Epistemic Logic for verifying runtime verification communication protocols

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In this work

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Jasmine Xuereb

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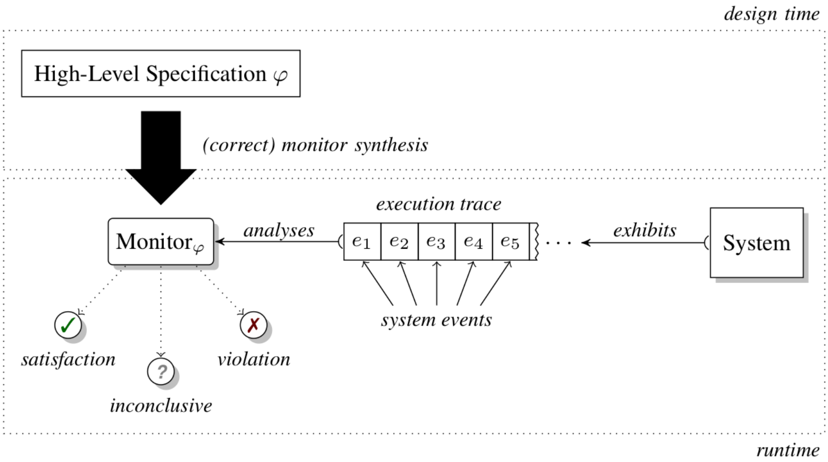
What is this about?



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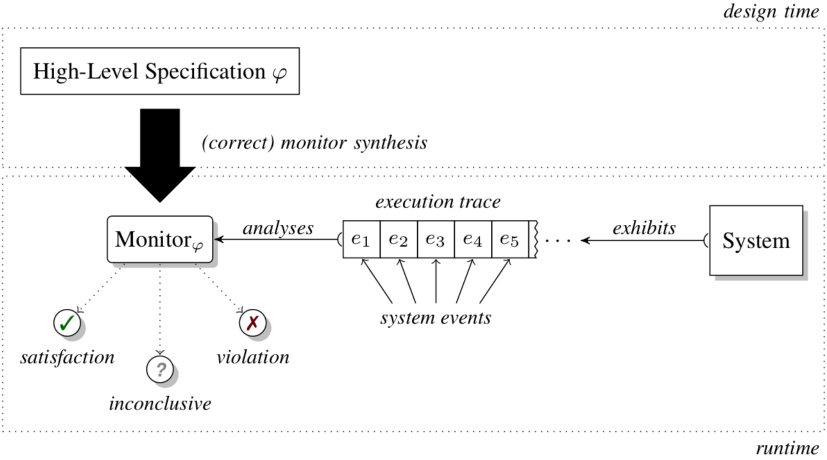

How about monitoring a global property over many systems/components/agents?

Aspects of the problem

- Stating global properties - what does “now” mean?.
- Tackling asynchronous components (trace collection, local clocks).
- Processing **many** traces at runtime.

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Logic | Parallel Setup | **Monitoring Setup**

The Logic: $Hyper^1$-sHML

$$
\begin{array}{llllll}
\varphi ::= \exists_\pi \varphi & \mid \forall_\pi \varphi & \mid \varphi \wedge \varphi & \mid \varphi \vee \varphi & \mid \psi \\
\psi ::= \mathtt{tt} & \mid \mathtt{ff} & \mid [A]\psi & \mid \langle A \rangle \psi & \\
\quad\quad \mid \psi \wedge \psi & \mid \psi \vee \psi & \mid \max x.\psi & \mid \min x.\psi & \mid x,
\end{array}
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where $\pi \in \Pi$, $x \in V$, and $A \subseteq \textsc{Act}_{\Pi}$ is consistent.

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Example: The formula

$$\forall_\pi [a]\mathtt{ff} \sqcap \exists_\pi [b](max\ x.([a]\mathtt{ff}\ \wedge\ [b]x))\ ,$$

over $\textsc{Act} = \{a, b\}$, means that none of the traces start with a, and $b^\omega \in T$.

The Monitors

Sets of traces have different cardinalities. $\Rightarrow$ The monitor for a property should treat the cardinality as a parameter!

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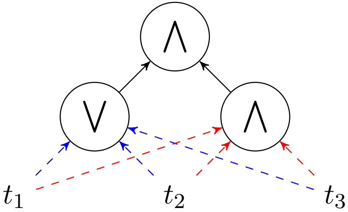

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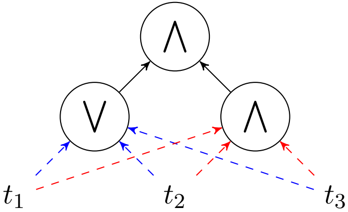

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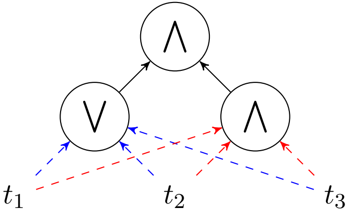

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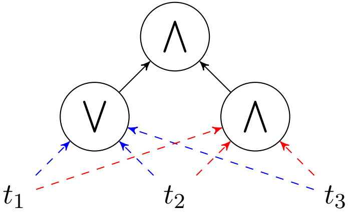

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Instead: Syntax!

$$M \in \textsc{Cmon} ::= \bigvee [m]_k \quad | \quad \bigwedge [m]_k \quad | \quad M \vee M \quad | \quad M \wedge M$$

$$m ::= yes \quad | \quad no \quad | \quad end \quad | \quad a.m \quad | \quad m + n \quad | \quad rec\ x.m \quad | \quad x$$

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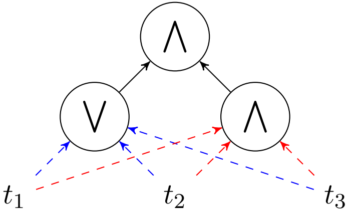

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$$m ::= yes \;|\; no \;|\; end \;|\; a.m \;|\; m + n \;|\; rec\ x.m \;|\; x$$

How do we go from syntax to circuits?

Monitor semantics:

$$\frac{s[m_{[i]}] = yes}{s \to s[{}^{yes}/\bigvee[m]_k]} \qquad \frac{s[m_{[i]}] = no}{s \to s[\bigvee[m]_k \backslash i]} \qquad \frac{s[m_{[i]}] = end}{s \to s[\bigvee[m]_k \backslash end_i]}$$

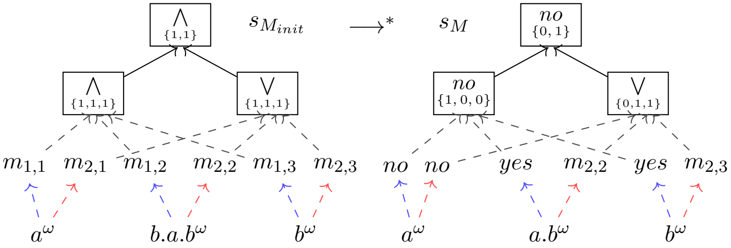
$$\frac{s[\bigvee[m]_k] = 0}{s \to s[{}^{no}/\bigvee[m]_k]} \qquad \frac{s[\bigvee[m]_k] = 2^k}{s \to s[{}^{end}/\bigvee[m]_k]}$$

Instrumentation:

$$\frac{m \xrightarrow{\tau} m'}{m \triangleleft t \xrightarrow{\tau} m' \triangleleft t} \qquad \frac{m \xrightarrow{a} m'}{m \triangleleft a.t \xrightarrow{a} m' \triangleleft t} \qquad \frac{\forall j \in \{1, \dots r\},\ m_{j[i]} \triangleleft t \xrightarrow{a} m'_{j[i]} \triangleleft t'}{s \triangleleft (\overrightarrow{m} \triangleleft T) \to s \triangleleft (\overrightarrow{m}[{}^{m'_{j[i]}}/{}_{m_{j[i]}},\ \forall j] \triangleleft T[{}^{t'}/{}_{t}])}$$

$$\frac{s \to s'}{s \triangleleft (\overrightarrow{m} \triangleleft T) \to s' \triangleleft (\overrightarrow{m} \triangleleft T)} \qquad \frac{s \triangleleft (\overrightarrow{m} \triangleleft T) \to s \triangleleft (\overrightarrow{m}[{}^{v}/{}_{n_{j[i]}}] \triangleleft T[{}^{t'}/{}_{t}])}{s \triangleleft (\overrightarrow{m} \triangleleft T) \to s[{}^{v}/{}_{g_{m_{j[i]}}}] \triangleleft (\overrightarrow{m}[{}^{v}/{}_{n_{j[i]}}] \triangleleft T[{}^{t'}/{}_{t}])}$$

Formula: $\forall_\pi [a]\texttt{ff} \sqcap \exists_\pi [b](max\ x.([a]\texttt{ff}\ \wedge\ [b]x))$.
Monitor:



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And we proved we **can** have these.

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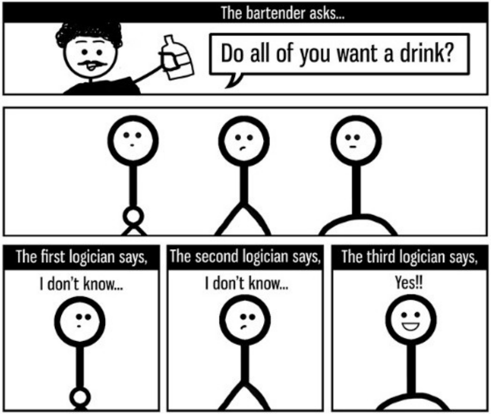
Three Logicians walk into a bar



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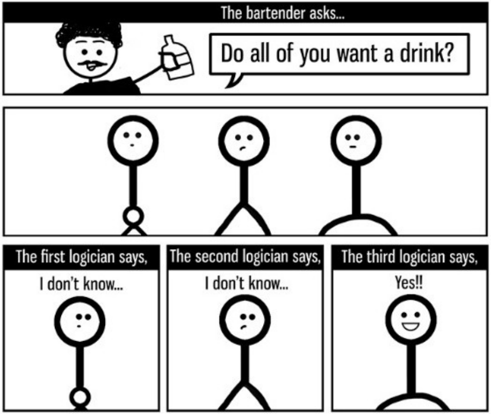

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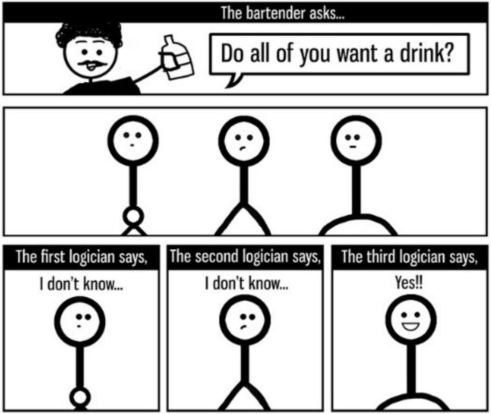

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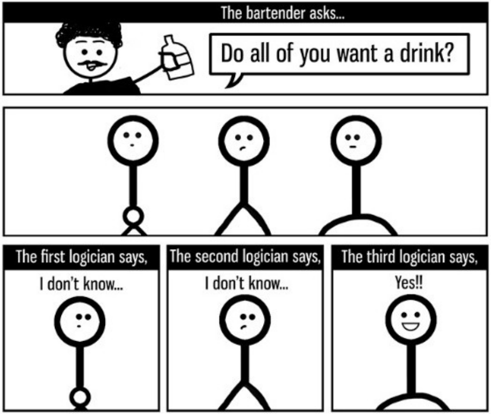
We want:

- Use this (correct) proofs to extract good monitoring procedures.



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We want:

- Use this (correct) proofs to extract good monitoring procedures.
- Hopefully extract them automatically (proofs and protocols).

Definition (Multi-agent epistemic logic)

For a set of agents $\mathcal{A}$, a formula ϕ in the multi-agent modal logic is defined as:

$$\phi ::= \top \quad | \; \bot \quad | \; p \quad | \; \neg\phi \quad | \; \phi \wedge \phi \quad | \; K_i\phi \quad | \; C_G\phi$$

where p is an atomic formula, $i \in \mathcal{A}$, and $G \subseteq \mathcal{A}$. Implication and disjunction can be defined from the other operators as usual.

Lets get our hands dirty!

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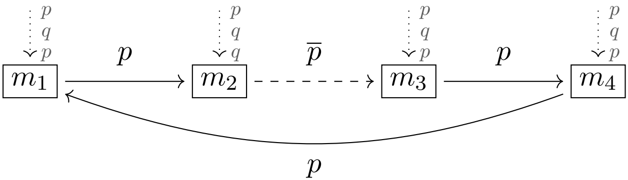
- This logic can help us express the ***state*** of knowledge between agents in some distributed setup.
- Evolution of knowledge of agents (monitors) coming soon.



A Communication Protocol for

$$\varphi = \forall\pi\forall\pi' max\ x([p_\pi, \overline{p}_{\pi'}]\mathtt{ff} \wedge [p_\pi, p_{\pi'}]x \wedge [\overline{p}_\pi, \overline{p}_{\pi'}]x)\ ,$$

i.e. "all traces agree on p."

An example correctness proof - Natural Deduction!

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Now what? Automate proofs (tableaus), use logic that expresses the *acquisition of knowledge*, even more success.

Thank you for your attention!

Questions?