Particle filter-based information acquisition for robust plan recognition

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Overview

1. Previous research
2. Particle filter-based state estimation
3. Revised plan recognition
4. Revised information acquisition/ sensor management

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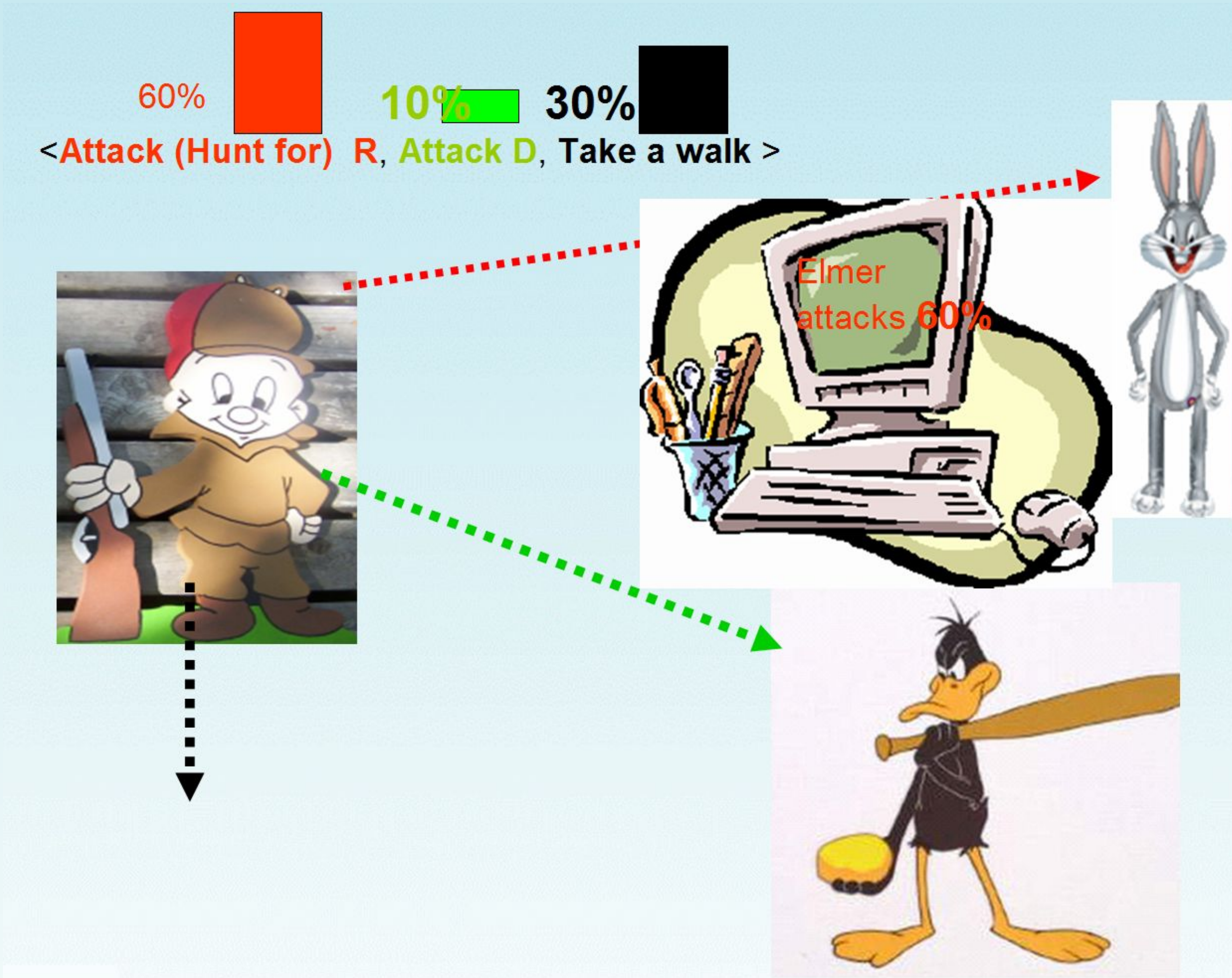
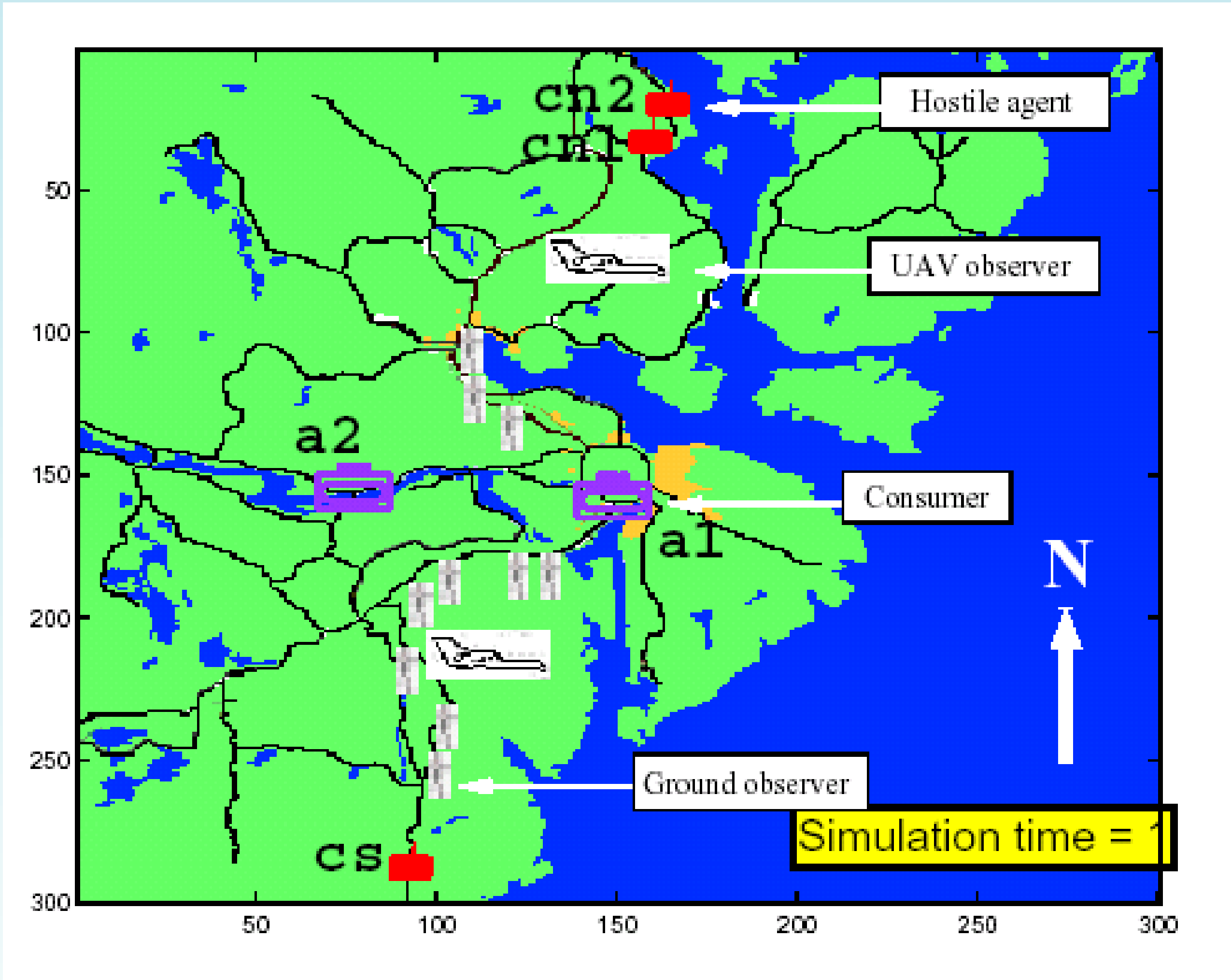
- Purpose of plan recognition
  - Provide estimates of enemy plans/intentions from observations
  - Establish *predictive situation awareness*
- Purpose of sensor management/information acquisition
  - Facilitate plan recognition

1. Plan recognition



1. Multi-agent plan recognition

1. Decision support context



1. Plan recognition and predictive situation awareness

Hierarchical plan recognition is implemented (in our case) with a **Dynamic Bayesian Network** (DBN) and **fuzzy sets**.

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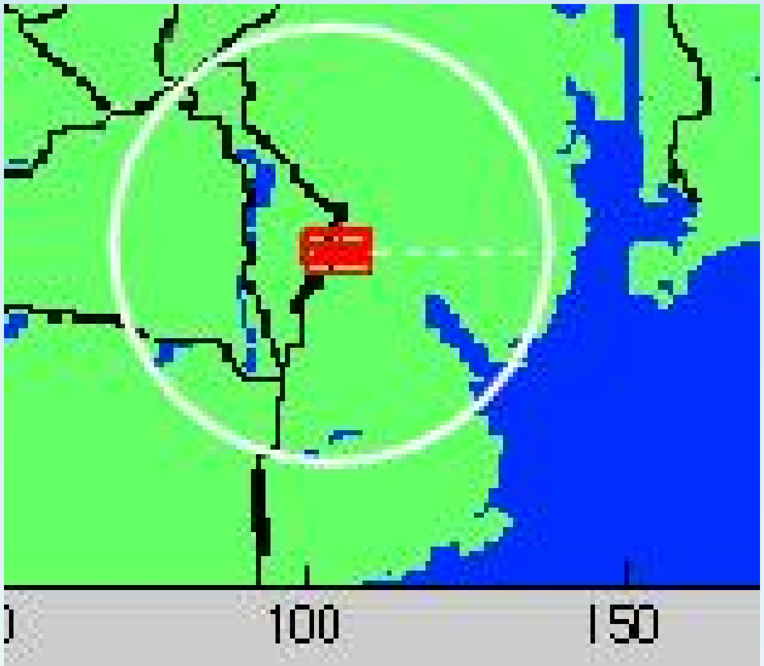
The main purpose of the information acquisition is to **connect information need to sensor services**.

2. Improving state estimation

Uncertainty radius
IEEE IRI-2004, Nov. 2004



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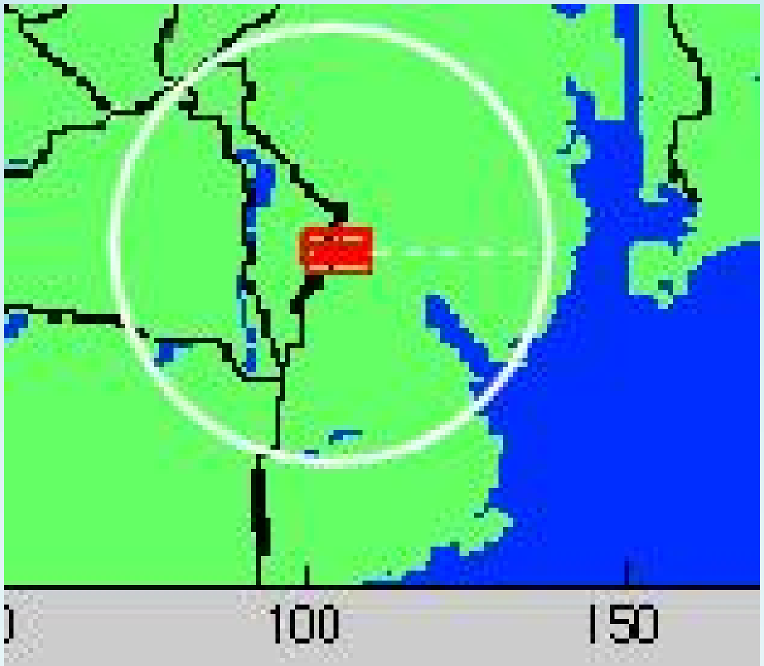
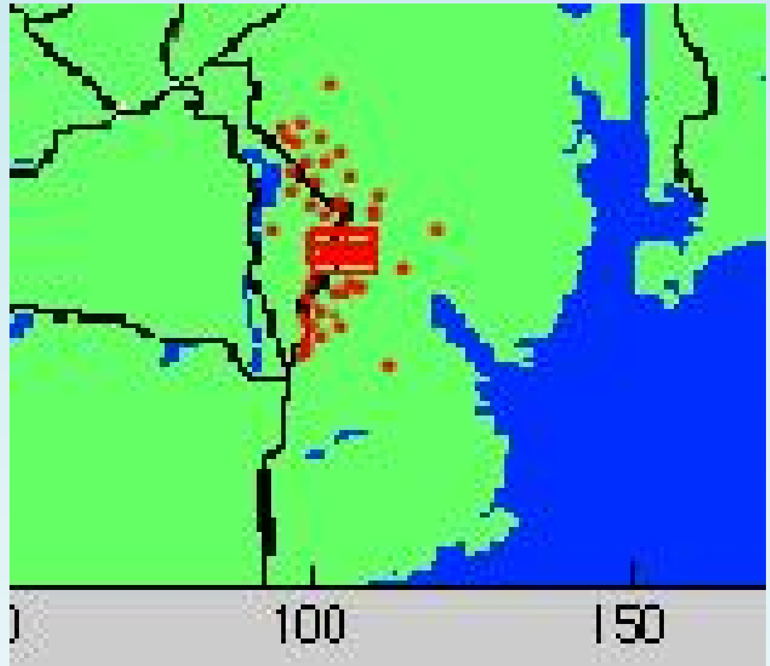


Particle set
current article



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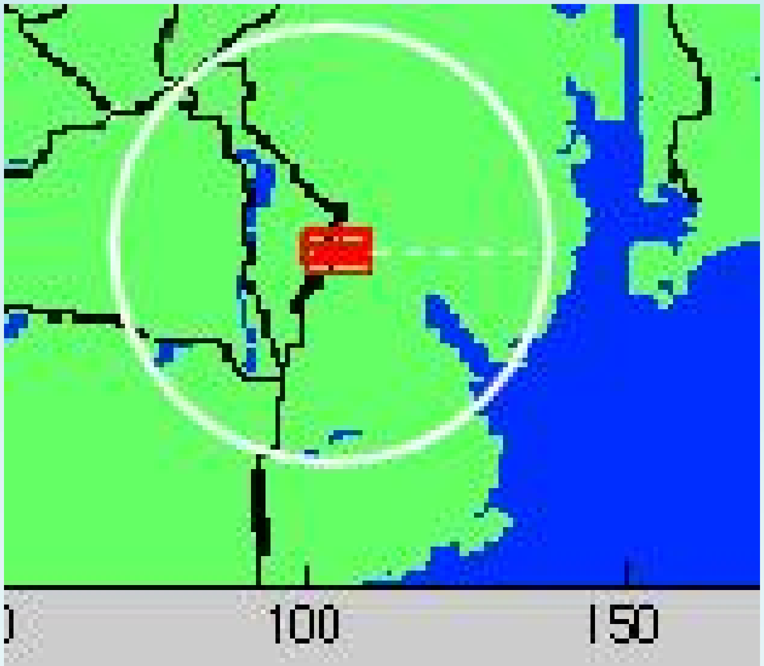

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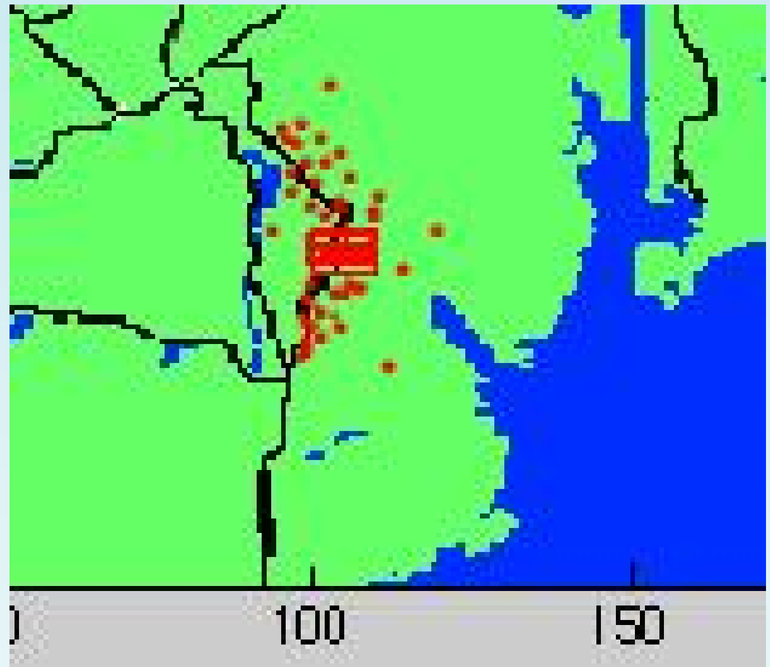


$$\mathbf{x}_t^{(i)} = [\ x \quad y \quad \phi \quad |v|\ ]$$

2. Advantages with particle set

1. Context/environment dependent state estimation;
2. The state estimate becomes less sensitive to spurious observations;
3. Amenable to efficient Monte Carlo simulation (sample from the particle set).

2. Particle filter properties

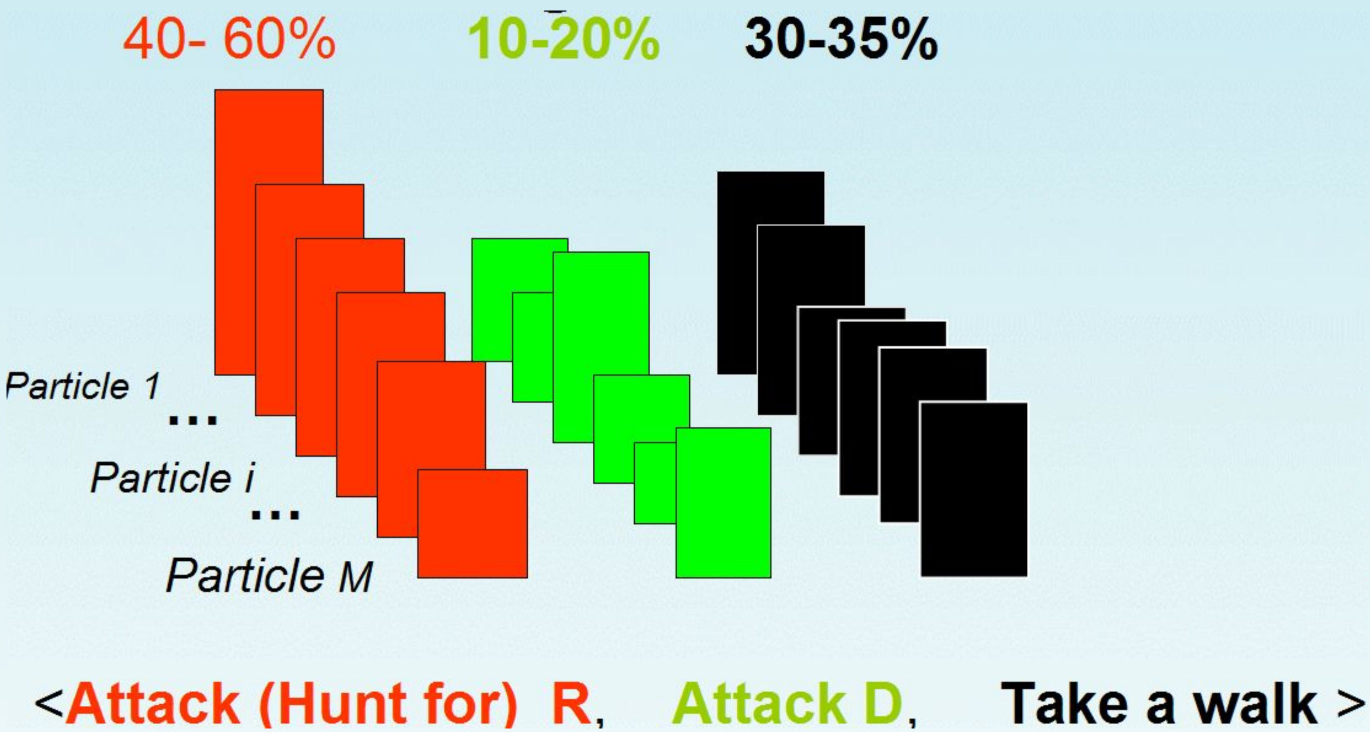
Implemented measures to counter problems with particle filter when observations are scarce:

1. Particles attracted by consumers (the presumptive targets)

2. Reinitialize particle filter when observations are too remote from the particles

3. Negative observations - remove corresponding particles where an agent should have been observed.

3. Robust plan recognition



3. Summarizing the set of distributions

Average distribution

$$\pi_{t-1}^{\text{cg}}(h) \triangleq \frac{1}{M} \sum_{m=1}^{m} \pi_{t-1}^{M}(h)$$

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Maximum entropy

$$\pi_{t-1}^{\mathsf{me}} \triangleq \arg \max_{\pi_{t-1}^{l} \in \mathbf{\Pi}_{t-1}} \mathtt{Entropy}(\pi_{t-1}^{l})$$

4. Sensor management

The sensor management part of this research concerns:

- task prioritization,
- task allocation, and
- sensor path planning.

4. Task prioritization based on high-level information

Threat (fuzzy set "High Threat") is here assumed to be a function of *company hostility*, *platoon hostility*, *time separation*, *impact*:

$$\mathtt{HT} = (\mathtt{Host_c} \cup \mathtt{Host_p}) \cap \mathtt{STimeS} \cap \mathtt{GI}$$

4. The fuzzy hostility set

$$\mathtt{Host_p}(\mathbf{x}^{(i)}) = \frac{\mathbf{w}_p^T \pi(\mathbf{x}^{(i)})}{\max(\mathbf{w}_p)},$$

where $\pi(\mathbf{x}^{(i)})$ is the plan distribution for particle $\mathbf{x}^{(i)}$ and $\mathbf{w}_p$ a weight vector. $\mathtt{Host_c}$ is defined analogously.

4. Statistical properties of $\mathtt{HT}$

Estimate threat mean and variance from particle set.

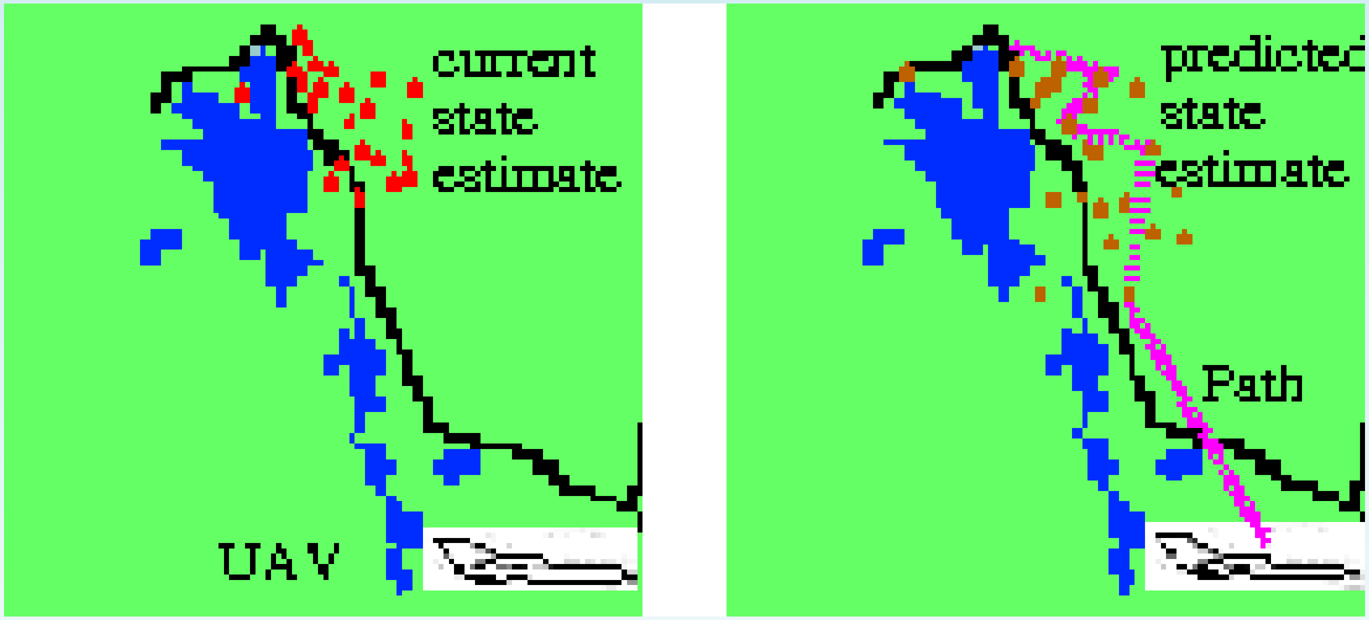
$$\hat{\mu}_{\mathtt{HT}} = \frac{\sum_{j=1}^{M} \mathtt{HT}(\mathbf{x}_t^{(j)})}{M}, \quad \hat{\sigma}^2_{\mathtt{HT}} = \frac{\sum_{j=1}^{M} \left(\mathtt{HT}(\mathbf{x}_t^{(j)}) - \hat{\mu}_{\mathtt{HT}}\right)^2}{M-1}.$$

Task priority $prio = (\hat{\mu}_{\mathtt{HT}}, \hat{\sigma}_{\mathtt{HT}})$

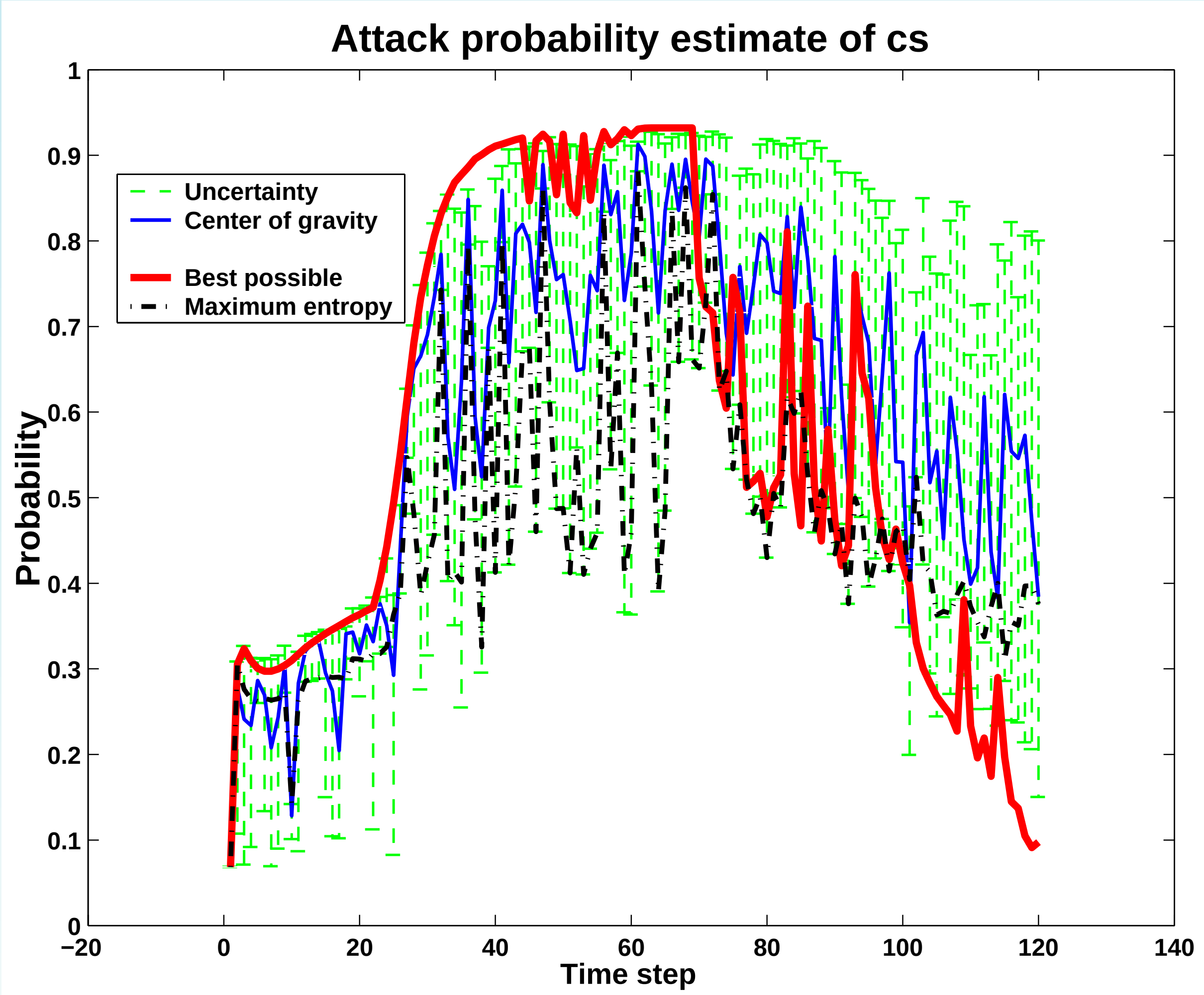
4. Task allocation

1. The priorities of tasks are re-evaluated in every time step
2. If there are several priorities elicited for the same task (agent), the most preferred one is allocated to the task
3. The task are ordered according to preference
4. For each task τ a most $suitable$ sensor (or service) is found . . .
5. and allocated to the task unless the cost is too high.

4. Path planning based on predicted future states



Results



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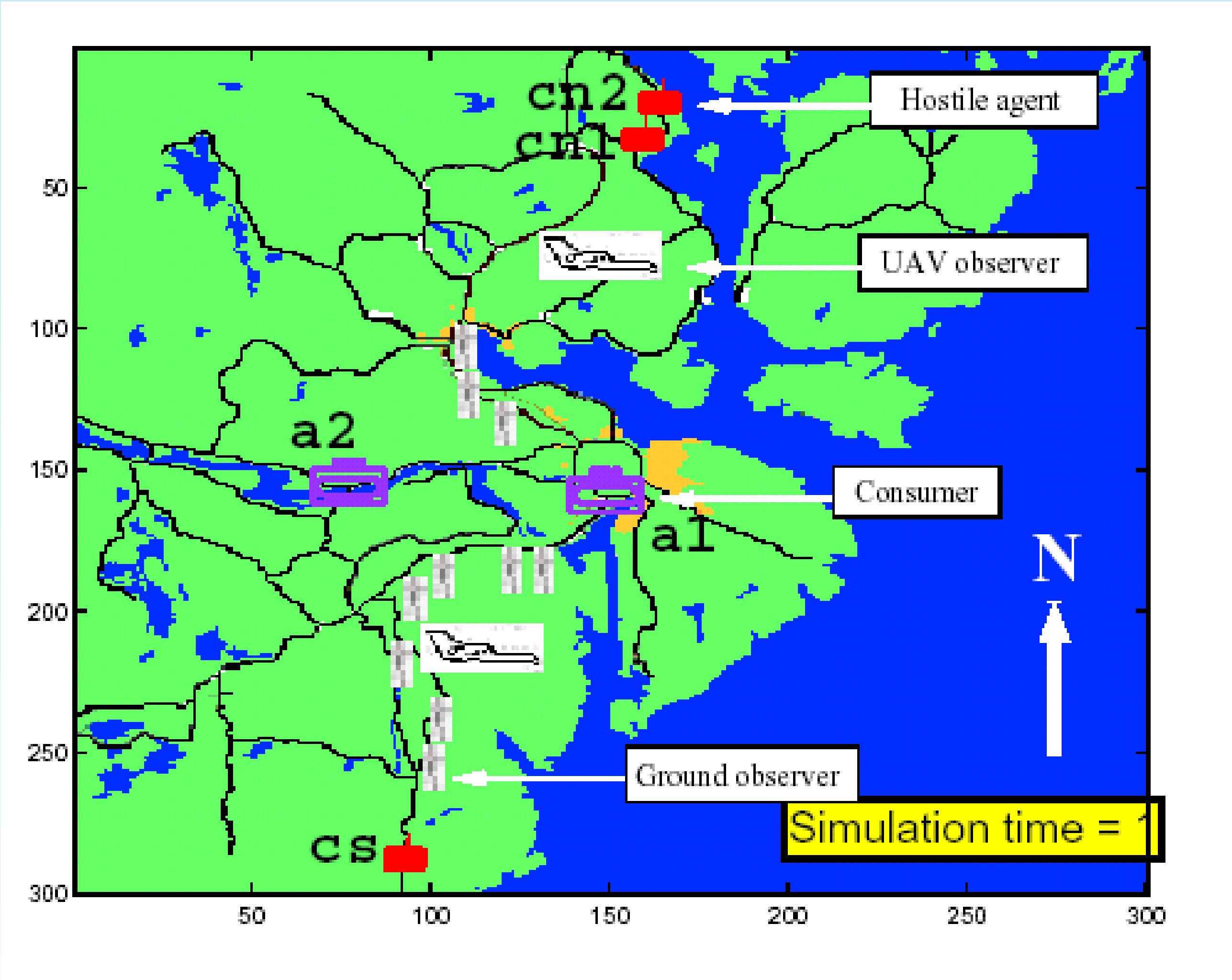
The scenario



Conclusions

- The (modified) particle filter appears to be a convenient tool for representing state uncertainty in the plan recognition process.
- The average plan distribution appears to be more useful than maximum entropy in our particular case.

Summary

Using the modified particle filter we . . .

- . . . introduced Bayesian robust plan recognition (with multiple plan distributions)
- . . . Monte Carlo estimate threats for task prioritization
- . . . have a context/environment dependent way to predict future states

Our implementation, furthermore integrates multiple objectives, heterogeneous sensors, long-term sensing actions, sensor preemption and mission-relevant sensor management.

Future directions

- Robust plan recognition requires further investigation;
- Distribution of information and control within the network needs more attention;
- Dependencies between tasks and between services;
- Extension of particles to include plan alternatives.