HyperPCTL: A Temporal Logic for Probabilistic Hyperproperties

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Presentation outline

1. Motivation
2. HyperPCTL Syntax and Semantics
3. HyperPCTL in Action
4. HyperPCTL Model Checking
5. Conclusion

Motivation

EDAS Conference and Journal Management System

Click on the menu items above to submit and review papers.

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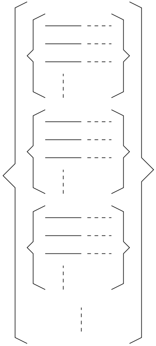
Classical trace properties cannot express relation among multiple traces

Hyperproperties (Clarkson, Schneider - 2010)

A hyperproperty is a set of sets of traces.



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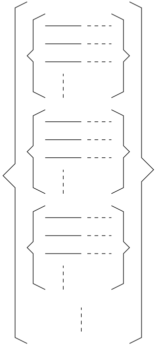

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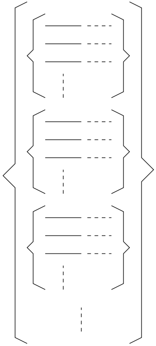

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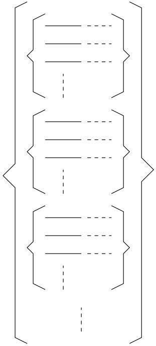

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- HyperCTL*

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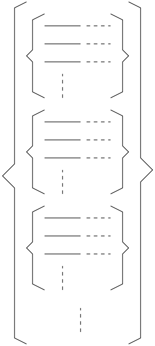

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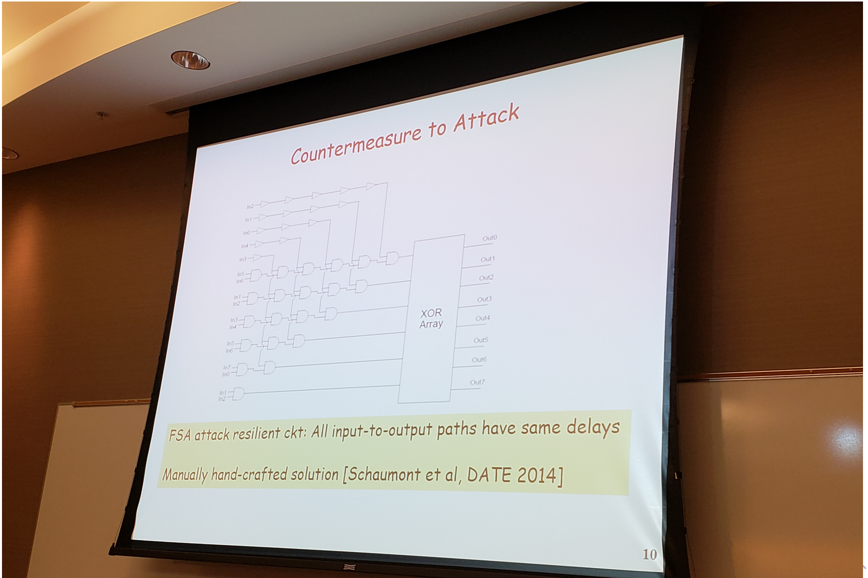
Hyperproperty Satisfaction

A system P satisfies a hyperproperty ψ (denoted, $P \models \psi$) iff Traces$(P) \in \psi$; i.e, language equality.

Timed Hyperproperties



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- If $h = 5$, then at termination, $\mathbb{P}(l = 1) = 1/4096$ and $\mathbb{P}(l = 2) = 4095/4096$.

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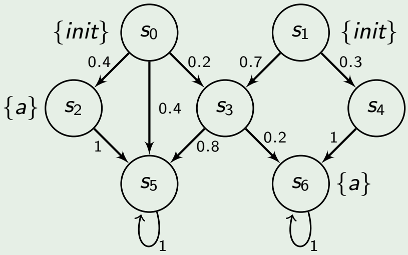
Presentation outline

HyperPCTL Semantics

Example



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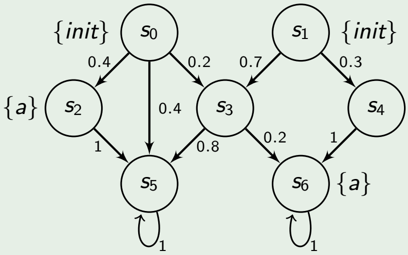

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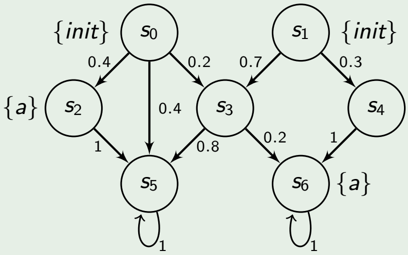

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$$Pr[\mathcal{A}(D_1) \in S] \leq e^{\epsilon} \cdot Pr[\mathcal{A}(D_2) \in S].$$

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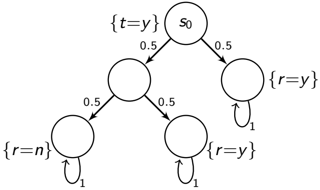

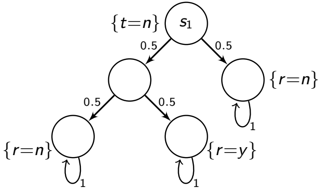

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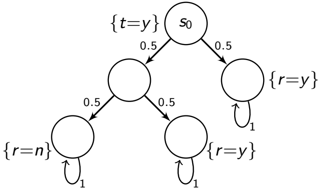

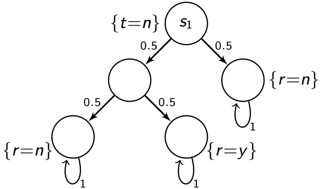

HyperPCTL formula for DP

$$\forall\sigma.\forall\sigma'.\Big[\Big(\big((t{=}n)_\sigma \wedge (t{=}y)_{\sigma'}\big) \Rightarrow \Big(\mathbb{P}\big(\Diamond(r{=}n)_\sigma\big) \leq e^{\ln 3}\cdot\mathbb{P}\big(\Diamond(r{=}n)_{\sigma'}\big)\Big)\Big] \wedge$$
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$$\psi_{\mathsf{pc}_1} = \forall \sigma. \forall \sigma'. c_\sigma \ \wedge \ \Big(\mathbb{P}(\Diamond e_\sigma) > \mathbb{P}(\neg c_{\sigma'} \, \mathcal{U} e_{\sigma'}) \Big).$$

HyperPCTL Examples

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Probabilistic Bisimulation

$$\varphi_{\text{pb}} = \forall\sigma.\forall\sigma'.\bigwedge_{i=1}^{k}\left[(a^i_\sigma \wedge a^i_{\sigma'}) \Rightarrow \left[\psi^{AP} \wedge \bigwedge_{j=1}^{k}\mathbb{P}(\bigcirc a^j_\sigma) = \mathbb{P}(\bigcirc a^j_{\sigma'})\right]\right]$$

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HyperPCTL Model Checking

Theorem 1

For a finite Markov chain $\mathcal{M}$ and HyperPCTL formula ψ, the HyperPCTL model checking problem (to decide whether $\mathcal{M} \models \psi$) can be solved in time $O(\text{poly}(|\mathcal{M}|))$.

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Theorem 2

The HyperPCTL model checking problem is PSPACE-hard in the number of quantifiers in the formula.

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We presented a polynomial-time model checking algorithm in the size of the input DTMC (exponential in the size of the input HyperPCTL formula).

Future Work

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Thank you!