

# Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation



## Overview

MURI Annual Review Meeting

Randy Moses

September 14, 2007



*MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation*



## Research Goal

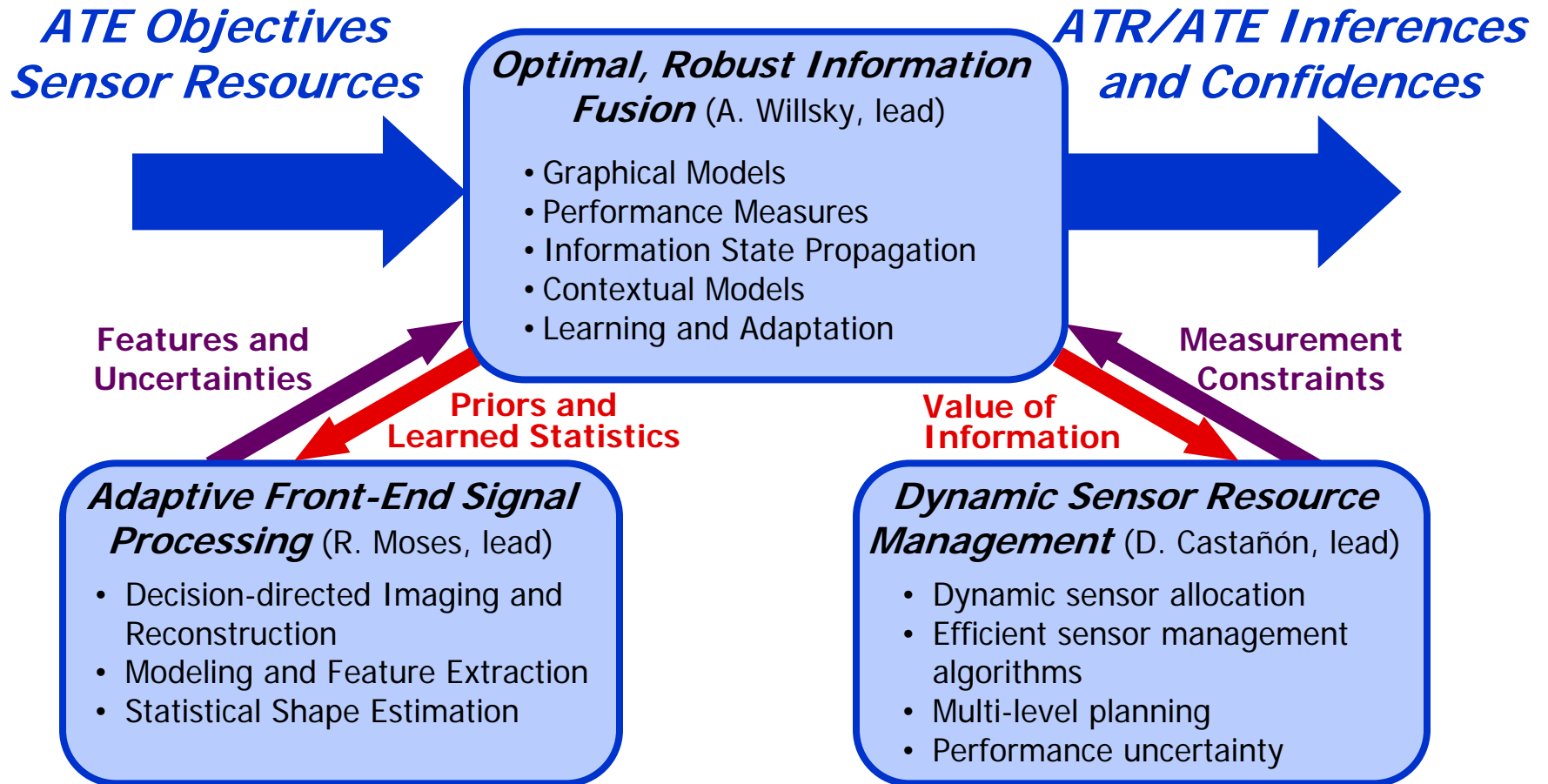
- *Develop an integrated systems theory that jointly treats information fusion, control, and adaptation for automatic target exploitation (ATE).*
  - Multiple, dynamic sensors
  - Multiple sensing modes
  - Resource-constrained environments



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



# Research Framework



**MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation**



# Research Framework

*ATE Objectives*  
*Sensor Resources*

*Optimal, Robust Information Fusion* (A. Willsky, lead)

*ATR/ATE Inferences and Confidences*

Features and Uncertainties

Inference-rooted metrics provide the common language across the system

Measurement Constraints

Priors and Learned **likelihoods**

Value of Information

*Adaptive Front-End Signal Processing* (R. Moses, lead)

**posterior probabilities**  
**information measures**

*Dynamic Sensor Resource Management* (D. Castanon, lead)

- Decision-directed Imaging and Reconstruction
- Modeling and Feature Extraction
- Statistical Shape Estimation

- Dynamic sensor allocation
- Efficient sensor management algorithms
- Multi-level planning
- Performance uncertainty



*MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation*



# Information Fusion: Key Research Questions

*ATE Objectives  
Sensor Resources*

*ATR/ATE Inferences  
and Confidences*

*How to effectively  
direct front-end  
signal processing?*

**Optimal, Robust Information Fusion** (A. Willsky)  
• Graphical Models  
• Performance Measure  
• Information State Pro  
• Contextual Models  
• Learning and Adaptat

**Inference on Graphical Models:**  
• Structures and algorithms for fusion, tracking, identification  
• Scalable algorithms  
• Learning and adaptation  
• Contextual Information

Features and Uncertainties

Priors and Learned Statistics

Value of Information

Constraints

**Adaptive Front-End Signal Processing** (R. Moses, lead)  
• Decision-directed Imaging and Reconstruction  
• Modeling and Feature Extraction  
• Statistical Shape Estimat

**Dynamic Sensor Resource Management** (D. Castanon, lead)  
• Dynam  
• Efficient  
level planning  
performance uncertainty

*What are the 'right'  
performance measures  
and bounds for FE and  
Sensor Mgmt?*

*State propagation  
in graphical  
models.*



*MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation*



# Signal Processing: Key Research Questions

*ATE Objectives  
Sensor Resources*

*Optimal, Robust Information  
Fusion* (A. Willsky, lead)

*ATR/ATE Inferences  
and Confidences*

*Problem formulations that admit  
context, priors and directed  
queries*

*Features and  
Uncertainties*

*Priors and  
Learned Statistics*

*Measurement  
Constraints*

*Adaptive Front-End Signal  
Processing* (R. Moses, lead)

- Decision-directed Imaging and Reconstruction
- Modeling and Feature Extraction
- Statistical Shape Estimation

- *Flexible imaging and reconstruction*
- *Unified Parametric/Nonparametric processing*
- *Feature uncertainty characterization*
- *Statistical shape estimation*
- *Adaptation and Learning*

- algorithms
- Multi-level planning
- Performance uncertainty

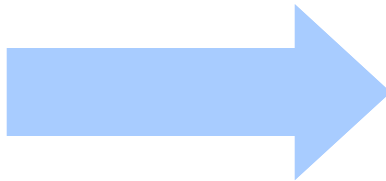


*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



# Sensor Management: Key Research Questions

*ATE Objectives*  
*Sensor Resources*



*Optimal, Robust Information Fusion* (A. Willsky)

- Graphical Models
- Performance Measure
- Information State Propagation
- Contextual Models
- Learning and Adaptation

- *Integrate ATE performance based on graphical models*
- *Manage evolution of "information state" in support of ATE missions*

- *Active control of trajectories, sensor modes, activities*
- *Multi-modal, heterogeneous platforms*
- *Adaptive Sensor Management*
- *Scalable real-time algorithms for theater-level missions*

- Modeling and Feature Extraction
- Statistical Shape Estimation

*Dynamic Sensor Resource Management* (D. Castañón, lead)

- Dynamic sensor allocation
- Efficient sensor management algorithms
- Multi-level planning
- Performance uncertainty

Value of Information

Measurement Constraints



*MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation*



# MURI Payoff

*Goal: Develop an integrated theory for ATE systems that combines information fusion, platform control, signal processing, and adaptation.*

## *Research Outcomes:*

- *An integrated theoretical framework for dynamic information exploitation systems.*
- *Theoretical foundations for adaptivity and learning in complex inference systems.*
- *New algorithms and performance metrics for coupled signal processing, fusion, and platform control.*

## *Payoff:*

- *Systematic design tools for end-to-end design of multi-modal, multi-platform ATE systems.*
- *Active platform control to meet ATE objectives.*
- *System-level ATE performance assessment methods.*
- *Adaptive, dynamic ATE systems.*



*MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation*





# MURI Team

## *UNIVERSITY TEAM:*

- Ohio State University (lead)
  - Randy Moses (PI)
  - Lee Potter
  - Emre Ertin
- Massachusetts Institute of Technology
  - Alan Willsky
  - John Fisher
  - Mujdat Çetin (also Sabanici U.)
- Boston University
  - David Castañón
  - Clem Karl
- University of Michigan
  - Al Hero
- Florida State University
  - Anuj Srivastava

*AFOSR:* David Luginbuhl

*AFRL POC:* Greg Arnold



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



## Kickoff Meeting Feedback

- Strongly positive on team expertise and interactions.
  - Already up to speed
- Strongly supportive of research plan
- Maintain emphasis on fundamental research.
- Maintain research continuity
  - Interactions among the MURI PIs
  - Interactions with government labs and industry



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



## Year 1 Advances

- Regularized Tomography for Sparse reconstruction
  - Sparse apertures
  - Sparse 'objects' (targets or scenes)
  - Anisotropy characterization
  - Reconstruction for wide angle and circular SAR
  - Decision-directed reconstruction
  - Lots of cross-pollination, especially OSU, BU, MIT
- Shape Statistics for Curves and Surfaces
  - Shape Analysis
  - Bayesian Classification from Shapes



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



## Year 1 Advances II

- Distributed Estimation and Management
  - MIMO radar fusion with calibration errors
  - Distributed estimation with unreliable communications
- Sensor Management:
  - Adaptive data fusion
  - Adaptive waveform scheduling
  - Real-time SM algorithms and performance bounds
- Scalable, flexible inference
  - Low-rank uncertainty estimation in graphical models
  - GM-based Tracking
  - Learning Model structure



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



## MURI Students

- 11 graduate students and 1 postdoctoral fellow fully supported by the MURI.
- 10 graduate students working on the MURI team with outside support (e.g. fellowships).
- 3 PhD and 3 MS degrees awarded in Year 1



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*




# ATE MURI Web Page

Main Page - Atemuri [http://projects.csail.mit.edu/atemuri/wiki/index.php/Main\\_Page](http://projects.csail.mit.edu/atemuri/wiki/index.php/Main_Page)

## Main Page

From Atemuri



**Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation**  
A Multidisciplinary University Research Initiative (MURI) Research Program

### Contents

- 1 MURI Team
- 2 Overview
  - 2.1 Executive Summary
- 3 Meetings
- 4 Publications
- 5 Reports
- 6 Code
- 7 Tutorial Information
- 8 Gain access
  - 8.1 Internal
  - 8.2 FrequentlyAskedQuestions

### MURI Team

- The Ohio State University:** Randy Moses (PI), Lee Potter, Emre Ertin
- Boston University:** David Castanon, W. Clem Karl
- Massachusetts Institute of Technology:** Alan Willsky, John W. Fisher III, Mujdat Cetin
- Florida State University:** Anuj Srivastava
- University of Michigan:** Al Hero

A complete roster and web page links may be found at MURIPeople.

### Overview

The goal of the research is to develop an integrated systems theory that jointly treats information fusion, control, and adaptation for automatic target exploitation (ATE) that addresses:

- Multiple, dynamic sensors
- Multiple sensing modalities
- Resource-constrained environments

### Executive Summary

1 of 2 8/16/2007 2:08 PM

- People
- Publications
- On-line research collaboration space
- Code
- Data resources



*MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation*



# Intra-team Interactions

- MURI research meeting in Boston Dec07
  - 30 participants, 25+ posters,
- Sensor Management Book Collaboration
  - *Foundations and Applications of Sensor Management*; Springer 2007; Editors: A. Hero, D. Castañón, D. Cochran, K. Kastella
- Student Committees
  - D. Castañón (BU) on Jason Williams' (MIT) dissertation committee
  - J. Fisher (MIT) on Shantanu Joshi's (FSU) dissertation committee
- Numerous Research Interaction Visits
  - A. Hero → MIT sabbatical Au06
  - Fisher → FSU; Joshi Ph.D. committee
  - Moses → 3 visits to MIT Summer 2006
  - Fisher → UMich July07
  - Çetin → OSU Aug07 (video-conference)



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



# Publications and Students

- 54 Publications
  - 13 Journal publications
  - 41 Conference proceedings papers
- Student Graduate Degrees
  - Jason Williams (MIT) PhD
  - Raghuram Rangarajan (UMich) PhD
  - Shantanu Joshi (FSU) PhD
  - Christian Austin (OSU) MS
    - PhD on this MURI
  - Kush Varshney (MIT) MS
    - PhD on this MURI
  - Subhojit Som (OSU) MS
    - PhD on this MURI



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*





# Interactions and Transitions I

- Presentations at 15 conferences
- Scientific Advisory Boards
  - Castañón: Air Force SAB
  - Hero: ARL TAB
  - Willsky: DARPA POSSE;
  - Willsky: Chief Scientific Consultant to BAE-AIT
  - Hero: National Research Council
- Research Formulation Workshops
  - Srivastava organized ARO Workshop on Challenges and Opportunities in Image Understanding
    - Moses, Fisher, Hero, Arnold presented
  - Hero organized ARO Workshop on Signal and Information Processing
    - Moses, Fisher, Castañón presented
  - Ertin: AFRL ATR Modeling Workshop



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



## Interactions and Transitions II

- Transitions:
  - Sparse aperture research -> AFRL GREP program
  - Srivastava statistical shape analysis to Northrup-Grumman via Innovation Alliance Award
  - A. Hero directed Mike Davis (GD-AIS) research on MIMO radar networks
  - MURI LADAR model identification and radar scheduling provided to Lincoln Laboratory
  - Summer internships
    - Julie Jackson: AFRL Dayton, Summers 06 and 07
    - Kerry Dungan: AFRL Dayton, Summer 07
    - Ahmed Fasih, SET Corp. Dayton, Summers 06 and 07
    - Christian Austin: SET Corp. Dayton, Summer 06
    - Kyle Herrity: FAAC, Inc Ann Arbor MI, Summer 07



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



# Today's Presentations

*ATE Objectives  
Sensor Resources*

*ATR/ATE Inferences  
and Confidences*

*Optimal, Robust Information  
Fusion (A. Willsky, lead)*

**Optimal, Robust Information Fusion in  
Uncertain Environments (Willsky)**

- Information State Propagation
- Contextual Models
- Learning and Adaptation

**Information-Driven Inference in  
Resource-Constrained Environments  
(Fisher)**

Features and  
Uncertainties

Priors and

Value of

**Adaptive Radar Sensing Strategies (Hero)**

*Adaptive Front-End Signal  
Processing (R. Moses, lead)*

*Dynamic Sensor Resource  
Management (D. Castanon, lead)*

**Sparse Reconstruction and Feature  
Extraction (Potter, Çetin, Ertin, Karl,  
and Moses)**

**Tools for Analyzing Shapes of Curves  
and Surfaces (Srivastava)**

**Algorithms and Bounds for  
Networked Sensor Resource  
Management (Castañón)**

- D
- E
- a
- Multi-level planning
- Performance uncertainty



*MURI: Integrated Fusion, Performance Prediction,  
and Sensor Management for Automatic Target  
Exploitation*



# Agenda

9:00 - 9:25	Intro and Overview (Moses)
9:25 - 10:00	Optimal, Robust Information Fusion in Uncertain Environments (Willsky)
10:00 - 10:30	Adaptive Radar Sensing Strategies (Hero)
10:30 - 10:50	Break
10:50 - 11:30	Sparse Reconstruction and Feature Extraction (Potter-includes Çetin, Ertin, Karl, and Moses)
11:30 - 12:00	Tools for Analyzing Shapes of Curves and Surfaces (Srivastava)
12:00 - 1:00	Lunch (and Government mini-retreat) <b>Blackwell Ballroom</b>
1:00 - 1:30	Algorithms and Bounds for Networked Sensor Resource Management (Castañón)
1:30 - 2:00	Information-Driven Inference in Resource-Constrained Environments (Fisher)
2:00 - 2:30	Summary (Moses)
2:30	Break and Government caucus
~3:30	Feedback and Discussion



*MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation*