Value-centered Information Theory for Adaptive Learning, Inference, Tracking, and Exploitation

[http://wiki.eecs.umich.edu/voimuri]

ARO W911NF-11-1-0391
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Investigators: Al Hero (PI), Raj Nadakuditi, John Fisher, Jon How, Alan Willsky, Randy Moses, Emre Ertin, Angela Yu, Michael Jordan, Stefano Soatto, Doug Cochran






2nd Year VoI MURI Review: Agenda

Time	Activity
8:00 – 8:30	Check in at ARL visitor office
8:30 - 8:35	Welcome, Liyi Dai
8:35 - 8:50	Project overview, Al Hero
8:50 - 10:15	Thrust area I: Learning and Representation
	Overview, Michael Jordan
	PI Summaries, Michael Jordan, Stefano Soatto, Al Hero, Angela Yu
10:15 - 10:30	Break
10:30 - 11:35	Thrust area II: Information Fusion
	Overview, John Fisher
	PI summaries, Raj Rao Nadakuditi, Emre Ertin, John Fisher
11:35 - 12:00	Collaborative highlights
12:00 - 12:15	DURIP testbed, Emre Ertin
12:15 - 2:15	Lunch and poster session
2:15 - 3:20	Thrust area III: Information Exploitation
	Overview, Doug Cochran
	PI summaries: Randy Moses, Jon How, Doug Cochran
3:20 - 3:30	Wrap-up, Al Hero
3:30 - 4:30	Government discussion and de-briefing
4:30	Adjourn

MURI coPIs you will hear from today

Al Hero
Michigan

Raj Nadakuditi
Michigan

Randy Moses
Ohio State

Emre Ertin
Ohio State

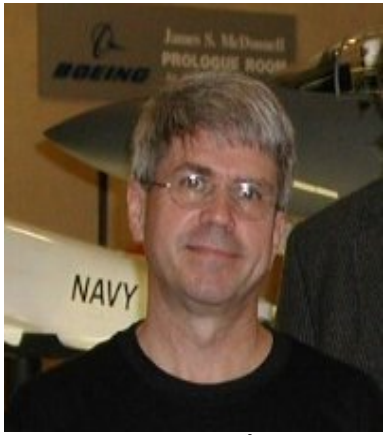
Jon How
MIT

John Fisher
MIT

Angela Yu
UCSD

Stefano Soatto
UCLA

Mike Jordan
UC Berkeley



Doug Cochran
Arizona State

Our MURI's principal aim

- To derive a comprehensive set of principles for task-specific information extraction, distributed information fusion, and information exploitation that can be used to design the next generation of autonomous and adaptive sensing systems.

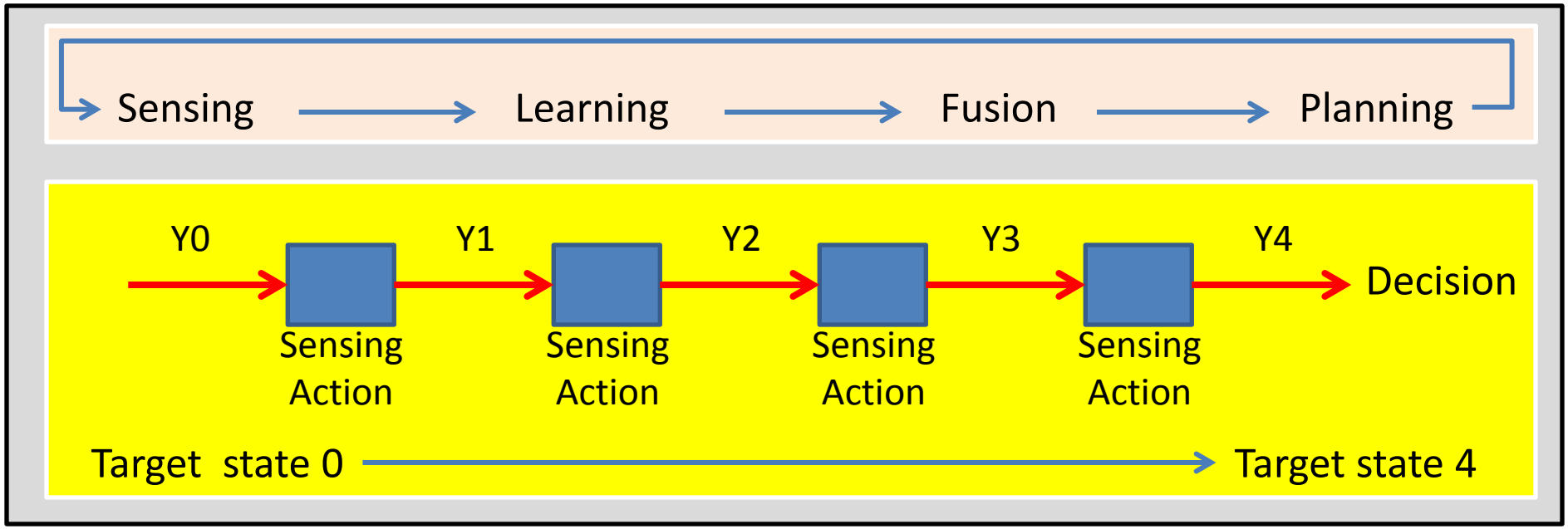
- **Specific objectives:**

  - Develop analytical frameworks for quantifying value of information.
  - Study fundamental tradeoffs for information collection and fusion
  - Develop info processing algorithms with performance guarantees
  - Validate theory and algorithms on sensing testbeds at MIT, OSU, UCSD and UCLA

- **Technical approach:** value-centered information theory, machine learning and control.

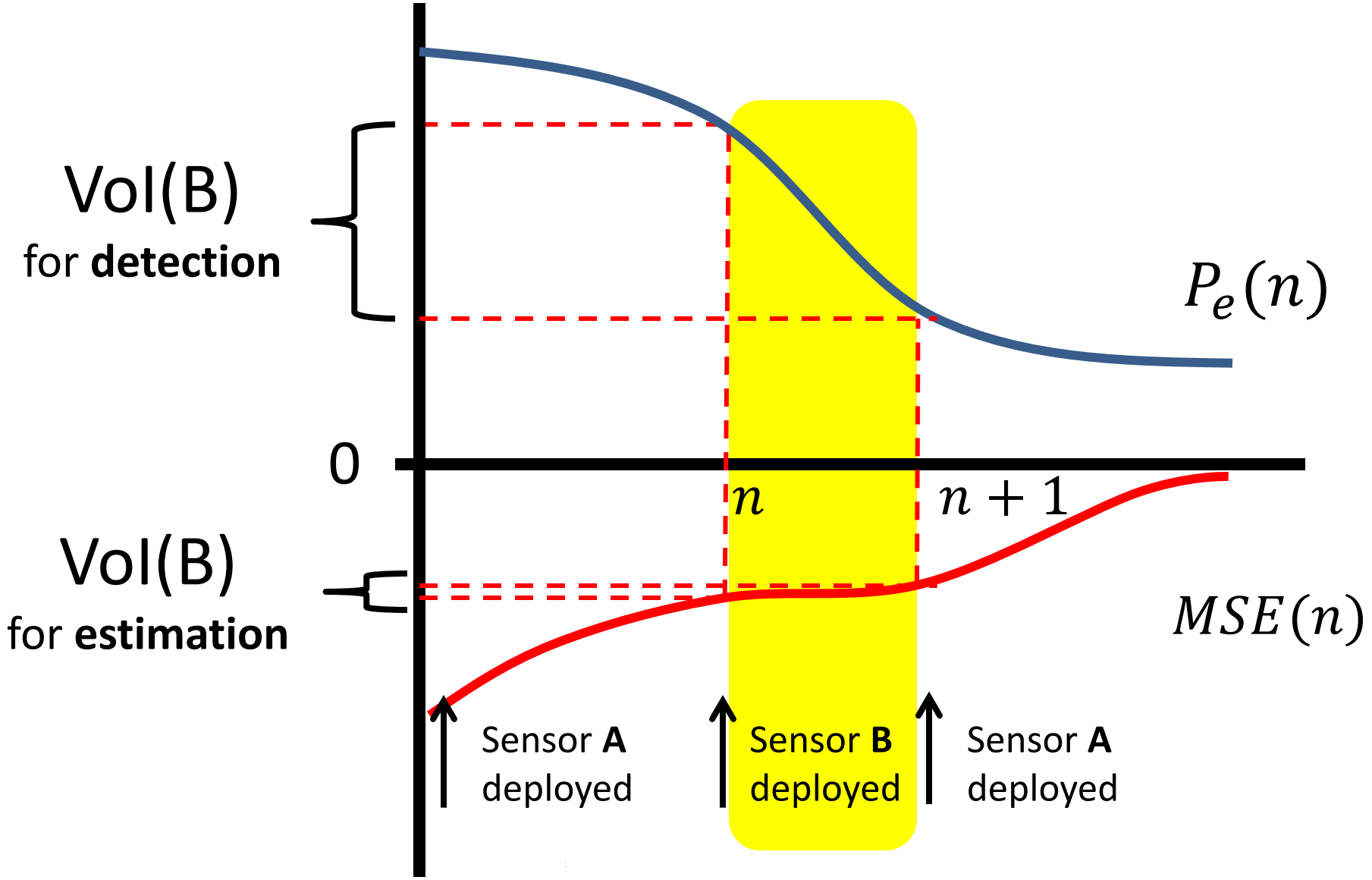
Value-centered information theory

Adaptively measure variables Y0, Y1, … for decisionmaking



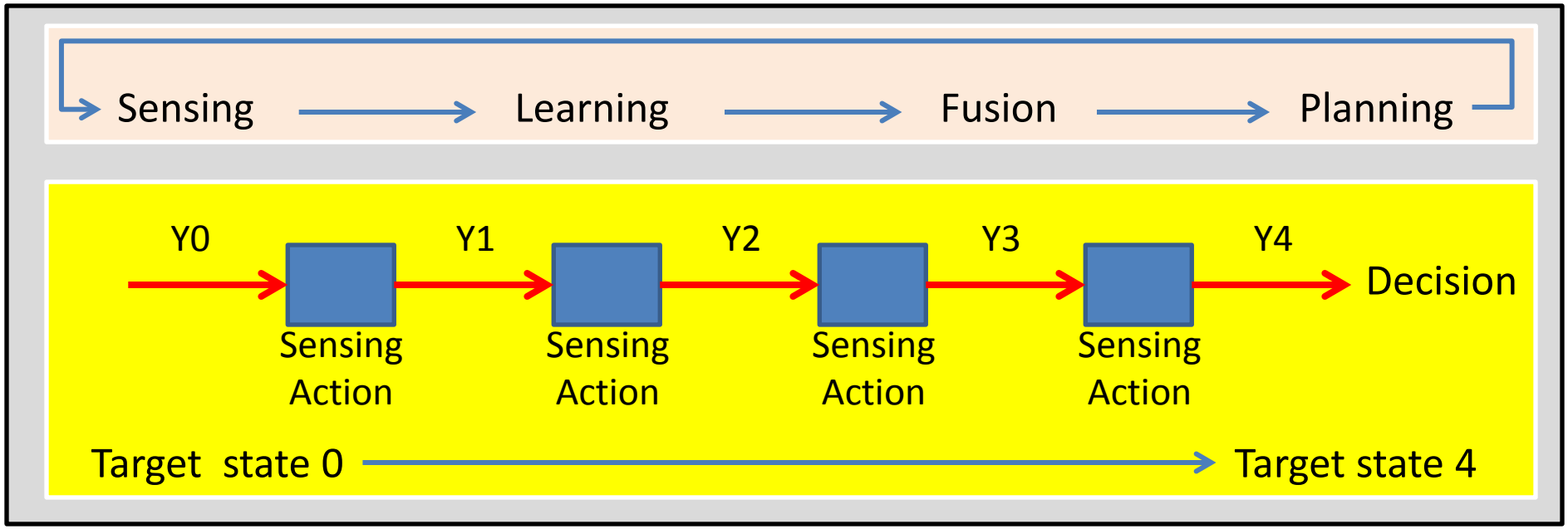
- Each sensing action acquires a sample (snapshot) Yn
- Yn contains information about target state, clutter, and sensor quality
- What is the intrinsic value of this information with respect to decision?

Value of information accrued from a snapshot



Value-centered information theory

Adaptively measure variables Y0, Y1, … for decisionmaking



Our MURI has so far focused on the following:

- Scalable information metrics that account for decision task
- Characterization of phase transitions, scaling laws, and bottlenecks
- VoI-driven fusion strategies for distributed data collection
- Applications to active vision, sensor nets, radar, human-in-the-loop

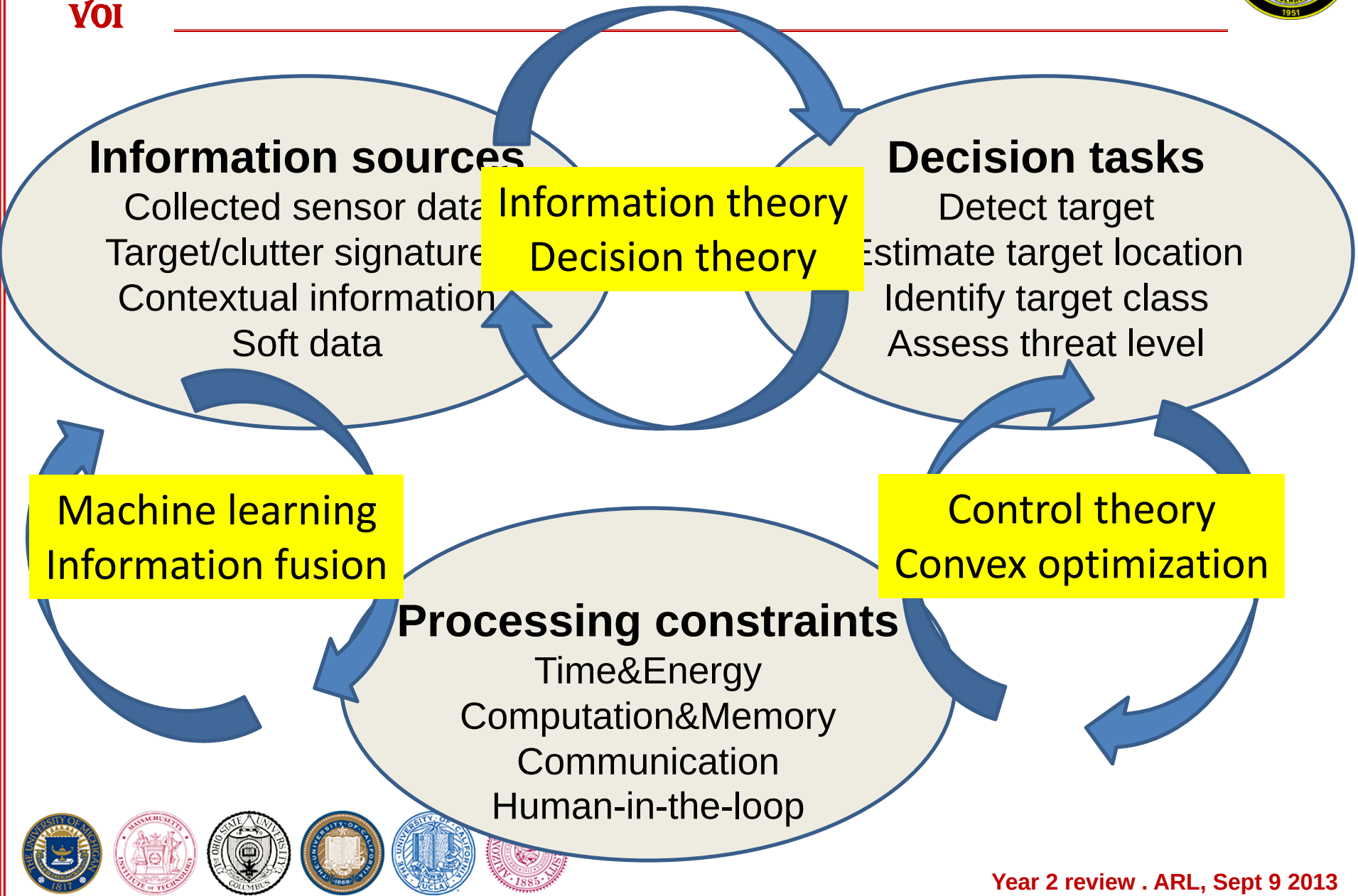
Design space is high dimensional

Information sources
Collected sensor data
Target/clutter signatures
Contextual information
Soft data

Decision tasks
Detect target
Estimate target location
Identify target class
Assess threat level

Processing constraints
Time&Energy
Computation&Memory
Communication
Human-in-the-loop

Theory applicable to design space



Theory applicable to design space

Central questions addressed by our MURI

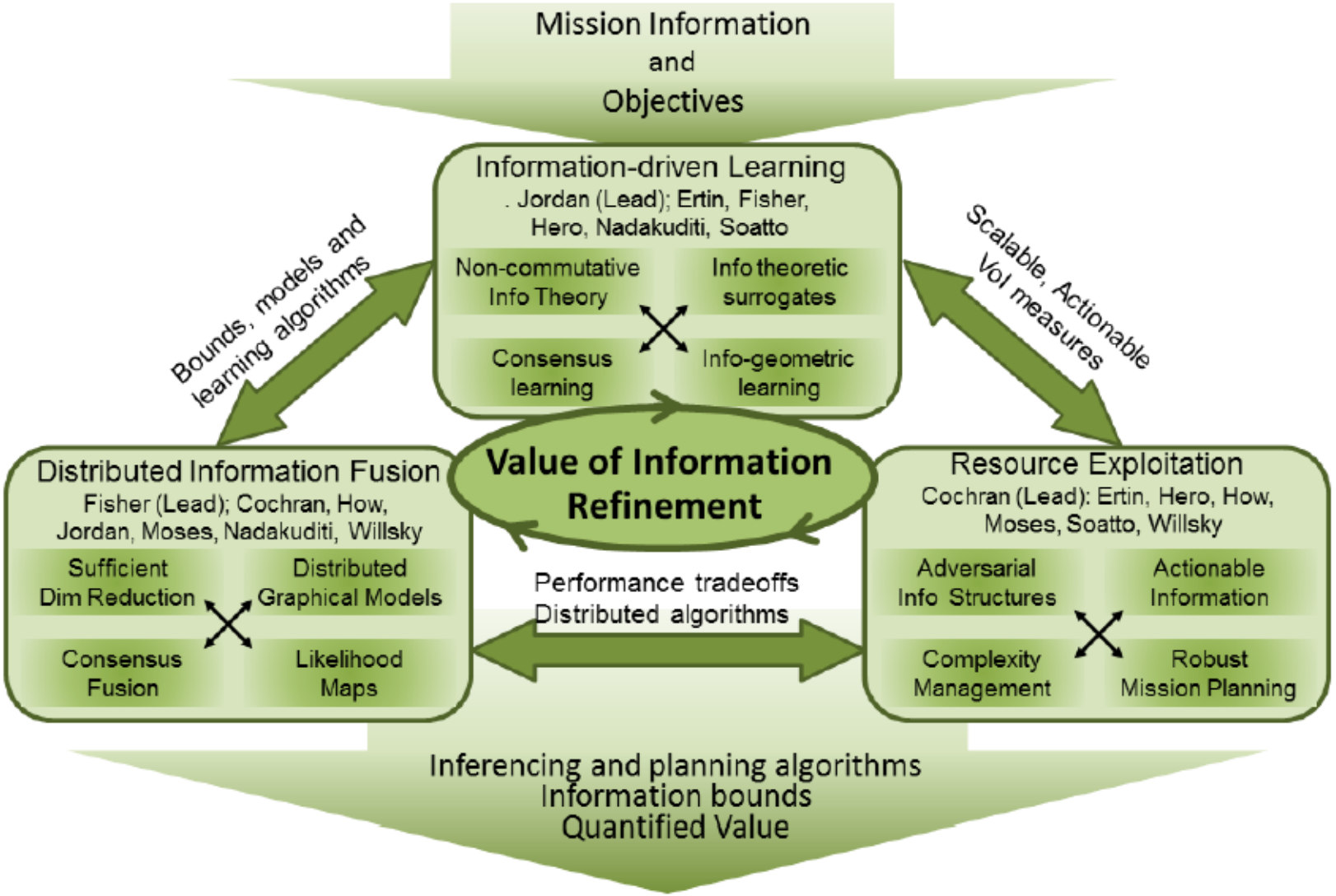
What is intrinsic value of information for a task?
How do constraints affect value?
What algorithms ensure max value?
How to overcome computational bottlenecks?

Our technical approach to address questions

Value-centered information theory
Information-driven data fusion
Information-aware controlled sensing/processing

Communication

Research program: High level view



Research program: High level view

Learning and representation of high dimensional data

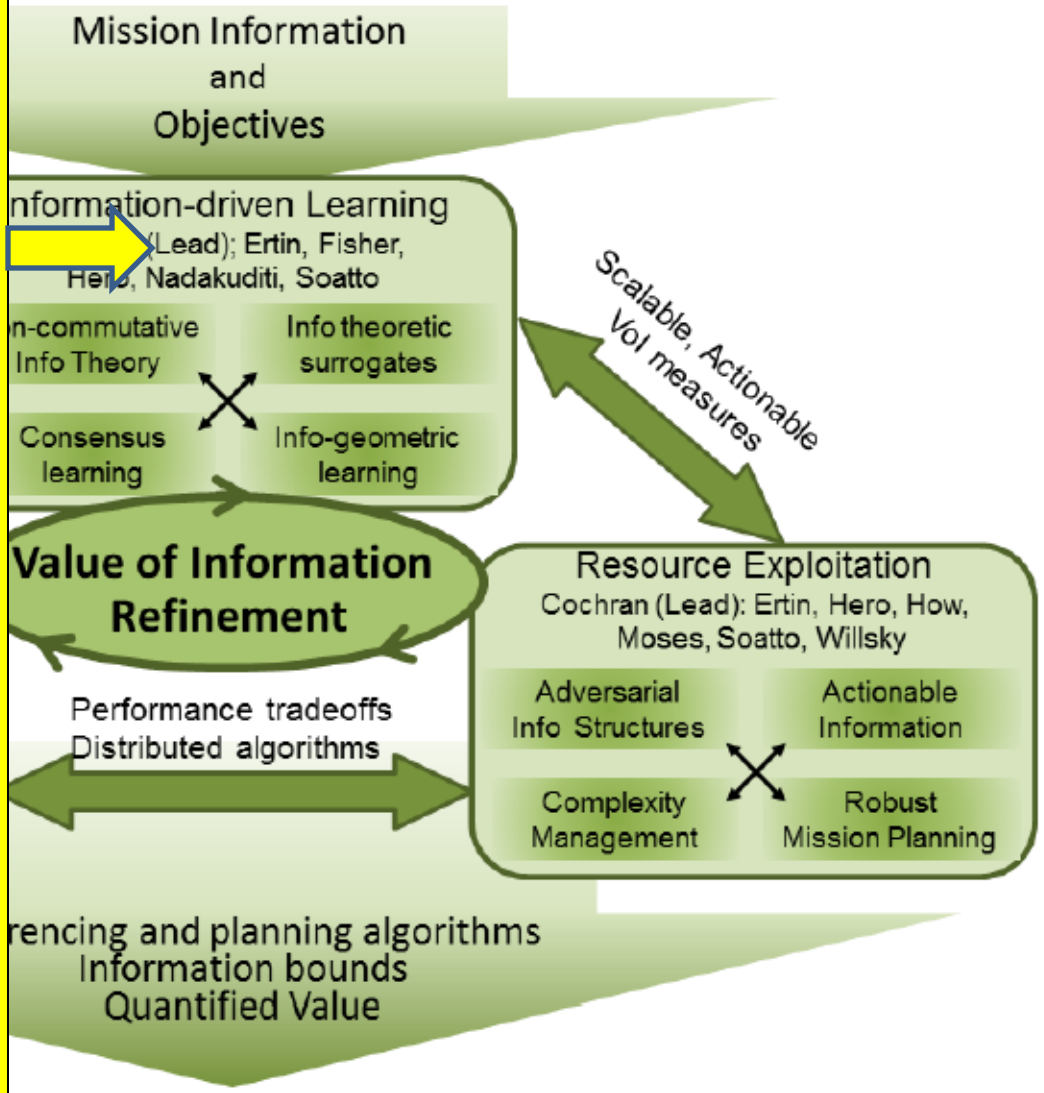
- Spatio-temporal learning (Fisher/Hero)
- Sparse sum product cov estim (Hero/Nadakuditi/Ertin)

VoI with humans-in-the-loop

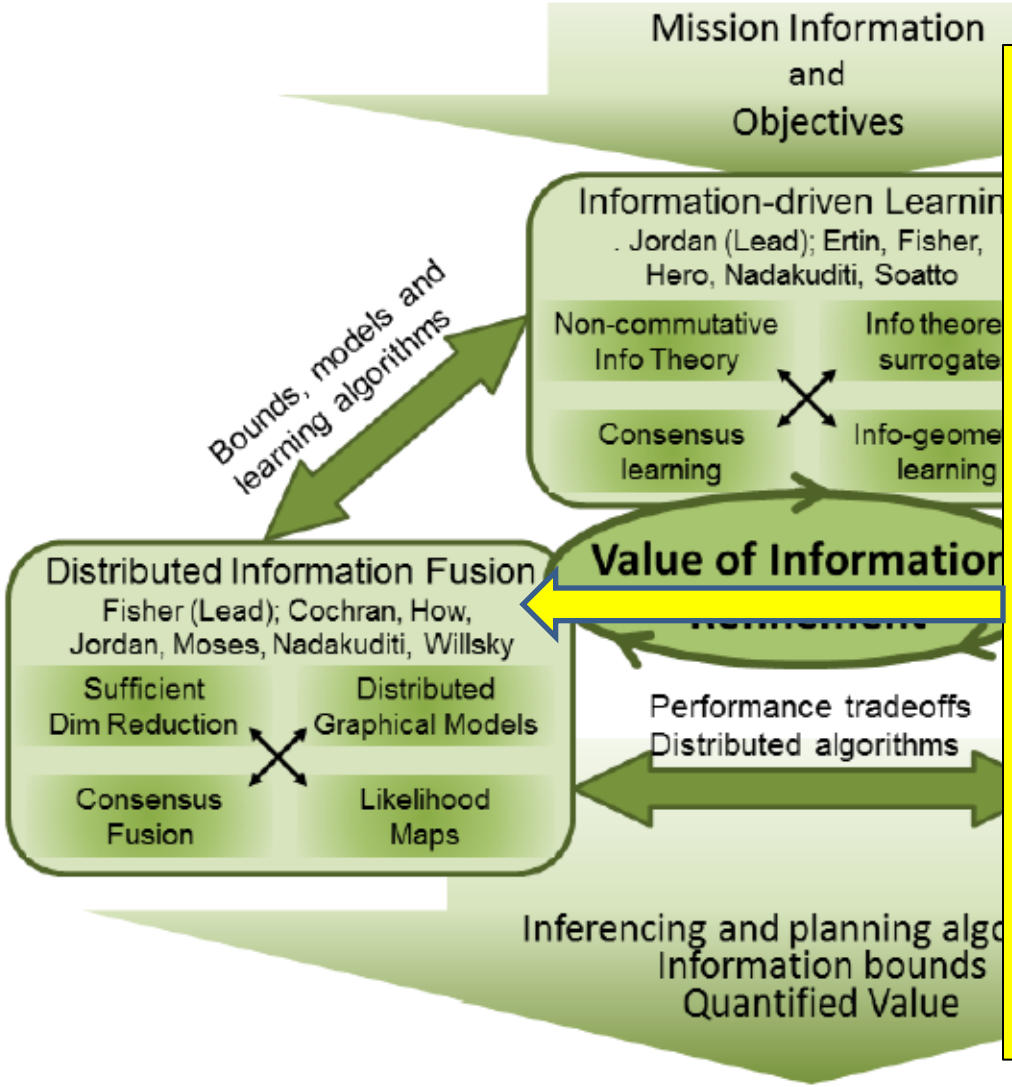
- Cooperative human-machine decisionmaking (Hero/Yu)
- Learning to rank human preferences (Jordan)

VoI performance bounds

- Effect of privacy, computation, and side-information (Jordan/Hero/Nadakuditi…)



Research program: High level view



Information-driven multimodality fusion

Distributed fusion of LIDAR/EO image sensors (Fisher)

Information theoretic signal subspace processing

Optshrink subspace detection (Nadakuditi/Cochran)

Distributed inference in sensor networks

Aggregating local information for decision-level fusion (Moses)

Local neighborhood processing as alternative to BP (Hero).

Research program: High level view

Information-driven adaptive sensing

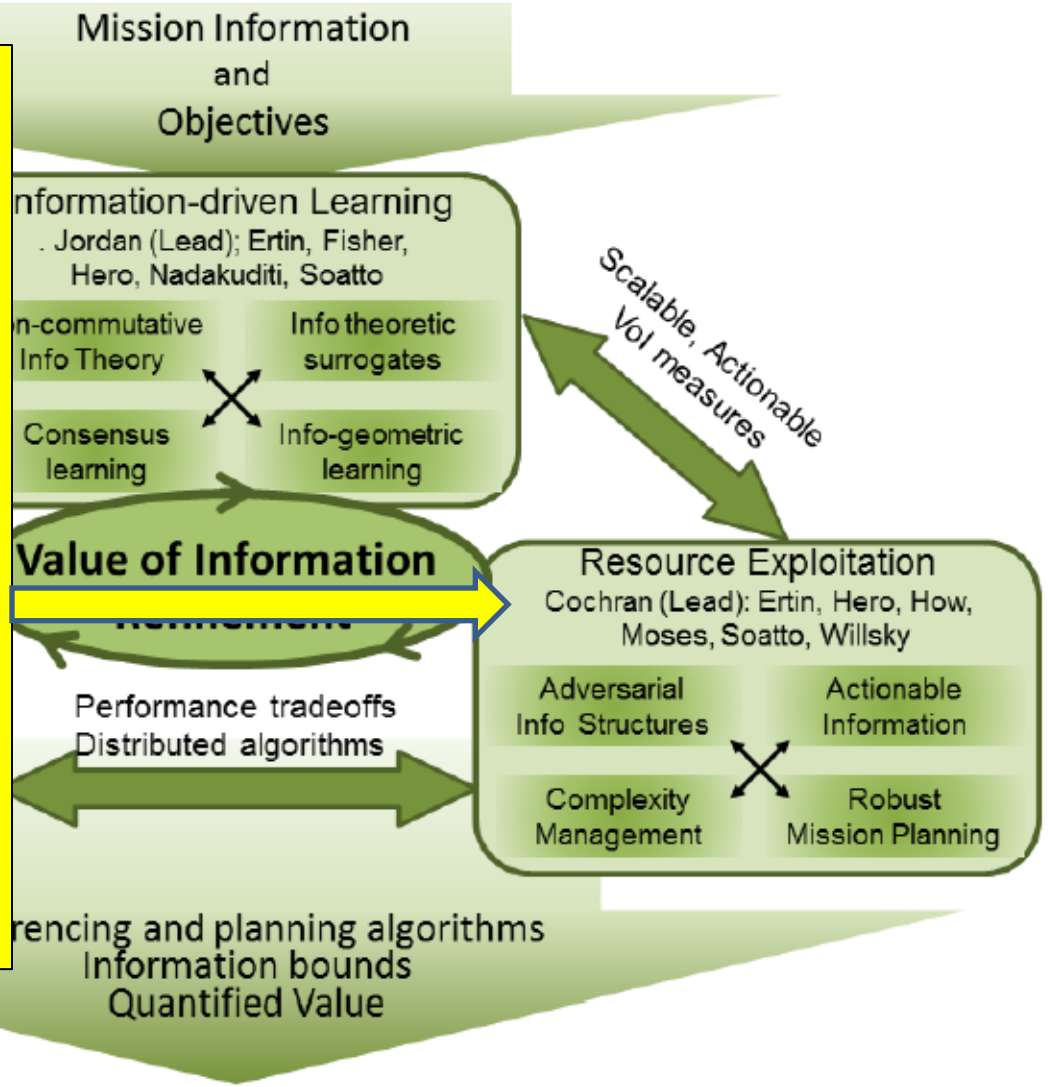
Active Information Exploitation for Resource Management (Cochran)

Robust planning for coupled systems

Adaptive VOI-based algorithms for distributed information fusion (How)

Active learning

Information-maximizing control with visibility (Soatto)



What have we learned so far?

- There are important fundamental VoI tradeoffs
  - Model vs sample complexity for fusion (Hero 12, Nadakuditi 13)
  - Computation vs sample complexity for fusion (Jordan 12, Fisher 13)
  - Energy vs geometry in active vision (Soatto 12)

- Computational bottlenecks can be overcome by using good proxies
  - Information theoretic surrogates (Soatto 12, Fisher 12, Cochran 12)
  - Convex and concave-convex proxies (Hero 12-13, Ertin 12, Cochran 13)
  - Submodular myopic strategies (Fisher 12)

- Distributed processing framework can benefit from VoI perspective
  - Second order marginal MLE for SN (Hero 13)
  - VoI-aware censoring for tracking in sensor nets (How 12, Moses 12)
  - Cooperative human-machine interaction (Hero 13)

Previous government comments

- **The government committee was pleased to see that the MURI team produces high quality, fundamental research results**
  We continue to maintain a rigorous foundational research focus

- **The poster session is an excellent idea, and should be an example for other MURI reviews**
  We have expanded the poster session this year.

- **The team has a good start with connecting research with Army laboratories…. The team is strongly encouraged to continue/expand the collaboration with ARL, AMRDEC, and other DoD laboratories**
  We have expanded our collaborations with DoD.

Previous government comments

- **Collaborations among team members at different universities have been planned, and the team is encouraged to take actions as soon as possible to strengthen collaboration among team members**
  See today's session on collaborations and posters

- **Future research is encouraged to place more emphasis on multimodality sensors, particularly visual modality**
  We have expanded visual modality activities (video, LIDAR)

- **Experimental validation and verification is encouraged. Team responded with a pending DURIP proposal to ARO…It's desirable to have plans in place to validate and verify research results using carefully designed experiments, which is particularly important for modalities other than radar, such as visual imagers.**
  DURIP was funded. Other modalities will also be validated.

Previous government comments

- **The committee noted that a wide range of research topics are being addressed, and encouraged the team to coordinate research efforts toward establishing a rigorous, foundational framework of value of information for distributed fusion.**

  We have maintained focus on foundational problems and have coordinated through several ongoing collaborations.

Today's posters

1. *N. Asendorf* and R. R. Nadakuditi, "The Performance of Deterministic Matched Subspace Detectors: Informative Versus Useful Subspace Components" Abstract
2. *T. Broderick,* N. Boyd, A. Wibisono, A. Wilson, and M.I. Jordan, "Streaming Variational Bayes"
3. *L. Crider,* R. R. Nadakuditi, and D. Cochran, "Analyze-Fuse vs. Fuse-Analyze in Multiple-channel Emitter Detection" Poster
4. *B. Mu,* G. Newstadt, J. How, and A. Hero, "Heterogeneous Agent Target Assignment in an Unknown Environment"
5. *R. T. Suryaprakash* and R. R. Nadakuditi, "The Performance of MUSIC-Based DOA In White Noise With Missing Data" Abstract
6. *T. Tsiligkaridis* and A. Hero, "Covariance Estimation In High Dimensions via Kronecker Product Expansions"
7. *T. Tsiligkaridis,* B. Sadler, and A. Hero, "Collaborative 20 Questions for Target Localization"
8. *N. Sugavanam,* and E. Ertin, "Sensor Selection and Placement in Adversarial Setting"
9. Y. Zeng, C. Wang, *S. Soatto,* and S.-T. Yau, "Nonlinearly Constrained MRFs: Exploring the Intrinsic Dimensions of Higher-Order Cliques"
10. *D. Teng,* and E. Ertin, "Sequential Testing with Quantized Beliefs"
11. *D. Teng*, and E. Ertin, "Learning Articulation Manifolds for Target Signatures"
12. *G. T. Whipps,* E. Ertin, and R. L. Moses "Decentralized EM for a Mixture of Factor Analyzers"
13. *G. T. Whipps,* E. Ertin, and R. L. Moses "Distributed Detection with Collisions in a Single-hop Wireless Sensor Network"
14. *S. Zhang* and A. J. Yu, "Forgetful Bayes and Myopic Planning: Human Decision Making in a Bandit Setting"