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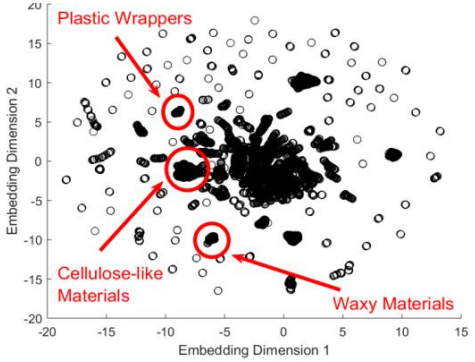
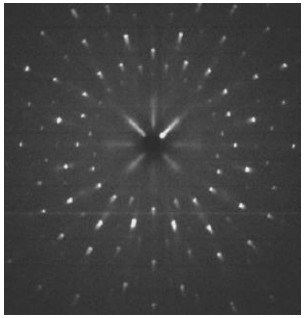
What's the deal with X-ray diffraction?





Joel Greenberg
Department of Electrical and Computer Engineering
Duke University
ADSA 20

Disclosures

- Co-founder, President and CEO of QUADRIDOX
  - University spinout company founded to transition the tools, technologies, and expertise generated at the University into real-world solutions.
  - Specializes in physics-based system simulation and information-theoretic tools for system design and analysis, including Monte-Carlo.

So What? Who Cares?

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- Space: aviation security - detecting explosive/prohibited materials in bags (checkpoint or checked bag)
- Problem: more efficient and effective security requires
  - increased P_D and lower P_{FA}
  - decreased divestment
  - expanded threat space (e.g., HMEs)
  - reduced dependence on human operators
- Solution: **X-ray transmission?**
- Results: all problems solved?
- TRL: 9
- Contact me: joel.greenberg@duke.edu

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  - reduced dependence on human operators
- Solution: **hybrid X-ray transmission** [for some material specificity] + **X-ray diffraction** [for more material specificity]
- Results: all problems solved?
- TRL: 1-9 [my work: 1-6]
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Transmission and diffraction (XRD)

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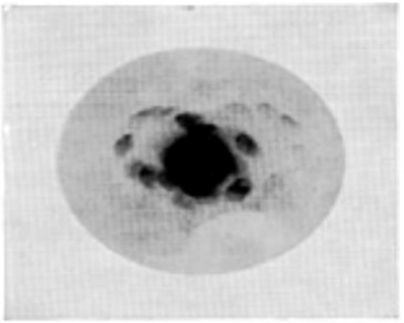
- Scatter signal is generated everywhere transmission contrast arises, but carries fundamentally different, material-specific information
  - **Transmission**: sensitive to electron density, some degree of chemical composition
  - **XRD**: sensitive to electron density, atomic/molecular structure

1895



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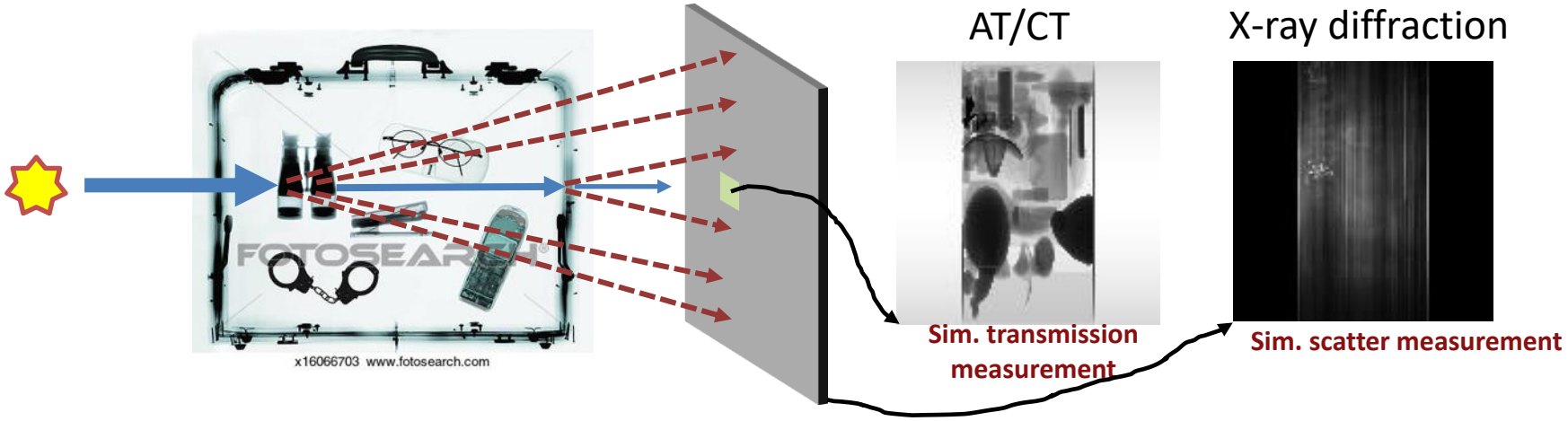
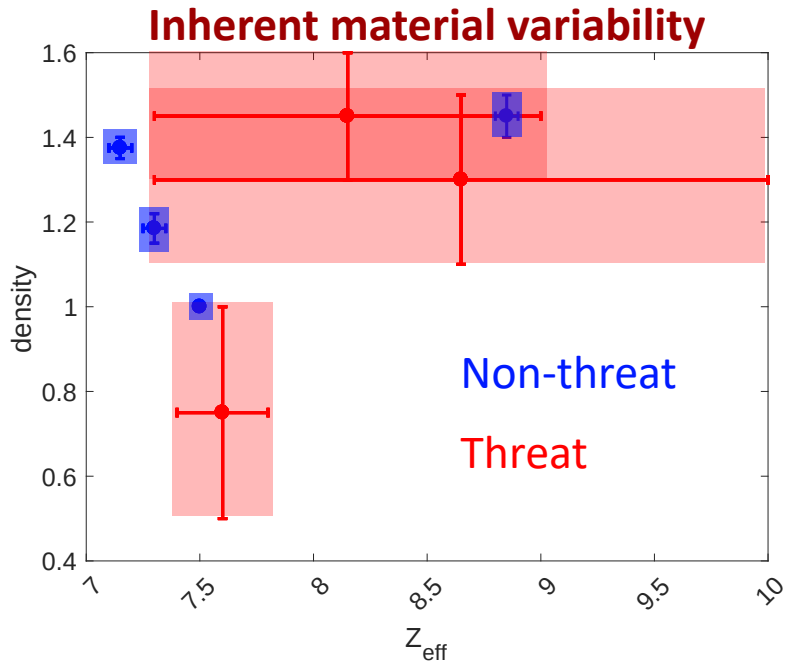
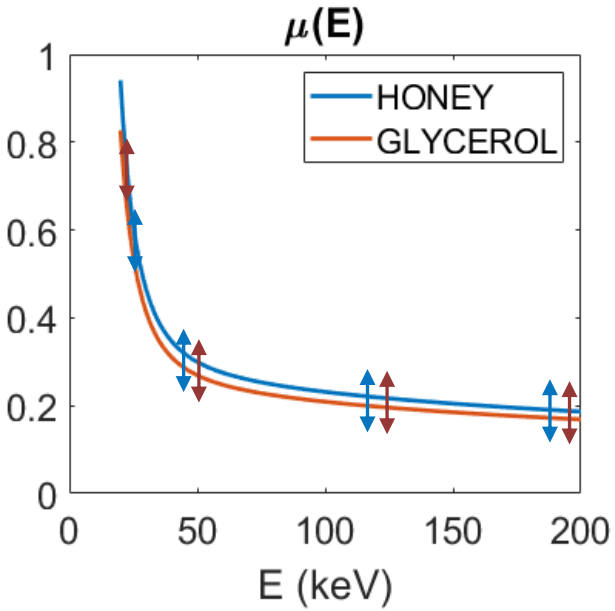


Transmission-based detection

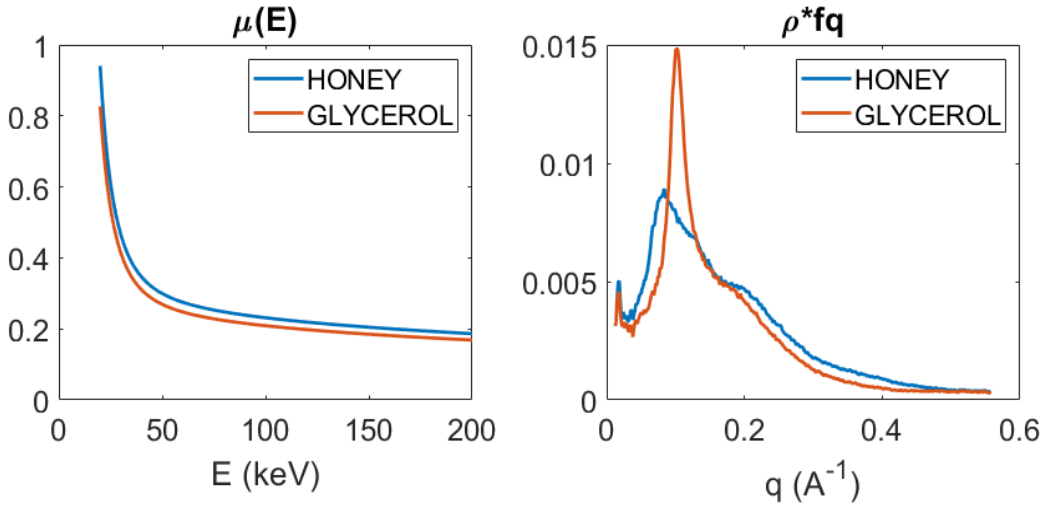
- Fast, high-resolution imaging with mature technology (AT/CT)
- Material discrimination is fundamentally limited by physics and intrinsic material variability
- There are some materials that can never be adequately identified via transmission
  - leads to **high false alarm rates** (P_{fa}) and/or a **limited list of target threats**





https://www.engineeringtoolbox.com/density-materials-d_1652.html
Iovea, International Symposium on Digital industrial Radiology and Computed Tomography, June 25-27, 2007, Lyon, France

XRD opportunity



Benefits

- 10's of new, physics-based features
- XRD information is largely orthogonal to transmission
  - Especially good for crystalline materials, organics, some LAGs
  - Can be independent of density
- Tomography with only 1 (or few) views

Operational Impacts

- 'Fully' automated threat detection
  - Material-specific information not requiring operator interpretation
- Complementary to AT/CT
  - Resolve existing false alarms/reduce P_{FA}
  - Improve P_D
- Small-footprint volumetric imaging

Technical challenges

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- Requires non-COTS components
  - Development time
  - Cost ($)
- Lack of insight into baggage in XRD space
- Slow
- Poor spatial resolution
- Sensitivity to clutter

Technical challenges

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Arrays of room-temperature photon-counting and energy-sensitive detectors are now available

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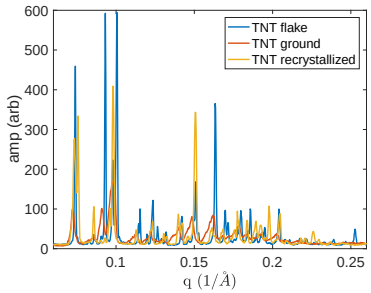

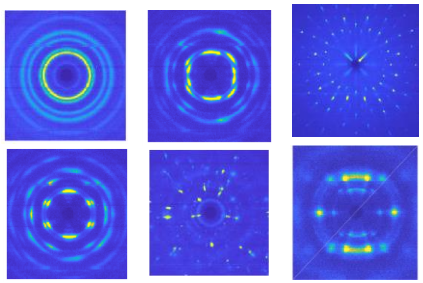

Work by OEMs, TSL, and ALERT via R1-C.3 have explored a broad range of signatures and their variability (see http://people.duke.edu/~jag27/ALERT.html)

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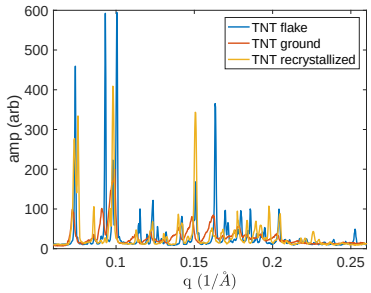

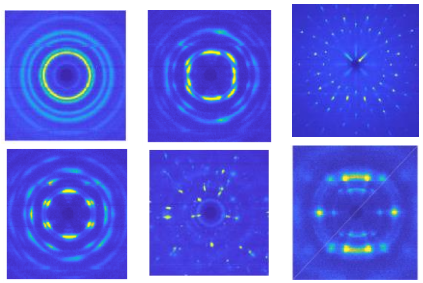

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Existing technology*

Smiths/Duke SP
(coded aperture XRD)

Smiths HDX10065
(pencil beam XRD)

Smiths XDi
(inverse fan beam XRD)

Halo HXT 132
(FCT XRD)

XRDT solutions exist and have been/are being commercialized

J.A. Greenberg, X-Ray Diffraction Imaging, CRC Press, 2018

*list is representative, not exhaustive

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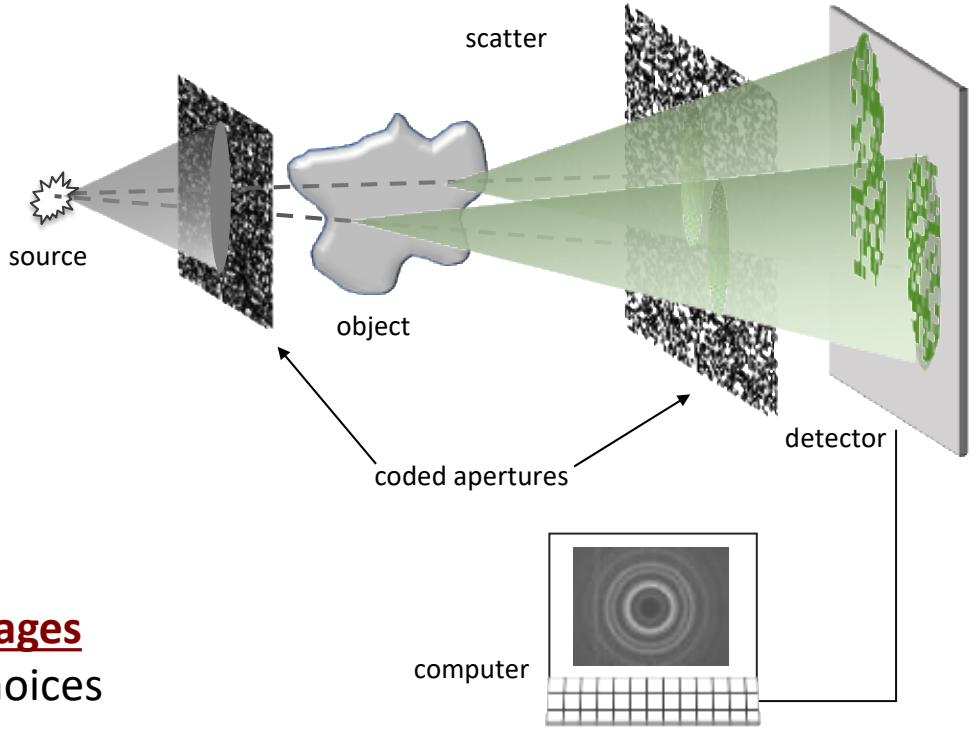
Coded aperture XRDT (CAXRDT)

Smiths/Duke SP
(coded aperture XRD)

Coded aperture XRDT approach



Advantages

- Flexible design choices
- High throughput
- Operational via COTS components
- Exploits Moore's law (CPU/GPU)

J.A. Greenberg, X-Ray Diffraction Imaging, CRC Press, 2018

CAXRDT for alarm resolution

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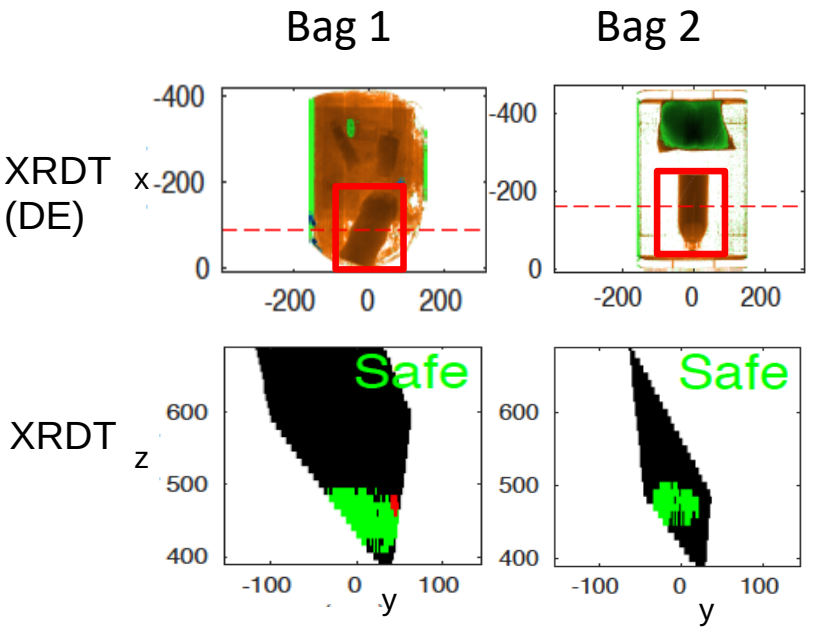
- Our previous DHS S&T efforts have have enabled the development of a scientific prototype CA-XRDT system that has demonstrated enhanced alarm resolution relative to AT

Scientific prototype (XRDT) **Smiths 6040i (DE)**



70/86 of false alarms resolved

Diallo et al, Proc. SPIE 10632, (ADIX) III, 1063209 (27 April 2018)
Greenberg et al., Proc. SPIE 10187, (ADIX) II, 1018708 (May 1, 2017)

Current work: hybrid scanners

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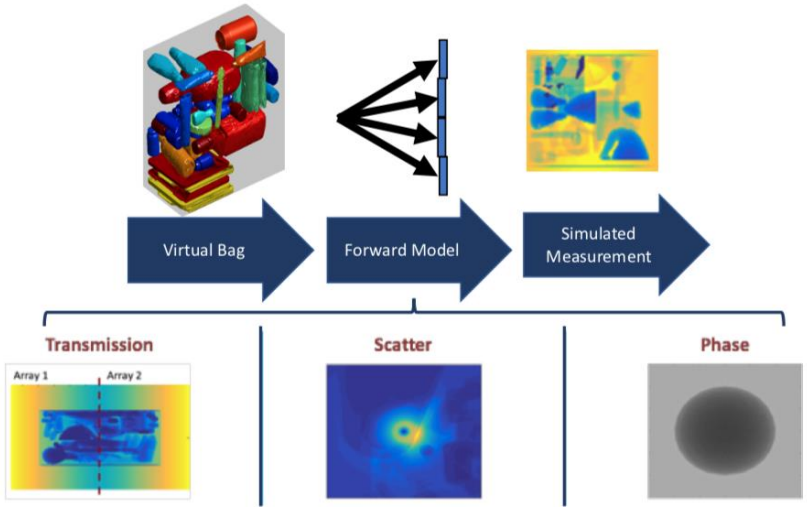
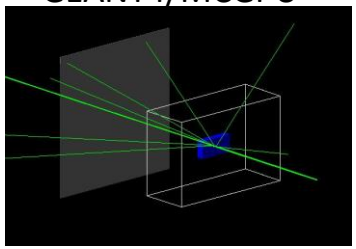
Studying/designing hybrid transmission + scatter systems for the aviation checkpoint

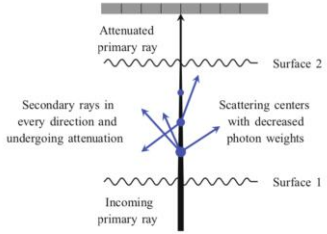
- Using/improving our home-built/customized modeling tools
  - fast, flexible X-ray physics simulation tools
  - Synthetic bag generation tools
- Novel XRDT architectures matched to COTS components
- Information theoretic analysis
  - What are the ultimate performance limits on such a hybrid system
- Novel feature engineering and classification



GEANT4/MCGPU



Deterministic



Gong et al., NIMB 415 (2018); Gong et al., NIMB 449 (2019)

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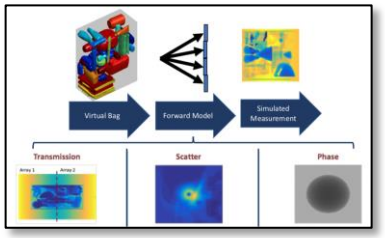

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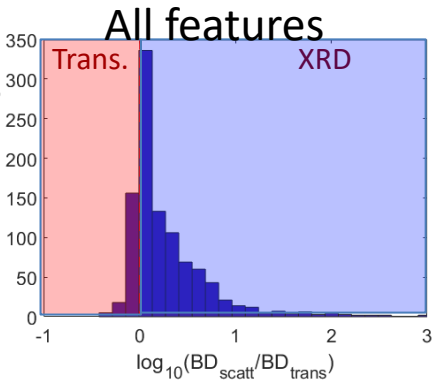

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Carpenter et al., Proc. SPIE 109997, ADIX IV (2019)

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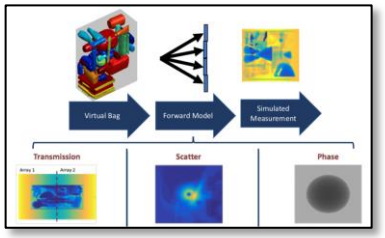

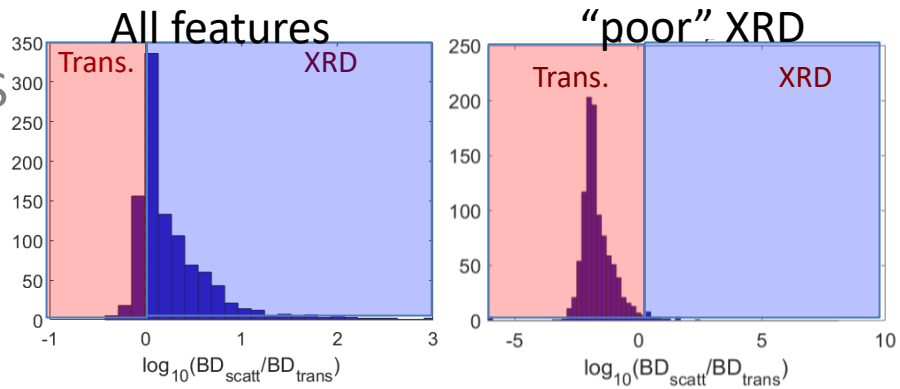

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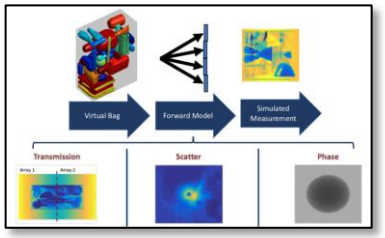

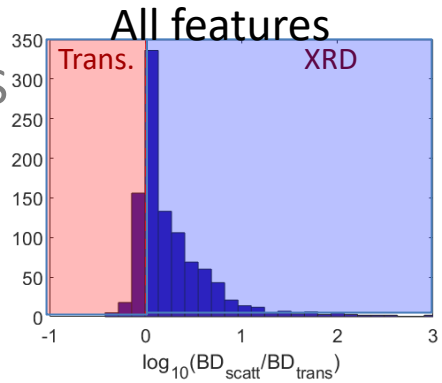

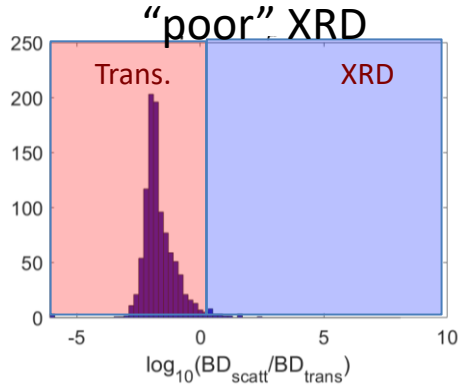

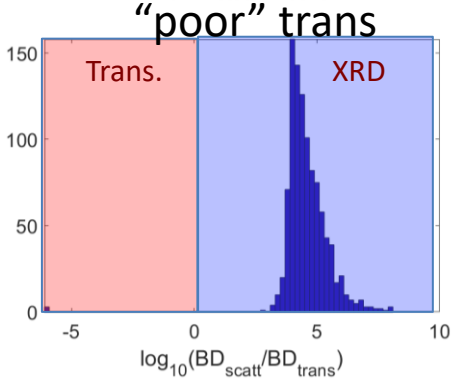

Carpenter et al., Proc. SPIE 109997, ADIX IV (2019)

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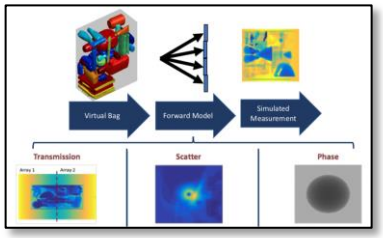

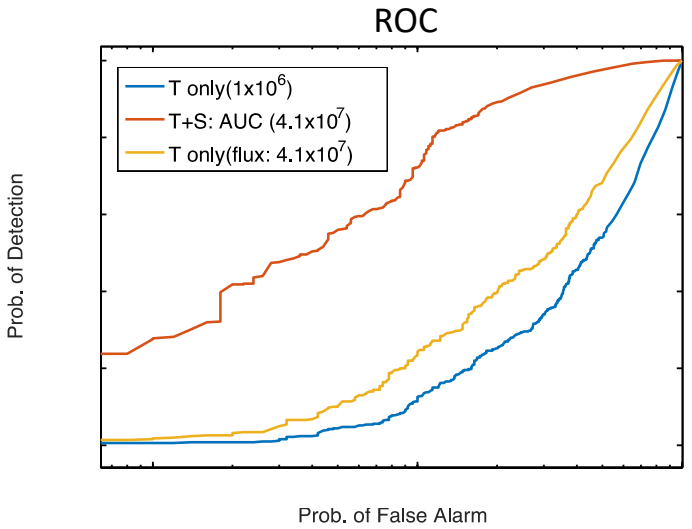

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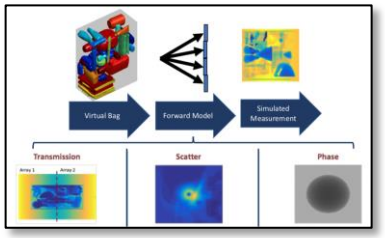

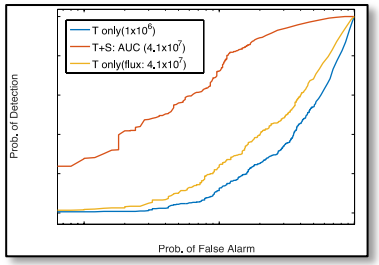

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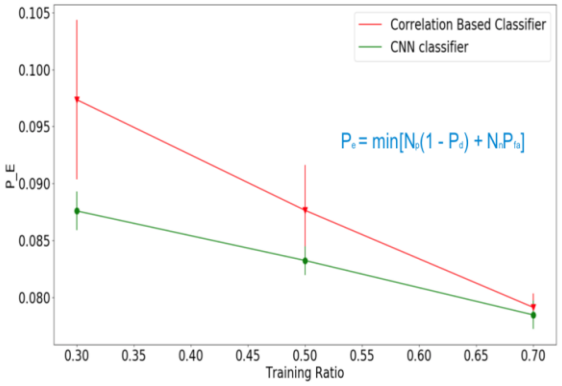
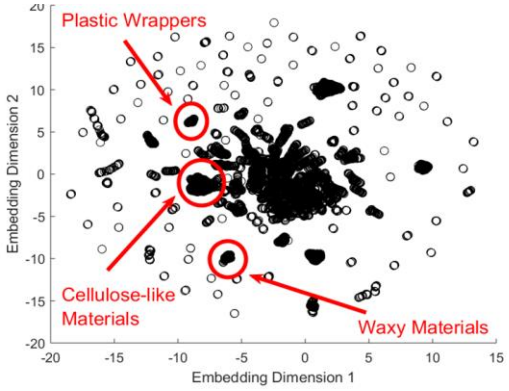
Deep learning



Dimension reduction



Diallo et al., Proc. SPIE 1099910, ADIX IV (2019);
Royse et al., Proc. SPIE 10999-12, ADIX IV (2019)

Non-technical challenges

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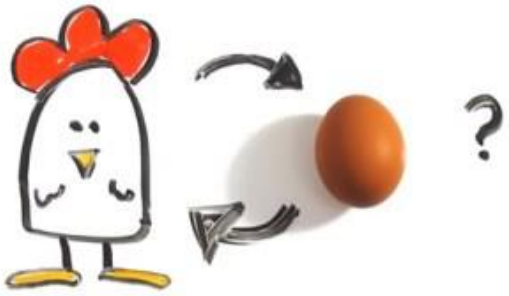
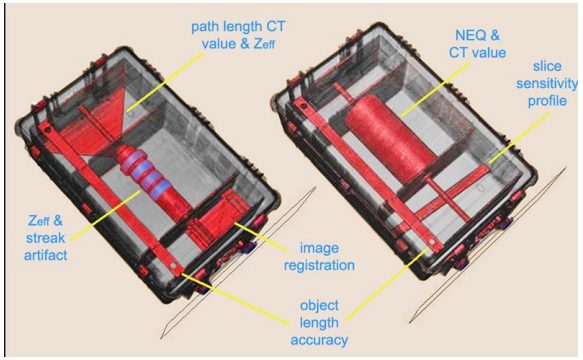
- Requirements
  - None exist that address capabilities of XRDT
- Standards/test objects
  - How to fairly/adequately compare XRDT to other solutions?
- Inline certification
  - How best to certify inline module/system?
- Fundamentally no simulants
  - Relevant testing is difficult





Acknowledgements

Prof. Anuj Kapadia
Prof. Scott Wolter

Prof. Michael Gehm
Prof. Amit Ashok
Dr. Anuj Kapadia
Dr. Souleymane Diallo
Dr. Chris Gregory
Dr. Josh Carpenter

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This material is partially based upon work supported by the U.S. Department of Homeland Security, Science and Technology Directorate, Office of University Programs, under Grant Award 2013-ST-061-ED0001 and contract 70RSAT18CB0000044. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.