Taming the Torrent: Future Military Signal Processing and Information Fusion

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Vision

The Nation's Premier Laboratory for Land Forces.

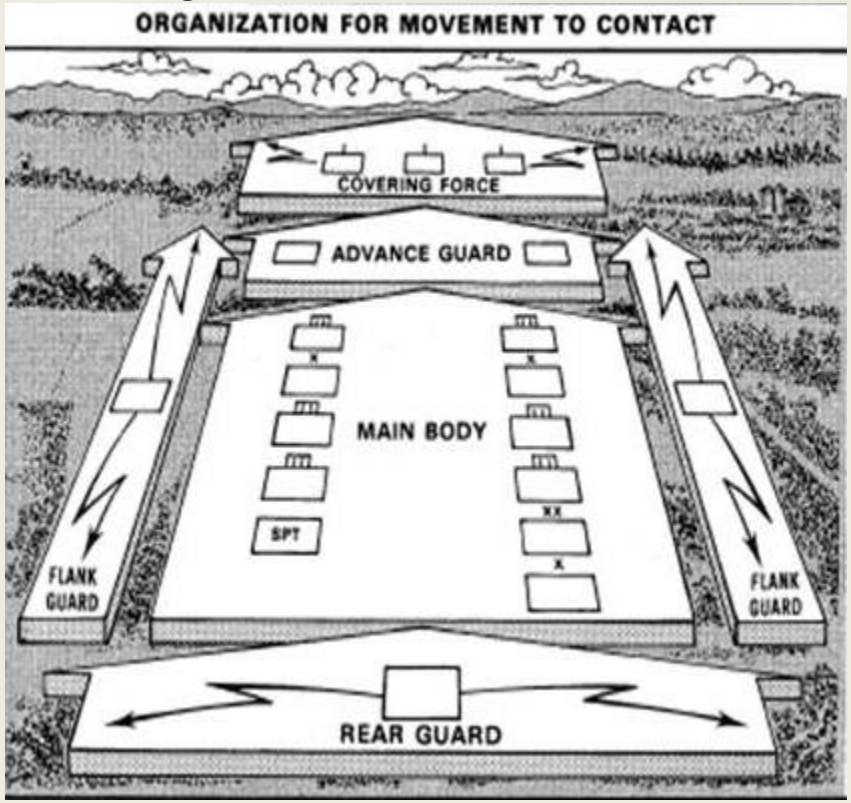
Mission

DISCOVER, INNOVATE, and TRANSITION Science and Technology to ensure dominant strategic land power

Making today's Army and the next Army obsolete

TRADOC Unifying Concept for the Future

AirLand Battle:
Flight outnumbered, and win



Unified Land Operations:
Prevail in a complex world

ARL's S&T Strategy- Perform fundamental research to inform the *Army Operating Concept* for the "Deep Future" (2050)

ARL S&T Campaigns

Functional Campaigns

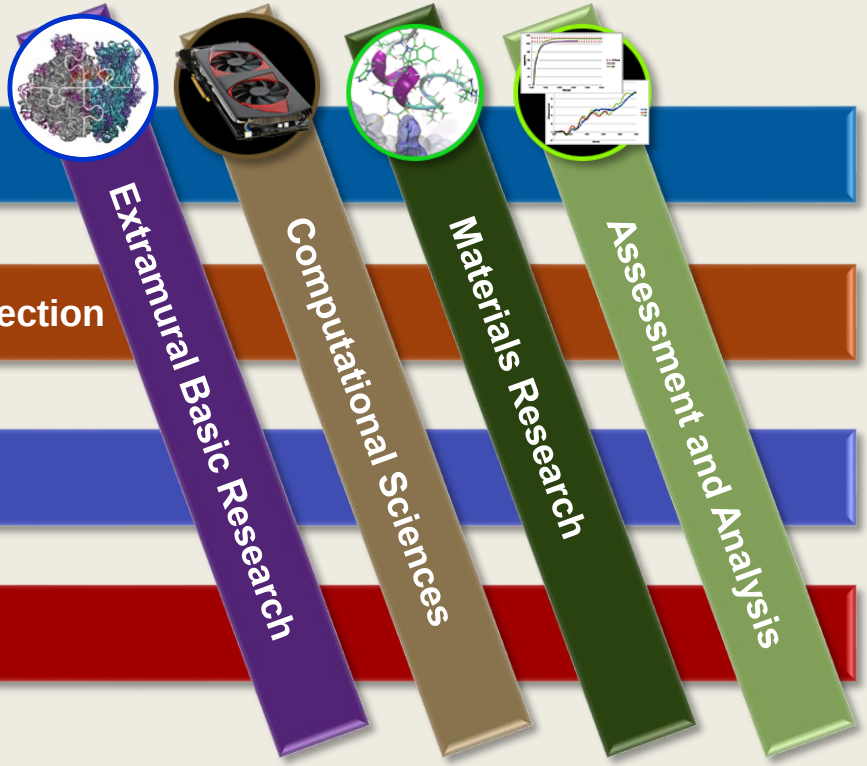
SOLDIER — Human Sciences

SHOOT — Sciences for Lethality & Protection

MOVE — Sciences for Maneuver

COMMUNICATE — Information Sciences

Cross Cutting Campaigns



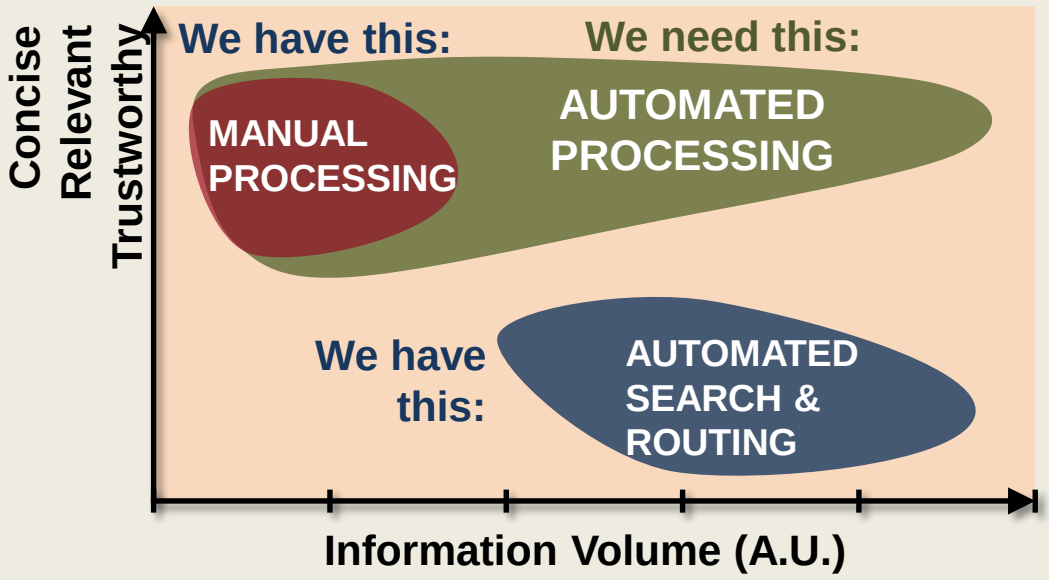
- **A coherent understandable strategy**
- **Ultimately leading to new warfighter capabilities**

ARL Campaign Publications http://www.arl.army.mil/publications

ARL Essential Research Areas

- Human Agent Teaming
- Artificial Intelligence and Machine Learning
- Cyber and Electromagnetic Technologies for Complex Environments
- Distributed and Cooperative Engagement in Contested Environments
- Tactical Unit Energy Independence
- Manipulating Physics of Failure for Robust Performance of Materials
- Science of Manufacturing at the Point of Need
- Accelerated Learning for a Ready and Responsive Force
- Discovery

Data Processing Challenges



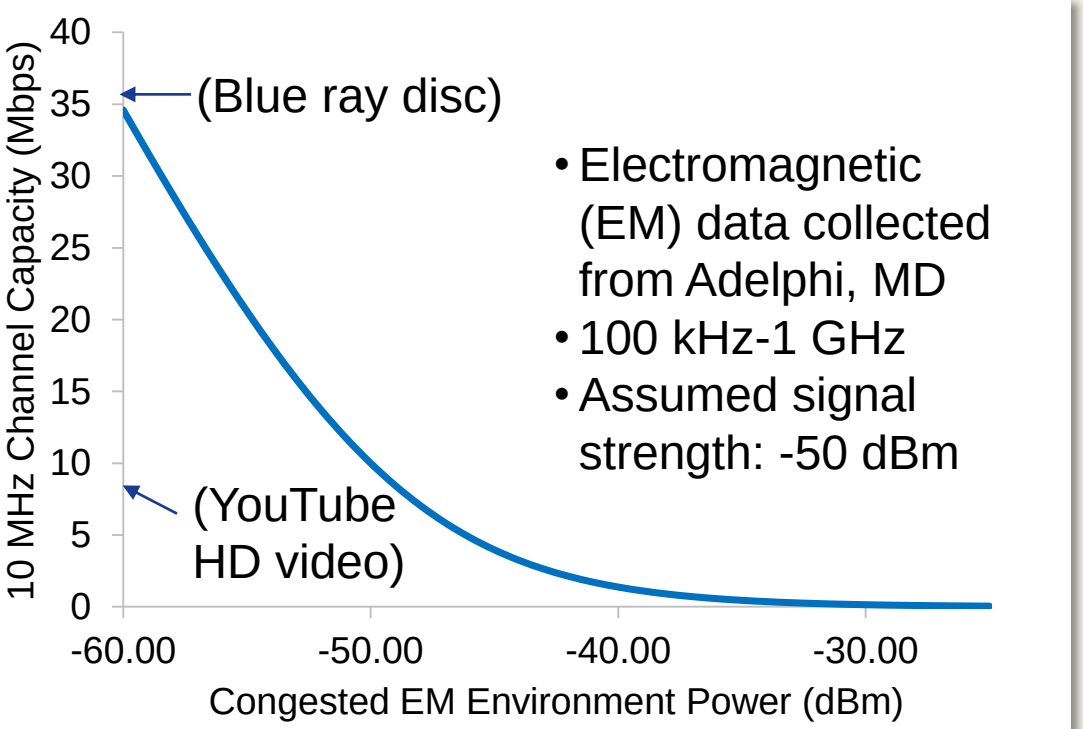
Commercial Efforts

- Industry investing heavily in deep learning (~$1B in start-ups since 2010 with 300 this year alone, >$1B OpenAI, Google $400M DeepMind acquisition, Google release of Tensor Flow, etc.)

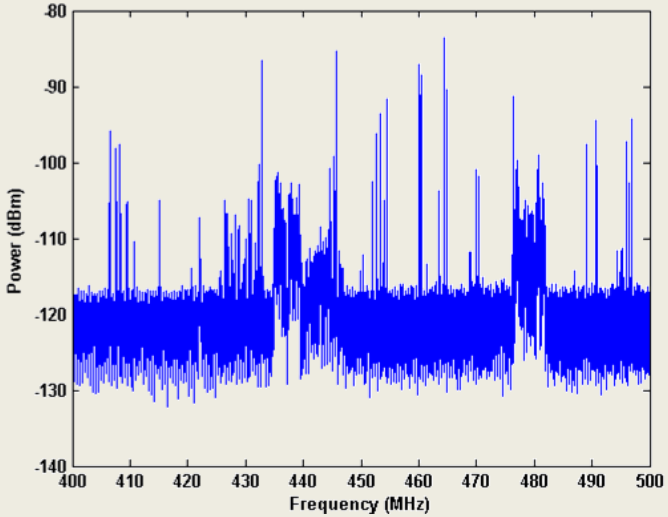
Army-Specific Challenges

- Constrained and contested environments
- Limited training datasets
- Heterogeneous computational and communication
  - Limited power/energy resources
  - Ensure trust/credibility

Electromagnetic Congestion



- Electromagnetic (EM) data collected from Adelphi, MD
- 100 kHz-1 GHz
- Assumed signal strength: -50 dBm



Typical 100 kHz sample

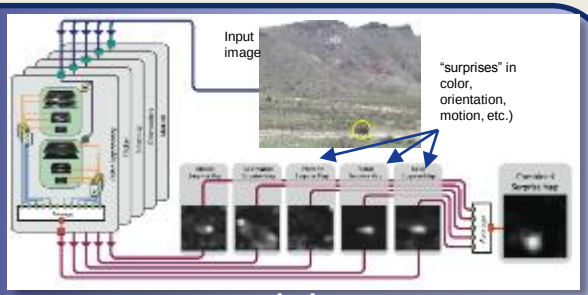
U.S. FCC raised >$41 billion by auctioning EM space to the private sector

- Maximum channel capacity **= situational awareness** in current mode of operation
- Background EM congestion high and continues to increase
- Problem is exponentially more significant in a hostile environment

Essential Research Areas

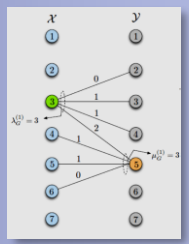
Deep Learning

- Human trainers
  - Machine learning from sparse training sets



Information Fusion

- New algorithms for increased confidence from hard / soft information sources

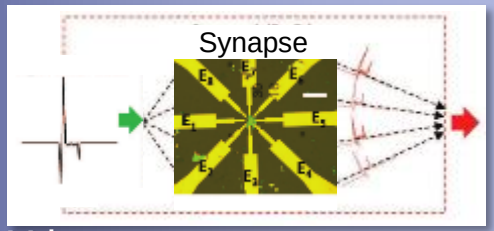


Human/Autonomy Teaming

- Humans adapt
  - Robotics augment human cognition
    - Teams outperform individuals

Neuromorphic Processing

- Pre-processing (i.e., DVS cam.)
  - Emulate bio-Materials, 1000X lower power



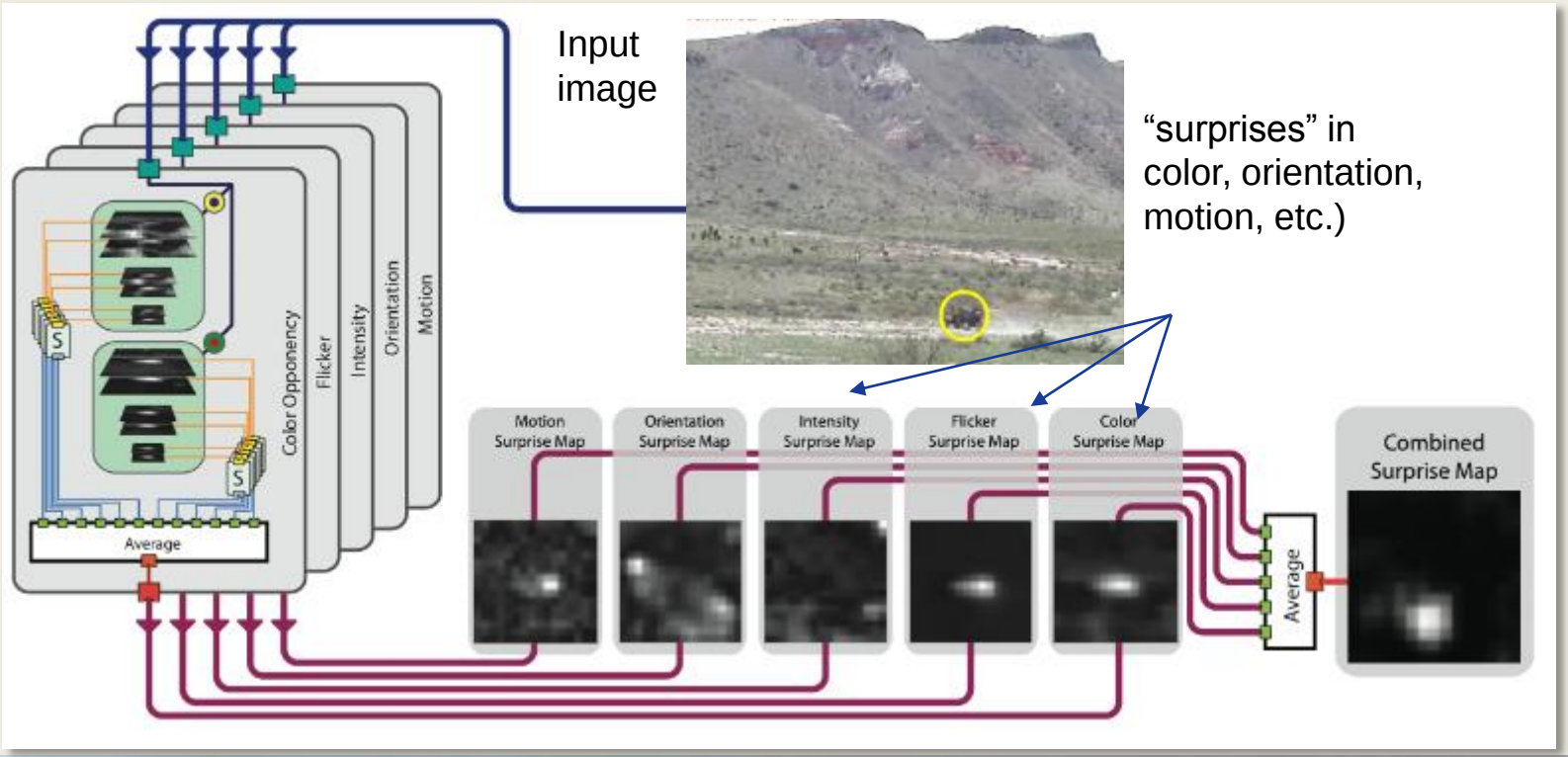
Near → Mid → Far

Taming the Torrent: Assuring timely and essential information for contested physical, cyber, and social battlefields

Deep Learning

Army Deep Learning

- Military-specific training datasets are sparse
  (e.g., most ISR imagery is normal activity)
- Need to implement efficient processing at the sensor
- One approach: "Surprise" detection



Human-Autonomy Teaming

Human-Autonomy Interaction Today:

- Humans adapt to complexities of real-world operational environments
- Consequently, humans **allowed** or even **required** to make critical decisions

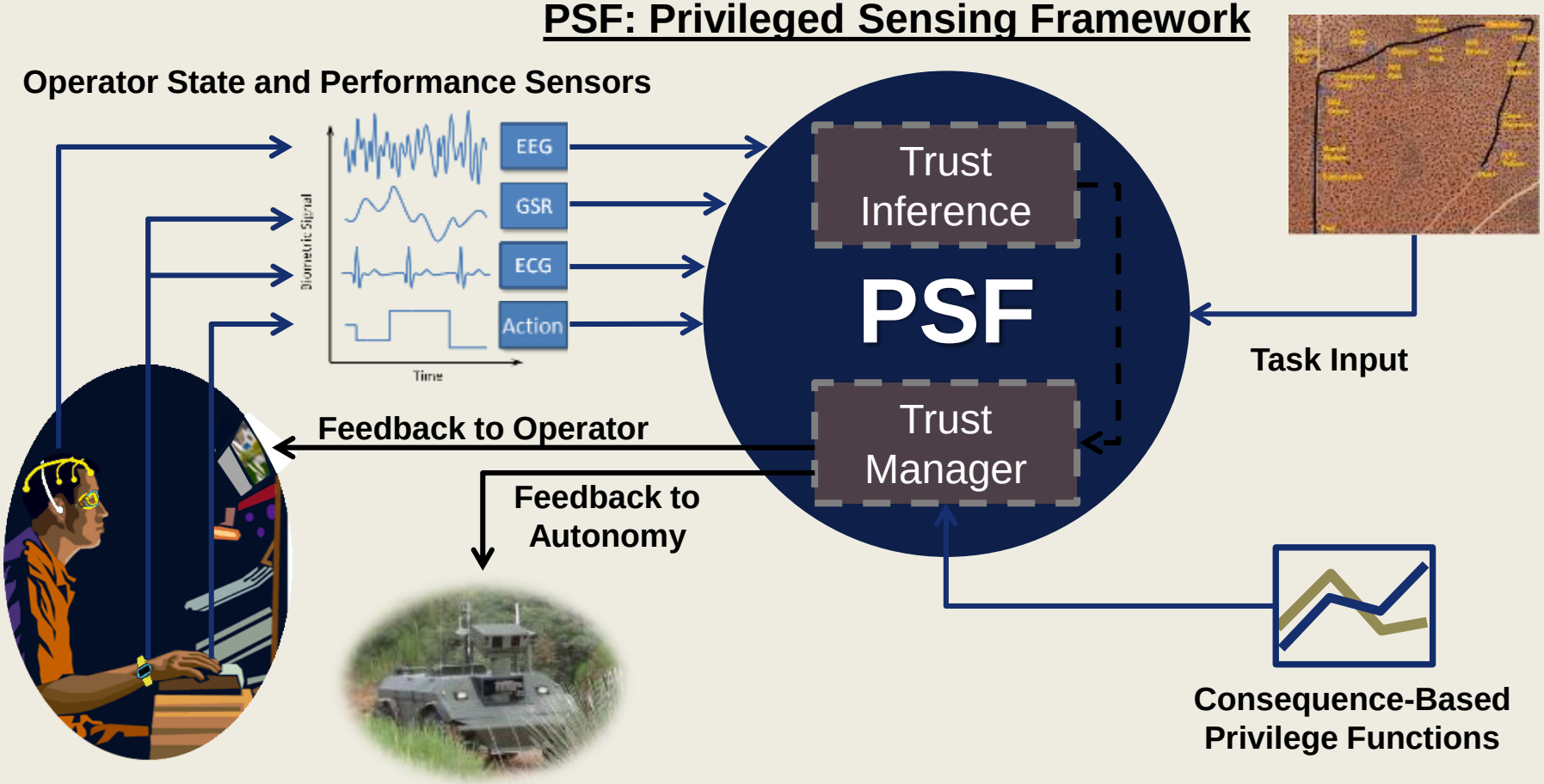
Future:

- Dynamic reinforcement learning, guided through feedback provided by human oracles
- Robotic assets augment human cognitive limitations
- Demonstration of Heterogeneous (human-bot) teams outperforming homogeneous teams (human-only / bot-only)

How do we share authority and account for dynamic performance fluctuations of humans in methodologies designed to integrate unique capabilities of human-autonomy teaming?

Trust Management System

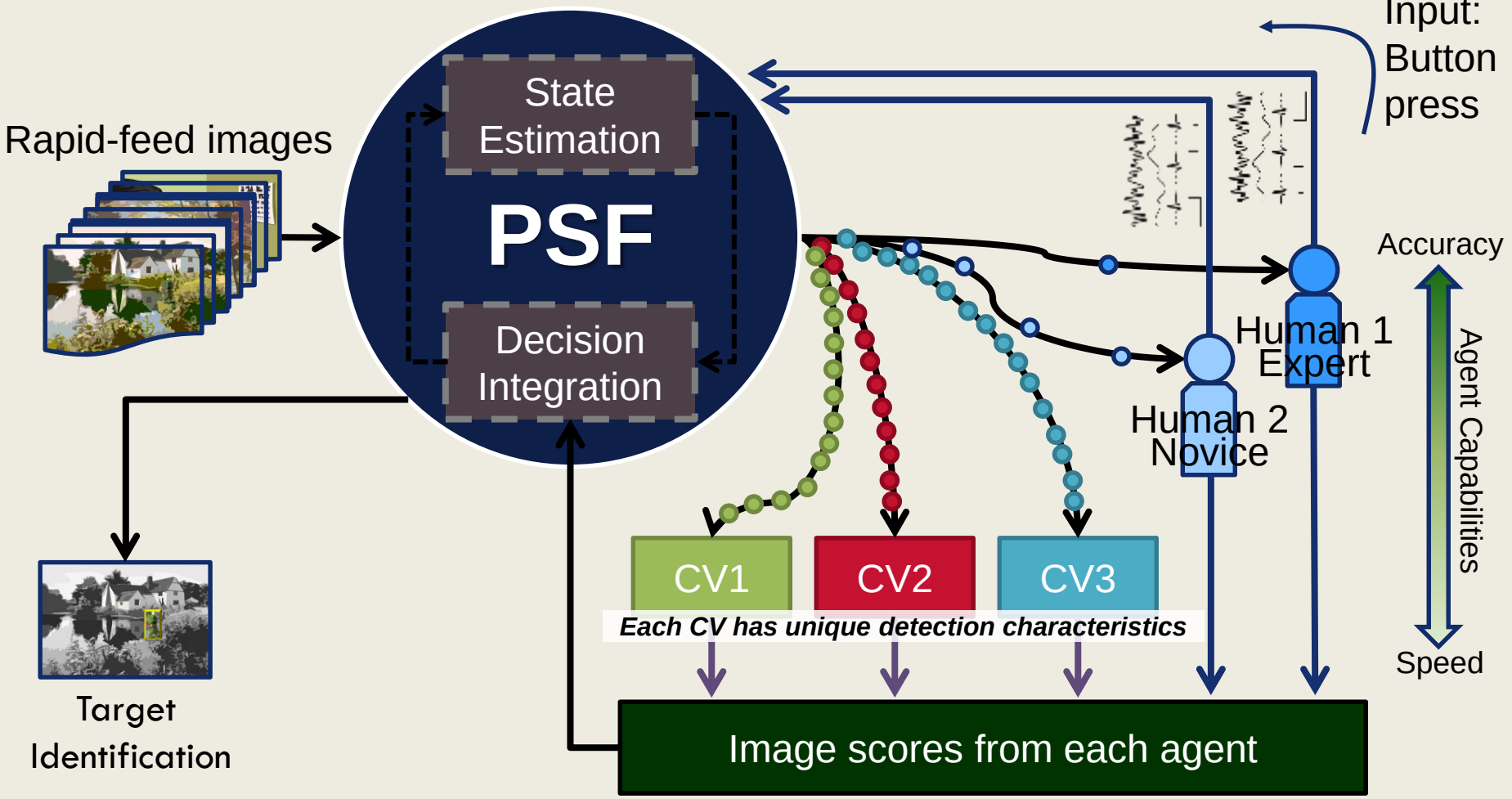
PSF: Privileged Sensing Framework



Develop and validate management of autonomy trust by incorporating *a priori* knowledge of perceived risk and consequence in order to appropriately balance operator and autonomy capabilities

Target Recognition

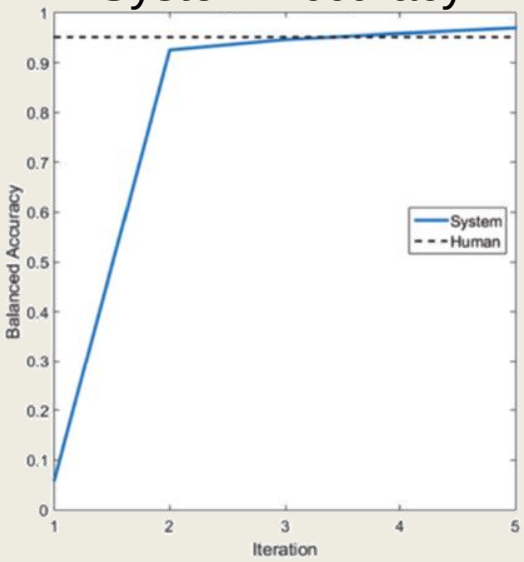
PSF: Privileged Sensing Framework



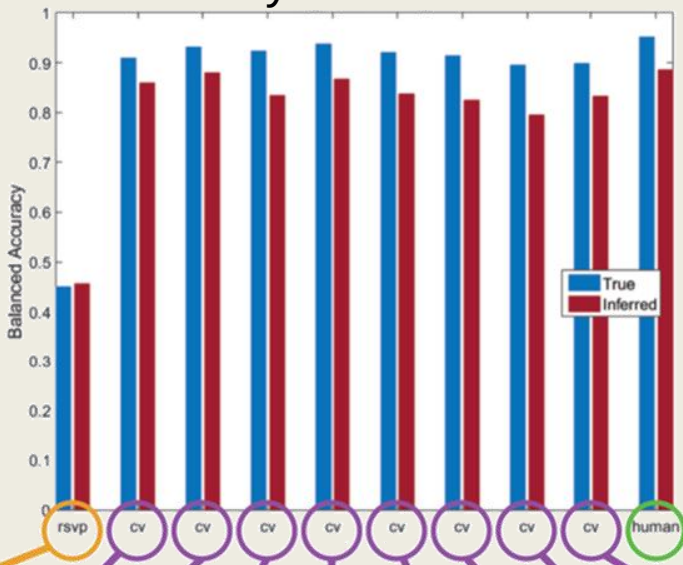
Improved joint human-autonomy target recognition by leveraging and combining unique strengths of each agent

Human/AI Target Recognition

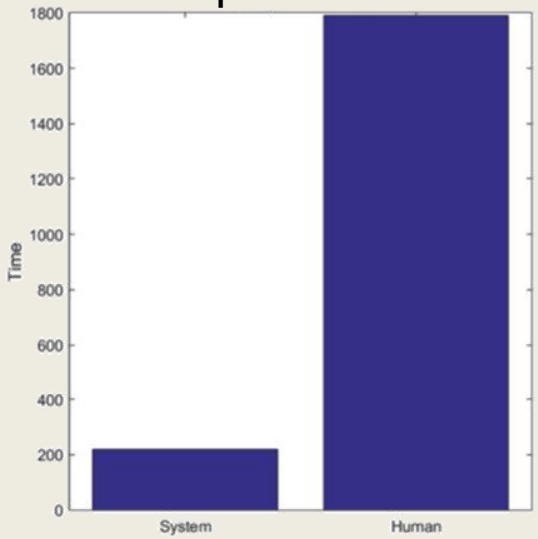
System Accuracy

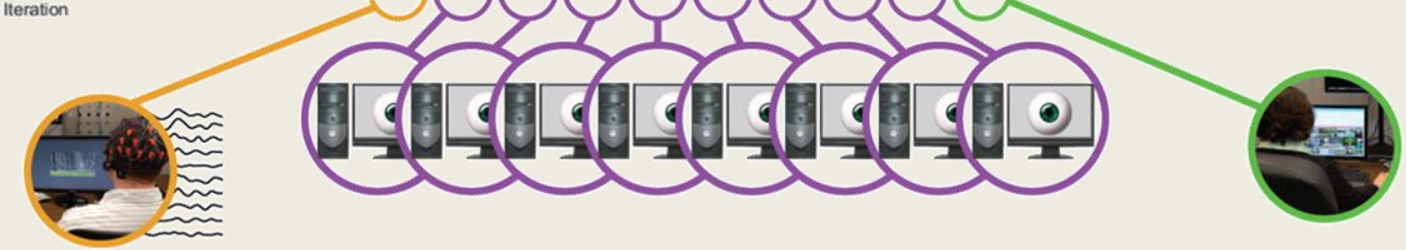


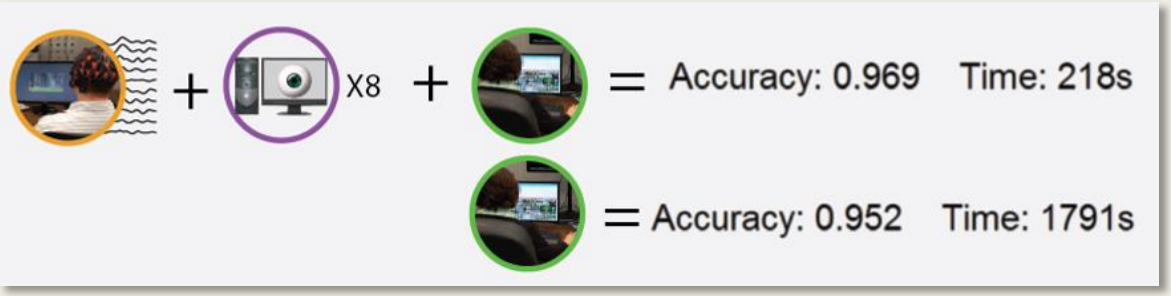
Accuracy For 5th Iteration



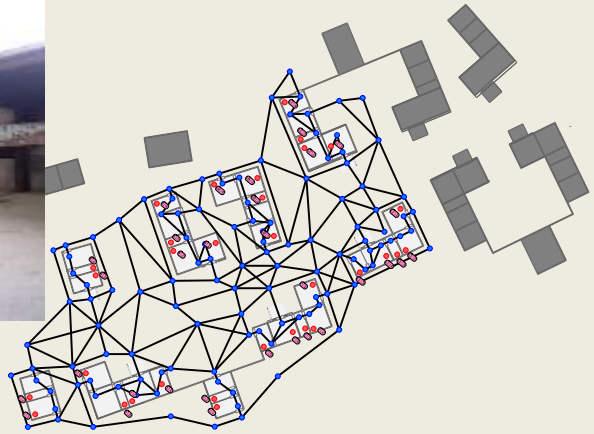
Completion Time

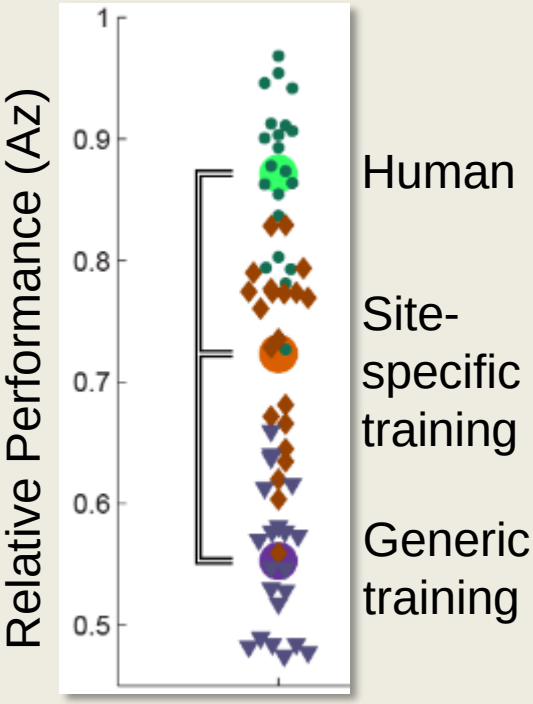


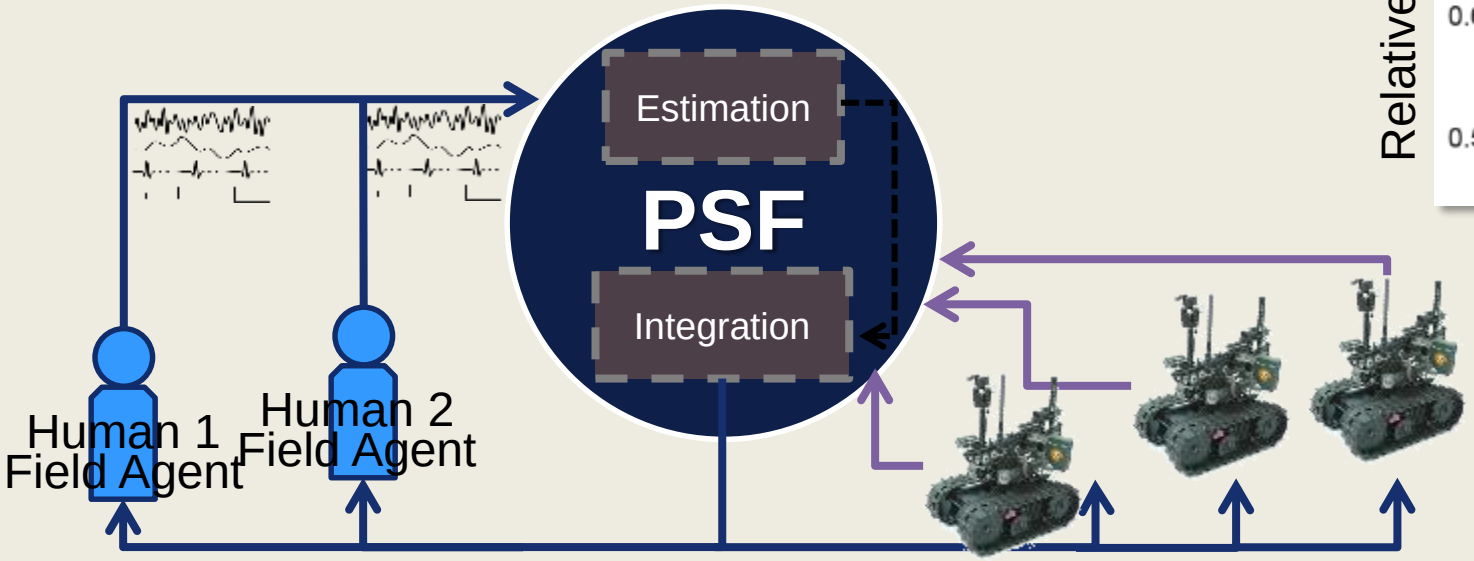




Robotic Exploration







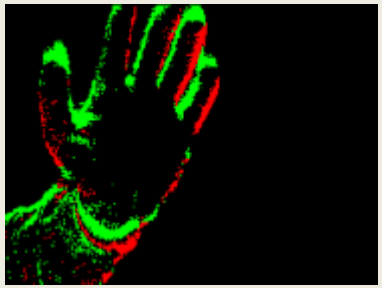
Improved joint human-aided autonomous navigation loop closure

Processing Forward

Desired Outcomes

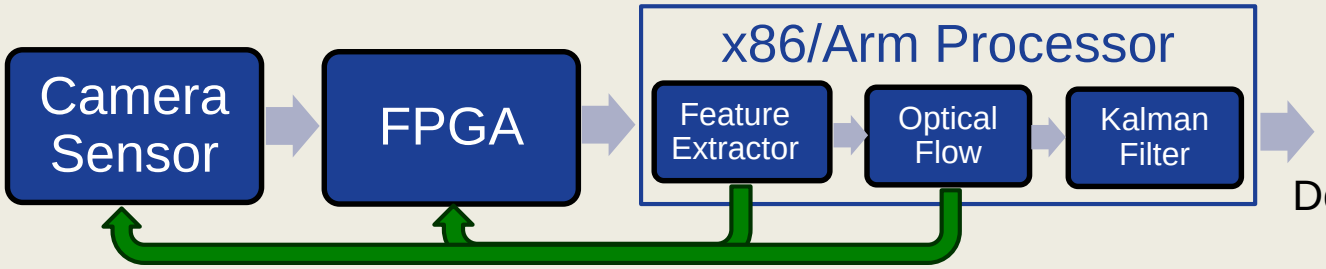
- Push processing forward to the sensor (EO/IR, hyperspectral, RF, acoustic, CBRNE) to pre-process, send only relevant info.
- Lower susceptibility to Electronic Warfare (jamming, hacking)
- Utilize power efficiently for persistent operation

Traditional Electro-Optic (EO) imaging



Dynamic Vision Sensor (DVS)

Current Research Example:



Desired x, y, z, roll, pitch, yaw (192 bits/cycle)

EO: 240x180 (1.3 Mbps)
30 Hz, ~2,000 mW

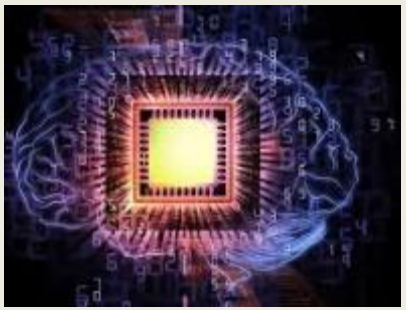
Mbps Bandwidth → **34,000 nJ/bit**

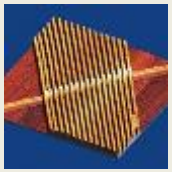
DVS: 240x180 (100 kbps)
50K Events/s
~60 KHz, ~10 mW

kbps Bandwidth → **0.08 nJ/bit**

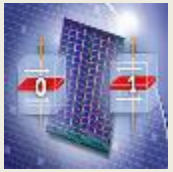
Future Research: Can both EO and DVS functions be carried out on one sensor?

Neuromorphic Computing





Memristor



Spin Torque

Brain-Inspired Processing

- Exceptionally low power (1000x)
- Massively parallel
- Distributed & redundant coupled storage and computation
- Simple unified building blocks (neuron-like)
- Should be compatible with commercial Si processing

Limitations & Applications

- Only implements neural networks
- Ideally suited for: Image Discrimination, Pattern Matching, Machine Learning for Big Data, Decision-Making (Autonomous Vehicle Control, Tactical Planning), and **Dynamic Vision Sensors (DVSs)**

Object classification through motion patterns

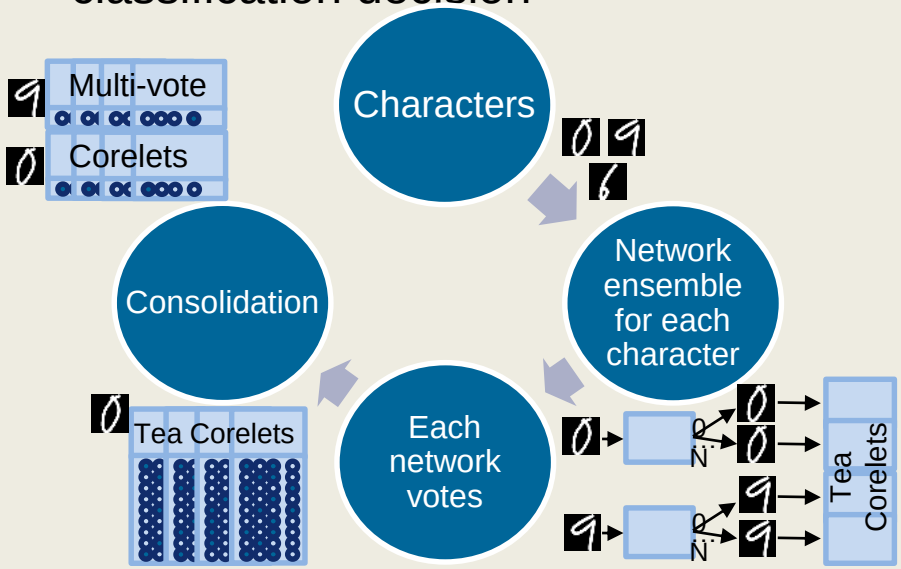
DVS For Image Classification

Challenge: Spikes generated from a moving stimulus typically not present simultaneously

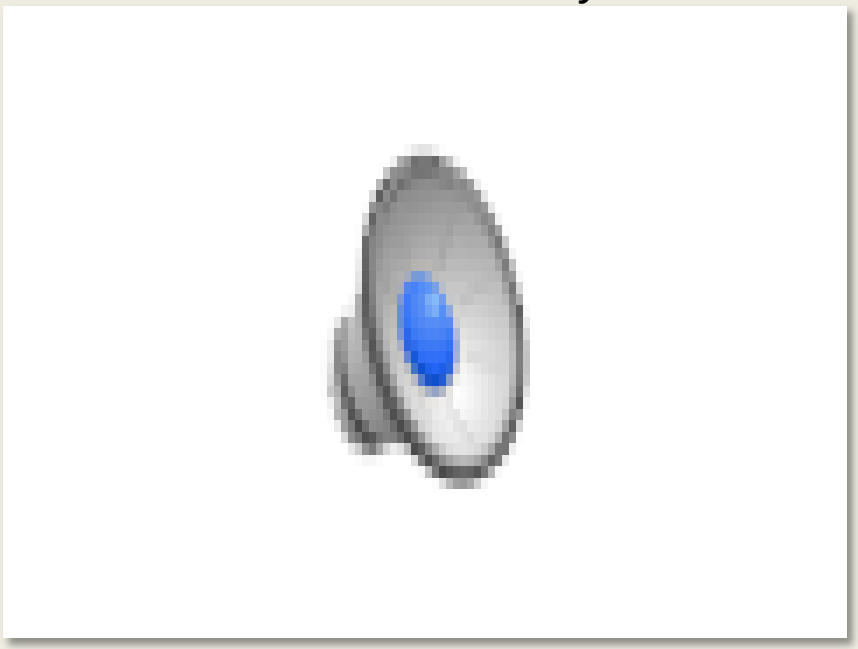
Solution: Layer of short-term memory neurons on top of the classifier to increase probability of joint spikes

DVS Test Bed: Handwritten Number Classification

- DVS camera mounted on a pan-tile table to create additional spikes
- 1000 samples from the N-MNIST dataset (spiking version of MNIST—28x28 pixel handwritten samples)
- 100 ms sampling intervals
- 5 core probabilistic network trained and implemented on TrueNorth (IBM)
- Weighted max vote for sample classification decision



DVS output | Memory accumulation



(1,2,3,… playback at 1/10th real time)

- Memory filter improved classification accuracy from 30% to 81%
- Streaming video benefits enabled at the tactical edge (power, bandwidth consumption each 200X lower)

Ensuring Source Credibility

Problem:

- Some information sources may be unreliable, biased, or conflicting

Solution:

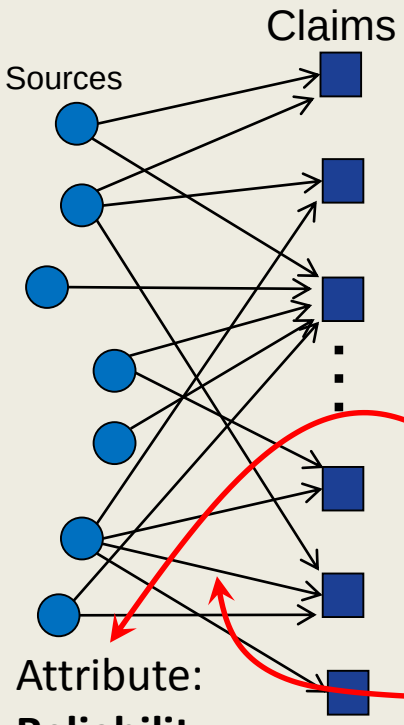
- Generative models using estimation-maximization to estimate accuracy
- Cramer-Rao Lower Bounds shown to characterize uncertainty of estimates
- Implicit assumption is that on average, a majority of sources tell the truth

Boston Bombing

Hurricane Sandy

Egypt unrest

Sample (anonymous) tweet datasets



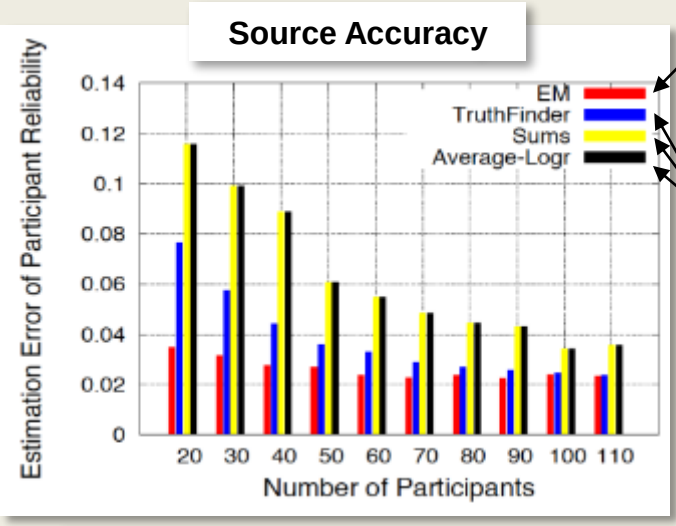
- Define a_i as:
  - P (source$_i$ makes a correct claim| the claim)
- Define b_i as:
  - P (source$_i$ makes an incorrect claim | the claim)
- What are the source reliability parameters that maximize the probability of received observations?

$$P(SC|\theta) = \sum_z P(SC, z|\theta)$$

Insight: Source generative models provide a means to develop constraint-aware fact-finders and performance bounds

Method Validation

Synthetic Data:

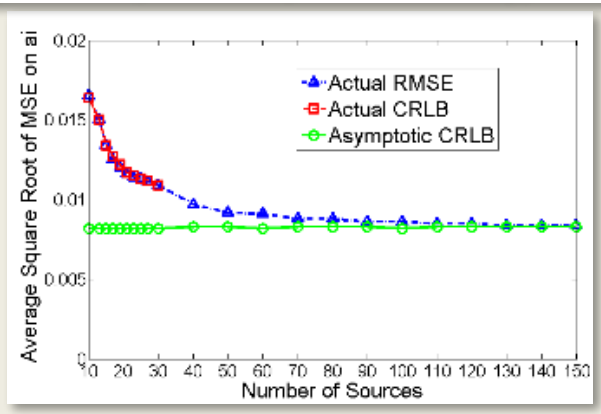


Estimation-maximization (EM)

Baseline "fact-finding" approaches

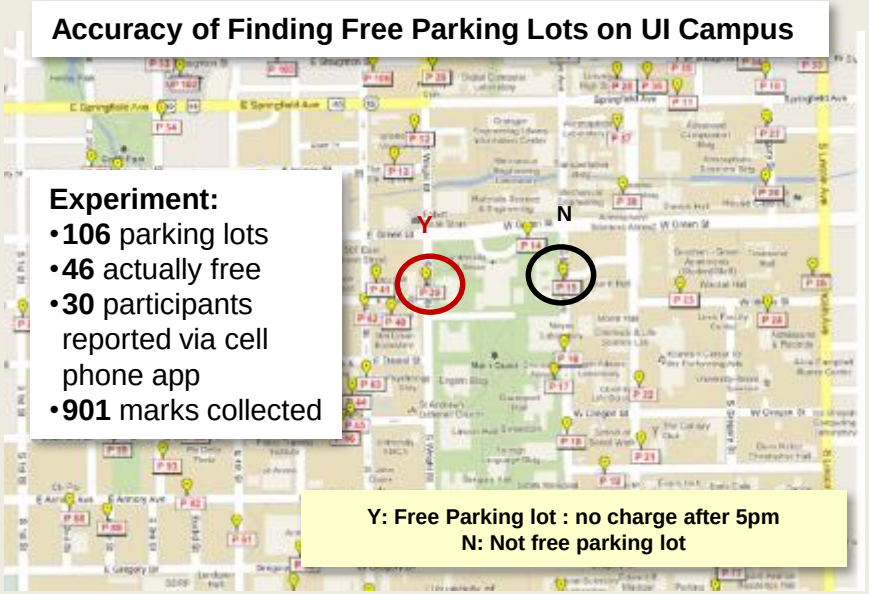
Similar improvements obtained using EM for reducing false negatives & positives (claim accuracy)

EM estimator achieves Cramer-Rao Lower Bound (CRLB)



(Wang, Abdelzaher, Kaplan, Social Sensing: *Building Reliable Systems on Unreliable Data*, Morgan Kaufmann, March 2015)

Real Data:



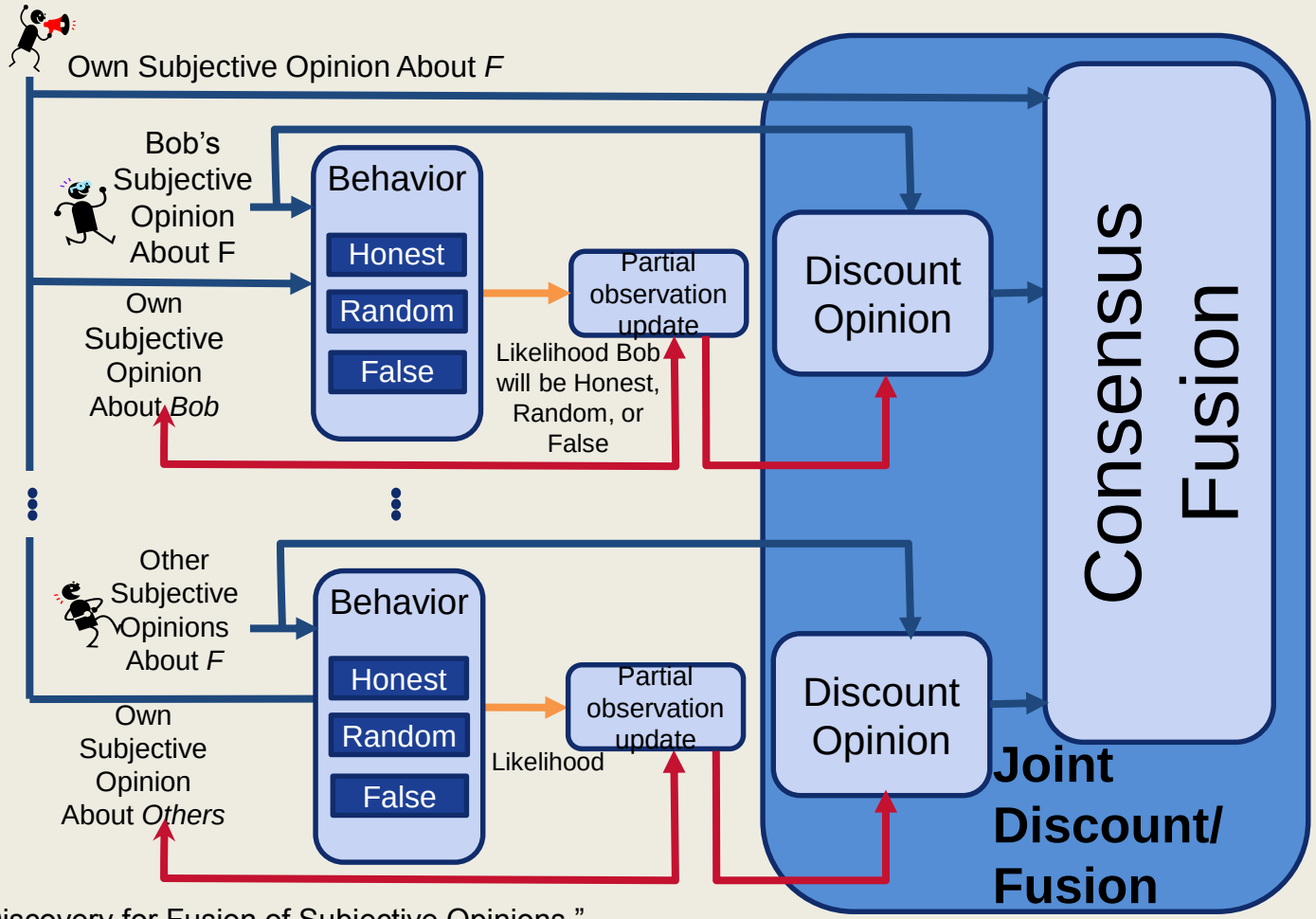
Schemes	False Positives	False Negatives
EM	**6.67%**	**10.87%**
Average-Log	16.67%	19.57%
Truth-Finder	18.33%	15.22%
Voting	21.67%	23.91%

Current work: Experiments on Twitter tweet credibility using Apollo platform

Resolution of Conflicts

- Sources may report conflicting information (incompetence, malicious deception, faulty electronics, etc.)

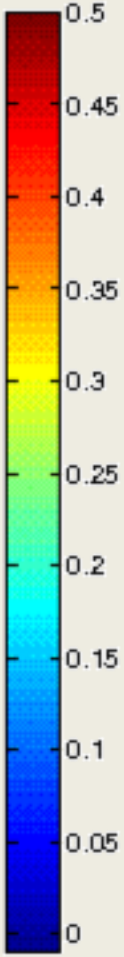
- Typically, source reports are discounted before fusion.
- Here, a new joint discount/fusion method improves performance by finding coherence in source reports, and even increases confidence when sources are (consistently) false.



("Source Behavior Discovery for Fusion of Subjective Opinions," *ISIF/IEEE Fusion 2016*, Heidelberg, Germany, 2016)

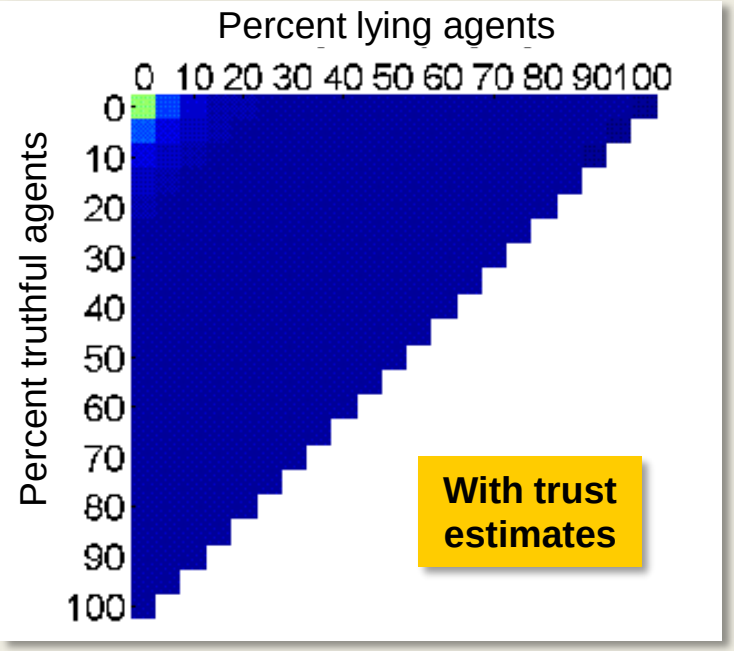
Joint Discount/Fusion Results

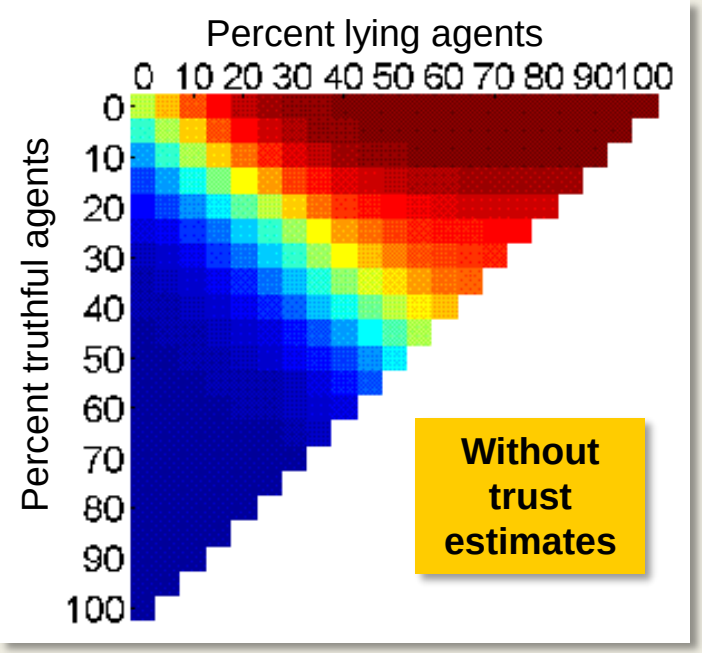
RMS fusion error:



Experiments over simulated data (100 agents):

- Truthful agents defined as 70% true, 15% false and 15% random
- Lying agents defined as 70% false, 15% true, and 15% random
- Any remaining agents (100-X-Y) are random agents, defined as 70% random, 15% true, 15% false





Method works well even for false agents, as long as random agents are <90%

When sources are unknown, methods lock onto coherence and report truth as long as truth > false.

U.S. ARMY RDECOM

Open Campus Initiative

ARL

Past: Current Defense Laboratory Model

Gates and high walls provide 20th century security, but are barriers to 21st century innovation

Defense laboratories relatively unchanged since inception (NRL 1923)

Present & Future: Open Campus Initiative

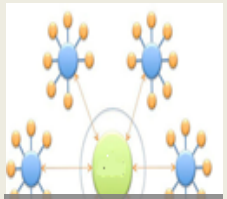
Reduction in barriers to facilitate collaboration with academia, industry, and small business

Less bureaucracy and paperwork

Open areas for researchers and access to existing facilities

Collaboration between ARL and external scientists

Career path for students and scientists



Hub and Spoke Model

Collaborator presence through EUL

Novel staff opportunities

An enhanced defense research environment that fosters discovery and innovation through collaboration on fundamental research

Sensor Information Testbed COllaborative Research Environment (SITCORE)

Potential end-users for technology transition

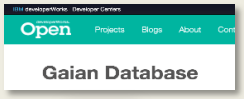
Military SMEs

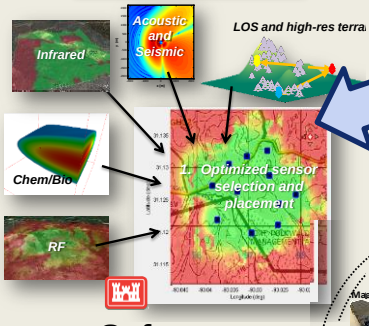
ARL S&Es

CTA & ITA Partners

NATO OTAN

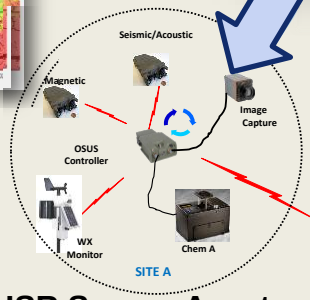
Coalition Partners



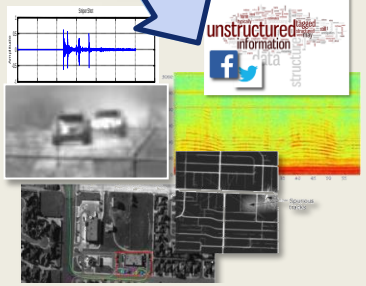


Software Algorithms & Tools

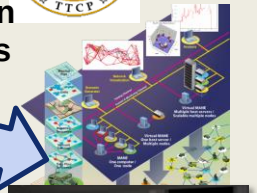
Collaborative R&D Sandbox

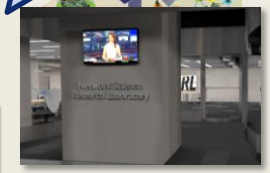


ISR Sensor Assets



Multimodal Datasets





Network Science Research Laboratory (NSRL)

Description:

Virtual research environment allowing collaboration from other locations including DoD, industry, academic, & coalition facilities

How to Access:

http://aodr.arl.army.mil

Military-relevant datasets via the Automated Online Data Repository (AODR), e.g.:

- "Bluegrass" (Wide Area Motion Imagery, U.S. restricted)
- "Belgium" (unrestricted)

Algorithms developed under other government programs, e.g.:

- Improved Fusion Algorithm System (IFAS), developed under Army SBIR

Questions?