SAND2014-18799PE

Visual Cognition, Visual Analytics, and National Security Sensemaking: Interdisciplinary Research at Sandia National Laboratories

Dr. Laura Matzen

Sandia National Laboratories

Exceptional service in the national interest

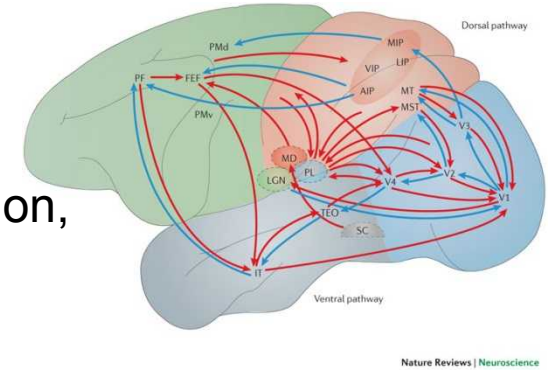
U.S. DEPARTMENT OF ENERGY

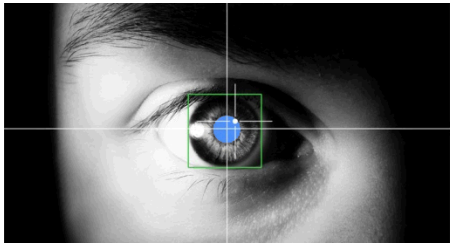
NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Taking human cognition into account when designing and evaluating new methods for interacting with data

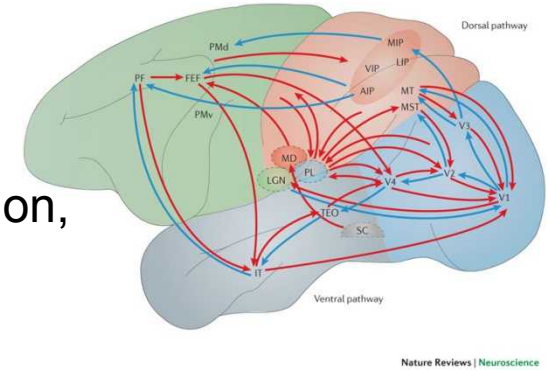
- Current eyes-on-pixel, manual searching processes are effective, but do not scale
- When developing new algorithms/tools/modes of interaction, need to support human cognitive strengths to retain effectiveness



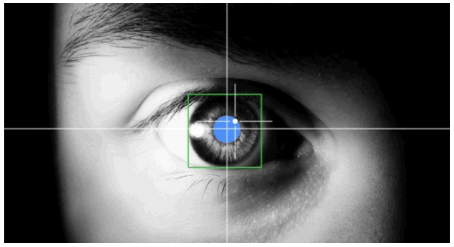


Taking human cognition into account when designing and evaluating new methods for interacting with data

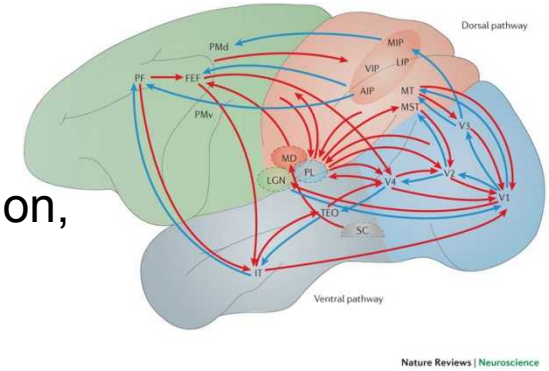
- Current eyes-on-pixel, manual searching processes are effective, but do not scale
- When developing new algorithms/tools/modes of interaction, need to support human cognitive strengths to retain effectiveness



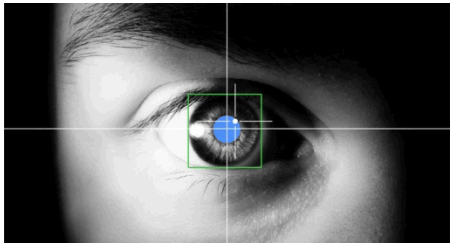
- People are not good at explaining their cognitive processes
  - We are using empirical behavioral and eye tracking studies to identify the features/relationships that are crucial for analysts' understanding of data



Taking human cognition into account when designing and evaluating new methods for interacting with data



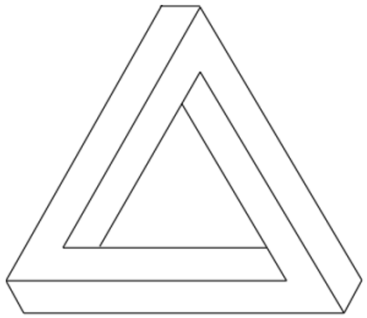
- Current eyes-on-pixel, manual searching processes are effective, but do not scale
- When developing new algorithms/tools/modes of interaction, need to support human cognitive strengths to retain effectiveness

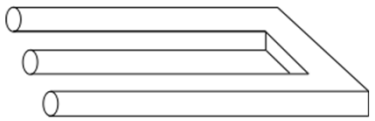


- People are not good at explaining their cognitive processes
  - We are using empirical behavioral and eye tracking studies to identify the features/relationships that are crucial for analysts' understanding of data
    - This research contributes to scientific understanding of visual cognition
      - We have unique access to analysts with different domains of experience
    - This research will inform system design and enable evaluations of new tools from the perspective of human cognitive needs

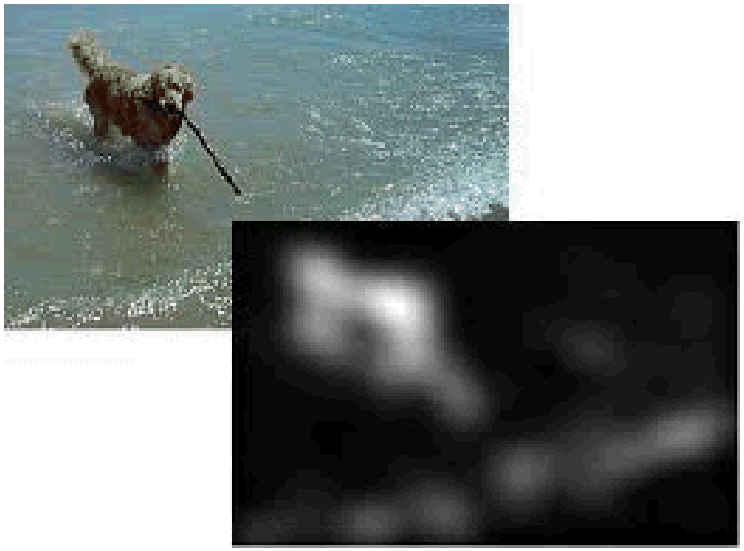
Visual Cognition Basics

- The human visual system is VERY good at:
  - Finding patterns
  - Making inferences
- Perceptual systems are constantly receiving ambiguous information and trying to make sense of it
- Draws on both perceptual cues and conceptual knowledge (bottom-up and top-down processing)
  - Relatively little is understood about top-down processing



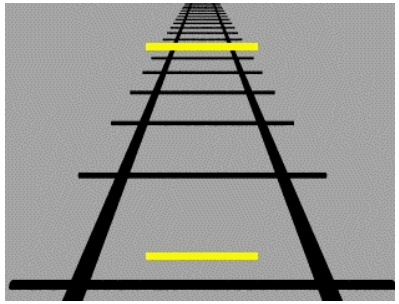


Visual Attention



- 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

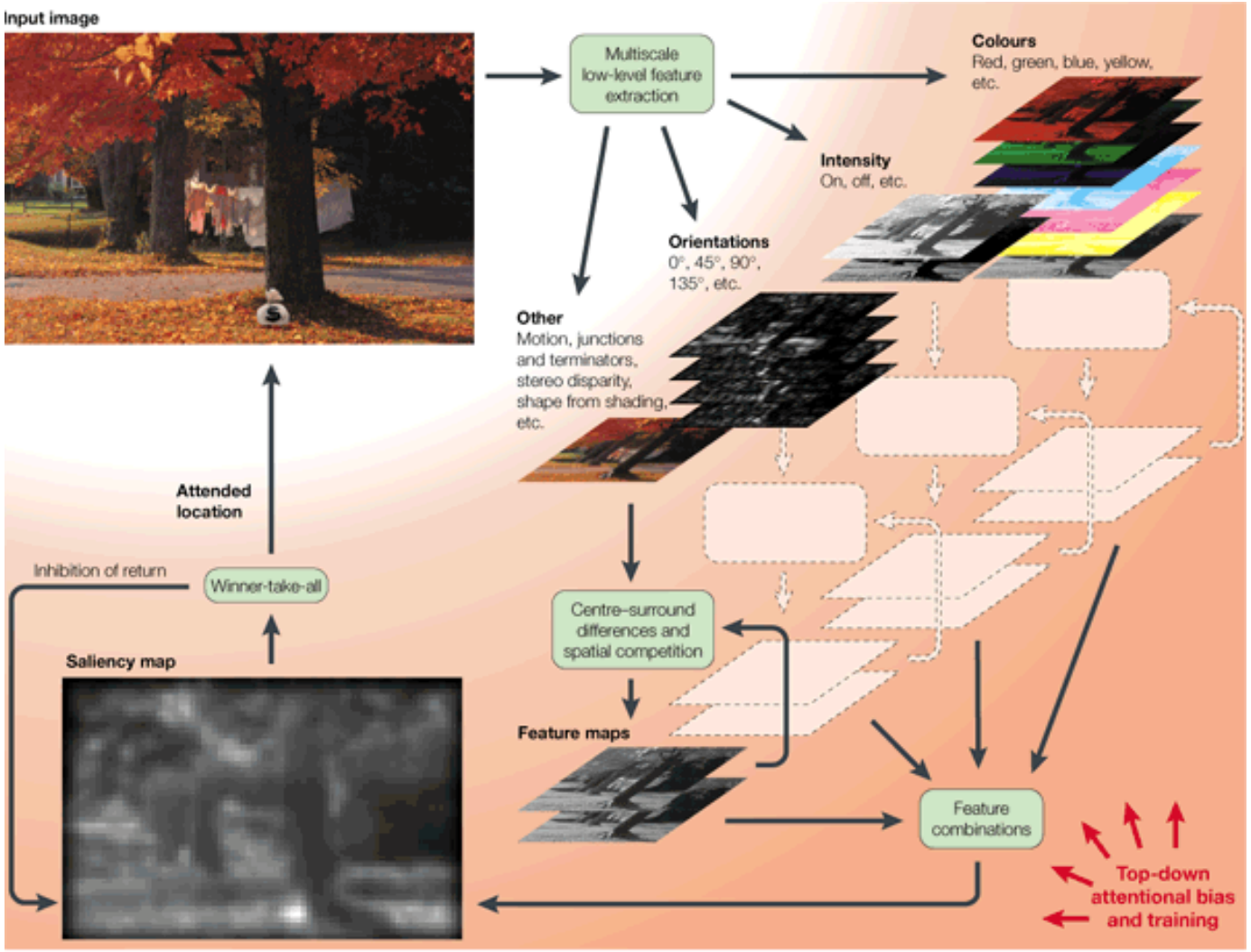
- Top-down
  - Driven by viewer's goals
  - Affected by cognitive load, working memory, past knowledge and experience
  - Has a very powerful influence on bottom-up perception
  - Parameters are NOT well understood



Top-down expectations can override perception of the bottom-up physical features of the stimulus

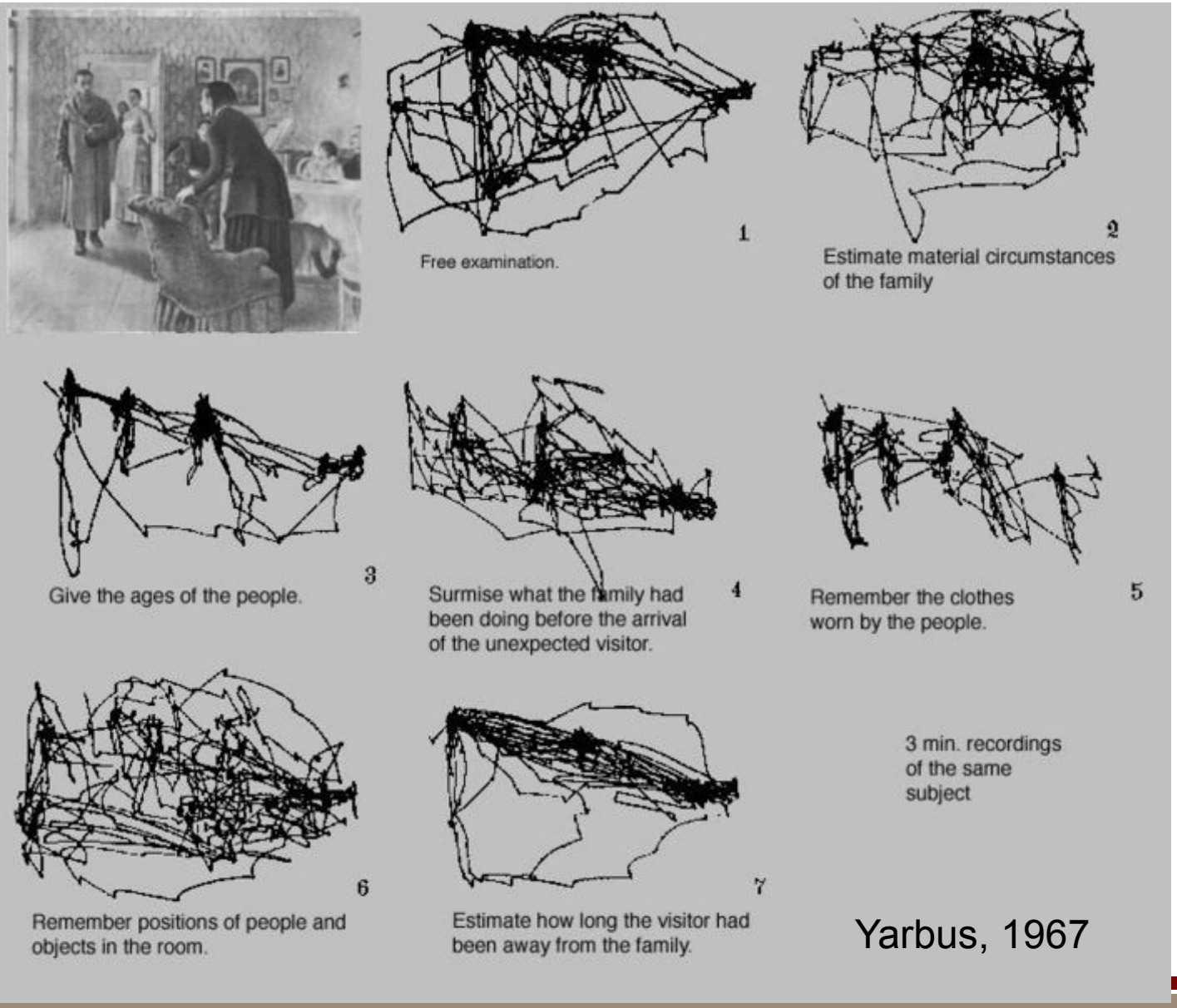
http://www.richardgregory.org/experiments/video/chaplin.htm

Bottom-up Saliency Models



(Itti & Koch, 2001)

Top-down control of eye movements

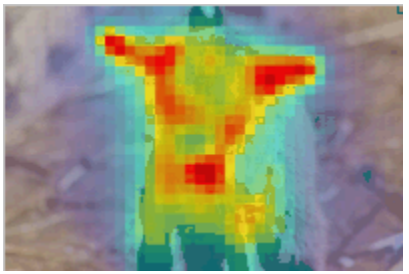


Yarbus, 1967

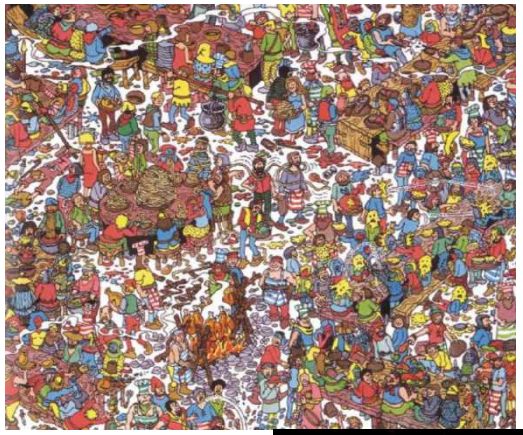
Illustrates top-down aspects of visual search:

- The person's task influences eye movements

Visual Attention



- Visual attention has two stages:
  1) Attention is distributed uniformly across a scene
  2) Attention is concentrated to a specific area and information is processed serially (sequential fixations)



- Wolfe's Guided Search Model:
  - Bottom-up *AND* top-down information create a pre-attentive "ranking" of items for attentional priority
  - Feature processing creates an activation map
  - Viewer attends to highest priority item first, then moves down the list

A Key Research Question

- ***Can we model top-down visual saliency for a domain expert performing a particular task?***
  - In other words, can we predict where an expert will look in an image?

11

A Key Research Question

- ***Can we model top-down visual saliency for a domain expert performing a particular task?***
  - In other words, can we predict where an expert will look in an image?

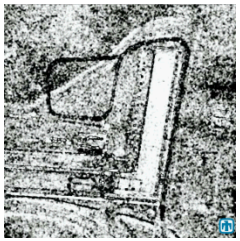
- Why do we care?
  - ***Advances scientific understanding of visual cognition***
    - There are NO models of top-down attention – this is a major gap in the literature
  - ***Numerous applications***
    - Informing system design
      - Top-down model defines user's needs
      - Could identify ways to offload user's working memory load
    - Evaluating new designs
    - Identifying potential sources of error – What is likely to be missed?
    - Training new users

12

Core Scientific Questions:

What features capture attention in non-optical imagery?
How does domain experience influence visual search/inspection?
How can top-down visual attention be modeled?
Do people with expertise in one domain perform differently on domain-general tasks?

SAR
CCD Products

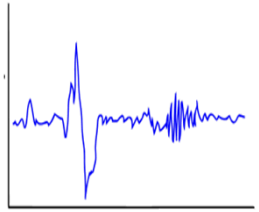


Intended to make important features more salient

TSA
False color X-rays

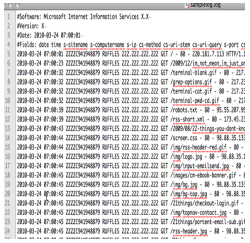
Intended to make important features more salient

Design Engineers
Waveforms



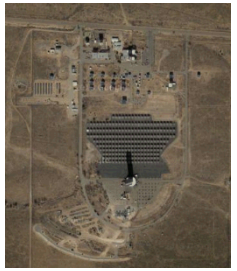
Visualizations of raw data

Cyber
Log Files



Raw data

NGA
Satellite Imagery



Similar to optical imagery

Novices

Experienced with optical imagery only

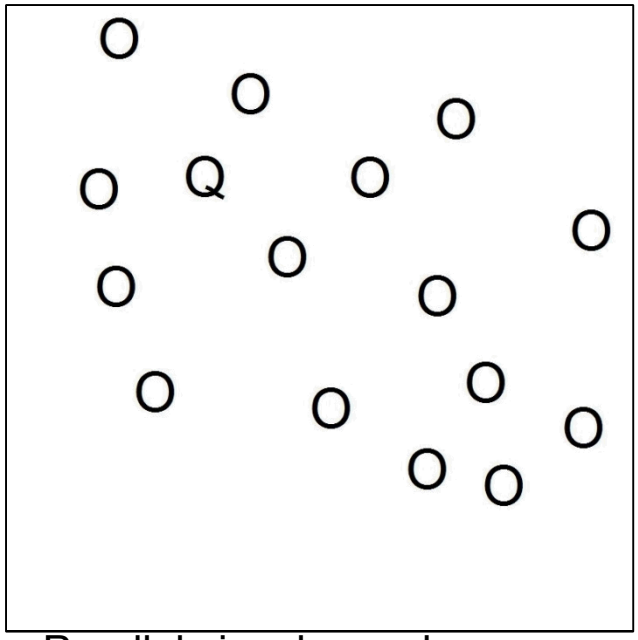
All participants will complete a battery of domain-general tasks and a domain-specific tasks

Domain-general tasks

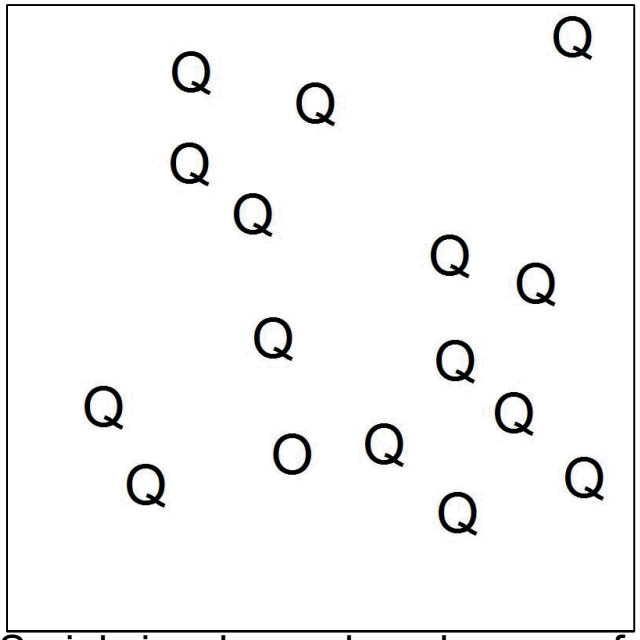
- Parallel vs. Serial Visual Search
- Visual Inspection Task
- Spatial working memory, Mental rotation, Useful field of view

Domain-general tasks

- Parallel vs. Serial Visual Search
- Visual Inspection Task
- Spatial working memory, Mental rotation, Useful field of view



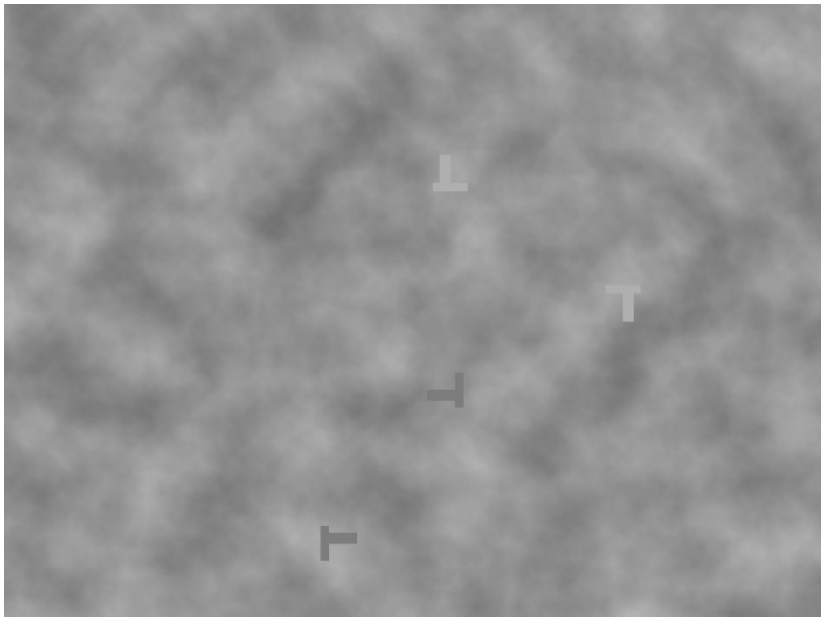
Parallel visual search – unique features "pop out"

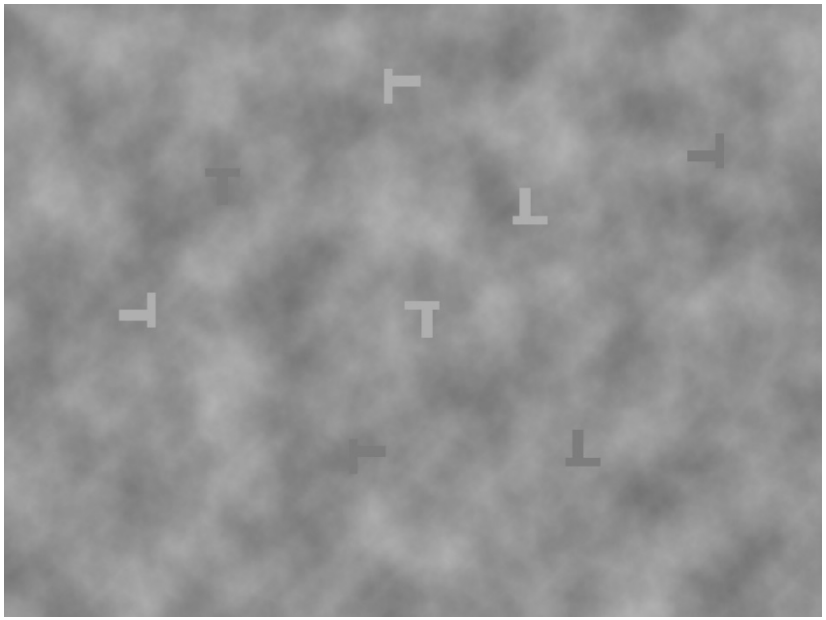


Serial visual search – absence of a feature requires deliberate searching

Domain-general tasks

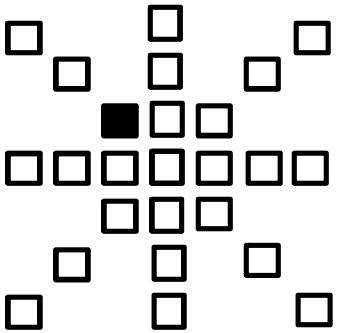
- Parallel vs. Serial Visual Search
- Visual Inspection Task
- Spatial working memory, Mental rotation, Useful field of view

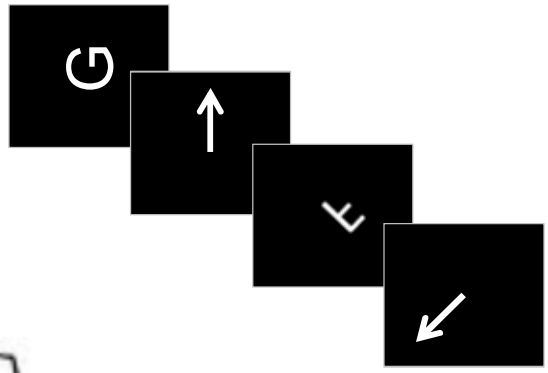


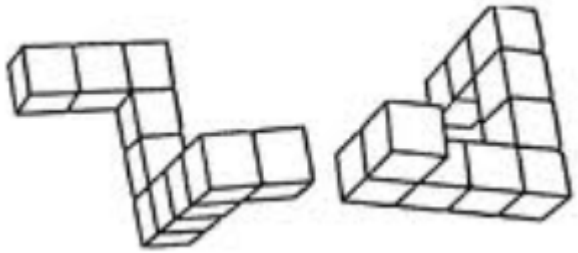


Domain-general tasks

- Parallel vs. Serial Visual Search
- Visual Inspection Task
- Spatial working memory, Mental rotation, Useful field of view

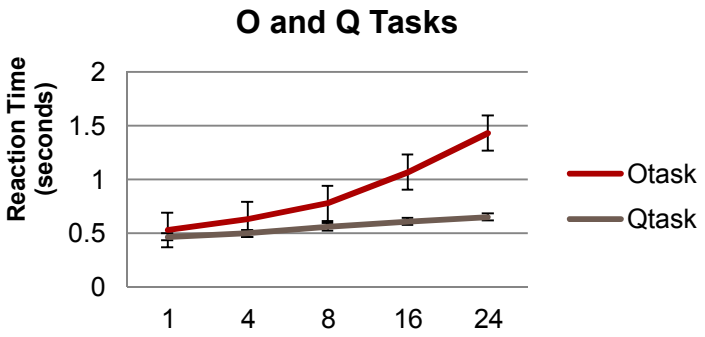


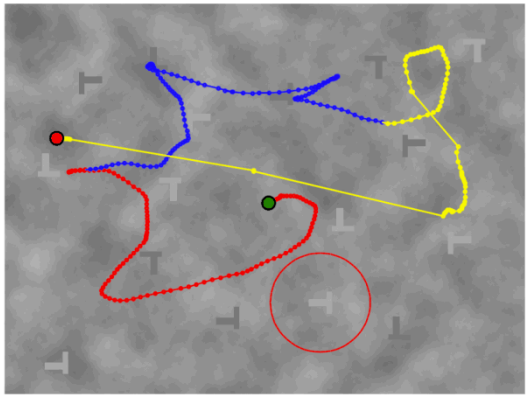


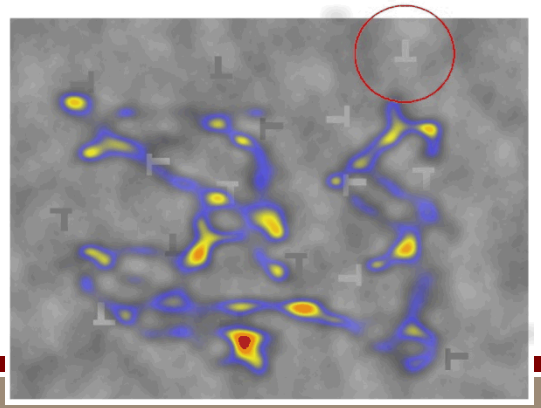


Data Acquired

- 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
  - New approaches:
    - Contrasting bottom-up saliency maps with recorded gaze patterns
    - Modeling influence of top-down saliency
    - Recurrence Quantification Analysis

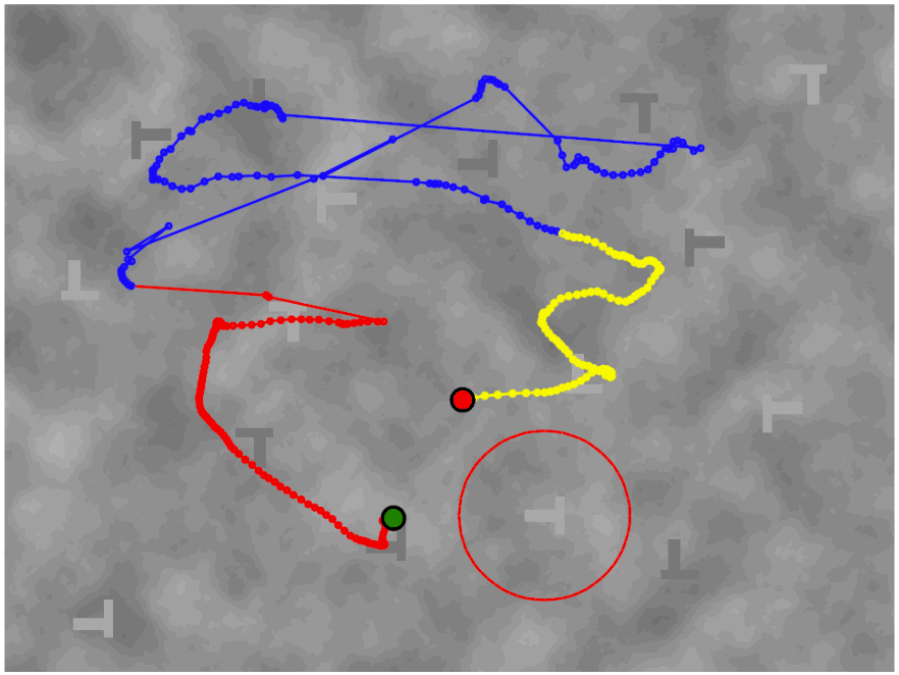


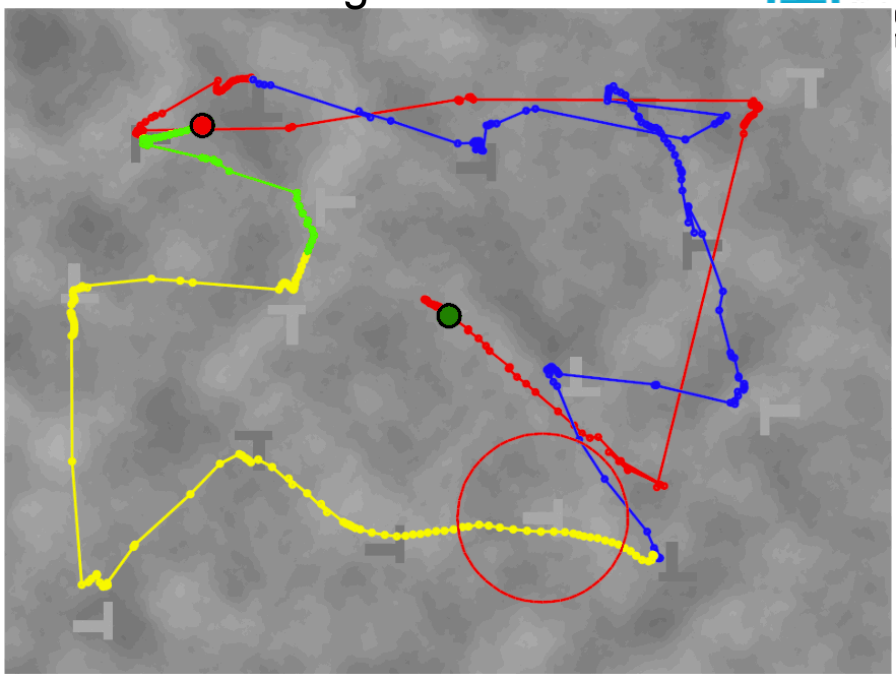


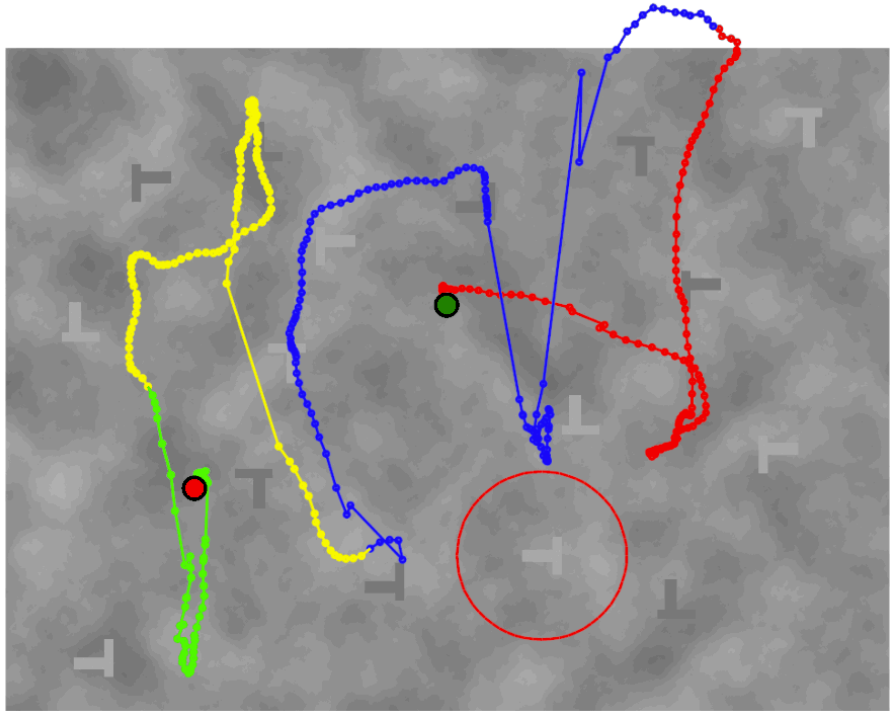


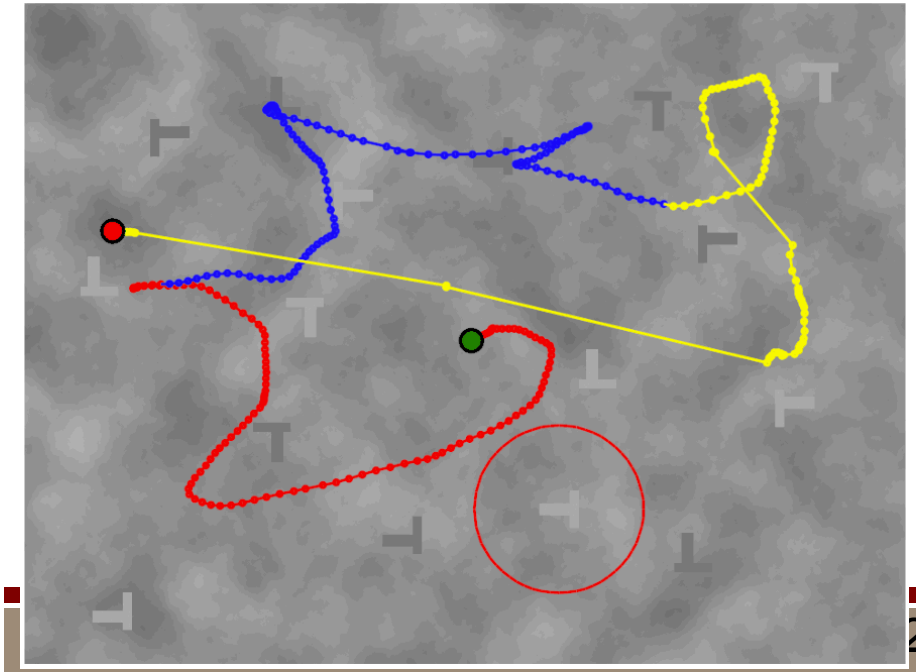
Eye Tracking Analyses: Domain-general Tasks

Search Patterns – Who found the target?

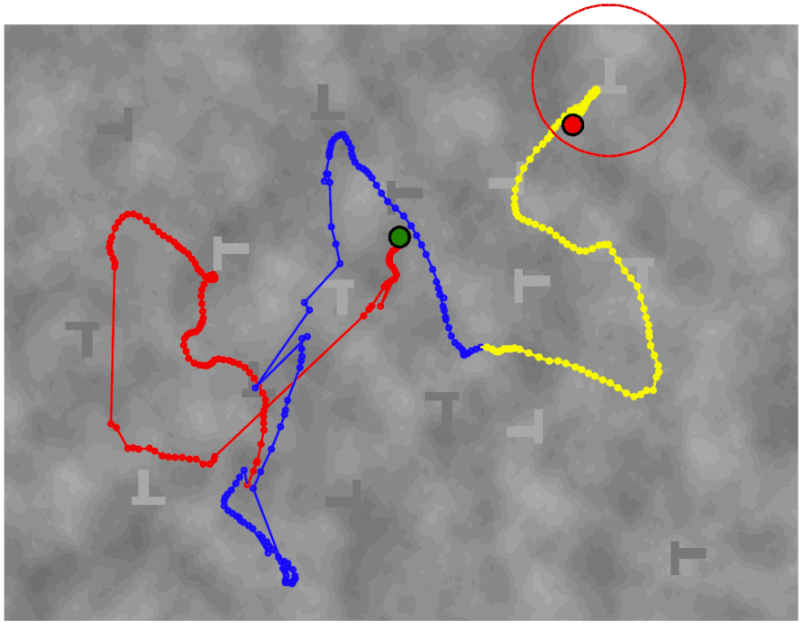






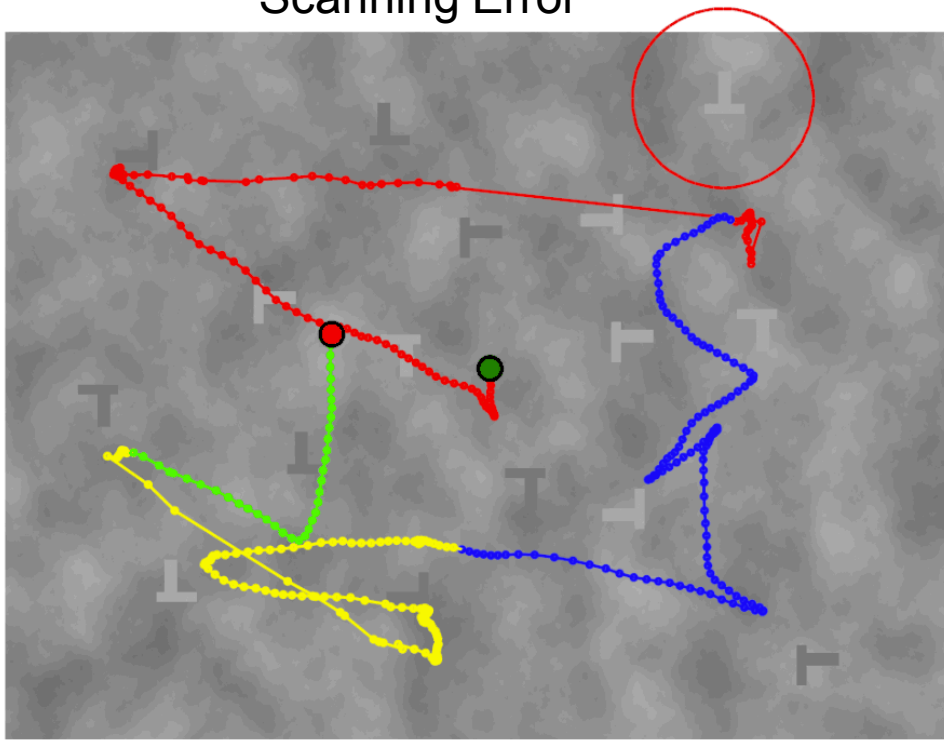


Classification of Error Types

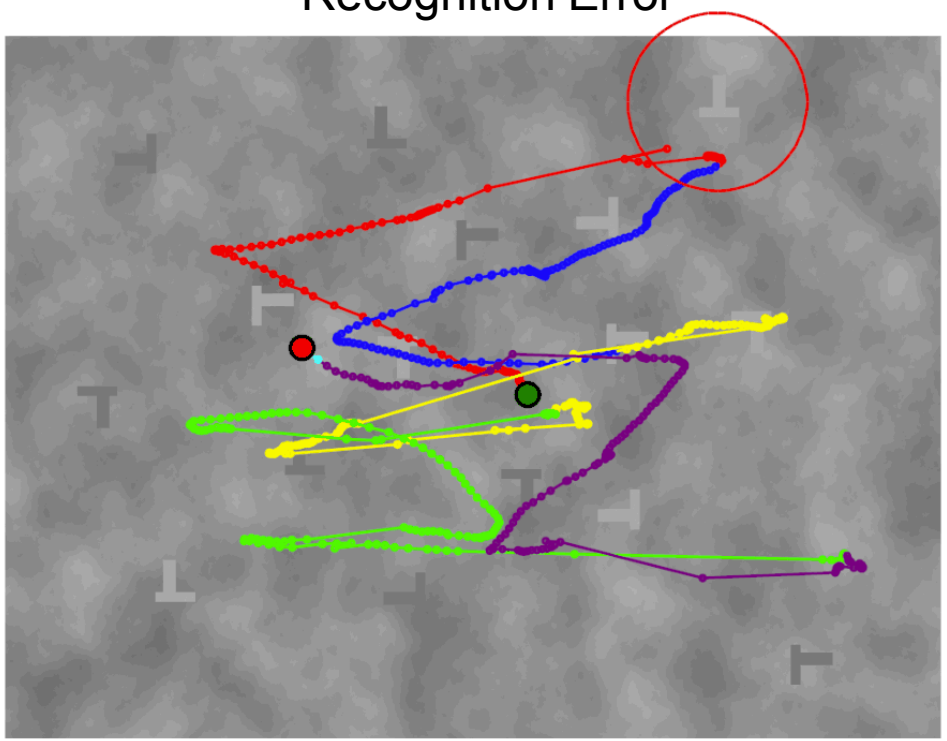


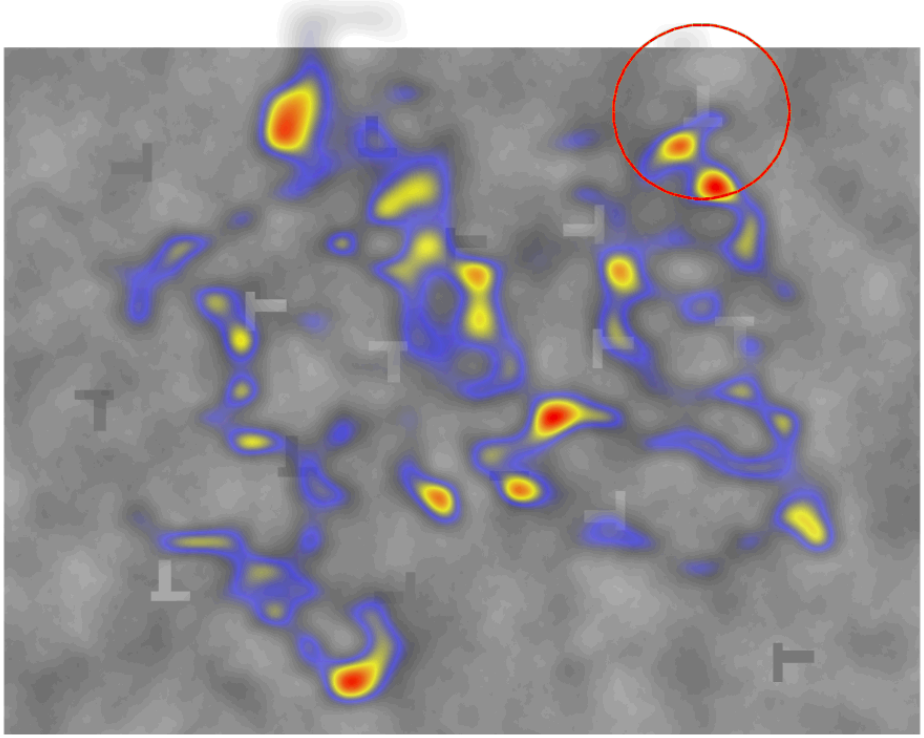
Correct identification of target

Scanning Error

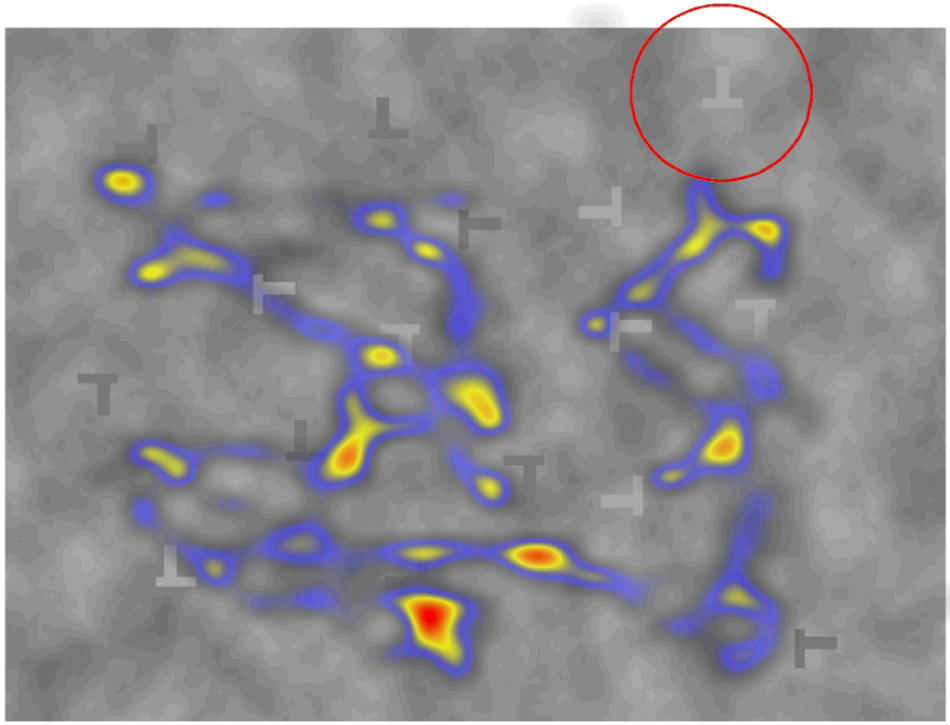


Recognition Error





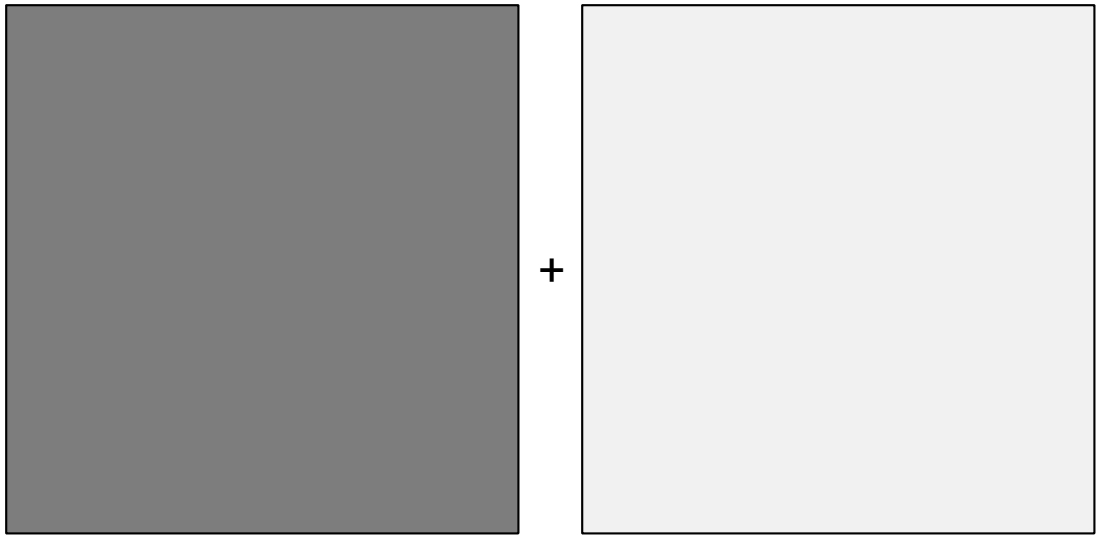
Correct



Incorrect

Domain-specific task for SAR

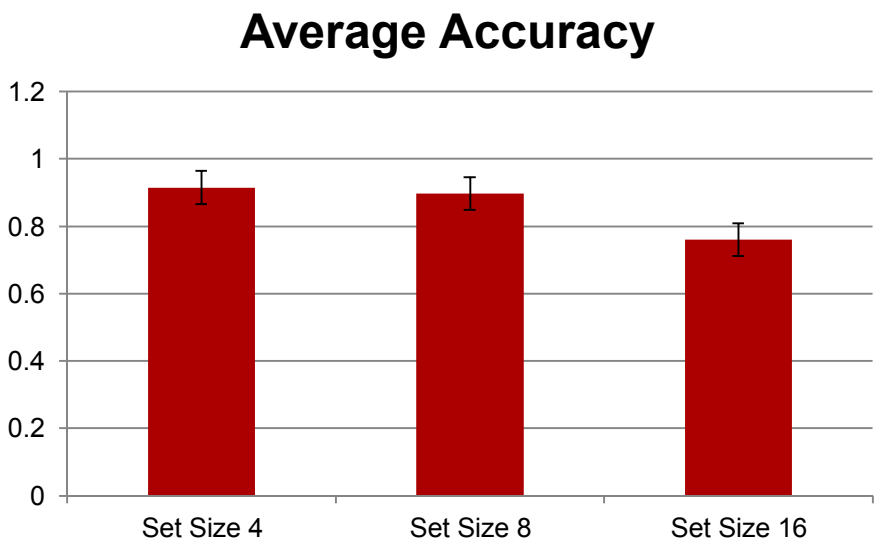
- Threat detection task using two images, presented side by side
  - 50% prevalence of threats
  - Participants rate images on 1-4 scale
    - sure no, unsure no, unsure yes, sure yes

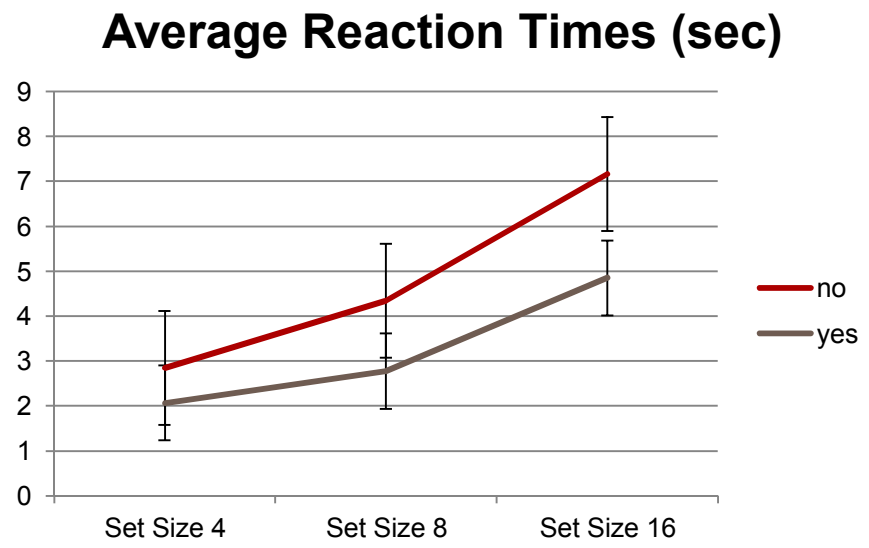


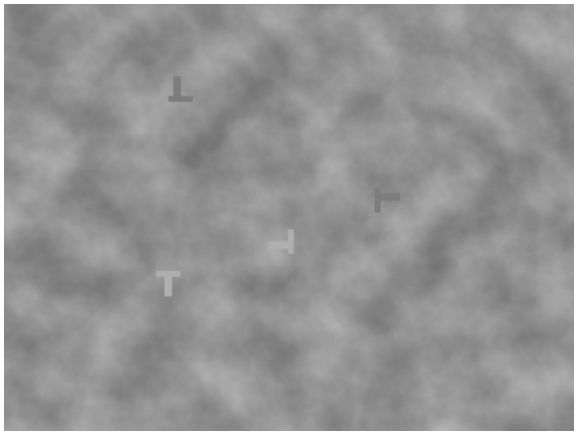
Participants to date on SAR task

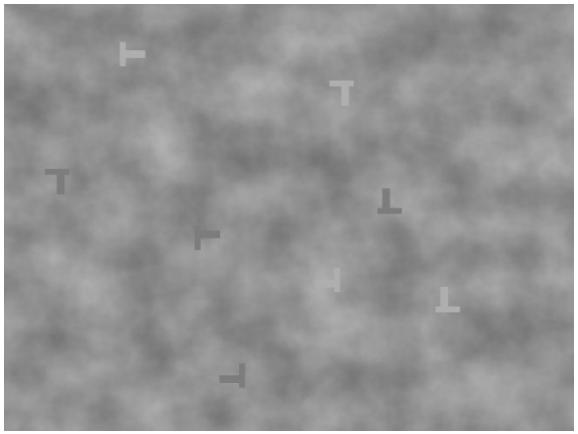
- 3 SAR imagery analysts
- 9 engineers experienced with the domain
- 5 engineers who work on in other SAR domains
- 2 Liaison Staff
- 4 SAR novices

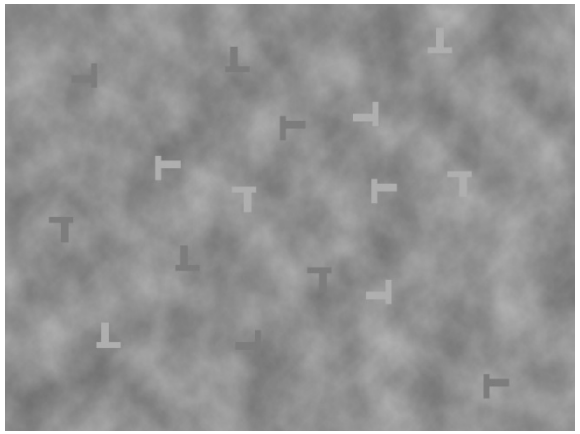
T&L Visual Inspection Task



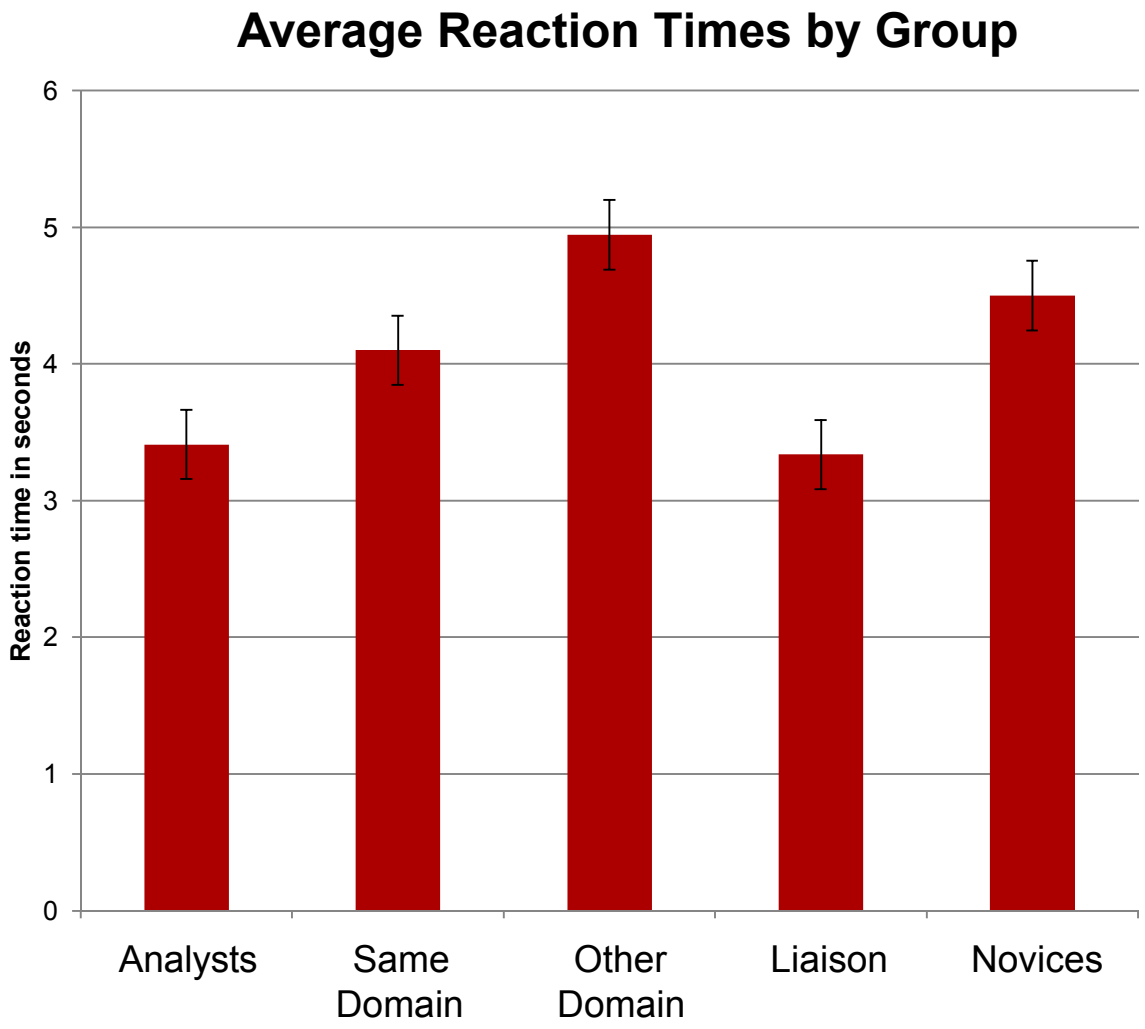






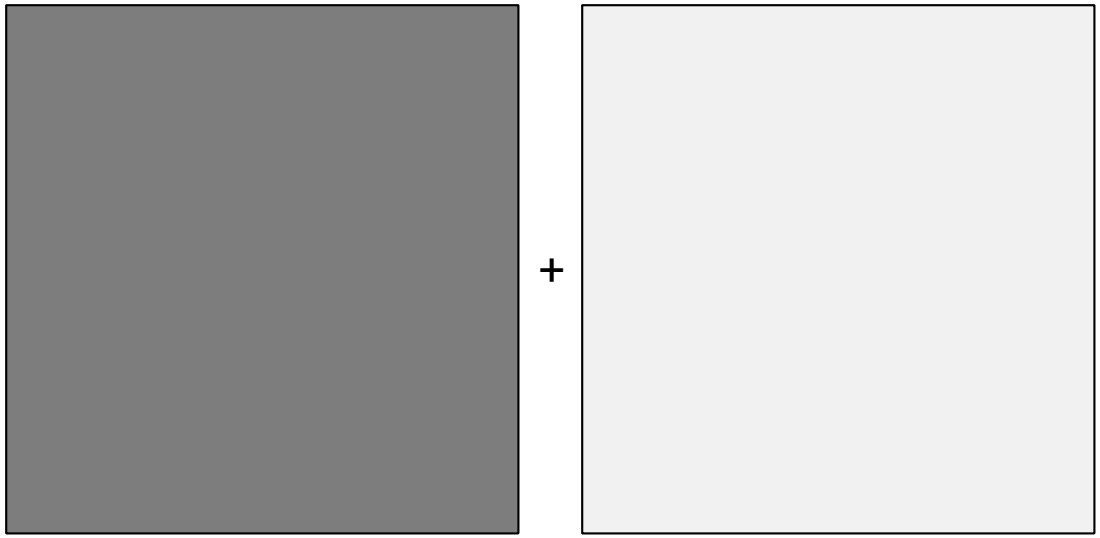


Group Differences

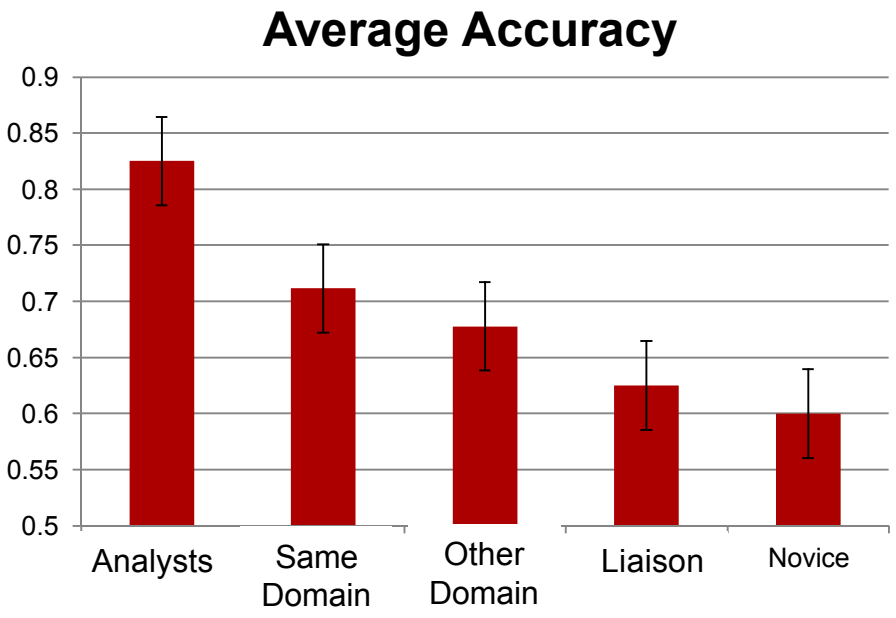


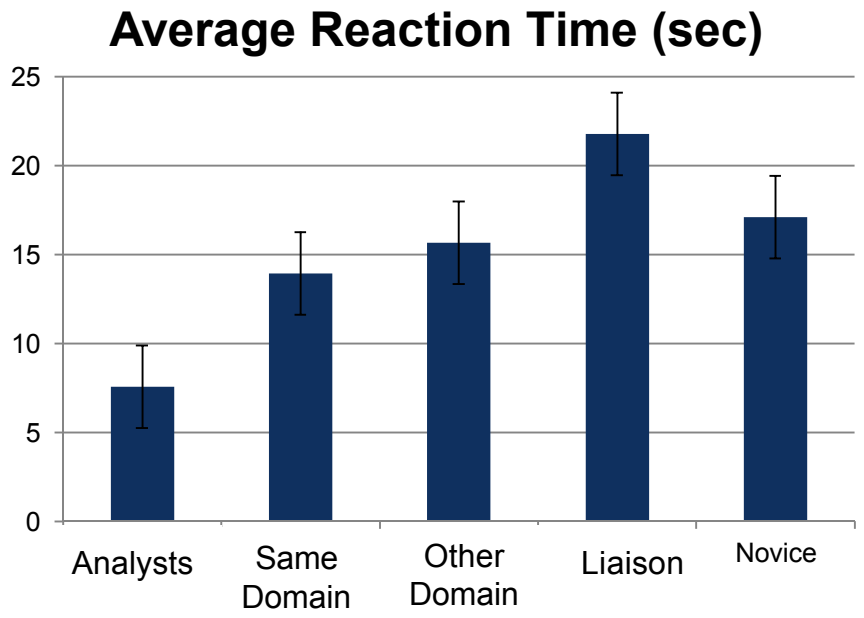
Domain-specific task for SAR

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

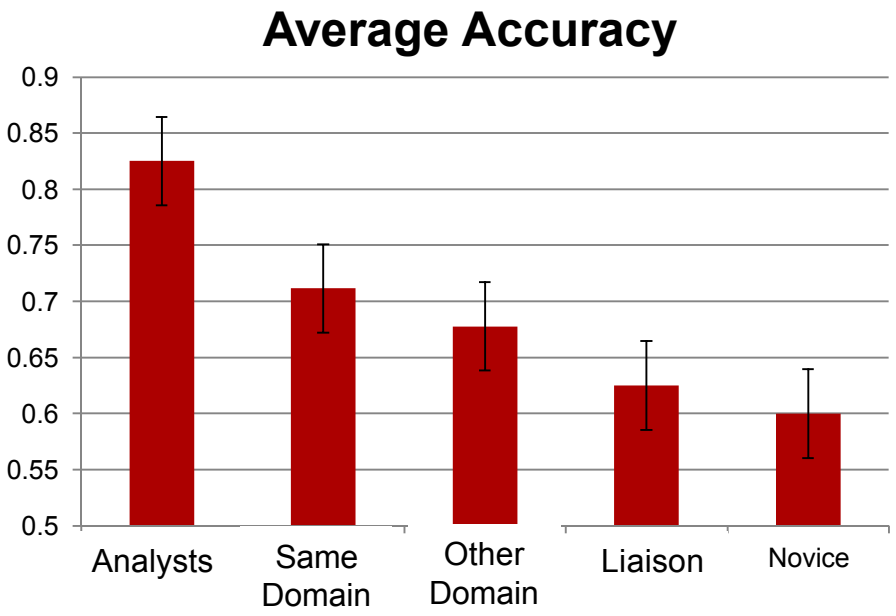


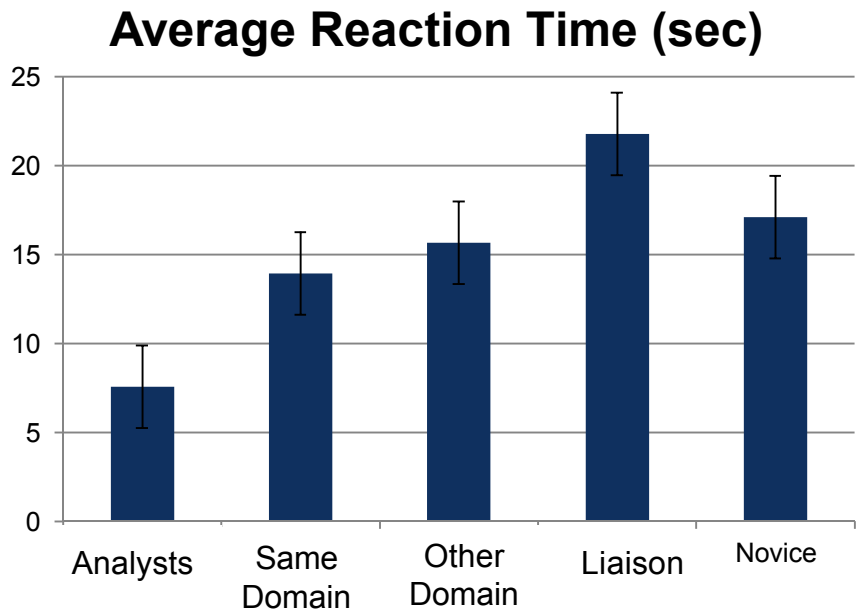
Behavioral Data

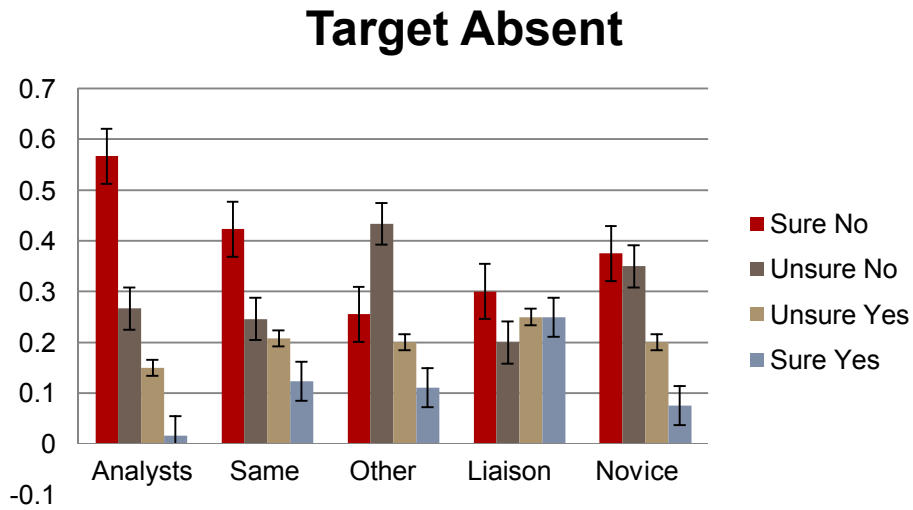


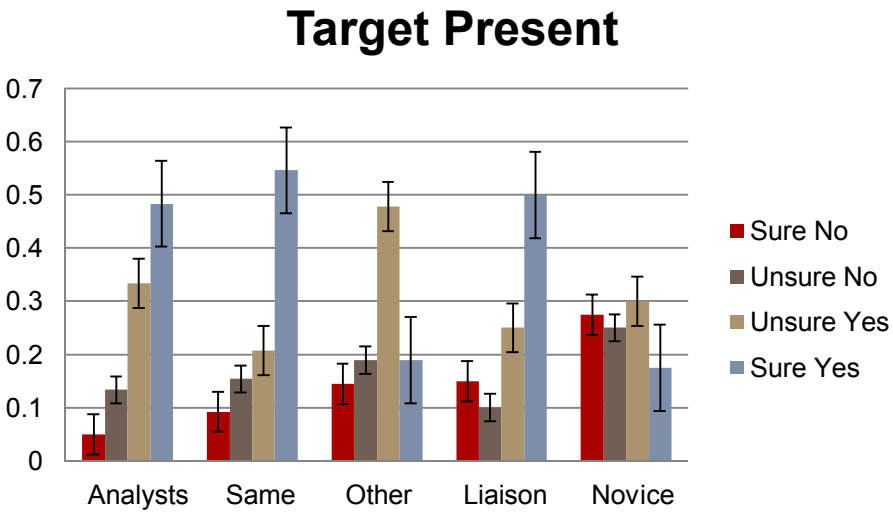


Behavioral Data

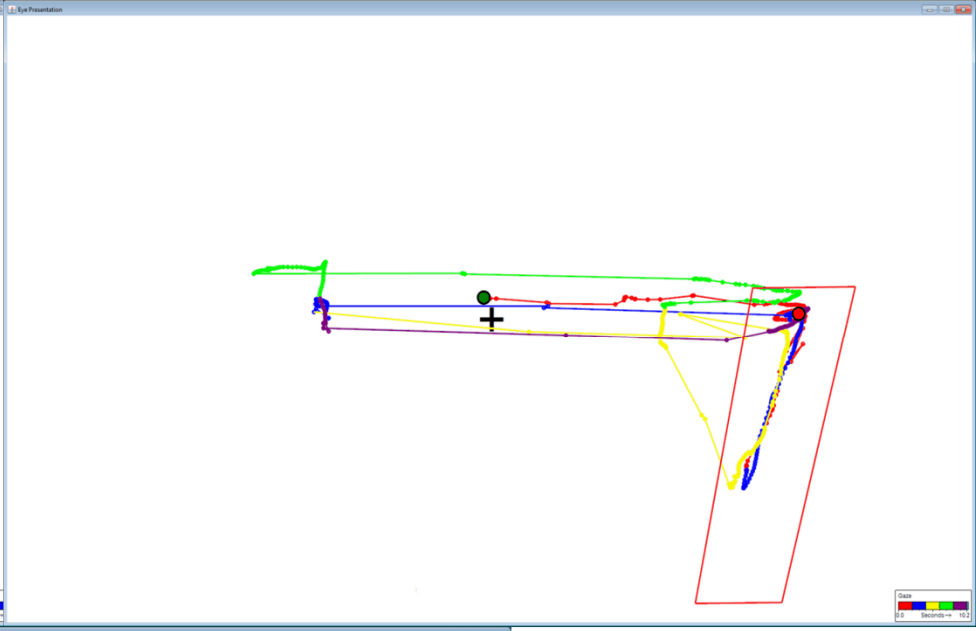









Eye Presentation
Gaze
0.0 Seconds


Eye Presentation
Gaze
0.0 Seconds 19.2

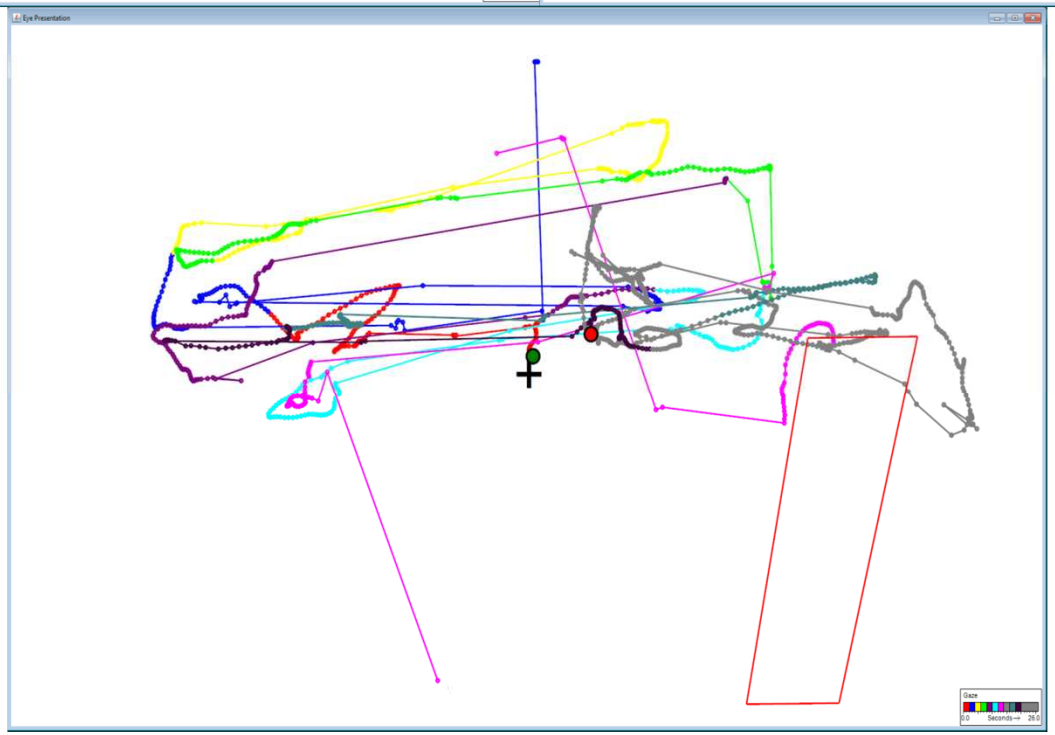
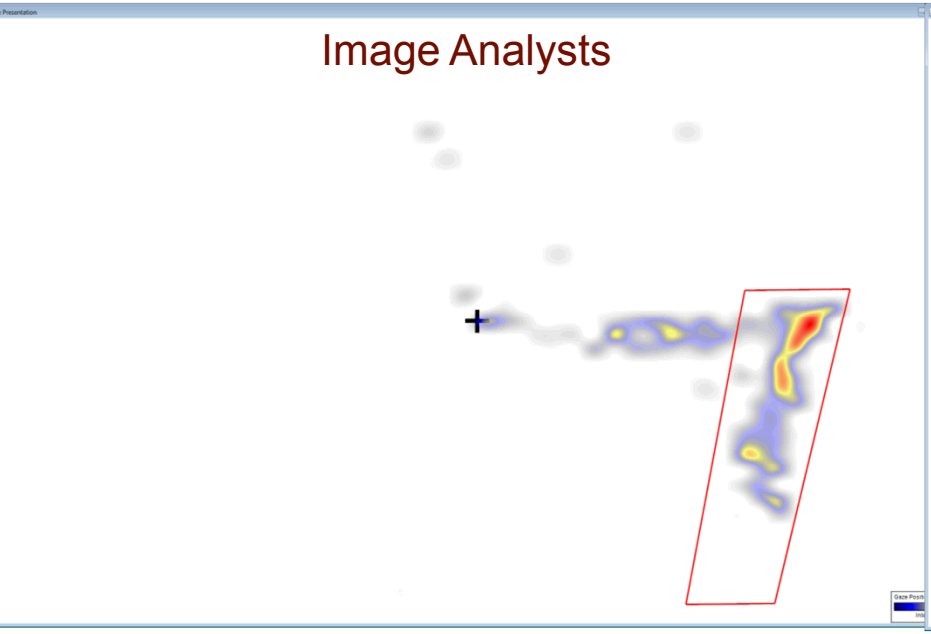
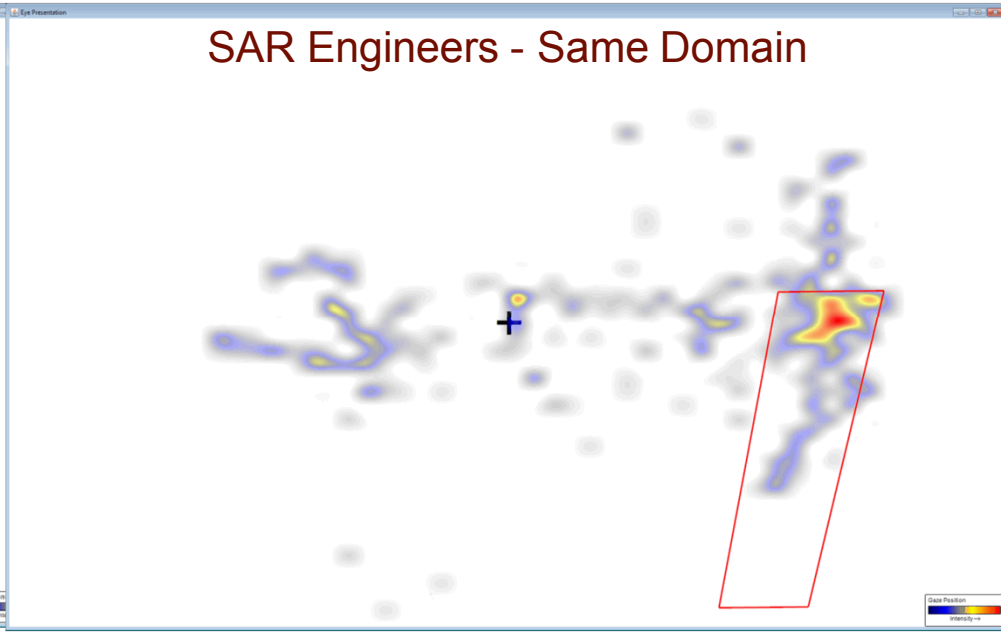

Eye Presentation
Gaze
0.0 Seconds 28.0

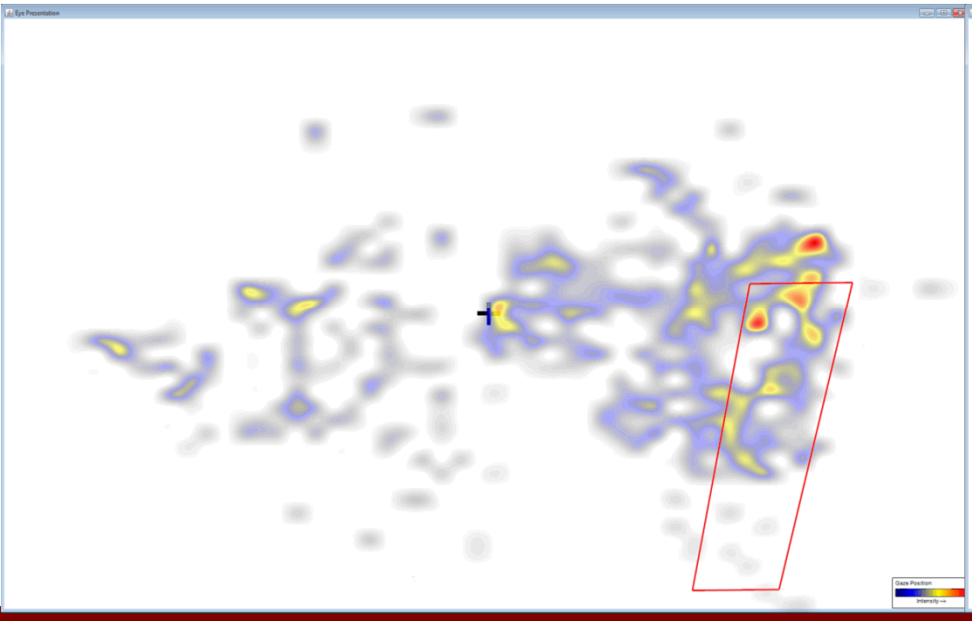
Image Analysts



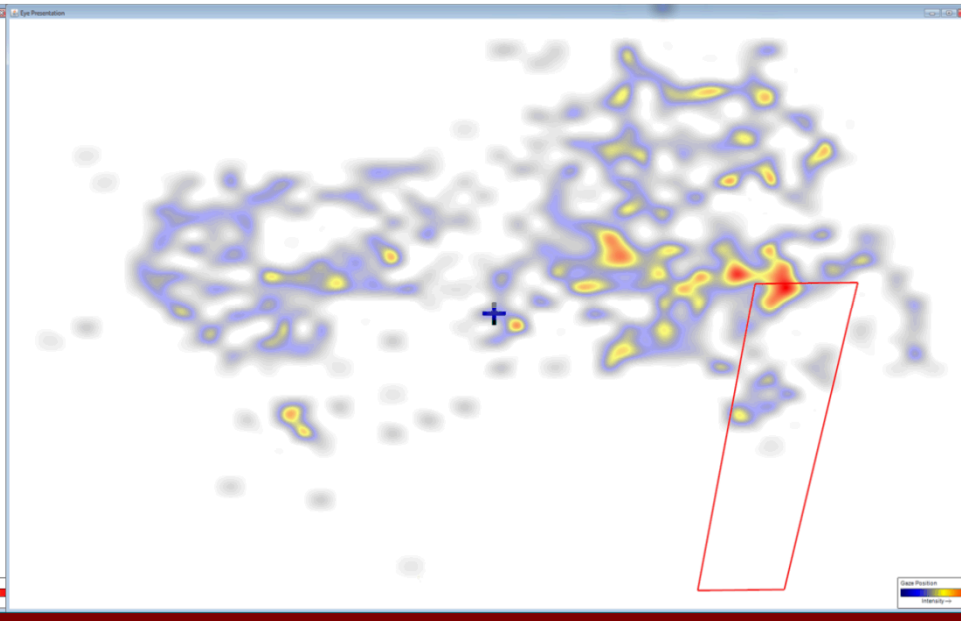
SAR Engineers - Same Domain



SAR Engineers – Different Domain

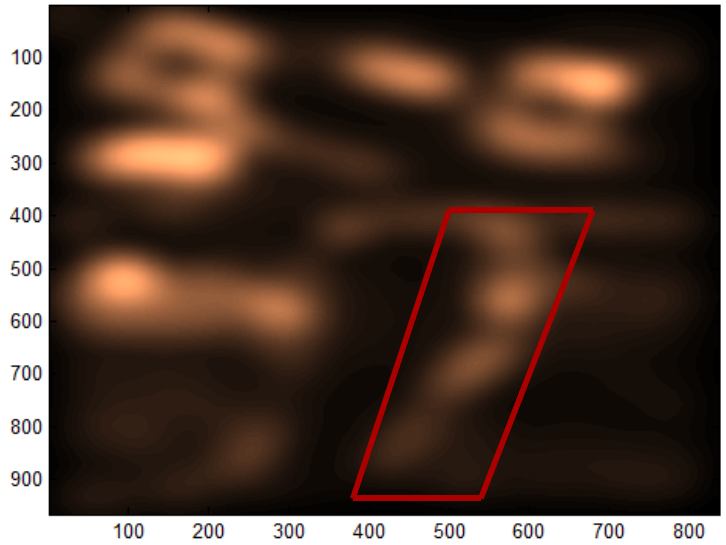


Novices

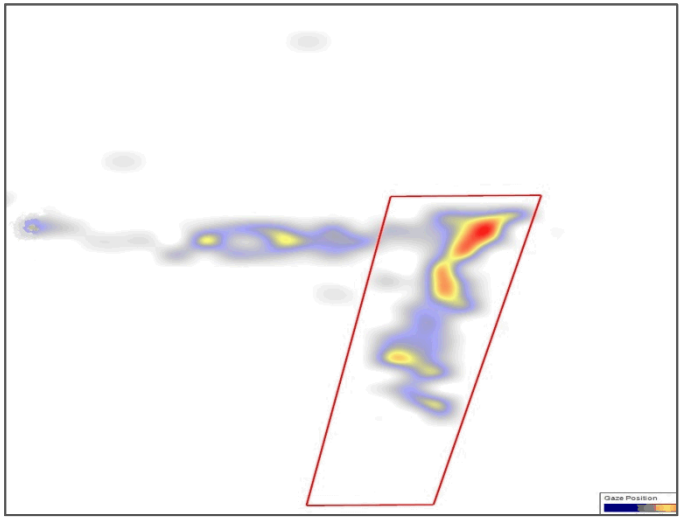


Top-down vs. Bottom-up

Salience Map



Gaze Map



Empirical First Spiral for Top-down Modeling

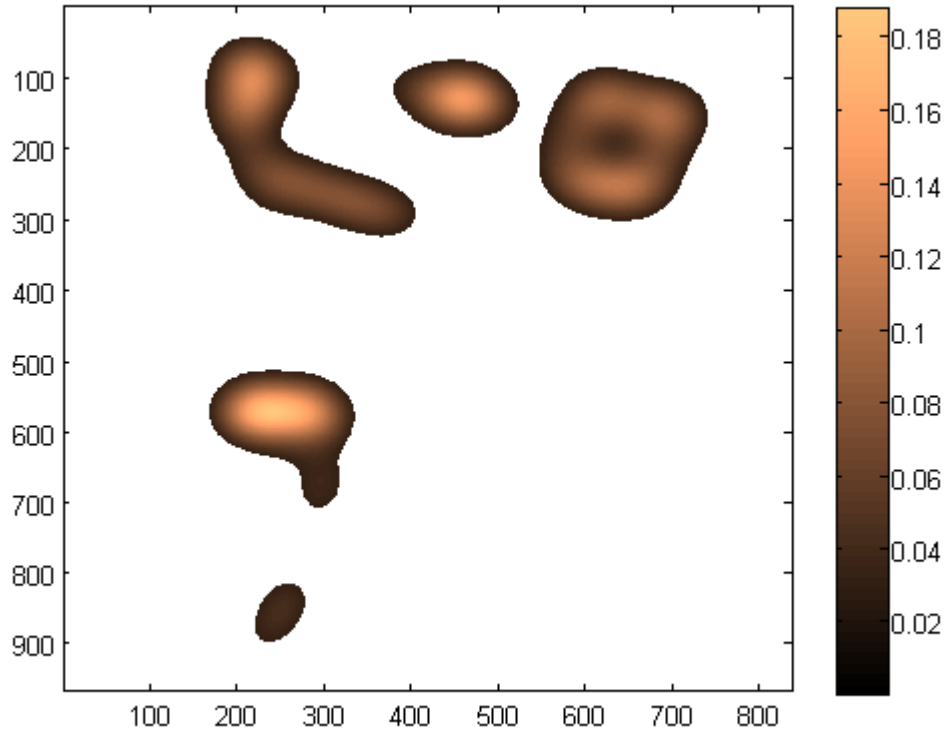
- The first model spiral will test our ability to predict expert fixation patterns for a given image, search goal and previously identified goal-relevant regions

- We propose that top-down elements could be applied to the output of a bottom-up model as filters or amplifiers of modeled fixation patterns

- Developing filters based on image features
  - Terrain features for SAR
  - False color features for TSA X-rays

SAR Example

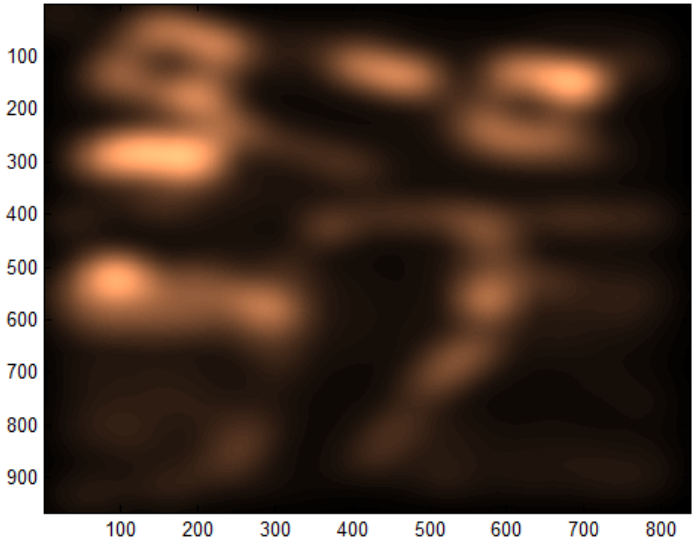
Masking out bottom-up salience from task-irrelevant features



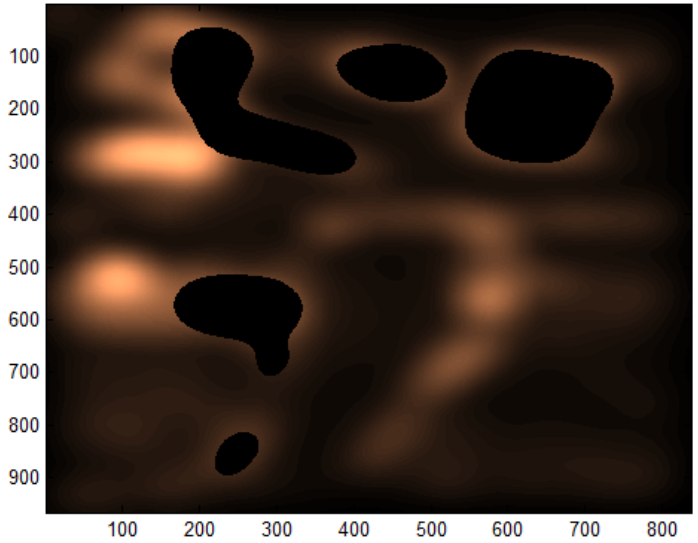
Mask of shadows – high contrast, low importance

Modified bottom-up salience map

Original



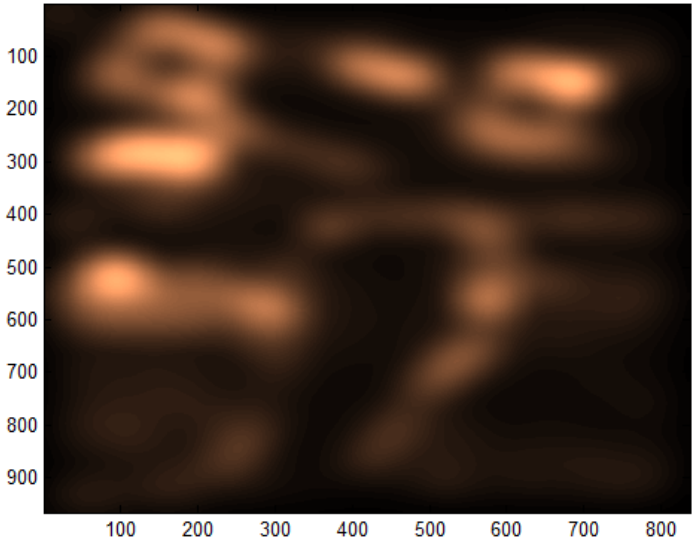
Modified



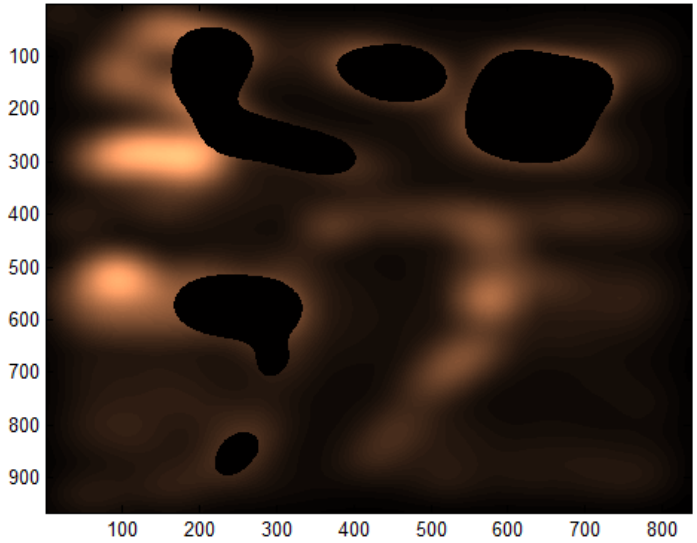
Note: This Illustrates a simple mask. Advanced models will be smoothed proportional to useful field of view.

Modified bottom-up salience map

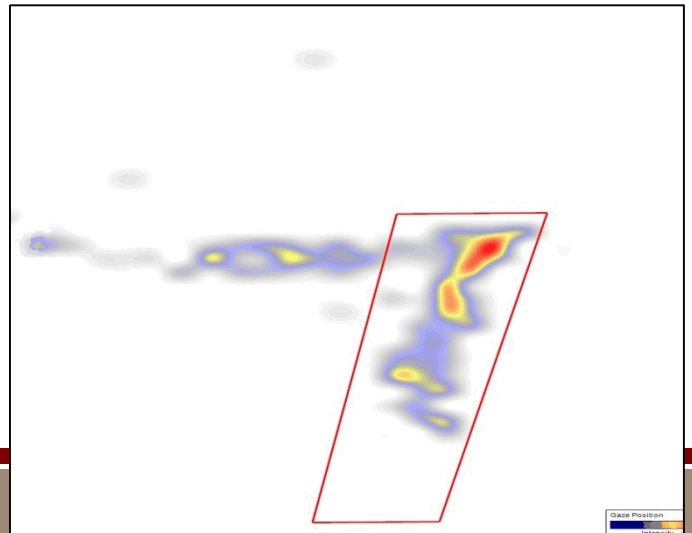
Original



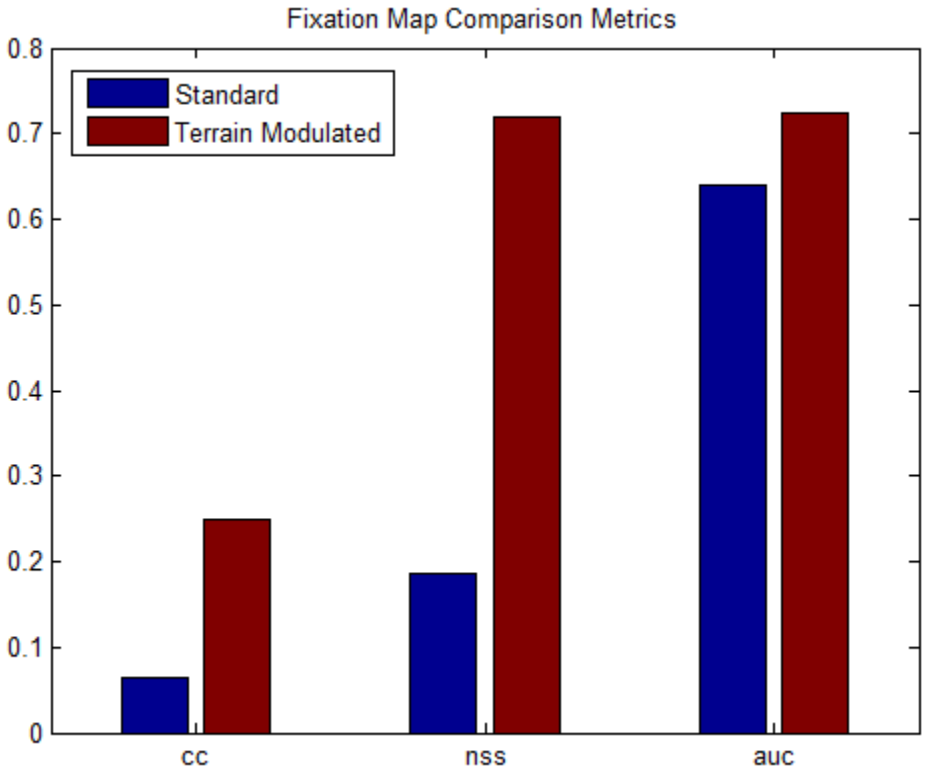
Modified



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

Next Steps

- Ongoing data collection across all participant populations
- Incorporating superpixel segmentations into eye tracking analysis
- Yarbus-style study of relationship between eye movements and task for SAR imagery
  - Threat detection task vs. radar image quality task
- Continue development of top-down model
  - Refine masks based on superpixel segmentations
  - Test model's ability to predict an analyst's gaze path

Empirical First Spiral for Modeling

- Because the elements of human cognition are difficult to directly observe through automated means, we propose that top-down elements could be applied to the output of a bottom-up model as filters or amplifiers of modeled fixation patterns
- The first model spiral will test our ability to predict expert fixation patterns for a given image, search goal and previously identified goal-relevant regions

Sandia National Laboratories

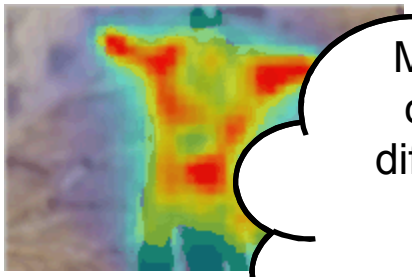
Shneiderman's mantra* highlights a user's cognitive needs at various strategic stages in visual information retrieval: Overview, Zoom, Filter, Details on Demand

Is this an accurate & concise top-down model of visual search? If not, what else is needed?

How can we compute expected fixation patterns for experts engaged in goal-driven visual tasks?

Which, if any, components of the model are domain independent?

* Shneiderman, B., "The eyes have it: a task by data type taxonomy for information visualizations," *Visual Languages, 1996. Proceedings., IEEE Symposium on* , vol., no., pp.336,343, 3-6 Sep 1996



Model components originate from two different sources that influence an individual's visual search process

Image content (this is the only source that is directly modeled in many bottom-up models)

Human cognition (this is the hard part - difficult to directly observe through automated means!)