Partially Occluded Weapons Identification Through Partonomy

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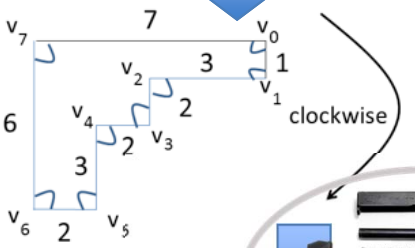
Visual Identification of Weapons and their Parts

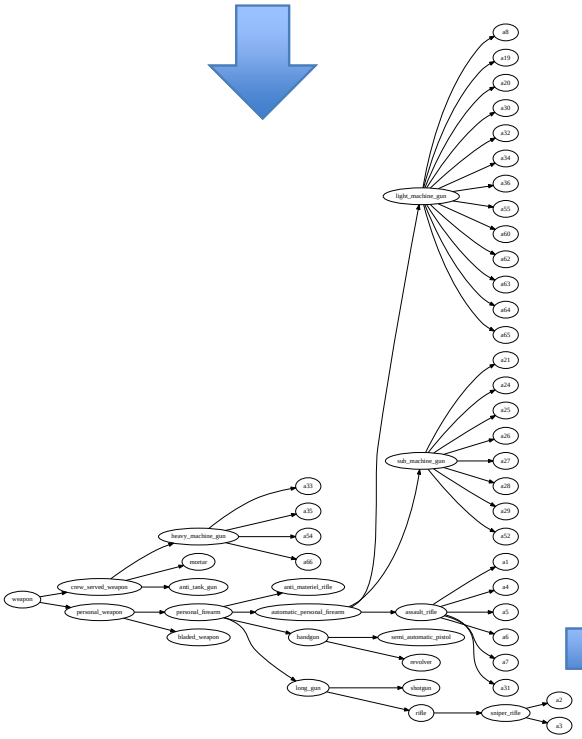
- What space/topic/area is being addressed?
  - Visual identification of weapons, surveillance in various settings. Including soft targets.
- What problem have you solved?
  - Automatic, identification of firearms in images, including partially occluded ones, and the threat assessment posed by the weapon on the scene.
- How have you solved the problem?
  - Fusion of low level features extracted from images and high level information retrieved from the ontology/meronomy through search and matching.
- Why should TSA, DHS and the audience care about your solution?
  - Our solution identifies occluded weapons and parts at different check points and times
  - Works in real-time, scalable, expandable to non-weapon domains and x-ray images
- How did we get involved in the security field?
  - Developed the first boundary labeled conceptual and visual ontology/meronomy and methods for automatic segmentation, labeling, searching, matching, identification
- What else can you do for the security field?
  - May determine if a weapon could be assembled by parts detected at different points and times.

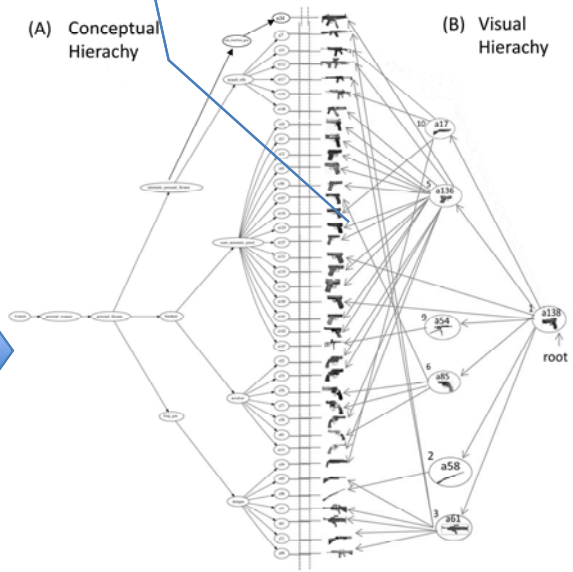
Threat recognition framework

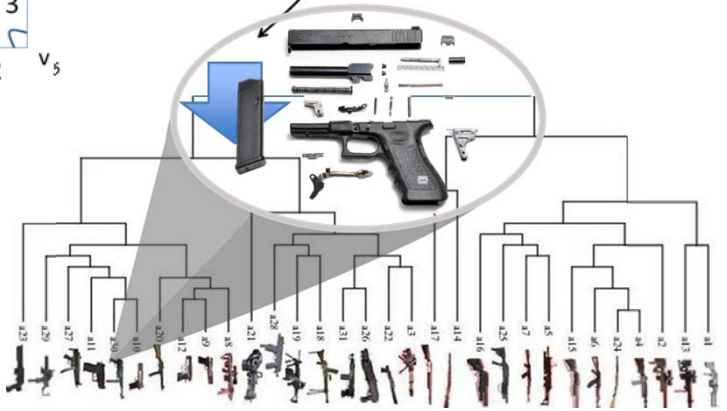
(SIG_P220
(ISA pistol)
(material metal, stainless_steel, aluminum)
(color black)
(weight 800, 1130) ; unit: grams
(length 198) ;unit: millimeters
(has_parts magazine)
(variants p245, p225, p6, p220_rail, p220_carry, p220_compact, p220_combat)
(image
(contour SIG-220_ob_b_500_10_10_15.JPG)
(convex_hull SIG-220_CH_100_10_10_15.PNG.png.png))
(texture coarse, smooth, regular)
(ratio 1x7)
)

Threat Level =
Weapon + Context









[1,4]

SEGMENTATION – Active Contours

Figure 1. Weapons' parts extraction using S-ACES active contour.

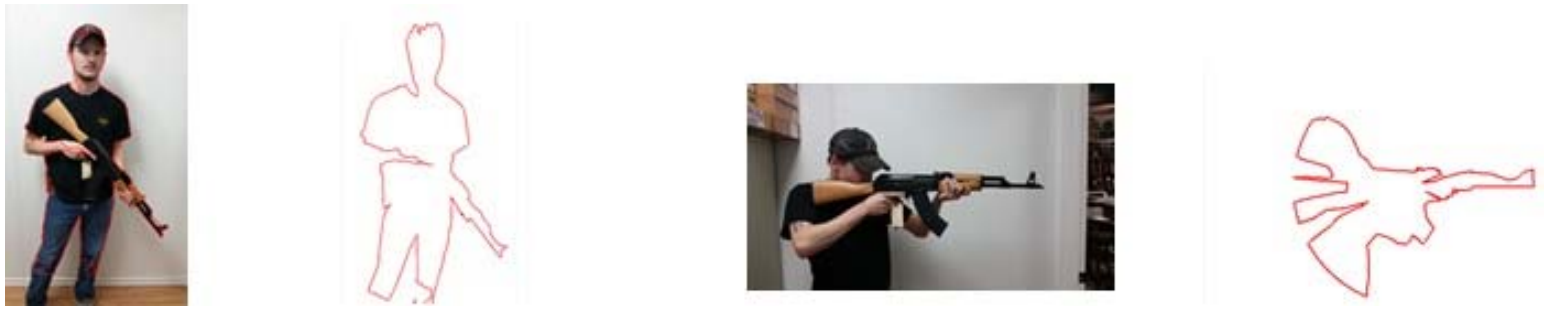
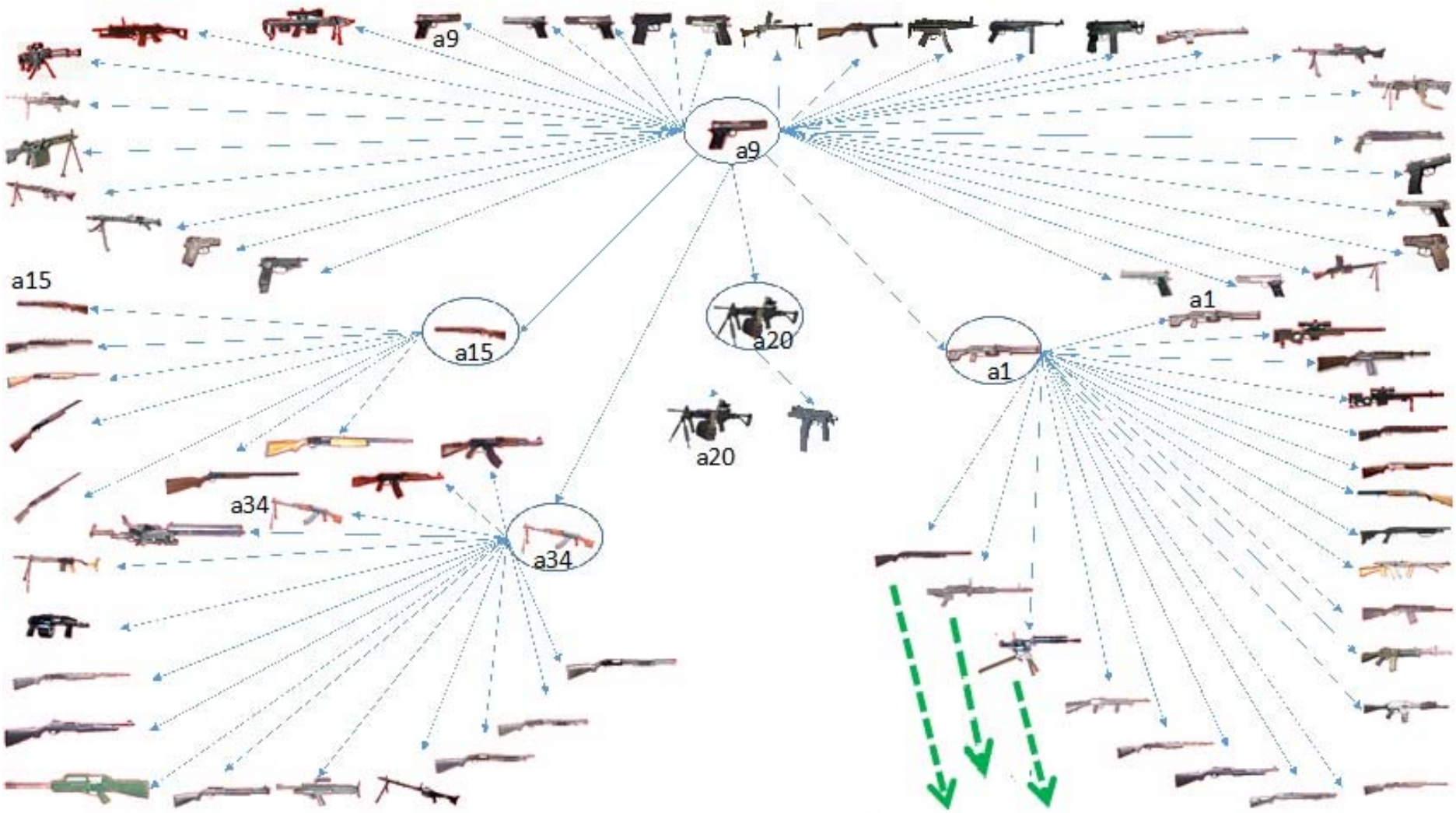


Figure 2. Human and weapons parts' boundaries extraction using S-ACES [6].
IMAGE SIZE: 400x710 , 512 x 288 run time 0.135 sec, 0.119 sec, CPU 2.4 GHz

Figure 3. Extraction of human and weapons parts' boundaries using LPAC active contour.

Visual Hierarchy - Search and Mapping [3.4]



links to Conceptual Hierarchy

Branch and bound search algorithm based on sequence alignment

- a cluster is examined
  - if representative is similar “enough” to the queried object
- links from best matches are followed into Conceptual Hierarchy
  - for semantic evaluation [4]

Search and Matching – Rotational, Scaling Invariant, results from [1]

Query (existing)	Cluster	Results	Time
a11	a9	a11 %100, a12 %83, a13 %83, a41 %82, a56 %85	78ms
a25	a20	a25 %100	62ms
a36	a34	a36 %100, a61 %80	62ms
a58	a15	a16 %88, a46 %92, a50 %95, a58 %100, a59 %88, a70 %89	62ms
a62	a9	a62 %100	46ms

Known in current ontology

overall accuracy - 100% [1]

Confidence Interval 100%

Query (not included)	Cluster rep.(s)	7 Best Matches	Search Time (ms)
	a136	a129 90% 86% 83% 82% 82% 82% +81%	125
		78%	156
		79% 76% 75% 74%	
	a54	a126 80% 76%	
		82%	373
	a136	a137 84% 81% 81% 80% 80% 79%	

Unknown to current ontology

Accuracy ~70% within super—class

Confidence Interval [63.25%, 77.75%] with 95% of confidence [1]

non-weapon object

no matches

100% [1]

GUN ONTOLOGY-MERONOMY

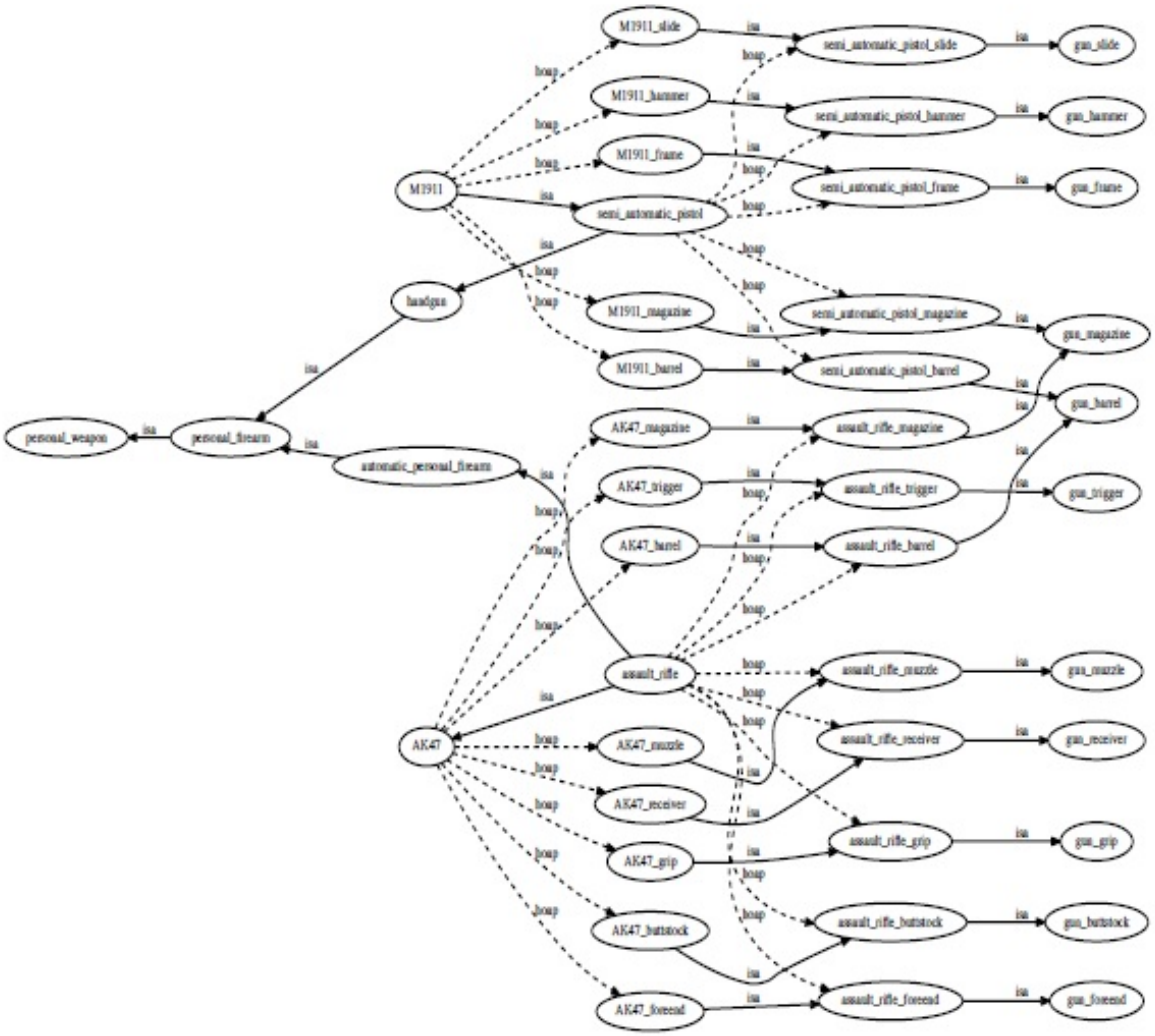
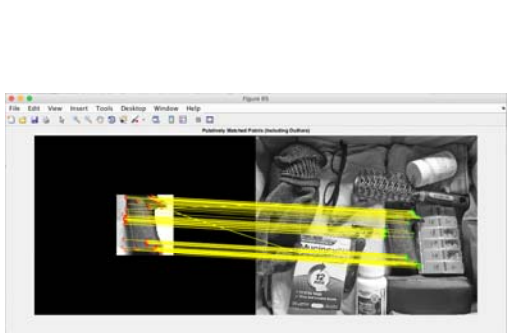
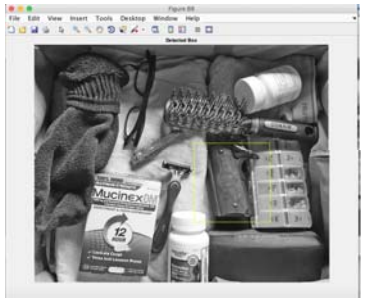


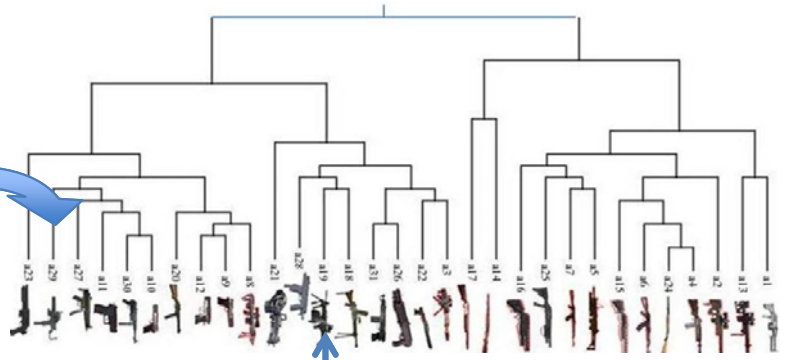
Figure 4. Part of the current ontology with hyperonymic (isa; solid line) and meronymic (hoap; has object as part: dashed line; strict inverse of part-of) relationships [2].

Framework - present research

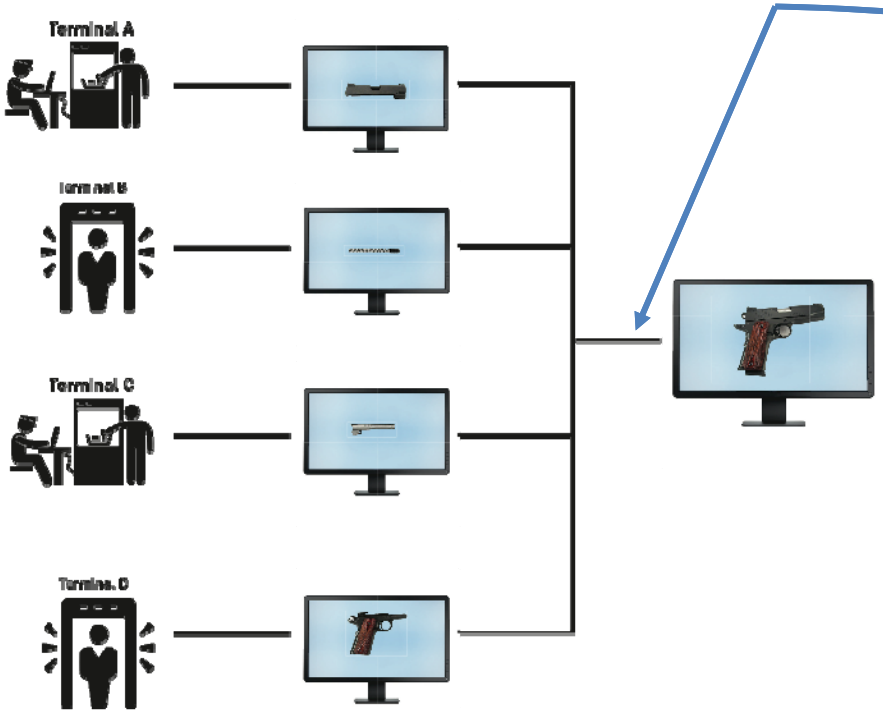
1. Weapons' parts detection at Check Points
2. Virtual assembling of weapons

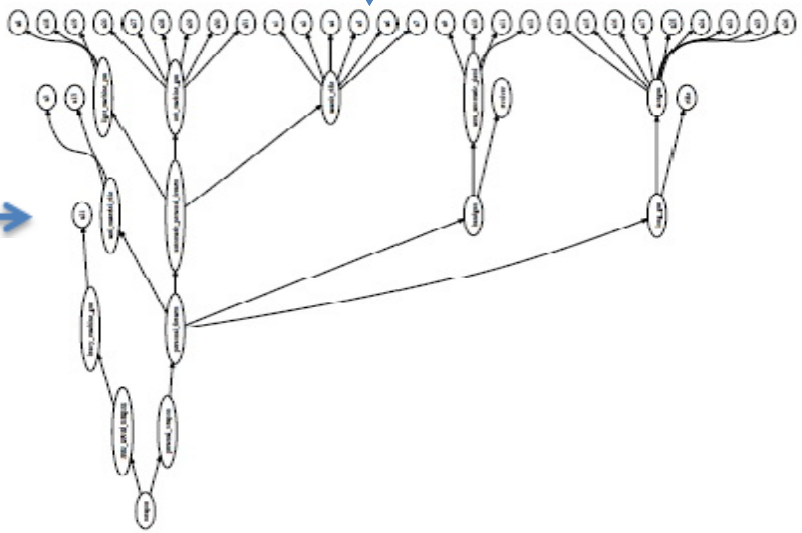






[4]





Spotting Target in a Cluttered Environment – SURF matching, segmentation

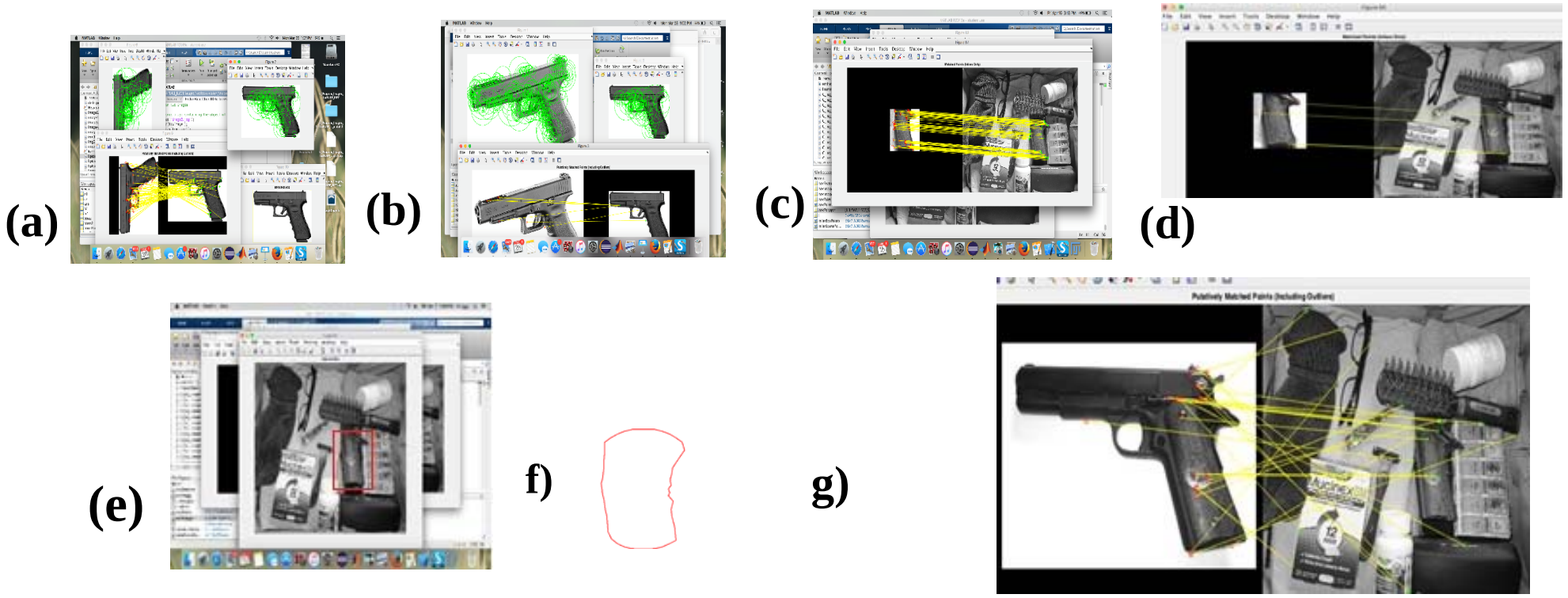


Figure 5. **(a)** and **(b)** Matching SURF [5] points under rotations and orientation; **(c) (d)** SURF [5] matching of a weapon's part with a luggage stuff; **(e)** the best match; **f)** its boundary extracted; **g)** best match with a weapon.

Automatic Parts Identification from Partonomy (Meronomy)

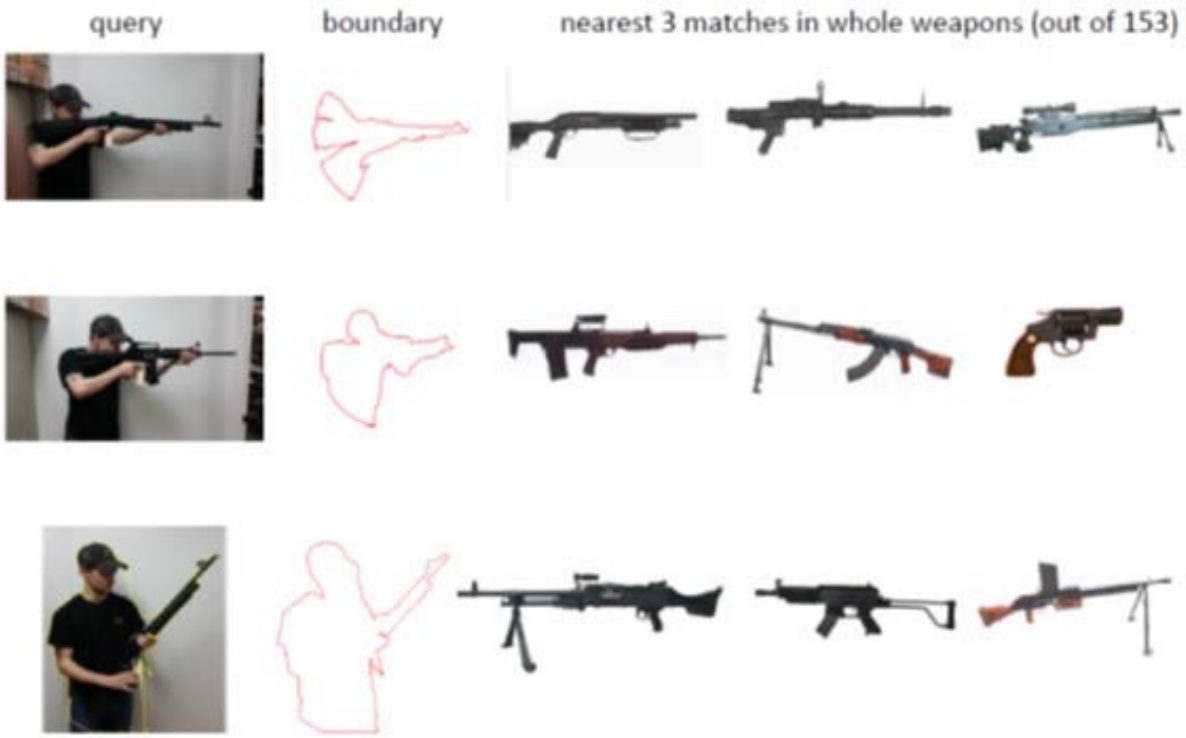


Figure 6. a) Extraction – run time 0.12 sec CPU 2.4 GHz [6]

b) Size ontology/meronomy 153 weapons + 30 parts

c) search-match – run time 0.6 sec [6].

c) query with known weapon/part – 100% identification success

d) query with unknown weapon/part - 55% successful identification of the 3rd ancestor

e) Confidence Interval - [48%, 62%] with 95% of confidence.

Potentials, Limitations, Input, Testing

- Which weapons can be detected?
  - All firearms in the ontology and those not in the ontology but within the virtual class.
- Can knives be detected?
  - Yes, if we add that branch to the ontology
- What are the limitations on disassembly and occlusion?

  - Disassembled gun: no theoretical limit, smaller generic parts may lead to false positives
  - Partially occluded guns: ratio of occlusion to recognition
- What are the sources of images?
  - Visual
  - We are adapting and developing new segmentation and extraction methods for x-ray
- What causes false alarms?
  - False positives: anything visually resembling a gun (airsoft guns, toys, models)
  - Experiments with a set of non weapon images - 100% distinction
- How did you test the method?
  - On our labeled ontology/meronomy - 183 images of weapons and parts
  - Query with weapons/parts and non weapon images.

Backup Slides

Team Members:

1. **Dr. Salvatore Attardo** – Dean, College of Humanities, Social Science, and Arts – Professor, Linguistics, Ontology;
2. **Dr. Nikolay M. Sirakov-** Professor, Math and Computer Sciences – about 120 papers in image analysis, segmentation, extraction, matching, classification, reconstruction;
3. **Dr. Abdullah Arslan** – Professor, Computer Science – papers in the field of clustering, matching, search, identification;
4. **Dr. Christian Hempelmann** – Professor, Ontological Semantic Technology Lab, computational linguistics, ontological semantics information security;
5. **Dr. Grady Blount** – Department Head – Applied Science; Professor, Physics
6. **Dr. David Hurley** –papers on law enforcement personnel and security; counter-intelligence agent; DIA, NASIC, CENTOM, EUCOM, AFRL, USAFC, DARPA.
7. **Tracy Adkins** – Weapons consultant.
8. **Divya Solomon** – Master Student – Computer Science - Ontology;
9. **Chetana Nimmakayala** – Master Student - Computer Science – SURF/SIFT.

Backup Slides

Ontology/Partonomy

- sample gun concept with properties: Davis Industries P380
  - incomplete selection of concepts
  - second-most common semi-automatic pistol involved in crimes in the U.S. in 1994

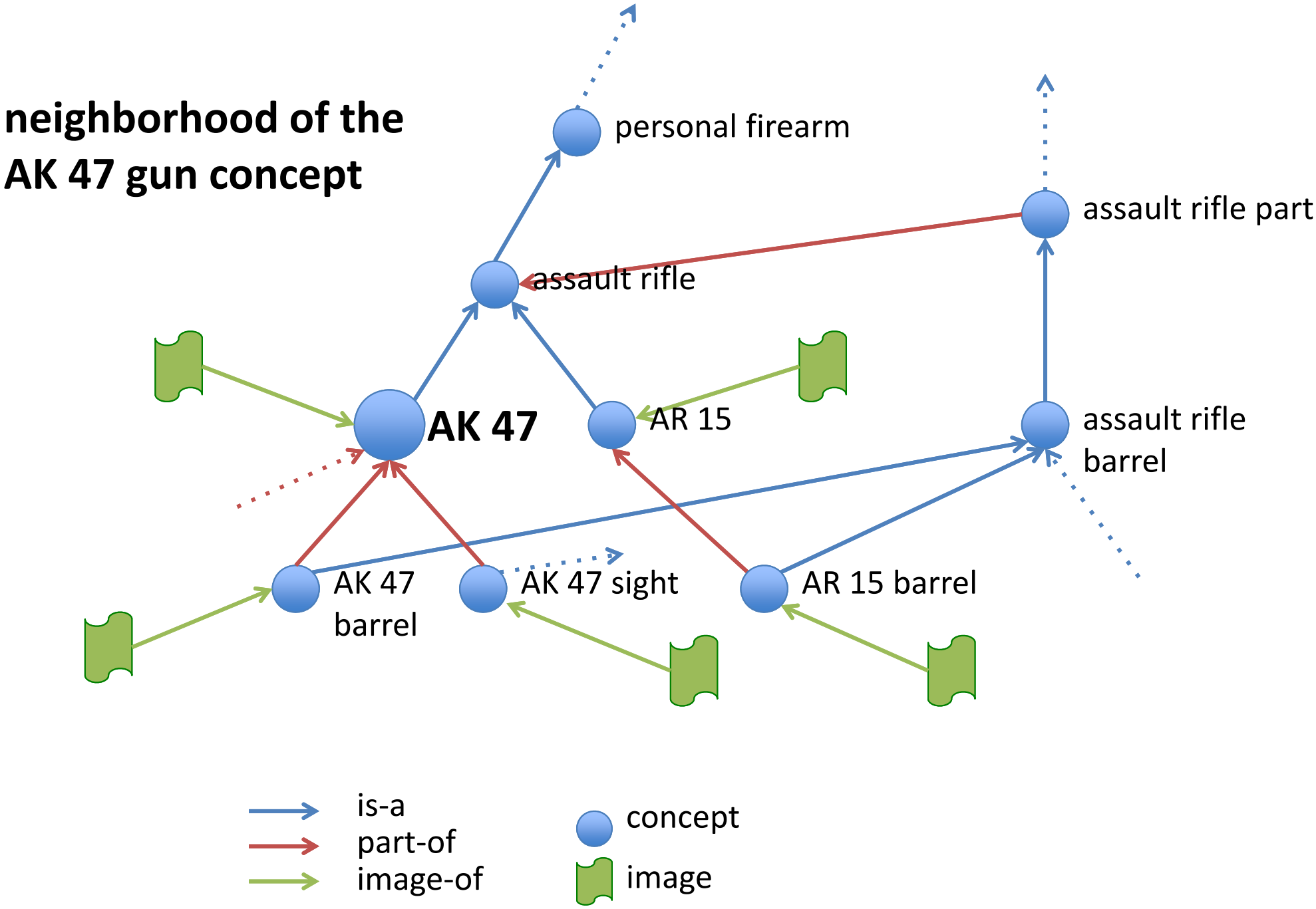
- Davis_Industries_P380
  - is-a semi_automatic_pistol
  - type-of-fire semi_automatic [inherited]
  - caliber 0.38
  - magazine-size 5
  - rate-of-fire 15 [3x magazine]
  - magazine-type detachable, internal
  - barrel-length 2.75
  - hoap Davis_Industries_380_frame
    Davis_Industries_barrel
    …

Backup Slides
Ontology/Partonomy

- Types of gun part-to-gun relationships:
  - **essential**: gun is not *this* gun without part
    e.g., removable sight, scope, butt are *not* essential parts;
  - **characteristic**: gun is definitely *this* gun with *this* part
    e.g., curved AK magazine or front sight of that gun;
  - **adjacent** to another part: parts that are identified as adjacent in image and known to be adjacent in gun confirm identification.

- Threat assessment
  - from gun image to identified gun: direct threat value
  - (fallback) from gun image to identified gun class: average class threat
  - from part image to gun: direct threat value
  - (fallback 1) from part image to gun class: average class threat
  - (fallback 2) from part image to part class: average ancestor class threat

Backup Slides



Backup Slides - References

1. Abdullah N. A., C. F. Hempelmann, S. Attardo, G. P. Blount, N. M. Sirakov, **2015**, "Threat assessment using visual hierarchy and conceptual firearms ontology," *Opt. Eng., 54(5), 053109 (2015). doi:10.1117/1.OE.54.5.053109,* April 06, 2015.

2. Abdullah N. A., C. F. Hempelmann, S. Attardo, G. P. Blount, N. N. Sirakova, N. M. Sirakov, **2015**, "Identification of Partially Occluded Firearms Through Partonomy", Invited Paper: Automatic Target Recognition XXV, edited by Firooz A. Sadjadi, Abhijit Mahalanobis, Proc. of SPIE Vol. 9476, 94760U • © 2015 SPIE • CCC code: 0277-786X/15/$18 doi: 10.1117/12.2184102.

3. Christian F. Hempelmannb, Abdullah N. Arslana, Salvatore Attardoc, Grady Price Blountd, N. M. Sirakov**, 2014**, 'Assessing the Threat of Firearms: New Threat Formula, Resources, and Ontological Linking Algorithms,' *Signal Proc, Sensor/Information Fusion and ATR XXIII, In Ivan Kadar Ed.,* Proc. SPIE, Vol. 9091, 9091OU-1-12,ISBN: 9781628410280

4. Arslan A. N., C. F. Hempelmann, C. Di Ferrante, S. Attardo, and N. M. Sirakov. **2013**. "From Shape to Threat: Exploiting the Convergence Between Visual and Conceptual Organization for Weapon Identification and Threat Assessment**." Invited Paper. Recipient of the Lockheed-Martin Best Paper Award.** In: Sadjadi, Firooz A. and Abhijit Mahalanobis. Eds. Automatic Target Recognition XXIII. Proc. of SPIE 0277-768X, V. 8744. Bellingham, WA: SPIE. 87440P. pp. 1-15. doi: 10.1117/12.2015591.

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6. Christian F. Hempelmann, Abdullah N. Arslan, Salvatore Attardo, Grady P. Blount and Nikolay M. Sirakov, **2016,** " Real life identification of partially occluded weapons in video frames ", Proc. SPIE 9844, automatic Target Recognition XXVI, 98440Y (May 12, 2016); doi:10.1117/12.2224344; http://dx.doi.org/10.1117/12.2224344