Space & Time: Tackling Semantic Challenges in MBSE for Cyber-Physical Systems(CPS)

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History and Motivation

- **Cooperative Agreement**: NIST 70NANB11H148 (2012-2014) Modeling and Synthesis of Cyber-Physical Systems
- **Motivation:** Need for "built-in" smartness (knowledge) infrastructure in MBSE for "correct by design" CPS

Domains and Spatio-Temporal Semantics are essential for efficient reasoning, control and decision making in safety-critical CPS

Summary Results and Future work

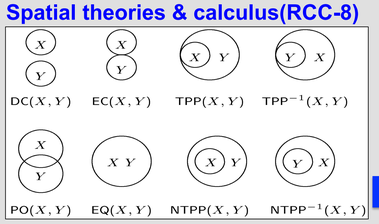
- **Sample Results**: Ontological framework for Time-based reasoning for MBSE of CPS*(CSER2013)*, Semantic Platforms for CPS*(INCOSE2014)*, Tubes and Metrics for solving the Dilemma Zone problem*(ICONS2015)*. ***Applications:*** Safety critical Transportation systems(0D,1D,2D+t), Unmanned & Building systems(2D,3D+t+TZ), Energy(2D+t+TZ)…
- **Future work:** (1) Integrated spatio-temporal reasoning algorithm for safety-critical CPS, (2) Synthesis of physically-aware control software for distributed CPS, (3) Application to more complex CPS problems

Current state of the research

Spatio-Temporal Framework for MBSE of CPS

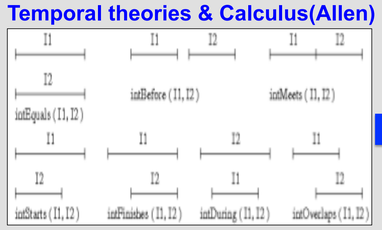
- ✓**Ontologies-based semantic framework** for CPS modeling and analysis; Time and Space as meta-domains
- ✓**Modular, flexible, reusable reasoning-enabled platform :** System-level property (safety) study - as a decision problem - in MBSE for CPS
- ✓**Decidable fragments of temporal and spatial calculus** in support of reasoning services/ algorithms

Spatial theories & calculus(RCC-8)



Space formalization

Temporal theories & Calculus(Allen)



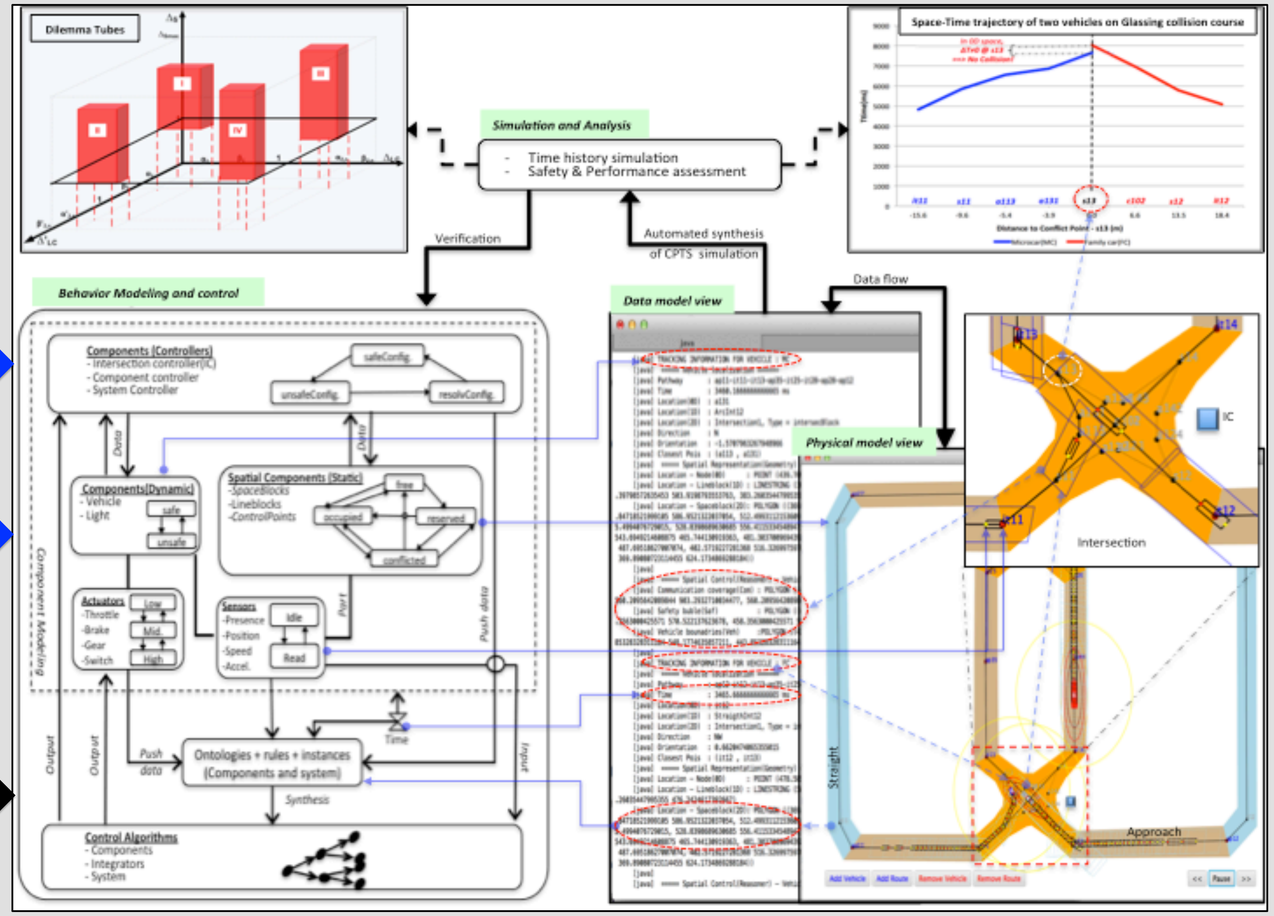
Time formalization

Descripion Logics-based semantics(DL)

Name	Syntax	Semantics	Symbol
Top	$\top$	$\Delta^{\mathcal{I}}$	$\mathcal{AL}$
Bottom	$\bot$	$\emptyset$	$\mathcal{AL}$
Intersection	$C \sqcap D$	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$	$\mathcal{AL}$
Union	$C \sqcup D$	$C^{\mathcal{I}} \cup D^{\mathcal{I}}$	$\mathcal{U}$
Negation	$\neg C$	$\Delta^{\mathcal{I}} \setminus C^{\mathcal{I}}$	$\mathcal{C}$
Value restriction	$\forall R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \forall b.\ (a,b) \in R^{\mathcal{I}} \rightarrow b \in C^{\mathcal{I}}\}$	$\mathcal{AL}$
Existential quant.	$\exists R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \exists b.\ (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}$	$\mathcal{E}$
Unqualified number restriction	$\geqslant n\, R$ $\leqslant n\, R$ $= n\, R$	$\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}}\}\rvert \geq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}}\}\rvert \leq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}}\}\rvert = n\}$	$\mathcal{N}$
Qualified number restriction	$\geqslant n\, R.C$ $\leqslant n\, R.C$ $= n\, R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}\rvert \geq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}\rvert \leq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}\rvert = n\}$	$\mathcal{Q}$
Role-value-map	$R \subseteq S$ $R = S$	$\{a \in \Delta^{\mathcal{I}} \mid \forall b.(a,b) \in R^{\mathcal{I}} \mapsto (a,b) \in S^{\mathcal{I}}\}$ $\{a \in \Delta^{\mathcal{I}} \mid \forall b.(a,b) \in R^{\mathcal{I}} \mapsto (a,b) \in S^{\mathcal{I}}\}$	
Agreement and disagreement	$u_1 = u_2$ $u_1 \neq u_2$	$\{a \in \Delta^{\mathcal{I}} \mid \exists b \in \Delta^{\mathcal{I}}.\ u_1^{\mathcal{I}}(a) = b = u_2^{\mathcal{I}}(a)\}$ $\{a \in \Delta^{\mathcal{I}} \mid \exists b_1, b_2 \in \Delta^{\mathcal{I}}.\ u_1^{\mathcal{I}}(a) = b_1 \neq b_2 = u_2^{\mathcal{I}}(a)\}$	$\mathcal{F}$
Nominal	I	$I^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$ with $\lvert I^{\mathcal{I}}\rvert = 1$	$\mathcal{O}$

Applies to

➢ *Implementation:* Spatio-temporal modeling and reasoning for CPTS



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