

Large-Scale Estimation in Cyber-Physical Systems: Model Attention, Mismatch, Refinement, and Learning

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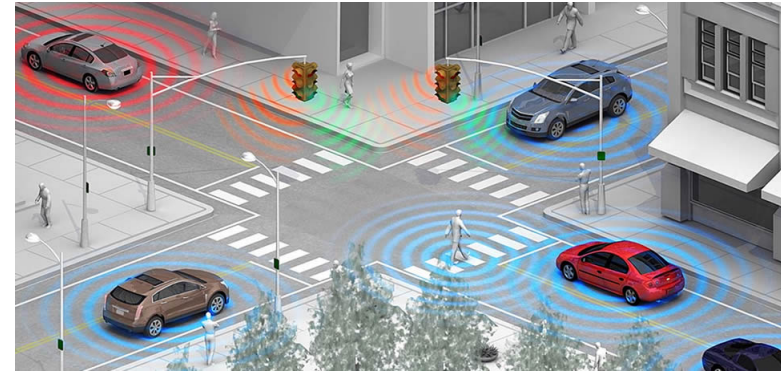


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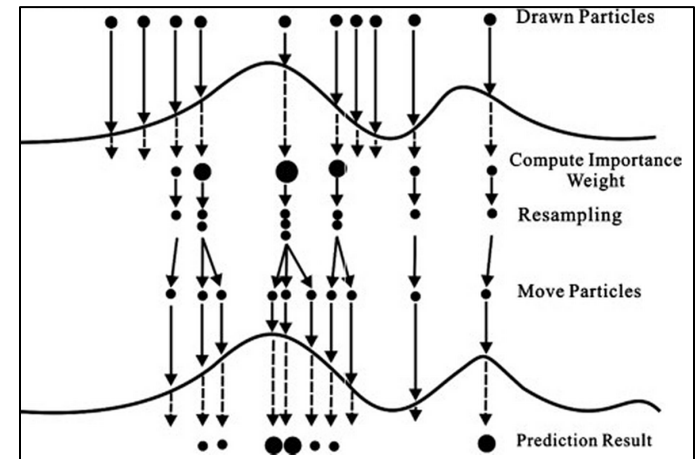
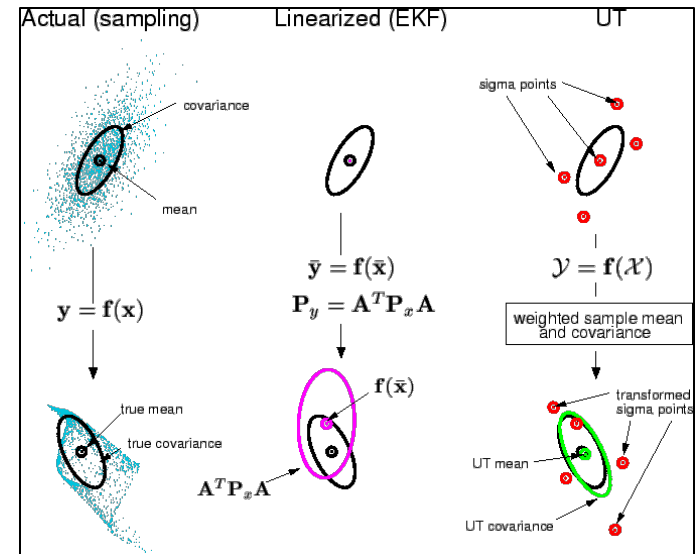
Why Estimation in CPS?

- Uncertainty inherent in the physical world
- Is a task in itself
 - Active monitoring in sensor networks
- Disturbances, degradation
 - Adversarial interruption
 - Natural system changes

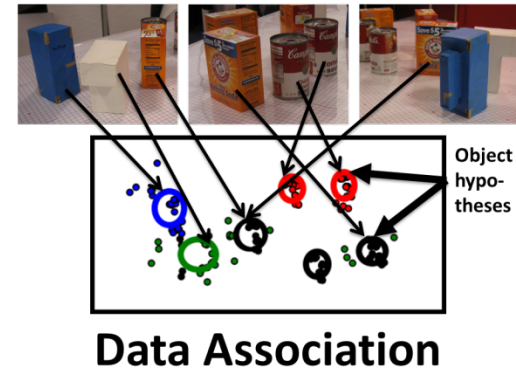
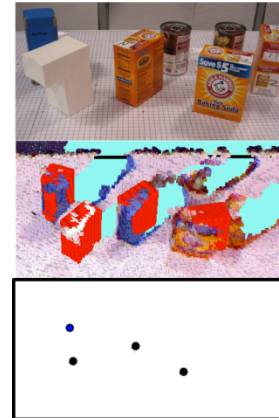
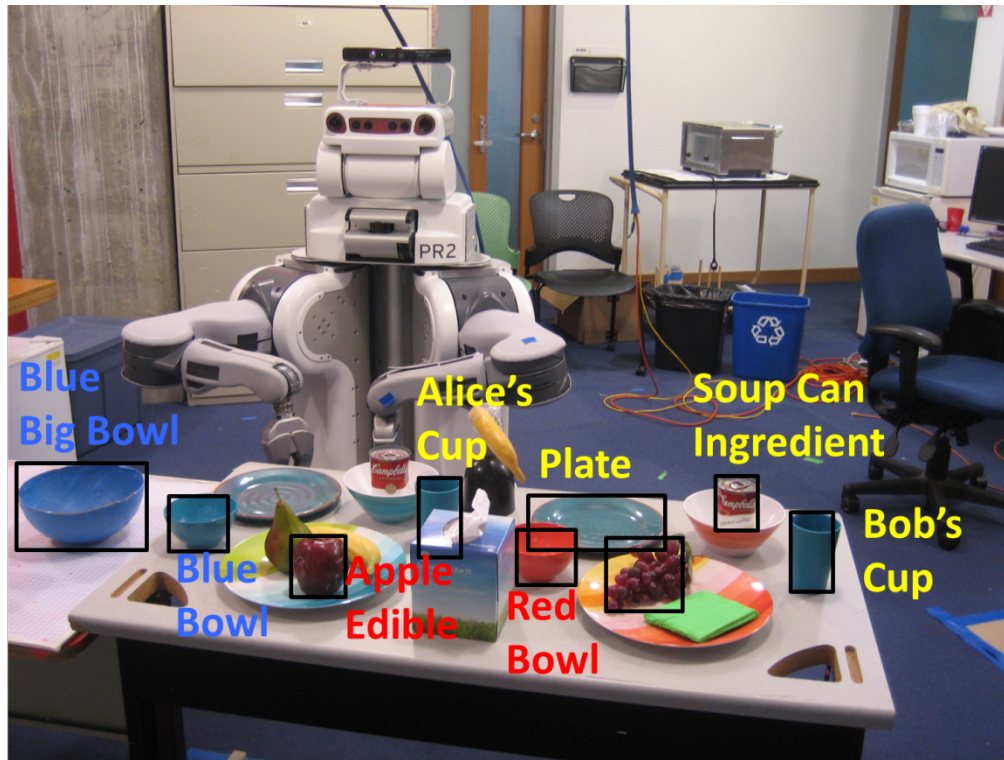


Traditional Tools Are Insufficient

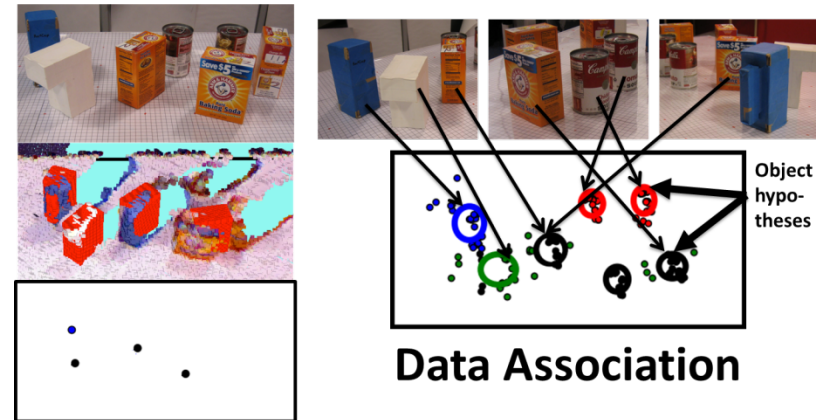
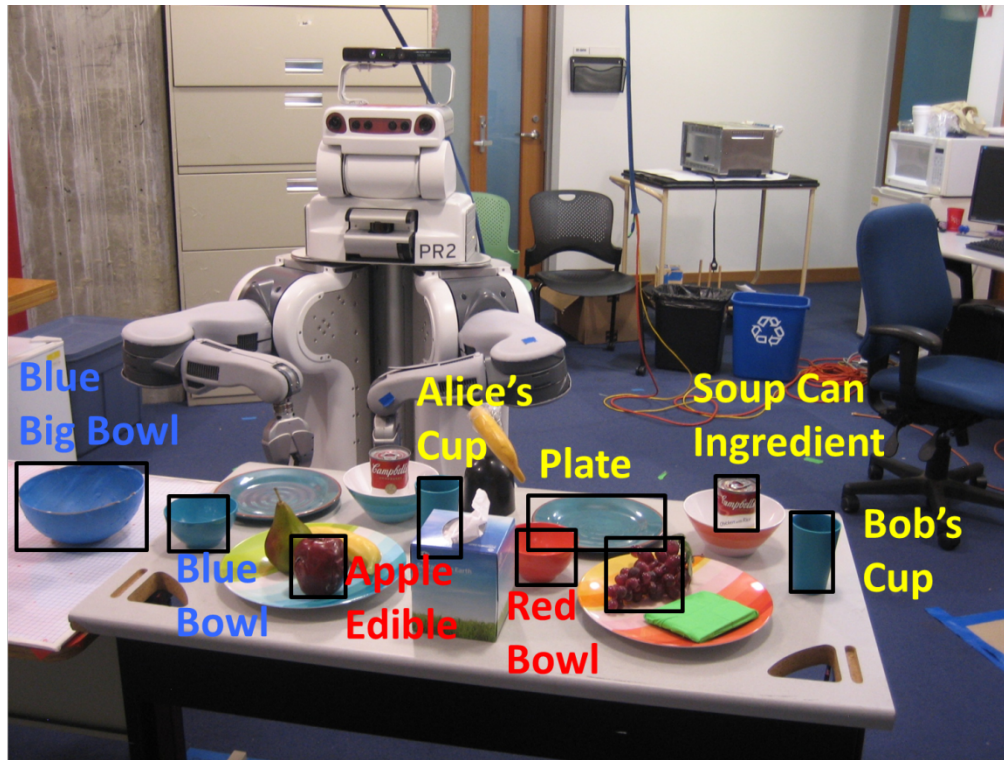
- Kalman filters (Gaussians)
- Particle filters (Samples)
- Can these scale the world?



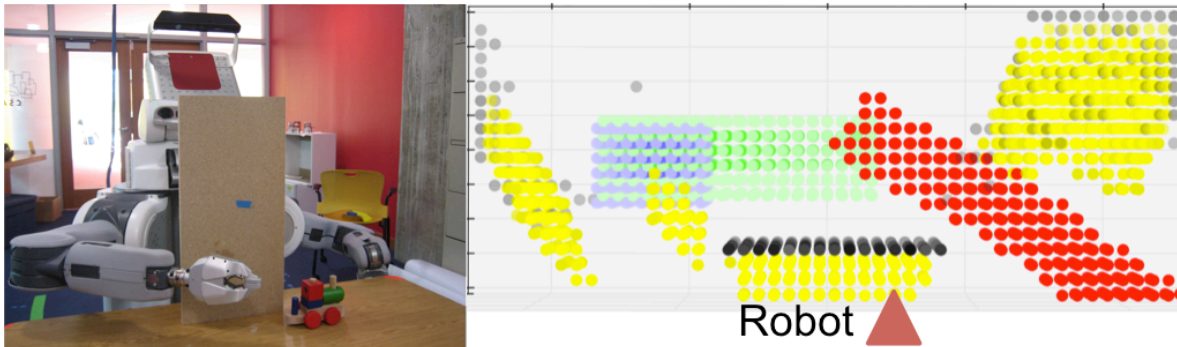
Semantic world modeling from partial views



Semantic world modeling from partial views



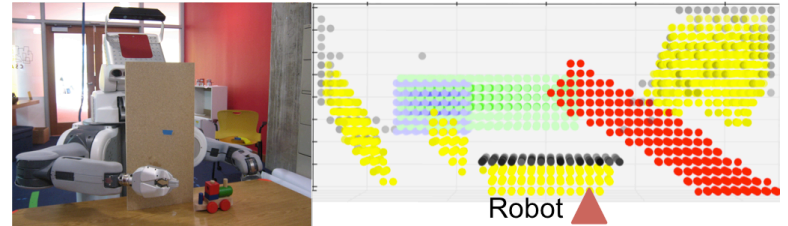
Combine object and metric spatial information



Result: Joint estimation of object attributes and geometry

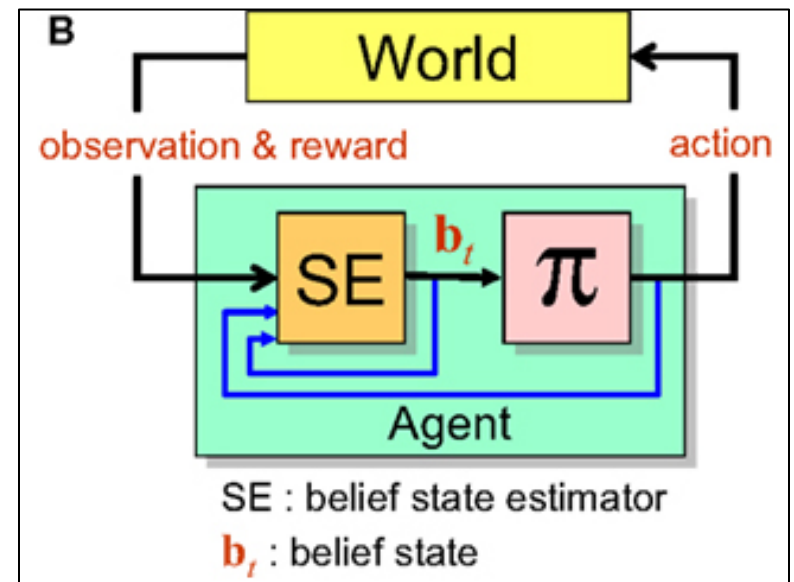
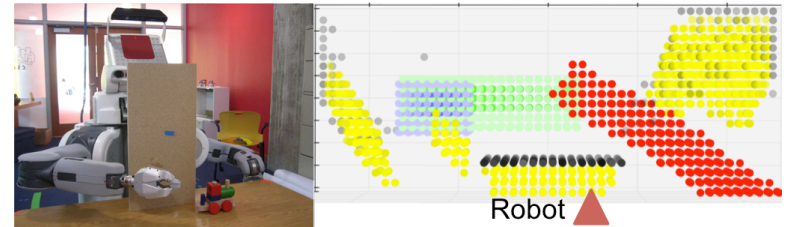
Rethinking Estimation Strategies

- Online efficiency
 - Filter models separately
 - Merge at query time



Rethinking Estimation Strategies

- Online efficiency
 - Filter models separately
 - Merge at query time
- All models are wrong
 - Refine where needed
- Tightly integrate **task** (action selection) & **state** (estimation)



Proposed Framework

- Instead of using a monolithic estimator:
 - Initialize with **minimal** estimator for task
 - Detect when initial model too restrictive for task
 - Refine, adapt, and learn **locally** (not global)
- Attention: Task relevance
- Mismatch: Fault detection
- Refinement: Model class expansion
- Learning: Parameter estimation

Proposed Framework

- Attention: Task relevance
 - Only a small subset of variables matter
- Mismatch: Fault detection
 - Tolerances automatically informed by task
- Refinement: Model class expansion
 - Explore larger model class
 - for small subset of variables only**
- Learning: Parameter estimation
 - Non-parametric ‘models’ as a final refinement

Proposed Framework

- Attention: Task relevance
 - Human-in-the-loop for **interpretable** guidance
- Mismatch: Fault detection
 - Fault detection & identification / diagnosis
- Refinement: Model class expansion
 - Connections to active learning / feature selection
 - Robustness guarantees?
- Learning: Parameter estimation
 - Grammars and hierarchies of models