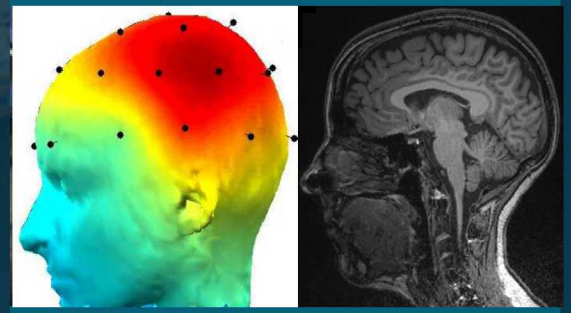
SAND2020-2278C

The Machine Must Give Way to the Human Brain:

A survey of interdisciplinary research on cognition at Sandia National Laboratories

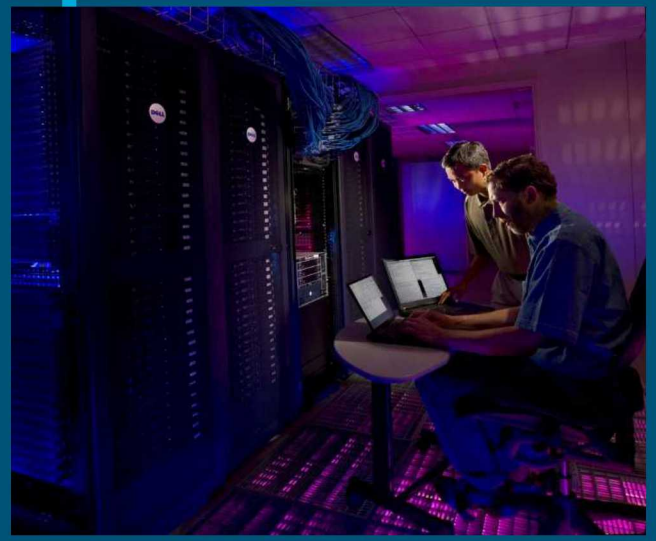


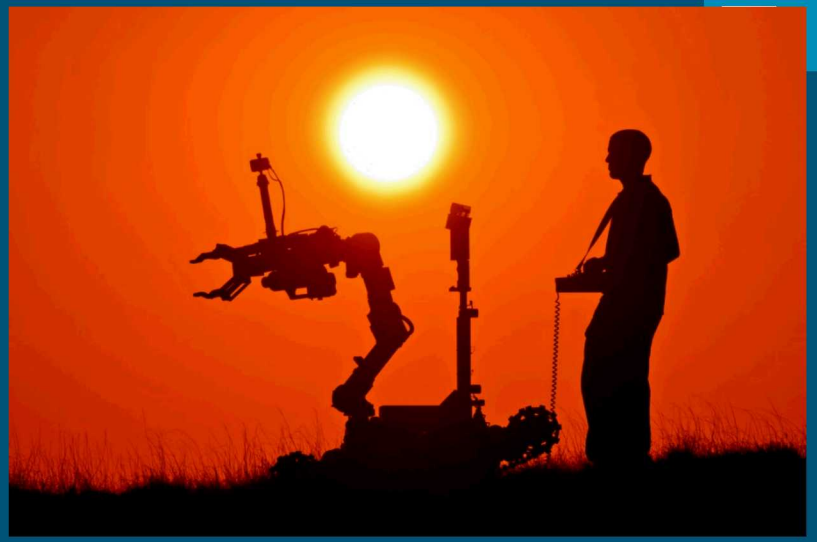
Laura Matzen, Ph.D.

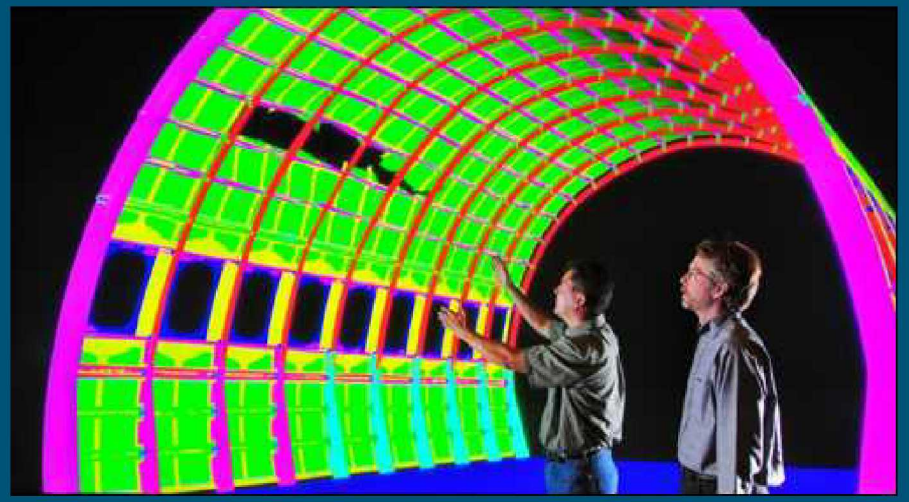
Applied Cognitive Science Department (6672)

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.


The Sandia Laboratory Story - 1958 Educational Military Documentary - WDTVLIVE42
9:34 / 33:05



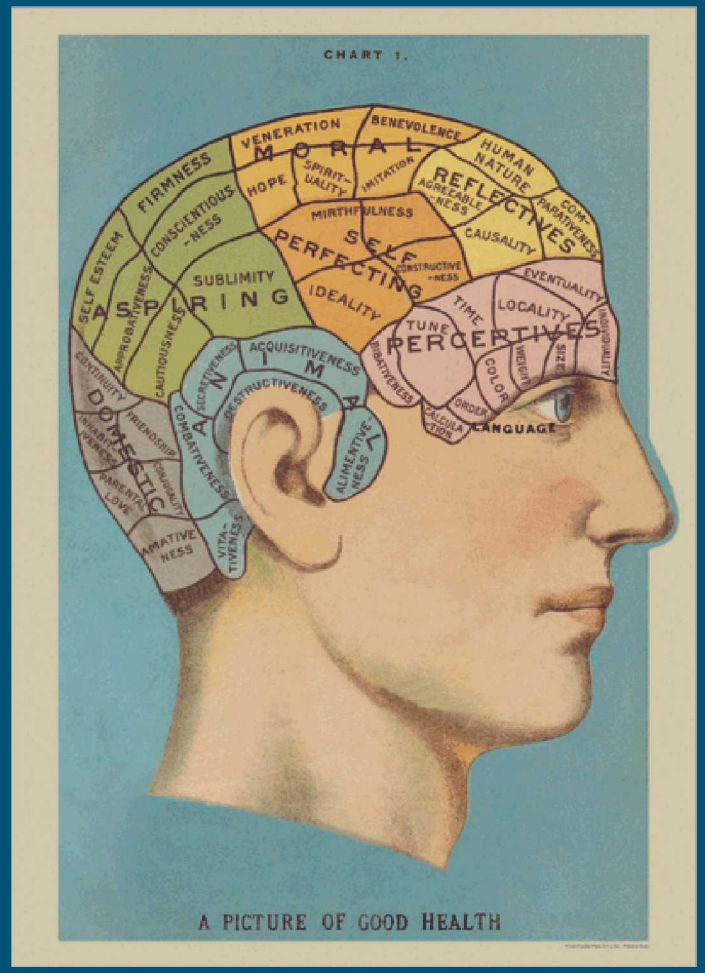




Overview of Cognitive Science

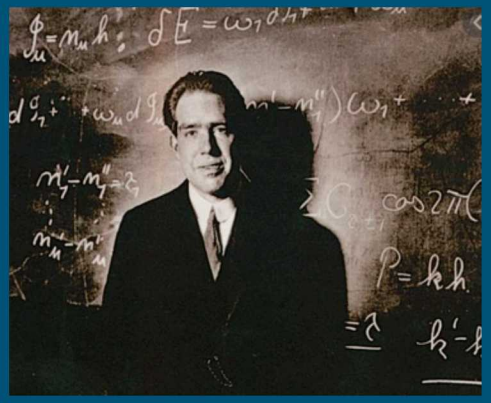
- Cognitive science is the interdisciplinary study of the mind
  - Draws on psychology, linguistics, artificial intelligence, and neuroscience

- Key research areas include:
  - Perception
  - Attention
  - Learning and Memory
  - Reasoning and Decision Making
  - Emotion
  - Communication

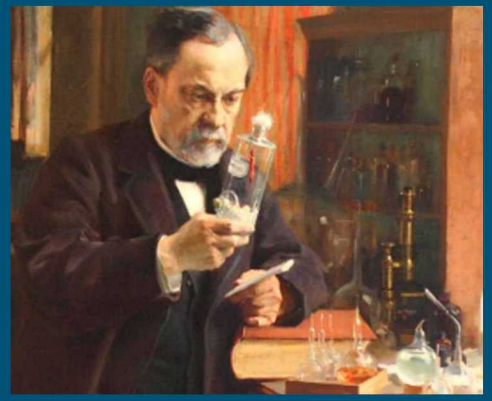


Quest for fundamental understanding?

High

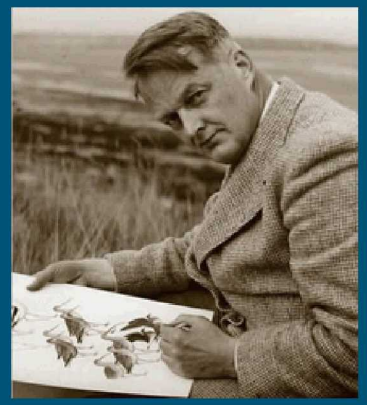


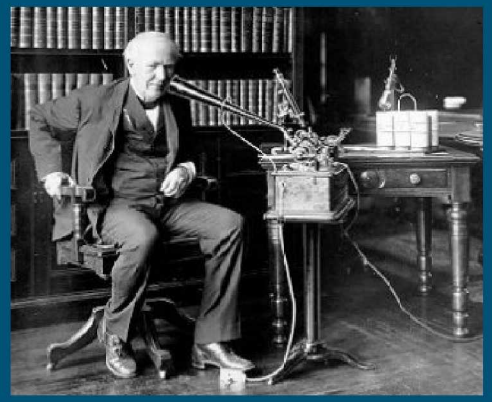
Basic Research



Use-inspired Basic Research

Low





Applied Research

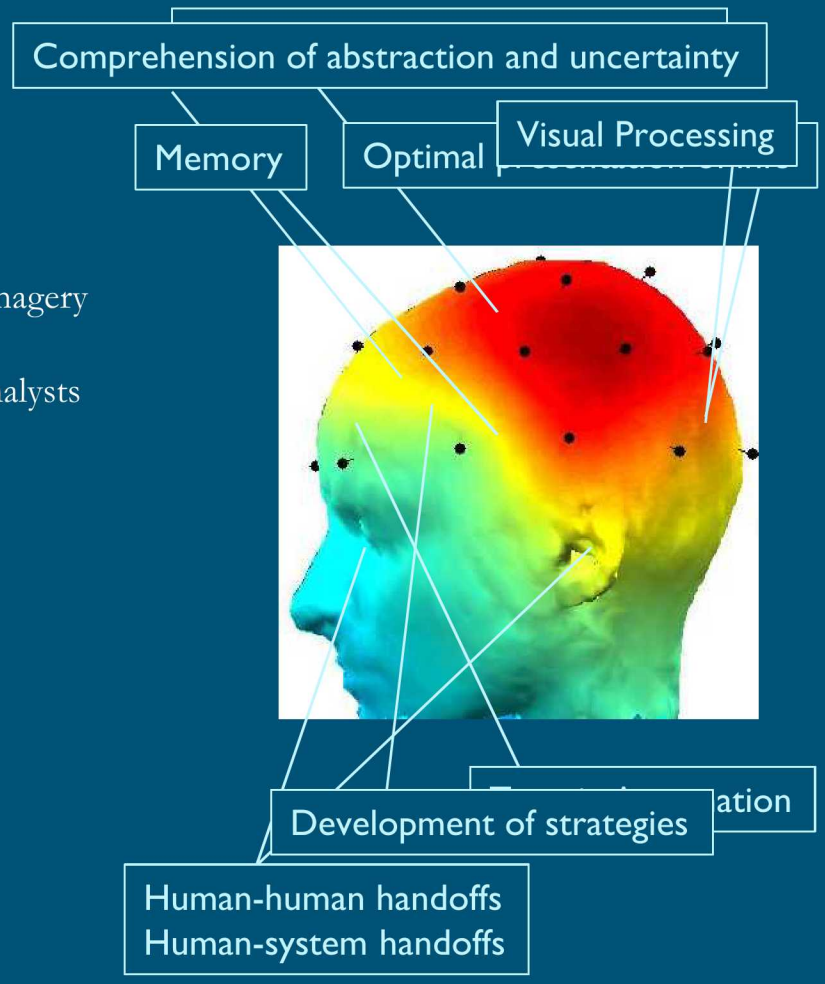
Low High

Considerations of use?

Adapted from Donald Stokes (1997)

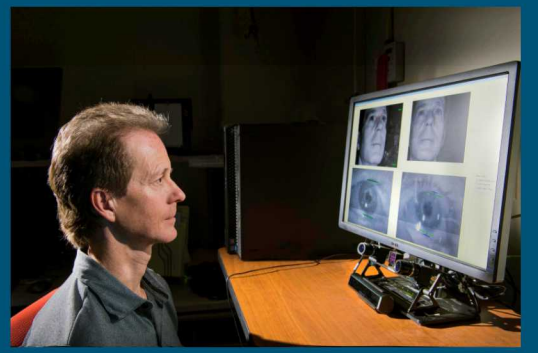
General Cognition Research Areas

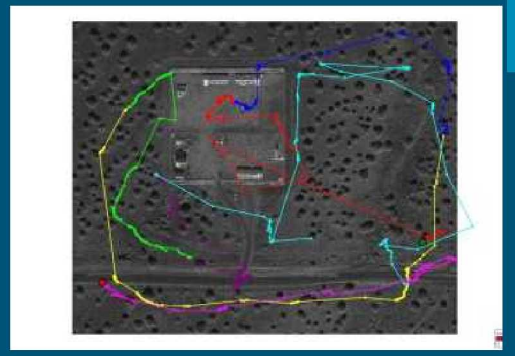
- Decision making in high-consequence environments
  - Assessing and improving human performance
  - Optimizing human-system interactions
  - Situational Awareness
- Visual Cognition
  - Informing the design of scalable human-computer imagery analysis systems
  - Studying development of expertise in professional analysts
- Mitigating errors and cognitive biases
  - Training and expert/novice differences
  - Tracking analytic progress
  - Communicating uncertainty
- Team Cognition
  - Transfer of knowledge
  - Roles and handoffs
  - Shared situational awareness

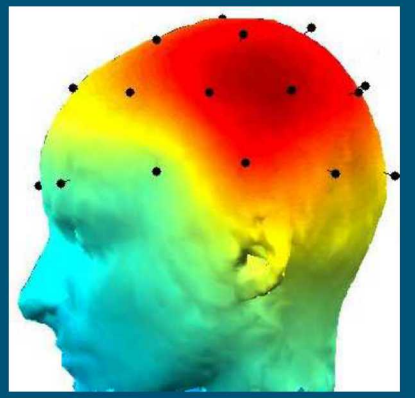


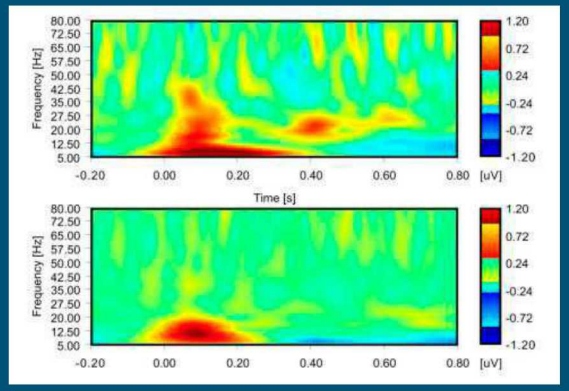
Cognitive Science Research Capabilities at Sandia

- Behavioral Methods
  - Quantitative behavioral testing
  - Human factors methods
  - Ethnographic methods
- Physiological Methods
  - Eye tracking
  - Electroencephalography (EEG)
  - Physiological monitoring via wearable devices
- Other neuroscience methods
  - Transcranial direct current stimulation (tDCS)
  - Access to other neuroimaging methods through university partnerships
- Testing environments
  - Human Performance Laboratory
  - Human Factors Laboratory
  - Augmented and virtual reality environments
  - Simulators
  - Field studies (e.g., airports)
  - Sandia facilities (e.g., participants' work environments)









Humans interacting with information

Trying to make sense of it

Trying to remember it

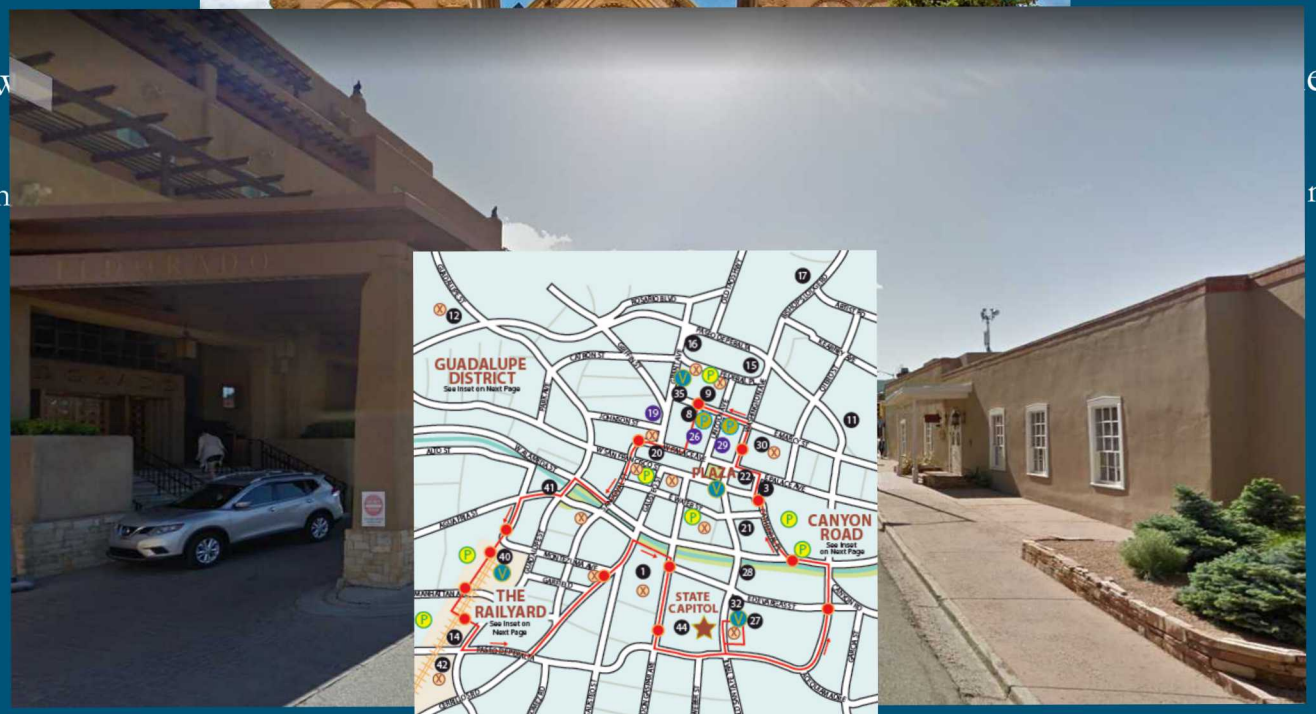
Trying to pass it along to other people or systems

Images: IAEA Imagebank, Flickr

Prior research on spatial learning

There are at least three different levels of spatial knowledge:

- Landmark knowledge – memory for objects encountered in the environment
  - Does not include memory for the landmark's location
- Route knowledge – me tric point of view)
  - Does not include areas of
  - Does not include metric k
- Survey know ent (allocentric point of view)
  - Marked by th not travel between them



Spatial Learning in the Nuclear Safeguards Context

120 Sandia employees (47 female, mean age 37, age range 18-69)

- 24 participants assigned to each of 5 spatial learning conditions

All participants began by studying a map (except for a no-map control group), then they were led through the basement and mezzanine of a former nuclear facility. The experimenter pointed out landmarks along the way.

After the tour, participants were tested on their spatial learning and memory for the landmarks

Landmark knowledge: Ability to distinguish between landmarks and unseen items

Route knowledge: Ability to draw the route and landmarks on a blank map

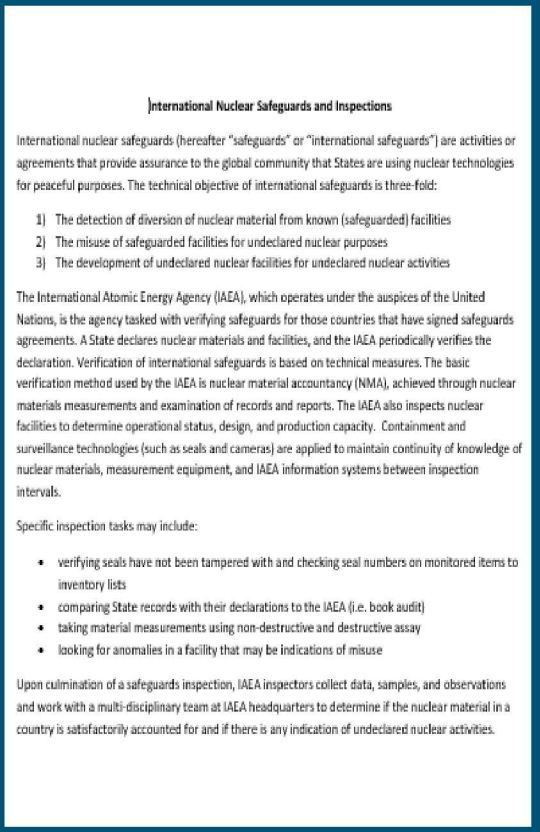
Survey knowledge: Ability to point to landmarks from the starting point of the route

Ability to find shortcuts between pairs of landmarks

Participants were divided in the analysis based on their sense of direction, as measured by the Santa Barbara Sense of Direction Scale (Hegarty et al., 2002)

Experimental Environment

Map Conditions



International Nuclear Safeguards and Inspections

International nuclear safeguards (hereafter "safeguards" or "international safeguards") are activities or agreements that provide assurance to the global community that States are using nuclear technologies for peaceful purposes. The technical objective of international safeguards is three-fold:

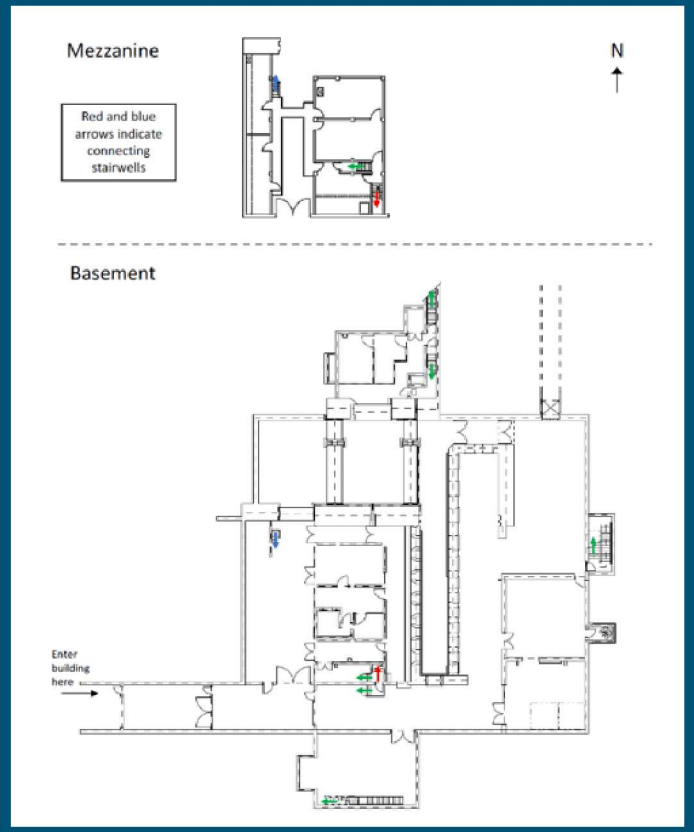
1) The detection of diversion of nuclear material from known (safeguarded) facilities
2) The misuse of safeguarded facilities for undeclared nuclear purposes
3) The development of undeclared nuclear facilities for undeclared nuclear activities

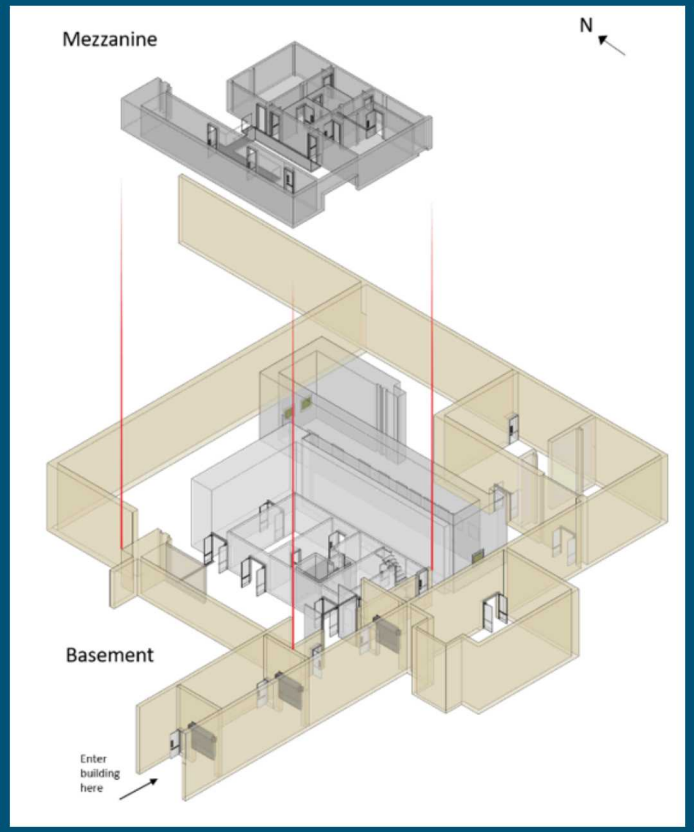
The International Atomic Energy Agency (IAEA), which operates under the auspices of the United Nations, is the agency tasked with verifying safeguards for those countries that have signed safeguards agreements. A State declares nuclear materials and facilities, and the IAEA periodically verifies the declaration. Verification of international safeguards is based on technical measures. The basic verification method used by the IAEA is nuclear material accountancy (NMA), achieved through nuclear materials measurements and examination of records and reports. The IAEA also inspects nuclear facilities to determine operational status, design, and production capacity. Containment and surveillance technologies (such as seals and cameras) are applied to maintain continuity of knowledge of nuclear materials, measurement equipment, and IAEA information systems between inspection intervals.

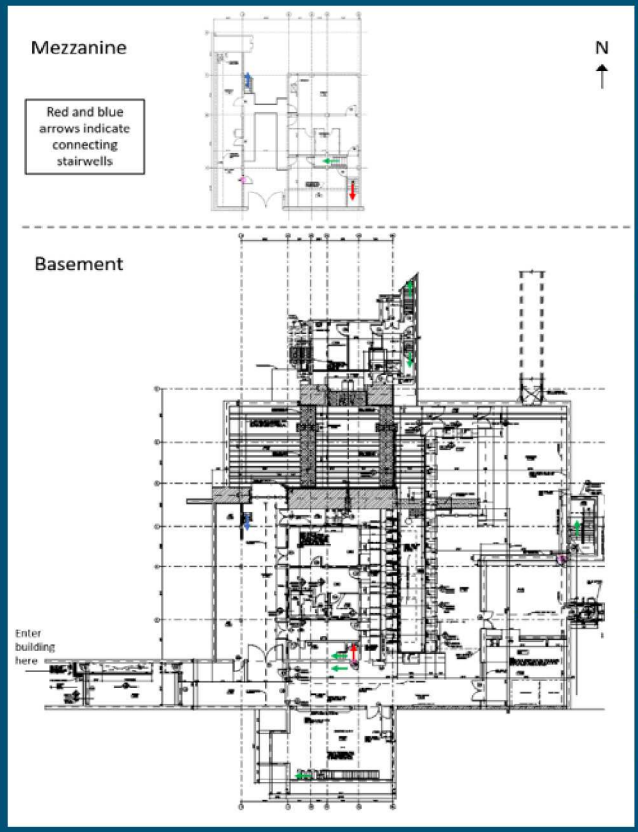
Specific inspection tasks may include:

- verifying seals have not been tampered with and checking seal numbers on monitored items to inventory lists
- comparing State records with their declarations to the IAEA (i.e. book audit)
- taking material measurements using non-destructive and destructive assay
- looking for anomalies in a facility that may be indications of misuse

Upon culmination of a safeguards inspection, IAEA inspectors collect data, samples, and observations and work with a multi-disciplinary team at IAEA headquarters to determine if the nuclear material in a country is satisfactorily accounted for and if there is any indication of undeclared nuclear activities.







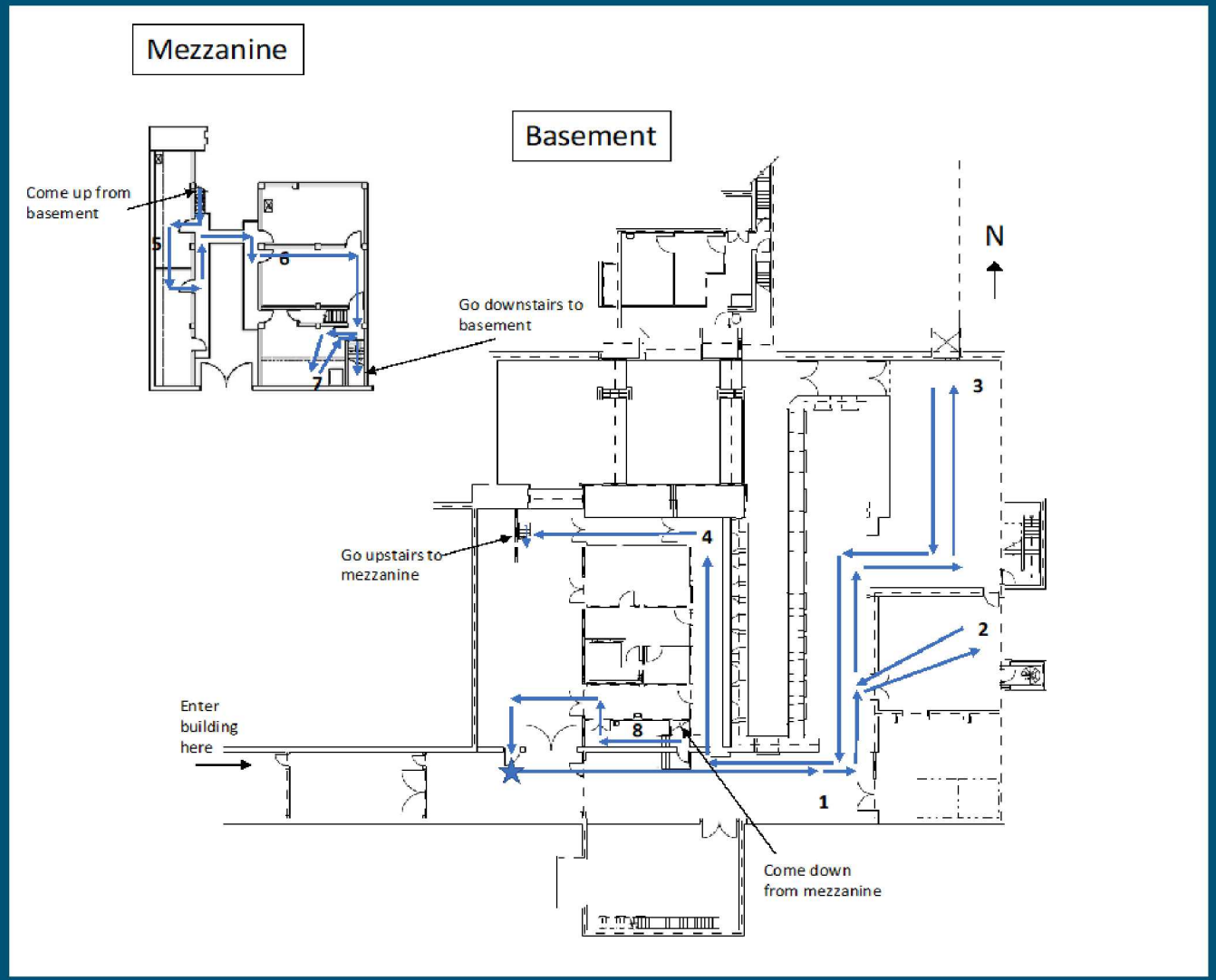
No Map
Read handout

2D Simple Map
Study only
Study + carry

3D Simple Map
Study + carry

2D Blueprint
Study + carry

Route and Landmarks



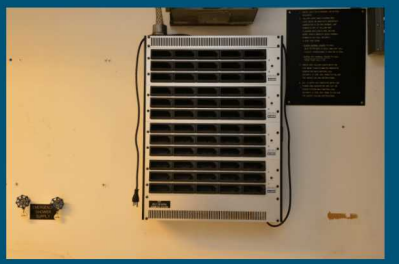
Landmarks

1. Manipulator mockup
2. Glove box
3. Overhead crane
4. Instrument cabinet
5. Atom art
6. Capped Pipe
7. Water meter
8. Dosimeter charger







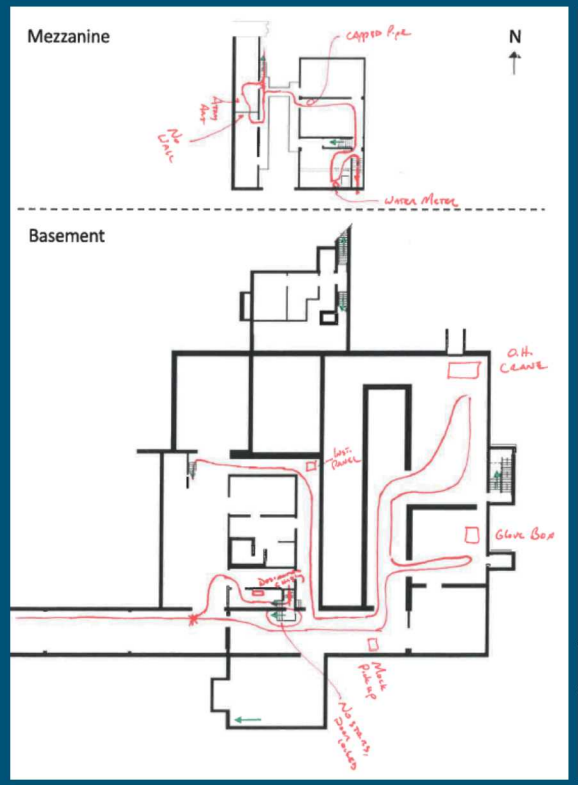



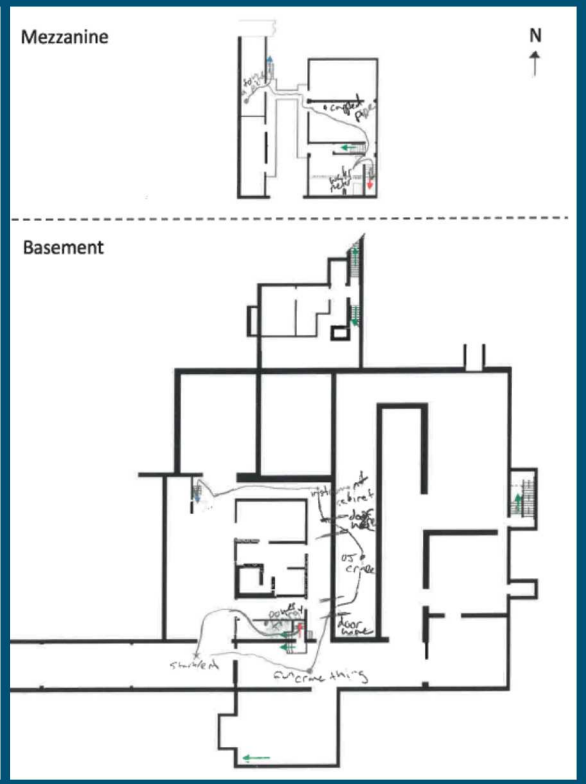
Tests of Spatial Learning

Landmark knowledge: Ability to distinguish between landmarks and unseen items



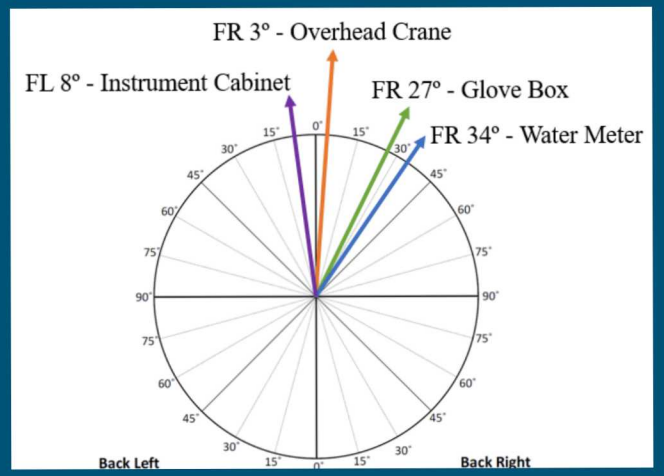
Route knowledge: Ability to draw the route and landmarks on a blank map

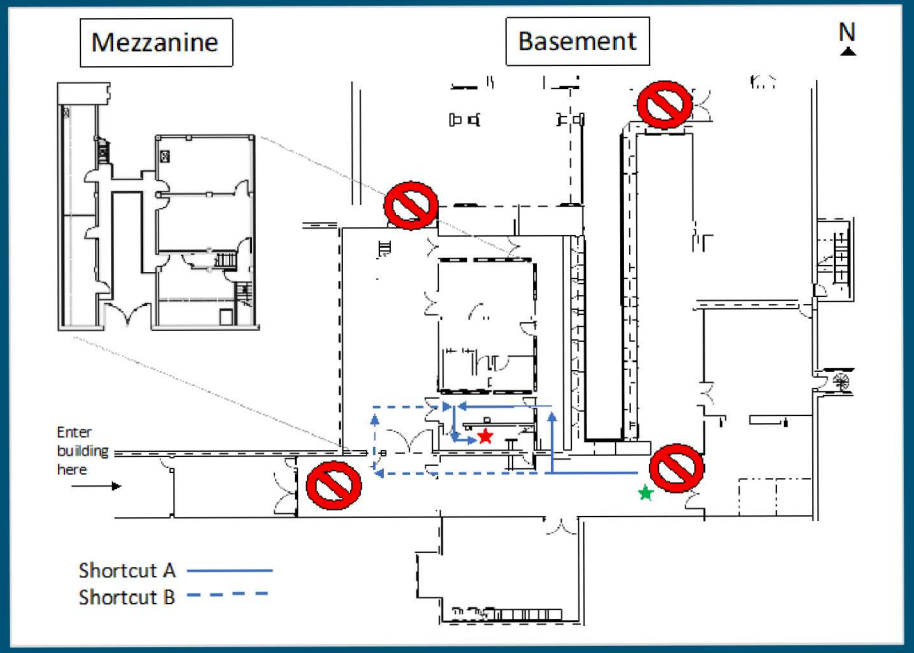




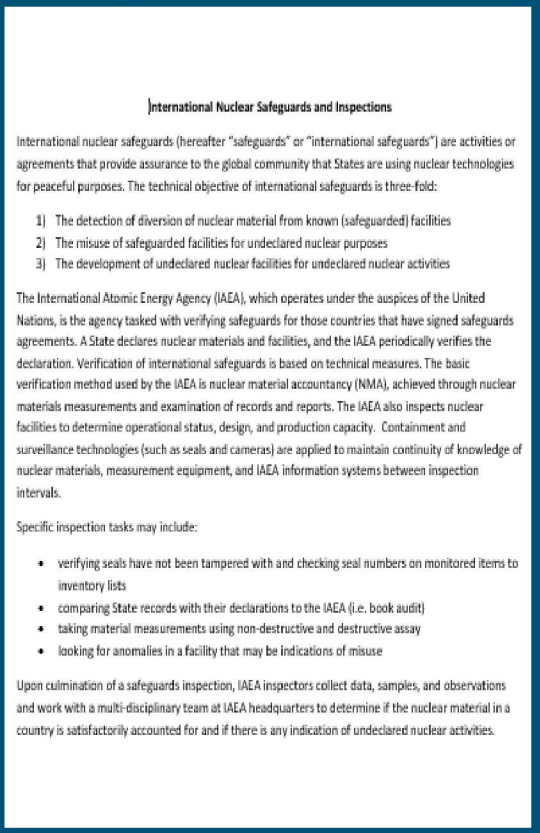
Tests of Spatial Learning

Survey knowledge: Ability to point to landmarks from the starting point of the route
Ability to find shortcuts between pairs of landmarks





Results



International Nuclear Safeguards and Inspections

International nuclear safeguards (hereafter "safeguards" or "international safeguards") are activities or agreements that provide assurance to the global community that States are using nuclear technologies for peaceful purposes. The technical objective of international safeguards is three-fold:

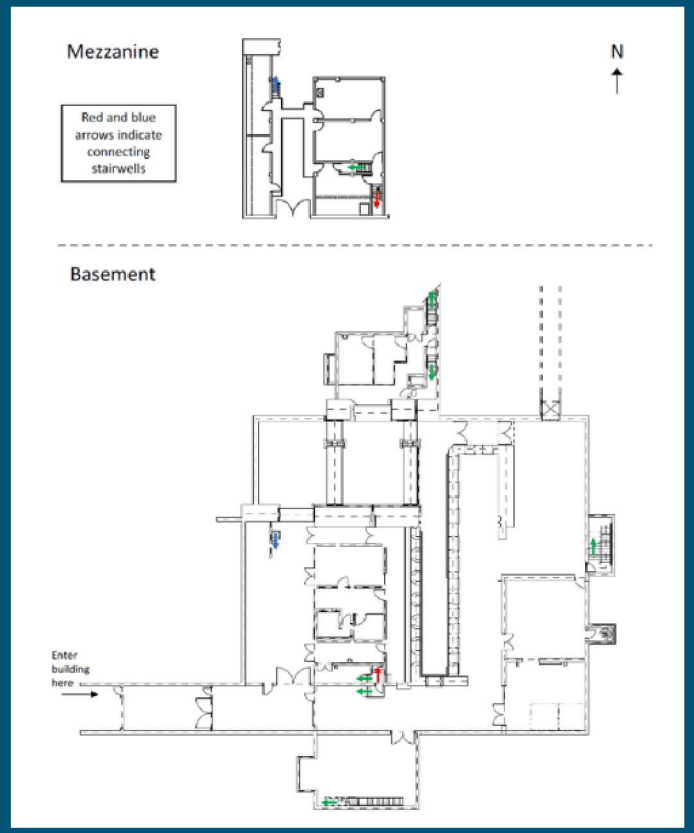
1) The detection of diversion of nuclear material from known (safeguarded) facilities
2) The misuse of safeguarded facilities for undeclared nuclear purposes
3) The development of undeclared nuclear facilities for undeclared nuclear activities

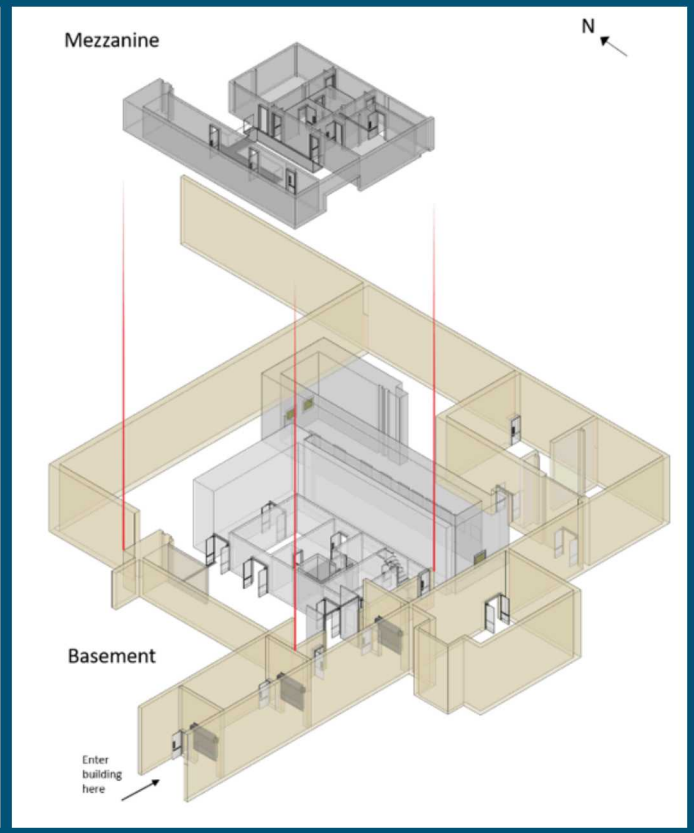
The International Atomic Energy Agency (IAEA), which operates under the auspices of the United Nations, is the agency tasked with verifying safeguards for those countries that have signed safeguards agreements. A State declares nuclear materials and facilities, and the IAEA periodically verifies the declaration. Verification of international safeguards is based on technical measures. The basic verification method used by the IAEA is nuclear material accountancy (NMA), achieved through nuclear materials measurements and examination of records and reports. The IAEA also inspects nuclear facilities to determine operational status, design, and production capacity. Containment and surveillance technologies (such as seals and cameras) are applied to maintain continuity of knowledge of nuclear materials, measurement equipment, and IAEA information systems between inspection intervals.

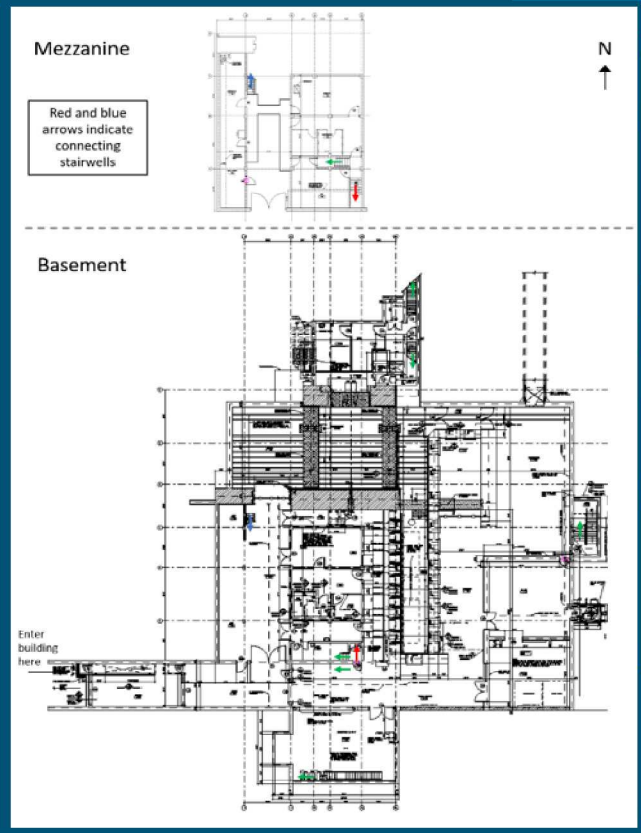
Specific inspection tasks may include:

- verifying seals have not been tampered with and checking seal numbers on monitored items to inventory lists
- comparing State records with their declarations to the IAEA (i.e. book audit)
- taking material measurements using non-destructive and destructive assay
- looking for anomalies in a facility that may be indications of misuse

Upon culmination of a safeguards inspection, IAEA inspectors collect data, samples, and observations and work with a multi-disciplinary team at IAEA headquarters to determine if the nuclear material in a country is satisfactorily accounted for and if there is any indication of undeclared nuclear activities.







No Map

2D Simple Map

3D Simple Map

2D Blueprint

People with good and poor senses of direction performed equally well

People with a good sense of direction performed better

People with a poor sense of direction performed worse

People with a good sense of direction performed worse

People with a poor sense of direction performed the same as in No Map condition

Results – Awareness of surroundings

Target Landmarks

Incidental Landmarks

Unseen Items

People who carried a simple map had a harder time recognizing incidental landmarks

- Trying to use the map distracted them from paying attention to their surroundings

Recommendations for spatial learning in complex environments

Know your abilities!

- If you have a poor sense of direction, a map might hurt more than it helps
- If you have a good sense of direction, an easy-to-read map is very helpful

Teamwork

- When working in a team, only one person should track progress on the map
- Others should pay attention to their surroundings

Simple is better

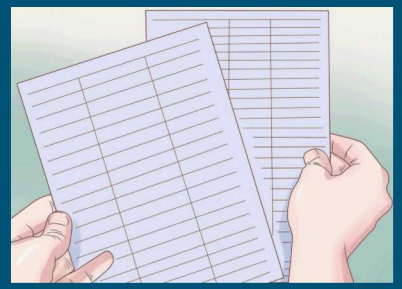
- Detailed blueprints were not helpful for spatial learning
- 3D maps did not provide additional benefit beyond 2D maps
- Studying a map before entering the building was just as effective as carrying the map along

Stites, M. C., Matzen, L. E., & Gastelum, Z. N. (In press). Where are we going and where have we been? Examining the effects of maps on spatial learning in an indoor guided navigation task. *Cognitive Research: Principles and Implications*.

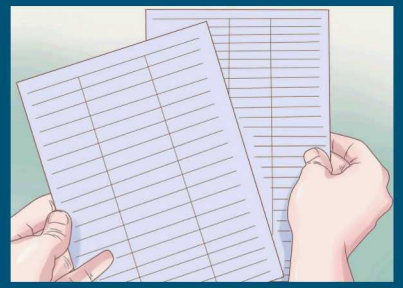
Gastelum, Z. N., Stites, M. C., & Matzen, L. E. (2019, May). The role of maps in site knowledge and wayfinding: A human performance evaluation for international nuclear safeguards inspections. In *Proceedings of the European Safeguards Research and Development Association Symposium 2019*

Once an inspection is completed…

What is the best way to record your observations so that you can make use of them several months later?


What is the best way to transfer this information to another team?

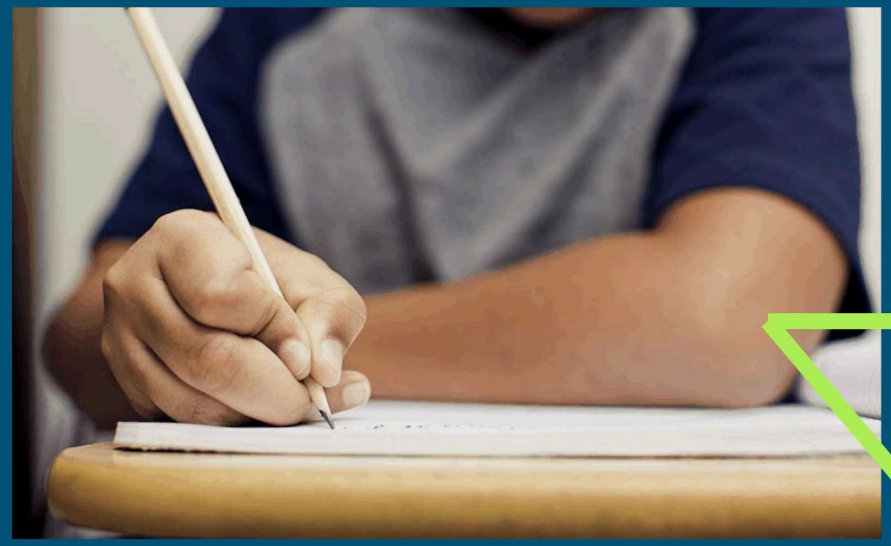



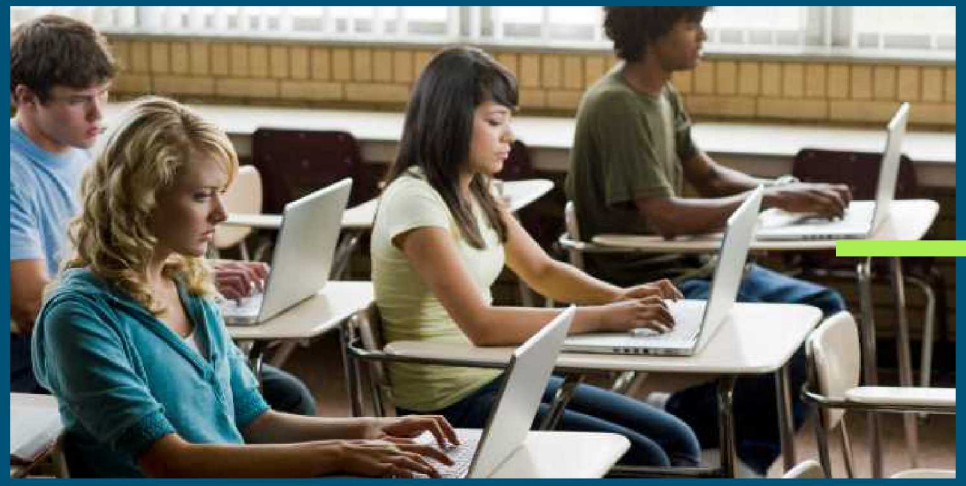

Knowledge Transfer

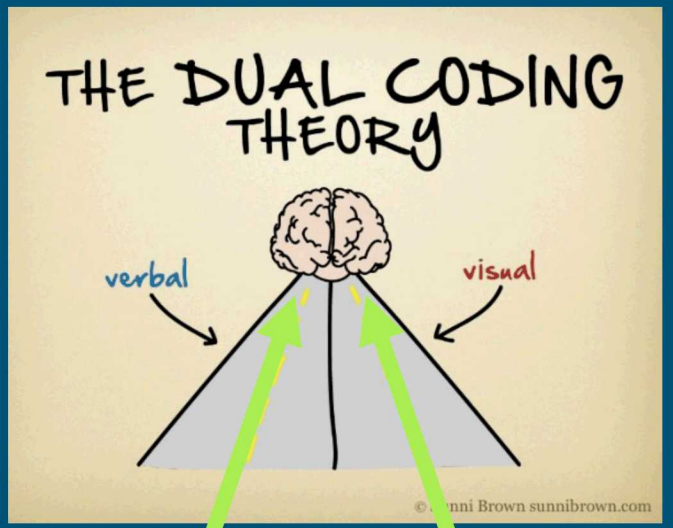
Successful shift handoffs:

- In-person
- Structured
- Well-established expectations
- Sufficient Time Allocated
- Use of **boundary objects**

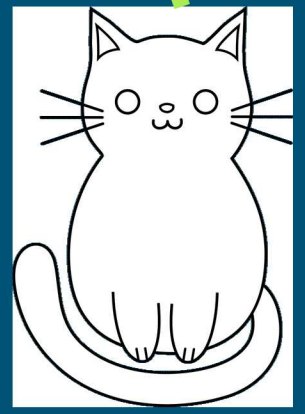
Cognitive Science of Note-Taking







Cat



Gaps in Existing Literature

Note-taking to transfer knowledge within IAEA-relevant constraints

- Best use of available technology
- Best strategies in absence of technology

Identify characteristics of effective boundary objects

Extend cognitive science research to use more varied stimuli, experimental constraints, and time delays

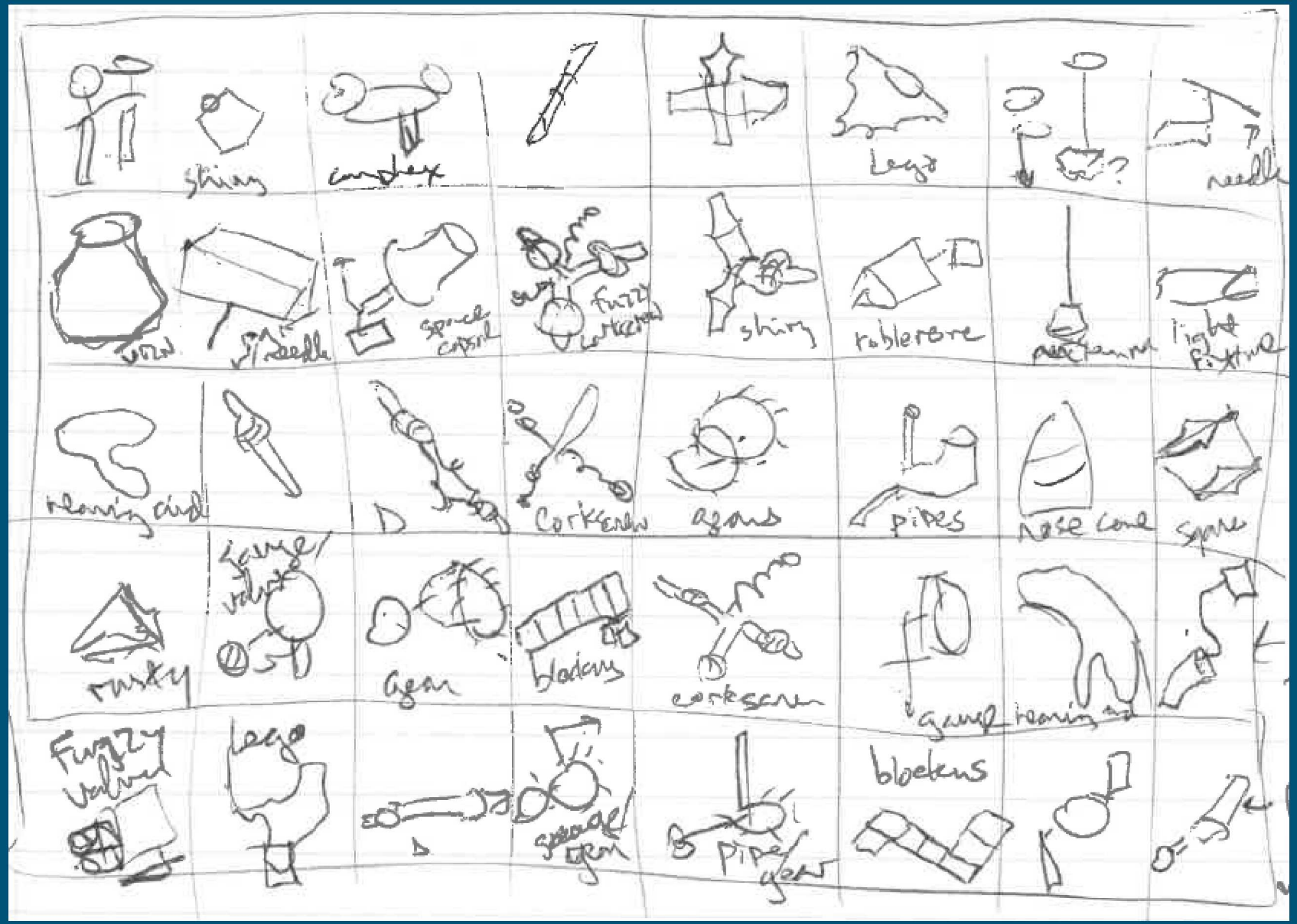
Current Study

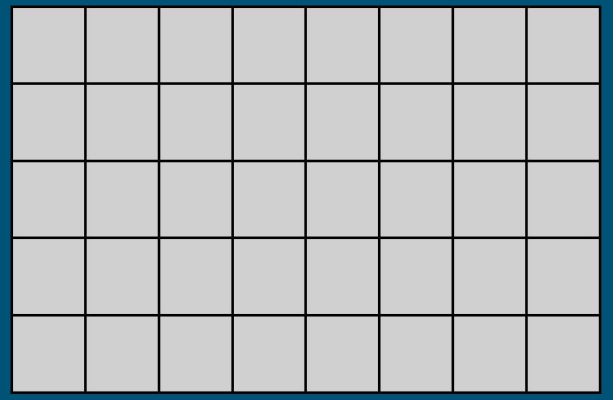
1) What is the most **effective note-taking method** for transfer of complex visual knowledge?
2) How does note-taking method impact one's **confidence** in assessments of changes?
3) Do some note-taking methods enable more **efficient knowledge transfer**, measured by time to complete the study?
4) Are there **individual differences** in terms of which types of notes are most effective?

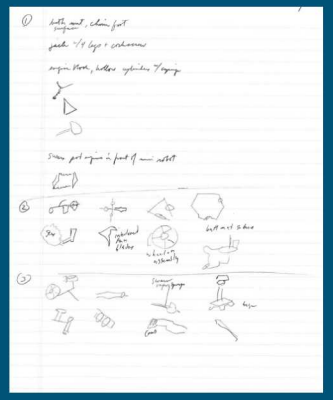
							

40 images x 4 test boards = 160 unique, difficult-to-name images

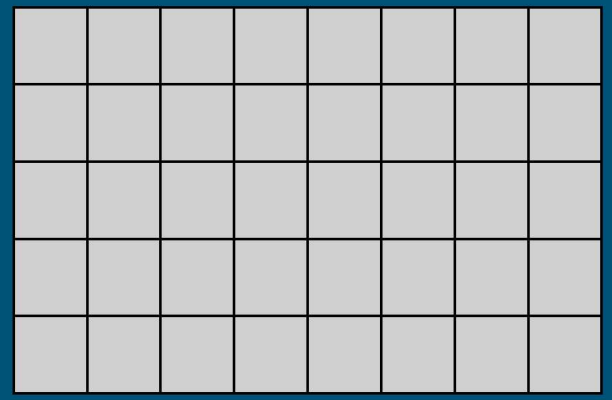
Items courtesy of the IARPA Machine Intelligence from Cortical Networks (MICrONS) project


shiny
Lego
shiny
rubberore
Corkscrew
pipes
nose cone
rusty
gear
blades
corkscrew
Fuzzy velvet
Lego
blades
pipe gear

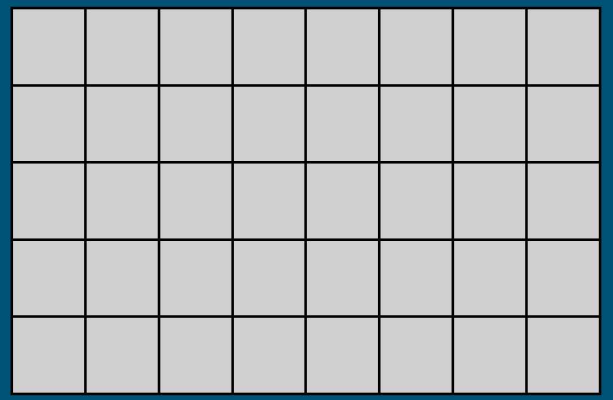


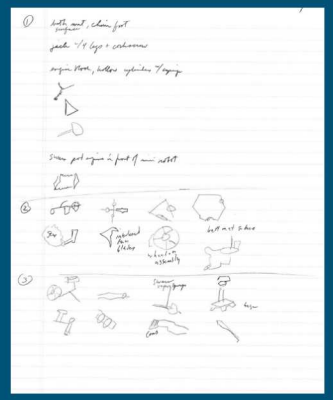


Written Notes

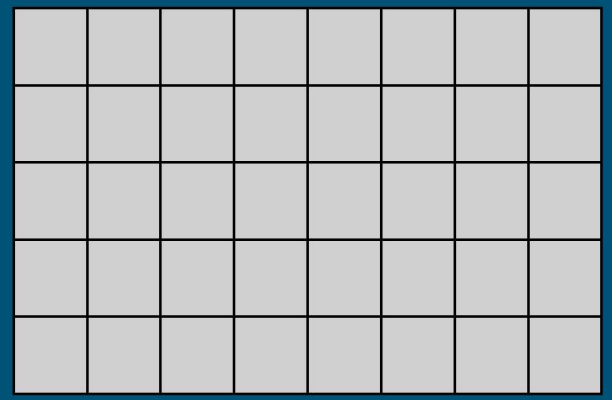


Camera





Camera + Written Notes



No Notes (Memory Only)

Participants had 12 minutes to study or take notes for each board
Order of note taking conditions was counterbalanced across participants

Three Experiments

Experiment 1:

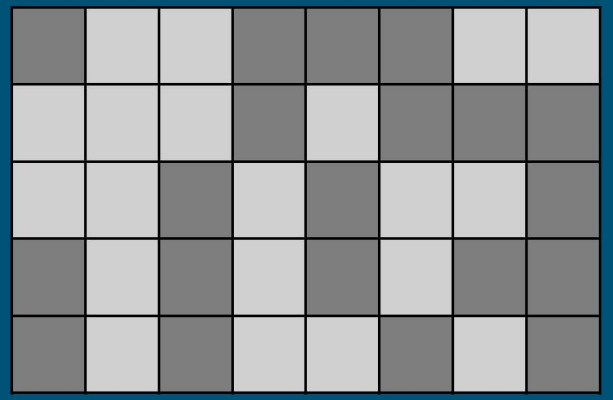
- Participants returned 2 days later and tried to use their notes to detect changes in the image arrays
- 20 participants (7 female, mean age 44, range 24-68)

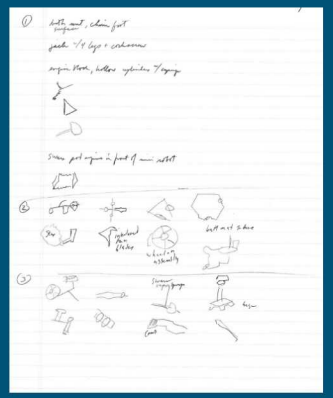
Experiment 2

- Participants from Experiment 1 returned 6-9 months later and tried to use their notes to detect changes
- 16 participants (6 female, mean age 42, range 24-68)

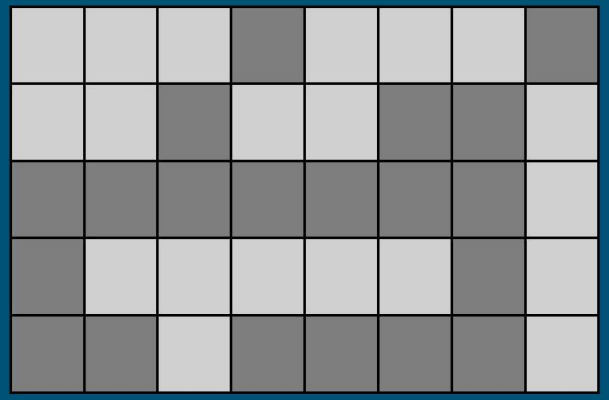
Experiment 3

- New participants used the notes from Experiment 1 to try to detect changes
- 18 participants (9 female, mean age 33, range 19-62)

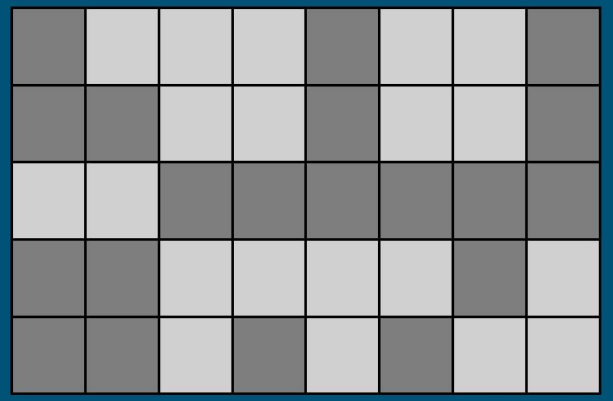




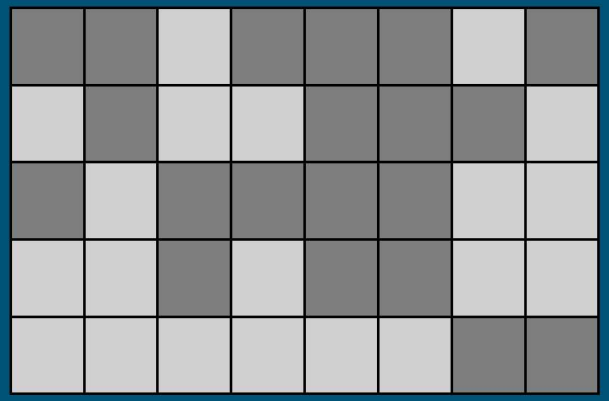
Written Notes



Camera



Camera + Written Notes



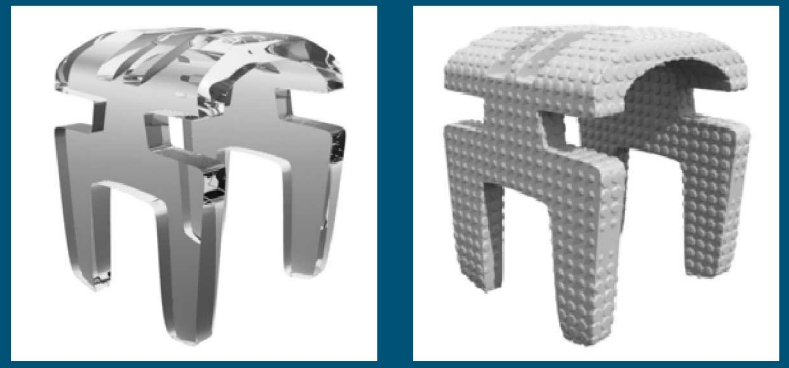
No Notes (Memory Only)

At test, half of the items had changed

Participants had 12 minutes per board to write down which items had changed, what kind of change, and how confident they were

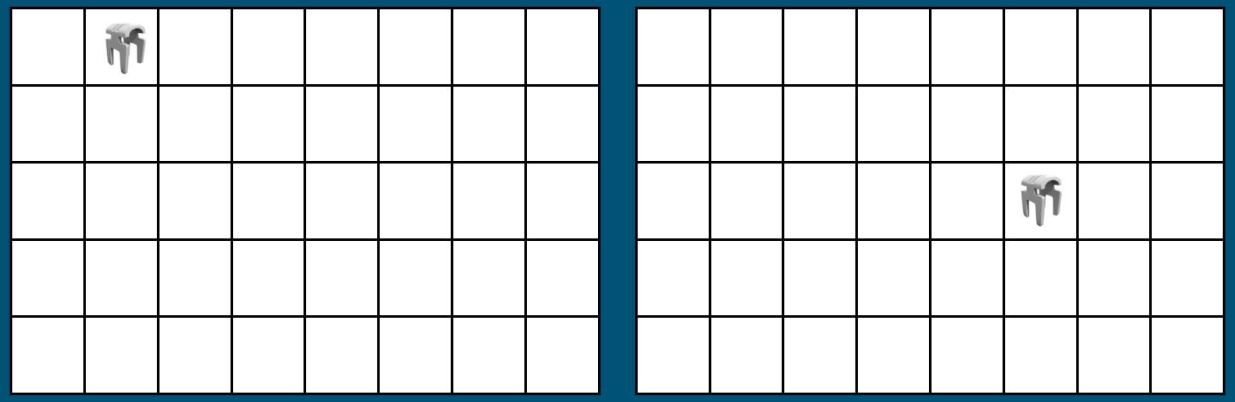
Four Change Types

Material Change (4)

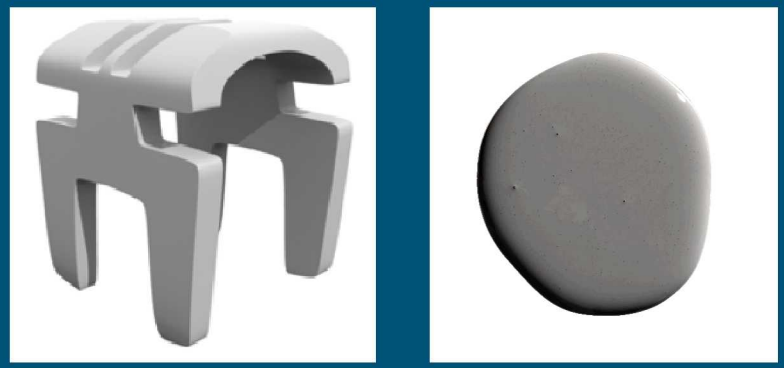


Orientation Change (4)

Location Change (6)



Replacement (6)



Results

Detecting Changes:

- Participants performed equally well with camera and camera + notes
- Performance was lower, but reasonably good for notes only

Identifying Change Types: (material, location, etc…)

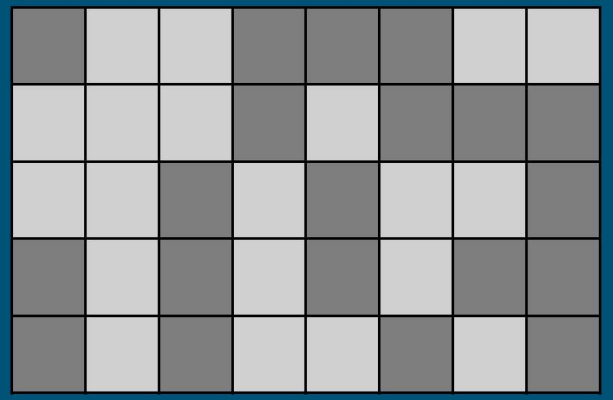
- Camera and camera + notes were best
- Notes alone were not useful for detecting material changes
- Notes that included both drawings and words were the most effective

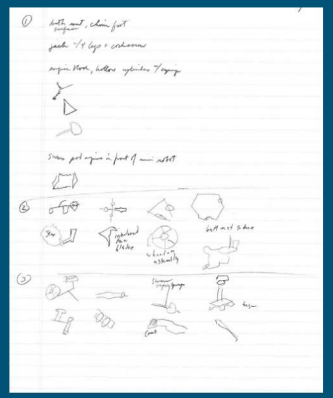
Confidence:

- Using the camera gave people a false sense of confidence in their responses. They were highly confident even when they missed a change

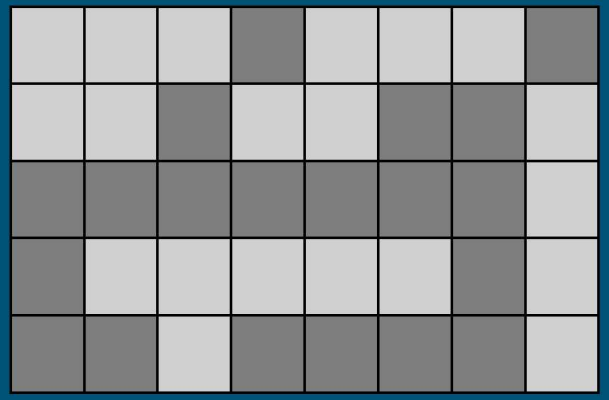
Response Times:

- At study, participants were fastest when using the camera
- At test, the camera conditions were slowest. Viewing images one-by-one was slower than looking at a page of notes

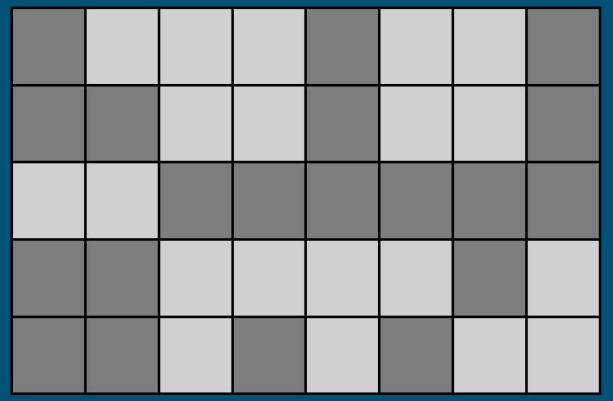




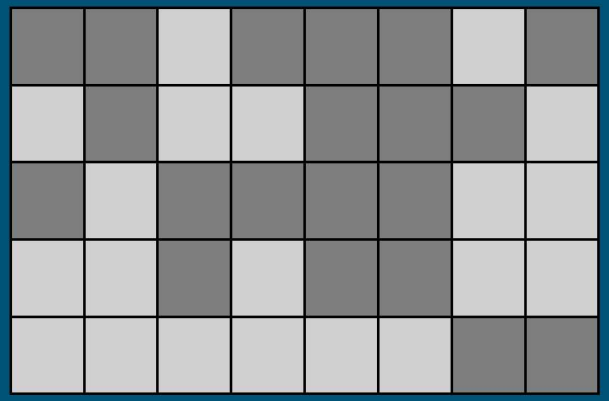
Written Notes



Camera



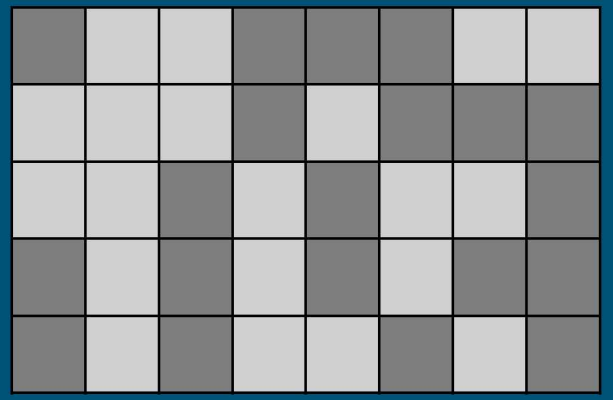
Camera + Written Notes

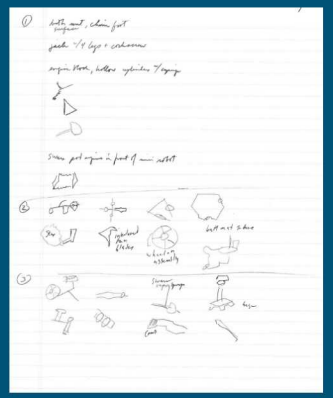


No Notes (Memory Only)

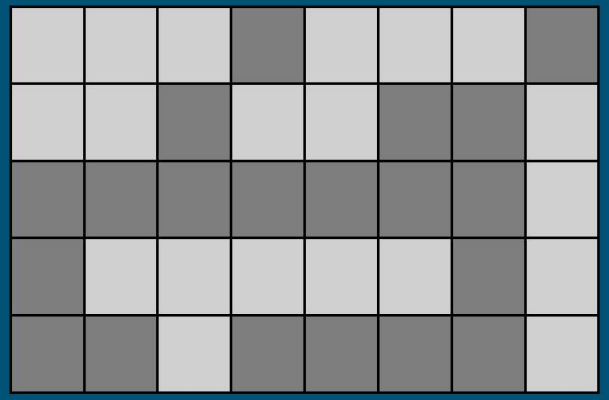
Experiment 2

16 participants returned 6-9 months after their first session

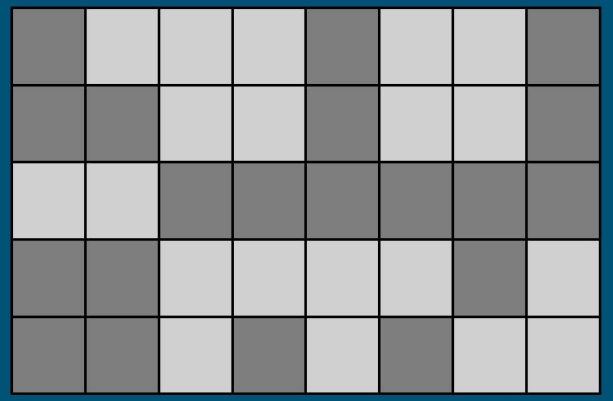




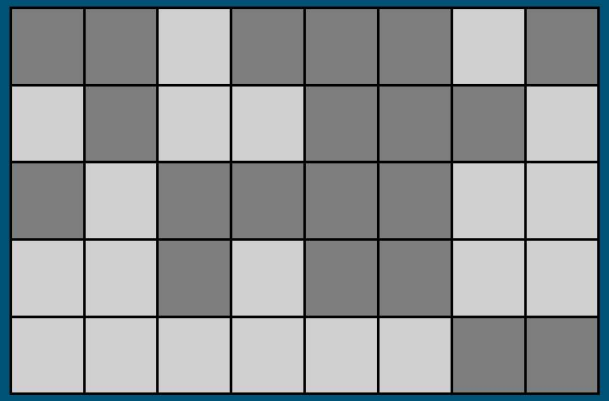
Written Notes



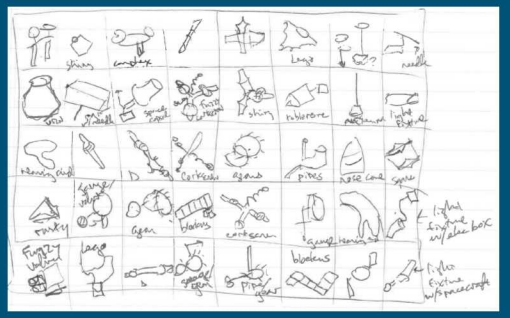
Camera

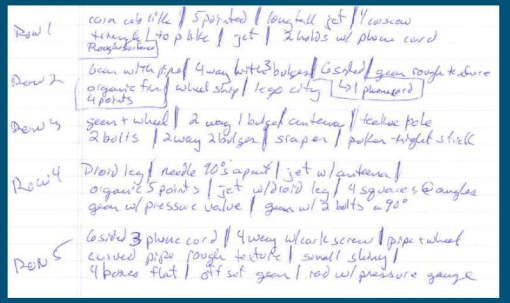


Camera + Written Notes



Someone else's notes





Experiment 2

16 participants returned 6-9 months after their first session

Experiment 2 Results

Detecting Changes:

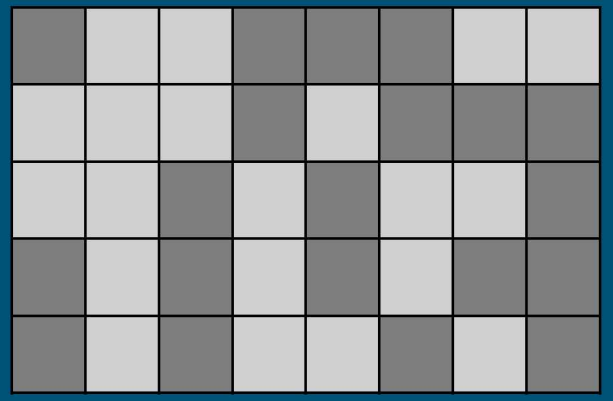
- Participants performed equally well with camera and camera + notes
- Performance was lower for notes alone, but people performed equally well when using their own notes or someone else's notes
- Verbal notes were less useful than notes that included drawings

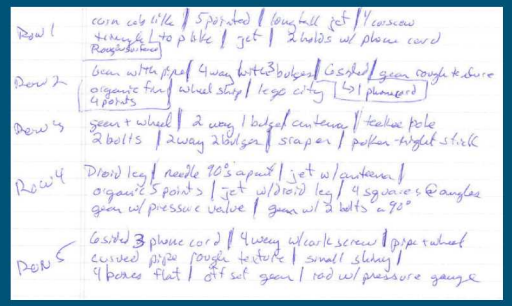
Identifying Change Types: (material, location, etc…)

- Camera and camera + notes were best
- Performance was lower for notes alone, but people performed equally well when using their own notes or someone else's notes

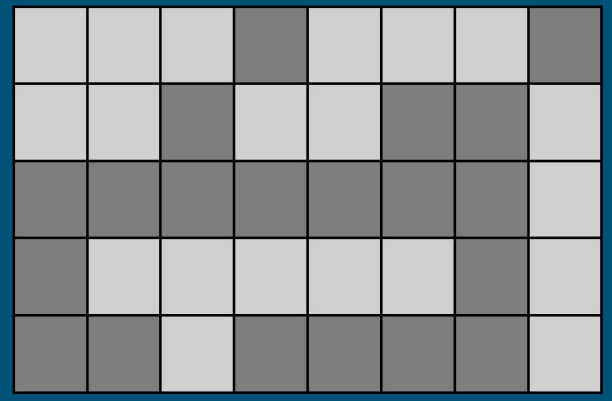
Confidence:

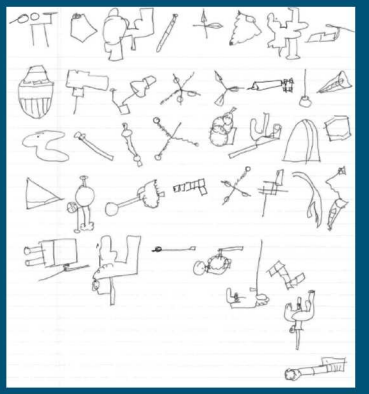
- People were more confident when using their own notes compared to using someone else's notes



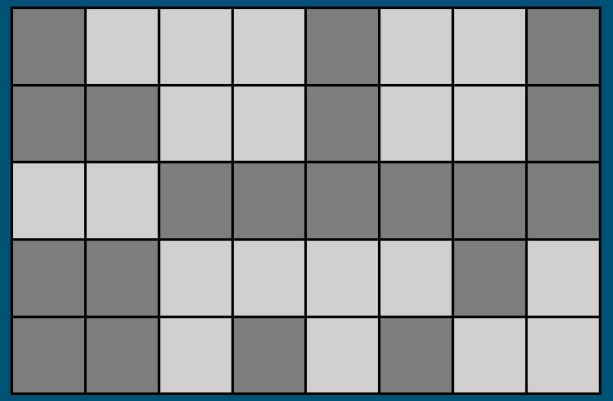


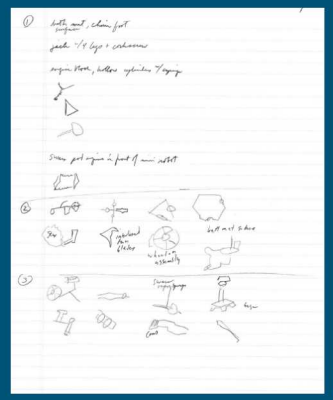
Verbal Notes



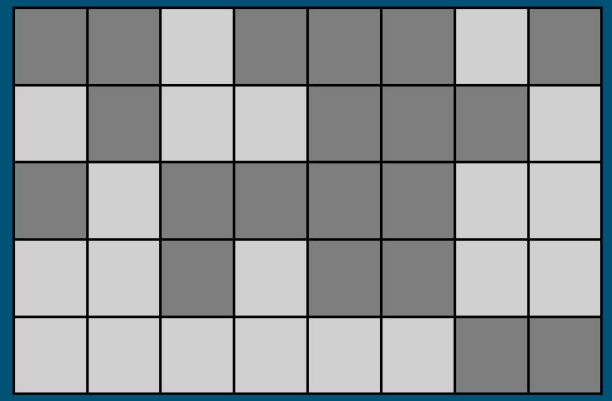


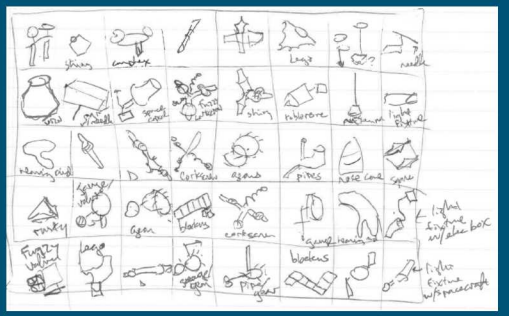
Drawings Only





Verbal + Drawings List





Verbal + Drawings Grid

Experiment 3

18 participants completed all boards using someone else's notes

Experiment 3 Results

Detecting Changes:

- Verbal notes were less useful than notes that included drawings

Identifying Change Types: (material, location, etc…)

- Similar performance for all types of notes
- Material changes were particularly difficult to detect

Confidence:

- People were more confident when using notes that contained drawings

Response Times:

- People were significantly slower when using verbal-only notes

Recommendations

Photographs are the most effective way to transmit complex visuo-spatial information

- Cameras should be used whenever possible
- Notes describing the context of the photographs are helpful
- Beware of overconfidence when using photos to detect changes over time

When using a camera isn't possible, combining visual and verbal representations is most effective

- Take advantage of dual coding theory – multiple representations are beneficial
- Take care to note material/texture in notes, when important
- People may not like to use someone else's notes, but they are likely to perform just as well as with their own notes

Stites, M. C., Matzen, L. E., Smartt, H. A., & Gastelum, Z. N. (2019, July). Effects of note taking method on knowledge transfer in inspection tasks. In *International Conference on Human-Computer Interaction* (pp. 594-612). Springer, Cham.

Gastelum, Z. N., Matzen, L. E., Stites, M. C., & Smartt, H. A. (2019, July). Human performance testing on observation capture methods for international nuclear safeguards inspections: Transferring knowledge from the field to headquarters and back. In *Proceedings of the Institute of Nuclear Materials Management Annual Meeting 2019*.

Our experiments in the safeguards domain:

- Identified gaps in the existing cognitive science literature
- Used carefully-designed experiments to test the impact of different information formats on human performance
- Produced recommendations that take the IAEA inspectors' constraints into account
- Contributed to the scientific literature
  - Spatial learning in complex indoor environments
  - Knowledge transfer outside of shift-handoff settings
  - Note taking outside of classroom settings

Beyond specific recommendations for specific domains, what else can we do with the information we gain from applied cognitive science studies?

Human-centered data science:

- Building data collection/analysis/display pipelines based on the needs of the human analyst

Modeling cognitive processes:

- Enable predictions about future performance
- Allow for more rapid evaluation of tools/systems

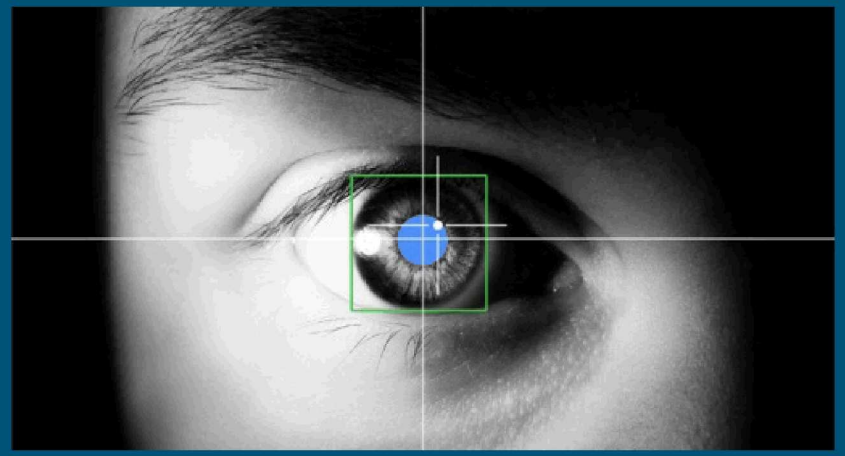
Enhance training for people performing highly specialized tasks

- Understand expert-level performance
- Speed up skill acquisition
- Minimize human errors

Human-centered data science

How can we find the best balance for human/system performance as data sets grow too large for current analysis methods?

- Many domains use eyes-on-pixel analysis approaches that are effective, but do not scale
- New tools/algorithms/visualizations/modes of interaction, we need to support human cognitive strengths to retain effectiveness



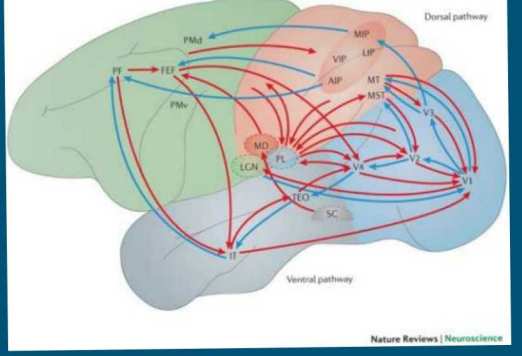
Visual Cognition and Data Visualizations

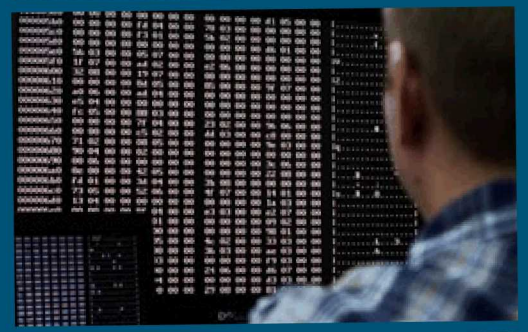
Humans rely heavily on visual processing (~60% of the brain), so it is a natural way to interact with data

- Data visualizations are widely used to support human decision making

How do we know if visualizations are <u>effective</u> in supporting decision making?

- Evaluating this is HARD!
- Sandia's visual cognition work is aimed at expanding the scientific understanding of visual cognition in complex human/system interactions
  - Can inform system design, provide new ways to evaluate visual tools from the perspective of human cognition

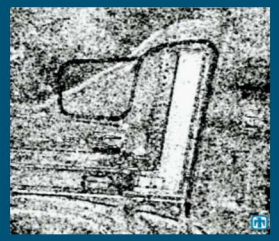




Research Domains

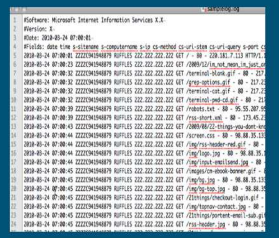
Developing methods to assess the utility of visualizations
Understanding expert vs. novice performance in visual cognition
Studying tools that change the scope of an analyst's interactions with data
Development of new methods for analyzing eye movement data

International Nuclear Safeguards

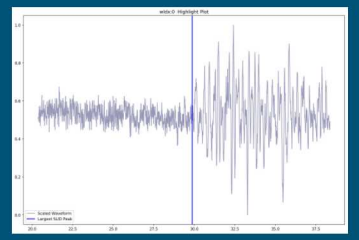


Synthetic Aperture Radar

False Color X-rays



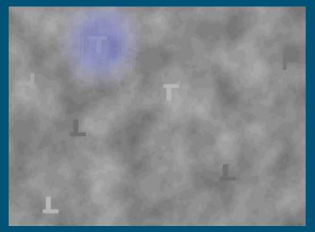
Cyber Event Logs



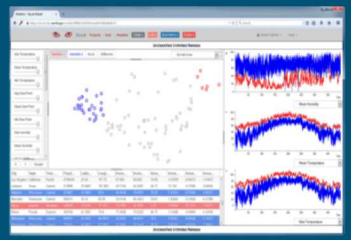
Seismic Data

```
// cnd is unknown on entry to this fragment
a1 = alloc();
a2 = alloc();
a3 = alloc();
b1 = a2;
b2 = a2;
*a1 = PUBLIC;
*a2 = SENSITIVE;
*a3 = a2;
if (cnd == 0) {
    *a3 = a1; }
if (cnd == 1) {
    *a3 = a2; }
if (cnd == 2) {
    *a3 = a2; }
pp1 = a3;
p2 = *pp1;
if (cnd == 2) {
    b2 = p2; }
if (cnd == 1) {
    b1 = p2; }
if (cnd == 0) {
    b2 = p2; }
print(*b2);
```

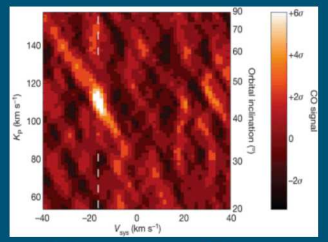
Code Analysis



Machine Learning Outputs



Engineering Test Results

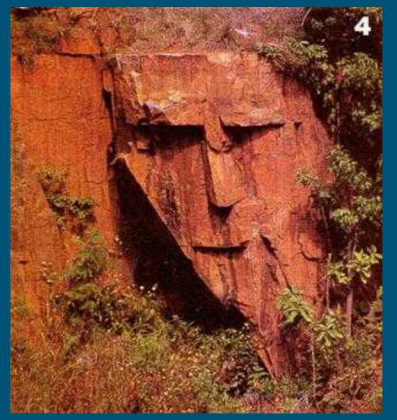


Abstract Data Visualizations

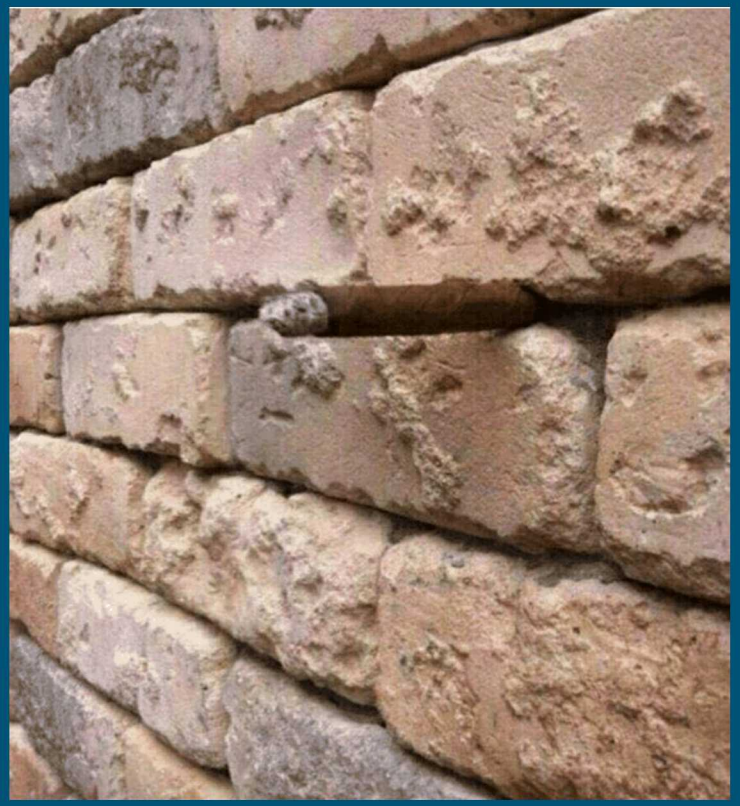
Visual Cognition Basics

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



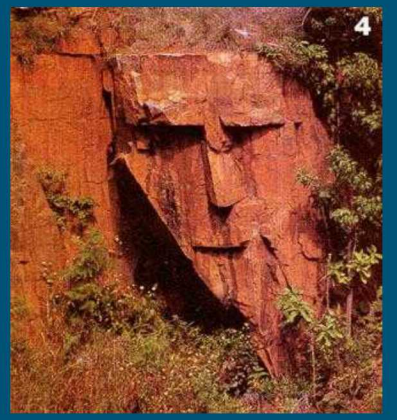
Draws on both:

- Perceptual cues (*bottom-up processing*)
- Conceptual knowledge (*top-down processing*)

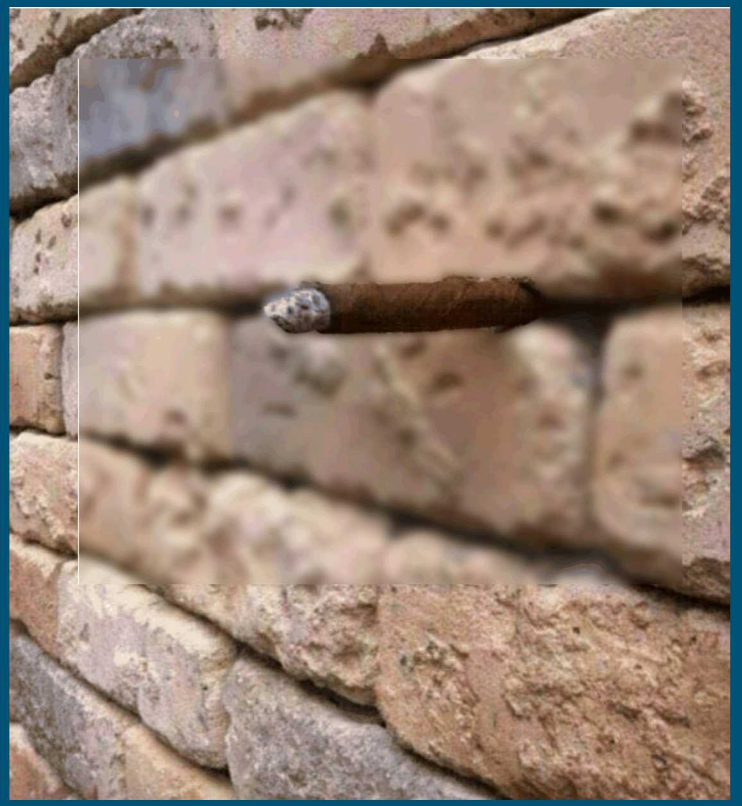
Visual Cognition Basics

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



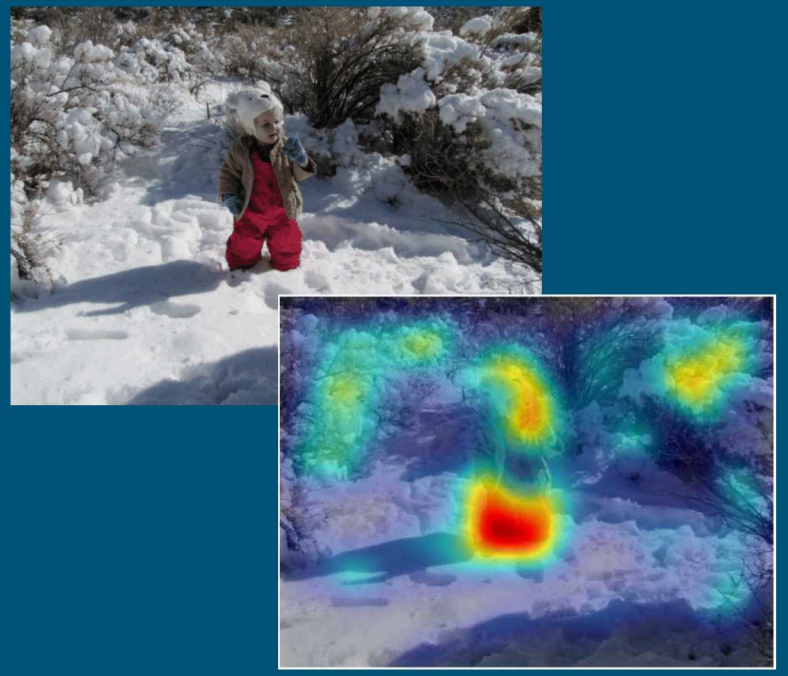
Draws on both:

- Perceptual cues (*bottom-up processing*)
- Conceptual knowledge (*top-down processing*)

Visual Attention

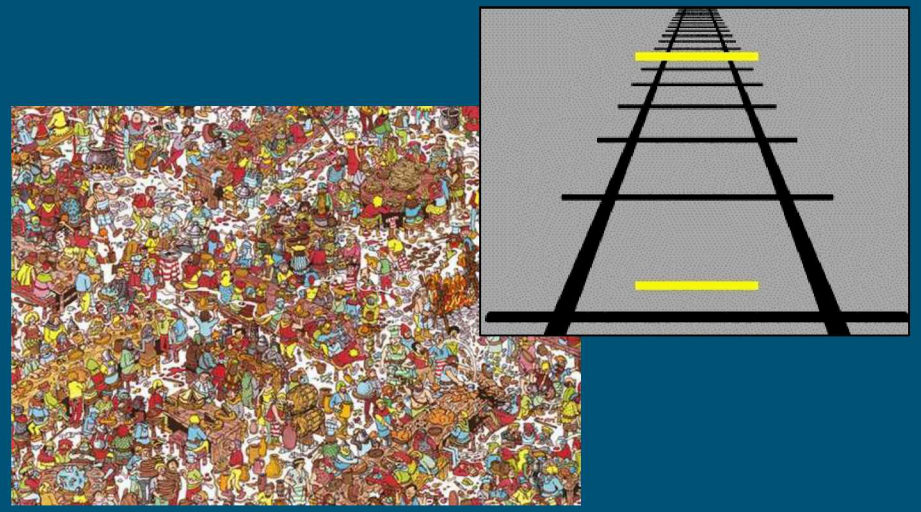
Bottom-up

- 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

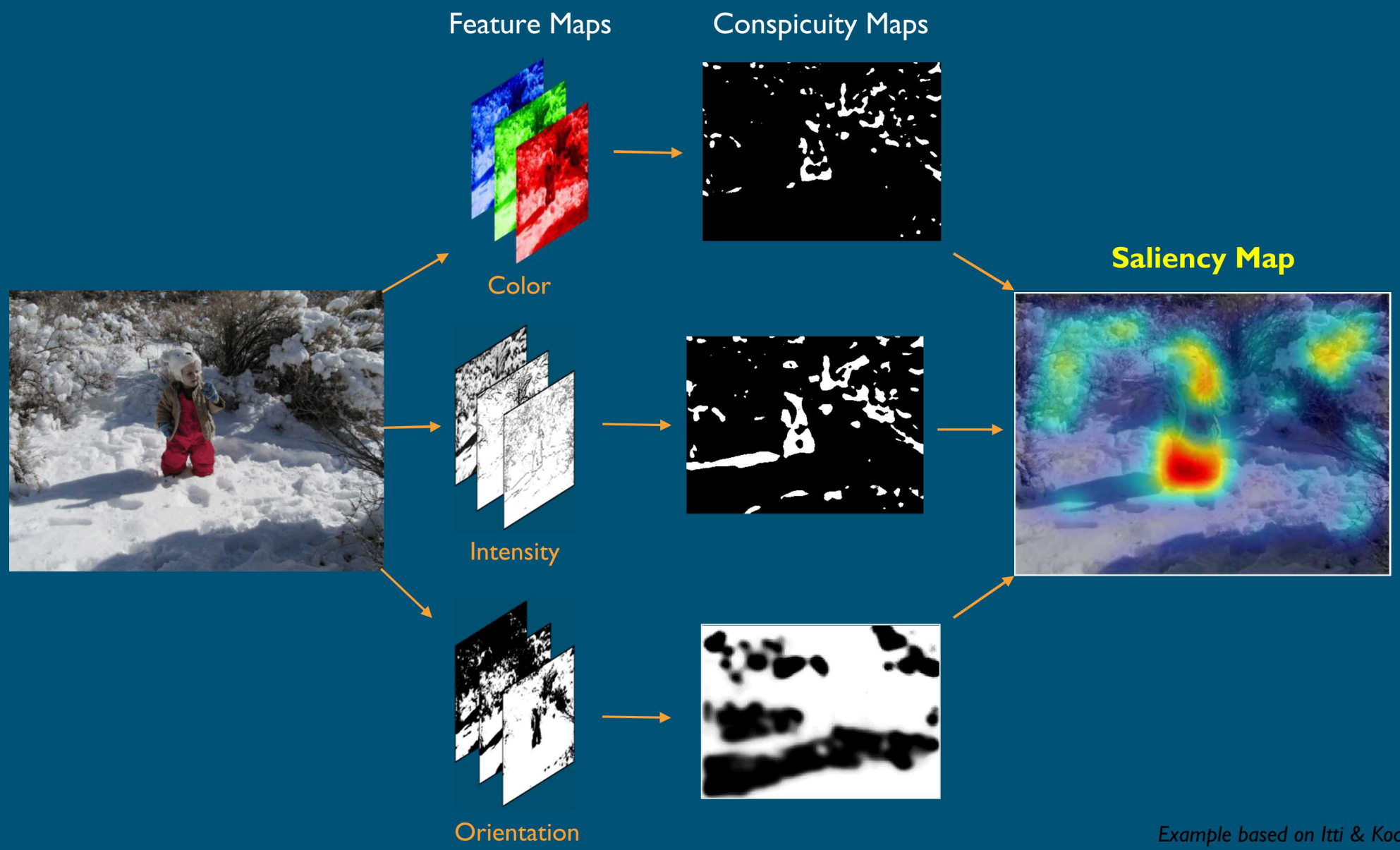


Top-down

- Allocated voluntarily according to viewer's goals and expectations
- Affected by cognitive load, working memory, past knowledge and experience
- Has a very powerful influence on bottom-up perception
- Parameters are NOT well understood



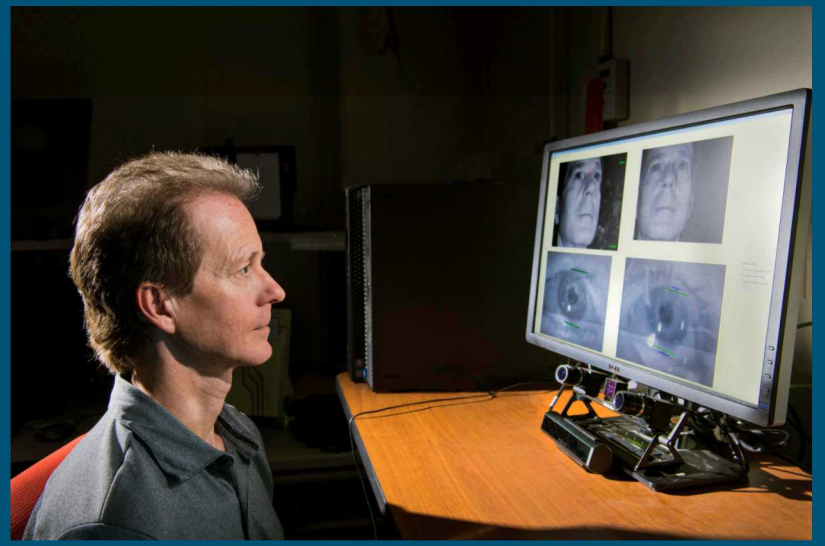
Bottom-up visual saliency can be modeled



Example based on Itti & Koch (2001) model

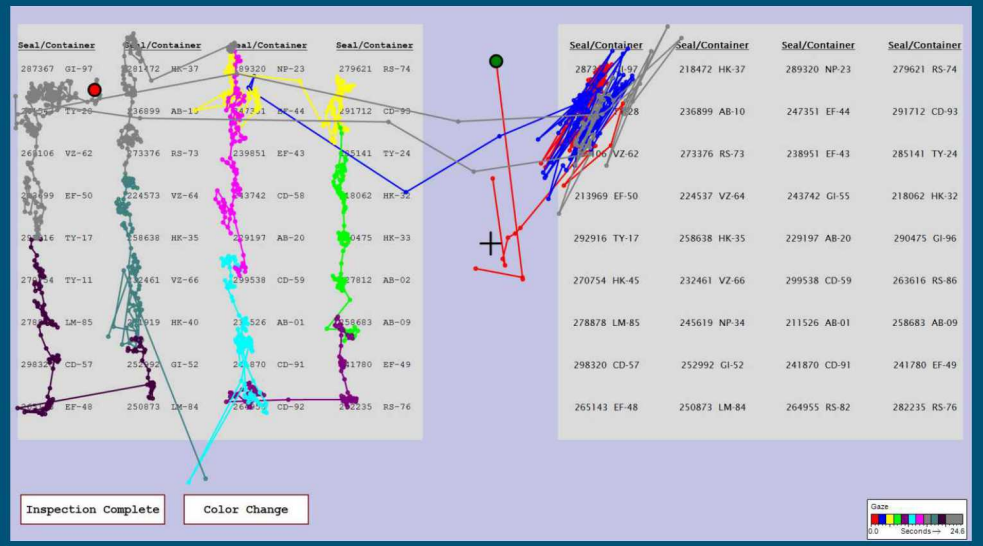
Methods for Studying Visual Cognition

Interviews with domain experts
- Understand current tools and workflow

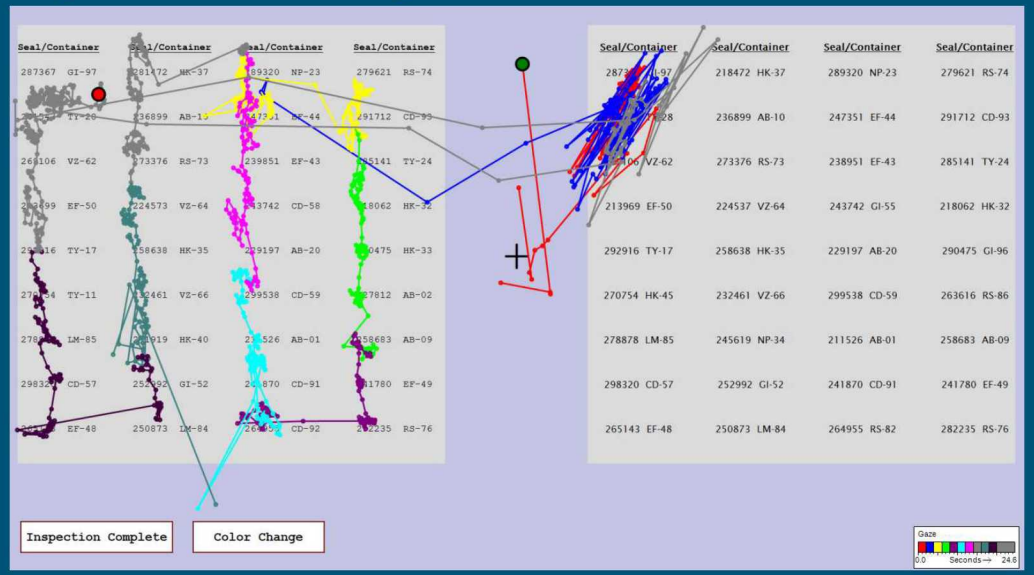


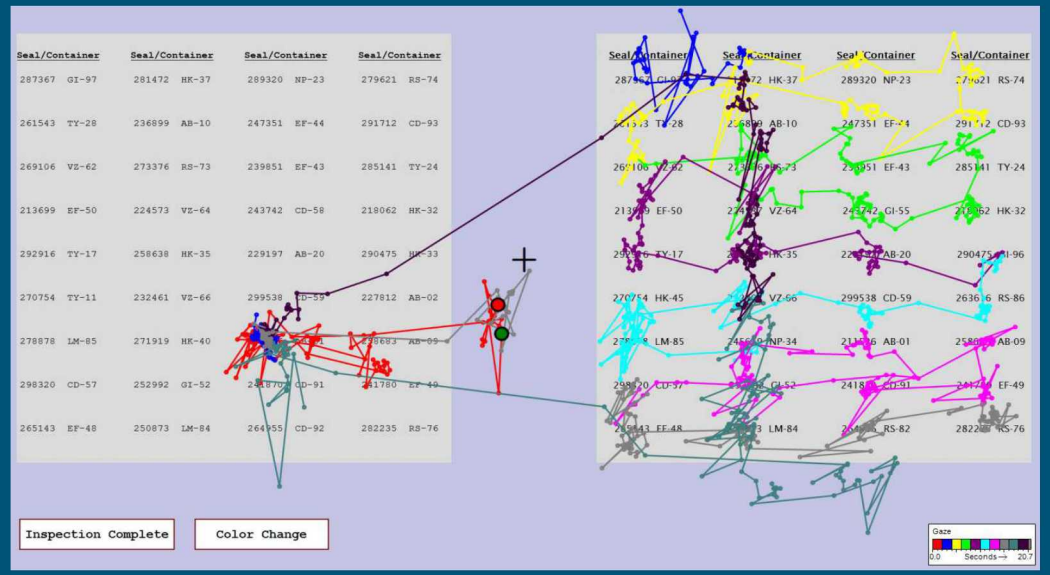
Behavioral studies
- Reaction time
- Accuracy

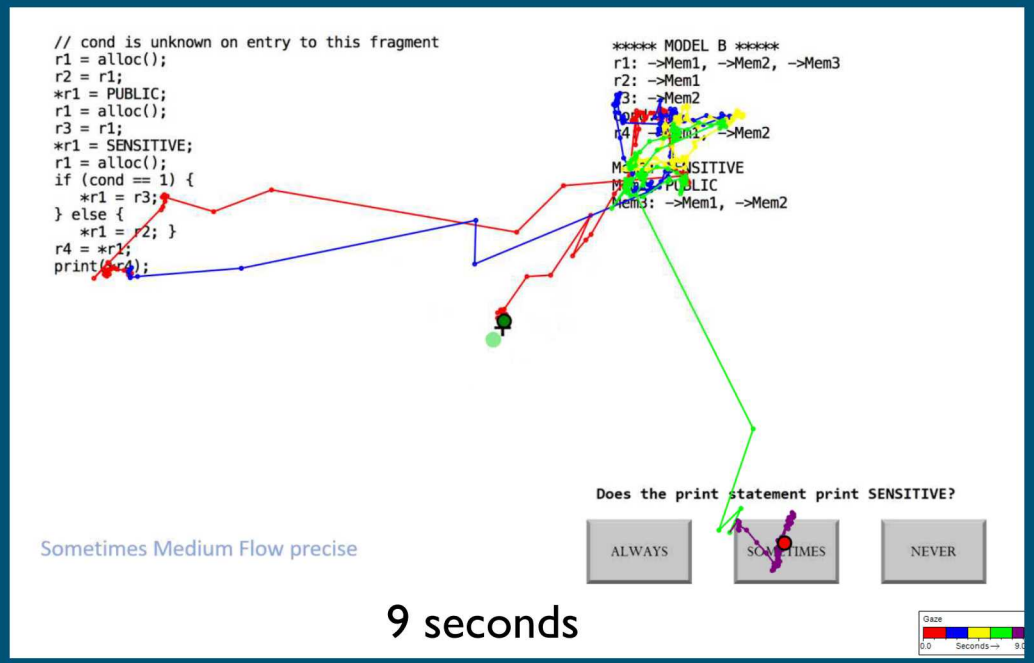
Eye Tracking studies
- Quantitative:
  - Time to first fixation in region of interest (ROI)
  - Percentage of fixations in ROIs
  - Counts and frequencies of transitions between ROIs
  - Classification of error types (scanning error, recognition error, decision error)
- Qualitative:
  - Characterization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



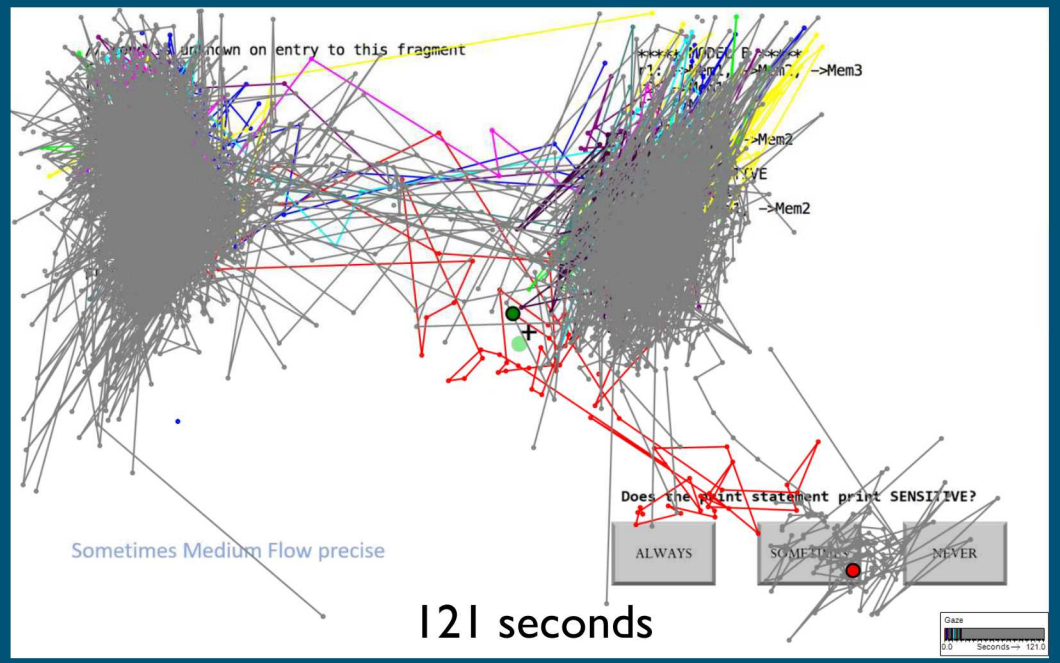
Eye Tracking Data







9 seconds

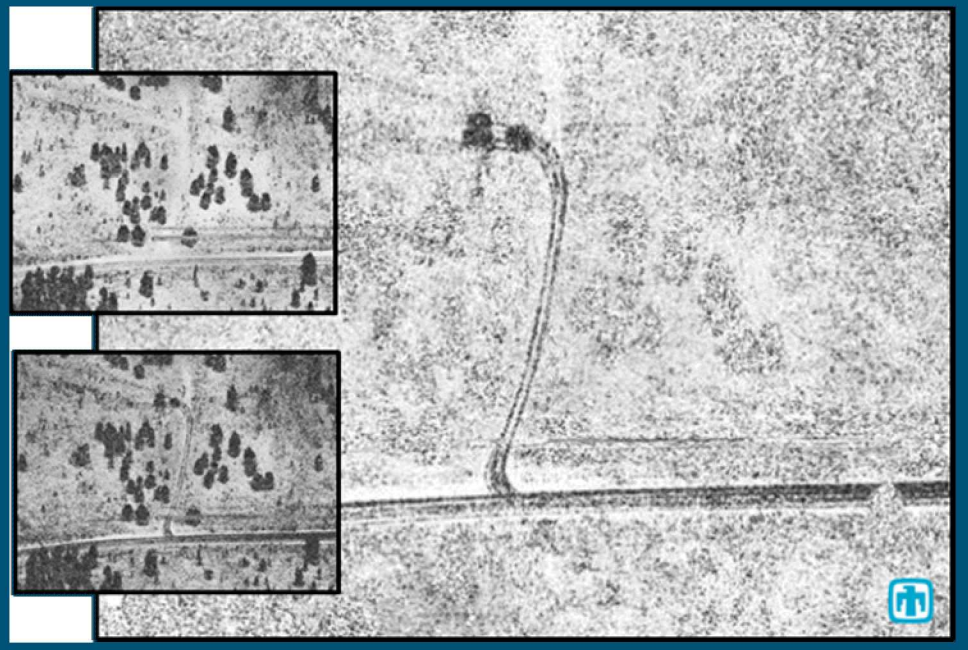


121 seconds

An Example: Synthetic Aperture Radar (SAR) Imagery Analysis

SAR analysts recognize and classify patterns using SAR imagery.

The same scene is imaged repeatedly over extended periods of time, allowing the analyst to see changes.



Courtesy of Sandia National Laboratories, Airborne ISR

What features of the SAR and CCD images support imagery analysts' task?

What are the most visually salient features?

- Are those the most important ones?

What are the most task-relevant features?

- Is task performance different for experienced and inexperienced analysts?

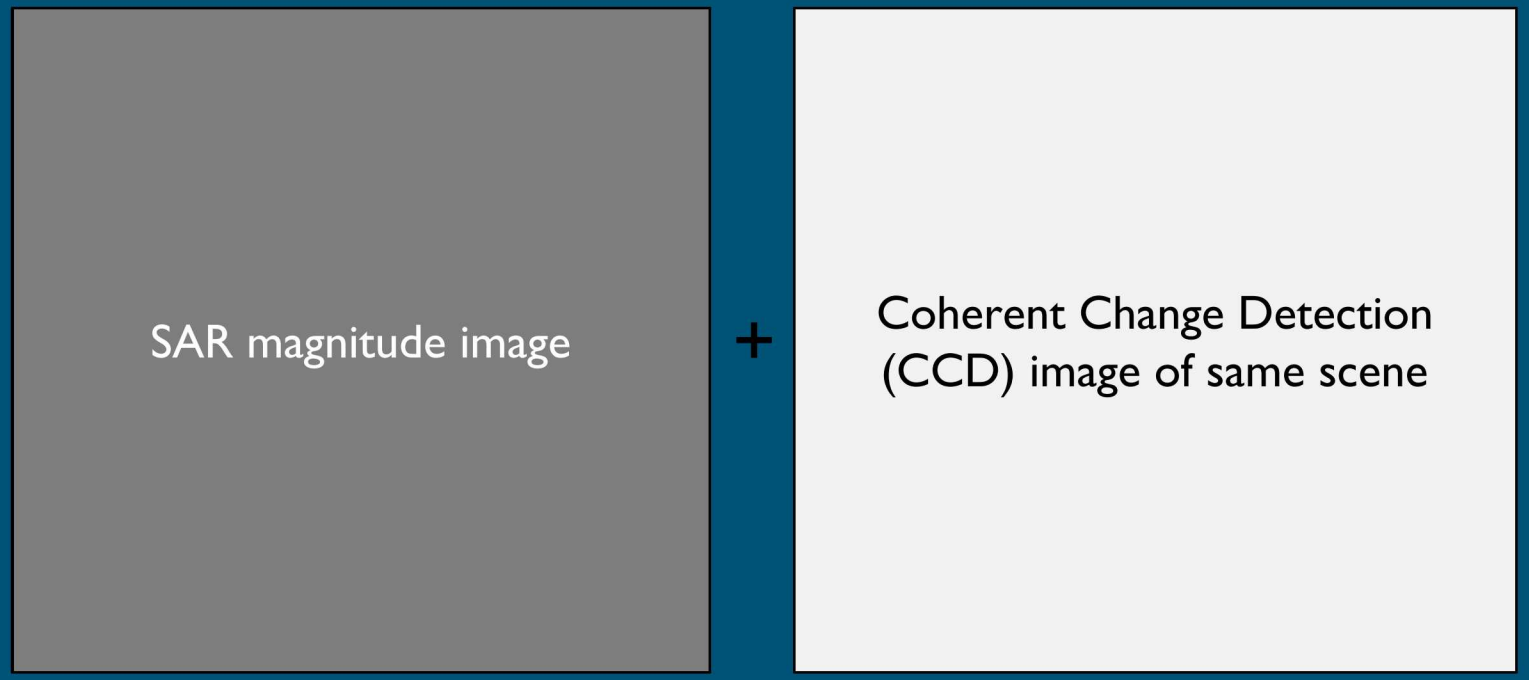
Eye tracking data collected from experienced and inexperienced viewers

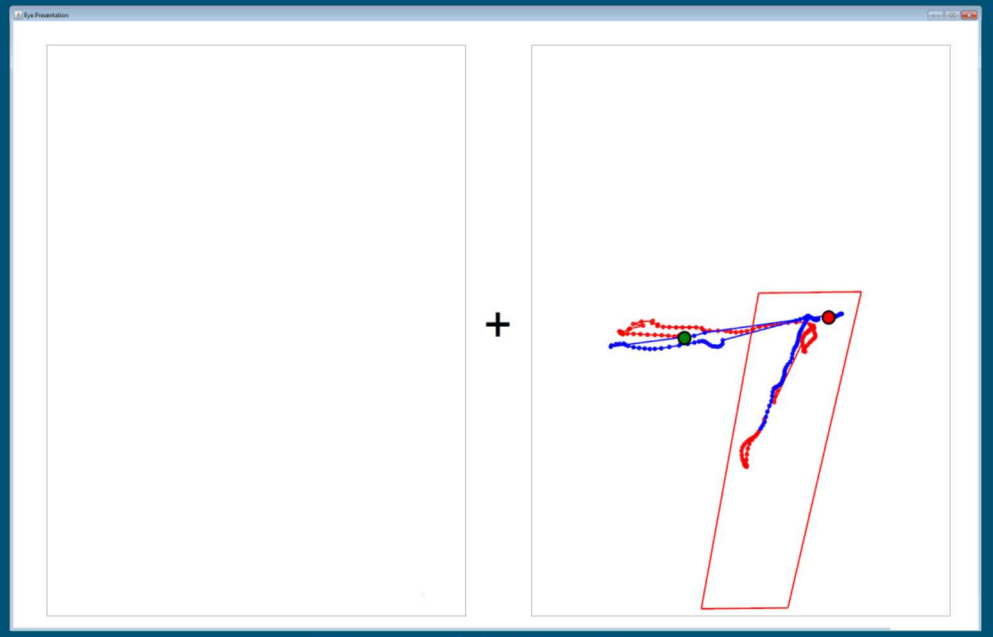
Gaze patterns compared to visual saliency and task-relevant image features

SAR Eye Tracking Study - Task

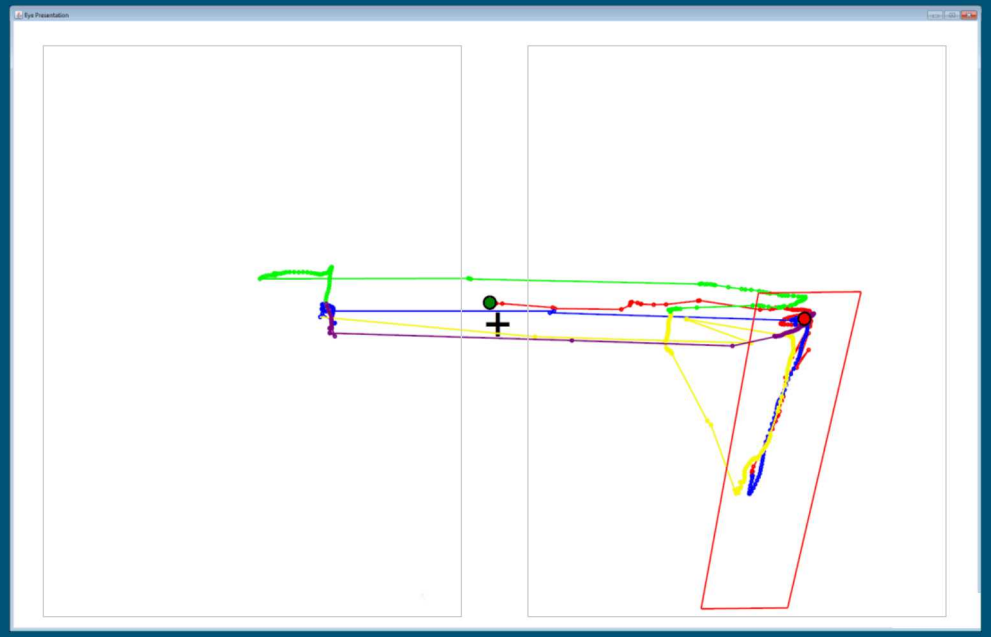
Target detection task using two images, presented side by side

- Participants were expert SAR analysts, SAR engineers, and novices

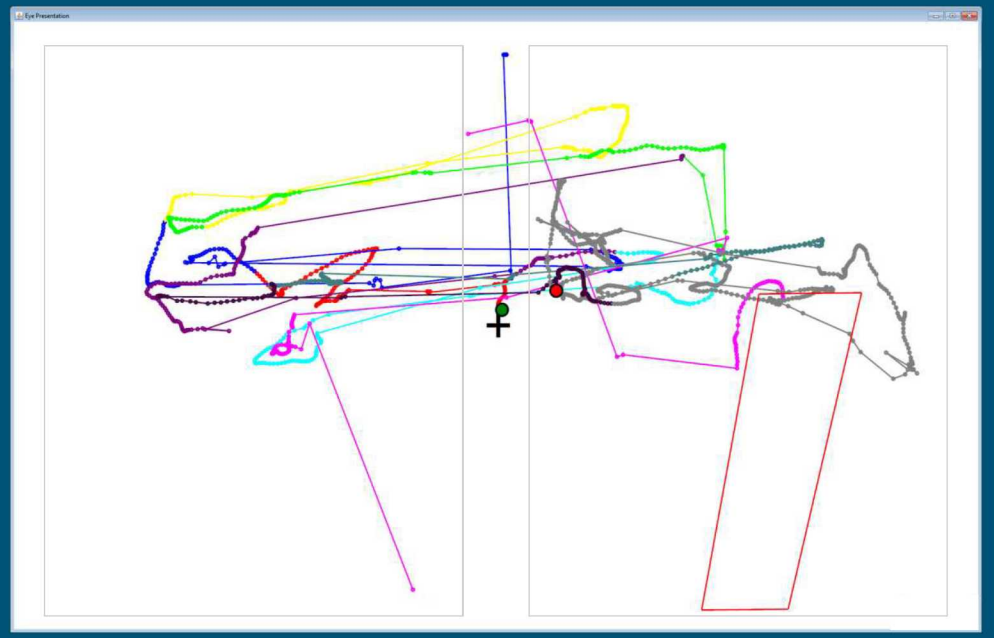




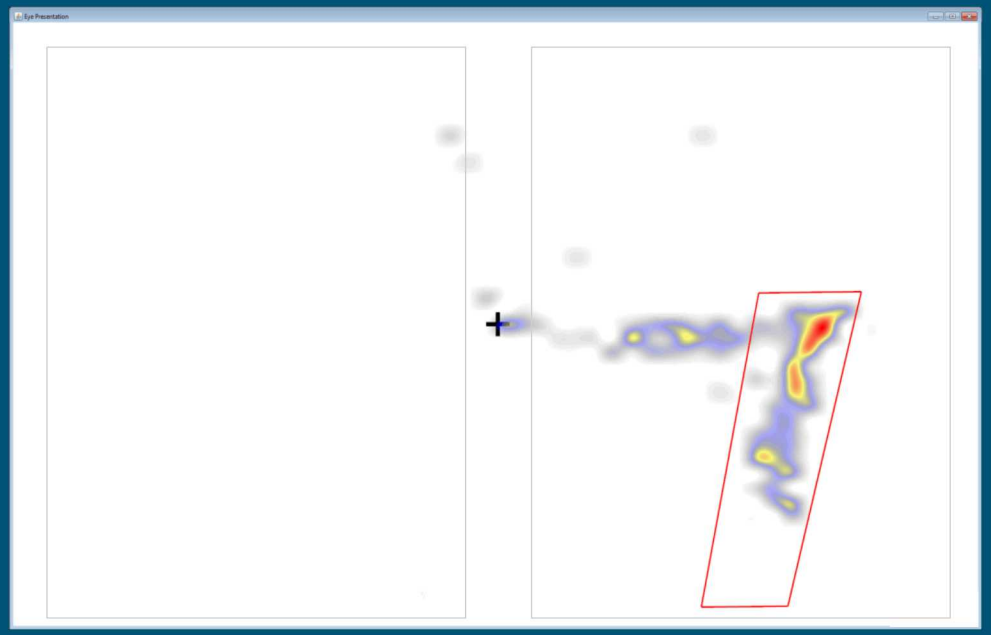
Expert SAR Analysts



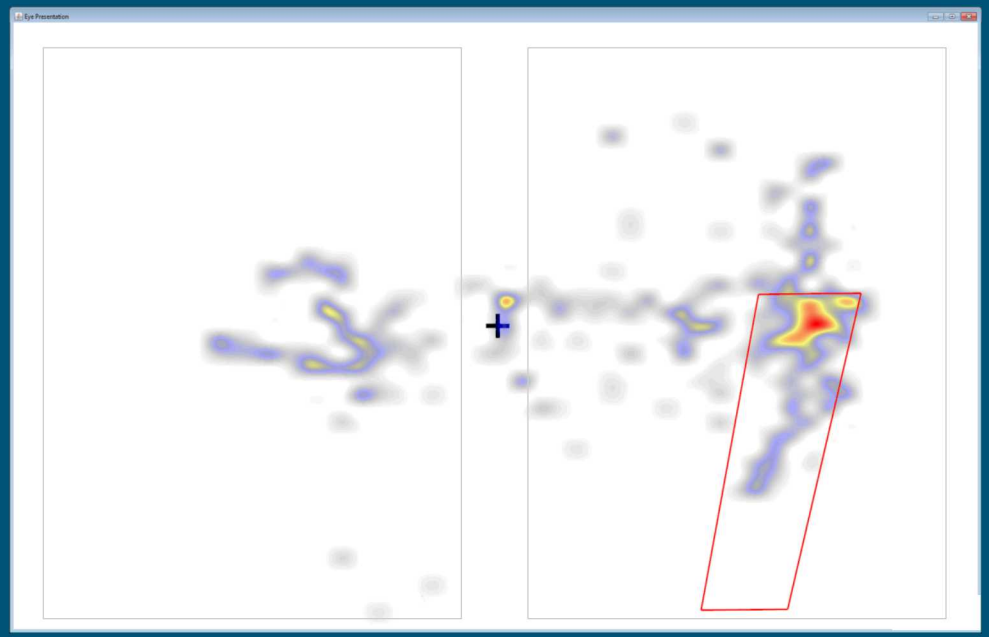
Knowledgeable Non-Analysts



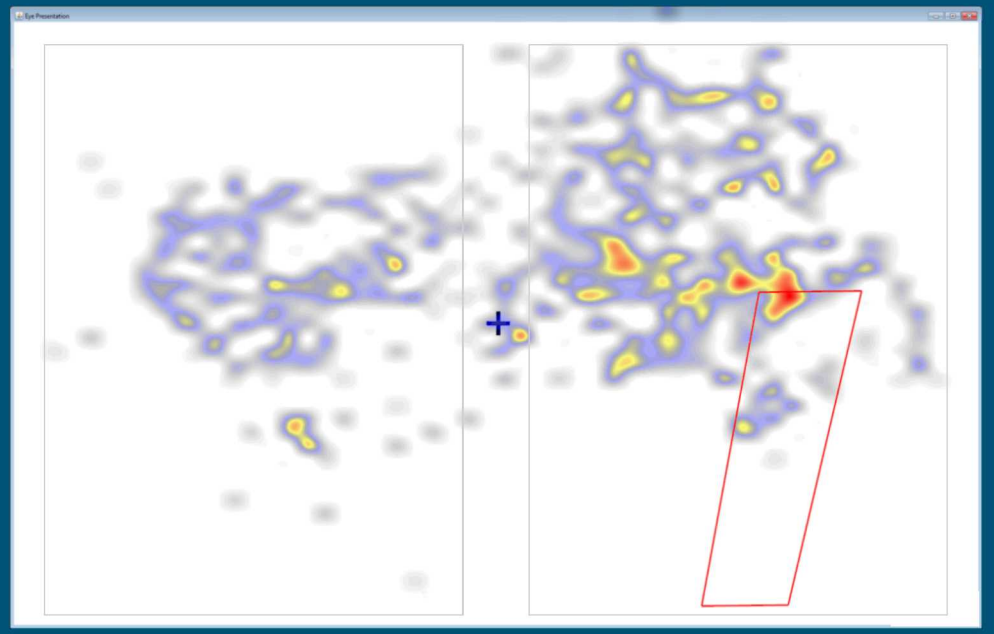
Novices



Expert SAR Analysts

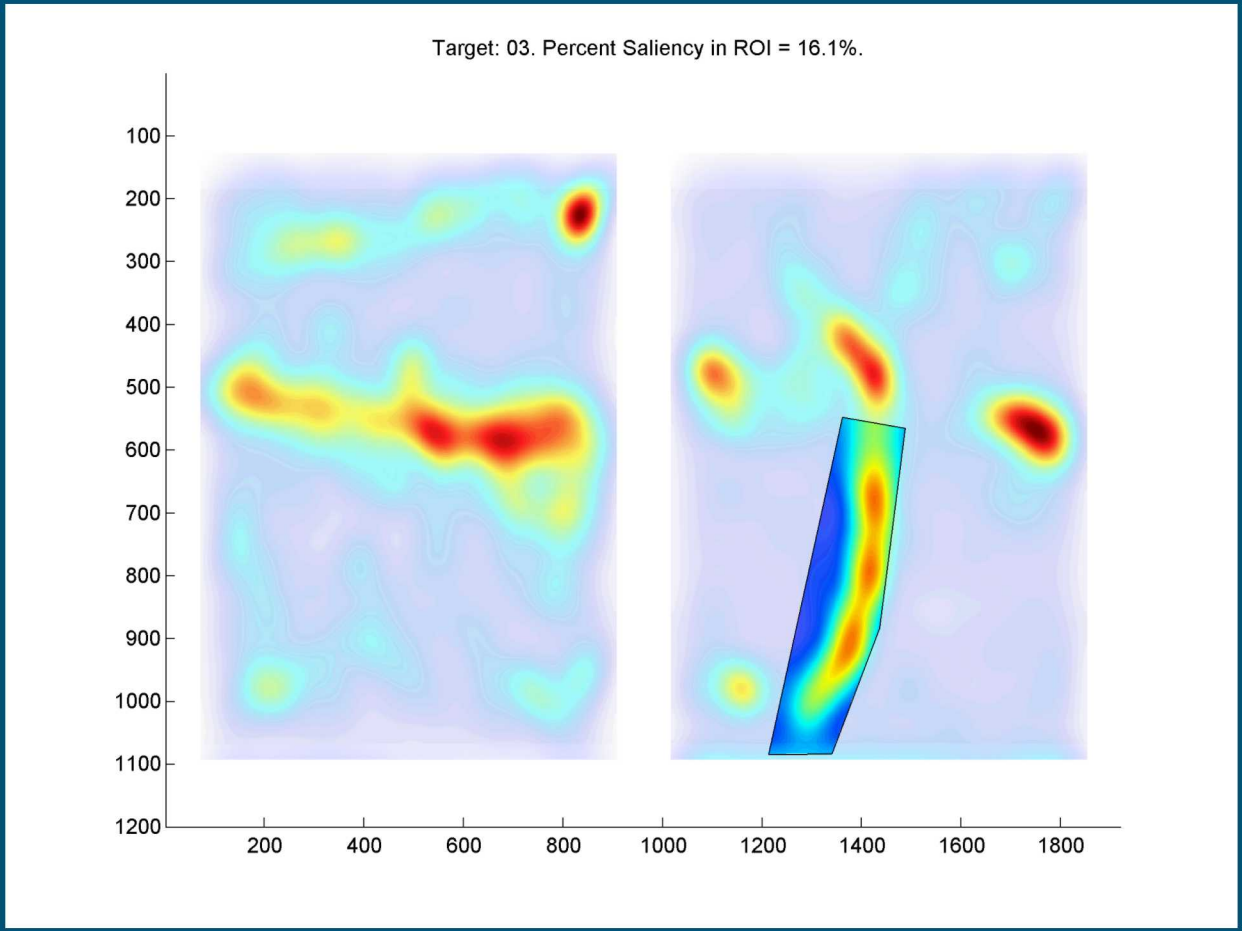


Knowledgeable Non-Analysts



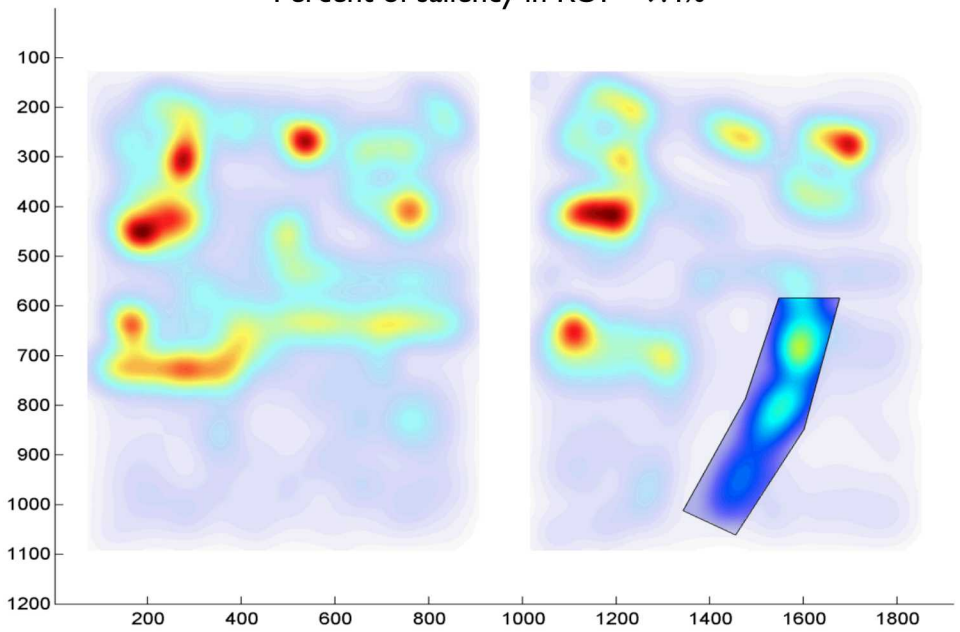
Novices

Comparison of Gaze Maps and Saliency Maps

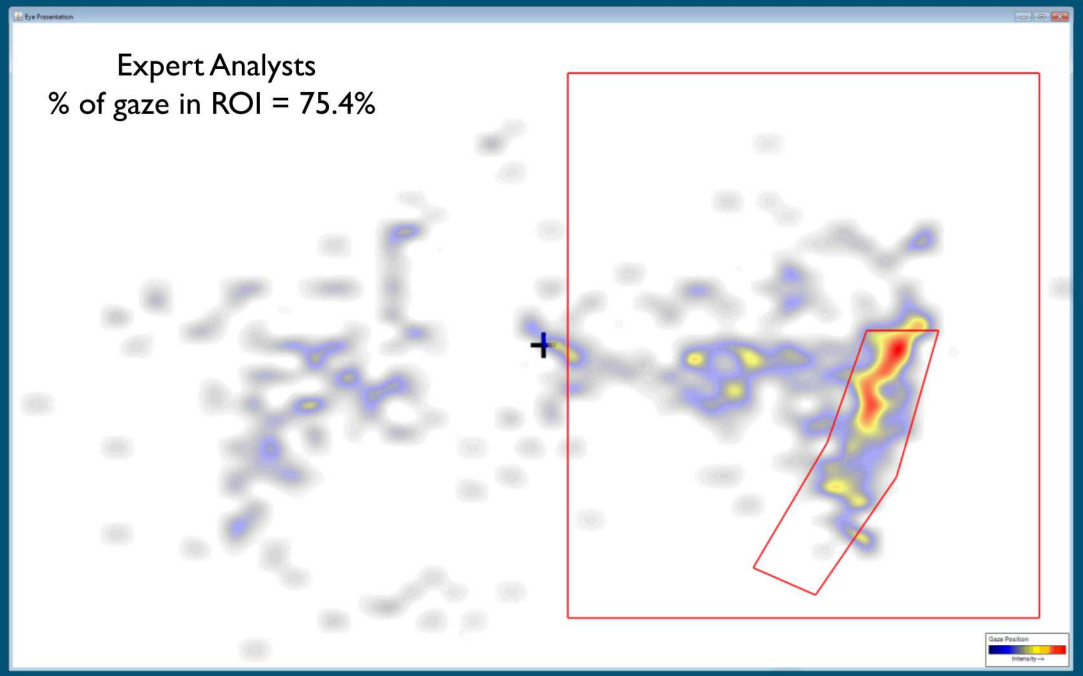


Eye tracking gaze maps, which represent a combination of top-down and bottom-up saliency, can be compared to maps of bottom-up saliency to examine the differences between the two

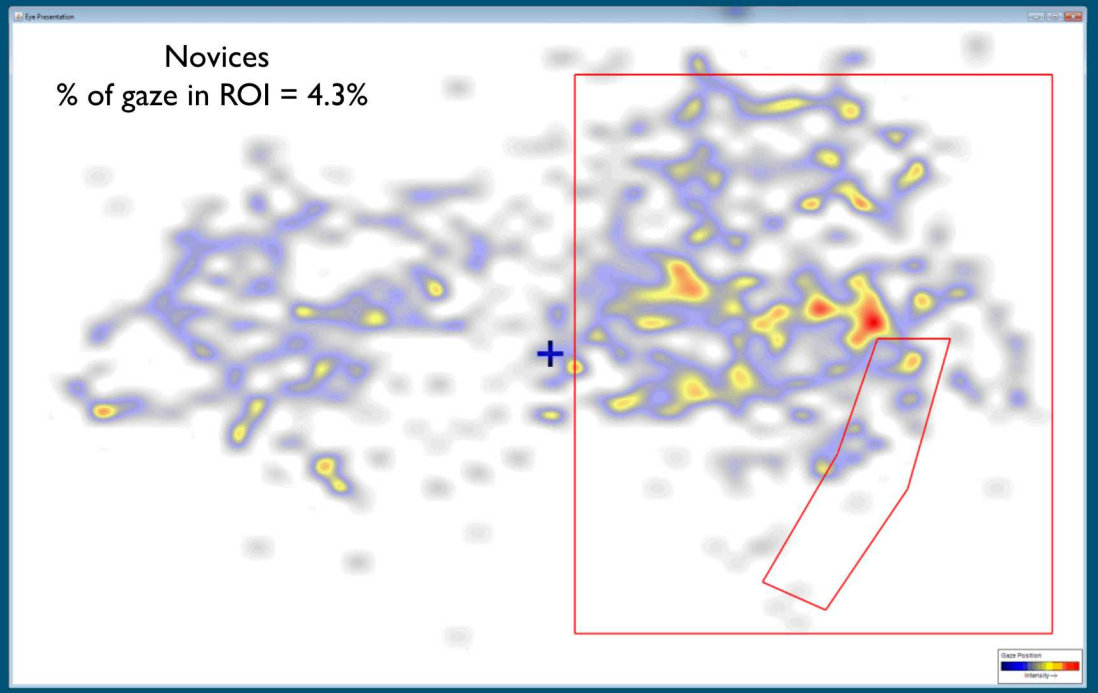
Percent of saliency in ROI = 9.4%



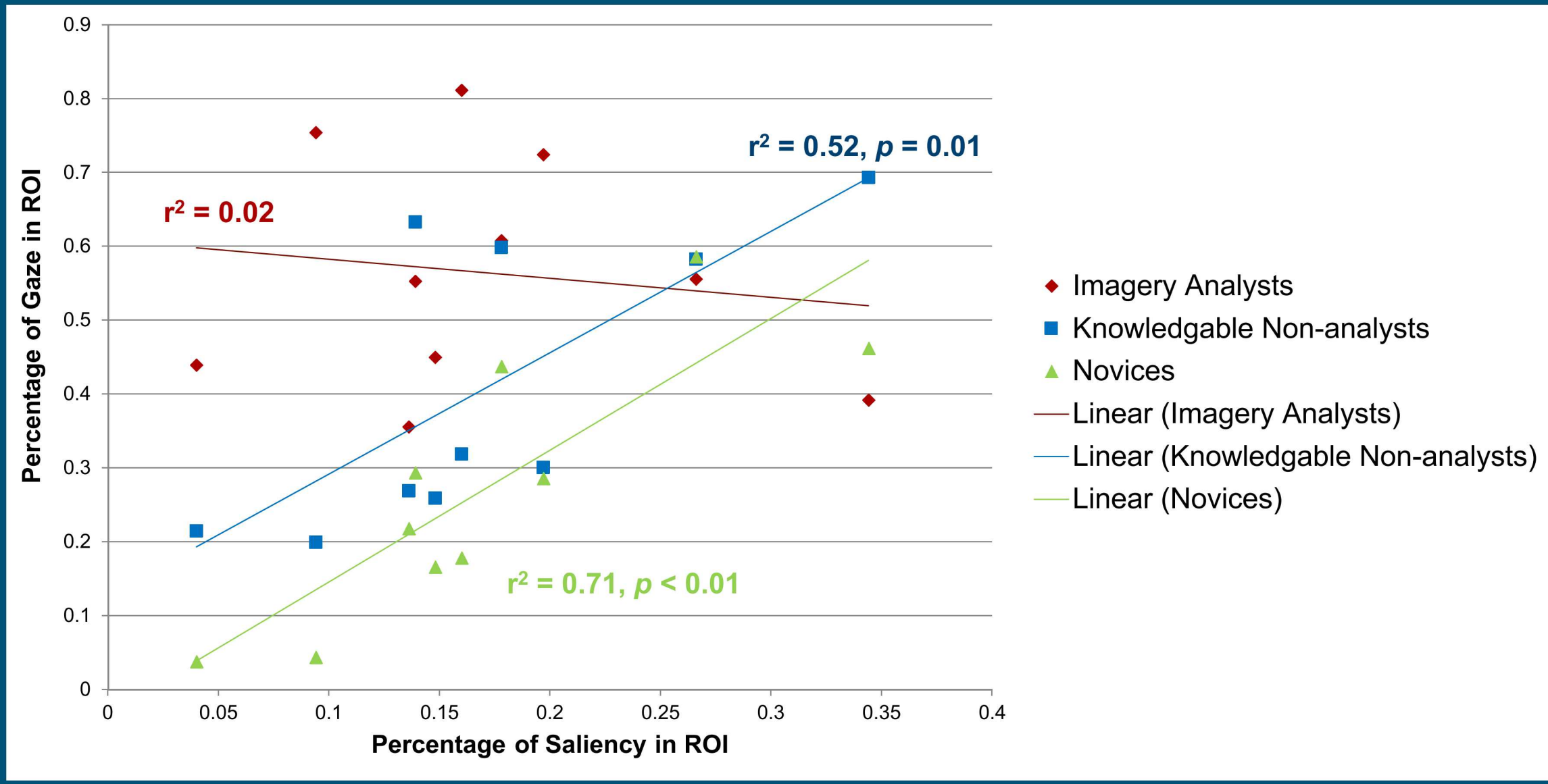
Expert Analysts
% of gaze in ROI = 75.4%



Novices
% of gaze in ROI = 4.3%



Correlation between gaze and saliency



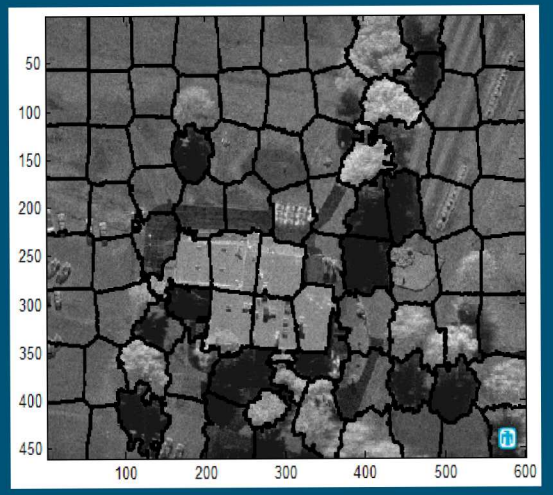
Applying Eye Tracking Results

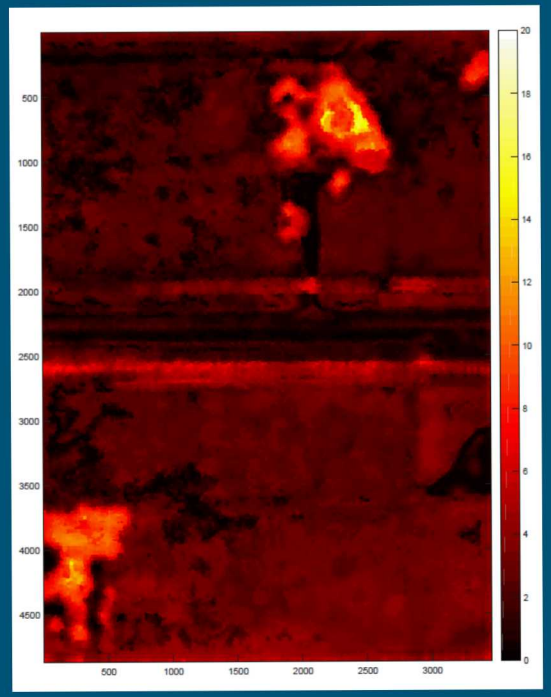
Improve training of new analysts by understanding what visual features experienced analysts use

Modulate visual saliency of features that are task-relevant or task-irrelevant

Tune automatic feature detection algorithms to use parameters similar to expert analysts

- Outputs should aid analysts in maintaining their high level of performance as the scale of the data changes





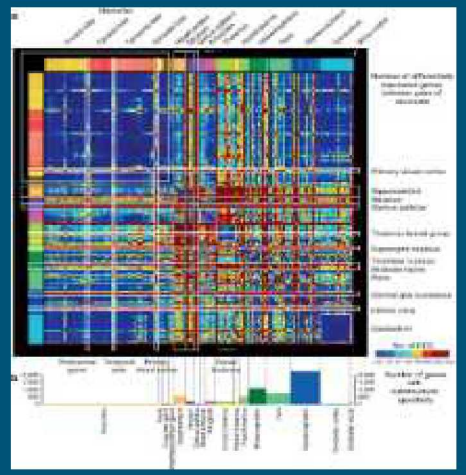
Matzen, L. E., Haass, M. J., Tran, J., & McNamara, L. A. (2016). Using eye tracking metrics and visual saliency maps to assess image utility. *Electronic Imaging, 2016*(16), 1-8.

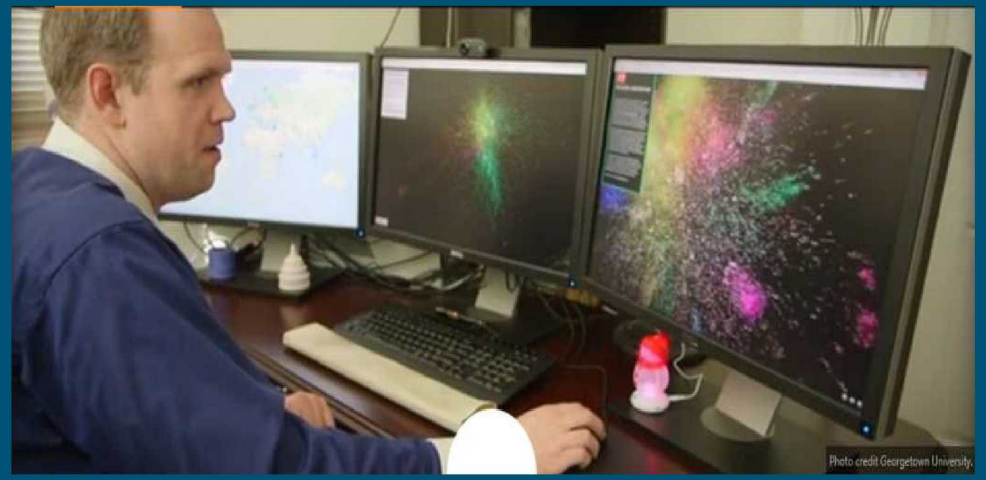
Abstract Data Visualizations

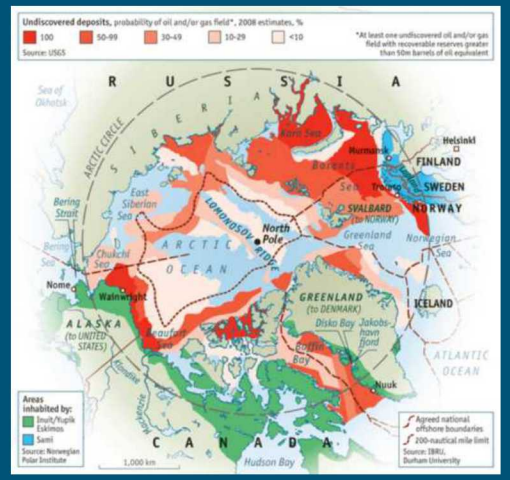
Using a combination of saliency maps and eye tracking was very useful for scene-like visualizations, such as SAR

Can we use salience models to help design and evaluate abstract data visualizations?

- Effective visualizations should draw the viewer's attention to the most important or task-relevant information (Jänicke & Chen, 2010)

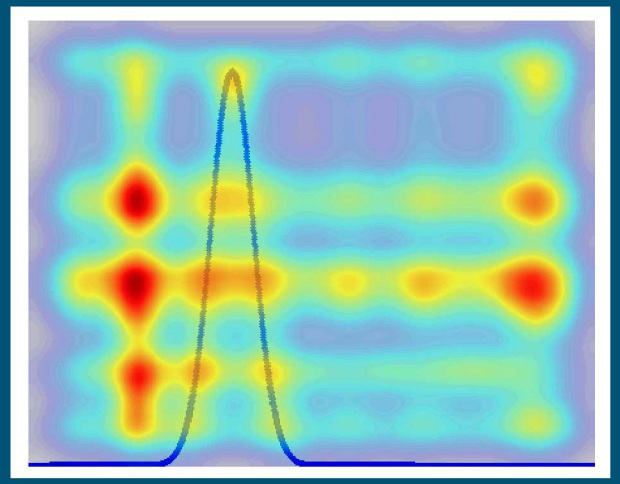




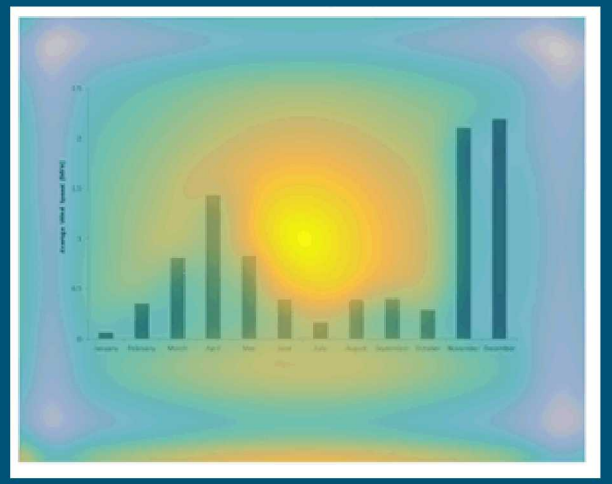


However…

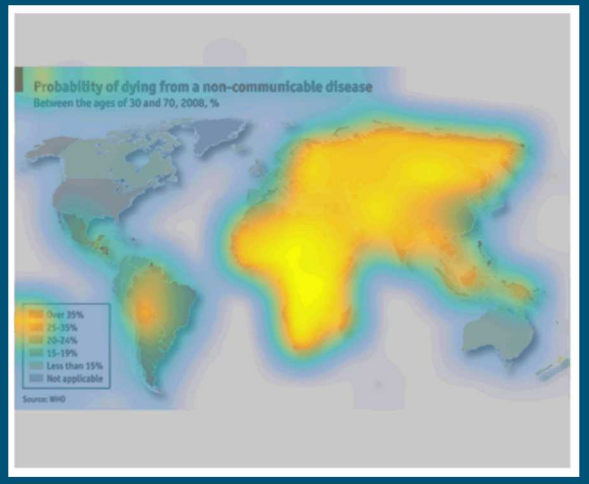
Existing saliency models fail for abstract visualizations!



Graph-Based Visual Saliency (2006)
(see also Itti & Koch, 2001)

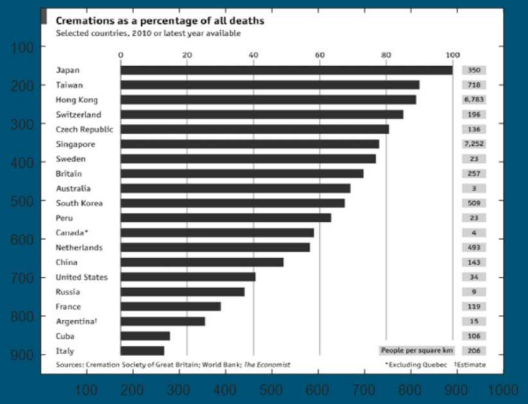


Ensembles of Deep Networks Model (eDN)
(Vig, Dorr & Cox, 2014)

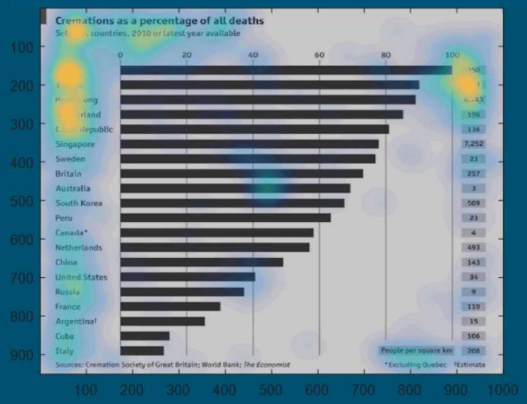


Boolean Map-Based Saliency Model (BMS)
(Zhang & Sclaroff, 2015)

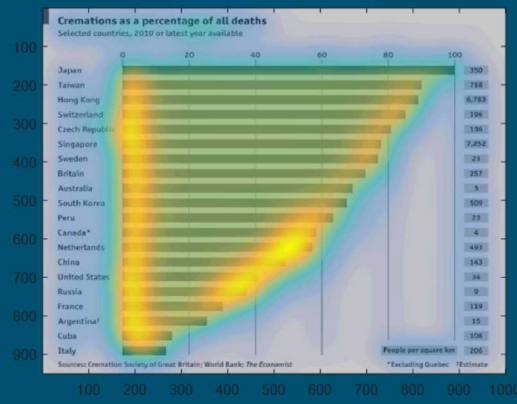
Visualization*



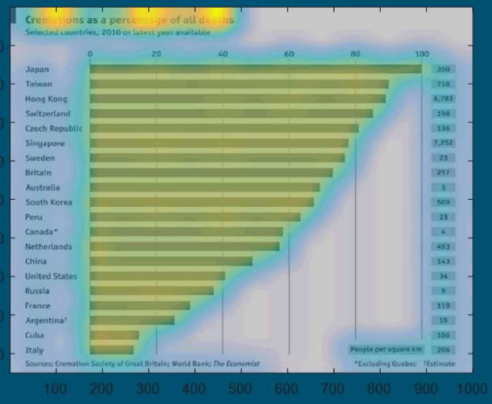
Human Subjects Fixation Map



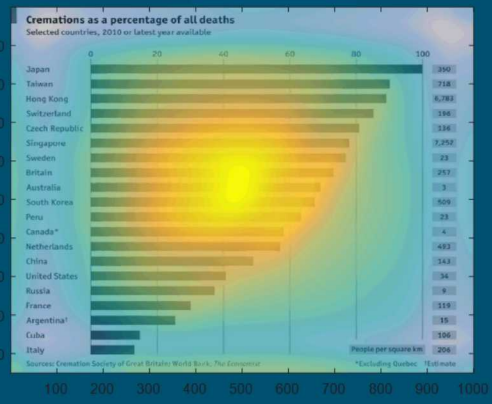
Itti & Koch



BMS



eDN



*From MASSVIS Dataset, Borkin et al., 2013; http://massvis.mit.edu

Data Visualization Saliency (DVS) Model

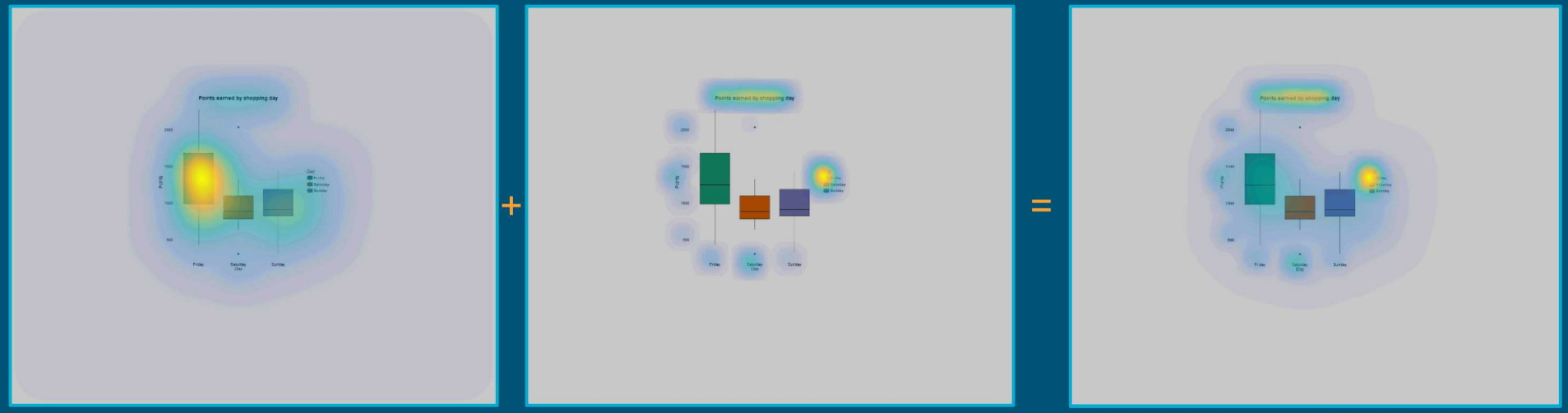
We compared eye tracking data and saliency maps for a large set of visualizations to identify the problems in the existing models

The DVS model was designed to address those problems

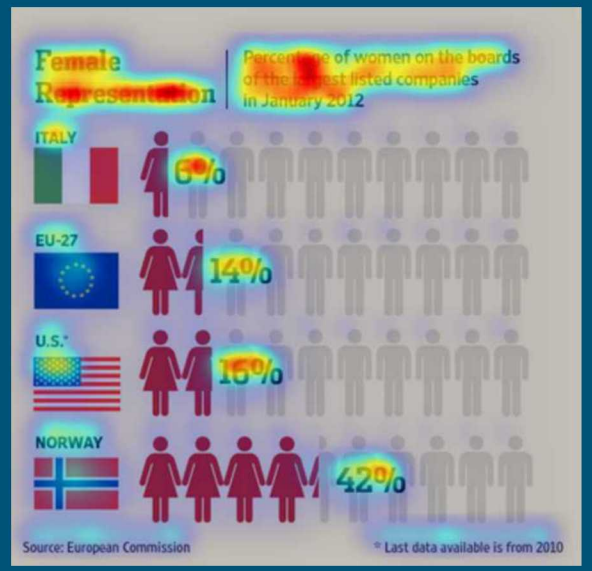
- DVS model provides a significantly better match to human fixation data than prior saliency models
  - Greater than one standard deviation improvement for most metrics!

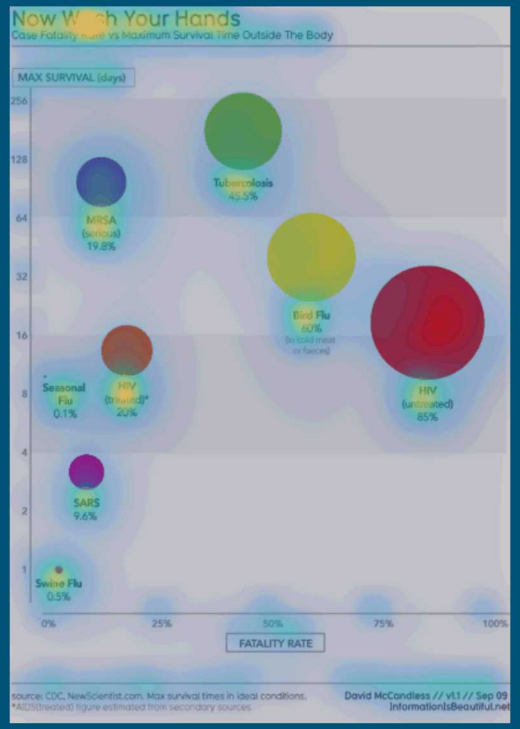
DVS is a weighted combination of two components:

Modified Itti Saliency Map + Text Saliency Map = Data Visualization Saliency Map

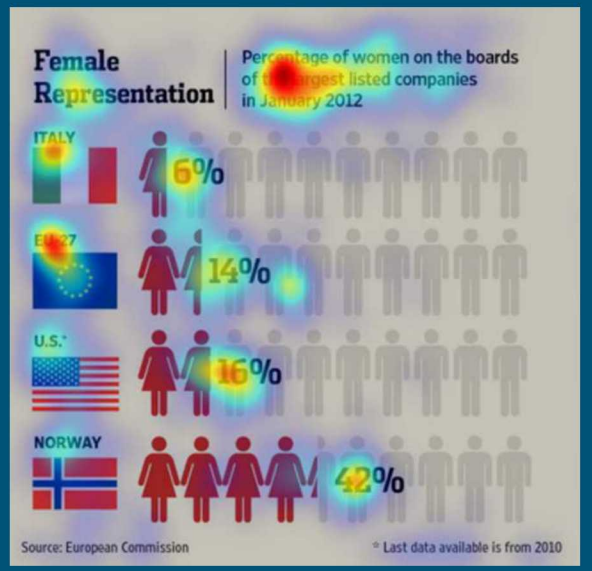


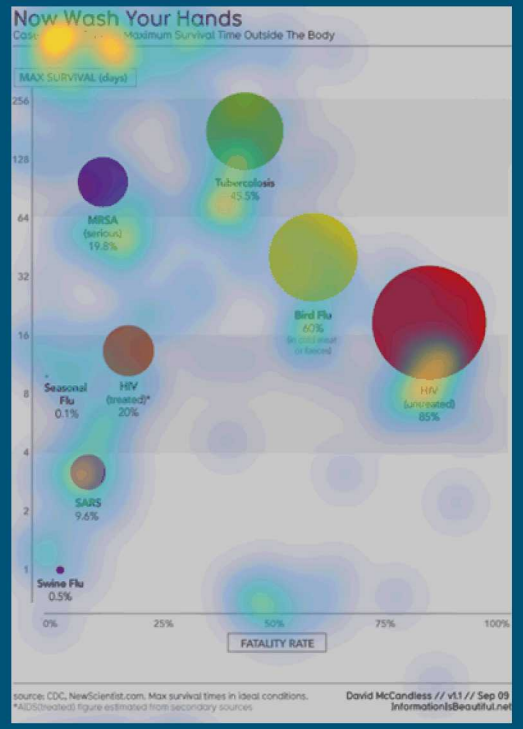
DVS model predictions





Actual fixations

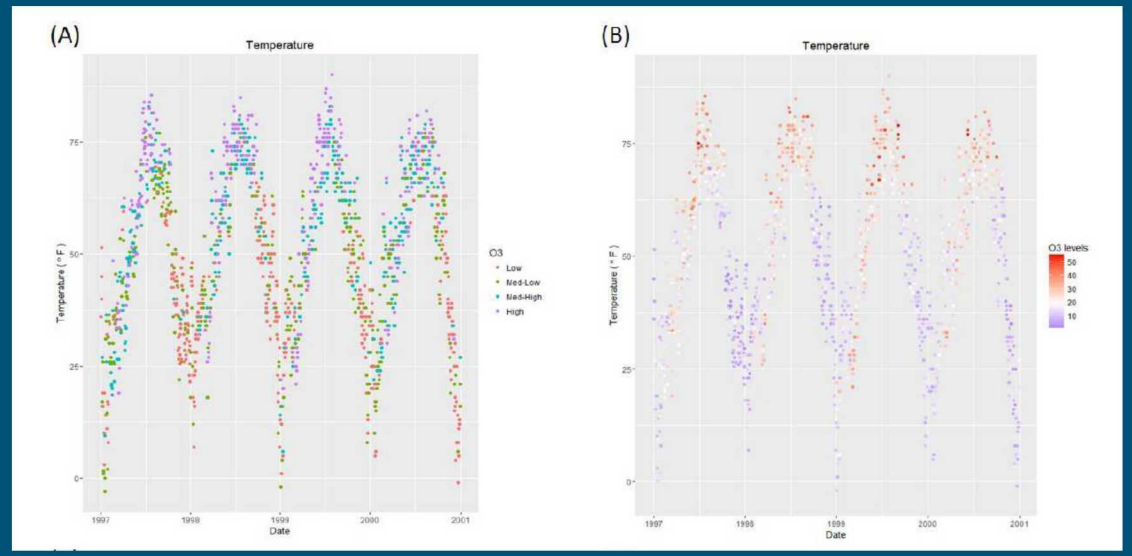




Examples of applying DVS model - Qualitative

Same data plotted two ways

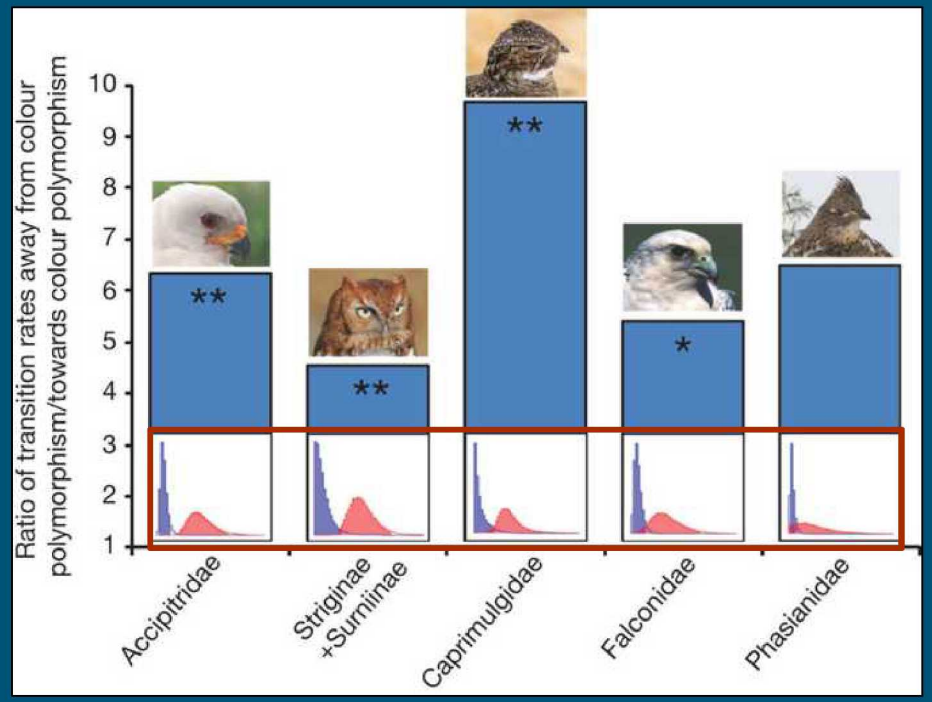
- Default ggplot2
- Diverging color scheme

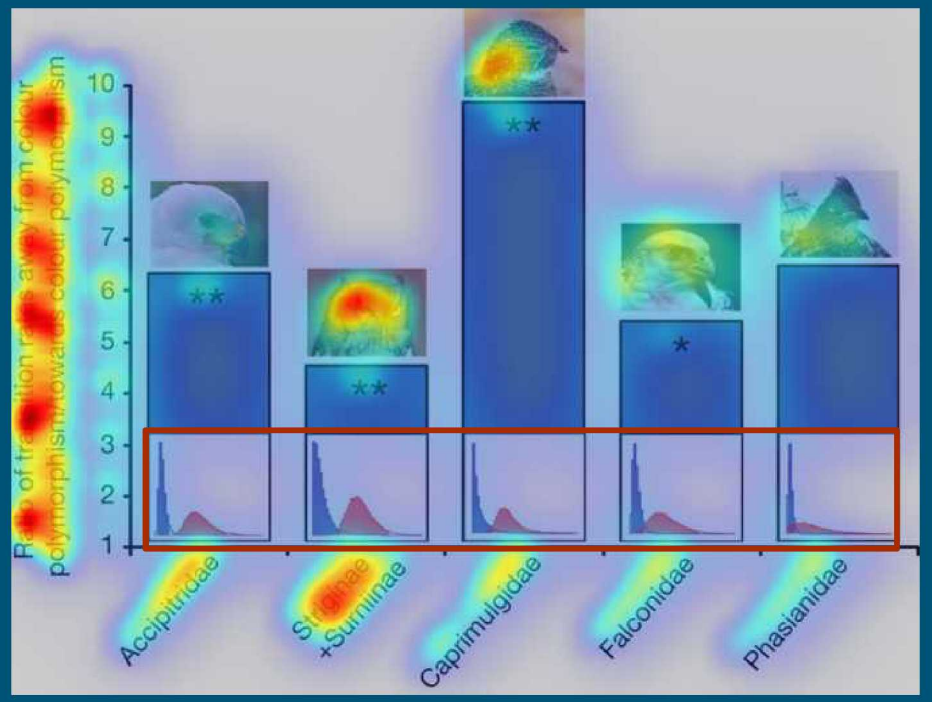


Examples of applying DVS model – Qualitative or Quantitative

Saliency maps can be compared to a relevancy map defined by the vis designer (Jänicke and Chen, 2010)

- Comparisons can be done categorically or using one (or more) metrics
- Can also define regions of interest and calculate the percentage of saliency





Abstract Data Visualizations - Summary

The DVS model is an example of how aspects of human cognition can be modeled and used to improve systems, data analysis pipelines, and human-system performance

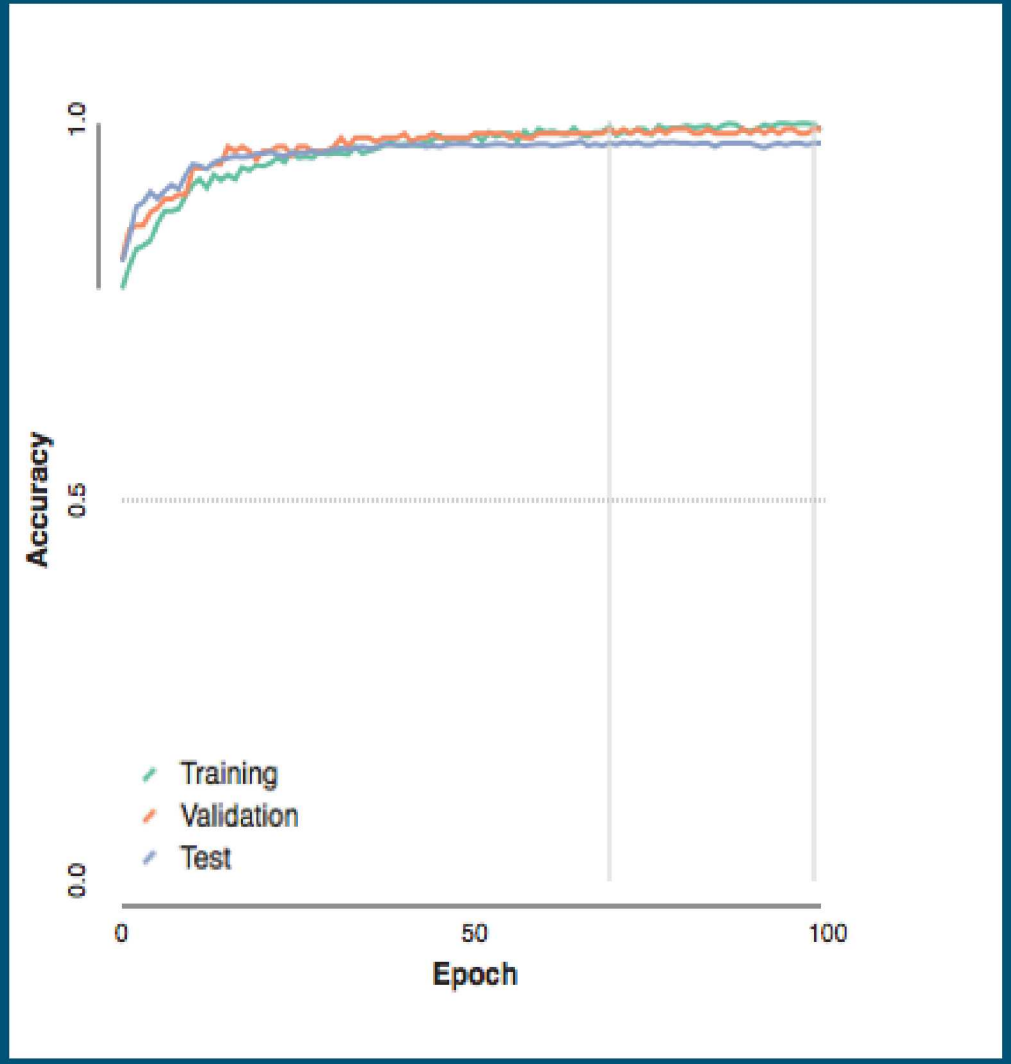
You can download the model here (runs in MATLAB):

tinyurl.com/DVSmodel

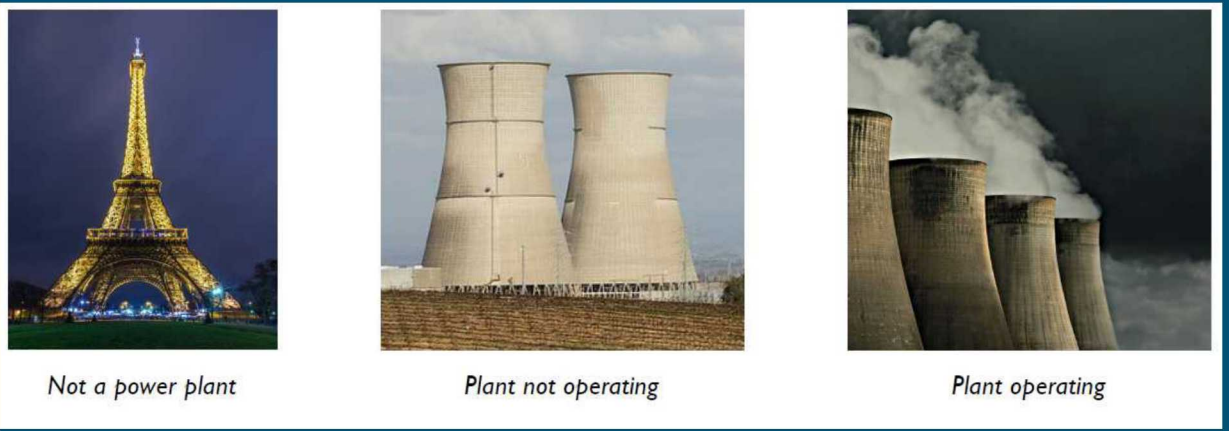
Matzen, L. E., Haass, M. J., Divis, K. M., Wang, Z., & Wilson, A. T. (2017). Data visualization saliency model: A tool for evaluating abstract data visualizations. *IEEE Transactions on Visualization and Computer Graphics*, *24*(1), 563-573.

Matzen, L. E., Haass, M. J., Divis, K. M., & Stites, M. C. (2017, July). Patterns of attention: How data visualizations are read. In *International Conference on Augmented Cognition* (pp. 176-191). Springer, Cham.

What if your visualizations are outputs from a machine learning tool?



Machine learning/deep learning (MLDL) model performance continues to improve…



…but there will always be some errors.

p cooling tower = 1.00000

p cooling tower = 0.96455

Our questions…

How do ML/DL errors impact human performance?

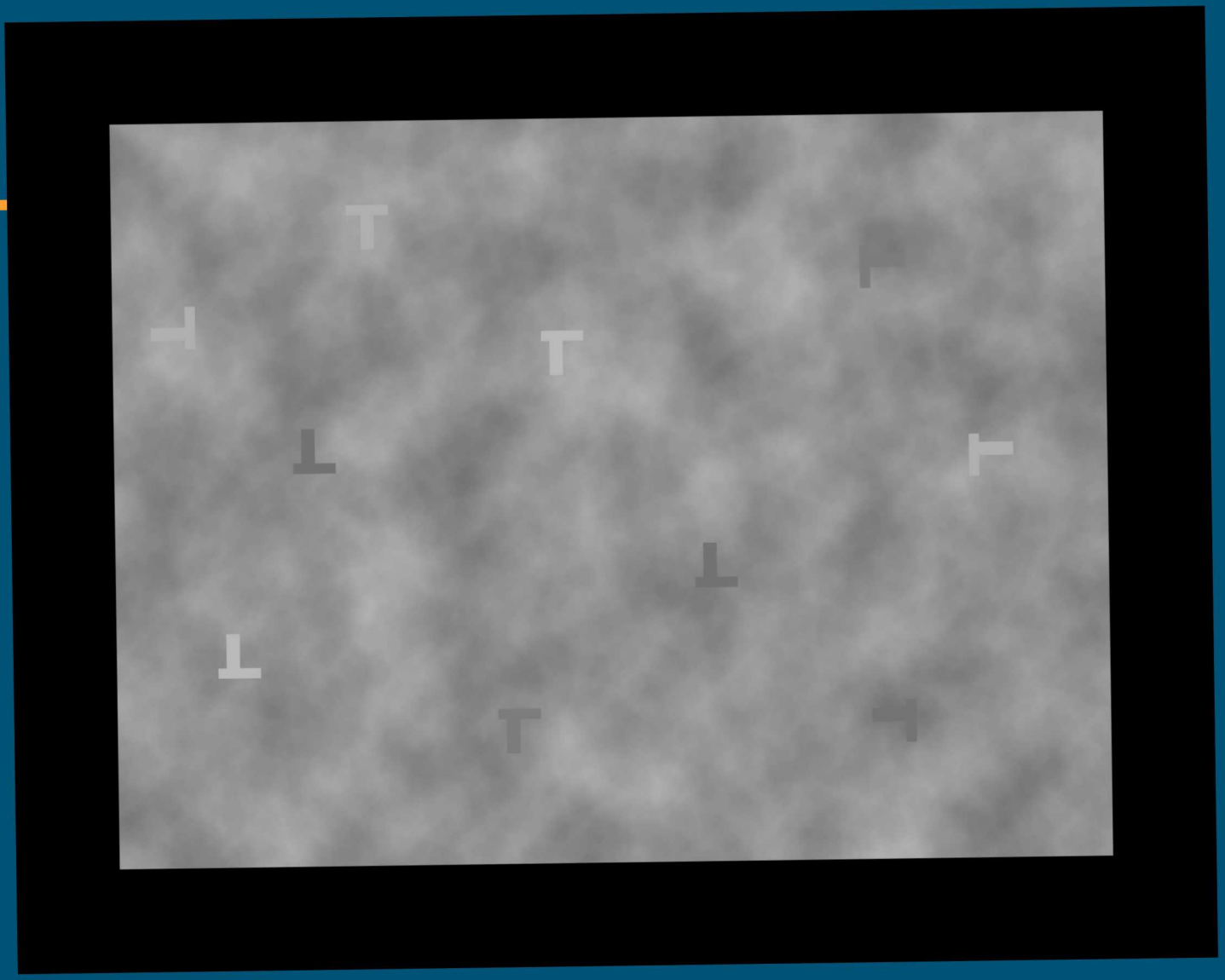
- Error Type
- Error Frequency
- Visual Representation of Output

Characterizing how these factors impact cognition will help to determine the performance requirements and visualization designs for ML/DL tools

Our questions…

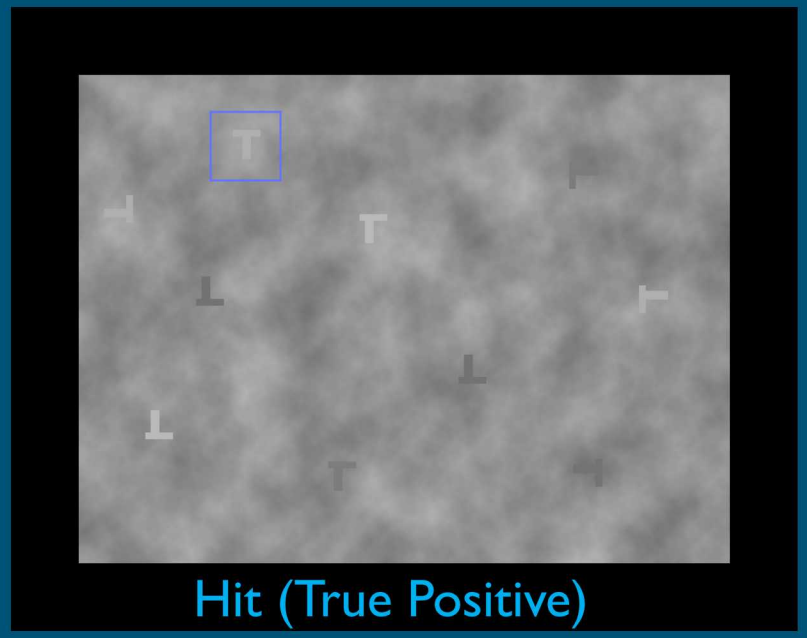
Initial domains of interest:

- Object Detection
- Image Classification
- Information Retrieval

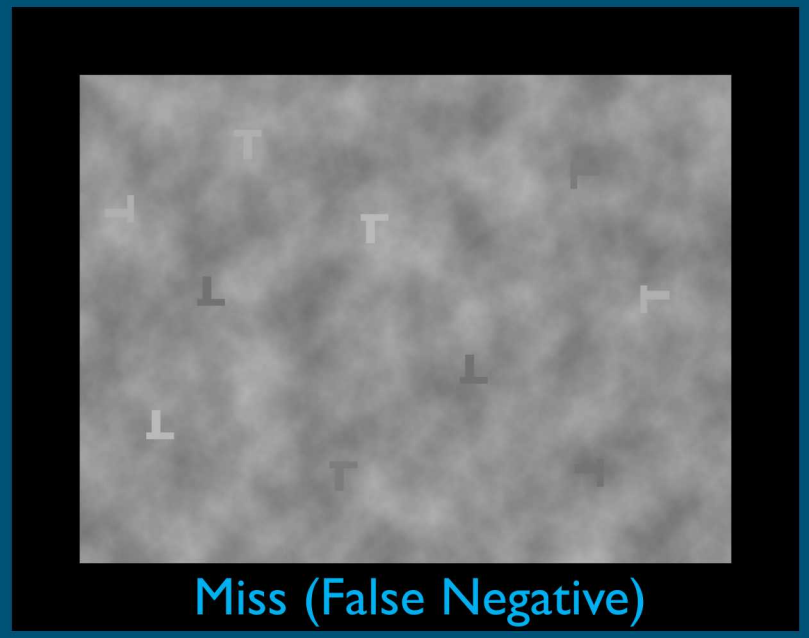


Domain-general object detection task

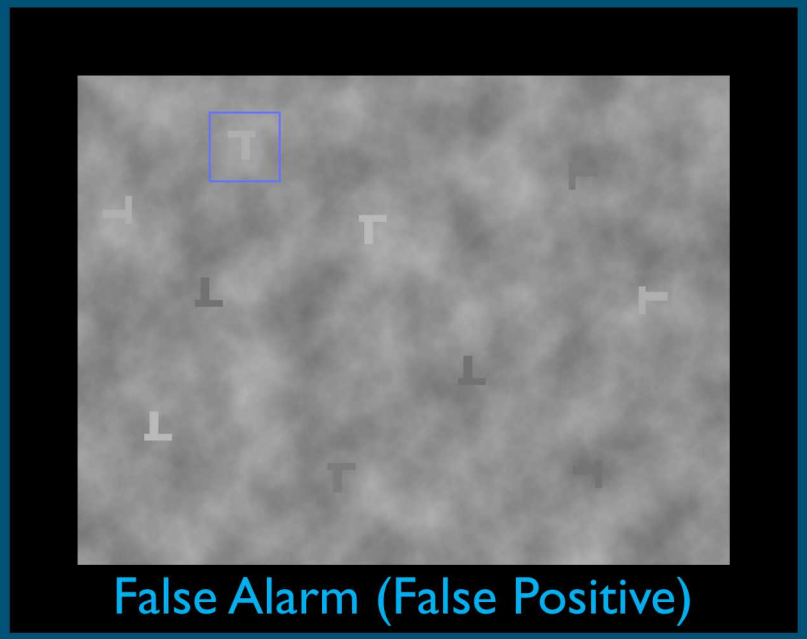
Manipulating Error Types and Frequencies



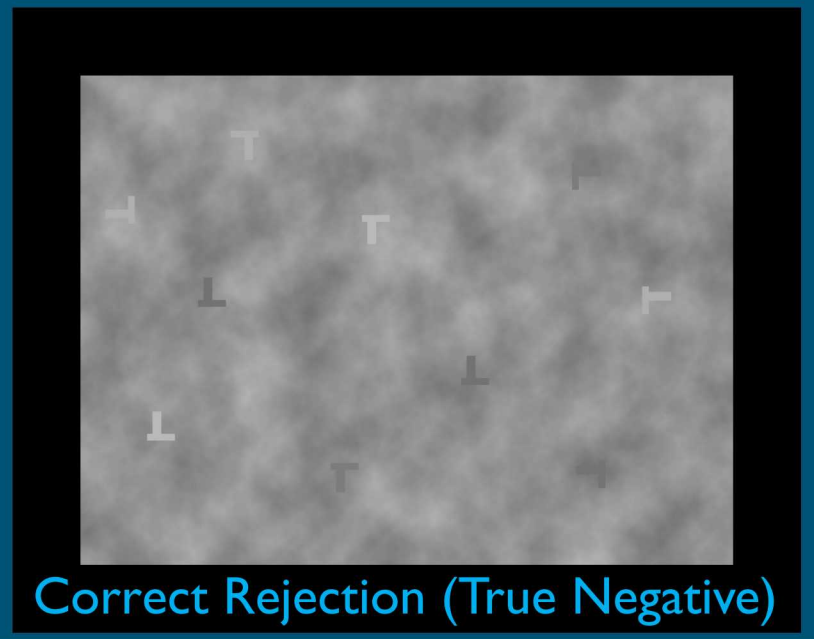
Hit (True Positive)



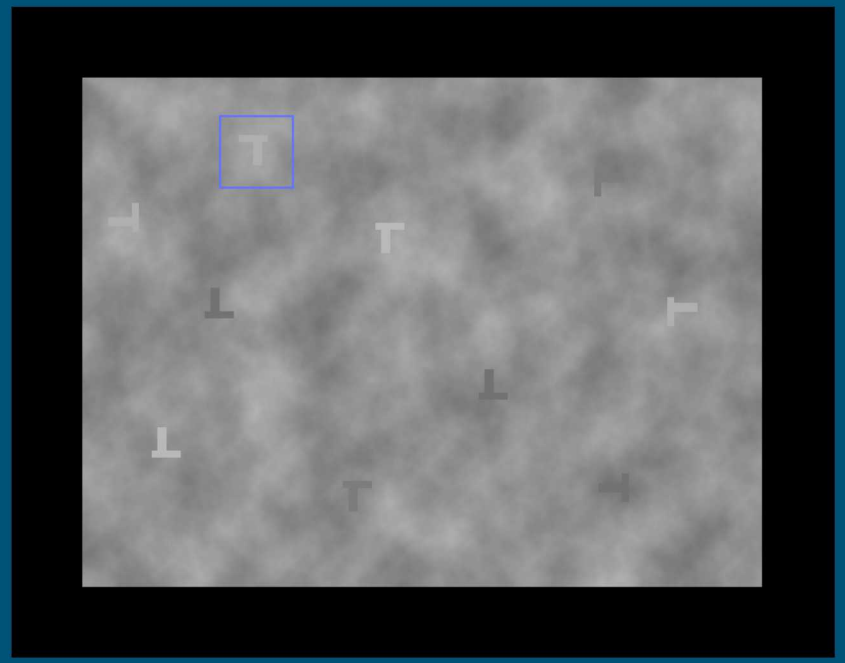
Miss (False Negative)



False Alarm (False Positive)



Correct Rejection (True Negative)

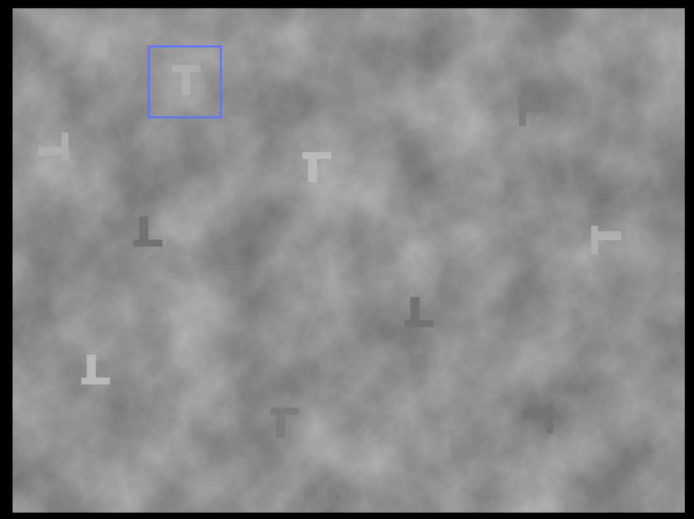


…And combinations of false alarms/misses

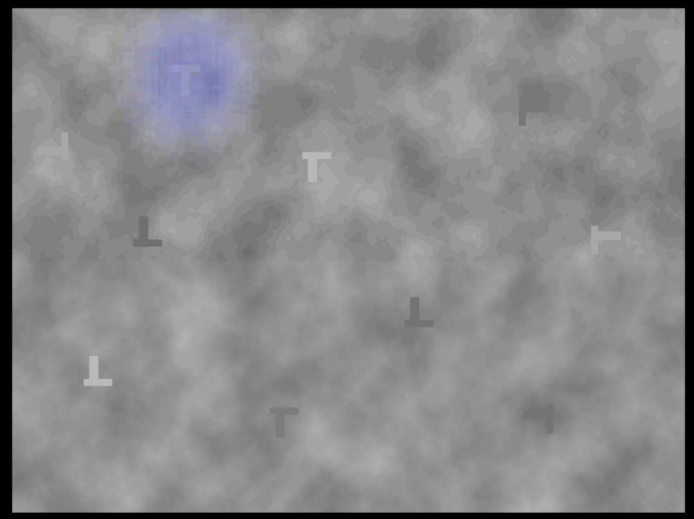
Can also have “worse” false alarms/misses

Different error frequencies make the models overpredictive (lots of true and false positives) or underpredictive (lots of true and false negatives

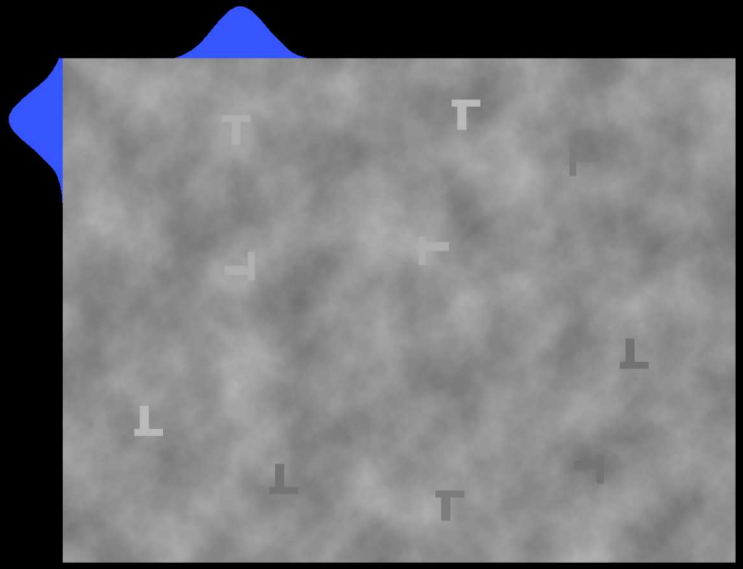
Manipulating Visual Representations of Output



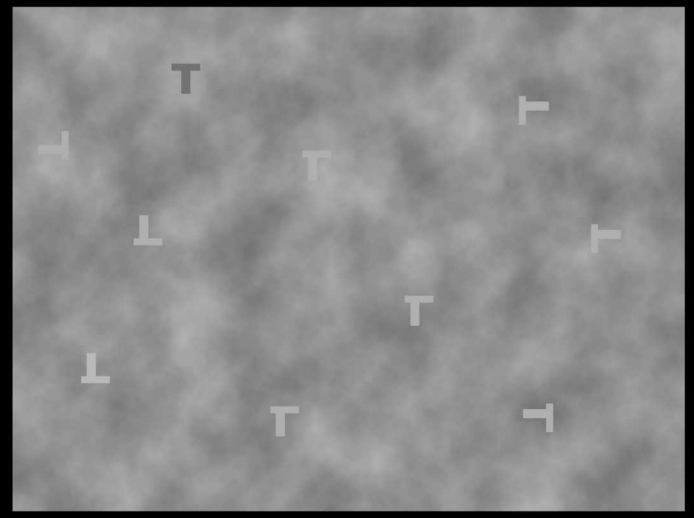
Bounding Box



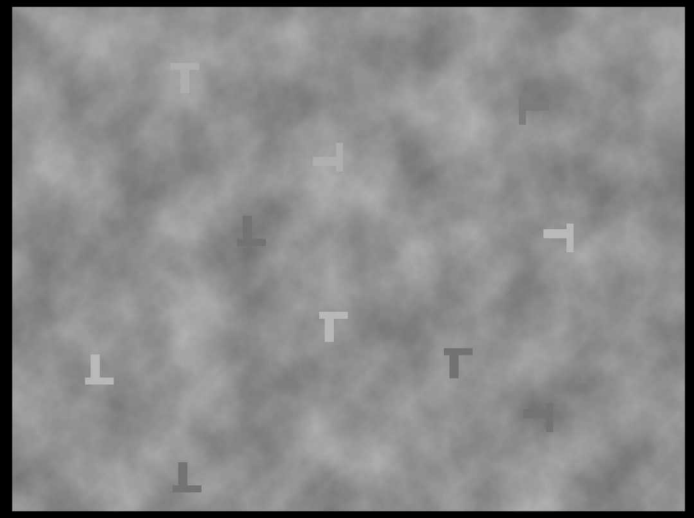
Heat map



Histogram



Color Coding



The target is in the top left quadrant

Thank you!

Contact: lematze@sandia.gov