In Processes, We Believe!

Marrying Process Algebra and Epistemic Logic

Francien Dechesne and Mohammad Mousavi

TbILLC: Special Session on Logic, Information and Agency

Outline

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Background of the research

VEMPS project (2006-2009)

using epistemic logic for verification of security protocols

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(dynamic) epistemic logic
$\Updownarrow$
process algebra, formal semantics, verification of distributed processes, security

The prototypical example: Dining Cryptographers

Operational vs. Epistemic

The Gap

approach\spec	**Protocol**	**Goal**
Operational	Intuitive	Non-trivial; Difficult with Knowledge Properties
Epistemic	Laborious	Intuitive; combination of epistemic and temporal constructs

Operational Approach: basic process algebra

Simple PA: Syntax

$$\begin{array}{lcl} a & ::= & a[?,!](\overrightarrow{k}) \\ p, q & ::= & a \mid a; p \mid p + q \mid p \parallel q \end{array}$$

1. receive: $a?(\overrightarrow{k})$, send: $a!(\overrightarrow{k})$, individual actions or synchronizations: $a(\overrightarrow{k})$;

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   where send and receive synchronize.

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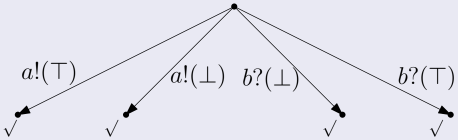
Semantics:
labelled transition system generated by syntactic rules
(SOS: Structural Operational Semantics)

Operational Approach: basic process algebra

Simple PA: Intuitive Semantics

$$\sum_{i \in \{\top, \bot\}} (a!(i) + b?(i))$$



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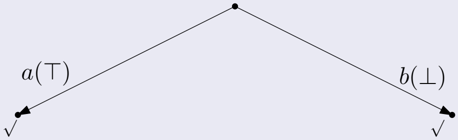

Our approach

We try to bridge the gap by specifying *action visibilities* in the process algebraic protocol specification.
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Structural Operational Semantics: derived formally from PA-term syntax through set of rules.

(Reference: "Operational and Epistemic approaches to protocol analysis: Bridging the Gap", LPAR 2007. Cf. `http://www.win.tue.nl/~mousavi/pai.htm`)

Bridging the gap: our proposal

- We extend actions in a simple process algebra with identity-annotations

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- SOS-rules generate an *Annotated* LTS
- which can be decomposed into LTS and Kripke model.
- On these ALTSs we can check properties in our epistemic temporal language.
- (Spoiler) these ALTSs are like Interpreted Systems

Decorated actions:

$(J)\alpha$: action α is perceived as α by $i \in J$ and as $\rho(\alpha)$ by others.

Process Algebraic Framework with epistemics

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where

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Simple PA with views: Syntax

$$\begin{array}{lcl} d & ::= & (J)a[?,!](\overrightarrow{k}) \\ p, q & ::= & d \mid d;p \mid p+q \mid p \mid\mid q \end{array}$$

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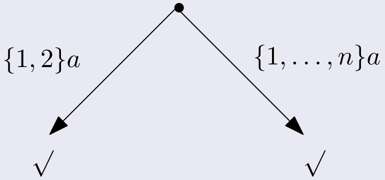
($\Rightarrow \rho$ is now part of the protocol specification!)

Simple PA with views: example

$$(\{2\}b! + (\{1,\ldots,n\})a) \mid\mid (\{1\})b?$$



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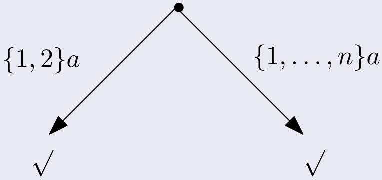

Suppose $\rho(b) = c$. Then in the left branch, $\{3,\ldots,n\}$ see c.

Formal semantics: operational part (Summarized)

$$(\mathbf{a})\,\frac{}{(d,\pi)\overset{d}{\Rightarrow}\surd_{\pi\frown d}}$$

$$(\mathbf{s0})\,\frac{(x_0,\pi)\overset{d}{\Rightarrow}(y_0,\pi')}{(x_0;x_1,\pi)\overset{d}{\Rightarrow}(y_0;x_1,\pi')} \qquad (\mathbf{s1})\,\frac{(x_0,\pi)\overset{d}{\Rightarrow}\surd_{\pi'}}{(x_0;x_1,\pi)\overset{d}{\Rightarrow}(x_1,\pi')}$$

$$(\mathbf{n0})\,\frac{(x_0,\pi)\overset{d}{\Rightarrow}(y_0,\pi')}{(x_0+x_1,\pi)\overset{d}{\Rightarrow}(y_0,\pi')} \qquad (\mathbf{p0})\,\frac{(x_0,\pi)\overset{d}{\Rightarrow}(y_0,\pi')}{(x_0\parallel x_1,\pi)\overset{d}{\Rightarrow}(y_0\parallel x_1,\pi')}$$

$$(\mathbf{p4})\,\frac{(x_0,\pi)\overset{(\mathrm{J})?a}{\Rightarrow}(y_0,\pi') \quad (x_1,\pi)\overset{(\mathrm{J}')!a}{\Rightarrow}(y_1,\pi'')}{(x_0\parallel x_1,\pi)\overset{(\mathrm{J}\cup\mathrm{J}')a}{\Rightarrow}(y_0\parallel y_1,\pi\frown(\mathrm{J}\cup\mathrm{J}')a)}$$

Formal semantics: epistemic part (Summarized)

$$\frac{}{\pi \stackrel{i}{=} \pi} \qquad \frac{i \in J}{\pi \frown J(a) \stackrel{i}{=} \pi \frown J(a)} \qquad \frac{\pi \stackrel{i}{=} \pi' \quad i \notin J \quad \rho(a) = \rho(b)}{\pi \frown J(a) \stackrel{i}{=} \pi' \frown J(b)}$$

$$\frac{\pi \stackrel{i}{\cdots} \pi' \quad i \notin J \quad \rho(a) = \tau}{\pi \frown J(a) \stackrel{i}{=} \pi} \qquad \frac{\pi \stackrel{i}{\cdots} \pi' \quad i \notin J \quad \rho(a) = \tau}{\pi \stackrel{i}{=} \pi' \frown J(a)}$$

Seminal book:

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Interpreted Systems as semantics for epistemic temporal logic.

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Interpreted Systems as semantics for epistemic temporal logic.

Transition systems with rich states:

- global state is n-tuple of local states
- indistinguishability relations between global states generated on the basis of local state for each agent.

Interpreted Systems: framework

- Agents $\mathcal{I} = \{1, \ldots, n\}$
- Local states L_i, global states:$L = \prod_{i=1}^{n} L_i$
- Run r: a sequence of global states
- Protocol R: set of runs
- Valuation function $\nu : L \rightarrow \Phi$
- Indistinguishability $\overrightarrow{l} \overset{i}{\approx} \overrightarrow{l'}$ iff $l_i = l'_i$

Interpreted system: (R, ν)

Our focus: protocol component (not valuation)

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Motivation

Work in progress!

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We want to

- Link the process algebra specs to ISs
- Allow to transform results from one to the other:
  - PA as a syntax for generating ISs
  - exploited analysis tools available for IS
  - characterize semantic properties of classes of PA specs

Trace: sequence of decorated actions.

$[\![-]\!]_{aux}$: *CCSi* process $\mapsto$ set of traces.

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IS for PA

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where $\mid\mid_{tr}$ auxiliary function

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P \mid\mid_{tr} \emptyset \quad \doteq \quad \emptyset \mid\mid_{tr} P \qquad \doteq \quad P
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\{\langle\rangle\} \uplus P \mid\mid_{tr} Q \quad \doteq \quad P \mid\mid_{tr} \{\langle\rangle\} \uplus Q \qquad \doteq \quad (P \mid\mid_{tr} Q)
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$$
\begin{array}{l}
\{(\mathtt{J})\alpha \frown tr\} \uplus P \mid\mid_{tr} \{(\mathtt{J}')\alpha' \frown tr'\} \uplus Q \quad \doteq \\
\qquad (\mathtt{J})\alpha \frown (\{tr\} \uplus P \mid\mid_{tr} \{(\mathtt{J}')\alpha' \frown tr'\} \uplus Q) \cup \\
\qquad (\mathtt{J}')\alpha' \frown (\{(\mathtt{J})\alpha \frown tr'\} \uplus \{tr\} \uplus P \mid\mid_{tr} Q) \cup \\
\qquad \bigcup \{(\mathtt{J} \cup \mathtt{J}')a \frown (\{tr\} \uplus P \mid\mid_{tr} \{tr'\} \cup Q) \mid (\mathtt{J}')a \frown tr' \in Q \\
\qquad\quad (\alpha = a? \wedge \alpha' = a!) \vee (\alpha = a! \wedge \alpha' = a?)\}
\end{array}
$$

IS for PA

$$[\![p]\!]_{tr} = \{tr \mid tr \in [\![p]\!]_{aux} \wedge closed(tr)\}$$

(‘$closed(tr)$: tr contains no send or receive actions)

Formal Results

Comparing operational and IS-semantics:

- There is a one-one correspondence between local states of the protocol in IS semantics and local trace projections in operational semantics

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Consider finite initialized and prefix-closed (fipc) ISs. Characterizing the class of ISs generated:

- If $|A| = 1$: for each fipc interpreted system R, there is a process algebraic description p such that $[\![p]\!]_{tr} = R$.
- For $|A| \geq 2$ and at least 2 agents: there exist fipc ISs that cannot be generated by any process algebraic specification.

Towards Characterization

Cf. embedding of DEL in ISs (van Benthem et al):

- Perfect Recall: by construction
- Synchronicity: depends on properties ρ
- Uniform No Miracles: ??

Future work: relate different ρ-types to structural properties of epistemic relations in ISs.
(E.g. with additional parameters distinguishing more groups of agents.)

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Any questions?

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Thank You!!!