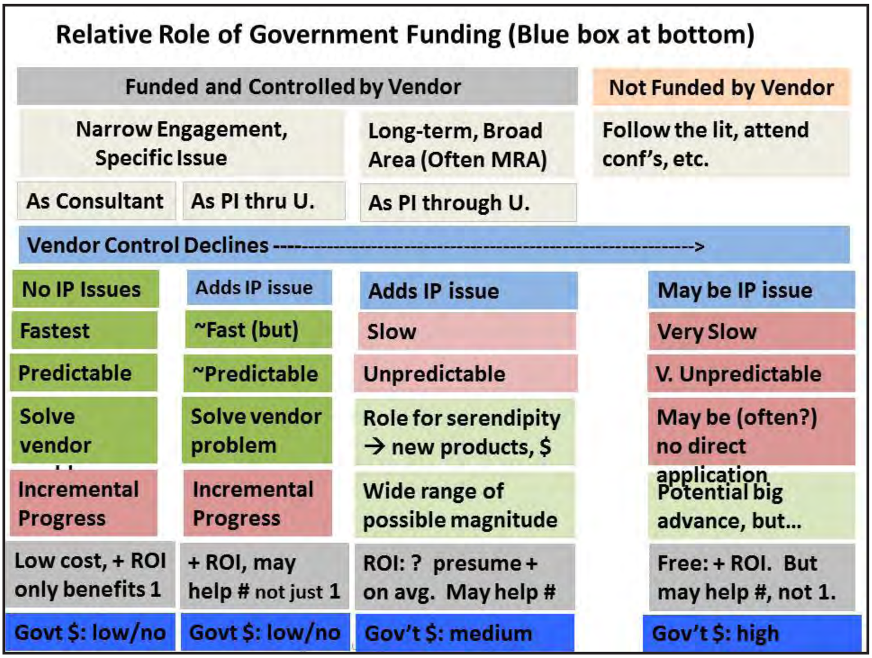


Do Vendors Make Money from Engaging with 3rd Parties? (Silver box)

Funded and Controlled by Vendor			Not Funded by Vendor
Narrow Engagement, Specific Issue		Long-term, Broad Area (Often MRA)	Follow the lit, attend conf's, etc.
As Consultant	As PI thru U.	As PI through U.	
Vendor Control Declines -->			
No IP Issues	Adds IP issue	Adds IP issue	May be IP issue
Fastest	~Fast (but)	Slow	Very Slow
Predictable	~Predictable	Unpredictable	V. Unpredictable
Solve vendor	Solve vendor problem	Role for serendipity → new products, $	May be (often?) no direct application
Incremental Progress	Incremental Progress	Wide range of possible magnitude	Potential big advance, but…
Low cost, + ROI only benefits 1	+ ROI, may help # not just 1	ROI: ? presume + on avg. May help #	Free: + ROI. But may help #, not 1.



Relative Role of Government Funding (Blue box at bottom)

Funded and Controlled by Vendor			Not Funded by Vendor
Narrow Engagement, Specific Issue		Long-term, Broad Area (Often MRA)	Follow the lit, attend conf's, etc.
As Consultant	As PI thru U.	As PI through U.	
Vendor Control Declines -->			
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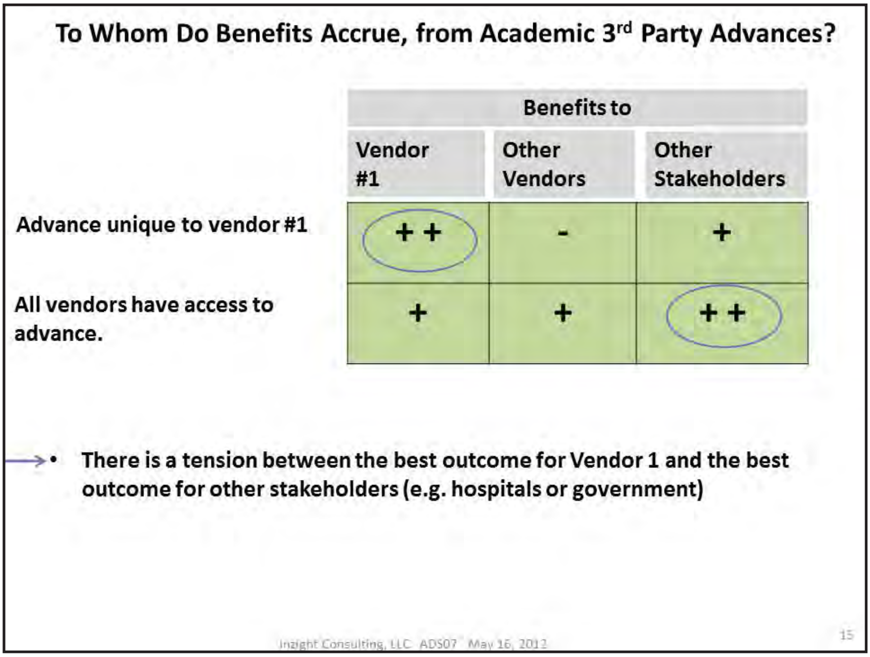
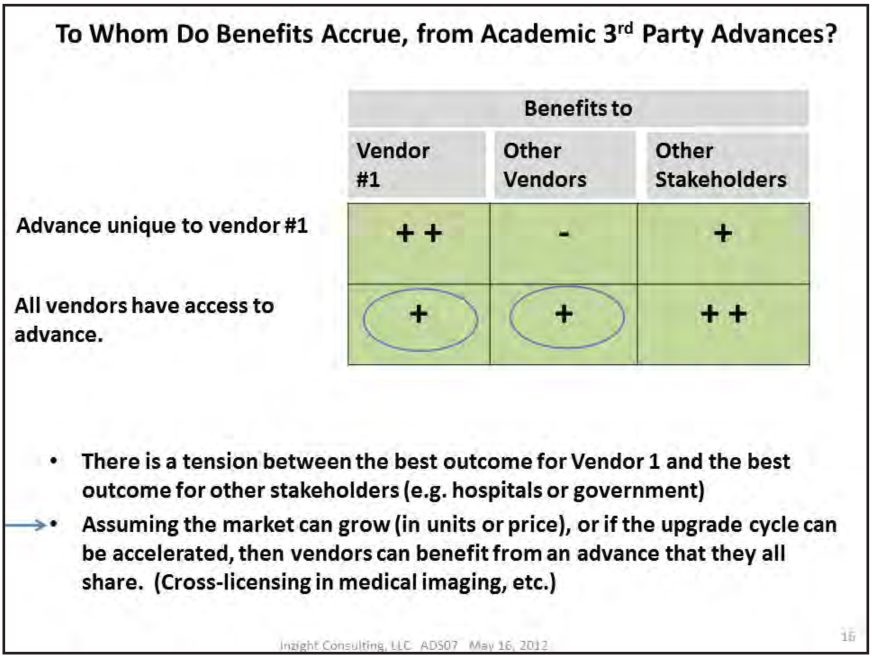
Fastest	~Fast (but)	Slow	Very Slow
Predictable	~Predictable	Unpredictable	V. Unpredictable
Solve vendor	Solve vendor problem	Role for serendipity → new products, $	May be (often?) no direct application
Incremental Progress	Incremental Progress	Wide range of possible magnitude	Potential big advance, but…
Low cost, + ROI only benefits 1	+ ROI, may help # not just 1	ROI: ? presume + on avg. May help #	Free: + ROI. But may help #, not 1.
Govt $: low/no	Govt $: low/no	Gov't $: medium	Gov't $: high



To Whom Do Benefits Accrue, from Academic 3rd Party Advances?

	Benefits to		
	Vendor #1	Other Vendors	Other Stakeholders
Advance unique to vendor #1	+ +	-	+
All vendors have access to advance.	+	+	+ +

- There is a tension between the best outcome for Vendor 1 and the best outcome for other stakeholders (e.g. hospitals or government)



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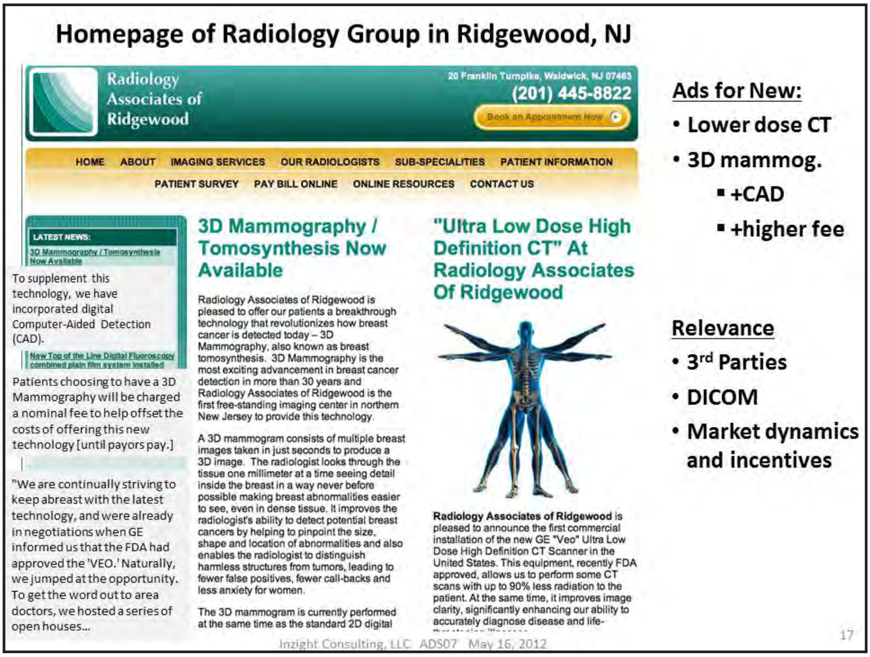
	Benefits to		
	Vendor #1	Other Vendors	Other Stakeholders
Advance unique to vendor #1	+ +	-	+
All vendors have access to advance.	+	+	+ +

- There is a tension between the best outcome for Vendor 1 and the best outcome for other stakeholders (e.g. hospitals or government)
- Assuming the market can grow (in units or price), or if the upgrade cycle can be accelerated, then vendors can benefit from an advance that they all share. (Cross-licensing in medical imaging, etc.)



Homepage of Radiology Group in Ridgewood, NJ

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- Lower dose CT
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  - +CAD
  - +higher fee

Relevance
- 3rd Parties
- DICOM
- Market dynamics and incentives

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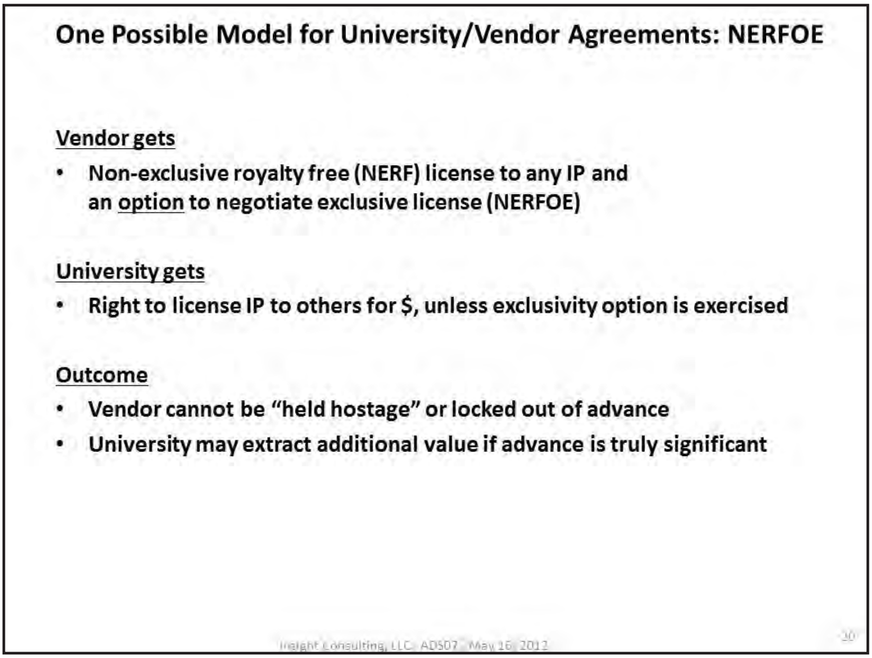
Vendors Protect Their Interests with Research Agreements, etc.

- NDA and data restrictions
- Publication review (NDA Issues; IP issues) (Not always observed)
- IP provisions
- May use Master Research Agreements (MRA)
  - Can take 3 to 6 months to negotiate
- Non-compete agreements
- Relationships and Trust



One Possible Model for University/Vendor Agreements: NERFOE

Vendor gets

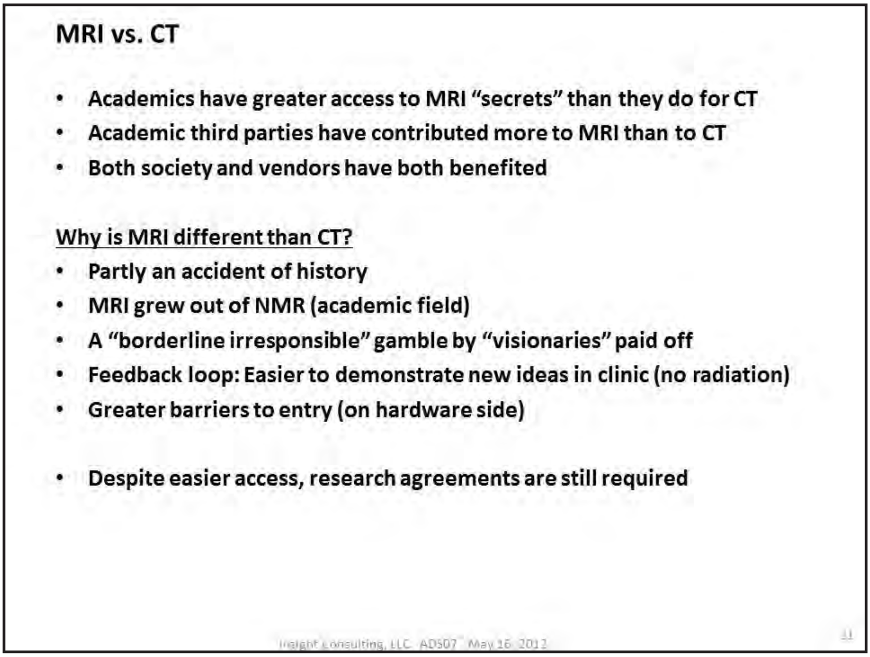
- Non-exclusive royalty free (NERF) license to any IP and an option to negotiate exclusive license (NERFOE)

University gets

- Right to license IP to others for $, unless exclusivity option is exercised

Outcome

- Vendor cannot be "held hostage" or locked out of advance
- University may extract additional value if advance is truly significant



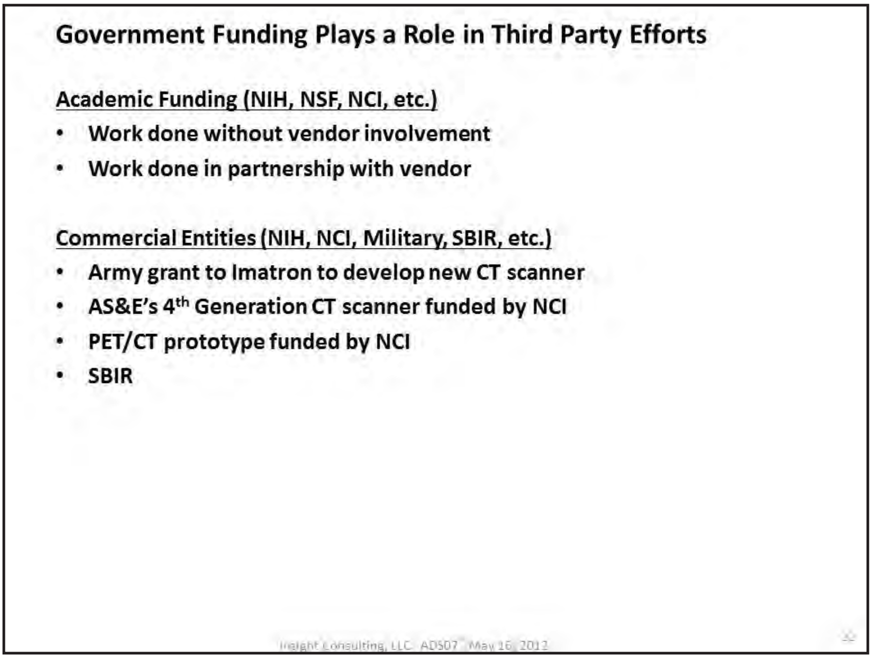
MRI vs. CT

- Academics have greater access to MRI "secrets" than they do for CT
- Academic third parties have contributed more to MRI than to CT
- Both society and vendors have both benefited

<u>Why is MRI different than CT?</u>

- Partly an accident of history
- MRI grew out of NMR (academic field)
- A "borderline irresponsible" gamble by "visionaries" paid off
- Feedback loop: Easier to demonstrate new ideas in clinic (no radiation)
- Greater barriers to entry (on hardware side)

- Despite easier access, research agreements are still required



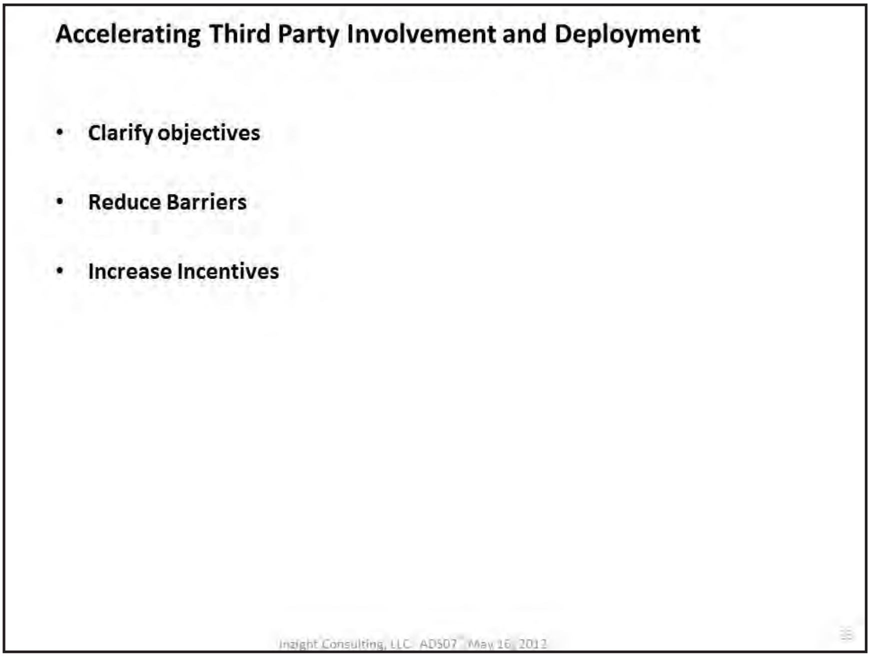
Government Funding Plays a Role in Third Party Efforts

<u>Academic Funding (NIH, NSF, NCI, etc.)</u>

- Work done without vendor involvement
- Work done in partnership with vendor

<u>Commercial Entities (NIH, NCI, Military, SBIR, etc.)</u>

- Army grant to Imatron to develop new CT scanner
- AS&E's 4th Generation CT scanner funded by NCI
- PET/CT prototype funded by NCI
- SBIR



Accelerating Third Party Involvement and Deployment

- Clarify objectives
- Reduce Barriers
- Increase Incentives

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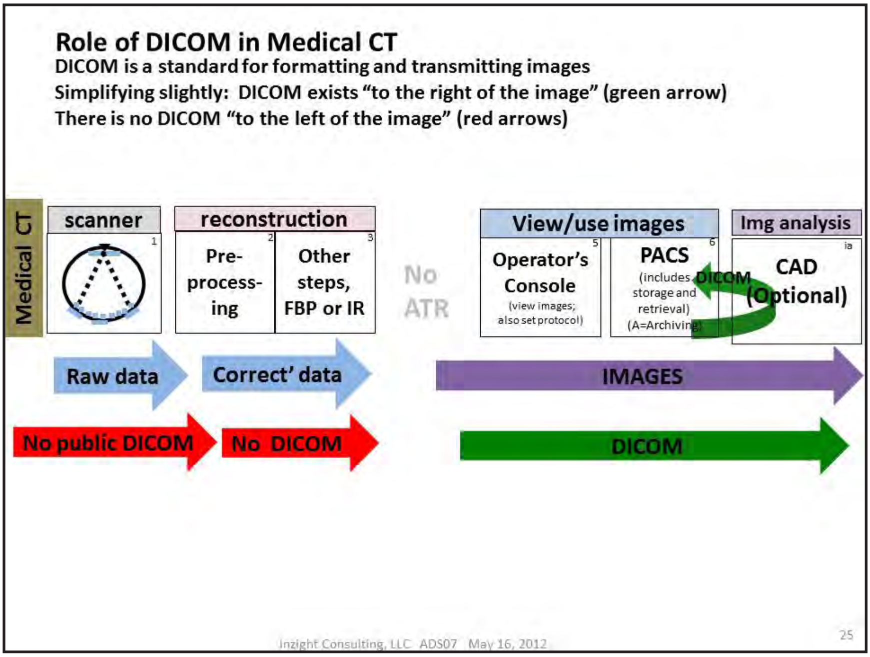


Role of DICOM in Medical CT

DICOM is a standard for formatting and transmitting images
Simplifying slightly: DICOM exists "to the right of the image" (green arrow)
There is no DICOM "to the left of the image" (red arrows)

Medical CT

scanner 1

reconstruction

Pre-processing 2

Other steps, FBP or IR 3

No ATR

View/use images

Operator's Console 5
(view images; also set protocol)

PACS 6
(includes storage and retrieval)
(A=Archiving)

DICOM

Img analysis

CAD ia
(Optional)

Raw data

Correct' data

IMAGES

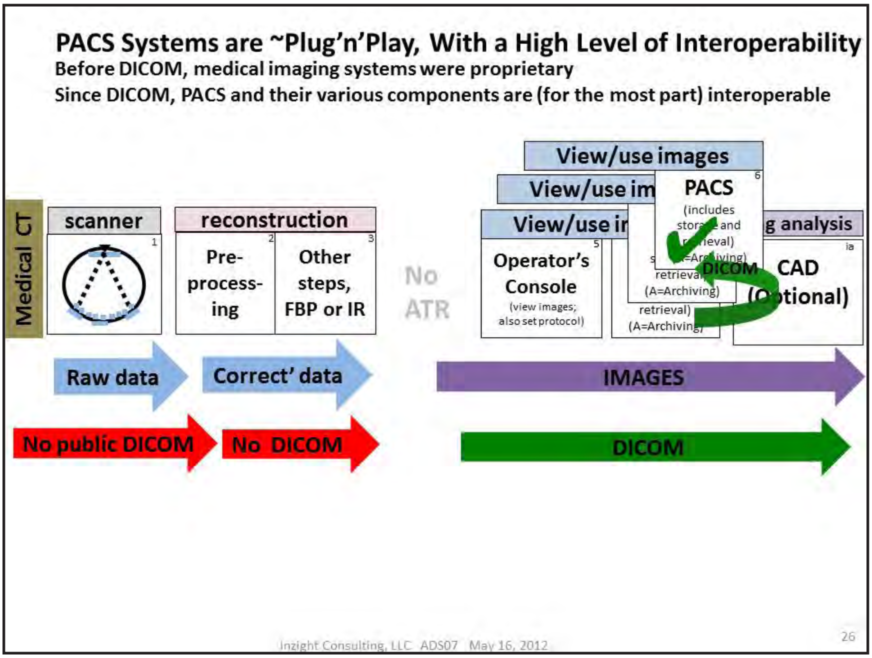
No public DICOM

No DICOM

DICOM

Inzight Consulting, LLC ADS07 May 16, 2012

25



PACS Systems are ~Plug'n'Play, With a High Level of Interoperability

Before DICOM, medical imaging systems were proprietary
Since DICOM, PACS and their various components are (for the most part) interoperable

Medical CT

scanner 1

reconstruction

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View/use images

View/use im

View/use ir

Operator's Console 5
(view images; also set protocol)

PACS 6
(includes storage and retrieval)
(A=Archiving)

retrieval)
(A=Archiving)

DICOM

g analysis

CAD ia
(Optional)

Raw data

Correct' data

IMAGES

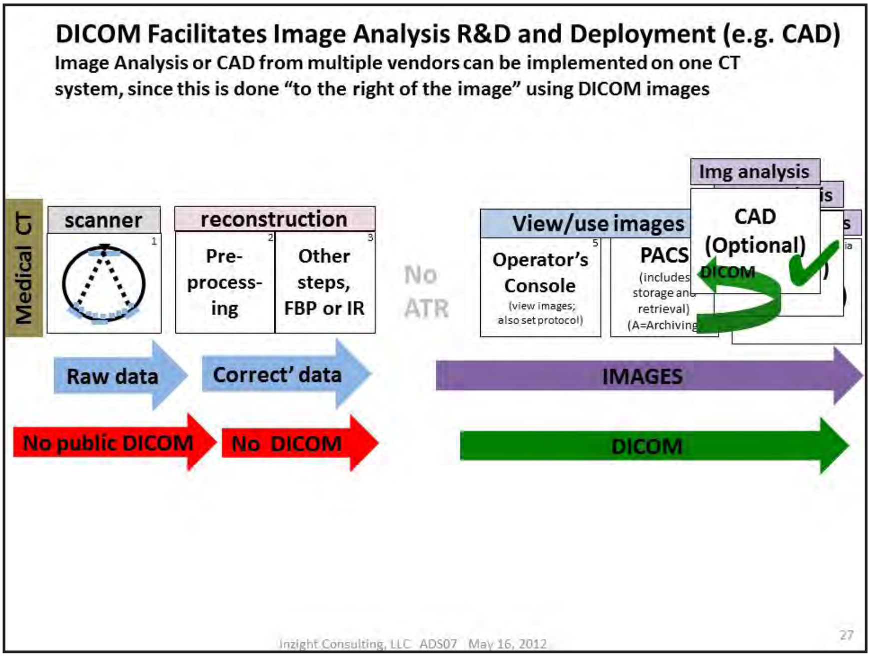
No public DICOM

No DICOM

DICOM

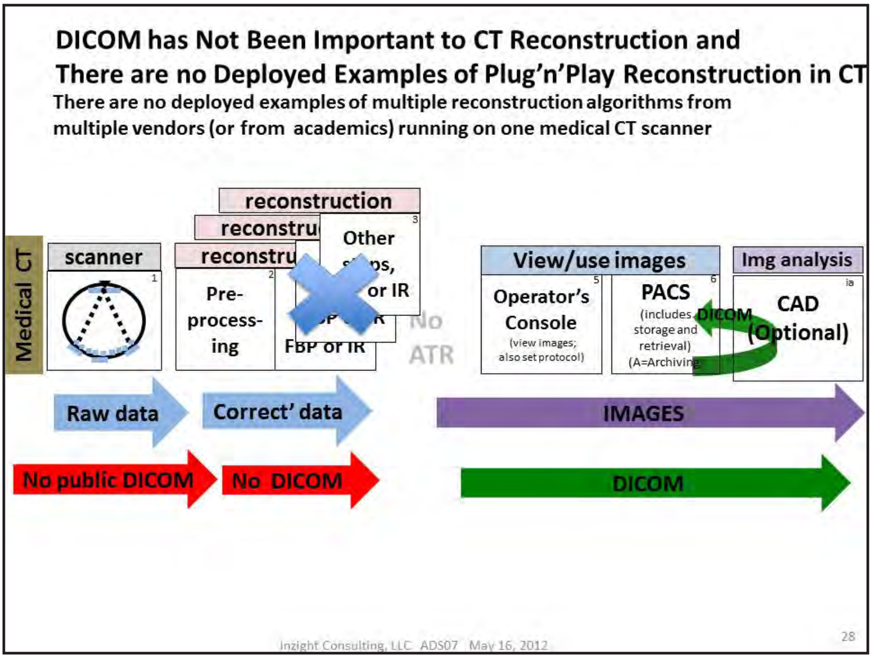
Inzight Consulting, LLC ADS07 May 16, 2012

26



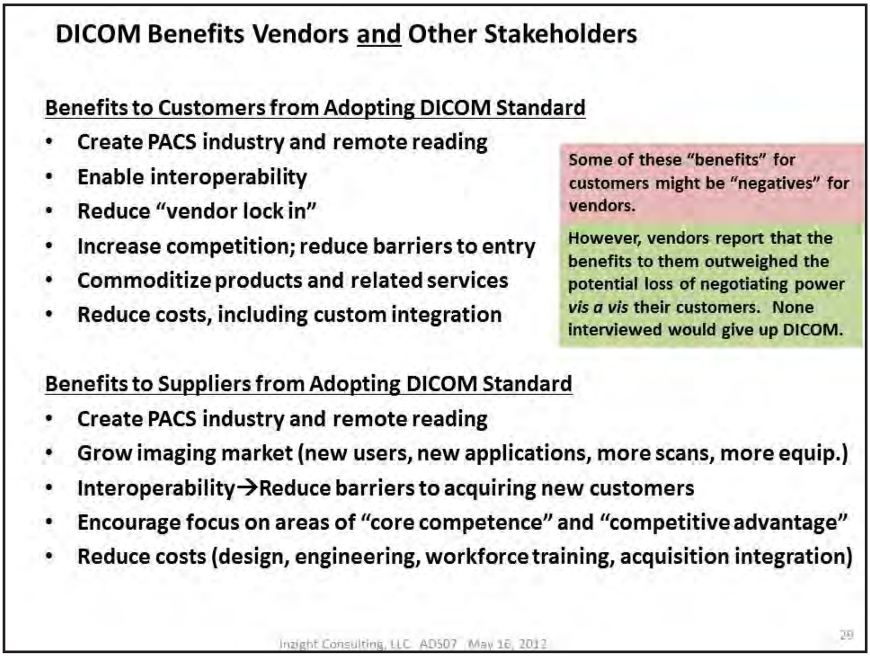
DICOM Facilitates Image Analysis R&D and Deployment (e.g. CAD)

Image Analysis or CAD from multiple vendors can be implemented on one CT system, since this is done "to the right of the image" using DICOM images



DICOM has Not Been Important to CT Reconstruction and There are no Deployed Examples of Plug'n'Play Reconstruction in CT

There are no deployed examples of multiple reconstruction algorithms from multiple vendors (or from academics) running on one medical CT scanner



DICOM Benefits Vendors and Other Stakeholders

Benefits to Customers from Adopting DICOM Standard

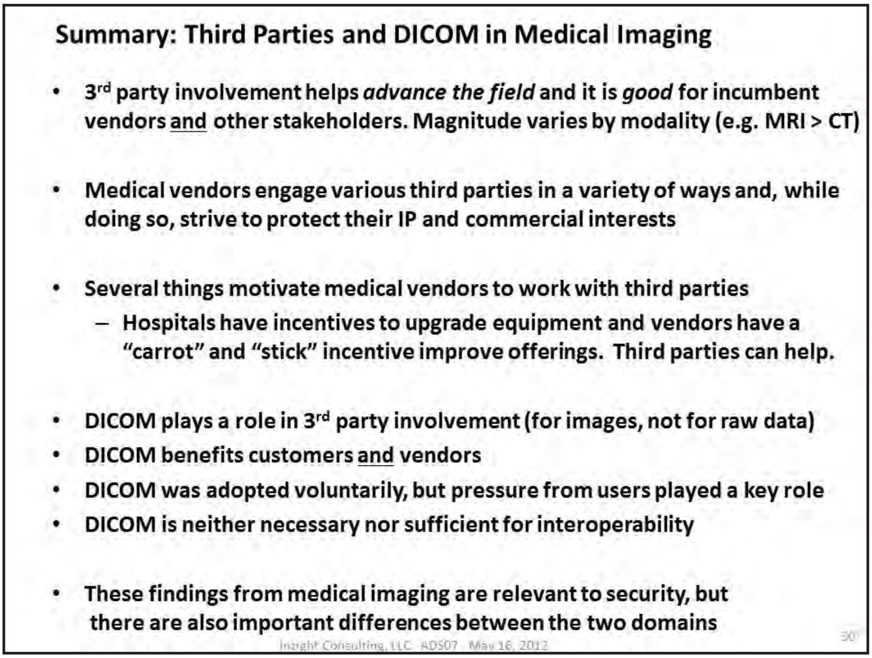
- Create PACS industry and remote reading
- Enable interoperability
- Reduce "vendor lock in"
- Increase competition; reduce barriers to entry
- Commoditize products and related services
- Reduce costs, including custom integration

Some of these "benefits" for customers might be "negatives" for vendors.

However, vendors report that the benefits to them outweighed the potential loss of negotiating power *vis a vis* their customers. None interviewed would give up DICOM.

Benefits to Suppliers from Adopting DICOM Standard

- Create PACS industry and remote reading
- Grow imaging market (new users, new applications, more scans, more equip.)
- Interoperability→Reduce barriers to acquiring new customers
- Encourage focus on areas of "core competence" and "competitive advantage"
- Reduce costs (design, engineering, workforce training, acquisition integration)



Summary: Third Parties and DICOM in Medical Imaging

- 3rd party involvement helps *advance the field* and it is *good* for incumbent vendors and other stakeholders. Magnitude varies by modality (e.g. MRI > CT)
- Medical vendors engage various third parties in a variety of ways and, while doing so, strive to protect their IP and commercial interests
- Several things motivate medical vendors to work with third parties
  - Hospitals have incentives to upgrade equipment and vendors have a "carrot" and "stick" incentive improve offerings. Third parties can help.
- DICOM plays a role in 3rd party involvement (for images, not for raw data)
- DICOM benefits customers and vendors
- DICOM was adopted voluntarily, but pressure from users played a key role
- DICOM is neither necessary nor sufficient for interoperability
- These findings from medical imaging are relevant to security, but there are also important differences between the two domains

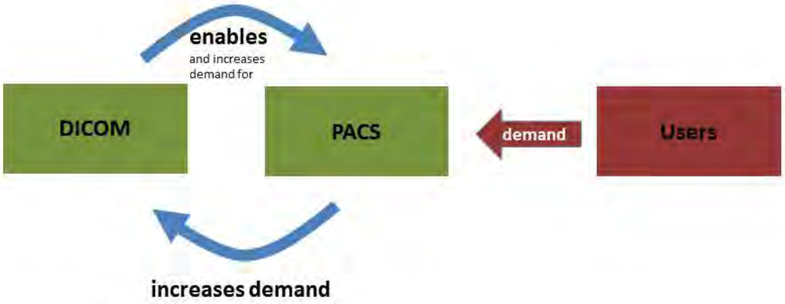
End

Backup

DICOM and PACS Created a Virtuous Circle of Increased Demand

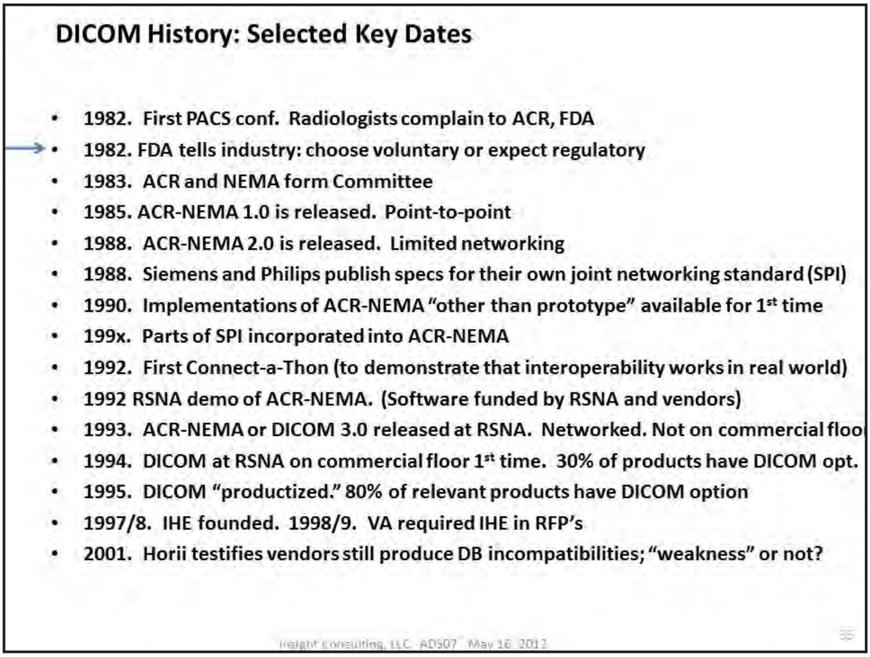
One vendor pointed out: "People say DICOM enabled PACS. But you can also say that the market demand for PACS created demand for DICOM. The two were 'chicken and egg.' "

Also note that the User Demand (red arrow) is Demand in three overlapping senses: 1) Market Demand (users will buy it), 2) Users insist on it, and 3) there is a compelling logical use or "need" for it.



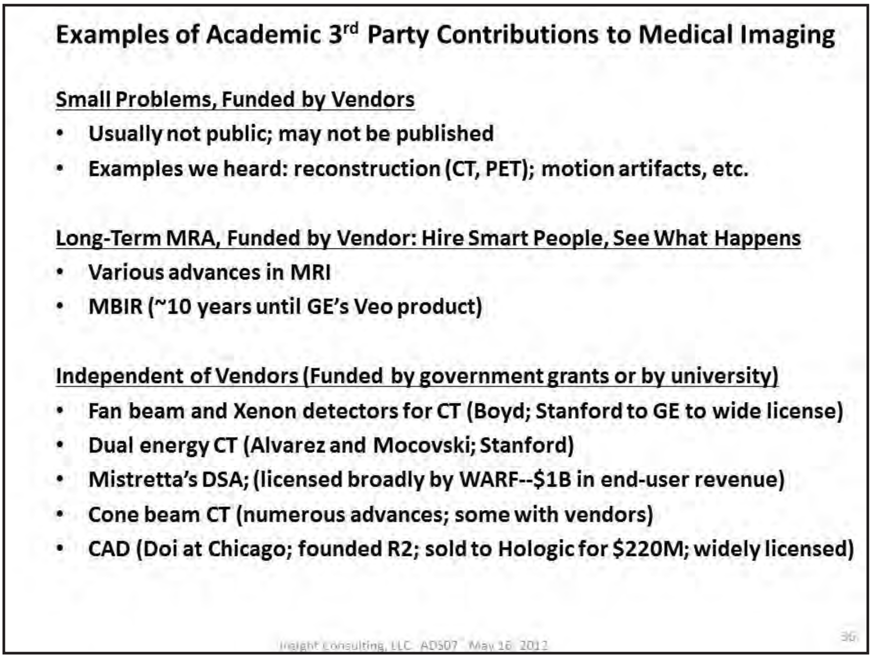
DICOM History: Selected Key Dates

- 1982. PACS conference. Need identified. MD complain to ACR, FDA.
- 1982. FDA tells industry: choose voluntary or expect regulatory
- Next 10 years: slow progress, some resistance, foot dragging
- 1990. Implementations "other than prototype" available for 1st time
- 1992-1994 RSNA demos; sense of possible→sense of inevitable
- 1994-5 DICOM at RSNA on commercial floor. 30%→80% products
- Ongoing: Connect-a-thons continue; needed to demonstrate interoperability



DICOM History: Selected Key Dates

- 1982. First PACS conf. Radiologists complain to ACR, FDA
- 1982. FDA tells industry: choose voluntary or expect regulatory
- 1983. ACR and NEMA form Committee
- 1985. ACR-NEMA 1.0 is released. Point-to-point
- 1988. ACR-NEMA 2.0 is released. Limited networking
- 1988. Siemens and Philips publish specs for their own joint networking standard (SPI)
- 1990. Implementations of ACR-NEMA "other than prototype" available for 1st time
- 199x. Parts of SPI incorporated into ACR-NEMA
- 1992. First Connect-a-Thon (to demonstrate that interoperability works in real world)
- 1992 RSNA demo of ACR-NEMA. (Software funded by RSNA and vendors)
- 1993. ACR-NEMA or DICOM 3.0 released at RSNA. Networked. Not on commercial floo
- 1994. DICOM at RSNA on commercial floor 1st time. 30% of products have DICOM opt.
- 1995. DICOM "productized." 80% of relevant products have DICOM option
- 1997/8. IHE founded. 1998/9. VA required IHE in RFP's
- 2001. Horii testifies vendors still produce DB incompatibilities; "weakness" or not?



Examples of Academic 3rd Party Contributions to Medical Imaging

Small Problems, Funded by Vendors

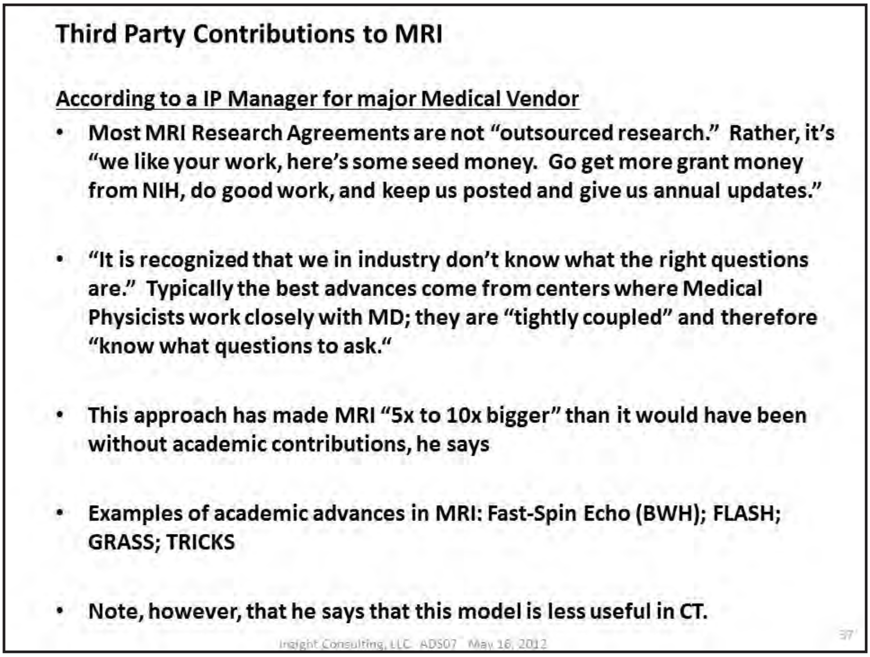
- Usually not public; may not be published
- Examples we heard: reconstruction (CT, PET); motion artifacts, etc.

Long-Term MRA, Funded by Vendor: Hire Smart People, See What Happens

- Various advances in MRI
- MBIR (~10 years until GE's Veo product)

Independent of Vendors (Funded by government grants or by university)

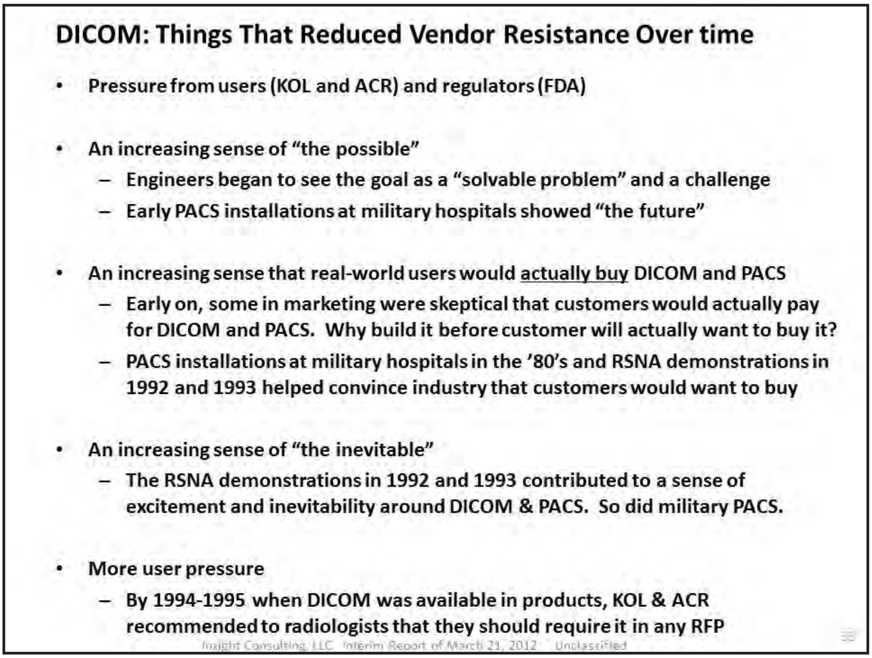
- Fan beam and Xenon detectors for CT (Boyd; Stanford to GE to wide license)
- Dual energy CT (Alvarez and Mocovski; Stanford)
- Mistretta's DSA; (licensed broadly by WARF--$1B in end-user revenue)
- Cone beam CT (numerous advances; some with vendors)
- CAD (Doi at Chicago; founded R2; sold to Hologic for $220M; widely licensed)



Third Party Contributions to MRI

<u>According to a IP Manager for major Medical Vendor</u>

- Most MRI Research Agreements are not "outsourced research." Rather, it's "we like your work, here's some seed money. Go get more grant money from NIH, do good work, and keep us posted and give us annual updates."
- "It is recognized that we in industry don't know what the right questions are." Typically the best advances come from centers where Medical Physicists work closely with MD; they are "tightly coupled" and therefore "know what questions to ask."
- This approach has made MRI "5x to 10x bigger" than it would have been without academic contributions, he says
- Examples of academic advances in MRI: Fast-Spin Echo (BWH); FLASH; GRASS; TRICKS
- Note, however, that he says that this model is less useful in CT.



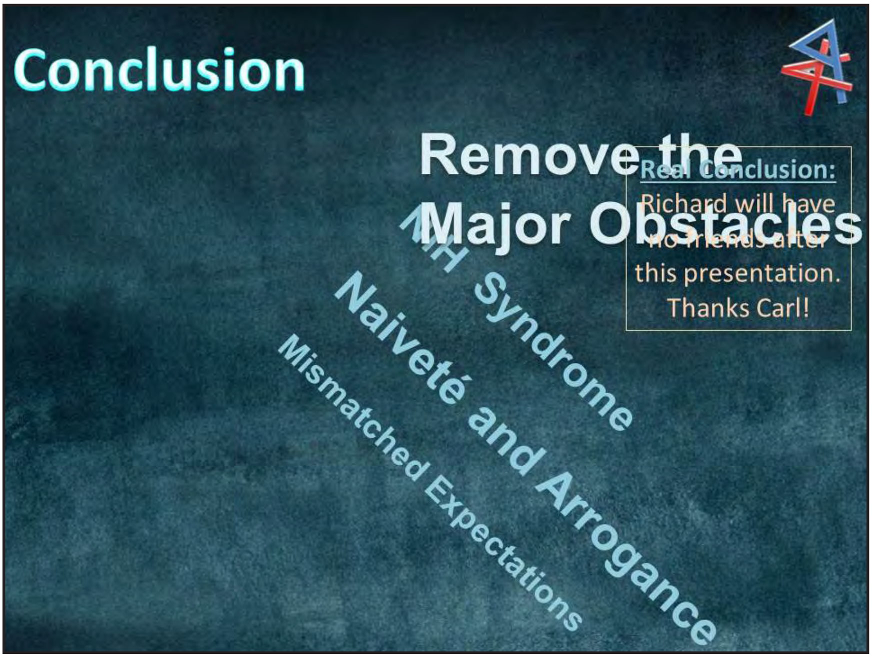
DICOM: Things That Reduced Vendor Resistance Over time

- Pressure from users (KOL and ACR) and regulators (FDA)
- An increasing sense of "the possible"
  - Engineers began to see the goal as a "solvable problem" and a challenge
  - Early PACS installations at military hospitals showed "the future"
- An increasing sense that real-world users would <u>actually buy</u> DICOM and PACS
  - Early on, some in marketing were skeptical that customers would actually pay for DICOM and PACS. Why build it before customer will actually want to buy it?
  - PACS installations at military hospitals in the '80's and RSNA demonstrations in 1992 and 1993 helped convince industry that customers would want to buy
- An increasing sense of "the inevitable"
  - The RSNA demonstrations in 1992 and 1993 contributed to a sense of excitement and inevitability around DICOM & PACS. So did military PACS.
- More user pressure
  - By 1994-1995 when DICOM was available in products, KOL & ACR recommended to radiologists that they should require it in any RFP

16.28 Richard Bijjani: Accelerating 3rd party involvement

ROBEHR ANALYTICS

Richard Robehr Bijjani, Ph.D.
rbijjani@robehr.com



Conclusion

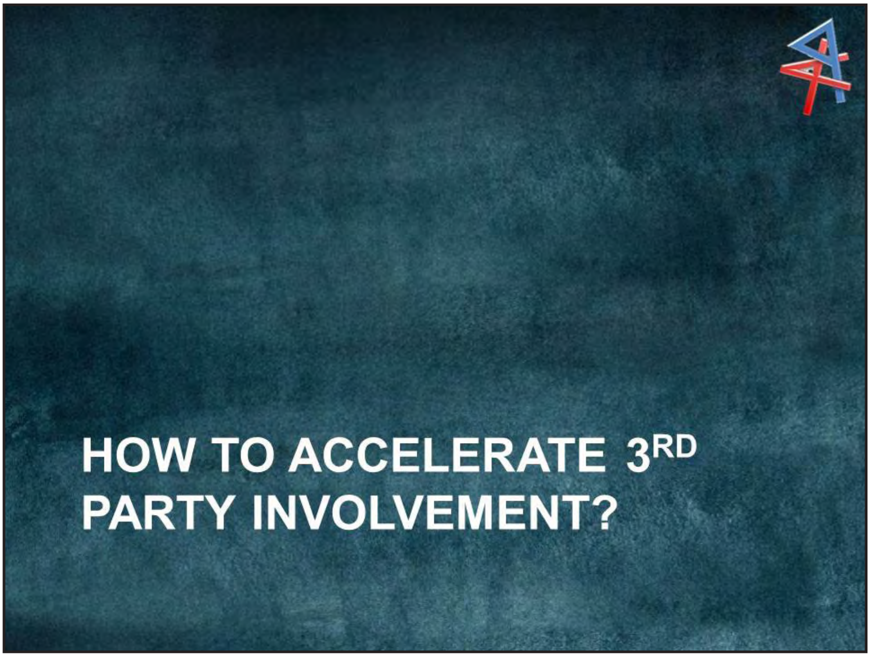
Remove the
Major Obstacles

NIH Syndrome

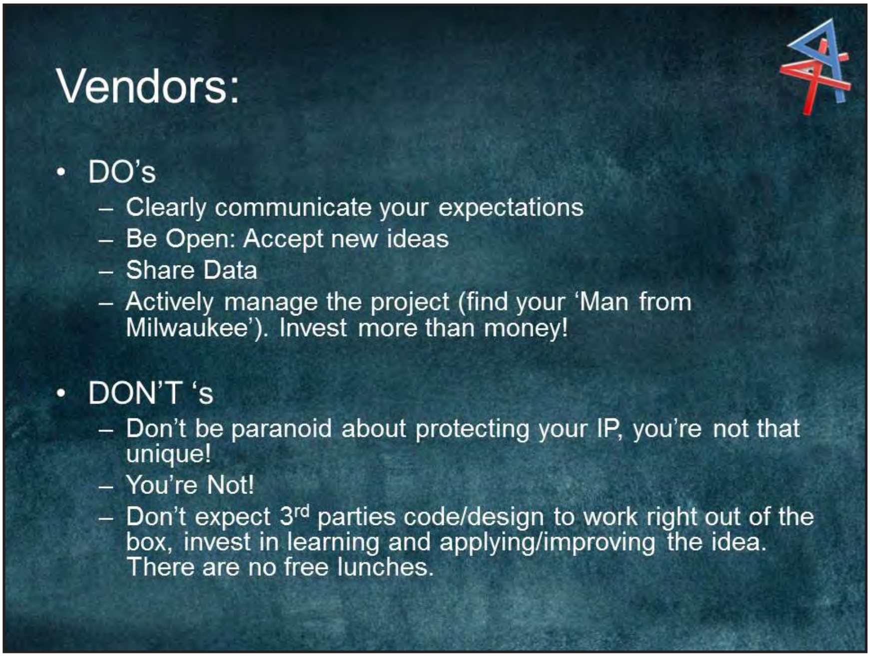
Naiveté and Arrogance

Mismatched Expectations

Real Conclusion:
Richard will have
no friends after
this presentation.
Thanks Carl!

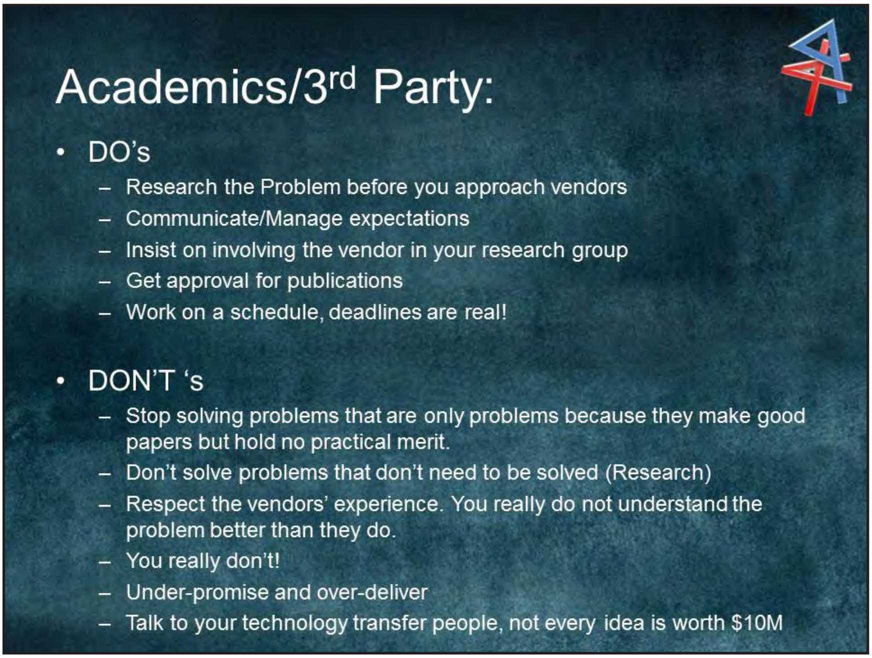


HOW TO ACCELERATE 3RD PARTY INVOLVEMENT?



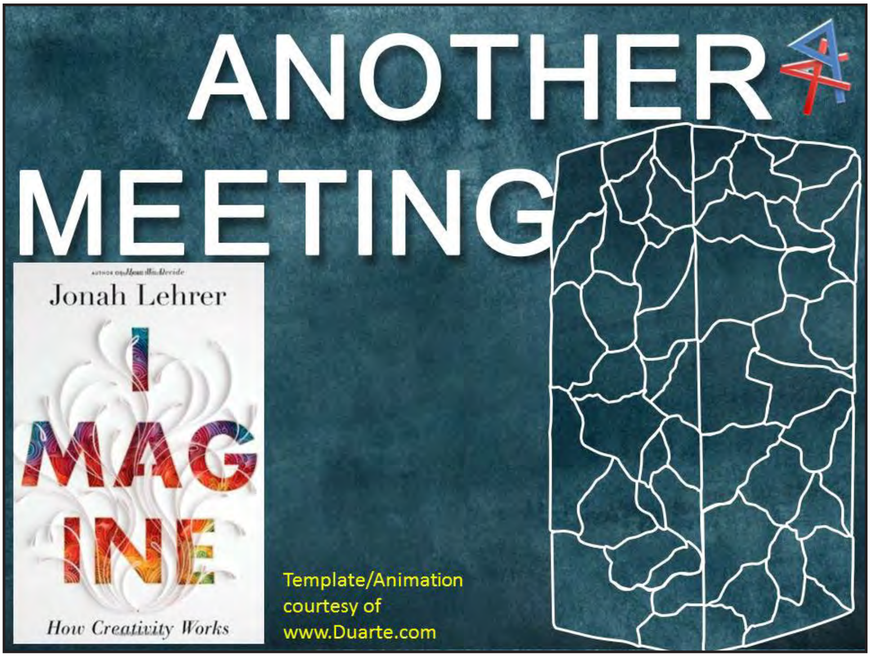
Vendors:

- DO's
  - Clearly communicate your expectations
  - Be Open: Accept new ideas
  - Share Data
  - Actively manage the project (find your 'Man from Milwaukee'). Invest more than money!
- DON'T 's
  - Don't be paranoid about protecting your IP, you're not that unique!
  - You're Not!
  - Don't expect 3rd parties code/design to work right out of the box, invest in learning and applying/improving the idea. There are no free lunches.



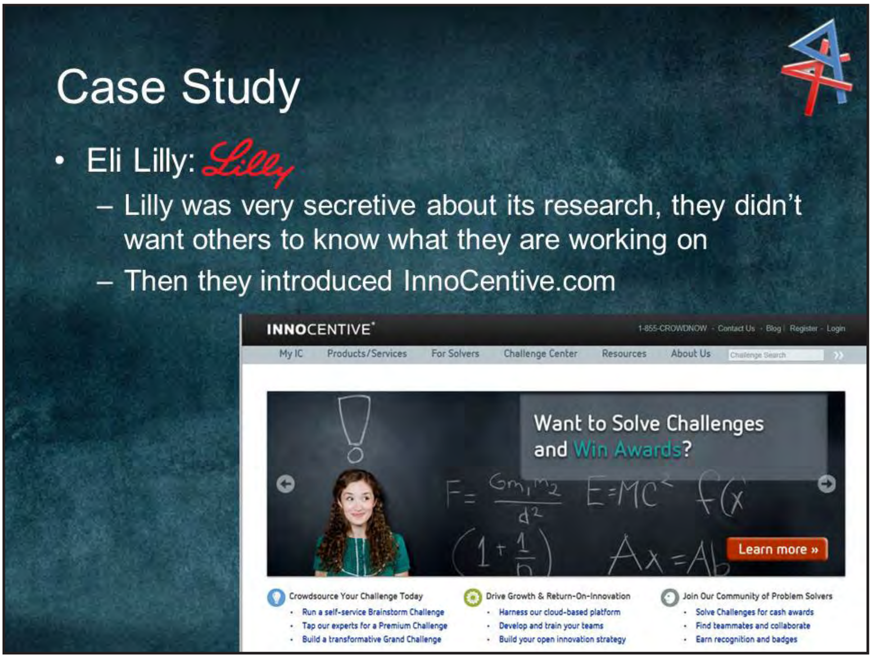
Academics/3rd Party:

- DO's
  - Research the Problem before you approach vendors
  - Communicate/Manage expectations
  - Insist on involving the vendor in your research group
  - Get approval for publications
  - Work on a schedule, deadlines are real!
- DON'T 's
  - Stop solving problems that are only problems because they make good papers but hold no practical merit.
  - Don't solve problems that don't need to be solved (Research)
  - Respect the vendors' experience. You really do not understand the problem better than they do.
  - You really don't!
  - Under-promise and over-deliver
  - Talk to your technology transfer people, not every idea is worth $10M



ANOTHER MEETING

Template/Animation
courtesy of
www.Duarte.com



Case Study

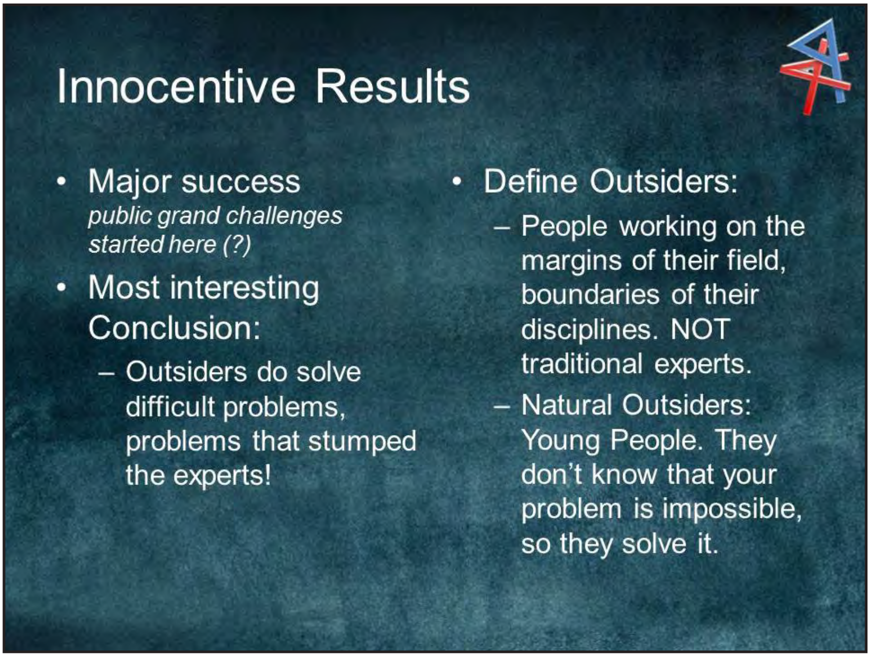
- Eli Lilly: *Lilly*
    - Lilly was very secretive about its research, they didn’t want others to know what they are working on
    - Then they introduced InnoCentive.com

Want to Solve Challenges and Win Awards?

Crowdsource Your Challenge Today
- Run a self-service Brainstorm Challenge
- Tap our experts for a Premium Challenge
- Build a transformative Grand Challenge

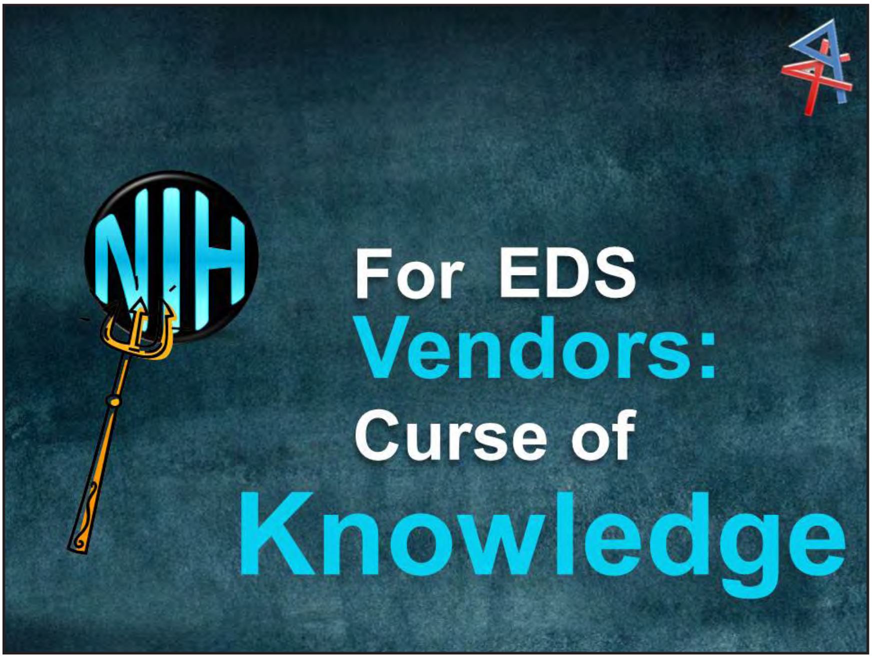
Drive Growth & Return-On-Innovation
- Harness our cloud-based platform
- Develop and train your teams
- Build your open innovation strategy

Join Our Community of Problem Solvers
- Solve Challenges for cash awards
- Find teammates and collaborate
- Earn recognition and badges



Innocentive Results

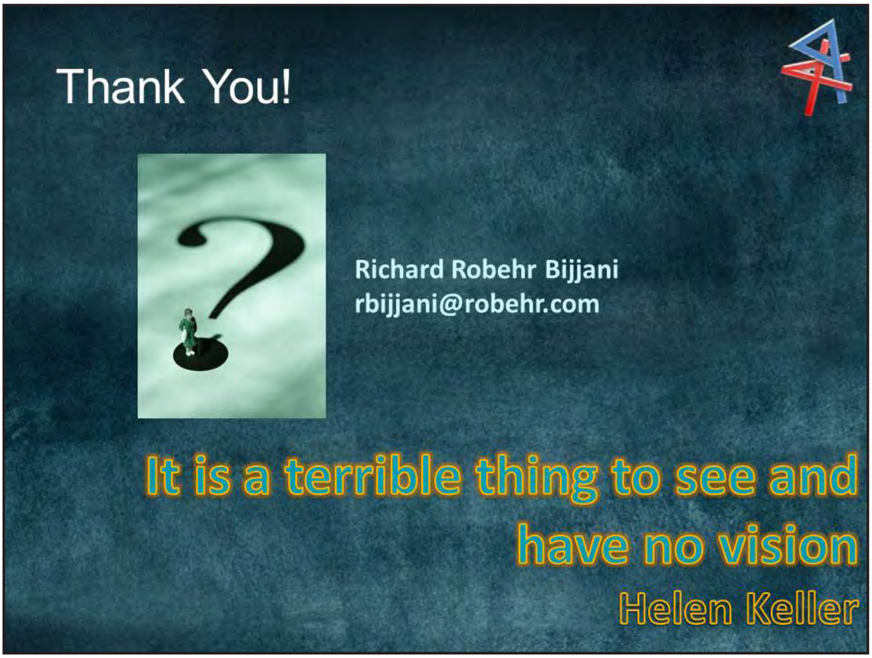
- Major success
  public grand challenges started here (?)
- Most interesting Conclusion:
  - Outsiders do solve difficult problems, problems that stumped the experts!
- Define Outsiders:
  - People working on the margins of their field, boundaries of their disciplines. NOT traditional experts.
  - Natural Outsiders: Young People. They don't know that your problem is impossible, so they solve it.



For EDS Vendors: Curse of Knowledge

3rdP

Do Your
Homework
Respect
Experience

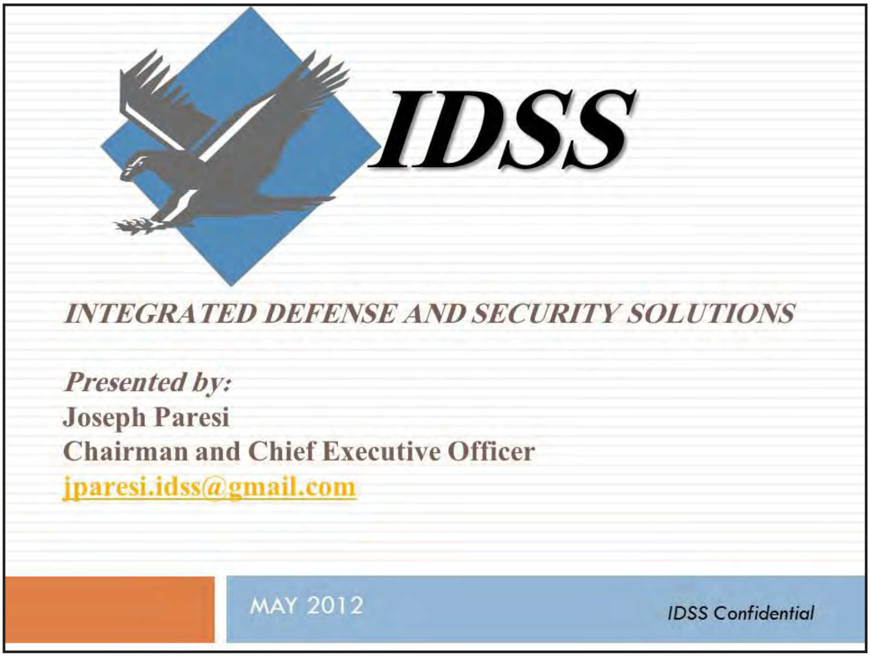


Thank You!

Richard Robehr Bijjani
rbijjani@robehr.com

It is a terrible thing to see and
have no vision
Helen Keller

16.29 Joseph Paresi: Integrated Defense and Security Solutions



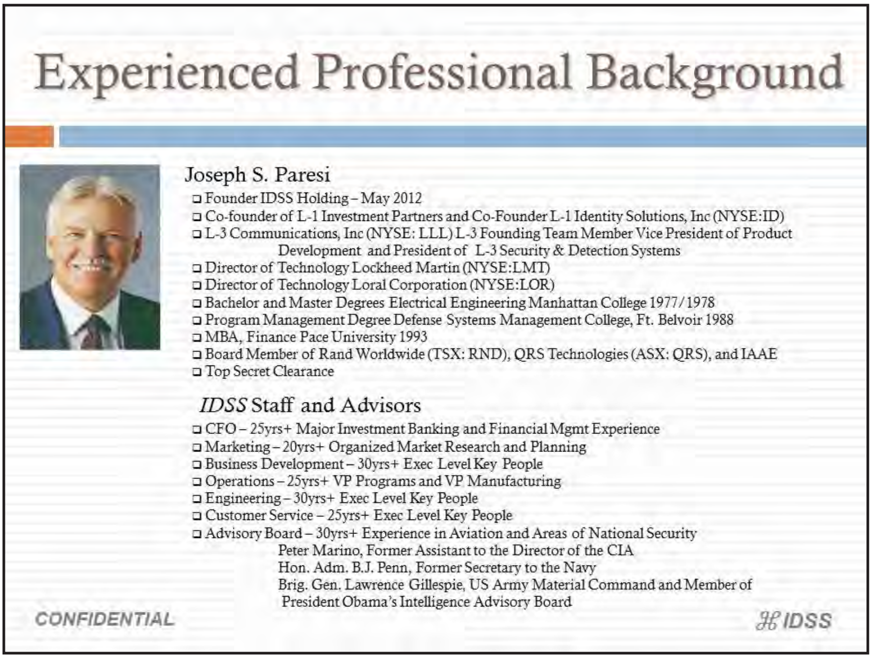
IDSS

INTEGRATED DEFENSE AND SECURITY SOLUTIONS

Presented by:
Joseph Paresi
Chairman and Chief Executive Officer
jparesi.idss@gmail.com

MAY 2012

IDSS Confidential



Experienced Professional Background

Joseph S. Paresi

- ❑ Founder IDSS Holding – May 2012
- ❑ Co-founder of L-1 Investment Partners and Co-Founder L-1 Identity Solutions, Inc (NYSE:ID)
- ❑ L-3 Communications, Inc (NYSE: LLL) L-3 Founding Team Member Vice President of Product Development and President of L-3 Security & Detection Systems
- ❑ Director of Technology Lockheed Martin (NYSE:LMT)
- ❑ Director of Technology Loral Corporation (NYSE:LOR)
- ❑ Bachelor and Master Degrees Electrical Engineering Manhattan College 1977/1978
- ❑ Program Management Degree Defense Systems Management College, Ft. Belvoir 1988
- ❑ MBA, Finance Pace University 1993
- ❑ Board Member of Rand Worldwide (TSX: RND), QRS Technologies (ASX: QRS), and IAAE
- ❑ Top Secret Clearance

IDSS Staff and Advisors

- ❑ CFO – 25yrs+ Major Investment Banking and Financial Mgmt Experience
- ❑ Marketing – 20yrs+ Organized Market Research and Planning
- ❑ Business Development – 30yrs+ Exec Level Key People
- ❑ Operations – 25yrs+ VP Programs and VP Manufacturing
- ❑ Engineering – 30yrs+ Exec Level Key People
- ❑ Customer Service – 25yrs+ Exec Level Key People
- ❑ Advisory Board – 30yrs+ Experience in Aviation and Areas of National Security
  - Peter Marino, Former Assistant to the Director of the CIA
  - Hon. Adm. B.J. Penn, Former Secretary to the Navy
  - Brig. Gen. Lawrence Gillespie, US Army Material Command and Member of President Obama's Intelligence Advisory Board

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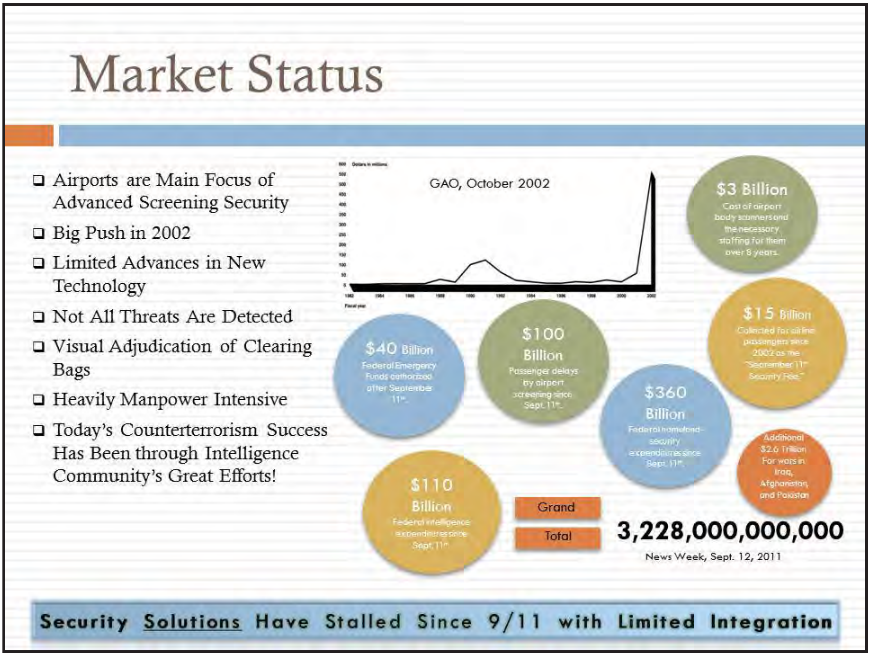


Market Status

- ❑ Airports are Main Focus of Advanced Screening Security
- ❑ Big Push in 2002
- ❑ Limited Advances in New Technology
- ❑ Not All Threats Are Detected
- ❑ Visual Adjudication of Clearing Bags
- ❑ Heavily Manpower Intensive
- ❑ Today's Counterterrorism Success Has Been through Intelligence Community's Great Efforts!

$3 Billion Cost of airport body scanners and the necessary staffing for them over 8 years.

$40 Billion Federal Emergency Funds authorized after September 11th.

$100 Billion Passenger delays by airport screening since Sept. 11th.

$15 Billion Collected for airline passengers since 2002 as the "September 11th Security Fee."

$360 Billion Federal homeland-security expenditures since Sept. 11th.

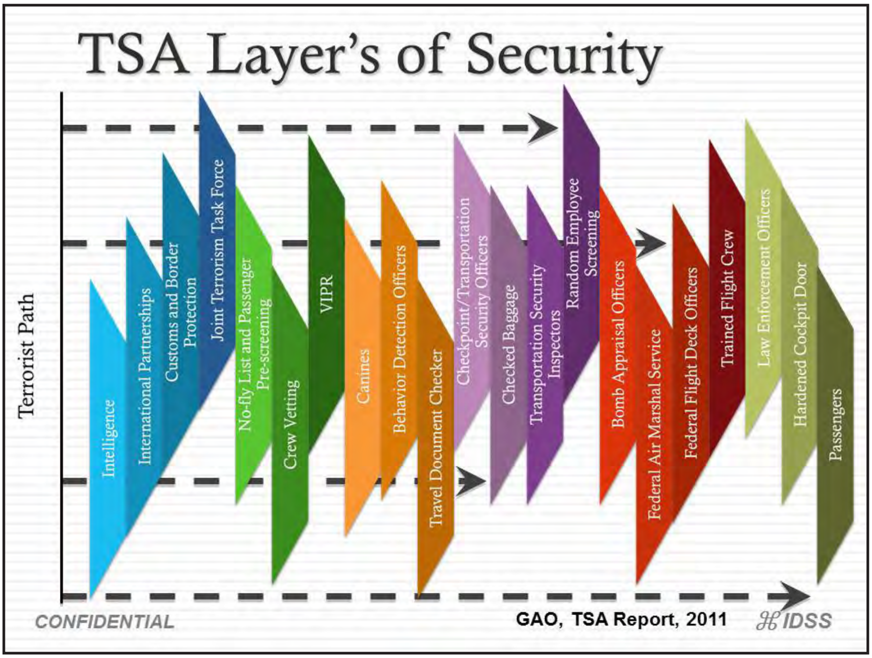
Additional $2.6 Trillion For wars in Iraq, Afghanistan, and Pakistan

$110 Billion Federal intelligence expenditures since Sept. 11th

Grand Total **3,228,000,000,000**

News Week, Sept. 12, 2011

Security Solutions Have Stalled Since 9/11 with Limited Integration



TSA Layer's of Security

Terrorist Path

Intelligence
International Partnerships
Customs and Border Protection
Joint Terrorism Task Force
No-fly List and Passenger Pre-screening
Crew Vetting
VIPR
Canines
Behavior Detection Officers
Travel Document Checker
Checkpoint/Transportation Security Officers
Checked Baggage
Transportation Security Inspectors
Random Employee Screening
Bomb Appraisal Officers
Federal Air Marshal Service
Federal Flight Deck Officers
Trained Flight Crew
Law Enforcement Officers
Hardened Cockpit Door
Passengers

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GAO, TSA Report, 2011

HIDSS

Terrorist Threat Targets

Modes of Transportation
- Airports
- Trains
- Bridges
- Tunnels

Entertainment Facilities
- Sports Arena
- Concerts
- Theaters

Key Landmarks

Monuments

Tourist Areas

Most Targets Have Not Yet Been Secured Properly

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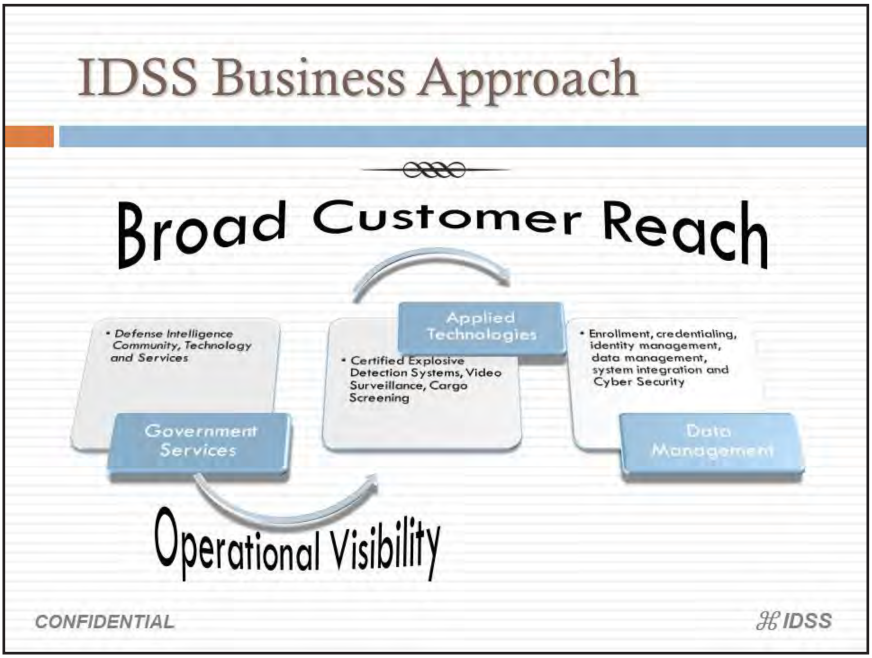

IDSS Business Approach

Broad Customer Reach

Applied Technologies
- Certified Explosive Detection Systems, Video Surveillance, Cargo Screening

Government Services
- *Defense Intelligence Community, Technology and Services*

Data Management
- Enrollment, credentialing, identity management, data management, system integration and Cyber Security

Operational Visibility

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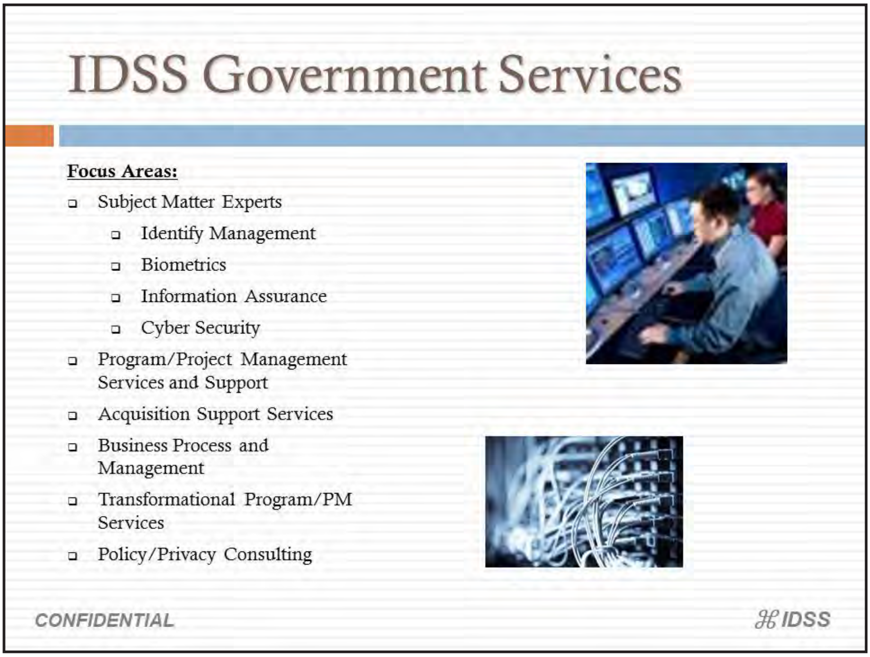

IDSS Government Services

Focus Areas:

- Subject Matter Experts
  - Identify Management
  - Biometrics
  - Information Assurance
  - Cyber Security
- Program/Project Management Services and Support
- Acquisition Support Services
- Business Process and Management
- Transformational Program/PM Services
- Policy/Privacy Consulting

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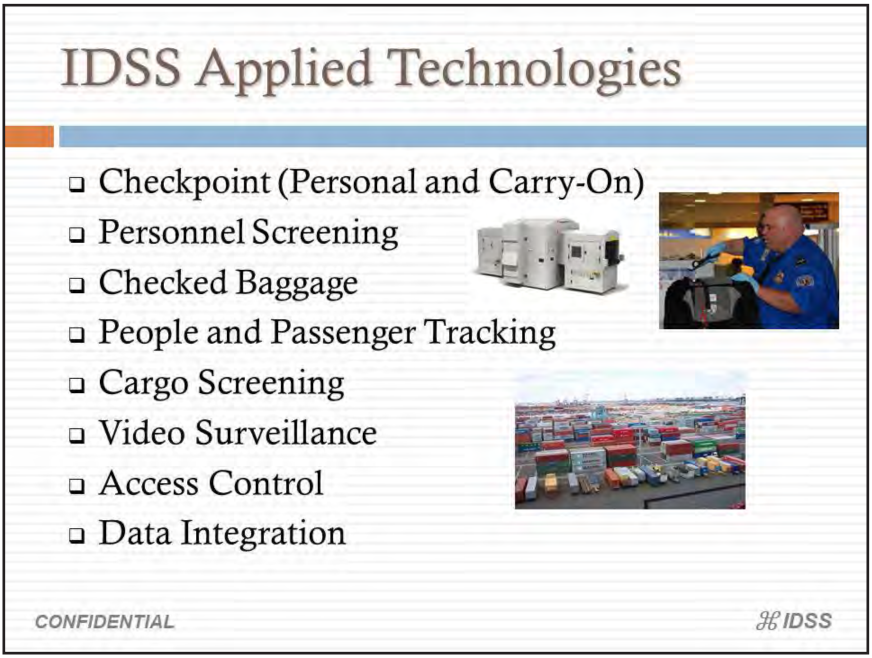

IDSS Applied Technologies

- Checkpoint (Personal and Carry-On)
- Personnel Screening
- Checked Baggage
- People and Passenger Tracking
- Cargo Screening
- Video Surveillance
- Access Control
- Data Integration

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IDSS

IDSS Data Management

- Advanced ID Technologies
- Advanced Credentialing Solutions
- Applied Cloud Computing
- Integrated Database Management
- Fast ID Validation Systems
- Defense Base Access Control
- Advanced Driver License Solutions
- Advanced Vehicle ID Systems
- Integrated Biometric Solutions

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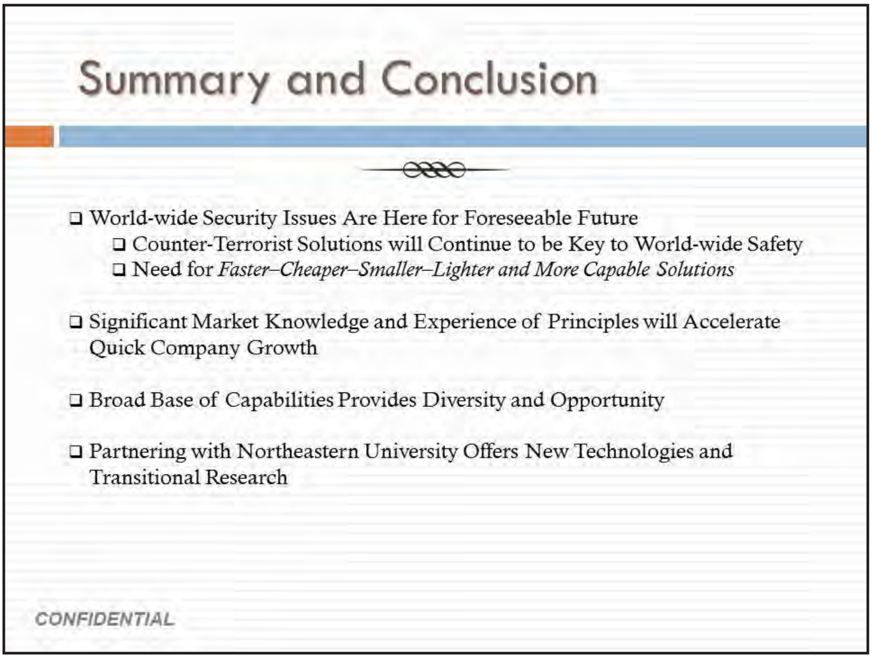

Summary and Conclusion

- World-wide Security Issues Are Here for Foreseeable Future
  - Counter-Terrorist Solutions will Continue to be Key to World-wide Safety
  - Need for *Faster–Cheaper–Smaller–Lighter and More Capable Solutions*
- Significant Market Knowledge and Experience of Principles will Accelerate Quick Company Growth
- Broad Base of Capabilities Provides Diversity and Opportunity
- Partnering with Northeastern University Offers New Technologies and Transitional Research

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16.30 Harry Martz: Takeaways, Next Steps

Homeland Security

Takeaways, Next Steps

Harry E. Martz, Jr.[1] and Carl Crawford[2]

[1]Lawrence Livermore National Laboratory
[2]DHS, S&T, Explosives Division Associate

LLNL-PRES-XXXX-DRAFT
(IM#)

May 16, 2012
Version 1

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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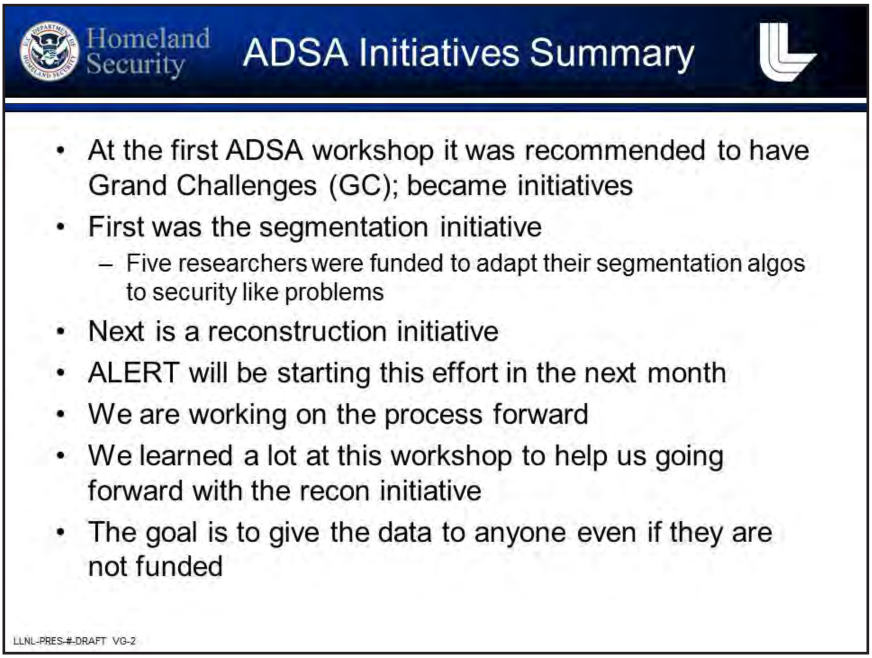

Homeland Security

ADSA Initiatives Summary

- At the first ADSA workshop it was recommended to have Grand Challenges (GC); became initiatives
- First was the segmentation initiative
  - Five researchers were funded to adapt their segmentation algos to security like problems
- Next is a reconstruction initiative
- ALERT will be starting this effort in the next month
- We are working on the process forward
- We learned a lot at this workshop to help us going forward with the recon initiative
- The goal is to give the data to anyone even if they are not funded

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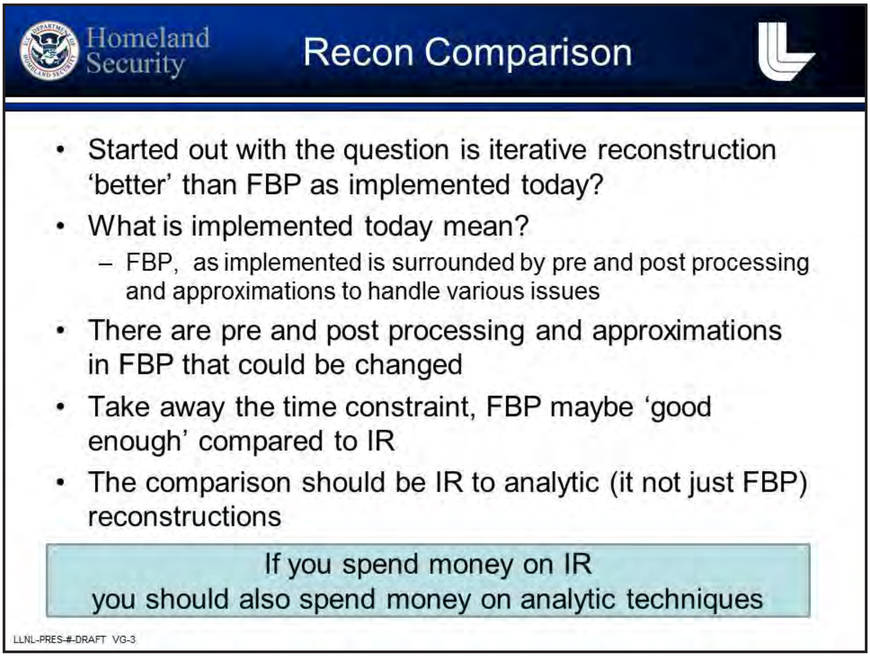
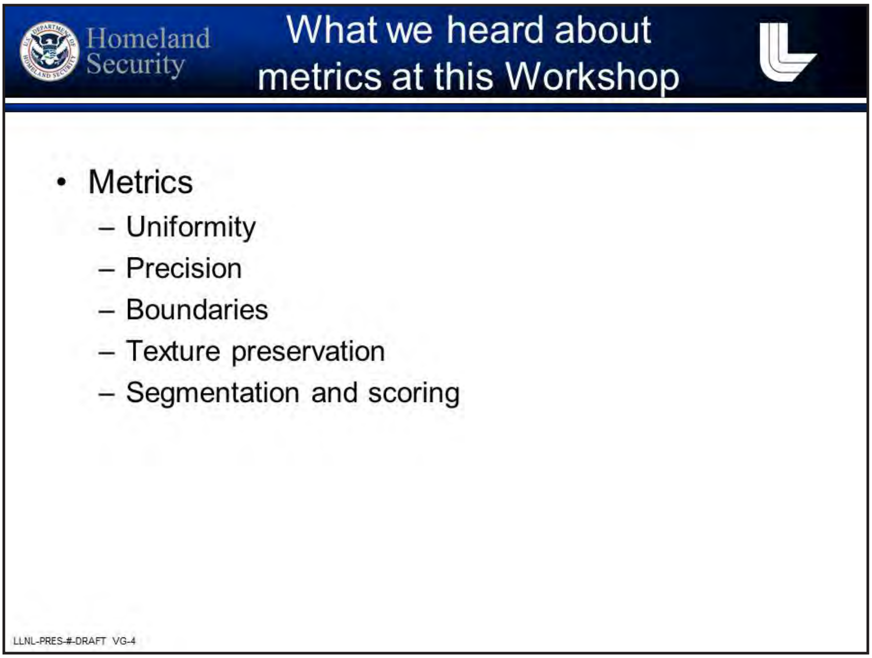


Recon Comparison

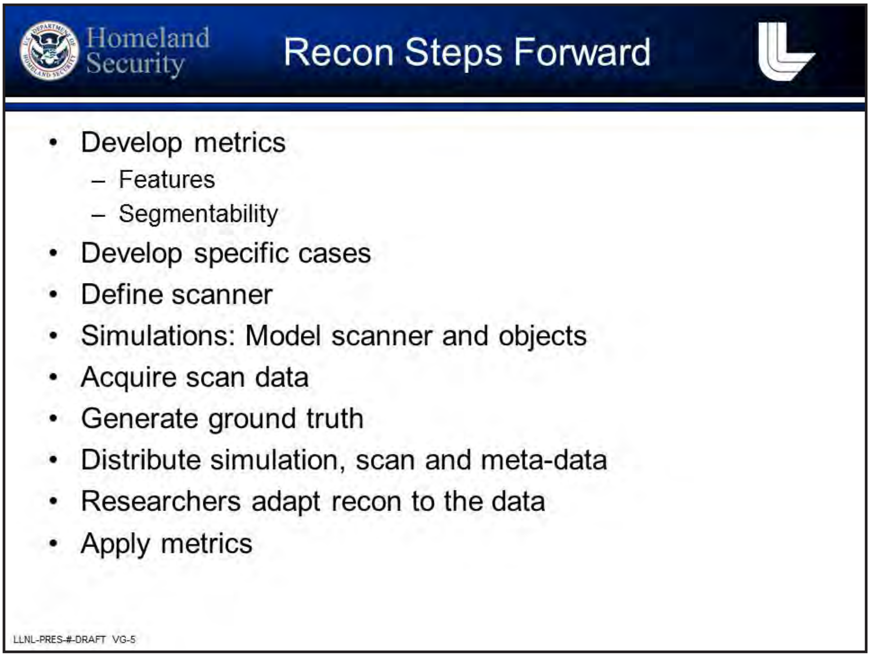
- Started out with the question is iterative reconstruction ‘better’ than FBP as implemented today?
- What is implemented today mean?
  - FBP, as implemented is surrounded by pre and post processing and approximations to handle various issues
- There are pre and post processing and approximations in FBP that could be changed
- Take away the time constraint, FBP maybe ‘good enough’ compared to IR
- The comparison should be IR to analytic (it not just FBP) reconstructions

If you spend money on IR
you should also spend money on analytic techniques



What we heard about metrics at this Workshop

- Metrics
  - Uniformity
  - Precision
  - Boundaries
  - Texture preservation
  - Segmentation and scoring



Homeland Security

Recon Steps Forward

- Develop metrics
  - Features
  - Segmentability
- Develop specific cases
- Define scanner
- Simulations: Model scanner and objects
- Acquire scan data
- Generate ground truth
- Distribute simulation, scan and meta-data
- Researchers adapt recon to the data
- Apply metrics

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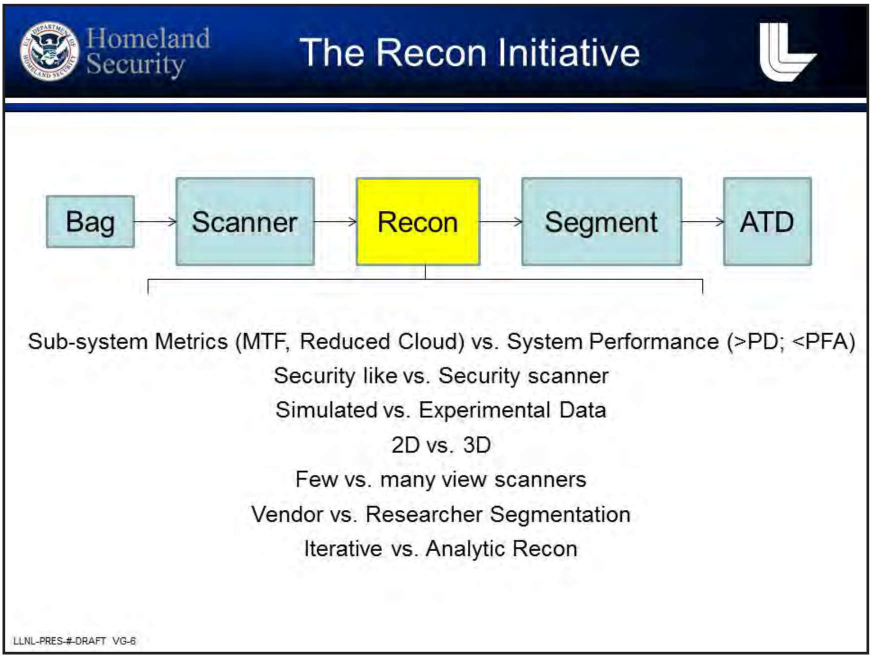

Homeland Security

The Recon Initiative

Sub-system Metrics (MTF, Reduced Cloud) vs. System Performance (>PD; <PFA)

Security like vs. Security scanner

Simulated vs. Experimental Data

2D vs. 3D

Few vs. many view scanners

Vendor vs. Researcher Segmentation

Iterative vs. Analytic Recon

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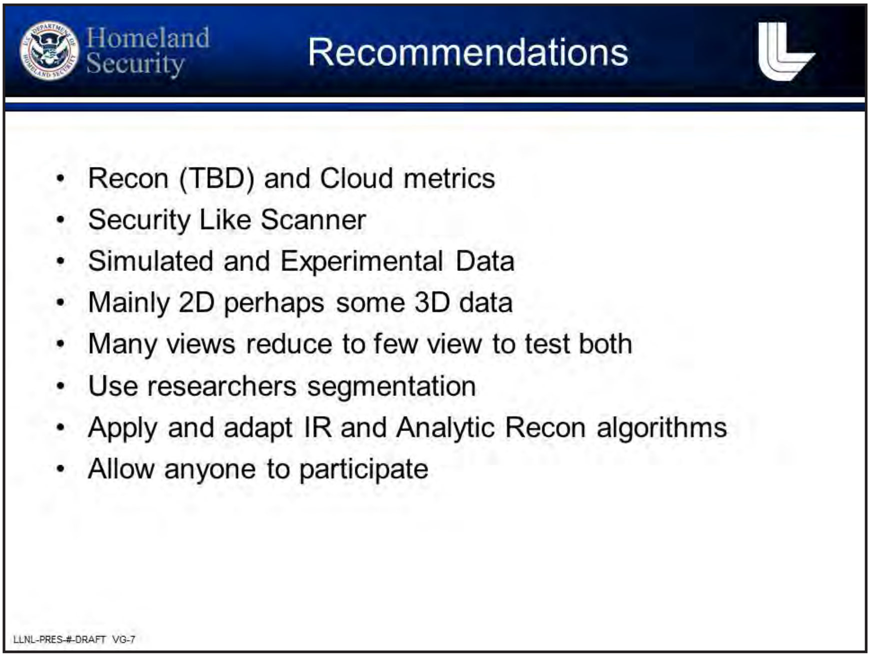

Recommendations

- Recon (TBD) and Cloud metrics
- Security Like Scanner
- Simulated and Experimental Data
- Mainly 2D perhaps some 3D data
- Many views reduce to few view to test both
- Use researchers segmentation
- Apply and adapt IR and Analytic Recon algorithms
- Allow anyone to participate

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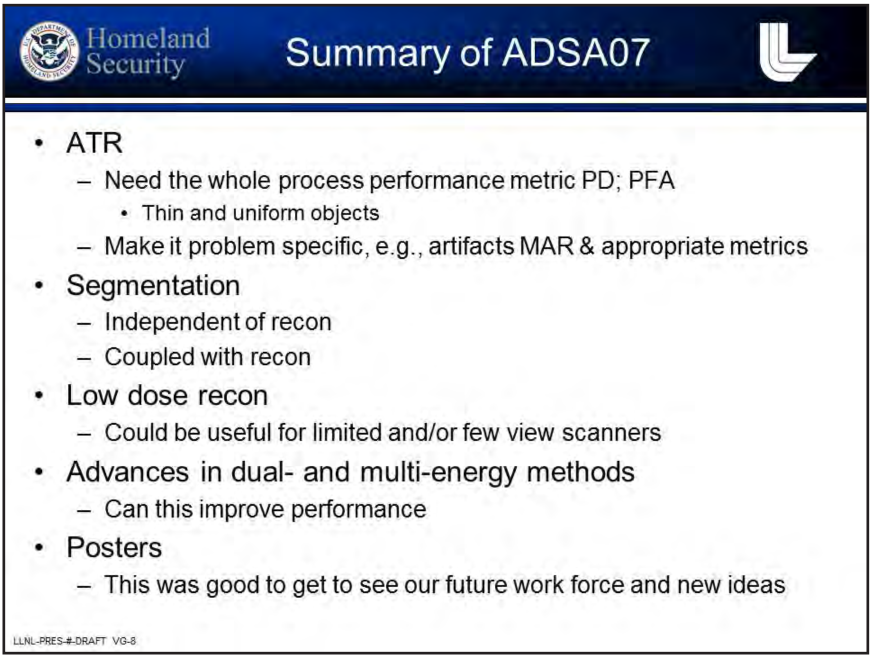

Summary of ADSA07

- ATR
  - Need the whole process performance metric PD; PFA
    - Thin and uniform objects
  - Make it problem specific, e.g., artifacts MAR & appropriate metrics
- Segmentation
  - Independent of recon
  - Coupled with recon
- Low dose recon
  - Could be useful for limited and/or few view scanners
- Advances in dual- and multi-energy methods
  - Can this improve performance
- Posters
  - This was good to get to see our future work force and new ideas

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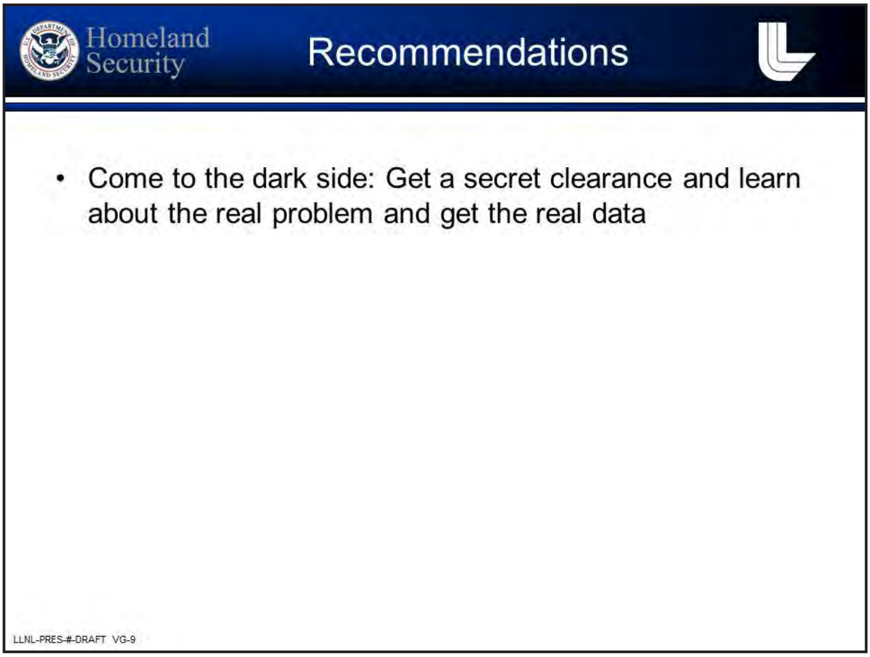

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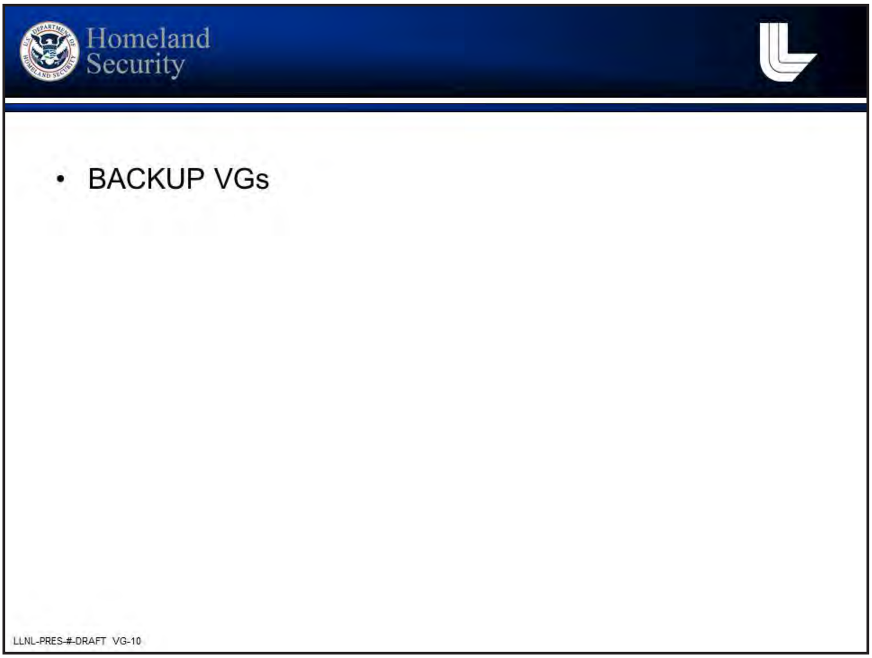
Recommendations

- Come to the dark side: Get a secret clearance and learn about the real problem and get the real data



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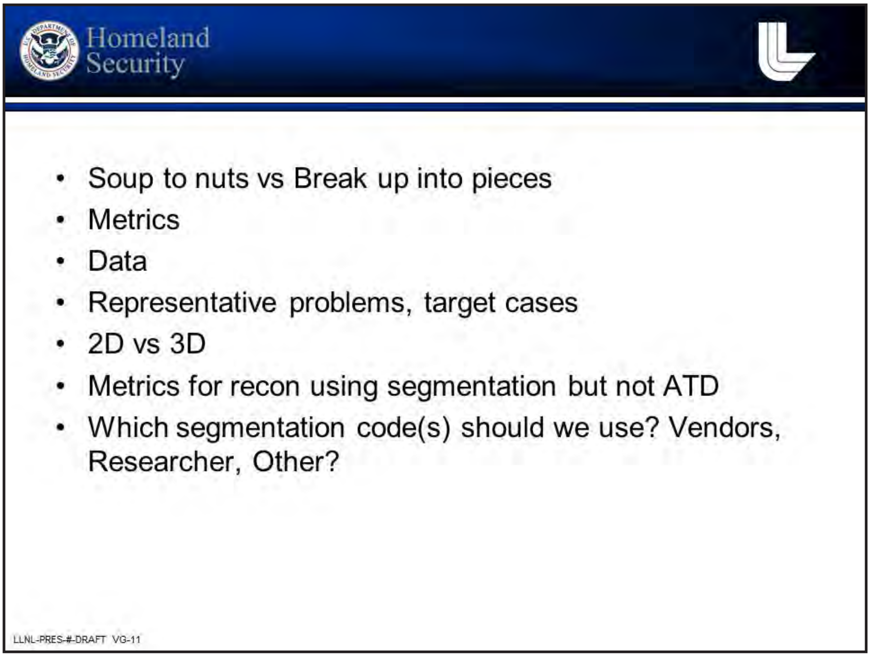
- BACKUP VGs



- Soup to nuts vs Break up into pieces
- Metrics
- Data
- Representative problems, target cases
- 2D vs 3D
- Metrics for recon using segmentation but not ATD
- Which segmentation code(s) should we use? Vendors, Researcher, Other?

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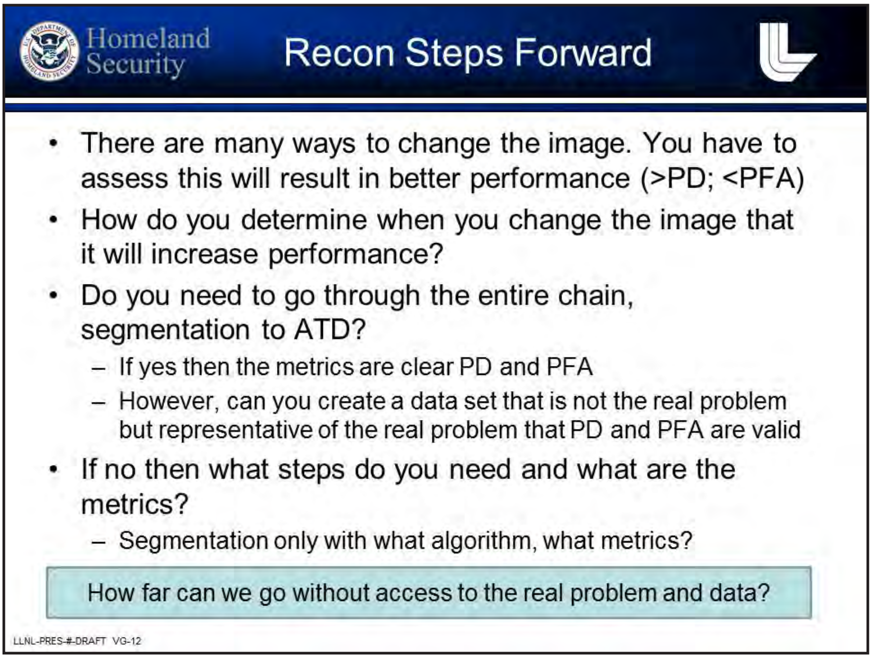

Recon Steps Forward

- There are many ways to change the image. You have to assess this will result in better performance (>PD; <PFA)
- How do you determine when you change the image that it will increase performance?
- Do you need to go through the entire chain, segmentation to ATD?
  - If yes then the metrics are clear PD and PFA
  - However, can you create a data set that is not the real problem but representative of the real problem that PD and PFA are valid
- If no then what steps do you need and what are the metrics?
  - Segmentation only with what algorithm, what metrics?

How far can we go without access to the real problem and data?

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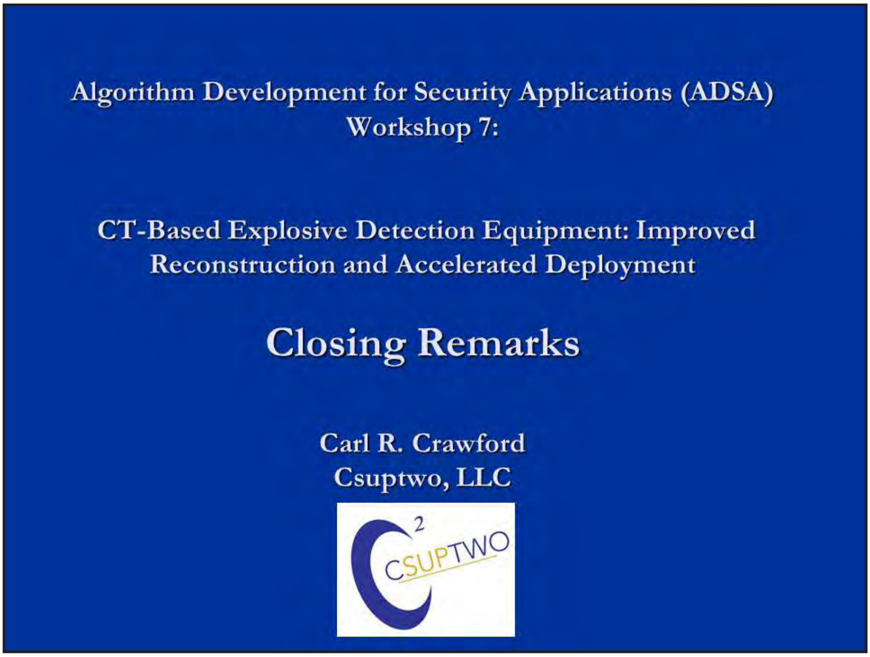
16.31 Carl Crawford: Closing Remarks



Algorithm Development for Security Applications (ADSA)
Workshop 7:

CT-Based Explosive Detection Equipment: Improved Reconstruction and Accelerated Deployment

Closing Remarks

Carl R. Crawford
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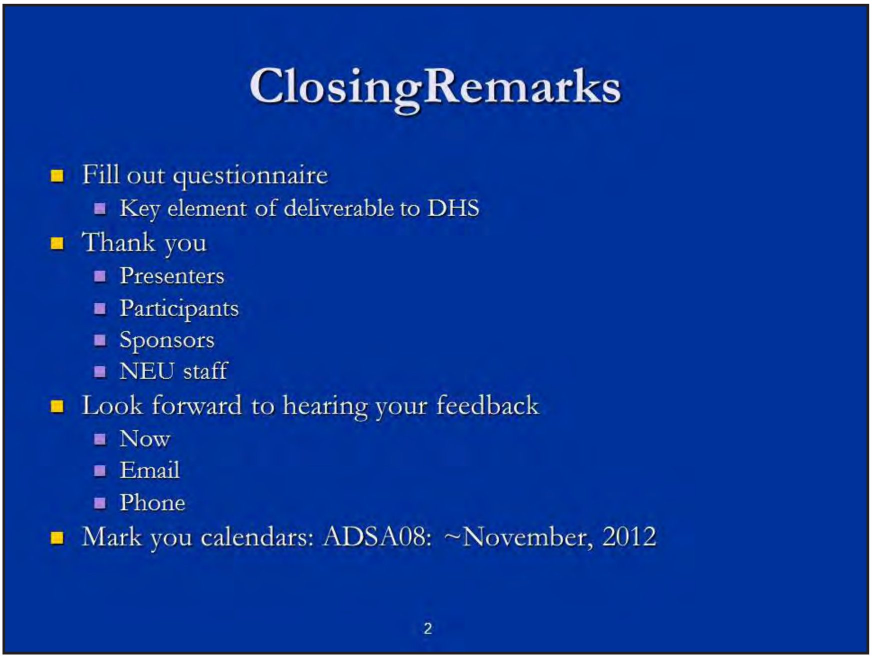

ClosingRemarks

- 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: ADSA08: ~November, 2012

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AWARENESS AND LOCALIZATION
OF EXPLOSIVES-RELATED THREATS

Awareness and Localization of Explosives-Related Threats
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