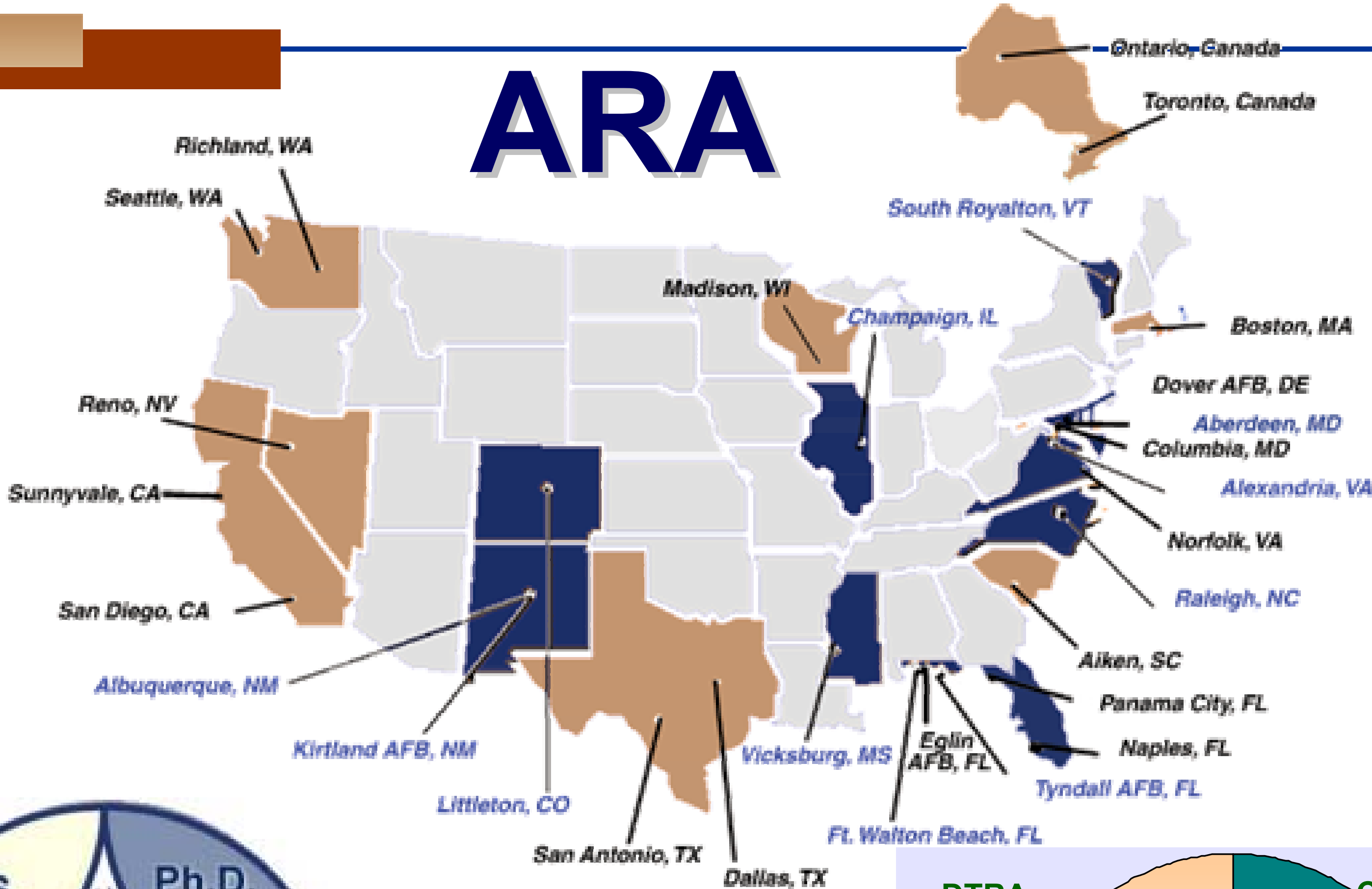
Probabilistic Model-Based Multi-Sensor Fusion for Remaining Life Prediction

Presented at:
DARPA Prognosis Bidder's Conference, D.C.
26-27 September 2002

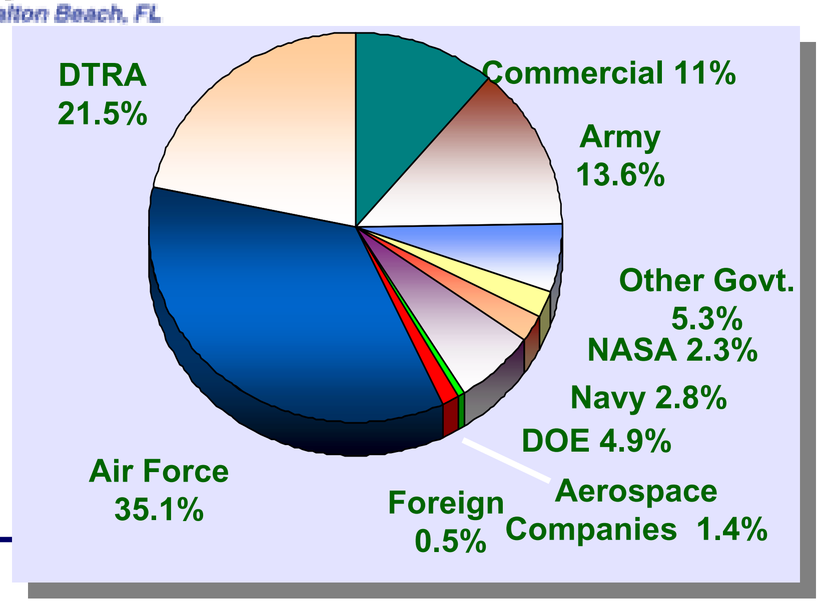
Prepared by
Dr. Justin Y. Wu
Applied Research Associates, Inc.
8540 Colonnade Drive, Suite 301
Raleigh, NC 27615
jwu@ara.com (919) 876-0018

APPLIED RESEARCH ASSOCIATES, INC.

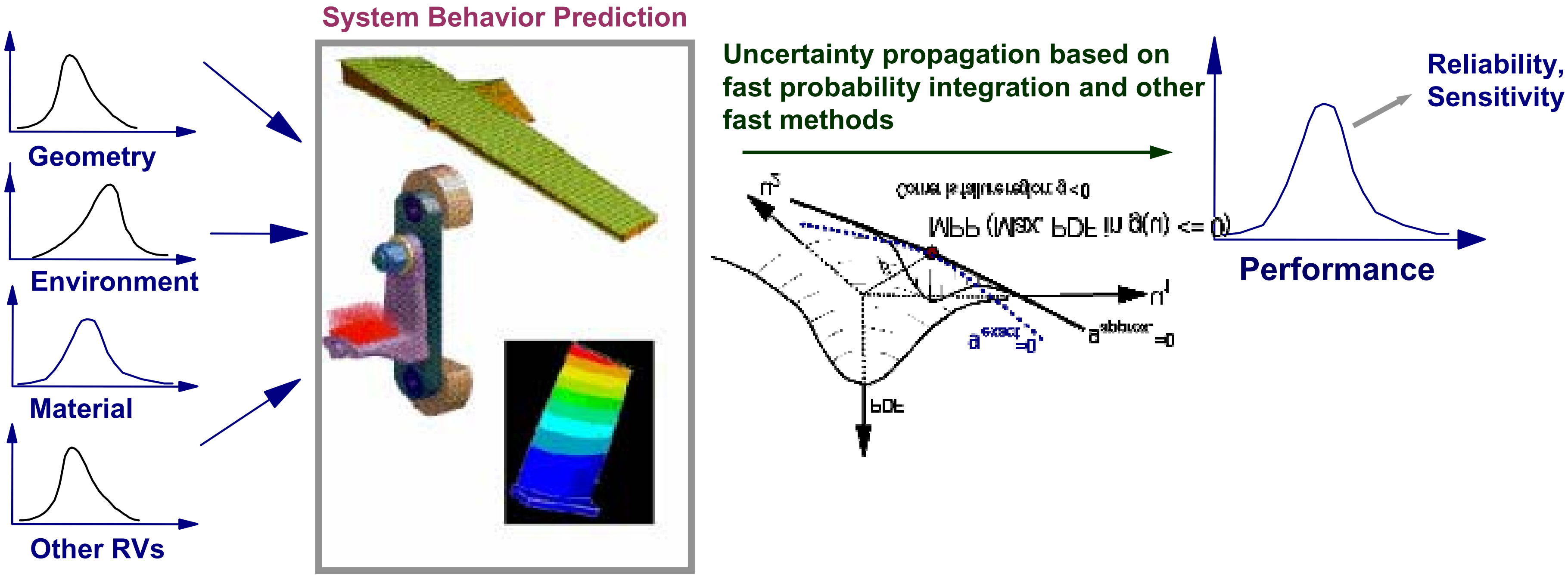
ARA



- 700 Employees



Probabilistic Methods for Physics-Based Applications



Para. and Model Random Variables:
- Dependent, Non-normal Joint PDF
- Random field
- Possibility membership

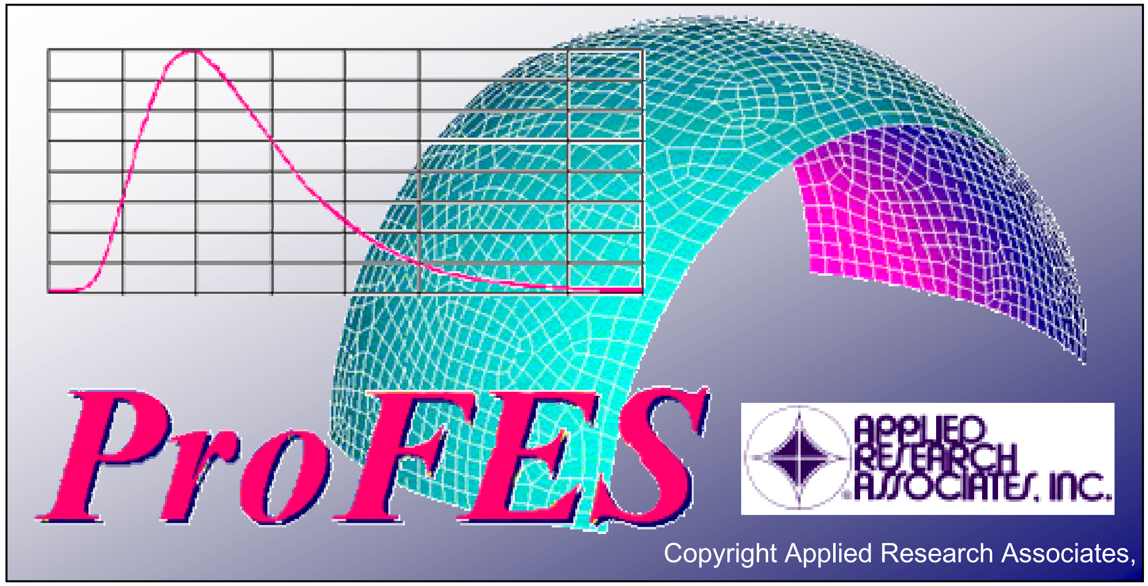
Physics-Based Models:
- Finite element
- Comp. fluid dynamics
- Damage mechanics
- Other physics-based models
- System modeling using fault tree

Probabilistic Methods:
- First-Order reliability (FORM)
- Second-Order (SORM)
- Adv. Mean Value
- Adaptive response surface
- Latin Hypercube sampling
- Adaptive importance sampling
- Markov Chain Monte Carlo
- Stochastic optimization
- Possibilistic-probabilistic anal.

Risk/Uncertainty Management
- Bayesian update
- Ranking/Prioritization
- Trade offs
- Planning (maintenance, test, etc.)

Probabilistic Function Evaluation System

- State of the art probabilistic analysis engine
  - Fast methods do not require MCS
  - Stochastic Optimization
  - Possibilistic analysis
- Simple linking to 3rd party applications

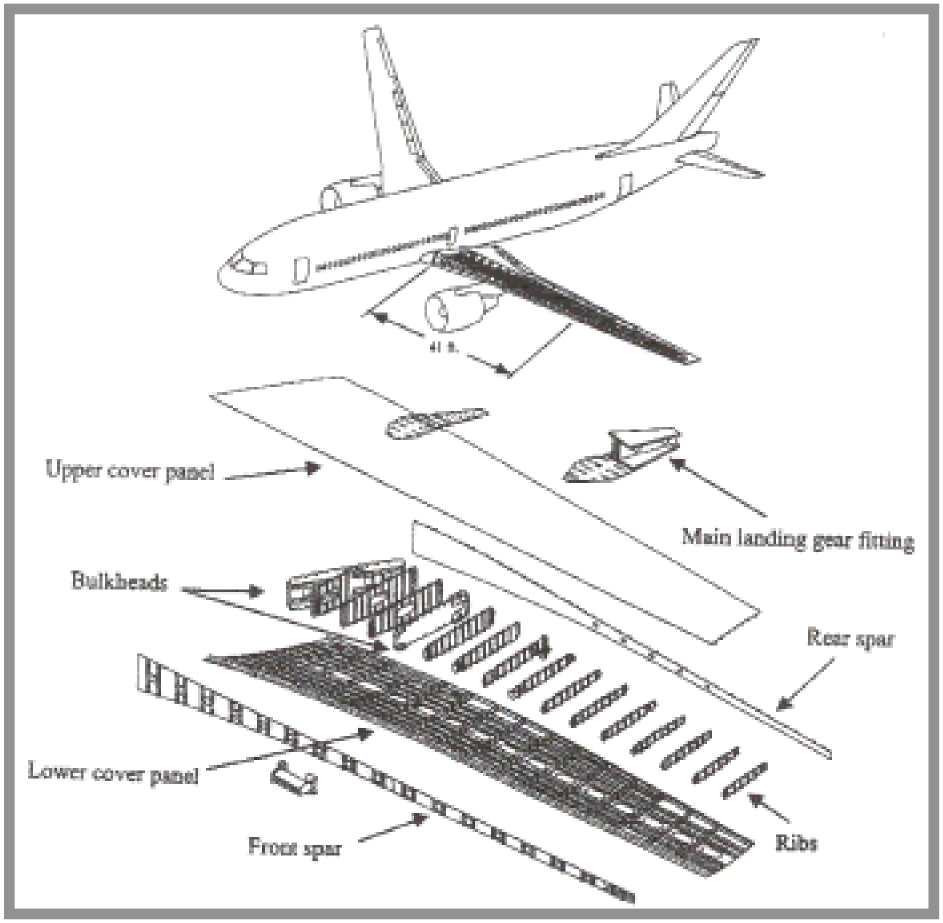


Sponsors: USAF, NASA, ARA

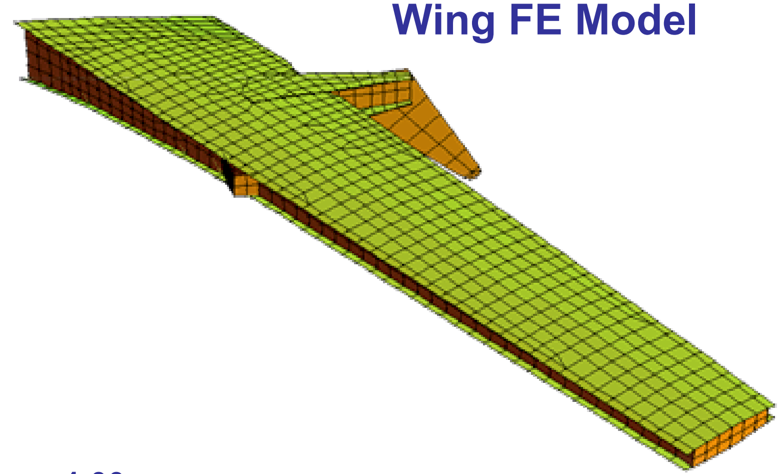
Optimization Under Uncertainty Using ProFES

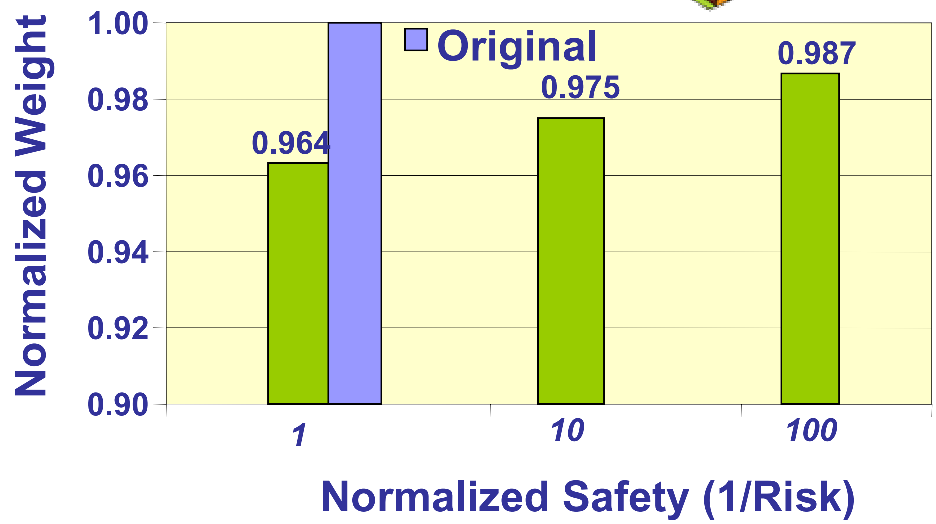
Sponsor: NASA

Transport Aircraft Wing



Wing FE Model



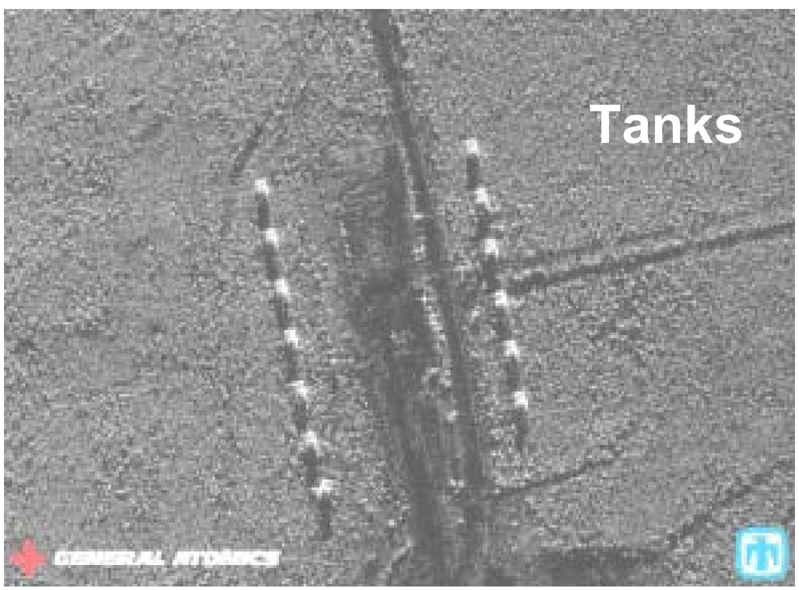


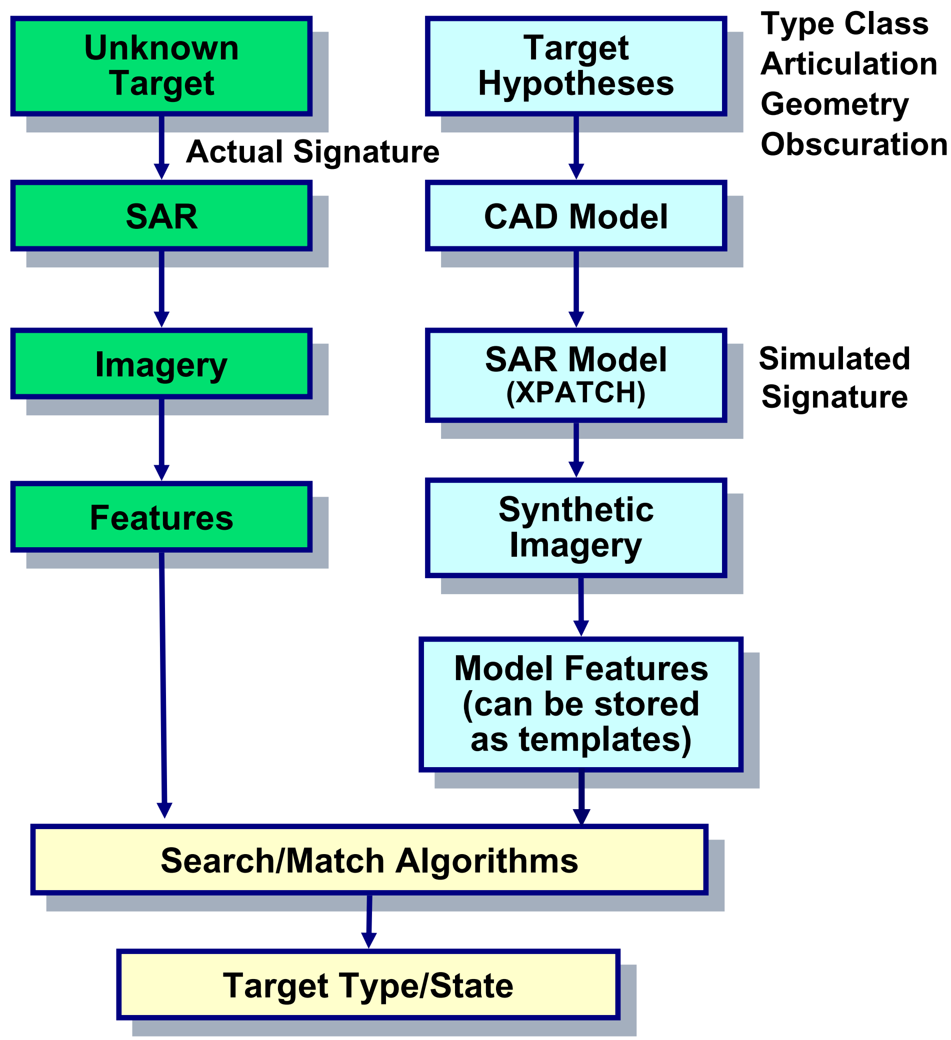
Probabilistic Model-Based Sensor Fusion

- Problem Description
  - Low-observability targets require improved detection-discrimination capability using multiple sensors and/or multi-looks and require data fusion algorithms
  - Sensor and ATR performances affected by uncertainties in weather, geological, terrain and other clutter and environmental conditions
    - Uncertainty (randomness) cannot be treated as variability (deterministic unknown)
- Why Consider Uncertainties
  - Provides quantitative confidence of hypothesis matching, not just which is best match, to assist in go/no go decisions
  - Support systematic sensor and data/information management under uncertainties

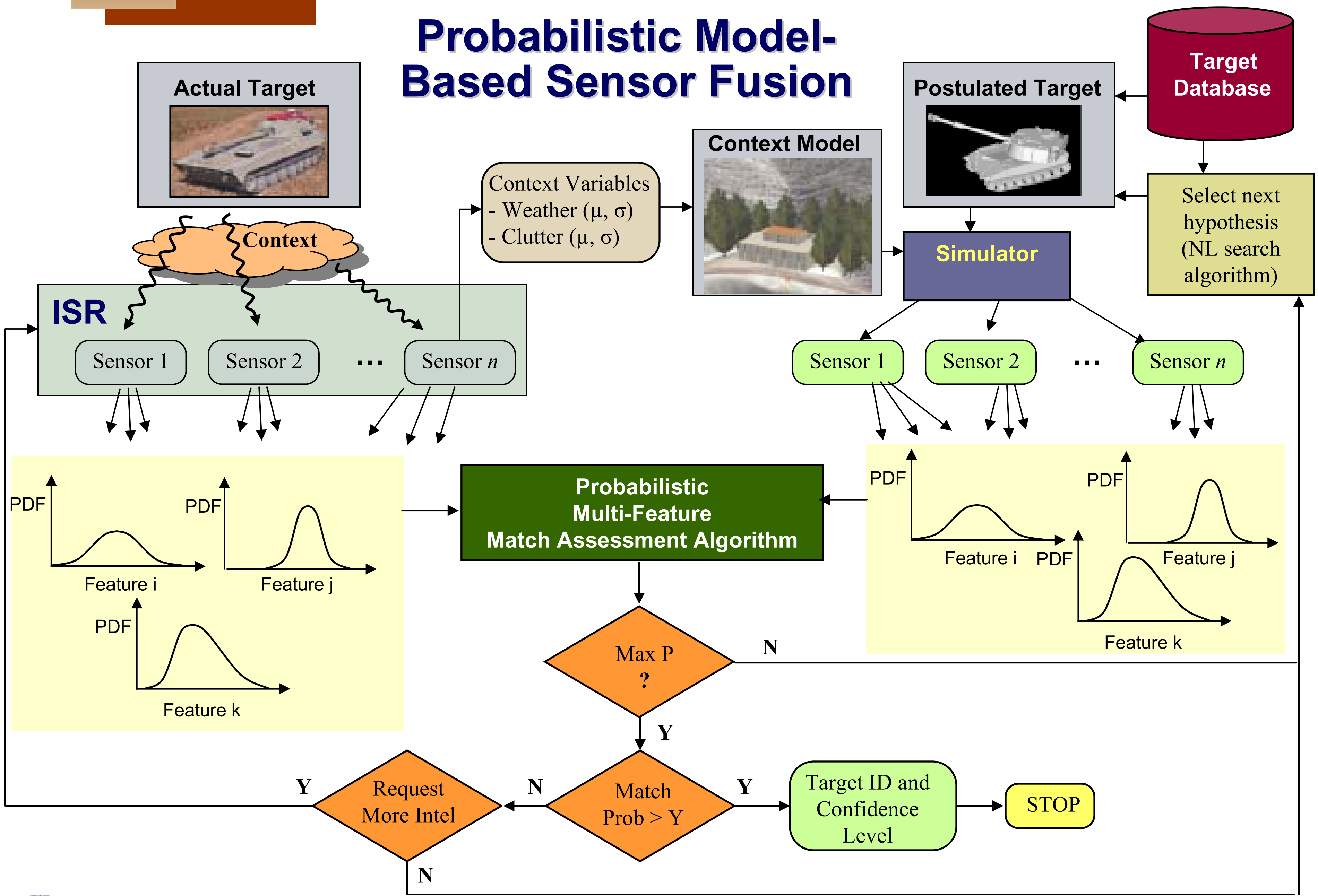
Model-Based Approach Example

- Example is target recognition using Synthetic Aperture Radar (based on paper by Subotic, Gorman, and Welby, 2001 & DARPA MSTAR program)
- Use CAD geometry model and physics-based radar signature model model to generate and extract features
- Use hypothesis-and-test approach to find the best-matched target type/state





Probabilistic Model-Based Sensor Fusion

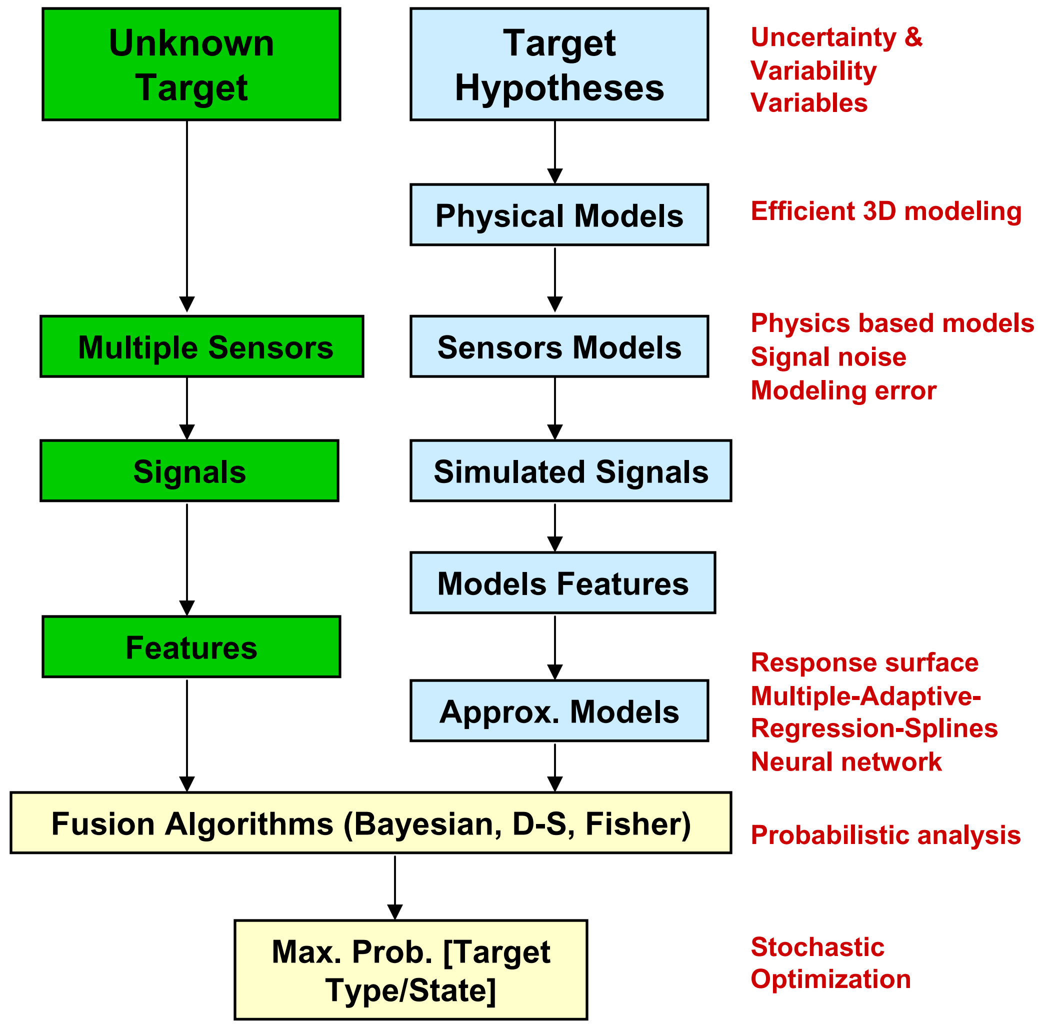


ARA

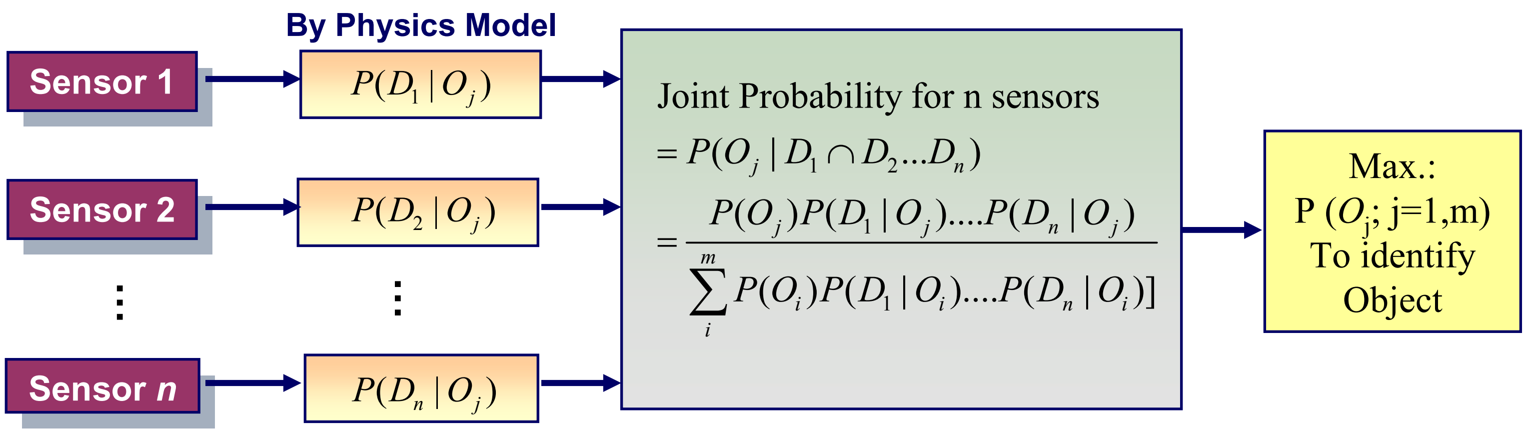
Probabilistic Model-Based Sensor Fusion

R&D Challenges

- Multiple sensors/looks
  - SAR, Laser, Thermal, MSI, Acoustic …
- More physics models
  - XPATCH, NVTHERM, IIMRC, …Others
- Sensor signal noise and bias
- Sensor reliability
- Context characterization
  - Uncertainty (random)
  - Variability (realization)
- Fusion algorithms
  - At data, feature, or decision levels
  - Data requirement issues
  - Dependency issues
  - Produce and validate confidence levels
- Computational efficiency
  - Stochastic optimization is computationally intensive



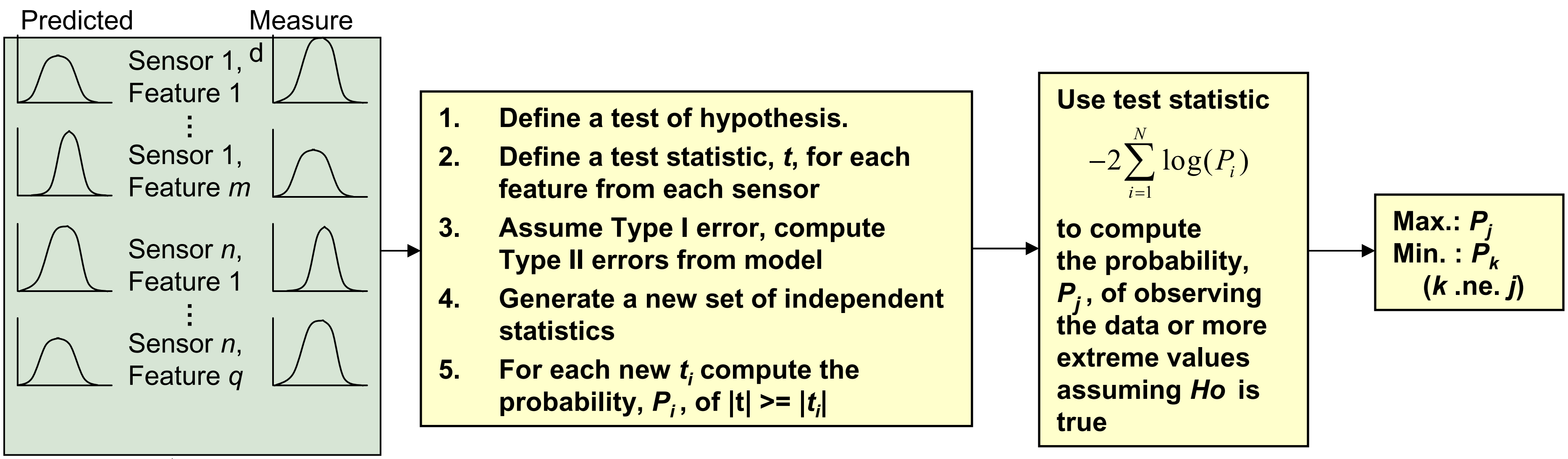
Multi-Sensor Fusion at Decision Level

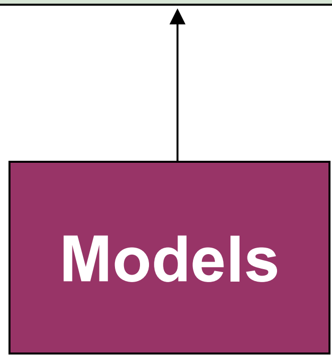


$D_k | O_j$ = Declaration by sensor k for object type j

- **Bayesian fusion disadvantages:**
  - **Difficult to define prior likelihoods**
  - **Competing hypotheses must be mutually exclusive**
  - **Cannot handle more general uncertainty (e.g., conflicting evidence)**
- **Dempster-Shafer evidence theory removes the above 2nd and 3rd limitations**
- **An approach without prior likelihood is being investigated at ARA**
  - **Treat dependency between features or sensor of same or different types**
  - **Use efficient computational probabilistic and stochastic optimization schemes**

A Probabilistic Multi-Feature Match Algorithm





- **Features:**
  - **Does not require prior likelihood**
  - **Different features treated as additional sensors**

Prognosis Applications

- Model-based method for target recognition is directly applicable to Prognosis, where the objective is to predict damage state and remaining life