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A Situation Analysis Toolbox for Course of Action Evaluation

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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 for situation analysis

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

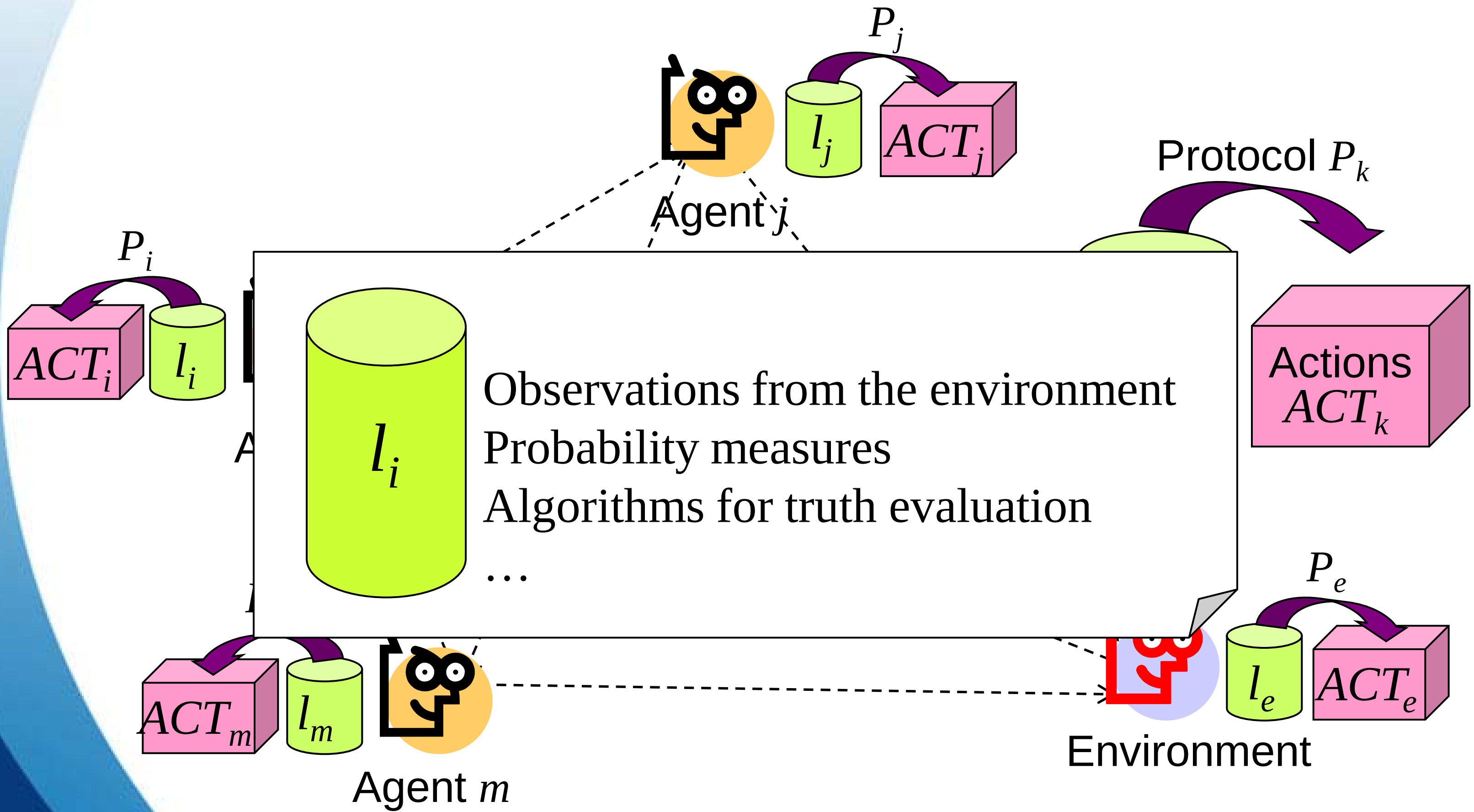
R. Fagin, J. Y. Halpern, Y. Moses, and M. Y. Vardi. Reasoning about knowledge. The MIT Press, Cambridge, MA, 2003.

Interpreted Systems Semantics for situation analysis

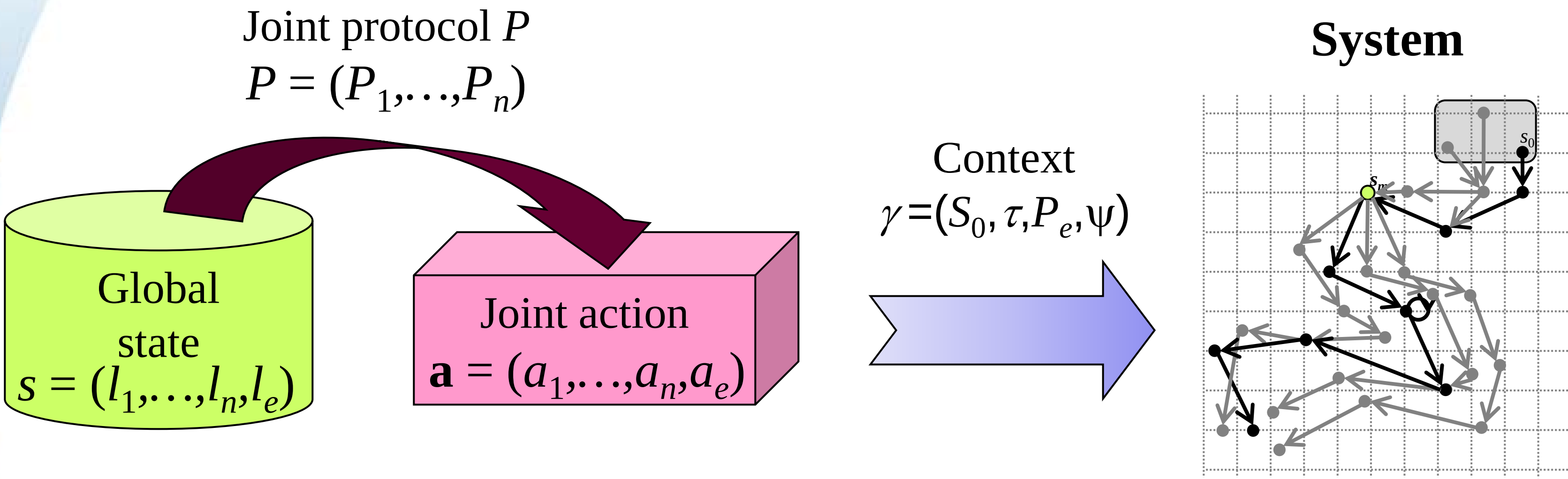
- Hypothesis: ***Interpreted Systems Semantics*** *is a general framework for* ***situation analysis*** *and high-level information fusion applications*
- Arguments:
  - Designed for **distributed systems** analysis;
  - **Situations** are adequately represented by state transition systems;
  - The notions 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**.

P. Maupin and A.-L. Jousselme. A general algebraic framework for situation analysis. In *Proc. of the 8th Int. Conf. on Information Fusion, Philadelphia, PA,* USA, July 2005.

Elements of the model (1)



Elements of the model (2)



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

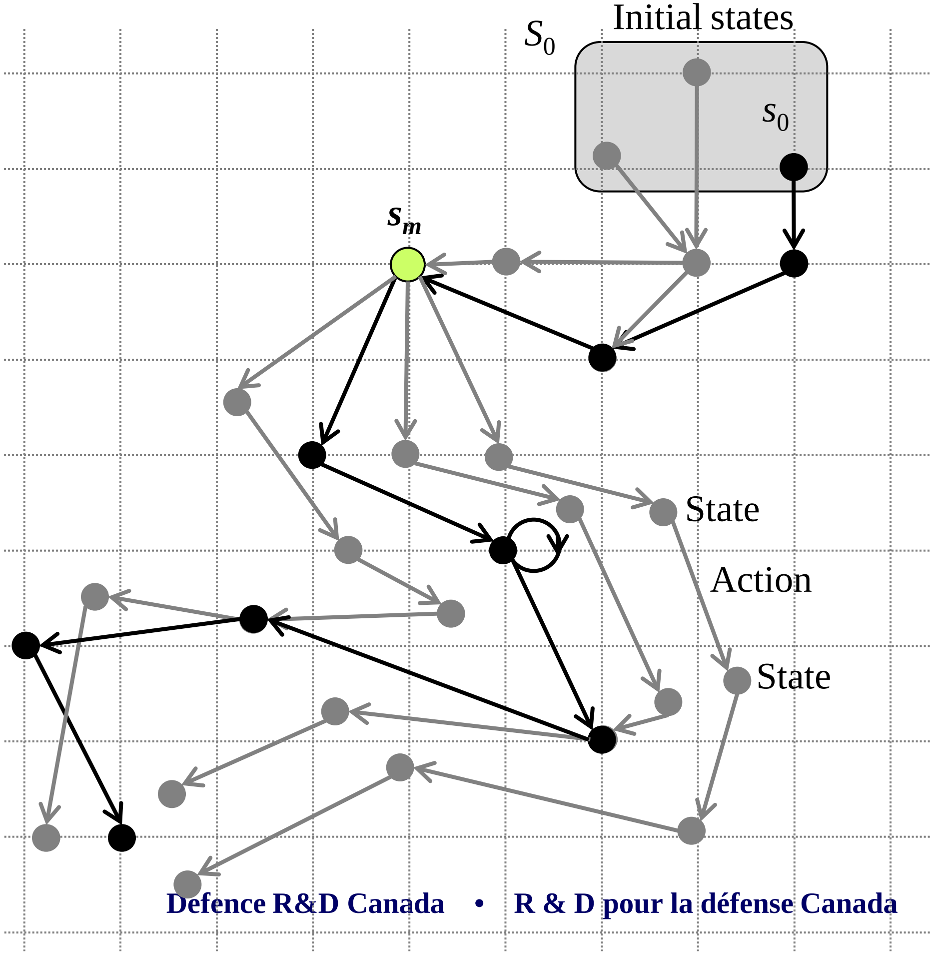
π is an interpretation function for formulas in $\mathcal{L}(\Phi)$

Situation

A *situation* is the subsystem $\mathscr{I}(r,m)$ of $\mathscr{I}$, that is the system representing *P* in the interpreted context $(\gamma_{(r,m)},\pi)$

<u>3 remarkable cases:</u>

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 ϕ if it is able to compute its truth value

$$(\mathcal{I}, r, m) \models A_i\phi \text{ iff } \mathsf{A}_i(\phi, l_i) \neq \text{“?”}$$

Algorithm for truth evaluation

$$\mathsf{A}_i = \mathsf{alg}_i(r, m)$$

Local data = Observations

$$l_i = \mathsf{obs}_i(r, m)$$

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

→The fact that the algorithm can compute the truth value of ϕ does not mean that this is the correct truth value.

→ Awareness is a practical notion of knowledge

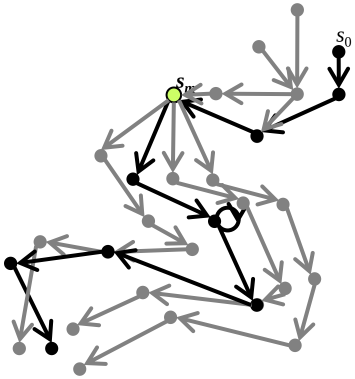
Situation analysis *(proposed approach)*

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

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

Queries

Is ϕ true ?
Will ϕ be true at all future steps ?
Is ϕ always true ?
Does Agent 1 knows ϕ ?
Does everybody in group G knows ϕ ?

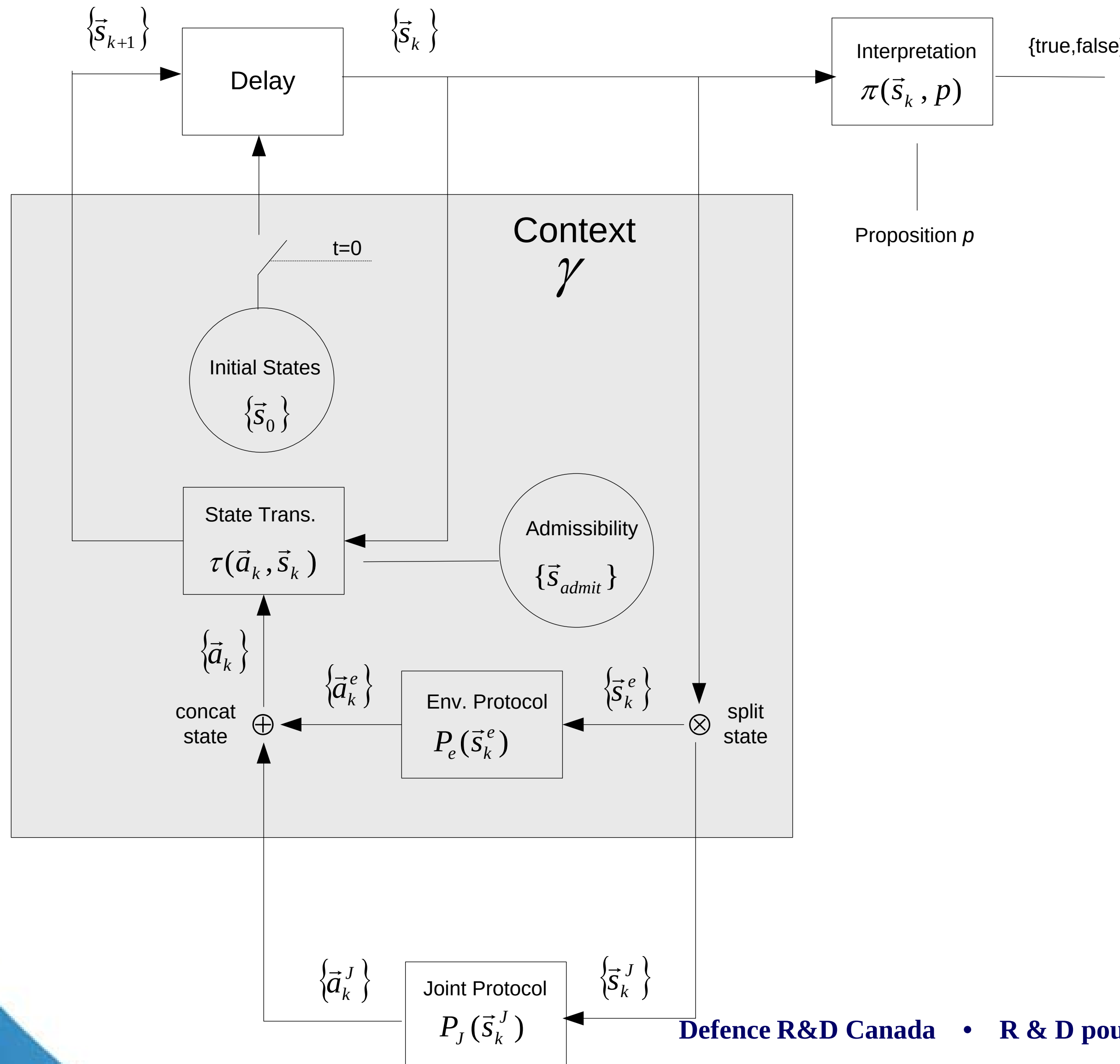


Situation

YES

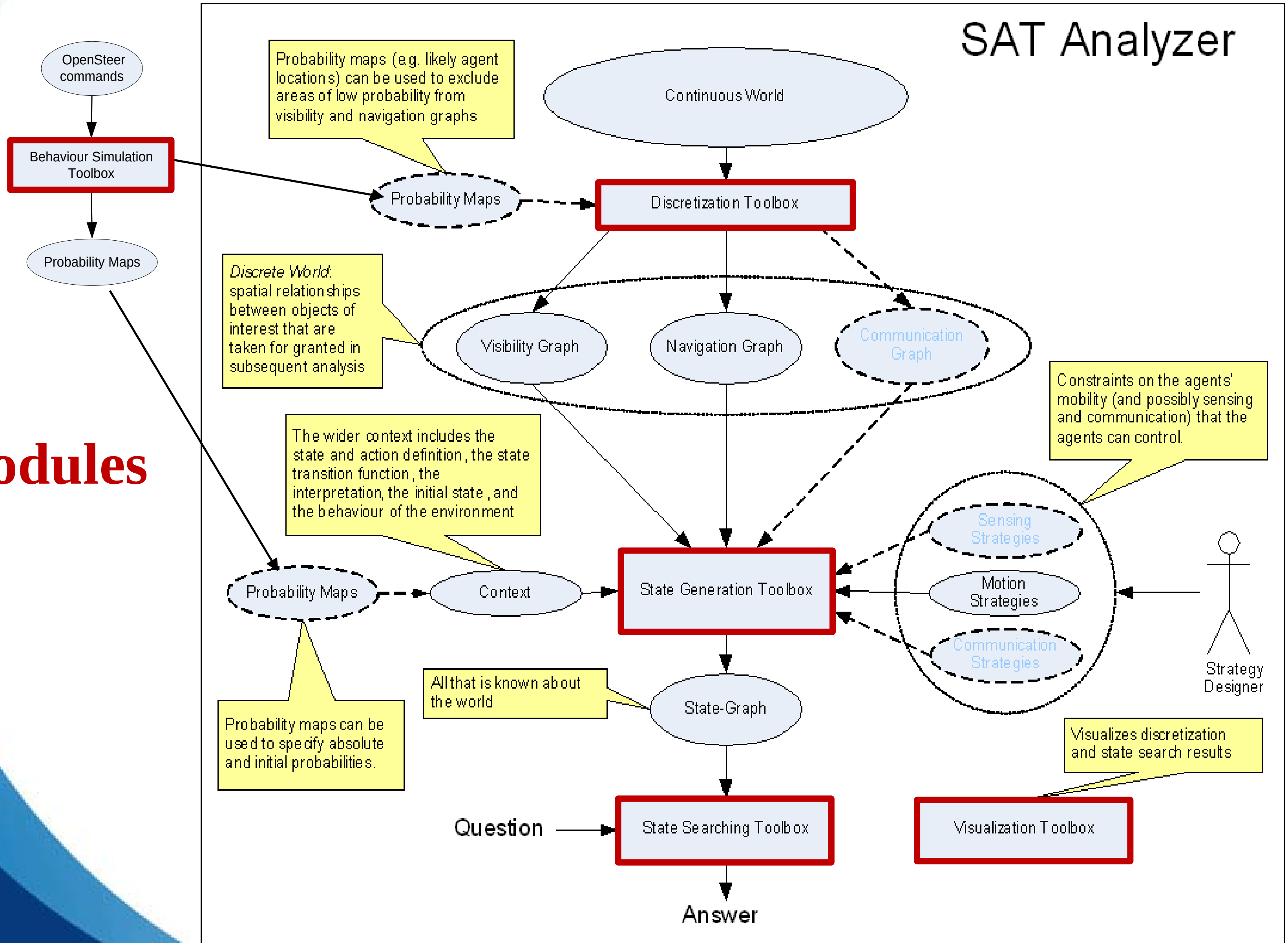
NO

Engineer view of Interpreted Systems



SAT – A Situation Analysis Toolbox

5 modules



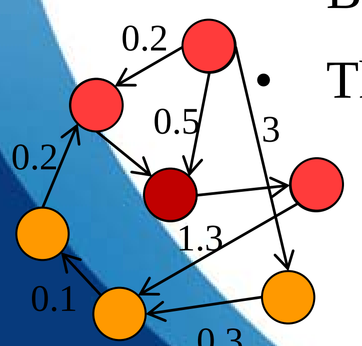
SAT – A Situation Analysis Toolbox

2 purposes:

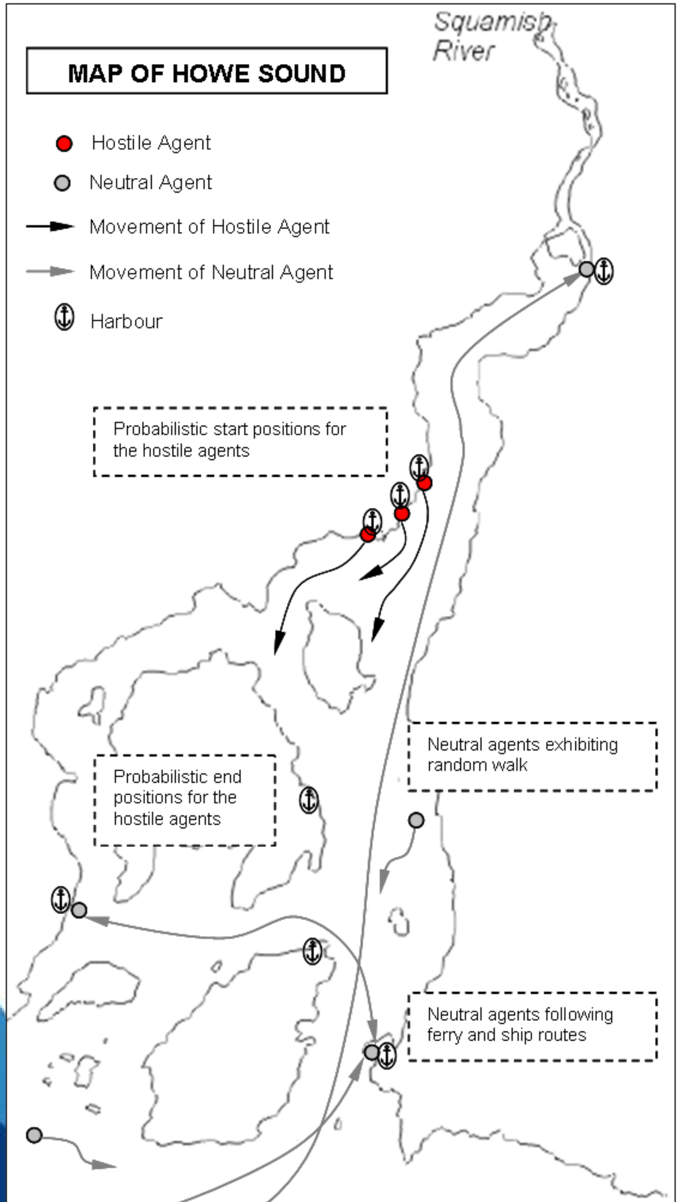
1. Situation **generation**
2. Situation **analysis**

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).

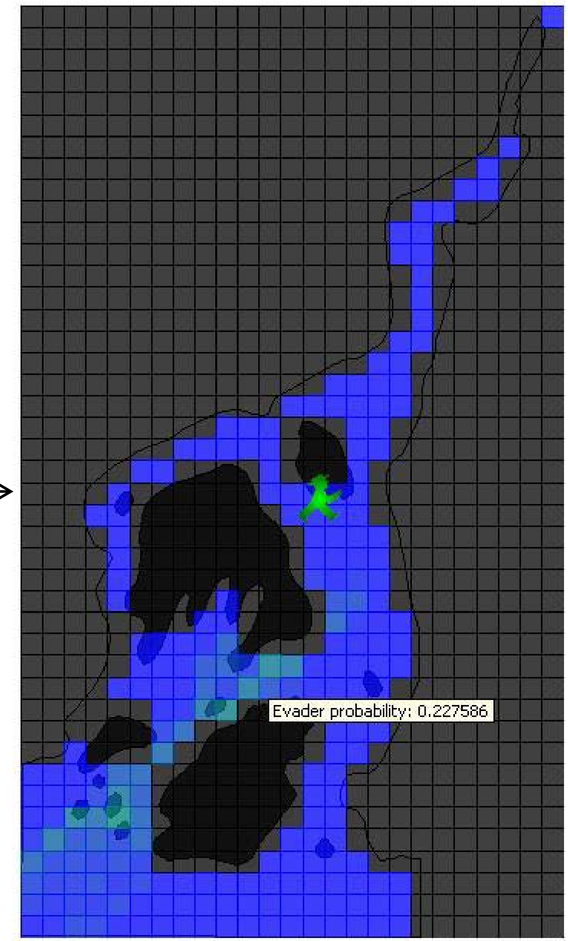
Can we guarantee that the smugglers will be detected ?

SAT – *Behaviour Simulation Toolbox*

Continuous world
(GIS map)

Partial knowledge
on evader's behaviour

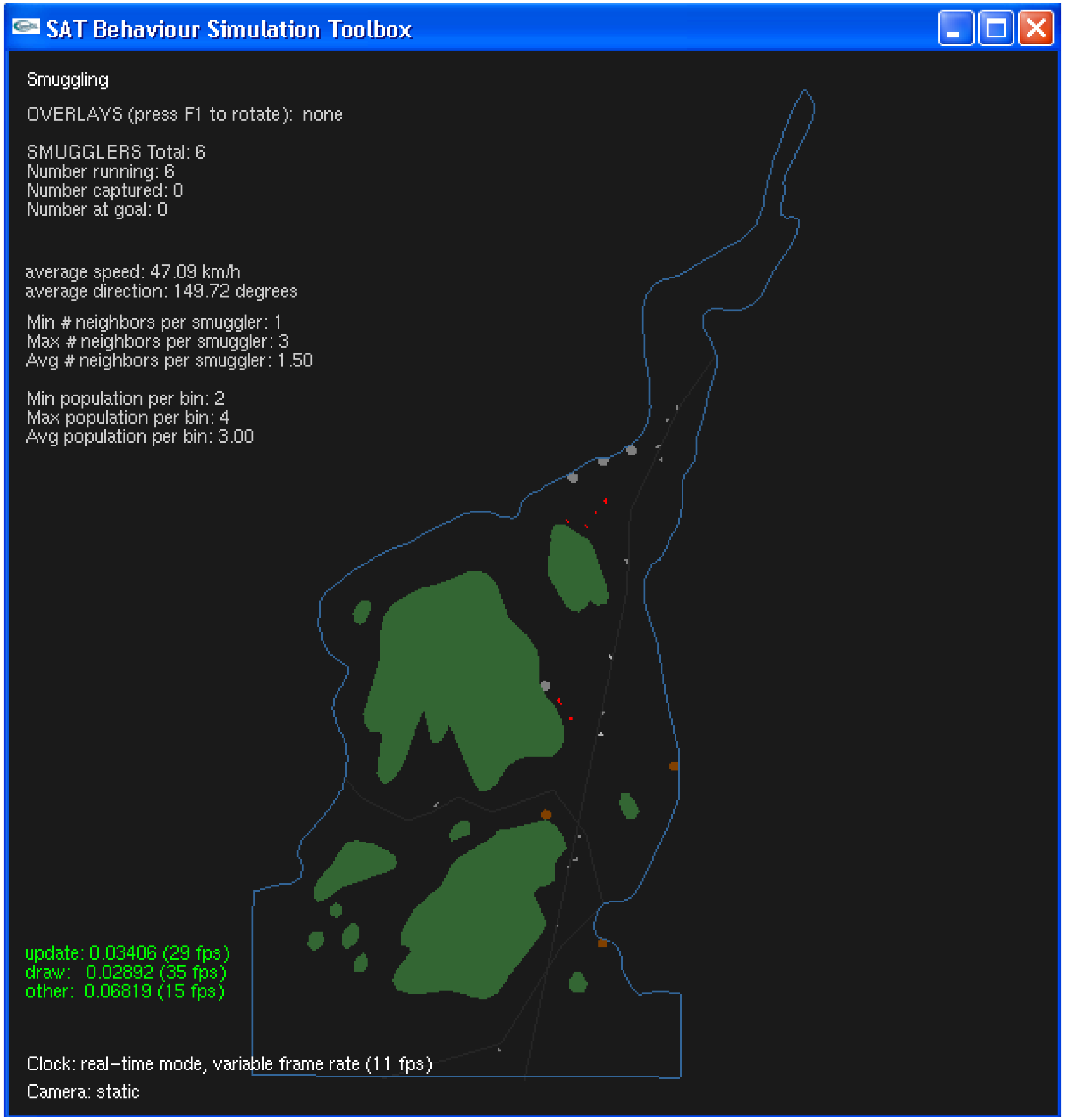
Behaviour simulator



Probability map
(agent containment)

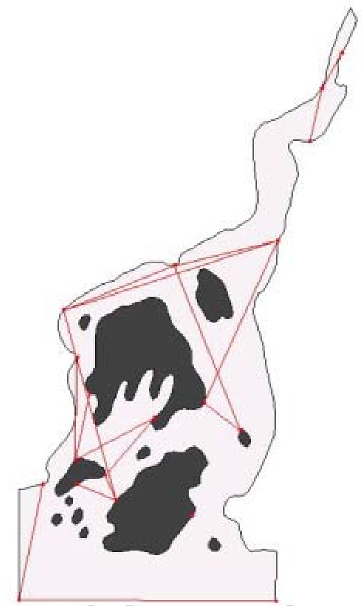
SAT – *Behaviour Simulation Toolbox*

Opensteer library



SAT – *Discretisation Toolbox*

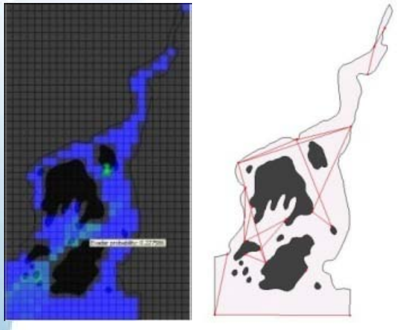
Discretiser



Visibility graph

Navigation graph

SAT - *The State Generation Toolbox*

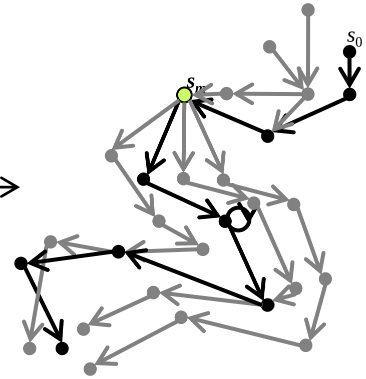


```
case of
   if PosP=PosE do Λ
   if PosE∈ Voisinage(PosP) do Move-to(PosE)
   else Move-to(n'importe quel nœud adjacent)
   Observe
end case
```

Context

γ

State generator



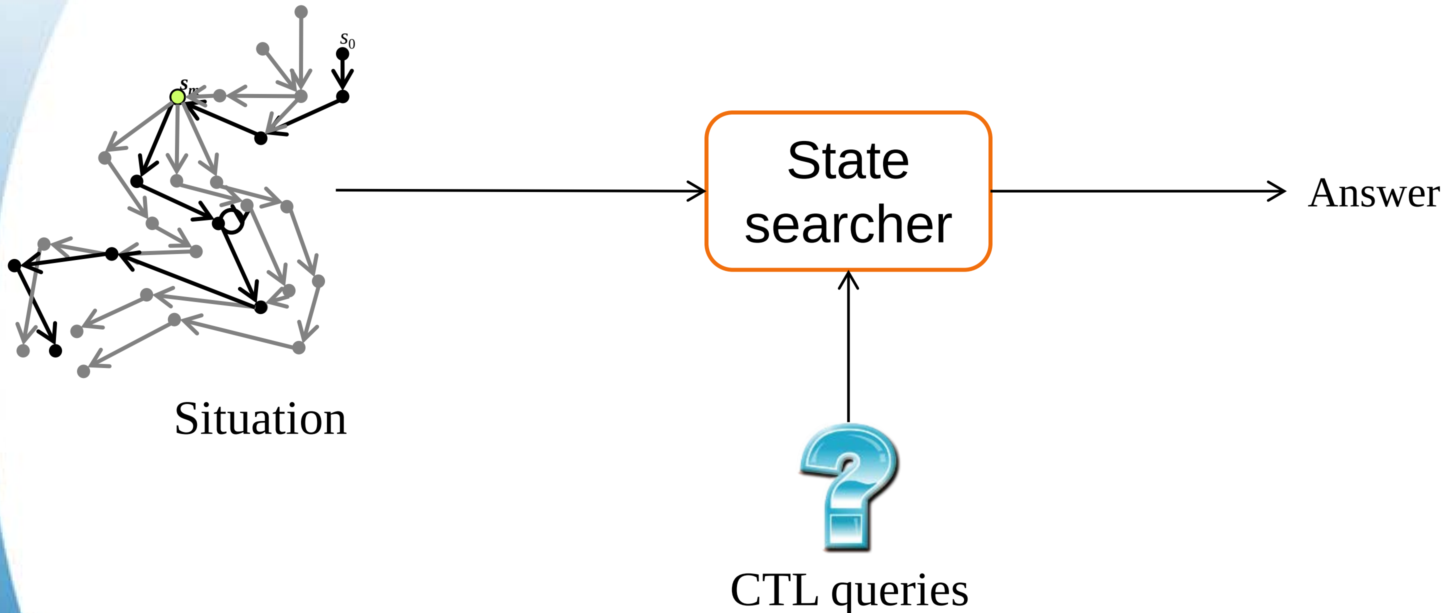
Situation
(state transition system)

P

```
case of
   if PosP=PosE do Λ
   if PosE∈ Voisinage(PosP) do Move-to(PosE)
   else Move-to(n'importe quel nœud adjacent)
   Observe
end case
```

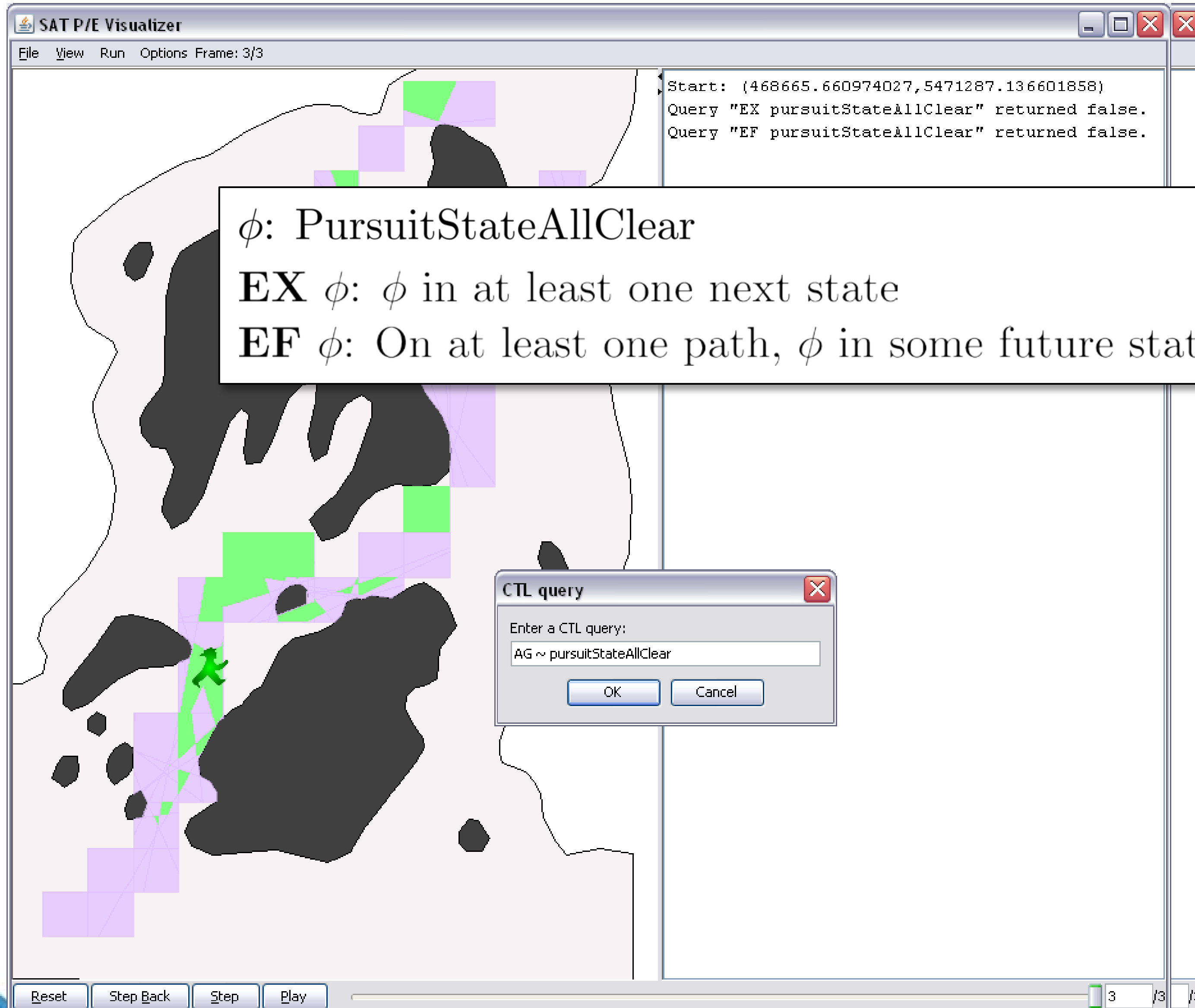
Joint strategy

SAT – *State Searching Toolbox*



AX ϕ	ϕ in all next states.
EX ϕ	ϕ in at least one next state.
A [ϕ **U** ψ]	on all paths, ϕ until ψ.
E [ϕ **U** ψ]	on at least one path, ϕ until ψ.
AF ϕ	On all paths, in some future state, ϕ.
EF ϕ	On at least one path, in some future state, ϕ.
AG ϕ	On all paths, in all future states, ϕ.
EG ϕ	On at least one path, in all future states, ϕ.

SAT – *Vizualisation Toolbox*



ϕ: PursuitStateAllClear

EX ϕ: ϕ in at least one next state

EF ϕ: On at least one path, ϕ 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.

<u>Further works</u>:

- Epistemic and probabilistic queries
- Customise to account for other applications

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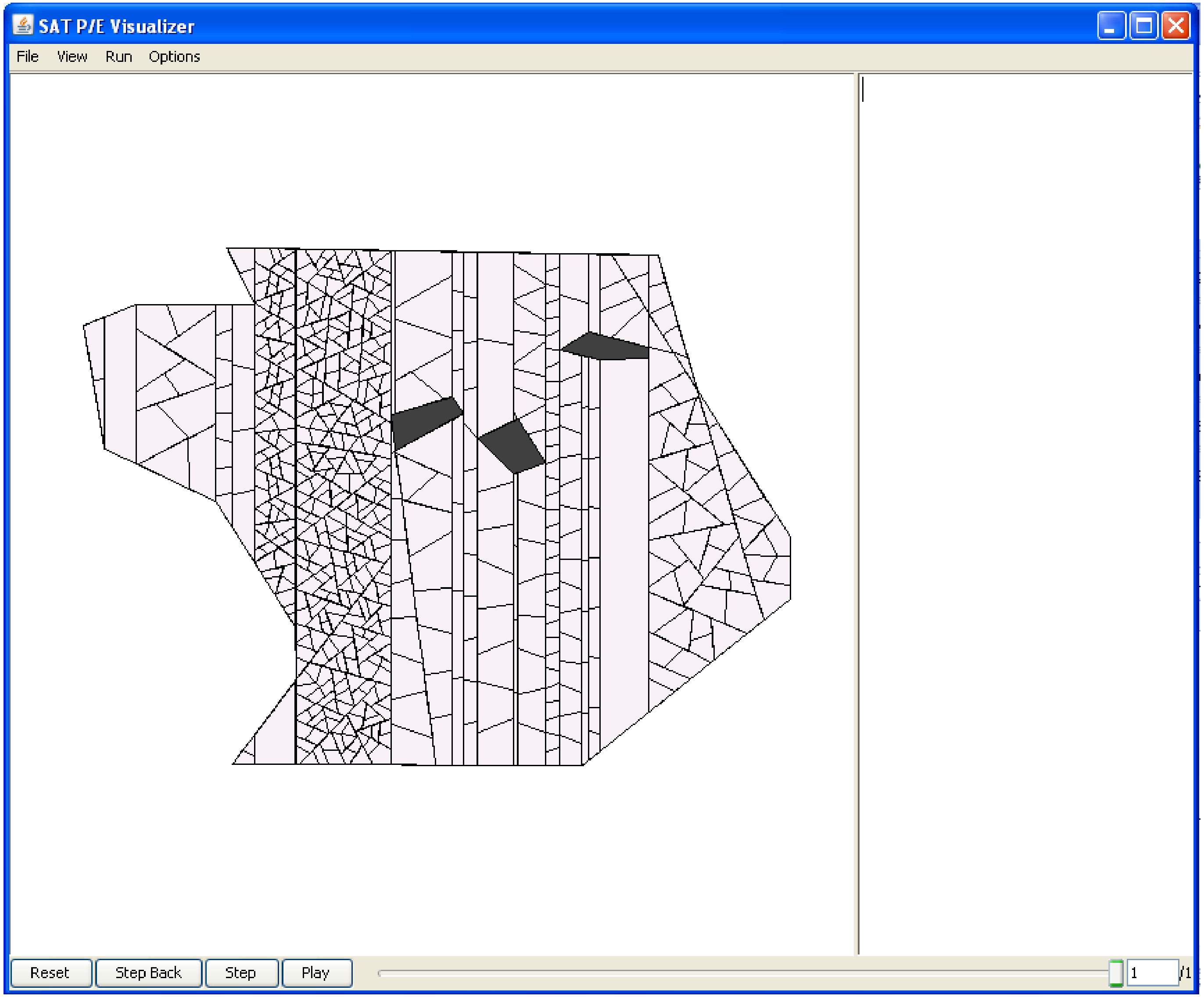
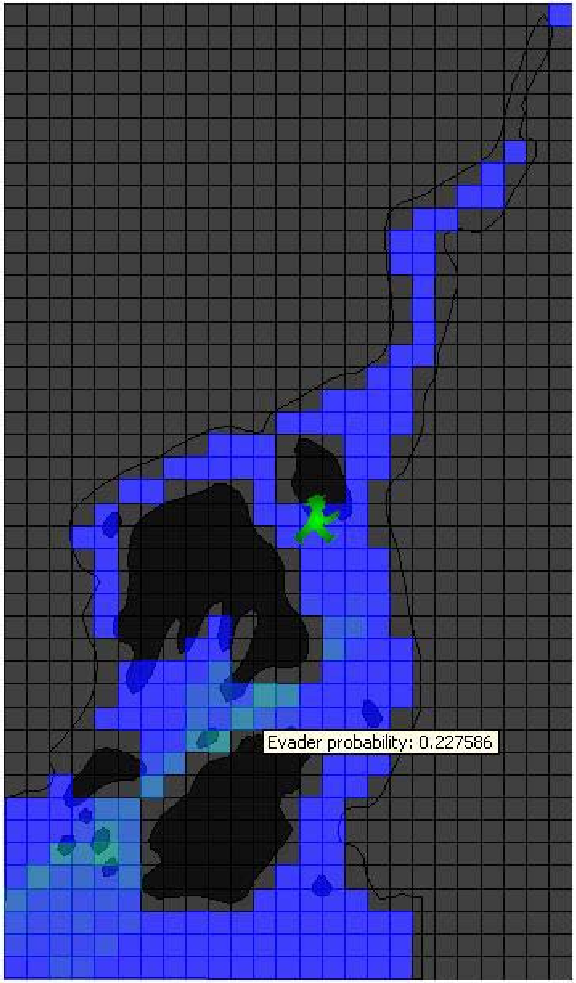
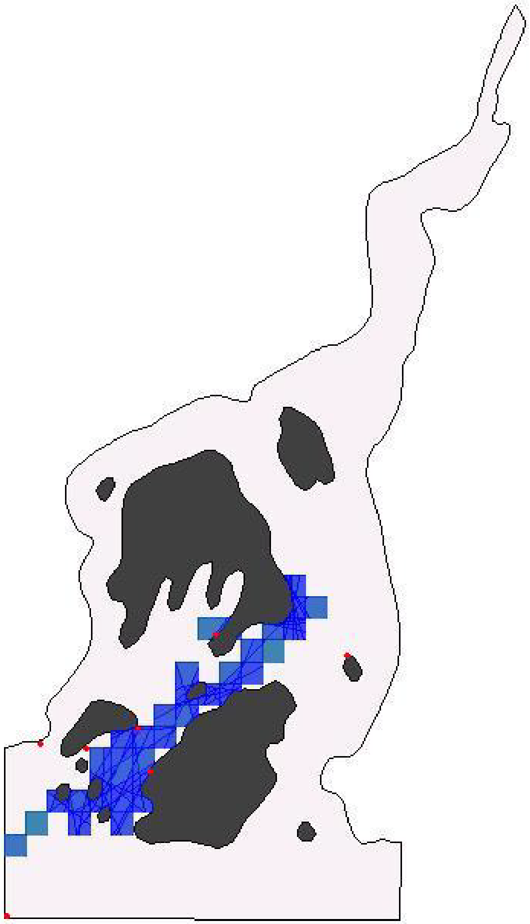
SAT - *Vizualizer*







Probability map