SAND2016-1655C

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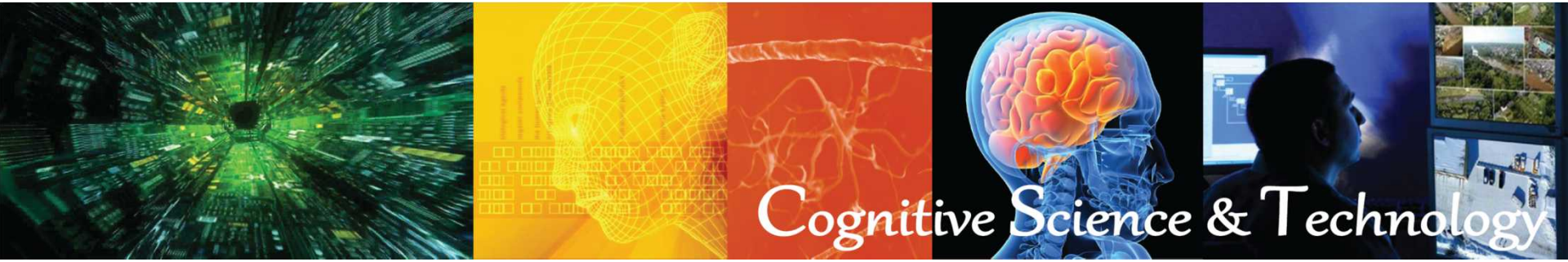

Using Eye Tracking Metrics and Visual Saliency Maps to Assess Image Utility

Laura Matzen, Michael Haass, Jonathan Tran & Laura McNamara

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration | LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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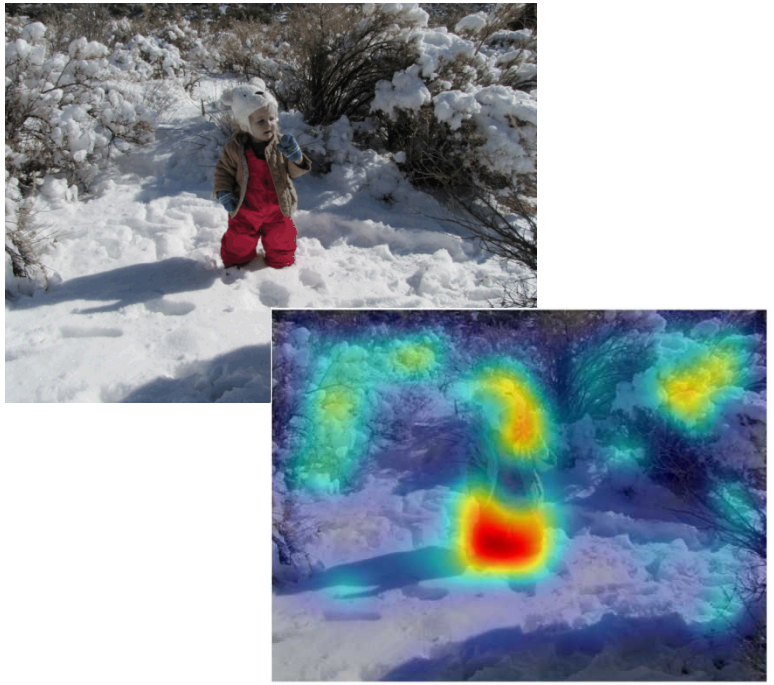
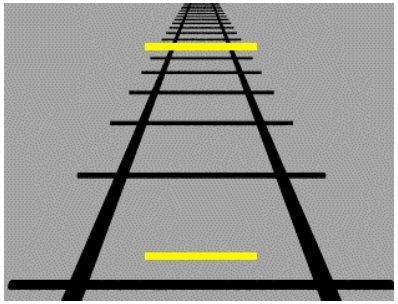
Visual Attention



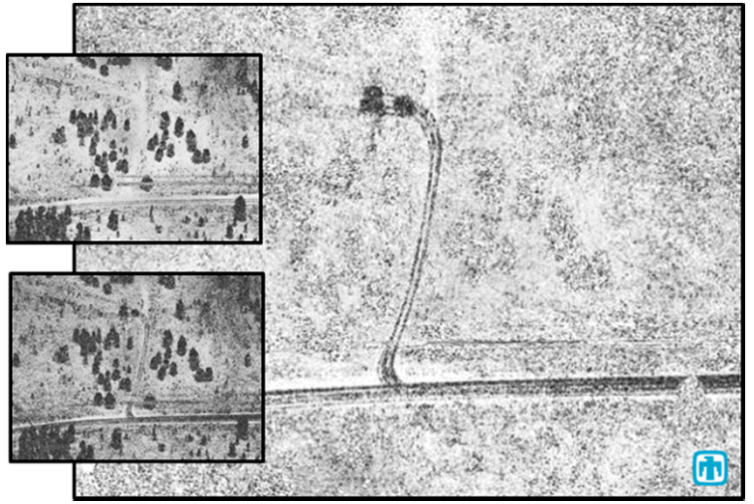
- Bottom-up
  - Driven by properties of stimulus
    - ***Visual salience*** (contrast between features of a stimulus and the features of its neighbors) captures attention
  - Parameters are well understood and can be modeled

- Top-down
  - Driven by viewer's goals
  - Affected by cognitive load, working memory, past knowledge and experience
  - Has a very powerful influence on bottom-up perception
  - Parameters are NOT well understood



A Case Study: Synthetic Aperture Radar (SAR) Imagery Analysis

- SAR analysts recognize and classify patterns using SAR imagery.
- The same scene is repeatedly imaged over extended periods of time, allowing the analyst to see changes.

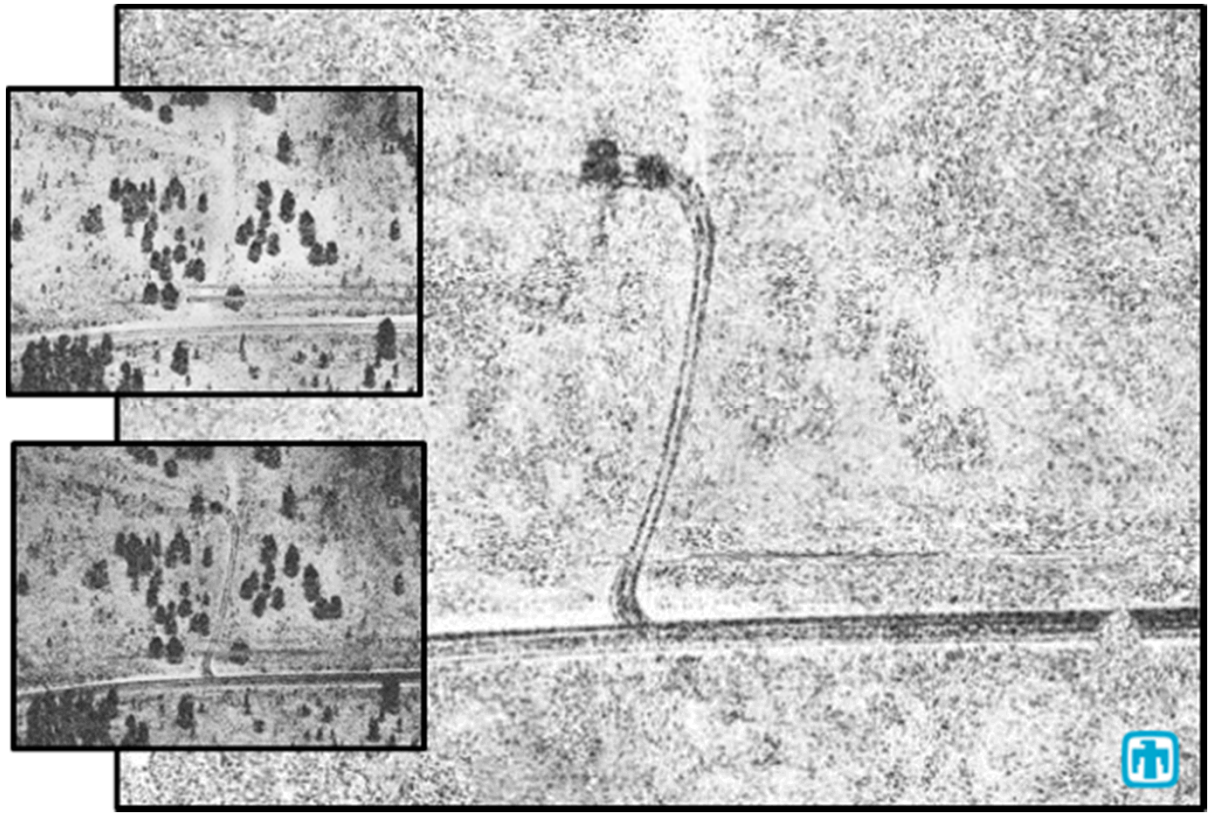


Courtesy of Sandia National Laboratories, Airborne ISR

A Case Study: Synthetic Aperture Radar Imagery Analysis

Courtesy of Sandia National Laboratories, Airborne ISR

A Case Study: Synthetic Aperture Radar Imagery Analysis



Courtesy of Sandia National Laboratories, Airborne ISR

Study Details

Sandia National Laboratories

Participants:

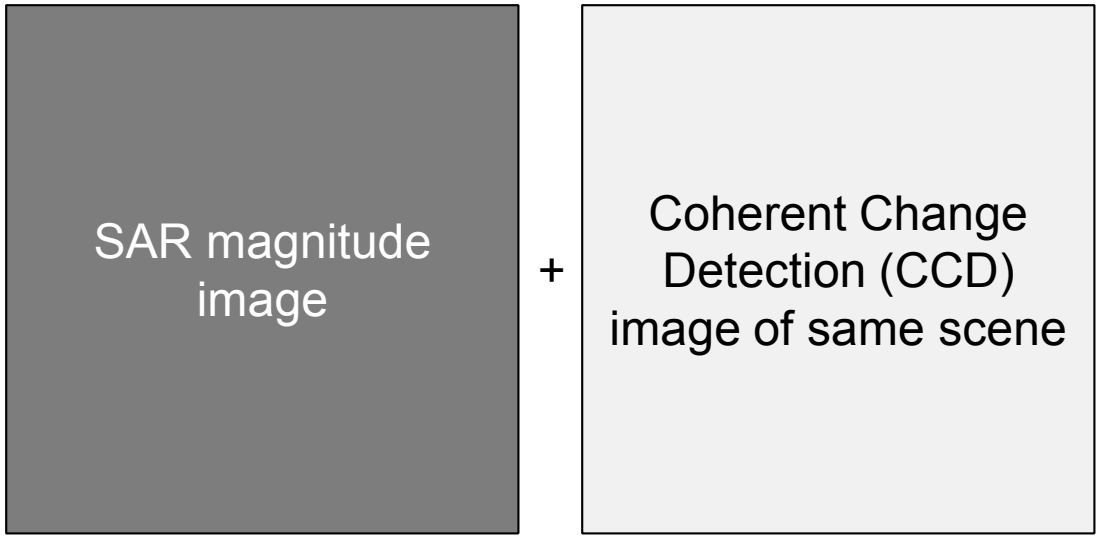
- 8 SAR imagery analysts, 8 engineers experienced with the domain, 8 SAR novices

Data collected:

- Behavioral
  - Reaction time, Accuracy
- Eye Tracking
  - Quantitative
    - Time to first fixation in region of interest (ROI)
    - Percentage of fixations in ROIs
    - Counts and frequencies of transitions between ROIs
    - Classification of error types (scanning error, recognition error, decision error)
  - Qualitative
    - Characterization of scan paths
    - Characterization of search strategies
    - Identification of features with high top-down saliency

Domain-Specific Task: SAR

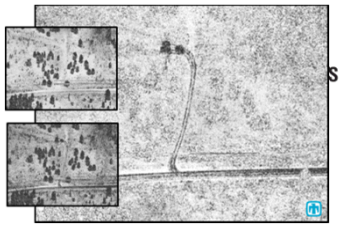
- Target detection task using two images, presented side by side
  - 50% prevalence of targets
  - Participants rate images on 1-4 scale
    - sure no, unsure no, unsure yes, sure yes

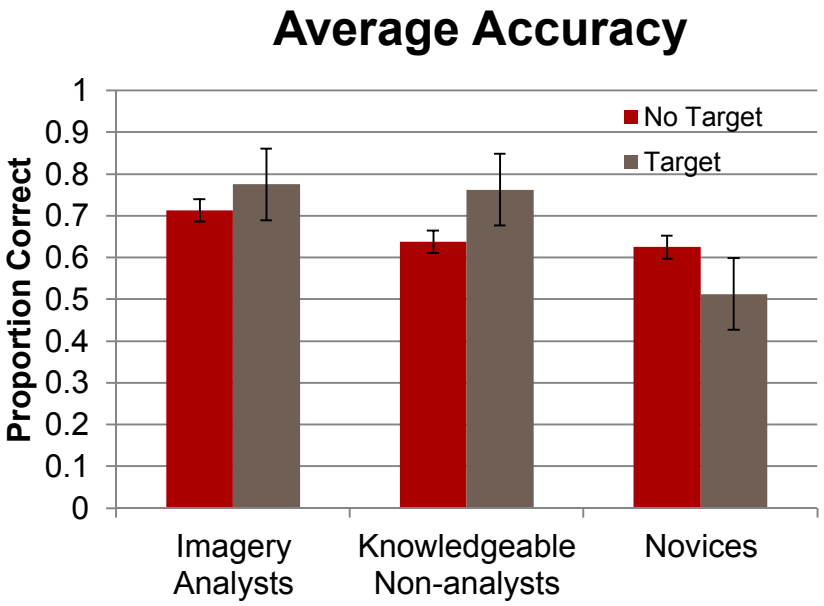


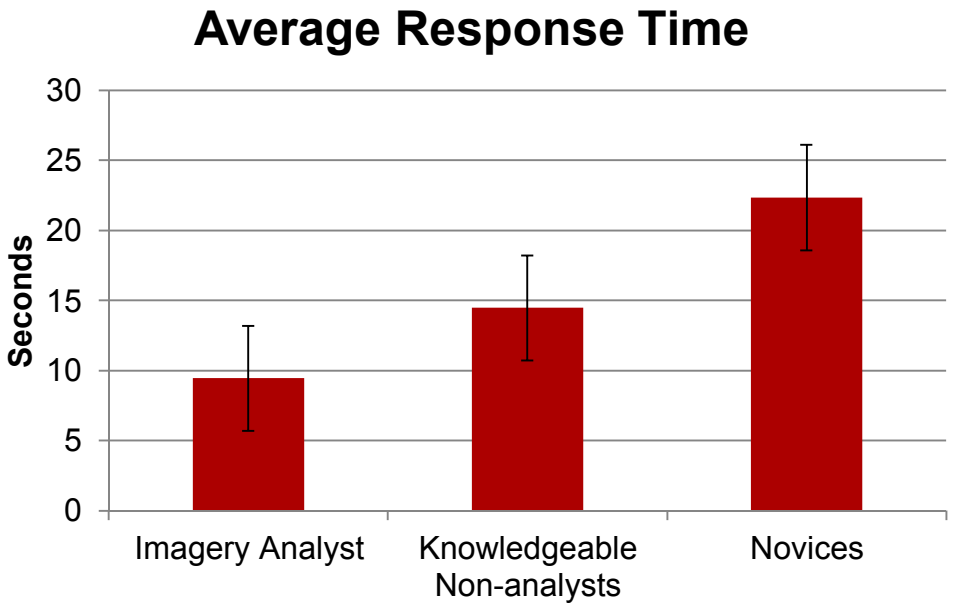
Participants to date on SAR task

- 8 SAR imagery analysts
- 10 engineers experienced with the domain
- 5 engineers who work on in other SAR domains
- 7 SAR novices

SAR Task Results

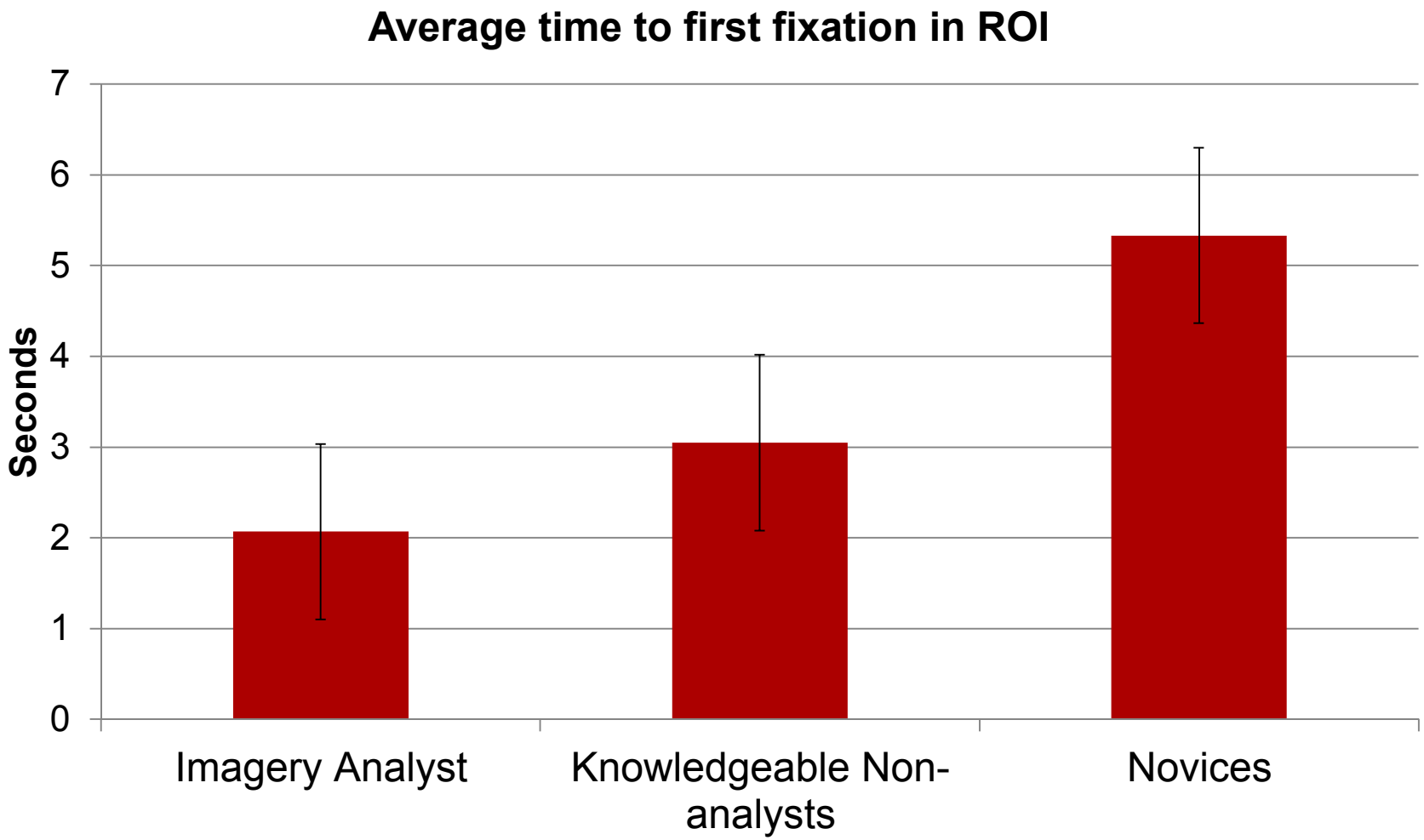




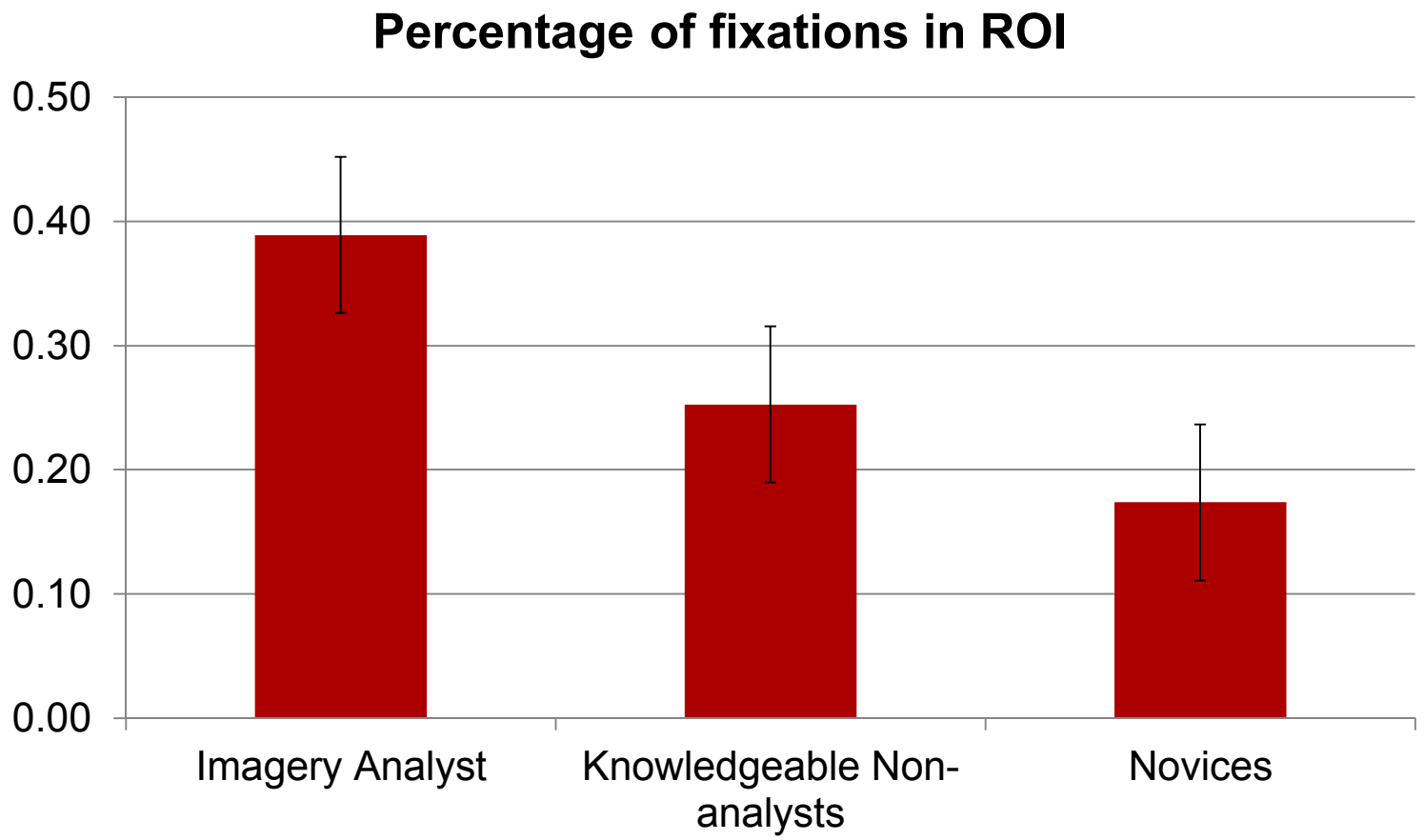


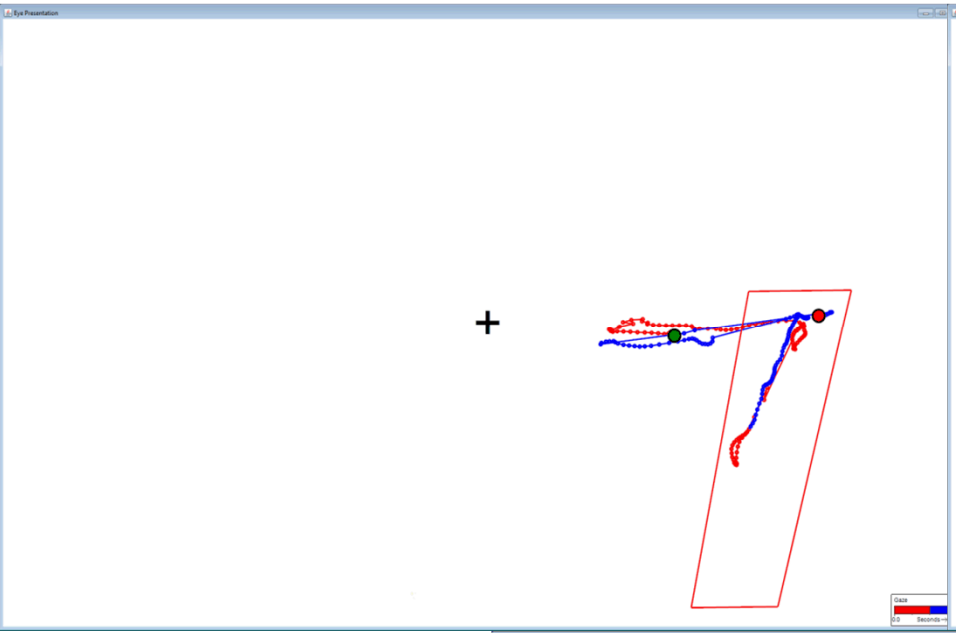
- Imagery analysts and knowledgeable non-analysts were significantly more accurate than the novices.
- Imagery analysts were significantly faster than the knowledgeable non-experts and novices.
- Knowledgeable non-analysts were significantly faster than the novices.

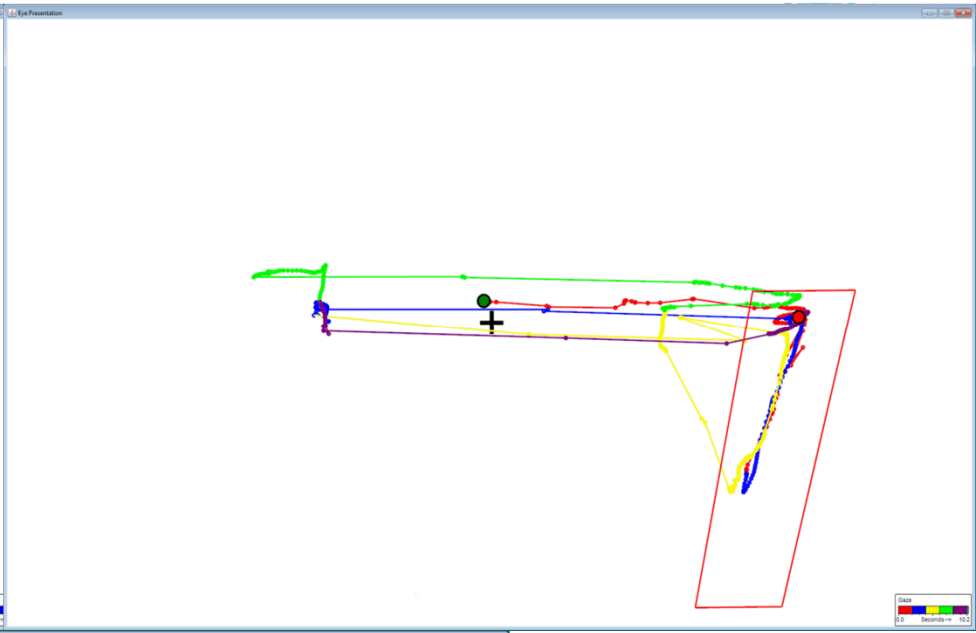
SAR Task - Eye Tracking Results



SAR Task - Eye Tracking Results




Eye Presentation
Gaze
0.0
Seconds


Eye Presentation
Gaze
0.0
Seconds

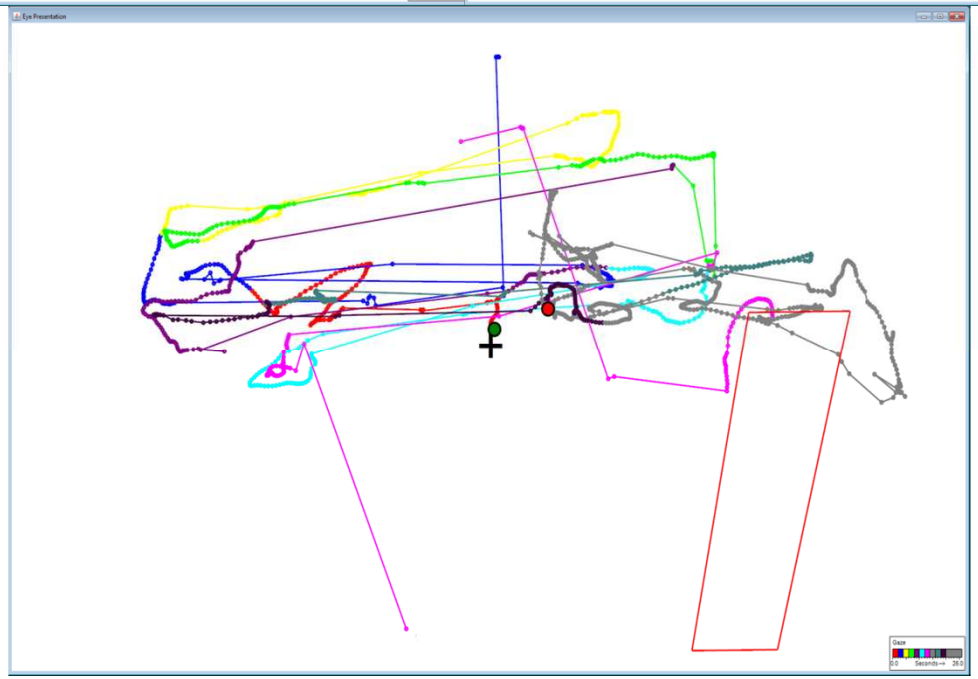
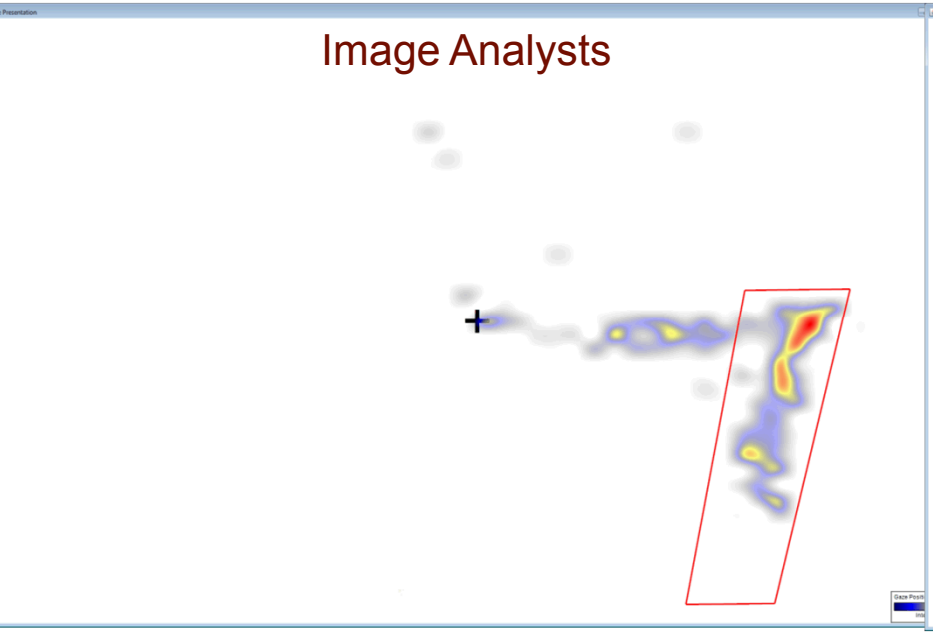
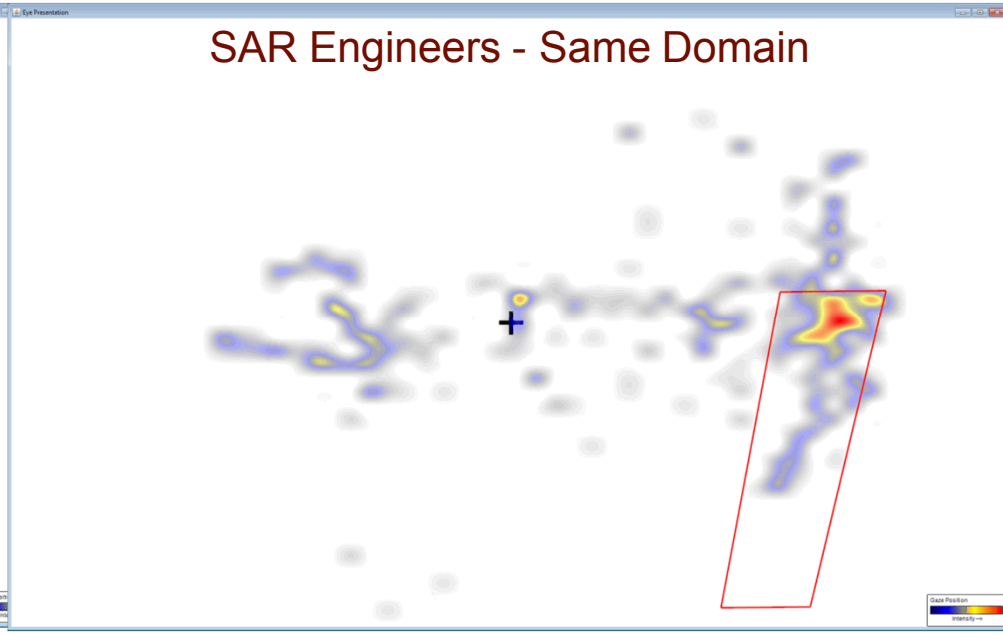

Eye Presentation
Gaze
0.0
Seconds

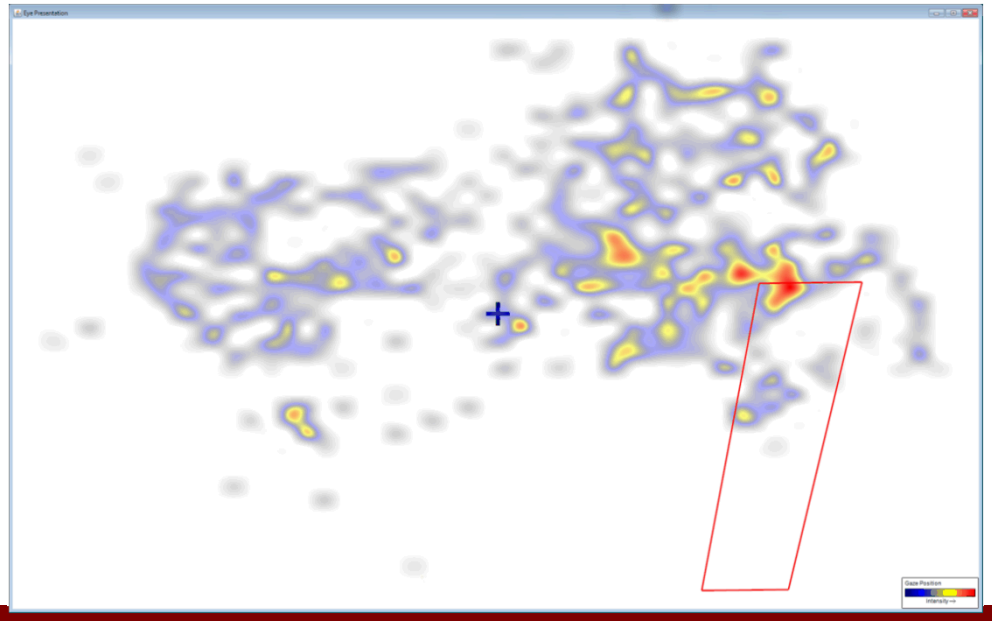
Image Analysts



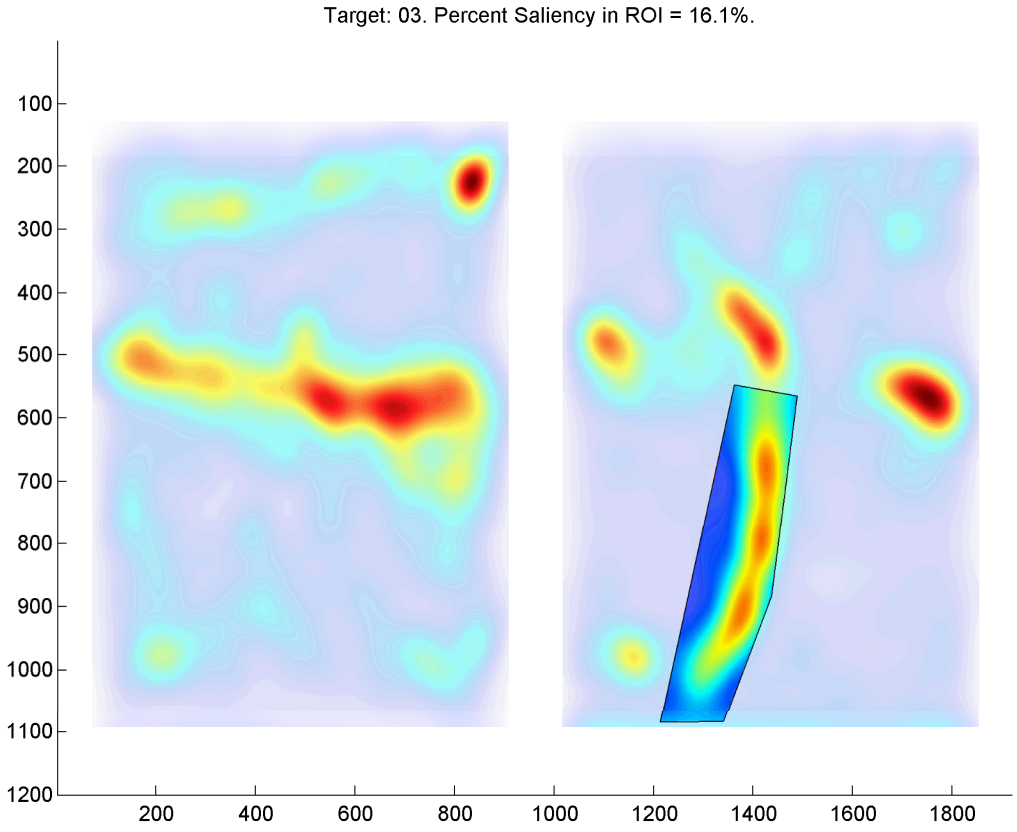
SAR Engineers - Same Domain



Novices

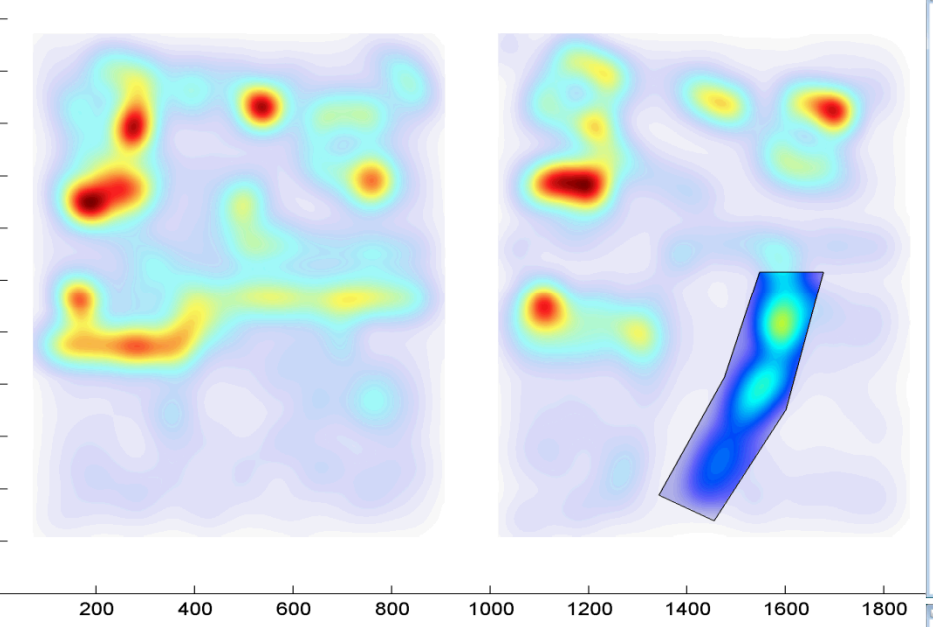


Bottom-up Saliency

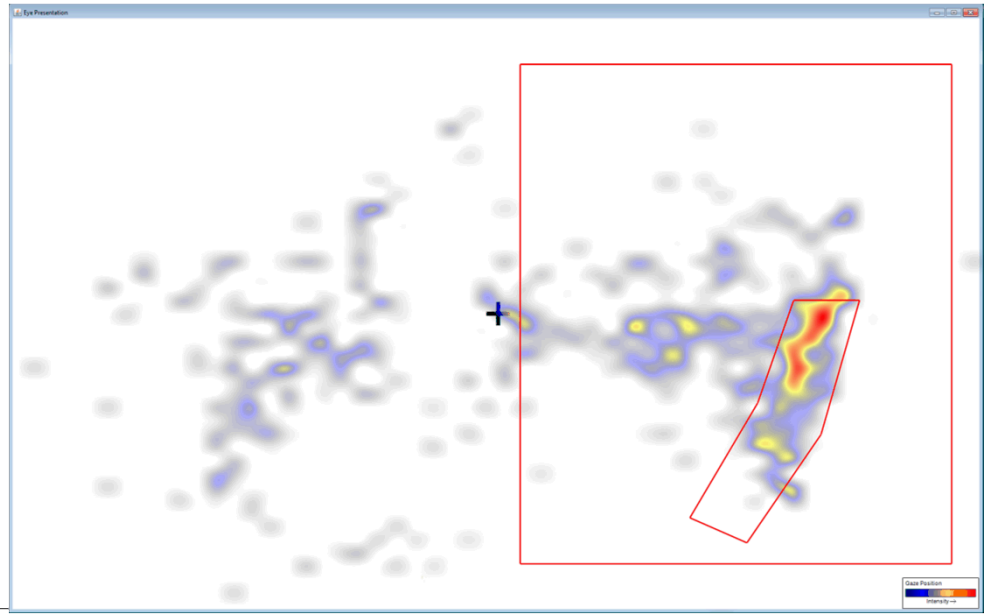


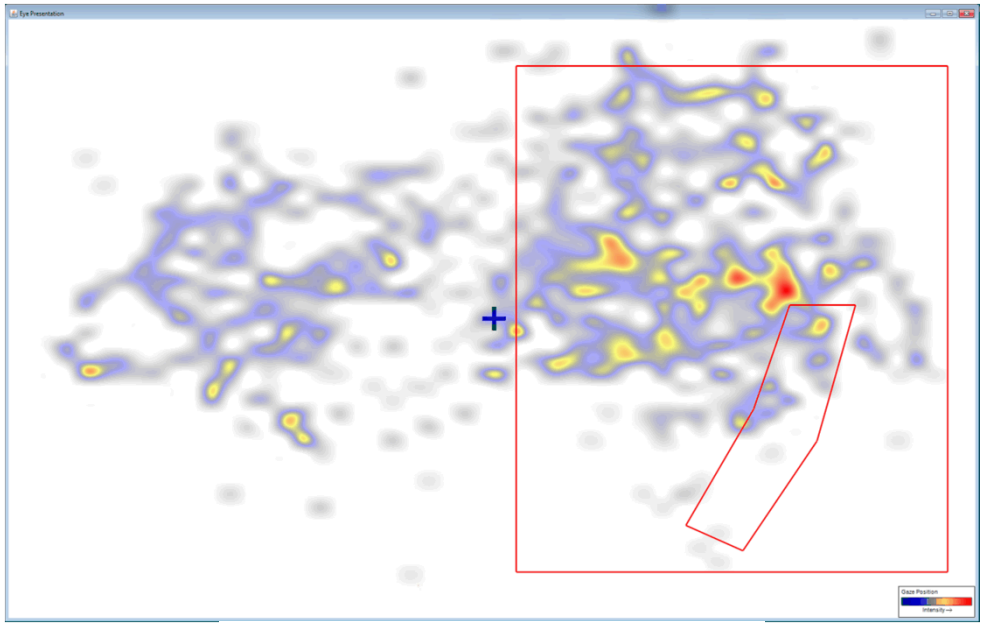
Eye tracking gaze maps, which represent a combination of top-down and bottom-up saliency, can be compared to maps of bottom-up saliency to examine the differences between the two

Percent of saliency in ROI = 9.4%



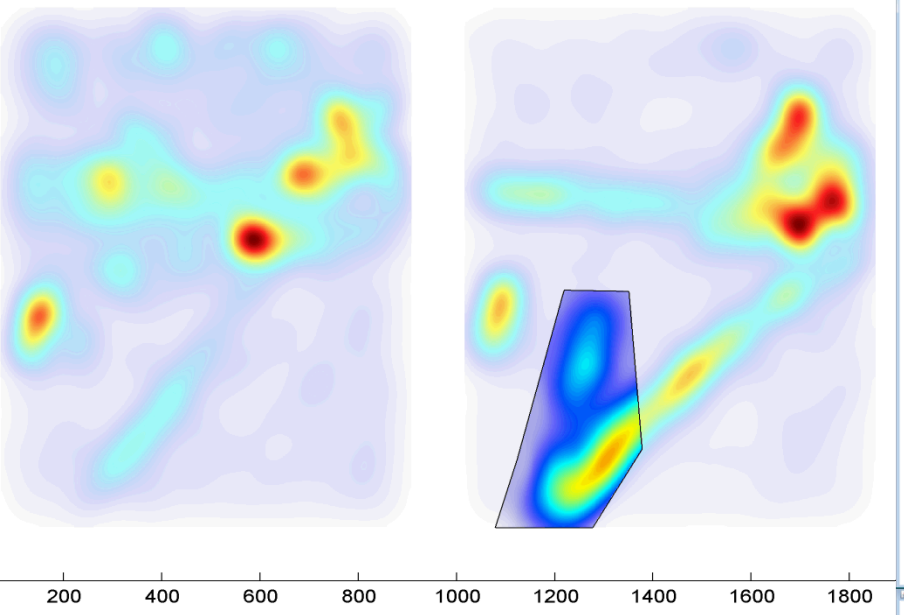
Imagery Analysts - % of gaze in ROI = 75.4%



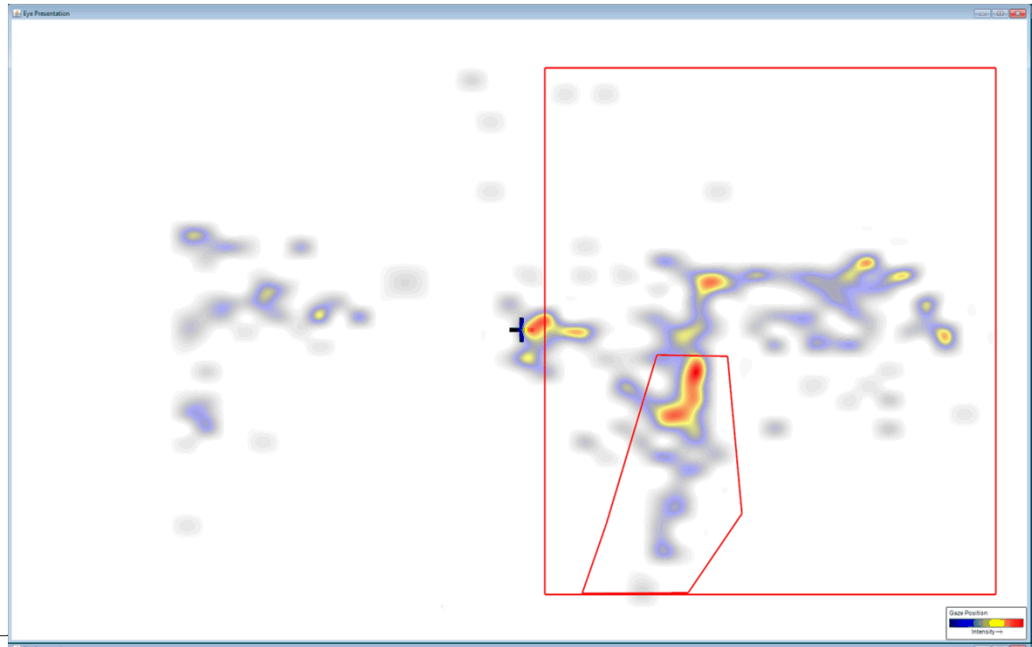


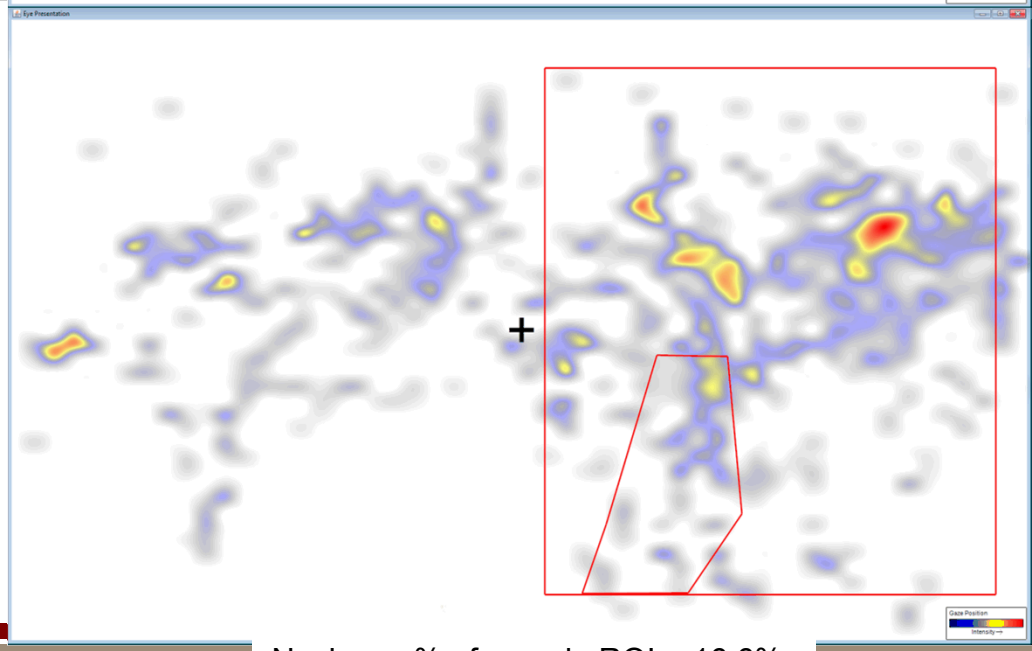
Novices - % of gaze in ROI = 4.3%

Percent of saliency in ROI = 14.8%



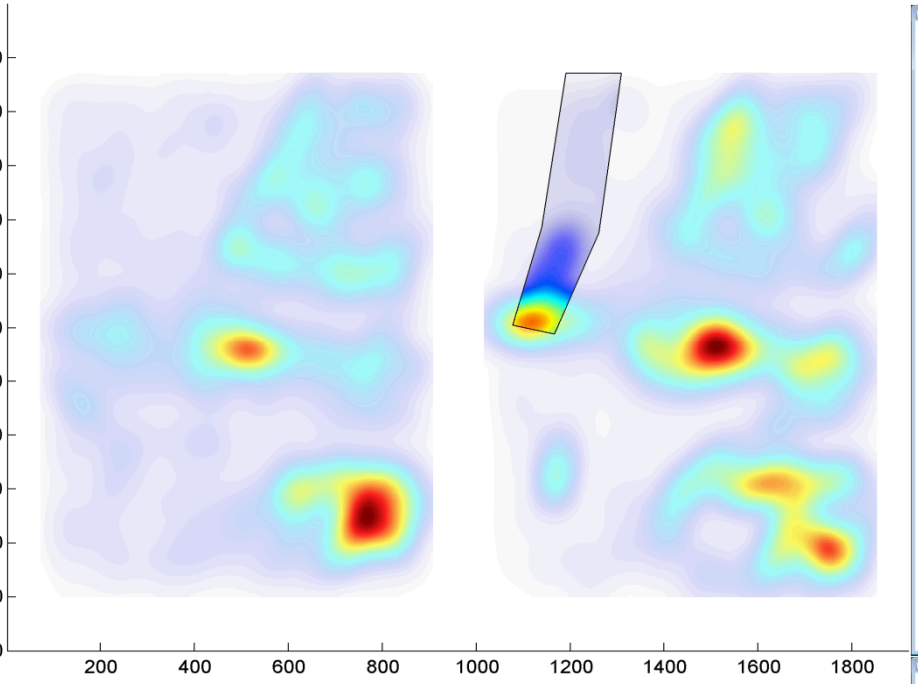
Imagery Analysts - % of gaze in ROI = 45.0%



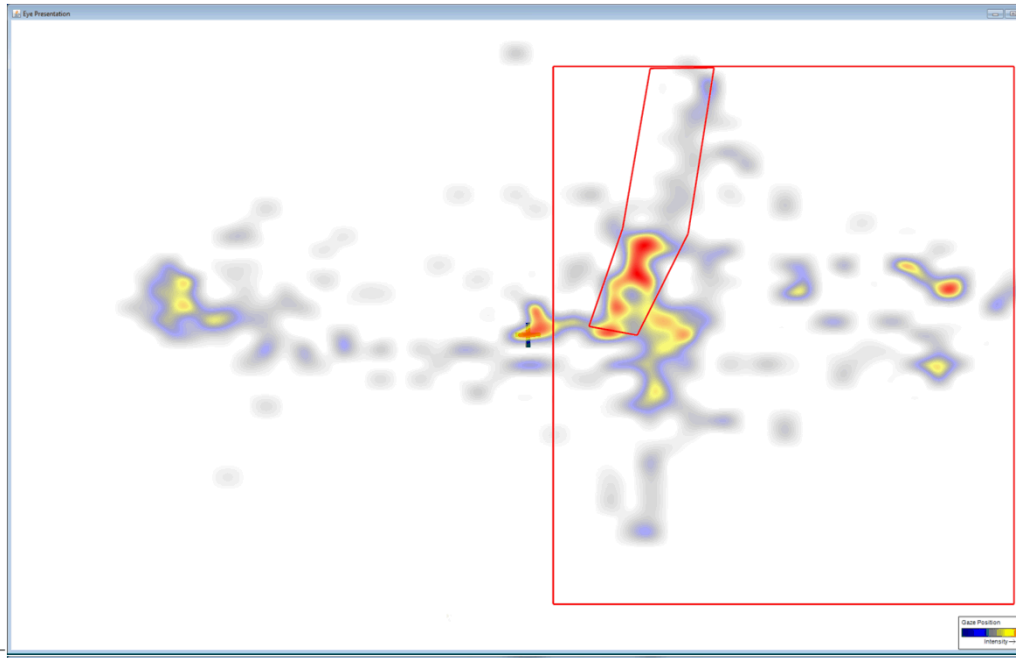


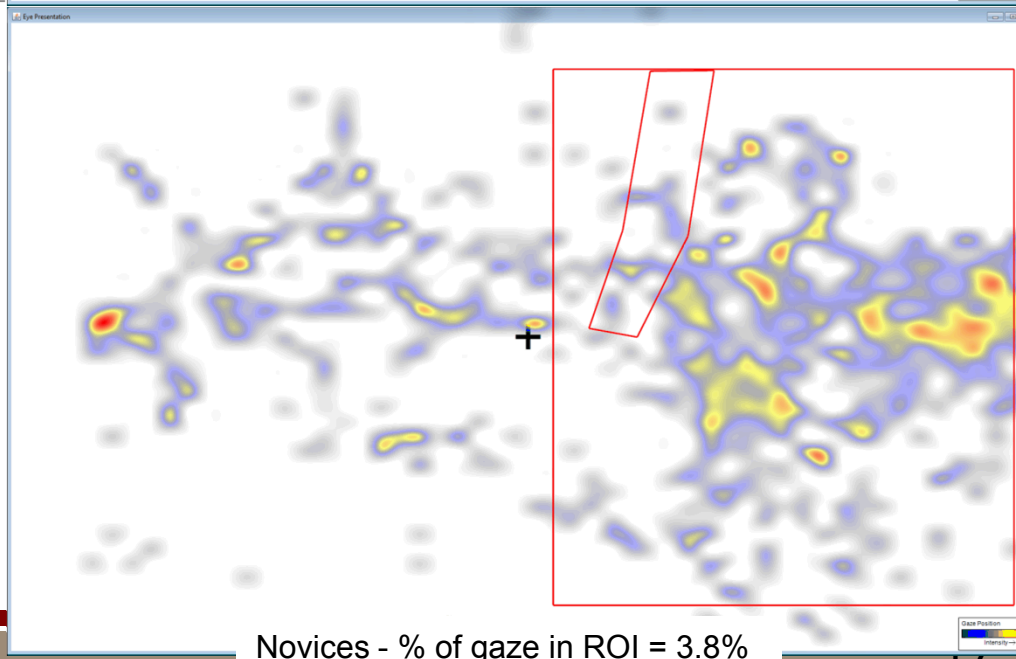
Novices - % of gaze in ROI = 16.6%

Percent of saliency in ROI = 4.0%



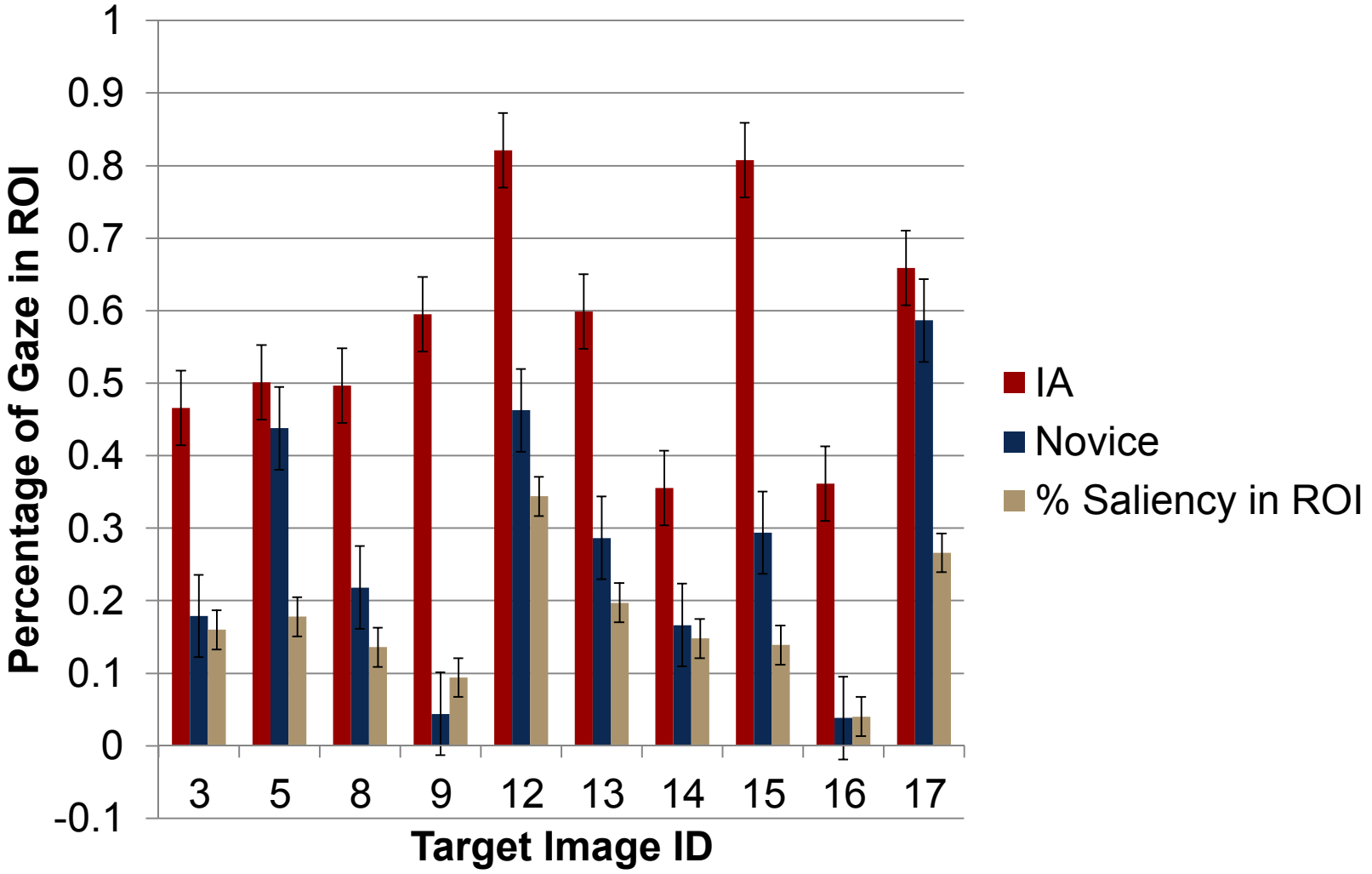
Imagery Analysts - % of gaze in ROI = 44.0%



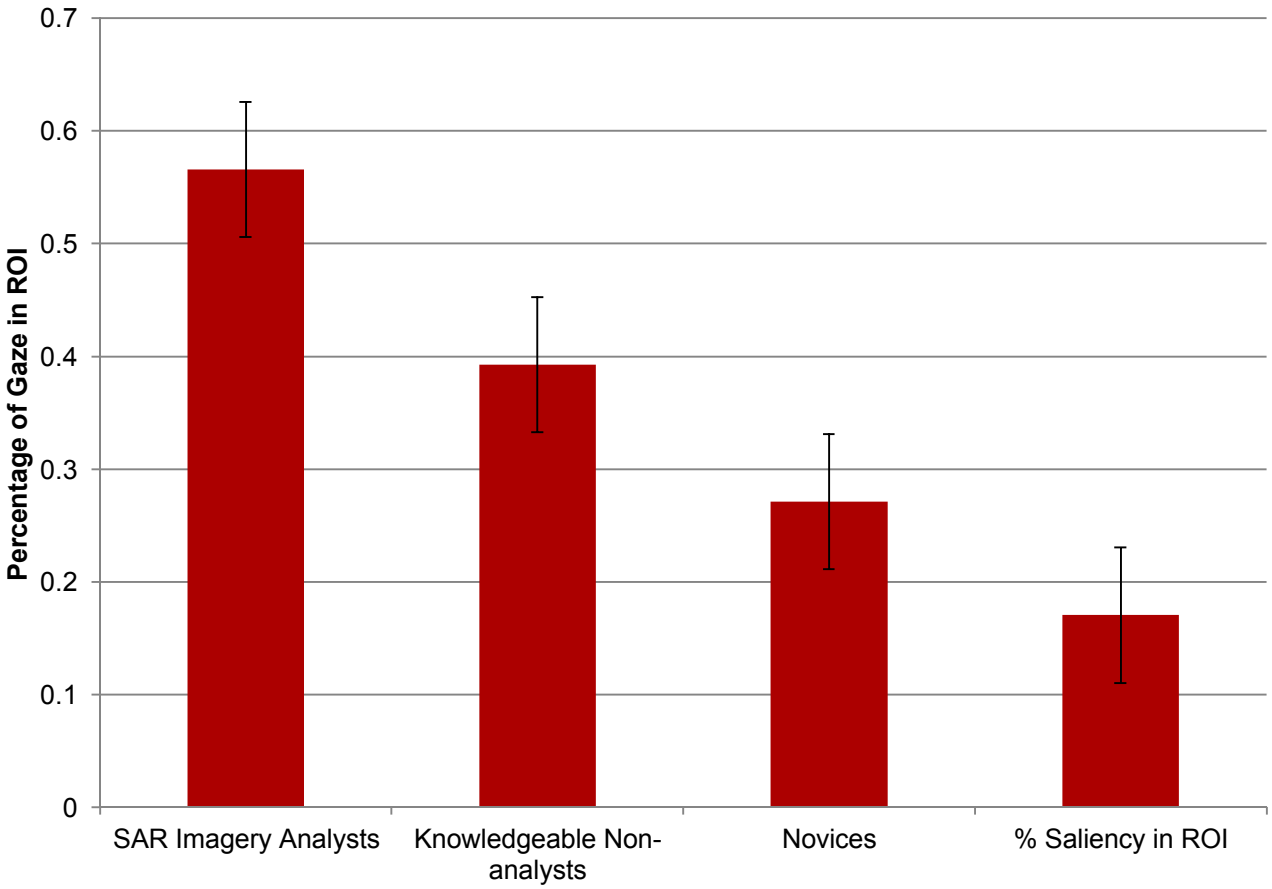


Novices - % of gaze in ROI = 3.8%

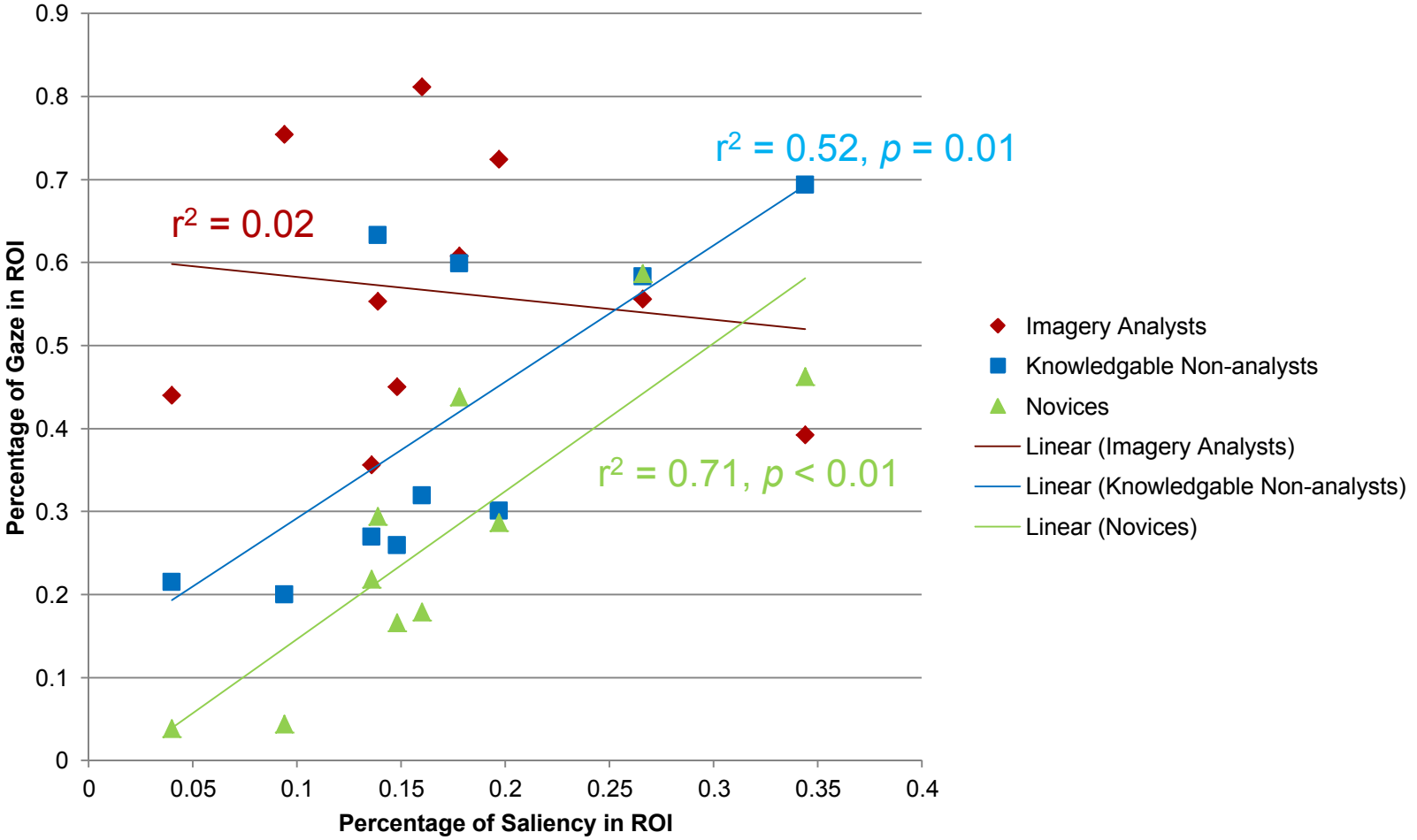
Comparison for all target trials



Collapsed across target trials



Correlation between gaze and saliency



Modeling top-down visual attention and cognitive biases

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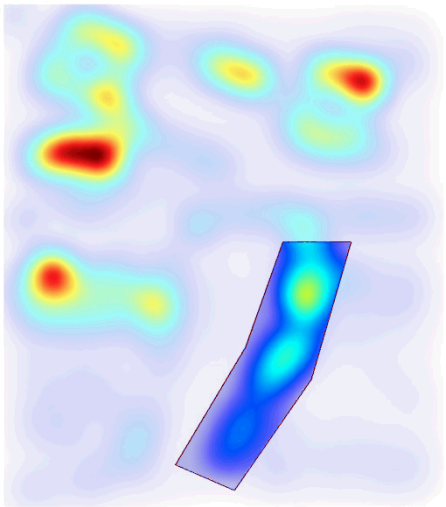
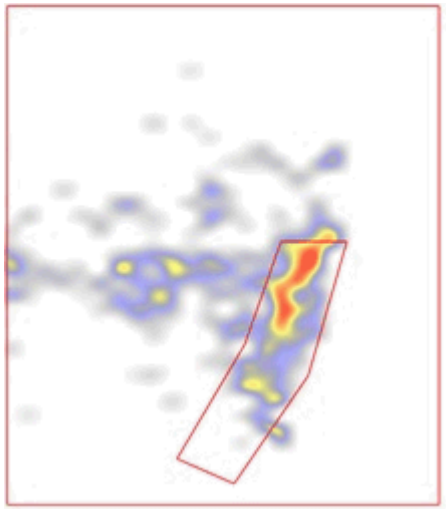
- What visual features do experts ignore, even when they have high visual saliency?
  - This reveals efficiencies and cognitive biases
- Creating masks of bottom-up saliency for specific features allows for quantitative comparisons

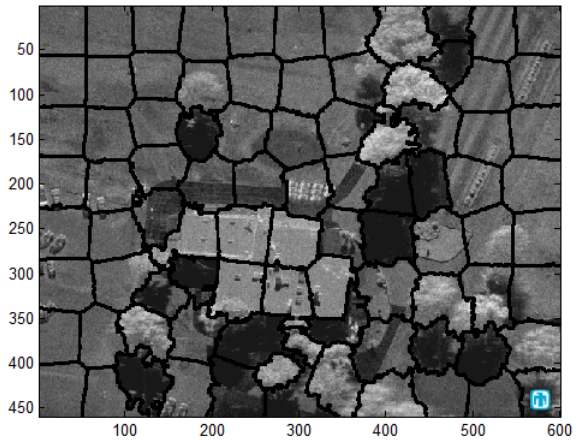




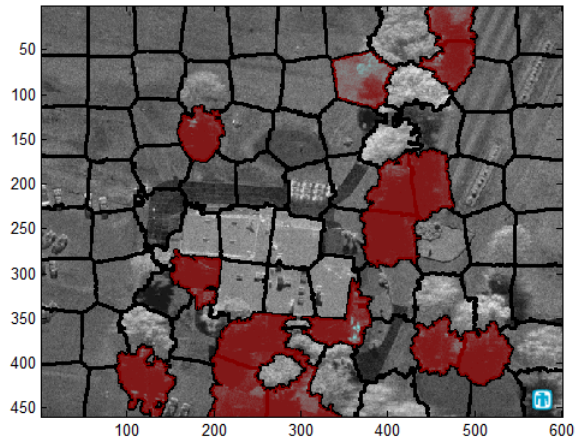
Reducing Salience Estimates in Shadow Regions

- Pixel-statistical methods used to segment[1] the scene and characterize the segment properties[2]
- These properties can serve as filters to modulate traditional saliency estimates
  - SAR Phenomenology - shadow regions have low coherence

Segment



Classify



[1] M. M. Moya, et al, "Superpixel segmentation using multiple SAR image products" RADAR SENSOR TECHNOLOGY XVIII, Proceedings of SPIE VOL 9077, Conference on Radar Sensor Technology XVIII, MAY 05-07, 2014, Baltimore, MD

[2] M.M. Moya, et al., "Superpixel Classification for Signature Search in Synthetic Aperture Radar Imagery," Conference on Data Analysis (CoDA), March, 2014, Santa Fe, NM.

SAR Image courtesy of Sandia National Laboratories, Airborne ISR

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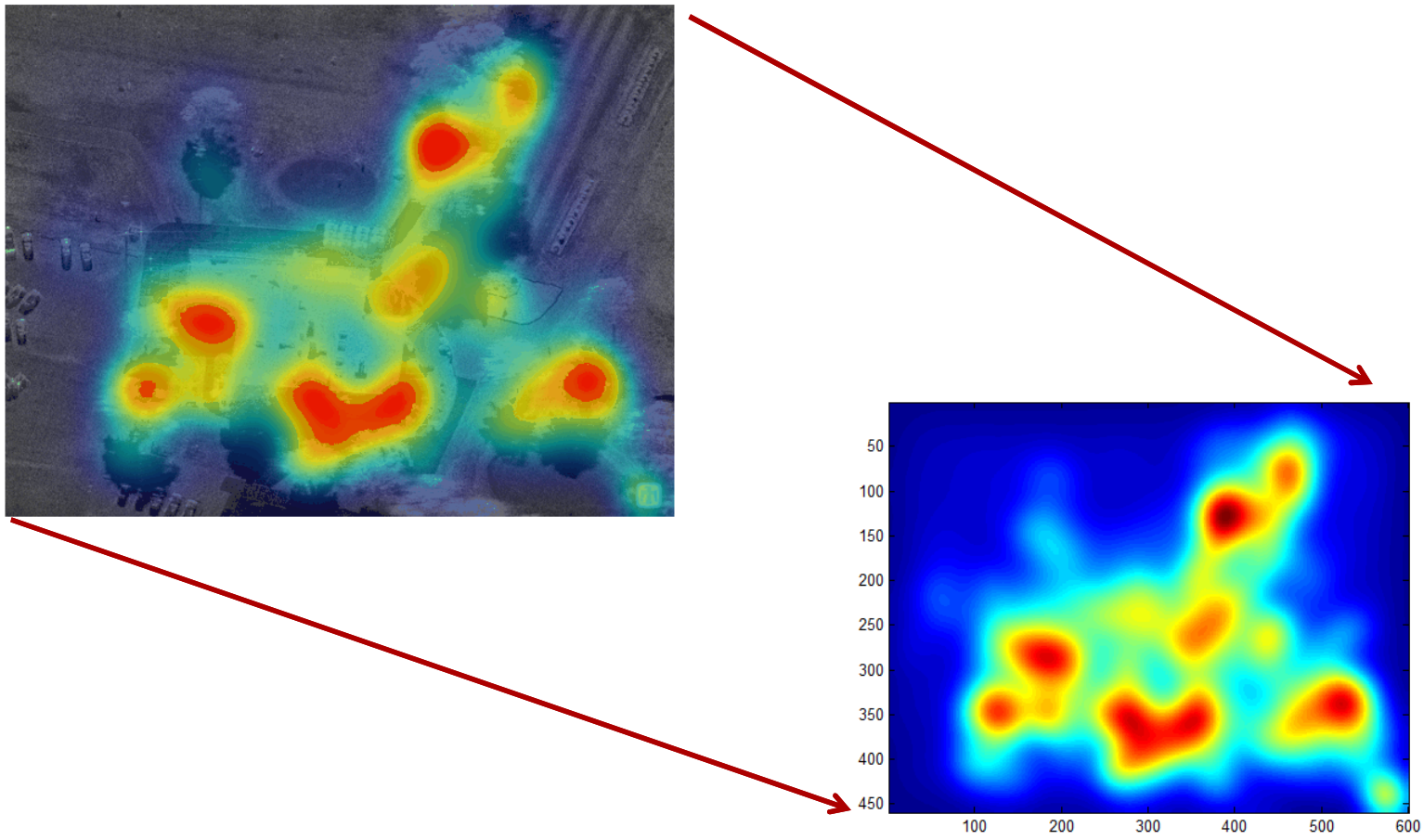
Method (1): Natural Scene Saliency Map



[1] Itti citation

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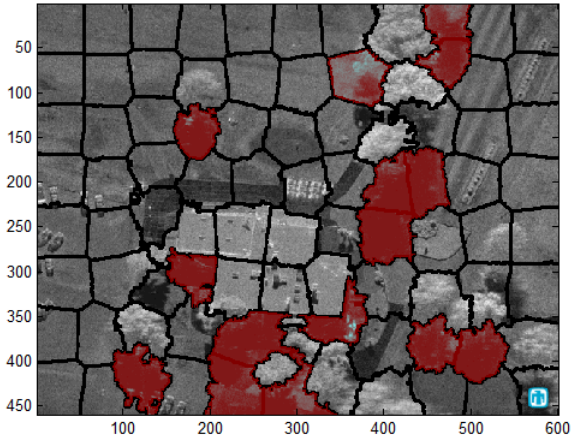
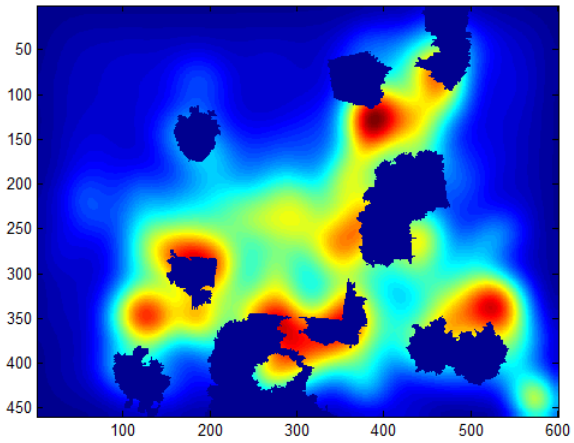
Method (2): Select and Filter Based on Superpixel Characteristics

- Select superpixels with certain characteristics (i.e. shadows)
  - Classify using pixel statistics within each superpixel



- Apply mask to original saliency map
  - Can add Gaussian, or other smoothing to reduce discontinuities



SAR image courtesy of Sandia National Laboratories, Airborne ISR

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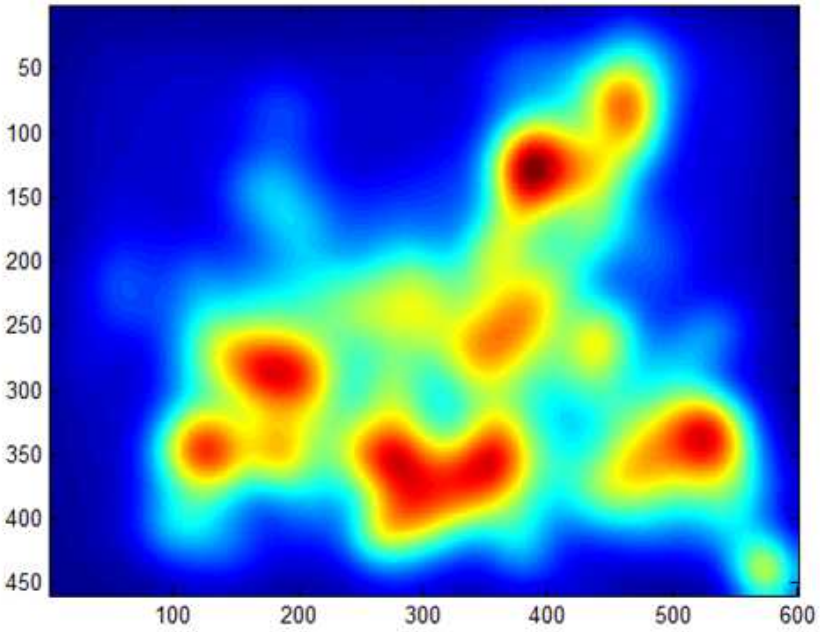
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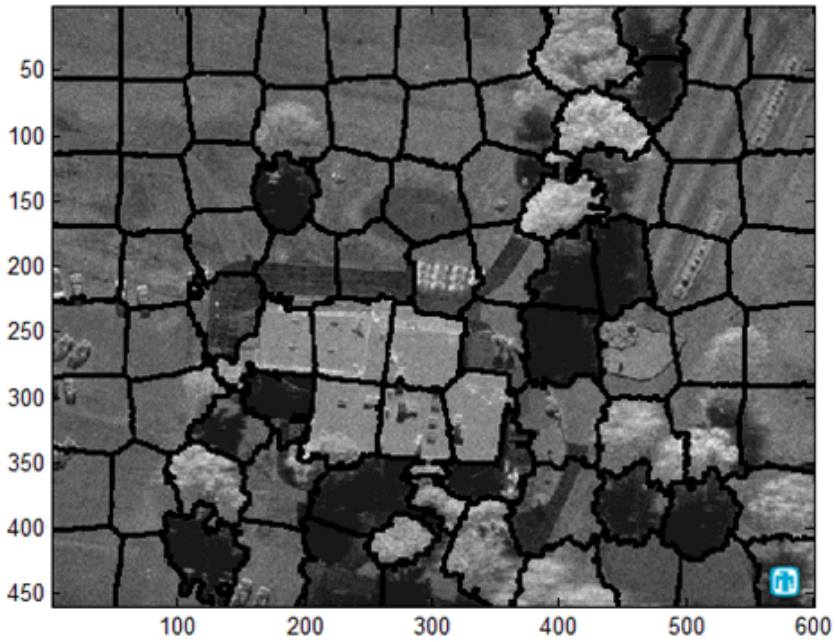
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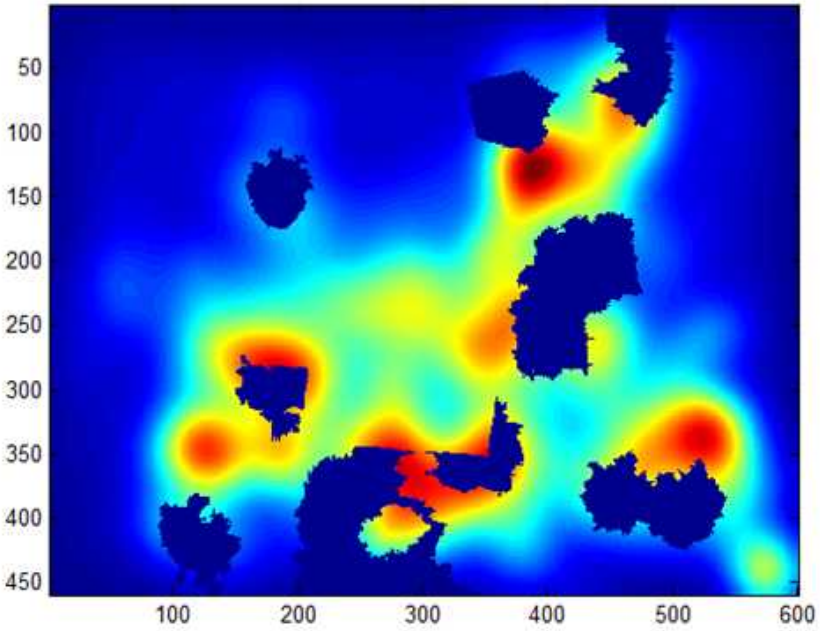
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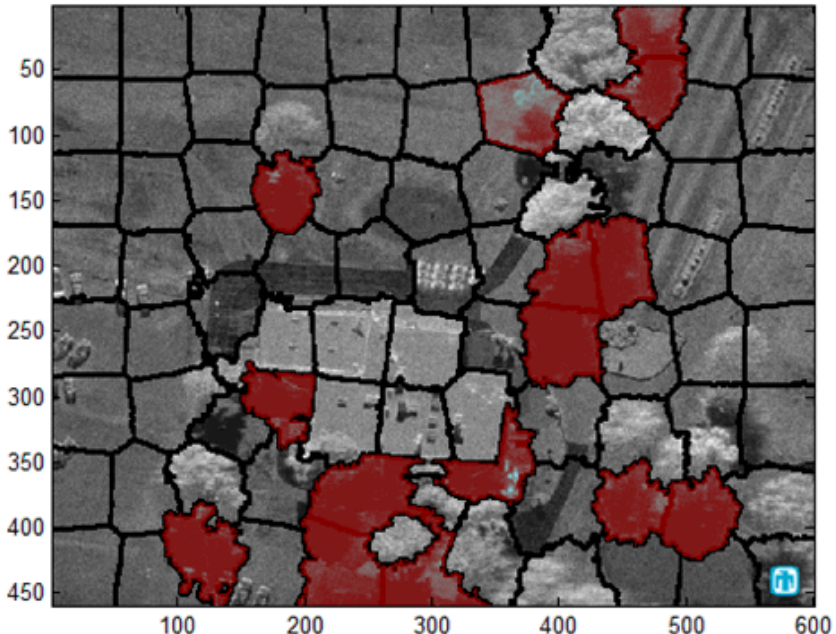
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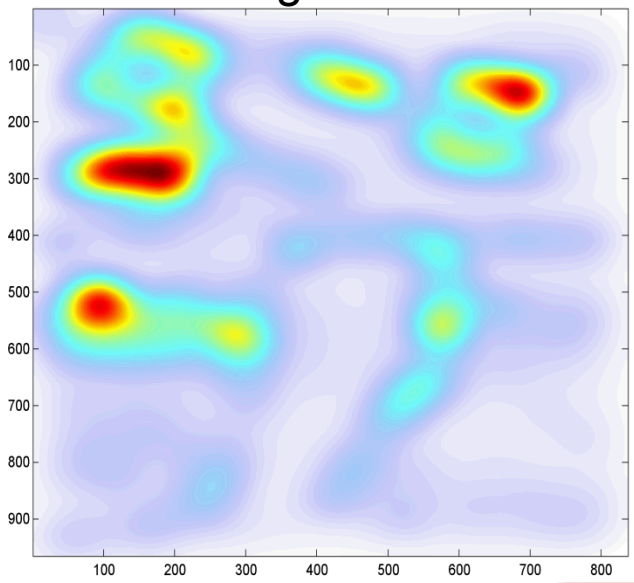
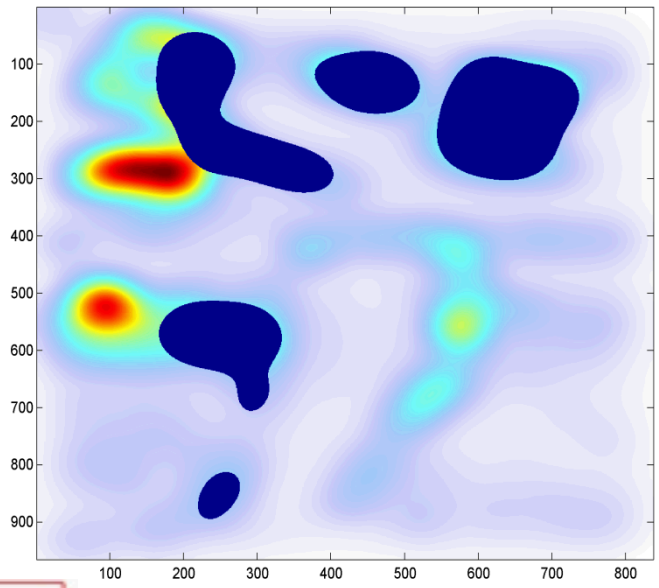
Modified bottom-up salience map

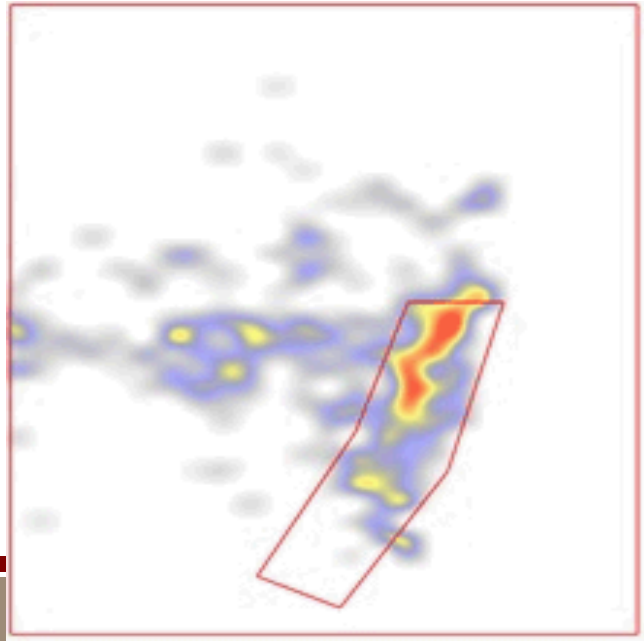
Original



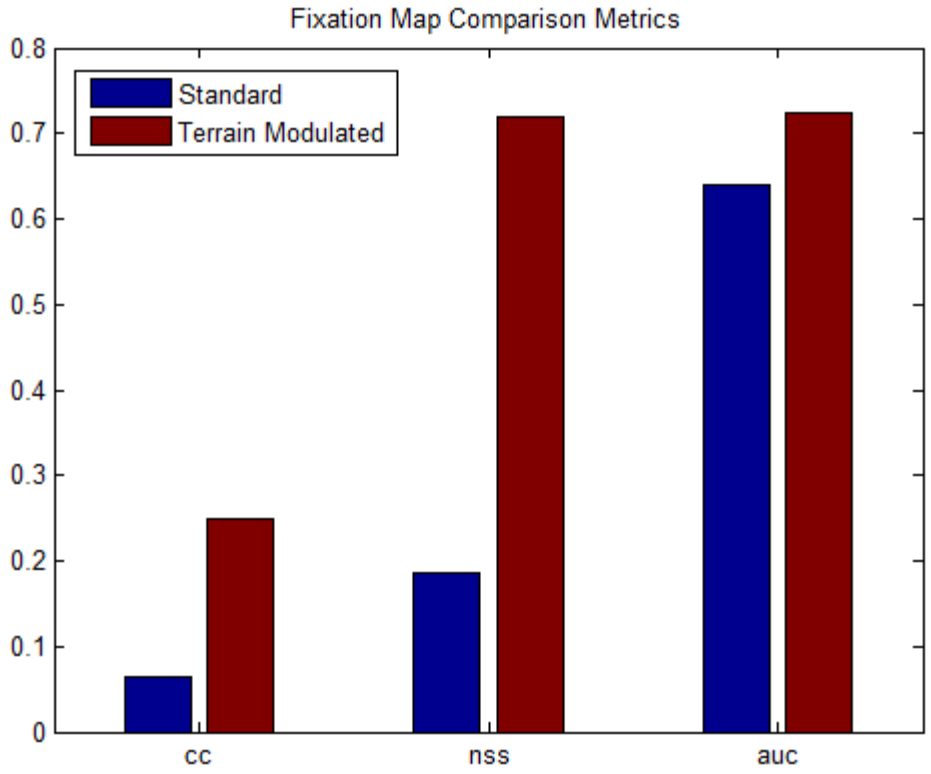
Modified



Gaze Map

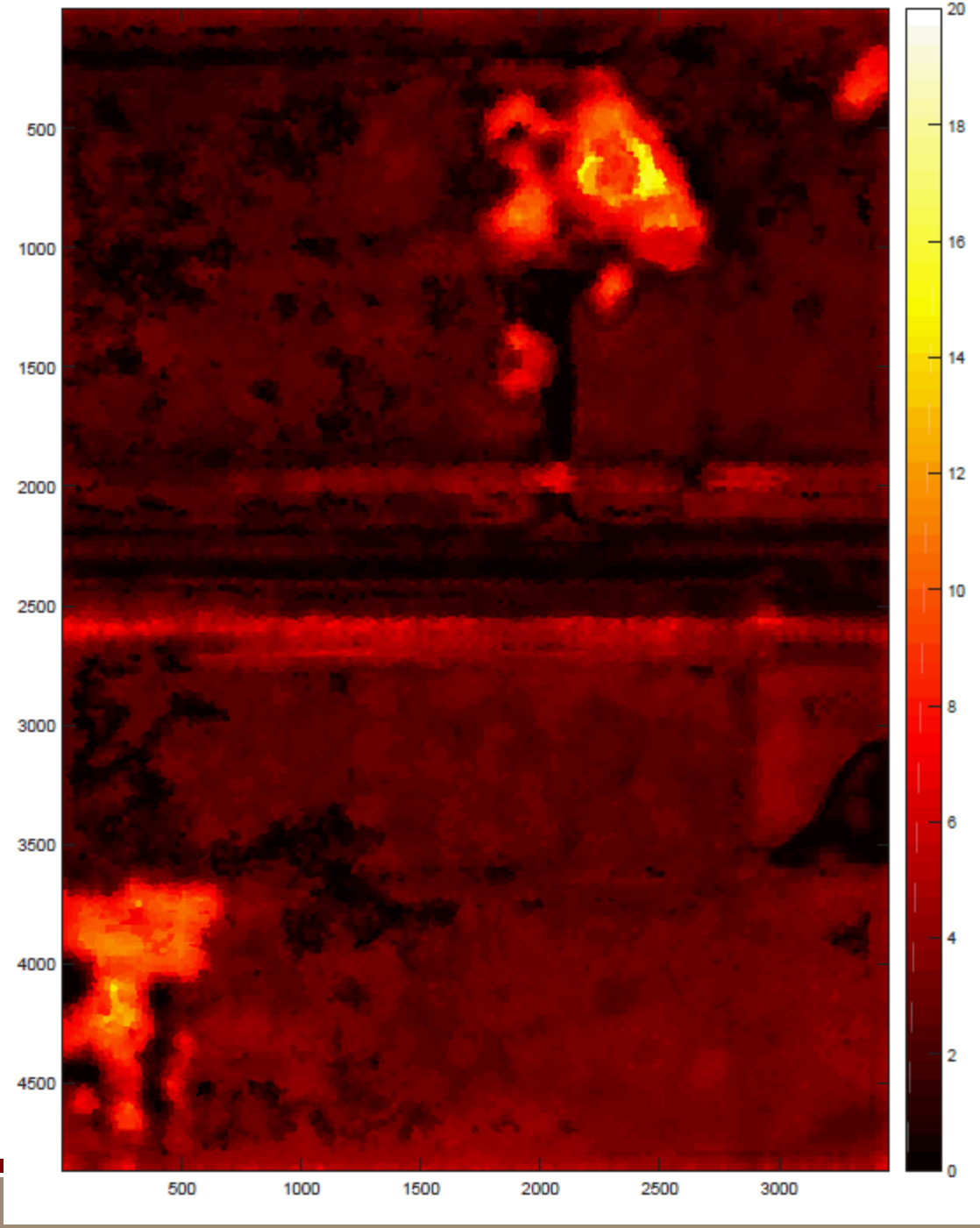


Saliency Map Modulated by Terrain Class is More Similar to Analyst Gaze Maps



- Linear correlation (cc) improvement factor is 3.8X
- Normalized scan path saliency (nss) improvement factor is 3.9X
- Area under receiver-operator curve (auc) improvement factor is 1.1X

Borji, A., et al. (2013). "Quantitative Analysis of Human-Model Agreement in Visual Saliency Modeling: A Comparative Study." IEEE Transactions on Image Processing **22(1): 55-69.**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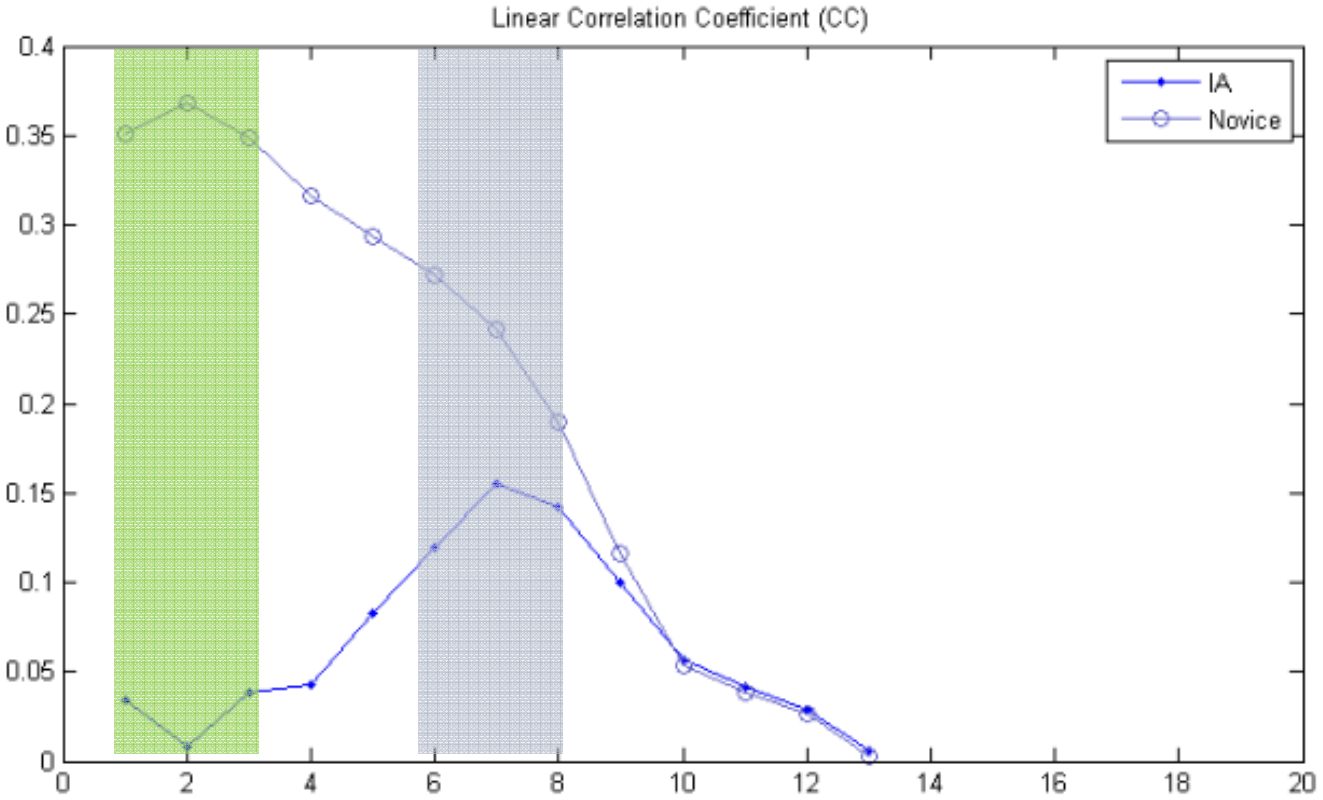
More evidence that experienced IAs know where to look

- Results support our hypothesis:
  - Match between gaze maps and regions that support change detections peaks ~2-3 for novices and ~7 for IAs
  - ***Gaze maps of IAs are more correlated to regions that support change detection***

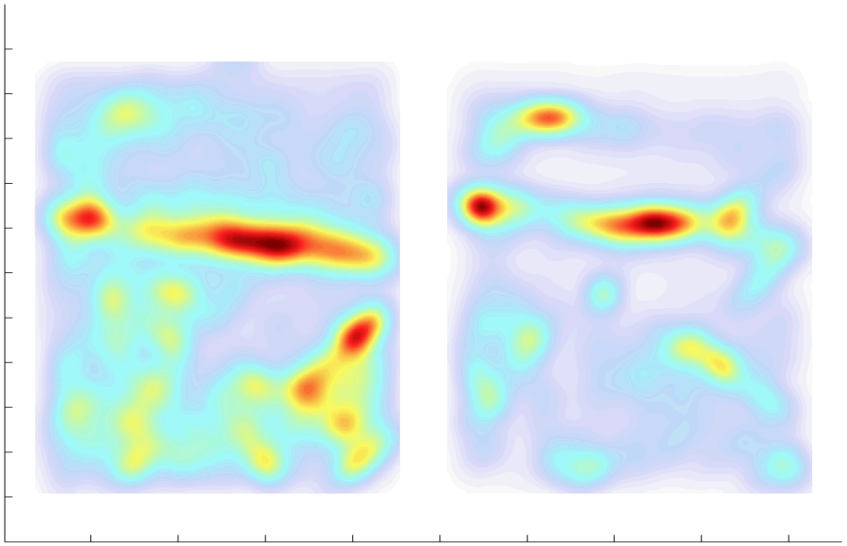


Summary

- Comparing gaze maps to saliency maps reveals information about top-down visual attention
  - Novice viewers are more likely to look at highly salient regions
  - Experts disproportionately view task-relevant regions, ignoring other features despite their high saliency
- Contributions of specific visual features to top-down and bottom-up saliency can be assessed through masking selected features in saliency maps
- Gaze patterns reveal cognitive biases by showing which features/regions are systematically ignored by experts
  - Changes in target's appearance or likely locations could lead to errors

Backup Slides

Examples of images without targets

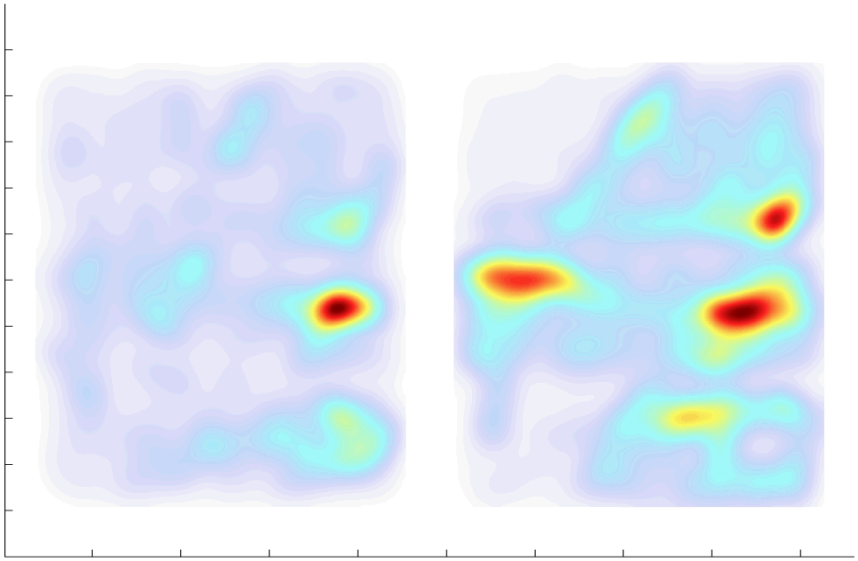


Novices

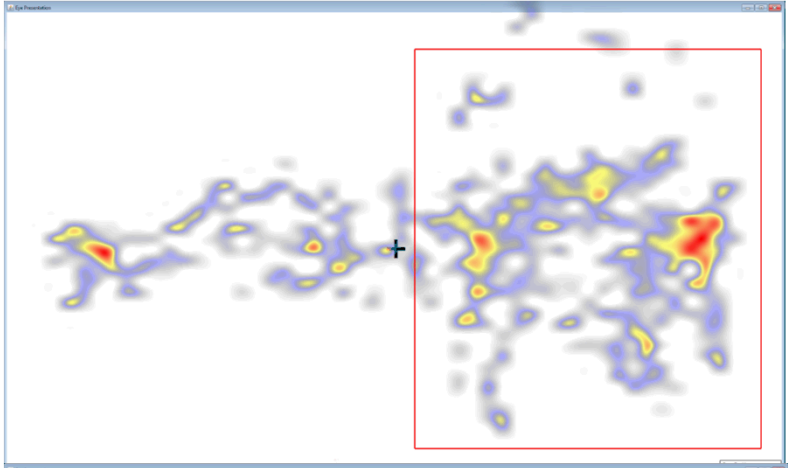
Non-experts

Experts

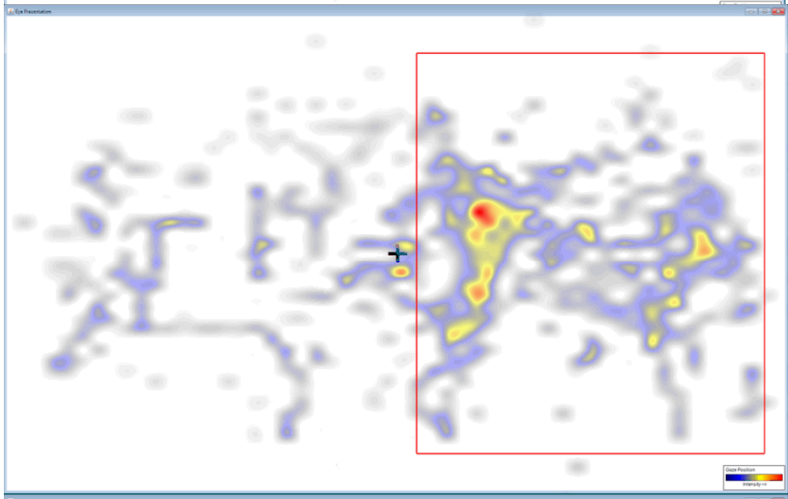
Examples of images without targets



Novices



Non-experts



Experts