Applying Spreading Activation Networks to enhance C2WindTunnel Functionality

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Organizational Network modeled in CAESAR III

- **DTC Chief**
  - F2T2EA: Find, Fix, Target, Track, Engage, Access
  - Assign/reassign new targets
  - Coordinate among units
  - Schedule non-critical surveillance
  - Planning, scheduling, and allocation of resources
Organizational Model for ISR

- **ISR**
  - Intelligence, Surveillance, Reconnaissance
  - Combat, Situation assessment: PED: Processing, Evaluation, and Dissemination
  - planning related to data analysis activities.
Extending current organizational model

- Extend vignette to multiple, simultaneous activities
- Introduce more involved tasks that require planning
- Have to deal with tight schedules and limited resources

**How?**
- Introduce more decision making capabilities into the individual organizational nodes

**Spreading Activation Network Partial Order Planner (SA-POP)**
SA-POP Research and Development Challenges

Research Challenges
1. Efficiently handle uncertainty in planning
2. Incorporate resource-aware scheduling with planning

Development Challenges
1. Take advantage of functionally interchangeable components to efficiently meet resource constraints
2. Plan with multiple interacting goals, but produce distinct operational strings

SA-POP is available at:
http://www.dre.vanderbilt.edu/~jkinnebrew/SA-POP/index.html
SA-POP: Planning in DRE Systems with Components

**Task** is an abstraction of functionality
- Multiple (parameterized) components may have the same function but different resource usage

**Task Network** specifies probabilistic effects and requirements for tasks
- Condition nodes specify data flow and system/environmental conditions
- Task nodes have links to/from condition nodes specifying effects/preconditions
- Links incorporate probabilistic information about domains

**Task Map** allows conversion between tasks and components
- Maps tasks (functionality abstraction) to parameterized components (implementation)
- Associates expected or worst case resource usage with each implementation

**Operational String** specifies a component-based application to achieve a goal
- Set of tasks along with ordering and timing constraints
- Data connections between tasks
- Implementation (parameterized component) suggested for each task
SA-POP: Expected Utility Calculation using Spreading Activation

Forward propagation of probabilities

Backward propagation of utilities

Task node

Effect nodes

Precondition nodes

Effect Link Weights

Precondition Link Weights

**Precondition Link Weights**

\[
w_{ij} = \frac{P(a_j^+ | c_i = true) - P(a_j^- | c_i = false)}{P(a_j^+ | c_i = true) + P(a_j^- | c_i = false)}
\]

\[a_j^+ \rightarrow \text{Action } a_j \text{ was successful}\]

**Task Network**

**Task Map**

Spreading Activation

Planning

Scheduling

SA-POP

\[w_{jk} = P(c_k = true | a_j^+) \text{ or } P(c_k = false | a_j^-)\]

\[a_j^x \rightarrow a_j \text{ was executed}\]
SA-POP: Operational String Generation

Four hierarchical decision points in each interleaved planning+scheduling step:

Partial Order Planning:

1. **Goal/ subgoal choice**: choose an open condition, which is goal or subgoal unsatisfied in the current plan.
2. **Task choice**: choose a task that can achieve current open condition.

Resource Constrained Scheduling:

3. **Task instantiation**: choose an implementation for this task from the Task Map.
4. **Scheduling decision(s)**: adjust task start/end time windows and/or add ordering constraints between tasks to avoid potential resource violations.

*Continue recursively*
SANet Example

Key:
- Task (Estimated Prior Probability)
- Condition (Initial state)
SANet Example: (Goal: C14 & C15 = TRUE)
SANet Example: (Goal: C14 & C16 = TRUE)

Key:
- Task (Estimated Prior Probability)
- Condition (Initial state)

Table 2. Example task map

<table>
<thead>
<tr>
<th>Task</th>
<th>Implementation</th>
<th>Resource Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Impl1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>Impl2</td>
<td>1</td>
</tr>
<tr>
<td>A3</td>
<td>Impl3</td>
<td>1</td>
</tr>
<tr>
<td>A4</td>
<td>Impl4</td>
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<td>A10</td>
<td>Impl10</td>
<td>1</td>
</tr>
<tr>
<td>A11</td>
<td>Impl11</td>
<td>1</td>
</tr>
</tbody>
</table>

Resource capacity = 5

Resource capacity = 3
Example Overview

• Two types of damage (A & B) can be assessed
  - F-22 most effective for assessing damage A
  - Hen&Chicks most effective for assessing damage B
  - F-22 and Hen&Chicks can both reach targets in same amount of time

• Three targets have been attacked
  - Targets X & Y
    - High priority
    - Assessing damage A is important, and also assessing B is preferred
  - Target Z
    - Medium priority
    - Assessing damage B is important, and also assessing A is preferred

• Spreading activation network
SA-POP Input & Output

• SA-POP Inputs
  - Current condition values (others default to False for this example)
  - Goal conditions identified with utility
  - Resource availability (as explicit availability/unavailability or known unavailability from other active plans)
  - Set of active plans that can be modified or cancelled.

• SA-POP Outputs
  - Operational String to achieve goal (or notification that it can not be achieved)
    • Ordered set of tasks, with asset/resource to use for each
    • Probability of achieving each goal condition
    • Overall expected utility
  - Set of any other modified or cancelled operational strings
DTC Chief (Recommend Rule) Scenario

- DTC Chief receives notification Target X attacked
- SA-POP Input
  - Condition (Target X attacked) Value = True
  - Condition (Damage A assessed) Utility = 20
  - Condition (Damage B assessed) Utility = 4
  - Task Map: 1 F-22, 1 H&C, 1 ISR available
  - Other OpStrings: None to modify
- SA-POP Output
  - Probability (Damage A assessed) = 90%
  - Probability (Damage B assessed) = 85%
  - Expected Utility = 21.4
- Operational String:

\[\text{(Target X)}\] Task F-22 [1 F-22] \rightarrow \text{(Target X)} F-22 Collect Data [1 F-22] \rightarrow \text{(Target X)} Assess Damage [0.1 ISR]

- DTC Chief Recommend Rule sends token including recommendation to use F-22 for reconnaissance of Target X and the OpString of the complete plan (which can affect the rules/planning at other CPN nodes).
• DTC Chief receives notification Target Z attacked

• SA-POP Input
  – Condition (Target Z attacked) Value = True
  – Condition (Damage A assessed) Utility = 2
  – Condition (Damage B assessed) Utility = 10
  – Task Map: 1 H&C, 0.9 ISR available
  – Other OpStrings: None can be modified or cancelled

• SA-POP Output
  – Probability (Damage A assessed) = 80%
  – Probability (Damage B assessed) = 90%
  – Expected Utility = 10.6
  – Operational String:

• DTC Chief Recommend Rule sends token including recommendation to use H&C for reconnaissance of Target Z and the OpString of the complete plan.
DTC Chief (Recommend Rule) Scenario (cont.)

- DTC Chief receives notification Target Y attacked

SA-POP Input
- Condition (Target Y attacked) Value = True
- Condition (Damage A assessed) Utility = 20
- Condition (Damage B assessed) Utility = 4
- Task Map: 0.8 ISR available
- Other OpStrings: Any can be modified or cancelled

SA-POP Output
- Target Y OpString Cancelled
- Probability (Damage A assessed) = 80%
- Probability (Damage B assessed) = 90%
- Expected Utility = 19.6
- Operational String:
  - (Target Y) Task H&C [1 H&C]
  - (Target Y) H&C Collect Data [1 H&C]
  - (Target Y) Assess Damage [0.1 ISR]

- DTC Chief Recommend Rule sends token including recommendation to use H&C for reconnaissance of Target Y and cancel plan for Target Z, as well as the OpString of the Target Y plan