A Situation Analysis Toolbox for Course of Action Evaluation

Patrick Maupin, Anne-Laure Jousselme, Hans Wehn, Snezana Mitrovic-Minic, Jens Happe

R & D Defence Canada - Valcartier  MacDonald, Dettwiler and Associates (MDA)
Outline

1. Formalisation of the Situation Analysis process
   – Situation, Situation awareness, Situation analysis

2. Situation Analysis Toolbox (SAT) implementing the previous theoretical concepts
   – Modeling situation as a pursuit-evasion game
   – Counter-smuggling vignette
   – Five Modules
     1) Behaviour simulation toolbox
     2) Discretisation toolbox
     3) State generation toolbox
     4) State searching toolbox
     5) Visualization toolbox

3. Conclusions
Interpreted systems semantics is an epistemic logical approach proposed in the 1995 for the analysis of distributed systems by Fagin, Halpern, Moses and Vardi.

Interpreted Systems Semantics for situation analysis

- **Hypothesis:** *Interpreted Systems Semantics is a general framework for situation analysis and high-level information fusion applications*

- **Arguments:**
  - Designed for **distributed systems** analysis;
  - **Situations** are adequately represented by state transition systems;
  - The notions of Situation, Situation Awareness and Situation Analysis can be **formally defined**;
  - Allows reasoning about **knowledge**, **uncertainty** and **time**;
  - The framework is general enough so that **Generalized Information Theory** can be **framed** into ISS;
  - Can take advantage of both **model checking** and inductive decision procedures.

Elements of the model (1)

Observations from the environment
Probability measures
Algorithms for truth evaluation
…
Elements of the model (2)

Joint protocol $P$

$P = (P_1, ..., P_n)$

Global state $s = (l_1, ..., l_n, l_e)$

Joint action $a = (a_1, ..., a_n, a_e)$

System

Context $\gamma = (S_0, \tau, P_e, \psi)$

\[ \mathcal{I} = \langle S, P, \gamma, \pi \rangle \]

$\pi$ is an interpretation function for formulas in $\mathcal{L}(\Phi)$
A *situation* is the subsystem $\mathcal{I}(r,m)$ of $\mathcal{I}$, that is the system representing $P$ in the interpreted context $(\gamma(r,m), \pi)$.

3 remarkable cases:
1. Global state
2. Given a single initial state
3. Full spectrum of possible paths
Awareness as resource-boundedness

An agent is *aware* of a formula $\phi$ if it is able to compute its truth value

$$(\mathcal{I}, r, m) \models A_i \phi \iff A_i(\phi, l_i) \neq "?"$$

Algorithm for truth evaluation

$$A_i = \text{alg}_i(r, m)$$

with

$$A_i(\phi, l_i) = \begin{cases} \text{Yes if } \phi \text{ is true} \\ \text{No if } \phi \text{ is false} \\ ? \text{ if the agent is unable to compute} \end{cases}$$

→ The fact that the algorithm can compute the truth value of $\phi$
   does not mean that this is the correct truth value.
→ Awareness is a practical notion of knowledge
Situation analysis (proposed approach)

Situation analysis is the process of verifying properties of the interpreted system expressed by a formula $\phi_{KT}$

$$(I, r, m) \models \phi_{KT}$$

Queries

- Is $\phi$ true?
- Will $\phi$ be true at all future steps?
- Is $\phi$ always true?
- Does Agent 1 knows $\phi$?
- Does everybody in group $G$ knows $\phi$?
Engineer view of Interpreted Systems

\[
\begin{align*}
\{\tilde{s}_{k+1}\} & \quad \rightarrow \quad \text{Delay} \\
\{\tilde{s}_k\} & \quad \rightarrow \quad \text{Interpretation} \quad \pi(\tilde{s}_k, p) \\
\{\tilde{s}_0\} & \quad \rightarrow \quad \text{Initial States} \\
\tau(\tilde{a}_k, \tilde{s}_k) & \quad \rightarrow \quad \text{State Trans.} \\
\{\tilde{a}_k\} & \quad \rightarrow \quad \text{Admissibility} \quad \{\tilde{s}_{\text{admit}}\} \\
{\tilde{s}_k}^e & \quad \rightarrow \quad \text{Env. Protocol} \quad P_e(\tilde{s}_k^e) \\
{\tilde{s}_k}^j & \quad \rightarrow \quad \text{Joint Protocol} \quad P_j(\tilde{s}_k^j) \\
\end{align*}
\]
SAT – A Situation Analysis Toolbox

5 modules

- Probability Maps
  - Discrete World: spatial relationships between objects of interest that are taken for granted in subsequent analysis
  - Probability maps can be used to specify absolute and initial probabilities

- Behaviour Simulation Toolbox
  - OpenSteer commands
  - All that is known about the world

- Probability Maps
  - Continuous World
    - Probability maps (e.g., likely agent locations) can be used to exclude areas of low probability from visibility and navigation graphs

- State Generation Toolbox
  - Context
  - Constraints on the agents' mobility (and possibly sensing and communication) that the agents can control

- State-Graph
  - Sensing Strategies
  - Motion Strategies
  - Communication Strategies

- State Searching Toolbox
  - Question
  - Answer

- Visualization Toolbox
  - Visualizes discretization and state search results

SAT Analyzer
SAT – A Situation Analysis Toolbox

2 purposes:
1. Situation generation
2. Situation analysis
Situations as pursuit-evasion (PE) games

- Pursuer and evader agents are constrained to move within a **graph** whose nodes are possible locations and whose edges denote paths between two locations.

- PE consists in a game between two teams having opposite goals, the players jointly seeking to maximize (resp. to minimize) a function of distance.

- Each agent has a **visibility** sensor of sensing range $r$ meaning that the agent can see a node if it is within its range.

- Capture occurs when a pursuer and the evader are at the same position (node) at the same time.

- Basic action: Move from one node to an adjacent node.

- The evader's strategy $P_e$ is unknown to the pursuers.
Counter-smuggling vignette

A smuggling operation has been reported in Howe Sound (north-west of Vancouver on Canada’s West Coast).

*Can we guarantee that the smugglers will be detected?*
SAT – Behaviour Simulation Toolbox

Continuous world (GIS map)
Partial knowledge on evader’s behaviour

Behaviour simulator

Probability map (agent containment)
SAT – Behaviour Simulation Toolbox

Opensteer library
SAT – Discretisation Toolbox

Discretiser

Visibility graph
Navigation graph
SAT - The State Generation Toolbox

Context

Joint strategy

Situation
(state transition system)
SAT – State Searching Toolbox

Situation

State searcher

Answer

CTL queries

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AX $\phi$</td>
<td>$\phi$ in all next states.</td>
</tr>
<tr>
<td>EX $\phi$</td>
<td>$\phi$ in at least one next state.</td>
</tr>
<tr>
<td>A $[\phi \ U \ \psi]$</td>
<td>on all paths, $\phi$ until $\psi$.</td>
</tr>
<tr>
<td>E $[\phi \ U \ \psi]$</td>
<td>on at least one path, $\phi$ until $\psi$.</td>
</tr>
<tr>
<td>AF $\phi$</td>
<td>On all paths, in some future state, $\phi$.</td>
</tr>
<tr>
<td>EF $\phi$</td>
<td>On at least one path, in some future state, $\phi$.</td>
</tr>
<tr>
<td>AG $\phi$</td>
<td>On all paths, in all future states, $\phi$.</td>
</tr>
<tr>
<td>EG $\phi$</td>
<td>On at least one path, in all future states, $\phi$.</td>
</tr>
</tbody>
</table>
$\phi$: PursuitStateAllClear

$\text{EX } \phi$: $\phi$ in at least one next state

$\text{EF } \phi$: On at least one path, $\phi$ in some future state
Conclusions

• The Situation Analysis Toolbox (SAT) implements formal notions of situation analysis based on epistemic state transition systems.

• The SAT generates situations based on
  1. an abstract version of the environment (visibility graph) enriched with probability maps of presence of agents, built through modeling emerging behaviour.
  2. the execution of a joint strategy derived from pursuit-evasion game theory.

• The SAT analyses the situation through logical queries.

Further works:
  – Epistemic and probabilistic queries
  – Customise to account for other applications
SAT - Vizualizer
Probability map