Large-scale Multi-agent Simulation for Studying Detection, Tracking and Prediction of Threats

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USC Information Sciences Institute
Center for Research on Unexpected Events (CRUE)

IPAM Crime Hot Spots
2 February 2007

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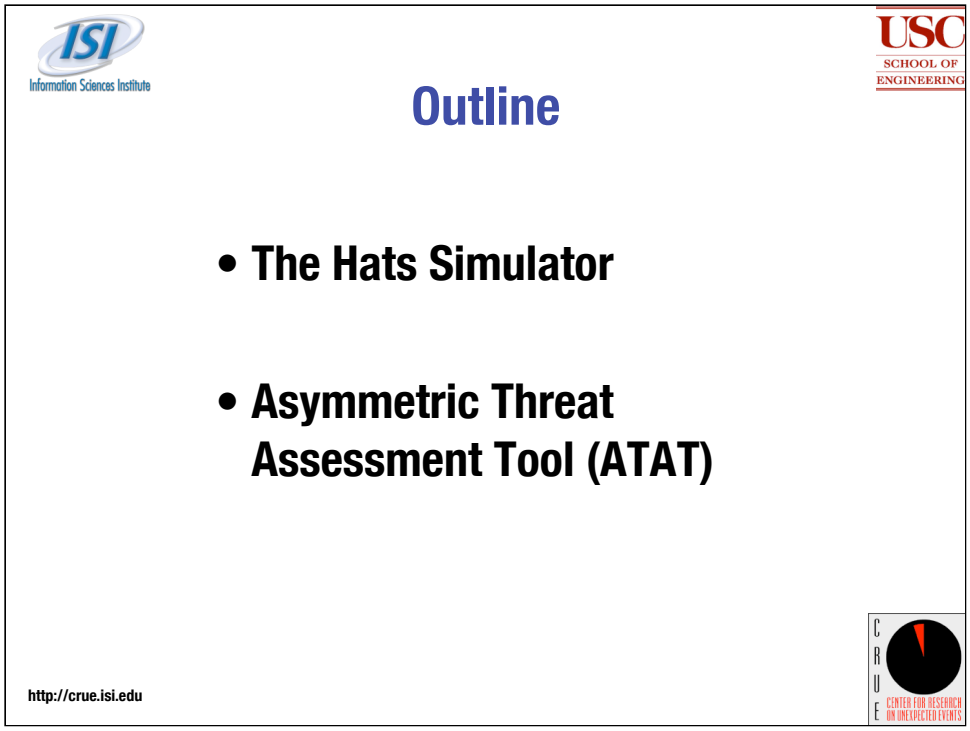
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Outline
• The Hats Simulator
• Asymmetric Threat
Assessment Tool (ATAT)
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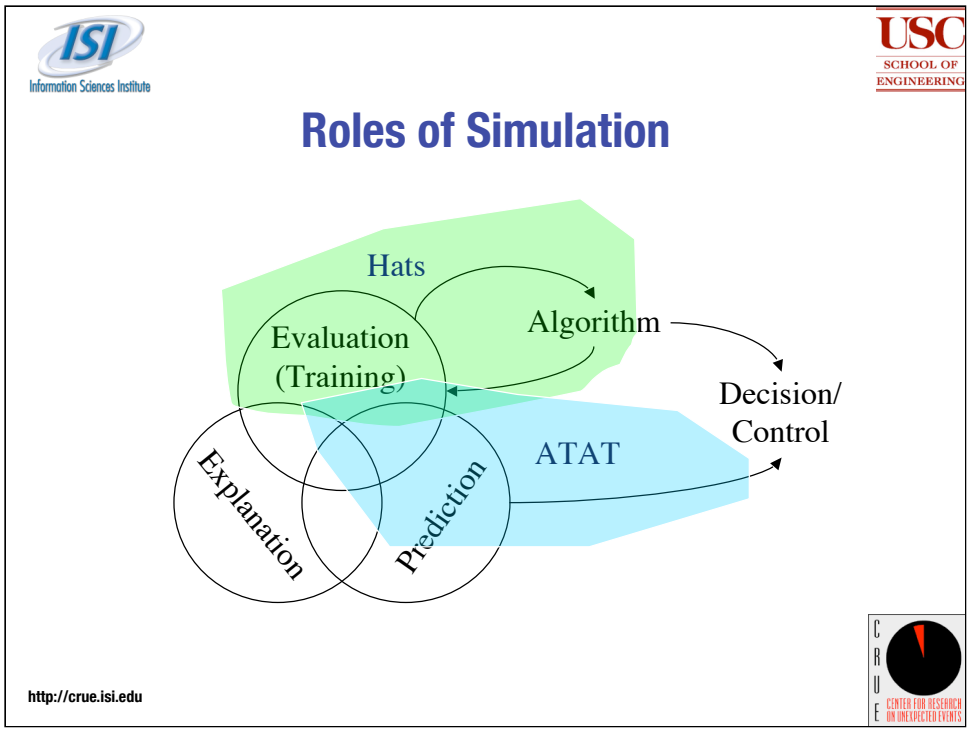

Evaluation: Using simulation as a virtual world in which you know ground truth

and can evaluate technology intended to uncover that truth

Explanation: A model that tells us why something happened - identifies laws

Prediction: Helps determine what will happen

Explanation ≠ Prediction!

Evaluation is how we have used Hats

ATAT is aimed at prediction

The Hats Simulator

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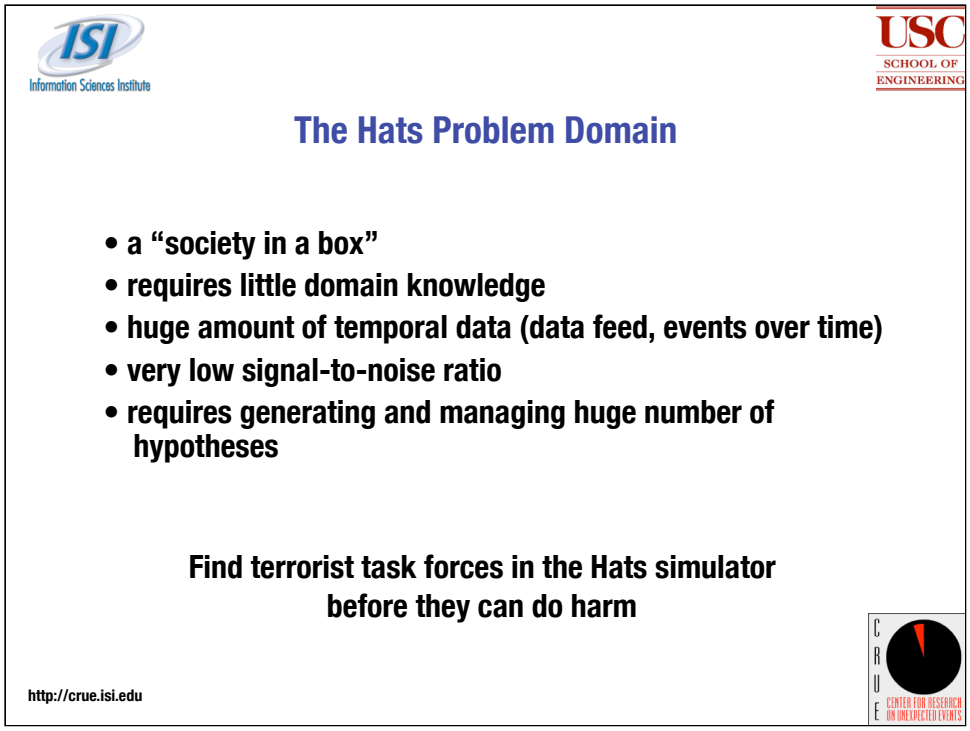
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The Hats Problem Domain
• a "society in a box"
• requires little domain knowledge
• huge amount of temporal data (data feed, events over time)
• very low signal-to-noise ratio
• requires generating and managing huge number of hypotheses
Find terrorist task forces in the Hats simulator before they can do harm
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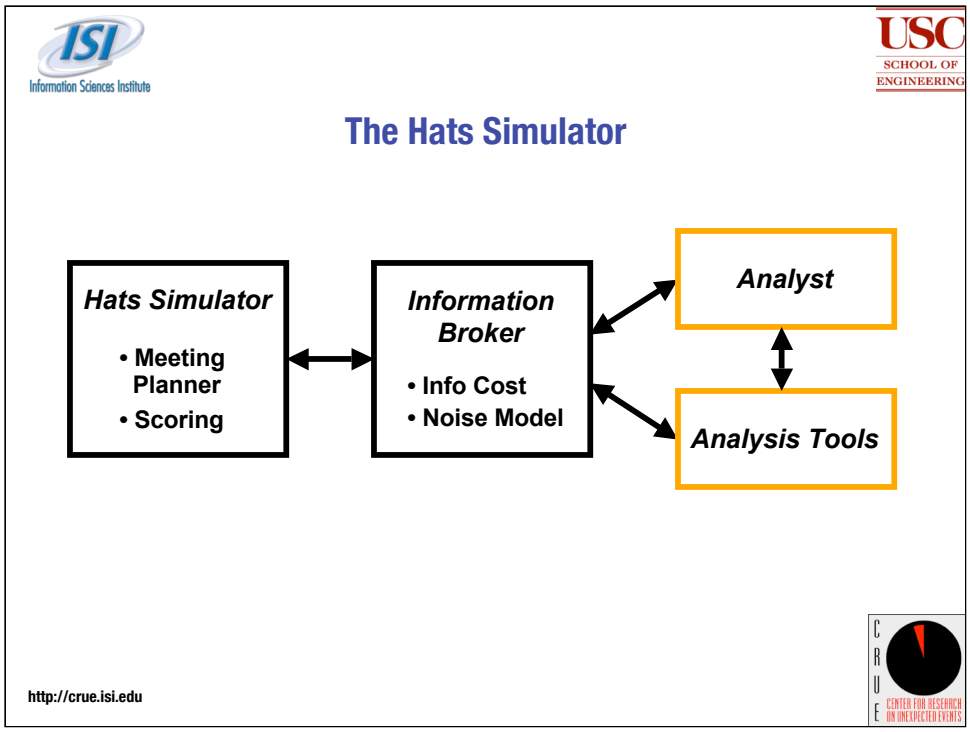
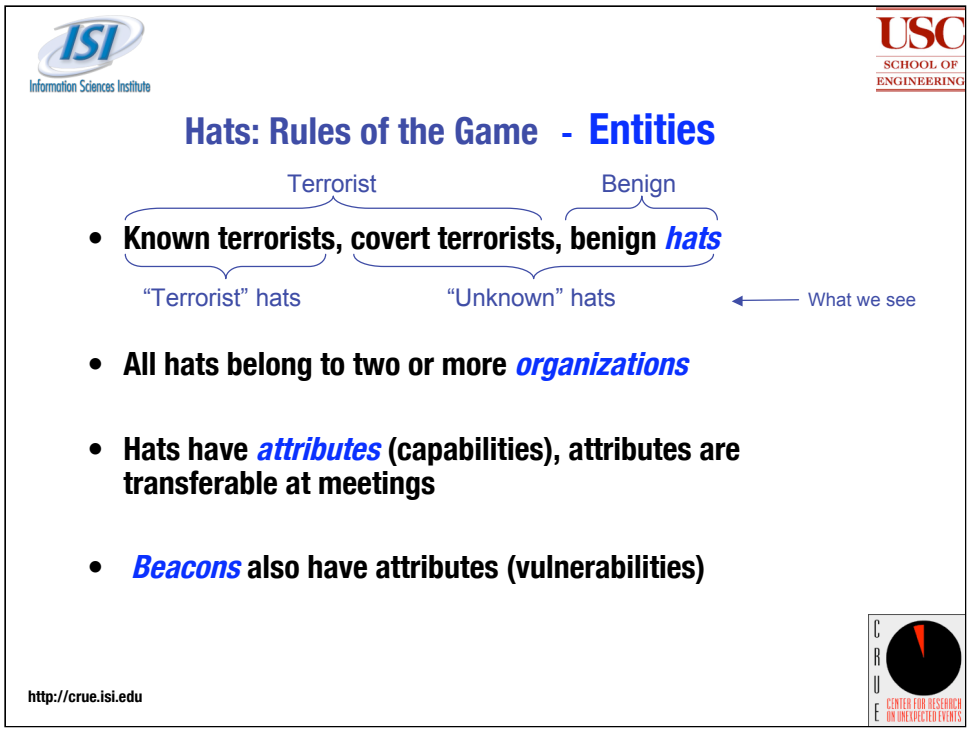
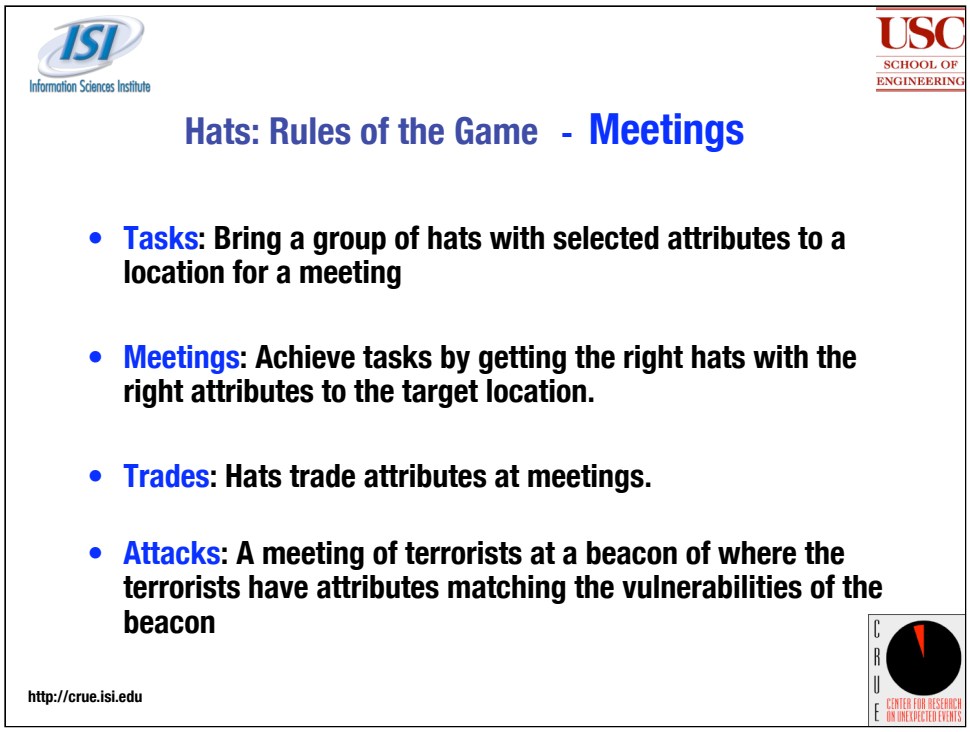


The Hats architecture



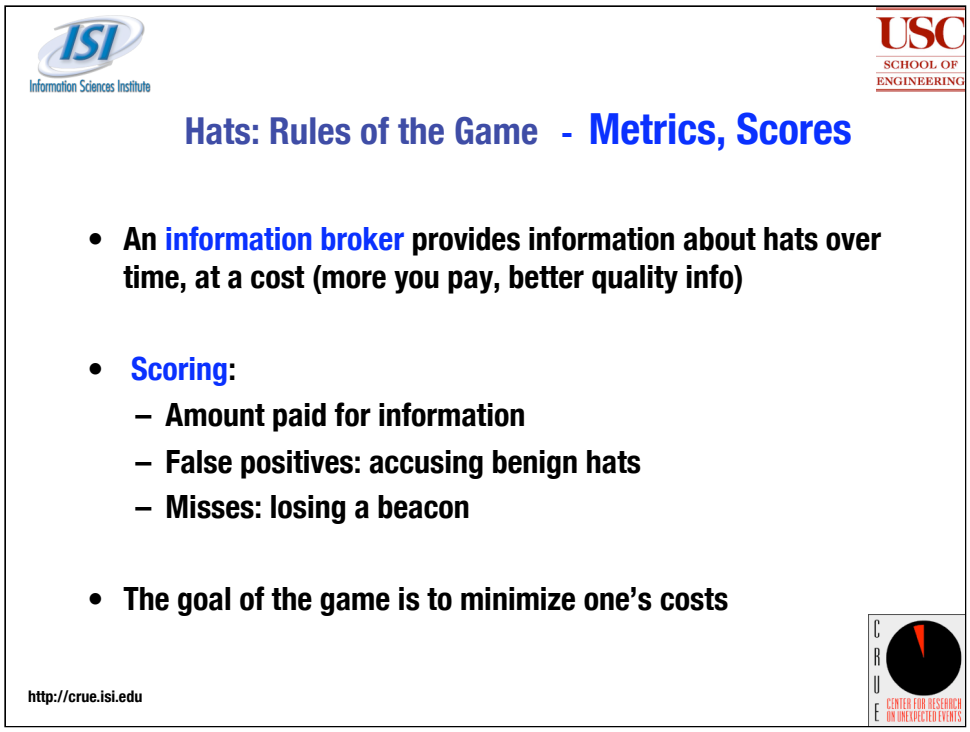
Very simple domain ontology

Modeling organization membership: a kind of mixture model



Model as task-driven (planned) behavior because we are interested in identifying INTENTION

Intention represents motivation and intended outcome.



Cost: the RESOURCE MANAGEMENT problem associated with information gathering and QUALITY

Player Actions

- **Pay** for information
- **Arrest** Hats
  - Successful if
    - (a) hat is a terrorist
    - (b) hat is currently part of terrorist task force
  - Else, *false arrest*
- Raise beacon **Alert Level**

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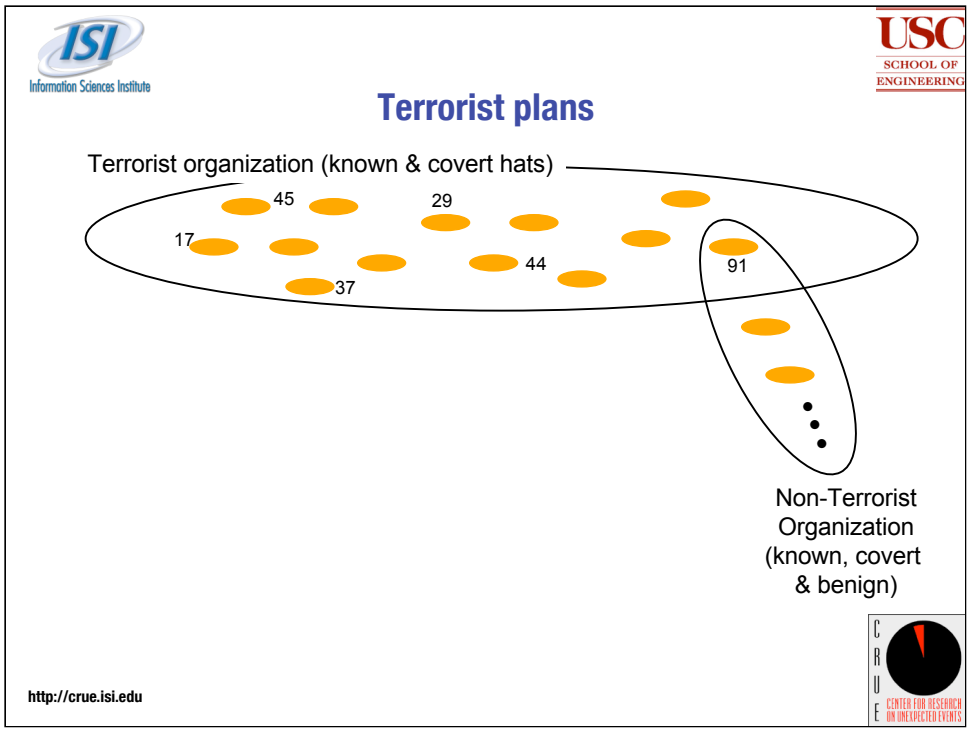
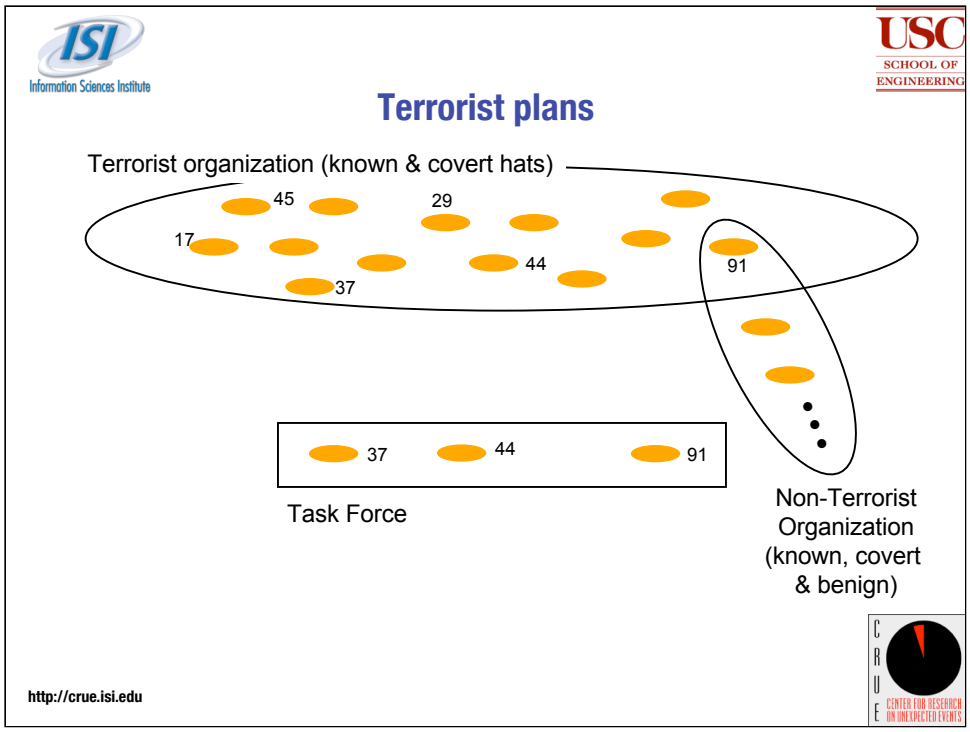


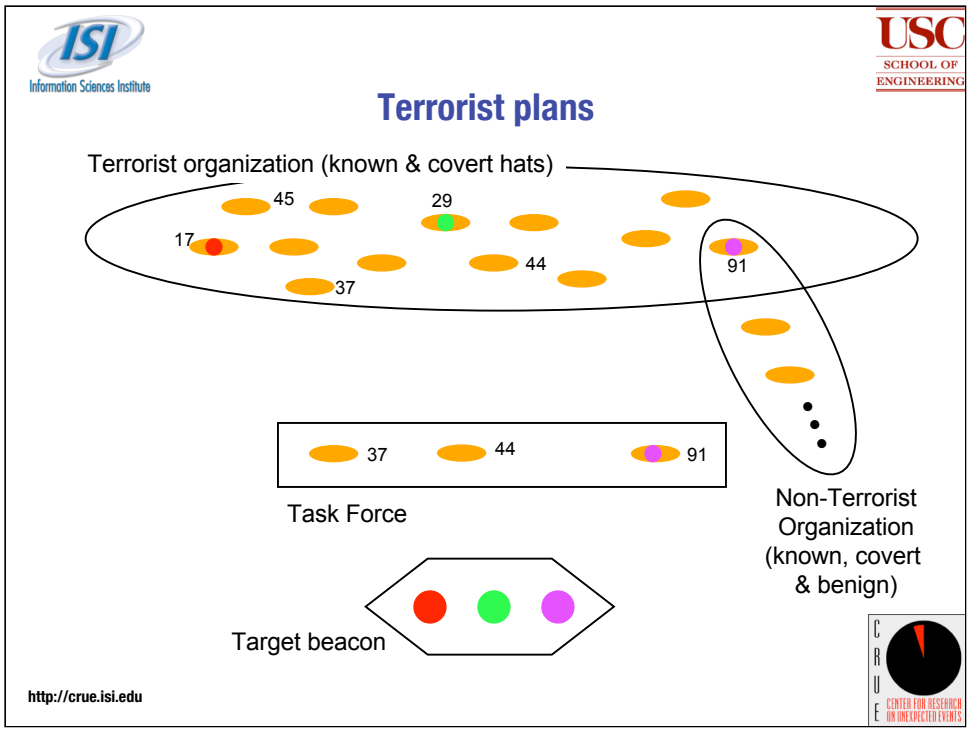
A quick walk-through of planner behavior

Schematic depiction of two organizations
NOTE: size of “ovals” does not indicate relative sizes of organizations

Hats may be members of multiple organizations (organizations overlap)

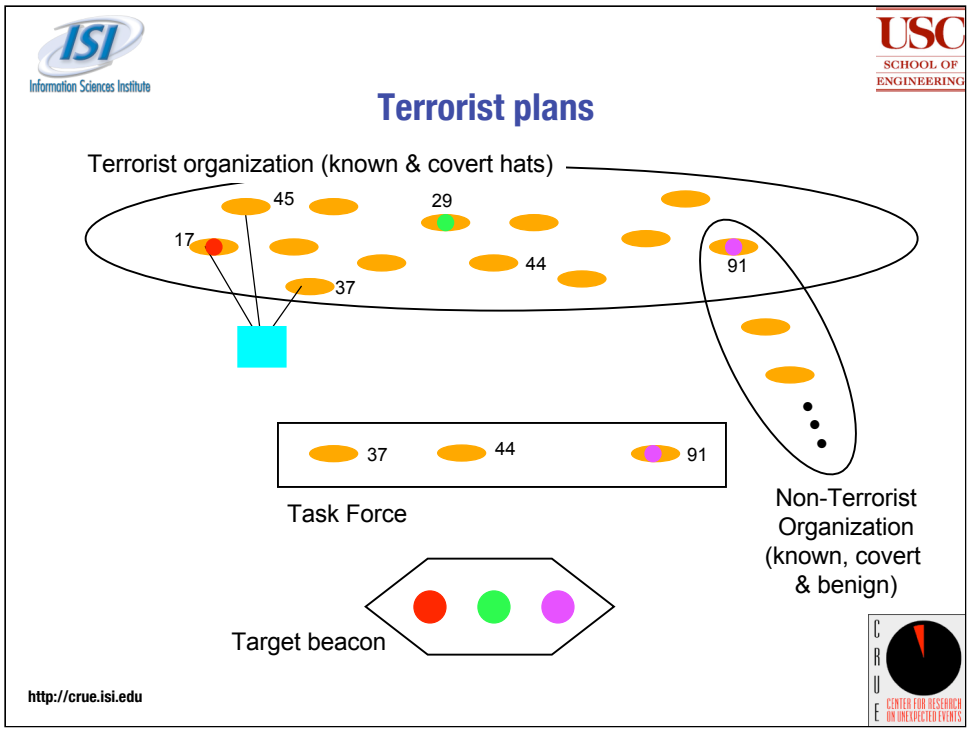


Planner selects task force out of available hats

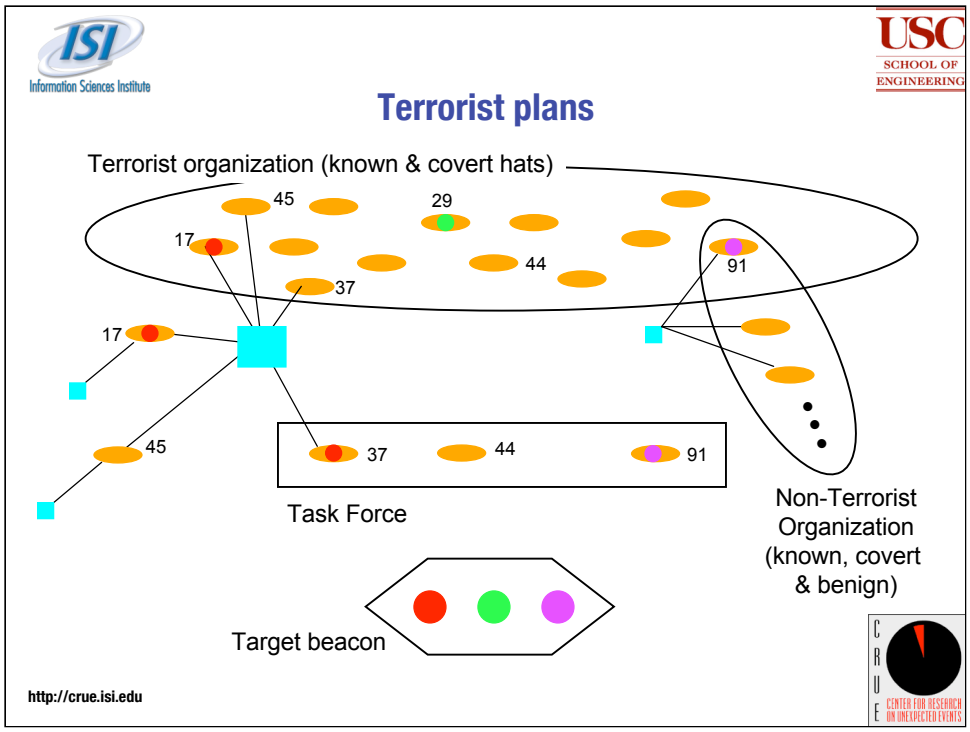


Planner selects target beacon

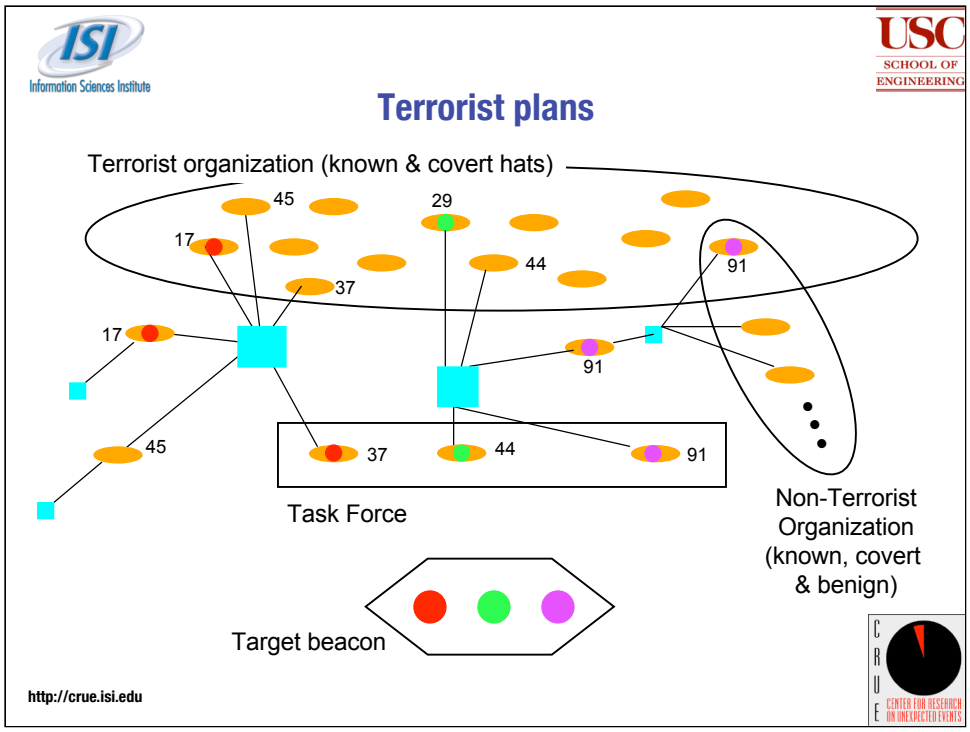
Capabilities must match beacon vulnerabilities; task force may not already carry required capabilities



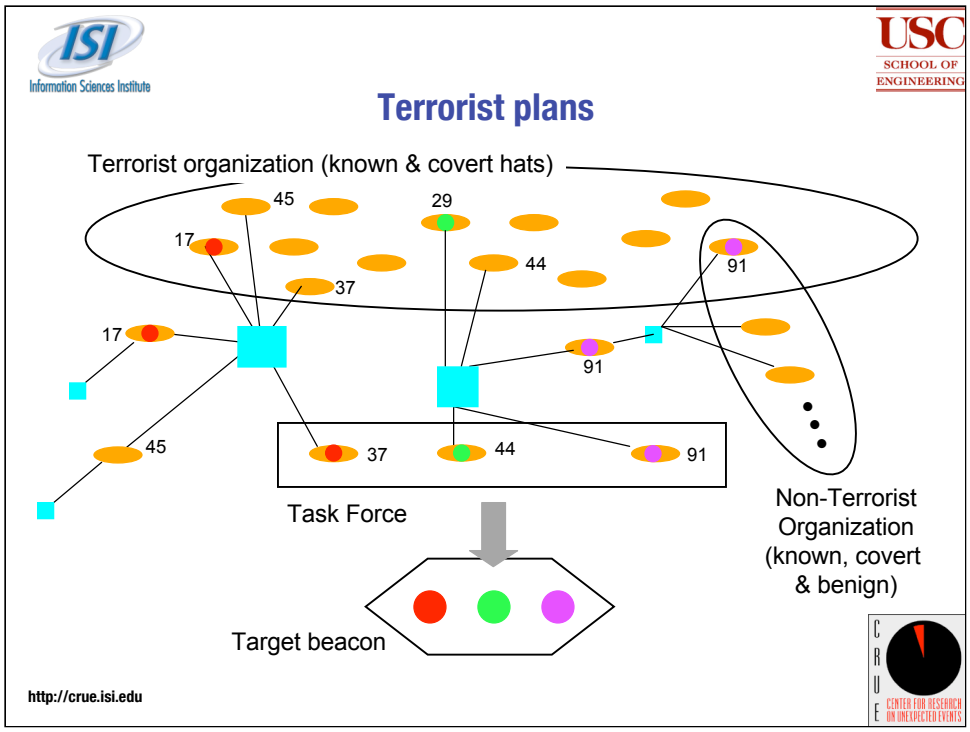
Planner plans series of meetings between hats



Capabilities are traded in meetings



Eventually task force hats have all required capabilities



Terrorist task force converges on beacon and attacks

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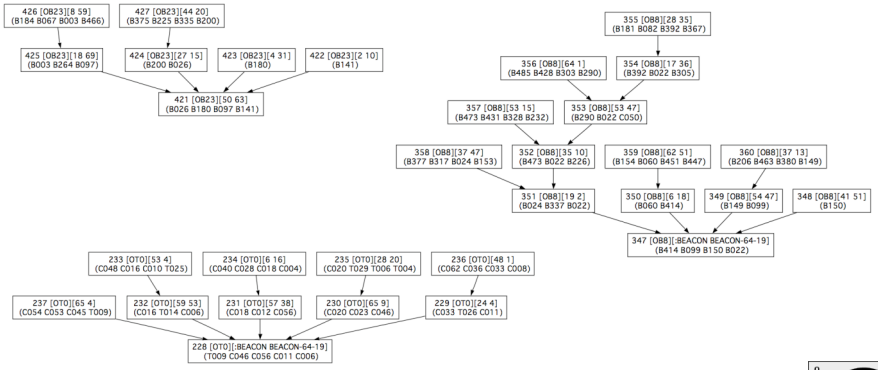
Example Meeting Trees (Planned Tasks)



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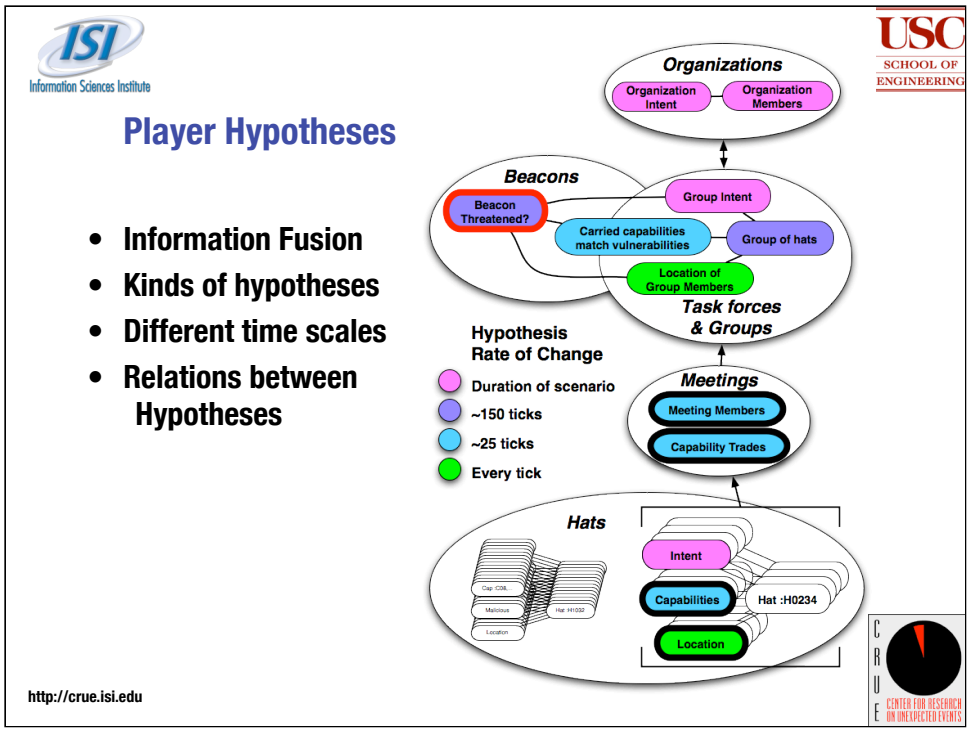
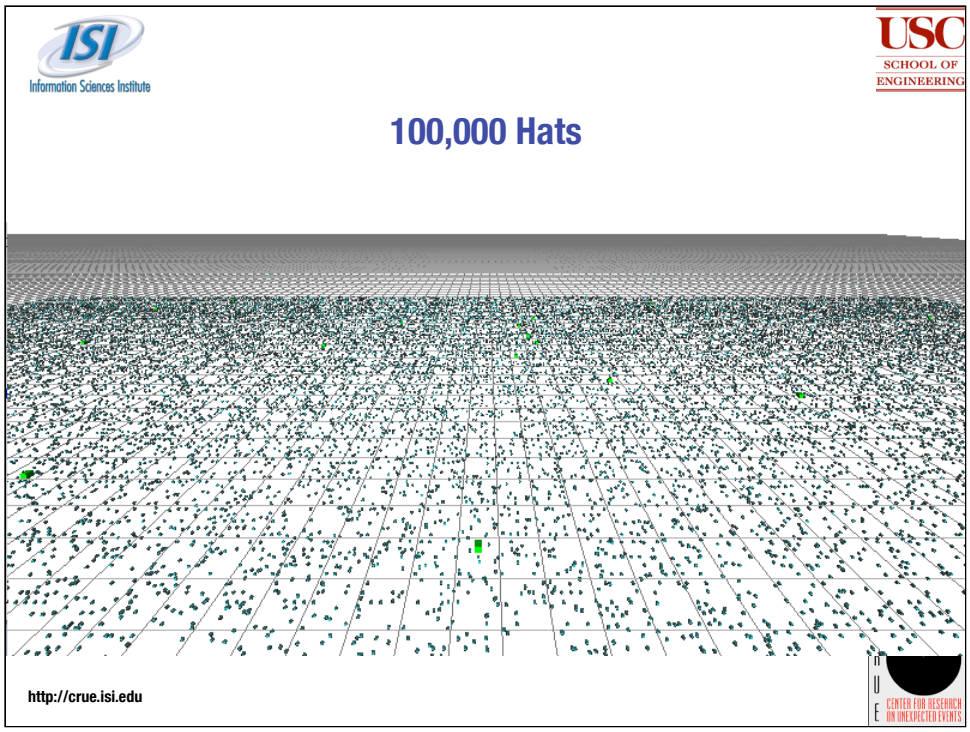


Kinds of hypotheses analyst must keep track of.

Bold black ovals represent information we can directly query (from the information broker)

The bold red Beacon-Threatened? oval represents the hypothesis we are generally most interested in



Snapshot of 100,000 hats

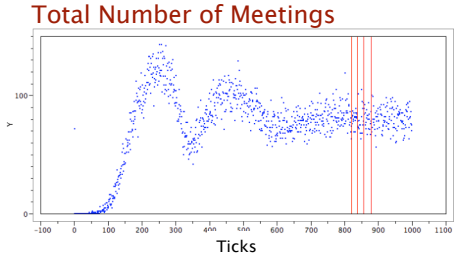
The purpose of this slide is to emphasize the large quantity of available data: all of these entities updating at each tick

Green boxes are beacons.

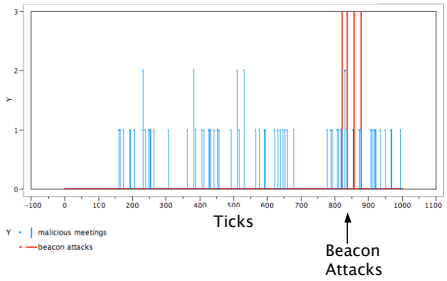
Clearly can't be solved by simple visual inspection.

Large Datasets

Total Number of Meetings



Number of Terrorist Meetings



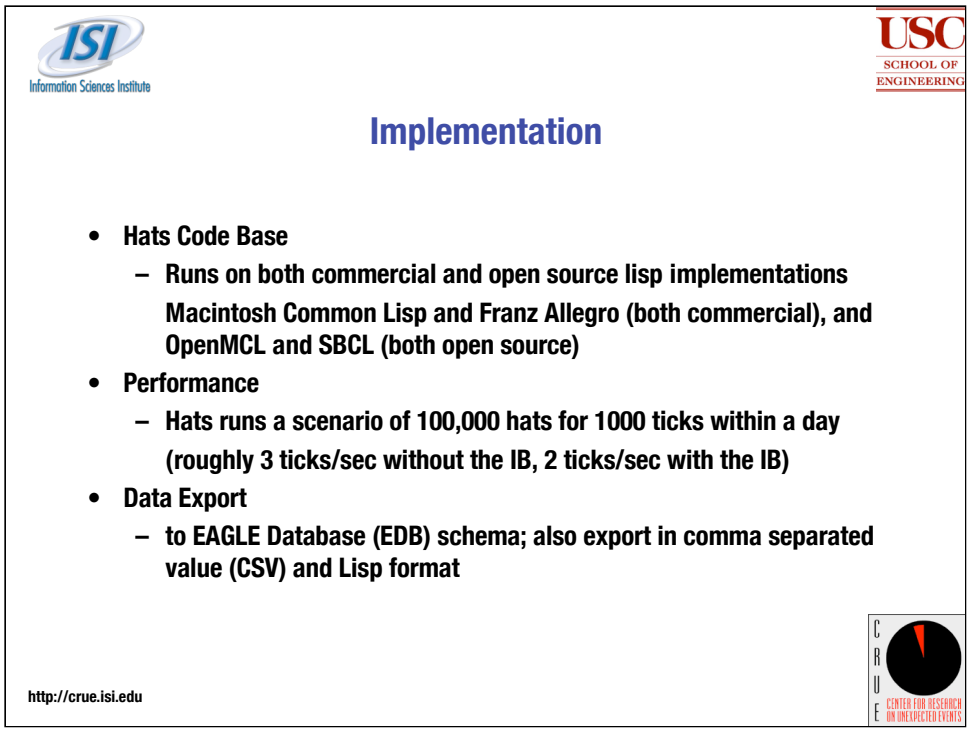
Example Simulation Stats:

100,000 Hats, 1000 Ticks

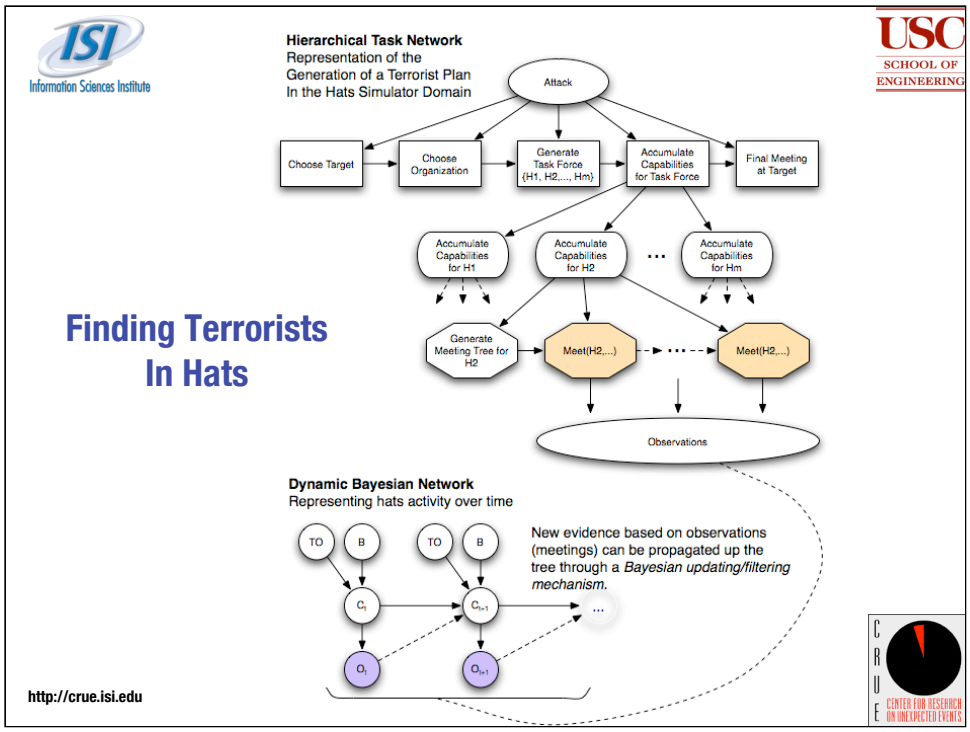
Population: 100,022 benign
216 covert terrorists
30 known terrorists
= 100,268 total
4000 Organizations
1000 ticks: 00d:10h:27m:06s:624ms (40 seconds per tick)
100K population: 00d:00h:03m:17s:423ms
74,060 meetings
Meeting Graph: **100,268 vertices and 7,312,974 edges**

500,000 Hats, 500 Ticks

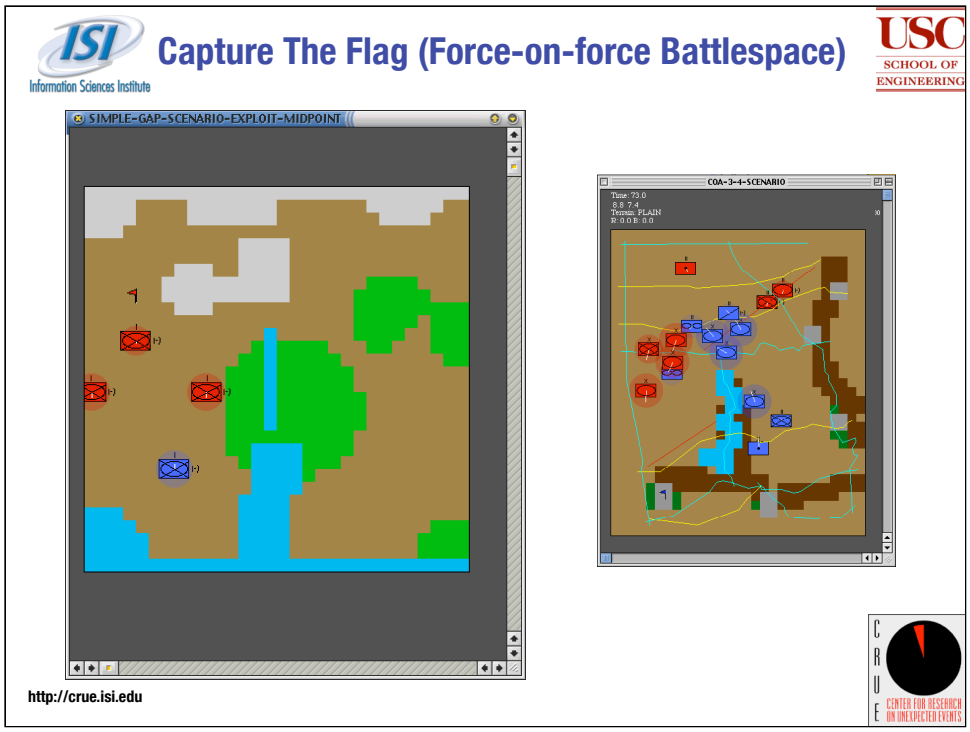
Population: 500,013 benign
204 covert terrorists
30 known terrorists
= 500,247 total
20,000 Organizations
500 ticks: 02d:13h:21m:08s:665ms (7.5 minutes per tick)
500K population: 00d:00h:26m:00s:196ms
168,666 meetings
Meeting Graph: **500,247 vertices and 27,997,531 edges**



Summary of Implementation and performance



Approach we're exploring for tracking threats in Hats.

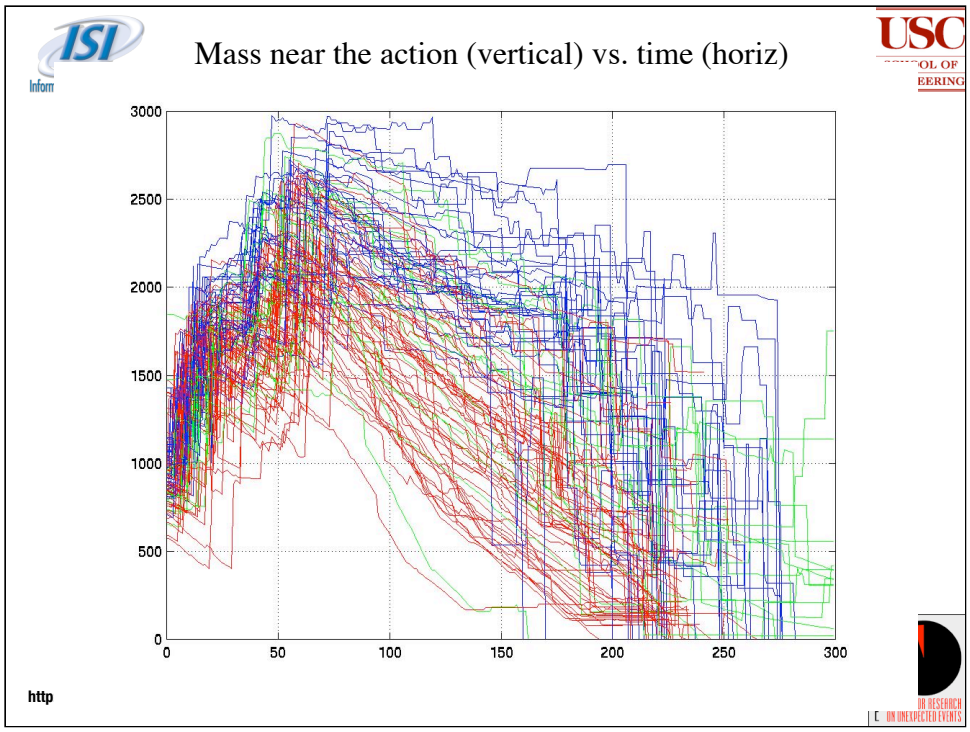


Prior work on Capture the Flag war-game simulator:

http://www-eksl.cs.umass.edu/research/ctf/

Simulation permits Monte Carlo simulation runs, re-running the simulation while varying the initial conditions.

This uncovers the likelihood of possible ways the scenario might unfold (depends on variables measured)



This slides shows and example of what we can learn from Monte Carlo simulation trials. The trajectories represent MNTA ("mass near the action" -- how much of blue-force's mass is near the "center" of the action) for 100 Monte Carlo trials (for a scenario like the one picture on the left in the previous slide). Trajectories are colored red if Red forces captured the flag in the south-west corner, blue if the Red forces were disabled by Blue, and green if time expired. MNTA is shown on the vertical axis, time on the horizontal axis. Clearly, Blue won most of the trials. In general, trials begin with Blue MNTA increasing to a maximum value at around time 100, then dropping off as Red and Blue units are destroyed or disabled.

Asymmetric Threat Assessment Tool (ATAT)

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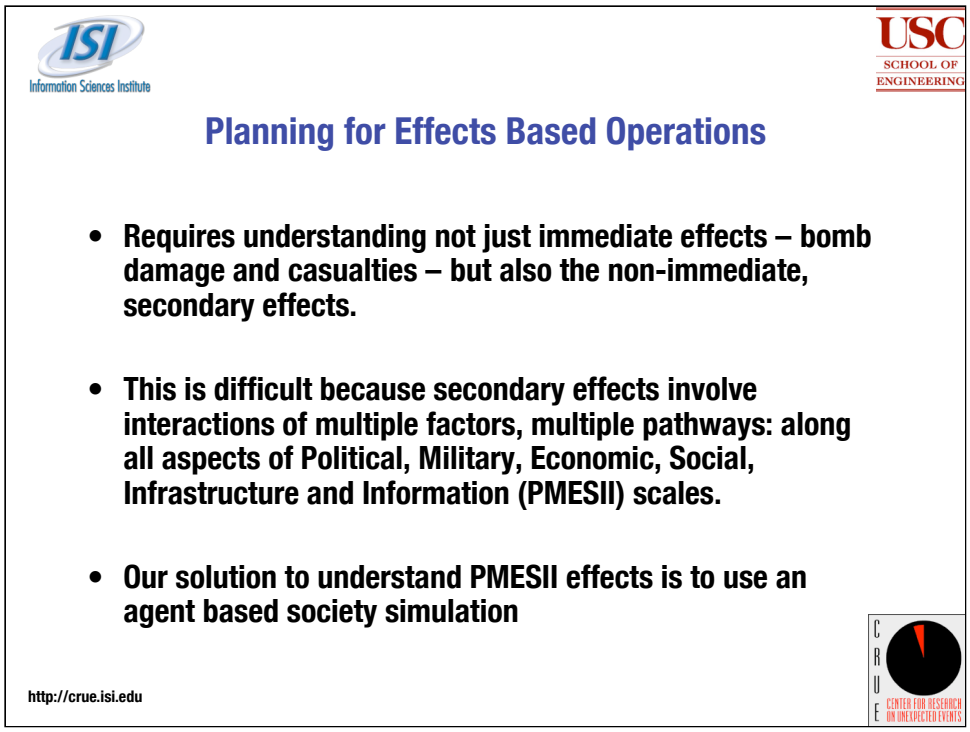
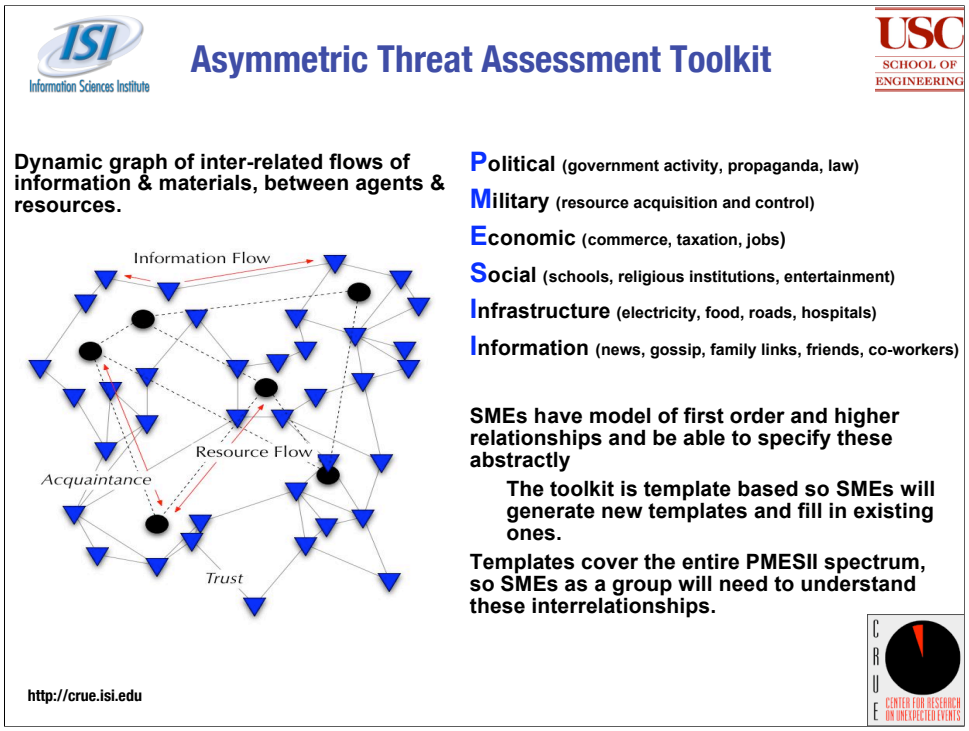


Explicitly model interacting casual chains including both physical and psychological levels.



The networks overlap and produce first and second order effects

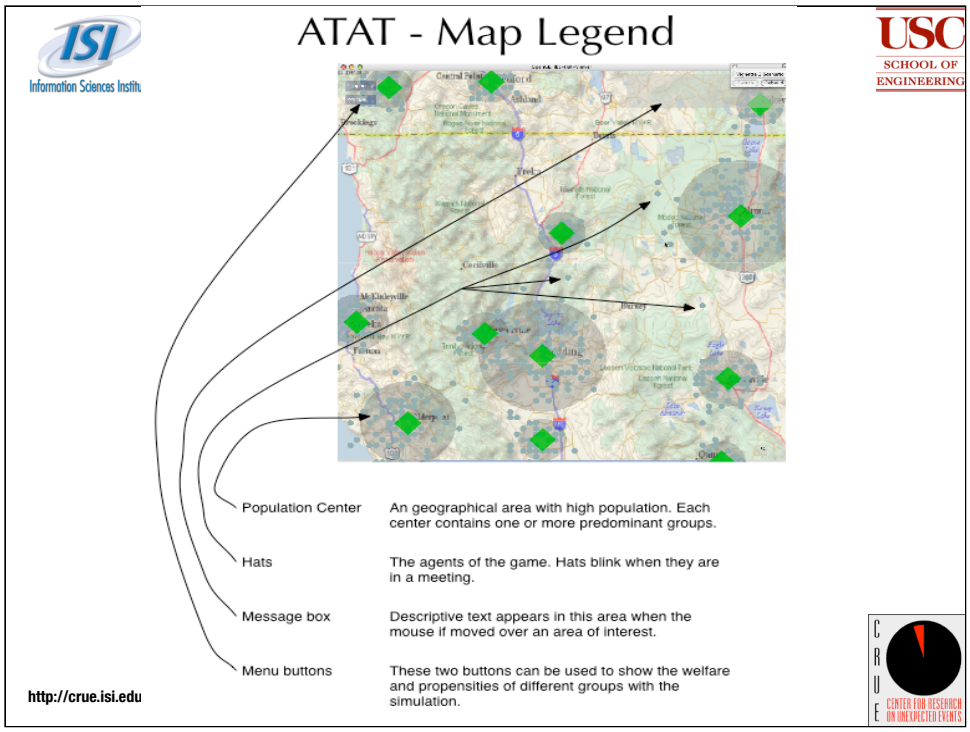
The networks are also dynamic:

resources are created and destroyed;

agents make and break links between resources and between other agents;

information alters the behavior and attributes of the agents.

The response of an agent embedded in such a network will depend on their initial inclinations, the inclinations of their peers, their social role and so on. Understanding such an agent and how an action will alter its behavior is far from trivial



2-dimensional world with population centers, abstract factories and agents

Population centers and factories are connected by links over which materials move.

Each agent has a home in a population center.

Factories consume and produce materials and resources that move over links.

Agents work at factories.

(Materials and supply are not explicitly modeled in the ATAT prototype.)

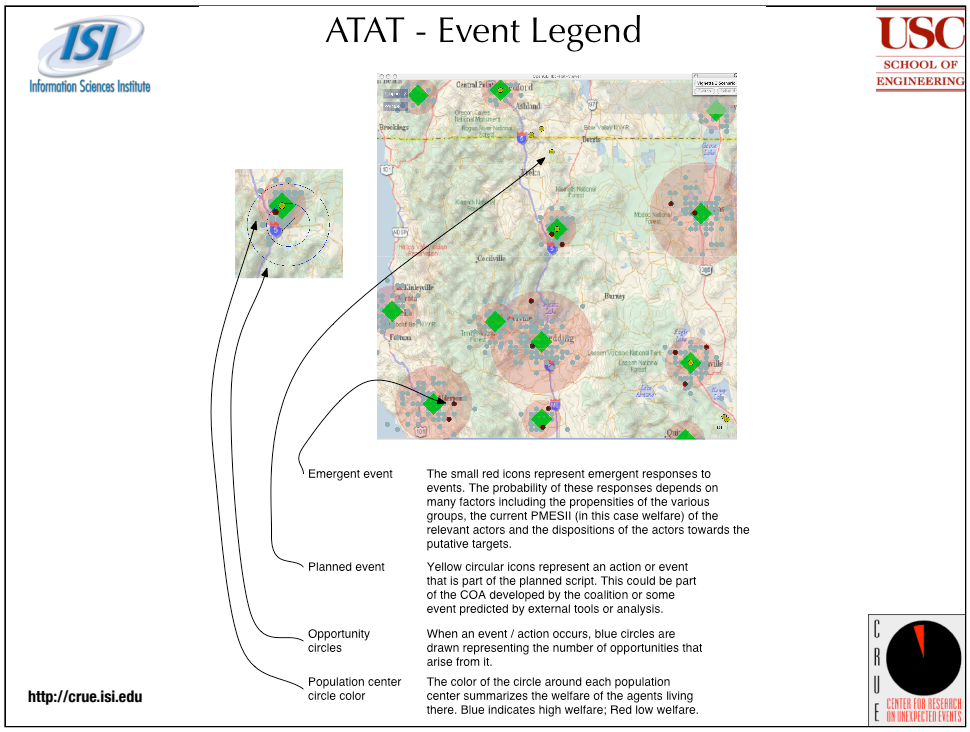
Agents may also belong to numerous groups, of which there are many types:

social, family, ethnic, religious and so on.

Agents have dispositions towards other agents based on their group memberships.

Agents also have propensities towards action and attributes describing their state (happiness, welfare, and so on).

Dispositions, propensities and attribute values all change as the simulator runs.



During a simulation run, the player takes actions such as

degrading a factory,

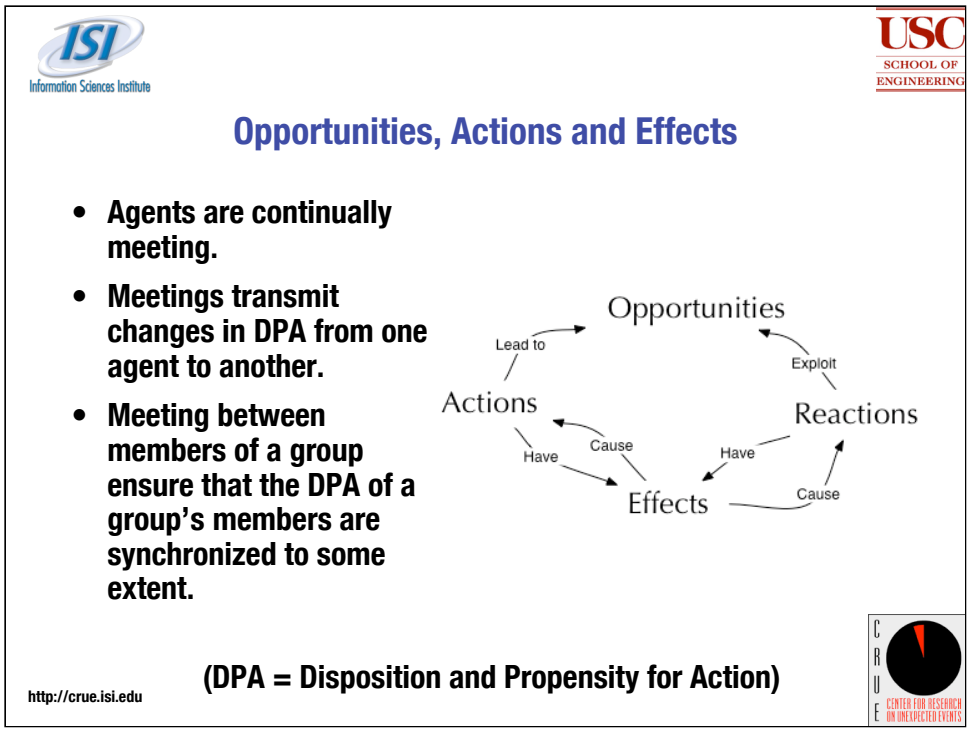
attacking a militia group, or

building a new population center.

These actions produce events in the simulation.

Agents who directly experience events have strong reactions to them.

Agents who experience events indirectly have weaker reactions.



An agent's reaction depends on many factors:

the kind of event, the perpetrator, the agent's disposition towards the perpetrator and so forth.

All reactions perturb an agent's dispositions, propensities and attributes (DPA).

Transmission depends on

the two agent's disposition towards one another and

on other agent attributes like welfare, leadership, and initiative.

Events also produce opportunities:

e.g., a troop movement event produces the opportunity to attack the troops as they move.

Opportunities provide groups with the *chance* to act.

Groups will act if their propensities towards action are high enough.

A group's action may produce another event that will then produce more opportunities and possibly more reactions.

Action / opportunity / reaction cycle

Agents witness events directly or hear about them indirectly

Witnessing events leads to changes in agent DPA.

ATAT - Example Use Scenario

- Analyst abstracts and describes scenario:
  - Population sub-groups, allegiances, resource needs and goals.
  - Resource facilities and linkages
  - Military capabilities and limitations
- Simulator generates networks based on these parameters and starts simulation
- Simulator tracks changes in population moods, resource fluctuations, and information flow;
  - Analyst takes actions to guide flows towards desired PMESII effects
    - E.g., reducing meeting rates, arresting terrorists, creating new resources
  - Due to information failures and terrorist activity, these actions may fail and the situation must be steered dynamically

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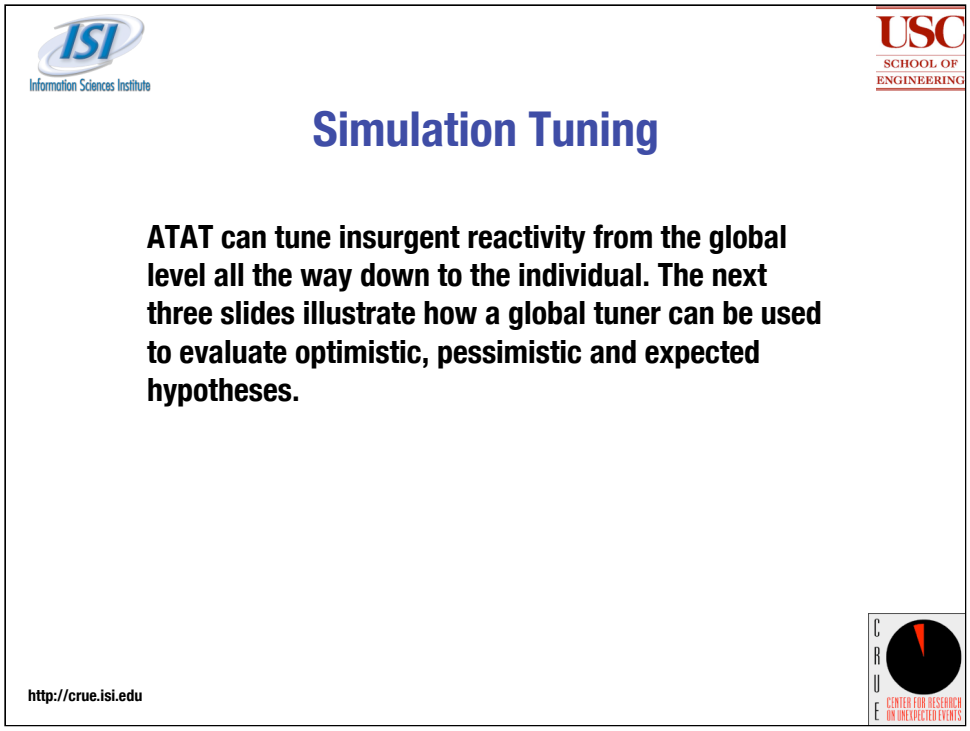
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Simulation Tuning
ATAT can tune insurgent reactivity from the global level all the way down to the individual. The next three slides illustrate how a global tuner can be used to evaluate optimistic, pessimistic and expected hypotheses.
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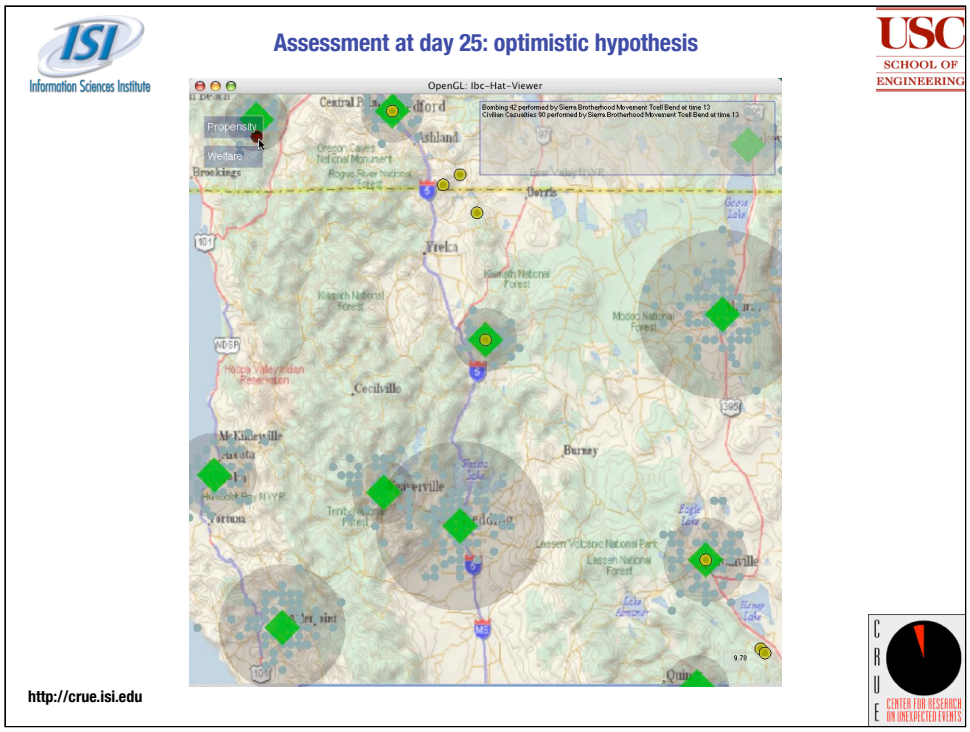


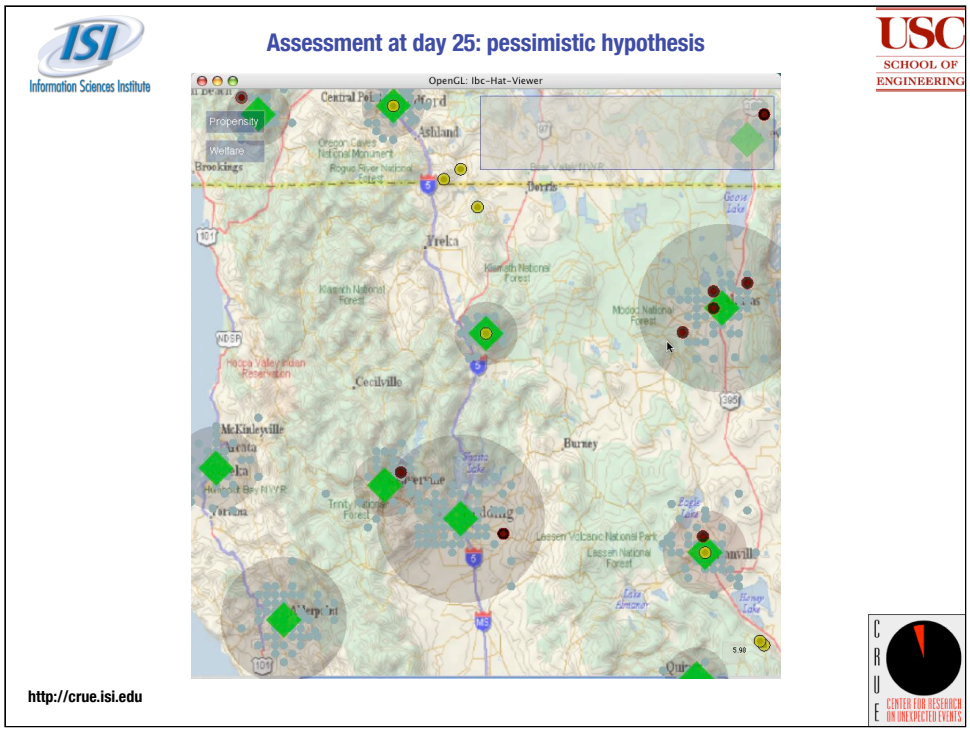
Insurgent and relevant events have been scripted into the ATAT and the system has been simulated to day 25.

Yellow circles represent the events described in the InSums.

Red circles represent insurgent events created by our simulator. They show areas where agents with propensities for insurgent behaviors are known to act and have significant probabilities of doing so.

Of note on the initial assessment given the ATAT's initial models:

- insurgent behavior by CNM and SBM militias in Alturas
- terrorist behavior in Susanville
- increasing civilian unrest in Medford (indicated by the shaded red circle about Medford on the map)



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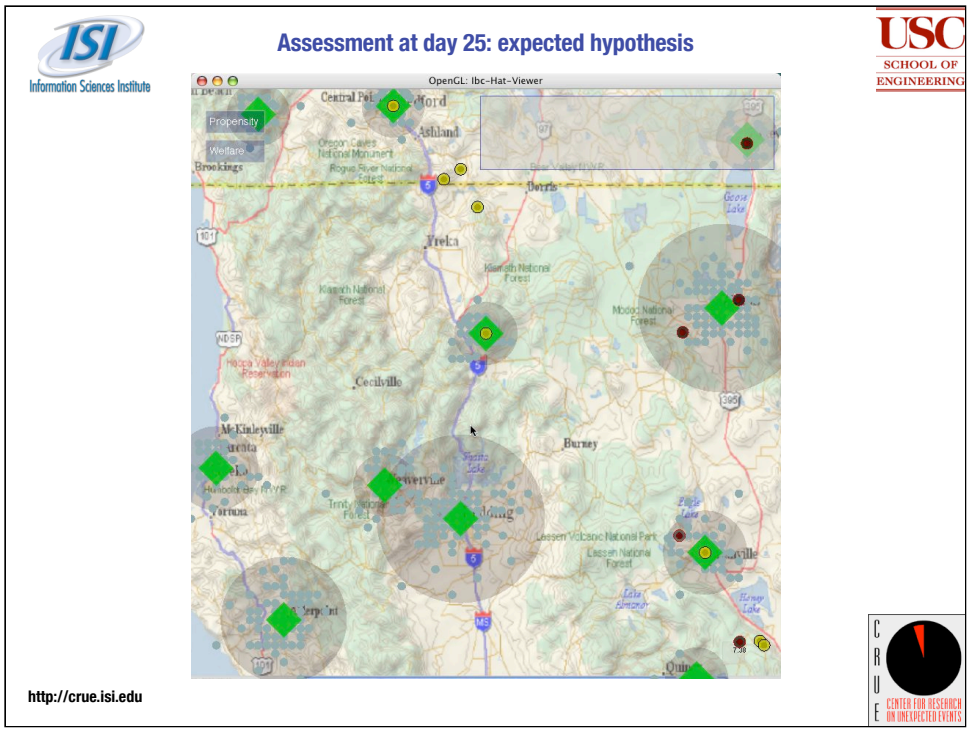

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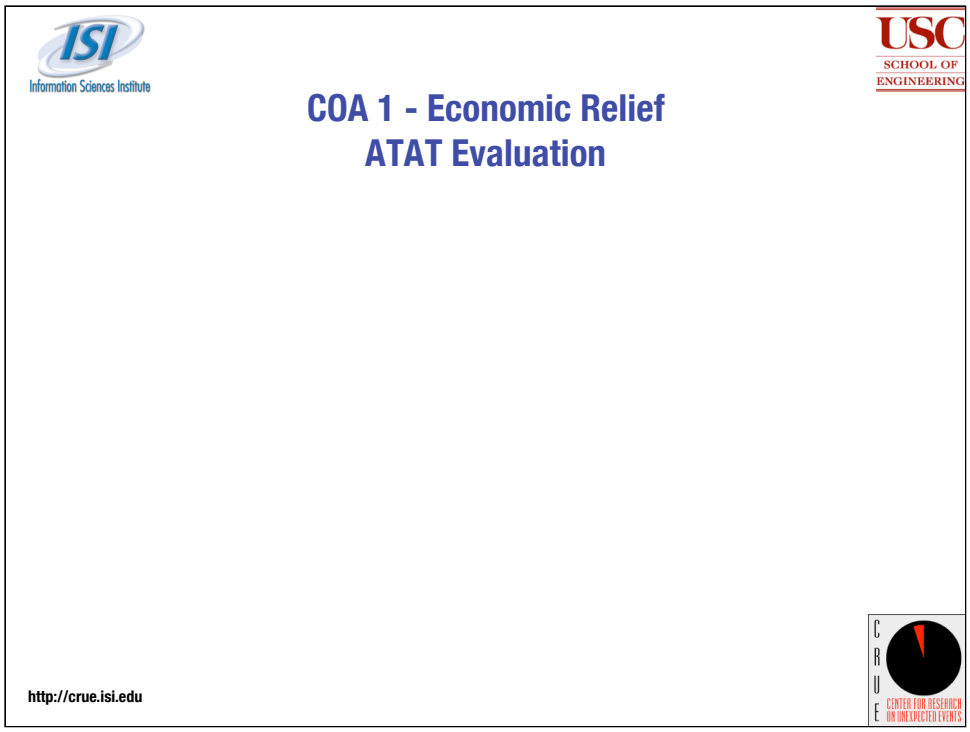
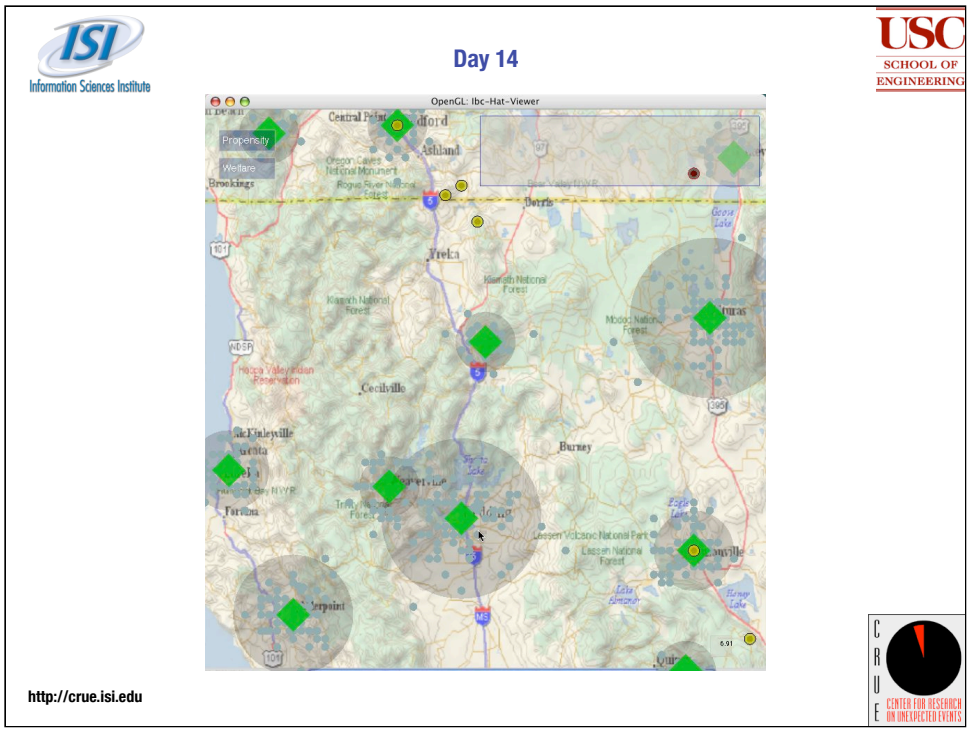
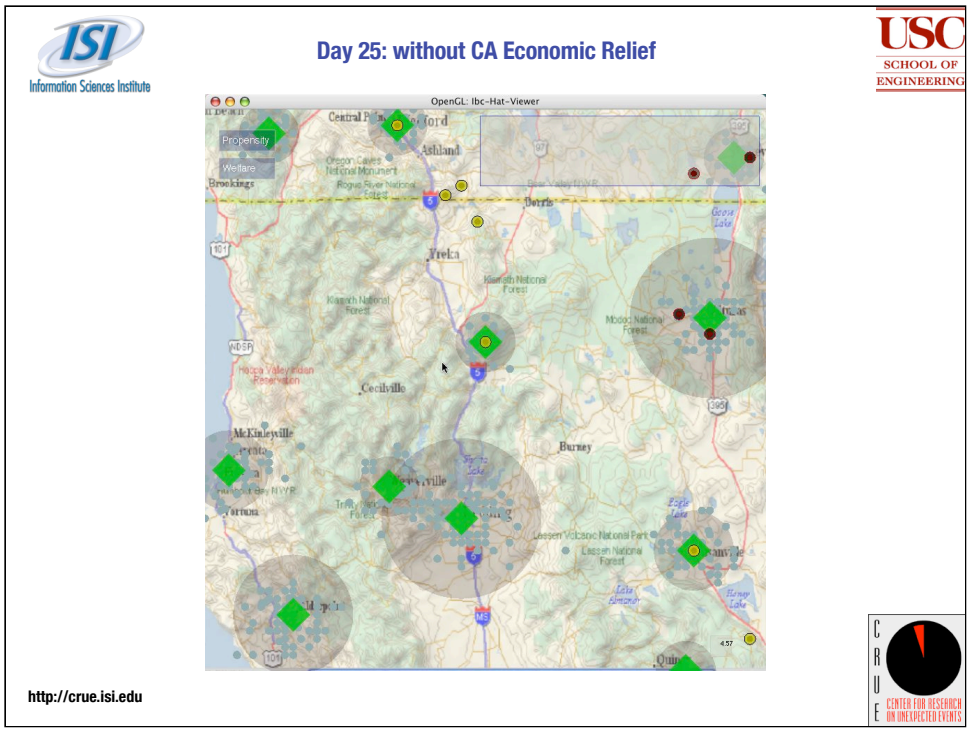


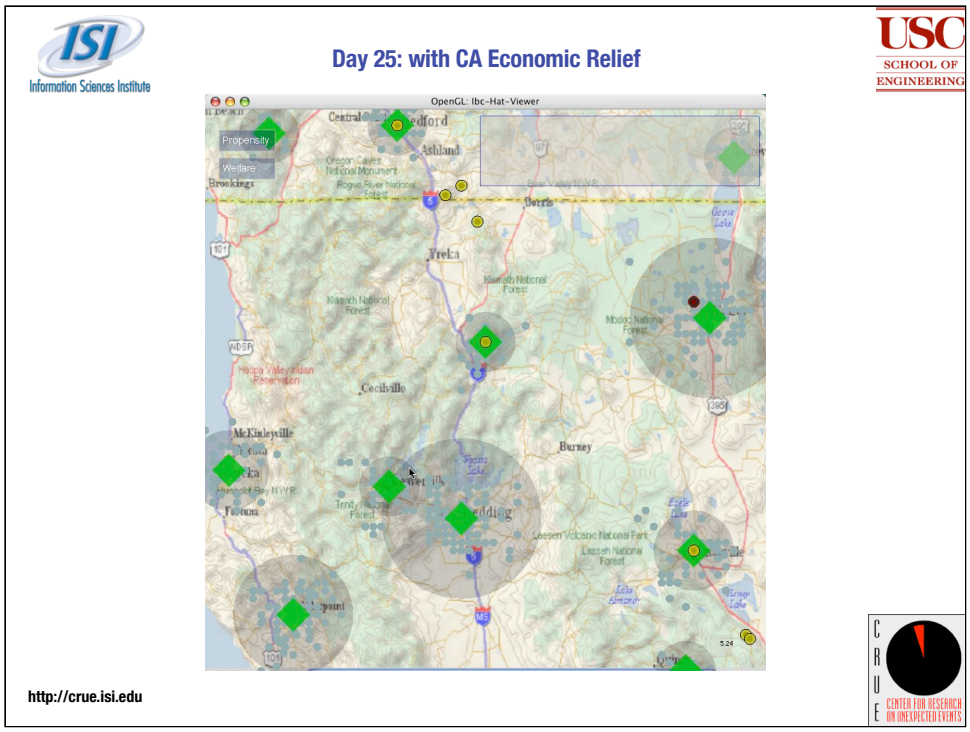
The next three slides demonstrate evaluation of a planned course of action (COA) involving simulated economic relief.



Initial state before COA commences



Worst case scenario (no economic package/humanitarian aid). Economic situation continues to deteriorate and insurgent activity is more widespread. More importantly, behaviors are less localized (to Alturas and Bend).



Assumption is that coalition offers economic/humanitarian relief to Californian civilian population improving overall welfare state. Incidence of insurgent behavior is mitigated somewhat in CA, though conditions along the OR border, and into OR, are relatively unchanged.

ATAT Summary

- The ATAT is a tool for modeling effects beyond bomb damage assessment (BDA) and body counts because it:
  - Provides an abstract model of malicious activity as a dynamic process where coalition and insurgent actions are interpreted subjectively by the agent population.
  - Enables "what-if" analysis of situation dependent actions and re-actions
  - Models the terrorist adversary as an enemy that can take direct and indirect actions.
- Aids in training for non-linear effects, unexpected consequences, and cross spectrum PMESII reasoning.

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