Strategic Study
Workshop Series

Algorithm Development for Security Applications

October 2009 Workshop
Final Report

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

Northeastern University

FINAL REPORT

Algorithm Development for Security Applications Workshop π ς

Northeastern University
October 7-8, 2009

Conducted by:

Awareness and Localization of Explosives-Related Threats (ALERT)

A Department of Homeland Security Center of Excellence

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1. Disclaimers

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

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2. Executive Summary[1]

A workshop was conducted to discuss the implementation of a grand challenge for segmenting objects of interest (OOI) from volumetric CT scans of baggage. OOIs are known items that are inserted into baggage along with objects that are normally packed into baggage. Segmentation means finding the voxels corresponding to the OOIs in the images that result from the volumetric CT scans. The OOIs, along with the contents of the baggage, are designed to create scenarios that a segmentation algorithm would encounter from scans on state-of-the-art CT scanners used in security applications.

Segmentation and classification are the two steps that are usually found in algorithms that perform automated threat recognition (ATR). Only the segmentation step of ATR is of interest for this grand challenge.

The objectives of the workshop were to discuss the following aspects of executing the grand challenge:

- CT segmentation grand challenge definition
- Dataset creation
- Participant identification
- Entry criteria and funds allocation
- Segmentation algorithm development and testing
- Independent validation and testing of the segmentation algorithms
- Demonstration of algorithms
- Creation of final report

This report summarizes the workshop content and presents outcomes that address the objectives. The majority of the material that deals with these objectives can be found in the slides corresponding to presentations made during the workshop and the homework provided in advance of the workshop. The slides and the homework are included in this report as appendices.

The main outcomes of the workshop are as follows:

- The grand challenge for segmenting OOIs from volumetric CT images should be performed.

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[1] This report is available as a hard copy, on the Internet and on a CD. Please contact ALERT at Northeastern University (alert-info@ece.neu.edu) for access to these three formats.

- A number of refinements to the grand challenge were suggested.
- There are relevant precedents in the medical imaging and other communities (e.g., the Netflix grand challenge) that should be researched in order to follow their best practices.
- A precise specification for the grand challenge will lead to better results.
- Collaboration among researchers increases the speed of technology development.
- It is speculated that advanced reconstruction algorithms will have a bigger impact on the performance of CT-based explosives detection equipment compared to advances in segmentation. However, a prerequisite for developing reconstruction algorithms is having segmentation algorithms available in order to assess the impact of improved image quality on segmentation. Therefore, it may be necessary to complete the grand challenge for CT segmentation before implementing a grand challenge for reconstruction.
- Working groups should be held instead of workshops in order to get the grand challenges initiated. The first working groups should discuss the problem cases for segmentation and the specifications for the grand challenges.[2]
- Third parties have begun to work on the problems described in the two workshops held to date. This is due, in part, to disclosing problem statements and putting datasets into the public domain.
- Providing mentorship to the participants will enhance the value of the segmentation algorithms developed by the participants.

[2] A classified meeting was held on 2/8/2010 to discuss problem cases. The results of this meeting will be folded into future requirements for the grand challenge.

3. Introduction

The US Department of Homeland Security (DHS) Science & Technology Directorate (S&T), Explosives Division (EXD), in coordination with the Transportation Security Administration (TSA), has identified requirements for future explosive detection scanners that include a larger number of threat categories, higher probability of detection per category, lower false alarm rates and lower operating costs. One tactic that DHS is pursuing to achieve these requirements is to create an environment in which the capabilities of the established scanner vendors could be enhanced or augmented by third-party algorithm developers. A third-party developer in this context refers to academics, national labs, subject matter experts (SME), small companies and organizations other than the established scanner vendors.

DHS is particularly interested in adopting the model that has been used very successfully by the medical imaging industry, in which university researchers develop algorithms that are eventually deployed in commercial medical imaging equipment. This model has improved the ability of the end user (i.e., radiologist) to identify, locate and treat potential cancerous abnormalities. Note that when we speak of an algorithm, we are talking about the mathematical steps. The actual implementation is beyond the scope of the workshops.

One tactic that DHS is using to stimulate third-party algorithm development is to sponsor workshops addressing the research opportunities that may enable the development of next-generation algorithms for homeland security applications. The first such workshop, entitled "Algorithm Development for Security Applications Workshop (ADSA01)," was held at Northeastern University (NEU) on April 23-24, 2009.[3] The workshop was led by Professor Michael B. Silevitch (NEU) as part of the DHS Center of Excellence (COE) for Awareness and Localization of Explosives-Related Threats (ALERT[4]).

The main recommendation of the first workshop was to establish grand challenges for various aspects of threat detection and various screening modalities. The aspects include (1) preprocessing, reconstruction and post

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[3] For details see "Final Report, Algorithm Development for Security Applications Workshop," Northeastern University, April 23-24, 2009.

[4] ALERT in this work plan refers to the Center of Excellence (COE) at NEU.

processing of sensor data, (2) image segmentation, (3) classification and (4) improved operator performance. The screening modalities include x-ray computed tomography (CT) for checked and carry-on baggage, advanced imaging technology (whole body imaging), cargo inspection, and stand-off detection of explosives and weapons.

It was further recommended at the first ADSA workshop that the first grand challenge should develop advanced segmentation algorithms from volumetric (CT) data for the purpose of enhancing ATD algorithms for CT-based explosives detection systems for checked and for carry-on baggage. Three sets of volumetric data should be obtained by scanning actual baggage containing OOIs. The three datasets are designated as training, validation, and evaluation datasets. Participants should be selected and funded to develop segmentation algorithms. The participants should develop their algorithms using the training and validation datasets and report their results on the validation dataset. The algorithms should be independently tested and evaluated using the validation and evaluation datasets, the latter dataset should not be provided to the participants. The first phase of this grand challenge entails the creation, coordination and distribution of essential technical information and materials into the public domain: data sets, sensor descriptions and acceptance criteria for advanced algorithms.

The second ADSA workshop was held at NEU on October 7-8, 2009, under the direction of Professor Silevitch, Harry Martz (LLNL) and Carl Crawford (DHS S&T). The purpose of the second workshop was to discuss the efforts necessary to get relevant data to the third parties to enable them to develop algorithms in particular how to implement a grand challenge for segmenting OOIs from volumetric CT data. In essence, the purpose of the second workshop was to review the details for the CT segmentation grand challenge. The objectives of the workshop were delineated by the following loosely quoted statement from Doug Bauer (DHS S&T):

> "Our overarching goal is to better protect the American people in travel environments against an evolving range of threats. We need the best hardware and the best algorithms [and implementation in the airports]. We think that the medical field can help provide a framework for us and we brought you together for a multidisciplinary approach. Some questions that need to be addressed include:] how do we preserve openness to innovation? How do we meet the near-term requirements of DHS without forsaking academic research??"

The purposes of this report are to present the findings from the second workshop and to present the requirements for the CT segmentation grand challenge.

4. Report Organization

The remainder of this report is organized as indicated in the following table.

Sec.	Title	Contents and Notes
		Report Body
5	Outcomes	Presents the main outcomes of the workshop.
6	CT segmentation grand challenge	Provides the requirements for the grand challenge for segmenting OOIs from CT images
7	Future efforts	Presents recommendations for other tactics to implement the ideas generated at this workshop other than for the CT segmentation grand challenge.
8	Lessons learned	Presents a list of items that could have been implemented better or differently, and recommendations for improvement for future workshops.
9	Notes	Contains notes about the workshop and the preparation of this report.
10	Acknowledgements	Identifies people and organizations that helped organize the workshop and prepare this report.
		Appendices
11	Agenda	Agenda for the workshop
12	Overview	Overview of the workshop; used as part of the invitation for participants.
13	Planning committee	List of people who organized the workshop.
14	Invitation	Invitation sent to people to participate.
15	Speaker assignment	Instructions for the speakers (presenters).
16	Acronyms	A glossary of acronyms and terms used in this report and the presentations.
17	Attendee list	A list of people who attended the workshop.

18	Biographies	Biographies of the people who attended the workshop.
19	CT segmentation grand challenge outline	Outline of the plan for the grand challenge before the workshop was held.
20	Scanning requirements	Requirements for the scanner to be used to collect data for the grand challenge.
21, 22	Minutes	Minutes taken during the workshop.
23	Homework – deliverables	Homework assignments that were provided to the workshop organizers.
24	EDS review	An overview of EDS scanners including their certification and testing.
25	LLNL SOW	A statement of work for 3rd parties to train, validate and be evaluated on the development of an ATR for liquid explosives in TRX data.
26	Presentations	Slides that were presented at the workshop.

5. Outcomes

The main outcomes of the workshop are described in the following points.

1. EDS scanners are capable of detecting 100% of threats at an unacceptably high probability of false alarm (PFA). Minimizing PFA may be restricted because of inaccuracies in the measurements of features generated by the segmentation step of an ATD. These inaccuracies are caused by CT artifacts such as partial volume and streaks, which may lead to split and aggregated objects. Improved segmentation, which is the goal of this grand challenge, should lead to reduced inaccuracies and hence lower values of PFA.

2. The workshop participants continued to speculate that improvements in reconstruction algorithms will have a bigger impact on reducing PFA than improved segmentation algorithms. In particular, developing reconstruction algorithms optimized for segmentation was deemed to be important. Iterative reconstruction (IR) algorithms were thought be the best path for improved reconstruction. If implementation is an issue with IR, then hybrid algorithms should be considered. The term hybrid means a mixture of filtered back projection and IR. A prerequisite for developing reconstruction algorithms is having available automated threat detection algorithms. Therefore, it is necessary to complete the grand challenge for CT segmentation before implementing a grand challenge for reconstruction. We recommend that a small number of researchers be funded to begin work on advanced reconstruction algorithms with a restricted scope compared to a grand challenge. The results of this work will lead to defining grand challenges for reconstruction and other topics.

3. A number of technical changes to the grand challenge for image segmentation were made. These changes are listed here and incorporated in the specification for the grand challenge that can be found in the next chapter.

    a. Segmenting all objects is too difficult. Segmenting easy cases does not benefit the industry. For example, detecting a high-density bulk threat hidden in clothing is an easy case. The grand challenge should concentrate on difficult cases. However, easy cases should be scanned in order to help participants learn how to develop their ATDs.

b. Choosing OOIs that span a range of densities and atomic numbers greater than the ranges spanned by actual explosives. Threats and simulants should not be scanned. Instead known objects such as water and plastics should be scanned. Their features should be reported as mass, density, volume and effective atomic number, if available.

c. Optimizing the reconstruction of raw projection data to match existing EDS equipment.

d. Reconstructing at better image quality to assess the impact of better image quality if the scanner used for collecting images for the grand challenge has better image quality than state-of-the-art security scanners.

e. Designing mathematical phantoms and simulated projection data that can be reconstructed for testing segmentation algorithms.

f. Building physical phantoms to match the mathematical phantoms.

g. Attempting to preserve the bag sets so that they can be scanned on future scanners.

h. Running image quality phantoms while scanning bags to assure that the scanners are operating correctly.

i. Collecting raw data so that the reconstruction grand challenge for CT can be run on the same bag set used for the segmentation grand challenge.

j. Running computer simulations and doing research to verify that the acceptance criteria for segmentation are useful. Metrics should be based on surfaces and not volumes. Voting metrics should not be used.

4. A number of operational changes to the grand challenge for image segmentation were made. These changes are listed here and incorporated in the specification for the grand challenge that can be found in the next chapter.

   a. Delivering executables or computers running the executables may limit the participation of people who have toolkits running on specialized equipment. Therefore, testing and validation runs should be allowed over the Internet.

   b. The Netflix grand challenge demonstrated that collaboration is important. Incentives and vehicles should be provided to that participants in the grand challenge can collaborate. In particular, metrics for various segmentation algorithms should be shared.

   c. The specification should be reviewed by as many people as possible to identify issues before the grand challenge begins.

   d. A method to assess algorithms should be made available on the internet.

   e. A sample segmentation program, with scoring, should be provided to participants.

   f. Consider hiring consultants to help define acceptance criteria.

5. A number of programmatic changes to the grand challenge for image segmentation were made. These changes are listed here and incorporated in the specification for the grand challenge that can be found in the next chapter.

   a. The EDS vendors agreed to meet with the leadership of the grand challenge in order to define the problem cases that should be addressed.

   b. A committee should be established in order to advise the leadership of the grand challenge.

   c. All datasets should be placed in the public domain. However, journaling should be in place on the data usage to record who is accessing the data.

6. The implementation of algorithms was discussed at length but without definite conclusion. The following topics are issues and should be addressed in the future.

   a. Royalty payments.

   b. IP ownership.

   c. Implementation issues such as coding standards, operating environment, exception handling, specification maintenance.

   d. Need to determine if foreign nationals can be participants. Not permitting foreign nationals will likely conflict with university policies.

7. Algorithms related to human factors are still difficult to consider because of the need to assess the performance of operators (TSOs).

8. There is a need to catalog applicable literature. The literature includes journal articles and patents.

9. There are opportunities for DHS and ALERT to advertise grand challenges at multiple medical imaging conferences and other conferences not related to medical imaging.

6. CT Segmentation Grand Challenge

The purpose of this chapter[5] is to provide the technical details[6] for how the grand challenge[7] will be conducted. In particular, the following steps in implementing the grand challenge will be discussed.

1. Program Definition
2. Dataset Creation
3. Participant Identification
4. Algorithm Development
5. Independent Validation
6. Deliverables from Participants
7. Final Report and Symposium

The discussion is presented in outline form in order to reduce the amount of text that has to be written, especially for grammatical purposes. After peer review, this section will be converted into a formal specification.

1. Task 1: Program Definition. The purpose of this task is to write a detailed specification for the grand challenge. In essence, the task consists of converting the material in this chapter into a self-contained specification. At present, some of the specifications are intertwined for the purposes of presenting the material in an outline format. The specification will contain sections that discuss the following items that follow.

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[5] An earlier version of this chapter, which is included an appendix, was used as the basis of presentations made at ADSA02. This version has been updated based on the comments made at the workshop.

[6] This chapter may also be denoted a specification. The purpose of releasing this material is to obtain external peer review so that the details of the grand challenge can be worked out before it is initiated.

[7] The term grand challenge as used in this chapter refers to the grand challenge for CT segmentation unless explicitly stated otherwise.

a. Program Outline
    i. Technical
        1. Program Definition
        2. Dataset Creation
        3. Participant Identification
        4. Algorithm Development
        5. Independent Validation
        6. Deliverables from Participants
        7. Final Report and Symposium
    ii. Operational
        1. Program Team
        2. Budget
        3. Schedule
        4. Legal Issues
b. Scope
    i. Segmenting OOIs from volumetric CT data collected on single- or dual-energy scanners.
    ii. OOIs
        1. Shall span ranges of density and atomic number greater than the ranges of actual threats.
        2. Shall be placed in easy, medium and difficult containers.
        3. Shall be placed in baggage with minimal, moderate and maximal clutter.
c. Executable requirements
    i. Inputs:
        1. CT volumetric data in specified (TBD) format
    ii. Transfer function
        1. Segment objects
        2. Estimate object features
    iii. Outputs:
        1. Label images indicating which voxels correspond to the OOIs.
        2. Features
            a. Technical
                i. Mass
                ii. Density
                iii. Volume
                iv. Zeff (if available)
            b. Operational

i. Formulas for generating features will be provided.

3. Scoring
    a. The results of scoring the segmentation shall be provided.
    b. An algorithmic description along with sample code will be provided to the participant.

iv. Sample segmentation code will be provided to demonstrate how to read and write results, including calculation of features and scoring the results.

2. Dataset Creation: the details of creating the datasets (i.e., CT scans of objects) are defined in this section.
    a. Dataset definition
        i. Definitions
            1. What objects need to be segmented: we are only concerned with OOIs in order to calculate metrics based on their features. False alarm objects are not of interest yet.
            2. What objects can be used for OOIs: objects with well-defined features (density, mass, Z-eff, mass, volume). Water, plastics and rubbers may be used.
            3. What are the important cases (easy, medium, and difficult)?
        ii. Process
            1. Obtain feedback from ADSA02 participants on the detailed requirements for the grand challenge
            2. Have classified meeting with certified SSDs to specify the difficult cases
            3. Final decision on bag makeup will be made by the project team
    b. Acquire tools and materials: additional information can be found in the appendix.
        i. Locate and fund use of a medical, security or industrial scanner
        ii. Acquire N items for contents of bags. The items include the following items from stream of commerce (SOC) bags:
            1. Clothing
            2. Personal items

3. Perishables (fruit, vegetables)
4. Food in containers
5. Electronics
6. Liquids
7. OOIs (should be homogenous so that the presence of texture is not used in the segmentation algorithm)
8. Minimum masses for all items and dimensions of sheets have to be specified.

iii. Acquire M luggage items
1. Define how to pack K different configurations of bags using the M luggage and the N objects.
2. Use LLNL data on the prevalence of objects to pack the baggage.
3. Pack bags to produce artifacts in the images such as cupping, CT number shifts, streaks, rings and bands to create difficult cases.

iv. Scan contents of N items in isolation and record the following features:
1. Dimensions
2. Mass
3. Volume
4. Density
5. Zeff if possible
6. Digital picture
7. Written description

v. Pack and scan M bags each in K orientations
1. Document packing
    a. Digital picture
    b. Written description
2. Document orientation
    a. Digital picture
    b. Written description

vi. Generate labels showing location of objects in each bag
1. Manual segmentation/outlining
2. TBD multiple experts

vii. Store dataset at LLNL

viii. Archive bags and objects so that the can be scanned on future scanners and SSD scanners; it is desirable to save packed suitcases so that they can be scanned on future scanners. If perishables were inserted, they should be removed before storage.

c. Phantom scanning and simulation (calibrated objects)[8]
    i. Specify bag and contents consisting of mathematical shapes
    ii. Construct bag
    iii. Scan bag
    iv. Create Forbild (University of Erlangen format) phantom description
    v. Create simulated projection data similar to CT scanner
    vi. Scan image quality phantom along with bags to assure that the scanner is operating correctly
d. Details of scanner used for scanning: see appendix for updated specifications.
    i. Scan on CT scanner representative of SSD scanners
    ii. Scanner specs
        1. Scan FOV: 50 cm
        2. Scan modes: helical or step-and-shoot
        3. Dual energy: desirable
        4. Resolution: 1 mm isotropic (10% of MTF or SSP)
        5. Pixel size: 1 mm isotropic
        6. Potentials:
            a. 140 – 180 kV
            b. 80 – 120 kV
            c. 40 kV difference between high and low energies
        7. Dose: 20 mAs
            a. Consider higher dose to get ~noise-less data and degrade retrospectively
        8. Projections: 512 view per rotation per energy
        9. Reconstruction steps:
            a. Cone beam correction: exact or hybrid
                i. Filtered back projection preferred because of schedule
                ii. Iterative (statistical) possible for 2nd phase
            b. Kernel: LPF matching pixel spacing
            c. Dual energy decomposition
            d. State-of-the art corrections including

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[8] Phantoms are a type of bag to be scanned at Point 2.b.iv.

            i. Bad-pixel
            ii. Offset (dark current)
            iii. Air (gain)
            iv. Crosstalk
            v. Afterglow (decay)
            vi. Spectral (detector dependent)
            vii. Beam hardening (detector independent)
            viii. Bad detection correction
            ix. Logarithm
            x. Adaptive filter
            xi. Scatter correction
    10. Scan time: < 15 minutes per volumetric scan

iii.

iv. Material distribution
    1. Reconstructed images
        a. Images reconstructed with different algorithms may be provided
        b. Details on the reconstruction algorithm will be provided.
        c. Only one dataset will be labeled
    2. Raw data
    3. Corrected data
    4. Scan log
        a. Date/time
        b. Operator
        c. Scan description
        d. Digital pictures of bag and contents
        e. Written description
    5. Scanner description
    6. Reconstruction algorithm
        a. Mathematical description
        b. Code (offline) for reconstruction

v. Possible scanner types
    1. Existing EDS scanner, new or legacy
    2. Existing medical scanner, new or legacy
    3. Scanner for another application such as non-destructive evaluation (NDE)
    4. Custom designed for GCs

vi. Possible scanner locations
    1. Scanner provider's factory or associated site

2. Medical clinic
3. National laboratory such as LLNL
4. COE (NEU)
5. Tyndall Air Force Base
6. TSIF – may not be possible because of possible ownership issues of data and bias towards specific vendor

vii. Selection criteria
1. Availability of existing scanners.
2. Development time for new scanners.
3. Cost of developing new scanners that would fit into the time frame of this project; given the provisional funding allocations, it is unlikely that a new scanner could be developed for this project.
4. Cost of using scanners for scanning GC dataset.
5. Ability to supply the requested information.
6. Technical specifications for the scanners.
7. Locations where scanning could be performed per the list given above.
8. Comments on and suggestions for conducting GCs.
9. Maturity of equipment to be provided.

viii. Cost of database generation
1. TBD $ max
2. Team will support bag creation, logging and scanning
3. evaluation set

e. Dataset Labeling
i. Method: manual or semi-automatic – code may have to be written to perform this function
ii. Outputs:
1. Bounding box
2. Voxels of objects of interest
iii. Who:
1. Staff from team
2. May need to assess variability of different humans used for segmentation

f. Acceptance criteria
i. Technical
1. Volume overlap

            2. Distance to surface
            3. Feature accuracy
            4. Need to review literature from medical image grand challenges in particular work of Warfield, et al.
        ii. Operational
            1. Report values of metrics
            2. Have provisional acceptance criteria (i.e., thresholds)
            3. Code will be provided to report acceptance criteria
    g. Dataset distribution
        i. Datasets and specifications archived at LLNL
        ii. Datasets in the public domain: NDA and clearance not required to access
        iii. Registration is required in order to track data
3. Dataset types
    a. Types
        i. Training
        ii. Validation
        iii. Evaluation
        iv. *Simple* for entrance examination
        v. Phantoms
            1. Match mathematical phantom
            2. Image quality phantom
    b. Uses
        i. Participants
            1. Develops algorithm on *training* dataset
            2. Tests on *validation* dataset
        ii. Team
            1. Independently confirms participant results on *validation* dataset
            2. Tests on *evaluation* dataset
    c. Generated by
        i. Splitting datasets collected in dataset creation step into thirds
        ii. Randomly selecting data
        iii. Put some cases not seen in training or validation sets into evaluation dataset
4. Participants Identification
    a. Finding Participants

i. Process
   1. Advertising in peer-reviewed journals and at conferences
   2. Email solicitation of participants at algorithm development workshops
   3. Word of mouth
   4. Literature review
   5. Posting of solicitation on the Internet
   6. Review with NEU legal to make sure sufficiently expansive
   7. Presentation at various conferences

b. Participant proposal
   i. Technical
      1. Goals
      2. How goals will be achieved
      3. Existing technology
         a. Description
         b. Applicability to security problem
         c. Results of execution of *simple* test set
      4. Knowledge of security problem
   ii. Administrative or format considerations
      1. 10-page
      2. No payment for proposal
      3. Proposal
      4. Will not be returned
      5. Will not be disclosed outside of project team

c. Participant selection
   i. Criteria
      1. Knowledge of image segmentation
      2. Knowledge of the security field
      3. Existence of working segmentation algorithms
      4. Results of the entrance examination
      5. Having resources to work on the grand challenge
   ii. Selection team
      1. Independent review board; process reviewed by NEU legal department
      2. Establish scoring criteria
      3. Review with legal to make sufficiently unbiased
      4. TBD who will be on this team

5. Deliverables to participants
   a. The spec corresponding to this outline

   b. Datasets
   c. benchmark segmentation and metrics code[9]
   d. Contact information for help
6. Participant Algorithm Development
   a. Time frame: 6 months
   b. Mentoring: provided by the team
      i. At least monthly via tele-con
      ii. At least one face-to-face meeting
   c. Status reports: monthly
   d. Funding
      i. TBD $ to each participant
      ii. Non-funded participants may still participate
         1. Have algorithm evaluated
         2. Present at symposium
      iii. SSDs may not receive funding, but may participate
         1. Will be required to report the results of their algorithms
         2. Will not be required to disclose algorithm details
7. Independent Validation
   a. Validation dataset
      i. Match participant results
      ii. Iterate as necessary
      iii. Participant may be present
   b. Evaluation data set
      i. Test code on this set
      ii. Dataset not shared with participant
      iii. Results are shared
   c. Other
      i. The results of the independent testing will be shared with the participants.
8. Deliverables from participants
   a. An executable program that implements the participant's algorithm
      i. The executable may be invoked on a remote computer
      ii. Participants must guarantee that the evaluation dataset is not copied for future use.
   b. Executable requirements
      i. OS(s): TBD

[9] Entrance exam would entail replacing algorithm portion with new algorithm. Description of new algorithm would have to be delivered.

   - ii. Hardware: TBD
   - iii. Speed: < 5 minutes per volumetric CT dataset
- c. A report that contains the following information:
   - i. User manual for executable
   - ii. Results of running algorithm on training and testing datasets including:
      1. Accuracy of locating objects
      2. Accuracy of bounding boxes for located objects
      3. Accuracy of volume, mass and density
- d. Algorithm description including:
   - i. Mathematics
   - ii. Implementation considerations
   - iii. Strengths and weaknesses
   - iv. Extensibility to other images (resolution, noise, artifacts) and modalities
   - v. Possibility for future improvements
   - vi. Comments on special cases
      1. splitting
      2. combining
      3. problematic cases
- e. Code (available on the net)
   - i. Source
   - ii. Build instructions
   - iii. Description of
   - iv. All parameters ("knobs") that are typically used to tune algorithms for optimal performance should be clearly defined.
   - v. Sensitivity testing of all tuning parameters should be required.
- f. Recommendations for changes to the grand challenge process

9. Final Report and Symposium
   - a. Final report contents
      - i. Strengths and weakness of each participant for each of the following topics:
         1. Ability to segment objects per the acceptance criteria
         2. Quality of report
         3. Ease of use of the deliverable
      - ii. Recommendations for additional development on the algorithms
      - iii. Recommendations for changes to future grand challenges

iv. Notes:
    1. Final report will be in the public domain
b. Symposium
    i. Duration: 2 day
    ii. Participants bring computers or network access
    iii. New dataset provided and results reported in real time
    iv. Each participant will present algorithm and results
    v. Funding:
        1. For two people from each participating group
        2. Non-funded participants pay their own way
10. Program Team, Budget, Schedule and Legal Issues
    a. Team
        i. Members
            1. NEU/ALERT
                a. Michael Silevitch
                b. John Beaty
                c. David Castanon
                d. Carey Rappaport
                e. Hire-1
            2. LLNL
                a. Harry Martz
                b. Staff-1 or Hire-1
            3. DHS
                a. Carl Crawford
        ii. Roles
            1. Co-PI: Silevitch and Martz
            2. Program Manager: Beaty
            3. Project Engineer: Crawford
            4. Possible subject matter experts (SME):
                a. Castanon
                b. Rappaport
                c. Warfield
            5. Staff:
                a. NEU Hire-1
                b. LLNL Staff-1 or Hire-1
        iii. Responsibilities
            1. PI
                a. Set strategy
                b. Interface with DHS
            2. Program Manager
                a. Create program plan

        - b. Set program schedules
        - c. Track progress
        - d. Track finance
        - e. Write status reports
        - f. Maintain who/what/when/where lists
        - g. Initiate and execute contracts
      - 3. Project Engineer
        - a. Lead execution of technical aspects of program plan
- b. Budget
  - i. Program manager (PM) to fill out
- c. Schedule
  - i. Program manager (PM) to fill out
- d. Legal Issues
  - i. Contracts
    - 1. NEU/ALERT with DHS
    - 2. NEU/ALERT with participants
    - 3. LLNL with DHS
  - ii. IP
    - 1. Owned by participants
    - 2. License
      - a. Royalty-free to Gov. and its agents for research purposes
      - b. License to anyone who wants one
  - iii. Fundamentals of algorithm freely distributed
    - 1. Code in public domain
    - 2. Publication (or submission to journal) required

7. Future Efforts

This section contains recommendations for future efforts to increase the involvement of third parties in the development of advanced algorithms for security applications[10].

1. The following issues related to the adoption of algorithms should be addressed in future workshops:

    a. Royalty payments.
    b. IP ownership.
    c. Implementation issues such as coding standards, operating environment, exception handling, specification maintenance.

2. Have workshops on the following topics

    a. Grand challenges
    b. Stand-off detection
    c. Automated threat detection
    d. Image reconstruction
    e. Cargo screening
    f. Whole body imaging (advanced imaging technology, AIT)
    g. Sensor fusion

3. Conduct grand challenges for the following topics

    a. X-ray CT
        i. Image segmentation
        ii. Image reconstruction
        iii. Automated threat detection
        iv. Sensor modeling
    b. WBI/AIT
        i. Sensor modeling
        ii. Sensor design
        iii. Threat detection
        iv. New sensors
    c. Human operator performance
        i. PD versus PFA
        ii. Effect of TIP

[10] Some of these recommendations are from the final report for ADSA01 with minor modifications.

4. Publicize grand challenges at conferences and workshops, through announcements in journals, and via word of mouth.

5. Create a website where information and material about threat detection can be exchanged. Use RSS or equivalent to alert people about new content.

6. Establish a method to seed and reward people for developing advanced algorithms.

7. Find ways to create a feedback loop from the field performance of scanners back to researchers. In particular, disseminate lists of problem misses and sources of false alarms.

8. Create a bibliography of applicable literature and abstract the materials.

8. Lessons Learned and Mitigation

Lessons Learned	*Mitigation*
The agenda, as prospectively written, did not provide enough time for discussion and statements from the participants.	Increase the length of the workshop, allow more time for round-the-room sessions and discussions.
Many of the presentations were preempted by discussion. The net effect was positive.	Allow more time for discussions. Distribute the presentations in advance of the workshop.
Participants were anxious to discuss the specification for the grand challenge.	Distribute the specification in advance of the workshop. Discussion of the specification should be one of the first items on the agenda.
Having third parties present technologies allows the discussion of problems with the technologies.	Continue with third parties making presentations.
Participants need more background information.	Distribute patents and reprints before the meeting.
The term "grand challenge" has the connotation of a competition with a large prize given to the winner. Per ADSA02, it means creating an environment where people can compete in the academic sense and then share their results. Probably too late to use a different term.	Make sure all documents and presentations define what is meant by a grand challenge.

Lessons Learned	*Mitigation*
May have created the impression that a third party has to come from academia.	Emphasize that third parties may be in National Labs and industry other than the traditional vendors.
There was too much discussion about what topics were classified, SSI or proprietary.	Need to resolve these issues outside of the workshop. Discussions after the workshop indicated that there are clear guidelines from DHS on these subjects and that the guidelines should be followed.
There was a lot of discussion on the definition of a threat or threat-like object.	Use the term object of interest (OOI) as a placeholder and segregate the discussion of the definition of an OOI.
Still not enough images were shown, especially of problem cases.	Show more images.
Backgrounds of participants could have been even broader.	Invite people from other disciplines, e.g., NDE.
Scope of the project not always clear.	Present objective statement at beginning.
Wiki website cannot be used because of SSI concerns	Create moderated website.

9. Notes

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

1. The final report will be distributed as a hardcopy, via the Internet and a CD, subject to approval from DHS.
2. There was so much discussion during the workshop that some of speakers (mainly Crawford and Martz) did not present most of their slides in their presentations. Their slides – the ones that were presented and the ones that were not – are included in the appendix.
3. The timing in the agenda was only loosely followed because of the amount of discussion that took place during the presentations.
4. A number of extra people joined the workshop and are not listed in the list of participants. These people included Sergey Simanovsky (Analogic) and Elan Scheinman (Reveal Imaging).

10. 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, TSA, for their vision to involve third parties in the development of technologies for security applications.
- Suriyun Whitehead for coordinating the participation of DHS and TSA.
- Northeastern University for hosting the workshop.
- Mariah Nóbrega for handling logistics before and during the workshop.
- Deanna Beirne and John Chen for providing audio-visual assistance.
- Rachel Harger for assembling the final report.
- Richard Moore for setting up a Wiki-based website for algorithm development.
- Harry Martz, Brian Loughlin, Mariah Nóbrega and Rachel Harger for taking the minutes during the workshop.
- Homer Pien and Doug Boyd for supplying scans of simulated IEDs on medical scanners.
- Ralf Birken, Harry Martz and David Castanon for reviewing this report.

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

11. Appendix: Agenda

Wednesday, October 7, 2009

8:00 AM **Registration/Continental Breakfast**

9:00 AM **Welcoming remarks**
- Michael Silevitch, Northeastern University
- Doug Bauer, DHS S&T
- Harry Martz, Lawrence Livermore National Laboratory

9:30 AM **Workshop overview and objectives**
- Carl Crawford, Csuptwo

10:00 AM **Comments on first algorithm development workshop**
- Carl Crawford, Csuptwo

10:30 AM **Coffee Break**

10:45 AM **Overview of CT-based explosives detection equipment**
- Harry Martz, Lawrence Livermore National Laboratory

11:30 AM **Segmentation challenges**
- Harry Martz, Lawrence Livermore National Laboratory

12:00 PM **Break and get box lunch**

12:30 PM **Review of automated threat detection algorithms**
- Carl Crawford, Csuptwo

1:30 PM **Medical Grand Challenges**

Detection of multiple sclerosis lesions
- Simon Warfield, Harvard Medical School

Liver segmentation from CT datasets
- Marc Kachelriess, University of Erlangen

3:30 PM **Break**

3:45 PM **LLNL third-party algorithm development project**

- Harry Martz, Lawrence Livermore National Laboratory

4:45 PM **Metal artifact reduction in CT security scanning**
- Homer Pien, Massachusetts General Hospital

5:00 PM **Testing human factors**
- Jeremy Wolfe, Harvard Medical School

5:30 PM **Open Discussion**

6:00 PM **Reception (sponsored by Csuptwo)**
Location: Kerr Hall, the Fenway

7:00 PM **Working dinner**
- Talk: "Statistical image reconstruction for security applications," Xiaochuan Pan, University of Chicago
- Talk: "The Netflix grand challenge and the importance of collaboration," Matthew Merzbacher, Morpho Detection

Thursday, October 8, 2009

7:30 AM **Breakfast**

8:00 AM **Introduction to Day 2**
- Carl Crawford, Csuptwo

8:15 AM **Details of the segmentation grand challenge for security**
(Discussion of Chapter 6 of final report from first workshop)
- Carl Crawford, Csuptwo

10:00 AM **Break**

10:30 AM **Extensibility to other Grand Challenges**
- Carl Crawford, Csuptwo

11:30 AM **Break and get lunch**

12:00 PM **Summary and feedback on grand challenges**
DHS S&T
- Suriyun Whitehead, DHS S&T
  Academia
- David Castañón, Boston University
  Vendors
- Jim Connelly, L-3 Communications
  Third-party industry
- Carl Smith, Guardian Technologies
  National Labs
- Tim White, Pacific Northwest National Laboratory

1:15 PM **Around the room**
- All participants

1:45 PM **Closing remarks**
- Harry Martz, Lawrence Livermore National Laboratory
- Michael Silevitch, Northeastern University
- Doug Bauer, DHS S&T

2:00 PM **Workshop concludes**

12. Appendix: Overview

The Department of Homeland Security (DHS) has requirements for future scanners that include a larger number of threat categories, higher probability of detection per category, lower false alarm rates and lower operating costs. One tactic that DHS is pursuing to achieve these requirements is to create an environment where the capabilities of the traditional vendors of security systems could be augmented by the development of algorithms by third parties. A third party in this context means people and organizations other than the traditional vendors. Examples of third parties include academics, national laboratories and companies other than the traditional vendors. DHS is particularly interested in following the model used by the medical imaging industry, in which university researchers have developed numerous algorithms that have eventually been deployed in commercial medical imaging equipment[11].

A tactic that the DHS is using to stimulate academic and industrial third party algorithm development is to hold workshops addressing the research opportunities that may enable the development of next generation algorithms for Homeland Security applications. The first such workshop, which was entitled "Algorithm Development for Security Applications (ADSA) Workshop," was held at Northeastern University (NEU) on April 23-24, 2009[12]. The workshop was led by Professor Michael B. Silevitch (NEU) as part of the DHS Center of Excellence (COE) entitled Awareness and Localization of Explosives-Related Threats[13] (ALERT). The sponsors of the workshop were DHS and ALERT[14].

The main recommendation of the first workshop was that grand challenges should be established for different aspects of threat detection and for different modalities. The aspects of threat detection include reconstruction and processing of sensor data, image segmentation, automated threat detection and improved operator performance. The modalities include x-ray

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[11] When we speak of an algorithm, we are talking about the mathematical steps. The actual implementation, usually in a general purpose computer, is beyond the scope of this discussion.

[12] Final Report, Algorithm Development for Security Applications Workshop, Northeastern University, April 23-24, 2009.

[13] http://www.northeastern.edu/alert

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

CT for checked and carry-on baggage, whole body imaging, cargo inspection and stand-off detection. Implementing grand challenges will entail putting the following information and materials into the public domain: data sets, sensor descriptions and acceptance criteria. People working on grand challenges should be provided financial incentives to advance the state of the art.

It was further recommended at the first workshop that the first grand challenge should be to develop advanced segmentation algorithms from volumetric CT data for the purpose of enhancing automated threat detection algorithms for Explosives Detection Systems (EDS) and for CT-based checked baggage scanners for the check-point.

The participants at the first workshop further recommended that subsequent grand challenges be held for advanced reconstruction algorithms for CT-based equipment and then run grand challenges for different aspects of other modalities such as multi-view line scanners (known as advanced technology [AT]) and whole body imagers (WBI).

The purpose of the second workshop is to discuss the process required to execute the grand challenges for segmenting volumetric CT data. The following list shows the topics that will be addressed at the 2nd workshop.

1. Program definition
2. Dataset creation
3. Participant[15] identification
4. Algorithm development
5. Independent evaluation
6. Demonstration of algorithms and write final report

Thank you for participating in this workshop!

Michael Silevitch, Northeastern University
Carey Rappaport, Northeastern University
David Castañón, Boston University
Horst Wittmann, Northeastern University
John Beaty, Northeastern University
Carl Crawford, Csuptwo, LLC
Harry Martz, Lawrence Livermore National Laboratory

[15] We use the term *participant* to mean the third party who develops an algorithm.

13. Appendix: Planning Committee

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

Michael Silevitch, Northeastern University
Carey Rappaport, Northeastern University
David Castañón, Boston University
Horst Wittmann, Northeastern University
John Beaty, Northeastern University
Carl Crawford, Csuptwo, LLC
Harry Martz, Lawrence Livermore National Laboratory

The final report was edited by:

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

Logistics for the workshop were handled by:

Rachel Harger, Northeastern University
Mariah Nóbrega, Northeastern University

14. Appendix: Invitation

The 2nd workshop on advanced algorithm development for security applications will be held at Northeastern University (NEU) on October 7th and 8th. The topic for this workshop will be the process used by 3rd parties to develop advanced algorithms. This process is denoted as *implementing grand challenges*. The workshop will focus on an initial challenge to develop advanced segmentation algorithms for volume CT scanners used to detect explosives in checked and carry-on bags. Other grand challenges for other modalities and applications will be peripherally addressed. A preliminary agenda for the workshop is enclosed below.

The workshop is being led by Professor Michael Silevitch (NEU) as part of a Center of Excellence award from the DHS entitled Awareness and Localization of Explosives-Related Threats (ALERT, www.northeastern.edu/alert) and by Harry Martz (Lawrence Livermore National Laboratory). I will be the moderator for the workshop.

Please let me know if you are interested in attending the workshop, can recommend other people who would be interested in attending, and if you have feedback on the agenda.

If possible, we want to limit participation to one person per company. We will be paying travel expenses for people coming from academia and national labs.

Please feel free to contact me (see below for contact information), Michael Silevitch (msilevit@ece.neu.edu or 617-373-3033) or Harry Martz (martz2@llnl.gov or 925-423-4269) on all matters related to the workshop.

Thank you for your consideration of the workshop and we look forward to your participation.

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Preliminary Agenda (Version 8)

Objectives

1. Discuss the process by which the research community can produce advanced algorithms for Homeland Security applications. This process is denoted the *Grand Challenge.*

2. Segmentation of objects from volume CT scans of checked and carry-on luggage will be the focus of the workshop.

3. The goal of the workshop is to define the elements of a comprehensive strategic implementation plan for the challenge of image segmentation and how this implementation is extensible to other grand challenges.

Agenda Topics

1. Welcoming remarks
    a. NEU
    b. DHS/TSA
2. Workshop overview
    a. Objectives
    b. Ground rules
3. Comments on first workshop
4. What are grand challenges?
    a. Overview/definition/issues
    b. Revealing problems that need to be solved
    c. Generic model of application
    d. Relationships to other grand challenges
    e. Medical example (IEEE TMI article on liver segmentation)
5. Review of CT-based explosive detection
    i. Hardware
    ii. Reconstruction
    iii. Segmentation
    iv. Automated threat detection
    v. Deployment
    vi. False alarm problem
6. Tutorial on state of the art in image segmentation algorithms
    a. Medical imaging
    b. NDE
    c. Security

7. Implementing the Segmentation Grand Challenge for x-ray CT images of checked and carry-on luggage
    a. Elements of the implementation
        i. Challenge data collection
        ii. Challenge data dissemination
        iii. Use of existing algorithms on challenge data
        iv. Analysis and scoring of results
        v. Fostering of advanced development
    b. Panel discussion
8. Extensibility to other Grand Challenges
    a. Topics
        i. Reconstruction
        ii. Detection
        iii. Human factors
        iv. Sensor modeling and development (hardware)
    b. Modalities/Applications
        i. WBI
        ii. Stand-off IED detection
        iii. Cargo Screening
9. Discussion – stakeholders
    a. Academia
    b. DHS/TSA
    c. 3rd party industry
    d. Vendors
10. Framing the final report
11. Closing remarks
    a. Around the room
    b. NEU
    c. DHS

15. Appendix: Speaker Assignment

Thank you for agreeing to present at the forthcoming algorithm development workshop on October 7-8.

Enclosed is a copy of the agenda. Please let me know if you need more/less time for your presentation or if the title should be changed. We recommend that you present using the laptop that Northeastern will provide. Please let Mariah know if you need special equipment (she is copied on this email).

Please note the following points about your presentation:

1. Presentations are in the public domain.
2. Classified and SSI material cannot be presented.
3. You agree to have your presentation distributed with the final report from the workshop.
4. Allow ample time during your presentation for questions and discussion; recall that this is a workshop and not a conference.
5. Presenters of opening and closing remarks may speak without slides.

For those of you speaking in the 2-PM session on the second day entitled "Summary and feedback on grand challenges," (Whitehead, Castanon, Connelly, Smith and White), I ask that you prepare a 10-minute presentation using slides. You might have to overlap your preparation with other sessions and breaks. The presentations do not have to be polished.

Again, thank you for presenting at the workshop.

16. Appendix: Acronyms

AAPM	American Association of Physicists in Medicine
ADSA	Algorithm Development for Security Applications
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.
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
ASTM	American Society for Testing and Materials
AT	Advanced technology
ATD	Automated threat detection. This term is deprecated in favor of the term ATR.
ATR	Automated threat resolution. This term has replaced the term ATD.
BAA	Broad agency announcement
BHS	Baggage handling system
BIR	Baggage inspection room
BLS	Bottled Liquids Scanners
BPSS	Boarding Pass Scanning Systems
BU	Boston University
CAD	Computer aided or assisted detection
Cambria	TSA procurement program for next-generation check-point scanners
CAPPS	Computer Assisted Passenger Prescreening System
CAT	Credential Authentication Technology
CERT	Certification testing at the TSL
CIA	Central Intelligence Agency
COE	Center of excellence, a DHS designation
CONOP	Concept of operations
COP	Concept of Operation
CPI	Cast & Prosthesis Imagers

CRT	Certification readiness testing
CT	Computed tomography
CTsegGC	CT segmentation grand challenge; in places “GC” is deleted from this acronym.
CTreconGC	CT reconstruction grand challenge; in places “GC” is deleted from this acronym.
DAS	Data acquisition system
DHS	Department of Homeland Security
DHS S&T	DHS Science & Technology division
DICOM	Digital Imaging and Communications in Medicine; http://medical.nema.org
DICOS	Digital Imaging and Communications in Security. NEMA standard for image format for security; NEMA IIC Industrial Imaging and Communications Technical Committee.
DOD	Department of Defense
DR	Digital radiology
EDS	Explosive detection scanner that passes TSL’s CERT.
ETD	Explosive trace detection
FA	False alarm
FAA	Federal Aviation Administration
FAT	Factory acceptance testing
FBI	Federal Bureau of Intelligence
FOUO	For official use only
FOV	Field of view
Gordon-CENSSIS	The Gordon Center for Subsurface Sensing and Imaging Systems, at NEU
GC	Grand challenge
HME	Homemade explosive
HMS	Harvard Medical School
HVPS	High voltage power supply
IED	Improvised explosive device
IEEE	Institute of electrical and electronic engineers
IGT	Image guided therapy
IHE	Integrating the Healthcare Enterprise
INL	Idaho National Laboratory
IQ	Image quality

JND	Just noticeable difference
L-3	L-3 Communications
LAC	Linear Attenuation Coefficient
LLNL	Lawrence Livermore National Laboratory
LS	Line scanners (projection scanners)
Manhattan II	TSA procurement program for next-generation EDS
MC	Monte Carlo [modeling]
MIC	Medical Imaging Conference (IEEE)
MMW	Millimeter wave
MRI	Magnetic resonance imaging
MV	Multiple view
NDA	Non-disclosure agreement
NDE	Non-destructive evaluation
NEMA	National Electrical Manufacturers Association
NEU	Northeastern University
NIST	National Institute of Standards and Technology
NQR	Nuclear Quadrupole Resonance
OOI	Object of interest. The object that a segmentation
ONR	Office of Naval Research
OSARP	On screen alarm resolution protocol/process
OSR	On screen resolution
PD	Probability of detection
PET	Positron emission tomography
PFA	Probability of false alarm
PPV	Positive predictive value
QR	Quadruple resonance
RED	Remote explosive detection (stand-off)
RFI	Request for information
ROC	Receiver operator characteristic
RPI	Rensselaer Polytechnic Institute
RSNA	Radiology Society of North America
SAT	Site acceptance testing
SBIR	Small business innovation research
SCS	Standard Communication in Security
Sensitivity	Probability of true positive
SME	Subject matter expert

SOC	Stream of commerce
SOP	Standard operating procedure
Specificity	1 – probability of false positive
SPECT	Single photon emission computed tomography
SPIE	International society for optics and photonics
SSD	Security system developer. Vendor of complete security device such as L-3, Reveal, Analogic or Morpho Detection
SSI	Sensitive security information
STIP	Security Technology Integrated Program
TBD	To be determined
THZ	Tera-Hertz imaging
TIP	Threat image projection
TMI	Transactions on Medical Imaging. An IEEE journal publication.
TQ	Threat quantity; minimum mass required for detection. Value(s) is classified.
TRX	TIP-ready x-ray line scanners
TSA	Transportation Security Administration
TSL	Transportation Security Lab, Atlantic City, NJ
TSO	Transportation security officer; scanner operator
WBI	Whole body imaging; a deprecated term for AIT
XRD	X-ray diffraction

17. Appendix: Attendee List

Name	*Affiliation*
Doug Bauer	Department of Homeland Security
John Beaty	Northeastern University
Richard Bijjani	Reveal Imaging
Carl Bosch	Surescan
Charles Bouman	Purdue University
Doug Boyd	Telesecurity Sciences
Peer-Timo Bremer	Lawrence Livermore National Laboratory
David Castañón	Boston University
Philip Cheney	Northeastern University
Jim Connelly	L-3 Communications
Carl Crawford	Csuptwo
Pia Dreiseitel	Smiths Detection
Xin Feng	Marquette University
Ted Grant	Department of Homeland Security
Dan Gudmundson	Optosecurity
Marc Kachelriess	University of Erlangen
W. Clem Karl	Boston University
David Lieblich	Analogic
Edwin Marengo	Northeastern University
Harry Martz	Lawrence Livermore National Laboratory
Tejas Mehta	Rapiscan
Matthew Merzbacher	Morpho Detection
Eric Miller	Tufts University
Rick Moore	Massachusetts General Hospital
Bill O'Reilly	Mercury Computers
Xiaochuan Pan	University of Chicago
Johnny Park	Purdue University
Homer Pien	Massachusetts General Hospital
Visvanathan Ramesh	Siemens Corporate Research
Carey Rappaport	Northeastern University
Oliver Ruebel	University of Kaiserslautern
Jean-Pierre Schott	Lawrence Livermore National Laboratory

Greg Sharp	Massachusetts General Hospital
Michael Silevitch	Northeastern University
Steve Skrzypkowiak	TSA
Carl Smith	Guardian Technologies
Simon Streltsov	LongShortWay
Mario Sznaier	Northeastern University
Simon Warfield	Harvard Medical School
Tim White	Pacific Northwest National Laboratory
Suriyun Whitehead	Department of Homeland Security
Michael Winer	American Science and Engineering
Horst Wittmann	Northeastern University
Jeremy Wolfe	Harvard Medical School
Birsen Yazici	Rensselaer Polytechnic Institute
George Zarur	Department of Homeland Security

Students

Limor Eger	Boston University
Chitra Subramanian	Northeastern University

18. Appendix: Participant Biographies


Doug Bauer


John Beaty


Richard Bijjani


Carl Bosch

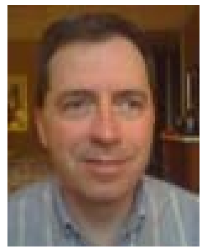

Charles Bouman


Douglas Boyd


Peer-Timo Bremer


David Castañón


Philip Cheney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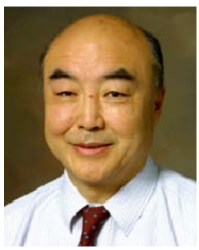
Carl Crawford


Pia Dreiseitel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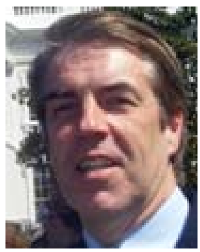

Ted Grant


Dan Gudmundson


Marc Kachelriess


W. Clem Karl


Edwin Marengo


Harry Martz


Tejas Mehta


Matthew Merzbacher


Eric Miller


Rick Moore


Bill O'Reilly


Xiaochuan Pan


Johnny Park


Homer Pien


Visvanathan Ramesh

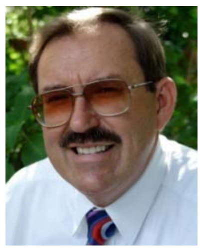

Carey Rappaport


Oliver Ruebel

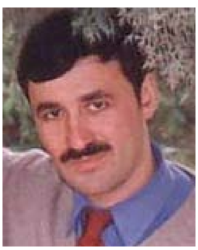

Jean-Pierre Schott

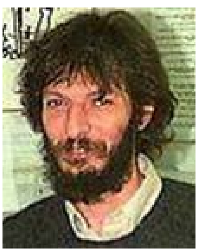

Sergey Simanovsky


Michael Silevitch

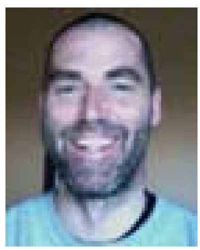

Steve Skrzypkowiak


Carl Smith


Simon Streltsov


Mario Sznaier

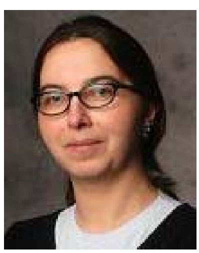

Simon Warfield


Timothy White


Michael Winer


Horst Wittmann


Jeremy Wolfe


Birsen Yazici

Douglas C. Bauer

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Science and Technology Division
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Dr. Douglas Bauer is the Program Executive for Basic Research within the Explosives Division of the Science and Technology Directorate at the Department of Homeland Security (DHS). He has management responsibility for a multi-million dollar program in explosives basic and applied research, homemade explosives (HME) characterization, detection and damage assessment, development of the next generation EDS x-ray technologies, and counter IED basic research in prevention, detection, response and mitigation. Dr. Bauer also has management responsibility for two new university-based Centers of Excellence addressing explosive threats in transportation through fundamental research. Previously, Dr. Bauer was Acting Director of the Countermeasures Test Beds (CMTB), an activity to carry out Operational Test and Evaluation (OT&E) for counter terrorism technologies. Legacy CMTB projects for which he is still responsible include the Air Cargo Explosives Detection Pilot Project (ACEDPP) in three different airports and consultation on security systems for surface transportation application.

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. He is a registered professional engineer in two states (New York, Pennsylvania) and a member of the D.C. bar, admitted to practice before federal courts. He is a certified Program Manager Level I and received the Under Secretary's award for Program Management and the Secretary's award for Excellence in 2007.

John Beaty

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Dr. Douglas Boyd has contributed to the fields of imaging technology, accelerator and beam physics, superconducting systems, nuclear physics, and medical physics. Following his graduate studies in nuclear physics at Rutgers, Dr. Boyd continued his research at Bell Labs under a post-doctoral fellowship program. He then moved to Stanford University and was the project leader for the world's first pion radiotherapy facility. As part of this program he was one of the early developers of fan-beam, Xenon-detector CT scanners. In 1976 Dr. Boyd joined the faculty in at UCSF with the intent to establish a laboratory to develop the next generation of no-motion CT scanners, with emphasis on cardiac imaging. This led to the foundation of Prior of Imatron, Inc., which since 1982 became the leader in development of electron beam Cardiac CT Scanners (EBCT).

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

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Dr. Marc Kachelreiss is Professor of Medical Imaging at the Institute of Medical Physics (IMP) of the Friedrich-Alexander University of Erlangen-Nürnberg. Originally, he studied physics with a focus on theoretical particle physics. He received his physics diploma in 1995. Then, he started with his dissertation at the Institute of Medical Physics (IMP) under the guidance of Prof. Dr. Willi A. Kalender. He developed reconstruction algorithms to reduce metal artifacts in x-ray computed tomography (CT). In parallel, Dr. Kachelriess introduced a new method that allows to generate motion-free images of the human heart using standard CT data. Thereby the clinical feasibility of retrospective electrocardiogram-correlated image reconstruction from CT data was proven. This method is now in world-wide use in clinical CT scanners. Dr Kachelriess received his Ph.D. at the IMP in 1998.

Since then, Dr. Kachelriess has extended the cardiac imaging approaches to future scanner generations. His research covers image reconstruction of cone-beam CT data, iterative image reconstruction, image reconstruction algorithms in general, and high performance implementations. He is involved in developing algorithms for automatic exposure control (AEC) for CT, methods to reduce CT artifacts, dual energy CT (DECT) algorithms, and patient dose reduction techniques. His work also includes the design and development of micro-CT scanner hard- and software, micro-CT pre- and postprocessing software and image quality optimization techniques as well as the design and implementation of high performance image reconstruction software for luggage CT scanners.

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Previously, Dr Schott was Director of Advanced Development at Medispectra, managing directors, managers, engineers, scientists and consultants of the algorithm, image processing, database and software groups. He also architected the overall classification and image processing algorithms and led the cross-functional team, including external counsel, which produced 9 patent applications covering the intellectual property of the key technology. Dr. Schott has also served as Director of Engineering at Synapix, managing the entire engineering department, including 2D and 3D graphics groups, QA, documentation, UI and computational geometry.

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Stephen Skrzypkowiak earned his PhD degree in electrical engineering from the University of South Florida (USF). He has also held teaching and research positions at USF. Steve is a consultant to the DHS, TSA and TSL and has been since 2002. He currently supports these agencies in the technical review of various detection systems, revision of the explosive certification standard and the development of various detection and procurement specifications. He provides technical support for various TSL research projects. He is the TSA consultant Point of Contact to the DICOS committee in the working groups of Digital Radiography (DR), Computed Tomography (CT), Threat Detection (TD) and Technical committees. He was a DHS consultant as a technical support member to the IEEE P Draft Standard for Evaluating the Image Quality of X-ray Computed Tomography (CT) Security-Screening Systems. He developed the Computed Tomography Image Quality (CTIQ) hardware and software to measure the image quality of Explosive Detection Systems for the Transportation Security Laboratory (TSL). As Director of Engineering, Steve led the L-3 communication team from the development of the 3DX6000 through TSA certification and fielding before becoming

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Mr. Carl Smith holds a Bachelor of Science from the US Naval Academy and a MS in Systems Management from the University of Southern California. He joined Guardian Technologies in June 2005 as the Director and then Vice President of Operations responsible for all program management efforts. He developed processes and procedures from product initiation through production and support. Significant efforts included: planning and implementing Quality Management Process that resulted in the company's Quality Management Program certification to the ISO 9001: 2000 with Design Standard; responsible for all research and development activities for adapting explosive detection software to additional scanning systems; and, developed field data collection and test procedures for US laboratory tests and overseas field trials. Prior to joining Guardian, Mr. Smith was Vice President Systems Engineering Division for Delex Systems, Inc. His division provided engineering, management, and financial analysis and advice to decision makers for major Department of the Navy acquisition programs. These efforts supported multiple domestic (6) and international (26) programs. Other positions include President and co-founder of CJC, Inc. and post merger, Vice President of Prometheus, and Senior Manager, KPMG Peat Marwick. A Naval Aviator Mr. Smith served in various operational and training billets, accumulating over 3,600 hours in 9 aircraft models. Mr. Smith commanded a reserve augment squadron and the Joint Transportation Reserve Unit supporting Commander in Chief Transportation Command.

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Dr. Simon Streltsov is the President and co-founder of LongShortWay Inc. in Cambridge, MA. Simon has previously worked for Alphatech Inc. in Burlington MA and Mercury Computers in Chelmsford MA. He has a Ph.D. in Manufacturing Engineering/Operations Research from Boston University.

LongShortWay, founded in 2003, is developing and supporting pattern analysis tools for detection of IED-related events and hard-to-find targets in cluttered radar data under AFRL, AF/ESC, JIEDDO contracts. LongShortWay approach to image segmentation represents the image as a proximity graph of pixel similarity and then clusters the graph to uncover the segments.

Simon Warfield

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Dr. Warfield is Associate Professor of Radiology at Harvard Medical School, Director of Radiology Research and Director of the Computational Radiology Laboratory (CRL) in the Department of Radiology at Children's Hospital. Dr. Warfield has served as the Principal Investigator of research grants funded by the National Institutes of Health and the National Science Foundation. He is an editor of Medical Image Analysis and an Associate Editor for IEEE Transactions on Medical Imaging.

Dr. Warfield founded the CRL in 2001 with the mission of improving our understanding of the structure and function of the brain and other organs of the human body, in order to improve our capacity to diagnose and treat disease. Dr. Warfield's research interests in the field of medical image computing have focused on the development of innovative algorithms to address the requirements of clinical care and translational research in medicine. This has included the development of novel algorithms for image segmentation and image registration, especially suited to quantitative assessment of early brain development utilizing advanced brain atlasing and pattern recognition approaches. The CRL develops and distributes open source software for pediatric image analysis.

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Dr. Timothy White is Research Scientist in the Radiation Detection and Nuclear Sciences groups at PNNL. Previously, Dr. White worked for 14 years in the Materials Characterization department at the Idaho National Laboratory (INL). At the INL, he was involved in a number of digital radiography (DR) and computed tomography (CT) projects covering a broad range of applications, including: development of a field portable, fan-beam DR and CT system for the characterization and remediation of chemical munitions; characterization and modeling of cargo x-ray scanners in order to generate accurate synthetic radiographs; development of lightweight, portable x-ray imaging systems and visualization tools for examination of improvised explosive devices; and the demonstration of CT techniques for materials characterization in hot cells. His research interests are in helical cone-beam x-ray tomography, three-dimensional x-ray imaging from limited-view data, visualization and interpretation of radiographic data, and applications of low-field nuclear magnetic resonance for contaminant detection. Dr. White received his Ph. D. in Optical Sciences from the University of Arizona.

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

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Mike Winer joined AS&E in 2004 as a Senior Program Manager for contract research and development where he currently leads programs for customers including ARMY CERDEC, DHS, DARPA, National Labs and other government agencies. Additionally, Mr. Winer manages internal research & development programs in an effort to improve the state-of-the art of X-ray technology in the area of security. Prior to AS&E, Mr. Winer was a Senior Program Manager in the Mid-Range Storage Division of EMC Corporation and Data General's High-End Server Division. He has extensive experience in new product development, supply chain, design for manufacturability and has held management positions in New Products Program Management – International Manufacturing Operations, as well as in Test Engineering. Mr. Winer holds a BSEE from Northeastern University.

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

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Jeremy Wolfe graduated summa cum laude from Princeton in 1977 with a degree in Psychology and went on to obtain his PhD in 1981 from MIT, studying with Richard Held. His PhD thesis was entitled "On Binocular Single Vision". Wolfe remained at MIT until 1991. During that period, he published papers on binocular rivalry, visual aftereffects, and accommodation. In the late 1980s, the focus of the lab shifted to visual attention. Since that time, he has published numerous articles on visual search and visual attention. In 1991, Wolfe moved to Brigham and Women's Hospital and Harvard Medical School where he is Professor of Ophthalmology. The lab is currently funded by the US National Institutes of Health and Department of Homeland Security. Wolfe teaches Psychology courses at MIT & Harvard.

Jeremy Wolfe is Past-President of the Eastern Psychological Association, President-elect of Division 3 of the American Psychological Association, and editor of the journal "Attention, Perception and Psychophysics". He won the Baker Memorial Prize for teaching at MIT in 1989. He is a fellow of the AAAS, the American Psychological Assocation (Div. 3 & 6), the American Psychological Society, and a member of the Society for Experimental Psychologists. He lives in Newton, Mass.

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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.

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19. Appendix: CT Segmentation Grand Challenge Outline[16]

1. Program Definition
    a. Program Outline
        i. Technical
            1. Program Definition
            2. Dataset Creation
            3. Participant Identification
            4. Algorithm Development
            5. Independent Validation
            6. Deliverables from Participants
            7. Final Report and Symposium
        ii. Operational
            1. Program Team
            2. Budget
            3. Schedule
            4. Legal Issues
    b. Scope
        i. Segmenting objects from volumetric CT data
        ii. Objects
            1. Phase 1: threat-like objects in problematic configurations
            2. Phase 2: all threat-like objects
            3. Phase 3: all objects
    c. Transfer function
        i. Inputs:
            1. CT volumetric data
        ii. Transfer function
            1. Segment objects
            2. Estimate object features
        iii. Outputs:
            1. Labels
                a. second sampled volume with the same number of voxels
                b. each object of interest is given a number

[16] This outline was used as the basis of the presentations made at ADSA02.

            c. voxels in label volume are assign object number corresponding to voxels in CT data
        2. Features
            a. Technical
                i. Mass
                ii. Density
                iii. Volume
                iv. Zeff
            b. Operational
                i. Formulas for generating features will be provided.

2. Dataset Creation
    a. Dataset definition
        i. Definitions
            1. What objects need to be segmented
            2. What cases should be concentrated on (easy, medium, difficult)
        ii. Process
            1. Obtain feedback from ADSA02 participants
            2. Have classified meeting with certified SSDs to hear about difficult cases
            3. Final decision on bag makeup made by project team
    b. Acquire tools and Materials
        i. Locate and fund use of medical or industrial scanner
            1. Use of security scanner unlikely, but should be pursued
        ii. Acquire 100 items for contents of bags. The items include the following items from stream of commerce (SOC) bags:
            1. Clothing
            2. Personal items
            3. Perishables (fruit, vegetables)
            4. Food in containers
            5. Electronics
            6. Liquids
            7. Sheet-like objects
        iii. Acquire 20 suitcases

1. Define how to pack 100[17] different configurations of bags using the 20 suitcases and the 100 objects.
2. Use LLNL data on the prevalence of objects to pack the bags.
3. Pack bags to produce artifacts in the images such as cupping, CT number shifts, streaks, rings and bands.

iv. Scan contents of 100 items in isolation and record the following information:
   1. Dimensions
   2. Mass
   3. Volume
   4. Density
   5. Digital picture
   6. Written description

v. Pack and scan 100 bags

vi. Generate labels showing location of objects in each bag
   1. Manual segmentation/outlining
   2. Might need multiple experts
   3. May be partially obviated with scans of calibrated (phantoms) objects

vii. Store dataset at LLNL

viii. Archive bags and objects so that the can be scanned on future scanners and SSD scanners

c. Phantom scanning and simulation (calibrated objects)[18]
   i. Specify bag and contents consisting of mathematical shapes
   ii. Construct bag
   iii. Scan bag
   iv. Create Forbild (University of Erlangen format) phantom description
   v. Create simulated projection data similar to CT scanner

d. Details of scanner used for scanning
   i. Scan on CT scanner representative of SSD scanners
   ii. Scanner specs

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[17] May reduce this number in order to concentrate on difficult cases. SSDs agreed to help identify difficult cases. A classified meeting may be required.

[18] Phantoms are a type of bag to be scanned at Point 2.b.iv.

1. Scan FOV: 50 cm
2. Scan modes: helical or step-and-shoot
3. Dual energy: desirable
4. Resolution: 1 mm isotropic (10% of MTF or SSP)
5. Pixel size: 1 mm isotropic
6. Potentials:
    a. 140 – 180 kV
    b. 80 – 120 kV
    c. 40 kV difference between high and low energies
7. Dose: 20 mAs
    a. Consider higher dose to get ~noise-less data and degrade retrospectively
8. Projections: 512 view per rotation per energy
9. Reconstruction steps:
    a. Cone beam correction: exact or hybrid
        i. Filtered back projection preferred because of schedule
        ii. Iterative (statistical) possible for 2nd phase
    b. Kernel: LPF matching pixel spacing
    c. Dual energy decomposition
    d. State-of-the art corrections including
        i. Offset
        ii. Air (gain)
        iii. Crosstalk
        iv. Afterglow
        v. Spectral (detector dependent)
        vi. Beam hardening (detector independent)
        vii. Bad detection correction
        viii. Logarithm
        ix. Adaptive filter
        x. Scatter correction
10. Scan time: < 15 minutes per volumetric scan

iii. Material distribution
1. Reconstructed images
    a. Images reconstructed with different algorithms may be provided
    b. Only one dataset will be labeled
2. Raw data

3. Corrected data
4. Scan log
    a. Date/time
    b. Operator
    c. Scan description
    d. Digital pictures of bag and contents
5. Scanner description
6. Reconstruction algorithm
    a. Mathematical description
    b. Code (offline)

iv. Possible scanner types
1. Existing EDS scanner, new or legacy
2. Existing medical scanner, new or legacy
3. Scanner for another application such as non-destructive evaluation (NDE)
4. Custom designed for GCs

v. Possible scanner locations
1. Scanner provider's factory or associated site
2. Medical clinic
3. National laboratory such as LLNL
4. COE (NEU)
5. Tyndall Air Force Base
6. TSIF

vi. Selection criteria
1. Availability of existing scanners.
2. Development time for new scanners.
3. Cost of developing new scanners that would fit into the time frame of this project.
4. Cost of using scanners for scanning.
5. Ability to supply the requested information.
6. Technical specifications for the scanners.
7. Locations where scanning could be performed per the list given above.
8. Comments on and suggestions for conducting GCs.
9. Maturity of equipment to be provided.

vii. Cost of database generation
1. $100k max
2. Team will support bag creation, logging and scanning
3. evaluation set

- e. Dataset Labeling
  - i. Method: manual
  - ii. Outputs:
    1. Bounding box
    2. Voxels of objects of interest
  - iii. Who:
    1. Staff from team
    2. Assess variability of different humans
- f. Acceptance criteria
  - i. Technical
    1. Volume overlap
    2. Distance to surface
    3. Feature accuracy
  - ii. Operational
    1. TBD if
       - a. Report values of metrics
       - b. Have acceptance criteria (i.e., thresholds)
- g. Dataset distribution
  - i. Datasets and specifications archived at LLNL
  - ii. Datasets in the public domain: NDA and clearance not required to access
  - iii. Anyone (everyone) can access data
  - iv. Registration is required in order to track data

3. Dataset types
   - a. Types
     - i. Training
     - ii. Validation
     - iii. Evaluation
     - iv. *Simple*
     - v. Phantom
   - b. Uses
     - i. Participants
       1. Develops algorithm on *training* dataset
       2. Tests on *validation* dataset
     - ii. Team
       1. Independently confirms participant results on *validation* dataset
       2. Tests on *evaluation* dataset
   - c. Generated by
     - i. Splitting datasets collection in Dataset creation step into thirds

ii. Randomly selecting data
iii. Put some cases not seen in training or validation sets into

4. Participants Identification
    a. Finding Participants
        i. Process
            1. Advertising in peer-reviewed journals and at conferences
            2. Email solicitation of participants at algorithm development workshops
            3. Word of mouth
            4. Literature review
            5. Posting of solicitation on the Internet
            6. Review with NEU legal to make sure sufficiently expansive
    b. Participant proposal
        i. Technical
            1. Goals
            2. How goals will be achieved
            3. Existing technology
                a. Description
                b. Applicability to security problem
                c. Results of execution of *simple* test set
            4. Knowledge of security problem
        ii. Administrative or format considerations
            1. 10-page
            2. No payment for proposal
            3. Proposal
            4. Will not be returned
            5. Will not be disclosed outside of project team
    c. Participant selection
        i. Criteria
            1. Knowledge of image segmentation
            2. Knowledge of the security field
            3. Existence of working segmentation algorithms
            4. Results of the entrance examination
            5. Having resources to work on the grand challenge
        ii. Selection team
            1. Independent review board; process reviewed by NEU legal department
            2. Establish scoring criteria
            3. Review with legal to make sufficiently unbiased

5. Deliverables to participants
    a. The spec corresponding to this outline
    b. Datasets
    c. benchmark code[19]
        i. CCL after eroded images
        ii. feature calculation
        iii. metric calculation
        iv. label image formation
    d. Contact information for help
    e. URL for wiki discussion
6. Participant Algorithm Development
    a. Time frame: 6 months
    b. Mentoring: provided by the team
        i. At least monthly via tele-con
        ii. At least one face-to-face meeting
    c. Status reports: monthly
    d. Funding
        i. TBD $ to each participant
        ii. Non-funded participants may still participate
            1. Have algorithm evaluated
            2. Present at symposium
        iii. SSDs may not receive funding, but may participate
            1. Will not be required to publish or disclose details on their algorithms
7. Independent Validation
    a. Validation dataset
        i. Match participant results
        ii. Iterate as necessary
        iii. Participant may be present
    b. Evaluation data set
        i. Test code on this set
        ii. Dataset not shared with participant
        iii. Results are shared
    c. Other
        i. The results of the independent testing will be shared with the participants.
8. Deliverables from participants

[19] Entrance exam would entail replacing algorithm portion with new algorithm. Description of new algorithm would have to be delivered.

- a. An executable program that implements the participant's algorithm
- b. Executable requirements
  - i. OS(s): TBD
  - ii. Hardware: TBD
  - iii. Speed: < 5 minutes per volumetric CT dataset
- c. A report that contains the following information:
  - i. User manual for executable
  - ii. Results of running algorithm on training and testing datasets including:
    1. Accuracy of locating objects
    2. Accuracy of bounding boxes for located objects
    3. Accuracy of volume, mass and density
- d. Algorithm description including:
  - i. Mathematics
  - ii. Implementation considerations
  - iii. Strengths and weaknesses
  - iv. Extensibility to other images (resolution, noise, artifacts) and modalities
  - v. Possibility for future improvements
  - vi. Comments on special cases
    1. splitting
    2. combining
    3. problematic cases
- e. Code (available on the net)
  - i. Source
  - ii. Build instructions
  - iii. Description of
  - iv. All parameters ("knobs") that are typically used to tune algorithms for optimal performance should be clearly defined.
  - v. Sensitivity testing of all tuning parameters should be required.
- f. Recommendations for changes to the grand challenge process

9. Final Report and Symposium
   - a. Final report contents
     - i. Strengths and weakness of each participant for each of the following topics:
       1. Ability to segment objects per the acceptance criteria
       2. Quality of report

        3. Ease of use of the deliverable
    ii. Recommendations for additional development on the algorithms
    iii. Recommendations for changes to future grand challenges
    iv. Notes:
        1. Final report will be in the public domain
  b. Symposium
    i. Duration: 2 day
    ii. Participants bring computers or network access
    iii. New dataset provided and results reported in real time
    iv. Each participant will present algorithm and results
    v. Funding:
        1. For two people from each participating group
        2. Non-funded participants pay their own way

10. Program Team, Budget, Schedule and Legal Issues
  a. Team
    i. Members
        1. NEU/ALERT
            a. Michael Silevitch
            b. John Beaty
            c. David Castanon
            d. Carey Rappaport
            e. Hire-1
        2. LLNL
            a. Harry Martz
            b. Staff-1 or Hire-1
        3. DHS
            a. Carl Crawford
    ii. Roles
        1. Co-PI: Silevitch and Martz
        2. Program Manager: Beaty
        3. Project Engineer: Crawford
        4. Subject matter experts (SME):
            a. Castanon
            b. Rappaport
            c. Warfield
        5. Staff:
            a. NEU Hire-1
            b. LLNL Staff-1 or Hire-1
    iii. Responsibilities
        1. PI

            a. Set strategy
            b. Interface with DHS
        2. Program Manager
            a. Create program plan
            b. Set program schedules
            c. Track progress
            d. Track finance
            e. Write status reports
            f. Maintain who/what/when/where lists
            g. Initiate and execute contracts
        3. Project Engineer
            a. Lead execution of technical aspects of program plan

b. Budget
    i. Program manager (PM) to fill out
c. Schedule
    i. Program manager (PM) to fill out
d. Legal Issues
    i. Contracts
        1. NEU/ALERT with DHS
        2. NEU/ALERT with participants
        3. LLNL with DHS
    ii. IP
        1. Owned by participants
        2. License
            a. Royalty-free to Gov. and its agents for research purposes
            b. License to anyone who wants one
    iii. Fundamentals of algorithm freely distributed
        1. Code in public domain
        2. Publication (or submission to journal) required

20. Appendix: Scanning Requirements

20.1 Overview

The purpose of this document[20] is to specify the requirements for scanning luggage in order to create databases to support grand challenges. The datasets will be used by algorithm developers to develop advanced reconstruction and threat detection algorithms. **The datasets will be available in the public domain to facilitate access by the academic community.** The expectation is that this specification will be iterated based on discussions with potential providers of CT scanning services.

20.2 Background

CT scanners are used to detect explosives in checked baggage. These scanners are certified by the Transportation Security Administration (TSA) and denoted explosive detection systems (EDS). The systems consist of a CT scanner to scan baggage and an automated threat detection algorithm (ATD) for finding explosives. The CT scanner includes a reconstruction computer on which raw data from the detectors contained in the scanner are converted to images. EDSs are produced by a number of vendors and are deployed at a number of airports. However, there are high labor costs related to clearing the bags that generate false alarms in the field.

DHS seeks the involvement of 3rd parties to develop advanced algorithms to improve the performance of EDS equipment. The term 3rd party means people, companies and institutions other than the vendors of the EDS equipment. In particular DHS seeks the involvement of academics and furthermore academics who have been involved with the development of algorithms for medical imaging. However, DHS seeks the involvement of any 3rd party who could develop advanced algorithms.

DHS has created Centers of Excellence (COE) at a number of universities to support the involvement of academia in Homeland Security. The COE for Awareness and Localization of Explosives-Related Threats (ALERT) is co-led by Northeastern University (NEU) and the University of Rhode Island (URI). This specification pertains only to the NEU component of ALERT (henceforth called NEU-ALERT). Researchers at the COEs are also considered to be 3rd parties.

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[20] An earlier version of this document was used to prepare the slides/talks for ADSA02. This version reflects comments made at the workshop.

A team comprised of personnel from DHS, Lawrence Livermore National Laboratory (LLNL) and NEU-ALERT may shortly begin executing grand challenges (GC) for advanced algorithm development. The first GC will be for algorithms to segment all objects in volumetric CT data. Participants in the GC will be given sets of volumetric data corresponding to scans of baggage containing known objects. Algorithm developers will develop an algorithm to segment the objects. The algorithms will report on how accurately the objects were segmented on a training set and a test set, both of which will be provided. The DHS- LLNL-NEU-ALERT team will independently grade the algorithms on a second dataset, which will not be provided to the algorithm developers. This GC is denoted GCseg.

A second GC will be for the development of CT advanced reconstruction algorithms, which would lead to increased probability of detection (PD) and probability of false alarm (PFA). The participants in this GC will be given the same datasets as provided for GCseg, along with raw- and calibration-data, and a complete description of the CT scanner on which the data was collected. This GC is denoted GCrecon.

It would be desirable to distribute the data from extant EDS equipment to the 3rd parties. However, this distribution may not be possible because the specifics of the scanners are proprietary and the participants will not be required to sign non-disclosure agreements. Therefore, if scanning on extant equipment is not possible, NEU-ALERT would like to scan baggage on non-EDS CT scanners such as medical or industrial (NDE) CT scanners.

The purpose of this specification is to provide foundation on which discussions can be held with parties who may be able to supply CT scanners that satisfy the requirements noted herein to support GCseg and GCrecon.

20.3 Technical Requirements

The CT scanner should meet or exceed the following characteristics:

Parameter	**Value**	**Notes**
Scan/reconstruction field of view (FOV)	50 cm	
Scan modes	Helical or step-and-shoot	
Dual energy	Desirable	
Resolution	1 mm, isotropic	Measured from 10% point of the MTF or SSP.
Pixel size	1 mm, isotropic	

Parameter	Value	Notes
Potential	140 – 180 kV, high energy 80-100 kV, low energy	
Dose	20 mAs	
Dynamic range	Shall not be limited by electronic noise for a 50-cm path length of density 0.3 g/cc.	
Projections	512 views per rotation per energy	
Reconstruction	1. Cone beam correction 2. TBD reconstruction kernel 3. Dual energy decomposition	
Image quality	Minimal artifacts caused by rings, bands, streaks, and scatter.	
Scan time	< 15 minutes per volumetric scan.	

The following personnel, material and support will be available when the database is created:

1. Baggage to be scanned. It is anticipated that 75 bags will be scanned. A total of 250 items in the bags will have to be scanned in by themselves; that is, not in bags.
2. Personnel to handle the baggage during scanning.

The provider of the CT scanner will supply the following information in support of GCseg.

1. Images corresponding to the scans of:
    a. Baggage
    b. Isolated scans of items in the baggage
    c. Quality assurance (QA) phantoms
2. The following documentation:
    a. Image format
    b. Description of reconstruction algorithms including dual energy decomposition
    c. An electronic record containing the details of the CT scanner and the object being scanned. Details of this electronic

record, known as a log file, will be provided in a separate specification to the scanning vendor.

The provider of the CT scanner will supply the following information in support of GCrecon:

1. Raw and calibration data
2. Information necessary to reconstruct the data:
    a. Scanner specification
    b. Data formats
3. Offline reconstruction software
4. Reconstructed images

20.4 Additional Information

The CT scanner may be one of the following types of scanners:

1. Existing EDS scanner, new or legacy
2. Existing medical scanner, new or legacy
3. Scanner for another application such as non-destructive evaluation (NDE)
4. Custom designed for GCs
5. Conventional single- or multi-detector row scanner
6. Flat panel detector

The scanner may be deployed at any of the following locations:

1. Scanner provider's factory or associated site
2. Medical clinic
3. National laboratory such as LLNL
4. COE (NEU)
5. Tyndall Air Force Base
6. TSIF

It is desirable to begin scanning on 2/15/2010, if not sooner.

Objects may be scaled (larger or smaller) to support scanners that do not match the FOV or resolution requirements noted above.

GCseg is intended for application to checked and carry-on luggage.

20.5 Discussion Points

1. Availability of existing scanners
2. Development time for new scanners.
3. Cost of developing new scanners that would fit into the time frame of this project.

4. Cost of using scanners for scanning.
5. Ability to supply the requested information.
6. Technical specifications for the scanners
7. Locations where scanning could be performed per the list given above.
8. Comments on and suggestions for conducting GCs.
9. Maturity of equipment to be provided.
10. Means for archiving and transmitting raw and image data
11. If requirements are too restrictive to participate, what changes are needed to overcome objections

Note: We will consider using scanners that do not meet the above specifications noted herein.

20.6 Scanning Requirements Acronyms

ALERT	Awareness and Localization of Explosives-Related Threats
AT	Advanced technology
ATD	Automated threat detection. This term is deprecated in favor of ATR.
ATR	Automated threat recognition. This term has replaced ATD.
COE	Center of Excellence, a DHS initiative
CT	Computerized tomography
DHS	Department of Homeland Security
EDS	Explosive detection system, equipment used to detect explosives in checked luggage as certified by the TSL
FOV	Field of view
FTP	File transfer protocol
GC	Grand challenge
GCat	GC for AT
GCatd	GC for ATD (CT)
GCosr	GC for OSR (CT)
GCrecon	GC for reconstruction (CT)
GCseg	GC for segmentation (CT)
GCwbi	GC for WBI
LLNL	Lawrence Livermore National Laboratory
MTF	Modulation transfer function
NDE	Non-destructive evaluation
NEU	Northeastern University

OOI	Object of interest. Items that are required to be segmented by ATR.
OSR	On-screen resolution
PD	Probability of detection
PFA	Probability of false alarm
SSP	Slice sensitivity profile
TBD	To be determined
TSA	Transportation Security Agency
TSIF	Transportation Systems Integration Facility, Ronald Reagan National Airport
TSL	Transportation security laboratory, Atlantic City, New Jersey
URI	University of Rhode Island
WBI	Whole body imaging

21. Appendix: Mariah Nóbrega/Rachel Harger Meeting Minutes

Day 1, October 7, 2009

Introductory comments

Michael Silevitch: Welcome. Let's thank Carl Crawford and Harry Martz for making this workshop happen. I would also like to thank my staff for taking care of the workshop logistics. Now I'd like to introduce Doug Bauer, our close partner at DHS who is overseeing this center. Doug was recently recognized at the presidential level for his technological achievements.

Doug Bauer: Thanks for coming to this session. Our focus is algorithm development segmentation, based on the outcome of the ASDA1 workshop.

__________??? Premise meeting immediate customer needs, but there is a need for a vibrant bed of research to give us breakthroughs where incremental steps will not suffice. EDS technology – an example of this – brings us here today. We need better performance on false alarm reduction and detecting ever-changing homemade explosives. When looking at related fields like medical imaging, we need to have peripheral vision, extract wisdom and learn lessons from the field.

A premium is placed not just on adaptation, but on creativity. The constant challenge is that federal budgeting imposes research constraints. At the same time, we can't lose the ability to conduct fundamental research. A balance is needed between trying fresh approaches and improving existing methods. We also need effective advocacy to make the case for why government investment is necessary. We want reactions to the Grand Challenge design and how federal funding is related to enterprise.

This is an important conversation. Thank you for being here.

MBS: Thank you, Doug. I'd like to introduce Harry Martz.

Harry Martz: Thank you, everyone. This will look like a short-term focus. We want everyone involved. Issues do include sensitive information, so this will be a high-level, but general discussion. We need vendor, third-party and academic input. We apologize if this can create a lack of clarity.

The long term is important too. How will this be achieved? Let's find out.

Carl Crawford

CC: Third-party involvement is possible, but there need to be rules. The stake in the first workshop was too broad so we're making it more narrow. For this workshop we're dealing predominantly with segmentation. This will be taken sequentially into reconstruction later on, but not now. Also, some things are eliminated because everything needs to be in the public domain.

HM: The question: Is there something out there we don't know about?

George Zarur: The government buys the least mediocre product, not the best product. The security field has been stagnant insofar as adopting medical techniques. Segmentation is a good start. Reconstruction algorithms need to harness modern computing power. My concern is false alarms, not threat detection. False alarms are both an economic and security issue. "Orthodoxy leads to mediocrity."

Simon Streltsov: Here's my concern: Defining challenges is good, but if you don't address the final problem, what are you really looking at? What's the point of this if it's classified?

GZ: We can have perfectly good data sets without worrying about classification. It's the methodology – detection techniques are cross-applicable.

Carl Bosch: Are images from the machine (??????) classified? Do we have guidelines?

GZ: If they're related to security, they're SSI. If they're related to physics, they're not SSI.

Simon Warfield: There's a close analogy between this situation and medical imaging. It's an end-end process.

CC: Like literature on if you develop an algorithm, how do you grade it?

David Lieblich: The canonical problem should help attract academics to this field. Hopefully the methodology will be transferrable to the details.

Peer-Timo Bremer: There's a disconnect here between development and application. We need to know what the actual issue to concentrate on is before we abstract the wrong thing.

Matthew Merzbacher: This is important for establishing relationships between experts and vendors.

Dan Gudmundson: You need to be able to define an objects before you can do anything with it.

SW: Normal, pathological variability is important to capture, in the medical field and in here.

????: It's not just specific objects, but also their orientations in bags.

Harry Martz "Overview of CT EDS"

PTB: What kind of computing power goes into those? Is there special hardware?

MM: 4 CPUs is standard

PTB: What's the cost?

MM: It depends.

BO: It depends on optimization.

CC: There's no incentive to vendors to provide this.

GZ: This has changed. The perspective is beginning to shift within the government as to what is best, the question is no longer how much does it cost but what is the value? Acquisition cost is minimal compared to operating and maintenance costs. The economics are not what concerns us, but we need real metrics.

JC: It depends on what the cost v FAR reduction.

CC: Assume $10K.

MM: I disagree with Carl. We don't do iterative reconstruction, not because we don't like it but because it's too expensive.

MBS: if iterative reconstruction solved the problem, would that drive things?

CB: Iterative reconstruction will never be as fast as filtered backprojection, but it's as fast as FBP was a few years ago. We can also do hybrids. The question is whether there is an intersection of value/outcome.

DL: This brings up the issue of differences between 3rd parties, vendors, and academics.

ES: I want to reinforce CC's point that there is no incentive. TSA is now giving incentives to go faster. I'm not convinced that they are on board with the reduced FAR. There's $1B in bigger/faster, but only millions/$10s of million in reduced FAR.

DG: If you make an algorithm that's great, people will compress it and make it affordable. This happened with a weapons detection algorithm that was compressed from 30 minutes to less than one second.

MK: Academics have no ability to optimize.

HM: Don't worry about it, we don't expect academics to optimize.

TM: There is a gap between government and vendors on data collection. The government knows what terrorists are up to. If there is some way to let vendors know what the problem is via real-time data, we would be more able to provide algorithms.

GZ: I just sent CC a reference to a book called National Security by Sadarin. This book was what made it clear to me that we are reactive and we need to get ahead of the curve. So far we have been lucky but that won't be forever.

CB: Why is shape not allowed?

HM: It is not allowed for certification, but you can use it in implementation.

CC: Shape can't be used to eliminate an object as a threat.

PTB: How important is automated?

CC: It's in the specs.

HM: I have an issue with that because the certification specified ATD and the practice is HITL if you look at the steps following in the EDS screening flow diagram.

DB: As I see it the cost is in hand-search after failing OSR. So that's the problem.

HM: Could OSR be automated?

OR: Is there info on % bags cleared at each level?

???: Can ATD help OSR by providing info?

HM: Yes, in addition to other info such as whether the person bought a one-way ticket.

GZ: In Israel they also use different algorithms depending on who it is – different FAR is acceptable for different people.

VR: No feedback loop?

HM: Yes, there isn't feedback and there should be.

VR: I meant by modifying the EDS to reflect the state of the world.

MM: Keep in mind this is the US model, not the international model. There is feedback on our models to some extent; within the box there is a pre-scan and based on that, the machine directs its slices.

ES: There has been discussion of dynamic screening like what they do in Israel. I submitted proposal 10 years ago using operators to help segment. The TSA (customer) doesn't care about that, they just look at the certification.

GZ: WE can't be pessimistic, organizations can evolve.

MBS: Yes, and this evolution happened in medical imaging before. Marshaling the academic community is another pressure to bear.

Harry Martz "Segmentation Challenges"

HM: Some considerations are x-ray attenuation, # of voxels.

ES: I worked on building 200 bags representing FA bags. It was difficult to build a bag that would consistently alarm. My criteria was that a bag would have to alarm 3/10 times to be accepted. Each bag would take hours to prepare. The orientation of the bag would affect the alarm, but even the same orientation wouldn't consistently alarm.

MM: And the chance of alarming once given previously alarming was not 100%.

HP: Is there a way to get the dataset?

GZ: There is no preclusion to getting the data through the vendors and it may be faster than going through the government.

JC: L3 would have to expend resources to prepare the dataset for release (SSI concerns).

???: PD given PD given PD is very high.

ES: We've thought about a system that is first high-speed then low-speed? But, you go back to the people buying systems and they're not interested.

JC: There are multiple architectures with pluses and minuses and different characteristics, and they don't necessarily suffer from the same problems.

MK: Would it help segmentation to take out artifacts? We can do that.

CC: Yes.

???: There are physical/imaging artifacts; this is mostly physical.

TM: To quantify the segmentation is important. The challenge for the Grand Challenge is to know how good it is, we can learn from medical imaging.

JP: Will the raw data be available?

CC/HM: Yes.

PD: Can we have artifact reduction by using phantoms?

HM: Yes.

Carl Crawford post-lunch presentation

GZ: Matthew, has anything come of high-resolution impact segmentation?

MM: I can't conclusively say it's an improvement. It's had an impact, yes, but some information is extraneous data that confuses the issue. We're looking at detection rather than FAR reduction.

SW: [References paper from 1990 that deals with all of the issues being discussed.] One thing that would be helpful is to have some libraries of CT threats.

JC: The bombs come in all sizes/shapes so a library won't provide you with all the information.

MM: The follow-on to that is when we find a gap, we don't know why.

SS: You can collect libraries of clutter objects.

JC: [Anecdote about algorithm that was outdated by shift in policy regarding bringing liquids on plane.]

SS: But this is an argument for faster updating of libraries.

DL: Unstable features.

XF: Segmentation = clustering, labeling.

CMR: Is there feedback?

RB: There is a lot at all levels. The assumption is that voxels aren't important alone, rather what their neighbors are is very important.

XF: How many classes of segmentation are there?

BY: About 15.

CC: The grand challenge means academic working on the problem. It's not money a priori.

DBauer: Yes, but the government needs to induce change. What are the kind of inductive changes that would broker innovation?

CC: What about foreign national involvement? Institutions?

DBauer: All these questions should be addressed to Carl and we will answer them all in consultation with the correct officials.

GZ: We do have some international agreements that may also be relevant.

CC: We have plans to make the database open.

BO: How can I talk about ideas that I may have?

DBauer: Academics should work through the ALERT COE and Michael Silevitch. Companies should submit to the BAA.

BO: I would be presenting proprietary company material.

DBauer: I can respect company confidentiality. This relates to another area I am interested in, which is companies pointing out interesting areas of basic research to government so that government can fund academics in those areas – we encourage that.

Marc Kachelriess

SW: There is a question of interpreting data to compare against.

HM: Are 20 scans sufficient?

HP: A couple of algorithms were developed with prior exposure to many other data sets/atlases.

HM: Is there an issue where an algorithm would perform poorly due to lack of exposure?

HP: Yes.

OR: Training means learning the shape model of a liver.

MK: In this case it also meant the texture, etc.

MBS: Are the papers linked that are referenced in your presentation?

MK: Yes, you'll be able to access them in the soft copy of the workshop final report.

Tejas Mehta: Are interactive algorithms being used in industry?

MK: Yes, but they're proprietary. Also, room needs to be allowed for interactive refinement.

SW: What would happen if you did region growing in liver segmentation? With the gall bladder nearby, a shape boundary is useful. If we had models for what commonly packed things looked like, we could use that information.

PTB: But you could have a million shapes.

SW: And we should deal with that to reduce clutter and artifacts. We don't want to rely on shape alone, but it could augment efforts.

???: But what about contextual information? Is this really applicable?

MK: And can you rely on surrounding objects in threat detection? What is the importance of volumetrics vs. shape boundaries?

Eric Miller: You can go to a multi-pronged approach. Define classes of common shapes based on priors and use features like z numbers and density. Bring in more prior information in combinations to get more sophisticated data.

MK: My other questions are: To what extent can we rely on physical properties? What shapes could be classified as no threat? An algorithm for every shape – is this too complicated to be feasible?

Simon Warfield

?????: Did they upload algorithms or the results?

SW: The results. They are publicly available. We wanted to see if people were able to segment new data sight unseen at our workshop. Basically, can these parameters really work?

HM: Was there a reason for being online vs. offline?

SW: Not really, just the time factor.

MK: Did they have access to remote computers?

SW: Yes, we didn't want to restrict their computing power.

??????: How would you keep them from stealing data?

SW: The data is available, but there is no frame of reference.

HM: What if the CHB and UNC-1 protocols did it differently?

SW: Technical considerations took that out of the picture, but ultimately they were very comparable.

MBS: What were the competitors' backgrounds?

SW: All academic science, I think. We didn't have industry because MS lesions used in clinical trials suffer from shifting variability. We need to demonstrate success in robustly, accurately identifying lesions. Detection of lesions is easier than finding the precise location of boundaries because the volumetrics are very difficult.

MK: Are all the scores at the onsite lower?

SW: Yes, even though the data are not that different.

MBS: None of your results approach the expert ratings.

SW: True, the expert rating was 90.

EM: What were the differences in images based on scores?

SW: The higher scores denote fewer false positives and greater sensitivity. There's a line to walk between specificity and sensitivity.

MK: Why was the expert score set at 90? You aren't using the same metrics.

SW: The challenges weren't conducted at the same time and the material wasn't really comparable.

MK: It would be interesting to see if we could improve on these results.

SW: Movement is a factor. This is thick-sliced data compared to CT, but dynamic data collection helps.

HM: What happened post-conference?

SW: The Web site is still up and the data are available for download, and will be for a long time. We've been improving on the algorithms. People participated due to access to data and objective analysis of their results – a gold standard. There was no prize factor, they were competing for the glory.

MBS: You could refer to this to get funding and increase your credibility for a grand challenge grant proposal.

SW: To sum up, we clearly articulated the challenge, found the protocol didn't quite work and went through iterations. The key value comes from creating a reference standard to provide common ground. This way, the challenge continues as an ongoing process, allowing for fresh approaches.

GZ: How long did the entire process take?

SW: About four months, not counting patient recruitment and gathering of base data.

Harry Martz

????: What is the 3-1-1 rule?

HM: Three items, one ounce, one bag in airports.

???: Is this carry-on or checked baggage?

HM: Carry-on.

MK: You can have a NDA with a vendor and convert it into raw data to make it accessible on the medical side.

HM: There are some cases where that might be true for industry as well, but it is a hurdle.

CC: Can you describe the keys?

HM: Basically, a bounding box – a quadrilateral – we'd put around the threat. So does it matter how these boxes are drawn? Well, depending on the metrics, that may affect results.

MM: Did you have any problems with dirty data?

HM: Yes. For example, we knew it was an LG bottle so we made assumptions based on the shape that weren't visible in the projection.

MM: But there were no classic data mining problems?

HM: None that we've uncovered as of yet, but there's always room for error. Another problem was not having that much data.

CC: Your validation process should have been done up front, not after the fact.

HM: That's a fair comment.

CS: We had an automated tool to measure our success, but anything inside the bounding box was considered a hit, regardless of volume.

HM: We thought about trying to fix that sort of thing, but it would have taken forever.

CC: So there were a lot of combined issues?

HM: Yes, coming down to how people combine scoring.

Jeremy Wolfe: And the same image could be both a miss and a false alarm.

Tim White: International standardization is an issue.

CC: Things need to be well-defined, even if there is no "right" answer.

MBS: Can we filter lessons learned in terms of where we are going?

HM: We'd need to get a little more specific.

SW: We had to iterate some things that we didn't realize would require clarification, like lesion definition.

MBS: Food for thought – a grand challenge effort could involve different data sets to engage students. A precedent would be robotics competitions.

HM: We should figure out how to make it like a videogame.

MM: It would be interesting to follow it up with some sort of combination.

Homer Pien

GZ: Matt, how much of this data did we include?

MM: None of the reconstruction at this point, not much – this is pre-image stuff.

HP: They don't score the pre-corrected data, just post-corrected.

Doug Boyd: ???? (Something about smoothing images)

HP: It's very hard to smooth images per se.

Jeremy Wolfe

CC: It's hard to test human factors, but we still have to do a better job at it.

JW: A TSO is a transportation security officer.

DB: This vetting process is a mystery that only occasionally has anything to do with anything.

JW: And it's a moving target with a huge gray area.

GZ: You said you're trying to insert "gold standard" cases into biopsy screening. Have you thought about inserting digital tumors?

JW: We're working on that at the moment.

GZ: Has the status of that been evaluated?

JW: There is University of Iowa software designed to do this in CT, I'll point you to it.

GZ: What's your opinion of the utility of this idea?

JW: I don't know yet, but it does have the potential to be extremely useful. There is a 3D TIP problem with volumetric data.

GZ: This has limited value for EDS if it needs to be done machine by machine. It's cost-prohibitive.

JW: However, the equivalent of an "eye chart" – where you don't test on each individual object a person is capable of seeing, can you see trees, can you see ducks – but extrapolate from a base set of images, that would create savings.

Day 2, October 8, 2009

CC: The purpose of Day 2 is to hold a discussion that ends in recommending deliverables to the government.

Doug Bauer

DB: What we need to accomplish today is a reflection, an interpretation of what's occurred. Here are my concerns for feedback.

- Our overarching goal is to protect the American people better in travel environments against an evolving, dynamic range of threats. We need the best hardware and best algorithm development. We think that the medical field can help provide a framework for us and we brought you together for a multidisciplinary approach.
- How do we preserve openness to innovation?
- How do we meet the near-term requirements of DHS without forsaking academic research?

The government wants to be a constructive, rather than obstructive, force.

MBS: It would help if there were a publishing venue, as there's no real journal available. We could talk to IEEE about creating a medical imaging analogue.

IEEE editor of Transactions on Image Processing: I'm a potential resource, and we could also be a potential venue. Our review system has ups and downs but I am personally trying to reach out in this area.

CC: Also, Rick Moore set up a website.

RM: Yes, I set up a Wiki for participants to get things kicked off after Doug vets it.

CC: I want to ask Tim White his thoughts.

TW: I think the conversation has to be a little more specific regarding what we provide and are provided in terms of DHS. What DHS wants us to work on needs to be defined and made accessible. ???????? (Continued talking, but couldn't hear)

RM: Could this group leverage information to develop direct specifications for the next generation of EDS?

?????: Are you saying, specs for the entire system?

RM: The incentive for vendors is to meet the spec. If composing that spec has been an issue, then maybe this group could have an impact.

Carl Smith: Have we been able to get information from the EU regarding their security levels?

DB: Yes, but the details are classified. The information is basically about certifying equipment, how they deal with homemade explosive threats, how these threats vary from the ones we are posed and how we could deal with our threats. There's different kinds of C4.

CS: But is it easier to get information from the EU?

PD: It's probably easier for the US to get EU info than vice versa.

CC: The assumption right now is that all ASDA data has to be in the public domain.

TM: Are different vendors' machines dramatically different?

HM: The difference gap is closing.

TW: And how much do those differences matter in a practical sense?

HM: They show us our current capabilities.

MM: I'm skeptical of this. We've gotten this to work to the first order of approximation, but that's not good enough. These require major tuning. Without working on images, you won't know which algorithm is best-suited. Second order ones are really different. Mixing and matching, then scoring the winner, that's not going to work.

TW: But finding a winner isn't our real goal, it's answering questions.

MM: Absolutely.

CC: Define a corner case for us.

MM: There are different configurations of explosive threats that strain our thresholds. A corner case is that last ten percent that's not straightforward.

SW: So what's the real problem to be solved? Workflow dictates the specification of the problem as well, and the time element. We need to demonstrate that extensive imaging can dramatically reduce the false alarm rate, and then move from best-case, high-resolution images to something that's logistically practical. Better imaging might translate to better solutions.

MM: Of course, there's always the money issue.

?????: There's no question we will need upgrades in about five years. But we need something with a near-term impact on the hardware base that's out there.

CC: Dialogue and student outreach are also goals. Main goals, and also things done in parallel.

Michael Ellenbogen: I'm less skeptical than my colleague. I think these methods can be translated to other systems and research will move forward toward both short- and long-term solutions. Collaboration will reduce our tunnel vision in the near term, and the long-term benefits could be huge.

PTB: We may underestimate the amount of work the last ten percent (corner cases) will take. The medical challenge was working on a problem coming in with NIH funding. A 1-2 year timeframe is just not realistic in terms of innovation. Don't go off the medical challenge, the challenges were very different.

CC: Funding is important, but smart people from different disciplines can bring to bear solutions.

SW: But I think the point about the liver challenge is that they had experience going in.

CC: We have a bootstrap problem. There's almost no literature in this field, and what there is currently is inaccessible to academics. We need to get going.

PTB: But the question is, do you start with the short-term or long-term goal?

CC: We are bounded by DHS for a short-term problem with a 1-2 year timeframe.

SW: Is this for a trajectory or a direct practical impact?

CC: Probably not one vendor, that's not fair.

SW: Without vendor data, there's very little we can do in the short term.

?????: Vendors want to see what's unique. We created a small piece of electronics that ripped raw data without permission. That's what it took to get the data. Bootstrapping is very difficult and getting on the radar of current vendors is too. There are really serious problems with accessing data from vendors because of industry competition. Without existing vendors competing in the grand challenge, there's no benchmark.

ME: Maybe this should be broken up into small challenges to access some data and show capability to vendors. You need to be let behind the curtain to some degree and we have methods to let you do that, if you prove yourself. We do this with partners and it works well; the mechanism exists.

MBS: We need to show a return on investment for vendors to give them an incentive to collaborate.

Xin Feng: What's missing? The difference between medical and security imaging has not been adequately addressed. We need technical specifications and specific needs. Also, as an academic, the bottom line is that we need data. That's the first step, generating a database with simulated data.

MM: It would be lovely to have a low barrier to entry for this challenge. We could get more minds, little ideas can be extremely valuable.

CC: So, to reiterate Suriyun, the goal is to define a class of problems and put it out there in the public domain.

???: You don't know what the hard problems are until you get a little behind the curtain. To get new ideas, proving your mettle on low-barrier ideas is a good idea. A measure of success could simply be how many people download the problem set. Short-term efforts can have a long-term legacy.

CC: That is, I believe, the objective.

HM: If we define some research problems, (???), I believe we can get permission to do that. I recommend that each vendor define a set of problems. (???)

???: To turn that around, if we give that data to academia, what will they do with it?

???: Third-party vendors are probably more suited to low-barrier ideas and academia is more interested in validating their ideas.

ME: It's just simple economics regarding R&D.

???: Now everything revolves around what the vendors will and will not do. This is interesting, but it's hard for me to justify my participation as a company with that focus.

CS: I think it's important to have the community present metrics.

???: But frankly, how is it to my advantage to work on this?

XF: I'm hearing a lot about requirements, but we need actual problems to solve. Is it possible to form task forces from all parties? How can we get concrete work started instead of just talking back and forth?

RB: We have a 200-bag set we're willing to potentially open up to the ALERT group, but there are difficulties regarding sensitivity.

CC: Let's take that off the table for now. Let's take this offline and figure it out afterwards.

MM: Our legal department will not touch it without a federal directive as a precondition.

CC: We'll make a note of it. There is precedent for industry and academic fusion in medical imaging development.

CB: But the basic point is that medical technology is not secure and security issues are. And those issues are unequivocally government responsibility.

DB: There is a government – DHS – classification guide to compare issues to and work with. You can't just ask about general data, it needs to be clearly defined.

CC: How do you resolve this?

RB: Everything needs to be submitted for approval.

SS: What will be the objectives?

CC: Ball is in the government's court, they have to fund.

RB: We can also provide data if the government asks us to.

CC; The report will be fed back to the government. It's a baby step.

HM: By getting one image, we'll make progress and learn things.

CC: Rough order of magnitude for each contract is $50-100K.

MBS: Long-range research contracts with national labs and others.

DBauer: TSA acquisition is on the order of hundreds of millions.

HW: Organizers need to think of the specs of the actual algorithm.

CC: Program definition is specifications definition. By the way, traditional vendors can participate but not get seed funding.

XF: Segmentation followed by classification.

MM: Divide problem into three classes.

CC: Feature extraction.

HM: Yes, compare histograms ???

JC: The question is whether you can separate one object from the rest.

XF: That is key.

???: Don't impose on people the way to do it, just give them the data and let them do it.

RB: ???

???: You have to take away problem of measuring from problem of detecting.

JC: What is a reasonable measure of good?

HM: One metric is # of objects, and voxels/object.

PTB: But if it's not important.

BO: But it's a primer.

DG: Is it segmentation or threat detection?

HM: Identify objects in the bag and certain features.

XF: Identify features before objects, because it informs objects.

SW: Metric related to detection, one related to segmentation, one related to features.

DL: You need some metrics on your testsets.

HM: We can recommend certain metrics but any additional criteria is good.

TM: Two levels of classification.

SW: Other features that might help in detection/evaluation might be included, but not as metrics.

JC: There is schizophrenia regarding segmentation v. threat identification.

MM: The hard part is deciding whether you are looking for the interior of objects, or the interior plus the border. These are difficult, interesting questions.

CB: Segmentation is application-specific. There may be a danger of deciding how to segment too soon.

DAC: You're talking about segmentation but mean identification.

OR: Is the laptop one object or multiple?

CC: I don't know.

OR: So maybe we need multiple algorithms with varying levels of detail.

JC: There needs to be a lot of thought put into the dataset. I don't care about the laptop, I care if there's a threat object inside. The vendors need to be involved because they have the deeper knowledge.

CC: Send me comments.

JC: Stop having workshops, start having working groups.

CS: Raw data was quite worthwhile.

HM: Jim keeps mentioning getting stuck on ATD.

CC: What about executables – should we require it?

SW: I don't think so. We just compared images previously.

PTB: Executables raise the barrier to entry tremendously.

MM: There are always ways around it, like Java or a public server.

DG: If we have to provide an executable, we wouldn't play.

MM: How much is that a limitation because of speed?

JP: We run Linux.

CC: We don't want to make a new dataset each time. Could the boxes could be brought to NU for testing?

MBS: Yes.

CC: Eligibility is open. Identification of who would be able to receive seed funding.

DBoyd: Scan bags on more than one scanner.

CC: Yes, good idea.

PTB: A 10 page writeup is a lot for a $50-100K proposal.

HM: It's 10 pages max.

MM: There could also be collaboration on ground-truthing.

CC: As a rough order of magnitude, we anticipate 5-10 participants being funded.

DL: Is there funding for industry to mentor?

MBS: Maybe.

CB: As far as IP, academia will have issues with IP because of the need for contracts.

MK: Will there be downsampling from 512 to make it more representative of scanners in the market?

CC: Would the vendors put out their specs?

JC: It's SSI.

MM: It's GE's call.

RB: If everyone was doing it.

DBoyd. Any medical scanner is limited to carry-on only because of size constraints.

David Castanon

CC: How much money for a grad student?

DC: $30k a year and overhead, so for me, $60k per year.

DB: Could you take on board that when we get periodic calls from CoE directors for conferences, we would like to get students there to present their research? I feel very strongly about this.

MBS: We do have students there.

DB: I want them on the stage.

MBS: Maybe during the breakout sessions? I'll mention it to Matt.

DB: We gotta get out of the way and give them room.

MBS: I agree.

Jim Connelly

JC: The goal is to get people interested and show that they have the technical capacity to grapple with this, not to immediately write code to drop directly into our program.

DB: I'd like vendor perspective – are 'corner cases' you encounter relatively generic or unique to individual vendors' equipment?

MM: They are similar, I would posit, but only if you are looking at the same features.

RB: I agree, usually there are commonalities.

JC: I think the key is, there's a lot that are common. We could identify quite a few and potentially abstract data, but that would require a more closed group due to sensitivity.

CC: How much support will you give us?

JC: That's a multi-tiered question. They paid for me to be here. Our involvement depends on your financial commitment.

DB: We've coverd the cost of experts for NEMA efforts. Is there a mechanism to do this here?

RB: If there's enough self-interest, we will participate for free.

JC: For us, it would change the dynamic.

MM: You'll get some participation gratis, but for more you'll have to pay. I have a limited amount of time for this as it's not one of my job responsibilities. Funding would make this obligation a higher priority.

Carl Smith

DB: We're still assessing the value of third-party involvement. I'd appreciate your thoughts offline on how to make the road less bumpy.

CS: What the medical industry did in 10-12 years, we're trying to do in 3-5. We'll talk about specific places in the infrastructure to facilitate that acceleration.

Tim White

TW: It's not so much the eight seconds it takes to scan a bag, but how many bags are being scanned. For example, in 2006 TSA opened more bags than U.S. medical scans were made. However, the medical folks still haven't solved that problem for their end.

- So how do we use medical and security screening differences to our advantage? We can get ground truth – how can we leverage that?
- Who participated in medical grand challenges? Experts in the same field, or a related field?
- Regarding our grand challenges, who do we need to get involved?

Academics have longer scale because they have to groom students.

MBS: How do you see national labs fitting into this?

TW: Timewise, between academia and industry. We can also be DHS arbiters on some level, like what Harry's doing.

Suriyun Whitehead

SW: TSA is interested in looking at total ownership cost. The government would be willing to bear the cost of potentially more cost-effective systems and algorithms regarding false alarm rates and threat detection. Small seed projects could still potentially lead to high-dollar acquisitions.

Final comments

MK: The slides could have been improved to give a more accurate visualization.

SS: I'm wondering whether we can work on already-existing data rather than waiting on the government.

Oliver Ruebel: We need to define the grand challenges in the right way to attract people and make sure that they are not too complex for people who are not already experts in the field.

Jean-Pierre Schott: I think we need to build on our momentum here to build broader support. Even working with five images, just something to start with.

???: You can use the CT data set on the disc that came with the conference for practice.

???: You really have to get the vendors involved to define, I'd rather see a delay with that put into place.

PD: We'll have to see if all this is feasible.

XF: I would like to see what we need to make the follow-up to this conference productive so it doesn't get shuffled to the background.

Johnny Park: Just making data available is a step. We shouldn't set our grand challenge expectations too high, but we need to get started.

VR: We need a flexible and adaptable framework that's very different from what the medical imaging folks are doing.

Mike Winer: What we learn here will be useful in helping us develop our systems.

Tejas Mehta: It's important to realize that medical imaging has a lot of algorithms, so we need to sift through and find the constructive ones for our purposes.

JW: What about a different tack – here's a stack of bags, let's improve the way to get them on the airplane.

CC: Can you help the government with human factors?

JW: It sounds like it would be a team thing.

DB: The hard part is: Do you improve the performance of the algorithms or of human beings? I can't even begin to answer that. It transcends what we're doing here but it's utterly relevant.

22. Appendix: Harry Martz Meeting Minutes

Day 1, October 7, 2009

Welcomes

MS: Interact, methodology & Strategy to implement GCs, Low hanging fruit and long term high risk R&D…You were given several handouts please use them.

DB: Want to look at meeting immediate TSA requirements, but more importantly we need the long-term R&D needs. The vendors now have done a great job in creativity and building and deploying equipment. However there is still a lot of room for improvement especially given the high FARs and the new threats to be detected. We need to extract as much information as we can no more and no less. Glad that there are students in the audience. Balance needed in that we are looking at fresh ways to improve the performance of technologies for more than just checked baggage but others as well. We need to draw from other fields and we need to do this evening in these austere times. Interested in the design of the grand challenge…that will come out of this and future workshops.

HM: Welcome

Carl Crawford Overview and Objectives

Q: Are you only really interested in just reconstruction?

CC Yes, but we are focusing on seg. Now, others later.

Q: If we improve recon now, given all the people in the room have that expertise,

Q What about classification?

CC: Yes but

MS: Put off recon now due to getting access to details on scanners.

GZ: Gave an intro. Vendors do not do R&D. We need to invigorate R&D and get the ideas into the security field. For security there is only one customer. Also know so little what is out there and what is the state of the art. Segmentation is a good start. There is great work on recon, have pushed vendors to look at new recon. They are just starting to show significant improvements, but they are very slow…speed of computers are different now but vendors still use old computers. Need new blood, new thinking. Not concerned about detection, I am concerned about FAR. We do not drive our business it is the adversary that does this. FAR will choke us off, not only an economic issue it is a security issue. Makensey and Co. investigation of the overall security issues. Will need too many screeners. Congress what can do with ~45k TSOs, that is all you will get. Be heretics…this is science and technology. Can we do better and am relying on each and everyone of you.

Simon Ramesh: What is needed from a systems point of view form the top down not from the bottom up. How best to reduce FAR? What are the parts that are important to the overall system including human factors. Need a systems perspective. Does performance modeling of systems.

Another Simon: Work in the DOD field, they are only doing piecewise R&D need to look at the entire system. Need to address the final problem not pieces of it, get great papers but not into the field to solve the problem.

GZ: DO not worry about classifications issues. We can get good data sets based on chocolate, honey, etc. CT does not care if it is C4 or honey, butter, milk etc.

CB Surescan: First report talks about the corner cases it is not the problem …are the images from a vendors machine SSI or classified, etc. Anything related to security is SSI, physics is not SSI…if we constructed a data set of corner cases then it most likely will be SSI right?

JC-L3: Just corners cases, yes. However, a mix of all may not be such a n issue.

CB Surescan: Medical field can get access to all data. Not so for security field, how does academia get access to data.

Simon (another one Medical): Concerned about the outcome of the patient, think about the interpretation and analysis and its overall outcome…need to consider n to n measures and how to relate them to industry.

CC: Simon is involved in Medical GC. People have determined how to grade algorithms. Shocking that it exists but iut is GREAT.

David Analogic: Part of the problem of dealing with the details is dealings with the details. What pone can do is try to extract the abstract fundamental problem to develop methodologies. Does not have to be exact security problem.

TImo LLNL: Want break through algos, but cannot get access to the actual data. It will be applies to case that are not applicable to the real problem. I need to know the actual problem issues…there is a dangerous…

MM Morpho: Understand both sides of the field in the business and also a professor…I wanted Carl do classification, that is because that is where I come from. Also said it is not going to work. What will work is partnerships amongst the experts…these partnerships will be a very valuable…The point of GC is not

Oliver: Need lots of data to not train on the wrong bags.

GZ: Nothing can keep you from buying bags and scanning them.

Charlie: Isn't the FAR something that can be worked on and it is not classified. As opposed to dealing with the TDR?

CC: Building a precise machine will make classification easier. Excluding the task to pass cert.

JC-L3: Finding anything but a bomb is a false alarm, trying to emphasize just FA items is not easy to separate from the detection problem. Changing the subject back to the data sets, a good thing about segmentation is a very good place to start. DO not recover the actual entire set of voxels, the higher the recovery then can push up thresholds to get lower FAR and maintain TDR. However, can get access to the datasets but need to be careful how representative they are. This is doable.

Dan G. Opto: If I ca'[t finds it I cant do much with it! The more accurate you chop out the object the better you can do…the physics starts to click and come in line. Don't initially want the paths lengths first this is the key to getting segmentation right. I am encouraged about the whole idea of starting with segmentation.

Timo: Most relevant literature is in patents. Can someone collect this.

CC: It is an action item to get a white paper on the patents or a bibliography

Pia SD Base line of the theoretical limits on this work, some materials you just cannot distinguish between them. Can we create a huge table on where are the problems, is it resolution, artifacts, etc…Medical people do not look at real high attenuating objects. There is nothing that you can fit into a bag that you cannot see.

CC: From my experience is that every thing is a problem. It is a very difficult to do a detailed study…

Elan : We have been funded to actually look at this problem, resolution was not the issue there are plenty of other problems that do impact FAR. We created a data set of what caused FAs and then tried to understand the effect on FAR. Most of the easy problems have been solved. There are a subset of individual problems that all contribute to the overall FAR problems, some can be addressed and some cannot be addressed. Problems mass confidence moving from 80% to 90% is the biggest hitter. Better recon to eliminate recon artifacts…aggregations, etc. 2D segmentation…but 3D is equally important…National geographic problem only alarms 1 out of 10, but the prevalence is so high then you get alarms and you think it alarms all the time…there must be many of them going through scanners. 100 bags were scanned by DHS in a medical scanner.

Univ of Chicago: New to this area this is interesting to here this discussion. What you need is a chain what are the steps and they need to be evaluated…one at a time. Resolution, contrast, etc. may not be relevant. Efficacy metrics, detection efficacy, then in the end George is right what do you need to do to reduce FAs?

CC: Want the RDSA for Security…

Tsu Fang: Segmentation in medical imaging. Look at cancer…if you want to find something inside your bag what features will be used to do this? Can you get enough features on your object you can improve recognition…If you want to win the battle you need to know your enemy…

CC: Data mining is an interesting Q. If you mine too much you may fail in the field.

RB Reveal: I thought your comments where right on given that you are not in the field. Issues however arise given the surrounding materials. This becomes the problem, especially when it gets concealed. This is one place where false alarms come from. There is a balance between threats and false alarms.

CC: Flipped through about 5-10 slides.

HARRY'S TWO TALKS PRESENTED ABOUT 5%

CC up again…You should put the patent n umber on every VG that it applies to in your prior art talk.

GZ: Asked Matthew if higher spatial resolution helps or hurts segmentation?

MM: It does impact segmentation…it yields cleaner segmentation and thus smaller FAs.

Note: Question of prevalence in the packing of bags.

Simon ?: Since the contents of bags are changing every day, yearly, etc. So instead of a fixed algorithm, could the algorithm be continuously trained on the airport bags continuously.

Fang: Note there is classification in segmentation…NOTE sure this is the correct note…The point was that segmentation is clustering and then you classify afterwards…this is correct and if you change the classification you do not necessarily have to redo segmentation/clustering.

Note: How to funds foreign national researchers within the US and outside the US.

Note: How do people disclose information that you do not want in the public but want some people to get access to it such as academicians? Bill from Mercury brought this up…

Note: DB from the previous workshop was how to get vendor research questions brought up and have academia or others address them if they can do so.

Note: Distribute the 2010? BAA for Industry…

Medical Grand Challenge talks

Mark:talk…

Testing was performed at the workshop.

Simon Warfield Talk

After quantitative segmentation volume, location, etc. HEM: This applies to our problem as well. Common evaluations have not occurred and this is an issue. Same data and same evaluation protocol required to be able to compare algorithms. Testing was performed at the workshop. Wanted to know who was accessing the data so it was PW protected…wanted the evaluation separate from the data. Automatic assessment on the web of their uploaded results. Just placed your algorithm. Reference (keys) from 3 raters. Specs were provided to the rates but it turned out they were too loose. IT probably will be useful to acquire data at higher quality than current systems, could degrade them and determine the best and what you can do on the current (degraded) deployed systems.

Jeremy Wolfe

Note: Contact Jeremy regarding the Iowa lung nodule insertion project. TIP for breast cancer

Day 2, October 8, 2009

Doug Bauer

Opening remarks. Nice set of questions for the workshop to guide the rest of the day to define the GC. Doug has enormous respect for the convening power such as the NAS. COE needs to do this as well and do it beyond there own partners. International mix whether foreign companies and students. Doug would like the attendees' thoughts on this topic.

MS: Talk to IEEE to create Transactions on Security?

Charlie Bouman: The IEEE has transactions that may be applicable for security papers.

Rick Moore Created a WICKI for this work…

Tim White Need to be specific on the data set. Need vendors to mentor the attendees, especially academia to make sure we work on the right problems.

Rick Moore: Could this group help specify the next generation EDS.

Carl Smith: The EU ECAC is doing a lot of similar things as going on at this meeting. Can we interact with and use some of their ideas? Carl off line mentioned to me about the EU non-threat list of materials. Most I think are for carry-on could we use some here?

Note: State that the NAS report on FAR reduction will be coming.

Richard Bejjani: Got a lot of our ideas from the digital communication jamming by scouring different fields of solutions…Richard is not skeptical as Matthew is. This is a way to get different people to work on our problems…both in the short term and long term.

Simon (GC guy): Said that will you fund 2 yrs to segment data or two years to improve a vendors system by 10% better than they have now.

Dan G. Created a vampire trap…bought vendors line scan machines and hooked off a vendor's machine extracted their data and then processed their data. In retrospect would like to have DICOS formatted data to make their life easier. Are the existing vendors going to participate in the test? We need to have a base line, otherwise how do we know that we have something better than what the vendors current have.

Elan: Maybe this is not a GC but some small projects such that vendors put out some data and people execute on the real data…mechanisms exist to do this…3rd parties show the capabilities the prize is you win a contract with a vendor to transfer the technology.

David C (NEU): Compared the Netflix and DARPA challenges…the later is more like what is needed here than the former, since the vendors are more looking at new ideas.

Matthew: The main problem with the DARPA challenge was the barrier to entry, we need to lower the barrier to entry for the DHS Challenge.

David C (NEU): Lack of literature is a problem, another is lack of domain expertise on what the problems are. What are the hard problems that are worthy of research and how to A measure of success is how many people down load the data set.

Matthew: A measure of success how many people down load the data set twice, i.e., more than one time.

CC: Put Jim Connolly's book chapter out into the workshop audience.

Big discussion on getting there only 90% of the way or do we need to go the whole distance getting the last 10% is the hard part…

HEM rec.: Have each vendor help or define a set of the corner cases. Have data acquired on all vendor machines.

Elan: Recommends using the 200 bag set developed by Reveal they are DHS property.

David (Analogic): If we acquire the data and put it into the public what about the 3rd party vendors?

Dan G (Opto): Prefers that the center of universe shifts away from the vendors (SSDs) and it is more open and the vendors would have to compete as well. If the center is not moved away from vendor centric then it is best to just couple directly to the vendors instead of participating in this GC. It is better now for me to go after the AT instead of the CT side.

Wang: It is nice to hear about both sides of the problem. Can we formulate smaller working groups and make something happen. The 10% of completing the problem is 90% of the work.

Note HEM: ask George can we get DHS approval to release or allow access to 3rd parties the data from vendors systems, vendors say it is O.K. if gov't says OK and not SSI.

Carl Bosch (SS): This is different since the medical stuff is not secure. The issue is that the DHS has not well define the things that are Classified, SSI or open.

Doug Bauer: If we have specific data then we can compare this against the DHS S&T Classification Guidance.

Carl the Grand Challenge DETAILS…

Measure Number of objects, and features, What is the truth? Features need to be defined. Can you use features…need features up front? Can define some features up front but any feature can be used just as long as they are defined. We should not tell segmenters what they can use…could use coke and diet coke, salted and unsalted peanut butter. Do not NEED to define what are threats vs non-threats for segmentation just distinguish one from another. Need to define the interior and exterior of objects, walls inside the container and the contents. Don't over segment non-threats but you need to over segment threats? For a laptop do you need to label the drive, boards etc. A lot of thought has to be put into a bag for this test. Concerns of things that should not be in a bag as opposed to what should be in a bag. The bags need to be defined to contain specific problems that need to be solved. Also metrics will take a lot of work. This will all have to be done with audience participations. Working groups (possibly funded) to get the bag set and metrics done. Need focused working groups to create the spec definition…needs to include vendors to define the bags to help define the corner cases they have. The data in the GC will be more beneficial to the participants well beyond the intent of the grand challenge.

If you want to distinguish???

Need to define the outputs as well as the inputs. Given all features suggested you need to define how they are calculated clearly defined them. Some no way executables, some you will need executables.

It all came down to a PCs vs Macs…could do it on a virtual machine…make the data accessible for two hours at a workstation…destroy the data afterwards…it could be protected…boxes will be sent to the COE to do the evaluations…

Livermore is a weird place.

Who is eligible and identification? Eligibility any one can access the data.

Could keep place holders for the perishables. Scan on many scanners up front and share only the data you want, thus would not have to archive the

Where is the data to be stored? I recommend at LLNL since we already have the database and we can allow open access with PW, at least I think so.

How voxels are in the object, how many did the segmenter get of the total number of voxels.

The proposal needs to be defined. We should specify a maximum number of pages…not a minimum. We should have a set of questions we want answered…

Scan many additional bags that may not have ground truth. This is useful for others…have participants to ground truth a sub set and share with all others.

Will the vendors be paid to be mentors…

VG 21: The 3rd bullet: Must license IP to all SSDs with the same terms…DHS NEEDS TO ADDRESS THIS ONE…

Will vendors put out specs of their systems…

Some vendors said that 20 mAs is high for their vendor systems.

Feedback

Dave C (NEU): Students are $30k no overhead and $60k with overhead

Doug wants the COEs to have students present to the under secretary not the COE directors…

Jim C. (L3): Segmentation is a critical part to detection and classification. Problem put a national geographic on topic of a VCR. Can you separate out the VCR and magazine. Be careful what you focus on, e.g., counting the number of the objects. The key is how well does the segmentation actually represent the contents of the bag. If you have artifacts going through the magazine those in it still need to be attributed to the mag. Vendors may be willing to run their segmentation and provide results for the starting point. THIS IS KEY IF WE CAN GET THE VENDORS TO ACTUALLY DO THIS!

Doug asked if the corner cases are about the same for all vendors or very different? MM: They are to first order the same. Dual E eliminates some and creates more

RB: They are about the same and they are due to CT issues.

JC: Need to get us (the vendors) all in the room (w/o academia due to classification issues) and have us create the corner cases for the contents in bags.

HEM: Could use this as an example and do this with and without putty inside the VCR.

Carl Smith (Guardian): Need a clear DHS objective is needed. Would be willing to contribute to the lack of domain knowledge. SIMPLE RULES, do not constrain the participants.

Tim White:

Suriyun:

Mark: Great, learned a lot…would like to see more pictures of the problem…

Simon: Can we get data that exists now to get it started.

Oliver: Try not to make the problem too difficult. No one will be able to do it.

JP: Get started with just a few images to get people to start to think and to start to understand the problem…can images be given out within a few weeks.

DB (Tele) Practice data is on the disk

Steve: Need to get the vendors involved…do not make it too difficult and take the time to get it right.

Pia: Much has been said…do not make it too difficult…

Wang: How do we make the followup on this workshop more successful…we will all be going our separate ways…What about small breakout groups to keep everyone communicating.

Johnny (NEU): Making the data available will be really good. Need to get more people engaded to make this happen.

HEM: How do we get started…get data out ASAP…Could make the LLNL data available on the Reveal bags….

Harry's end of workshop talking points:

Only medical field represented we need to tap the NDE and others as well.

23. Appendix: Homework

23.1 Homework #1

Summary:

The concept of a Grand Challenge sounds reasonable for a commercial business challenge. Application to a security issue raises serious concerns about maintaining the integrity of classified or SSI information. Broad dissemination of the proposed grand challenges could expose vulnerabilities in our national threat detection capability that could be exploited by terrorists. (For example, 6.5.13 is not practical unless there is a clear declaration that reconstruction and segmentation algorithms and associated evaluation data sets are <u>not</u> SSI or classified information).

The proposed roadmap for implementation of grand challenges is, however, reasonable:

- Start with image processing of CT-based EDS (reconstruction & segmentation)
- Define the problem and acceptance criteria (can anyone do this?)
- Provide data sets for training
- Develop algorithms that meet acceptance criteria on staged bags
- Transition algorithm (code) to secure environment for independent evaluation on a validation data set

Grand Challenges require more development and utilization of phantoms and simulants. The report does not specifically address the effort to develop and validate any phantoms and simulants. Are some of the "known non-threat objects" provided in the reference scans actually simulants and phantoms (along with known false alarm and other luggage objects)? The amount of effort required developing effective phantoms and simulants is not trivial.

Grand Challenges should be implemented with appropriate standards for software development, coding and verification. All parameters ("knobs") that are typically used to tune algorithms for optimal performance should be clearly defined. Sensitivity testing of all tuning parameters should be required.

Bridging and splitting are identified in the example Grand Challenge for Volumetric CT Segmentation. These artifacts have multiple causal factors (streaks, orientation, proximity, topology, etc.). Algorithm developers could optimize for a sample data set and still not achieve an overall optimal solution. Sample data sets would need to include cases that require joining and separation of both with target and false alarm items. A comprehensive data set would be very large.

Operator performance (On Screen Resolution (OSR)) is critical, but very difficult to measure. In using the same evaluator for repetitive assessments the results will be obscured by learning. If using different evaluators, the results will be biased by different operator technique and capability. A combination of multiple operators and multiple data sets will be required to obtain an effective metric.

The most interesting aspect of these Grand Challenges is the concept of the broad dissemination of thousands of scans and other relevant data to algorithms developers. This is much more data and content than is currently provided to new suppliers of explosive detection systems. The current paradigm is for vendors to independently collect false alarm scans at an airport installation and threat scans from targets made available at TSL. There is no avenue we know of for the government to provide independent third party scans to new suppliers. There is currently no data we know of that provides any metrics on operator effectiveness at OSR. We have the basic 3-page OSARP SOP for EDS with ETD, but no reference data set against which to evaluate system performance for OSR or to score our performance.

As a result, several questions are compelling:

Why would data be disseminated freely to third parties before it has been distributed to established EDS suppliers?

If this data will encourage optimization of algorithms and systems, why hasn't it been distributed to existing EDS suppliers already?

Who (what organization) is (will be) responsible for creating the data set(s) to be distributed as a Grand Challenge?

What is (will be) the role of TSL? And why aren't they a participant in this process?

What part of DHS/TSA has oversight for requirements, evaluation and enhancements to OSR? How is DHS/TSA working with current EDS suppliers to evaluate and improve current OSR capability?

23.2 Homework #2

First let me say that I thought this was a very, very successful workshop. I believe you and the DHS objectives were all met and I want to congratulate you for your excellent leadership.

It took me a while, including a brief discussion with you to understand the two objectives of the workshop: Come closer to a definition and general buy-in of the first grand challenge. And, to create a congenial and collaborative environment, including divergent representatives from Industry, National labs and Acedeme, that will not only support but actively contribute to the Grand Challenge.

Let me try to distill what I see as the road ahead, and as always, I am trying to find a simple, straight line between what I have and what I want. As far as I see, all the other great challenges had a clearly defined starting point, or initial set of specs, and a clearly defined or desired end point. The approach in between was left to the competitors to define: e.g. DARPA set as goal to drive autonomously from LA to Vegas, they did not specify e.g., the use of GPS or whether it's a three or 18 wheeler. And they had clear evaluation criteria for success. I learned that the case of algorithm development is quite a bit more complicated. Thus, from my perspective here is where I would spend my time:

1. What do we want to get out of this exercise? Whom do we need to collaborate with? How can we set the stage that there is maximum probability that the vendors or DHS have an interest in the outcome?

2. Clearly define the rules, the staring point and the desired outcome. This should be done by all participants in the workshop with their understanding that someone has to make a final decision.

3. Fill 30 bags with real stuff and stimulants, use 20 for testing/learning and 10 unknown for the challenge 4. Do not describe any approach to be taken but clearly define the evaluation criteria 5. Develop evaluation criteria which you share with all participants. Make sure these rules are tight and can be implemented without any further modification 6. The biggest problem seems to me to find a standard, generally acceptable evaluation procedure that is independent of any scanner or machine. From what I learned in the workshop, I do not know, whether this is possible, though.

4. Line up scanners/machines where the submitted results/algorithms can be tested, preferably at National Labs (I believe Idaho NL also has a

scanner) but do not tell competitors which machine is used for testing (they may fit the algorithm to fit the machine).

I believe the evaluation is an even bigger problem than the definition of the specs/goals or the rules. Why?: because there are no clear cut performance parameters which are ironclad. I remember with horror, the industrial salesmanship of performance numbers of IR viewers before the definition of D-star. Do we have to define a similar ironclad performance standard here?

Anyway, those are the thoughts of a non-expert coming out of the last algorithm workshop. Perhaps they are helpful in the way ahead or in the preparation of the final report of the last workshop.

23.3 Homework #3

I have reviewed the final report with a focus on chapter 6. Here are my comments.

In 6.5.1 item 1. I would replace "Reconstruction" by "Reconstruction and artifact removal".

My comments on 6.5.1 item 6:

Scanner modelling is important but requires to define certain categories of constraints (most scanners should not have moving parts, others must restrict themselves to one or a few view positions, etc.). On scenario modelling it may be helpful to have a Scanner-Killer-Contest, i.e. find scenarios that cannot be handled with a certain scanner (this may, however, contradict the requirements of 6.5.13 which state that everyone would have access to the information). For example sheets may not be resolved when they are oriented a special way.

6.5.6 item 3: I can offer help there since we have access to clinical CT

Scanners, to C-arm-CT scanners and to experimental CT devices. It may also be useful to use the data acquired and rebin to a different geometry. One can even change the scan protocol in a way to allow more flexible rebinning.

6.5.7 item 4: Disclosing data file formats is difficult for clinical CT scanners. The data may have to be converted to a different format before providing them.

6.5.13 item 5: Why only "national"? What about people from outside the US?

6.5.14 item 6: Maybe this item is misplaced. Do you really mean extra sessions just to identify participants? I may help organizing MIC sessions (this year, I am organizing an MIC workshop on High Performance Medical Imaging, for example). I may also help organizing special sessions for the Fully3D conference (which I will be organizing togehter with Magdalena Rafecas in Spain, 2011).

6.5.16: I find seed funding important, at least for the academic people.

For examples all scientists in my group are tied to certain projects and would not be able to participate in an unfunded Grand Challenge (nevertheless we would like to do so as long as the topic is image reconstruction or artifact removal).

6.5.19 (I am not sure if my comment really applies to this section):

Since I have already developed some algorithms for checked luggage scanning I would find it of importance to have access to the segmentation algorithms. Only then one can find the optimal reconstruction algorithm. My current experience is that we develop reconstruction algorithms for luggage scanning but that we currently look at the images as if they were intended for Diagnostic Radiology.

Having access to some detection algorithm could therefore help to further improve the image quality.

6.5.21: Can't the participants also sell the algorithm they developed?

6.6: "CT images of approximately ...". One should not only use standard CT images (acquired with clinical scanners). The images should be generated by reconstructing down-sampled data or data rebinned to a different geometry since it is not to be expected to obtain images of such high quality as in clinical CT. So some focus should be put on how to generate those input images. One also needs to address the issue of metal artifacts. While the input CT data may have been acquired at no more than 120 or 140 kV the systems that will be used for luggage scanning may use 200 kV or more. A DECT scan with a clinical CT scanner would allow to calculate images at higher tube voltages without further assumptions. Probably, those "images of approximately 100 bags" should be provided in approximately 10 different flavours (different tube voltages, different reconstruction algorithms, different scanner types, different noise, ...).

In general I would put only little focus on the computing time issue (throughput, combined time etc.). Once you have an algorithm that provides you with accurate and acceptable results you can nearly always find a way to improve its computational performance. Probably these issues should be kept separate: Have one competition to find a good algorithm (no matter how slow it is, as long as it is not slower than, say, two orders of magnitude of what is finally acceptable), and have another competition to find ways to speed up a given algorithm.

23.4 Homework #4

On the report, I suppose I have two main comments. First, my memory is that from the academic side one of the ideas that seemed to resonate was to have a "playground" of models and data that academics could use for experimentation and "what if" kinds of thinking. That thought, while in the minutes, seems lost in the current report. Second, and related, are some comments on "Grand Challenges".Grand Challenges can mean many different things. My memory of the discussion at the meeting was that it was felt that it would be useful to provide:

1. “challenge” *data sets* for people (e.g. academics) to experiment with. For example, this might follow the example of the DARPA MSTAR datasets which were made widely availableand sparked a generation of research in ATR: https://www.sdms.afrl.af.mil/datasets/mstar/targets.php. A more recent example from the Air Force is this: https://www.sdms.afrl.af.mil/datasets/gotcha/.

2. Associated models for the data where appropriate. In particular, for tomographic-like problems raw data without associated models is not much use for advanced algorithm development (this *is* mentioned in the report).

As I read Ch 6 it seems that "Grand Challenges" are envisioned to be quite short time scale things with clear performance goals associated.

The positive of this is that it does focus people and can produce short term results. BUT, I think the potential danger of such an approach is that it can lead to an emphasis on transition and development rather than long lead “breakthrough” research, since it often requires development of a complete system of some sort. A researcher focusing on a single aspect of the problem has trouble competing. At least I think this is something to consider in crafting whatever this will be. In particular, such grand challenges come sometime be a bad fit for academic enterprises with students working on theses over a multi-year horizon. A student will generally not be doing new algorithm development on a 6 month time frame while taking classes, passing exams, etc. At least most don't seem to...

For me a playground is access to models, data, etc of some controlled nature and with some "validation" with which I can try new things. Not necessarily including a task someone else has defined. A grand challenge might provide some of these as a byproduct (i.e. data, models, etc), but seems more goal oriented to me.

If the goal is short term results, challenges are probably the way to go, but they may not attract academia (unless a company or lab teams with academia). Even then, the student endeavor that is central to academic seems a, well, challenging match for a challenge.

23.5 Homework #5

As Michael may have told you, I am his collaborator and friend at CenSSIS / ALERT. Quite recently he has invited me to become acquainted with the goals of his ALERT center to explore ways of bringing my theories and algorithms to projects of common interest. I attended the recent workshop as part of Michael's people. I was there mostly as Michael's friend, exploring what his center is up to.

Having clarified this, let me now continue with a few general impressions. I was very impressed by the workshop that you organized. The idea of the grand challenge/competition is fantastic! I can tell you have assembled the right team and that you are in the right track with this idea.

I liked Michael's comment regarding the possibility of making the challenge/problem one of multiple levels, perhaps a problem of different levels of complexity that can allow participation by students of different levels, as well as both expert academics/industrials who are already working in biomedical imaging, security imaging, and so on (your current team, etc.), as well as a brand new group of theoreticians and signal processors who despite not being directly involved in this area may have an incentive to jump into it (other people). I think the latter issue is very important since one of the best ways of stimulating innovative thinking is to bring completely new players, with the hope that they may produce a fresh new look into the problems of concern.

I will continue the conversation with Michael, but for the moment I wanted to share with you my gratitude for allowing me to listen to a number of key talks by your team, and to express my constructive comments on the excellent work you are doing: Impressive.

23.6 Homework #6

Try to keep the contest simple as possible the first time. Use it to learn. Then do another - it's not a waste. Or, alternatively, I suggest two levels of contest. One would be as simple & clean as possible. Maybe "Write Java code (or ITK or something) to find all oranges (or tennis balls) in the bag." (I like the notion of finding a regularish-but-non-homogeneous object). Anyhow, the contest should have a very low barrier to entry - ideally provide the Java code for loading the image. Then you can have a parallel more difficult contest, as people are describing. The "simple" contest will be very easy to run (no specialized hardware - give us your "run anywhere" Java) and will get the maximum number of people in the game - with or without funding.

No matter what you do, run a post-hoc cross-correlation between all the results. Suppose you have five segmenters which are 60% good and one that is 50% good. But also suppose that the 60%ers all do well on the same 60% of "low hanging fruit", while the 50% actually does well on much of the 40% that remains (and not so well on the low-hanging). That would suggest a collaboration between the 50% team and one of the 60%ers. Maybe they could hybridize somehow. Ensemble methods work. Note that you should have a scoring metric that measures "successful independence" or something like that. If someone is good on a sample that nobody else is good at, that's notable.

Here's my hare-brained scheme. For the same bag set, provide:

a) raw (or prepped raw) data

b) best-possible-recon images (maybe iterative, or whatever) and/or basic "ugly" recon images

Now run two concurrent challenges:

1. reconstruct the raw as best you can

2. segment the images as best you can (whatever images are provided)

Then do the following post-hoc experiment:

-score each segmentation (and each reconstruction) using standard techniques.

- now pair each segmentation with the output from each reconstruction and see how each combo does.

It would be very interesting to see if the relative order of the segmentations stay the same without tuning. That is, did the "best segmentation" always score best (albeit lower or higher)? If so, that suggests that it really is "best" and not just "best tuned" to your reconstruction output. However, if the relative positions jump around, that suggests that tuning is critical. Likewise, evaluate the recons. Was the best always best across segmentation partners?

I'm happy to try to help with planning, as you need and time allows. Would love meetings to be somewhere a little more west-coast friendly (especially Livermore), but I know the drill.

23.7 Homework #7

1. Relative to the requirements of the grand challenges, detailed, quantitative models (both analytical as well as computational) of either existing sensors or suitable "approximate" sensors must also be provided. Mere "sensor descriptions" are not sufficient. This issue also arises on page 13 of the report. The Grand Challenge requires sensor simulators be put into the public domain.

2. There are a wide range of advanced reconstruction algorithms in addition to interior tomography. To single out only that method in the "Main Outcomes" section as well as Section 5.4.4 seems somewhat limiting.

3. The notion of "best possible performance" discussed on page 4 and again in Section 5.4.9 is incompletely specified. Performance is very much a function of the processing scheme as well as the modality. It is also dependent on the specification of the modality (how many projections, what is the energy spectrum etc). To say that a modality is "operating close to its best possible performance" is vacuous. All that can really be said in the context of this bullet point is that the information provided by the modality is sufficient to meet the requirements of the government.

4. The time-line for algorithms development and testing in Section 5.6 is not realistic in the case where graduate students are doing the work. Specifically, proof of concept would take 4-9 months (one to two semesters).

5. The a priori decision to address the topics in Section 6.5.1 individually immediately removes from consideration a number of approaches to some of the security issues that (a) are being pursued by members of the center and (b) hold promise for at least stimulating new ideas and ways of looking at these problems within the community if not actually helping to solve some of the problems outright. This is a shortsighted approach to structuring a basic research program.

6. The Grand Challenge structure as elucidated in this report fundamentally encourages a stovepiped, competitive approach to basic research as opposed to a more open, collaborative approach. Implementing a competition is certainly simpler than organizing a collaboration, but also is likely to provide less in the way of basic advances. There is an opportunity here to change the way business is done for addressing really hard problems. It is disappointing that the approach being pursued is so restrictive.

23.8 Homework #8

1. I agree on the general elements of the thrust discussed.

2. As I mentioned yesterday, we would like to emphasize a systems engineering view for advancing the state of the art.

3. Leveraging Medical imaging advances in reconstruction, segmentation and classification is a quick way to bring ideas into security, however - as has already been pointed out medical image segmentation exploits a number of contextual constraints including shape space, embedded context, etc. In my opinion, EDS requires a more general framework that may combine recent advances in AI, cognitive science, and machine learning and computer vision.

23.9 Homework #9

1. Regarding segmentation evaluation metrics, be a little careful. Dice and other overlap metrics do not work well for thin structures. Maximum surface distance has issues with spiculated structures. Etc.

2. Also, I'm concerned that producing a single large object vs two smaller adjacent objects is considered a problem with segmentation. You can never solve this if you focus only on segmentation. If two smaller objects are close enough in proximity, the decision logic should weigh this.

3. For a grand challenge, I suggest to make them very focused, and only address a single subtopic.

Example, year 1 is "volume estimation", year 2 is "images with wires", year 3 is "thin sheets", etc.

For Dice, please consult wikipedia, and original paper:

http://en.wikipedia.org/wiki/Dice%27s_coefficient

Dice LR. Measures of the amount of ecologic association between species. Ecology. 1945;26:297–302.

For current practice, I do recommend using Dice (or equivalent such as Jaccard). But also you need at least one other metric such as average surface distance. Algorithm A is only better than B if it is better in all metrics tested.

In the future, we should consider the suitability of each metric to the type of object (spheres, rods, sheets). This could be a good project for a student.

23.10 Homework #10

General Comments:

In particular in the context of "Grand Challenges" as described in the report, I believe it is very important to define standards for the data (as described in the document) as well as for the interfaces between the different system part. Ultimately the image acquisition, segmentation, object classification, data display, etc. need to be integrated in a common system. Defining standards not only for the data but also, e.g., for how the output of the segmentation and classification step should be defined, is important to facilitate the integration as well to imporve communication between different groups working on various aspects of the thread analysis pipeline.

The focus of the document with respect to segmentation seemed to be fully automated binary segmentation methods, i.e., methods that automatically (without human interaction) segment the data and assign each pixel/voxel to exactly one object. I would have the following questions in that regard: (i) Is the aspect of fuzzy/probabilistic segmentation of interest to the problem of thread assessment. (ii) In medical imaging and visualization the topic of uncertainty quantification and visualization has gained more interest. Would this also be of interest ot the DHS? For example, if a segementation algorithm would produce uncertainty information in terms of areas where the algorithm may not be able to accurately separate objects, could this information be used to trigger re-imaging of certain areas of the volume to improve the quality of the analysis?

As also mentioned in the document, I believe it is important to promote and strengthen the relationship between academia, national labs, and industry.

Chapter 6:

6.3: The option of providing sufficient seed funding is from my point of view essential if one wants to attract 3rd parties from academia and industry.

6.4: It is not clear whether a "Grand Challenge" asks for fundamentally new algorithms or just for the application/modifcation of existing work.

6.5.1: Besides the fundamental data acquisition and automated processing also advancements in visualization as the interface between the human actor and the software could be addressed in a Grand Challenge.

6.5.1: While addressing the various topics individually seems to be appropriate, I believe the interaction between the different parts/algorithms should be facilitated from the beginning, e.g., by defining standard for data exchange and providing a central resource (e.g. web database) for all grand challenges issued.

6.5.7: If available, then one may also want to provide as additional resources information about standard software libraries for data access (file readers) and data display to be used.

6.5.21: This may not be possible in all cases but to facilitate reproducibility of the work the participants should also be allowed to make their sources (code+data) publicly available.

6.6: The challenge appears to be somewhat unrealistic if only data that contains non-thread objects is available.

6.6/6.7: How are the results of the challenge shared with all participants and which results are shared?

23.11 Homework #11

I hear people, esp. vendors, constraining themselves to artificial restrictions - algorithms should always work, updating them is costly, shapes should not be used, "unstable" features should not be used. I understand that they got to be conservative - but it eventually comes to the hard question - do you want to write a lot of papers on methods and also to sell machines - or do you want to find explosives and use all abilities to do it.

I presume the latter - then I suggest that the "grand challenges" should NOT be restricted to conservative assumptions. Rather, it should assume, for example:

- A possibility of finding subtle features that are not part of certification
- A possibility of re-running the object thru the machine, possibly at different or same angle
- Using statistics per airport, passenger data,
- Using feedback from TSA inspectors in real time about changing false alarm rates, ...

Each of the factors above have a potential to reduce FA rate. For example, finding children shoes would be less of a signal if there is a child traveling.

Then, you can compare performance of algorithms that do or do not use various features and report to DHS - are they willing to spend X to change their CONOPs while reducing FA rate by Y.

I think the goal of R&D should be to determine potential performance under different acceptance assumptions. Then, this performance estimate will give the government the basis to system design: do they want to involve inspectors in feedback, do they want several runs through the machine. If the pay off from a technique is going to be huge, they may want to go through inconvenience of changing their processes, but not if it is marginal.

Re: meta-segmentation: you first do segmentation by looking at the observed lines. At this point you are using only geometric information around the pixels. At the next step you might want to add to that. For example, you have 2 boundaries that are on the same line but with a break between them. Same material observed on both sides - thus, these boundaries are part of the same one, just part of it was not observed. Or as discussed at the workshop, you may want to merge or break the objects based on knowledge of object forms.

I am using here analogy from tracking: you can use Kalman filter to connect nearby measurements, but then if there is a break in observations, you may want to do "track stitching" using considerations of whether this is the same target.

23.12 Homework #12

5.4.3:

This presents an interesting change to the ConOps of (current) checkpoint screening. It seems like this is a standalone GC – is it possible to optimize, or at least improve the efficiency of, check-point screening by changing the types of alarms and alarm-resolution protocol from EDS? I wonder if this sits in between the segmentation and human-factors GC's that are laid out in detail later?

5.4.11:

Video surveillance seems to fit cleanly in 5.4.7 (Orthogonal technologies). I think that the 5.4.7 could be expanded to include more than just fusion of ionizing-radiation techniques, but to include some combination of all available checkpoint data.

(maybe those first two points taken together form the skeleton of another GC – exploitation/fusion of all available checkpoint data to enhance efficiency of threat interdiction. "Fusion" is way too broad, but maybe by brainstorming a bit a chewable-sized problem could be identified (much like the segmentation problem is a subset of the larger EDS problem)

5.5:

Definition and description of the system elements seemed to be one of the main stumbling blocks in the initial meeting (details on the detector, for example). I think that to get buy in from academia it has to be made clear that for the GC, detail on the system is completely available (even if that means using an outdated scanner (or one from Harry's basement).

6.5 Questions about implementing GC's

1.1.9:

this seems ambitious – is the intent to collect CT data (and photos and descriptions) of each item in luggage and then pack (in different configurations) and scan the whole package?

1.1.19:

I think that threat data needs to be collected using the same system that was used for algorithm development. These data will not be shared with the participants, but will be used as the first pass of testing on the secure side of the classified fence. Then the same items that were used for the testing need to be scanned on a "real" scanner, with and without threats, and then "real" data. It seems like a lot of data that needs to be collected, but it also seems like the logical steps necessary to see where an algorithm fails.

On the other hand, if the goal is only improved detection, there is an argument to go right to the real thing.

I think that it needs to be clear to the participants that:

- you "win" if you are the best at segmentation on "clean" data (an open test that everyone can view)
- or, you "win" if you are the best on detecting threats on threat data collected on the same system used for clean data
- or, you "win" when your algorithm detects real threats in real scans 1.1.19
- or, you "win" when a vendor likes your approach and signs you to a contract

1.1.22

it is not clear where the vendor community sits in the development and testing and evaluation of the GC. I think that needs to be made clear to the participants, the vendors, and DHS.

6.6 Example for …. CT

additionally, empirical system-response data – images of resolution test patterns, calibration data for contrast resolution, etc. – need to be provided to the participants.

23.13 Homework #13

What baggage?

Handbags

Configuration

- clutch
- purse
- big bag

Material

- canvas
- nylon
- leather

Briefcase

Configuration

- photocase
- hardcase
- softside

Material

- leather
- vinyl
- Al, Mg and Ti
- nylon

Suitcase

Configuration

- standard
- rollaround

Material

- leather
- vinyl
- fiberboard
- nylon

Dufflebag

Configuration

- small (20 inches)
- medium (32 incles)
- large (60 inches)

Material

- leather
- vinyl
- nylon

Backpacks

Configuration

- school
- camping

Material

- leather
- vinyl
- nylon

Coats

- overcoat
- ski parka

Laptops

- metalcase (Al, Mg and Ti)
- plasticase

Content

- as previously described

24. Appendix: EDS Review

Overview of Deployed EDS Technologies

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Overview[1]

The term explosive detection system (EDS) is used by the TSA to describe equipment that is certified to detect explosives in checked bags. The EDS, as certified, by the TSL must consist of device for interrogating a bag and an automated detection algorithm (ATD) for evaluating the results of the interrogation. We only consider CT as the interrogation device in this report. A schematic drawing of a CT-based EDS is shown in Figure 2[2].

The output of the ATD is the binary decision of alarm or non-alarm. Alarms may true- or false-positives. Non-alarms may be true- or false-negatives. False positives are also denoted false alarms. The true detection means that the ATD reports an alarm when a threat is present in the scanned bag. The probability of detecting a threat given that a threat is present is denoted the probability of detection (PD). The probability of false alarm (PFA) is the case when an alarm is reported when a threat is not present in a bag. Certification in this context means passing tests for PD and PFA at the TSL.

The results of the EDS include CT cross-sectional images of the bag and specifics about the alarmed objects generated by ATD. These results are presented on a display so that a person may override the decision of ATD and declare the alarm to be a non-alarm. This process is denoted clearing.

Bags that are not cleared by the person are sent to a secondary inspection process. Here the bags may be opened or assessed with explosive trace detection (ETD) in order to clear the bags. Bags that are not cleared at this point are evaluated by an ordinance disposal team.

The CT scanner along with ATD is denoted Level 1 screening. The process of clearing on a display is denoted Level 2 screening. Secondary inspection is denoted Level 3 screening. Vendors of the deployed EDSs supply the TSA with equipment for all three levels. Therefore, the term EDS may include the equipment provided for Levels 1, 2 and 3.

A schematic diagram of an EDS and the levels of screening are shown in Figure 7. The decision processes used as a bag is scanned and cleared is shown in Figure 8. Shield alarms and exceptions are discussed below. Since most alarms are false alarms, the probability of alarm is oftentimes denoted the probability of a false alarm. The expenses associated with clearing false alarms occur in Levels 2 and 3.

[1] A table with acronyms and their definitions can be found at the end of this document.
[2] Figures can be found at the end of this document. The figures are numbered out of order because this report was derived from multiple other documents.

TSA Requirement Specifications

The TSA specifications that are relevant to the false alarm problem are discussed in this section. Some of the details are omitted because they are SSI or Classified.

An EDS must detect a number of categories of explosives. The PD for each category has to be greater than the threshold x. The average of the PDs for all the categories has to be greater than the threshold y, where $y > x$. The PFA for the EDS has to less than the threshold z. *Detection* must be performed automatically with a system denoted ATD. The humans that participate in Levels 2 and Level 3 are not tested as part of these requirement specifications.

The throughput of EDS must be at least 450 bags per hour. Multiple scanners may be configured in parallel to achieve this requirement. This throughout is measured without consideration of the TSO resolving false alarms. This condition is known as the *human is not in the loop*.

The EDS must report that exceptions occurred. The exceptions include cut bags, shield alarms, ATD time-outs, bag jams and scanner failures. Shield alarms are the largest source of exceptions; there is no requirement specification for shield alarms.

An EDS is also required to record data about the bags being scanned, the threats found by ATD, and the results of Level 2 and Level 3 screening. The data is collected by the FDRS.

Certification Testing

EDSs are certified to meet the above requirements at the TSL using tests that have been described in detail elsewhere [Management-Plan][3]. A summary of the tests is as follows.

Two sets of bags were created, one with one threat per bag and one with no threats per bag. The bags are preserved so that all vendors are tested with the same sets of bags. The bags are not representative of bags in the field because fragile, perishable and valuable items are not included. These test sets are not moved from the TSL so that testing could be performed at the factories of the vendors or on fielded systems.

The bags with threats are run through the EDS and the PD per category and the average of the PDs per category are calculated by summing the binary decision reported by ATD. The bags without threats are scanned and the decision reported by ATD is summed to report PFA. Throughput is measured on the set without threats.

[3] The notation [XXX] indicates a citation to an entry in the bibliography below.

The EDS that passes certification is denoted the certified system. Subsequent tests are designed to assure that all manufactured and deployed scanners match the performance of the certified system.

The following vendors have certified systems: GE[4] (and its predecessor InVision), L-3 Communications, Analogic and Reveal. The majority of the 1500 systems deployed after 9/11 are produced by GE, L-3 Communication and Reveal. All of the 1500 systems are based on CT.

GE has also certified systems based on XRD. However, the throughput of these scanners is too low to be deployed. Therefore, systems based on XRD are not discussed in this section.

Other Testing

Other tests are performed at the TSL in addition to certification. CRT and pre-cert are run to qualify a system before certification. After certification, a post-certification test is run to assure that there are certain configurations and locations of explosives that are not detected. The acceptance criteria for these tests are subjective. The basis for this additional testing appears to be based on the following statement from TSA's requirements: "The detection must not be dependent on the shape, position, or orientation of the explosive, or the configuration of an improvised explosive device (IED)" [Management-Plan].

EDSs are tested in a factory using a factory acceptance test (FAT) and when they are installed at a site using a site acceptance test (SAT). It is not known who controls FAT and SAT. FAT and SAT are run to assure that all systems match the certified system. However, the committee did not hear evidence to show that PD in the field matches the PD obtained during certification.

The vendors scan test phantoms (also known as test bags) periodically to assure that the scanners in the field are performing per specification. It is not known who controls the requirements for frequency of these scans. It is known that the acceptance criteria are set by the vendors.

Deployment

EDSs are deployed in a number of configurations. In-line means that the EDS given bags by the BHS. Stand-alone means that bags are fed manually. Stand-along systems can be in front or begin the check in counter.

[4] Since this report was initially written, GE has changed its name to Morpho Detection

An in-line deployment is shown in Figure 9 and depicted in Figure 1. The blocks in this figure are now described. The process that is followed in the field is denoted SOP.

An EDS consists of the following components: (1) **CT scanner**; (2) **automated threat detection (ATD)** algorithm; (3) **baggage viewing station (BVS)** and (4) **control computer (CC)**. The EDS is integrated with the following other components: (5) **baggage handling system (BHS)**; (6) **baggage inspection room (BIR)** and (7) **ordinance disposal team (ODT)**.

The **CT scanner** produces cross-sectional images of the bags. The images are either a set of contiguous slices, known as 3D or volumetric data, or a variable number of slices at varying slice spacing, known is selective slices. The CT scanner may be combined with an x-ray line scanner, which also denoted a digital radiography (DR) projection scanner. The images from the DR are used to determine where to acquire the selective slices.

The **ATD** processes the images produced by the CT scanner to locate threats. Zero or more threats may be found per bag. The output of the ATD includes descriptions of the threats including their locations within in a bag. Cleared bags (bags with no threats found by the ATD) are sent to the airplane. The performance of an ATD is characterized by its PD and PFA. PD is less than 100% and PFA is greater than 0%. ATD may run on computers in the CT portion of the EDS or on the BVS.

The **ATD** also analyzes the images of the bags and determines if a threat could be shielded from the x-rays used in the EDS. If shielded regions are found in the bag, the bag and its images are sent directly to the BIR.

The **BVS** displays images of bags that contain threats. A TSO may clear the decision of ATD using a protocol known as OSR or OSARP. The procedure used by the TSO during OSR is SSI. Bags cleared by the TSO per OSR are sent to the airplane. If ATD finds multiple threats, the TSO may clear some or all of the threats. The BVS is also known as a PVS. The use of the BVS is also denoted Level 2 screening.

The **BIR** receives bags that have not been cleared by the TSO using OSR on the BVS**.** TSOs visually inspect the threats or apply explosive trace detection (ETD) to attempt to clear threats. If the TSO clears the threats, the bag is sent to the airplane. Bags with remaining threats are transferred to an ordinance disposal team (ODT). The processing in the BIR is known as Level 3 screening. There may be a workstation, denoted the SVS, in the BIR, where the TSO examines the CT slices and the outputs of ATD. It may be possible that the threat, as found by ATD, is not found by the TSO or another item is mistaken for the threat.

The **BHS** consists of a set of conveyor belts, diverting mechanisms and a tracking system. The conveyor belts move bags in and out of the EDS, to the BIR and to the airplane. The diverting mechanisms move the bags between the different sections of the conveyor belts. There are a number of exceptions, in addition to shield alarms, that may cause a bag and its images to be sent directly to the BIR. The exceptions include shield alarms, mis-tracking, operator time-out errors, bag jams in the scanner, and scanner failures.

CT Scanner Hardware

CT scanners collect projections from different angular positions. The projections are inverted using the step denoted reconstruction to produce cross-sectional images. The images provide estimates of the object's linear attenuation coefficient, which is closely related to physical density, and optionally the atomic number. The images are contiguous, resulting in a 3D volume, or selective 2D slices, known as selective-slice. ATD follows reconstruction. A picture of the inside of a CT scanner is shown in Figure 3. The components of the CT scanner are now described.

A typical CT scanner is described in this section. Variations are noted in the text and after the description. CT scanners have five key subsystems: HVPS, x-ray source, detector, gantry, data acquisition system, and reconstruction algorithm.

The HVPS produces high-voltages required to drive the x-ray tube. The average potential of the HVPS is in the range 140 – 180 kV. Some systems use a DC waveform. Other systems add an AC component in order to collect high and low voltage information, as described below. The power of the HVPS is the range 500 – 5000 W.

The x-ray tube produces a Bremsstrahlung spectrum of x-rays from 0 keV to the peak potential of the HVPS.

The bag is transported through the EDS on a conveyor belt. The bag and the conveyor are not shown in Figure 3.

The detector detects x-rays that pass through a bag under inspection. The detector converts the x-ray photons to light. Photodiodes, which are mounted behind the detector, convert the light to electrical charge. There are one or more rows of detectors, where each row forms a fan-beam with x-ray tube as the vertex of the fan. The collection of detector rows forms a cone-beam.

The output of the detector is digitized by the DAS. The outputs of the DAS are either fan-beam or cone-beam projections. These projections are related to the line-integrals of the x-ray attenuation coefficient of the bag along the paths from the x-ray tube to the detectors.

The x-ray tube, HVPS, detector and the DAS are mounted on a gantry. The gantry rotates at approximately 0.5 seconds per rotation. The DAS is sampled at approximately a 1 kHz so that projections are obtained at various angular positions around the bag.

The conveyor belt may or may not be stationary when the gantry rotates around the bag. The scanner is considered to be a step-and-shoot variety if the conveyor is stationary. The scanner is considered to be a helical or spiral scanner if the conveyor is moving.

The outputs of the DAS are sent to a reconstruction computer to reconstruct cross-sectional images. The cross-sectional images are sent to another computer on which ATD is performed. The reconstruction and ATD computers are not shown in Figure 3.

Some EDSs combine CT with a DR scanner. The images from the DR are used to determine where selective cross-sectional images should be acquired. The deployed GE scanners use this combination.

The GE (InVision) scanners combine DR with a step-and-shoot CT scanner. Reveal and L-3 only use volumetric CT scanners. GE (InVision) and L-3 are single energy systems and therefore only produce measurements of the linear attenuation coefficient. The Reveal system obtains dual energy measurements and therefore can produce estimates of the atomic number.

Reconstruction

Most scanners use a process denoted filtered-back-projection (FBP) to reconstruct the cross-sectional images [Kak-Slaney]. The output of the DAS is corrected in order to generate the line-integral data required by FBP. The steps of reconstruction are shown schematically in Figure 4.

If the steps in correction cannot completely reverse the underlying physical effects, images will be degraded leading to inaccurate measurements of the linear attenuation coefficient, density and atomic number. The following operations may be performed during the correction step.

Step	Synopsis
Offset	The electronics (photodiode and amplifiers in the DAS) have dark currents. The dark currents are measured with the x-ray tube off and then subtracted. Temperature drift of the offset has to be considered.
Reference	The current supplied by the HVPS to the x-ray tube may vary. A reference detector measures the incident x-ray flux.
Beam hardening	The x-ray tube produces a polychromatic spectrum. The x-ray attenuation coefficient is a function of the photon energy, with lower energy photons being preferentially removed. A polynomial correction is applied. Unfortunately the different materials use different polynomials so artifacts will remain.
Spectral	Each detector has its own spectral response to polychromatic x-rays. This response is known as the detector's transfer function. The difference of the transfer function for each detector with respect the mean of the functions for all the detectors is corrected in order to prevent the insertion of concentric rings an bands in images.
Afterglow	The detector and DAS have finite impulse responses leading to a temporal blur of the projections. The impulse responses may be de-convolved.

Scatter	Scattered x-ray photons may reach the detector. Some scattered photons may be eliminated with anti-scatter plates placed in the septa between detectors. Additional algorithmic correction can be used to remove scatter based on measurements from auxiliary detectors or using the projections themselves.
Clamping	The DAS has a finite dynamic range, which is determined in part by the electronic noise in the DAS. The number of x-ray photons reaching the detector may be on the level of the electronic noise. The number of photons is clamped to a positive number. However, artifacts will still be generated in images when this condition occurs.
Gain	Each detector has its own gain. The gain is measured by scanning only air. The values of the air readings are used to scale the readings through a bag. The gains may be a function of the angular position of the gantry,
Logarithm	The DAS/detector combination integrates energy. In order to generate the line integrals required by FBP, the natural logarithm of the readings has to be taken.
Re-binning	The cone-beam projections are processed to form fan-beam or parallel-beam projections. If the projections were acquired using helical scanning, then the movement of the bag during data acquisition is removed using interpolation.

Reconstruction may also be performed using direct Fourier methods or iterative methods [Kak-Slaney]. The iterative methods are not generally used because of their computational expense relative to FBP.

Dual Energy Decomposition

The x-ray attenuation at the energies used for explosive detection is mainly determined by the Photoelectric effect and Compton Scatter. If two different readings are taken for each path from the x-ray source to the detector, each reading with a different x-ray spectral, then line integrals of the Photoelectric and Compton contributions can be found solving two nonlinear equations. These integrals can be reconstructed using FBP to produce images of the Photoelectric and Compton contributions. It is then possible to solve for the physical density and the effective atomic number on a voxel-by-voxel basis.

Different x-ray spectra may be generated by modulating the HVPS with an AC component or two sets of detectors can be stacked on top of each other so that one detector attenuates the photons seen by the second detector. The stacked configuration is known as sandwich detectors. The EDSs produced by Reveal are the only deployed scanners that use dual energy and they use sandwich detectors.

A detailed review of the use of dual energy for explosive detection can be found elsewhere [Ying].

Dual energy may be useful to separate threats from non-threats when only density is used by ATD.

Automated Threat Detection

A schematic diagram of ATD is shown in Figure 5. The purpose of ATD is to segment (find) objects in the cross-sectional images and then to classify if the object is a threat or a non-threat. Additional steps in ATD include compensation for imperfect correction in the CT reconstruction step and extraction of features such as density, atomic number and mass.

The density and atomic number of objects are compared to the values of known explosives. If these values are in the desired range and the mass sufficient, then the object is declared a threat. Vendors may use other features in their classification step, but these features are proprietary. CT is not specific to the chemical and molecular composition of explosives. False alarms occur when non-threats are share the same density and atomic number of threats.

Some vendors may also use the projection data and the images from the DR in their ATD algorithm. ATD may use different methods, denoted paths, for finding sheet and bulk explosives.

False Alarm Problem

False alarms will be generated if non-threats have the same density and atomic number as threats. This is shown in Figure 6 for density. The use of atomic number may be used to reduce the overlap in 2D space.

The correction step in CT reconstruction attempts to correct for imperfections in the projection data acquired during scanning. However, if the corrections are not perfect, then artifacts will be generated in images leading to imprecise measurements of object characteristics. This will require a broadening of the acceptance criteria on object characteristics in ATD leading to an increase in false alarms. Significant sources of errors in the correction step include scatter, beam hardening and the dynamic range of the DAS. These problems occur mainly when large, cluttered bags are scanned.

Because of the finite resolution of the scanner, physical objects may be fused together in the segmentation step of ATD. The characteristics of these fused objects may not be representative of the constitute objects. Artifacts caused by imperfect correction may cause the segmentation step to split objects into multiple smaller objects. The smaller objects may have masses under the mass limit. In order to detect these smaller objects, the mass threshold may have to be lowered, leading to the admission of additional non-threats.

Citations

[Management-Plan] *Management Plan for Explosives Detection System Certification Testing*, DOT/FAA/AR-01/19.

[Kak-Slaney] Kak, A. C., and Slaney, M., *Principles of Computerized Tomographic Imaging*, IEEE Press, 1988.

[Ying] Ying, Z., Naidu, R., and Crawford, C., "Dual Energy Computed Tomography for Explosive Detection," *Journal of X-ray Science and Technology*, vol. 14, 2006, pp. 235-256.

Acronyms/Definitions

2D	Two-dimensional
3D	Three-dimensional
AC	Alternating current
Alarm	A portion of a bag that is a potential threat as determined by the ATD
ATD	Automated threat detection
Bag	Item scanned by the EDS. This usually is a piece of luggage. But it could be items in bins or small pieces of cargo.
BHS	Baggage handling system
BIR	Baggage inspection room
BVS	Baggage viewing station
CC	Control computer
Clearing	The process of ATD saying that a threat is not present in a bag or that the decision of ATD is overridden by secondary inspection.
CRT	Certification readiness testing
CT	Computerized tomography
DAS	Data acquisition system
DC	Direct current
DOT	Department of Transportation
EDS	Explosive detection system. The EDS is composed of a CT scanner, ATD, a workstation, and a control computer.
ETD	Explosive trace detection
FAA	Federal Aviation Administration
FAT	Factory acceptance test
FBP	Filtered back-projection
HVPS	High voltage power supply
ID	Identification or identifier
IED	Improvised explosive device
Mis-track	A bag that cannot be tracked by the BHS
ODT	Ordinance disposal team
OSARP	On-screen alarm resolution protocol
OSR	On-screen resolution
PD	Probability of detection
PFA	Probability of false alarm
SAT	Site acceptance test
Shield	The condition when the EDS cannot view a portion of a bag because the x-ray beam is extinguished of the presence of clutter.
SOP	Standard operating procedure
SSI	Sensitive security information
Threat	A portion of a bag that is a potential threat as determined by the ATD
DR	Digital radiology line scanner
TSL	Transportation Security Laboratory, Atlantic City, NJ
TSO	Transportation security officer: operator of the BVS and worked in the

	BIR
XRD	X-ray diffraction
PVS	Primary viewing station
SVS	Secondary viewing station
FDRS	Field data reporting system

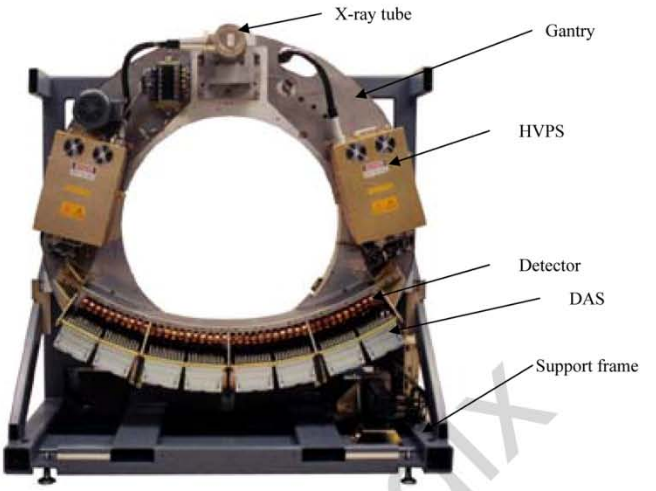


Figure 3. Picture of the inside of a L-3 eXaminer 6000. The annotated portions show the components of the x-ray beam line. [Permission granted from Analogic to reprint this figure.]

Figure 4. A schematic diagram of the CT reconstruction process.

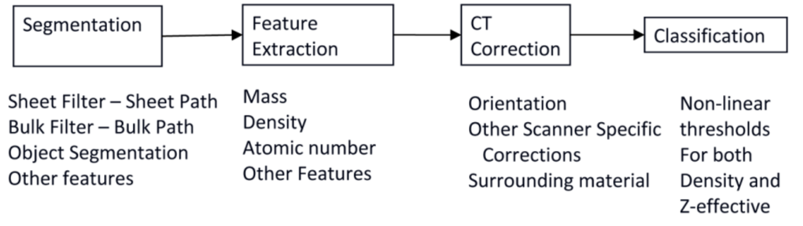


Figure 5. Simplified schematic diagram of one possible version of ATD.

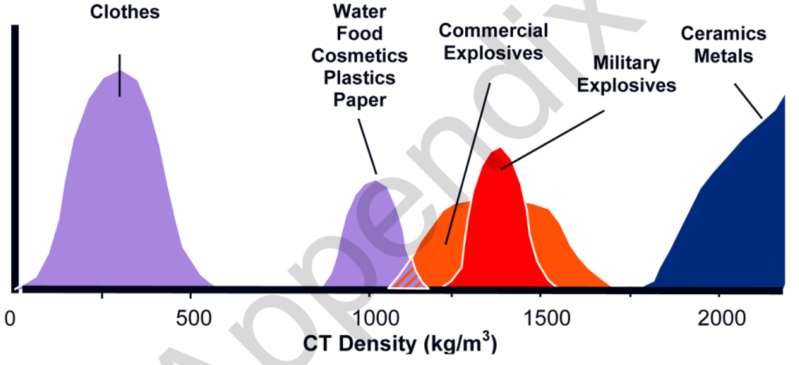


Figure 6. Overlap of threats and non-threats using in CT density space.

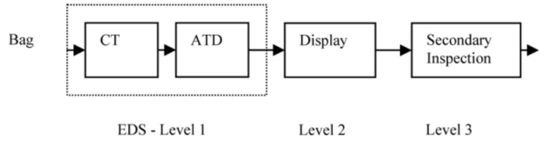


Figure 7: Schematic of an EDS and additional levels of screening used to resolve alarms from the ATD.

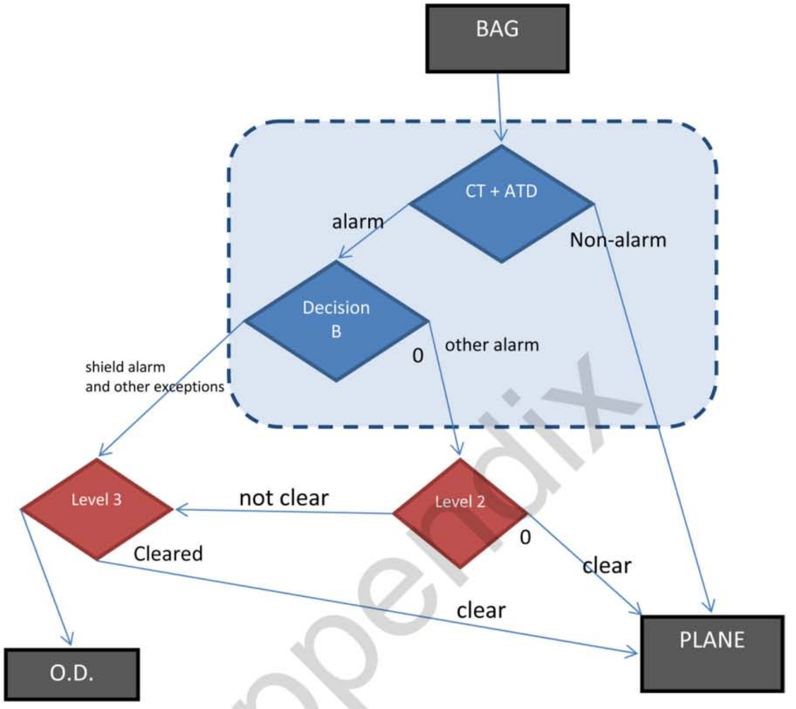


Figure 8: Schematic diagram of the decision process.

25. Appendix: LLNL Statement of Work

Statement of Work
Third Party Algorithm Development and Evaluation of Detection of Liquid Explosives in Dual-Energy Digital Radiographic/TIP Ready X-ray Images - Public Version

Faranak Nekoogar and Harry E. Martz, Jr.

Lawrence Livermore National Laboratory
Livermore, CA 94551

Work performed on the
Science & Technology Directorate of the
Department of Homeland Security
Statement of Work
PR RSEN-08-00066

October 6, 2009
LLNL-TR-417231-DRAFT

Lawrence Livermore National Laboratory

1

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Table of Contents

1. Summary

The purpose of this statement of work is for third party collaborators to train, validate and have Lawrence Livermore National Security, LLC (LLNS) evaluate algorithms to detect liquid threats in digital radiography (DR)/TIP[1] Ready X-ray (TRX) images that will be provided by LLNS through the Transportation and Security Administration (TSA). LLNS will provide a set of images with threat(s) to determine detection rates and non-threat images from airports to determine false alarm rates. A key including a bounding box showing the locations of the threats and non-threats will be provided for the images. It is expected that the Subcontractor shall use half of the images with their keys for training the algorithms and the other half shall be used for validation (third party evaluation) purposes. The Subcontractor shall not use the key to the second half of the data other than for the validation and reporting of the performance of its algorithm (not for training). The Subcontractor has 45 business days from the receipt of datasets and the Subcontract to:

- Run their detection/classification algorithms on the data;
- Deliver a final report describing their performance by generating Receiver Operator Characteristic (ROC) curves using their algorithm.;
- Deliver a copy of the third party's executable software (already trained and validated by the datasets) to LLNL accompanied by a user manual.

LLNS will evaluate the performance of the same algorithm on another separate set of data. LLNS' evaluation of the Subcontractor's algorithm will be documented in a final report within 30 days of receiving the executable code. This report will be sent to TSA and the report may be disseminated to the Subcontract at TSA's discretion.

[1] Threat image Projection.

2. Image Data

LLNS will provide a total of 360 images from two different DR/TRX. 180 images from each scanner; including 90 images with threat and another set of 90 images with "non-threat" materials with the following categories:

- No clutter/ no attenuation;
- Medium clutter/ medium attenuation;
- High clutter/ high attenuation.

1) Scanners

The data is obtained from two different DR/TRX scanners. LLNS will provide the scanners which will be designated scanner "A" or scanner "B" in the Digital Imaging and Communications in Medicine (DICOM) data element (0x0008, 0x1090), Manufacturer Model Name (see readme file that is sent separately when TSA-3rd Party NDA is signed). These two scanners are both single view and dual energy. The Subcontractor shall decide whether it wants to train, validate and be evaluated on only one or both scanners.

2) Threats

The threat will be labeled using a code name and many but not all will be liquids in Nalgene bottles of three volumes. Some other container types may include glass or Thermos bottles and some commercially available non-threat containers. Most containers are plastic and full. Threats and non-threats liquids can exist in the following categories:

A) Bin data:

a) Liquids (Nalgene and other bottles in bins);

b) Bottles in 3:1:1 baggies;

B) Luggage data:

a) Liquids (Nalgene and other bottles in bags);

b) 3:1:1 baggies.

There might be multiple threat items in one image and the bottles will be in different orientations. The minimum volume to be detected is 50 ml; algorithm should alarm on threat greater than or equal to 50 ml.

3) Image data

The supplied DR/TRX images are derived from the original dual-energy data produced from scanners and converted to DICOM compliant format. TSA will send a set of data files and a readme file to the Subcontractor once a Non-Disclosure Agreement (NDA) between TSA and the Subcontractor is signed. There is no image processing of the irradiance DR/TRX data. In some cases where the two energy images are originally combined into a single file, the data will be unfolded and provided as two (high and low energy channel data) separate images. Also, where more than one subject may have been depicted in a single image, the image will be extracted to include only one object group (luggage, bin etc).

4.) Keys

LLNS will provide keys to the images by defining a bounding box around each threat and most non-threat items (See Appendix A). Each bounding box will have a specific x-y coordinate system with upper left corner of the image representing (0,0). The bounding boxes will be defined by four coordinate points (each bounding box will be a quadrilateral). Keys will be provided in text file that includes:

File names;
Number of threats;
Number of bin images;
Number of luggage images;
Bounding box for each threat;
Bounding box for each non-threat liquid/gel.

Algorithms

The goals are to detect and differentiate liquid explosive threats from non-explosive liquids and also find all liquids in carry-on items using images described in the previous section to maximize threat detection levels while minimizing the level of false alarms.

1) *Reporting*

Algorithms should operate in automated threat detection (ATD) using two modes, bin mode and luggage mode as described below.

Mode A: Bins with threat and non-threat liquids either in exempt liquid form or 3-1-1 baggies;

Mode B: (B1) Luggage with a possibility of concealed liquid bottles or 3-1-1 baggies inside and (B2) possibly liquid explosive threat detection.

Once the two modes (bin and luggage) are executed, it is expected that the liquid threats and non-threats will be identified in mode A for bins and possibly mode B2 for luggage. These modes are more fully explained in 2) Scoring.

2) *Scoring*

It is desired that scoring is performed based on Rate of detection (Rd) and Rate of false alarm (Rfa) and reported by generating a Receiver Operating Characteristic (ROC) curve. A true detection is reported when the Subcontractor ATD algorithm results in at least a 75% overlap in area of the ATD algorithm bounding box to the bounding box provided in the validation key dataset and the ATD bounding box is not more than 25% larger in area than the bounding box in the key (Figure 1). Otherwise this is recorded as a missed detection. The parameters [e.g. thresholds or features (texture)] adjusted and fixed to generate the ROC curves should be clearly defined and documented in the third party report. If ROC curves cannot be generated, at a minimum the algorithm should be run with five parameter sets such that Rd is 50%, 60%, 70%, 80%, and 90% and the Rfa reported.

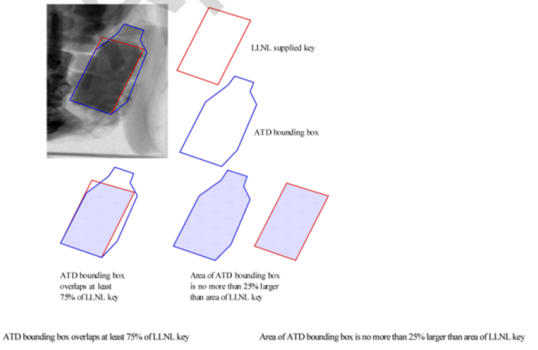


Figure 1. Limits on ATD bounding box minimum overlap and maximum total area. Key, bounding box and image depicted may not be representative

LLNL-TR-417231-DRAFT 7

Rd and Rfa used in the two modes[3] are:

In Mode A (exempt liquids **and** 3-1-1 haggles):

Rd(A)_represents the number of correctly detected threat items divided by the total number of threats;

RAfa(A) represents the number of false positives divided by the number of images; This is for airport data since the number of non-threats is unknown;

RTfa(A) represents the number of false positives divided by the total number of non-threat items (since number of non-threat items is known for Tyndall data).

In Mode B (luggage):

Rd(B l)_represents the number of detected liquid (threats & non-threats) items divided by the total number of threat and non-threat items;

Rfa(B1) represents the number of false positives (non-liquids detected) divided by the number of images;

Rd(B2)_represents the number of correctly detected liquids threats (only threats) divided by the total number of threats;

Rfa(B2) represents the number of false positives (non-threat liquids that alarm) divided by the number of images.

3. Deliverables

The deliverables include a performance report and executable software.

Report

The Subcontractor shall provide a on the performance of its detection/classification algorithm with bounding boxes that detects liquid bottles and differentiates threats from non-threats. It should specify the parameters of the bounding boxes and be clear whether the algorithm is operating under Mode A or Mode B and if Mode B distinguish between B1 and B2. Reporting should be as a function of volume and averaged across all volumes. The report shall include the ROC curves.

[3] The two modes do not have to be simultaneous for this initial evaluation, but should be in the future. 5

In its report, the Subcontractor shall use the code names for the threats and code names for volumes (to be defined in a separate document). Such report is considered to be at a minimum, Sensitive Security Information (SSI). Unless further directed by LLNS, the Subcontractor shall not submit reports if actual threats are listed without code name. Such report are considered to be Secret, National Security Information (SNSI) and requires written approval from the LLNS Contract Administrator and LLNS Technical Representative.

Software

The Subcontractor shall provide executable files to LLNS the following Operating system and input/output requirements:

Operating system:

Executable software should run under Windows XP or linux, or can be Matlab or IDL program code.[2]

Input/Output:

1) Input : DICOM compliant DR/TRX images and the desired Rd.
2) Output: ASCII file with the number of threat and non-threat detections. The format for this ASCII file is *given in* Appendix B.

If necessary, the Subcontractor shall also provide on-site assistance in the uploading and use of the executable files.

4. DHS and LLNS Evaluation

DHS and LLNS will review the reports. For the reports that show promising performance, LLNS will evaluate the performance of the algorithm's executable software based on running the software at LLNS on an additional (similar to the training and validation) set of DR/TRX images.

[2] We want to point out that it is difficult to get third party computers into LLNL, so we prefer executable software to run on our computers.

Appendix A
Key File Format

ImgXY_date_time_zz			Number_of_Threats=#			Number_of_Non-Threats=#			
Sample_name1	T/NT	Vol	Area	POx	POy	P1x	P1y	PNx	PNy
Sample_name2	T/NT	Vol	Area	POx	POy	P1x	P1y	PNx	PNy

Where XY=mode and data source:

AA	Mode A, Airport data
AT	Mode A, Tyndall data
BA	Mode B, Airport data
BT	Mode B, Tyndall data

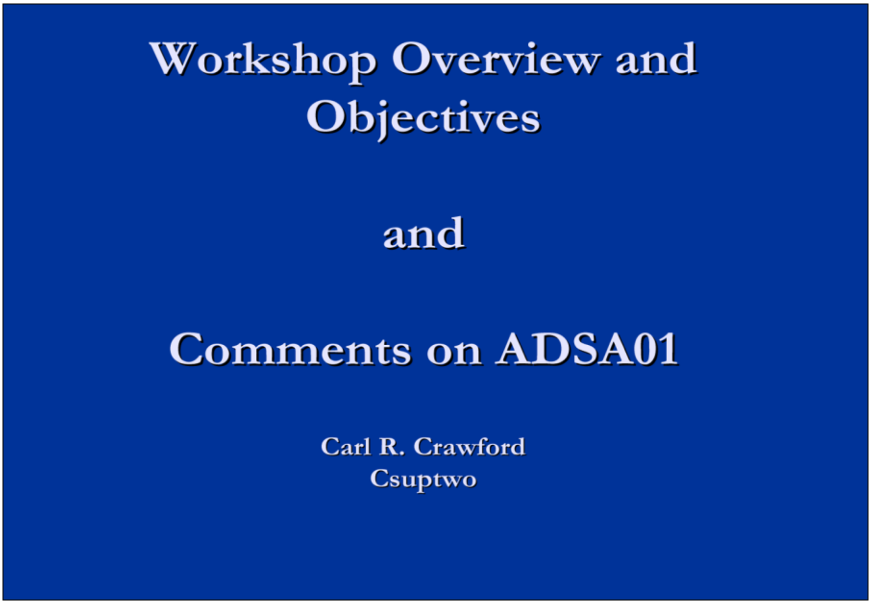
Zz= hi or lo	hi for high energy data, lo for low energy data
#	Number of threats or non-threats in image
Sample_name	Name of sample within specified boundary
T/NT	Threat/Non-Threat status of bounded region
Vol	Volume (ML) of sample (or net weight in grams, with units, e.g., 170g)
Area	Area of bounding region in pixels
POx	x coordinate of first vertex in bounding region
POy	y coordinate of first vertex in bounding region
P1x,y	Second vertex
PNx,y	Last vertex

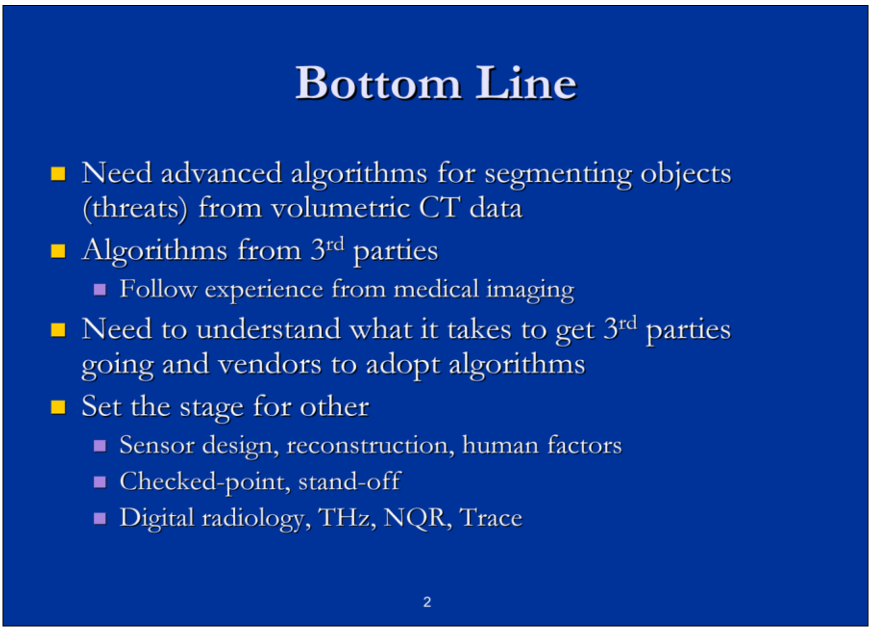
Example:

ImgAT_103008_170542_hi				Number_of_Threats=3			Number_of_Non-Threats=4						
A1	T	1125	3009	150	200	231	201	302	215	179	302	86	205
B2	T	1125	3000	75	105	186	191	107	362	201	210	205	104
C3	T	1125	3000	250	220	295	286	205	291	81	105	101	286
H2O	NT	1125	3000	274	157	332	156	340	216	275	222	274	157
Prell	NT	175	2000	149	238	153	226	215	161	212	151	149	238
Smuckers	NT	1567	2300	308	128	314	113	375	56	363	70	308	128
Honey	NT	1125	3000	69	313	127	318	114	371	59	366	69	313

26. Appendix: Presentation Slides

26.1 Carl Crawford Presentation 1-2 Slides





Rule #1

- All participants must
  - Talk
  - Discuss
  - Interrupt
  - Argue
- Applies to
  - Academia, industry, government, national labs

This is a workshop, not a conference, symposium, tutorial.

3

Am I a Terrorist?

- What's on my body?
- What's in my suitcase?
- What have I sent via cargo?
- Am I plotting with someone else?

4

Terrorists have escalated the problem

- Securing U.S. assets
  - Air
  - Sea
  - Land
- Need to detect for
  - Chemical and biological agents
  - Special nuclear materials
  - Dirty bombs
  - Explosives
  - Weapons
  - Drugs

5

Najibullah Zazi

"Najibullah Zazi also filled his cart with bottles of nail polish remover and hair dye agents like Clairoxide Liquid Developer."

"They knew the hydrogen peroxide - and the other acetone-based goodies that Zazi bought - could be used to make deadly bombs"

NY Daily News 9/27

6

Pan Am 103 Lockerbie, 1988

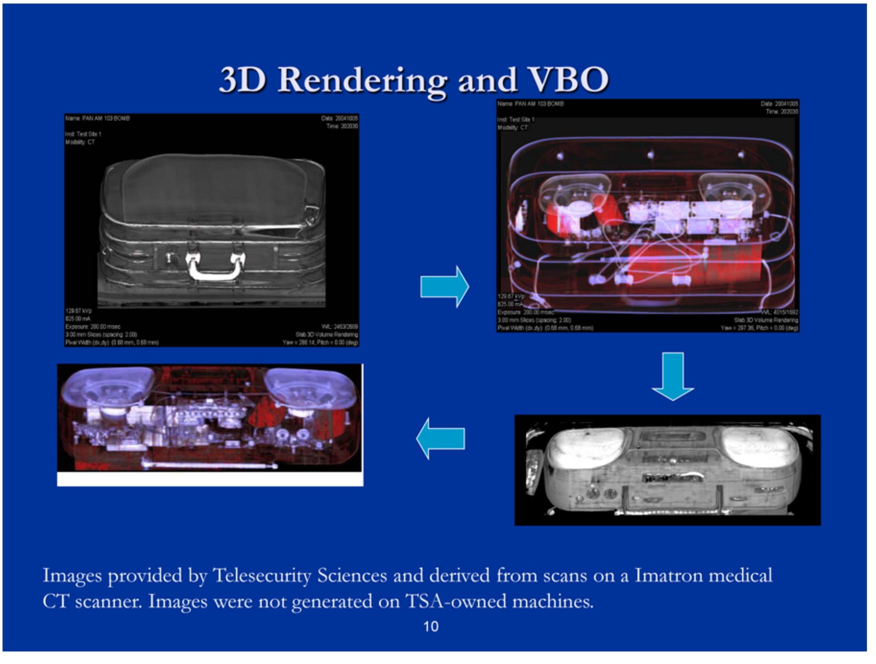
- Abdel Basset Ali al-Megrahi released in 2009
- Purported to have used explosive in boom box

7

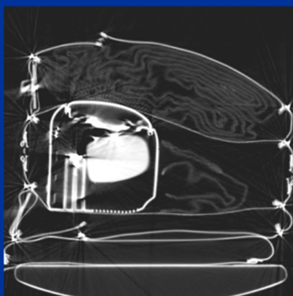
Pan Am IED

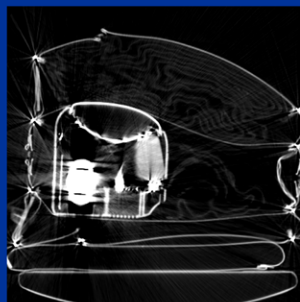
8


Checked Baggage EDS
All vendors use Computed Tomography (CT), which is used for medical imaging.
9


3D Rendering and VBO
Images provided by Telesecurity Sciences and derived from scans on a Imatron medical CT scanner. Images were not generated on TSA-owned machines.
10

Cross-Sectional Images





Workshop goal: 3rd party development of segmentation algorithms to find explosives in volumetric CT data

Images provided by Telesecurity Sciences and derived from scans on a Imatron medical CT scanner. Images were not generated on TSA-owned machines.

11

DHS Goals

- Security System Developers (SSD) doing an excellent job
- But, need
  - Increase probability of detection (PD)
  - Decreased probability of false alarm (PFA)
  - Detect more threats including wide-variation of home-made explosives (HMEs)
  - Reduced mass
  - Reduced labor costs
    - Eliminate human in the loop if possible

12

Some DHS Tactics

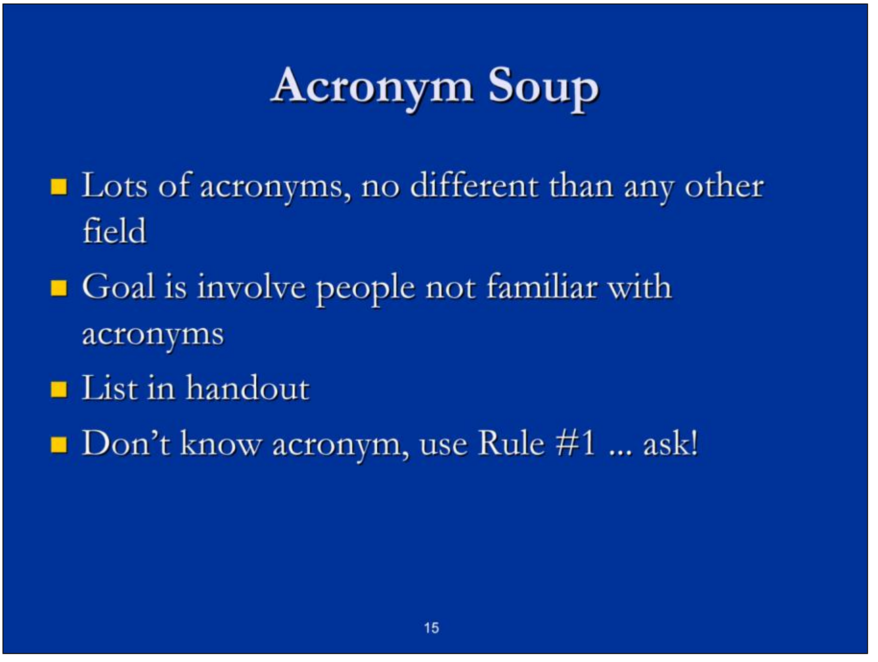
- Augment abilities of SSDs with 3rd party involvement
- 3rd parties
  - Academia
  - National labs
  - Industry other than SSDs
- Create centers of excellence (COE) at universities
- Hold workshops to educate 3rd parties and discuss issues with involvement of 3rd parties
- Algorithm development is focus of this workshop

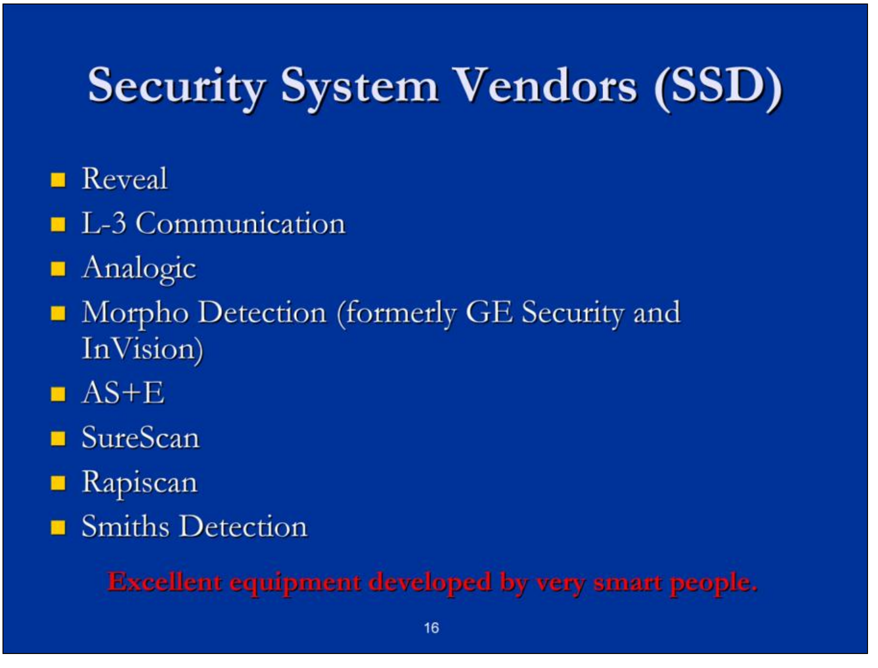
13

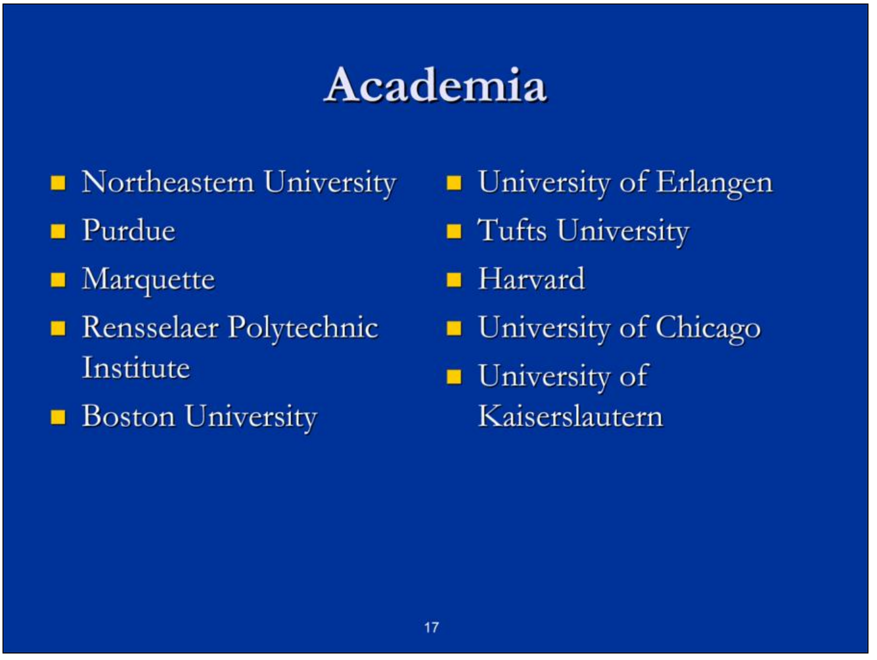
Algorithm Definition

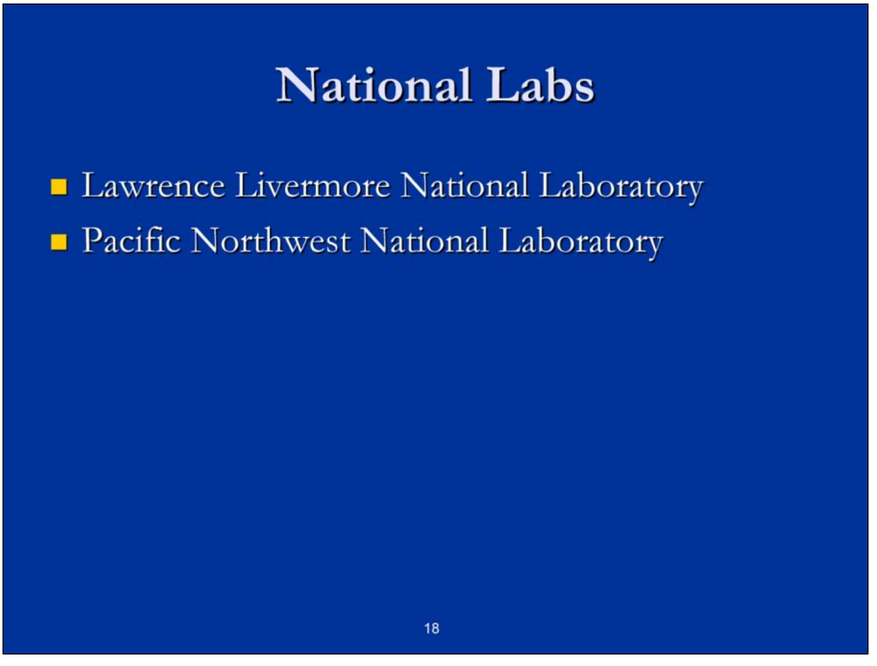
- Recipe to perform a task
  - Mathematical description
  - Deliverables: report, example code, test cases
- Implementation
  - Product coding: CPU, FPGA, GPU, Cell processor
  - Inputs, outputs, exceptions
  - Integration with other functions
  - Professional coding practices

14


Acronym Soup
Lots of acronyms, no different than any other field
Goal is involve people not familiar with acronyms
List in handout
Don't know acronym, use Rule #1 ... ask!
15


Security System Vendors (SSD)
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.
16


Academia
Northeastern University
Purdue
Marquette
Rensselaer Polytechnic Institute
Boston University
University of Erlangen
Tufts University
Harvard
University of Chicago
University of Kaiserslautern
17


National Labs
Lawrence Livermore National Laboratory
Pacific Northwest National Laboratory
18

3rd Party Industry

- Optosecurity
- TeleSecurity Sciences
- LongShortWay
- Siemens
- Guardian Technologies
- Mercury Computers

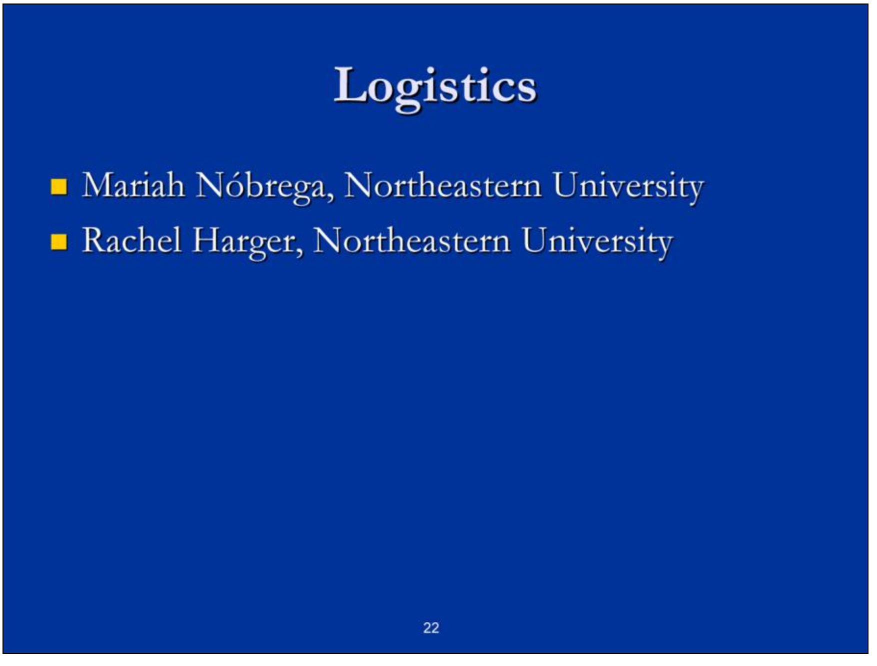
19

Government

- Department of Homeland Security
  - Science and Technology Directorate, Washington, DC
  - Transportation Security Laboratory, Atlantic City, NJ
- Transportation Security Administration

20


Committee
Michael Silevitch, co-chair, Northeastern University
Harry Martz, co-chair, Lawrence Livermore National Laboratory
Carey Rappaport, Northeastern University
David Castañón, Boston University
Horst Wittmann, Northeastern University
John Beaty, Northeastern University
Carl Crawford, moderator, Csuptwo, LLC
21


Logistics
Mariah Nóbrega, Northeastern University
Rachel Harger, Northeastern University
22

Acknowledgements

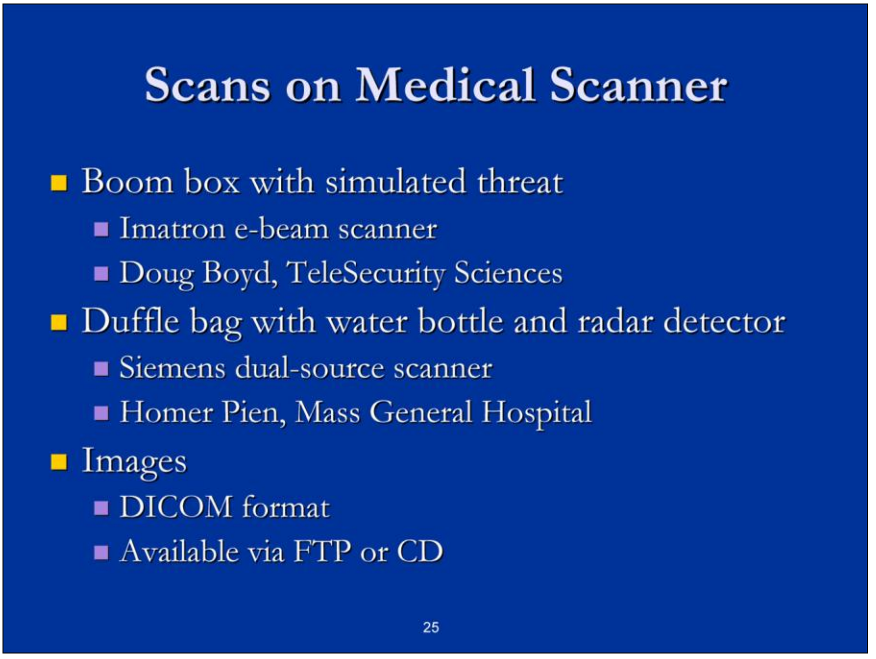
- Northeastern University (NEU)
- Awareness and Localization of Explosives-Related Threats (ALERT)
- Department of Homeland Security (DHS)
- Lawrence Livermore National Laboratory (LLNL)

23

Acknowledgements

- Speakers
- Participants
  - Homework
    - Still accepting, even after workshop concludes
  - Participating
- Various people/vendors for supplying presentation materials

24


Scans on Medical Scanner
Boom box with simulated threat
Imatron e-beam scanner
Doug Boyd, TeleSecurity Sciences
Duffle bag with water bottle and radar detector
Siemens dual-source scanner
Homer Pien, Mass General Hospital
Images
DICOM format
Available via FTP or CD
25


Review of First Workshop
Algorithms for check-point
All applicable modalities
CT, digital radiology, etc.
All applicable applications
carry-on items, whole body imaging, etc.
Discussion limited algorithms, not implementation and deployment
Final report available
26

Scope - Threats

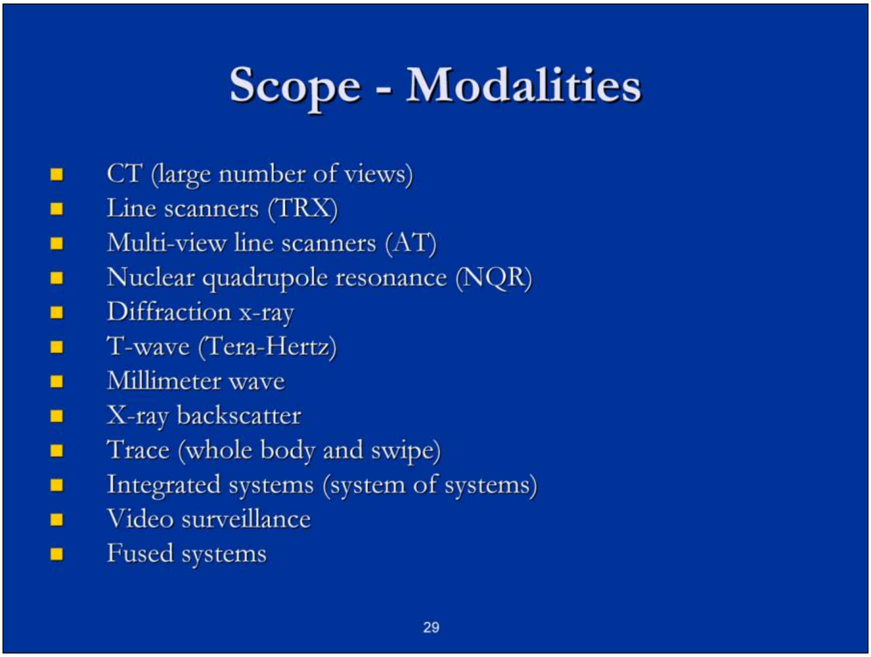
- Explosives
  - Military
  - Commercial
  - Home made explosives (HME)
  - Pre-cursors to HMEs
  - Improvised explosive devices (IED)
- Weapons

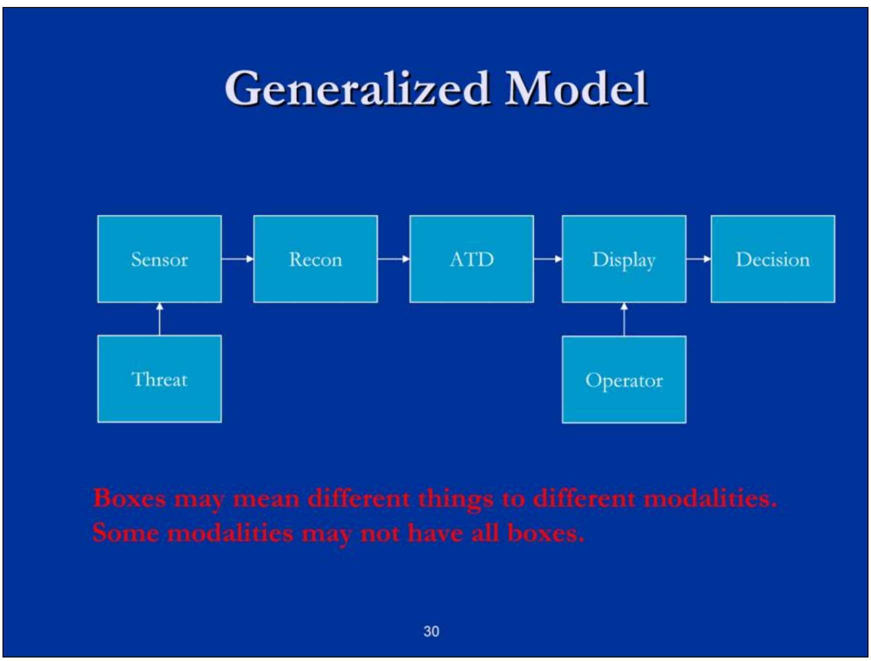
27

Scope - Applications

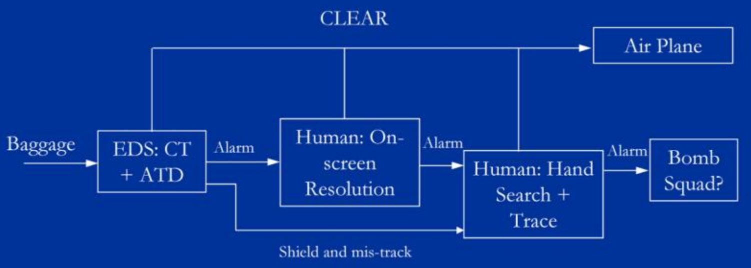
- Liquid scanner
- Shoe scanner
- Whole body imaging (WBI)
- Checked bag and other divested items scanner
- Visual inspection of people
- External information sources
  - About passenger
  - About potential threats
  - Integrating sub-critical masses at or post checkpoint

28


Scope - Modalities
CT (large number of views)
Line scanners (TRX)
Multi-view line scanners (AT)
Nuclear quadrupole resonance (NQR)
Diffraction x-ray
T-wave (Tera-Hertz)
Millimeter wave
X-ray backscatter
Trace (whole body and swipe)
Integrated systems (system of systems)
Video surveillance
Fused systems
29


Generalized Model
Sensor
Recon
ATD
Display
Decision
Threat
Operator
Boxes may mean different things to different modalities.
Some modalities may not have all boxes.
30

EDS Screening Flow Diagram



False alarms cost $1 billion and reduce operator vigilance

31

ADSA01 - Recommendations

- Organize grand challenges
  - CT first
    - Segmentation first
      - Better features from segmentation will improve classifier
      - Classifier crown-jewels of SSDs, especially features
    - Reconstruction second
      - Difficult to get data and to show improvements in PD/PFA
  - Then other modalities
  - Then other aspects of generalized model
    - Sensor modeling and design
    - Human factors

32

Grand Challenges Definition

- Standard model
  - Public domain
    - Data
    - Acceptance criteria
  - Prize
- Definition used here
  - Prize TBD
  - Funding TBD

33

Other Recommendations

- Scanner simulators
- Human factors – operator in the loop
- Advanced reconstruction
- System of systems – fusion
- Video surveillance

34

Non-Technical Recommendations

- Communications
  - Security system developers
  - Gov
  - 3rd parties (academia, industry, national labs)
- Incentives
  - 3rd parties
  - Security system developers

35

Lessons Learned

- All participants need to stay for all sessions including dinner
- No break-out sessions; difficult to integrate
- Increased hallway times
- More images and problems; 3rd parties will present
- Narrower focus; only CT segmentation this time
- More introductory material

36

Lessons Learned (2)

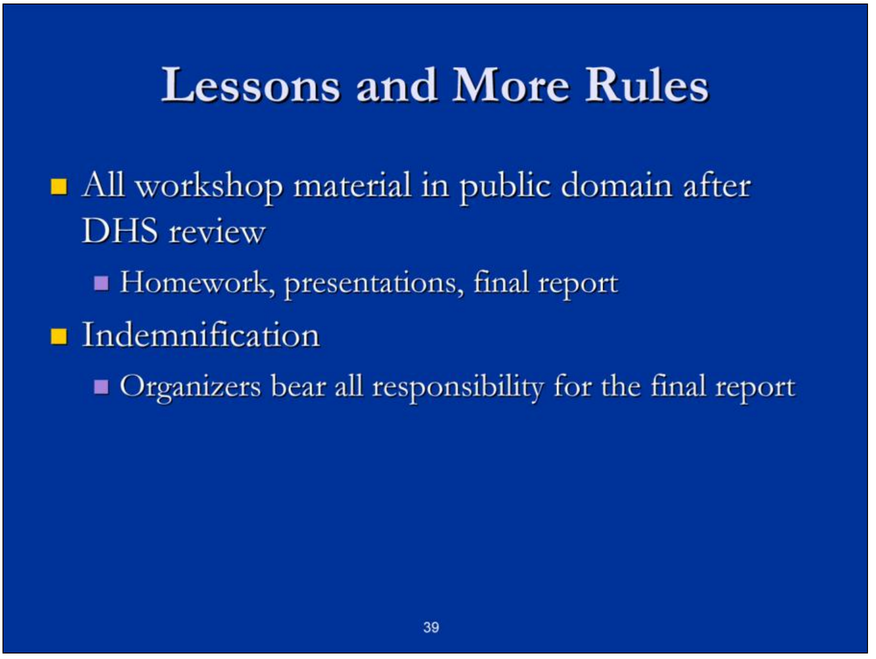
- Need to involve participants more
  - Agenda less aggressive
  - More around the room
- Gaps/issues not identified; 3rd parties will present
- Acceptance criteria need to be presented
- More images

37

Disclosure Issues

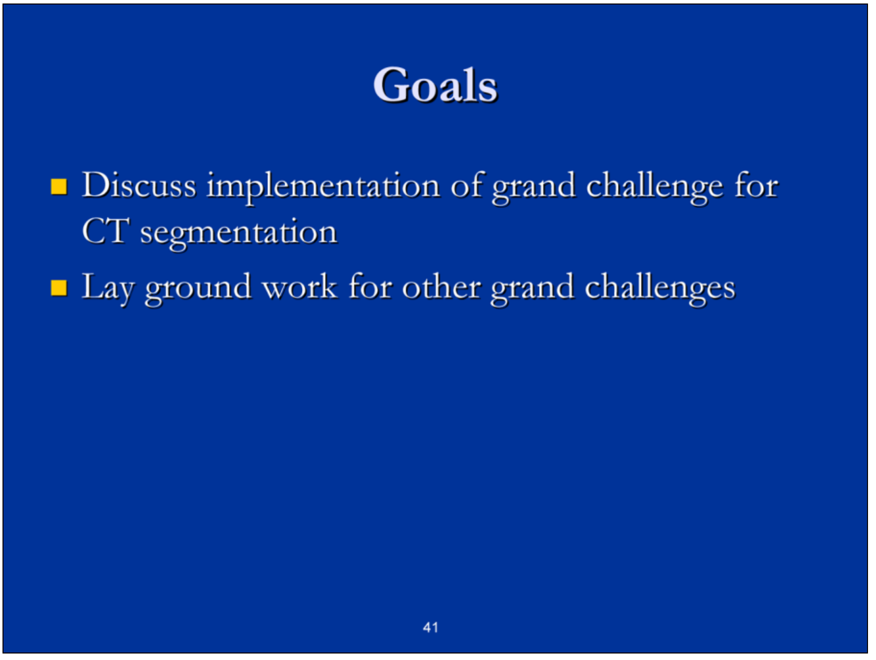
- Don't want to publically disclose:
  - Threat specifications
  - Issues with detecting threats
- Contractual issues with showing and using scans on government-owned equipment
- Solutions
  - Presentations made people other than gov/SSD
  - Images from medical scanners or public domain

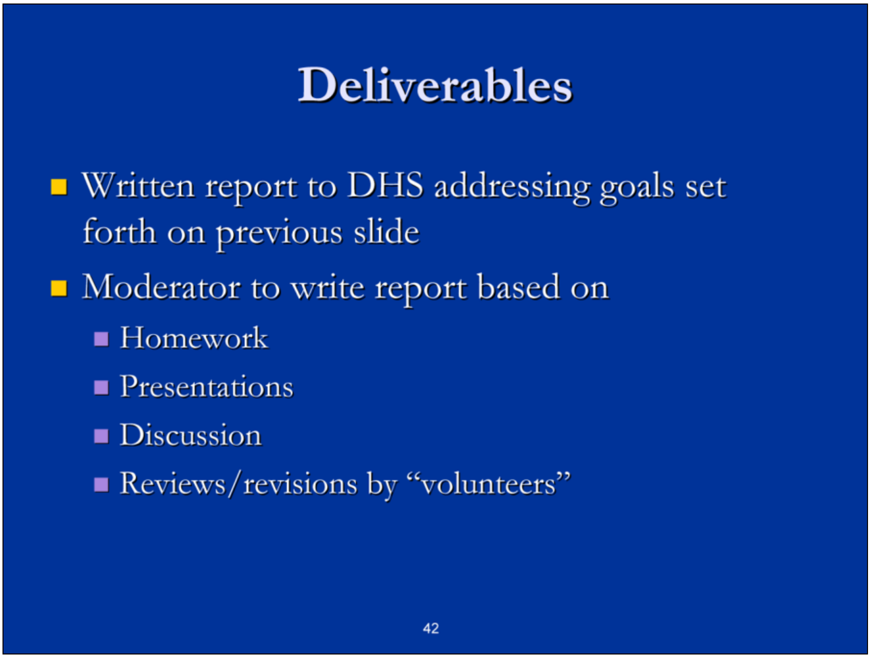
38

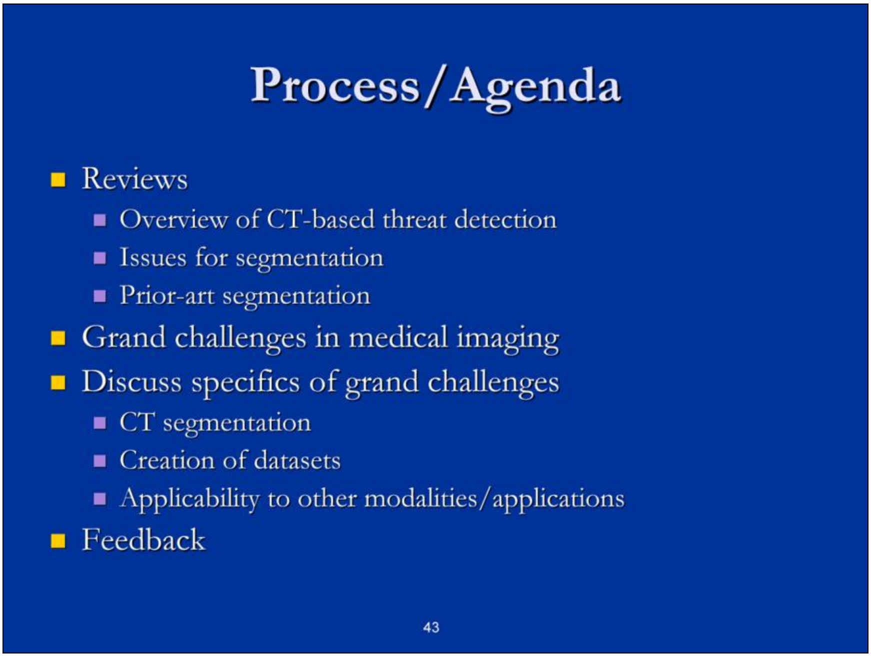

Lessons and More Rules
All workshop material in public domain after DHS review
Homework, presentations, final report
Indemnification
Organizers bear all responsibility for the final report
39

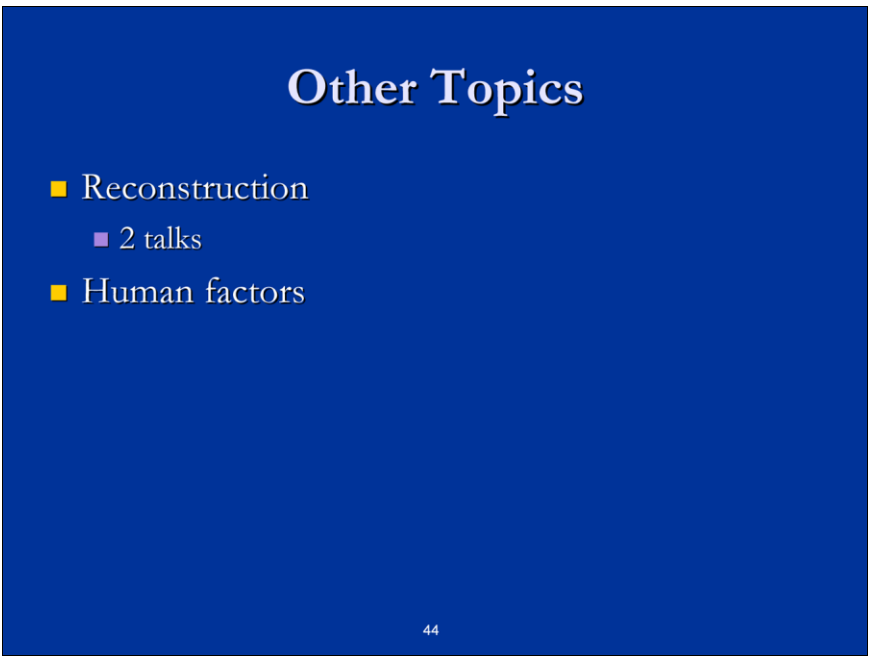

Workshop Definition
Not a conference
Serial presentation and discussion
Discussion permitted and required at all times by all participants
Parallel presentation/discussion
Attendance limited to allow discussion
Sorry that we were not able to accommodate all interested parties
Lay foundation for DHS to involve broader participation for advancing security technology
40

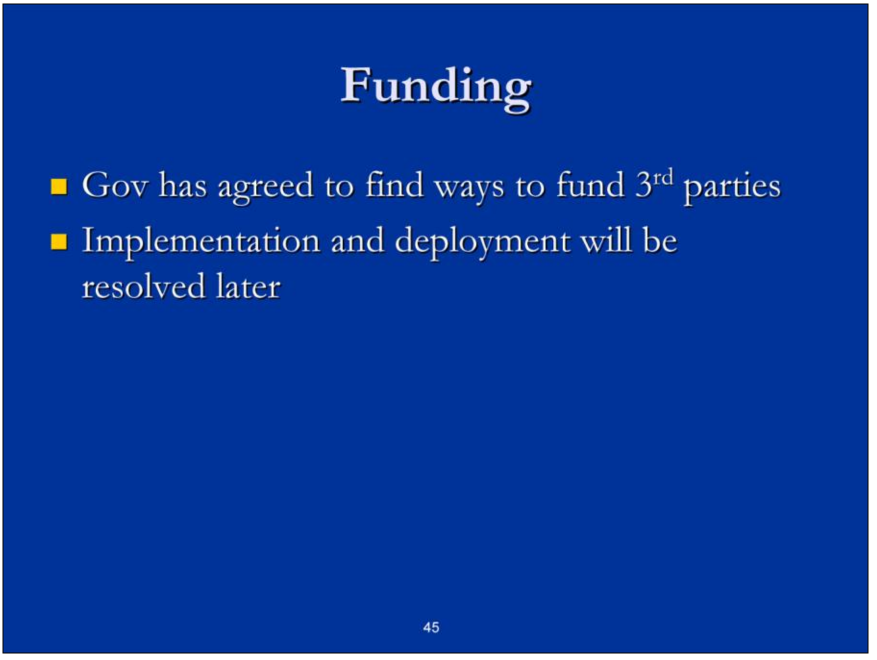
.

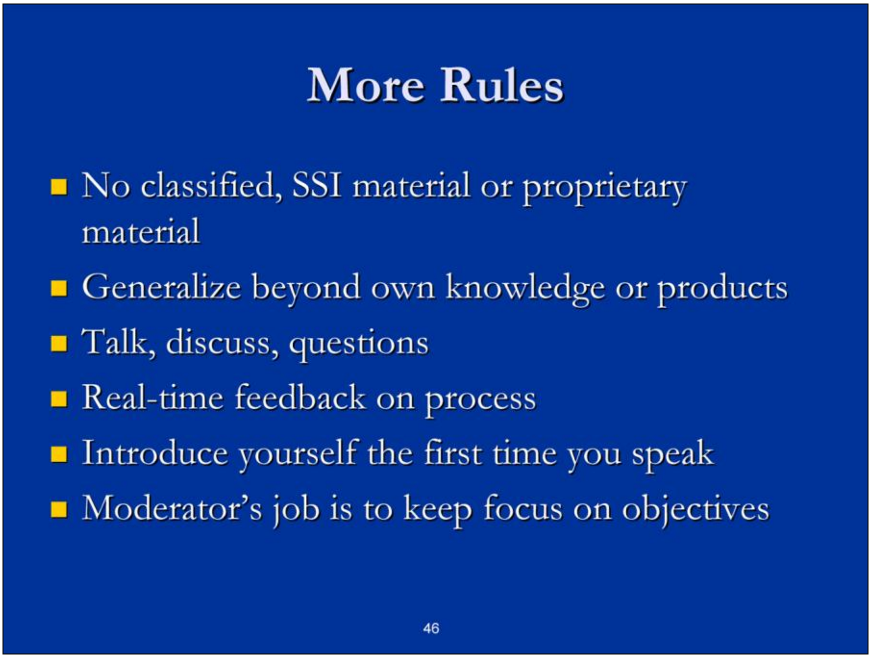

Goals
Discuss implementation of grand challenge for CT segmentation
Lay ground work for other grand challenges
41

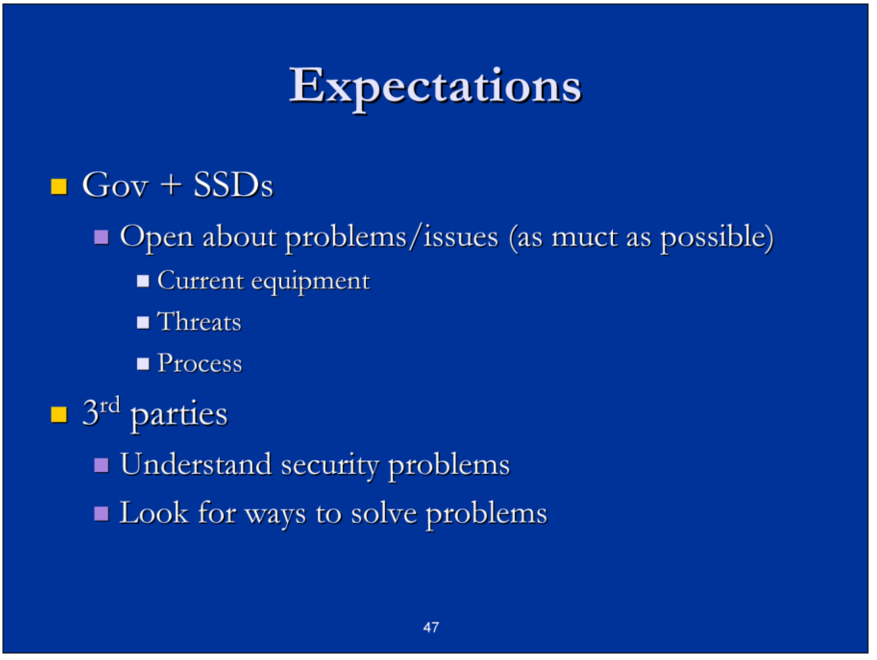

Deliverables
Written report to DHS addressing goals set forth on previous slide
Moderator to write report based on
Homework
Presentations
Discussion
Reviews/revisions by "volunteers"
42

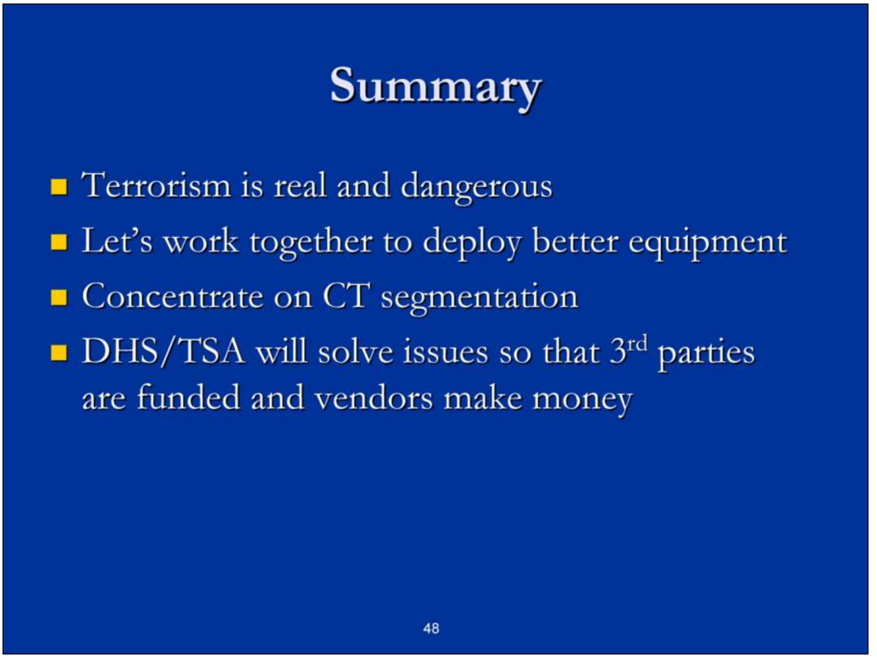

Process/Agenda
Reviews
Overview of CT-based threat detection
Issues for segmentation
Prior-art segmentation
Grand challenges in medical imaging
Discuss specifics of grand challenges
CT segmentation
Creation of datasets
Applicability to other modalities/applications
Feedback
43

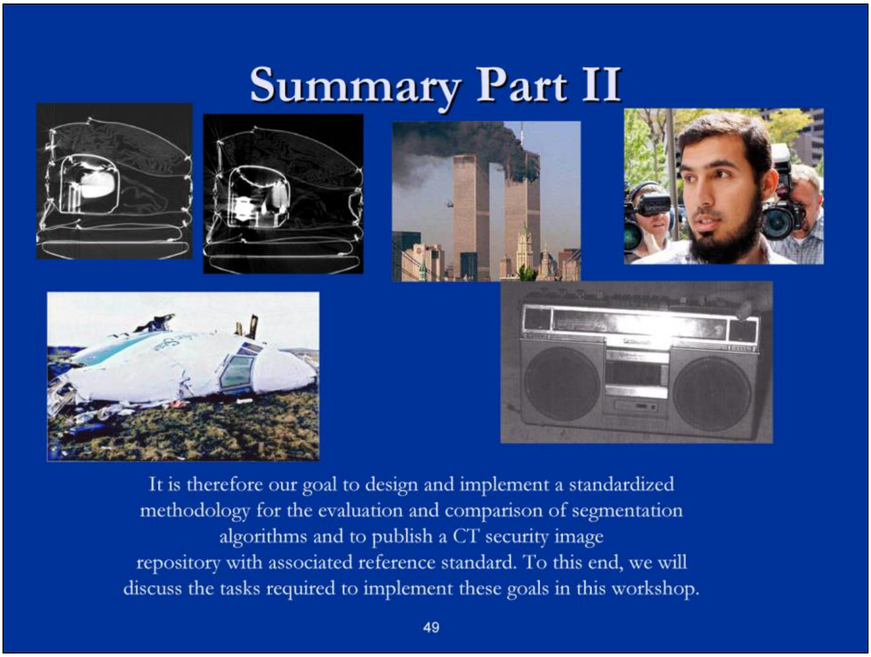

Other Topics
Reconstruction
2 talks
Human factors
44


Funding
Gov has agreed to find ways to fund 3rd parties
Implementation and deployment will be resolved later
45

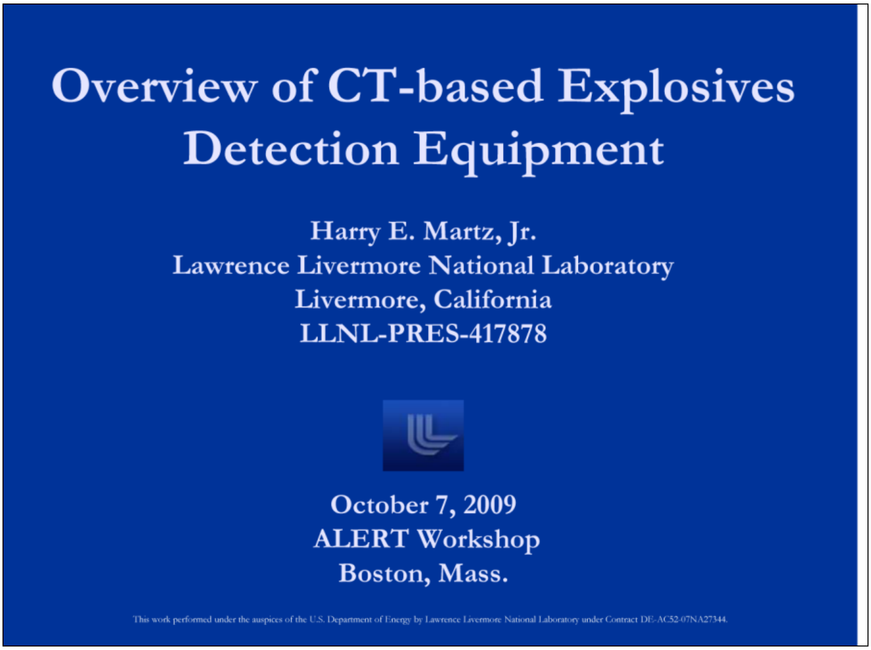

More Rules
No classified, SSI material or proprietary material
Generalize beyond own knowledge or products
Talk, discuss, questions
Real-time feedback on process
Introduce yourself the first time you speak
Moderator's job is to keep focus on objectives
46

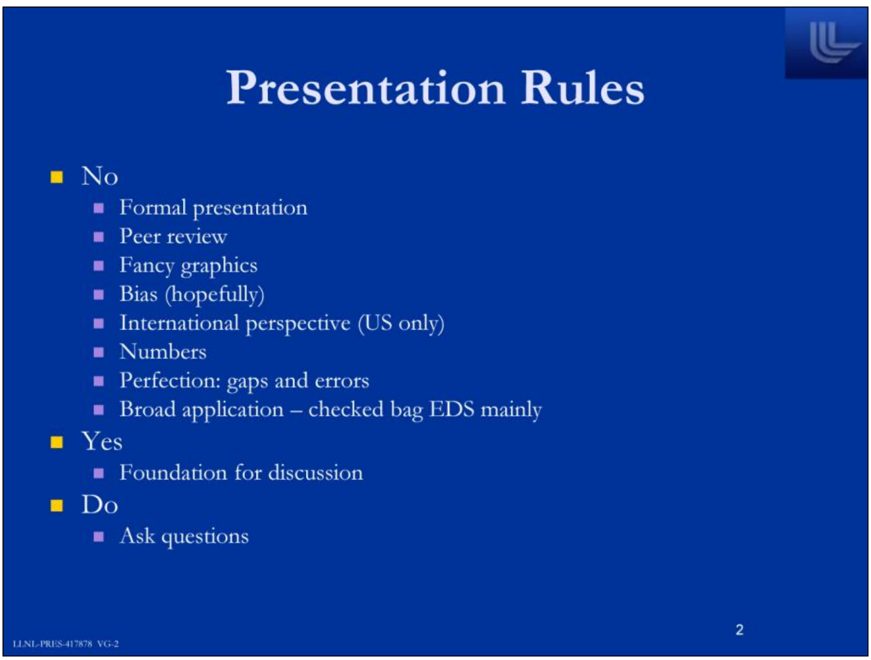

Expectations
Gov + SSDs
Open about problems/issues (as muct as possible)
Current equipment
Threats
Process
3rd parties
Understand security problems
Look for ways to solve problems
47

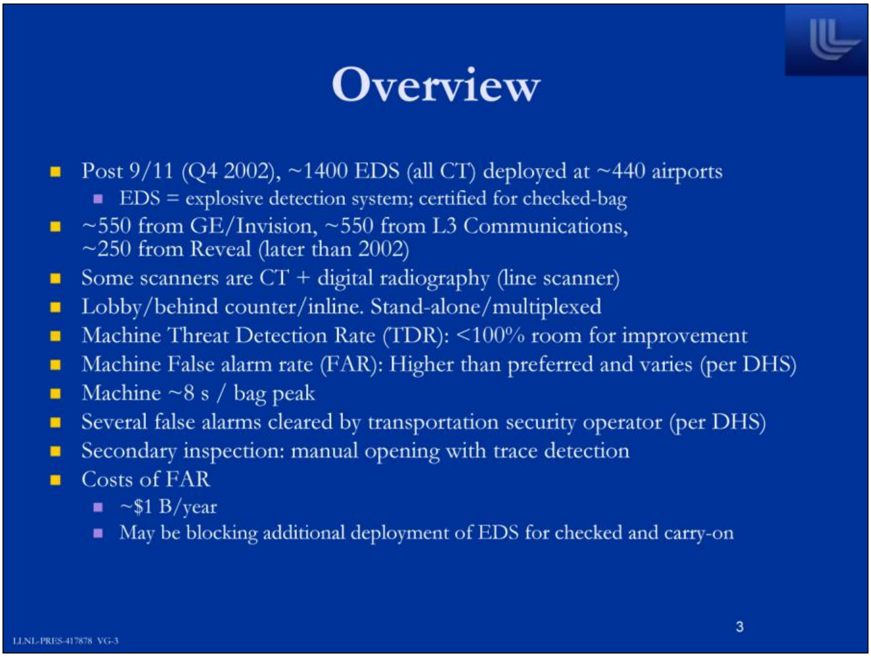

Summary
Terrorism is real and dangerous
Let's work together to deploy better equipment
Concentrate on CT segmentation
DHS/TSA will solve issues so that 3rd parties are funded and vendors make money
48

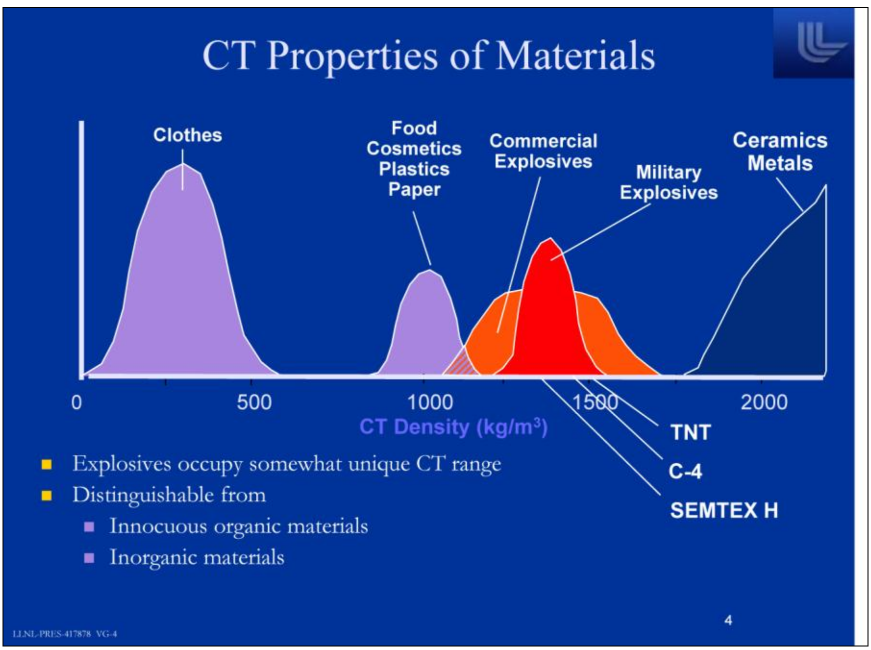

Summary Part II
It is therefore our goal to design and implement a standardized methodology for the evaluation and comparison of segmentation algorithms and to publish a CT security image repository with associated reference standard. To this end, we will discuss the tasks required to implement these goals in this workshop.
49

26.2 Harry Martz Presentation Slides

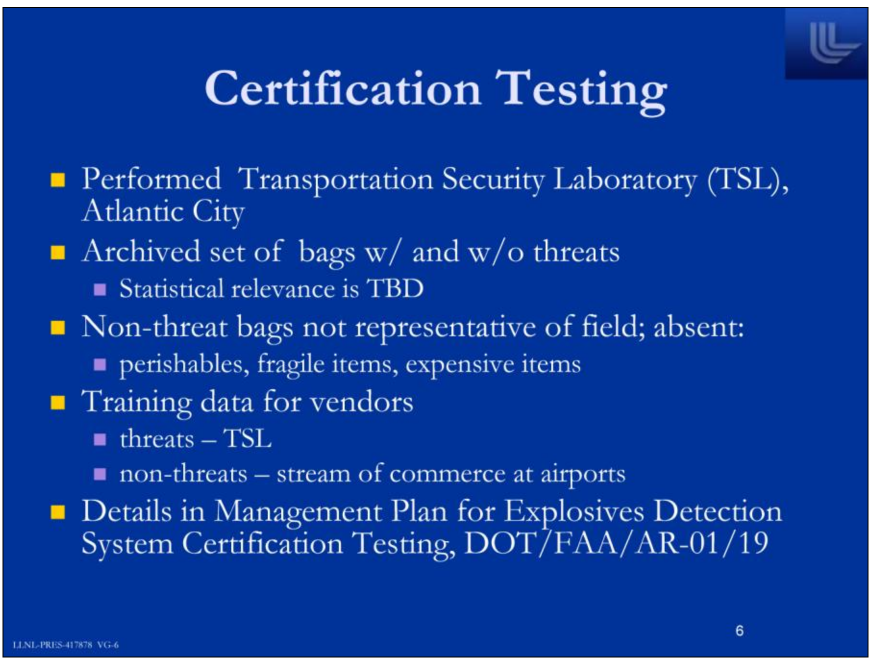


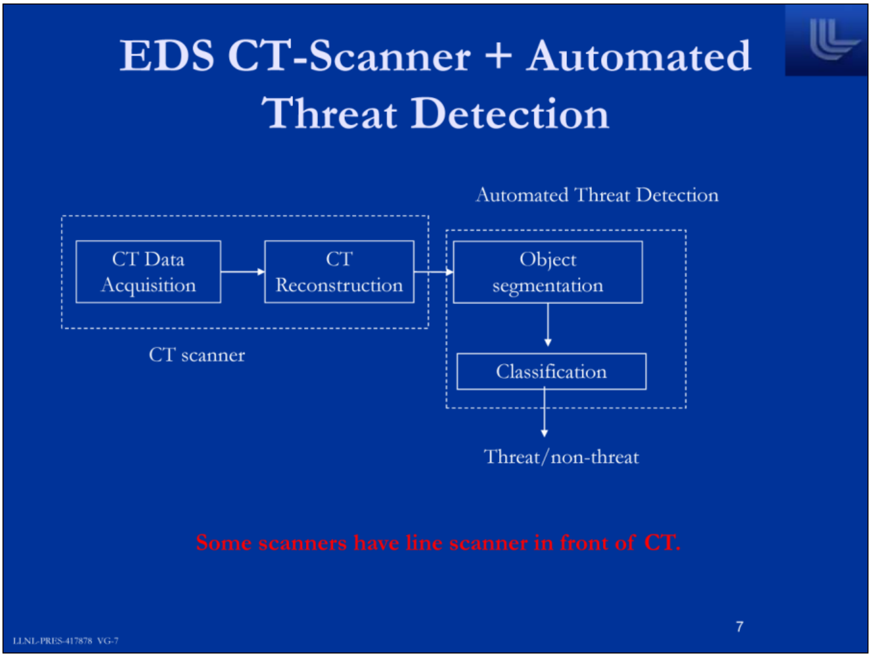


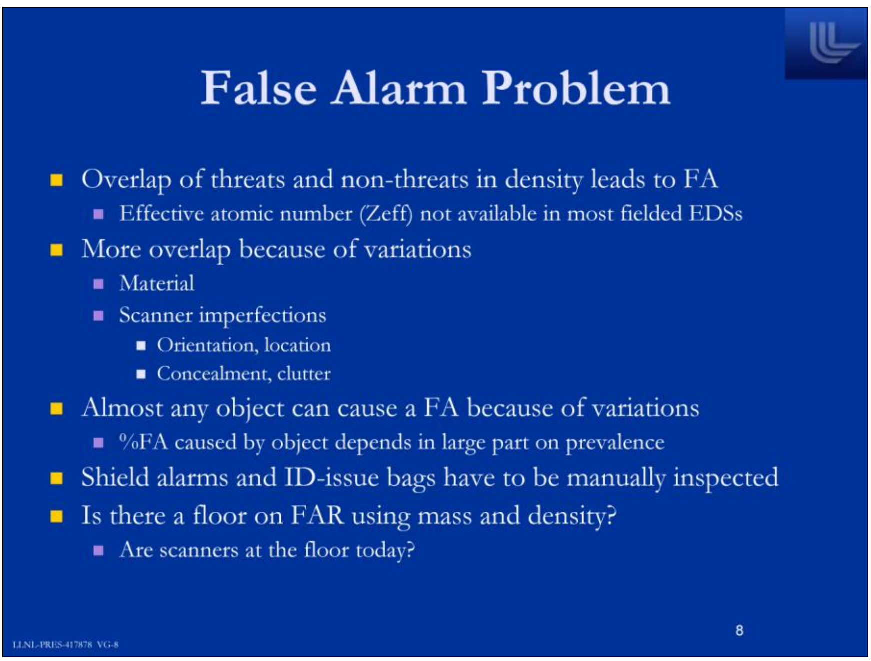

Overview
Post 9/11 (Q4 2002), ~1400 EDS (all CT) deployed at ~440 airports
EDS = explosive detection system; certified for checked-bag
~550 from GE/Invision, ~550 from L3 Communications, ~250 from Reveal (later than 2002)
Some scanners are CT + digital radiography (line scanner)
Lobby/behind counter/inline. Stand-alone/multiplexed
Machine Threat Detection Rate (TDR): <100% room for improvement
Machine False alarm rate (FAR): Higher than preferred and varies (per DHS)
Machine ~8 s / bag peak
Several false alarms cleared by transportation security operator (per DHS)
Secondary inspection: manual opening with trace detection
Costs of FAR
~$1 B/year
May be blocking additional deployment of EDS for checked and carry-on
LLNL-PRES-417878 VG-3
3

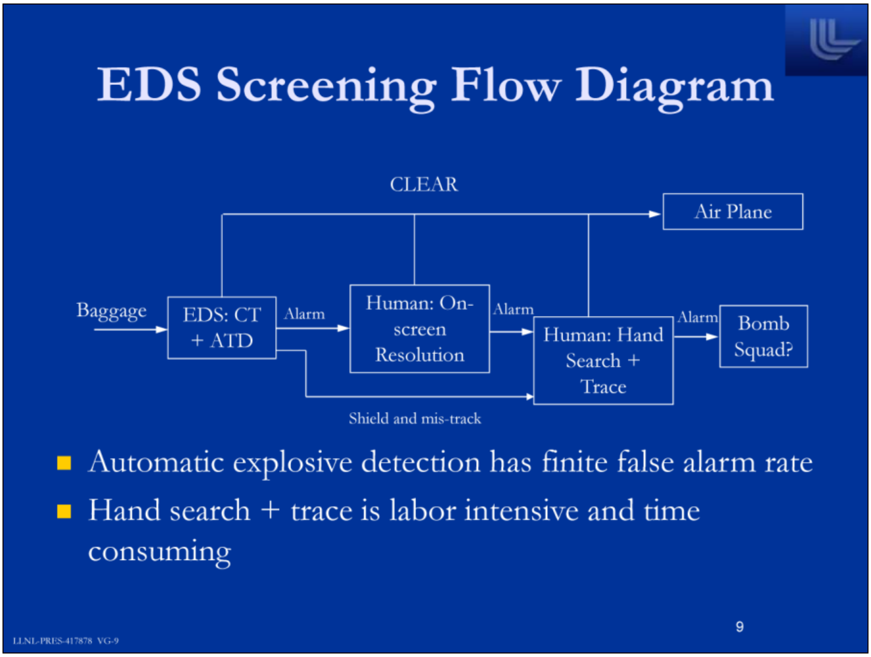

CT Properties of Materials
Clothes
Food
Cosmetics
Plastics
Paper
Commercial
Explosives
Military
Explosives
Ceramics
Metals
0
500
1000
1500
2000
CT Density (kg/m³)
TNT
C-4
SEMTEX H
Explosives occupy somewhat unique CT range
Distinguishable from
Innocuous organic materials
Inorganic materials
LLNL-PRES-417878 VG-4
4

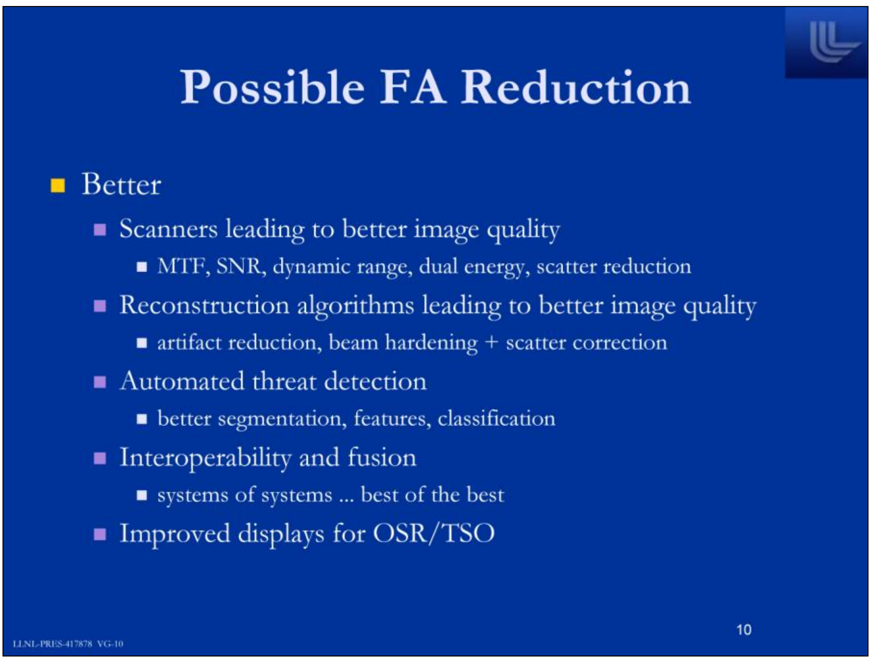

Certification Requirements
N classes of explosives: type and min mass
PD/class > X
PD ave > Y > X
PFA < Z
Use of shape not allowed, except sheets
Detect explosive, not IED components
Achieved with Automated threat detection (ATD)
Imaging device not required
>450 bags/hour (6-8 s/bag for recon and detection)
Without human in loop
Imaging device not required for cert, but is for OSR
LLNL-PRES-417878 VG-5
5

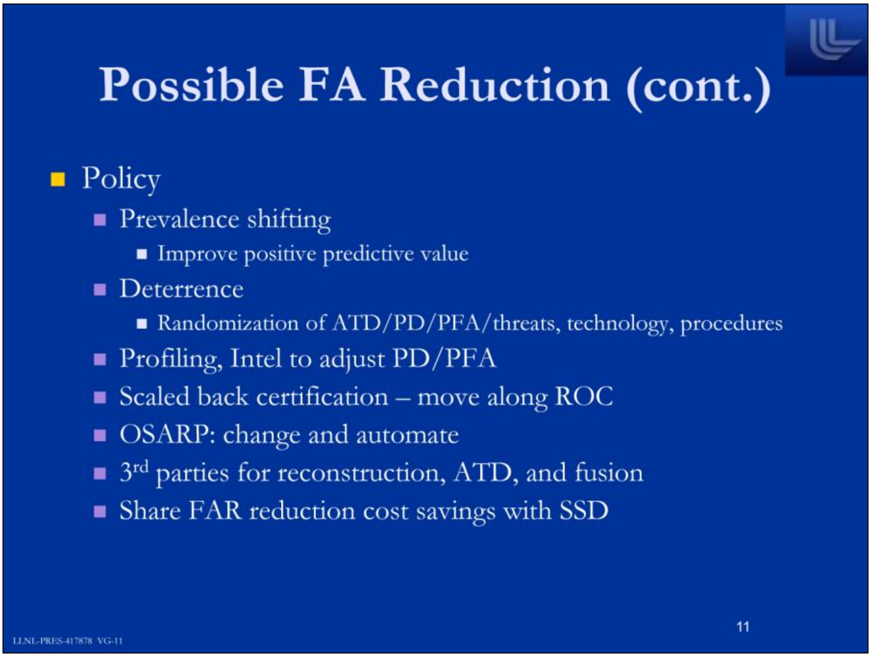

Certification Testing
Performed Transportation Security Laboratory (TSL), Atlantic City
Archived set of bags w/ and w/o threats
Statistical relevance is TBD
Non-threat bags not representative of field; absent:
perishables, fragile items, expensive items
Training data for vendors
threats – TSL
non-threats – stream of commerce at airports
Details in Management Plan for Explosives Detection System Certification Testing, DOT/FAA/AR-01/19
LLNL-PRES-417878 VG-6
6

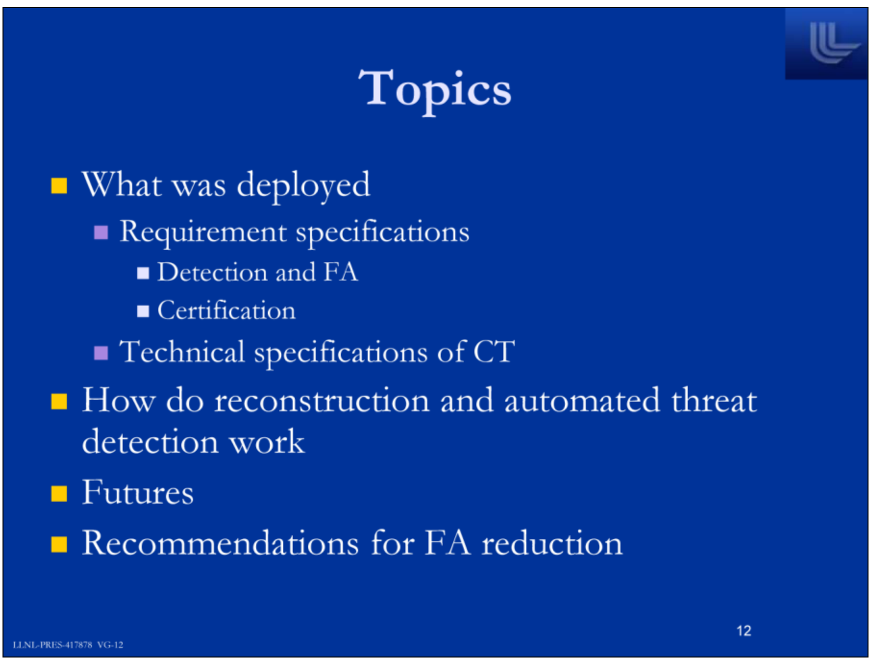

EDS CT-Scanner + Automated Threat Detection
Automated Threat Detection
CT Data Acquisition
CT Reconstruction
Object segmentation
Classification
CT scanner
Threat/non-threat
Some scanners have line scanner in front of CT.
7
LLNL-PRES-417878 VG-7

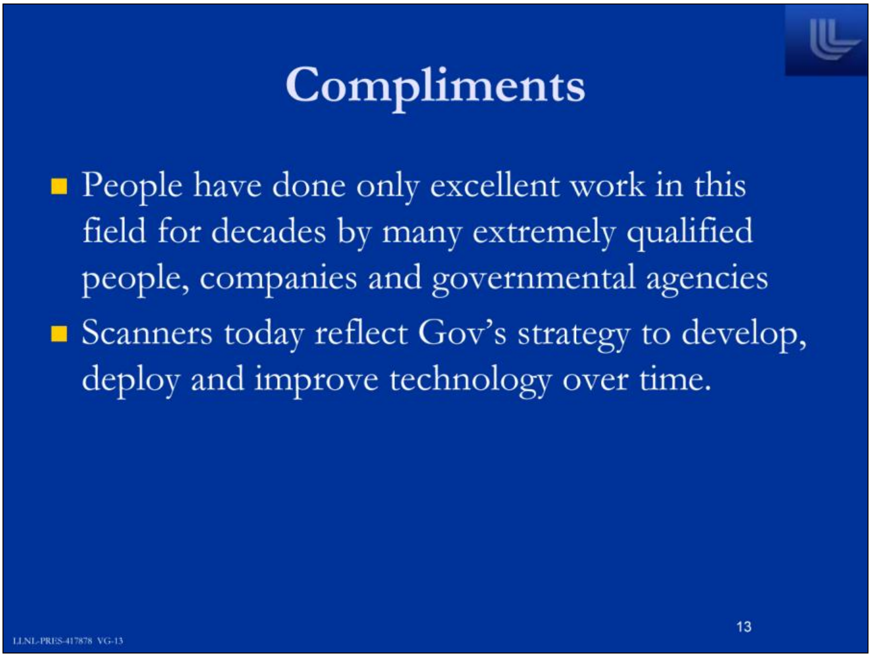

False Alarm Problem
Overlap of threats and non-threats in density leads to FA
Effective atomic number (Zeff) not available in most fielded EDSs
More overlap because of variations
Material
Scanner imperfections
Orientation, location
Concealment, clutter
Almost any object can cause a FA because of variations
%FA caused by object depends in large part on prevalence
Shield alarms and ID-issue bags have to be manually inspected
Is there a floor on FAR using mass and density?
Are scanners at the floor today?
8
LLNL-PRES-417878 VG-8

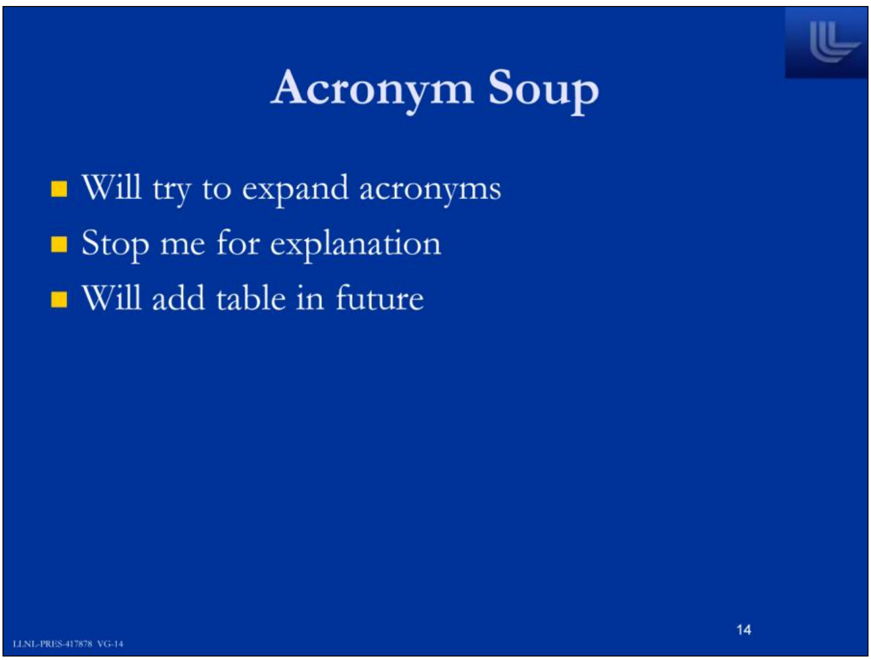

EDS Screening Flow Diagram
CLEAR
Air Plane
Baggage
EDS: CT + ATD
Alarm
Human: On-screen Resolution
Alarm
Human: Hand Search + Trace
Alarm
Bomb Squad?
Shield and mis-track
Automatic explosive detection has finite false alarm rate
Hand search + trace is labor intensive and time consuming
LLNL-PRES-417878 VG-9
9

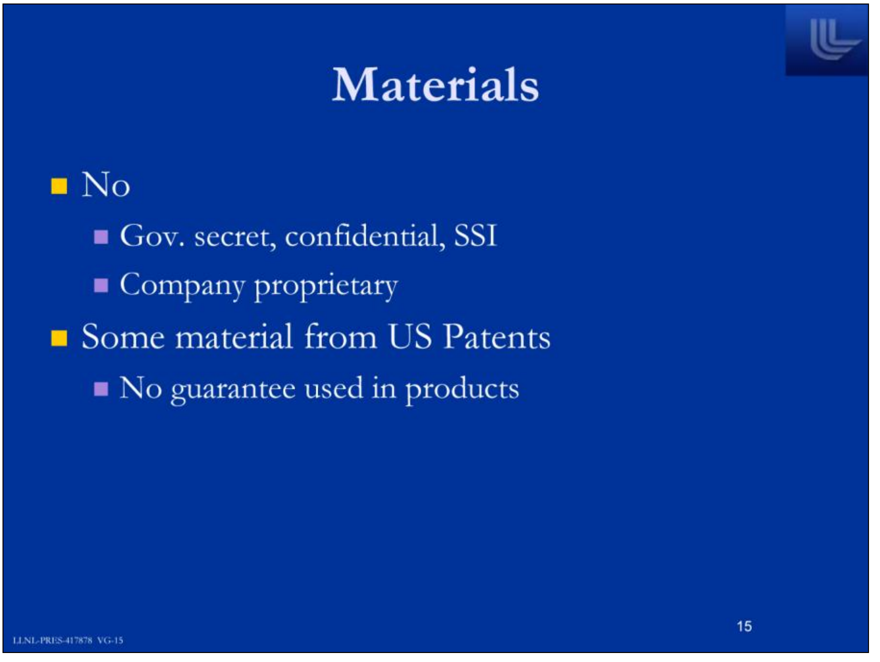

Possible FA Reduction
Better
Scanners leading to better image quality
MTF, SNR, dynamic range, dual energy, scatter reduction
Reconstruction algorithms leading to better image quality
artifact reduction, beam hardening + scatter correction
Automated threat detection
better segmentation, features, classification
Interoperability and fusion
systems of systems ... best of the best
Improved displays for OSR/TSO
LLNL-PRES-417878 VG-10
10

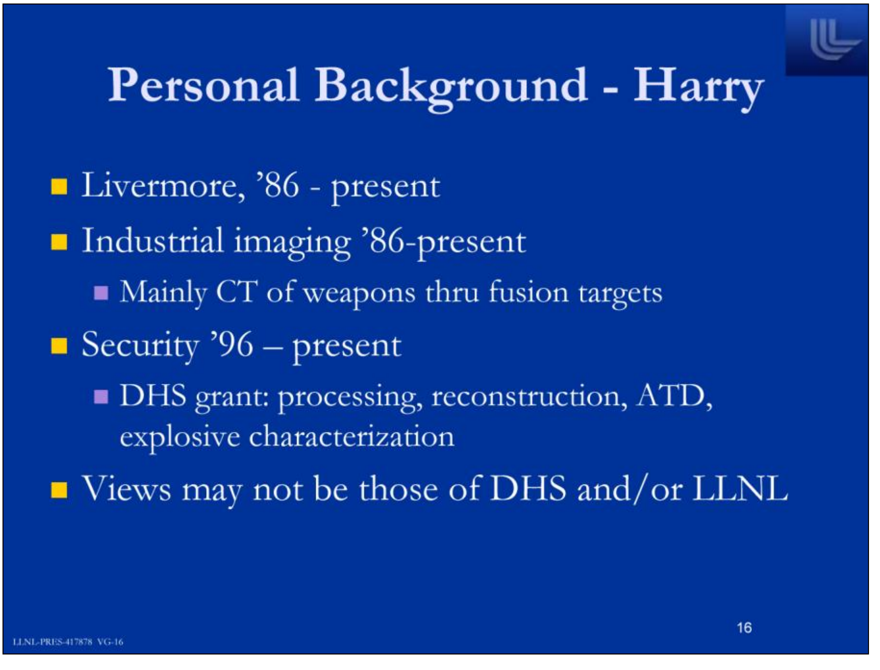

Possible FA Reduction (cont.)
Policy
Prevalence shifting
Improve positive predictive value
Deterrence
Randomization of ATD/PD/PFA/threats, technology, procedures
Profiling, Intel to adjust PD/PFA
Scaled back certification – move along ROC
OSARP: change and automate
3rd parties for reconstruction, ATD, and fusion
Share FAR reduction cost savings with SSD
11
LLNL-PRES-417878 VG-11


Topics
What was deployed
Requirement specifications
Detection and FA
Certification
Technical specifications of CT
How do reconstruction and automated threat detection work
Futures
Recommendations for FA reduction
12
LLNL-PRES-417878 VG-12


Compliments
People have done only excellent work in this field for decades by many extremely qualified people, companies and governmental agencies
Scanners today reflect Gov's strategy to develop, deploy and improve technology over time.
13
LLNL-PRES-417878 VG-13


Acronym Soup
Will try to expand acronyms
Stop me for explanation
Will add table in future
14
LLNL-PRES-417878 VG-14


Materials
No
Gov. secret, confidential, SSI
Company proprietary
Some material from US Patents
No guarantee used in products
15
LLNL-PRES-417878 VG-15


Personal Background - Harry
Livermore, '86 - present
Industrial imaging '86-present
Mainly CT of weapons thru fusion targets
Security '96 – present
DHS grant: processing, reconstruction, ATD, explosive characterization
Views may not be those of DHS and/or LLNL
16
LLNL-PRES-417878 VG-16

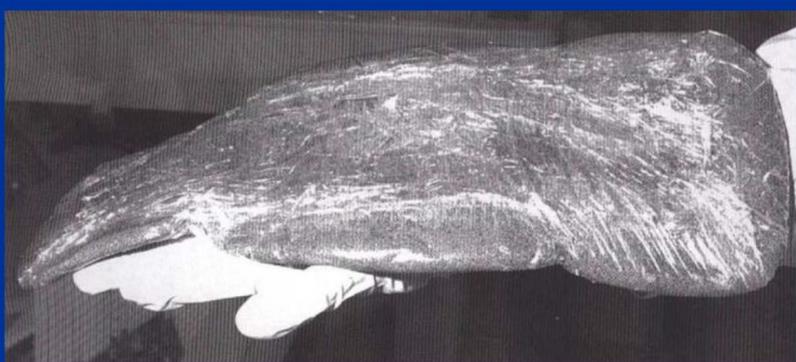
History

- 60s/70s hijackings to Cuba
  - X-ray line scanners installed at check-point
- Pan Am 103 Lockerbie, 1988

LLNL-PRES-417878 VG-17

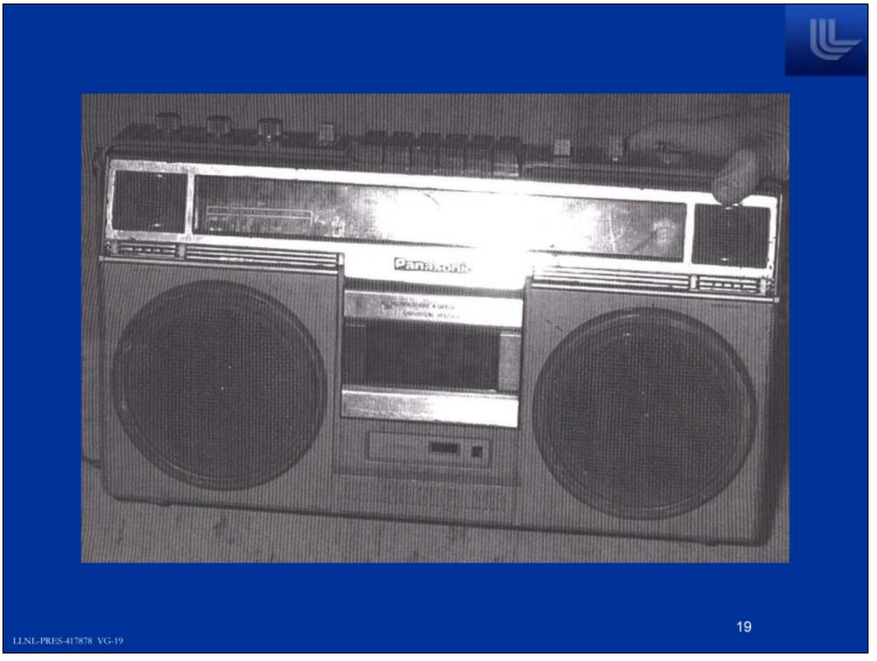
17

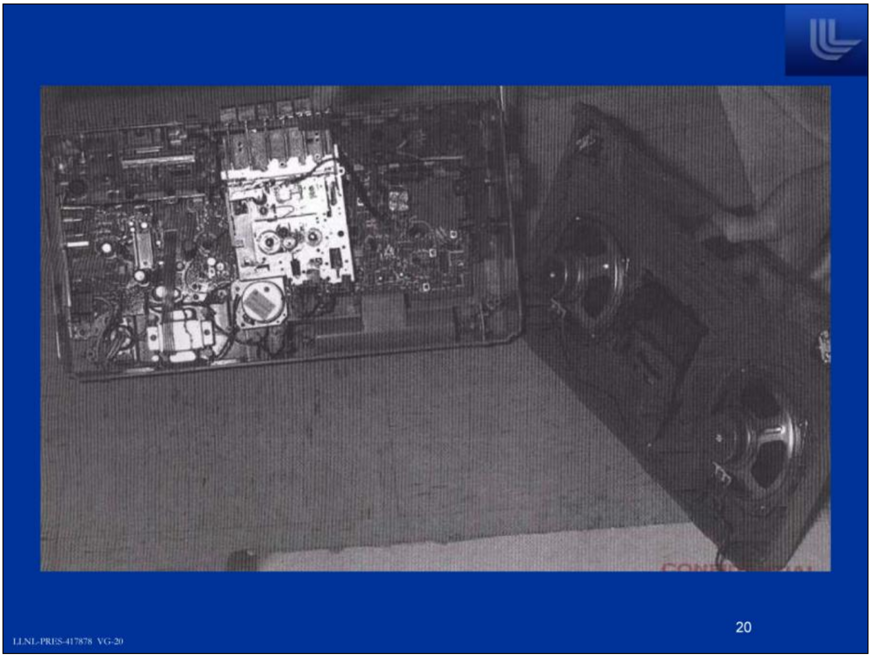
Threat

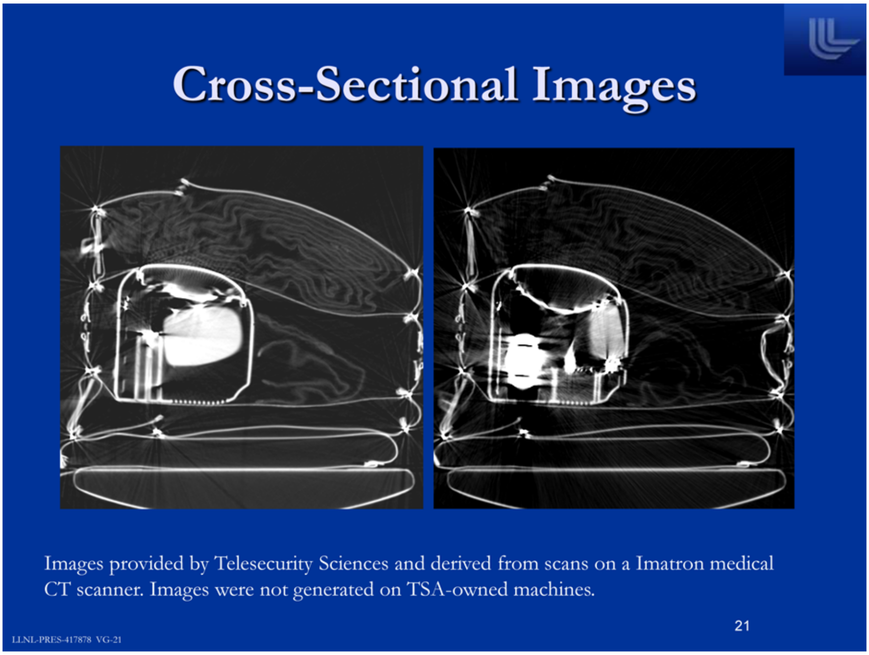


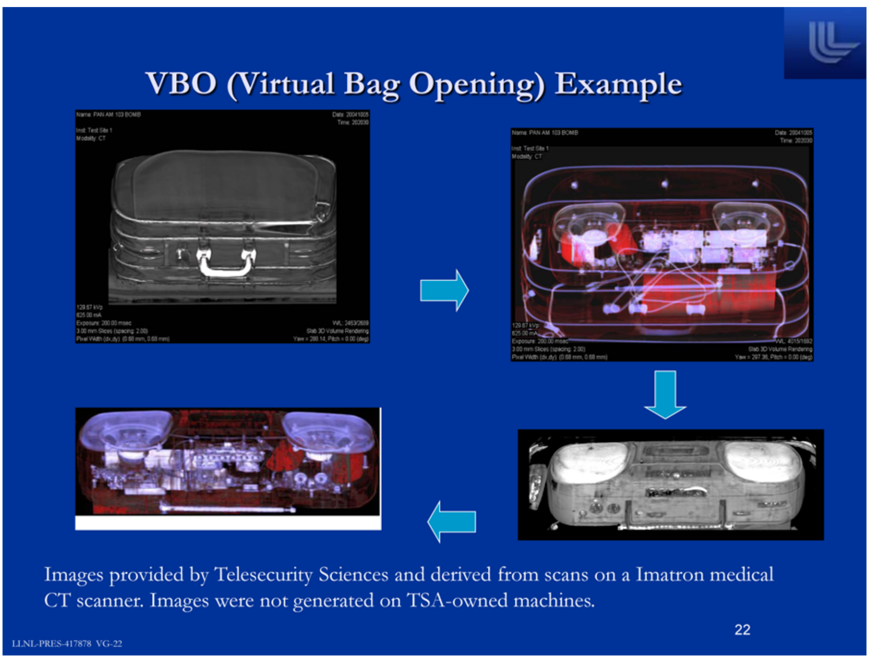
LLNL-PRES-417878 VG-18

18


Panasonic
19
LLNL-PRES-417878 VG-19


20
LLNL-PRES-417878 VG-20


Cross-Sectional Images
Images provided by Telesecurity Sciences and derived from scans on a Imatron medical CT scanner. Images were not generated on TSA-owned machines.
21
LLNL-PRES-417878 VG-21


VBO (Virtual Bag Opening) Example
Images provided by Telesecurity Sciences and derived from scans on a Imatron medical CT scanner. Images were not generated on TSA-owned machines.
22
LLNL-PRES-417878 VG-22

History (continued)

- Certification requirements established 1993
  - assistance from National Academy of Sciences
  - Cannot deploy unless certified
  - EDS means certified
- EDS Certification Management Plan
- Invision certified in 1994
- BAA for 2nd EDS 1996
- L3 certified in 1998

LLNL-PRES-417878 VG-23

23

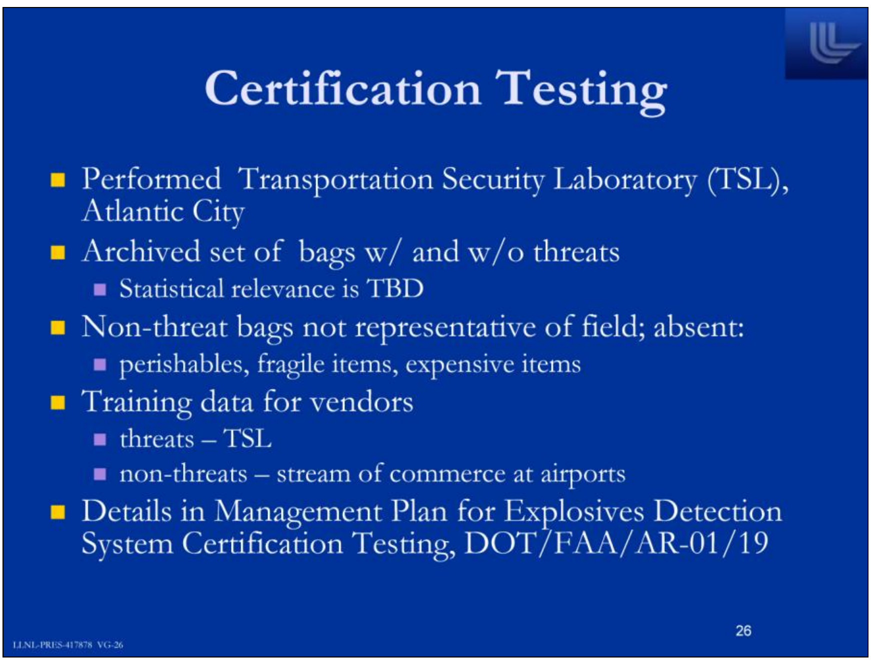
History (continued)

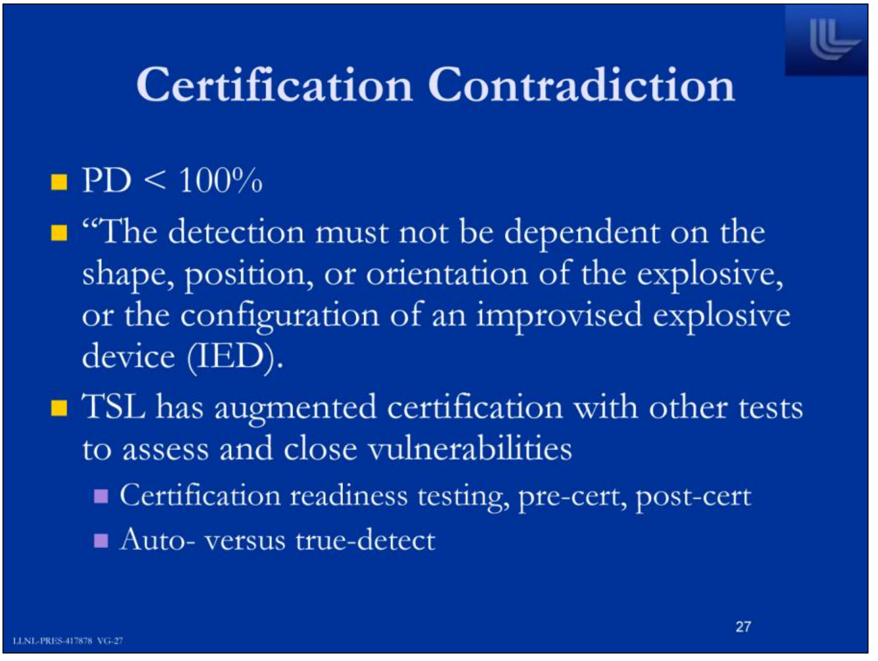
- Argus program – low cost scanners
  - L3 & Perkin Elmer (formerly Vivid)
- Phoenix program – reduced FA and cost
  - Analogic and Reveal – dual energy
  - Invision
- X-ray diffraction (GE) certified w/o x-ray CT
- 9/11
- 2002: Deployment of 1100 EDS (Invision and L3) along with 4k trace
- Post 2002 – high cost of FA
- Manhattan II: Next generation X-ray CT EDS

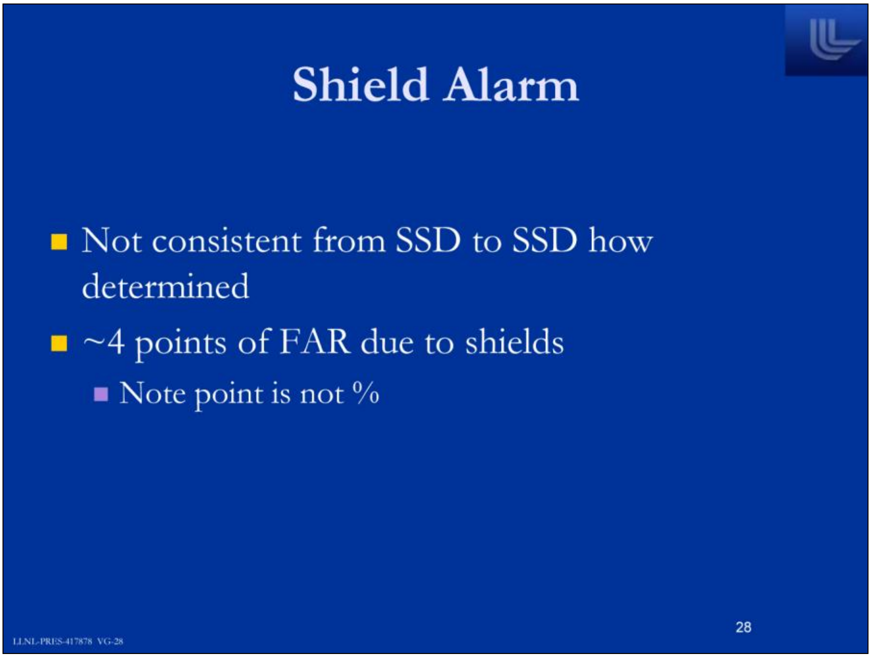
LLNL-PRES-417878 VG-24

24


Certification Requirements
N classes of explosives: type and min mass
PD/class > X
PD ave > Y > X
PFA < Z
Use of shape not allowed, except sheets
Detect explosive, not IED components
Achieved with Automated threat detection (ATD)
Imaging device not required
>450 bags/hour (6-8 s/bag for recon and detection)
Without human in loop
Imaging device not required for cert, but is for OSR
25
LLNL-PRES-417878 VG-25


Certification Testing
Performed Transportation Security Laboratory (TSL), Atlantic City
Archived set of bags w/ and w/o threats
Statistical relevance is TBD
Non-threat bags not representative of field; absent:
perishables, fragile items, expensive items
Training data for vendors
threats – TSL
non-threats – stream of commerce at airports
Details in Management Plan for Explosives Detection System Certification Testing, DOT/FAA/AR-01/19
26
LLNL-PRES-417878 VG-26


Certification Contradiction
PD < 100%
"The detection must not be dependent on the shape, position, or orientation of the explosive, or the configuration of an improvised explosive device (IED).
TSL has augmented certification with other tests to assess and close vulnerabilities
Certification readiness testing, pre-cert, post-cert
Auto- versus true-detect
LLNL-PRES-417878 VG-27
27


Shield Alarm
Not consistent from SSD to SSD how determined
~4 points of FAR due to shields
Note point is not %
LLNL-PRES-417878 VG-28
28

EDS (Bulk) Technology Options

- Penetrating Radiation
  - X-rays
    - transmission, back scatter, diffraction
  - Gamma Rays
  - Neutrons
- Electromagnetic
  - [Nuclear] Quadrupole resonance (NQR)
  - NMR/MRI
  - mm-Wave, THz
- Only x-ray CT and diffraction passed TSA certification
  - Detecting sheet explosives difficult
- *Passive-ETD*
  - *Trace Detection (sniffers)*


L3 Communication
Examiner 3DX6000
FAA certified in 1998
31
LLNL-PRES-417878 VG-31


Reveal – CT-80
TSA CERTIFIED EDS
TSA certified in January 2005
32
LLNL-PRES-417878 VG-32


X-ray Diffraction
Yxlon – Now GE
Throughput limited to ~50 bags/hour
33
LLNL-PRES-417878 VG-33

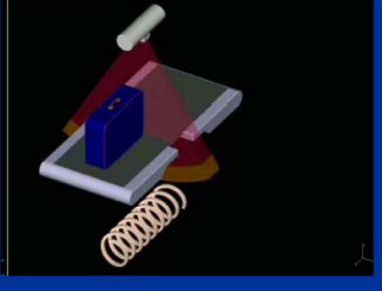

Analogic King-Cobra
34
LLNL-PRES-417878 VG-34

Tomography

- Uses projection images from different directions
- Uses mathematical reconstruction to produce tomographic (cross-sectional, slice) images
- Can be configured for axial or full volume (helical) scanning
- Images provide density (linear attenuation coef.)
  - Dual E effective atomic number is optional
- Explosive detection follows reconstruction

LLNL-PRES-417878 VG-35
35

Helical Scanning



Most CT machines use helical scanning to make images while The bag is moving. With multiple rows of detectors it is possible to Image the entire bag in 3D. GE uses radiograph and selective CT slices.

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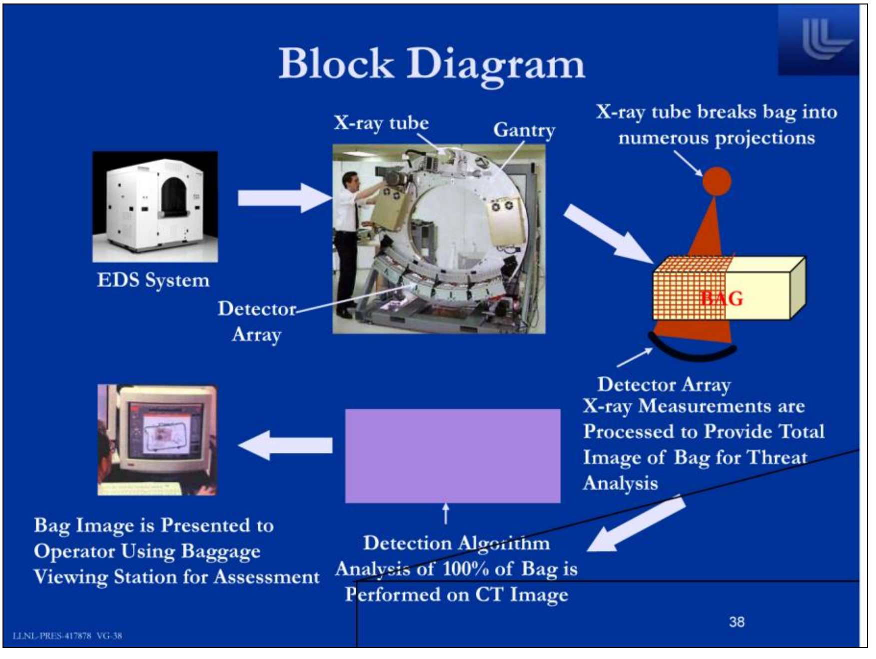
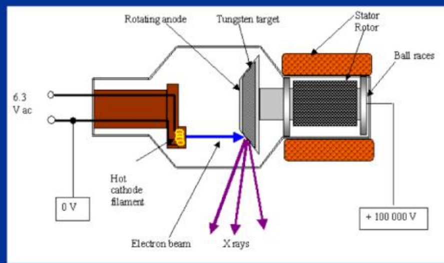
ANALOGIC
EXACT AN6000
•FAA Certified in 1999
•Full 3D volume CT
•>500 bags/hr
•Low False Alarm Rate
•Automatic Detection
•Designed for Checked Luggage
•Distributed by L3 Communications
•Footprint = 7 x 7 feet w/o conveyor
•Life Cycle Cost approx 25cents/bag
37
LLNL-PRES-417878 VG-37


Block Diagram
X-ray tube
Gantry
X-ray tube breaks bag into numerous projections
EDS System
Detector Array
BAG
Detector Array
X-ray Measurements are Processed to Provide Total Image of Bag for Threat Analysis
Bag Image is Presented to Operator Using Baggage Viewing Station for Assessment
Detection Algorithm Analysis of 100% of Bag is Performed on CT Image
38
LLNL-PRES-417878 VG-38

X-ray Tube



- Fixed x-ray anode
- Tungsten target
- Continuous operation
- Spot size 3 mm x 3 mm

LLNL-PRES-417878 VG-39

39

Detector and DAS

- Scintillator material $CdWO_4$
  - Convert x-ray photons to visible light
- Photodiode
  - Convert visible light to current
- Multi-row detector array
  - Helical scanning scheme
- DAS – data acquisition system
  - Integrating
  - A/D conversion

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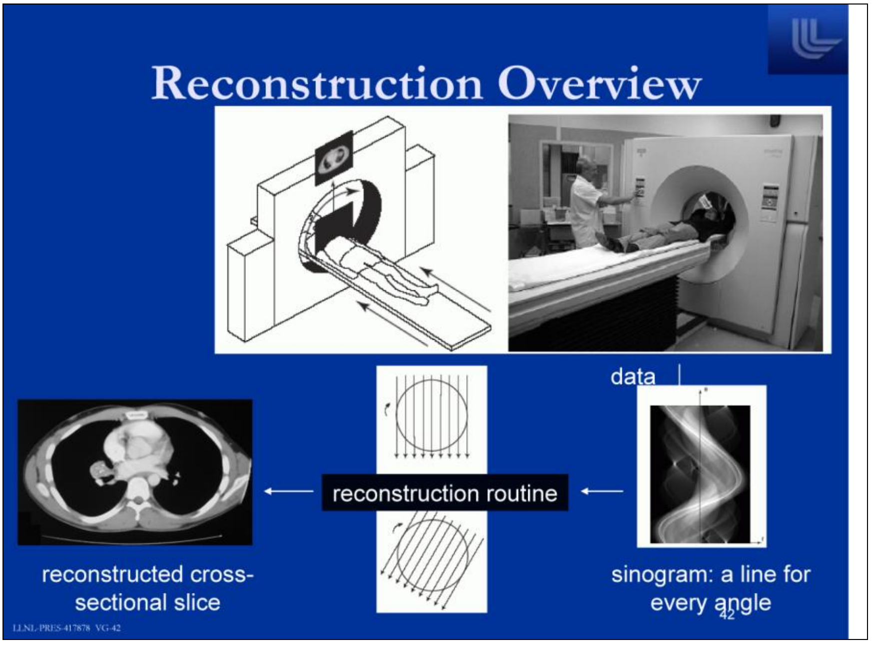
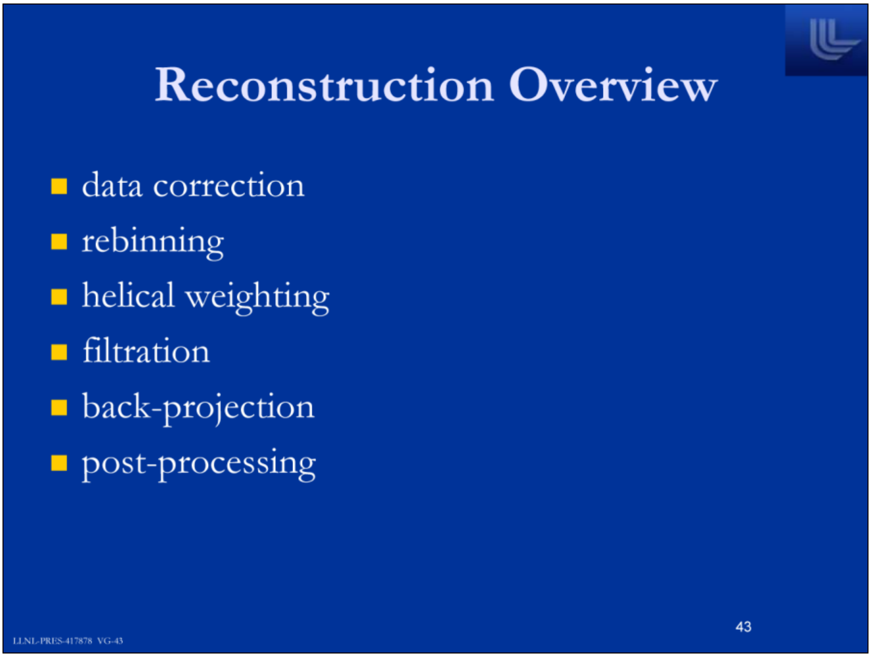
40

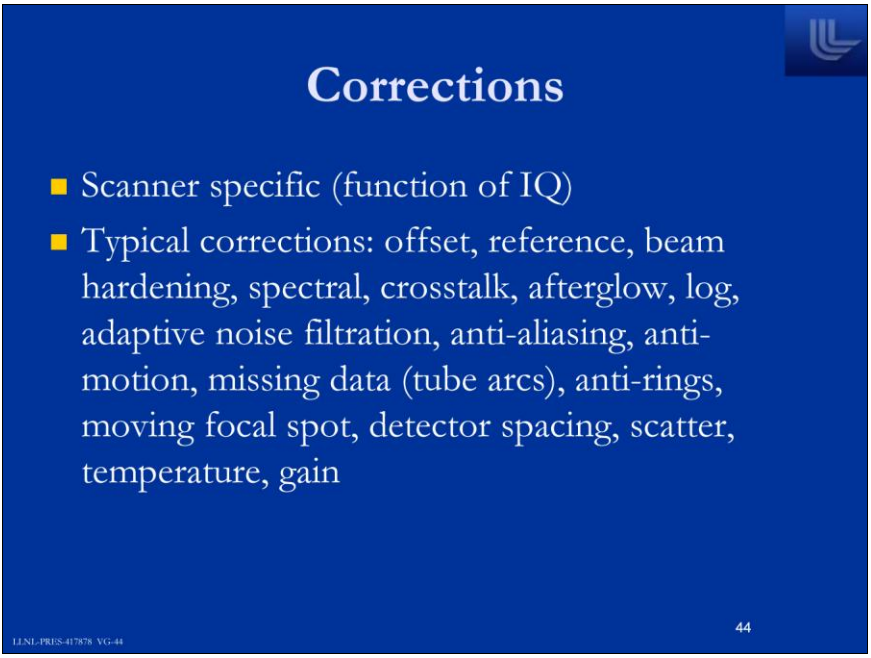
HVPS and Gantry

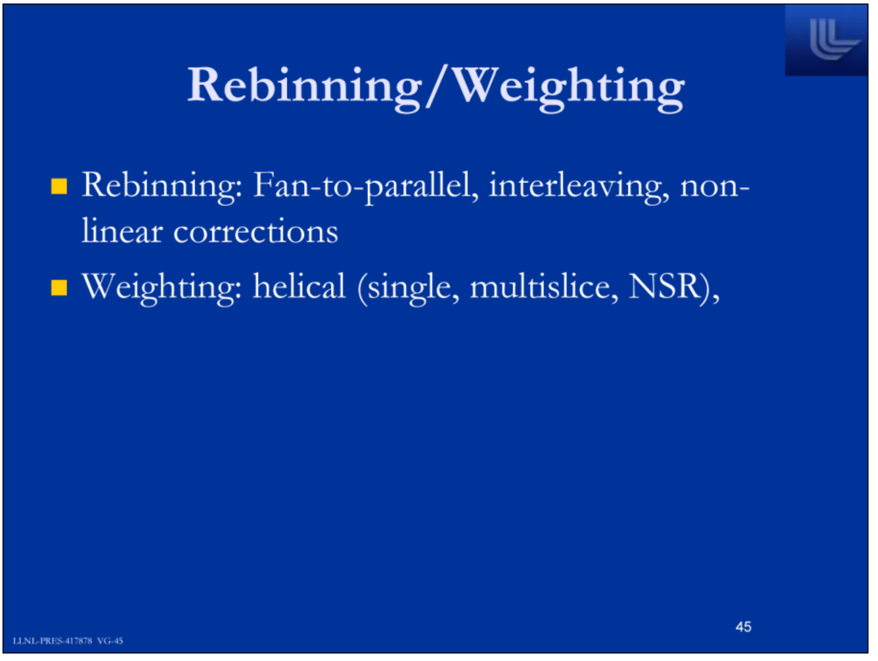
- High voltage power supply
  - Output 80 KV to 200 KV
  - Supply DC and AC for dual energy purpose
  - 500 – 5000 W
- Gantry
  - Aperture size varies from 60 – 100 cm in diameter
  - 90 rpm to 150 rpm

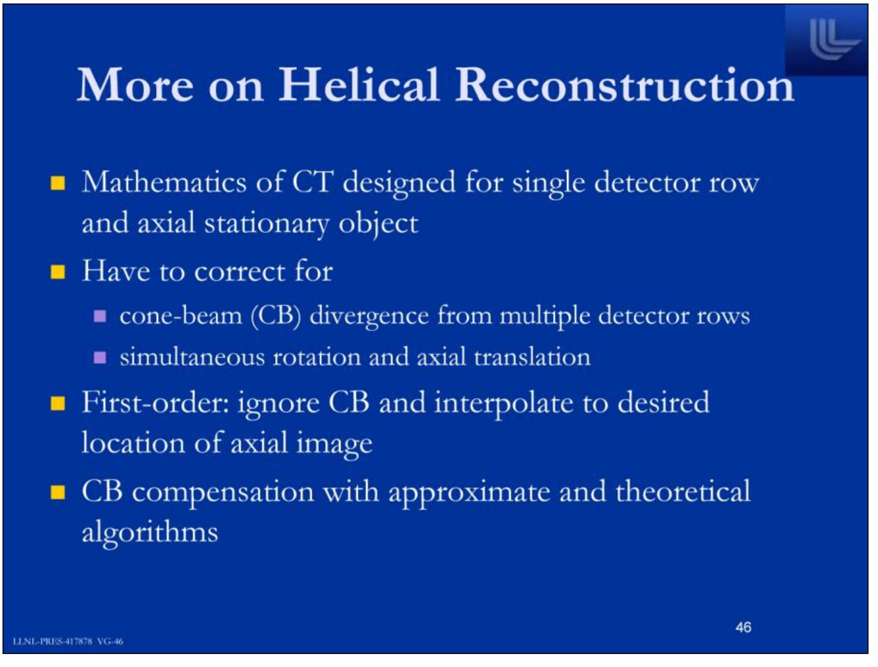
LLNL-PRES-417878 VG-41 41




Reconstruction Overview
data correction
rebinning
helical weighting
filtration
back-projection
post-processing
43
LLNL-PRES-417878 VG-43


Corrections
Scanner specific (function of IQ)
Typical corrections: offset, reference, beam hardening, spectral, crosstalk, afterglow, log, adaptive noise filtration, anti-aliasing, anti-motion, missing data (tube arcs), anti-rings, moving focal spot, detector spacing, scatter, temperature, gain
44
LLNL-PRES-417878 VG-44


Rebinning/Weighting
Rebinning: Fan-to-parallel, interleaving, non-linear corrections
Weighting: helical (single, multislice, NSR),
LLNL-PRES-417878 VG-45
45


More on Helical Reconstruction
Mathematics of CT designed for single detector row and axial stationary object
Have to correct for
cone-beam (CB) divergence from multiple detector rows
simultaneous rotation and axial translation
First-order: ignore CB and interpolate to desired location of axial image
CB compensation with approximate and theoretical algorithms
LLNL-PRES-417878 VG-46
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Non-Helical Scanners

- Some vendors (Invision) not using helical CT
- Using selective slicing.
  - Slice location from line-scan pre-scan
- GE moving towards volumetric/helical scanning. Grand challenges limited to volumetric data.

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Filtration

- High pass filter |ω| + low pass filter
- Families of kernels provided to trade off noise, artifacts, resolution
- Some data correction in filter

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[Filtered] Back Projection

- Smear filtered projections into reconstruction matrix
- Note: some vendors might not be using filtered back projection

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Post-Processing

- Scaling, offset
- De-ringing
- 2^{nd} pass beam hardening correction
- Nonlinear noise filtration

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Scanner Calibrations

- Detector gain (air), spectral, temperature, beam hardening, offsets, scatter, afterglow, cross-talk
- Geometric (source location), detector position
- Dual energy

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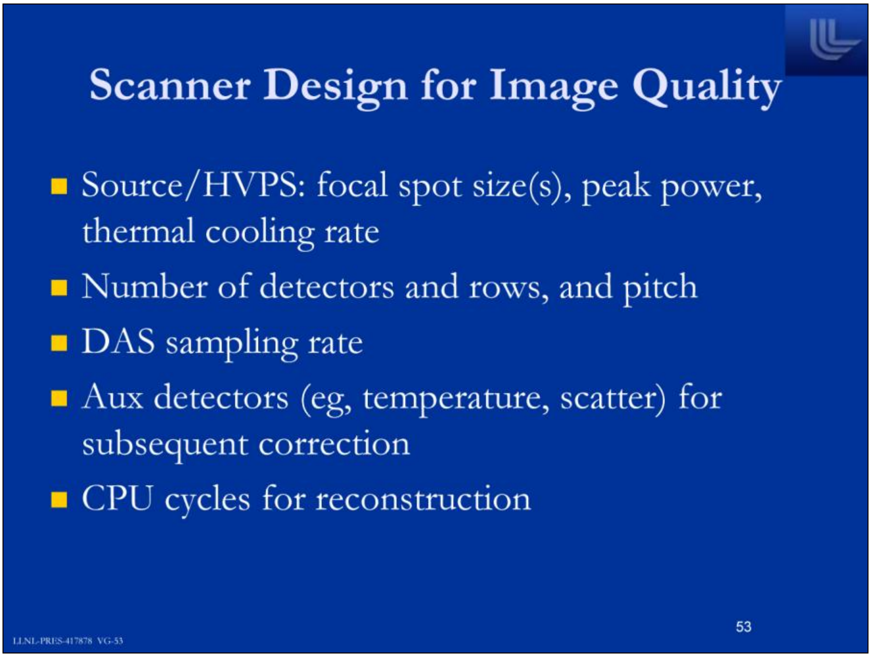
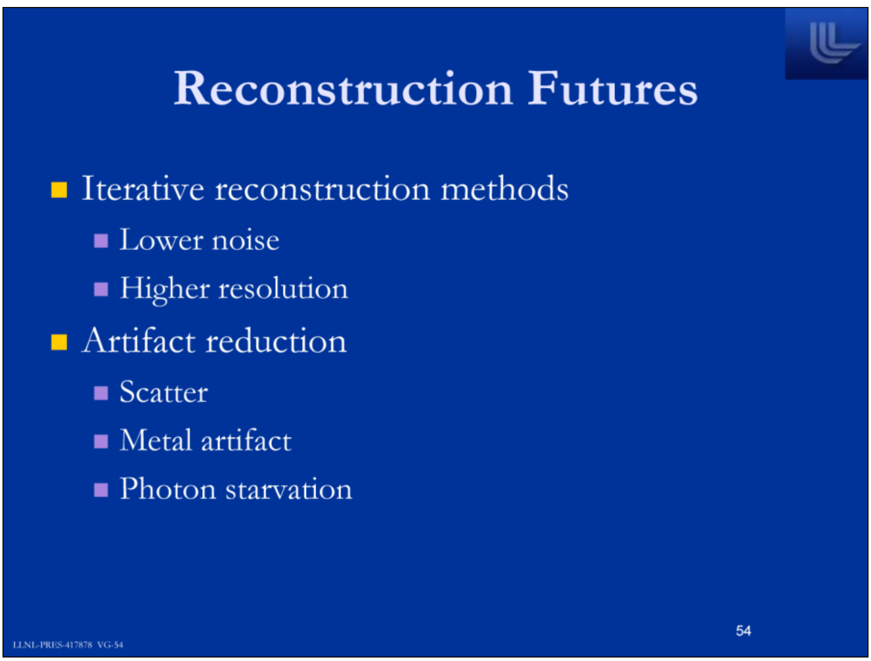
Image Quality Specifications

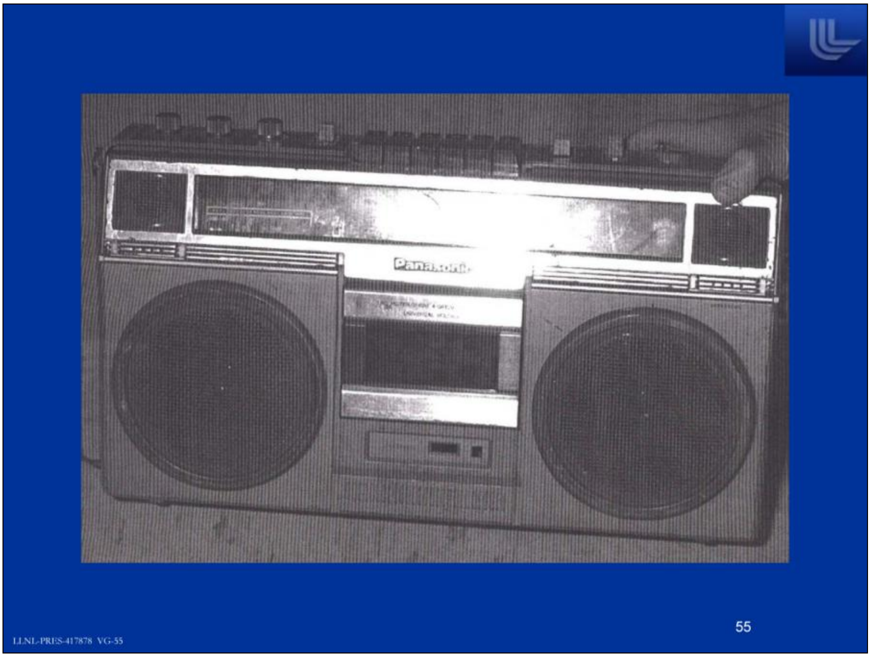
- Spatial resolution: radial/tangential (MTF) + spatial dependence (lp/cm), slice sensitivity profile (SSP) – size of the sweet spot
- Noise/low contrast/dose
- Artifacts
- Spatial uniformity

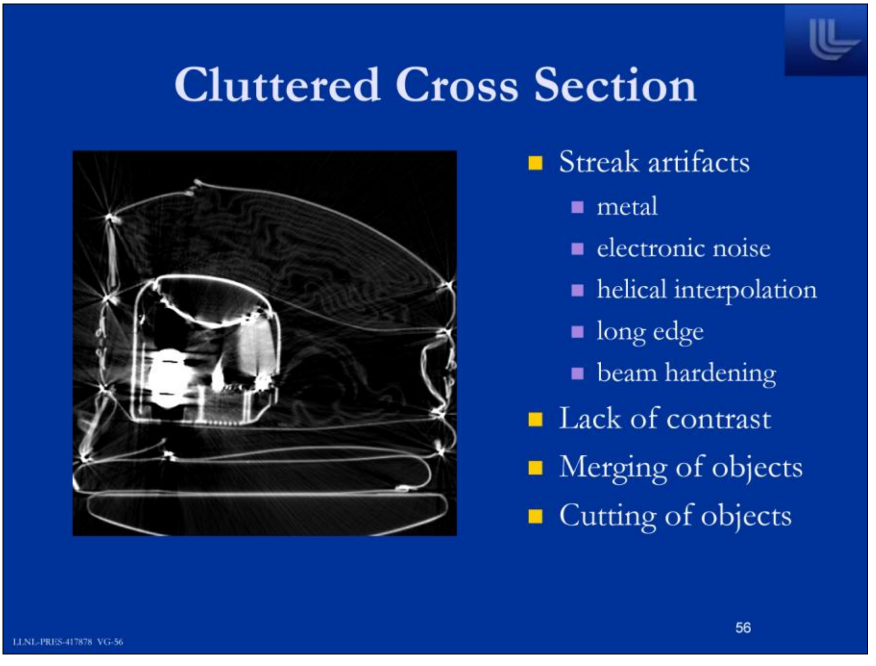
Scanners vary in resolution, noise, artifacts.

LLNL-PRES-417878 VG-52 52


Scanner Design for Image Quality
Source/HVPS: focal spot size(s), peak power, thermal cooling rate
Number of detectors and rows, and pitch
DAS sampling rate
Aux detectors (eg, temperature, scatter) for subsequent correction
CPU cycles for reconstruction
LLNL-PRES-417878 VG-53
53


Reconstruction Futures
Iterative reconstruction methods
Lower noise
Higher resolution
Artifact reduction
Scatter
Metal artifact
Photon starvation
LLNL-PRES-417878 VG-54
54


Panasonic
55
LLNL-PRES-417878 VG-55


Cluttered Cross Section
Streak artifacts
metal
electronic noise
helical interpolation
long edge
beam hardening
Lack of contrast
Merging of objects
Cutting of objects
56
LLNL-PRES-417878 VG-56

Dual-energy Review

- Interactions between materials and x-rays (30 keV to 200 keV) are dominated by Compton scatter and the photoelectric effect
- Compton scatter and the photoelectric effect are functions of x-ray photon energies and material properties
- Functions are separable (basis series expansion)

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Compton scatter and Photoelectric effect

- Total x-ray attenuation can be decomposed as follows:

$$\mu(x,y,z,E) = \underbrace{a_{\mathrm{c}}(x,y,z) f_{\mathrm{KN}}(E)}_{\text{Compton scatter}} + \underbrace{a_{\mathrm{p}}(x,y,z) f_{\mathrm{p}}(E)}_{\text{photoelectric effect}}$$

- Two measurements required to solve for line integrals of Compton and photoelectric coefficients

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Mechanisms for Dual Energy Measurements

- Simultaneous measurements
  - Sandwich detectors (Reveal)
    - Detector materials used as spectral filter
  - Energy resolving detectors (photon counting)
- Alternating measurements
  - X-ray source voltage switching (Analogic)
  - Oscillating mechanical filters
  - Combination

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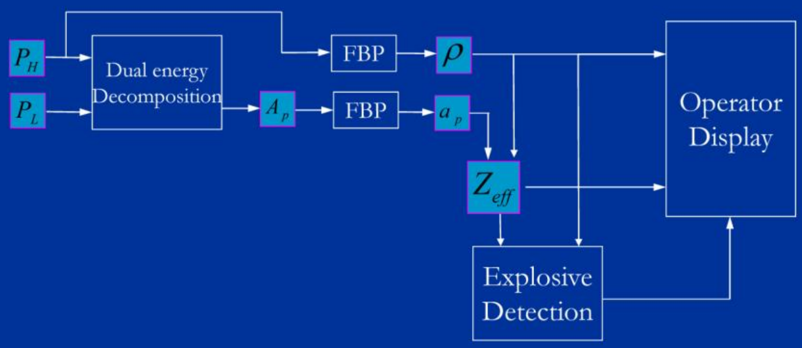
Dual Energy Algorithm



FBP = filtered back projection

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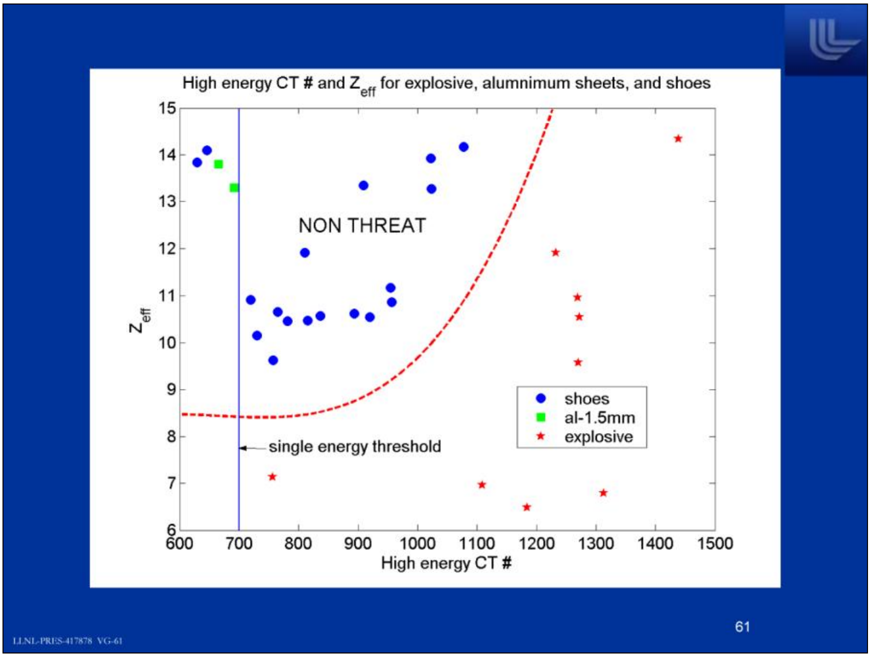
60



Explosives

Name	MW	C	H	N	O	N (%)	g/cm³
TNT	227.13	7	5	3	6	18.5	1.65
RDX	222.26	3	6	6	6	38.0	1.83
HMX	296.16	4	8	8	8	37.8	1.96
Tetryl	287.15	7	5	5	8	24.4	1.73
PETN	316.20	5	8	4	12	17.7	1.78
NG	227.09	3	5	3	9	18.5	1.59
EGDN	152.10	2	4	2	6	18.4	1.49
AN	80.05	-	4	2	3	35.0	1.59
TATP	222.23	9	18	-	6	-	1.2
DNB	168.11	6	4	2	4	16.7	1.58
Picric Acid	229.12	6	3	3	7	18.3	1.76

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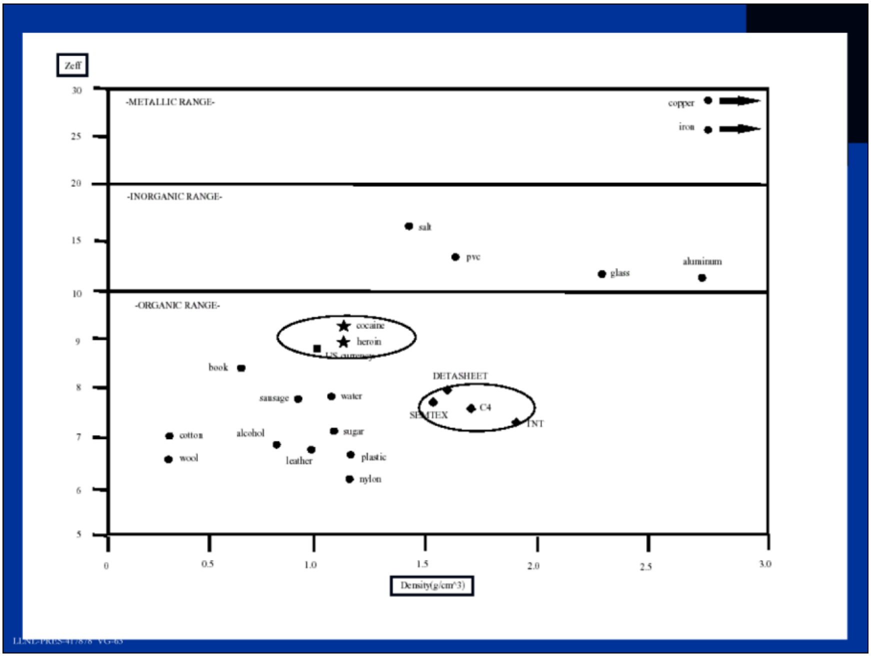
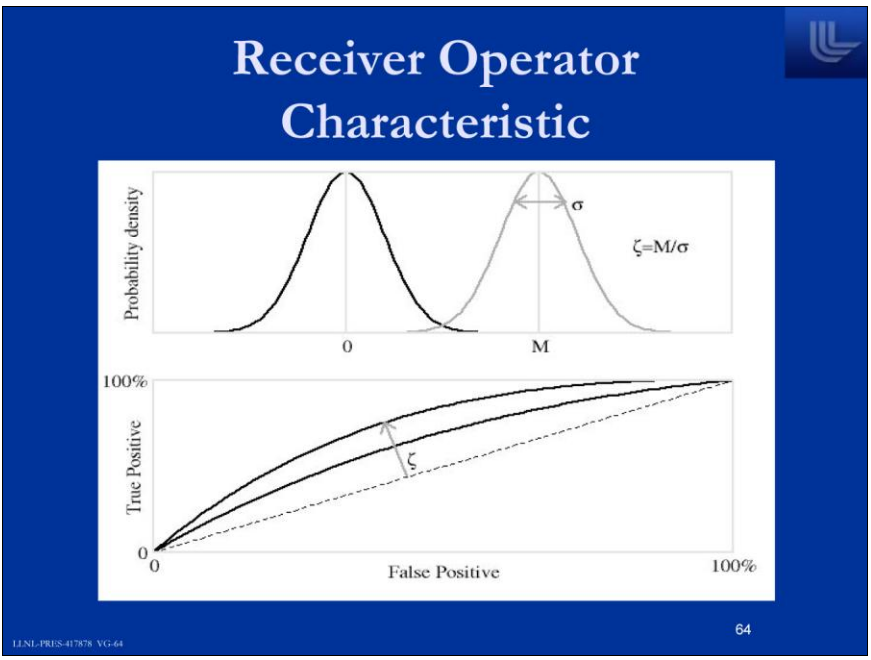

Zeff
30
25
20
15
10
9
8
7
6
5
-METALLIC RANGE-
copper
iron
-INORGANIC RANGE-
salt
pvc
glass
aluminum
-ORGANIC RANGE-
cocaine
heroin
book
DETASHEET
sausage
water
C4
TNT
cotton
alcohol
sugar
wool
leather
plastic
nylon
0
0.5
1.0
1.5
2.0
2.5
3.0
Density(g/cm^3)


Receiver Operator Characteristic
Probability density
σ
ζ=M/σ
0
M
100%
True Positive
ζ
0
0
False Positive
100%
64
LLNL-PRES-417878 VG-64

Automatic Detection

- Separate paths for sheet and bulk
- Morphology, region growing
- Correction for CT finite resolution
- Discrimination: mass, density, concealment
- Database of 1000s of bags
- Vary parameters to move along ROC
- Can use shape for detection but not for classification

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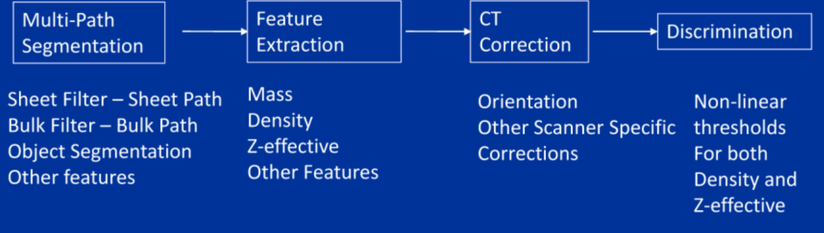
65

Detection Algorithms



LLNL-PRES-417878 VG-66

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Monkey and Duck!!!

- If you are looking monkeys, but they look like ducks, what do you look for?
- CT scanners turn monkeys into ducks because of scanner imperfections
  - Spatial dependent resolution
  - Artifacts
- A solution is to look for ducks

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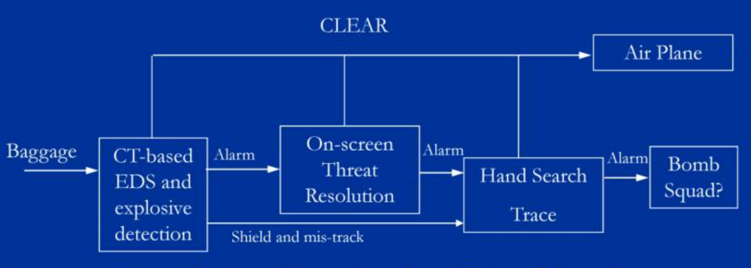
Baggage Screening Flow Diagram



- Automatic explosive detection has finite false alarm rate
- Hand search + trace is labor intensive and time consuming. ~$1B/year. OSR clears a fraction of the FAR

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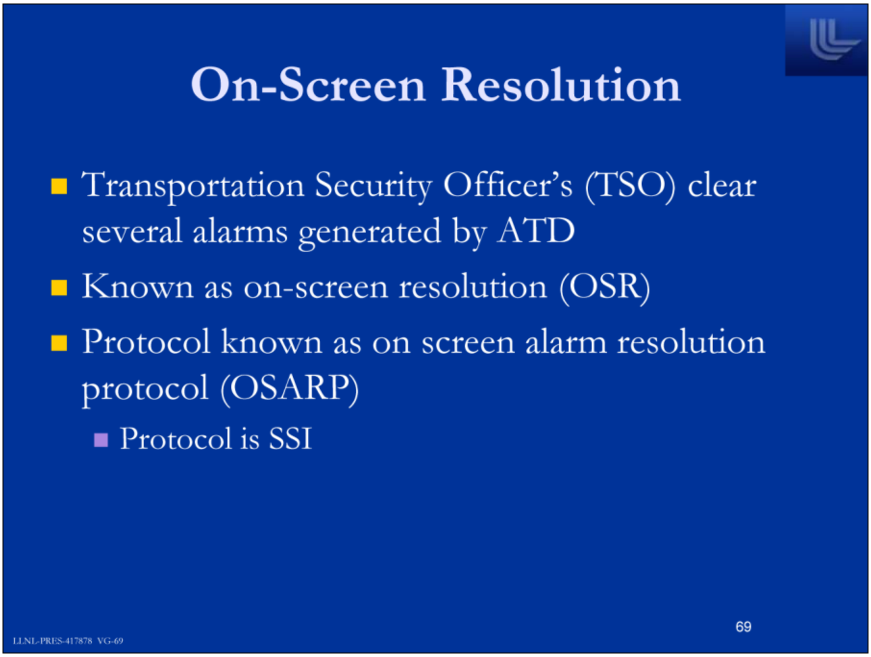
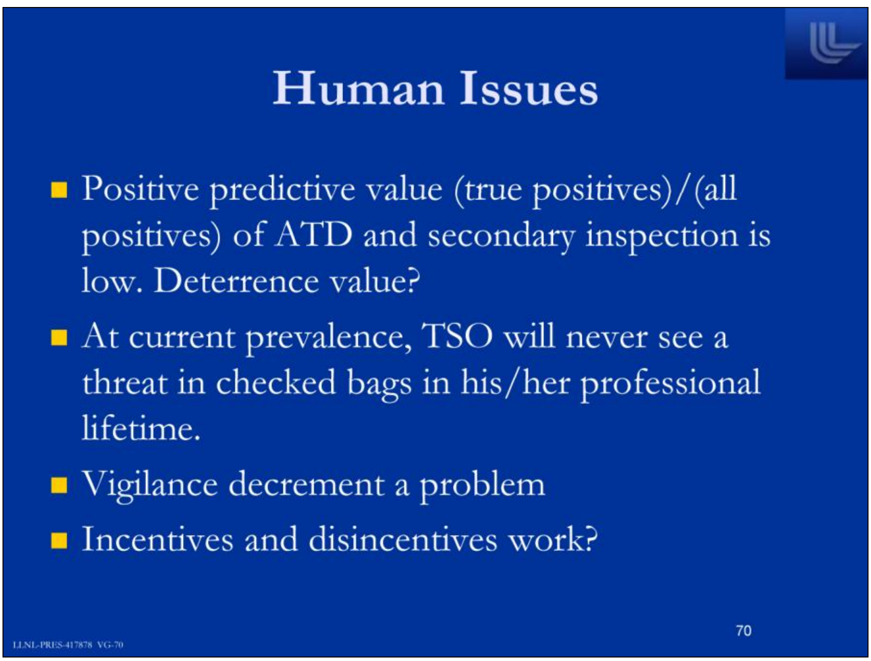
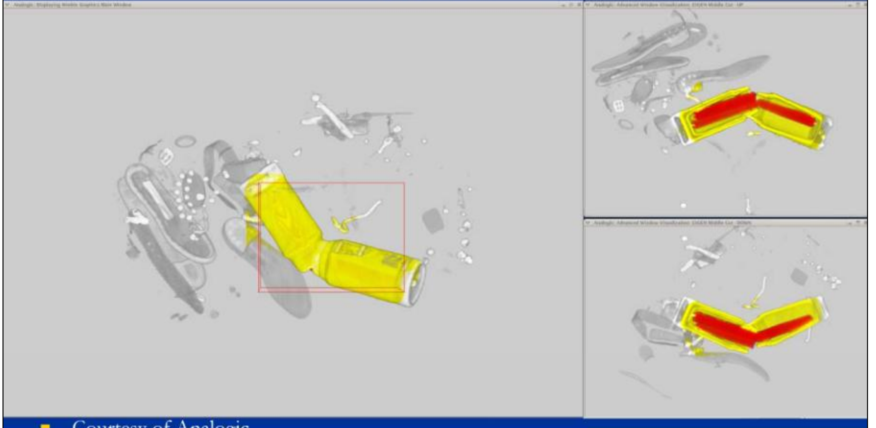

On-Screen Resolution
Transportation Security Officer's (TSO) clear several alarms generated by ATD
Known as on-screen resolution (OSR)
Protocol known as on screen alarm resolution protocol (OSARP)
Protocol is SSI
LLNL-PRES-417878 VG-69
69


Human Issues
Positive predictive value (true positives)/(all positives) of ATD and secondary inspection is low. Deterrence value?
At current prevalence, TSO will never see a threat in checked bags in his/her professional lifetime.
Vigilance decrement a problem
Incentives and disincentives work?
LLNL-PRES-417878 VG-70
70

Virtual Baggage Opening



- Courtesy of Analogic
- Sausage explosive (red) in two thermos bottles (yellow)
- Bag and objects are virtually opened at optimal location for unobstructed viewing

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Stereo Displays (Planar)

Huge Wow! factor ... not clear if operator performance improved.

72

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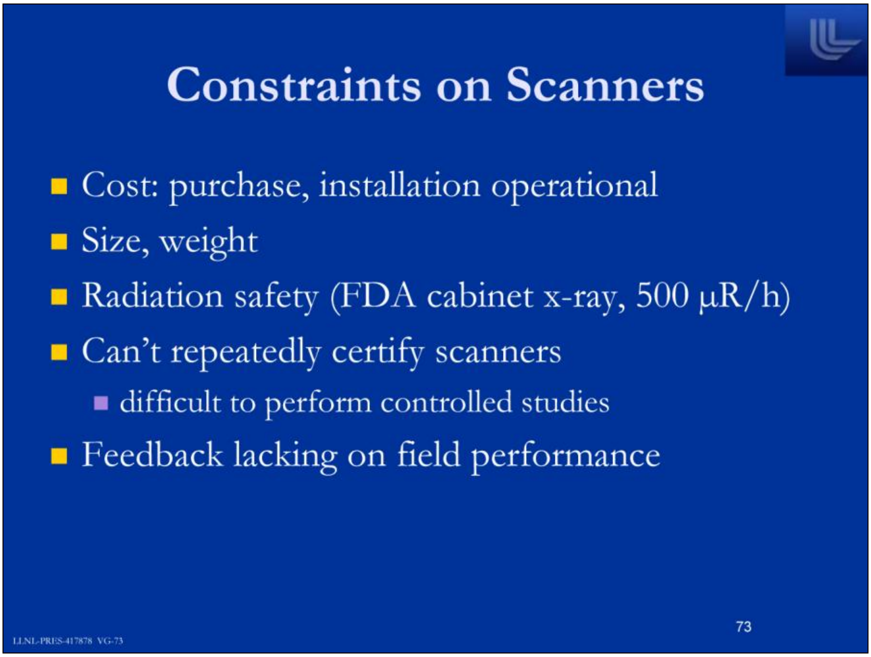
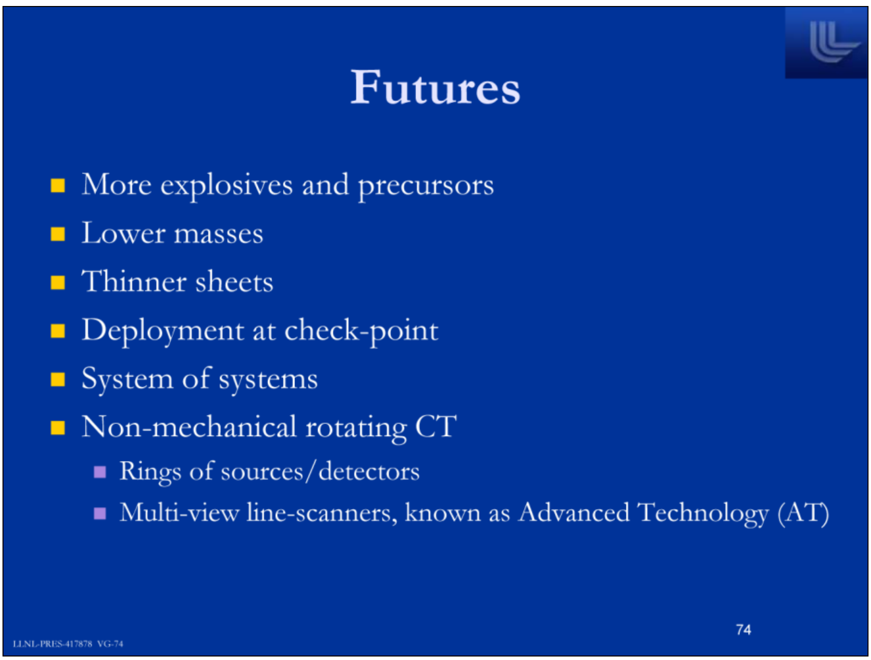

Constraints on Scanners
Cost: purchase, installation operational
Size, weight
Radiation safety (FDA cabinet x-ray, 500 μR/h)
Can't repeatedly certify scanners
difficult to perform controlled studies
Feedback lacking on field performance
73
LLNL-PRES-417878 VG-73


Futures
More explosives and precursors
Lower masses
Thinner sheets
Deployment at check-point
System of systems
Non-mechanical rotating CT
Rings of sources/detectors
Multi-view line-scanners, known as Advanced Technology (AT)
74
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Smiths – Non-Mechanical CT

2 and 5 view scanners; multiple sources. Non-mechanical also from Rapiscan, Surescan, L3, ...

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Possible Performance Improvements

- Better
  - Scanners leading to better image quality
    - MTF, SNR, dynamic range, dual energy, scatter reduction
  - Reconstruction algorithms leading to better image quality
    - artifact reduction, beam hardening + scatter correction
  - Automated threat detection
    - better segmentation, features, classification
  - Interoperability and fusion
    - systems of systems ... best of the best
  - Improved displays for OSR/TSO

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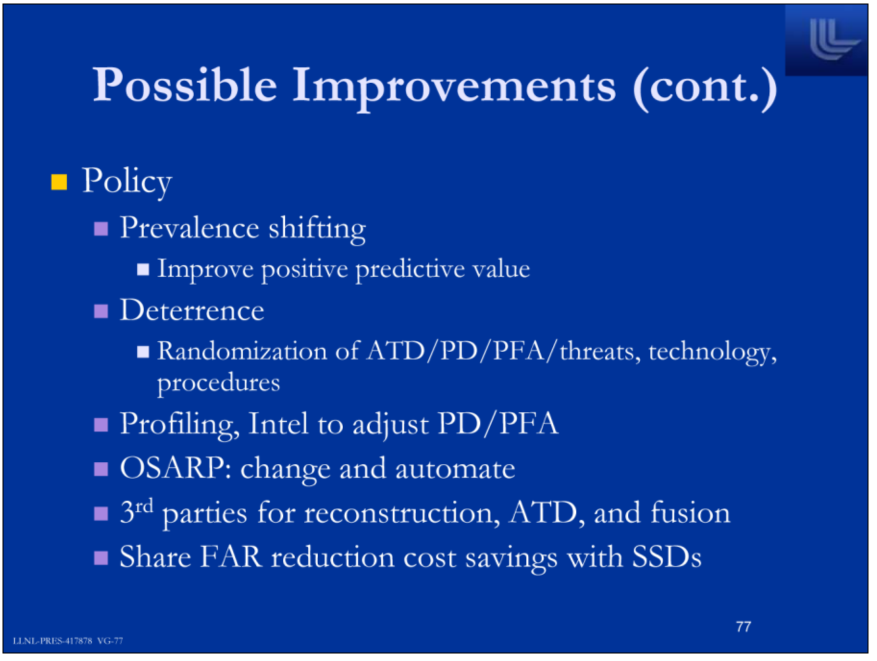
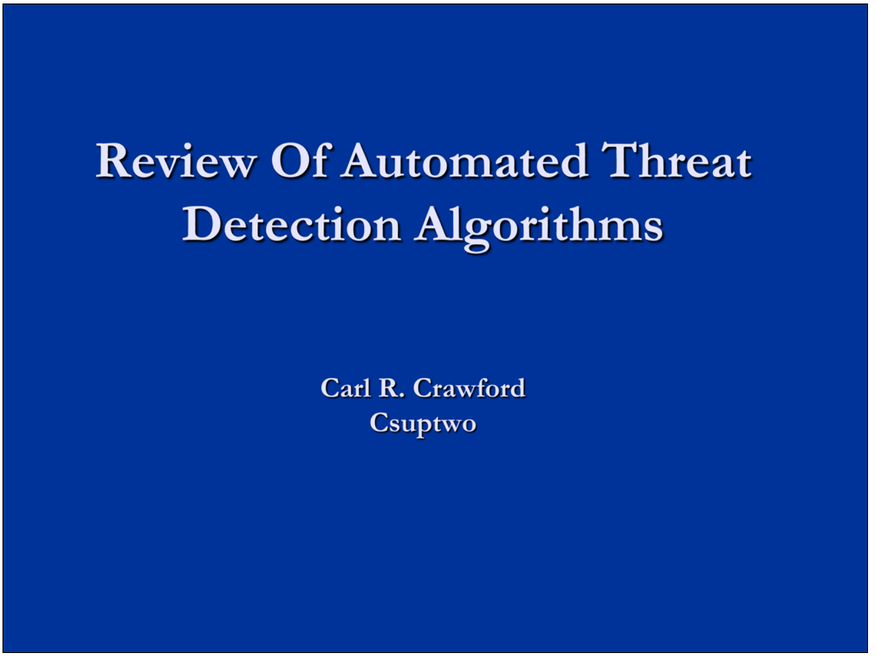
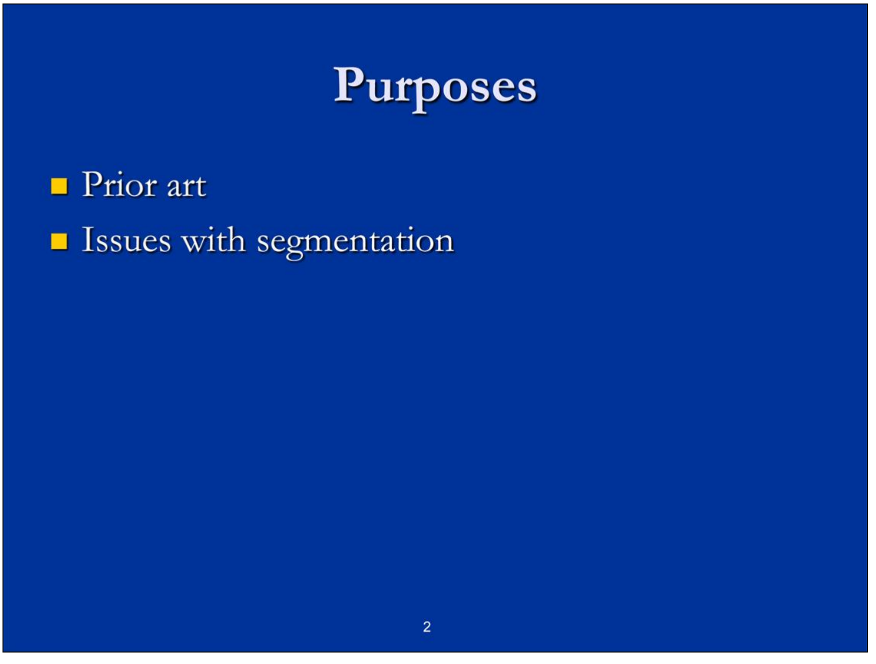

Possible Improvements (cont.)
Policy
Prevalence shifting
Improve positive predictive value
Deterrence
Randomization of ATD/PD/PFA/threats, technology, procedures
Profiling, Intel to adjust PD/PFA
OSARP: change and automate
3rd parties for reconstruction, ATD, and fusion
Share FAR reduction cost savings with SSDs
77
LLNL-PRES-417878 VG-77

26.3 Carl Crawford Presentation 3 Slides





Prior Art

- SSD proprietary
- Issues classified
- Solutions
  - Review patent literature, assume SSD's follow patents somewhat
  - Discuss issues as arise from CT

3

Disclosure

- Presentation based mainly on Analogic's ~20 ATD patents
- Crawford is inventor on most of these
- Discussions with Analogic to make sure that proprietary material is not disclosed
- Emphasize that talk is based on patents; no guarantee that patents are used in Analogic's products
- Analogic, and other SSDs, have trump cards during this presentation

4

Patent Search

- Did not do complete search and review
- Recommendation (ADSA02): do complete search and review prior art
- Patents from
  - Analogic
  - GE
  - Vivid
  - L-3

5

Bibliography

- Will be provided in final report
- Most Analogic ATD (and recon) patents at
  - www.csuptwo.com/patents2.html

6

Restrictions

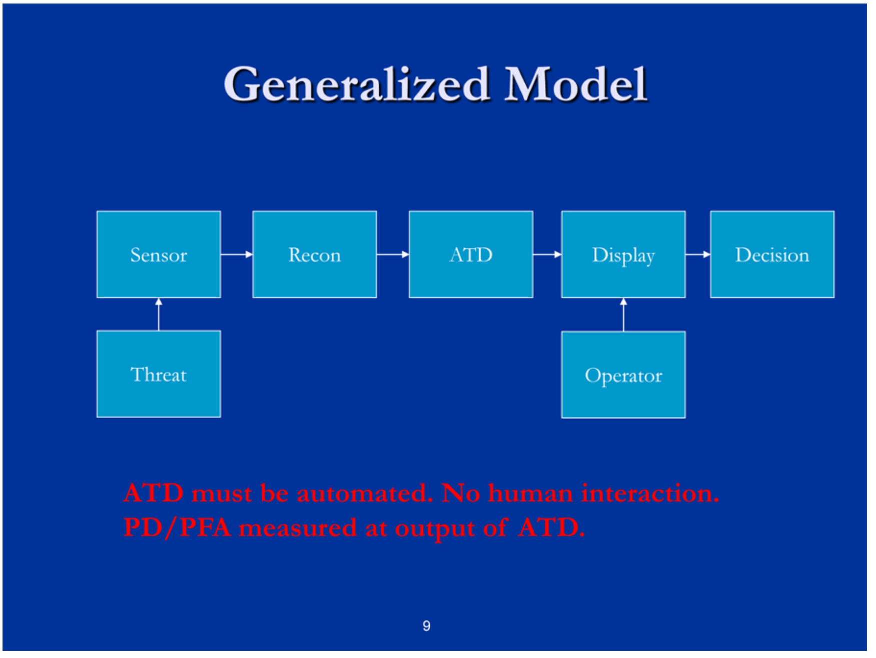
- Limit discussion to volumetric CT
  - Reveal, L-3, GE 9800, Analogic
  - Surescan, Rapiscan, Smiths Detection
- 3D region growing
- Segmenting *threat-like* objects

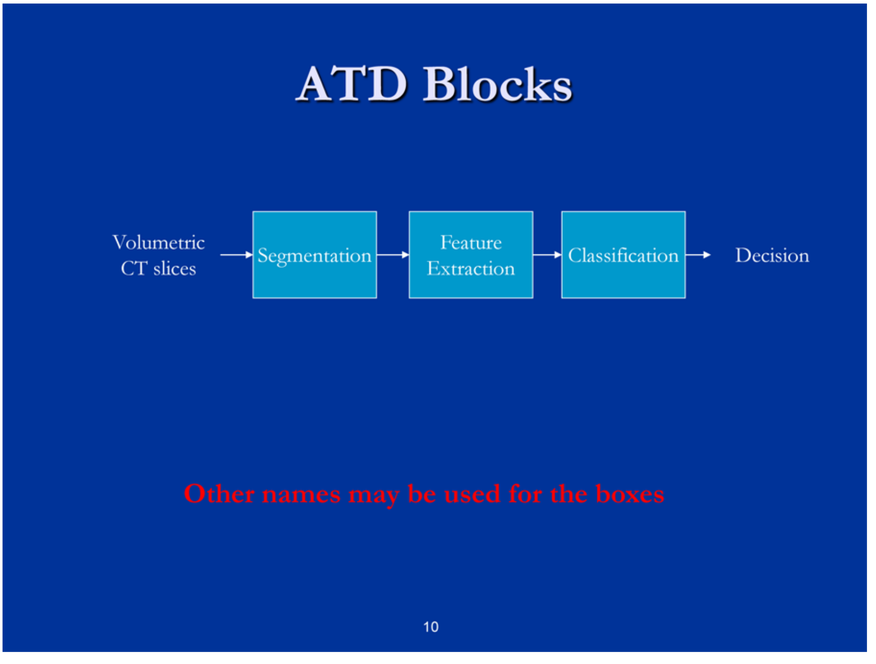
7

Exclude

- Selective slice scanners
  - Vivid/Perkin Elmer/L-3
  - GE
  - Combination of non-helical CT and line scanner
- Threat identification from projection (Radon) data

8


Generalized Model
Sensor
Recon
ATD
Display
Decision
Threat
Operator
ATD must be automated. No human interaction.
PD/PFA measured at output of ATD.
9


ATD Blocks
Volumetric CT slices
Segmentation
Feature Extraction
Classification
Decision
Other names may be used for the boxes
10

CT Images

- Images are of linear attenuation coefficient (LAC), which is related to mass density and elemental composition
- Estimates of mass, density, volume
- Dual energy allows
  - Mass density
  - Zeff
  - Photoelectric and Compton coefficients
- Spatial variations (texture)

11

Features

- Mass
- Mean: LAC, Zeff
- Standard deviation: LAC, Zeff
- Histograms
- Higher-order moments
  - Skew, kurtosis, entropy
- Texture
  - Wavelets

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CT Artifacts

- Finite and spatially dependent resolution
- Streaks
- Additive noise
- Rings, bands
- Low-frequency shading (cupping, dishing)
- CT number shifts

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Artifact Sources

- Finite focal-spot and detector apertures
- Beam hardening due to polychromatic sources
- Scatter
- Electronic and quantum noise
- Dark currents
- Quenching of x-rays
- Temperature drift
- Detector imbalances
- Motion
- Sampling
- Long straight edges
- Presence of metal and other attenuators
- High voltage power supply drifts
- Interpolations in reconstruction

14

Problems with Threats

- Not homogeneous
  - May have texture, voids, folds
- May be concealed in clutter

15

Connected Component Labeling (CCL)

- Start with all voxels as separate objects
- Join neighboring voxels that are *similar*
- Repeat until no more joining possible

16

CCL Problems

- Literature suggests following problems due to artifacts and threat features
  - Objects grown together – aggregates or compound objects
  - Threats split up into separate objects
  - Erode slices to prevent aggregates, but then lose thin threats
- Prior art solutions
  - Prevent split and aggregate objects prospectively
  - Combine split objects and split aggregate objects retrospectively

17

Monkey and Duck!!!

- CT scanners turn monkeys into ducks because of scanner imperfections
- If you are looking monkeys, but they look like ducks, what do you look for?
- Answer, ducks!

Bernie Gordon, Founder Analogic, circa 1997

L-3 has patent on looking for burred sheet explosives.

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IEEE Recommendation

- Circa 1997, IEEE ran a course on threat detection in Boston (across the river in Cambridge)
- Someone told Analogic to scan threats and non-threats. Sit in dark room for the weekend. Stare images.

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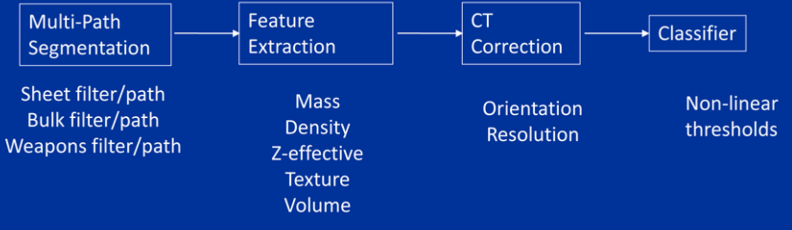
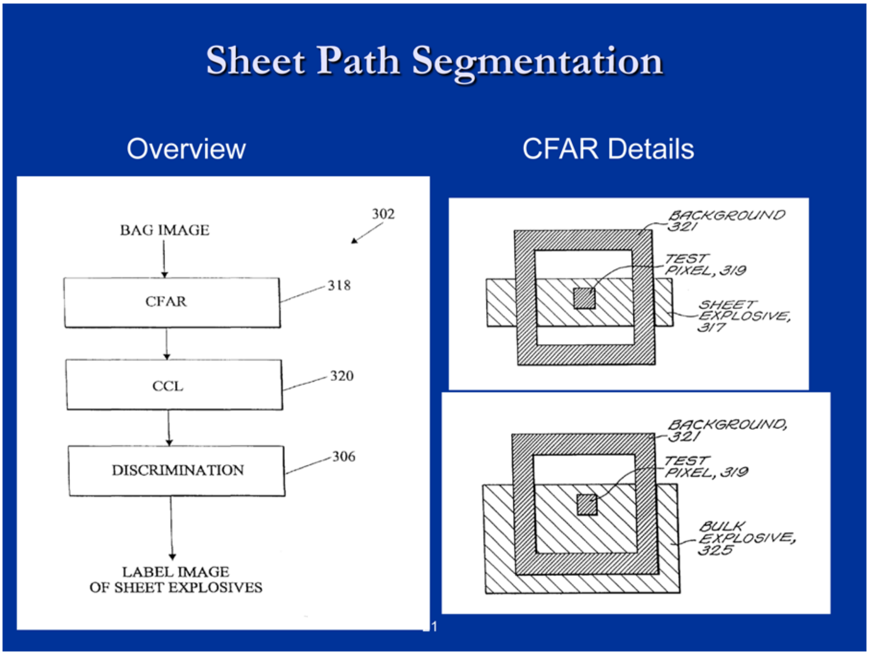
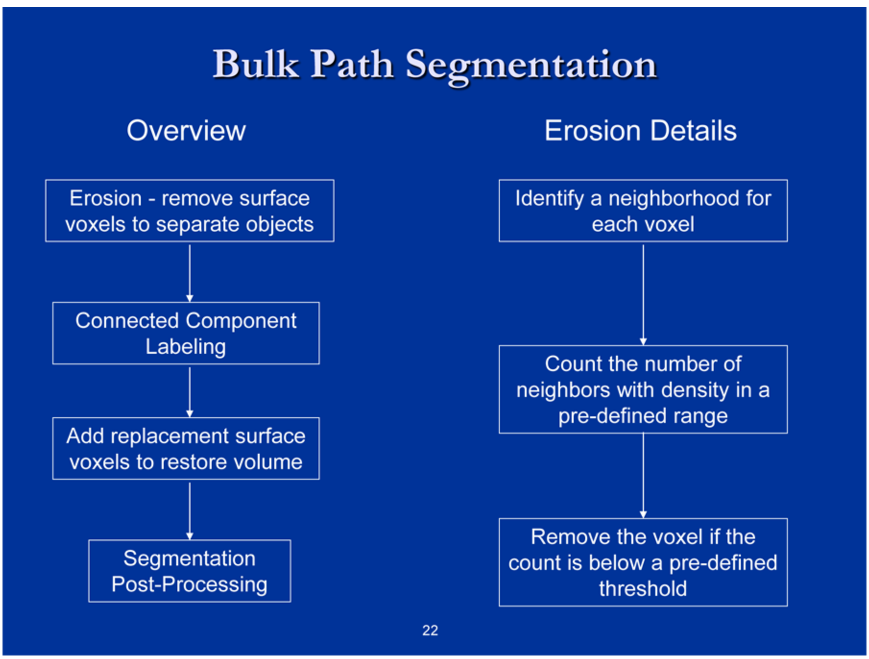
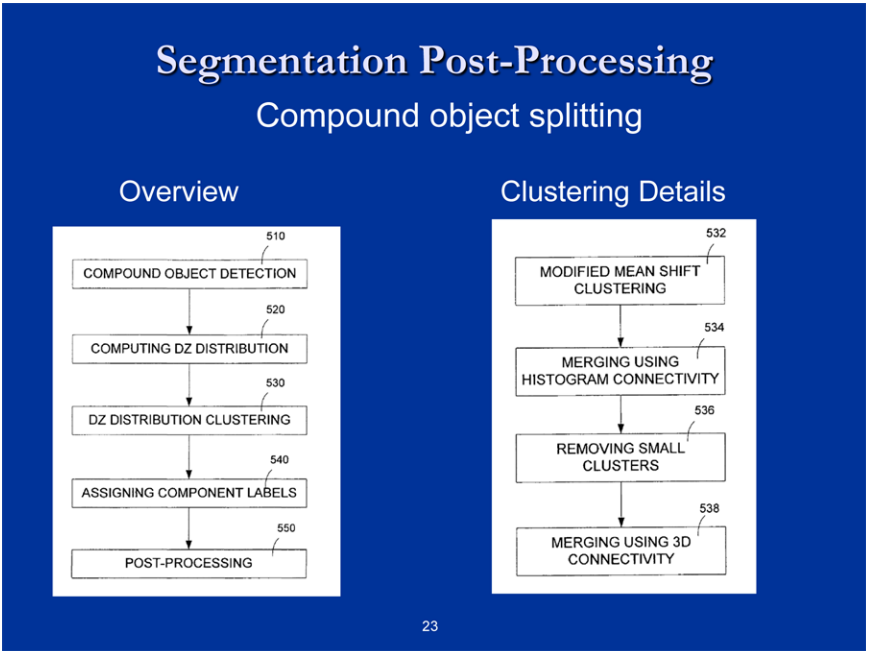
Detection Algorithm Overview

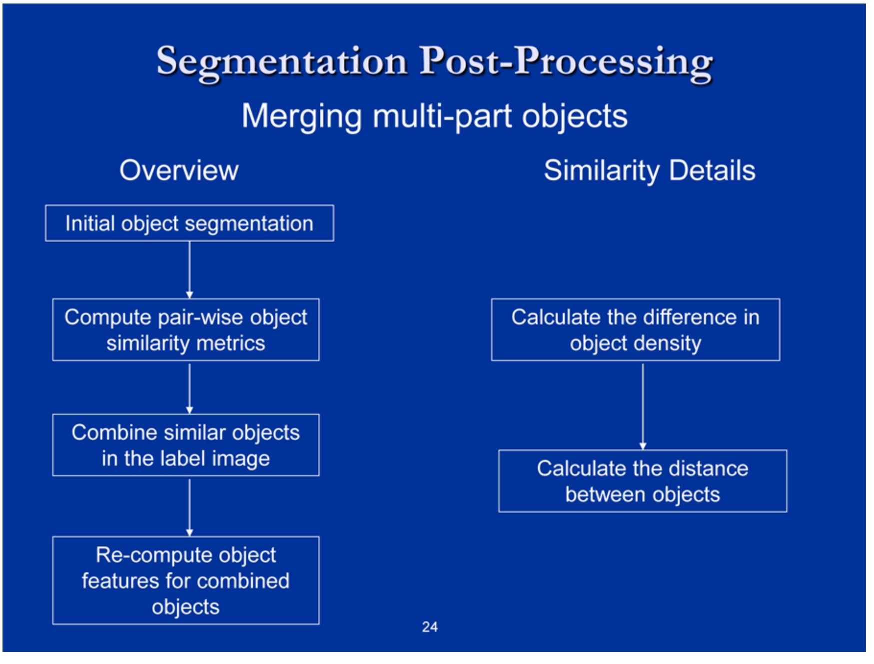


20


Sheet Path Segmentation
Overview
CFAR Details
BAG IMAGE
302
CFAR
318
CCL
320
DISCRIMINATION
306
LABEL IMAGE
OF SHEET EXPLOSIVES
BACKGROUND 321
TEST PIXEL, 319
SHEET EXPLOSIVE, 317
BACKGROUND, 321
TEST PIXEL, 319
BULK EXPLOSIVE, 325


Bulk Path Segmentation
Overview
Erosion - remove surface voxels to separate objects
Connected Component Labeling
Add replacement surface voxels to restore volume
Segmentation Post-Processing
Erosion Details
Identify a neighborhood for each voxel
Count the number of neighbors with density in a pre-defined range
Remove the voxel if the count is below a pre-defined threshold
22


Segmentation Post-Processing
Compound object splitting
Overview
Clustering Details
510
COMPOUND OBJECT DETECTION
520
COMPUTING DZ DISTRIBUTION
530
DZ DISTRIBUTION CLUSTERING
540
ASSIGNING COMPONENT LABELS
550
POST-PROCESSING
532
MODIFIED MEAN SHIFT CLUSTERING
534
MERGING USING HISTOGRAM CONNECTIVITY
536
REMOVING SMALL CLUSTERS
538
MERGING USING 3D CONNECTIVITY
23


Segmentation Post-Processing
Merging multi-part objects
Overview
Similarity Details
Initial object segmentation
Compute pair-wise object similarity metrics
Combine similar objects in the label image
Re-compute object features for combined objects
Calculate the difference in object density
Calculate the distance between objects
24

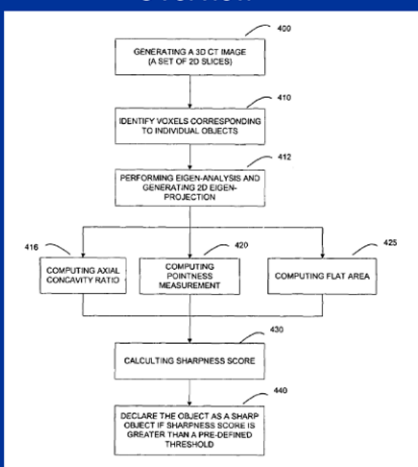
Mass Feature Extraction

CT Density Voxels
↓
Compare the density value of a voxel to a voxel density range
↓
If voxel value is within the density range: it is an object voxel
↓
Combine similar object voxel elements into an object
↓
Calculate effective object density
↓
Compare object density to a set of density ranges
↓
If density is within a defined range and associated defined mass range, calculate mass and compare to defined mass range

25

Sharp Object Feature Extraction

Overview



Pointness Feature Details

1. Calculating a 1-D profile from the eigen-projection
2. Computing a cumulative profile
3. Calculating an extent of the one-dimensional profile
4. Calculating two intercepts relative to the profile extent corresponding to 25% and 75% of the cumulative profile
5. Calculating the pointness measurement by finding the larger of the two intercepts.

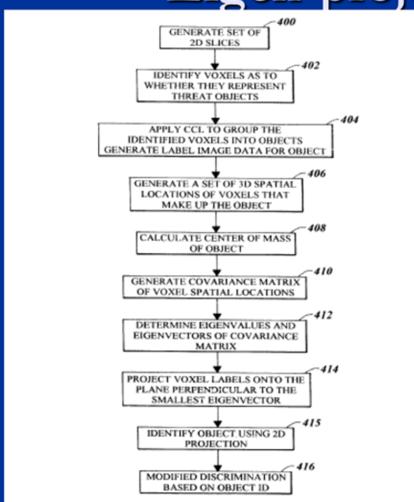
26

CT Corrections

- In bulks, replace surface voxels with core mean
- Monkey/duck – either look for duck or change duck to monkey
- In sheets, set thresholds based on blurred objects

27

Eigen-projections



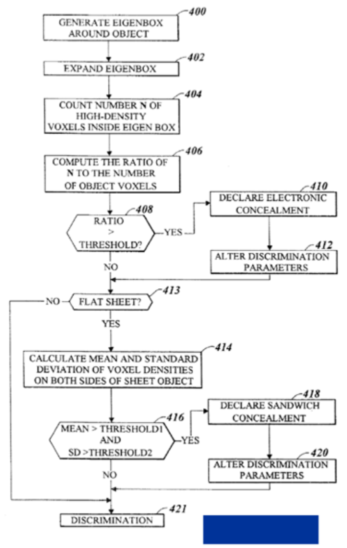
Project object voxels along direction of eign-vector corresponding to smallest eigen-value.

Reduces 3D segmentation to 2D, where your mind works.

Recall going into dark room for the weekend.

28

Non-linear Discrimination Thresholds



Electronic concealment generates streak artifacts

Sandwich concealment generates partial volume artifacts

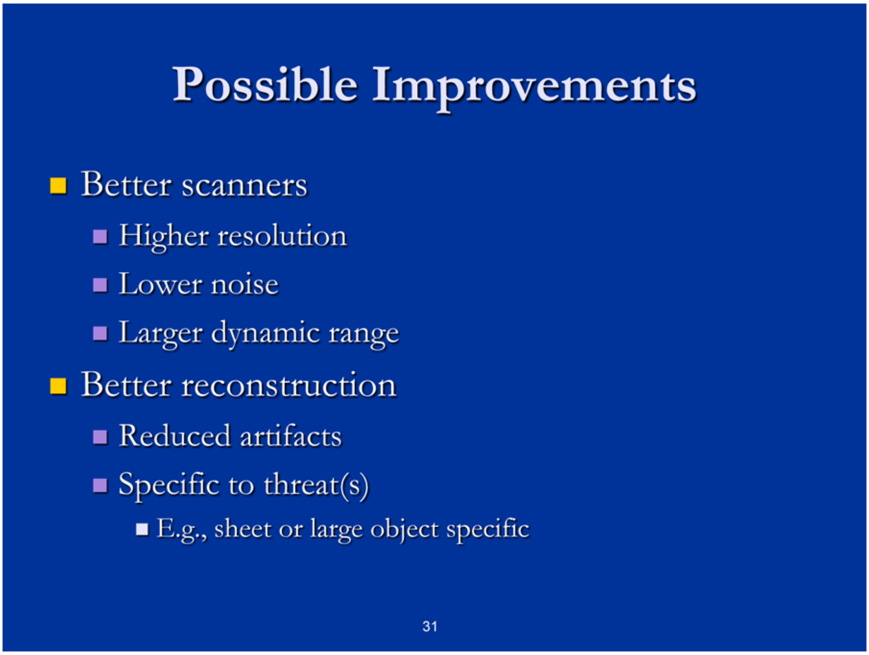
Corner cases: special cases for each type of threat and configuration

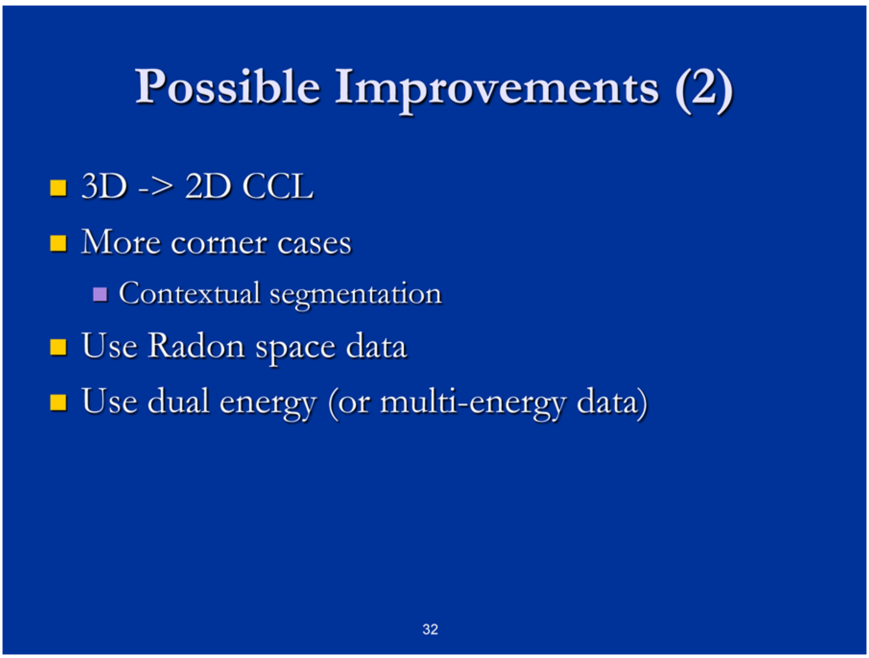
29

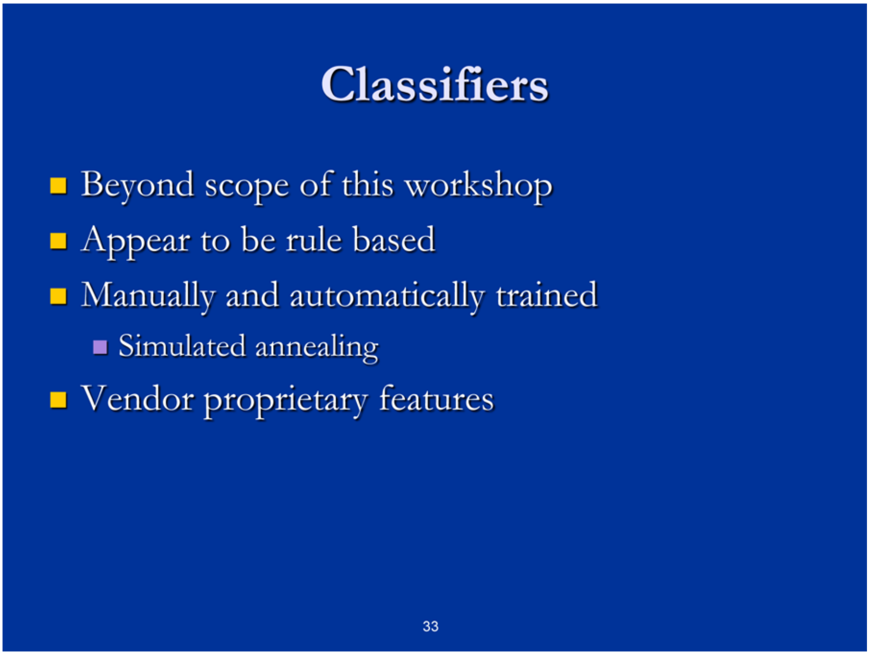
Other Paths

- Shield alarms
- *Difficult* configurations
  - Sheet in front/back of bag

30


Possible Improvements
Better scanners
Higher resolution
Lower noise
Larger dynamic range
Better reconstruction
Reduced artifacts
Specific to threat(s)
E.g., sheet or large object specific
31


Possible Improvements (2)
3D -> 2D CCL
More corner cases
Contextual segmentation
Use Radon space data
Use dual energy (or multi-energy data)
32


Classifiers
Beyond scope of this workshop
Appear to be rule based
Manually and automatically trained
Simulated annealing
Vendor proprietary features
33

26.4 Simon Warfield Presentation Slides

Computational Radiology Laboratory
Harvard Medical School
www.crl.med.harvard.edu

Children's Hospital
Department of Radiology
Boston Massachusetts

Grand Challenge in Medical Imaging: Segmentation of Multiple Sclerosis Lesions from MRI

Simon K. Warfield, Ph.D.
Associate Professor of Radiology
Director of Radiology Research
Department of Radiology
Children's Hospital Boston

Children's Hospital Boston
The Hospital for Children

Outline

- Why a grand challenge competition for medical image segmentation?
- Evaluation of disease burden and disease activity in Multiple Sclerosis
- The MS lesion segmentation competition
- Segmentation algorithms
- Validation of image segmentation (STAPLE)

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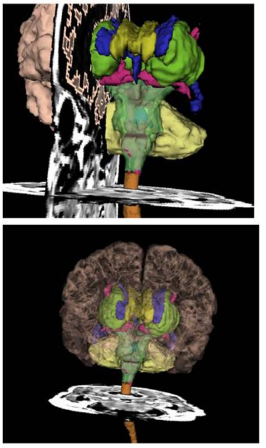
Slide 2

Segmentation

- Goal: identify or label structures present in the image.
- Many methods:
  - Interactive or manual delineation,
  - Supervised approaches with user initialization,
  - Alignment with a template,
  - Statistical pattern recognition.
- Applications:
  - Quantitative measurement of volume, shape or location of structures,
  - Provides boundary for visualization by surface rendering.



Newborn MRI Segmentation.

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Grand challenge: Segmentation

- Progress in segmentation in medical image analysis:
  - Many algorithms proposed
  - Hard to judge progress
- Experiments are performed on data selected by the researchers
- For most tasks, there is *easy* and *hard* data
- Studies on the same topic are therefore **incomparable**

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Grand challenge: Segmentation

"When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of the meager and unsatisfactory kind."

Lord Kelvin

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Grand challenge: Segmentation

- Public data repositories are just the first step towards a solution
- But:
  - Picking cases for such databases is common
  - Evaluation strategies differ between studies
- So the studies **are still incomparable**

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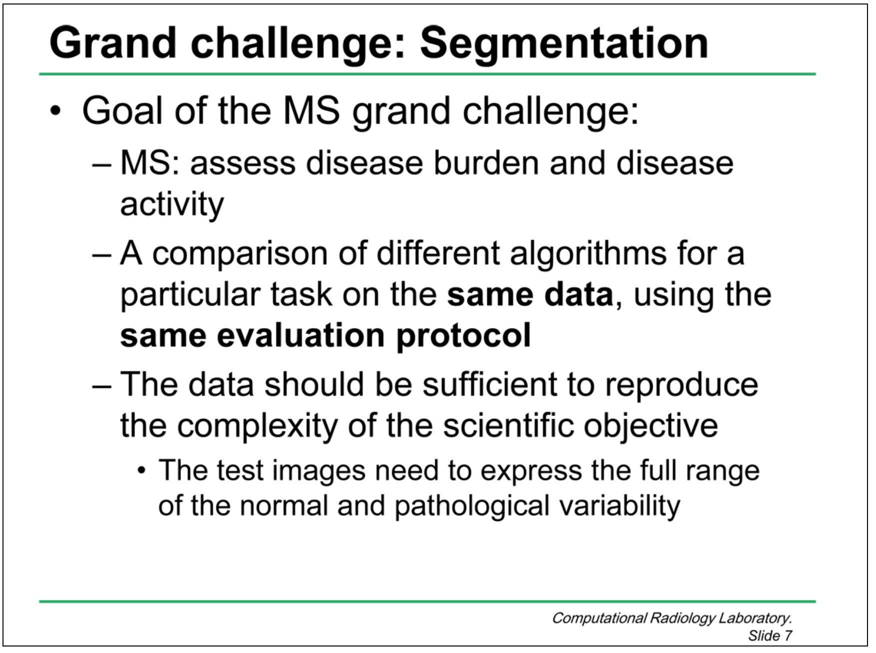
Grand challenge: Segmentation
• Goal of the MS grand challenge:
– MS: assess disease burden and disease activity
– A comparison of different algorithms for a particular task on the **same data**, using the **same evaluation protocol**
– The data should be sufficient to reproduce the complexity of the scientific objective
• The test images need to express the full range of the normal and pathological variability
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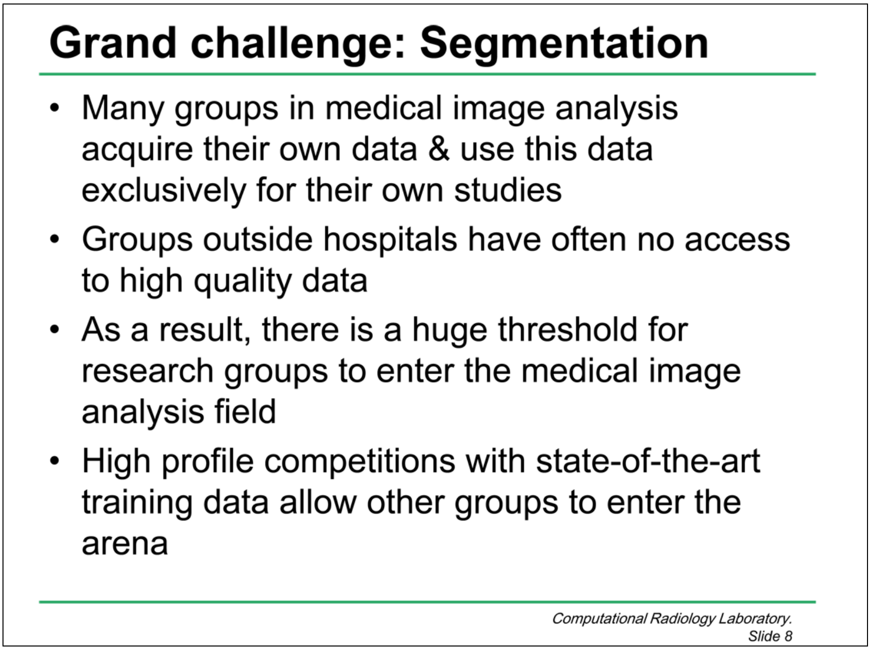
Grand challenge: Segmentation
• Many groups in medical image analysis acquire their own data & use this data exclusively for their own studies
• Groups outside hospitals have often no access to high quality data
• As a result, there is a huge threshold for research groups to enter the medical image analysis field
• High profile competitions with state-of-the-art training data allow other groups to enter the arena
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Multiple Sclerosis

- MRI provides images of brains of patients
- Can we assess disease burden ?
- Can we assess disease activity ?
- Can we provide a prognosis for an individual patient ?
- Can we better evaluate new disease modifying therapies ?

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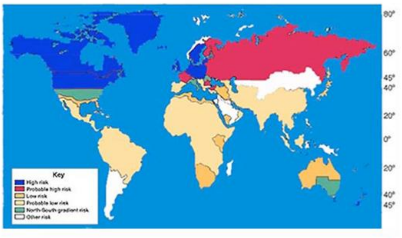
MS Lesion Segmentation

- Multiple Sclerosis
  - Demyelinating disease
  - Auto-immune, prevalence: ~1 per 1,000
  - Inflammation in white matter
  - Destruction of oligodendrocytes and myelin
  - Visually apparent in MRI as lesions



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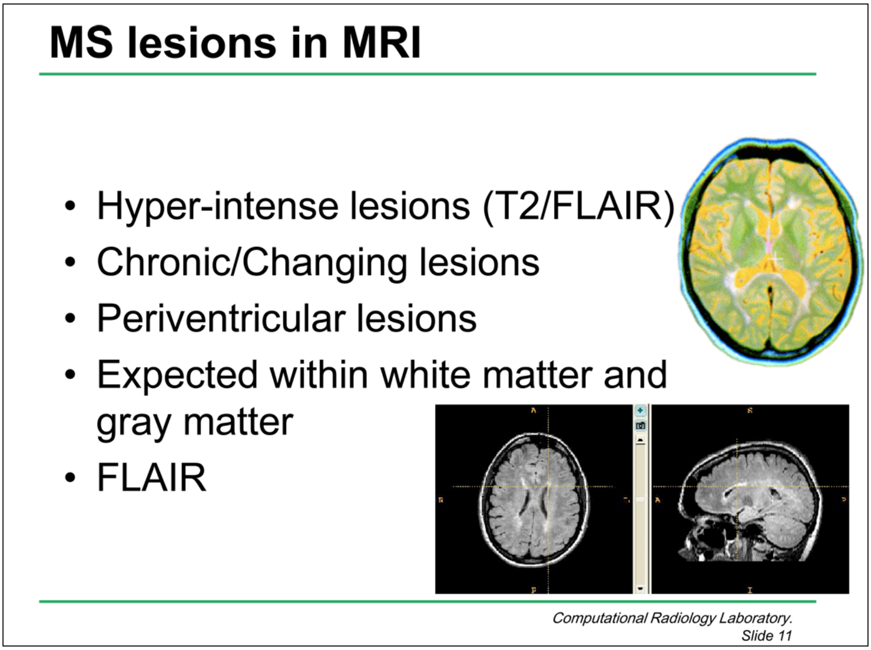
MS lesions in MRI
• Hyper-intense lesions (T2/FLAIR)
• Chronic/Changing lesions
• Periventricular lesions
• Expected within white matter and gray matter
• FLAIR
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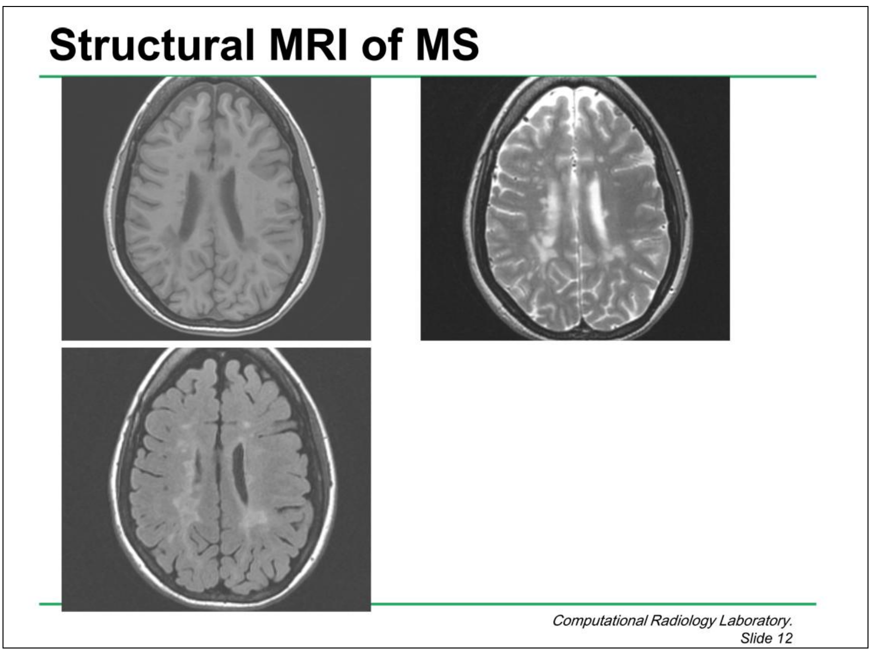
Structural MRI of MS
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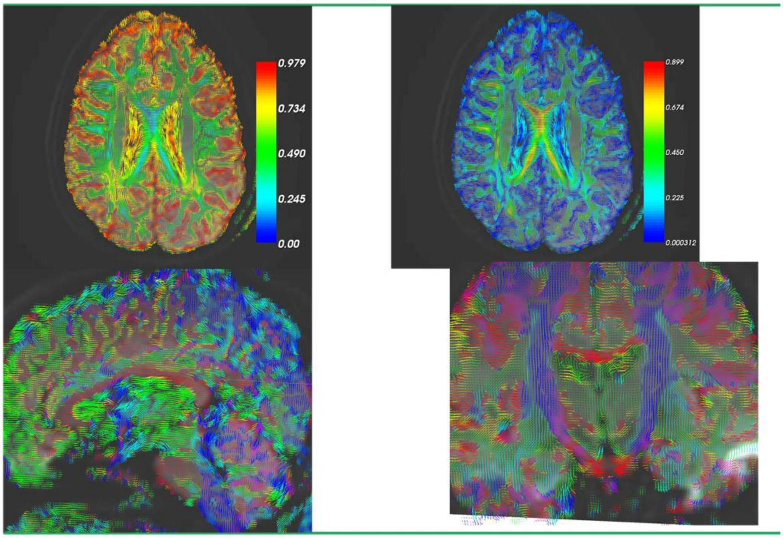
Diffusion Imaging in MS



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Structural MRI measures

- Segmentation of
  - Cortical gray matter
  - Basal ganglia
  - White matter
  - Cerebrospinal fluid
  - White matter lesions
- Lesion burden assessment:
  - White matter lesion volume
- Whole brain and regional tissue volume
- Atrophy assessment:
  - Brain parenchyma fraction
  - Cortical thickness

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MS Competition Image Data

- UNC datasets (Valerie Jewells)
  - 10 training, 10 + 4 testing datasets
- Boston CHB datasets
  - 10 training, 15 + 3 testing datasets
- Subjects at various stages of disease

- Pre-workshop and onsite testing: total 53 datasets
  - High-res T1w, T2w, FLAIR, DTI-FA, DTI-MD
  - Aligned and resampled at 0.5mm isotropic
    - Original data had 0.5x0.5mm in-plane for most datasets
    - Coarse b-spline based NMI registration (Rueckert) for DTI
- Random assignment to training and testing

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Reference Standard Segmentation

- Reference data from 3 raters:
  - Rater CHB: all cases (on time)
  - Rater UNC-1: only UNC training cases
  - Rater UNC-2: all cases (too late)
- 2 protocols: UNC-1 and CHB, similar on paper
  - UNC-2: trained on UNC method, adapted to match CHB
- Manual segmentation
  - Time intensive job: per case 1-2 hours (UNC, InsightSNAP)
- Training on CHB-rater
- Testing on CHB & UNC-2

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Metrics/Scores

- General metrics/scores
  - Volume difference: mm^3
  - Volumetric overlap (Tanimoto) error: 0 is best
  - Mean surface distance
  - True-Positive rate: #(Seg overlaps Ref) / #Ref
    - 100 is best
  - False Negative rate: #(Seg misses Ref) / #Seg
    - 0 is best, empty segmentation gives best score
- Volumetric too sensitive & variable, excluded
- Pre-workshop & onsite performance average

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Scores

- Metric scores of algorithms were scaled to be related to the expert segmentations
  - Within expert score set to 90

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The Methods

- 30 downloads, 9 submissions
- All fully automatic algorithms
  - 3 Outlier detection from classification
  - 4 intensity based classifier adapted for MS task
  - 1 Vector image joint histogram classifier
  - 1 Contextual model

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Onsite Testing Result

1st Author	Site	Rank Final
JC Souplet	INRIA	1 / 77
P Anbeek	Utrecht	2 / 76
N Sheen	JHU	3 / 75
D Garcia	Visage	4 / 71
S Bricq	MIV	5 / 68
J Morra	UCLA	5 / 68
M Scully	MRN	7 / 66
M Prastawa	Utah	7 / 66
DJ Kroon	Twente	9 / 61

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The Winning Scoresheet

Ground Truth	UNC Rater								CHB Rater									STAPLE		
All Dataset	Volume Diff.		Avg. Dist.		True Pos.		False Pos.		Volume Diff.		Avg. Dist.		True Pos.		False Pos.		Total	Specificity	Sensitivity	PPV
	[%]	Score	[mm]	Score	[%]	Score	[%]	Score	[%]	Score	[mm]	Score	[%]	Score	[%]	Score				
UNC test1 Case01	56.6	92	4.8	90	51.2	81	75.7	64	36.5	95	5.3	89	53.1	82	69.2	68	82	0.9936	0.3248	0.7049
UNC test1 Case02	7.7	99	4.1	92	54.4	82	72.5	65	87.8	87	3.5	93	40.9	75	31.9	90	85	0.9949	0.1782	0.8373
UNC test1 Case03	46.2	93	1.5	97	53.5	82	49.4	80	30.5	96	1.3	97	55.9	83	40.6	85	89	0.9947	0.6529	0.8708
UNC test1 Case04	90.6	87	8.6	82	34.2	71	86.4	57	85.5	87	7.1	85	48.1	79	86.4	57	76	0.9955	0.0587	0.5161
UNC test1 Case05	53.4	92	6.0	88	52.4	81	75.2	64	5.3	99	6.4	87	78.3	96	77.9	62	84	0.9906	0.3695	0.6164
UNC test1 Case06	81.1	88	7.0	86	41.4	75	71.4	66	15.5	98	19.4	60	62.5	87	86.9	57	77	0.9932	0.1438	0.5770
UNC test1 Case07	45.6	93	2.6	95	55.7	83	58.3	74	26.2	96	6.4	87	80.0	97	71.5	66	86	0.9883	0.5412	0.6463
UNC test1 Case08	21.1	97	3.9	92	63.8	88	65.2	70	28.9	96	10.6	78	94.4	100	76.1	63	85	0.9865	0.5983	0.5587
UNC test1 Case09	157.9	77	44.0	9	33.3	70	96.6	51	263.9	61	53.0	0	0.0	51	100.0	49	46	0.9733	0.1110	0.0873
UNC test1 Case10	73.0	89	13.0	73	45.0	77	85.2	58	525.2	23	22.5	54	83.3	99	93.8	53	66	0.9847	0.6041	0.5892
CHB test1 Case01	70.3	90	3.9	92	52.0	81	27.6	93	57.6	92	2.6	95	83.9	99	35.3	88	91	0.9990	0.2075	0.8462
CHB test1 Case02	32.7	95	6.2	87	63.6	88	84.1	58	71.3	90	2.3	95	63.2	87	41.3	84	86	0.9965	0.2960	0.8138
CHB test1 Case03	48.9	93	11.6	76	50.0	80	87.7	56	75.3	89	12.2	75	33.3	70	90.4	55	74	0.9958	0.2282	0.4562
CHB test1 Case04	50.2	93	5.2	89	72.7	93	81.0	60	76.1	89	3.8	92	72.2	93	50.0	79	86	0.9992	0.1735	0.9193
CHB test1 Case05	36.8	95	8.8	82	48.1	79	92.5	53	74.0	89	3.2	93	69.6	91	71.0	66	81	0.9940	0.1492	0.5690
CHB test1 Case06	69.9	90	6.7	86	16.7	61	93.0	53	68.6	90	6.6	86	27.3	67	90.6	54	73	0.9819	0.0284	0.1001
CHB test1 Case07	62.7	91	5.5	89	48.3	79	85.6	58	77.3	89	4.8	90	55.3	83	74.0	65	80	0.9913	0.1085	0.4856
CHB test1 Case08	49.6	93	2.1	96	81.5	98	74.8	64	66.3	90	2.3	95	61.8	87	62.9	71	87	0.9964	0.3129	0.8219
CHB test1 Case09	56.3	92	3.6	92	34.9	71	69.6	67	63.1	91	2.6	95	35.8	72	55.4	76	82	0.9949	0.2781	0.7949
CHB test1 Case10	3.4	100	7.4	85	68.4	90	93.4	53	49.4	93	3.9	92	79.3	97	76.4	63	84	0.9908	0.1984	0.5123
CHB test1 Case11	16.3	98	6.0	88	47.7	79	91.4	54	72.9	89	3.6	93	51.7	81	81.7	60	80	0.9920	0.1657	0.5317
CHB test1 Case12	86.0	87	7.1	85	12.0	58	81.7	60	86.1	87	6.8	86	15.4	60	77.7	62	73	0.9872	0.0200	0.1141
CHB test1 Case13	50.0	93	5.4	89	50.0	80	85.4	58	69.3	90	4.6	91	76.2	95	64.6	70	83	0.9938	0.3095	0.7506
CHB test1 Case15	71.9	89	2.6	95	53.4	82	44.6	82	62.9	91	1.9	96	57.4	84	49.7	79	87	0.9965	0.2639	0.8947
All Average test1	55.8	92	7.4	85	49.4	80	76.2	63	86.5	87	8.2	84	57.5	84	69.0	68	80	0.9919	0.2634	0.6089
All UNC test1	63.3	91	9.5	80	48.5	79	73.6	65	110.5	84	13.5	73	59.7	85	73.4	65	78	0.9895	0.3583	0.6004
All CHB test1	50.4	93	5.9	88	50.0	80	78.0	62	69.3	90	4.4	91	55.9	83	65.8	70	82	0.9935	0.1957	0.6150
UNC test2 Case01	44.1	94	1.8	96	61.1	86	25.6	94	41.8	94	1.6	97	78.1	96	29.4	92	94	-	-	-
UNC test2 Case02	24.2	96	14.8	70	40.0	74	89.4	55	467.8	32	41.0	16	66.7	89	97.0	51	60	-	-	-
UNC test2 Case03	2.5	100	18.5	62	40.0	74	90.8	54	273.3	60	29.6	39	100.0	100	95.4	52	68	-	-	-
UNC test2 Case04	7.7	99	15.2	69	50.0	80	89.7	55	73.1	89	33.1	32	75.0	94	94.3	52	71	-	-	-
CHB test2 Case01	73.1	89	4.6	91	52.5	81	60.8	73	76.9	89	2.8	94	66.7	89	55.6	76	85	-	-	-
CHB test2 Case02	27.4	96	5.8	88	45.3	77	83.4	59	70.5	90	3.3	93	44.0	76	72.0	66	81	-	-	-
CHB test2 Case03	22.8	97	33.5	31	0.0	51	100.0	49	150.8	78	36.8	24	0.0	51	100.0	49	54	-	-	-
All Average test2	28.8	96	13.5	72	41.3	75	77.1	63	164.9	76	21.2	56	61.5	85	77.6	62	73	-	-	-
All UNC test2	19.6	97	12.6	74	47.8	79	73.9	65	214.0	69	26.3	46	79.9	95	79.0	62	73	-	-	-
All CHB test2	41.1	94	14.6	70	32.6	70	81.4	60	99.4	85	14.3	71	36.9	72	75.9	63	73	-	-	-
All Average	43.6	94	10.7	78	44.7	77	76.7	63	123.3	82	14.6	70	58.1	84	73.5	65	77	-	-	-
All UNC	41.5	94	11.1	77	48.1	79	73.7	65	162.3	76	19.9	59	69.8	90	76.2	63	75	-	-	-
All CHB	45.7	93	10.2	79	41.3	75	79.7	61	84.3	88	9.3	81	46.4	78	70.8	67	78	-	-	-

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More Results: Pre vs Onsite

1st Author	Site	Rank Pre	Rank Onsite	Rank Final
S Bricq	MIV	1 / 82	9 / 54	5 / 68
JC Souplet	INRIA	2 / 80	2 / 73	1 / 77
N Sheen	JHU	3 / 80	3 / 69	3 / 75
D Garcia	Visage	4 / 79	5 / 62	4 / 71
P Anbeek	Utrecht	5 / 78	1 / 75	2 / 76
J Morra	UCLA	6 / 77	6 / 61	5 / 68
M Scully	MRN	7 / 67 / 73	7 / 59	7 / 66
M Prastawa	Utah	8 / 66	4 / 65	7 / 66
DJ Kroon	Twente	9 / 66	8 / 56	9 / 61

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More Results: Metrics

1st Author	Site	Rank Final	Rank Volume	Rank Distance	Rank TPR	Rank FNR
S Bricq	MIV	68	84	53	64	72
JC Souplet	INRIA	77	88	74	81	64
N Sheen	JHU	75	79	75	80	65
D Garcia	Visage	71	83	54	72	74
P Anbeek	Utrecht	76	87	79	78	61
J Morra	UCLA	68	86	58	63	78
M Scully	MRN	66	84	52	69	59
M Prastawa	Utah	66	86	48	57	72
DJ Kroon	Twente	61	44	72	76	53

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Results: CHB vs UNC rater

1st Author	Site	Rank CHB	Rank UNC	Rank Final
S Bricq	MIV	67	69	68
JC Souplet	INRIA	75	78	77
N Sheen	JHU	75	74	75
D Garcia	IRISA	72	70	71
P Anbeek	Utrecht	78	74	76
J Morra	UCLA	67	70	68
M Scully	MRN	65	66	66
M Prastawa	Utah	65	67	66
DJ Kroon	Twente	58	64	61

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Conclusion

- We have a winner!
- Metrics matter, but overall agreement
  - Slightly different ranking
- UNC vs CHB rater ratings differ minimally, despite only training on CHB rater
  - 2 comparable expert segmentations
  - Online competition continued after workshop

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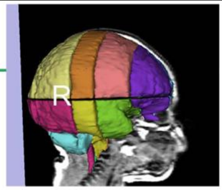
Image Segmentation



- Segmentation issues:
  - Interactive segmentation:
    - time consuming.
    - significant intra-rater and inter-rater variability (Warfield et al. 1995).
  - Automatic segmentation:
    - Challenges.
      - Imaging artifacts.
      - Normal and pathological variability.
    - Prospects:
      - Objective assessment of imaging data.

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Image Segmentation

- Interactive estimate of boundary, followed by solution of an optimization problem to find the final boundary:
  - Active contour/deformable models
    - Kass, Witkin and Terzopolous 1987
    - Xu and Prince 1998
    - Cootes, Taylor et al. 1995
  - Level set methods
    - Osher and Sethian 1988
  - Graph cut methods
    - Shi and Malik 2000

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Segmentation by Registration

- Construct an explicit template or atlas of the structures to be segmented.
- Align the template to the target by registration.
  - ANIMAL: Collins et al. 1997
  - Iosifescu et al. 1997
  - Rohlfing and Maurer 2005

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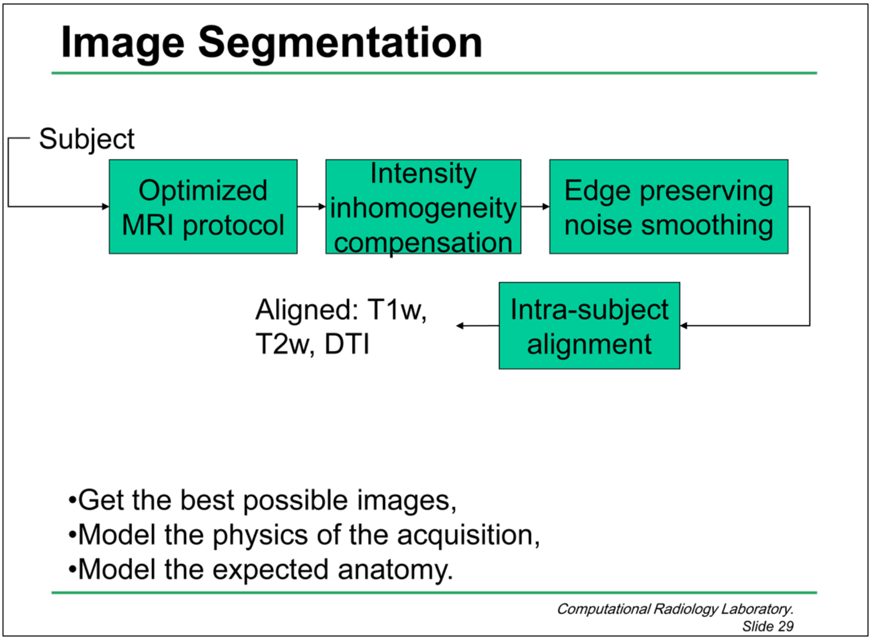
Image Segmentation
Subject
Optimized MRI protocol
Intensity inhomogeneity compensation
Edge preserving noise smoothing
Intra-subject alignment
Aligned: T1w, T2w, DTI
•Get the best possible images,
•Model the physics of the acquisition,
•Model the expected anatomy.
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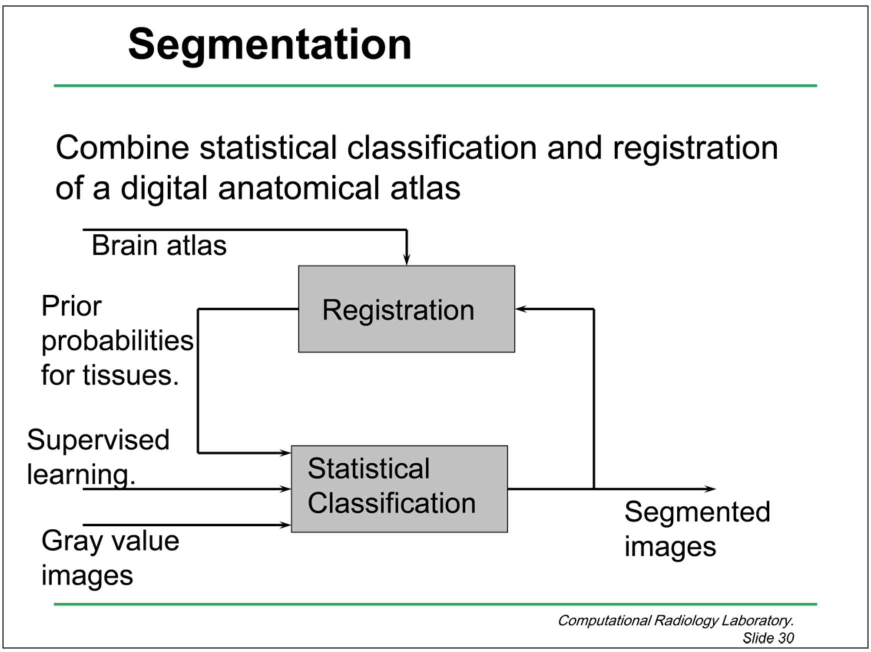
Segmentation
Combine statistical classification and registration of a digital anatomical atlas
Brain atlas
Registration
Prior probabilities for tissues.
Supervised learning.
Statistical Classification
Gray value images
Segmented images
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Validation of Image Segmentation

- Segmentation critical to creating imaging biomarkers.
- STAPLE (Simultaneous Truth and Performance Level Estimation):
  - An algorithm for estimating performance and ground truth from a collection of independent segmentations.
    - Warfield, Zou, Wells MICCAI 2002.
    - Warfield, Zou, Wells, IEEE TMI 2004.
    - Warfield, Zou, Wells, MICCAI 2006.
    - Commowick and Warfield IEEE TMI 2008.

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Validation of Image Segmentation

- Spectrum of accuracy versus realism in reference standard.
- Digital phantoms.
  - Ground truth known accurately.
  - Not so realistic.
- Acquisitions and careful segmentation.
  - Some uncertainty in ground truth.
  - More realistic.
- Autopsy/histopathology.
  - Addresses pathology directly; resolution.
- Clinical data ?
  - Hard to know ground truth.
  - Most realistic model.

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Measures of Expert Performance

- Repeated measures of volume
  - Intra-class correlation coefficient.
- Bland-Altman methodology:
  - Compares two methods, typically one new method to an established reference method.
- Spatial overlap
  - Jaccard: Area of intersection over union.
  - Dice: increased weight of intersection.
  - Vote counting: majority rule, etc.
- Boundary measures
  - Hausdorff, 95% Hausdorff.
- Measures of correct classification rate:
  - Sensitivity, specificity (Pr(D=1|T=1), Pr(D=0|T=0))
  - Positive predictive value and negative predictive value (posterior probabilities Pr(T=1|D=1), Pr(T=0|D=0))

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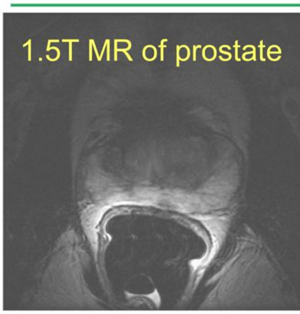
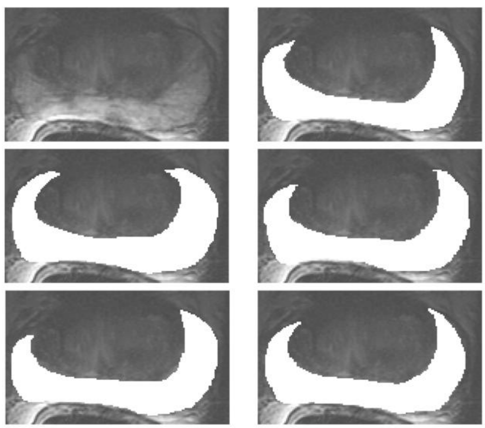
How to judge segmentations of the peripheral zone?



Peripheral zone and segmentations



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STAPLE: Estimation Problem

- Complete data density: $f(\mathbf{D}, \mathbf{T} \mid \mathbf{p}, \mathbf{q})$
  - Binary ground truth T_i for each voxel i.
  - Expert j makes segmentation decisions $D_{ij.}$
  - Expert performance characterized by sensitivity p and specificity q.
  - We observe expert decisions **D**. If we knew ground truth **T**, we could construct maximum likelihood estimates for each expert's sensitivity (true positive fraction) and specificity (true negative fraction):

$$\hat{\mathbf{p}}, \hat{\mathbf{q}} = \arg\max_{\mathbf{p},\mathbf{q}} \ln f(\mathbf{D}, \mathbf{T} \mid \mathbf{p}, \mathbf{q})$$

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Expectation-Maximization

- Since we don't know ground truth **T**, treat **T** as a random variable, and solve for the expert performance parameters that maximize:

$$Q(\theta \mid \theta^{(t-1)}) = E\left[\ln f(\mathbf{D}, \mathbf{T} \mid \theta) \mid \mathbf{D}, \theta^{(t-1)}\right]$$

- Parameter values $\boldsymbol{\theta}_j = [p_j \; q_j]^T$ that maximize the conditional expectation of the log-likelihood function are found by iterating two steps:
  - E-step: Estimate probability of hidden ground truth **T** given a previous estimate of the expert quality parameters, and take expectation.
  - M-step: Estimate expert performance parameters by comparing **D** to the current estimate of **T**.

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True Segmentation Estimate

$$W_i^k \equiv f(T_i = 1 \mid \mathbf{D_i}, \mathbf{p}^k, \mathbf{q}^k)$$

$$= \frac{\prod_j f(D_{ij} \mid T_i = 1, p_j^k, q_j^k) f(T_i = 1)}{\sum_{T_i'} \prod_j f(D_{ij} \mid T_i', p_j^k, q_j^k) f(T_i')}$$

$$= \frac{\alpha^k}{\alpha^k + \beta^k}$$

$$\alpha^k = f(T_i = 1) \prod_{j:D_{ij}=1} p_j^k \prod_{j:D_{ij}=0} (1 - p_j^k)$$

$$\beta^k = f(T_i = 0) \prod_{j:D_{ij}=0} q_j^k \prod_{j:D_{ij}=1} (1 - q_j^k)$$

$f(T_i = 1)$: prior probability true label at voxel i is 1.

W_i^k : conditional probability that true label is 1.

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Expert Performance Estimate

$$p_j^{k+1} = \frac{\sum_{i:D_{ij}=1} W_i^k}{\sum_{i:D_{ij}=1} W_i^k + \sum_{i:D_{ij}=0} W_i^k}$$

$$q_j^{k+1} = \frac{\sum_{i:D_{ij}=0} (1 - W_i^k)}{\sum_{i:D_{ij}=1} (1 - W_i^k) + \sum_{i:D_{ij}=0} (1 - W_i^k)}$$

p (sensitivity, true positive fraction) : ratio of expert identified class 1 to total class 1 in the image.

q (specificity, true negative fraction) : ratio of expert identified class 0 to total class 0 in the image.

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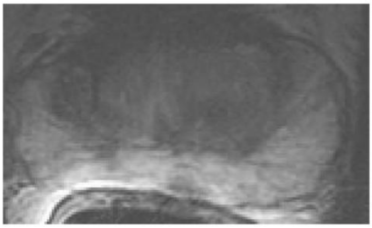
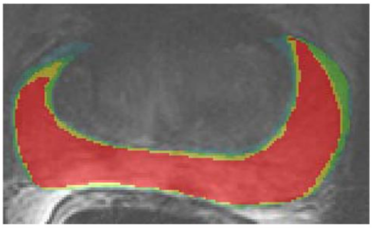
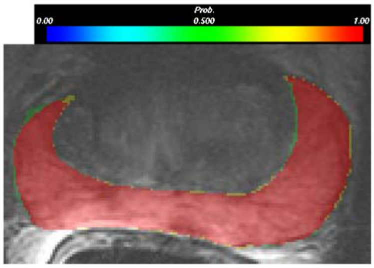
Prostate Peripheral Zone



	1	2	3	4	5
p_j	.879	.991	.937	.918	.895
q_j	.998	.994	.999	.999	.999
Dice	.913	.951	.967	.955	.944



Frequency of selection by experts.



STAPLE truth estimate

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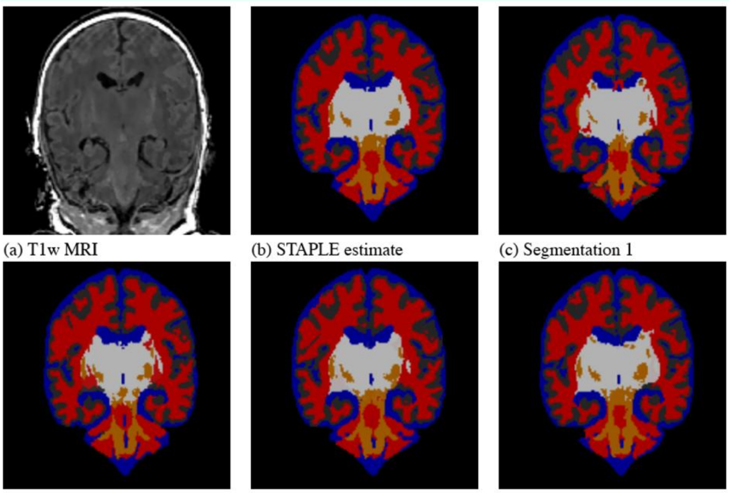
Newborn MRI Segmentation



(a) T1w MRI (b) STAPLE estimate (c) Segmentation 1
(d) Segmentation 2 (e) Segmentation 3 (f) Segmentation 4

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Newborn MRI Segmentation

Segmentation	BG	CGM	CSF	MWM	UNWM	SCG
1	0.997	0.763	0.945	0.889	0.914	0.904
2	0.998	0.937	0.926	0.961	0.899	0.920
3	0.999	0.939	0.903	0.911	0.922	0.985
4	0.999	0.958	0.923	0.900	0.973	0.945
5	0.998	0.871	0.911	0.934	0.913	0.954

Summary of segmentation quality (posterior probability Pr(T=t|D=t)) for each tissue type for repeated manual segmentations.

Indicates limits of accuracy of interactive segmentation.

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STAPLE Summary

- Key advantages of STAPLE:
  - Estimates ``true'' segmentation.
  - Assesses expert performance.
- Principled mechanism which enables:
  - Comparison of different experts.
  - Comparison of algorithm and experts.

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Conclusion

- Grand challenge of MS segmentation
  - Definition of the problem (the challenge)
  - Definition of the reference standard
  - Publically available training data and objective standardized evaluation
  - Hidden test data with objective standardized evaluation
  - Ongoing data and evaluation availability to the medical imaging community
  - Comparison of methods and validation with STAPLE.

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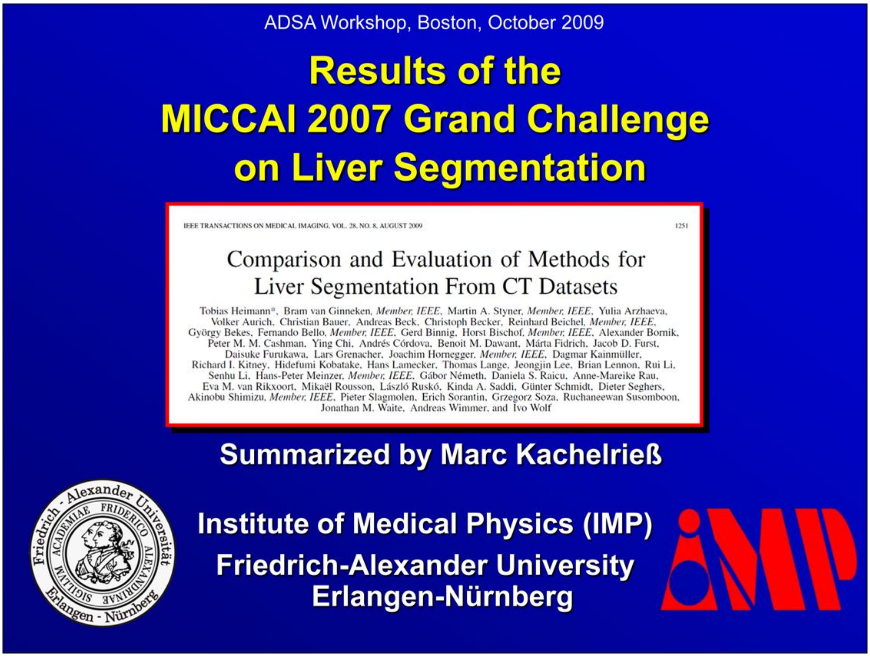
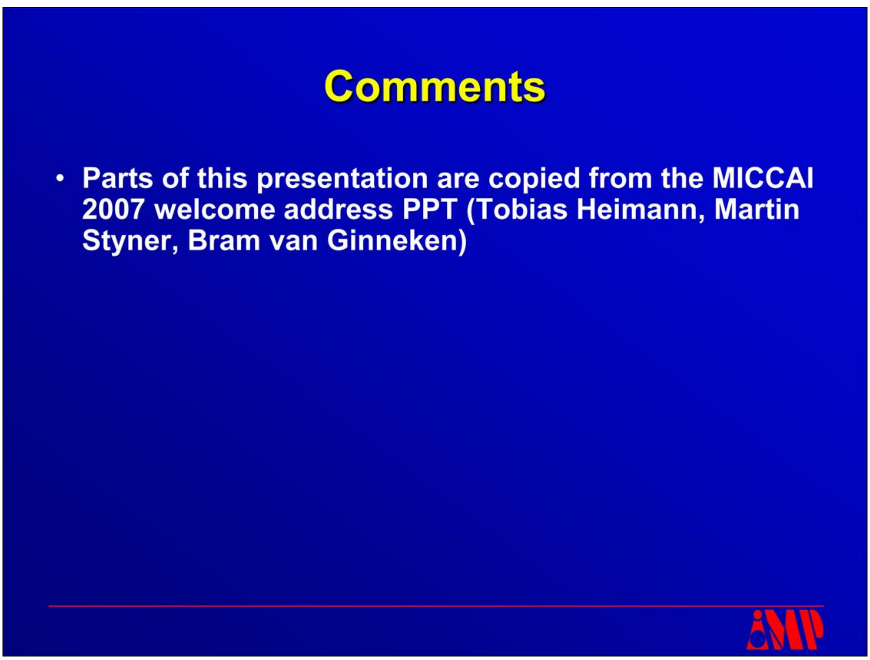
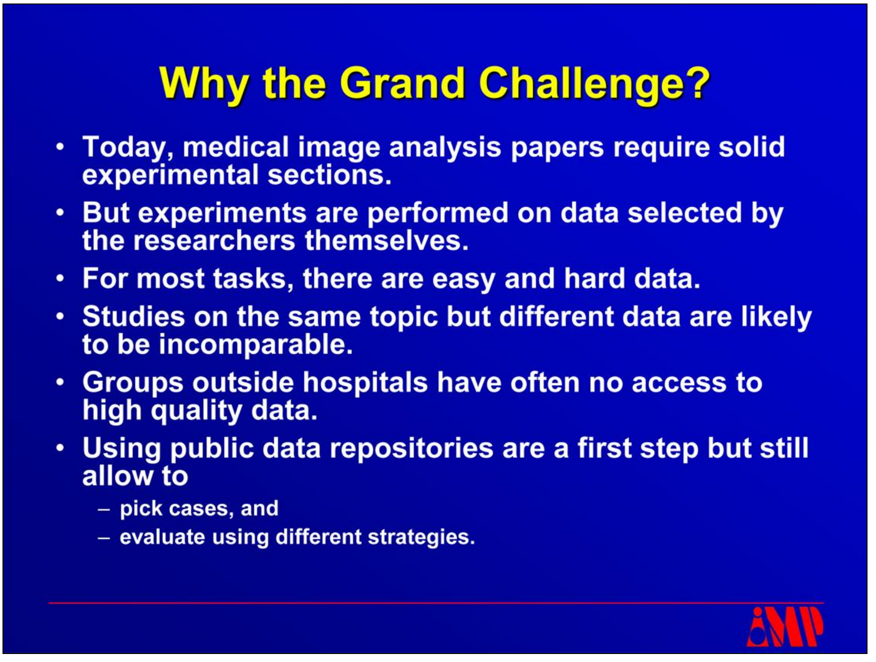
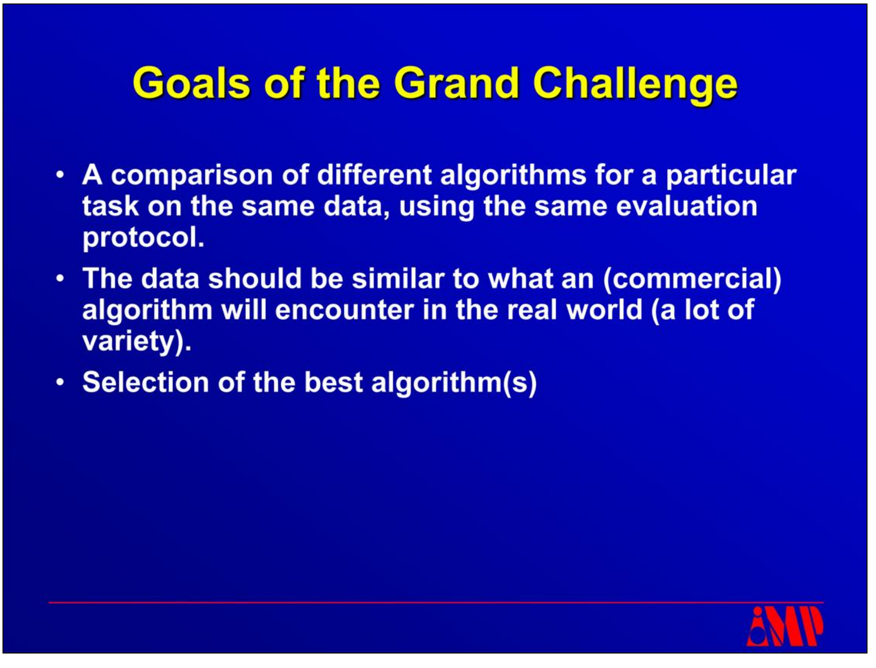
26.5 Marc Kachelriess Presentation Slides






Why the Grand Challenge?
• Today, medical image analysis papers require solid experimental sections.
• But experiments are performed on data selected by the researchers themselves.
• For most tasks, there are easy and hard data.
• Studies on the same topic but different data are likely to be incomparable.
• Groups outside hospitals have often no access to high quality data.
• Using public data repositories are a first step but still allow to
– pick cases, and
– evaluate using different strategies.

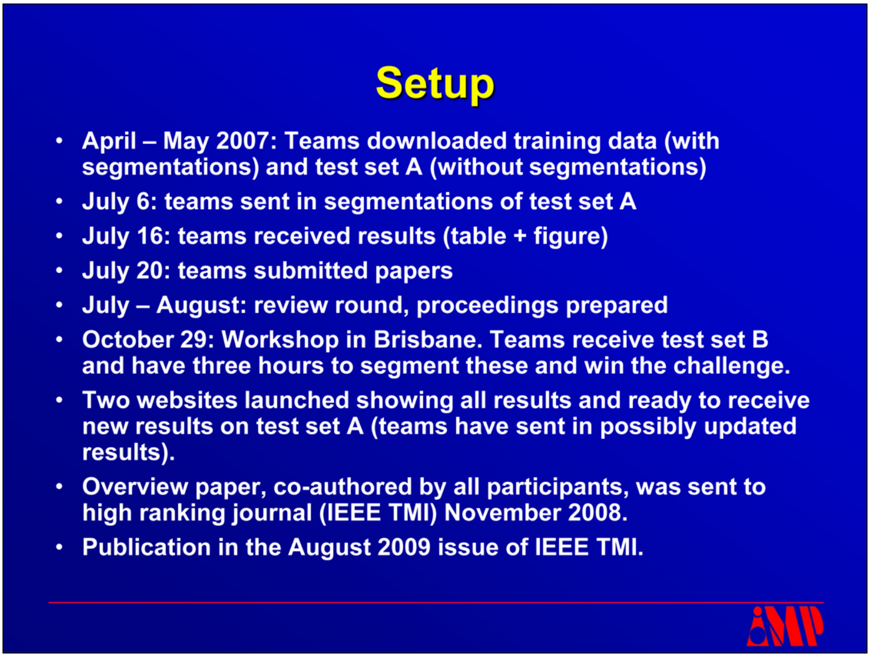

Goals of the Grand Challenge
• A comparison of different algorithms for a particular task on the same data, using the same evaluation protocol.
• The data should be similar to what an (commercial) algorithm will encounter in the real world (a lot of variety).
• Selection of the best algorithm(s)

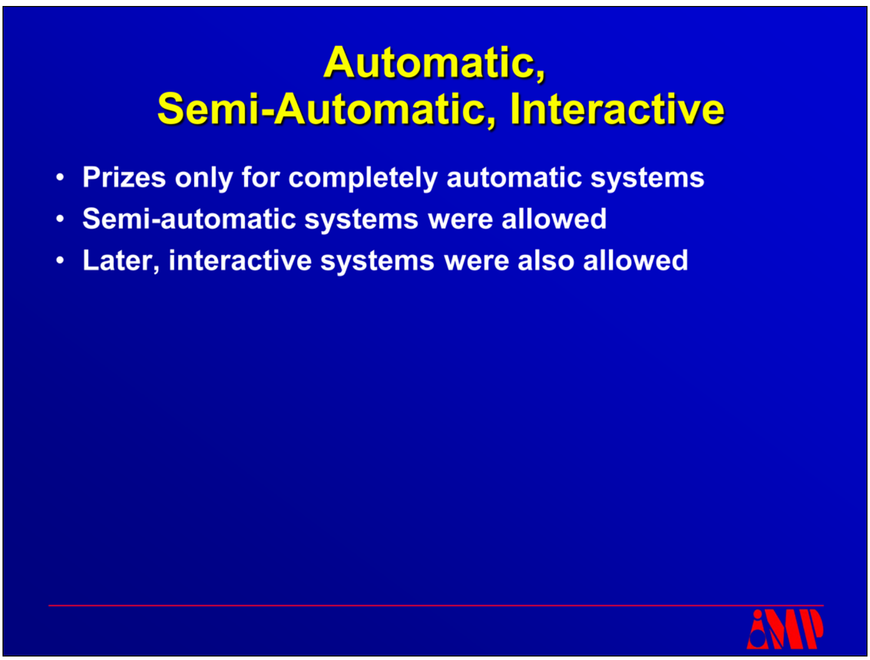
Result of the Netflix Competition

- www.netflixprize.com
- 22,041 teams from 161 countries signed up.
- 18,678 results were sent in by 2594 teams.
- Steady improvement: best result now 8.46% better than Netflix (10% wins $1M).
- A competition attracts enormous amounts of researchers to a field.

The Competition

- Segment the liver in abdominal CT scans
  - Data from different scanners and manufacturers and clinics
  - Training: 20 scans
  - Test set A: 10 scans
  - Test set B: 10 scans


Setup
• April – May 2007: Teams downloaded training data (with segmentations) and test set A (without segmentations)
• July 6: teams sent in segmentations of test set A
• July 16: teams received results (table + figure)
• July 20: teams submitted papers
• July – August: review round, proceedings prepared
• October 29: Workshop in Brisbane. Teams receive test set B and have three hours to segment these and win the challenge.
• Two websites launched showing all results and ready to receive new results on test set A (teams have sent in possibly updated results).
• Overview paper, co-authored by all participants, was sent to high ranking journal (IEEE TMI) November 2008.
• Publication in the August 2009 issue of IEEE TMI.


Automatic,
Semi-Automatic, Interactive
• Prizes only for completely automatic systems
• Semi-automatic systems were allowed
• Later, interactive systems were also allowed

Can this work?

- MICCAI refused workshop proposal: there will be not enough interest for this competition.
- Lobbying changed their mind.
- 44 teams signed up and downloaded data.
- 16 (= 10 + 6) systems for liver segmentation were submitted.
- 67 registrations for the workshop
- Sponsor money from Siemens and Chili Radiology

Scoring system

- Multiple segmentation performance metrics are in common use
- Five metrics were used
  - Volumetric overlap error (in %)
  - Relative volume difference (in %)
  - Average symmetric surface distance (in mm)
  - Root mean square symmetric surface distance (in mm)
  - Maximum symmetric surface distance (in mm)
- Gauged score:

$$\mathrm{Score}_i = \max\left(100 - 25\,\frac{\mathrm{AlgorithmError}_i}{\mathrm{AveragedUserError}_i},\ 0\right)$$

- Final score is the average of all 5 gauged scores.

The Automatic Algorithms

1. Shape-Constrained Segmentation with Heuristic Appearance Model, Kainmüller et al. [28]
2. Shape-Constrained Segmentation with Nonlinear Appearance Model, Heimann et al. [34]
3. Shape-Constrained Segmentation Using a Variational Framework, Saddi et al. [41]
4. Rule-Based Segmentation Using Scripting Language, Schmidt et al. [45]
5. Gradient Vector Flow Snake Using a Variational Framework, Chi et al. [46]
6. Three-Dimensional Region Growing, Ruskó et al. [49]
7. Shape-Constrained Segmentation Using a Local Shape Model, Seghers et al. [51] [52]
8. Bayesian Voxel Classification With Probabilistic Atlas and Level-Set Refinement, Furukawa et al. [53]
9. Non-Linear Voxel Classification With Multiatlas Segmentation, Rikxoort et al. [56]
10. Clustering, Voxel Classification and 2-D Region Growing, Susomboon et al. [61]

TABLE I
NUMBER OF TRAINING SAMPLES USED IN EACH AUTOMATIC METHOD. VALUES >20 MEAN THAT ADDITIONAL PROPRIETARY DATA WAS USED TO TRAIN THE ALGORITHM

Method	Number of used training samples
Kainmüller *et al.*	112
Heimann *et al.*	35
Saddi *et al.*	50
Schmidt *et al.*	0
Chi *et al.*	20
Ruskó *et al.*	0
Seghers *et al.*	20
Furukawa *et al.*	20
Rikxoort *et al.*	12
Susomboon *et al.*	20

The Interactive Algorithms

1. Graph-Cut and Interactive Refinement, Beichel et al. [64]
2. Region-Growing and Interactive Refinement, Beck and Aurich [68]
3. Two-Dimensional Level Sets with Transversal Contour Initialization, Dawant et al. [69]
4. Two-Dimensional Level Sets with Seed-Point Initialization, Lee et al. [71]
5. Three-Dimensional Level Sets with Orthogonal Contour Initialization, Wimmer et al. [75]
6. Atlas Matching Using B-Splines, Slagmolen et al. [78]

Characteristics

- Assumptions about patient orientation are made.
- Even then, a great deal of work needs to be done to find the correct initial pose or seed point.
- Often, parts of the segmentation are done slice-by-slice.
- Anatomy of surrounding organs (lung, heart, ribs, vena cava, skin) is used to
  - detect the liver (initial pose, seed point)
  - block segmentation boundary
- Very slow processing time (not optimized yet)

Techniques Used

- Statistical Shape Models
- Region Growing
- K-means clustering
- K-nearest neigbhor classification
- Appearance model
- Morphological operations
- Quadtree decomposition
- Graph-cut
- Level sets
- Active contours
- Probabilistic atlas

Results

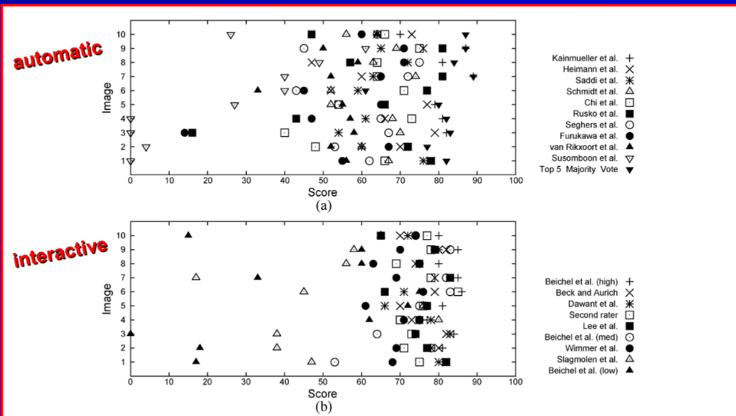


Fig. 2. Individual scores per image for all segmentation methods. All displayed scores are calculated according to (1). (a) Automatic segmentation methods. (b) Interactive segmentation methods.

Results

automatic

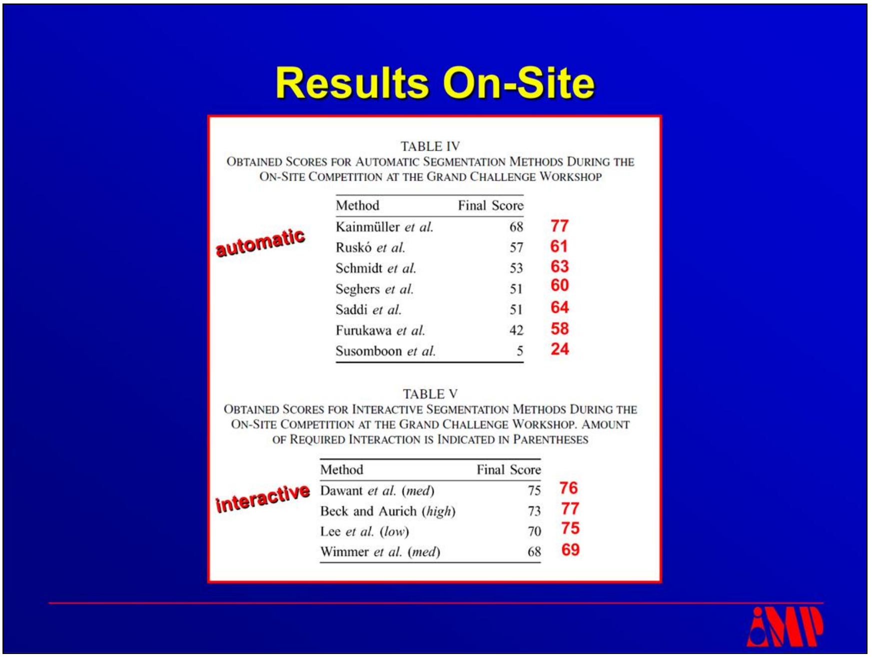
TABLE II
OVERVIEW OF RESULTS FOR AUTOMATIC SEGMENTATION METHODS. RESULTS FOR EACH MEASURE ARE REPORTED AS MEAN AND STANDARD DEVIATION OVER ALL TEST IMAGES, TOGETHER WITH MEAN SCORE. ALL SCORES ARE AVERAGED TO A FINAL SCORE GIVEN AS MEAN AND STANDARD DEVIATION OVER ALL IMAGES

Method	Runtime [min]	Overlap error [%]	Score	Volume difference [%]	Score	Avg. distance [mm]	Score	RMS distance [mm]	Score	Max. distance [mm]	Score	Final Score
Kainmüller *et al.*	15	6.1 ± 2.1	76	-2.9 ± 2.9	85	0.9 ± 0.3	76	1.9 ± 0.8	74	18.7 ± 8.5	75	77 ± 9
Heimann *et al.*	7	7.7 ± 1.9	70	1.7 ± 3.2	88	1.4 ± 0.4	65	3.2 ± 1.3	55	30.1 ± 10.2	60	67 ± 11
Saddi *et al.*	5.5	8.9 ± 1.8	65	1.2 ± 4.4	80	1.5 ± 0.4	62	3.4 ± 0.8	52	29.3 ± 8.4	62	64 ± 6
Schmidt *et al.*	6–20	10.4 ± 1.9	59	-4.9 ± 3.0	74	1.7 ± 0.4	56	3.1 ± 1.1	57	24.0 ± 8.0	68	63 ± 8
Chi *et al.*	34	9.1 ± 2.8	65	2.6 ± 6.3	73	1.7 ± 0.6	58	3.3 ± 1.2	54	30.8 ± 9.2	60	62 ± 11
Ruskó *et al.*	0.5	10.1 ± 4.5	61	-3.8 ± 6.4	72	1.7 ± 0.9	58	3.5 ± 2.3	53	26.7 ± 11.7	65	61 ± 21
Seghers *et al.*	30	10.7 ± 2.5	58	-6.8 ± 2.3	64	1.8 ± 0.4	55	3.2 ± 1.1	56	25.2 ± 10.1	67	60 ± 10
Furukawa *et al.*	36	10.8 ± 3.7	58	-7.3 ± 4.7	61	1.9 ± 1.1	53	3.7 ± 1.9	49	31.6 ± 12.7	58	56 ± 17
van Rikxoort *et al.*	45	12.5 ± 1.8	51	1.8 ± 4.2	80	2.4 ± 0.3	40	4.4 ± 1.5	40	32.4 ± 13.7	57	53 ± 8
Susomboon *et al.*	25	26.4 ± 24	31	-11.5 ± 30	42	10.2 ± 13	15	17.1 ± 18	12	74.0 ± 41.5	23	24 ± 22
Top 5 majority vote	-	5.0 ± 1.3	81	-0.7 ± 1.7	93	0.8 ± 0.3	81	1.7 ± 0.8	77	19.1 ± 8.4	75	81 ± 8

interactive

TABLE III
OVERVIEW OF RESULTS FOR INTERACTIVE SEGMENTATION METHODS. RESULTS FOR EACH MEASURE ARE REPORTED AS MEAN AND STANDARD DEVIATION OVER ALL TEST IMAGES, TOGETHER WITH MEAN SCORE. ALL SCORES ARE AVERAGED TO A FINAL SCORE GIVEN AS MEAN AND STANDARD DEVIATION OVER ALL IMAGES. THE AMOUNT OF REQUIRED INTERACTION IS INDICATED IN PARENTHESES

Method	Runtime [min]	Overlap error [%]	Score	Volume difference [%]	Score	Avg. distance [mm]	Score	RMS distance [mm]	Score	Max. distance [mm]	Score	Final Score
Beichel *et al.* MBR (*high*)	36	5.2 ± 0.9	80	1.0 ± 1.7	91	0.8 ± 0.2	80	1.4 ± 0.4	80	15.7 ± 3.5	79	82 ± 2
Beck and Aurich (*high*)	7	6.6 ± 1.6	74	1.8 ± 2.5	88	1.0 ± 0.3	74	1.9 ± 0.4	73	18.5 ± 4.1	76	77 ± 4
Dawant *et al.* (*med*)	20	7.2 ± 1.2	72	2.5 ± 2.3	86	1.1 ± 0.2	73	1.9 ± 0.5	74	17.1 ± 5.4	77	76 ± 5
Second rater		6.4 ± 1.0	75	4.7 ± 1.8	75	1.0 ± 0.2	75	1.8 ± 0.5	75	19.3 ± 5.6	75	75 ± 4
Lee *et al.* (*low*)	7	6.9 ± 1.4	73	1.3 ± 2.9	88	1.1 ± 0.3	73	2.1 ± 0.5	71	21.3 ± 4.0	72	75 ± 5
Beichel *et al.* CBR (*med*)	31	6.5 ± 1.1	74	1.1 ± 1.9	90	1.1 ± 0.4	72	2.5 ± 1.2	66	23.4 ± 10.5	69	74 ± 9
Wimmer *et al.* (*med*)	4–7	8.1 ± 1.1	68	6.1 ± 2.6	68	1.3 ± 0.2	67	2.2 ± 0.4	69	18.7 ± 4.6	75	69 ± 5
Slagmolen *et al.* (*med*)	60	10.4 ± 3.1	59	3.7 ± 6.2	70	2.0 ± 0.7	50	5.0 ± 2.4	34	40.5 ± 18.2	47	52 ± 19
Beichel *et al.* GC (*low*)	30	14.3 ± 9.4	48	3.1 ± 10.7	62	3.6 ± 3.1	34	7.9 ± 5.9	24	49.2 ± 20.4	38	41 ± 27



Results On-Site

TABLE IV
OBTAINED SCORES FOR AUTOMATIC SEGMENTATION METHODS DURING THE ON-SITE COMPETITION AT THE GRAND CHALLENGE WORKSHOP

automatic

Method	Final Score	
Kainmüller *et al.*	68	77
Ruskó *et al.*	57	61
Schmidt *et al.*	53	63
Seghers *et al.*	51	60
Saddi *et al.*	51	64
Furukawa *et al.*	42	58
Susomboon *et al.*	5	24

TABLE V
OBTAINED SCORES FOR INTERACTIVE SEGMENTATION METHODS DURING THE ON-SITE COMPETITION AT THE GRAND CHALLENGE WORKSHOP. AMOUNT OF REQUIRED INTERACTION IS INDICATED IN PARENTHESES

interactive

Method	Final Score	
Dawant *et al.* (*med*)	75	76
Beck and Aurich (*high*)	73	77
Lee *et al.* (*low*)	70	75
Wimmer *et al.* (*med*)	68	69

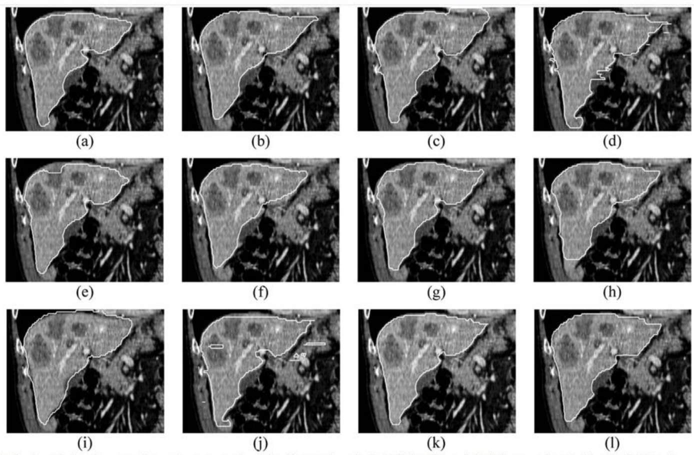
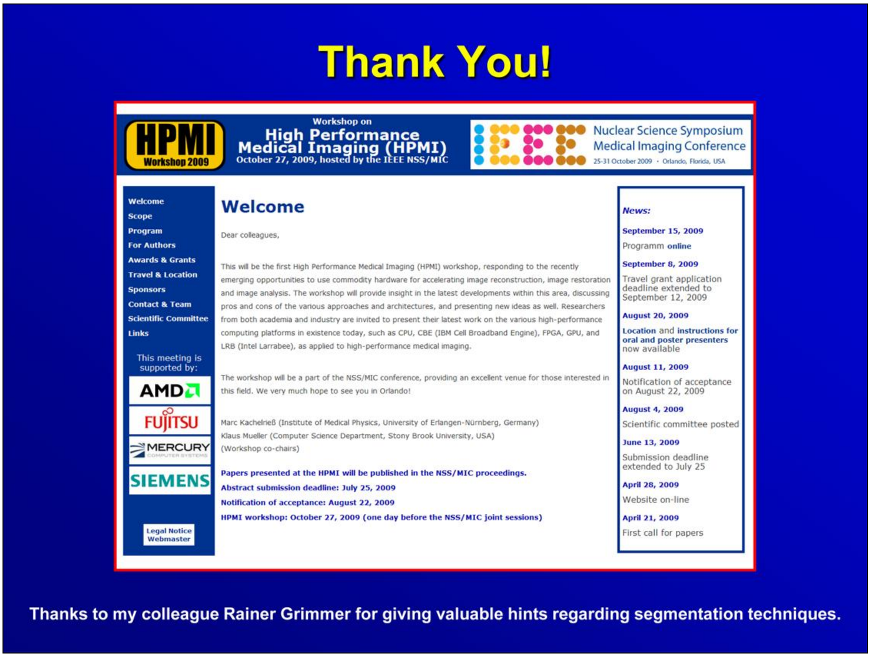


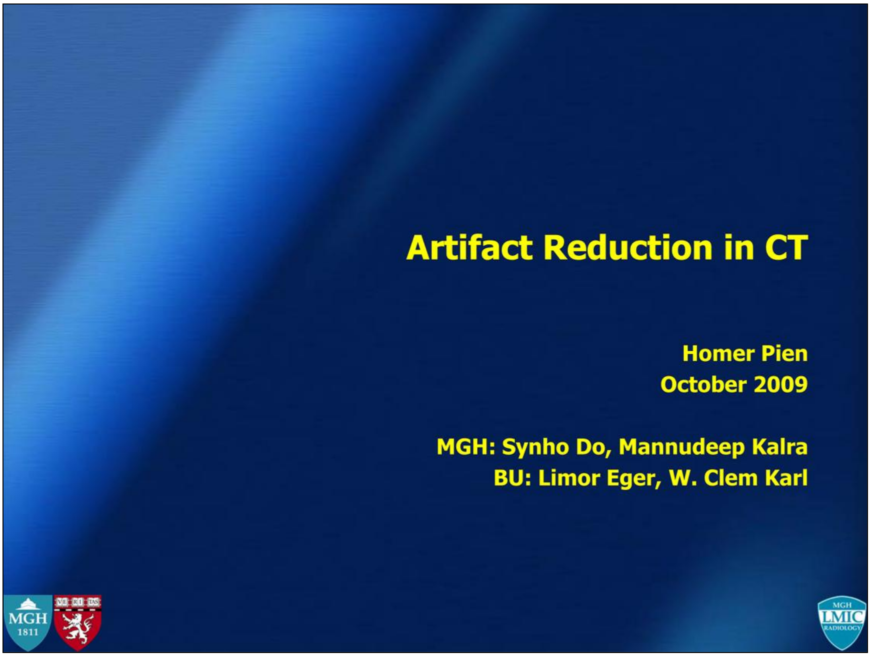
Fig. 3. Coronal view of segmentation results on one test image for all automatic methods. (a) Kainmüller *et al.* (b) Heimann *et al.* (c) Saddi *et al.* (d) Chi *et al.* (e) Ruskó *et al.* (f) Seghers *et al.* (g) Furukawa *et al.* (h) Schmidt *et al.* (i) van Rikxoort *et al.* (j) Susomboon *et al.* (k) Top five majority vote. (l) Reference.

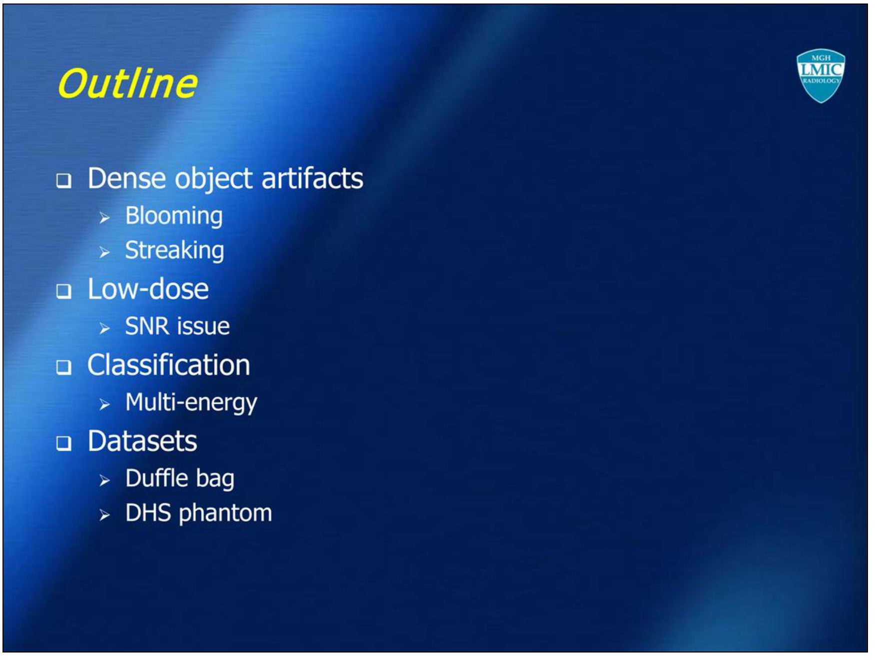
Questions Related to Threat Detection

- Where are shape models applicable to security?
- Can we rely on surrounding objects in threat detection?
- How reliable do we need to segment?
  - Are volumetric or distance measures important?
  - Do we need to determine the exact shape of the object?
- Isn‘t classification more important to threat detection?
  - In terms of liver segmentation: Is there a liver among the organs?
- In which cases can our segmentation/classification task rely on the physical properties of the threat?
  - Absorption
  - Scatter
  - ....
- How many and what kind of objects can be reliably detected and classified as being definitely no threat (i.e. the true negatives)?
- Do we need to make up a dedicated detection algorithm for every type of object (true negative or true positive)?

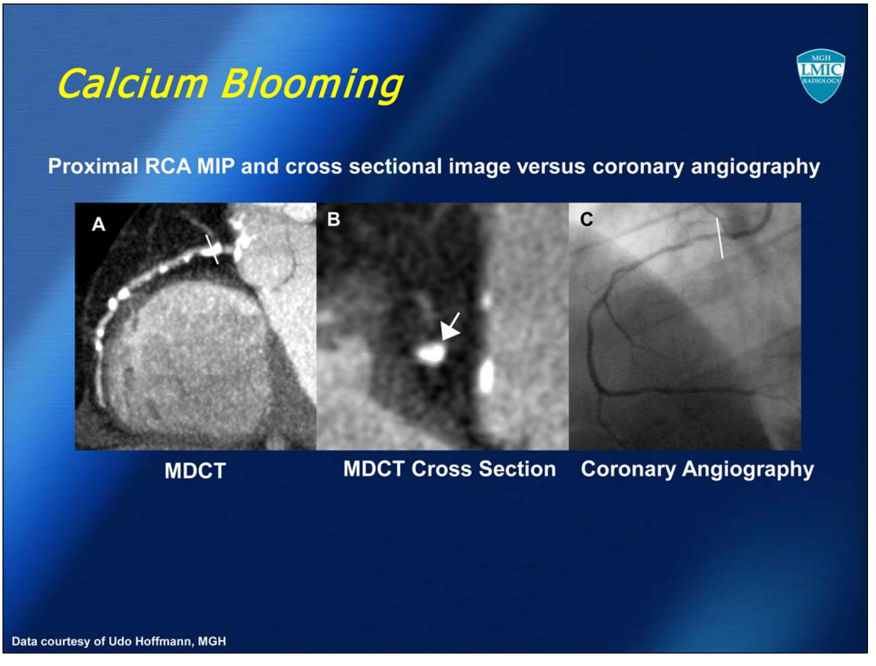

Thank You!
HPMI
Workshop 2009
Workshop on
High Performance
Medical Imaging (HPMI)
October 27, 2009, hosted by the IEEE NSS/MIC
Nuclear Science Symposium
Medical Imaging Conference
25-31 October 2009 · Orlando, Florida, USA
Welcome
Scope
Program
For Authors
Awards & Grants
Travel & Location
Sponsors
Contact & Team
Scientific Committee
Links
This meeting is supported by:
AMD
FUJITSU
MERCURY
COMPUTER SYSTEMS
SIEMENS
Legal Notice
Webmaster
Welcome
Dear colleagues,
This will be the first High Performance Medical Imaging (HPMI) workshop, responding to the recently emerging opportunities to use commodity hardware for accelerating image reconstruction, image restoration and image analysis. The workshop will provide insight in the latest developments within this area, discussing pros and cons of the various approaches and architectures, and presenting new ideas as well. Researchers from both academia and industry are invited to present their latest work on the various high-performance computing platforms in existence today, such as CPU, CBE (IBM Cell Broadband Engine), FPGA, GPU, and LRB (Intel Larrabee), as applied to high-performance medical imaging.
The workshop will be a part of the NSS/MIC conference, providing an excellent venue for those interested in this field. We very much hope to see you in Orlando!
Marc Kachelrieß (Institute of Medical Physics, University of Erlangen-Nürnberg, Germany)
Klaus Mueller (Computer Science Department, Stony Brook University, USA)
(Workshop co-chairs)
Papers presented at the HPMI will be published in the NSS/MIC proceedings.
Abstract submission deadline: July 25, 2009
Notification of acceptance: August 22, 2009
HPMI workshop: October 27, 2009 (one day before the NSS/MIC joint sessions)
News:
September 15, 2009
Programm online
September 8, 2009
Travel grant application deadline extended to September 12, 2009
August 20, 2009
Location and instructions for oral and poster presenters now available
August 11, 2009
Notification of acceptance on August 22, 2009
August 4, 2009
Scientific committee posted
June 13, 2009
Submission deadline extended to July 25
April 28, 2009
Website on-line
April 21, 2009
First call for papers
Thanks to my colleague Rainer Grimmer for giving valuable hints regarding segmentation techniques.

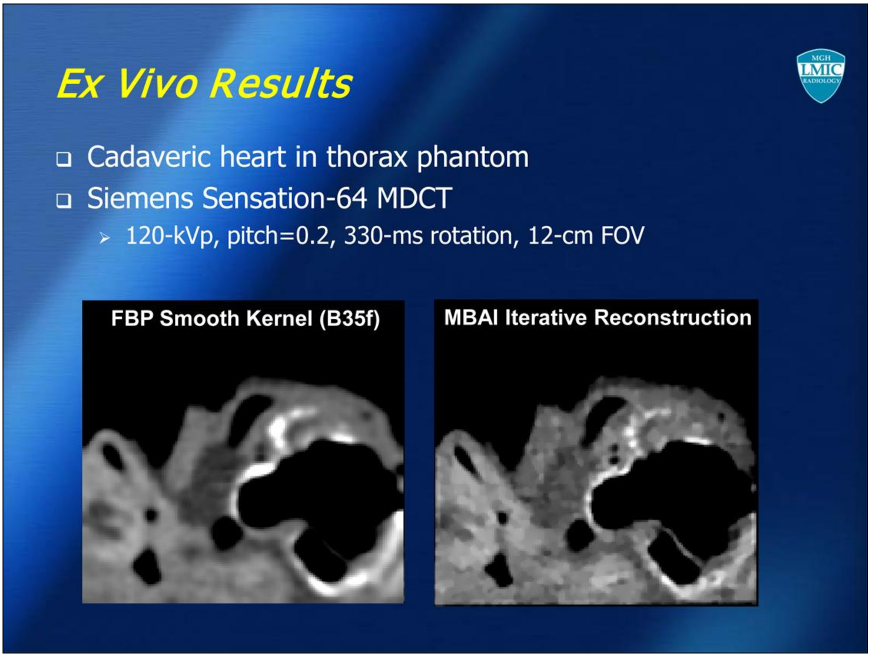
26.6 Homer Pien Presentation Slides

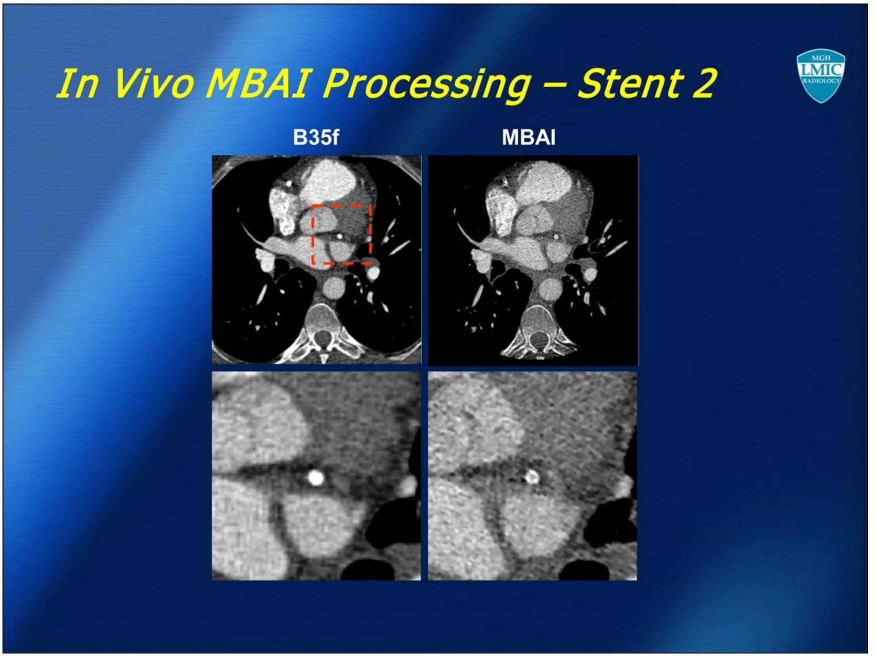





Outline
Dense object artifacts
Blooming
Streaking
Low-dose
SNR issue
Classification
Multi-energy
Datasets
Duffle bag
DHS phantom

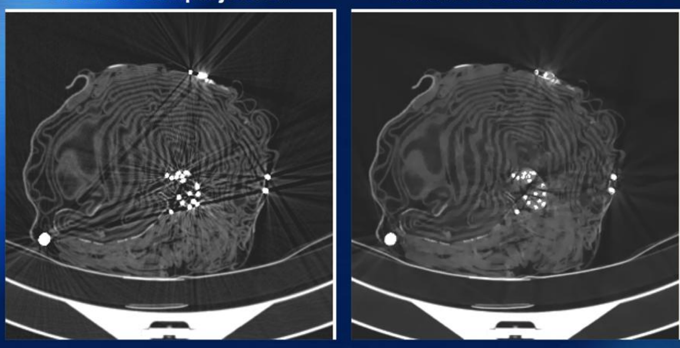

Calcium Blooming
Proximal RCA MIP and cross sectional image versus coronary angiography
A
B
C
MDCT
MDCT Cross Section
Coronary Angiography
Data courtesy of Udo Hoffmann, MGH


Ex Vivo Results
Cadaveric heart in thorax phantom
Siemens Sensation-64 MDCT
120-kVp, pitch=0.2, 330-ms rotation, 12-cm FOV
FBP Smooth Kernel (B35f)
MBAI Iterative Reconstruction


In Vivo MBAI Processing – Stent 2
B35f
MBAI

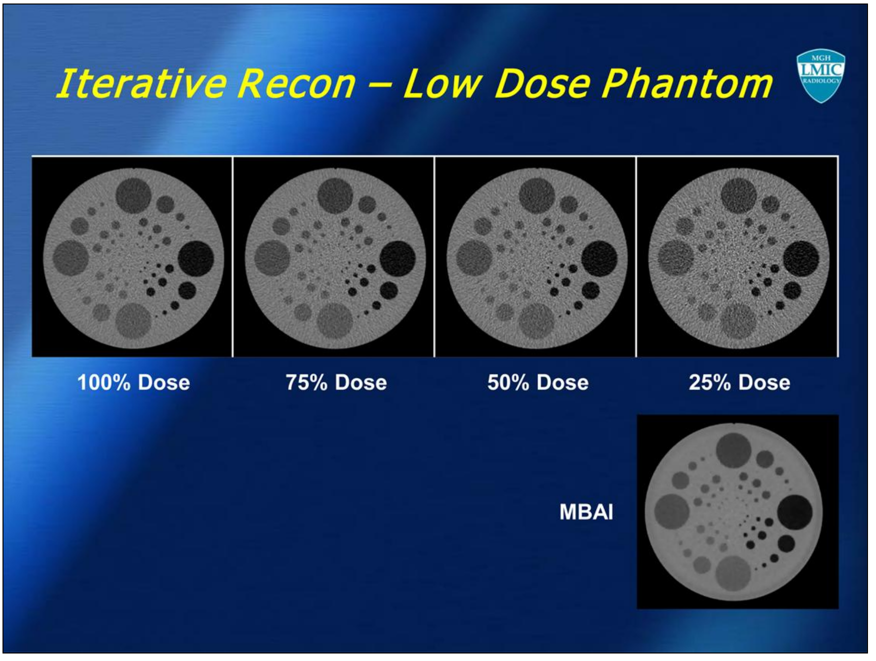
Streaks – Duffle Bag Dataset

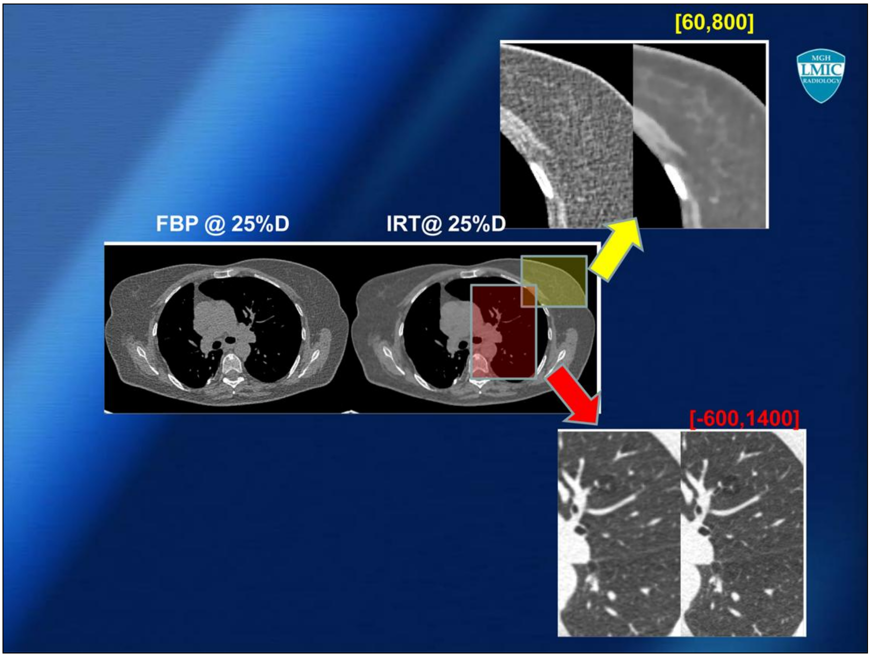
Filtered Backprojection | Iterative Reconstruction



Outline

- Dense object artifacts
  - Blooming
  - Streaking
- **Low-dose**
  - SNR issue
- Classification
  - Multi-energy
- Datasets
  - Duffle bag
  - DHS phantom

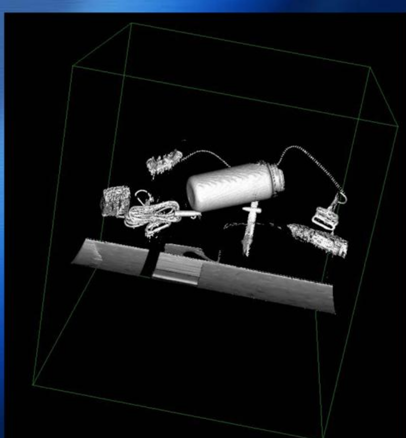

Iterative Recon – Low Dose Phantom
MGH LMIC RADIOLOGY
100% Dose
75% Dose
50% Dose
25% Dose
MBAI

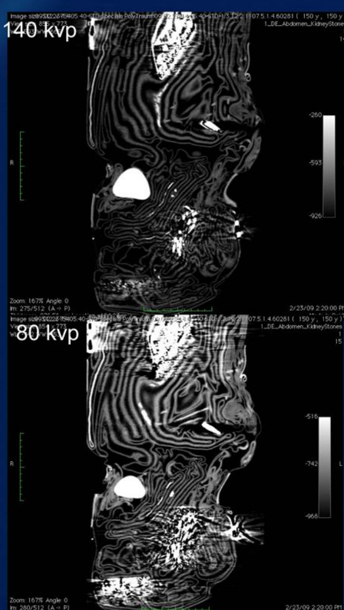

[60,800]
MGH LMIC RADIOLOGY
FBP @ 25%D
IRT@ 25%D
[-600,1400]

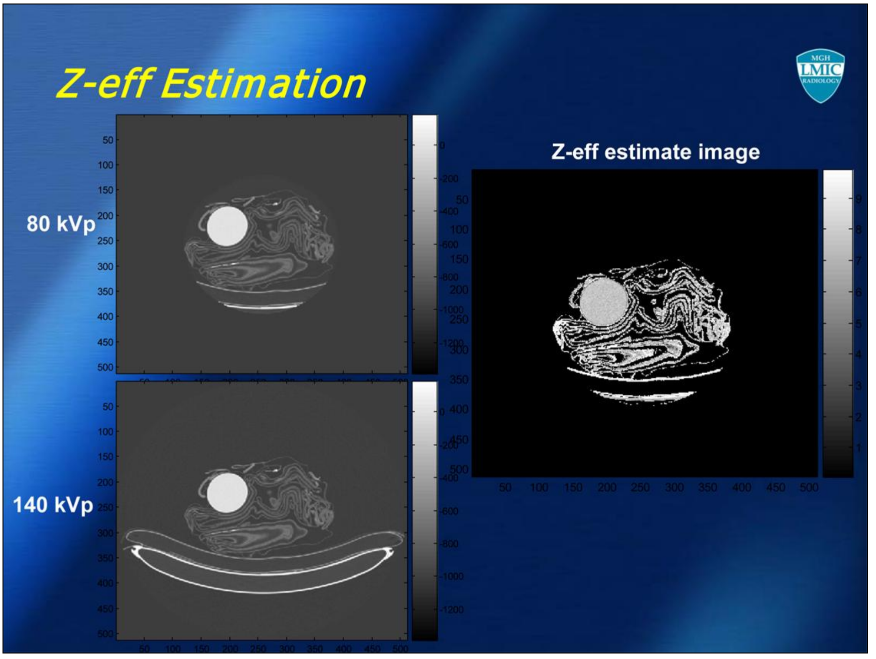
Outline

- Dense object artifacts
  - Blooming
  - Streaking
- Low-dose
  - SNR issue
- **Classification**
  - Multi-energy
- Datasets
  - Duffle bag
  - DHS phantom

Multi-Energy CT







Zeff – 1st Pass

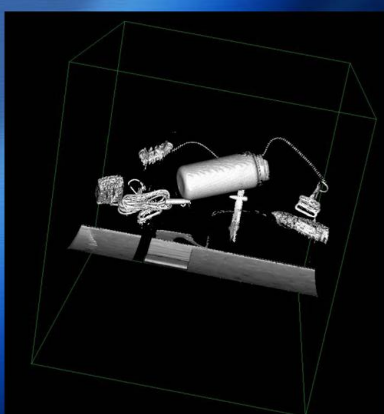
Material	True	Estimate	Stdev
Water	7.42	7.64	0.38
Delrin	6.95	6.21	0.91
Graphite	6.0	4.80	1.46
Copper	29.0	7.46	0.03

Medical multi-energy techniques work well for low-atomic materials

Outline

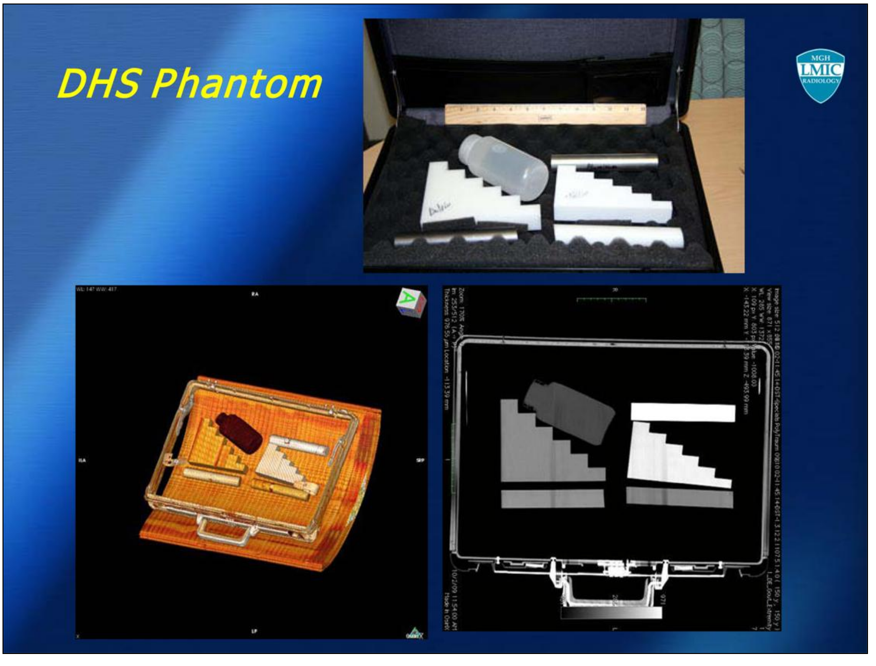
- Dense object artifacts
  - Blooming
  - Streaking
- Low-dose
  - SNR issue
- Classification
  - Multi-energy
- Datasets
  - Duffle bag
  - DHS phantom

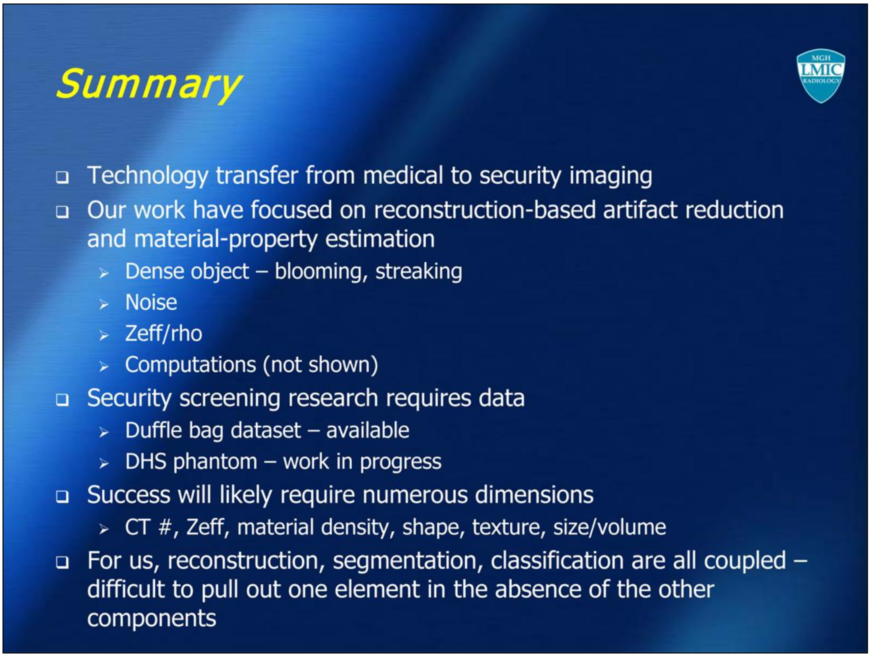
Duffle Bag Dataset

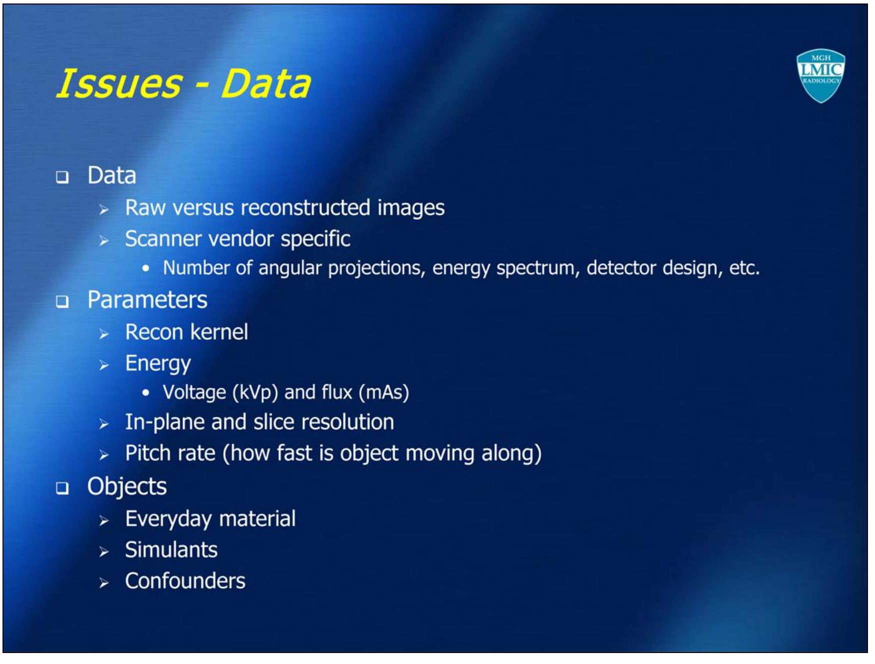


- A quick-and-dirty test of medical scanners for DHS apps
  - No "ground truth"
- Contents
  - Filled water bottle, radar detector and power supply, 2 bullets, and clothing
  - Bag's zipper and shoulder strap on top
- Image specs
  - 754 512x512 images
  - 140kVp, 0.6mm slices, 0.98x0.98mm pixels
  - D30f (smooth) recon kernel
- Available from Mariah Nobrega


DHS Phantom
MGH LMIC RADIOLOGY
DHS Pelican Case
Briefcase
Exterior
Interior
DI water
Al rod
Delrin wedge
Teflon wedge
Graphite rod
Delrin rod


DHS Phantom
MGH LMIC RADIOLOGY


Summary
MGH LMIC RADIOLOGY
Technology transfer from medical to security imaging
Our work have focused on reconstruction-based artifact reduction and material-property estimation
Dense object – blooming, streaking
Noise
Zeff/rho
Computations (not shown)
Security screening research requires data
Duffle bag dataset – available
DHS phantom – work in progress
Success will likely require numerous dimensions
CT #, Zeff, material density, shape, texture, size/volume
For us, reconstruction, segmentation, classification are all coupled – difficult to pull out one element in the absence of the other components


Issues - Data
MGH LMIC RADIOLOGY
Data
Raw versus reconstructed images
Scanner vendor specific
Number of angular projections, energy spectrum, detector design, etc.
Parameters
Recon kernel
Energy
Voltage (kVp) and flux (mAs)
In-plane and slice resolution
Pitch rate (how fast is object moving along)
Objects
Everyday material
Simulants
Confounders

26.7 Jeremy Wolfe Presentation Slides

Testing Human Factors

Jeremy Wolfe
Brigham & Women's Hospital
Harvard Medical School

Or
The human-in-the-loop loop

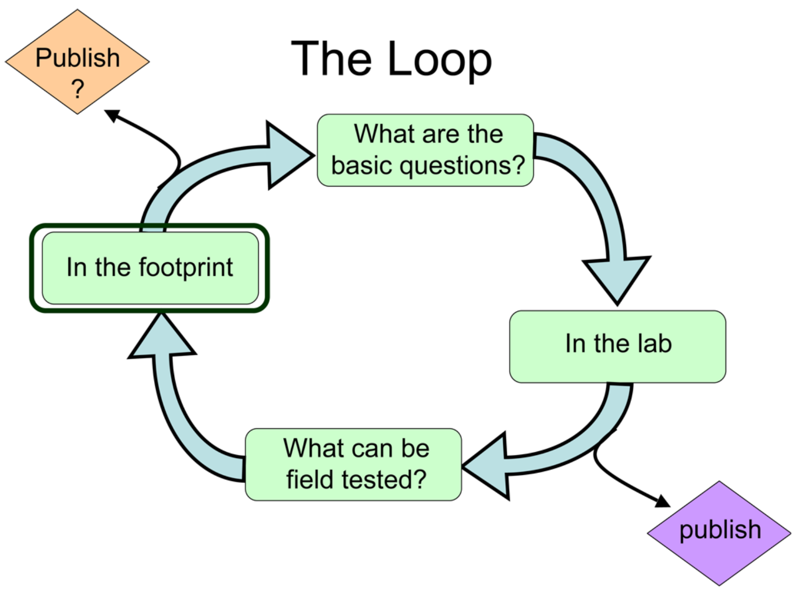
Jeremy Wolfe
Brigham & Women's Hospital
Harvard Medical School

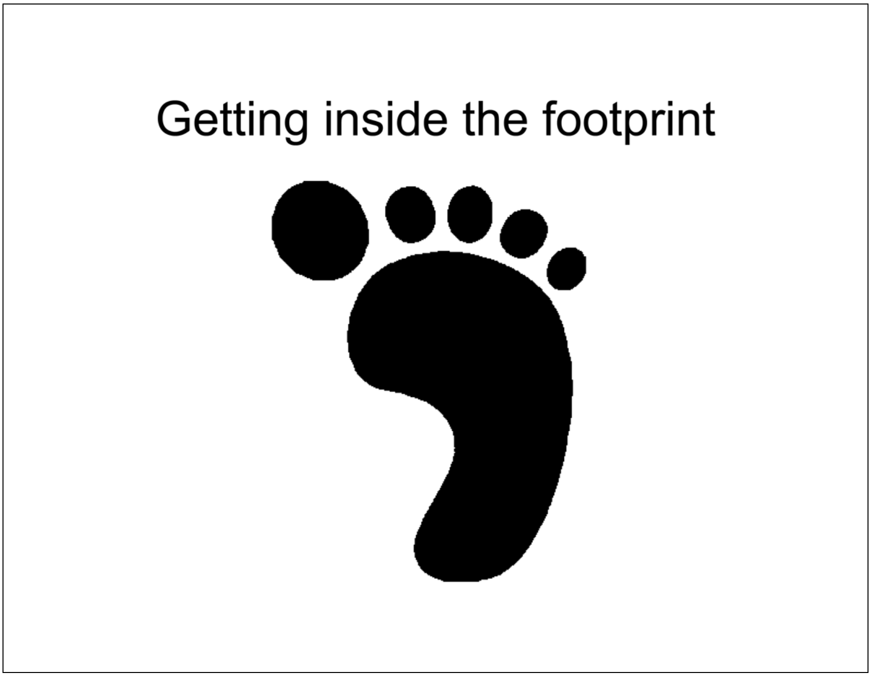
The fundamental goal

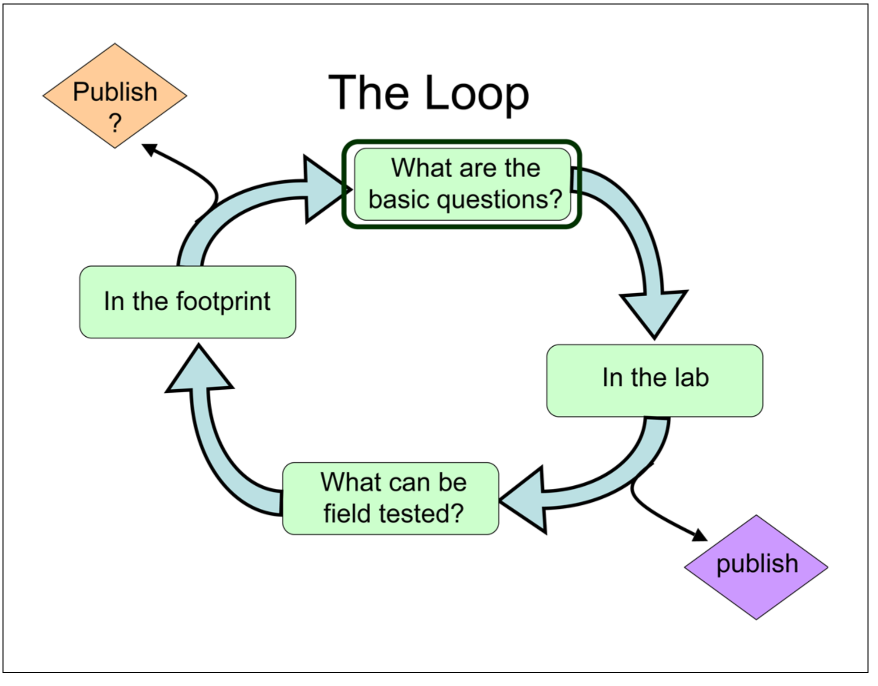
To understand the <u>basic</u> <u>science</u> that influence the performance of TSOs.

Note: This is (probably) not the same as "classic" human factors performance measures.

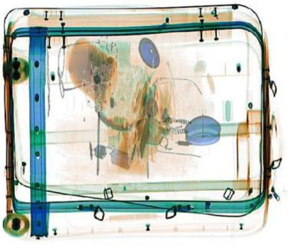
The Loop

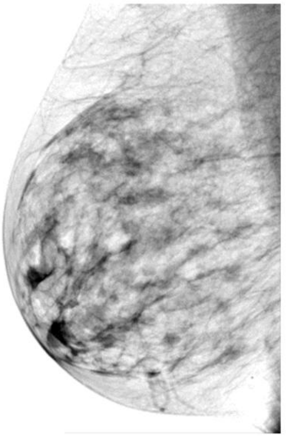



Getting inside the footprint

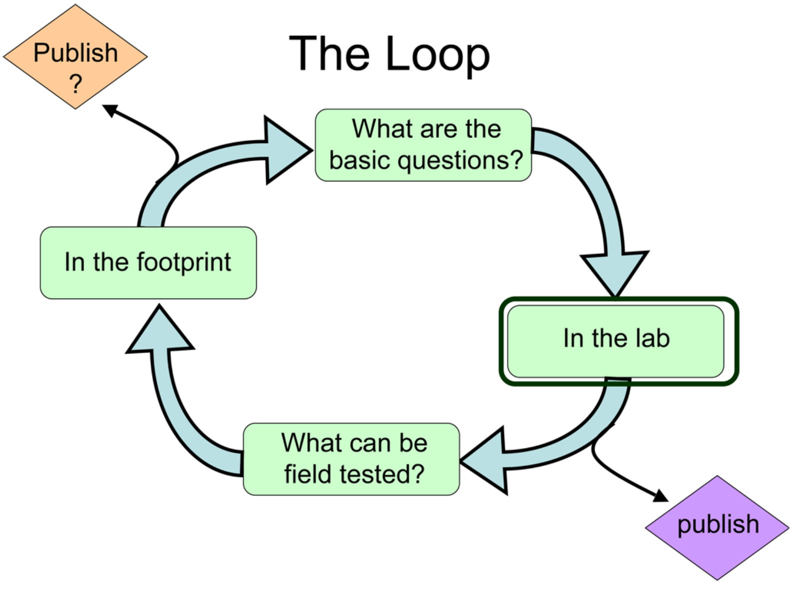

The Loop
Publish
?
What are the basic questions?
In the lab
What can be field tested?
In the footprint
publish

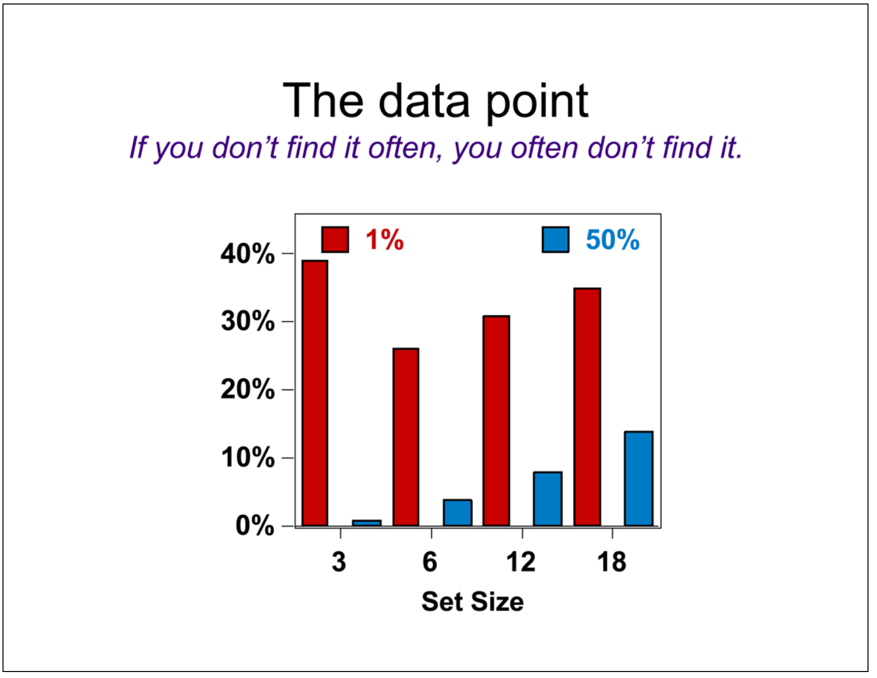
My example: Rare targets

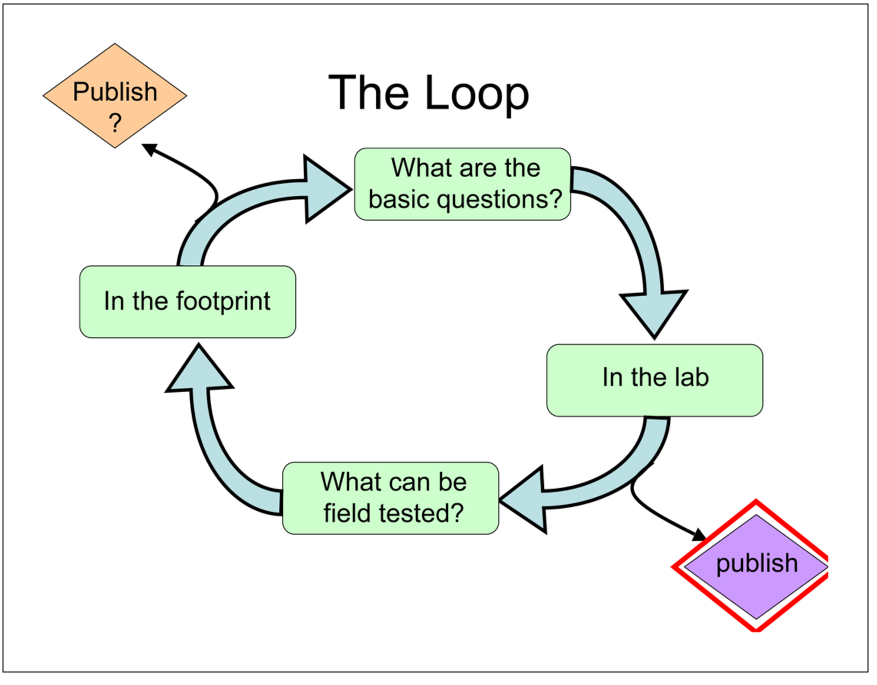


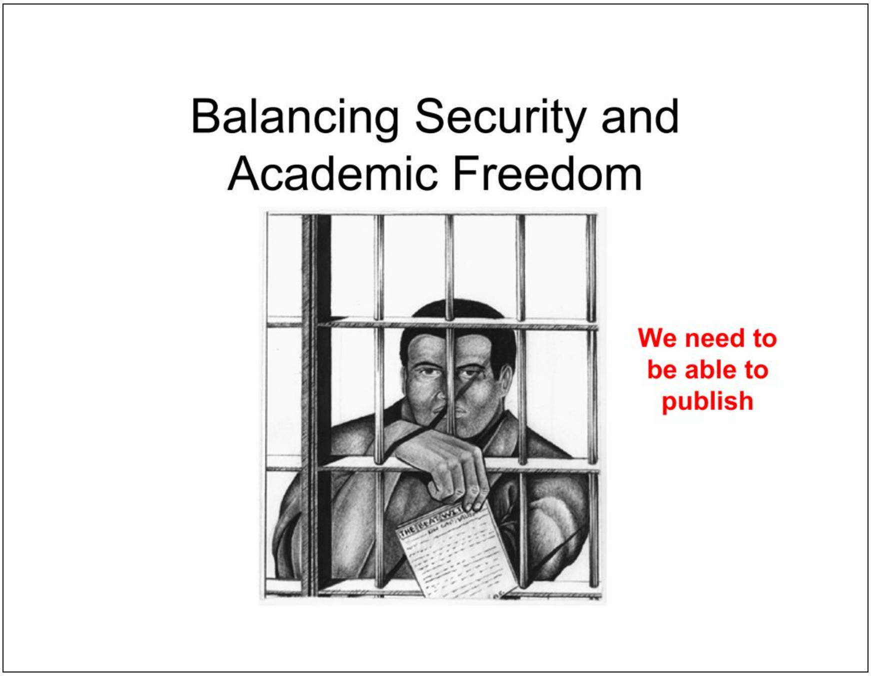


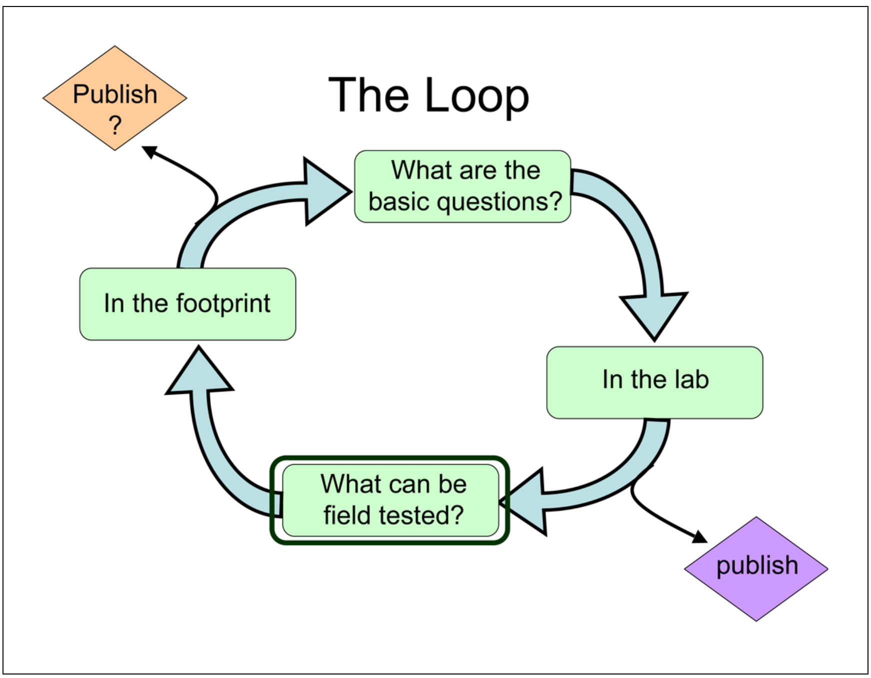
The Loop

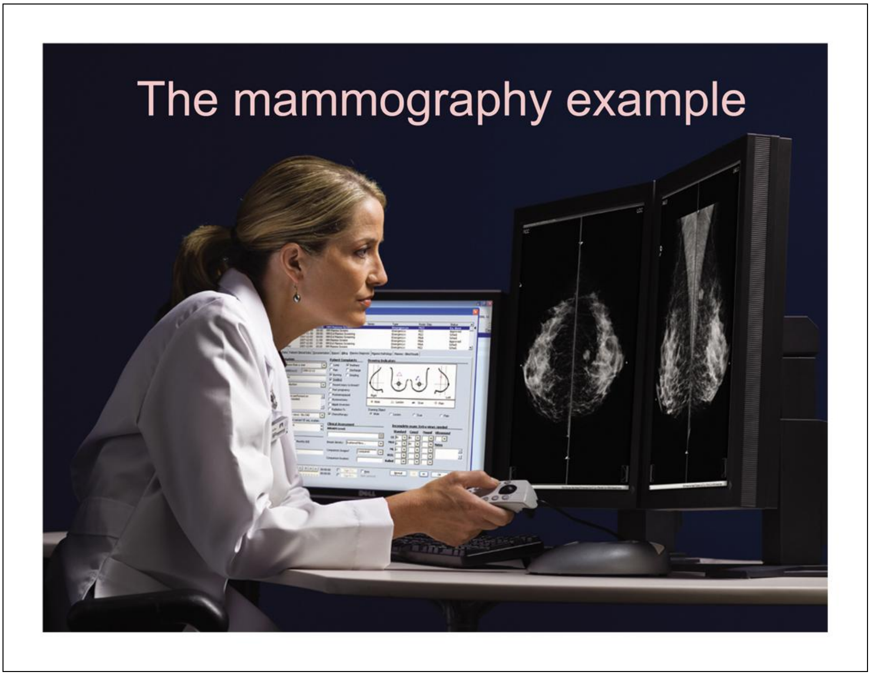


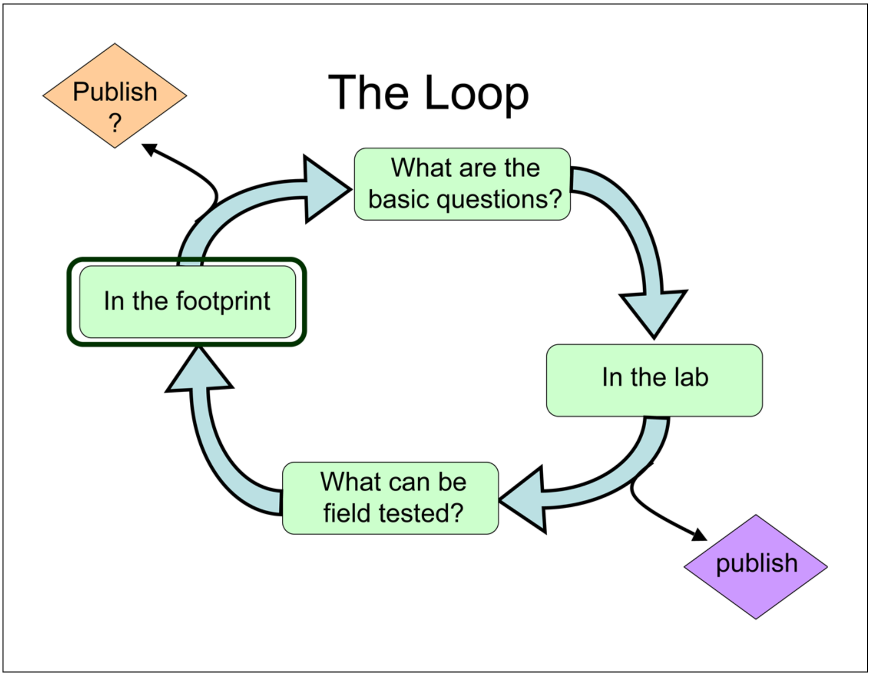

The data point
If you don't find it often, you often don't find it.
1%
50%
40%
30%
20%
10%
0%
3
6
12
18
Set Size


Publish
?
The Loop
What are the basic questions?
In the footprint
In the lab
What can be field tested?
publish


Balancing Security and
Academic Freedom
We need to
be able to
publish

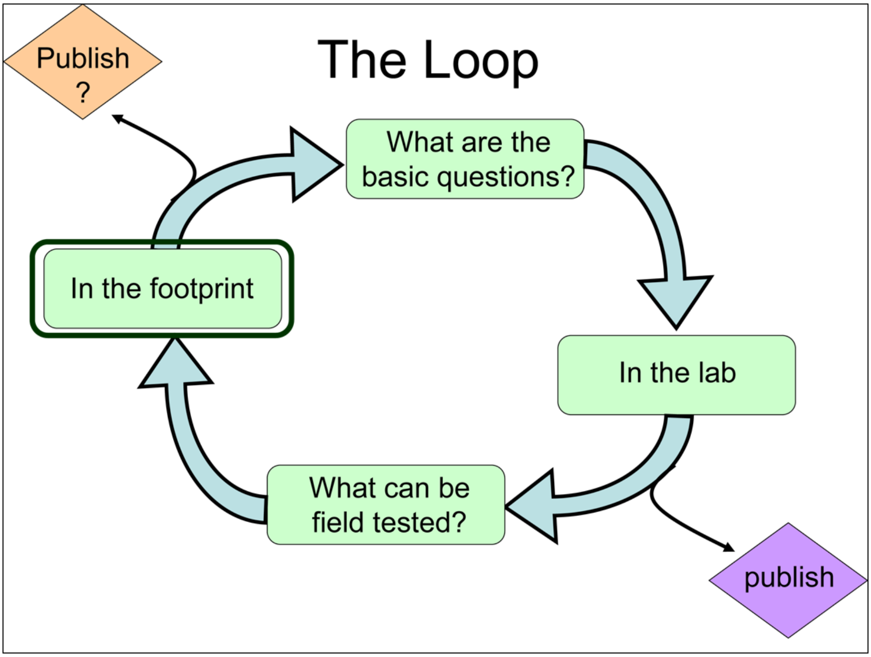

The Loop
Publish
?
What are the
basic questions?
In the footprint
In the lab
What can be
field tested?
publish


The mammography example


The Loop
Publish ?
What are the basic questions?
In the footprint
In the lab
What can be field tested?
publish

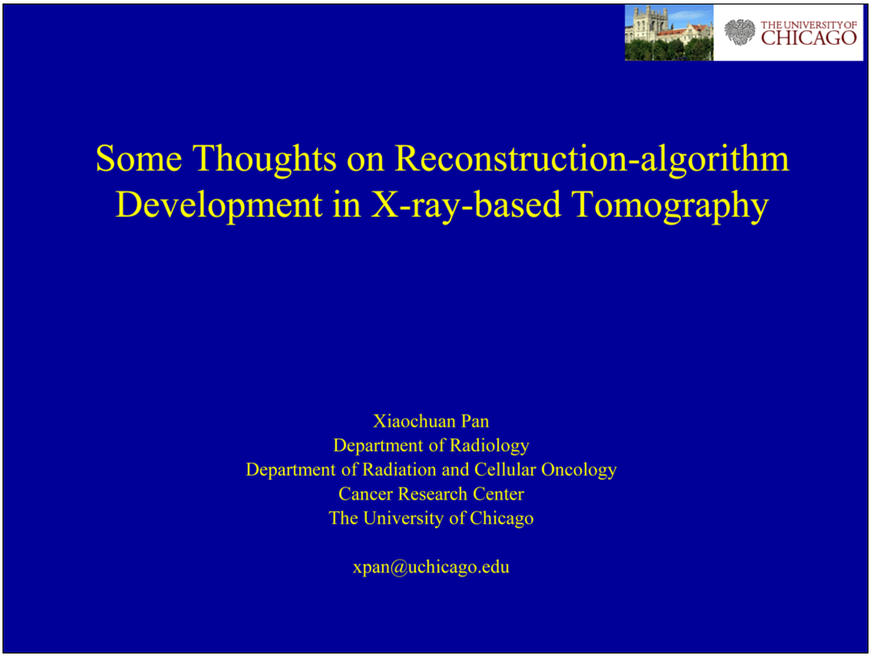
What are we doing at the checkpoint?

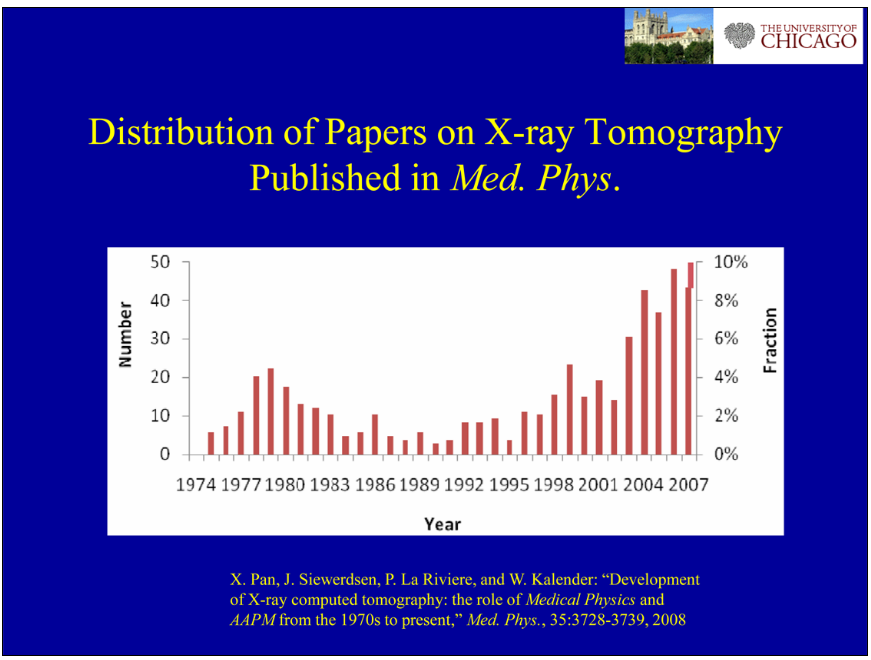
A footprint fantasy

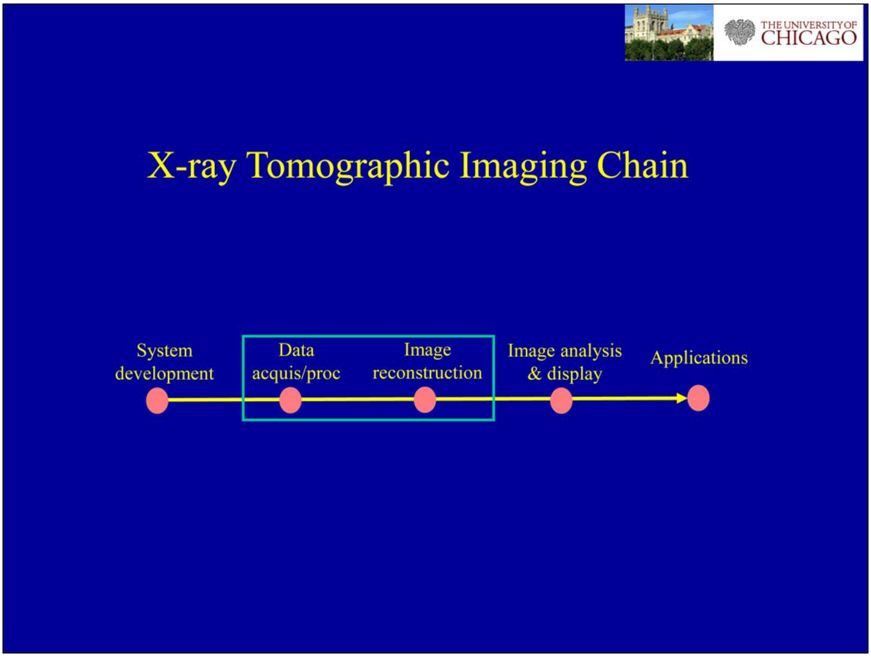

The Loop
Publish
?
What are the
basic questions?
In the footprint
In the lab
What can be
field tested?
publish

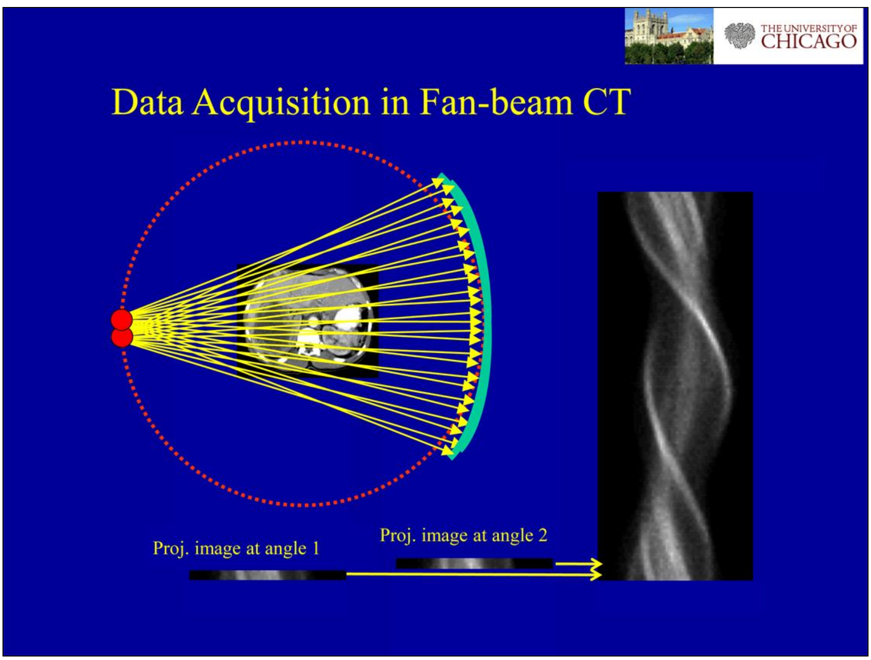
Thank-you

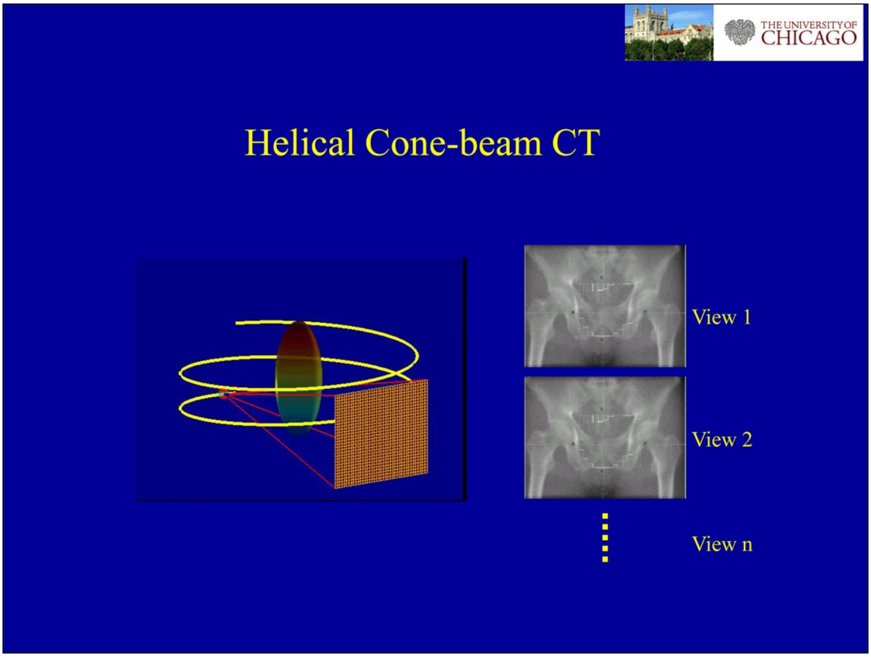
26.8 Xiaochuan Pan Presentation Slides






THE UNIVERSITY OF CHICAGO
X-ray Tomographic Imaging Chain
System development
Data acquis/proc
Image reconstruction
Image analysis & display
Applications


THE UNIVERSITY OF CHICAGO
Data Acquisition in Fan-beam CT
Proj. image at angle 1
Proj. image at angle 2


THE UNIVERSITY OF CHICAGO
Helical Cone-beam CT
View 1
View 2
View n

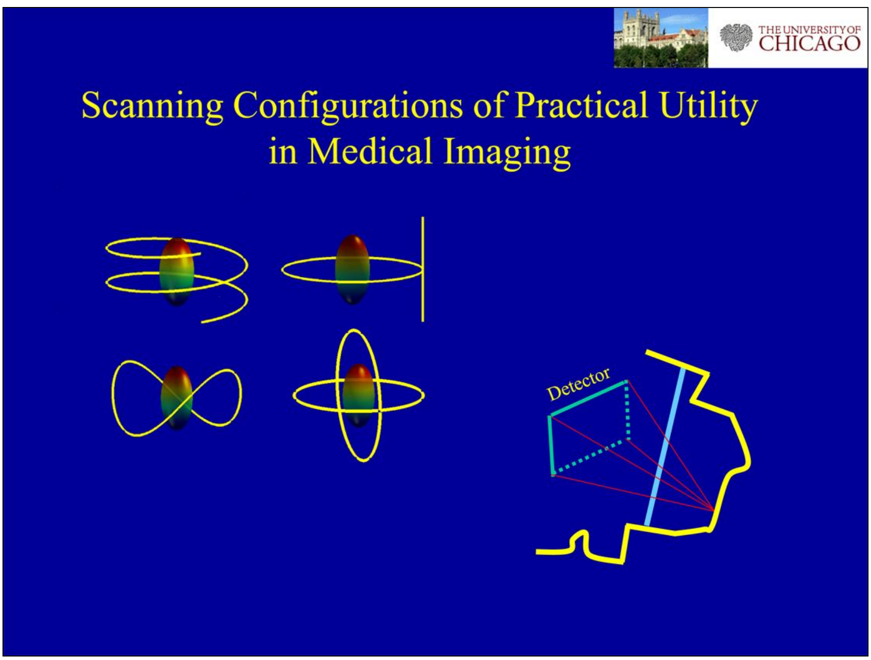
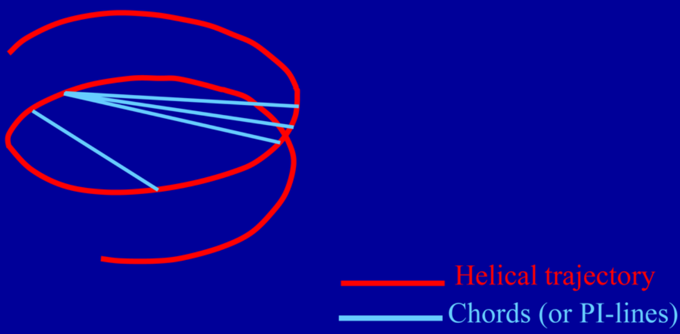

THE UNIVERSITY OF CHICAGO
Scanning Configurations of Practical Utility in Medical Imaging
Detector

Image Reconstruction on Chords in Helical CT

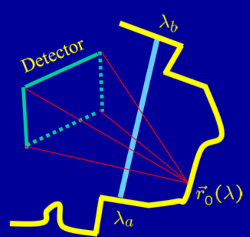


Analytic Inversion Formula

$$f(\vec{r}) = \int_{\mathcal{R}^3} d\vec{r}'\, K(\vec{r}', \vec{r})\, g(\vec{r}')$$

$$K(\vec{r}', \vec{r}) = \frac{1}{2\pi j} \int_{\mathcal{R}^3} d\vec{\nu}\, \mathrm{sgn}(\vec{\nu} \cdot \hat{e}_c \exp[2\pi j \vec{\nu} \cdot (\vec{r} - \vec{r}')]$$

$$g(\vec{r}') = \int_{\lambda_a}^{\lambda_b} \frac{d\lambda}{|\vec{r} - \vec{r}'|} \frac{\partial}{\partial q} p(\vec{r}_0(q), \vec{\beta})|_{q=\lambda}$$



THE UNIVERSITY OF CHICAGO

Image Properties – Constraints

- Compact support
- Positivity
- Sparsity (discrete cases)
- Compact bandwidth
- Separability
- ….

THE UNIVERSITY OF CHICAGO

Backprojection-filtration (BPF) Algorithm

$$f(\vec{r}) = -\frac{1}{4\pi^2}\frac{1}{\sqrt{(x_{c2}-x_c)(x_c-x_{c2})}}\left[\int_{\mathrm{R}}\frac{dx'_\pi}{x'_c - x_c}\, g_c(\vec{r}\,') \;+\; D(\vec{r}_0(\lambda_1), \hat{e}_c)\right]$$

$$g_{\sqcap}(\vec{r}\,') = \sqrt{(x_{c2}-x'_c)(x'_c - x_{c1})}\,\sqcap(x'_c)\, g(\vec{r}\,')$$

$$g(\vec{r}\,') \;=\; \int_{\lambda_1}^{\lambda_2} d\lambda \frac{\mathrm{sgn}[-\beta\cdot \hat{e_w}(\lambda)]}{|\vec{r}\,' - \vec{r}_0(\lambda)|}\frac{\partial P(u,v,\lambda)}{\partial \lambda}\Big|_{\hat{\beta}}$$

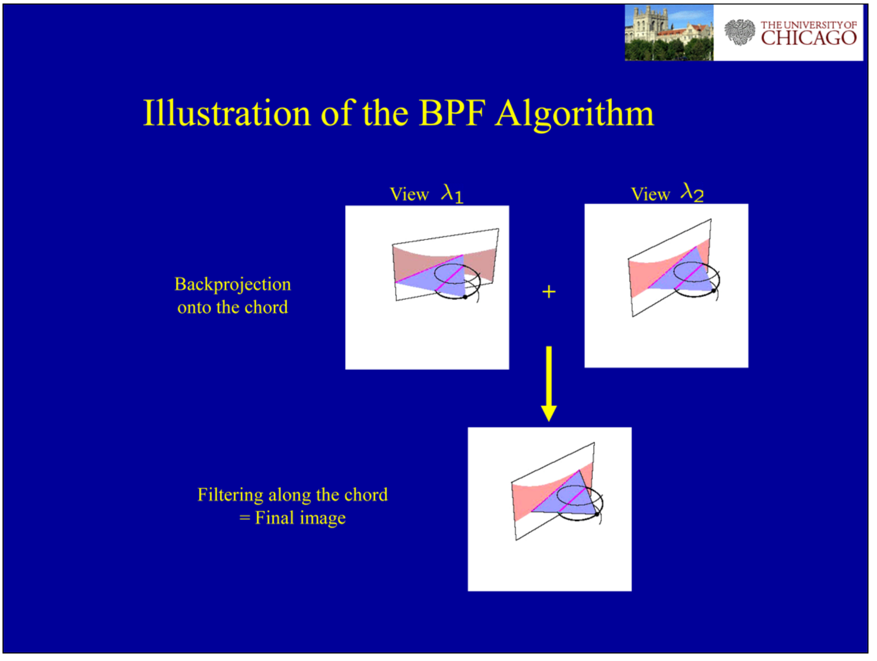
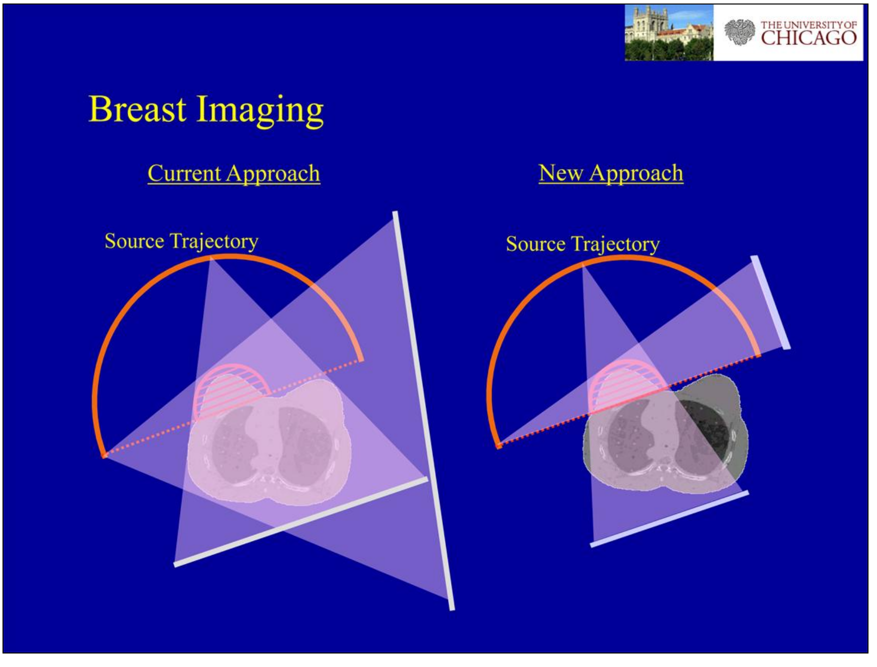
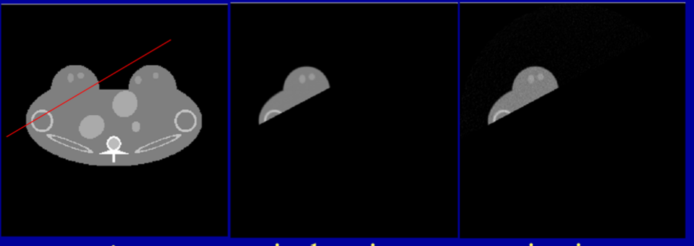


Illustration of the BPF Algorithm
View λ_1
View λ_2
Backprojection
onto the chord
+
Filtering along the chord
= Final image


Breast Imaging
Current Approach
New Approach
Source Trajectory
Source Trajectory

Targeted Breast ROI Imaging



true image noiseless image noisy image

BPF Algorithm: Form 1

$$f(\vec{r}) = -\frac{1}{4\pi^2}\frac{1}{\sqrt{(x_{c2}-x_c)(x_c-x_{c2})}}\left[\int_{\mathbf{R}}\frac{dx'_\pi}{x'_c-x_c}g_c(\vec{r}\,') \;+\; D(\vec{r}_0(\lambda_1),\hat{e}_c)\right]$$

$$g_\Pi(\vec{r}\,') = \sqrt{(x_{c2}-x'_c)(x'_c-x_{c1})}\,\Pi(x'_c)\,g(\vec{r}\,')$$

$$g(\vec{r}\,') \;=\; \int_{\lambda_1}^{\lambda_2}d\lambda\frac{\mathrm{sgn}[-\beta\cdot\widehat{e_w}(\lambda)]}{|\vec{r}\,'-\vec{r}_0(\lambda)|}\frac{\partial P(u,v,\lambda)}{\partial\lambda}|_{\widehat{\beta}}$$

BPF Algorithm: Form 2

$$f(\vec{r}) = -\frac{1}{4\pi^2}\frac{1}{\sqrt{(x_{c2}-x_c)(x_c-x_{c2})}}\left[\int_{\mathrm{R}}\frac{dx'_\pi}{x'_c - x_c}\,g_c(\vec{r}\,') \;+\; D(\vec{r}_0(\lambda_1),\hat{\mathrm{e}}_c)\right]$$

$$g_\Pi(\vec{r}\,') = \sqrt{(x_{c2}-x'_c)(x'_c - x_{c1})}\,\Pi(x'_c)\,g(\vec{r}\,')$$

$$\begin{aligned} g(\vec{r}\,') \;=\; & \int_{\lambda_1}^{\lambda_2}\frac{d\lambda}{|\vec{r}\,'-\vec{r}_0(\lambda)|^2}\left\{-\left[\frac{d\vec{r}_0(\lambda)}{d\lambda}\cdot\hat{\beta}\right]P(u,v,\lambda) + \left[\frac{d\vec{r}_0(\lambda)}{d\lambda}\cdot\hat{\mathrm{e}}_u(\lambda)\right]A\frac{\partial P(u,v,\lambda)}{\partial u}\right. \\ & \left. +\left[\frac{d\vec{r}_0(\lambda)}{d\lambda}\cdot\hat{\mathrm{e}}_v(\lambda)\right]A\frac{\partial P(u,v,\lambda)}{\partial v}\right\} + \left.\frac{P(u,v,\lambda)}{|\vec{r}\,'-\vec{r}_0(\lambda)|}\right|_{\lambda_1}^{\lambda_2} \end{aligned}$$

$$A(u,v) = \sqrt{u^2+v^2+S^2}$$

BPF Algorithm: Form 3

$$f(\vec{r}) = -\frac{1}{4\pi^2}\frac{1}{\sqrt{(x_{c2}-x_c)(x_c-x_{c2})}}\left[\int_{\mathrm{R}}\frac{dx'_\pi}{x'_c - x_c}\,g_c(\vec{r}\,') \;+\; D(\vec{r}_0(\lambda_1),\hat{\mathrm{e}}_c)\right]$$

$$g_\Pi(\vec{r}\,') = \sqrt{(x_{c2}-x'_c)(x'_c - x_{c1})}\,\Pi(x'_c)\,g(\vec{r}\,')$$

$$\begin{aligned} g(\vec{r}\,') \;=\; & \int_{\phi_0}^{\phi_0+\pi} d\phi\,\frac{\mathrm{sgn}[-\hat{\beta}\cdot\hat{\mathrm{e}}_w]}{A}\left\{\frac{SR}{S^2+u^2}+\frac{u}{S^2+u^2}\frac{dR}{d\lambda}\right\}^{-1} \\ & \times\left\{\left(S+\frac{u^2}{S}+\frac{u}{S}\frac{dS}{d\lambda}\right)\frac{\partial Q(u,v,\phi)}{\partial u}+\left(\frac{u\,v}{S}+\frac{v}{S}\frac{dS}{d\lambda}\right)\frac{\partial Q(u,v,\phi)}{\partial v}\right\} \end{aligned}$$

$$A(u,v) = \sqrt{u^2+v^2+S^2}$$

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Algorithm-performance Evaluation
(Technical Efficacy Metrics)

- RMSE
- Spatial Resolution
- Contrast Resolution
- Biases
- Variances
- SNR
- ….

- Spatially varying
- Statistically varying
- Object dependent

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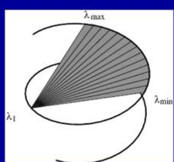
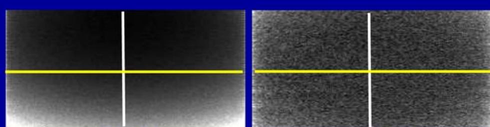
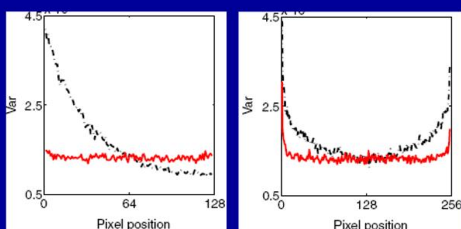
Noise Properties of BPF Algorithms



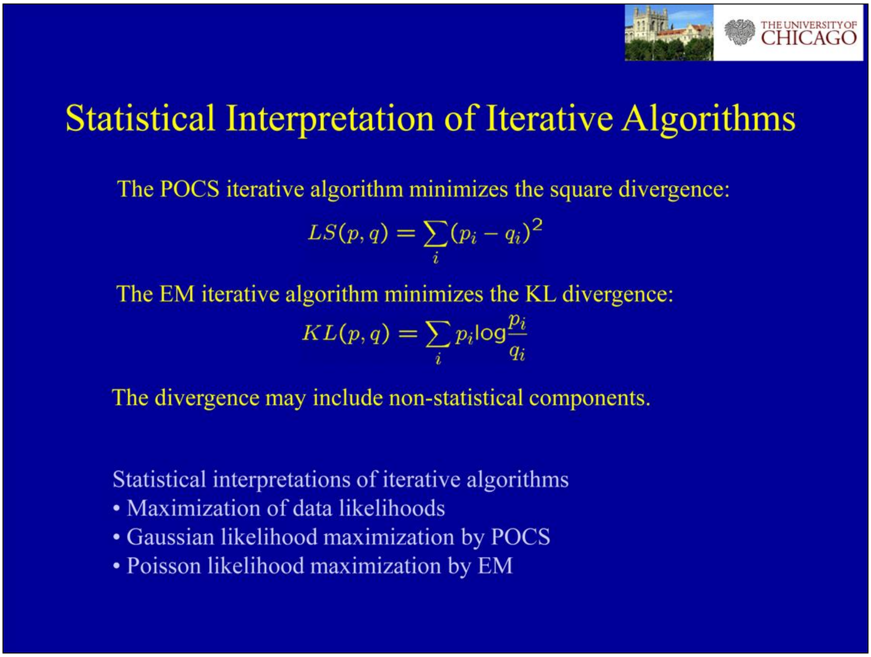


BPF 1 BPF 2



BPF 1 – – – –

BPF 2 ———


THE UNIVERSITY OF CHICAGO
Statistical Interpretation of Iterative Algorithms
The POCS iterative algorithm minimizes the square divergence:
$LS(p,q) = \sum_i (p_i - q_i)^2$
The EM iterative algorithm minimizes the KL divergence:
$KL(p,q) = \sum_i p_i \log \frac{p_i}{q_i}$
The divergence may include non-statistical components.
Statistical interpretations of iterative algorithms
• Maximization of data likelihoods
• Gaussian likelihood maximization by POCS
• Poisson likelihood maximization by EM

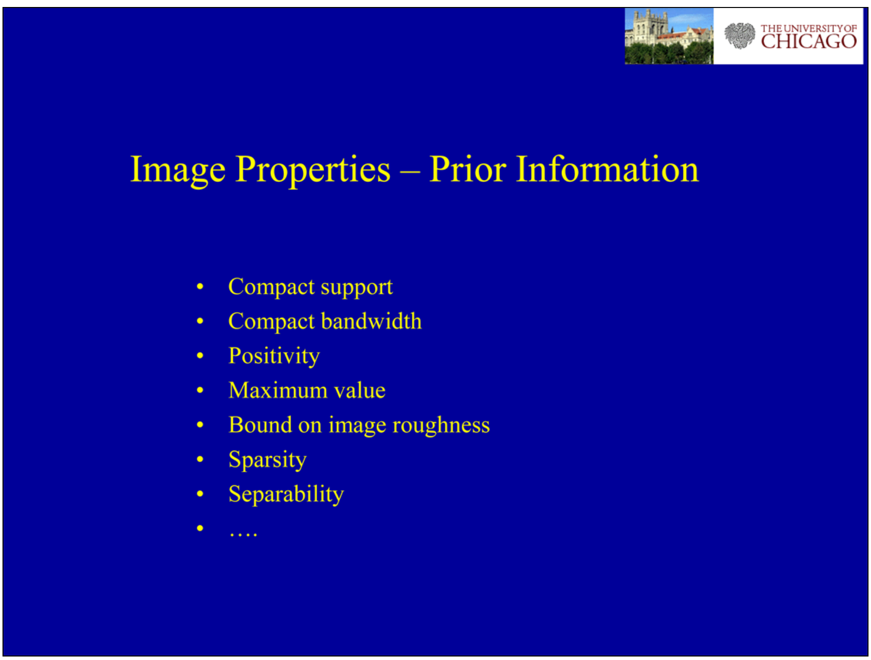

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Image Properties – Prior Information
• Compact support
• Compact bandwidth
• Positivity
• Maximum value
• Bound on image roughness
• Sparsity
• Separability
• ….

Image Reconstruction from Incomplete Data

- Discrete linear system $\vec{g} = \mathrm{M}\vec{f}$
- Under-determined problems
- Multiple solutions for the same data set
- Enforcement of *a priori* conditions – old, but useful, idea: set up a rule for selecting a solution from the feasible set of solutions

L_1-norm Constrained Optimization

$$\vec{f}^* = \mathrm{argmin}||\vec{f}||_1 \quad \text{subject to} \quad |\vec{g} - M\vec{f}^*| \leq \epsilon$$

$$\vec{f}^* \geq 0$$

- Algorithms have been developed based on this framework.
- They work well for images with sparse structures.
- Sparse images exist in certain situations of practical interest.
- Most of images of practical interest are not sparse.

Sparsifying Transform and Compressive Sensing

$\vec{\phi} = \Psi \vec{f}$ is a sparse function in transformed space

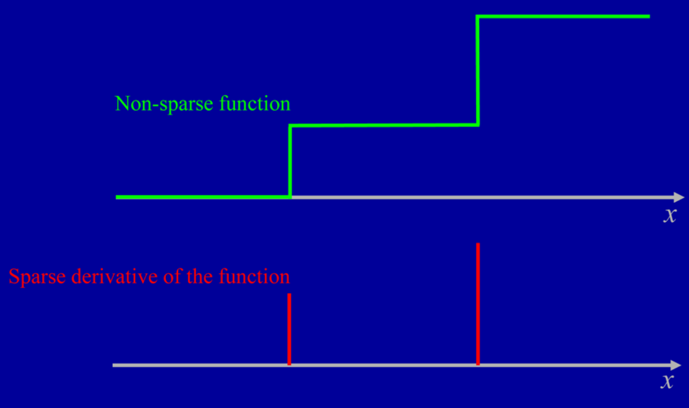
CS-optimization:

$$\vec{f}^* = \text{argmin}||\Psi \vec{f}||_1 \quad \text{subject to} \quad |\vec{g} - M\vec{f}^*| \leq \epsilon$$
$$\vec{f}^* \geq 0, \ldots$$

Constrained L_1-norm optimization:

$$\vec{f}^* = \text{argmin}||\vec{f}||_1 \quad \text{subject to} \quad |\vec{g} - M\vec{f}^*| \leq \epsilon$$
$$\vec{f}^* \geq 0, \ldots$$

Derivative Sparsifying Transform



Constrained TV-norm Optimization

$$\vec{f}^* = \text{argmin} \|\nabla \vec{f}\|_1 \quad \text{subject to} \quad |\vec{g} - M\vec{f}^*| \leq \epsilon, \quad \vec{f}^* \geq 0, \ldots$$

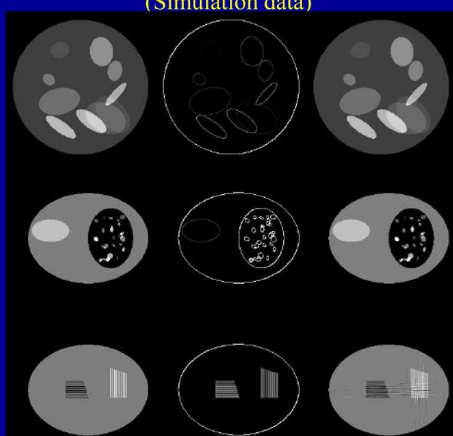
$\|\nabla \vec{f}\|_1$ is also referred to as the total variation of $\vec{f}$.

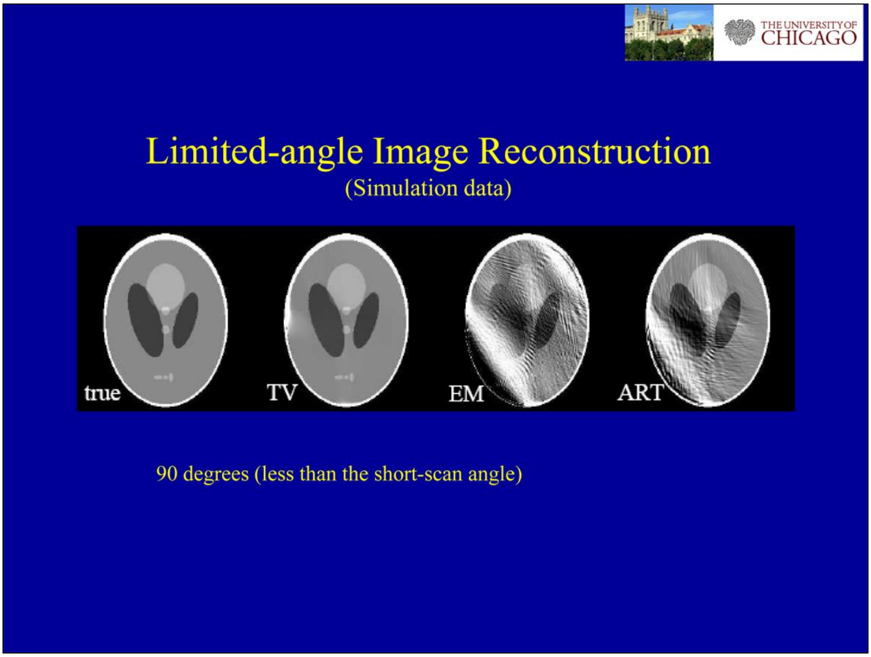
Constrained L_1-norm optimization

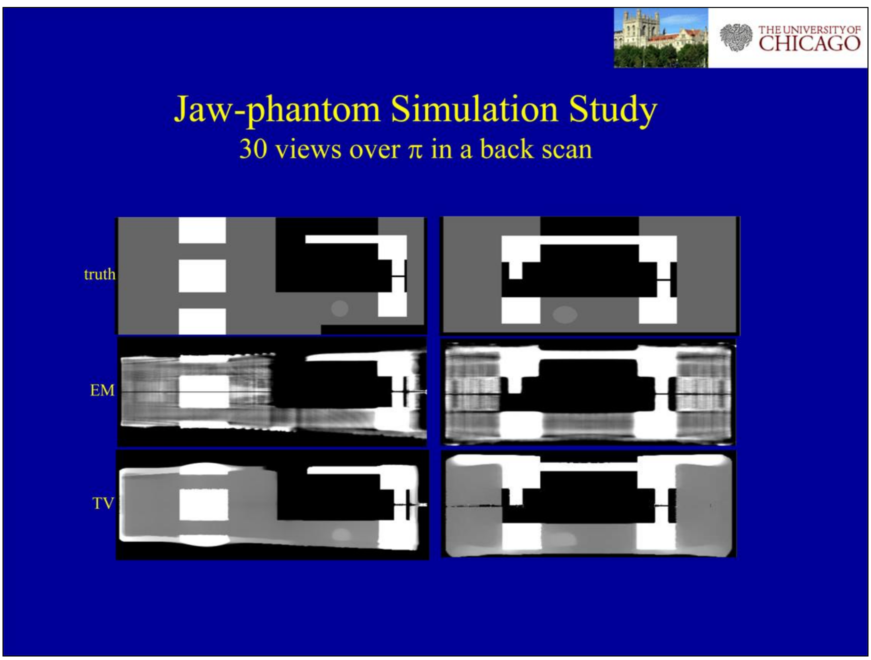
$$\vec{f}^* = \text{argmin} \|\vec{f}\|_1 \quad \text{subject to} \quad |\vec{g} - M\vec{f}^*| \leq \epsilon, \quad \vec{f}^* \geq 0, \ldots$$

20-view Image Reconstruction

(Simulation data)




THE UNIVERSITY OF CHICAGO
Limited-angle Image Reconstruction
(Simulation data)
true
TV
EM
ART
90 degrees (less than the short-scan angle)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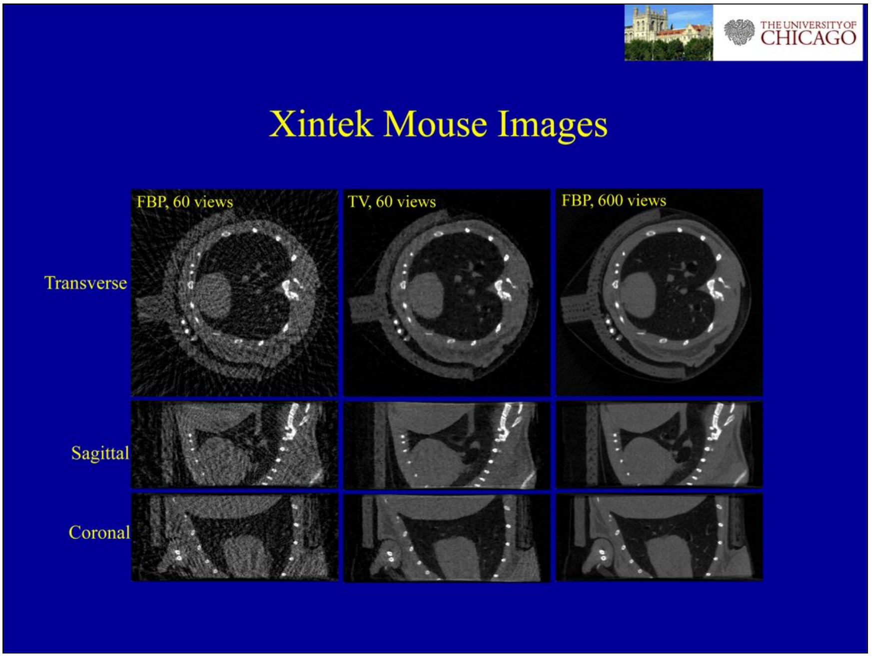
Jaw-phantom Simulation Study
30 views over π in a back scan
truth
EM
TV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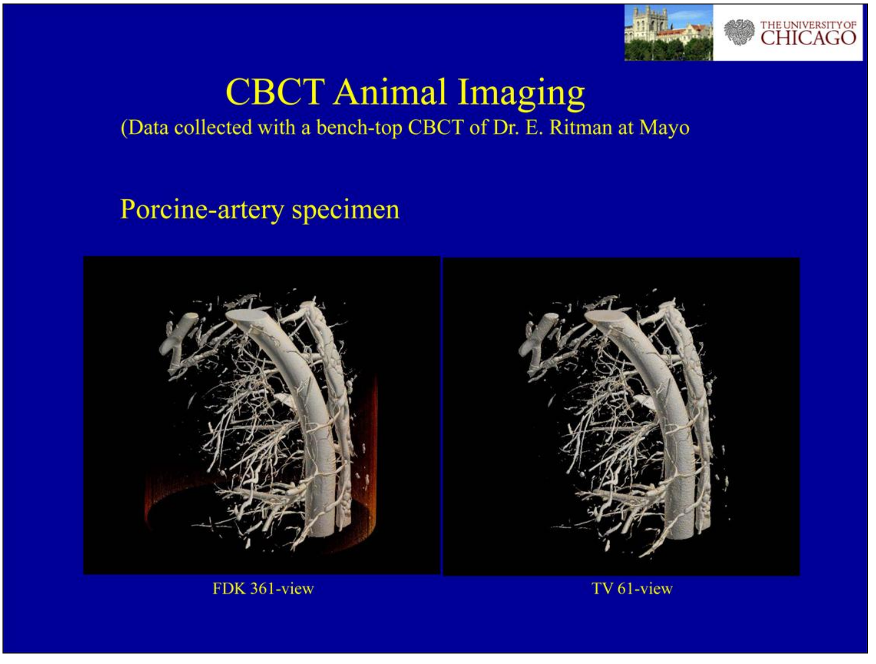
Xintek Mouse Images
FBP, 60 views
TV, 60 views
FBP, 600 views
Transverse
Sagittal
Coronal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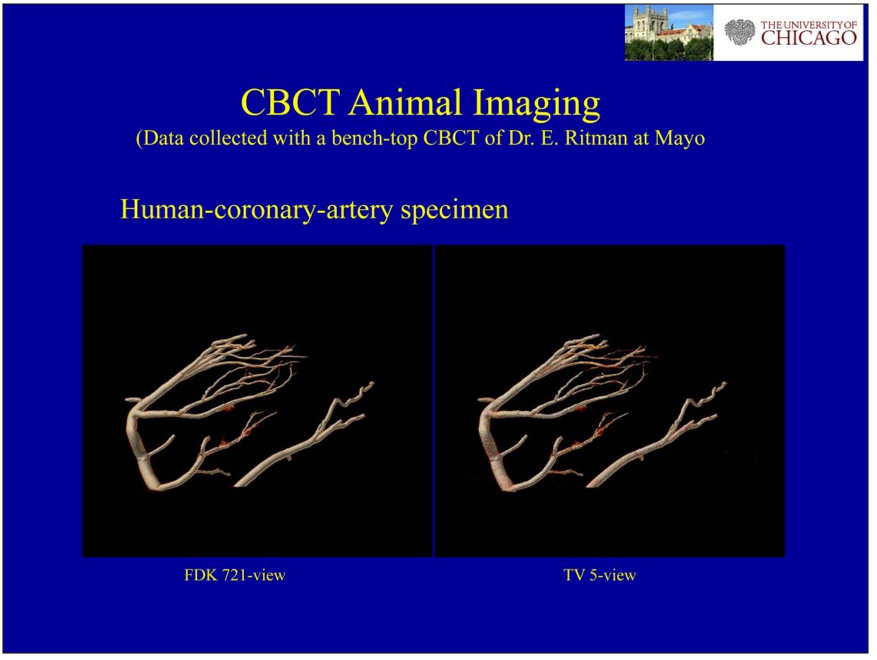
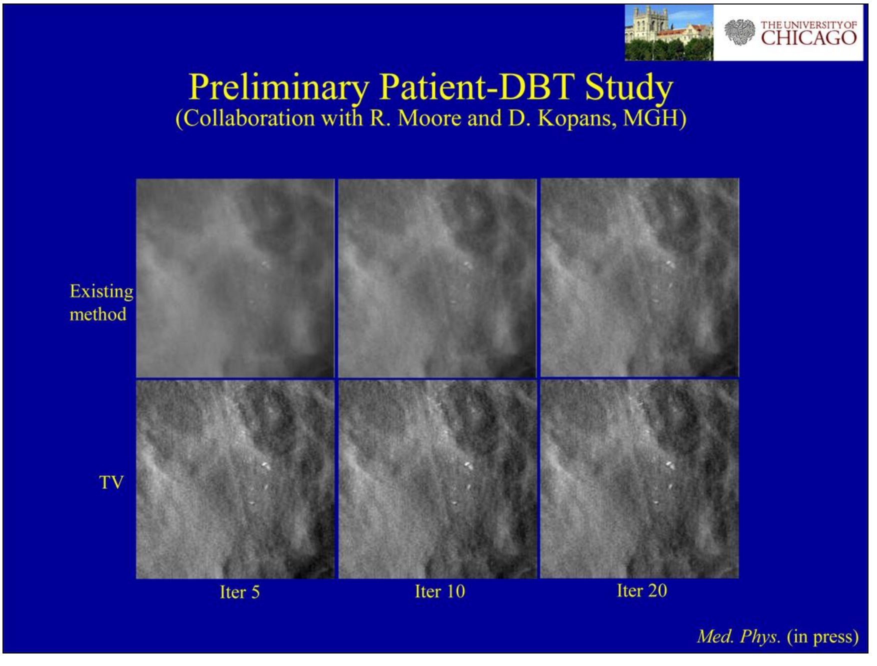
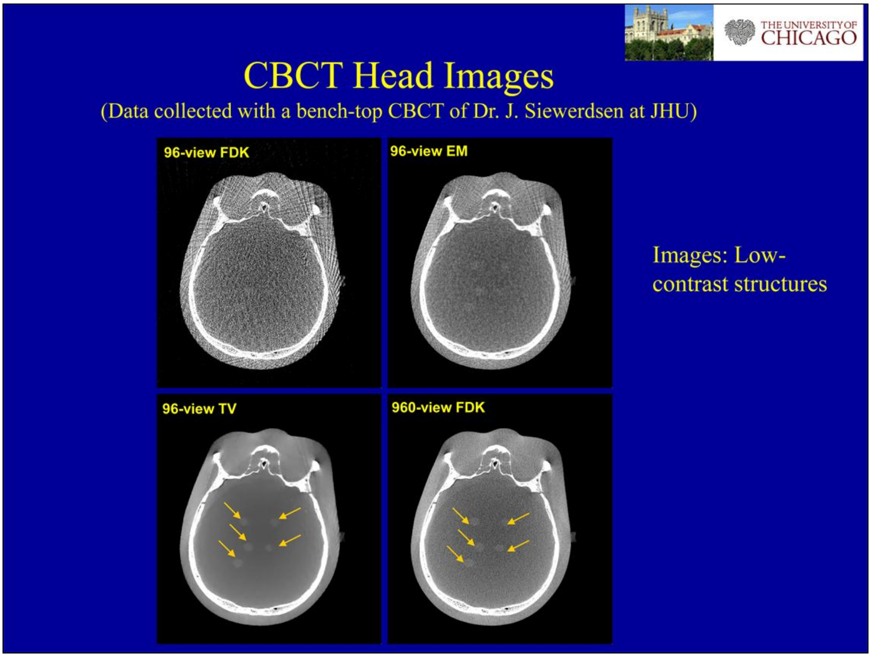
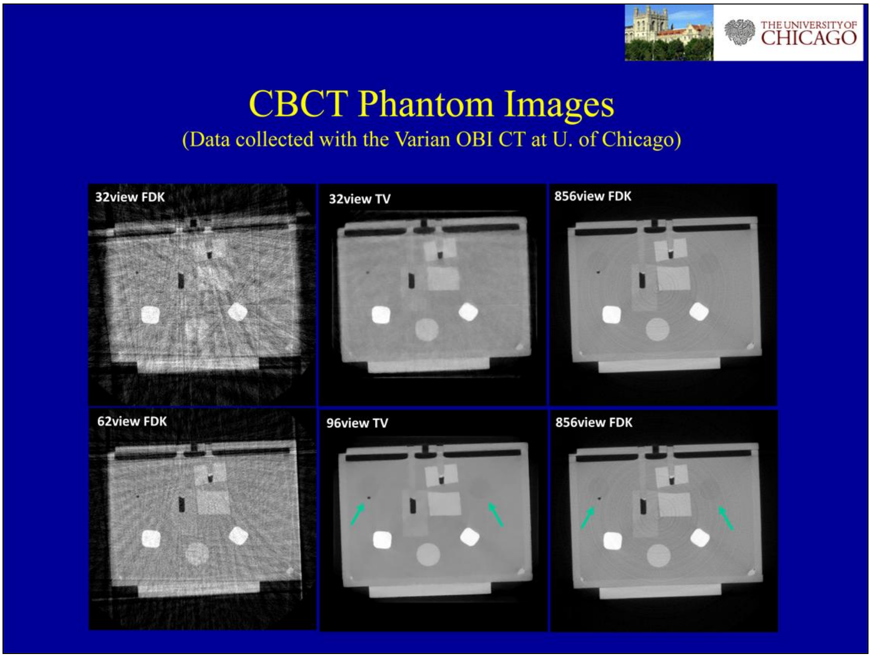
CBCT Animal Imaging
(Data collected with a bench-top CBCT of Dr. E. Ritman at Mayo
Porcine-artery specimen
FDK 361-view
TV 61-view


THE UNIVERSITY OF CHICAGO
CBCT Animal Imaging
(Data collected with a bench-top CBCT of Dr. E. Ritman at Mayo
Human-coronary-artery specimen
FDK 721-view
TV 5-view


THE UNIVERSITY OF CHICAGO
Preliminary Patient-DBT Study
(Collaboration with R. Moore and D. Kopans, MGH)
Existing method
TV
Iter 5
Iter 10
Iter 20
Med. Phys. (in press)


THE UNIVERSITY OF CHICAGO
CBCT Head Images
(Data collected with a bench-top CBCT of Dr. J. Siewerdsen at JHU)
96-view FDK
96-view EM
96-view TV
960-view FDK
Images: Low-contrast structures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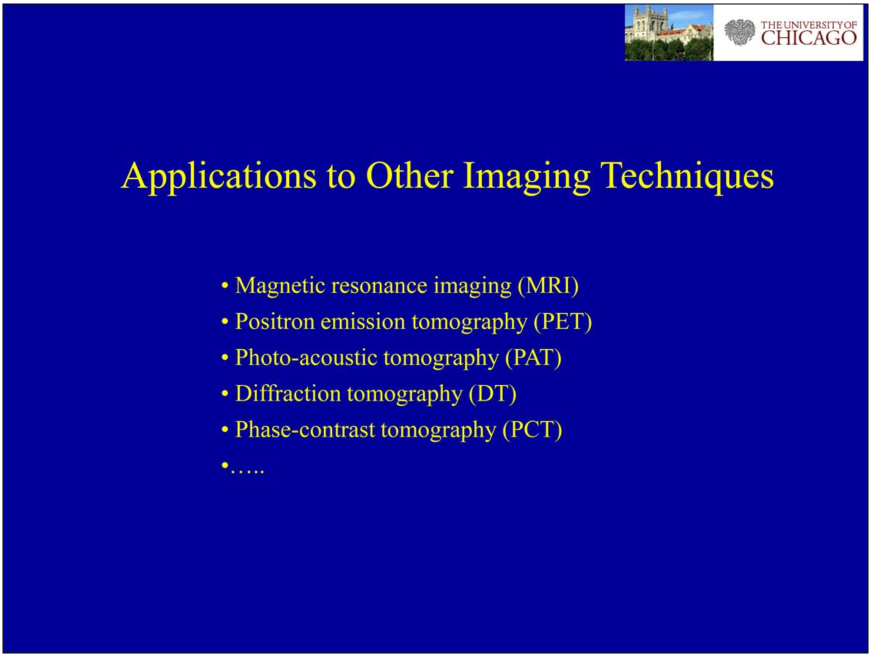
CBCT Phantom Images
(Data collected with the Varian OBI CT at U. of Chicago)
32view FDK
32view TV
856view FDK
62view FDK
96view TV
856view FDK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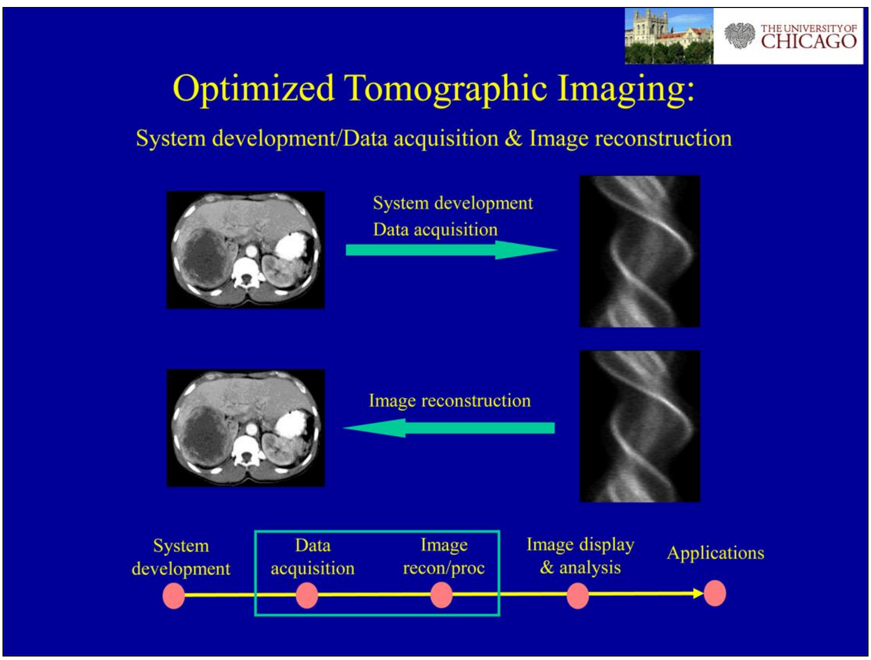
Applications to Other Imaging Techniques
• Magnetic resonance imaging (MRI)
• Positron emission tomography (PET)
• Photo-acoustic tomography (PAT)
• Diffraction tomography (DT)
• Phase-contrast tomography (PCT)
•…..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Optimized Tomographic Imaging:
System development/Data acquisition & Image reconstruction
System development
Data acquisition
Image reconstruction
System development
Data acquisition
Image recon/proc
Image display & analysis
Applications

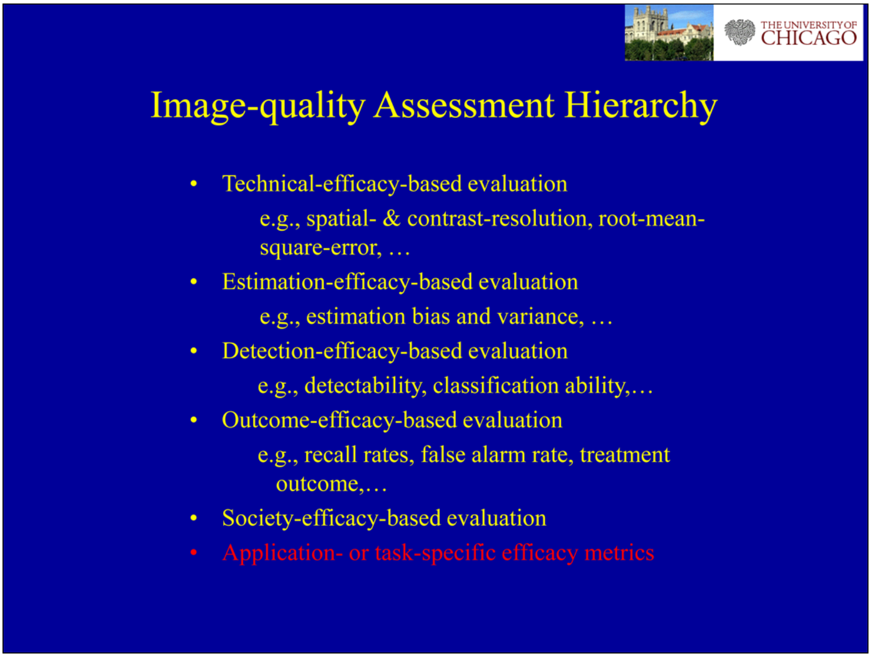
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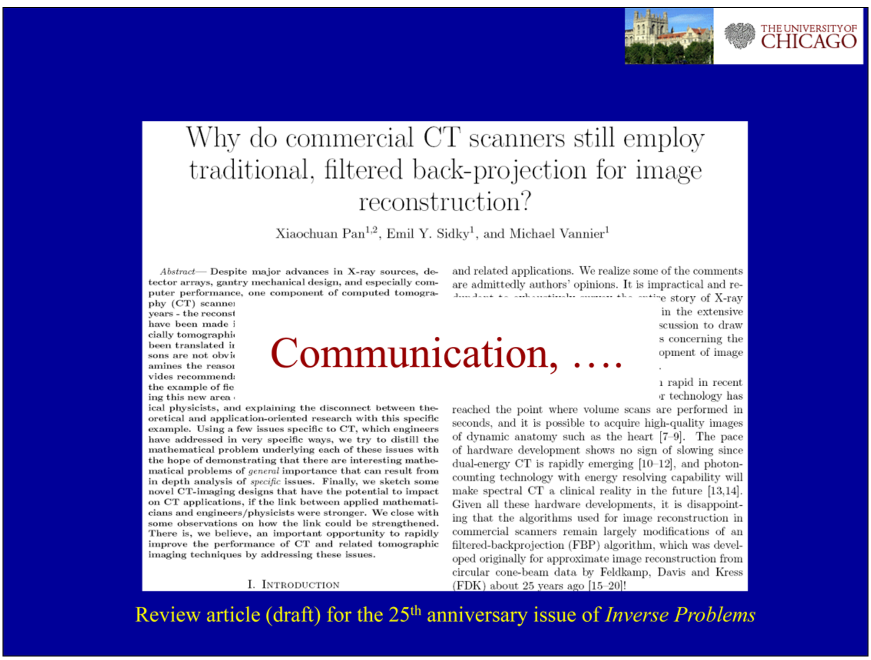
Image-quality Assessment Hierarchy
Technical-efficacy-based evaluation
e.g., spatial- & contrast-resolution, root-mean-square-error, …
Estimation-efficacy-based evaluation
e.g., estimation bias and variance, …
Detection-efficacy-based evaluation
e.g., detectability, classification ability,…
Outcome-efficacy-based evaluation
e.g., recall rates, false alarm rate, treatment outcome,…
Society-efficacy-based evaluation
Application- or task-specific efficacy metrics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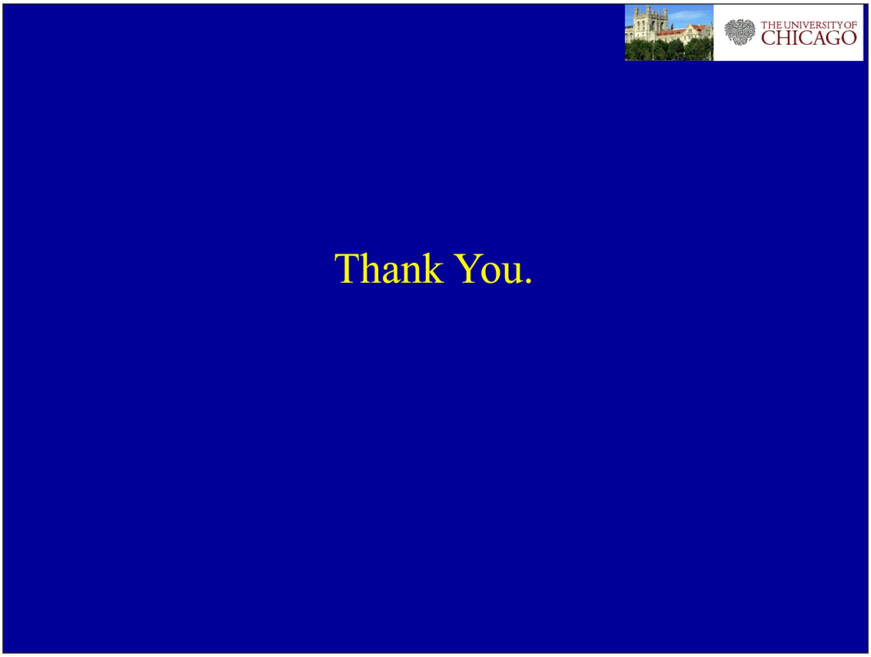
Why do commercial CT scanners still employ traditional, filtered back-projection for image reconstruction?
Xiaochuan Pan[1,2], Emil Y. Sidky[1], and Michael Vannier[1]
Abstract— Despite major advances in X-ray sources, detector arrays, gantry mechanical design, and especially computer performance, one component of computed tomography (CT) scanne
and related applications. We realize some of the comments are admittedly authors' opinions. It is impractical and re-
Communication, ….
ical physicists, and explaining the disconnect between theoretical and application-oriented research with this specific example. Using a few issues specific to CT, which engineers have addressed in very specific ways, we try to distill the mathematical problem underlying each of these issues with the hope of demonstrating that there are interesting mathematical problems of general importance that can result from in depth analysis of specific issues. Finally, we sketch some novel CT-imaging designs that have the potential to impact on CT applications, if the link between applied mathematicians and engineers/physicists were stronger. We close with some observations on how the link could be strengthened. There is, we believe, an important opportunity to rapidly improve the performance of CT and related tomographic imaging techniques by addressing these issues.
I. Introduction
reached the point where volume scans are performed in seconds, and it is possible to acquire high-quality images of dynamic anatomy such as the heart [7–9]. The pace of hardware development shows no sign of slowing since dual-energy CT is rapidly emerging [10–12], and photon-counting technology with energy resolving capability will make spectral CT a clinical reality in the future [13,14]. Given all these hardware developments, it is disappointing that the algorithms used for image reconstruction in commercial scanners remain largely modifications of an filtered-backprojection (FBP) algorithm, which was developed originally for approximate image reconstruction from circular cone-beam data by Feldkamp, Davis and Kress (FDK) about 25 years ago [15–20]!
Review article (draft) for the 25th anniversary issue of Inverse Problems


THE UNIVERSITY OF
CHICAGO
Thank You.

26.9 Matthew Merzbacher Presentation Slides

A Few Grand Challenges

Dr. Matthew Merzbacher
Manager
Machine Vision and Innovation
October 7, 2009

The Netflix Challenge and Others

Morpho Detection
SAFRAN Group

Grand Challenges

DARPA-sponsored robots over 150-mile course in <10 hours

- 2004: 30 teams
  - best effort <12KM
- 2005: 23 teams
  - all but one >12KM
  - 5 finished
- Extremely competitive

KDD Cup since 1997

- gene mapping, medicine, social networking

UCSD Data Mining contest

Programming Contests

Morpho Detection
SAFRAN Group

2 /
Merzbacher - ADSA
October 7, 2009

What is Needed to run a Grand Challenge?

Data, and lots of it
- labeled(?) training data (~ 2/3 of the data)
- test data (~ 1/3 of the data)
  - Open test data (?)
  - Closed test data
- Independent data sets

Well-specified conditions of contest that aren't too restrictive

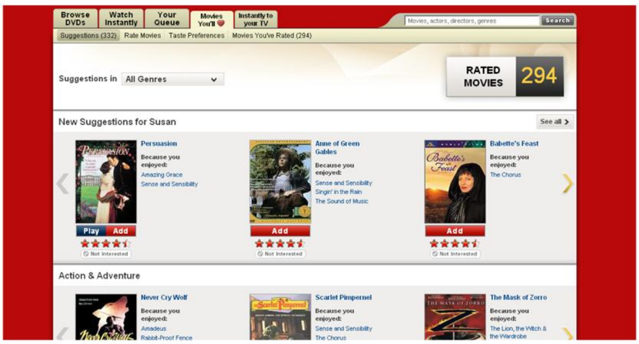
Baseline performance and good scoring standards

Publicity

An award (will generate publicity)

Morpho Detection SAFRAN Group Proprietary to Morpho Detection – do not redistribute without permission 3 / Merzbacher - ADSA October 7, 2009

Netflix



Netflix's recommender system needs improvement

Netflix has lots of clean data that is labeled (fairly) accurately
- 100 million ratings that over 480,000 users gave to nearly 18,000 movies
- <user, movie, date of grade>
  - What about shared accounts?

Morpho Detection SAFRAN Group Proprietary to Morpho Detection – do not redistribute without permission 4 / Merzbacher - ADSA October 7, 2009

Netflix Contest

$1M prize, $50K progress prizes (>1% improvement)

Multi-phased
- Careful selection of sets to make them independent and protect privacy (perturbation)
- public training ("query"), public ("quiz") & private test ("test")

Weekly -> daily submissions allowed

Clear Termination criterion:
- 10% improvement over baseline against public test set starts 30-day count-down

RMSE evaluation criteria

IP: Algorithm but not source published, Netflix non-exclusive license

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Outcome

Preliminaries over three years

BellKor's Pragmatic Chaos passed the 10% mark, starting 30-day countdown

Ensemble (Opera & a consortium) passed BPC, was re-passed, and passed again in the final minutes

Final score was… a Tie!
- A 20-minute loss by Ensemble
- Ensemble members claim satisfaction ($10M of business development)

The big winners: Netflix – cheap labor

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Team of Teams

$$\hat{r}_{ui} = b_{ui} + |\mathrm{N}(u)|^{-\frac{1}{2}} \sum_{j \in \mathrm{N}(u)} e^{-\beta_u \cdot |t_{ui} - t_{uj}|} c_{ij} + |\mathrm{R}(u)|^{-\frac{1}{2}} \sum_{j \in \mathrm{R}(u)} e^{-\beta_u \cdot |t_{ui} - t_{uj}|} ((r_{uj} - \bar{b}_{uj}) w_{ij}) + \sum_{j \in \mathrm{R}(u)} e^{-\gamma_u \cdot |t_{ui} - t_{uj}|} ((r_{uj} - \bar{b}_{uj}) d_{ij}).$$

Teams that had it wrong made the difference in making it right

BellKor – best basic algorithm (8% over baseline)

- + Pragmatic – rating a lot of movies means something different from rating a few
- + Chaos – Day of Week model

Need to combine very different styles to avoid re-using the same information

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Other Grand Challenges

Netflix Follow-up: $500K after 6 months, $500K after 18 months, no success requirements, includes more data fields

X-Prize for genomics, energy independence, space exploration

Genius Rocket for startups

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Do Grand Challenges Work?

Is “Dancing with the Stars” really Dancing? Are they Stars?

Pro:

- Stimulates activity
- Relatively inexpensive
- Can create partnerships
- Exciting – good publicity
- Grad Students and Startups will do anything for free (is that a pro or a con?)
- Competition

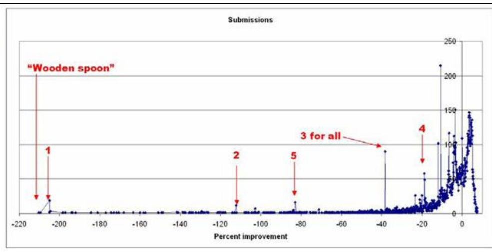
Con:

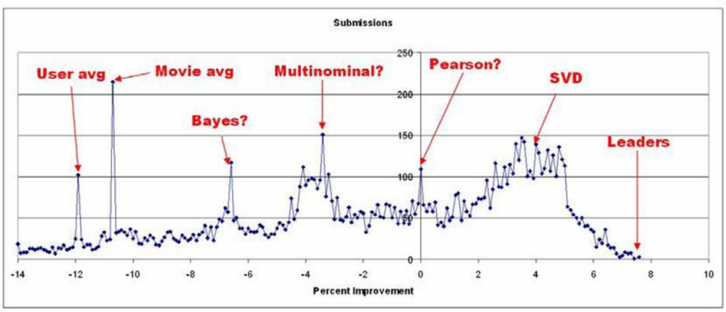
- Encourages short-cuts and gaming the system
- Yields short-term solutions that may not stimulate long-term thinking
- Competition instead of collaboration
- Second-place (and third-place) research can ultimately be best, but may be lost in publicity rush
- Privacy
- What about dirty data?

Morpho Detection SAFRAN Group | Proprietary to Morpho Detection – do not redistribute without permission | 9 / Merzbacher - ADSA October 7, 2009

Do GCs Work?

Is there low hanging fruit to be harvested?





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Thank You
Morpho Detection
SAFRAN Group
Morpho Detection
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October 7, 2009

26.10 Doug Bauer Presentation Slides

Seeking your guidance

- Design an interesting challenge
- How to style/define our contribution?
- Incentives? Money, structure, bragging rights?
  - Large Universities
  - Smaller Institutions
- Definition of success.
  - Partnerships.
  - Separate and applied algorithm development.
  - Transformative?
- Migration / Adaptation of Medical Application Segmentation to Security Applications.
  - Limitations of extensibility?

Government Contribution

- Manage / access to security, proprietary information with the need for real data.
  - Increasing PD against a wide variety of threats.
- Open Data Sets to reduce false alarms
  - Honey, butter, beeswax
- Funding vehicles
  - Grant, cooperative agreement, research money, BAA, SBIR?
- Use of the COE as an organizing force / convening group.
  - Execution of a Grand Challenge

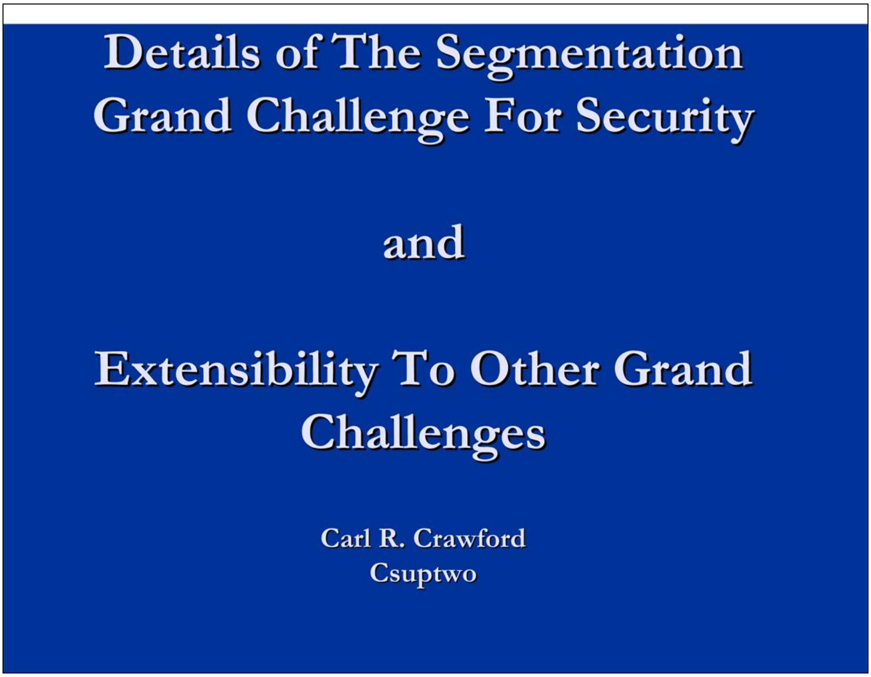
Next Steps

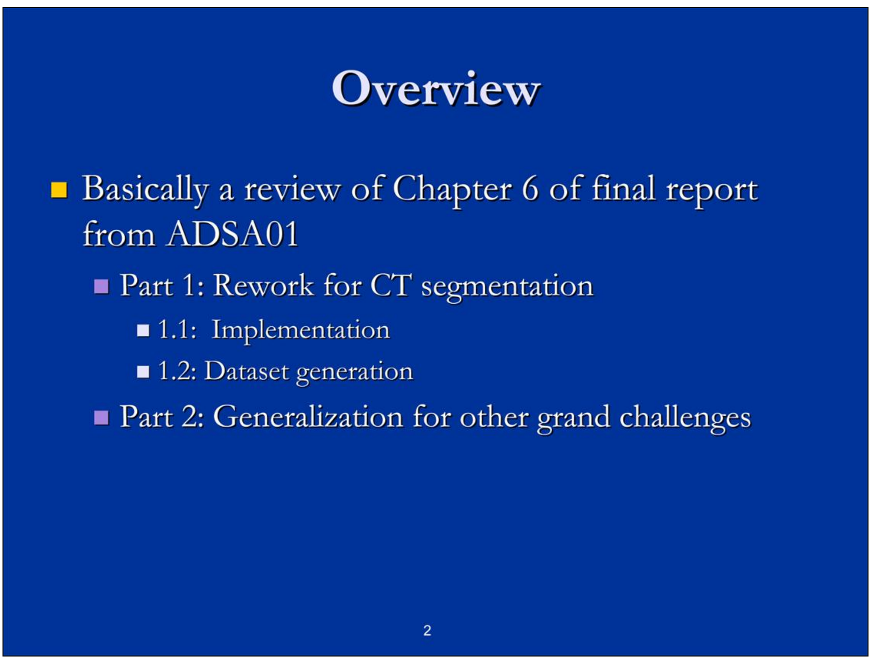
- Grand challenge iteration: Segmentation, Reconstruction, etc...
- Build links to RSNA, MICCAI

Next Steps (2)

- Following workshop, what is going to happen differently?
  - What should the enabler be? Scope? Potential?
- Describe for researchers the real importance, real market, real opportunity, real value.
- Need to stimulate conversation.

26.11 Carl Crawford Presentation 4-5 Slides





Goals

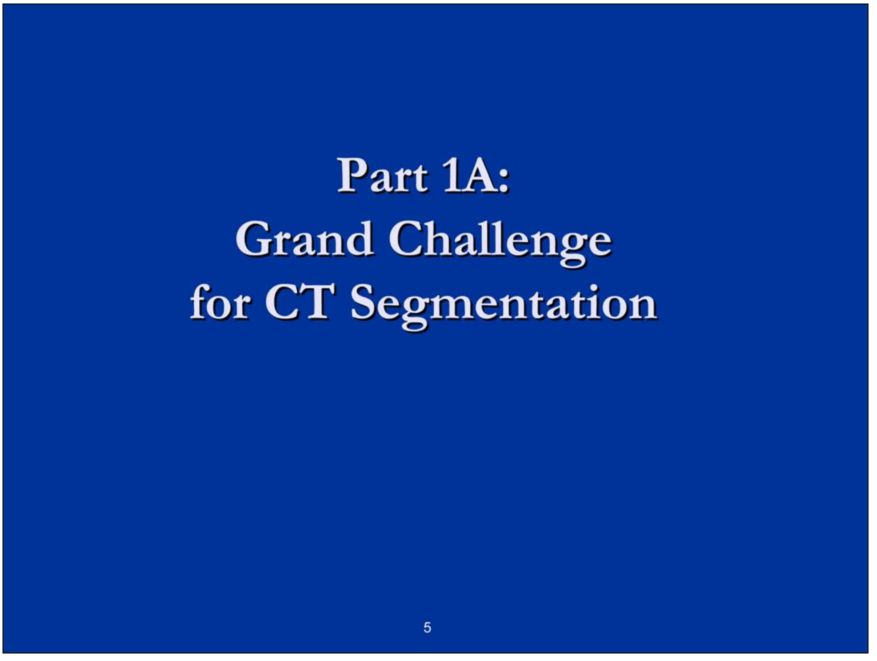
- Refine process
- Identify issues
  - Resolve if possible
  - Push-off for future resolution
- Help DHS establish funding policies

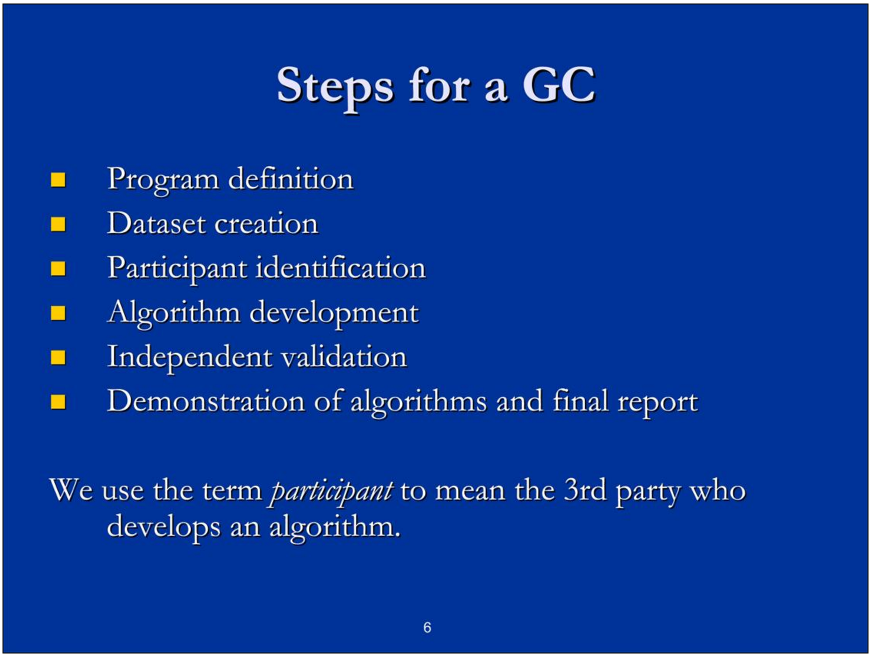
3

Algorithm Definition

- Recipe to perform a task
  - Mathematical description
  - Deliverables: report, example code, test cases
- Implementation
  - Product coding: CPU, FPGA, GPU, Cell processor
  - Inputs, outputs, exceptions
  - Integration with other functions
  - Professional coding practices

4


Part 1A:
Grand Challenge
for CT Segmentation
5


Steps for a GC
Program definition
Dataset creation
Participant identification
Algorithm development
Independent validation
Demonstration of algorithms and final report
We use the term *participant* to mean the 3rd party who develops an algorithm.
6

Program Definition

- What algorithm has to be developed?
- What are the inputs and outputs of the algorithm?
- What metrics are used for measuring performance?
- What are the programmatic issues related to the grand challenge?

7

Plan Contents

- Technical:
  - Input datasets for training and testing, including keys
  - Objects to be segmented (threat-like)
  - Executable: output format and runtime environment
  - Report structure
  - Acceptance criteria
- Non-Technical:
  - Contractual
  - Intellectual property issues
  - Funding
  - Participant eligibility and identification
  - Schedule

8

Use of Plan

- The project team will use the plan to:
  - Create datasets required by the algorithm developers
  - Select and fund participants
  - Monitor participants
  - Independently test algorithms
  - Demonstrate the algorithms and write the final project report
- The algorithm developers will use the plan to:
  - Develop and train algorithms
  - Demonstrate algorithms at a symposium
- Notes
  - A purpose of the second ADSA workshop is to provide inputs for this task.

9

Dataset Creation (1)

- Locate and fund use of medical or industrial scanner
- Acquire 100 items for contents of bags. The items include the following items from stream of commerce (SOC) bags:
  - Clothing
  - Personal items
  - Perishables (fruit, vegetables)
  - Food in containers
  - Electronics
  - Liquids
  - Sheet-like objects
- Acquire 20 suitcases

10

Dataset Creation (2)

- Define how to pack 100 different configurations of bags using the 20 suitcases and the 100 objects.
  - Use LLNL data on the prevalence of objects to pack the bags.
  - Pack bags to produce artifacts in the images such as cupping, CT number shifts, streaks, rings and bands.
- Scan contents of 100 items in isolation and record the following information:
  - Dimensions
  - Mass
  - Volume
  - Density
  - Digital picture
  - Written description
- Pack and scan 100 bags
- Generate keys showing location of objects in each bag
- Store dataset at

11

Phantoms

- Develop physical phantom(s)
- Provide
  - mathematical description
    - University of Erlangen
    - www.imp.uni-erlangen.de/forbild
  - simulated projection data and ground-truth images

12

Dataset Names and Uses

- The dataset will be randomly split into three datasets of equal size. The sets are denoted:
  - Training
  - Validation
  - Evaluation
- The datasets will be used as follows:
  - Participants
    - Develops algorithm on *training* dataset
    - Tests on *validation* dataset
  - Team
    - Independently confirms participant results on *validation* dataset
    - Tests on *evaluation* dataset

13

Dataset Notes

- The datasets will be non-proprietary, non-sensitive, and publically releasable information to the participants in the grand challenge.
- Ideally, the datasets will be accessible via the Internet.

14

Participant Identification

- Advertising in peer-reviewed journals and at conferences
- Email solicitation of participants at algorithm development workshops
- Word of mouth
- Literature review
- Posting of solicitation on the Internet

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Participant Proposal

- 10-page proposal
- Test on simple dataset
  - Entrance exam

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Participant Selection

- Knowledge of image segmentation
- Knowledge of the security field
- Existence of working segmentation algorithms
- Results of the entrance examination
- Having resources to work on the grand challenge

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Participant Notes

- It is desired to fund a mix of participants who will develop me-too, moderate improvement, and game-changer algorithms.
- Participants that are not selected to receive funding will be allowed to use the datasets to develop algorithms. Their algorithms, if requested, will be tested by the team. However, mentoring will not be provided.

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Algorithm Development

- Algorithms developed
  - 6 month period
- Participants mentored
  - Face-to-face meetings
  - Tele-cons
  - Monthly reports
- Evaluation program supplied

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Participant Report

- An executable program that implements the participant's algorithm.
- A report that contains the following information:
  - User manual for executable
  - Results of running algorithm on training and testing datasets including:
    - Accuracy of locating objects
    - Accuracy of bounding boxes for located objects
    - Accuracy of volume, mass and density
  - Algorithm description including:
    - Mathematics
    - Implementation considerations
    - Strengths and weaknesses
    - Extensibility to other images (resolution, noise, artifacts) and modalities
    - Possibility for future improvements
  - Recommendations for changes to the grand challenge process

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Participant Notes

- All resulting intellectual property will be owned by the participants.
- The government and its agents will have a royalty-free license to use the resulting algorithms for research purposes.
- Must license IP to all SSDs with same terms
- Participants will be required to present and publish their results.

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Independent Testing

- Test algorithms on 3rd dataset
- Notes:
  - The participants will be allowed to witness the independent testing. However, they will not be able to examine the datasets.
  - The results of the independent testing will be shared with the participants.

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Demonstration

- A two-day symposium will be held for the participants, vendors and DHS so that the participants may present their algorithms and demonstrate them live. A discussion of how the algorithms could be deployed will be held.

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Final Report

- Strengths and weakness of each participant for each of the following topics:
  - Ability to segment objects per the acceptance criteria
  - Quality of report
  - Ease of use of the deliverable
- Recommendations for additional development on the algorithms
- Recommendations for changes to future grand challenges
- Report will be in public domain

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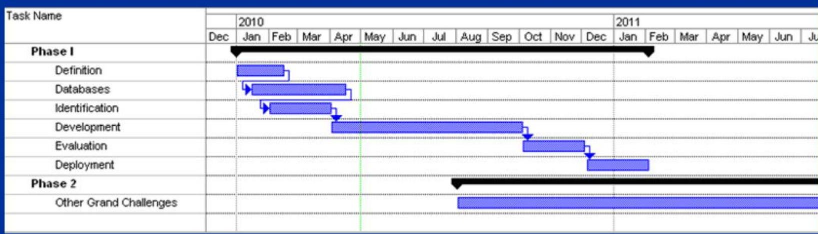
Schedule



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Part 1B: Data Collection for CT Segmentation Grand Challenge

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Types

- SSD scanner(s)
- Medical scanner
- NDE scanner
- LLNL scanner

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Specs for This Exercise

Parameter	Value
Scan/reconstruction field of view (FOV)	50 cm
Scan modes	Helical or step-and-shoot
Dual energy	Desirable
Resolution	1 mm, isotropic
Pixel size	1 mm, isotropic
Potential	140 – 180 kV, high energy 80-100 hV, low energy
Dose	20 mAs
Dynamic range	Shall not be limited by electronic noise for a 50-cm path length of density 0.3 g/cc.
Projections	512 views per rotation per energy
Reconstruction	1. Cone beam correction 2. TBD reconstruction kernel 3. Dual energy decomposition
Scan time	< 15 minutes per volumetric scan.

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Reconstruction

- Degrade resolution and noise to ~match commercial products
- Also provide high-resolution data?
- Document reconstruction

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Deliverables (GCseg)

- Images corresponding to the scans of
  - Baggage
  - Isolated scans of items in the baggage
  - Quality assurance (QA) phantoms
  - Digital pictures of items and packed bags
- The following documentation
  - Image format
  - Description of reconstruction algorithms including dual energy decomposition
  - An electronic record containing the details of the CT scanner and the object being scanned. Details of this electronic record, known as a log file, will be provided in a separate specification.

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Deliverables GCrecon

- Raw and calibration data
- Information necessary to reconstruct the data
  - Scanner specification
  - Data formats
- Offline reconstruction software
- Reconstructed images

Desirable to collection data for GCseg and GCrecon at same time.

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Discussion Points

- Availability of existing scanners.
- Development time for new scanners.
- Cost of developing new scanners that would fit into the time frame of this project.
- Cost of using scanners for scanning.
- Ability to supply the requested information.
- Technical specifications for the scanners.
- Locations where scanning could be performed per the list given above.
- Comments on and suggestions for conducting GCs.
- Maturity of equipment to be provided.

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Part 2:
Other Grand Challenges

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Components of a Grand Challenge

1. Define
    1. Problem to be solved
    2. Input and output data
    3. Acceptance criteria
2. Acquire and distribute sample input data
3. Identify and qualify participants
4. Fund participants
5. Participants train algorithm and then validate
6. Participants write a summary report
7. Supervise participants
8. Validate and evaluate algorithms
9. Write report
10. Down selection of a few promising algorithms
11. Iterate development of algorithm using sensitive and classified data
12. Deploy algorithm

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What algorithms can be addressed?

- Reconstruction
- Segmentation
- Identification of features for use in detection/classification
- Detection/Classification
- Operator performance
- Scanner and scenario (threats and non-threats in bags) modeling
- Fusion
- Notes:
    - Scanner and scenario models may not be an algorithm topic, but may possibly be part of an algorithm. This is part of implementing a good scanner and scenario simulator.
    - It is recommended that the topics be initially addressed individually. Over time, the interactions between the topics will have to be addressed.

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What modalities can be addressed?

- X-ray CT – transmission and scatter
- Threat-image-projection (TIP) ready x-ray (TRX) projection line scanner
- Multi-view line scanners (known as advanced technology [AT])
- X-ray back-scatter
- Coherent X-ray scattering (sometimes called X-ray diffraction)
- Active neutron and X-/Gamma-ray (e.g., Pulsed Fast Neutron Analysis)
- Explosive trace detection
- Millimeter wave and Terahertz imagery or spectroscopy
- Raman spectroscopy

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What applications can be addressed?

- Checked baggage screening
- Check point screening
  - Carry-on items
  - Passengers
  - Divested items
    - Liquids
    - Shoes
- Stand-off detection
- Cargo screening
- Multi-System fusion

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What are the recommended first two grand challenges?

- CT-based EDS
  - Segmentation
  - Reconstruction

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How should problems be defined?

- Specify general problem to be solved
- Define input data
- Define output data
- Define acceptance criteria, which are based on a significant advancement beyond the state of the art

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What type of scanners should be used to acquire input data?

- State-of-the-art security equipment (best case)
- Legacy security equipment
- Scanners from other applications such as medical imaging or non-destructive evaluation
- Custom-designed scanners
- Scanner simulators (mathematical models)

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What information should be provided about scanners used to acquire data?

- Description of source, sensor and geometry
- Details of calibration, correction and reconstruction
- Quality assurance results including scans of quality assurance phantoms
- Data file formats
- Scan protocols

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What objects should be scanned?

- A range of common objects carried by passengers
- Objects may have to be physically scaled to match the resolution of the scanning device
- Notes: As algorithms are moved towards possible implementation, then the algorithms should be tested on scans of the following objects:
  - Real threats (best case)
  - Simulants (next best)
  - Objects known to cause false alarms

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What information should be provided about objects?

- Written description
- Digital picture
- Dimensions
- Mass
- Volume
- Physical characteristics that are relevant to the scanning device. For example, for transmission x-rays, provide x-ray attenuation, density, texture and effective atomic number.

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How should objects be scanned?

- Bare
- Within a range of different types and sizes of luggage
- Concealed
- With various amounts of clutter and attenuation (many surrounding objects)
- At different locations and orientation in the scanner

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What object scanning information should be provided?

- Digital pictures of all objects bare and packed
- Overview of scan (text)
- List of objects to be distinguished from other objects
- Labeled versions of images showing which object is in each pixel.
- Truth data including bounding box key, attenuation, volume (e.g., number of voxels for CT)
- A log file that will be described in a separate document

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Where the information should be archived?

- ALERT COE
- DHS S&T EXD Image Database at LLNL
- Available in public domain without restriction
  - Password to log access

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Who should have access to the grand challenge information?

- Everyone/anyone, without limitation.
- There are no requirements on:
  - Having a security clearance
  - Having access to SSI, FOUO or classified information
  - Signing an NDA
  - Having a US citizenship
  - Working in the US
- Academia
- Vendors
- National laboratories
- 3rd party industry (not the system vendors)

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Data Access Notes

- It is desirable that all of the above parties have access to the data for grand challenges without restriction.
- May not be possible to provide seed funding to all participants or be able to formally evaluate all algorithms.
- Log access via password

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How shall participants be identified?

- Creation of a website for the grand challenge
- Word of mouth
- Advertising in journals and trade magazines
- Literature review
- Using the names provided in this report
- Adding sessions related to security at imaging conferences such as IEEE's Medical Imaging Conference (MIC).

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What criteria should be used to choose participants?

- Domain expertise in
  - Algorithms used related fields that are applicable to grand challenge
  - Technology and algorithms in the security field
- Existence and maturity of related algorithms
- Resource availability
- Development time
- Development cost (personnel and equipment)
- Notes: This section applies only to participants that receive seed funding.

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How shall participants be funded?

- Little or no seed funding
- Larger funding levels for demonstrating significant improvement over state-of-the art
- Royalties

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Who will implement and deploy the algorithms?

- Vendors (best case)
- System integrators

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How will algorithms be tested?

- Using input data that has not been provided to the participants
- Using acceptance metrics that are defined in advance
- Notes: The testing described in this section applies to the testing done by the organizers of the grand challenge. The participants will also be required to test their algorithms on datasets that will be provided with the training data.

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How will the algorithms be improved?

- A person with a security clearance will test algorithms with real scans of real threats.
- Algorithms may have to be tuned to specific threats and scanner

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What deliverables are required?

- Report including
  - Description of algorithm
  - Test methodology and results
  - List of issues and possible mitigations
  - Recommendations for future work
- Executable code

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What can the participants do with the results?

- Present at conferences
- Write journal articles
- Write dissertations
- Obtain patents

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What non-technical issues have to be resolved?

- Contracts with people who receive seed funding including ownership and use rights
- Intellectual property – patents and licenses
- Testing algorithms with real threats scanned on real scanners
- Review of publications and presentations
- Control of information and material by the DHS
- Need to resolve who own the rights to use algorithms if the Government supplies funding.

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Who are members of the team that drive grand challenges?

- DHS S&T
- ALERT COE
- National laboratories
  - LLNL
  - PNL
  - Sandia
- TSA

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What other funding vehicles exist to support grand challenges?

- DoD
- DARPA
- NSF
- SBIR

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How could participants be incentivized?

- Seed funding
- Follow-on funding
- Prizes
- Royalties
- Notes:
  - The incentives should be developed so that collaboration is encouraged.

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26.12 Suriyun Whitehead Presentation Slides

How do we move forward?

Thank you

- Thank you for actively participating.
- Thank you for sharing your concerns, helping to look for solutions.
- Thank you for engaging the Government in conversations.

Why is the Government Here?

- Listen, learn.

- Learn how to fund.
- Sponsor forum for introduction, discussion.
- "3rd party" involvement is useful.

- Real need, public safety.
- Provide opportunities to improve, transform, revolutionize.
- Understand ways to reduce barriers to participate.

Expanding Participation in the Field

- Educate, transfer of Domain Knowledge
  - Train students to work in the Security Domain
  - Draw in bright people to work on Security problems.

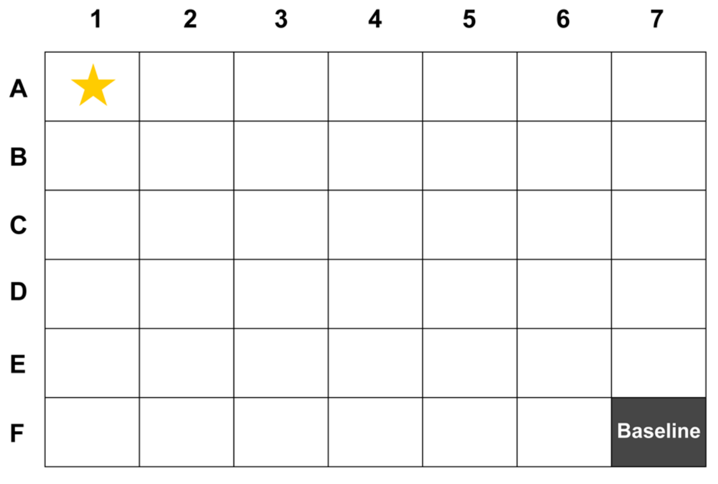
- Bootstrap to create literature, publications, intellectual property
  - Transformative?

- Path to better systems

"Algorithm" Workshop

- Research
  - Algorithm – Good idea, method.
  - Licensing, royalties
- Security System Vendors
  - Implementation, instantiation, integration, "productization", deployment, support, etc…
  - Acquisition (1..n), based on performance.

System Goal



What are we offering?

- Seed funding, source data, testing/evaluation support.
  - Government Furnished Information (GFI)
  - Exemplars
  - Explore with vendors releasing existing data
- Opportunity, facilitation.
- Gr~~oss subsidies, unlimited fund~~ing.

26.13 David Castañón Presentation Slides

DHS Challenge Problems: A View from Academia

- What Universities have
  - Ideas
  - Eager students with time looking for topics
  - Broad experience in diverse emerging technologies and applications
- What Universities lack
  - Domain expertise on DHS problems (lack of literature)
  - Equipment, Models
  - Student support

➔Participation in DHS research has significant hurdles
  - Will tend to stay in the "comfortable" known research channels: NIH, NSF, AFOSR, DOE, etc

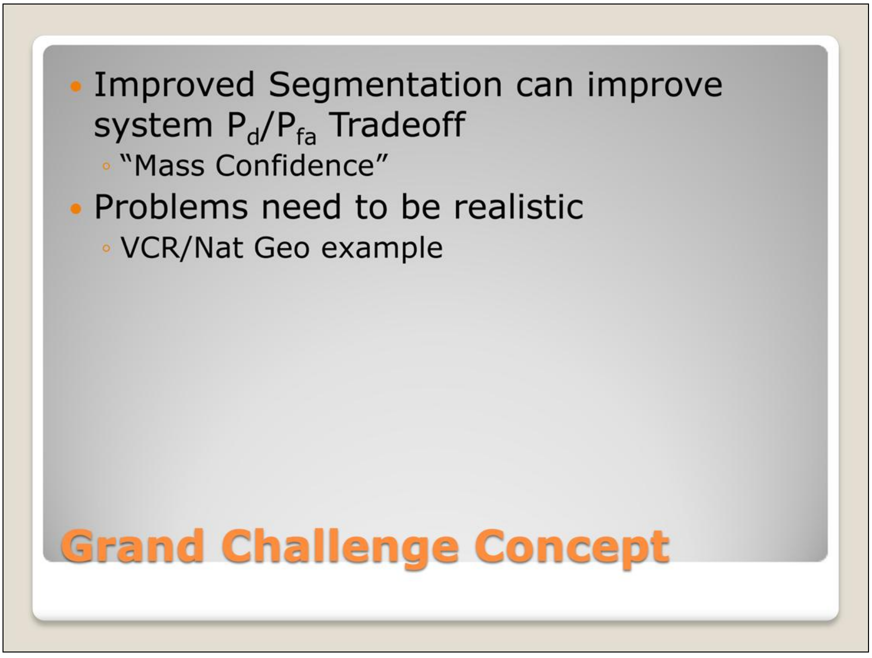
DHS Challenge Problems: Why Universities would Participate

- Challenge Problems may provide:
  - Domain expertise: what are the problems, metrics for success
  - Interesting topics for research
  - Easy access to problems at "low" financial cost
  - Mechanisms to evaluate rapidly value of ideas
  - Student support
  - Migration paths to other problems

DHS Challenge Problems: Some Recommendations

- Scope domain-relevant challenge that is not too domain-specific
  - Goal is to generate and validate ideas, not achieve “best” specific solutions
- Make challenge relevant enough so validated ideas will be of interest to DHS, vendors
- Difficult enough problem, requiring alternative ideas, worthy of research dissertations
  - Provide benchmarks and background work information\
- Broad distribution of challenge problem
  - Identify relevant conferences, journals and publish
  - Avoid distribution restrictions
  - Archive the benchmark for future use
  - Create “events” to showcase progress at chosen locations to stimulate interest
- Consider alternatives to provide support for students

26.14 Jim Connelly Presentation Slides



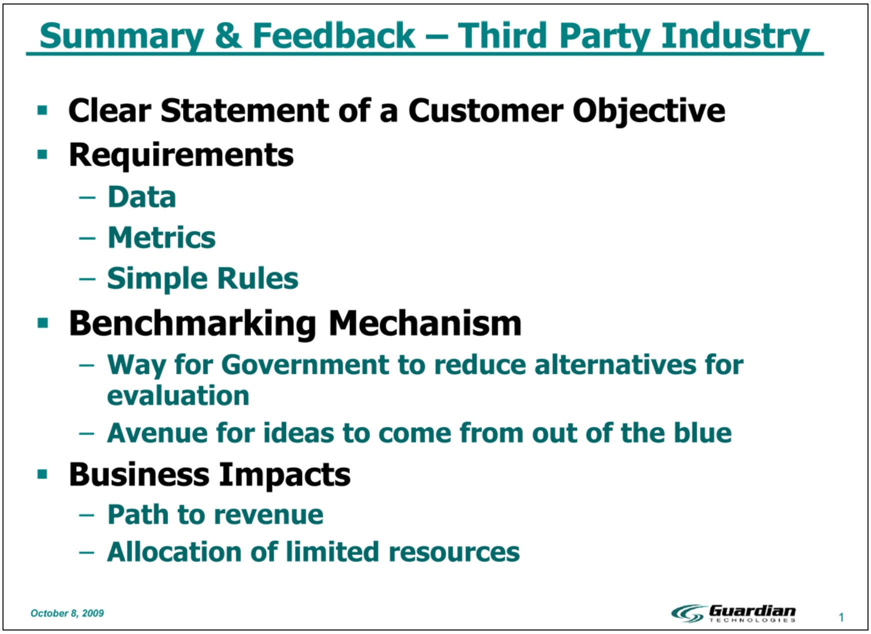
Grand Challenge Criteria

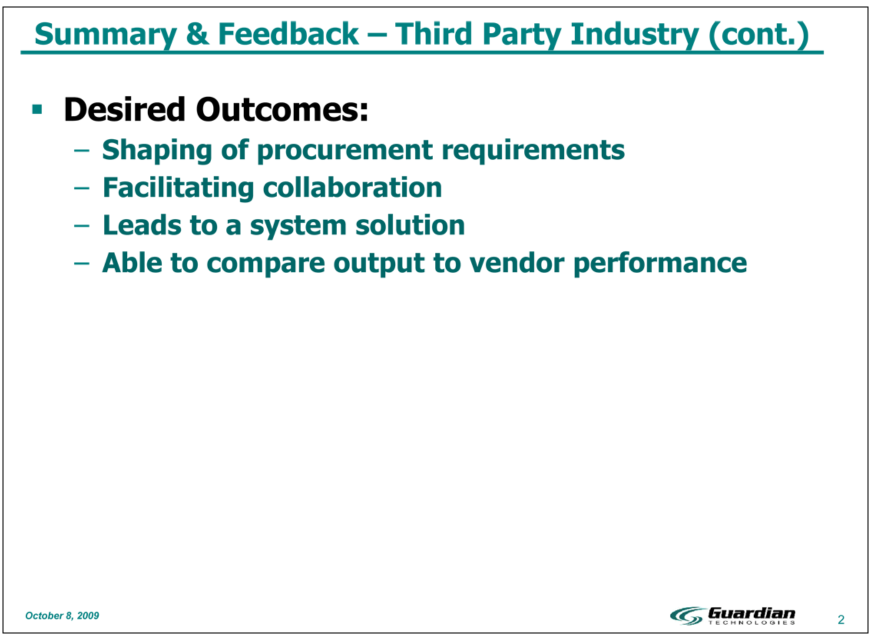
- Criteria will influence solutions/ideas
- Must be more basic than P_{fa} / P_d
  - Mass Captured - % of truth with penalty for non-truth
  - Secondary Metrics
    - Reported Avg. Density
    - Standard Deviation
    - Reported Mass
- Provide details on how to calculate

Database Establishment

- Will require a significant effort
  - Identification of realistic problems – CRITICAL effort
  - Creation/collection of images
  - Establish baseline performance based on SSD's current approaches
  - Establishment of ground truth detailed to voxel level
- Should reflect threat problems as well as false alarm
- Challenging but Do-able

26.15 Carl Smith Presentation Slides





26.16 Tim White Presentation Slides

- more bags are opened (after ATD) per year than the total number of medical CT scans
  - http://www.tsa.gov/research/screening_statistics.shtm
  - http://en.wikipedia.org/wiki/Computed_tomography
- How do we use the differences between medical and security screening to our advantage?
  - Ability to know ground truth (3 outta 4 rule).
- Who participated in the medical GC's? Liver segmenters or soft-tissue segmenters?

- Acceptable horizons
  - Academic – graduate student lifetime (>18mo?)
  - 3rd party – nearer term
  - Vendor – immediate (responding to customer need)
- How does vendor / DHS implementation history effect GC?
  - Tribal knowledge, mentoring, low-hanging fruit
- Alarms vs segmentation (3 outta 4 rule)
  - What does mean for the GC?
- Has anyone shown that if the security data were processed more carefully then the FAR would decrease?
- What does DHS want out of this? (is there a metric that will define success / failure?)

responsibities

- Vendors
  - Define the data sets that should be collected / are of interest
- Academics
  - Who will be involved? Only medical-imaging folks? Remote sensing?
  - Reaching beyond the COE's?
- DHS
  - Approve the sharing of data, rules of the game
- Labs
  - Running the game, judging/evaluation
  - Mentoring (students)

Whose problem is hardest?

Medical

- Looking for fuzzy things (what is the edge of the tumor)
- Tasks: detect (and quantify?) tumors, calcifications, …
- Rich literature

Security

- Tremendous patient variability
- Task: detect explosives
- Limited access to systems, data, problem definition

- Automated processing / detection difficult

Awareness and Localization of Explosives-Related Threats

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