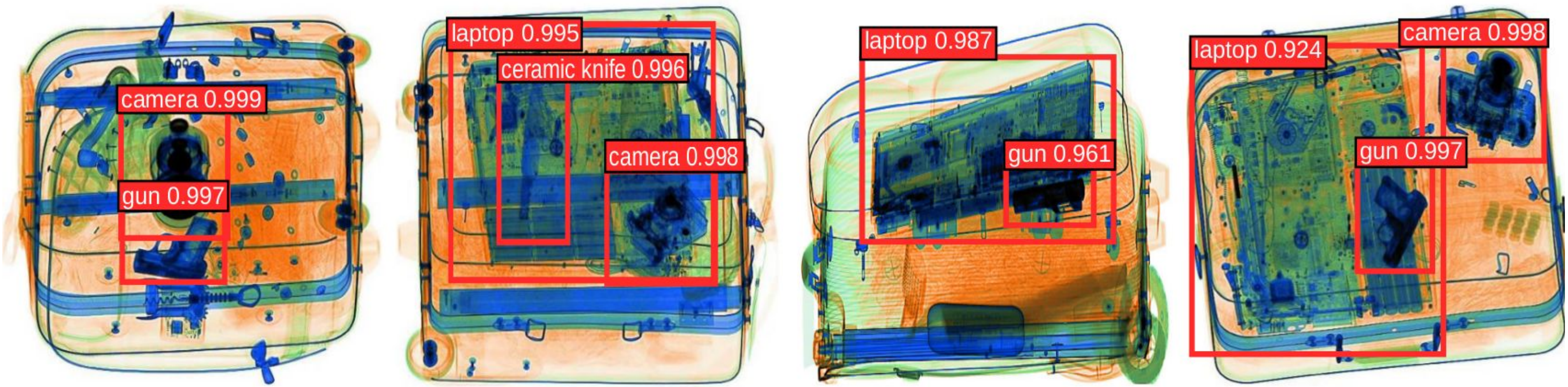
Automatic Threat Detection (ATD) for Baggage Security Screening

a brief update on image understanding research in baggage automatic threat detection



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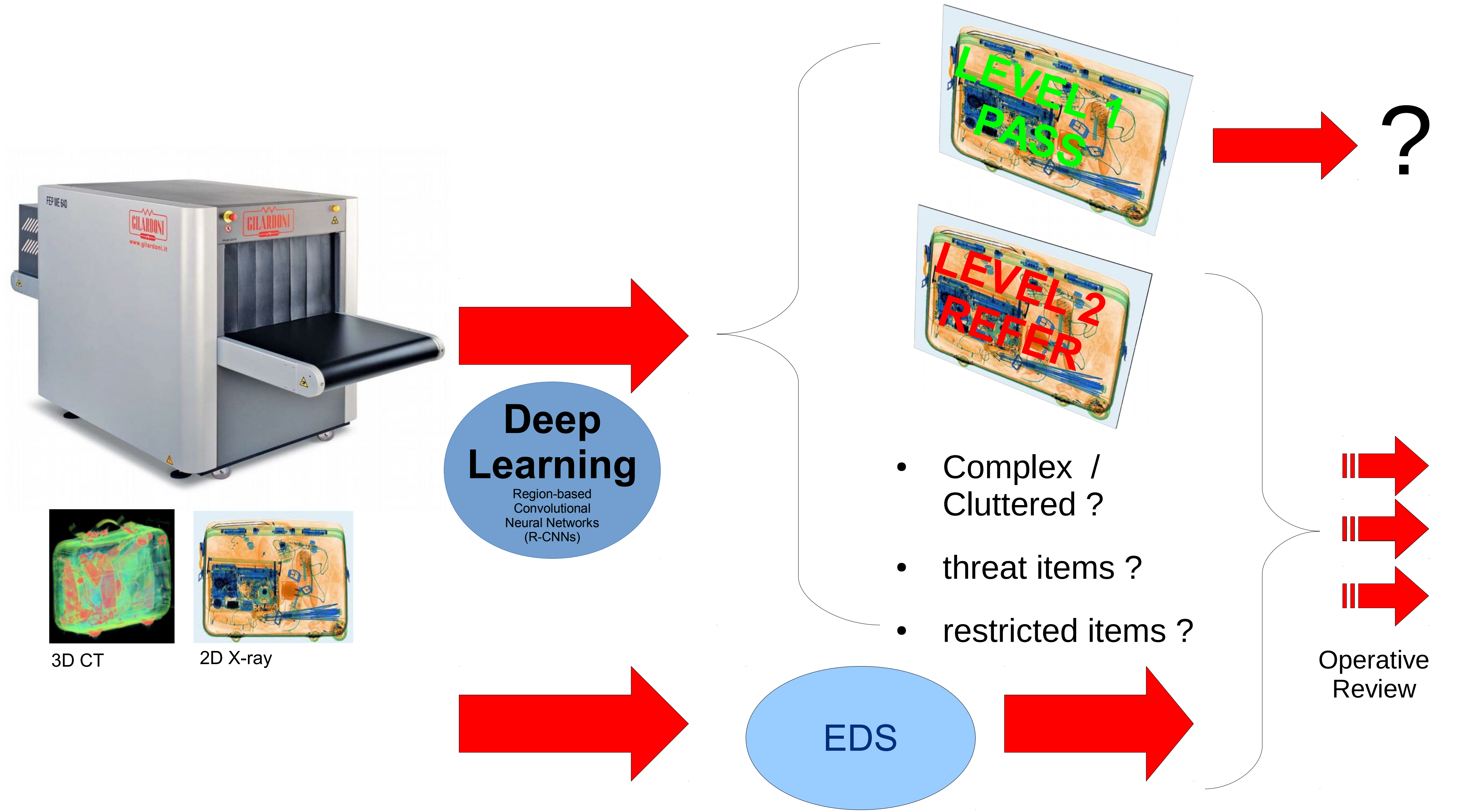
Oct 2017 – ADSA-17

What / How / Why ?

- **Baggage Inspection** (carry on and hold, extensible to freight)
- **Automatic Threat Detection** (by shape … guns / knives / other)
- **Automatic object detection & classification algorithms**
  - *using 2nd / 3rd generation deep learning techniques*
- **Potential Impact:**
  - software enhancement ("add-on") to existing X-ray or 3D CT hardware
  - high detection rates / low false positive
  - objects and parts of objects (dis-assembled)
  - augment existing screening capability / extend screening foot-print (buildings / postal / customs / prisions)

~98%+, < 1 sec., FP <1%, invariant

Concept of Operation



[X-ray/CT images: Durham University – Scanner Image: Gilardoni]

Durham

Durham University

- **3rd oldest** university in England (1832)
- **World leading** university (top 100)
- **UK ranking: top 5**
  Engineering & Computer Science
- **Engineering & Computer Science**
  - Nvidia Research Centre
  - Intel Parallel Computing Centre
- *Within* **X-ray Security:**
  - 10 years experience
  - threat detection, threat image projection, anomaly detection

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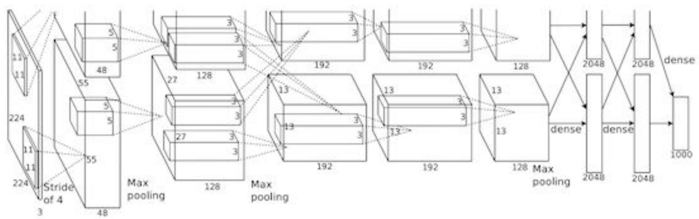
Deep Learning for ATD in 2D X-ray

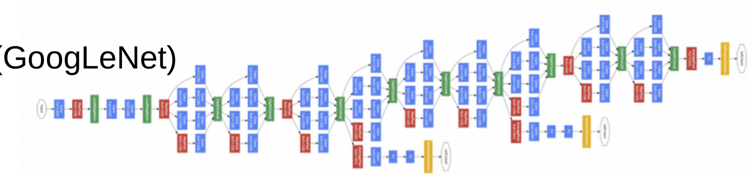
[CNN Approaches - 1st Generation]

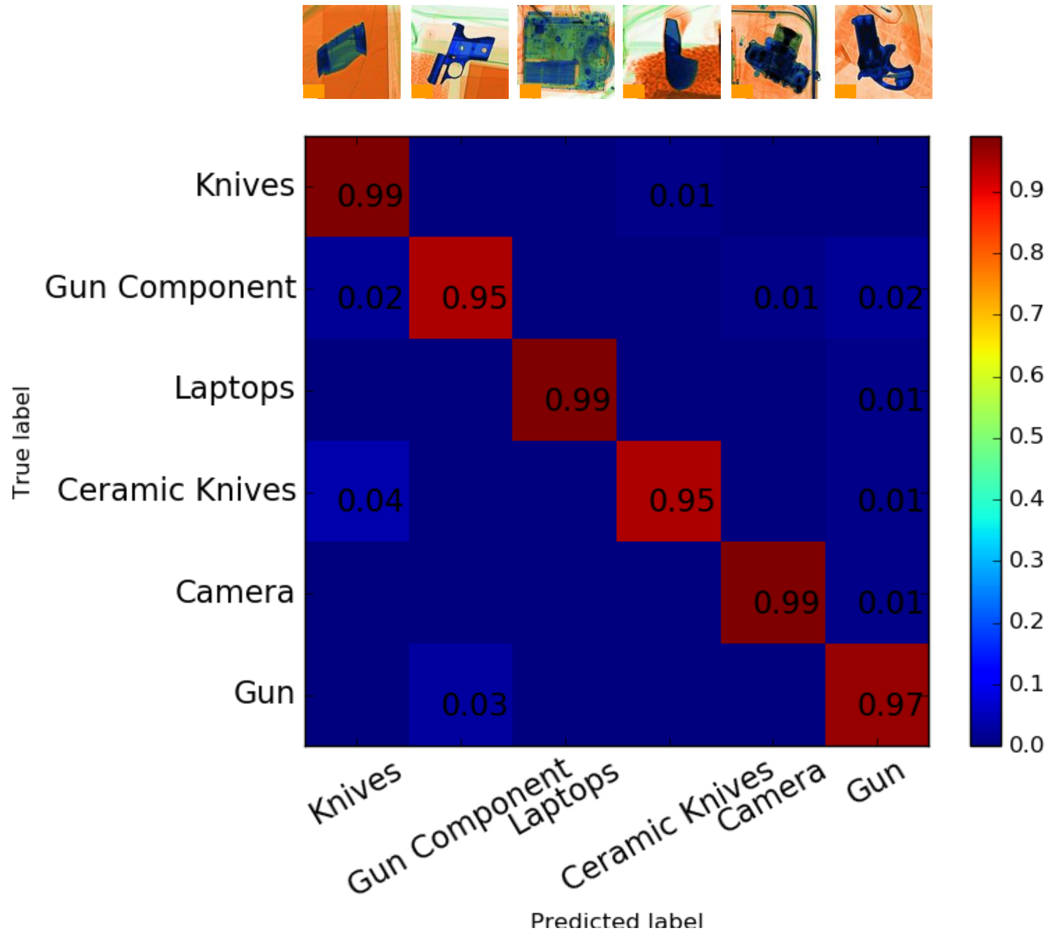
AlexNet



…

Inception (GoogLeNet)



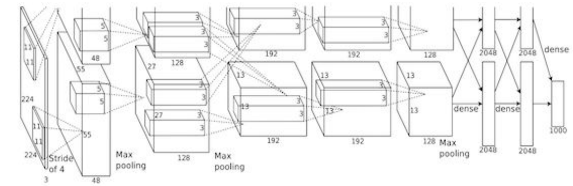


Method	Class	True +	False +
[Akcay et al. 2016]	Firearm	98.62	0.21

- 1st **generation** deep net approaches
  - **95% (True+)** over **6 object categories**
  - established X-ray ATD training via **transfer learning** [Akcay et al. 2016]

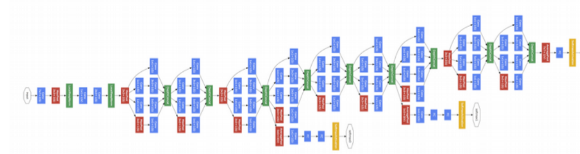
Some Technical Insight …

[1st Generation Approaches]

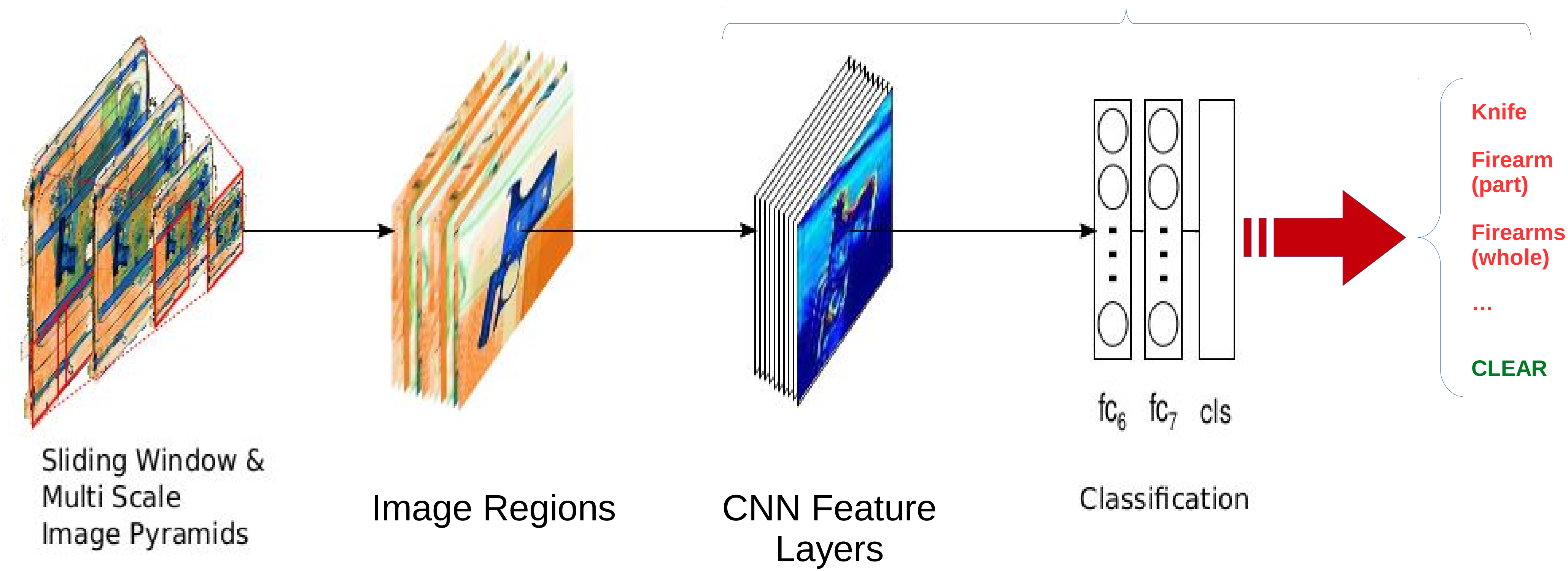


AlexNet

…



Inception (GoogLeNet)

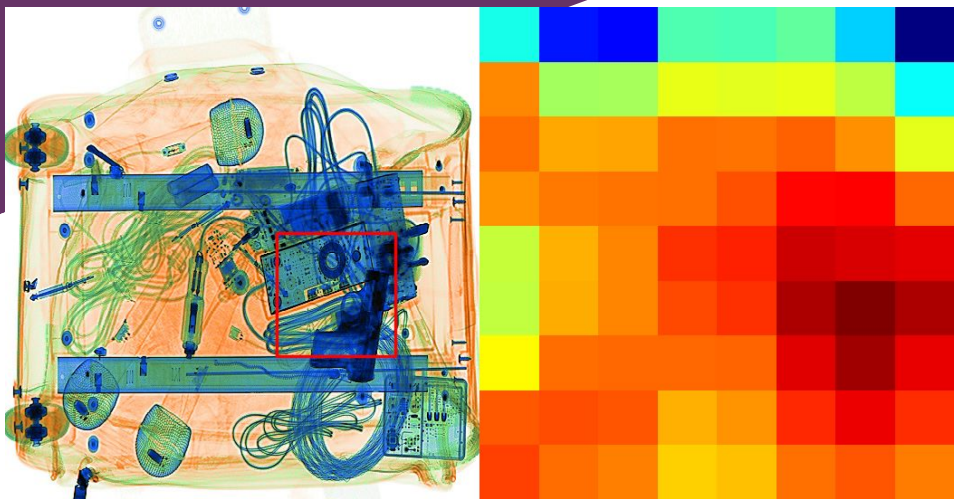


[Akcay et al. 2016]

- **full-image, multi-scale or patch-based** image search

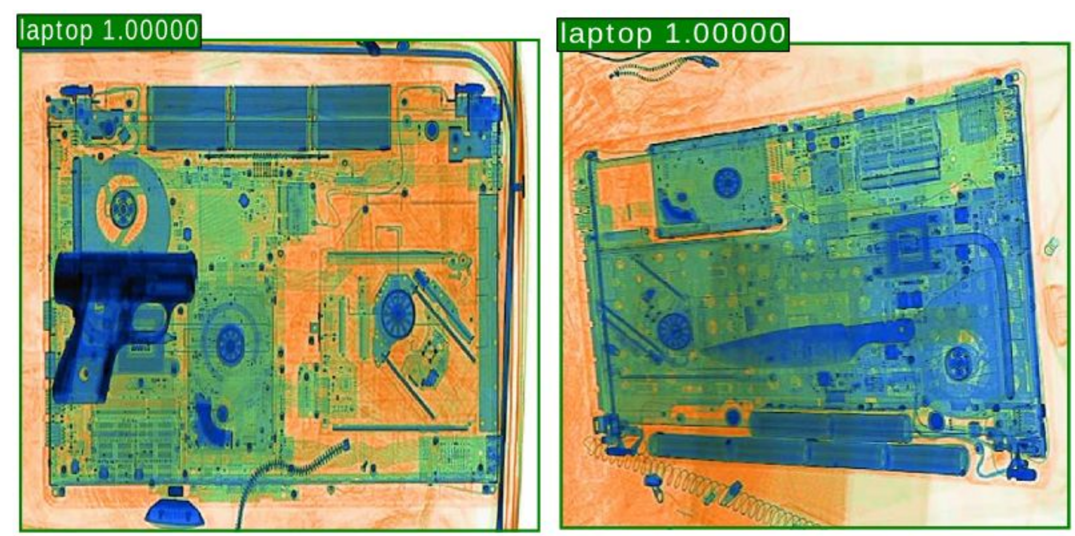
  → poor in image localization, loss of information (down-scaling/cross-patch)

Known Limitations
[1st Generation Approaches]



- **Poor** threat **localization**

  (where is the threat ?)

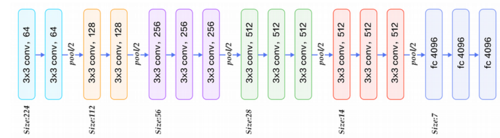


- **Feature saturation** for multi object search

  (this *is* a laptop, right ?)

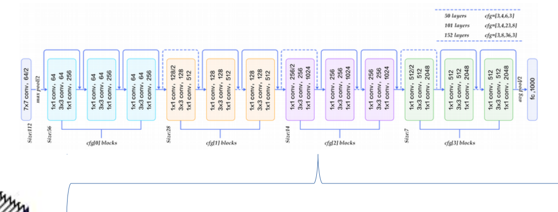
Advanced Detection Architectures

[2nd+ Generation Approaches]



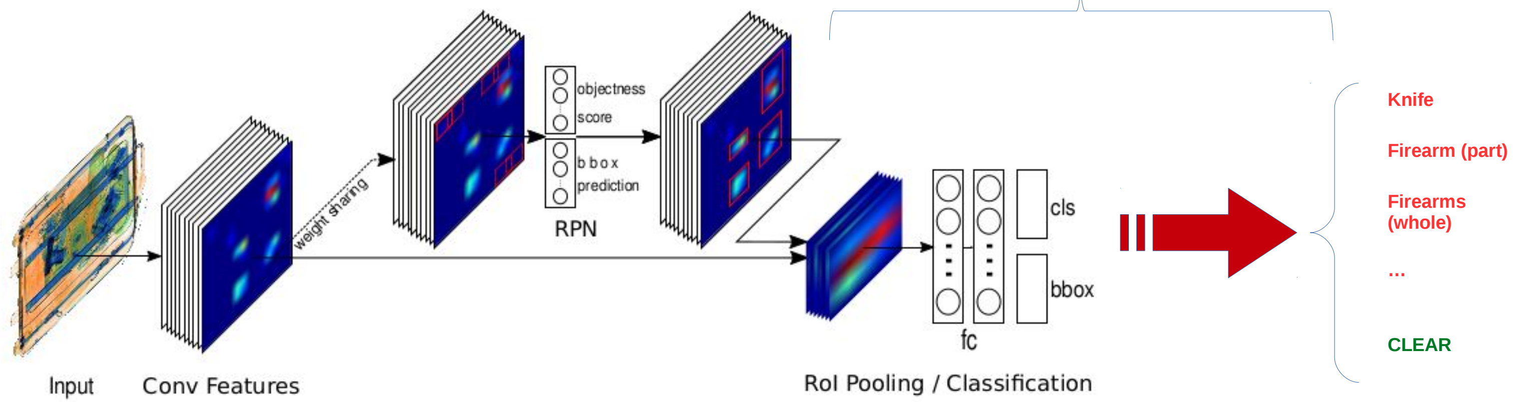
VGG-..

...

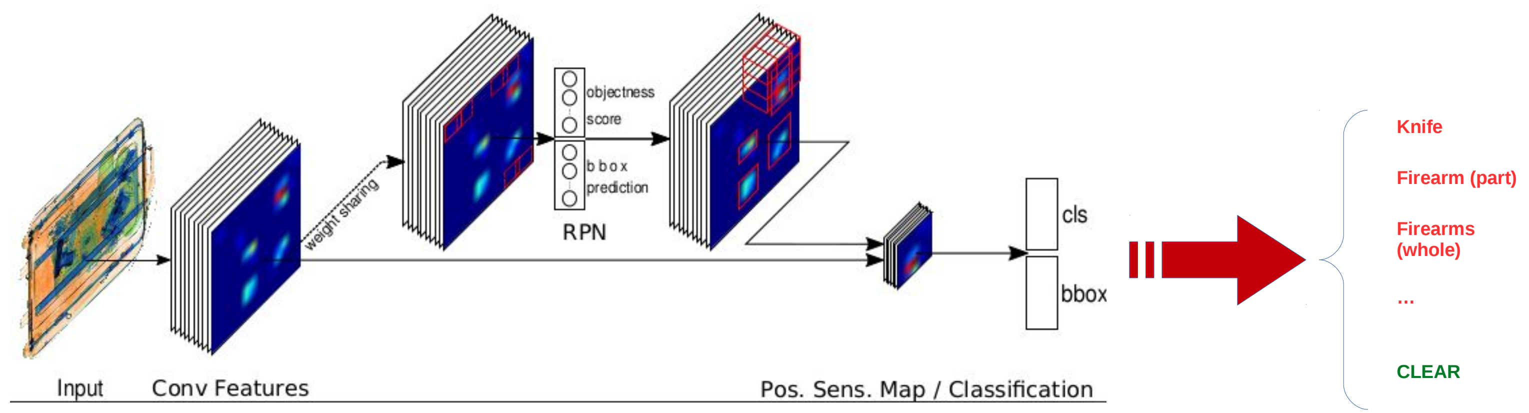


ResNet

(Faster) Region-based Convolutional Neural Network (F-RCNN)



Region-based Fully Convolutional Networks (R-FCN)



[Akcay et al. 2017]

- **2-stage approach**: region identification + classification

  → improved threat localization + improved detection performance

Detection Performance

[on Durham Data Set]

Durham University

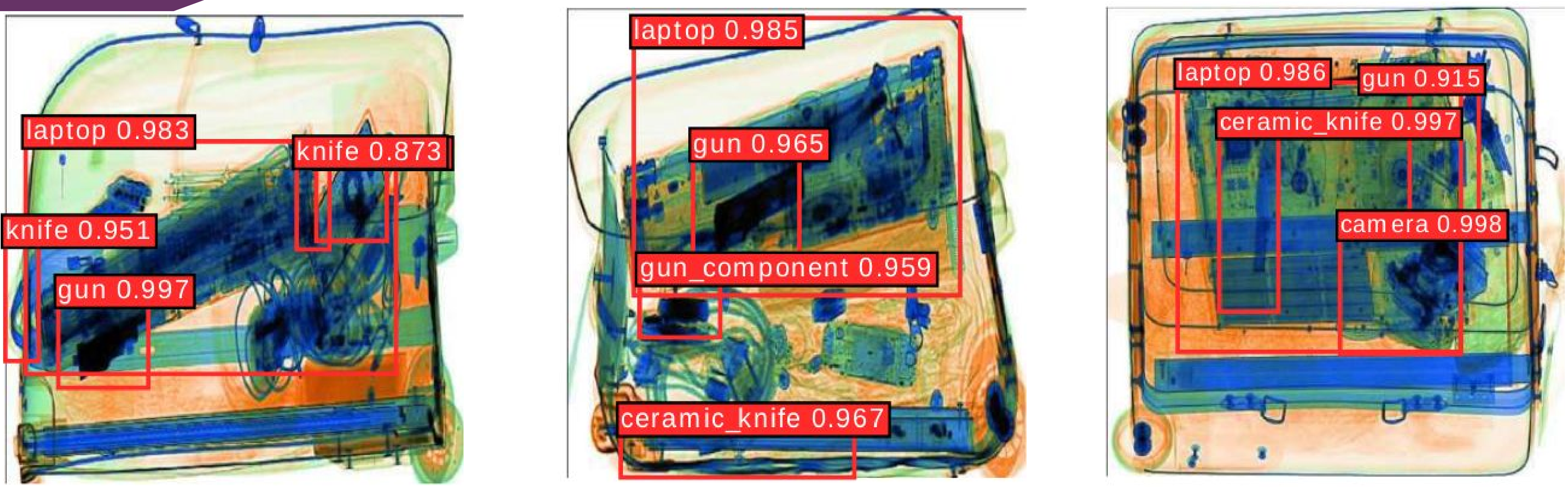
- 8747 X-ray security images of full *"stream of commerce"* bags with following annotated firearm objects: 3,187 gun, 1,178 gun component

R-CNN (2^{nd} Gen.) Stage 2 Model	**Firearms (accuracy)**	**Firearm Parts (accuracy)**	**mAP**
AlexNet	92%	86%	89%
ZF	95%	87%	91%
VGG-M	95%	88%	91%
VGG-16	96%	**94%**	**95%**
ResNet-50	**97%**	90%	93%

Similar performance.
Increased generality.

Detection Performance

[2nd+ Generation Approaches]



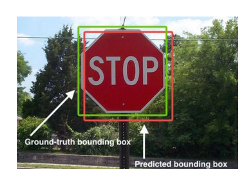
[Akcay et al. 2017]

- Improved **detection and localization**
- Trained over **corpus of ~10,000 images; tested over ~10,000**
- **Challenges** – knives + firearm components

- **Evaluation based on Localization**

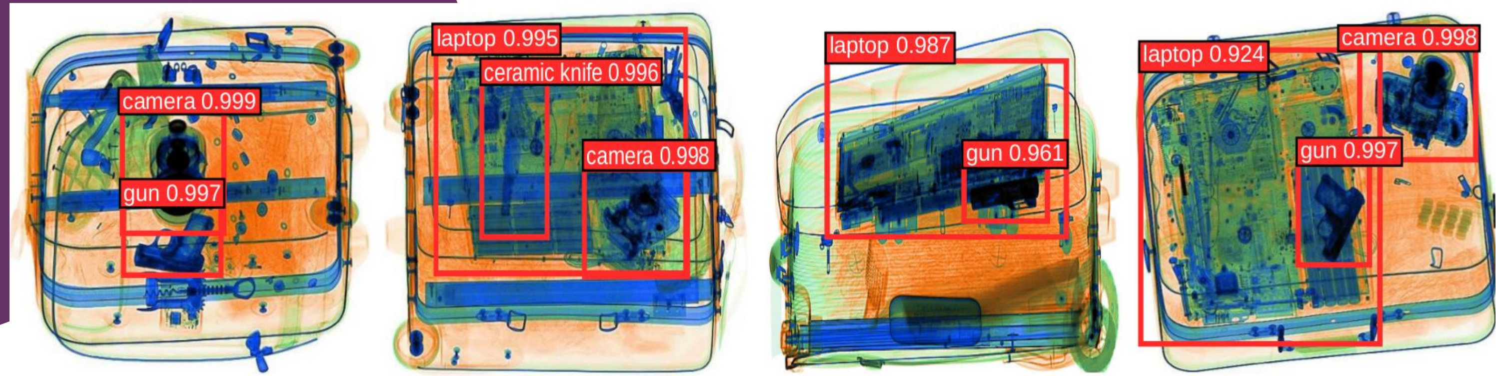
  mean Average Precision (mAP) = 0.97 (firearms) / 0.88 (multi threat)

  — **intersection over union (IoU) of detected threat region**



Detection Performance

[2nd+ Generation Approaches]



Model	Network	mAP	camera	laptop	gun	gun component	knife	ceramic knife
Multi-patch CNN (1st Gen.)	AlexNet	0.608	0.682	0.609	0.748	0.714	0.212	0.683
	VGGM	0.634	0.707	0.637	0.763	0.731	0.246	0.719
	VGG16	0.649	0.701	0.724	0.752	0.757	0.223	0.734
	ResNet-50	0.671	0.692	0.801	0.747	0.761	0.314	0.713
	ResNet$_{101}$	0.776	0.881	0.902	0.831	0.848	0.392	0.803
RCNN (2ndGen.)	AlexNet	0.647	0.791	0.815	0.853	0.582	0.188	0.658
	VGGM	0.686	0.799	0.855	0.869	0.658	0.210	0.723
	VGG16	0.779	0.888	**0.954**	0.876	0.832	0.304	0.819
F-RCNN (2ndGen.)	AlexNet	0.788	0.893	0.756	0.914	0.874	0.467	0.823
	VGGM	0.823	**0.900**	0.834	0.918	0.875	0.542	0.869
	VGG16	**0.883**	0.881	0.918	0.927	**0.938**	0.721	0.912 ✓
	ResNet-50	0.851	0.844	0.879	0.916	0.901	0.677	0.889
	ResNet$_{101}$	0.874	0.857	0.904	0.931	0.911	**0.732**	0.907
R-FCN (2ndGen.)	ResNet-50	0.846	0.894	0.928	0.932	0.918	0.506	0.896
	ResNet$_{101}$	0.856	0.887	0.906	**0.942**	0.925	0.556	**0.920**

Multi-Threat – {guns, parts, knives ...}

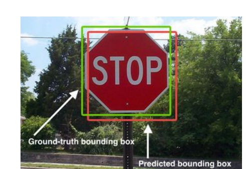
Model	Network	mAP	Firearm
Multi-patch CNN (1st Gen.)	AlexNet	0.753	0.753
	VGGM	0.772	0.772
	VGG16	0.806	0.806
	ResNet-50	0.836	0.836
	ResNet$_{101}$	0.847	0.847
RCNN (2ndGen.)	AlexNet	0.823	0.832
	VGGM	0.836	0.836
	VGG16	0.854	0.854
F-RCNN (2ndGen.)	AlexNet	0.945	0.945
	VGGM	0.948	0.948
	VGG16	0.960	0.960
	ResNet-50	0.951	0.951
	ResNet$_{101}$	0.960	0.960
R-FCN (2ndGen.)	ResNet-50	0.949	0.949
	ResNet$_{101}$	**0.963**	**0.963** ✓

Fire-arms – {gun, clear}

2nd Generation > 1st Generation

Evaluation score = mean Average Precision

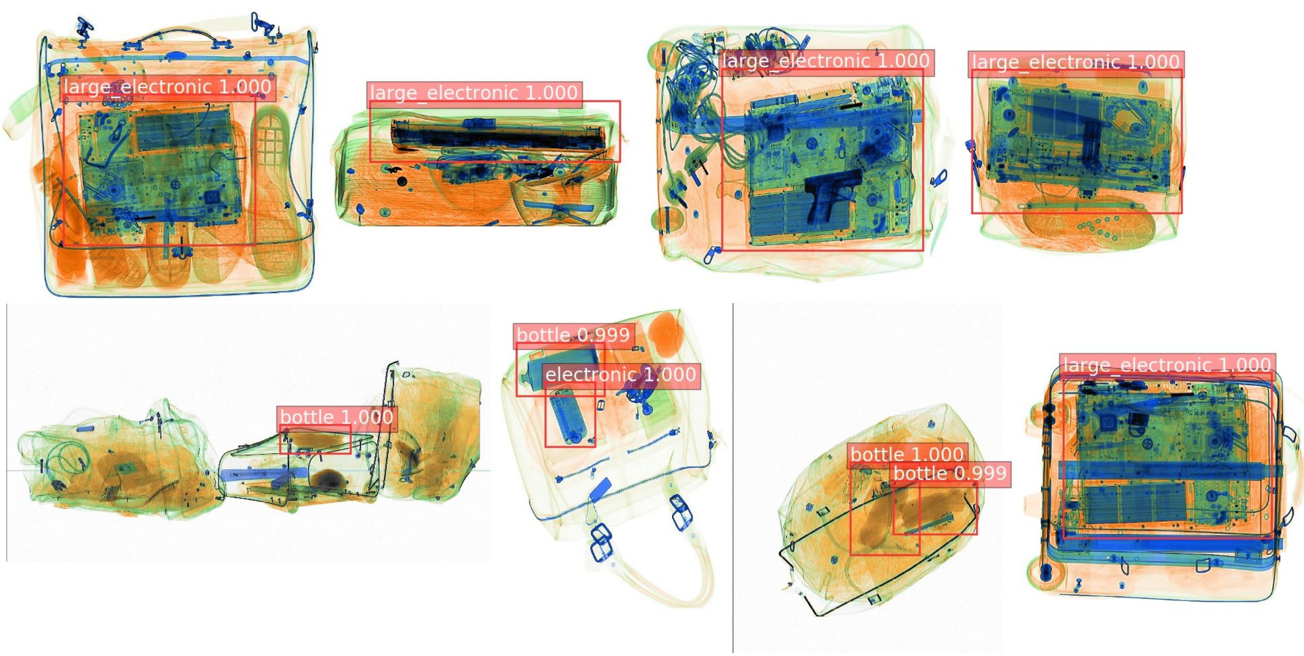
—intersection over union of detected threat region

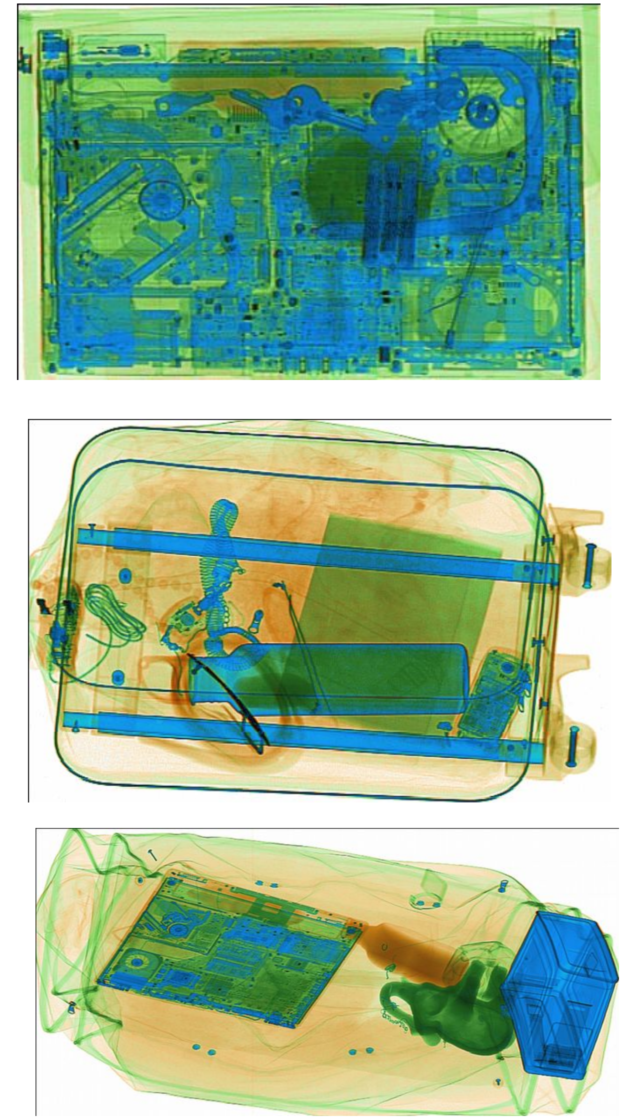


[Akcay et al. 2017]

Latest Research

[→ 3rd generation approaches]





- Detection: bottles / large electronics / firearms
- Anomaly Detection

Working with:

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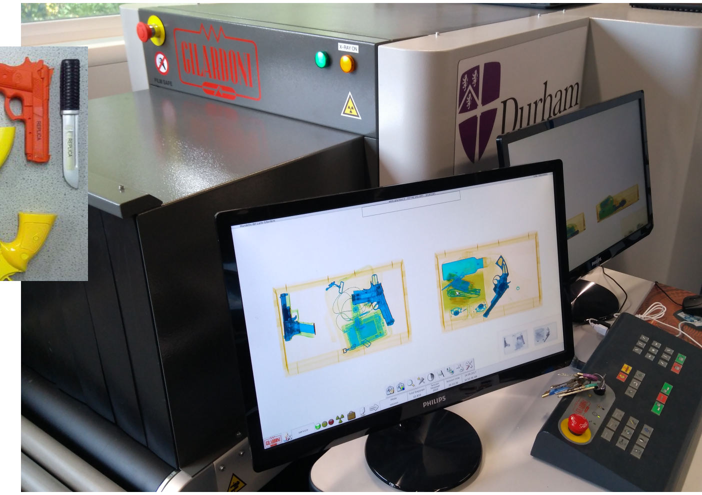
[Akcay, Ismail Breckon 2017+]

Experience in the Field ...

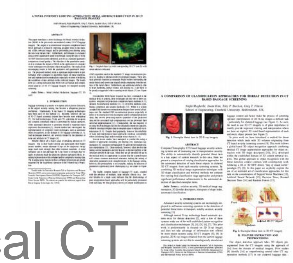


- **Training Data:**
  - CT : Reveal CT80 data (~800-1000 bags)
  - 2D X-ray : UK gov. + our own on-site X-ray scanner (~100,000+ images)

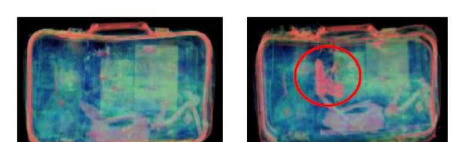
- **Funding:** 2007 → 2019+
  - *Today*: 10 years, 8 projects and 20+ publications later

HM Government

- **Publications:** *"never unreasonably withheld"*
  - published in leading conference / journal venues
  - wider impact in generalized 3D object recognition + medical CT



- **Algorithm Deployment:** 3D TIP solution



[Scanner Image: Durham University]

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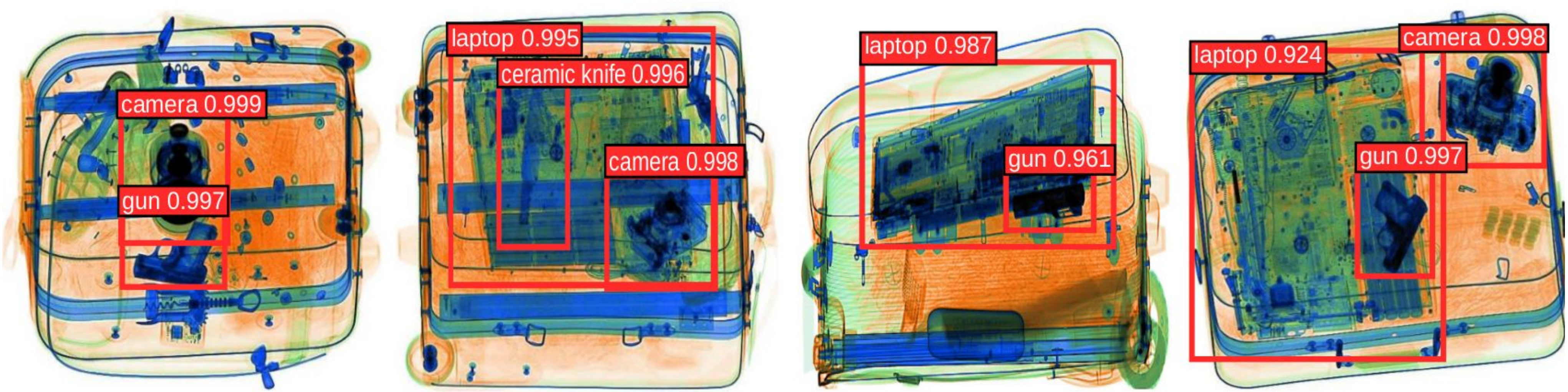

The support of the UK Home Office and UK Dept. for Transport in funding this work is gratefully acknowledged.

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References : Latest Technical Publications

2D X-ray ATD:

An Evaluation Of Region Based Object Detection Strategies Within X-Ray Baggage Security Imagery (S. Akcay, T.P. Breckon), In Proc. International Conference on Image Processing, IEEE, 2017.
Transfer Learning Using Convolutional Neural Networks For Object Classification Within X-Ray Baggage Security Imagery (S. Akcay, M.E. Kundegorski, M. Devereux, T.P. Breckon), In Proc. International Conference on Image Processing, IEEE, 2016. (to appear)
Improving Feature-based Object Recognition for X-ray Baggage Security Screening using Primed Visual Words (D. Turcsany, A. Mouton, T.P. Breckon), In Proc. International Conference on Industrial Technology, IEEE, pp. 1140-1145, 2013.

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3D CT ATD & Segmentation:

Materials-Based 3D Segmentation of Unknown Objects from Dual-Energy Computed Tomography Imagery in Baggage Security Screening (A. Mouton, T.P. Breckon), In Pattern Recognition, Elsevier, Volume 48, No. 6, pp. 1961–1978, 2015.
Object Classification in 3D Baggage Security Computed Tomography Imagery using Visual Codebooks (G.T. Flitton, A. Mouton, T.P. Breckon), In Pattern Recognition, Elsevier, Volume 48, No. 8, pp. 2489–2499, 2015.
3D Object Classification in Baggage Computed Tomography Imagery using Randomised Clustering Forests (A. Mouton, T.P. Breckon, G.T. Flitton, N. Megherbi), In Proc. International Conference on Image Processing, IEEE, pp. 5202-5206, 2014

3D CT TIP: Fully Automatic 3D Threat Image Projection: Application to Densely Cluttered 3D Computed Tomography Baggage Images (N. Megherbi, T.P. Breckon, G.T. Flitton, A. Mouton), In Proc. International Conference on Image Processing Theory, Tools and Applications, IEEE, pp. 153-159, 2012.

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All available open access - full listing including all other references.