# Optimal User Attention Allocation in a Multi-tasking Environment

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AFDD: Grant Taylor

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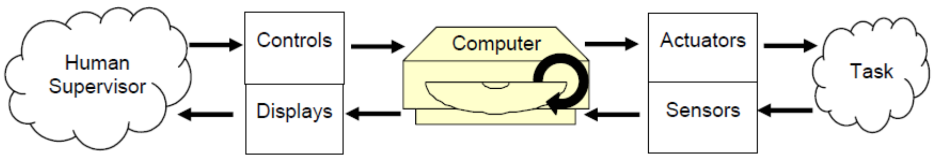
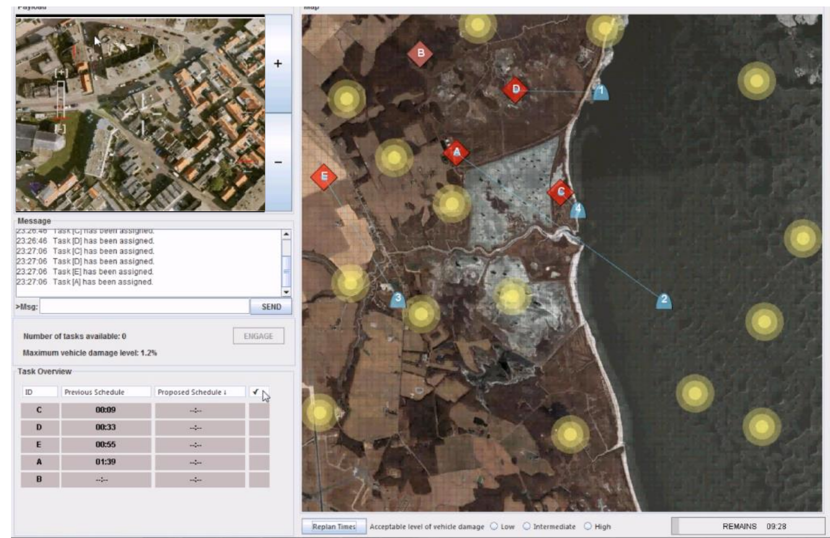
# What are we trying to do?

- Human operator in a supervisory role can become a bottleneck in a multi tasking environment

Human Supervisory Control (HSC): operator only intermittently interacts via an automated agent, receiving feedback and providing commands to a controlled process or task environment (Sheridan 1992)

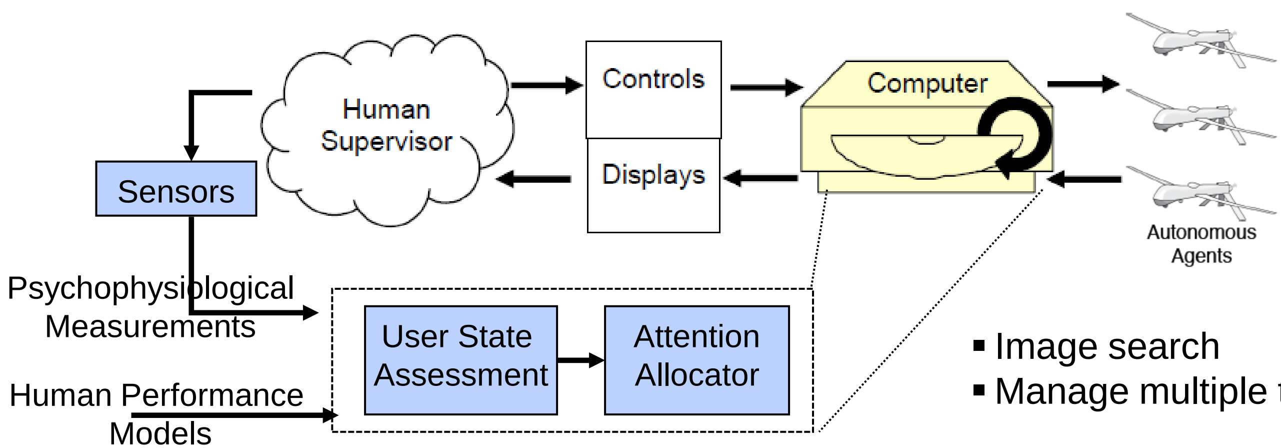



Cummings et. al. 2010



RESCHU: http://www.mit.edu/~yalesong/new/project.html

- Improve human effectiveness by guiding attention at multiple levels of decision making

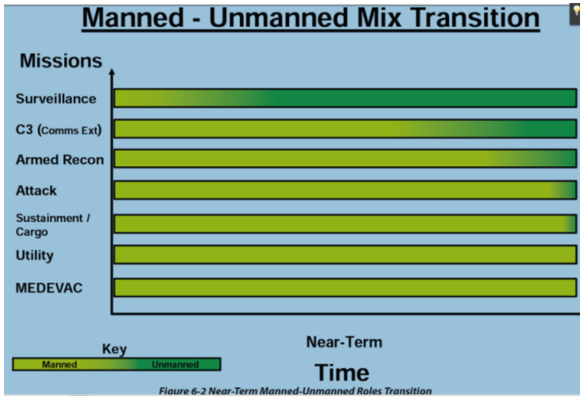



- Image search
- Manage multiple tasks

# Why?

- Network centric operations
  - Increased use of unmanned systems
  - Increased autonomy to invert human to machine ratio

=>Operators will increasingly play a supervisory role




https://fas.org/irp/program/collect/uas-army.pdf

- Challenges (Cummings et. al. 2010)
  - Information overload
  - Appropriate levels of automation
  - Adaptive automation
  - Attention allocation
  - Distributed decision making
  - Supervised monitoring of operators
  - Decision biases
  - Trust/reliability

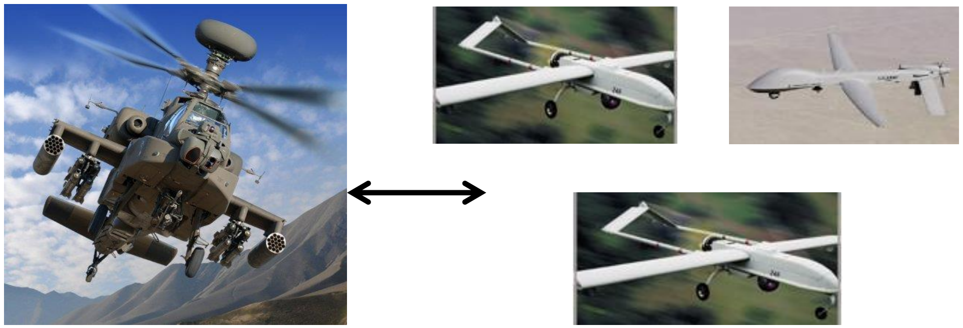
...

Real time assessment of pilot cognitive-affective state through psychophysiological measures for adaptive dynamic function allocation (augmented cognition)

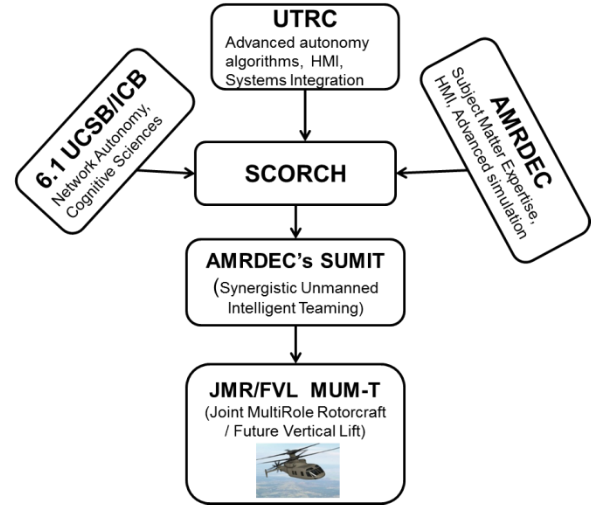
Optimal allocation strategy for set of dynamic tasks to balance time constraints with relative importance of tasks (stopping rules, primary task interruption)

# Operator Supervisory Role

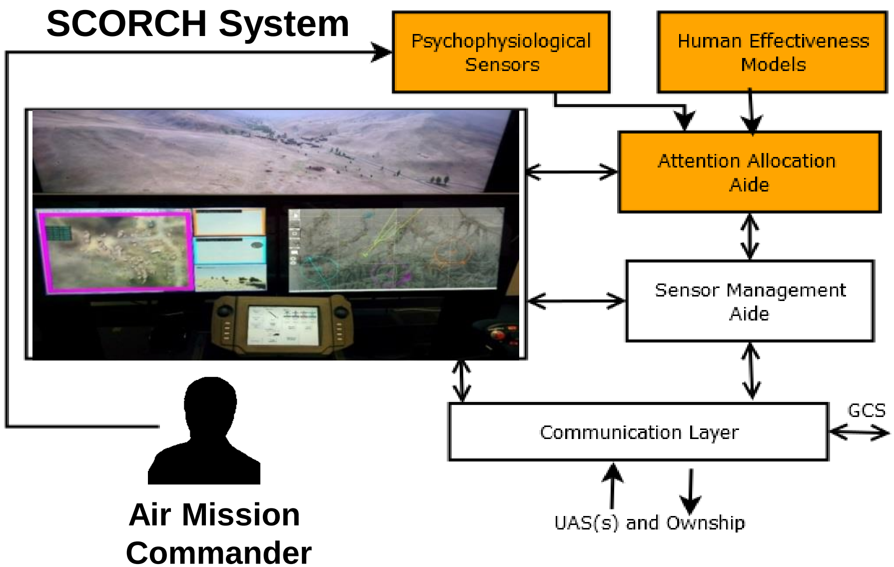
**Manned Unmanned Teaming Missions:**
Level 4 control of multiple autonomous UAS simultaneously with **manageable workload**
- Improve SA, survivability, and lethality



### Supervisory Controller for Optimal Role Allocation for Cueing of Human Operators (SCORCH): ICB/Army funded



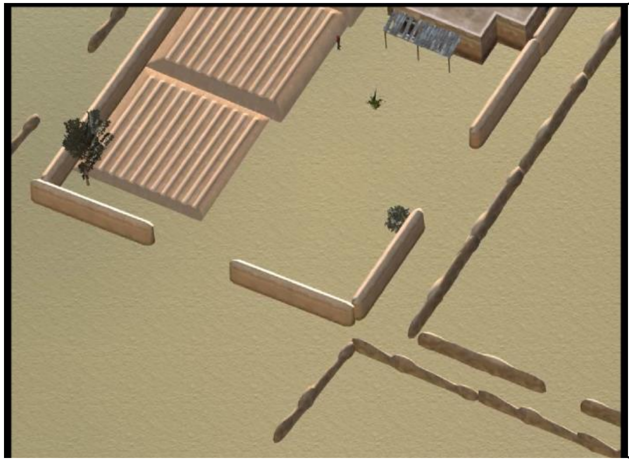

## SCORCH System




| Operator Tasks* | Examples |
|---|---|
| Perception | Target search/classification in UAV/ownship imagery |
| Payload Control | UAV/ownship sensor |
| Communication | Response to chat/voice messages |
| Monitoring | Mission progress, UAV/ownship health/status |

*Cognitive task analysis to systematically decide human and machine role/task allocation

# Search Attention Allocation (AA) Aide: Motivation



**Target Search/Classification**

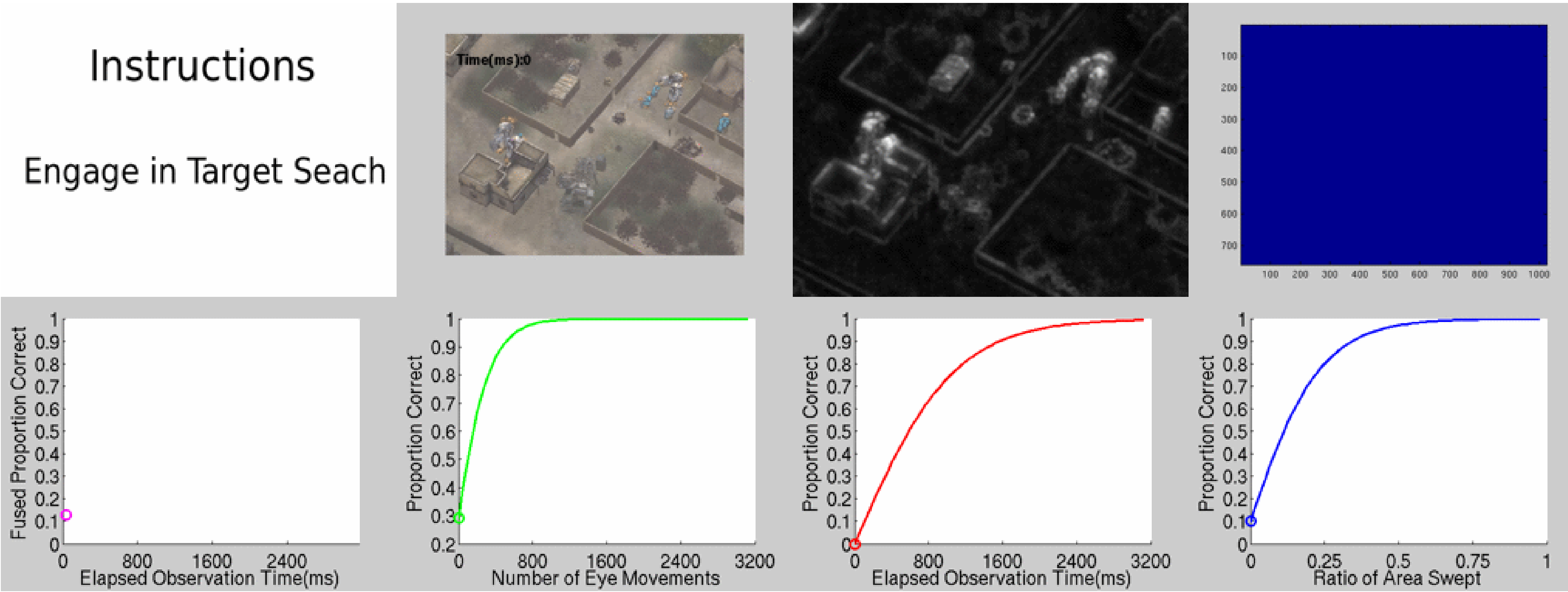
Hypothesis:

- Humans have difficulty administering their fixation and overall search times in challenging search tasks: missed detection, poor efficiency
- Dynamics of human information acquisition and eye-position data can be used to estimate probability that all information has been acquired => recommend search termination or exploration=>enhance human effectiveness

Challenges:

- Need task specific tractable models capturing dynamics of information acquisition
- Integration with real time eye tracking data
- Robustness

# Search AA Aide: Concept



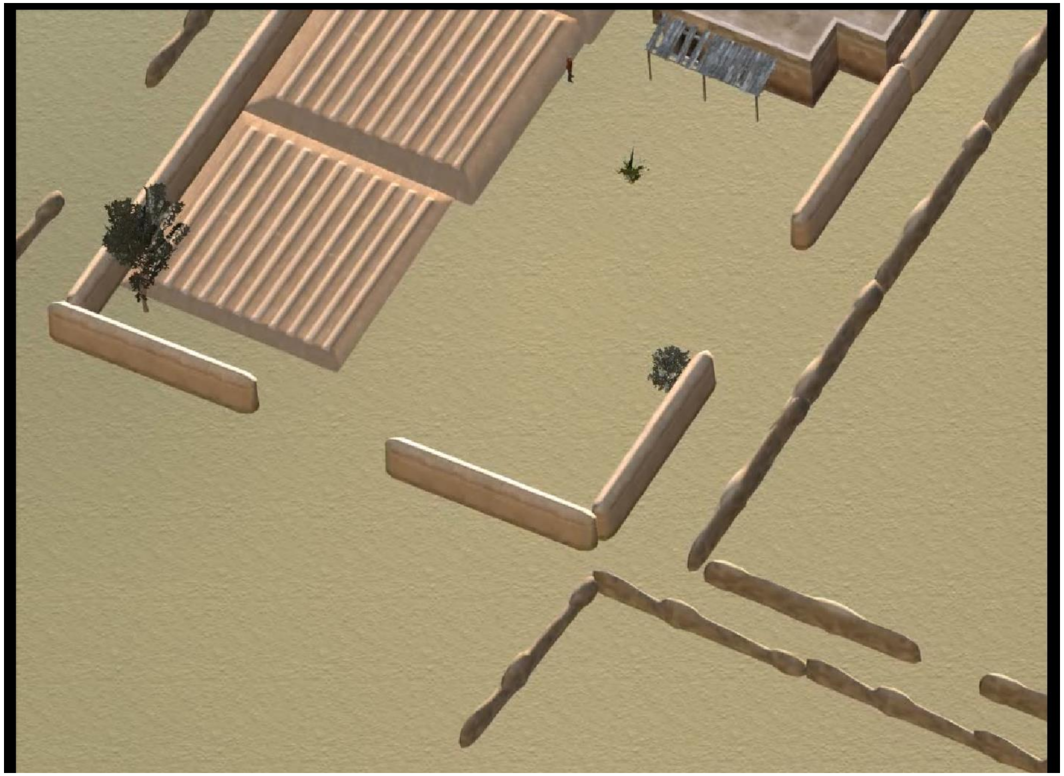

**Time Spent:** To avoid rush  or excessive time due to mind wandering

**Eye Movement:** User fatigued (miss targets), accidentally skips part of scene

**Exploration:** Avoid fixation at same regions

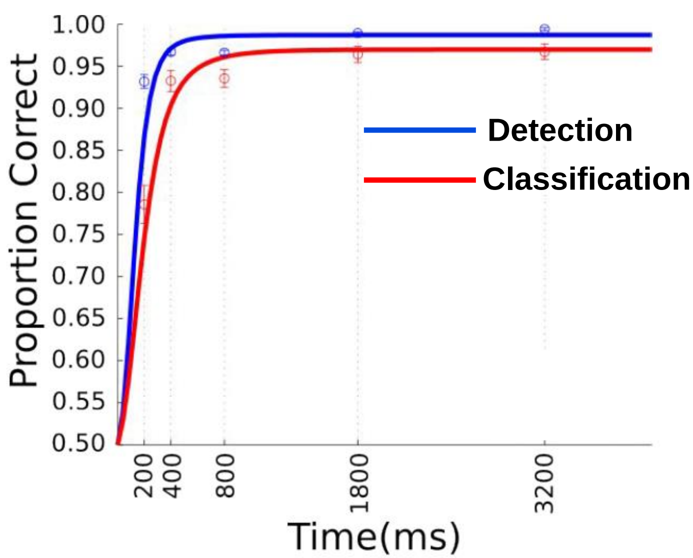
# Search AA Aide: Data for Psychophysics Studies

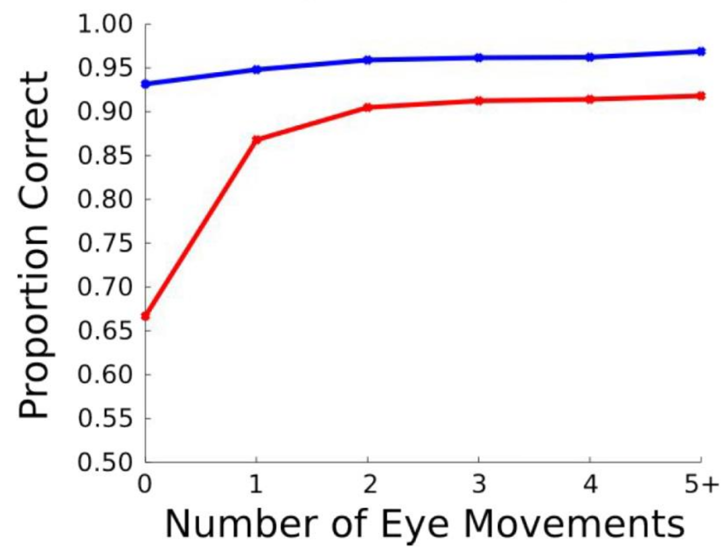
- Task:
  - **Detect target (person)** and **classify target** as armed or not
- Stimuli:
  - Slowly varying videos (generated in Army Lab simulation environment)
  - 50 % images contain a target, 50 % of the target-present images contain a person with a weapon
  - Different frame offsets to vary target position for multiple trials



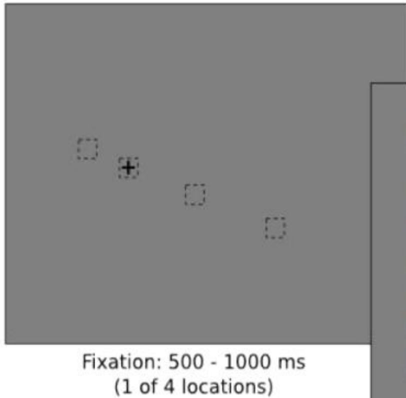
# Search AA Aide: Free Viewing Experiment


11 Observers
~2000 trials/obs

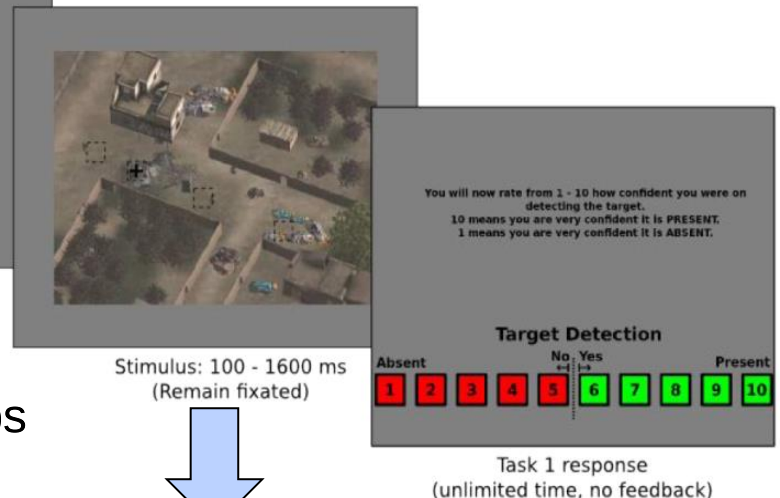


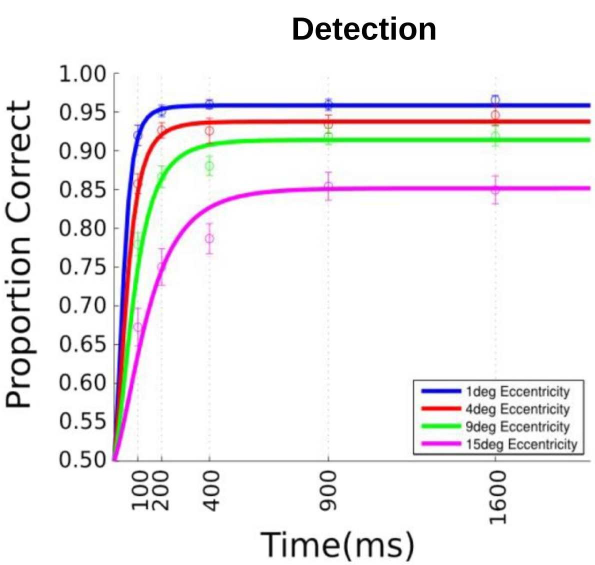



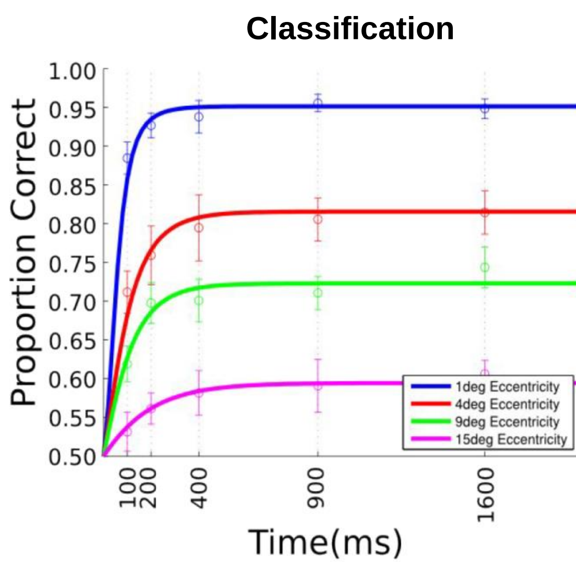
# Search AA Aide: Forced Fixation Experiment




13 Observers
~4000 trials/obs




Use these curves and sequence of fixations and saccades to characterize how well image has been explored?

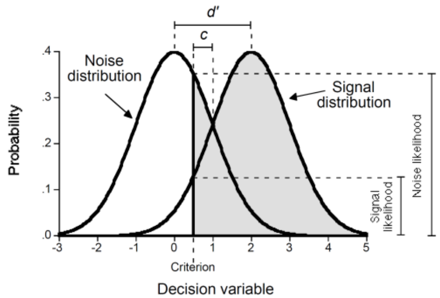
Detectability Map

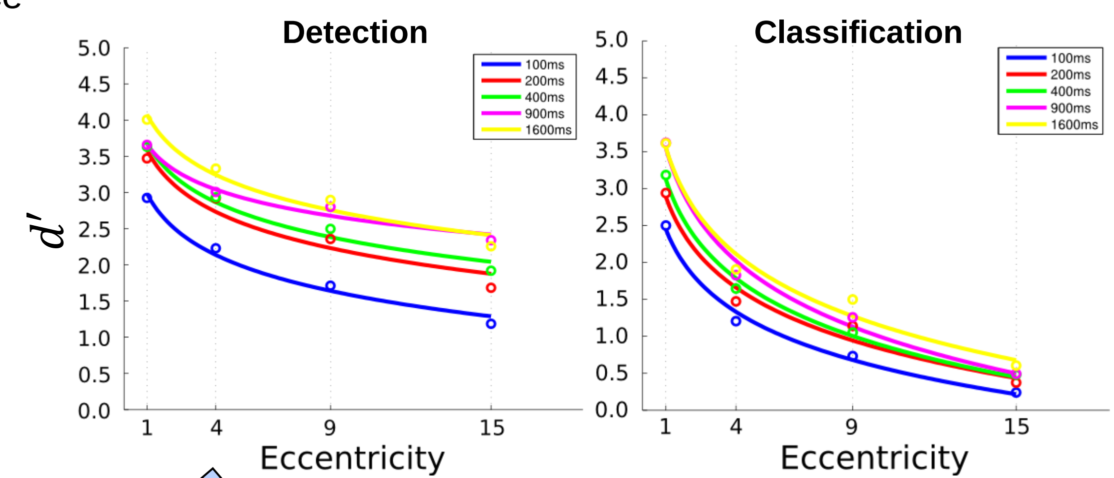
# Search AA Aide: Detectability Map

Signal Detection Theory: Transform in $d'$ space

$$d' = Z(HR) - Z\,(FAR)$$

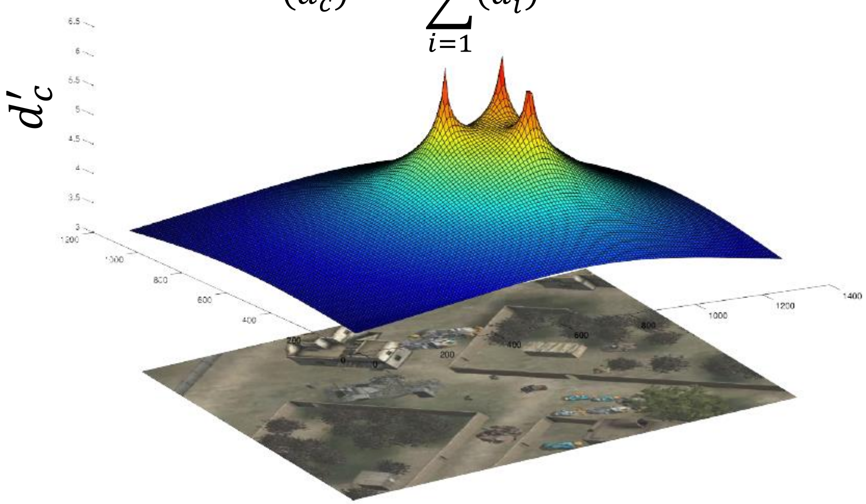
Sensitivity/ Detectability

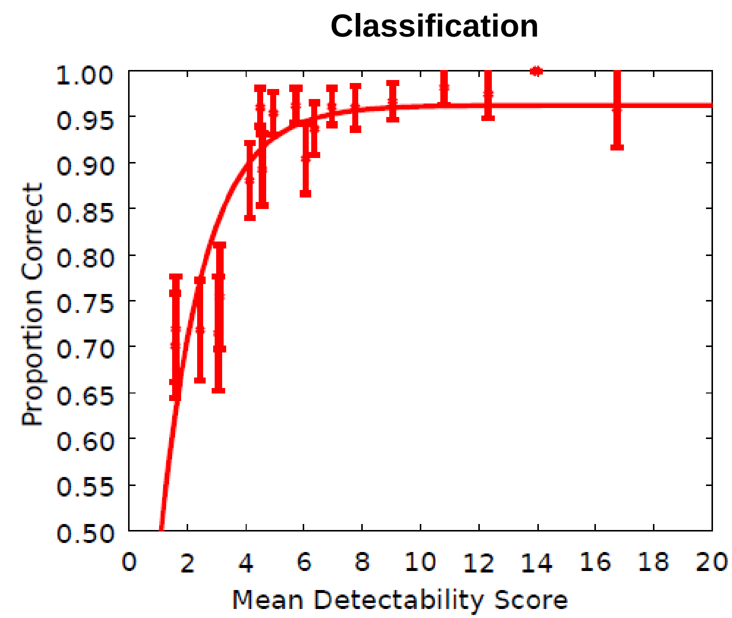



Compute detectability map per saccade (assumed independent) and add in $d'$ space

$$(d'_c)^p = \sum_{i=1}^{N} (d'_i)^p$$

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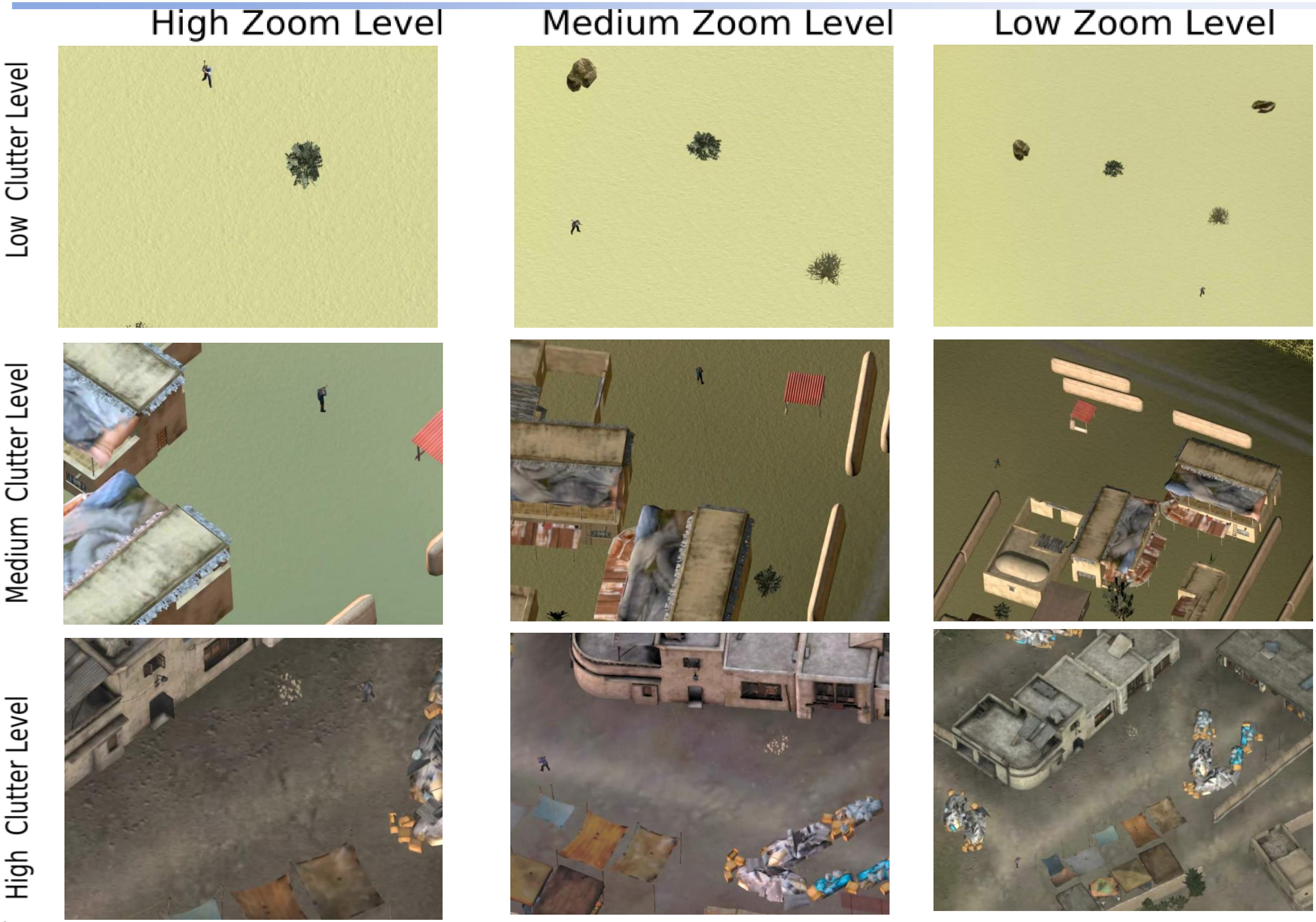
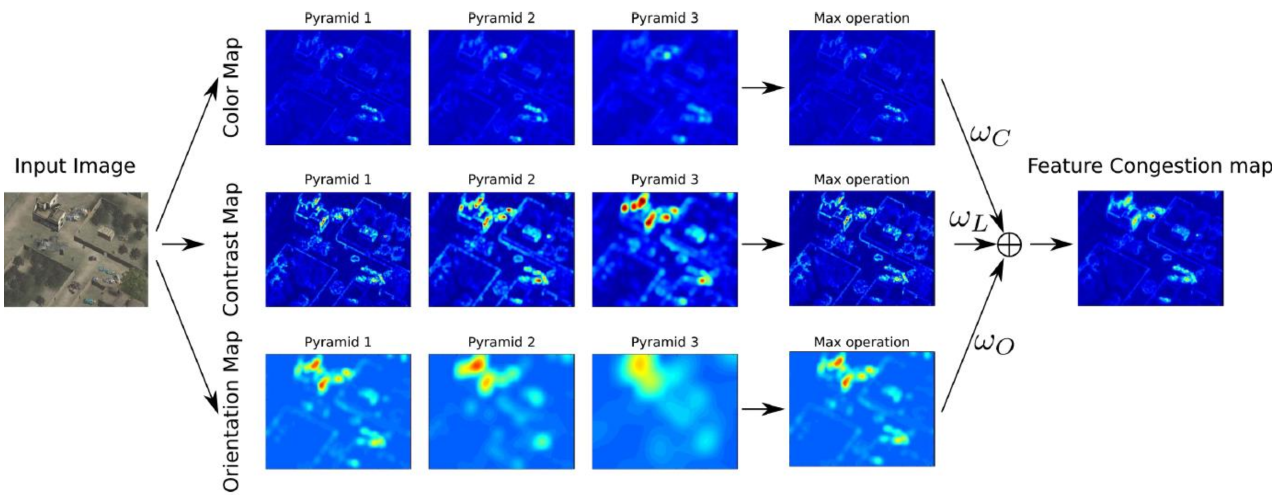
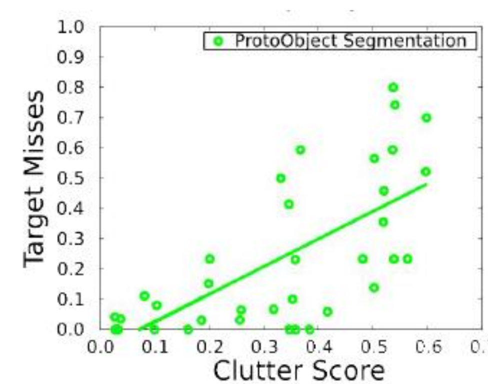
# Search AA Aide: Incorporate Zoom/Clutter Effects

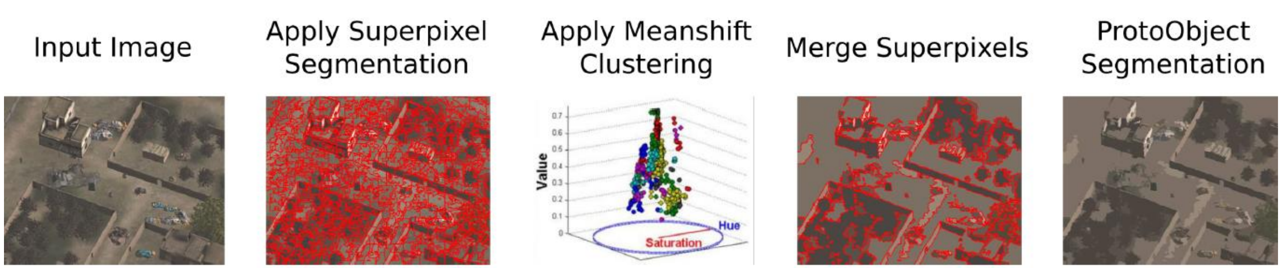


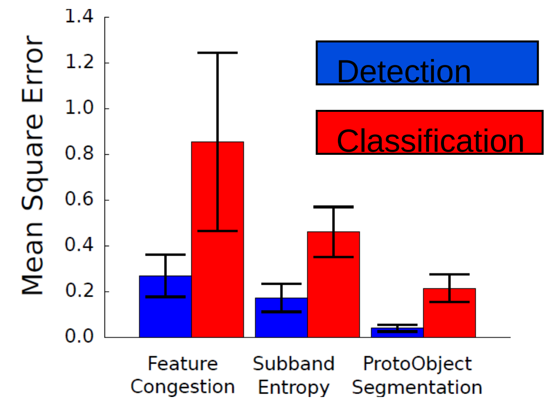
# Search AA Aide: Clutter Metrics

- Feature Congestion: Rosenholtz et al. (2005,2007)
- Subband Entropy: Rosenholtz et al. (2007); Simoncelli & Freeman (1995)
- ProtoObject Segmentation: Yu, Samaras & Zelinsky (2014)



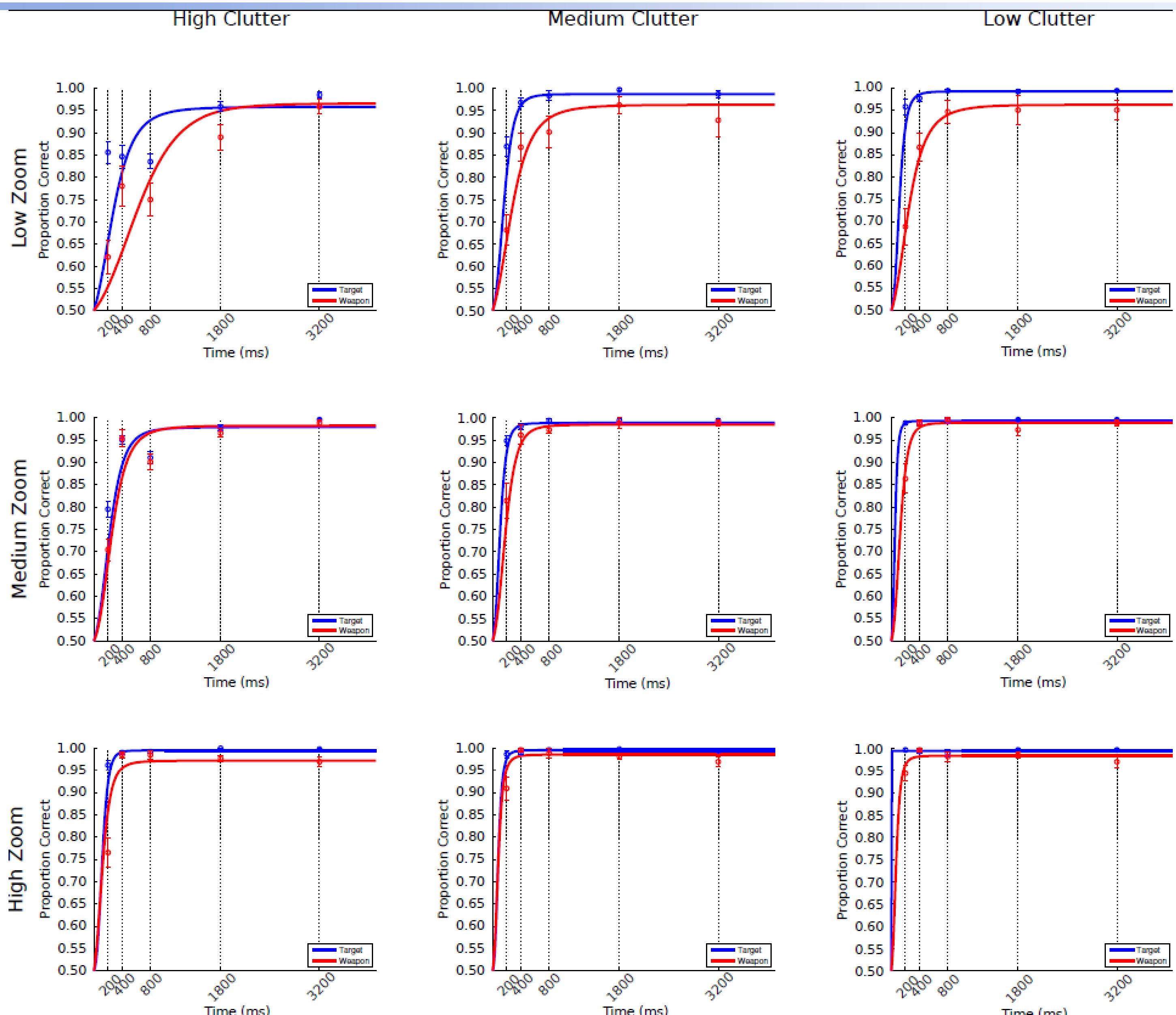



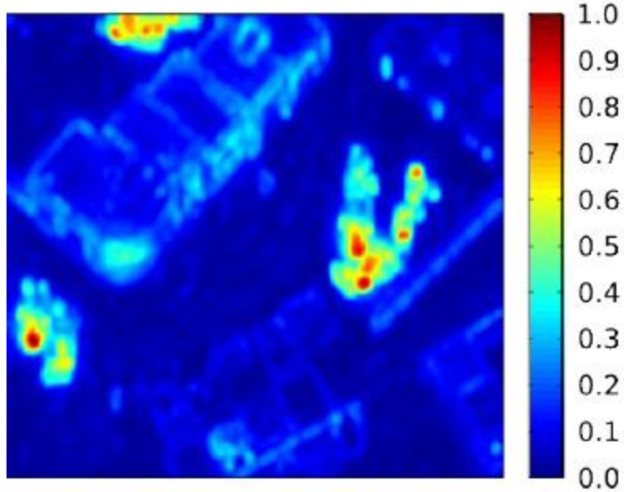

*Deza, A. et. al, The Influence of Visual Clutter on Search Guidance with Complex Scenes,* presented in Vision Sciences Society, 2016.

# Search AA Aide: Incorporate Zoom/Clutter Effects

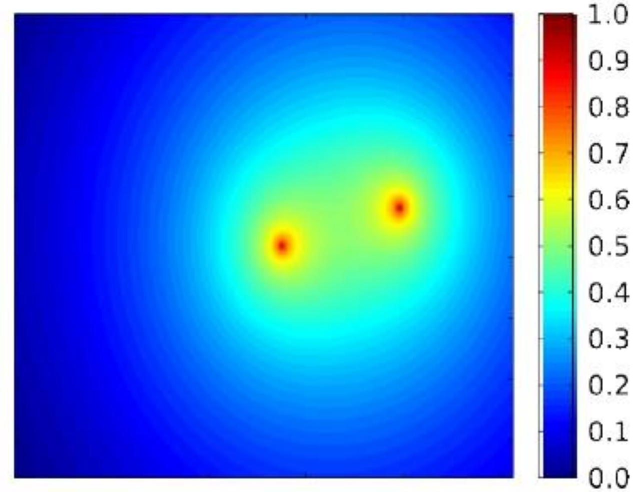


# Search AA Aide: Clutter Detectability Map

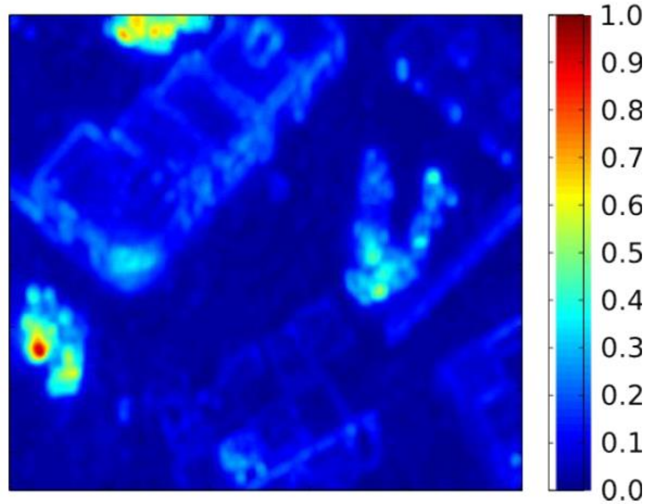
**Clutter Map**




**Detectability Map**

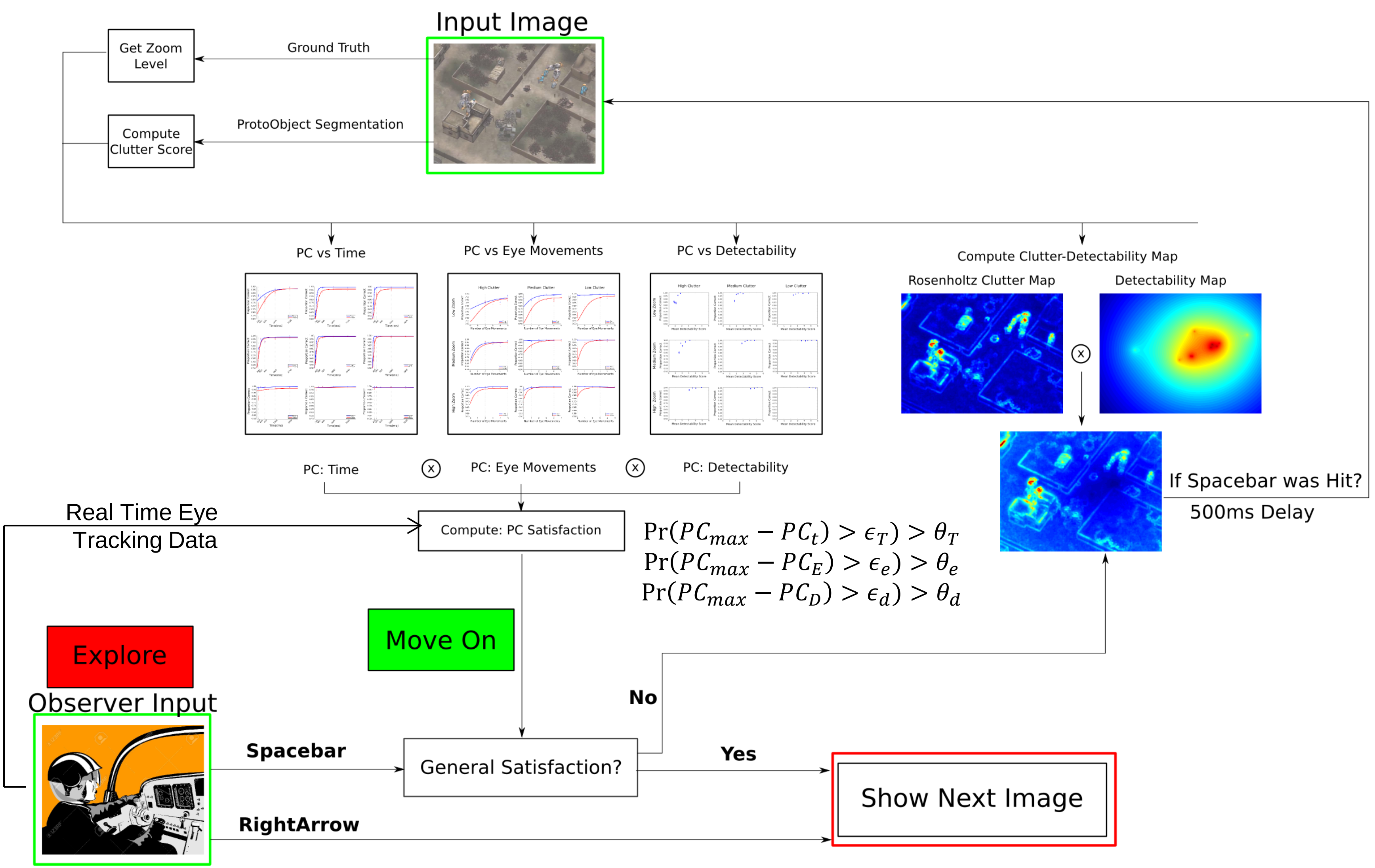



**Clutter × (1-Detectability Map)**



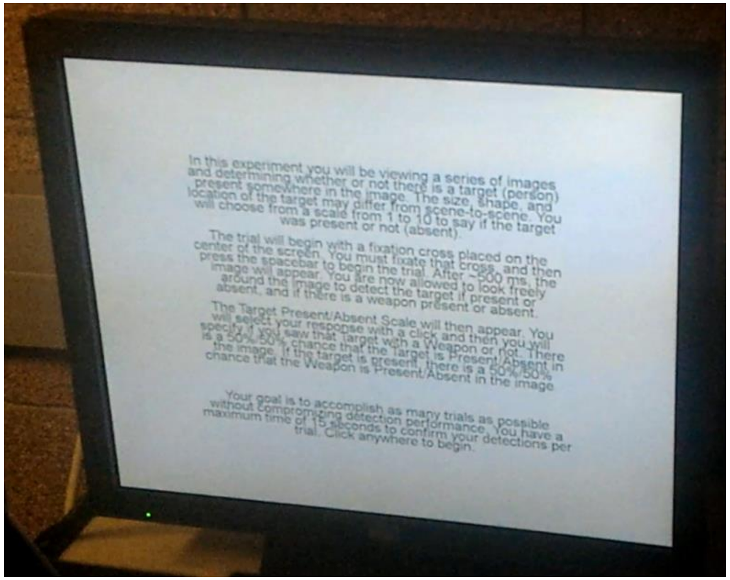

Feedback to user where to explore

# Search AA Aide: Implementation



# Search AA Aide: Experiments

- Goal: Accomplish as many search tasks (given max 15sec/task) as possible in 20min without compromising detection performance
  - 2 practice sessions (w/wo aide)
  - 4 test sessions (2 w aide/2 wo aide)
- Stimuli: Video imagery at different clutter/zoom
- Apparatus: EyeLink1000 eye tracker (500Hz)
- Data collection: User decisions, search times, aide trigger time, etc.




- Preliminary results:10 participants

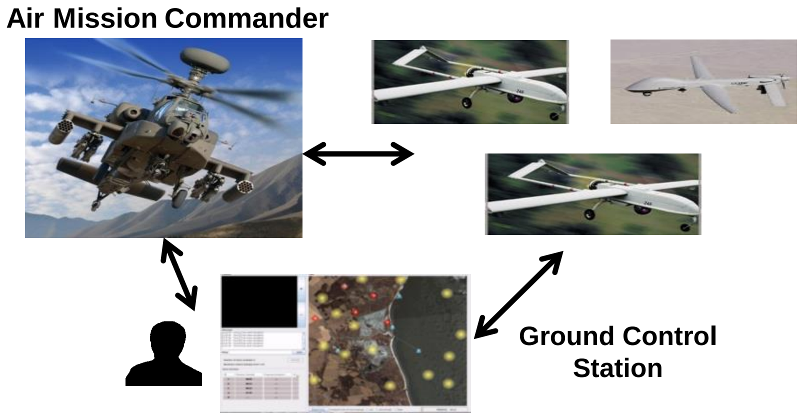
#search tasks completed:
- No Aide= 47
- With Aide = 55

Improved user search efficiency!

| | Hit Rate | Median Search Time (target present) | Median Search Time (target absent ) |
|---|---|---|---|
| | High Clutter | | |
| No Aide | 88% | 3.5s | 4.3s |
| With Aide | 94% | 2.9s | 3.3s |
| | Medium Clutter | | |
| No Aide | 97% | 2.1s | 3.6s |
| With Aide | 97% | 1.9s | 2.8s |
| | Low Clutter | | |
| No Aide | 96% | 2.4s | 2.6s |
| With Aide | 99% | 1.8s | 1.8s |

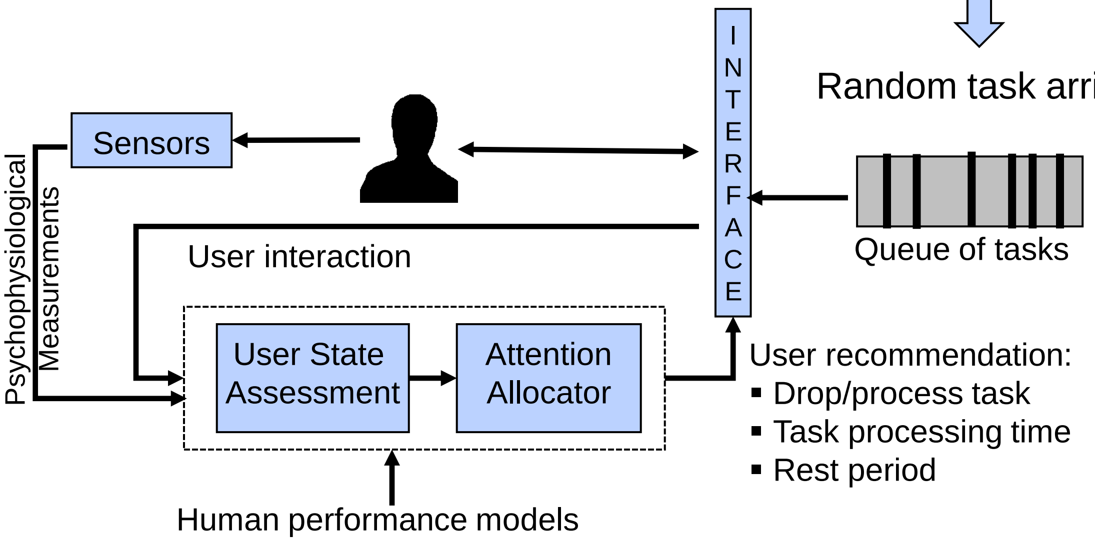
*Deza. A. et. al, Attention allocation aide for image search*, in preparation, 2016.

# Multiple Task Attention Allocation (AA) Aide: Motivation



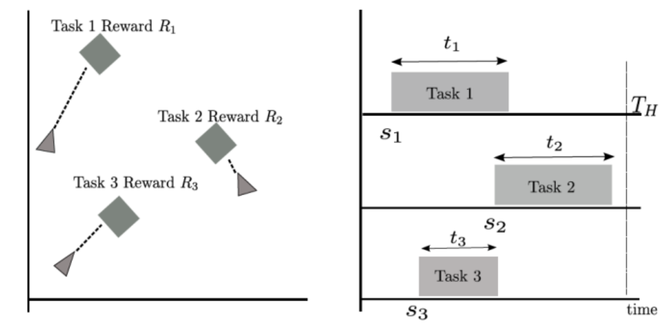

| Operator Tasks | Examples |
|---|---|
| Piloting | Ownship co-pilot tasks |
| Perception | Target search/classification |
| Payload Control | UAV/ownship sensor control |
| Communication | Response to chat/voice messages |
| Monitoring | Mission progress, UAV/ownship health/status |

**Problem Abstraction**



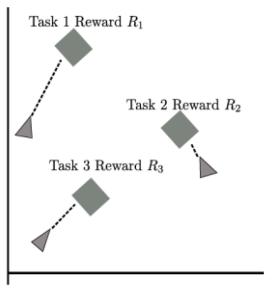

**OR**

Estimate of task start time available

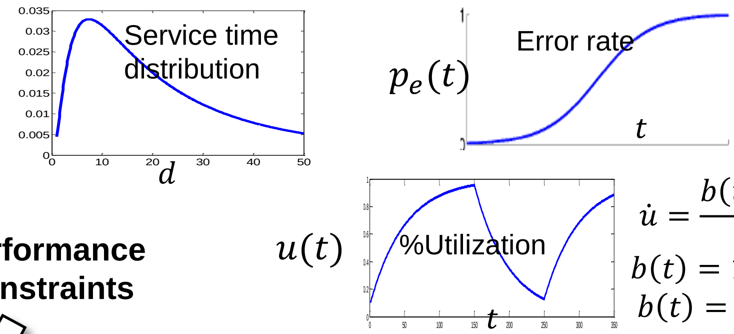



(Bertuccelli et. al., AIAA GNC, 2010; Crandall, & Cummings. AIAAInfotech 2007; Bertuccelli &. Cummings, IEEE Trans. SMC, 2012; Srivastava et. al.., ACC , 2011,2012; Savla, K. and E. Frazzoli, IEEE Proc. 2012)

# Multiple Task AA Aide: Problem Formulation




**Human performance models**




$$\dot{u} = \frac{b(t) - u(t)}{\tau}$$
$b(t) = 1, \rightarrow busy$
$b(t) = 0, \rightarrow idle$

**Estimate of task start time, task rewards**

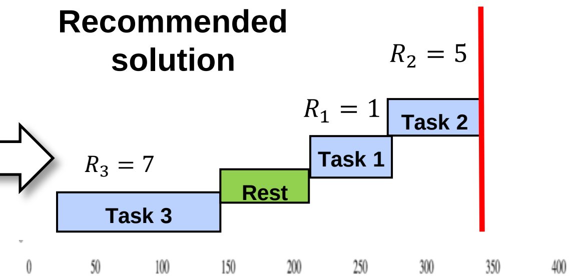
**Performance constraints**

**Objective**: Max cumulative reward $R$ over horizon

**Decision variables:**
- Task order: $x$
- Task time: $d$
- Rest time: $r$

**Multi-Task Attention Allocator: Receding Horizon Optimization**

**Recommended solution**




MILP

$$\max_x \sum_j \sum_i R_j x_j^i$$

s.t $\sum_i x_j^i \le 1 \forall i, \quad \sum_i x_j^i \le 1 \forall j,$

$$c_{i-1} + \sum_j s_j x_j^i \le c_i \ \forall i$$

$$\sum_j (s_j + d_j) x_j^i \le c_i \ \forall i$$

$$c_i \le T_H \ \forall i$$

- Variations (lead to MINLP): incorporate
  - Error rates, and task time as decision variables

$$\max_{x,d} \sum_j \sum_i R_j p_e(d_j) x_j^i$$

  - Utilization constraints, and rest time as decision variables

$$u(d, r, u_0) = (1 - (1 - u_0) e^{-\frac{d}{\tau}})\, e^{-\frac{r}{\tau}}, \quad u_m \le u \le u_M$$

  - Penalty on task waiting time

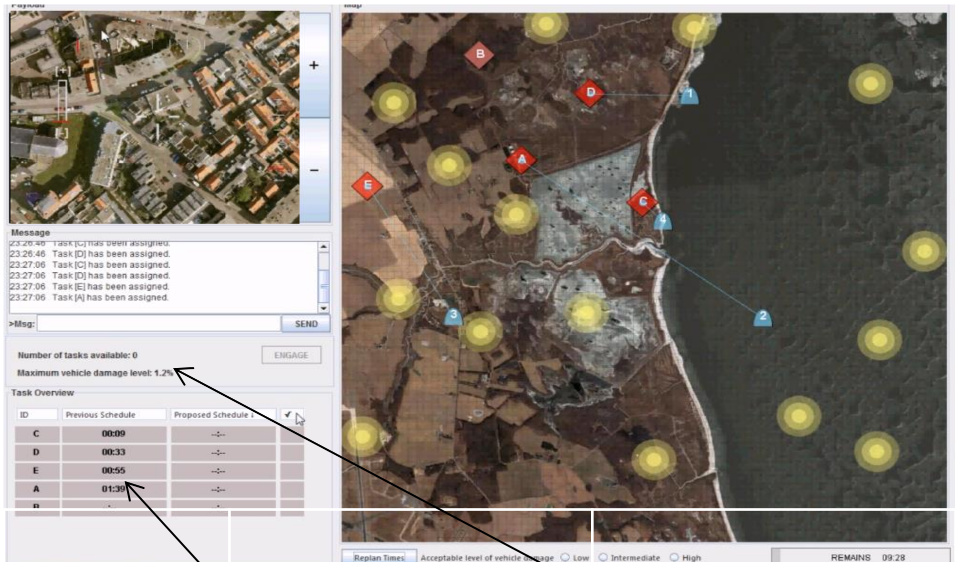
$$\max_x \sum_j \sum_i R_j (1 - \frac{(\sum_i x_j^i c_i - (s_j + d_j))}{s_j + d_j}) x_j^i$$

  - Switching costs, relook,..

# Multiple Task AA Aide: Test Bed

**Task Based Control (New RESCHU*)**

High level Supervisory Control
•Monitors vehicle exposure and chooses acceptable damage level
•Prompts automation (A* with threat avoidance) to replan
•Accepts all / individual plans
•Processes visual search tasks




| Timeline – text-based | Text-based schedule comparison | Maximum vehicle damage level shown |
|---|---|---|

Cummings, L., Bertuccelli, L., Macbeth, J. & Surana, A., *Task Versus Vehicle-Based Control Paradigms in Multiple Unmanned Vehicle Supervision by a Single Operator*, IEEE Trans on Human Machine System, 44(3), 2014.

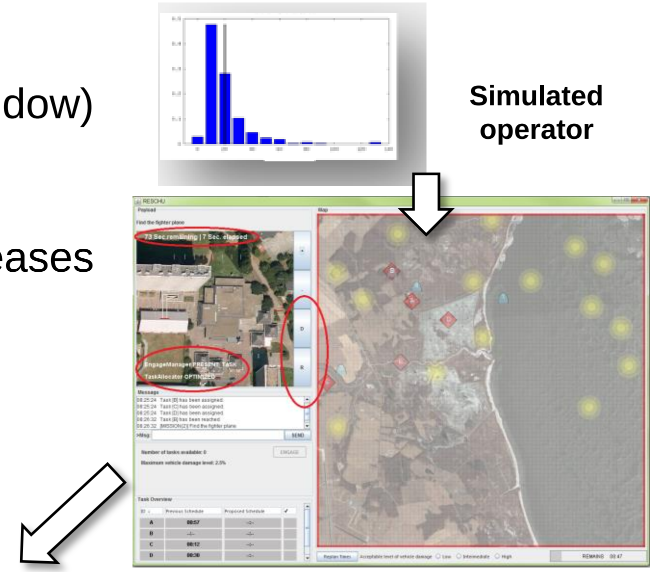
# Multiple Task AA Aide: Implementation


- State-machines based architecture to synchronize user engagement, attention allocator, optimizer and multi-UAV mission planner
- Receding horizon optimization to account for uncertainty in operator behavior

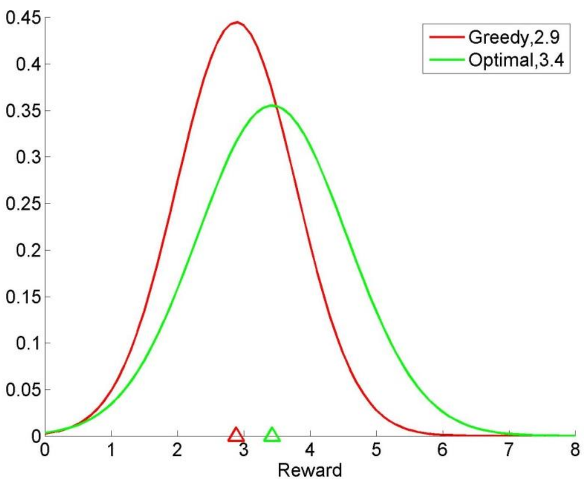
Leonardi, F., Bertuccelli, L. & Surana, A, *Optimization of human supervisors and cyber-physical systems*,, patent application filed, 2013.

# Multiple Task AA Aide: Numerical Studies

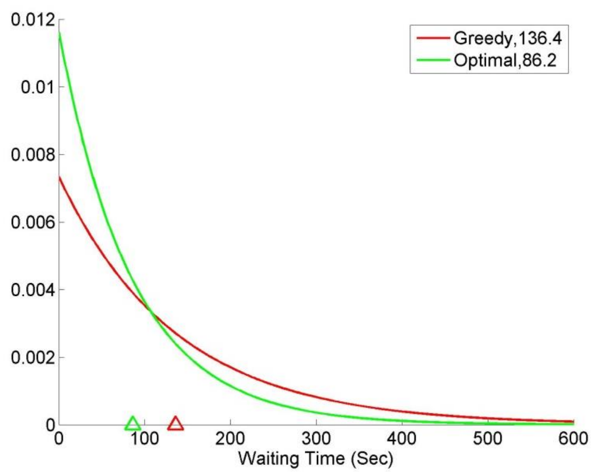
- Fixed total mission time (10min)
- Receding horizon optimization (4 tasks per horizon window)
- Different attention allocation policies:
  - Greedy: High reward first
  - Optimal: Maximize cumulative reward (reward increases if tasks remains unprocessed over a horizon)
- Random parameters
  - Service times (log-normal, from previous studies)
  - Reward (uniform)



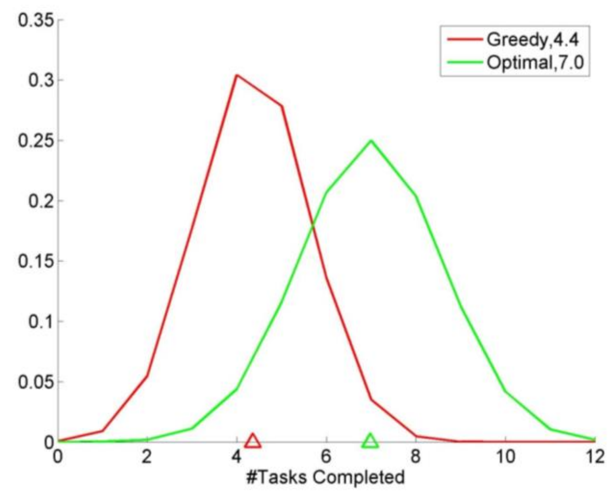

Total Mission Reward




Task Waiting Time

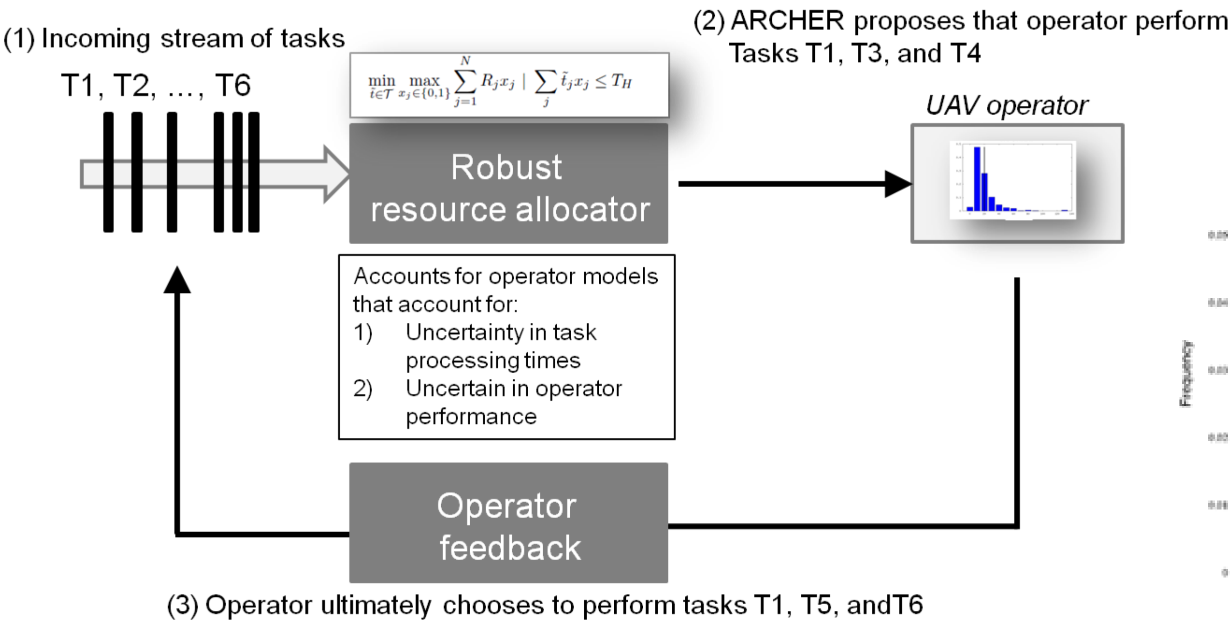


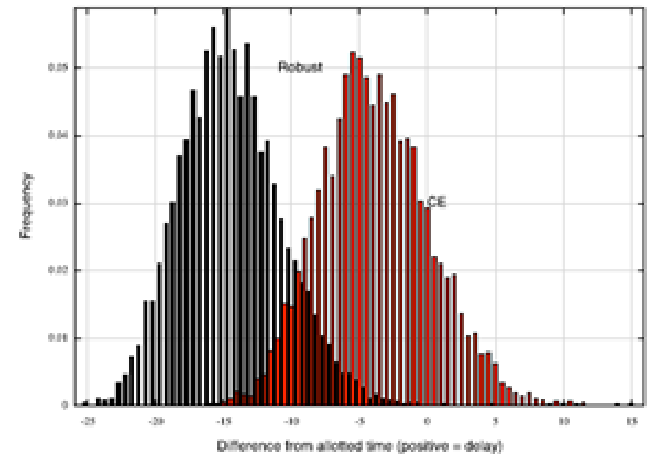

#Tasks Completed




Improved human-machine system performance

# Robustness in Attention Allocation



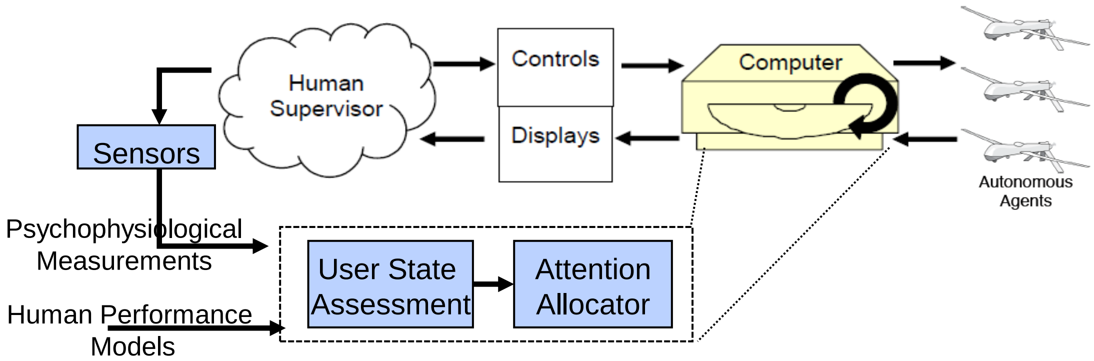



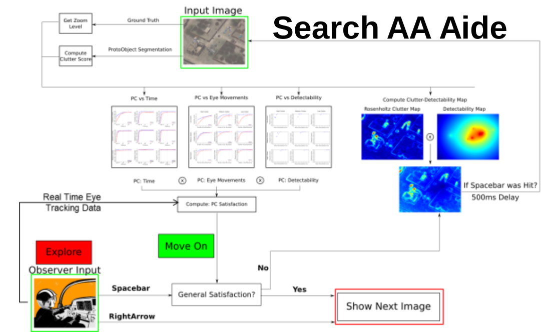

- Characterization of uncertainty in human models: certainty equivalent approach may not be satisfactory
- Tractable robust/stochastic optimization techniques
- Online adaptation
- Extensions for human teams

(Bertuccelli & Cummings, CDC, 2011; Peters & Bertuccelli, ACC 2016; Peters & Bertuccelli, AIAA J. of Aerospace Inf. Sys. 2016 (Under Review))

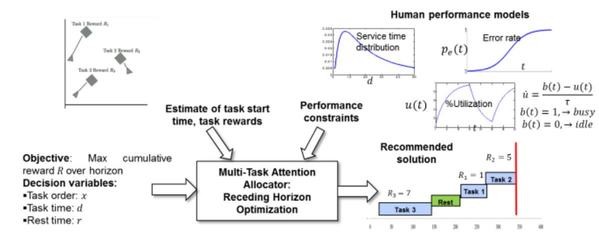
# Conclusions

➢ Summary: Attention allocation aide to enhance human effectiveness in a supervisory control setting




**Multi-Task AA Aide**



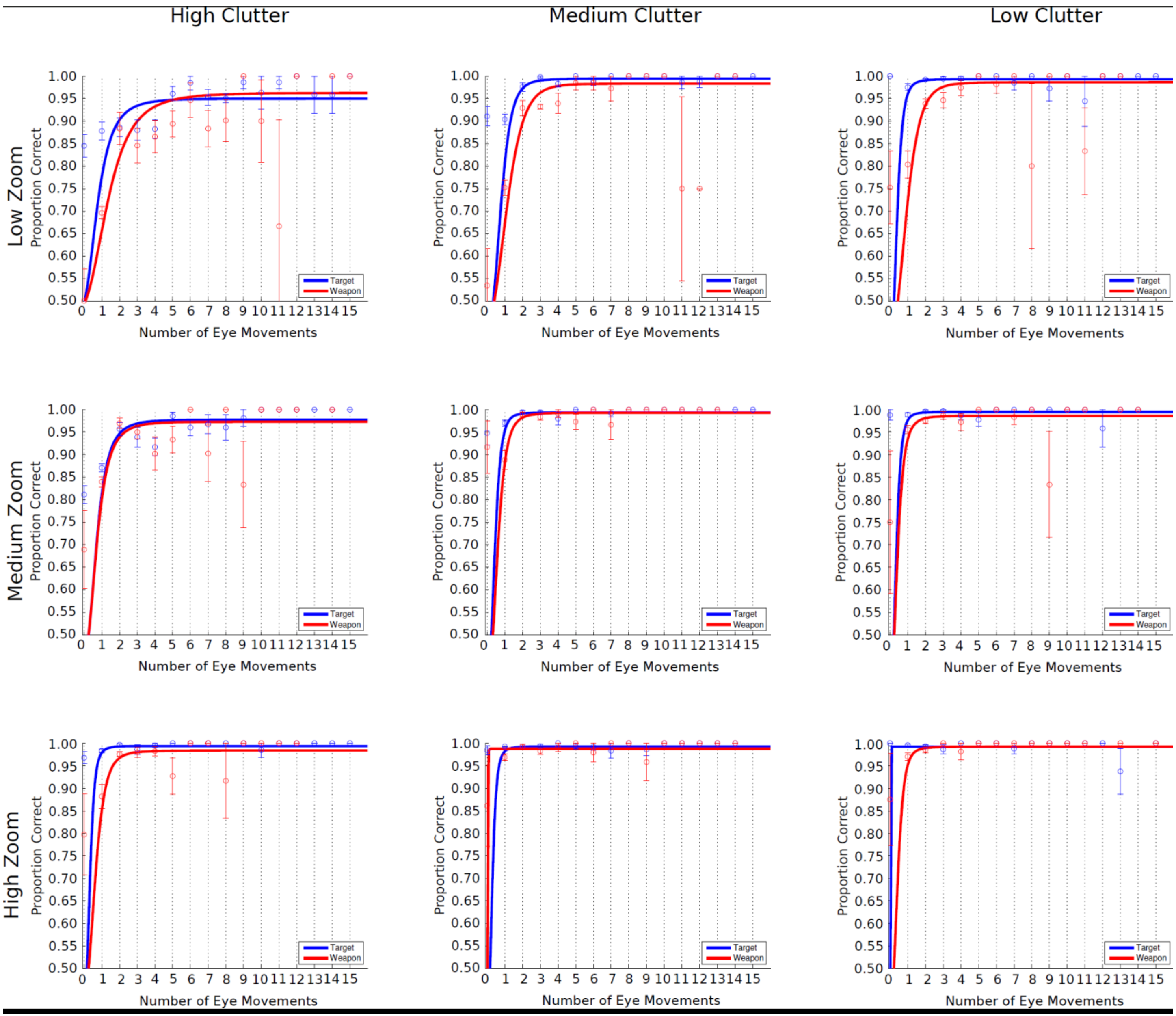

➢ Ongoing/Future Work

- Adaptation to SCORCH operational context: moving imagery, impact of computer vision algorithms and secondary tasks, real time implementation
- Detrimental operator state detection and changing level of automation
- Robustness to user uncertainties/variability
- Joint optimization of human machine teams*
- Trust/reliability

*Peters, J. et. al., *Human supervisory control of robotic teams, Integrating Cognitive Modeling with Engineering Design*, Control System Magazine, 2015.

# Back Up

# Incorporate Effect of Image Zoom and Clutter



# Incorporate Effect of Image Zoom and Clutter