Operational Neuroscience

Intelligence Community Forum

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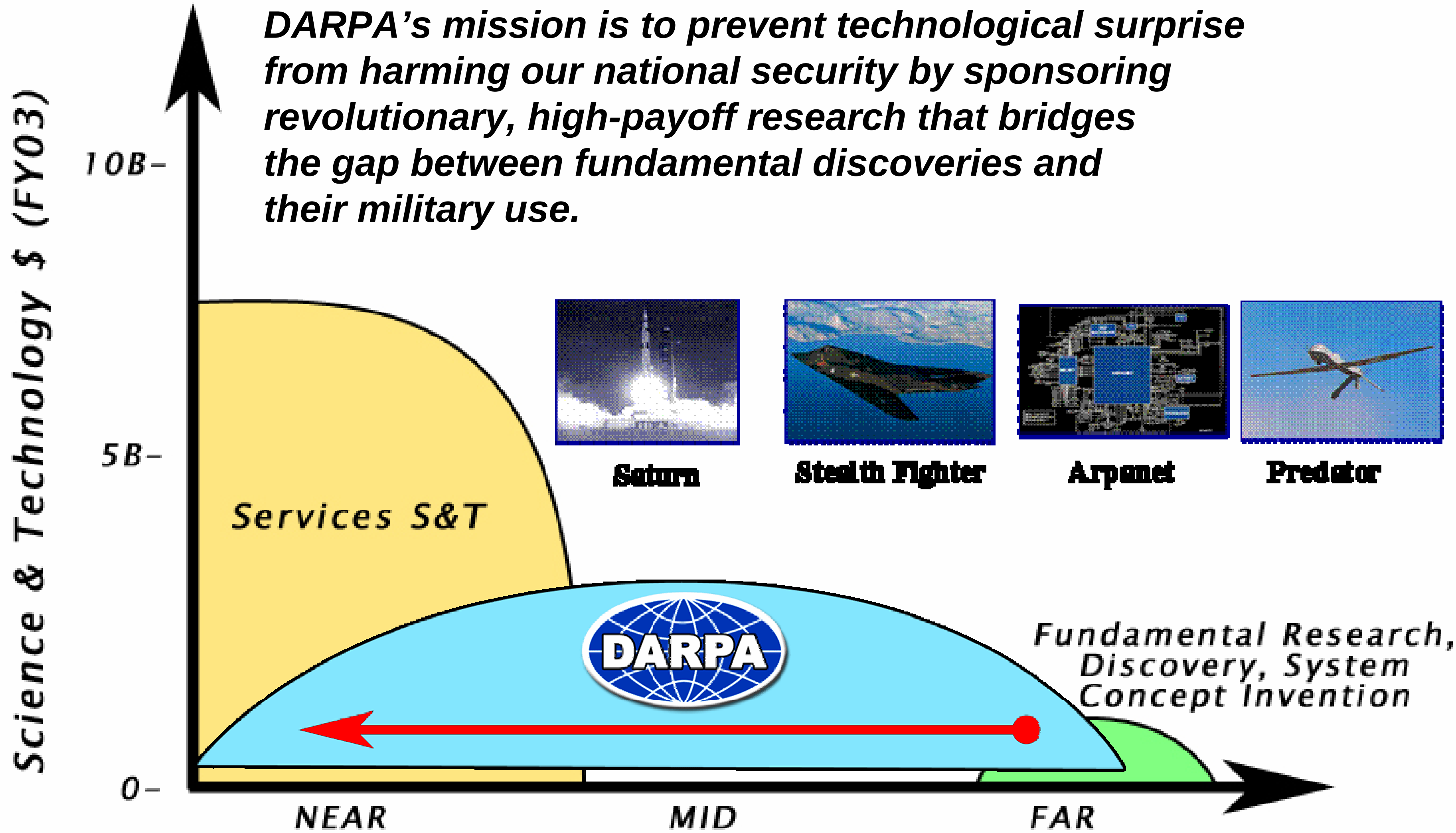
Program Manager

DARPA/DSO

Nov 5, 2008

DARPA's Mission

DARPA's mission is to prevent technological surprise from harming our national security by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their military use.



DARPA Strategic Vision

Strategic Thrusts

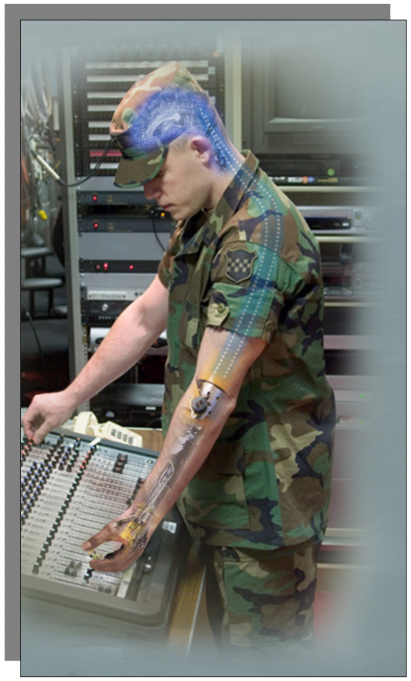
- Precision detection, tracking, and destruction of elusive targets
- Characterization of underground structures
- Urban Operations
- Networked manned & unmanned attack operations
- Assured use of space
- Cognitive systems
- **Bio-Revolution**
- Robust, secure self-forming networks

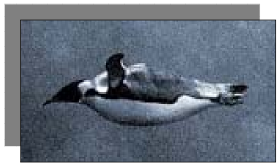
Enduring Foundations

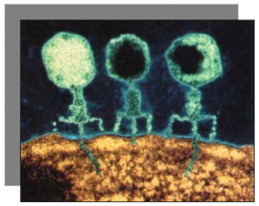
- Materials
- Microsystems
- Information Technologies

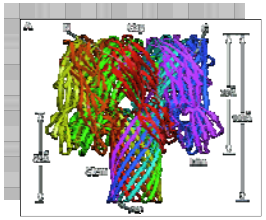
Bio-Detection

Chlorine Dioxide

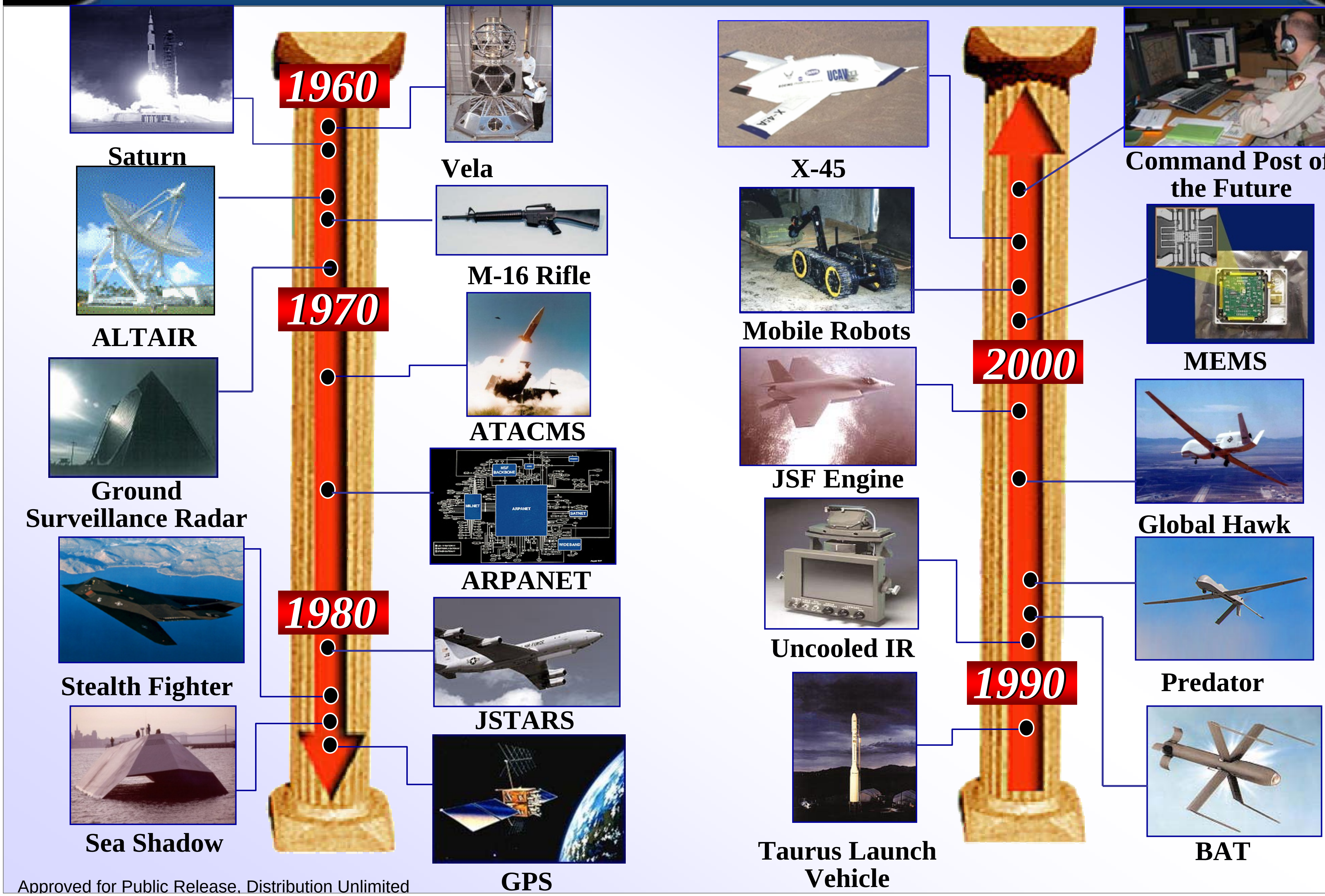




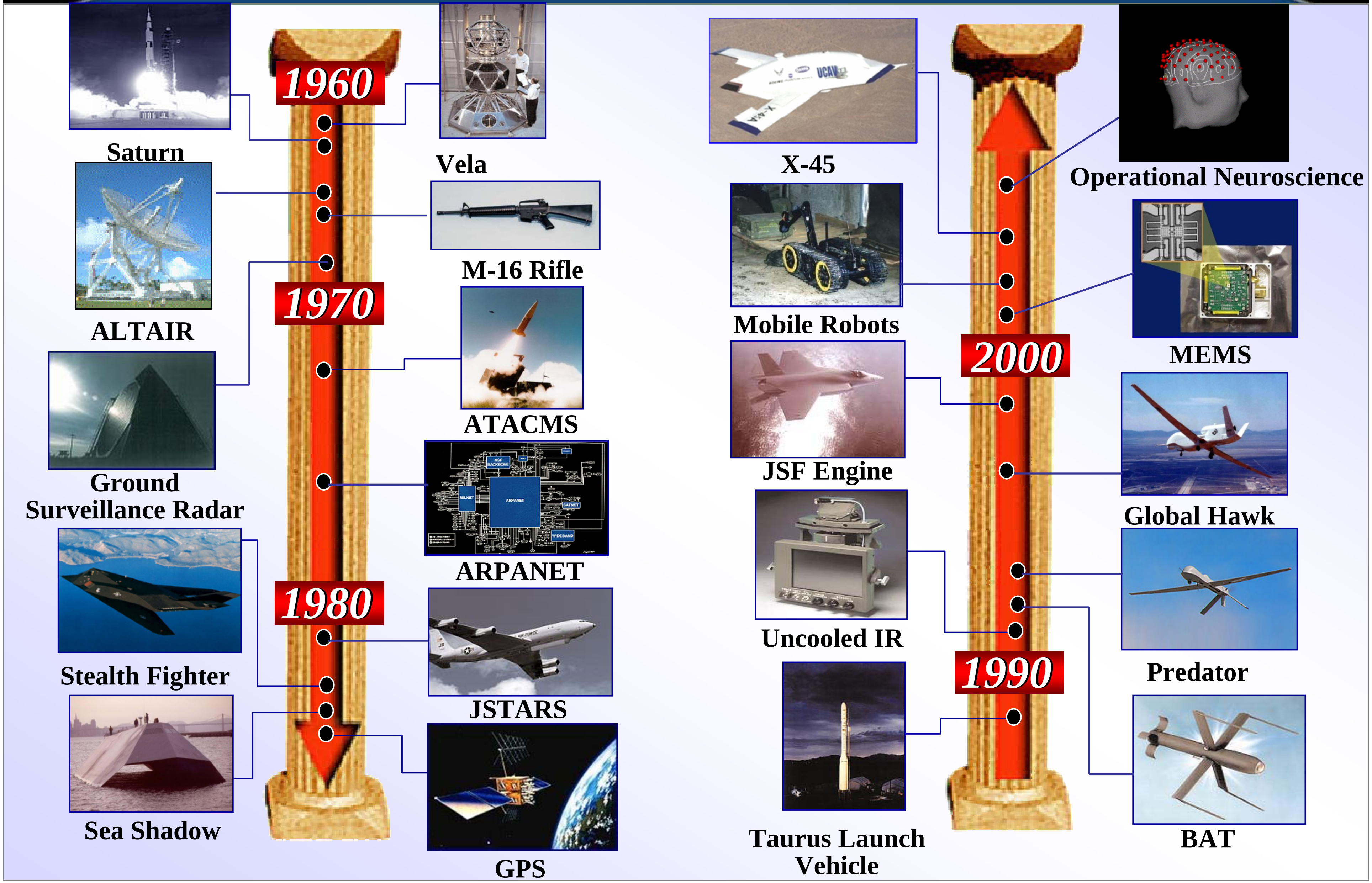




DARPA Accomplishments



DARPA Accomplishments



DARPA Technical Offices

Director, Tony Tether
Deputy Director, Bob Leheny

Tactical Technology

Dave Neyland
Steve Walker

- Air/Space/Land/Sea Platforms
- Unmanned Systems
- Space Operations
- Laser Systems
- Precision Strike

Strategic Technology

Barbara McQuiston
Larry Stotts, Brian Pierce

- Space Sensors/Structures
- Strategic & Tactical Networks
- Information Assurance
- Underground Facility Detection & Characterization
- Chem/Bio Defense
- Maritime Operations

Defense Sciences

Bob Leheny (Acting)
Leo Christodoulou

- Physical Sciences
- Materials
- Biology
- Mathematics
- Human Effectiveness
- Bio Warfare Defense

Information Processing Techniques

Chuck Morefield
Charlie Holland

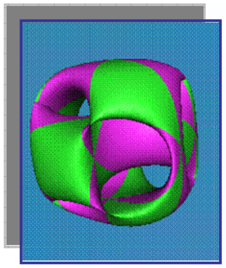
- Cognitive Systems
- Command & Control Systems
- Computer Language Translation
- High Productivity Computing
- Sensors & Processing

Microsystems Technology

Greg Kovacs
Dean Collins

- Electronics
- Photonics
- MEMS
- Algorithms
- Integrated Microsystems

Defense Sciences Office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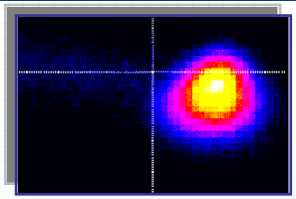
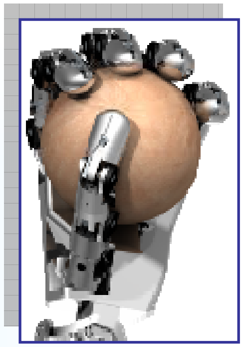

Quantum Mechanics


Zoology


Training and Simulation


Revolutionizing Prosthetics


Armor Systems

Mathematics

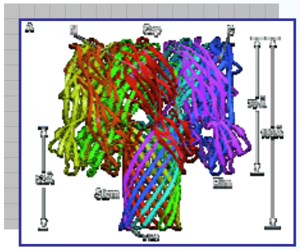
Physical Sciences

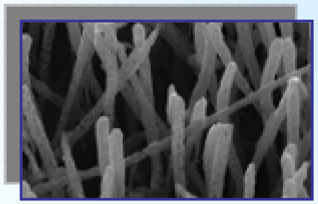
Biological Sciences

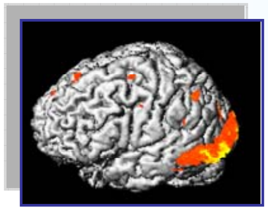
Engineering

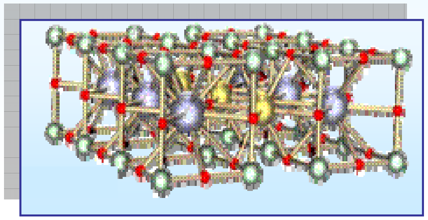
Mine the “Far Side of the Far Side”

Paradigm shifts in defense capabilities


Structural Biology

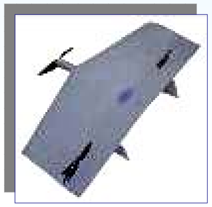

Nanotechnology


Neuroscience


Solid State Physics


Fuel Cells

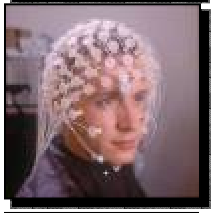

Big Dog

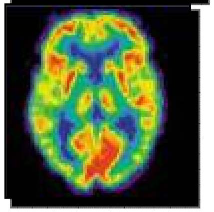

WASP UAV


Vaccine Manufacture

Methods to Understand Neural Basis of Human Cognition

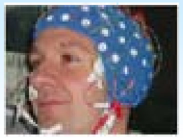
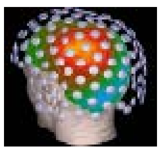
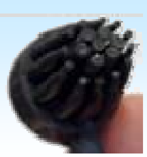
- Brain lesions and cognitive neuropsychology
- Electrophysiological recordings in primates (mammals)
- Pharmacological and genetic studies
- Transcranial magnetic stimulation
- Functional Neuroimaging
  - Hemodynamic-metabolic methods including PET/fMRI
  - Electric-magnetic methods including ERP and MEG

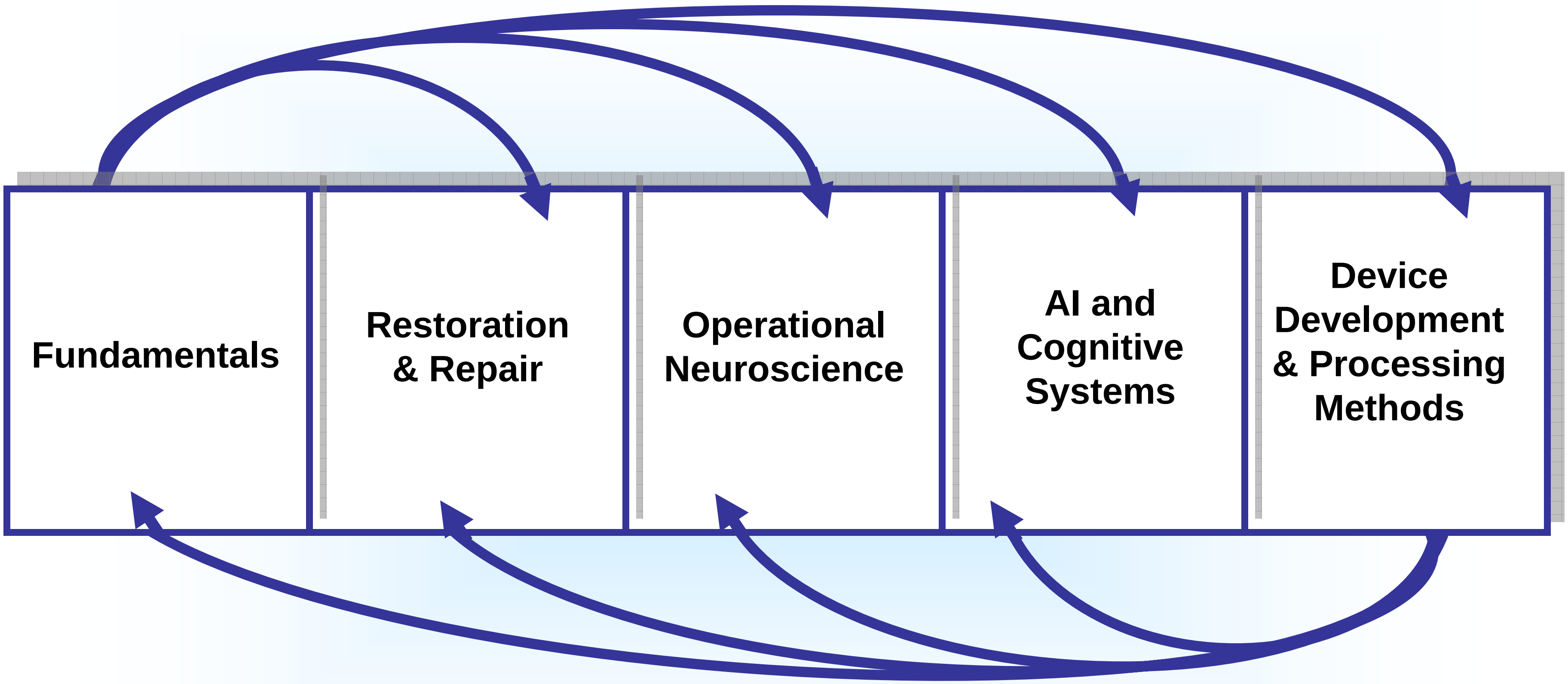



Functional neuroimaging allows the activity of all brain regions to be seen simultaneously – true network analysis is possible

Non-Invasive Sensor Technologies

Technology		Temporal Resolution	Latency	Spatial Resolution	Description	Operationally Feasible?
	EEG	ms	ms	cm	Measures electrical activity in the brain. Practical tool for applications - real time monitoring or brain-computer-interface.	Yes
	MEG	ms	ms	mm	Measures magnetic fields generated as a result of the brain's electrical activity. Research tool for investigating temporal properties of neuronal and cognitive processes.	**No**
	fMRI	s	min	mm	Measures the BOLD signal in neuronal tissue – oxygen uptake. Excellent structural localization of brain function. Important tool for foundational cognition research.	**No**
	PET	min	h	mm	Measures uptake of specially tagged molecules (e.g. glucose) in brain tissue following stimulus. Excellent spatial localization, poor temporally.	**No**
	fNIR	ms	ms	mm	Measures the ratio of oxygenation in cortical regions using near infrared light. Permits spatial and temporal measurements from the same volume of brain tissue.	Yes

My Vision of Neuroscience



Operational Neuroscience

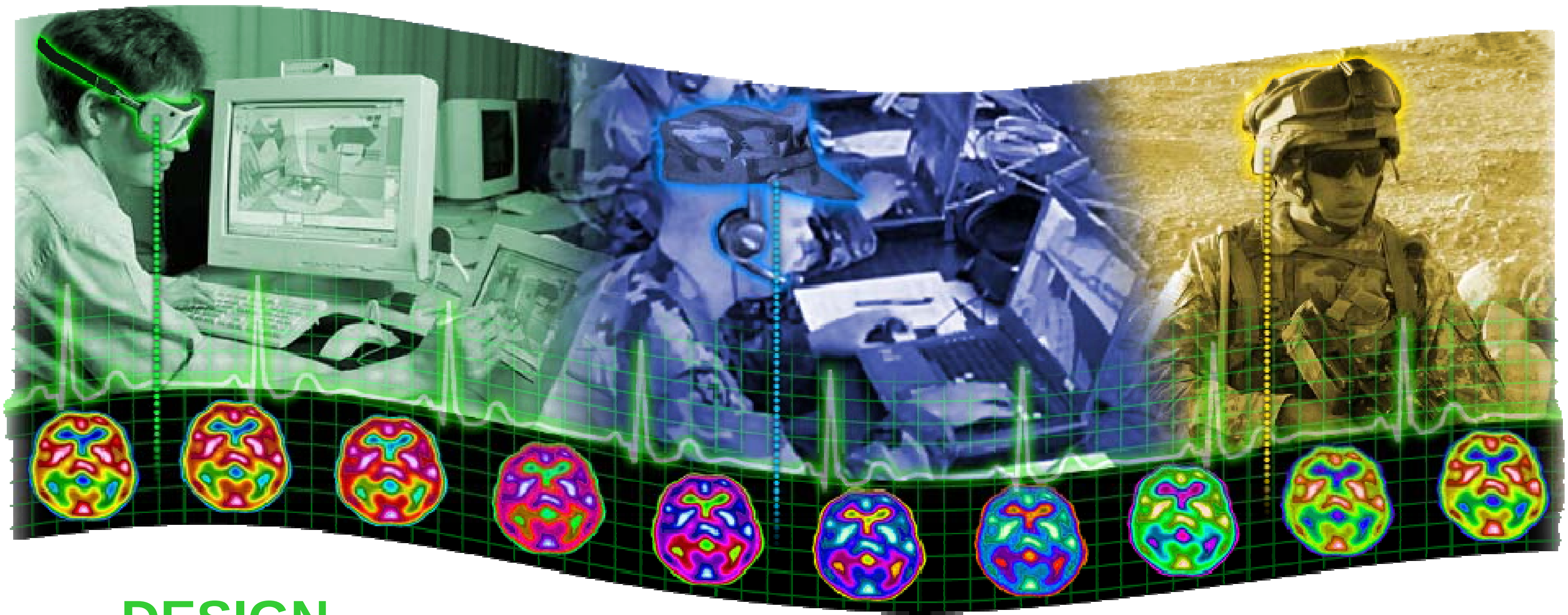
Brain activity can be monitored in real-time in operational environments with EEG

Desktop sleep deprivation assessment in desert stations

Dismounted training exercises lasting 7+ hours at a time

Images Courtesy of Honeywell, Aberdeen Test Center, and Advanced Brain Monitoring Inc.

Operational Neuroscience



DESIGN

TRAIN

OPS

ACCELERATED LEARNING

Program Vision

- Utilize neuroscience to understand the development of expertise through learning
- Use this understanding to directly facilitate and <u>accelerate</u> task learning for the warfighter

- Learning is a continuous challenge in the operational environment
- Current methods of learning fail to capitalize on basic lessons from neuroscience
- Measures of learning on key skills only as good as <u>*qualitative and subjective*</u> assessments

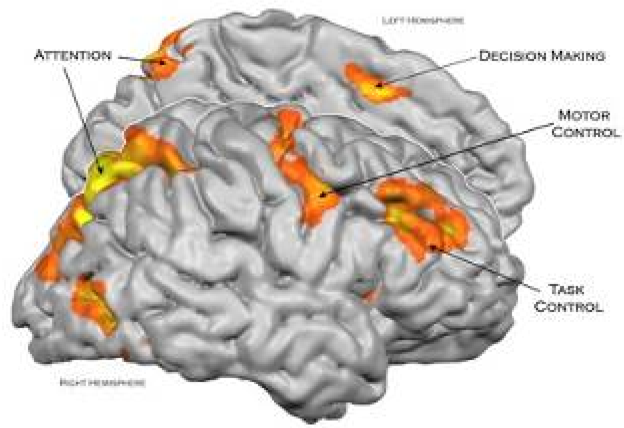
Using a neuroscience based approach, <u>change the paradigm</u> of learning in the military

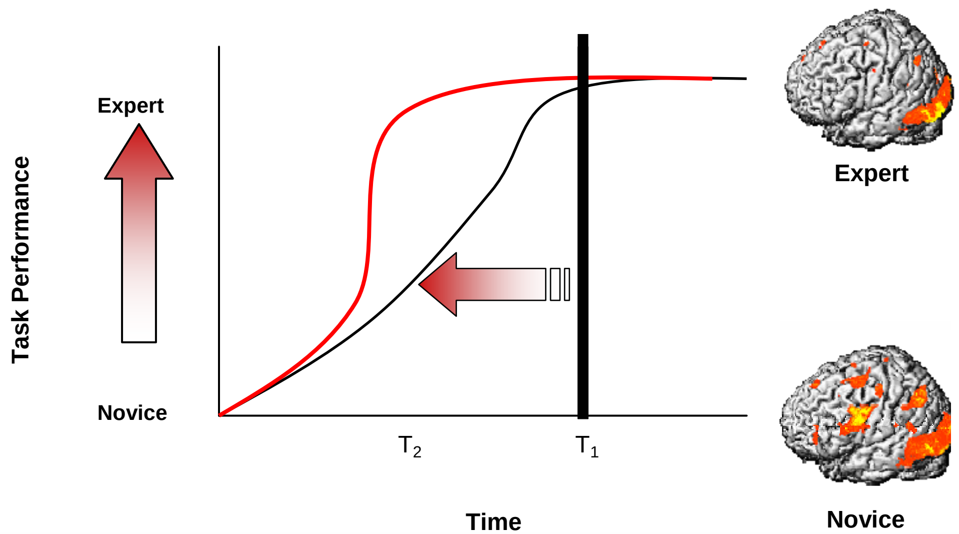
Phase I Goals

Utilize neuroscience to understand the development of expertise through learning to directly facilitate and accelerate task learning for the warfighter

Program Goals:

- Identify the neural basis of expert performance
- Track progression from novice to expert with classification of intermediary stages
- Demonstrate a two-fold increase in the progression between stages of the novice-to-expert path

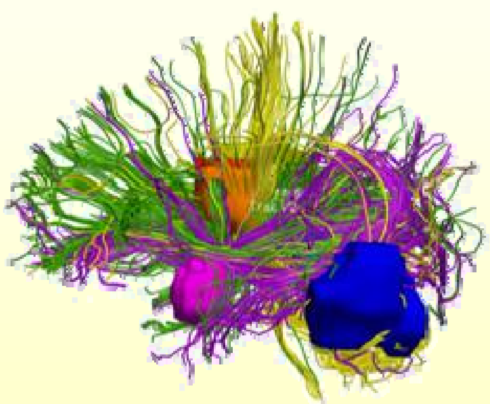




Phase I Approaches

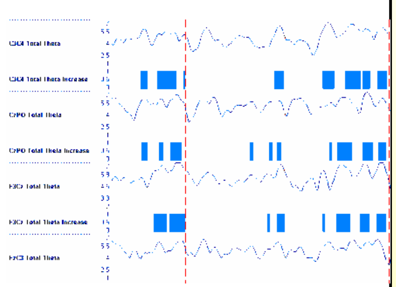
Optimized Task Qualities

- Apply multiple biological and cognitive findings about the user to customize the learning environment



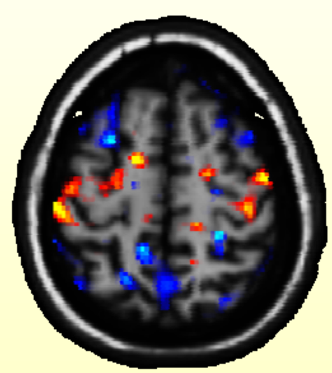
Neurofeedback

- Present the user with real-time feedback on brainwave activity in the form of a haptic feedback during training



Global Network Measures

- Determine and facilitate the neural mechanisms of consolidation (declarative and procedural memory, attention networks, memory chunking)



Direct Stimulation

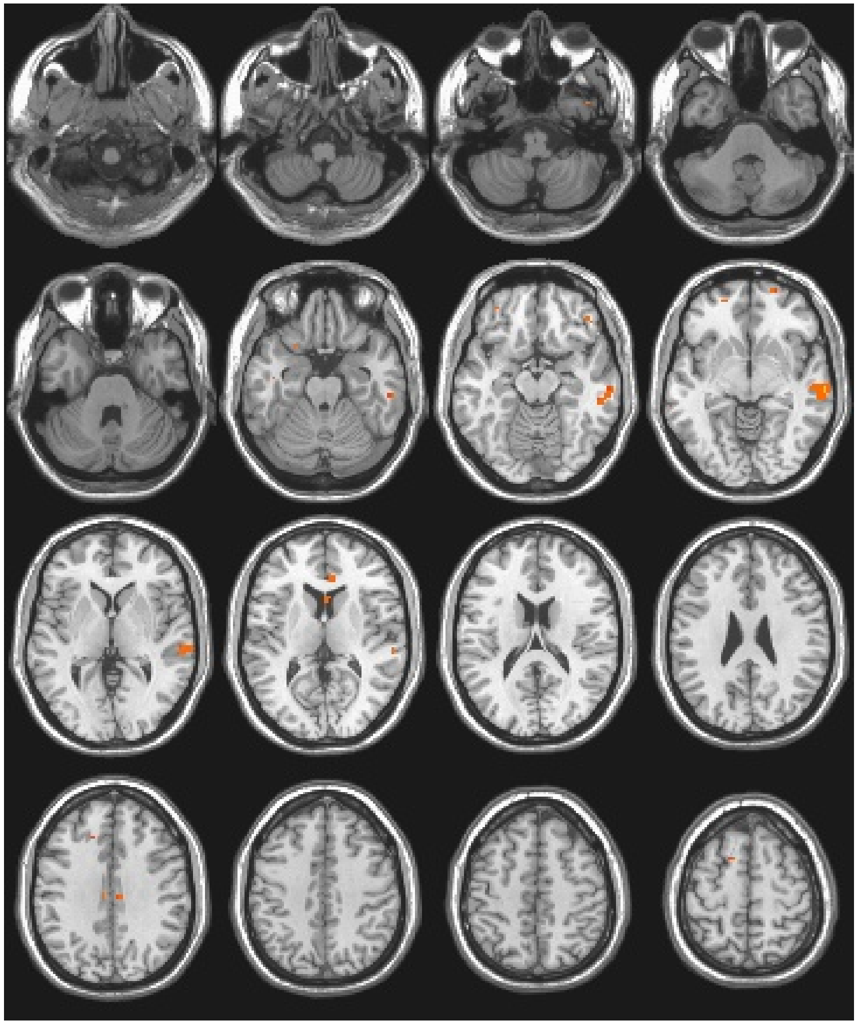
- Utilize techniques such as tDCS in combination with functional imaging to directly stimulate neural pathways critical for learning

Innovation

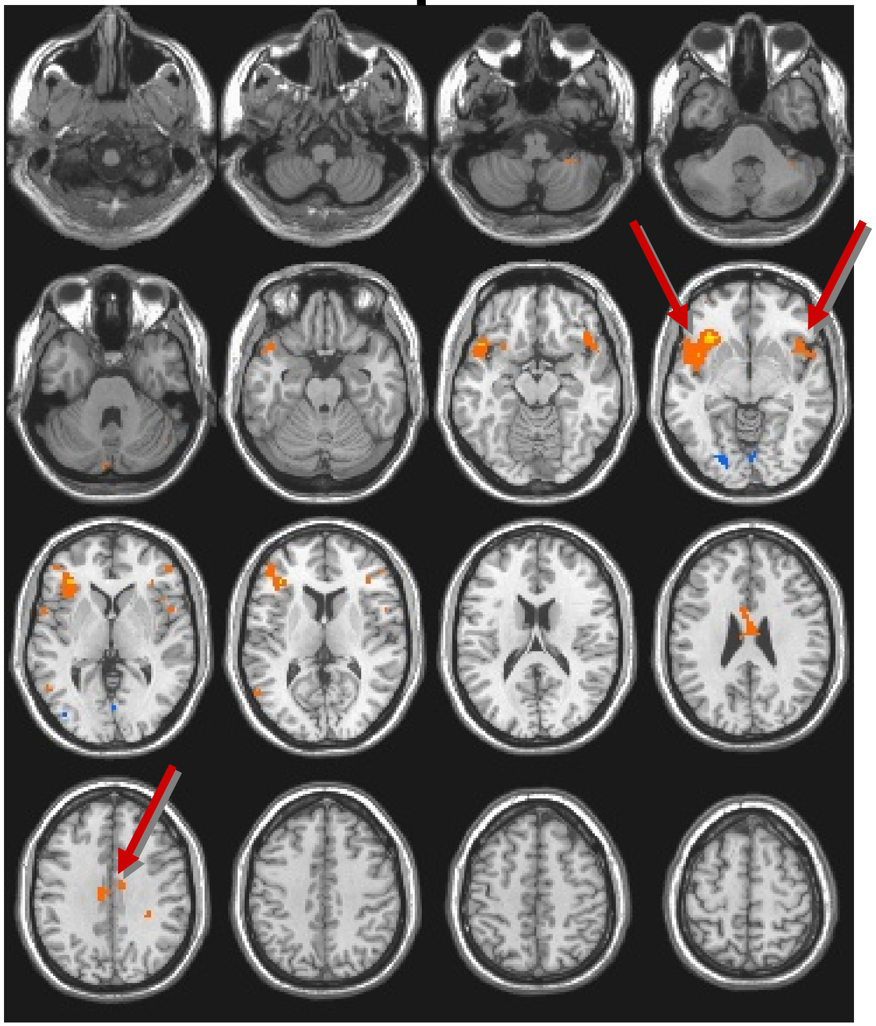
Accomplishment: fMRI Signatures of Novice Vs. Expert Behavior

Threat - Nonthreat Stimuli

Novice



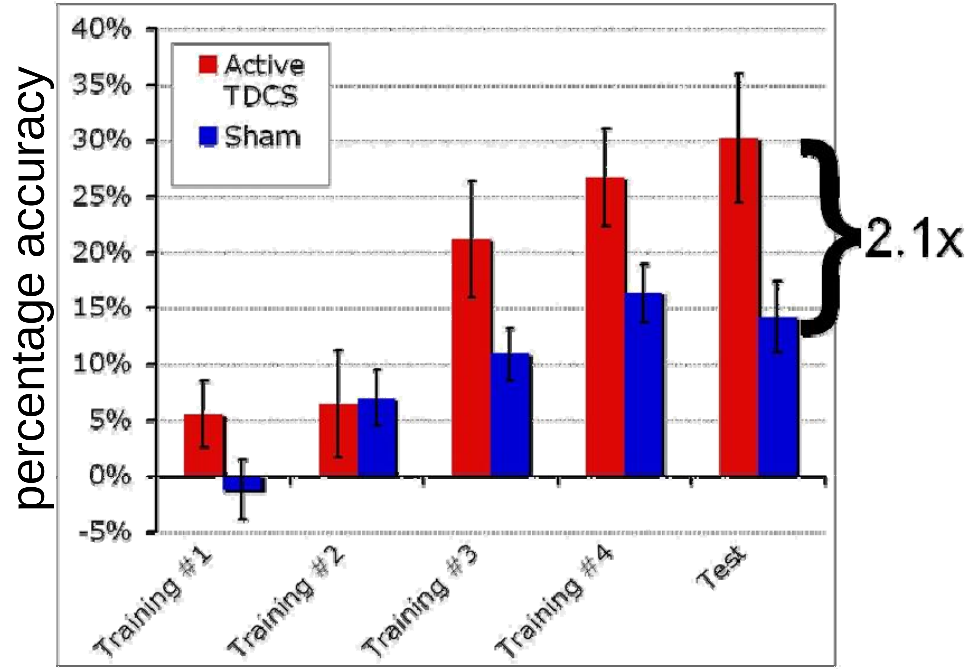
Expert



Accomplishment: Direct Stimulation leads to 2x Improvement

tDCS stimulation applied to the right sphenoid (right temple) at 2 milliamps for 30 minutes provides an improvement in learning vs. sham in threat detection training

•2.1x improvement (p=0.0093) in threat and non-threat detection accuracy
•3.1x improvement for threats alone (p=0.0004)



NEUROTECHNOLOGY FOR INTELLIGENCE ANALYSTS

NIA

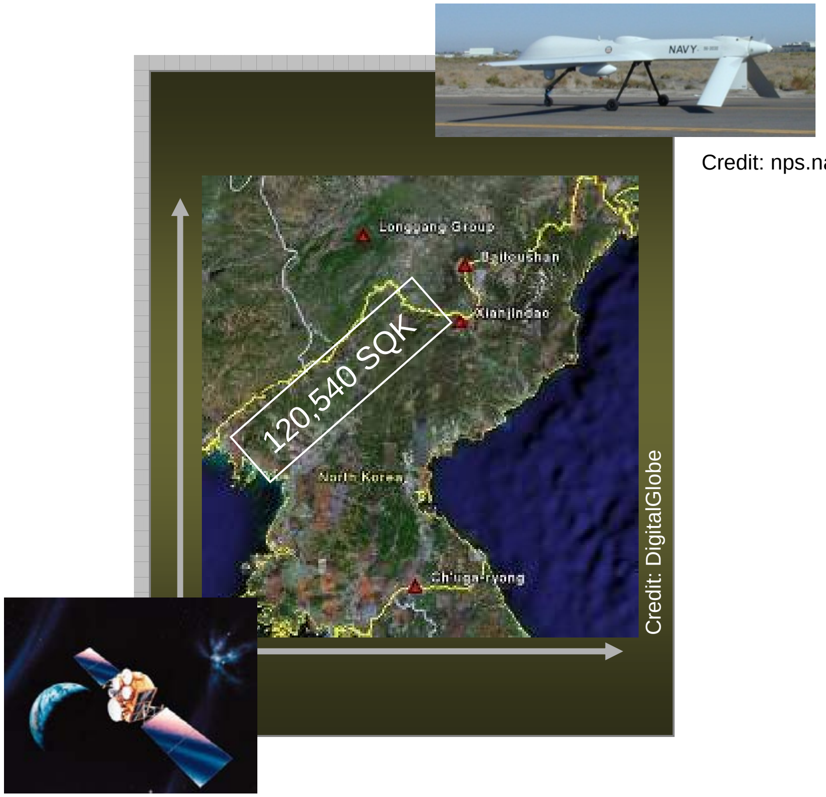
Problem: Imagery Overload

Operational Challenges

- Collections capabilities are increasing
  - Quantity
  - Modality
- Exploitation can require manual search through terabytes of overhead imagery

Resources

- Current brute-force method (Broad Area Search) is time- and labor-intensive
- Machine vision and ATR have not matched the detection sensitivity and flexibility of the human visual system
- Exploitation requires manually searching through ***terabytes*** of overhead imagery



Credit: nps.navy.mil

Credit: DigitalGlobe

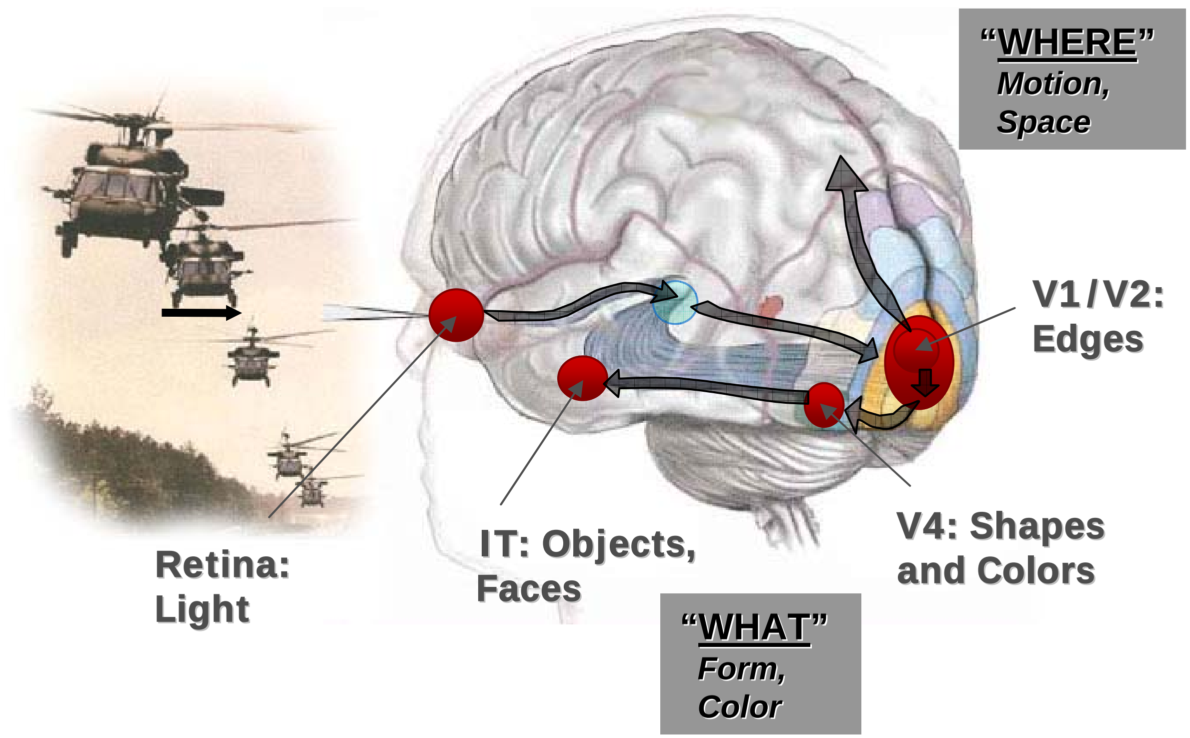
Credit: schreiver.af.mil

Result: Strategic analytical requirement exceeds available and foreseeable resources

One Solution: Leverage Human Perception

Human vision is fast, accurate and robust to changes

- **Speed: Earliest brain visual responses are <250 msec**
- **Accuracy: Human detection rate can be >>99%**
- **Robustness: Detection persists across a wide range of conditions**



NIA Solution: Brain-assisted exploitation – but how?

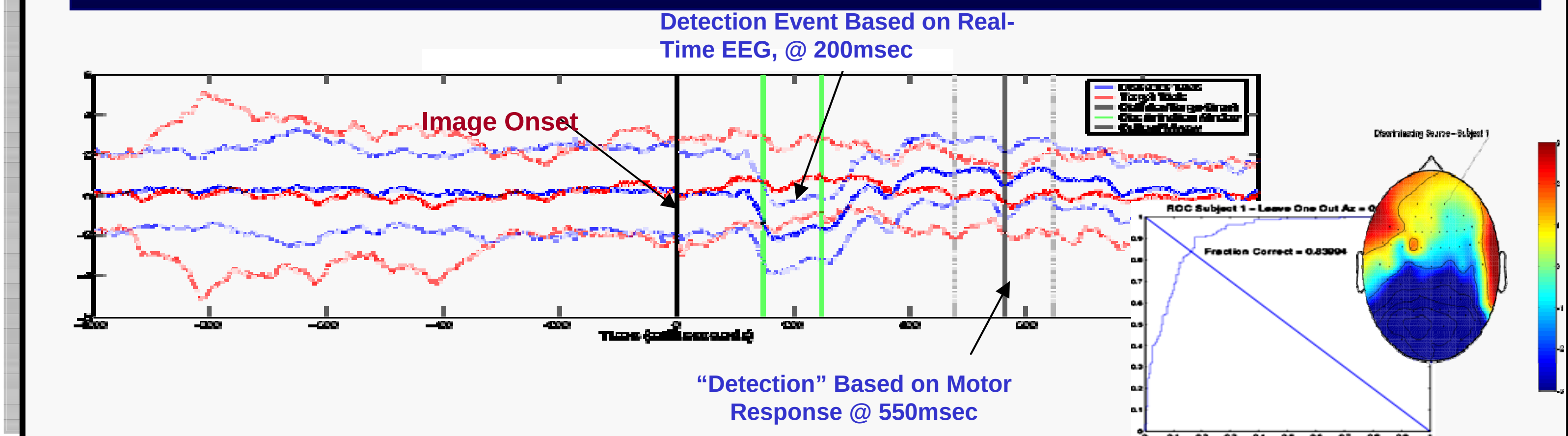
Science Behind NIA

Basic Science: Human visual detection events can be identified in EEG

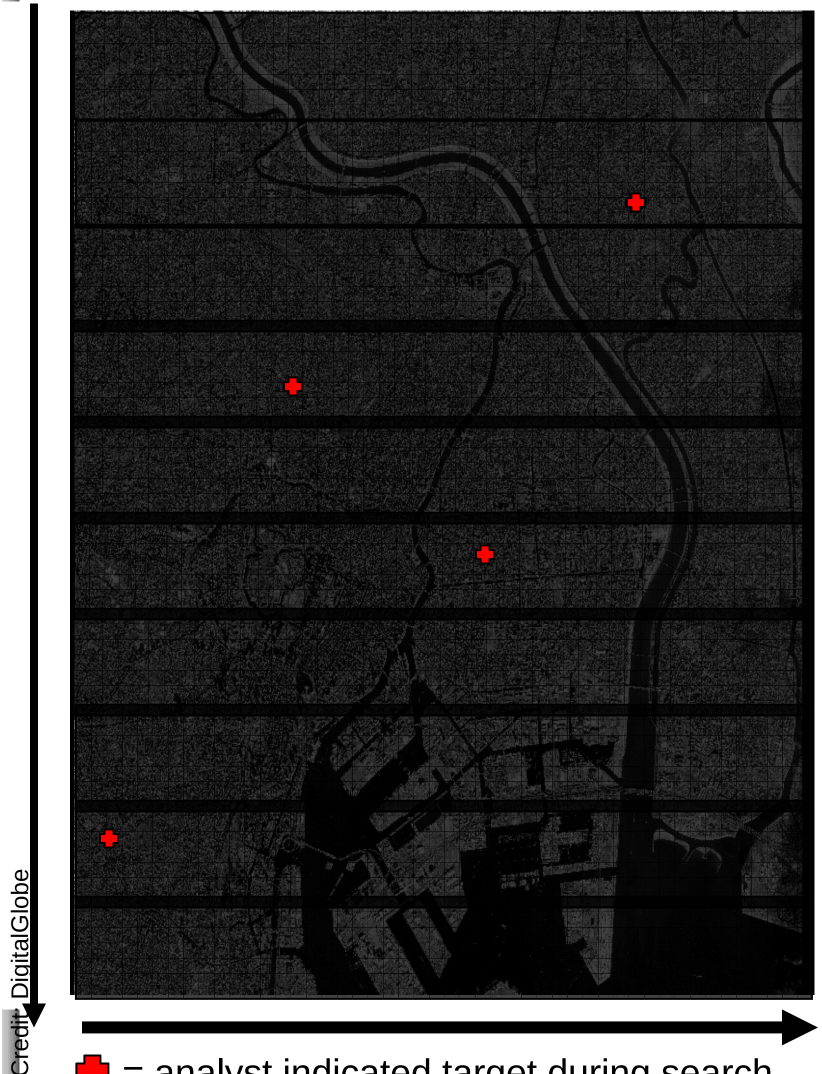
- EEG signatures during Rapid Serial Visual Presentation
- Brain events can be detected in one-third of the time needed to press a button (Thorpe et al, Nature, 1996)
- Signature in neurophysiological recordings demonstrates detection of target images for presentation rates of up to 72 images/sec (Keysers et al, JCN, 2001)
- Demonstrated with faces, natural scenes, multiple presentations

Real Time Signal Detection :

Individual visual target identification events can be detected in real-time
with an average accuracy of 83%!



Experimental Approach: Baseline



= analyst indicated target during search

Baseline (Broad Area Search) Task Example:

Total Area (urban, riverine, maritime) = 314.86 km^2

Targets: Helipads

Imagery Analysts were instructed to exploit the full scene manually in a geospatial software environment and to mark a defined target.

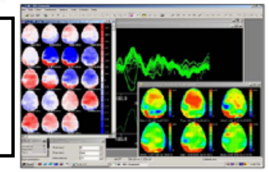
Exploitation was self-paced and analysts were allowed to search the image until satisfied all targets had been located.

Analyst-marked target set was compared to ground truth (by 2 or more IAs) for sensitivity calculation.

Estimated search time for trained IA: 135 minutes

Experimental Approach: NIA Triage

IA with neurophysiological sensors for image chip viewing (prototype display)

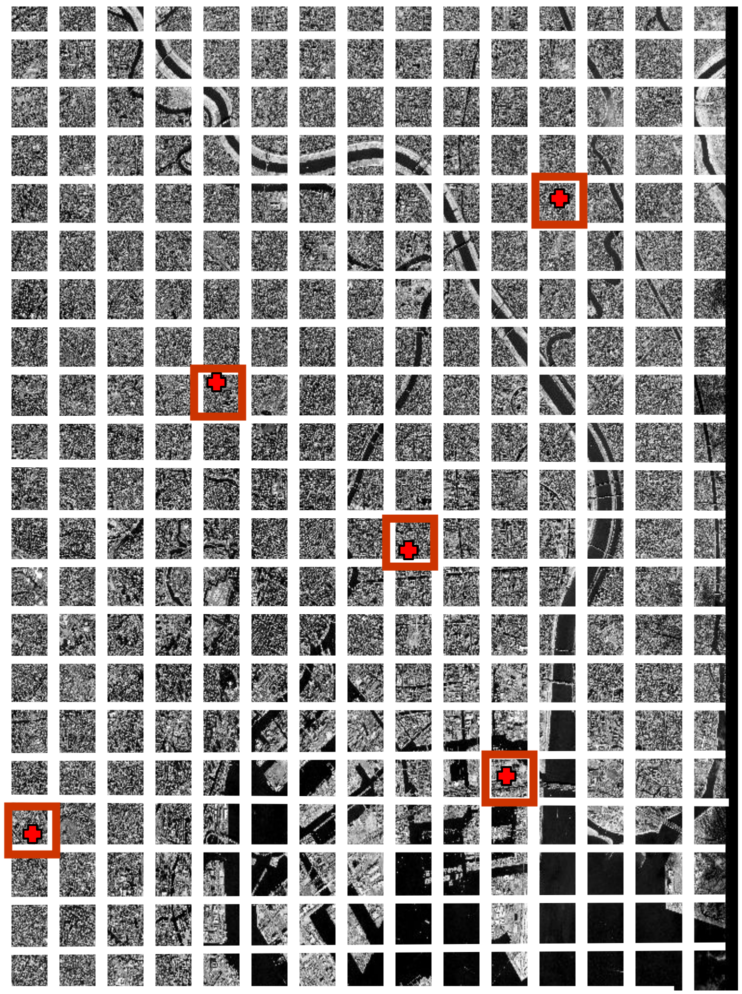


Full scenes were chipped into 512 pixels^2 (e.g. 3300 chips for 314.86 km^2 total area)

Chips were at a magnification suitable for exploitation (1:1) but sized to minimize eye movements during triage

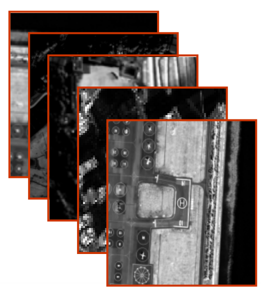
All chips were displayed rapidly (5-12 Hz) to IA. Neural signals were collected and classified in real time for target or non target properties

Triage mode time (10 Hz, including breaks): ~10 minutes



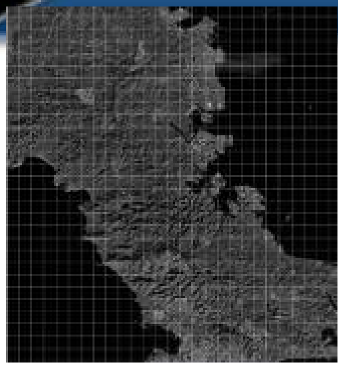
= targets indicated via neural signals during triage

All images: Credit: DigitalGlobe



Chips with high target probability given by neural signal are marked and compared to truthed data for sensitivity assessment

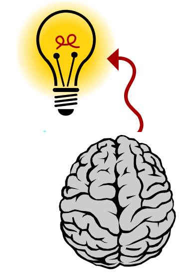
Phase I Results



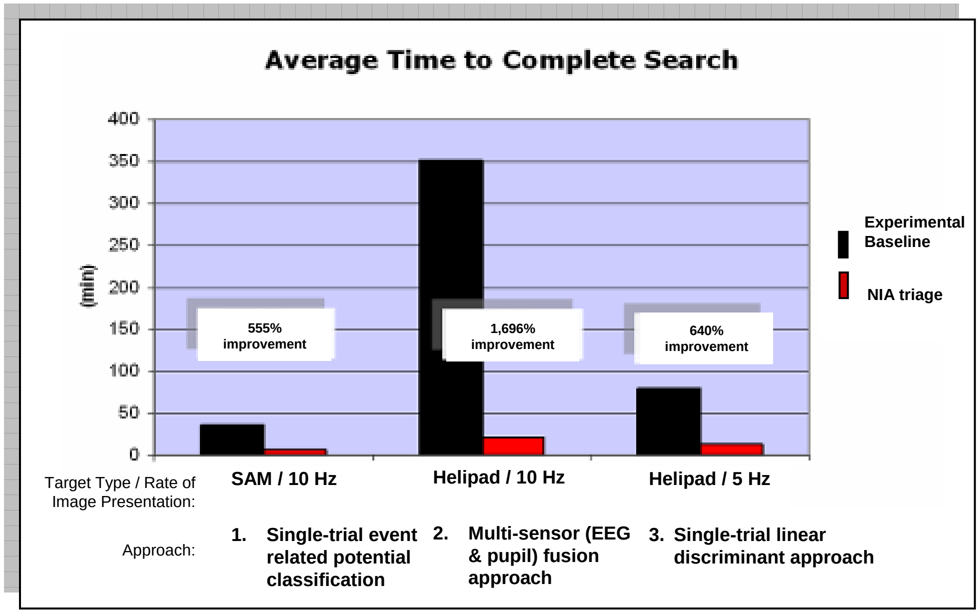
Original image tens of thousands of pixels wide and tall

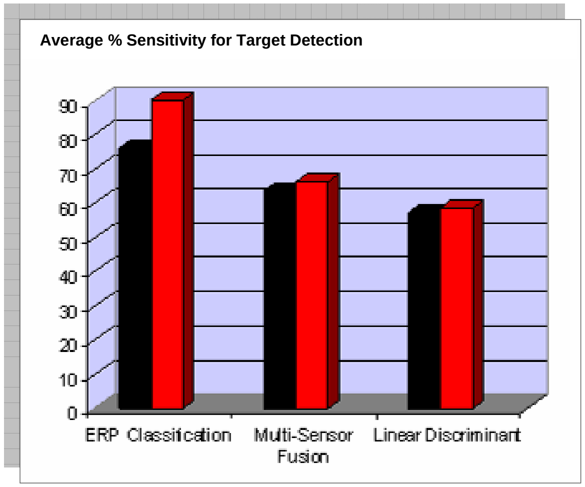
Decompose into chips few hundred pixels wide and tall

Present chips to users in high speed bursts (10 chips a second)



Evaluate neural activity to identify likely targets





Result: >300% throughput improvement and detection equal or better than current SOA

NIA Phase 2 Vision

Phase 2 Goal

Integrate modern neuroscientific techniques into imagery analysis workflow to improve throughput and quality of imagery analysis

Phase 2 Metrics

- Maintain 300% throughput increase in imagery exploitation in a realistic analyst software/hardware environment.
- Demonstrate greater than or equal to unassisted image analyst sensitivity.
- Maintain performance across 3 complex target classes and under variable operating conditions.

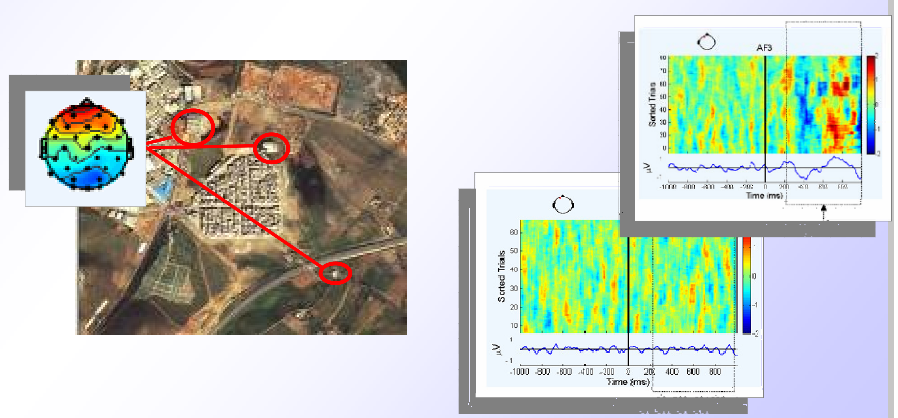
Phase 2 Technical Challenges

- Capture brain signals in real time during realistic imagery analysis on baseline imagery exploitation systems
- Categorize target detection brain signals based on object / scene complexity
- Integrate neuromorphic computational image analysis and physiological brain signals

Phase 2 Applied Science

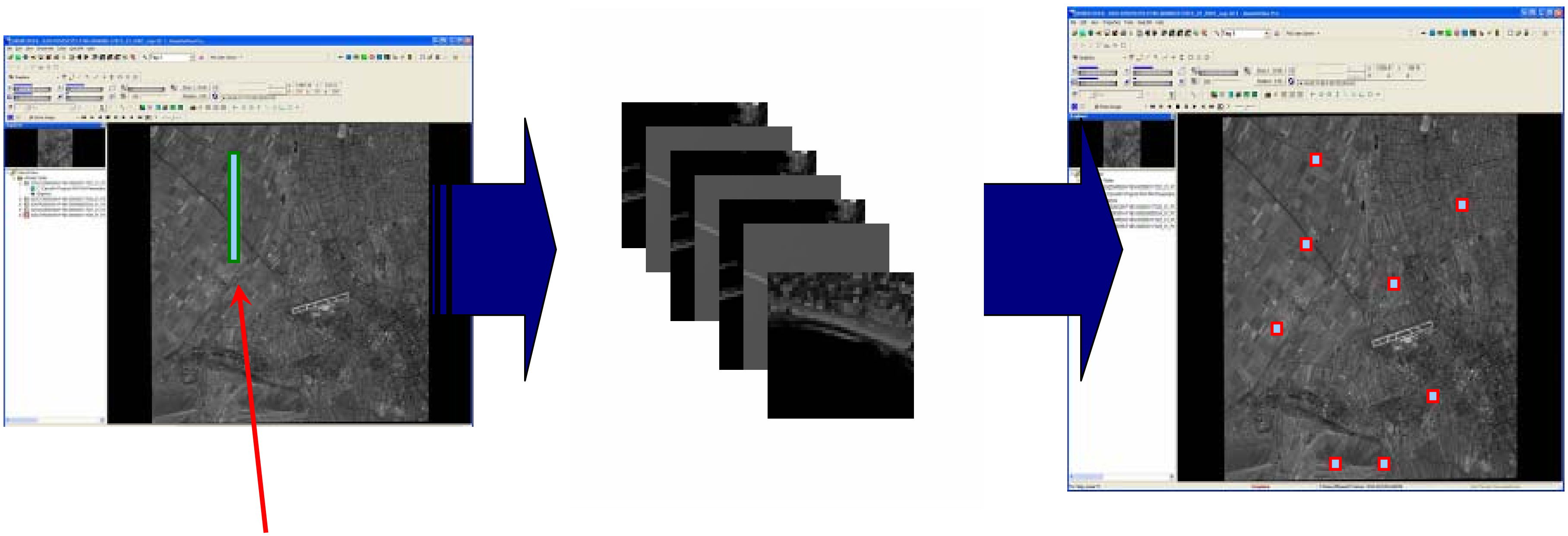
Apply Phase 1 breakthrough science in operational contexts

- **Extend capture of brain signals for target detection to:**
  - **Multiple imagery types**
  - **Diverse target and scene complexity**
- **Integrate brain-assisted search into standard imagery analysis software**
- **Leverage/converge with automated machine vision technologies**
- **Demonstrate with trained analysts with realistic tasks and environment**



Accomplishment: Remoteview Integration

Triage integration approach maintains context before RSVP and during verification



Triage Preview

RSVP Triage

Post-Triage Review

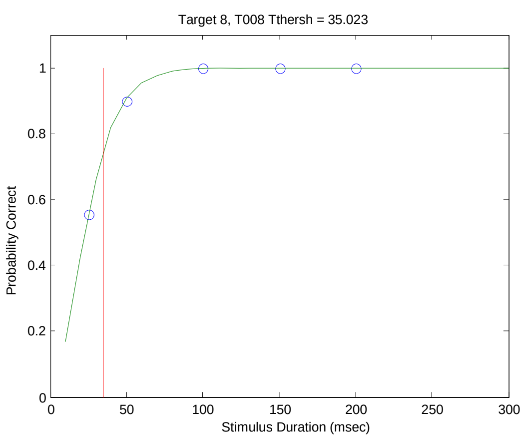
Analysts maintain "global view" before triage begins, and can "fly to" any target hit results during post-triage exploitation

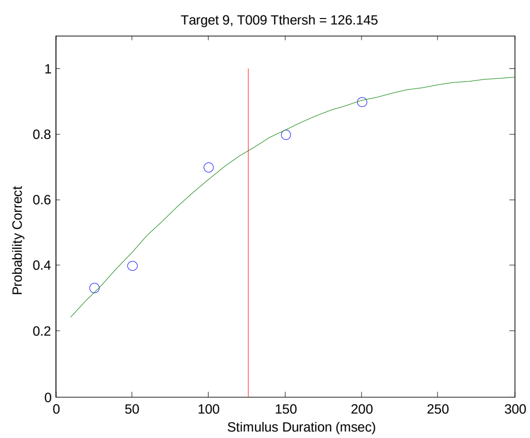
Credit: DigitalGlobe

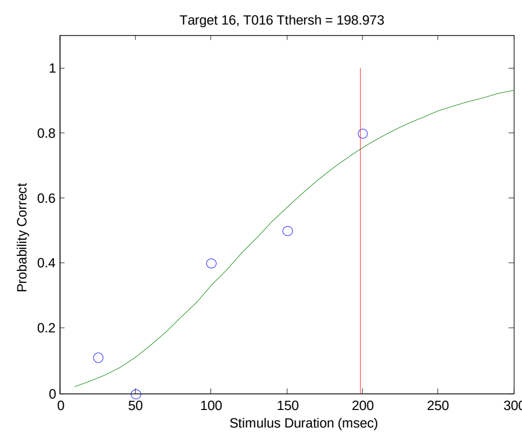
Accomplishment: Uncovering impact of image complexity

As targets become less stereotypical, the image stimulus duration necessary for correct detection increases

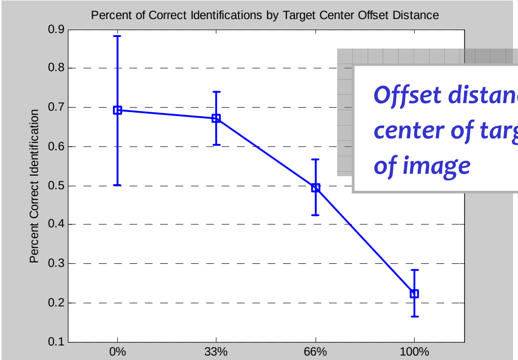
Credit: DigitalGlobe





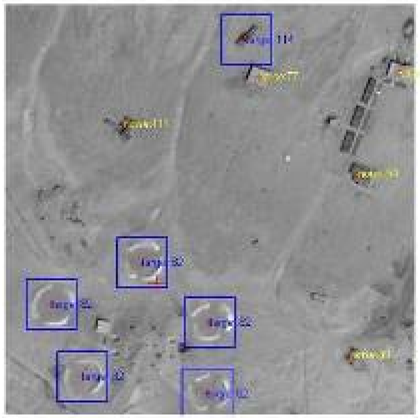


Accomplishment: Computer vision enables target centering enhancing detection

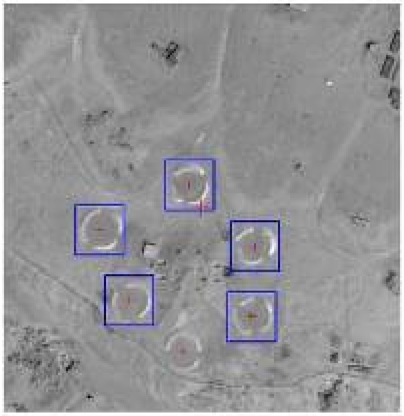


Offset distance from center of target to center of image

Human detection performance is weaker when targets are off-center



Result of default chipping



Result of computer vision aided chipping

Credit: DigitalGlobe

- **Computer vision techniques identify objects that share features with target of interest**
- **Small adjustments are made so that chipped images place likely targets at center of each chip**
- **Approach employed simple features (edges, intensity, spatial filter responses etc.) that are easy to implement and relevant across target types**
- **All targets in validation set were better centered**

Examples of New Target Types

Military Facility

Naval Order of Battle

Credit: DigitalGlobe

POL Storage

Cargo Ships

CT2WS

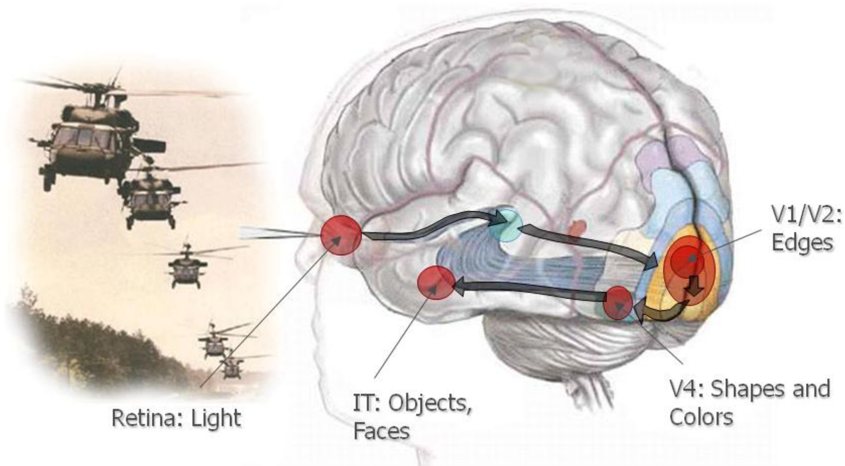
Cognitive Technology Threat Warning System

Problem: Situational Awareness

How can we take advantage of what we know about the mammalian visual system?

Operational Need for Ground-Based Persistent Situational Awareness

Current manual method is slow, imprecise and distance-limited



Using visual science knowledge how can we provide a tactical advantage to the warfighter?

- -Visual Pathways
- -Neural Signatures
- -Object Recognition and Classification

CT2WS aims to provide reliable early warning = More options, greater sphere of influence

Cognitive Technology Threat Warning System

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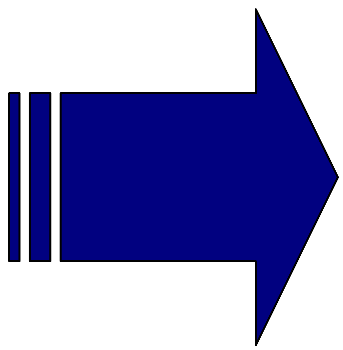
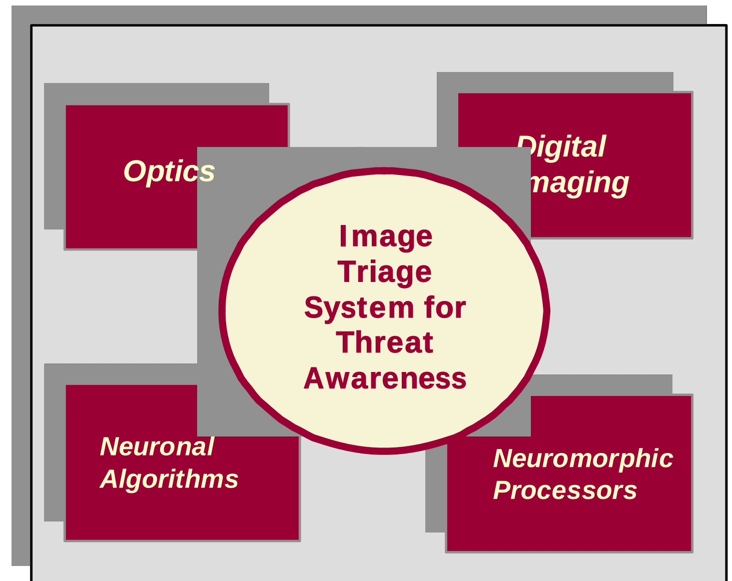
***Goal**: Tactical device which incorporates fusion of actual and simulated neural processing in real time to detect threats*

Current: 1000-2000 m



CT2WS: 1000-10000 m



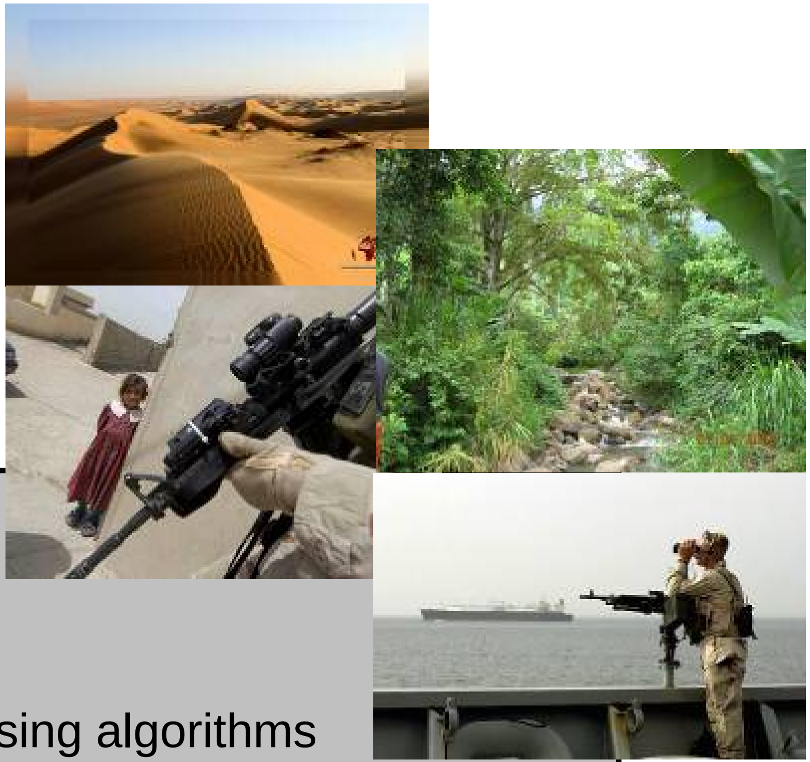
Current (M22): 9° 22'

CT2WS: 120° FOV

CT2WS Objectives

Detection Requirements

- Walking dismounts: 1 Km
- Stationary vehicles: 5 Km
- Moving vehicles: 10 Km
- FOV: 120°



Technologies

- Optics: Flat-field, wide-angle
- Imagers: High pixel-count, digital
- Image Algorithms: Cognitive visual processing algorithms
- Neurally-based target detection signatures → Brain in the loop
- Electronics: Ultra-low power analog-digital hybrid signal processing

Metric: Pd ≥ .98, False Alarm Rate < 10 in less than 5 min.

Scene Triage: ***Objects of Interest*** rapidly detected and presented to operator for discrimination

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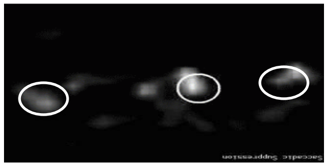
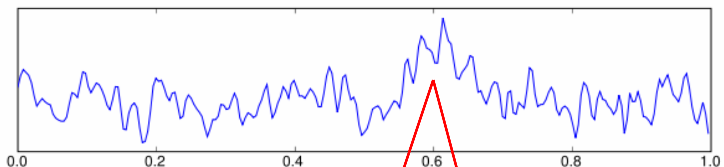
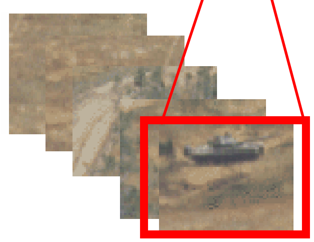
Implementation Concept

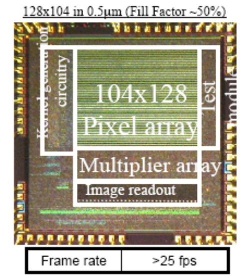


Cognitive algorithms scan ROI to give preliminary potential target information

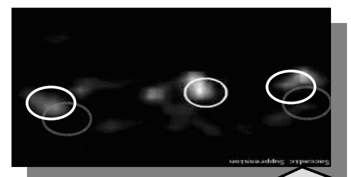
EEG coupled technology rapidly presents potential targets to user allowing neural signal classification of target/nontarget

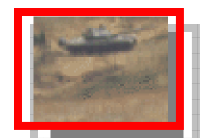






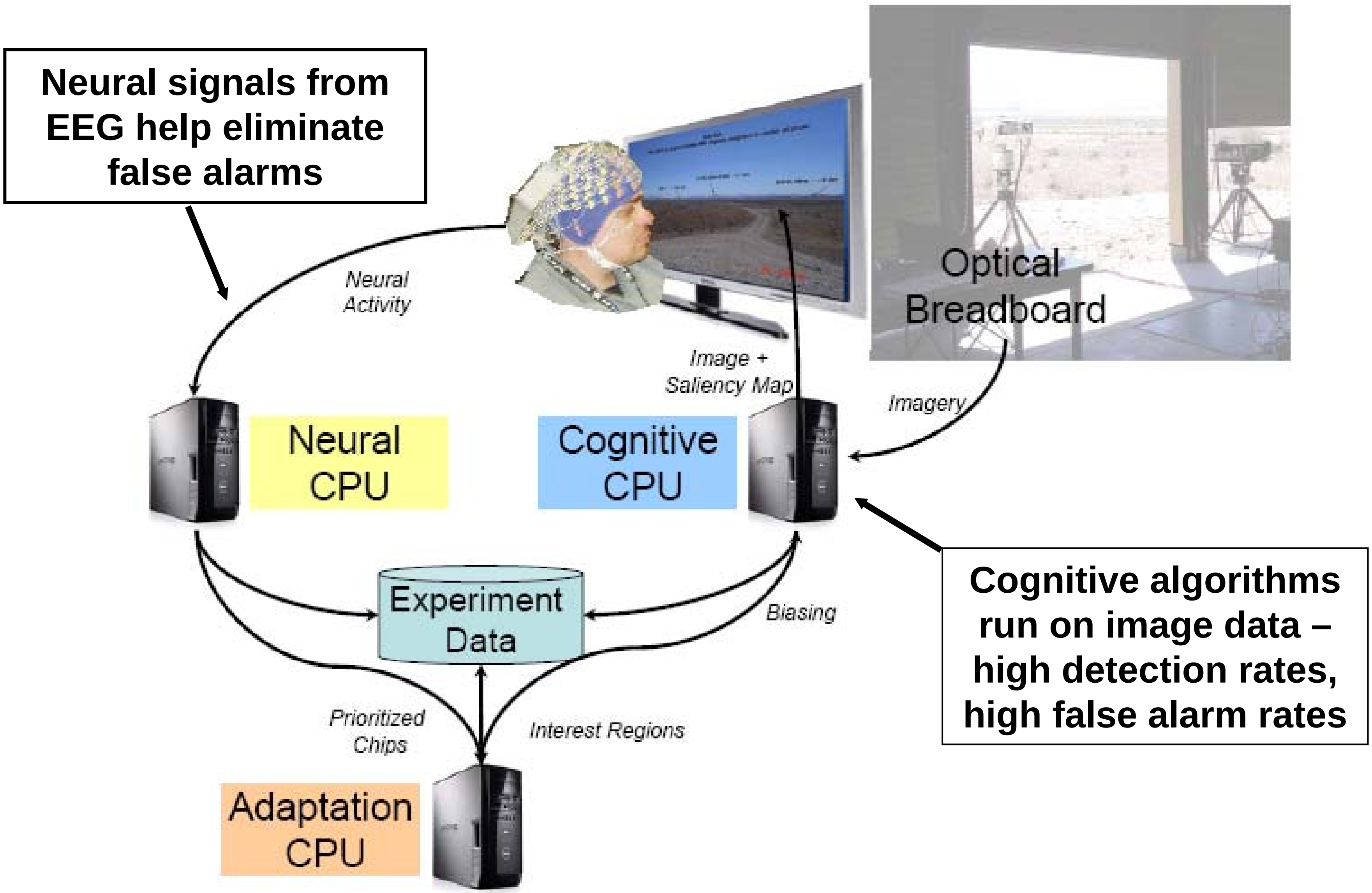
Neuromorphic processors provide a platform for algorithms to run with maximum efficiency





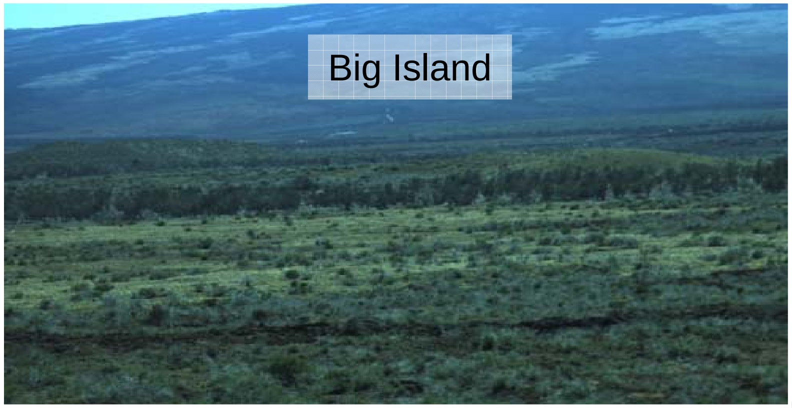
Algorithms can learn from the human, in real-time, to separate real targets from distractors, enhancing the overall utility of the system

Field Test Breadboard Concept



Data Collection and Field Test Locations

- **Data Collected from Test Sites**
  - YPG
    - 87 hours of daytime data
    - 15 hours of nighttime data
  - Hawaii
    - 100 hours of daytime data
    - 12 hours of nighttime data
- **Current performers in the field THIS week testing initial systems components**



Questions?

Ideas?

Where might you apply Neuroscience to future problems of interest to IC/DoD?