Mission Profiles and Evidential Reasoning for Estimating Information Relevancy in Multi-Agent Supervisory Control Applications

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Nathan Denny, Brett Walenz

(presented by Plamen Petrov, PhD)

21st Century Systems, Inc.

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Outline

- Introduction
- Background
- Architecture
- Missions Goal Congruence
- Belief Fusion Engine
- Conclusions and Future Work

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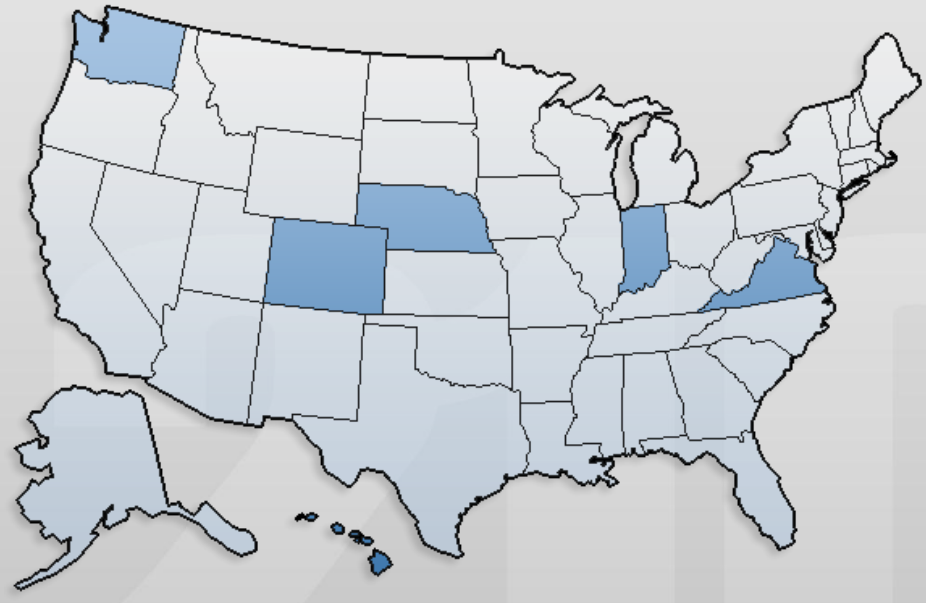

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Over a Decade of Success in Innovation

- 21CSI® specializes in data-driven decision support systems for time- & mission-critical uses
- Privately held
- Founded in 1996
- ~100 employees, 7 offices nationwide
- Patented software technology with extensive, ongoing internal R&D
- 100+ Small Business Innovative Research (SBIR) awards
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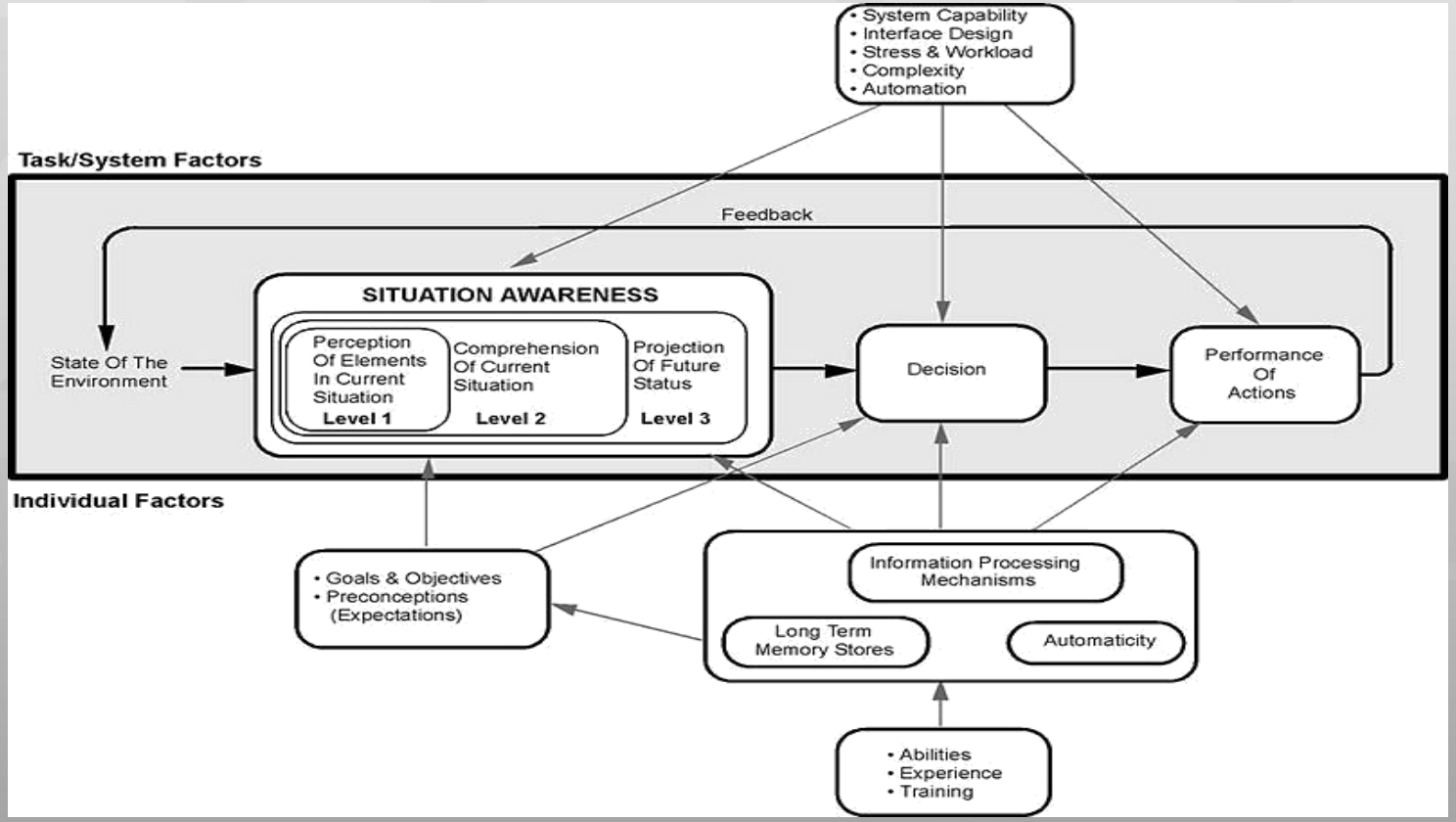
Introduction & Motivation

- Information overload → poor SA
- Needed: Mission-specific filtering
- Challenge prioritize/filter information congruent to mission goals
- Our approach: Multi-agent belief algebra combined with mission profiles & ontology

Background - SA

- Endsley's model
  - SA is a critical input in decision making



Background – Subj. Logic

- Subjective Logic is an opinion algebra
  - *opinion* $\omega^A(x)$ about proposition X by authority A
  - *belief* (b_x^A), *disbelief* (d_x^A), *uncertainty* (u_x^A), and relative *atomicity* (a_x^A)
  - *consensus* ($\oplus$) and *discount* ($\otimes$) operators

$$
\begin{aligned}
K &= u_x^A + u_x^B - u_x^A u_x^B \\
b_x^{A,B} &= \frac{b_x^A u_x^B + b_x^B u_x^A}{K} \\
d_x^{A,B} &= \frac{d_x^A u_x^B + d_x^B u_x^A}{K} \\
u_x^{A,B} &= \frac{u_x^A u_x^B}{K} \\
a_x^{A,B} &= \frac{a_x^A u_x^B + a_x^B u_x^A - (a_x^A + a_x^B) u_x^A u_x^B}{K - u_x^A u_x^B}
\end{aligned}
$$

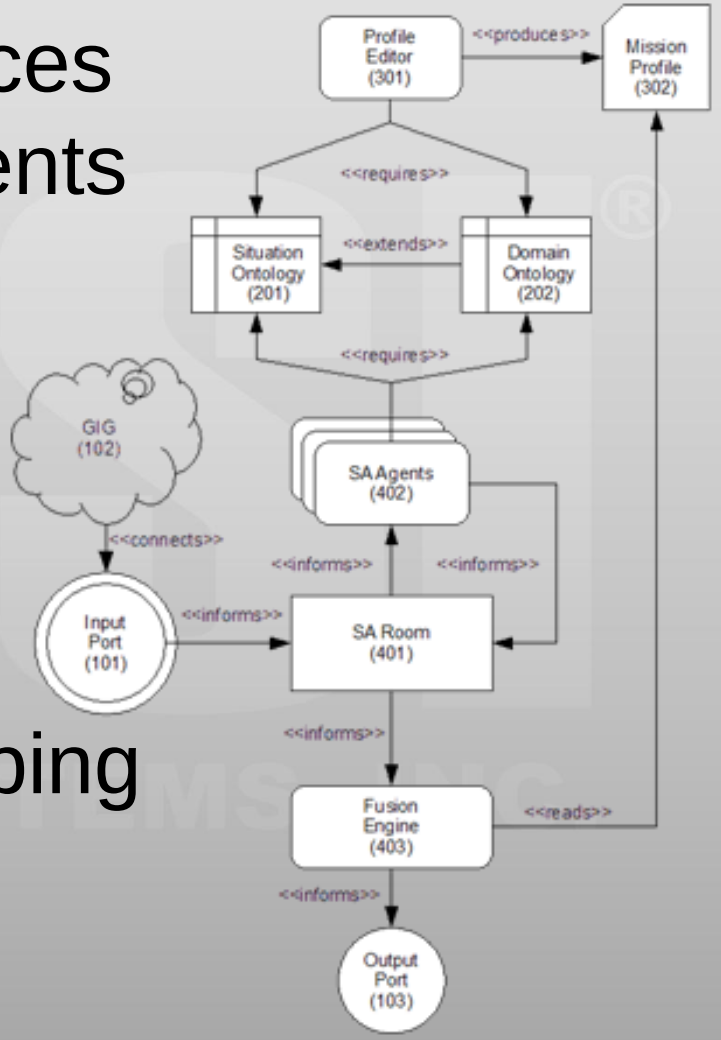
$$
\begin{aligned}
b_x^{A,B} &= b_B^A b_x^B \\
d_x^{A,B} &= b_B^A d_x^B \\
u_x^{A,B} &= d_B^A + u_B^A + b_B^A u_x^B \\
a_x^{A,B} &= a_x^B
\end{aligned}
$$

MAS and Subjective Logic

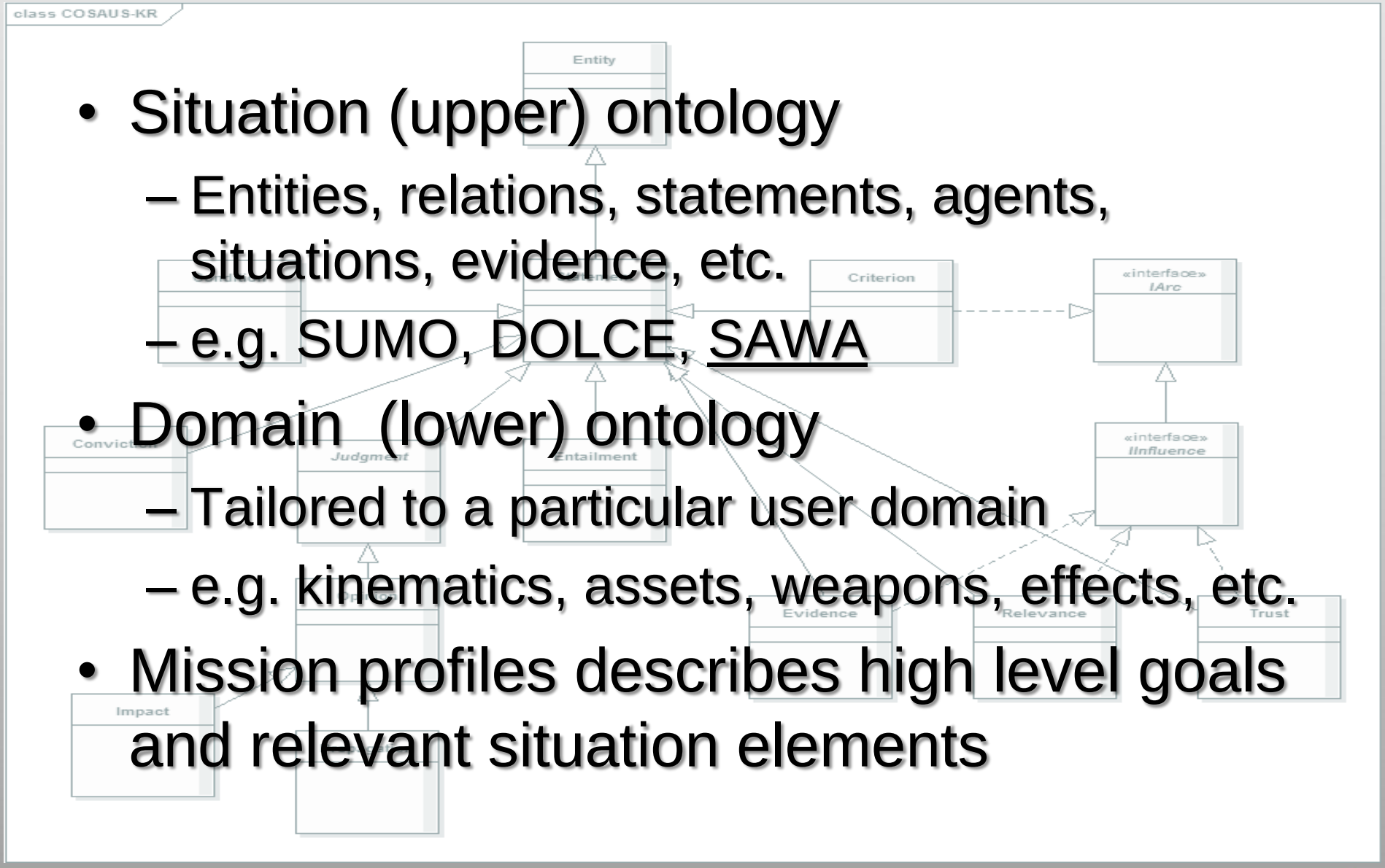
- Agents and agency
  - Perceive, Reason, Act (autonomously)
  - Small, situated, social (interact with others)
- Multi-Agent Systems
  - Distributed cooperating collections of agents
  - Interaction & collaboration can occur through opinion sharing, using Subjective Logic

Architecture - Overview

- Input: emulated GIG services through JC3IEDM statements
- Mission Profile & Editor
- SA Room and Agents
- Fusion Engine
  - Reasoning
- Output: statements describing the filtered situation



Ontology & Mission Profiles

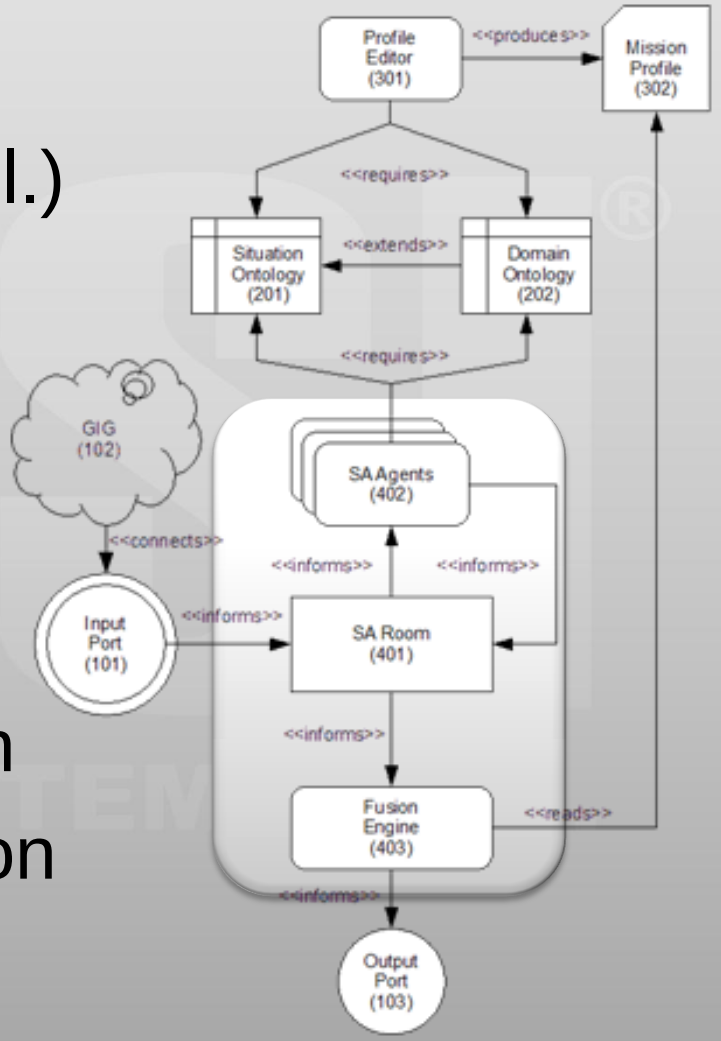


- Situation (upper) ontology
  - Entities, relations, statements, agents, situations, evidence, etc.
  - e.g. SUMO, DOLCE, SAWA
- Domain (lower) ontology
  - Tailored to a particular user domain
  - e.g. kinematics, assets, weapons, effects, etc.
- Mission profiles describes high level goals and relevant situation elements

Reasoning Components

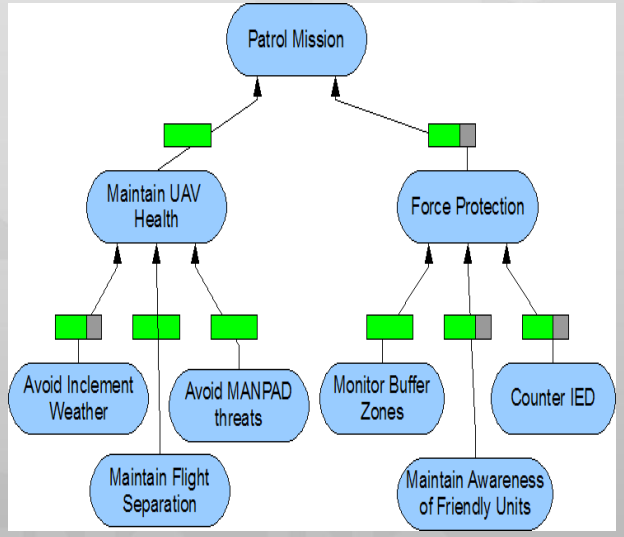
- Blackboard architecture
  - Situation Room (XMPP impl.)
- SA Agents → Reasoning
  - Entailments
  - Belief

  } Opinions
- Fusions Engine
  - Performs opinion unification
  - Assigns influence to situation elements



Mission Profiles

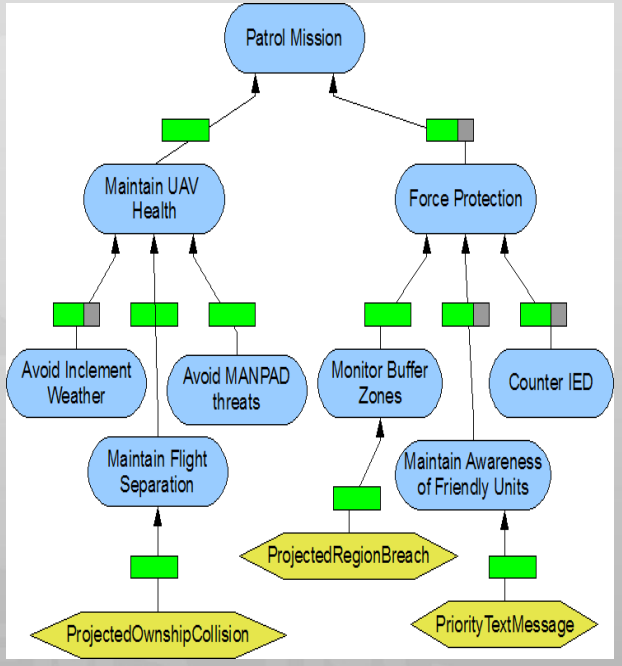
- A mission profile is a graph that captures commander's intent and mission goals
  - Level 1 – Mission Goals
    - Recursive goal decomposition
    - Relevance indicated by weights
    - Edited by the operator
    - Example: UAV Mission →



  - Level 2 – Conditions, Relations, Relevance
  - Level 3 – Trust and Relevance in Agents

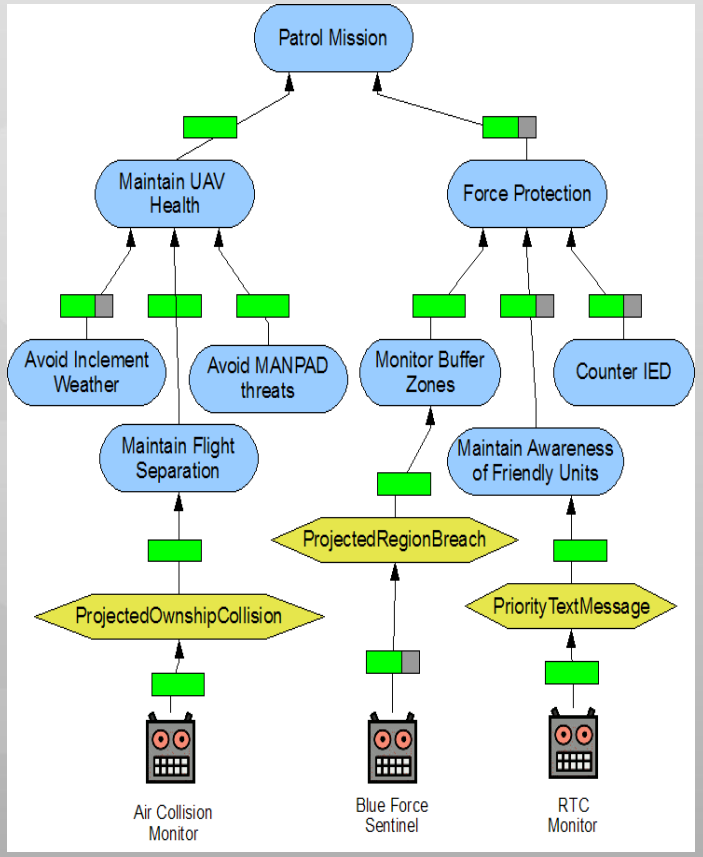
Mission and the Situation

- Level 2: conditions & relevance of situation elements
  - Link mission elements with situation elements
  - Define the impact of situation elements on mission elements
  - Example: ProjectedOwnshipCollision impacts “Maintain flight separation” mission component



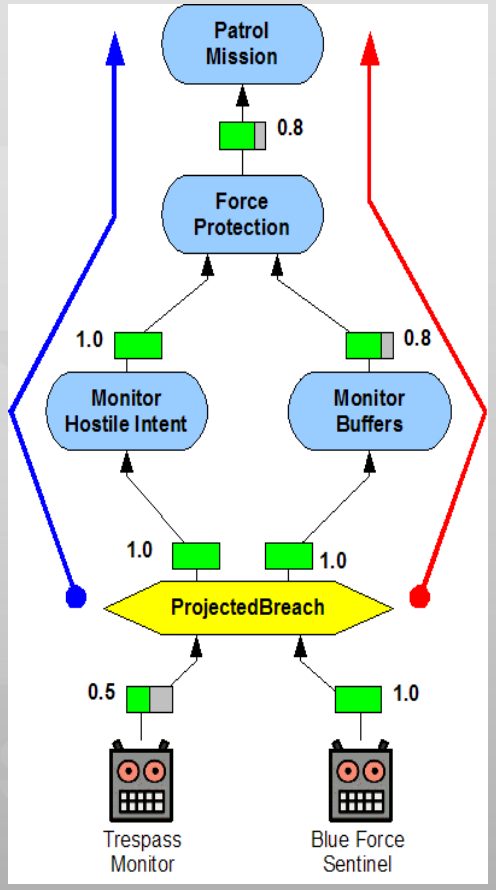
Mission and Agents

- Level 3: trust & relevance for contributing Agents
  - Agents produce judgments (opinions) on situation elements
  - Trust is derived from simulation exercises and can be modified by operator



Belief Propagation

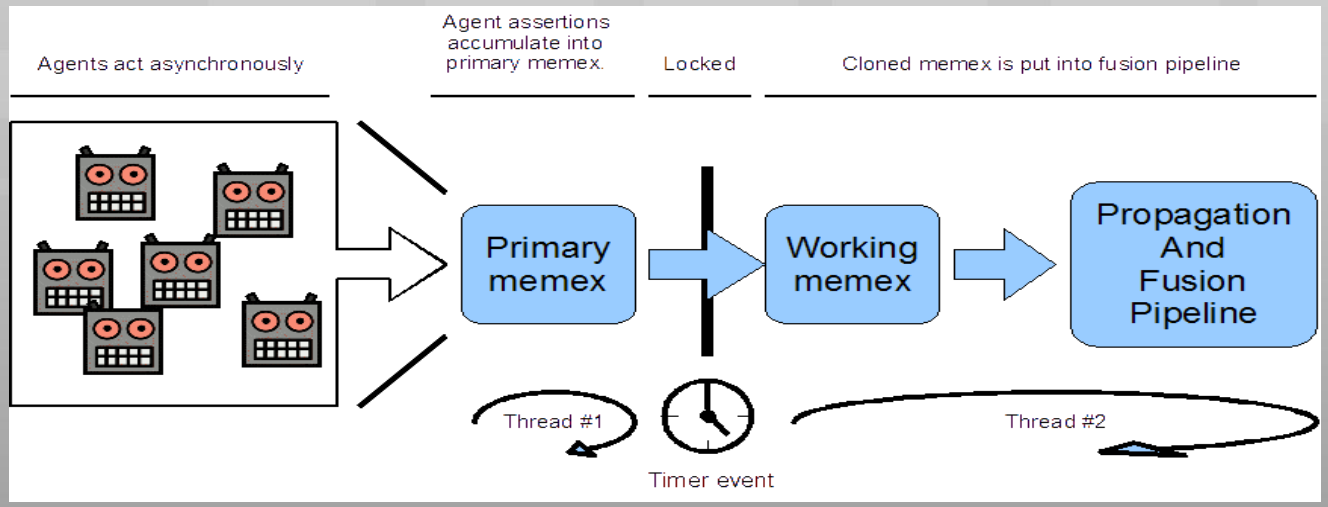
- Start with Agents issuing an opinion (belief) on evidence
- Apply Subjective Logic operators to Mission graph
  - Working set stored in a semantic network (memex)
- Use Evidential Reasoning Network (ERN®) Engine to propagate belief



Belief Fusion Engine

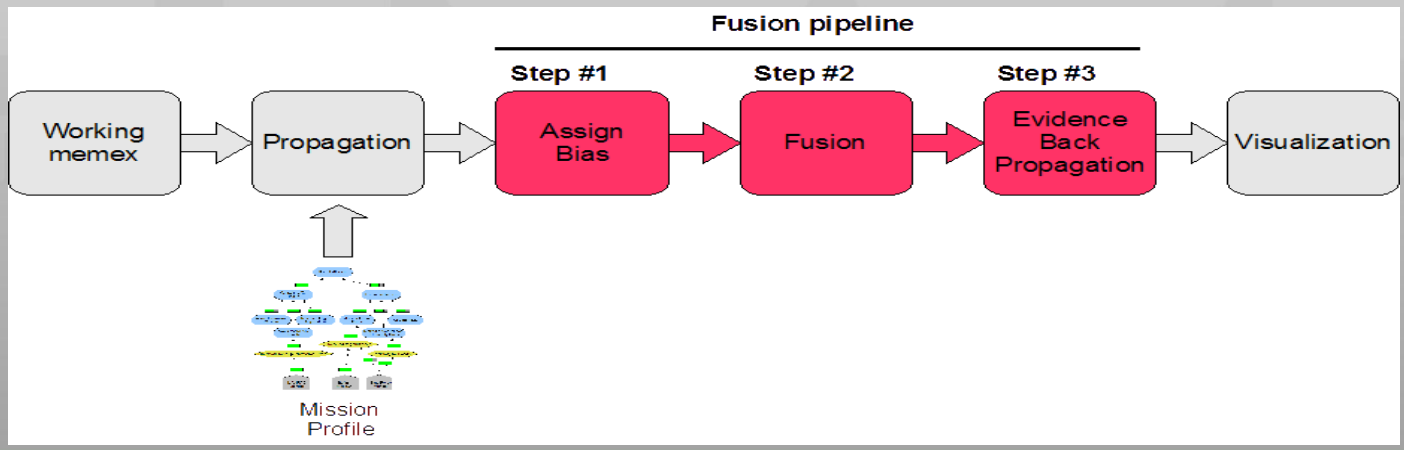
- Asynchronous Agents place judgments in SA Room
- Each Agent reasons opportunistically using heuristics
- Fusion Engine listens to SA room and builds local memory context (memex)
- At discrete time intervals*, working memex is sent to fusion pipeline

*Alternatively, a transactional logic implementation is possible

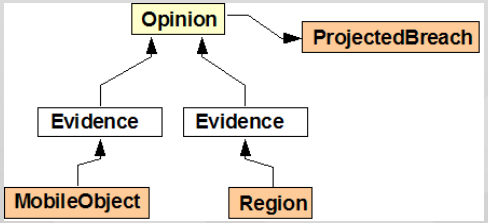


Belief Fusion – Cont'd

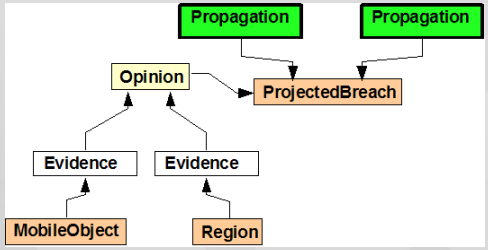
- Join working memex with mission profiles: captures propagation influence and inferred products
- Bias starts with total uncertainty then reallocating to belief or disbelief incrementally, as appropriate
- Fusion uses the SL consensus operator to collect Propagation nodes into Impact nodes
- Back propagation allows the reasoning products to flow down to the evidence elements that supported it



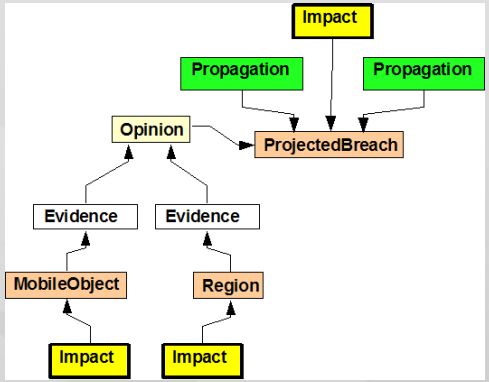
Example



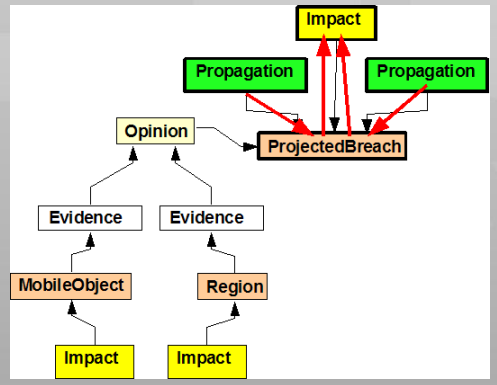
Initial memex state



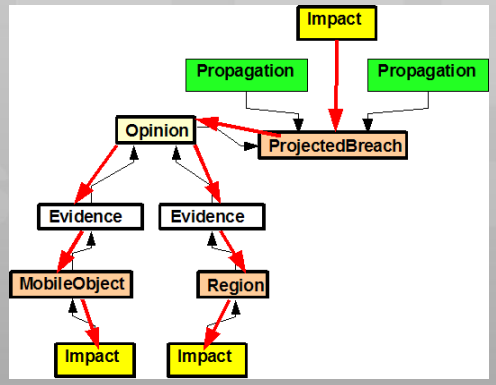
After computing propagations



After Fusion step #1



Accumulating propagations



Back propagation

Conclusions

- The system developed can increase SA by inferring higher-level relationships from lower-level information
- Contribution is a mission profile structure powered by an evidential reasoning network in a Multi-Agent environment
- The system was successful in a simulated environment for UAV command & control

Future Work

- System improvement after simulation and testing
- Theoretical improvements of the back-propagation system
- Improvements in authoring mission profiles
- Research towards a more robust transaction-based fusion engine

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Questions?

Contact:

plamen.petrov@21csi.com

402-880-3080

21st Century Systems, Inc.

6825 Pine Street, Ste 141

Omaha, NE 68106