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Form Approved
OMB No. 0704-0188

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1. REPORT DATE **07 NOV 2014**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Contract-Based Integration of Cyber-Physical Analyses, Poster**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Dionisio de Niz Ivan Ruchkin; Sagar Chaki; David Garlan**		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Software Engineering Institute Carnegie Mellon University Pittsburgh, PA 15213**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**1**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

er, the outputs of the former may be invalid.

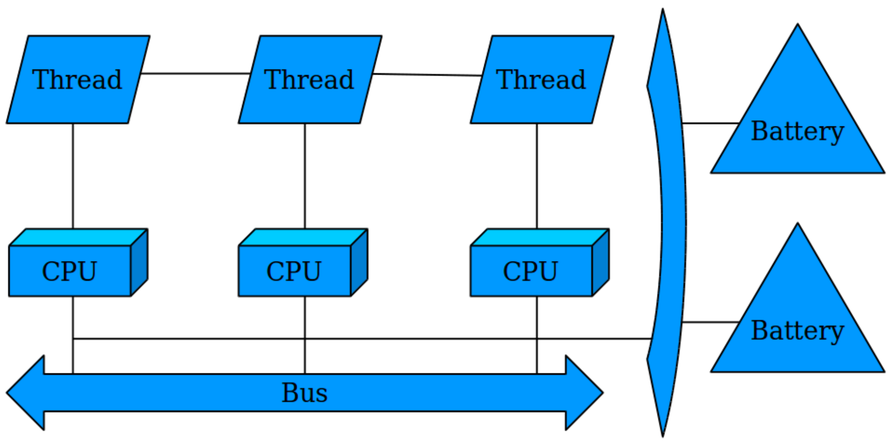
- Specification of such implicit assumptions and detection of their violation is left to human designers, who are often unable to cope with complexity.
- Analysis integration problems discovered late in development lead to expensive changes to the system.

Hence the research question:

- How to specify analysis compositions and verify their correctness?

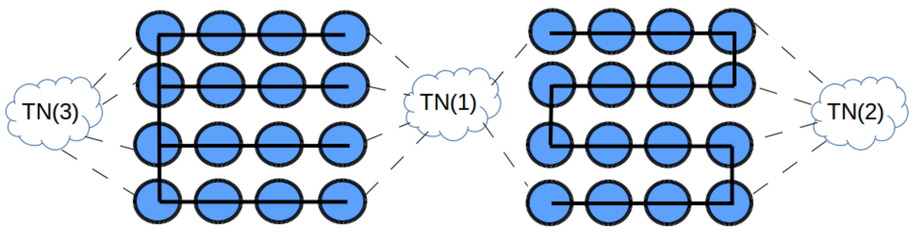
Example System

Consider an autonomous aircraft as an example CPS. It operates data with different classes of security, from normal to top secret (ThSecCl). Periodic threads (T) execute on several processors (C). The aircraft is powered with multi-cell reconfigurable batteries (B). The system's architecture shown below is specified in AADL.



A battery has a matrix of cells, and each cell has a current level of charge. A battery scheduler determines parallel and sequential connections between groups of cells in order to satisfy voltage and current output requirements.

Thermally, each cell exchanges heat with its neighboring cells (*thermal neighbors,* TN) through an electrical connector, affecting the risk of a *thermal runaway*.



policies SchedPol.

- $\mathcal{S}$ — a set of static functions that encode design-time properties. E.g., thread period Per, thread-to-CPU binding CPUBind, and system-wide Voltage.
- $\mathcal{R}$ — a set of runtime functions that encode dynamic properties. E.g., preemption relation canPrmpt(t_1, t_2) and number of cells in a battery b with i thermal neighbors TN(b, i).
- $\mathcal{T}$ — execution semantics of σ — a set of sequences of assignments to $\mathcal{R}$. We use Promela programs to implement the semantics.
- $[\![]\!]_\sigma$ — a domain interpretation of $\mathcal{A}$, $\mathcal{S}$, and $\mathcal{T}$. E.g., $[\![\text{SchedPol}]\!]_\sigma$ = {RMS, DMS, EDF}.

Formally, an AADL architectural model **m** is an interpretation $[\![]\!]_m$ of $\mathcal{A}$, $\mathcal{S}$, and $\mathcal{T}$. E.g., $[\![T]\!]_m$ = { SensorSample, $Ctrl_1$, $Ctrl_2$ }, $[\![\text{CPUBind}]\!]_m$ = { ($Ctrl_1$, CPU_1), ($Ctrl_2$, CPU_2), …) }.

$[\![]\!]_\sigma \cup [\![]\!]_m$ form a full interpretation of $\mathcal{A}$, $\mathcal{S}$, $\mathcal{R}$, and $\mathcal{T}$.

Analysis Contracts

Each analysis is assigned a *contract* — a tuple (I, O, A, G).

- Inputs $I \subseteq \mathcal{A} \cup \mathcal{S}$ declare elements that the analysis reads.
- Outputs $O \subseteq \mathcal{A} \cup \mathcal{S}$ declare elements that the analysis writes.
- Assumptions $A \subseteq \mathcal{F}_\sigma$ are logical statements that must be satisfied by every input model to the analysis: $\mathbf{m} \vDash A$.
- Guarantees $G \subseteq \mathcal{F}_\sigma$ are logical statements that must be satisfied by every output model of the analysis: $\mathbf{m} \vDash G$.

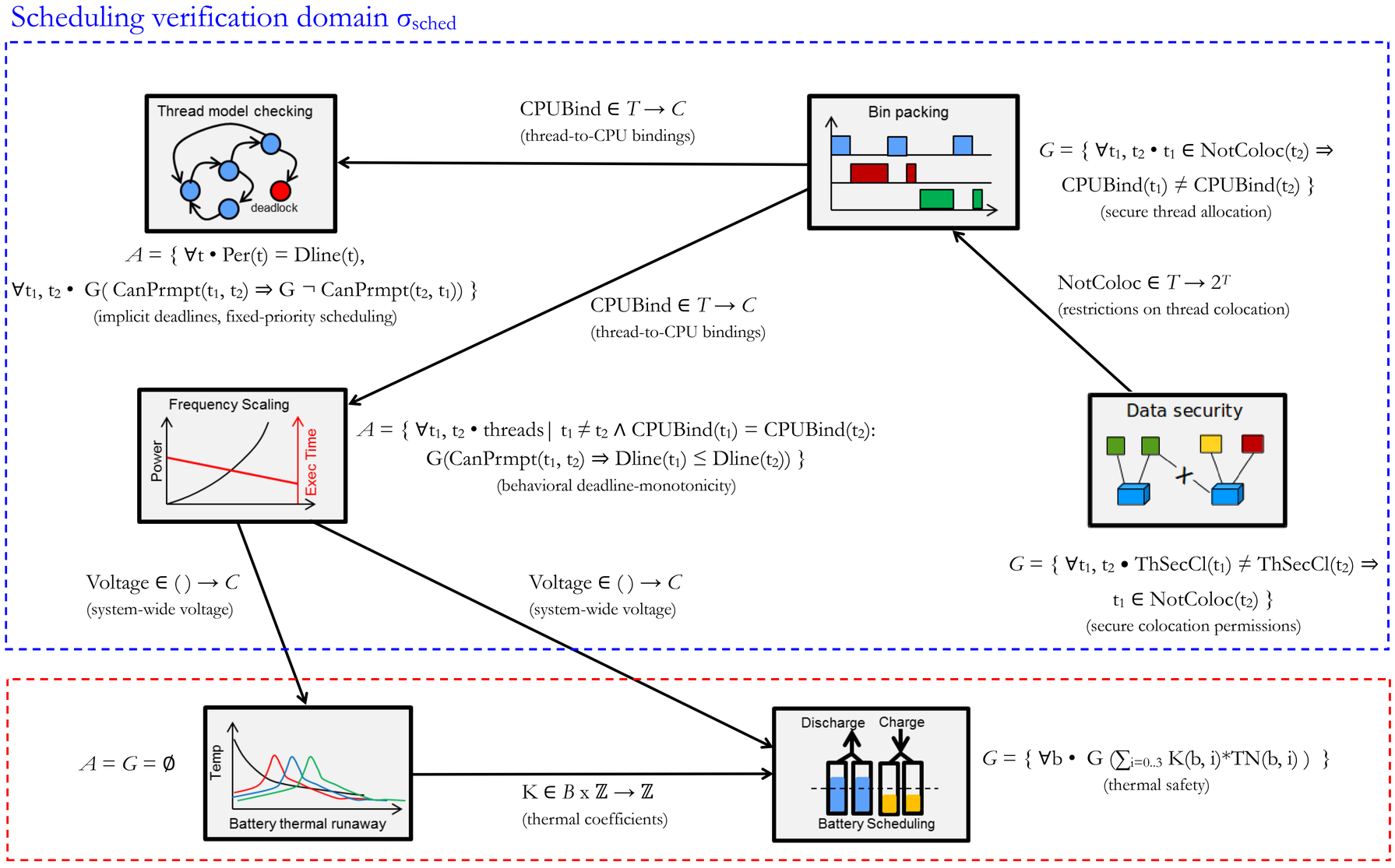
Assumption and guarantee formulas have the following syntax:

$$\mathcal{F}_\sigma ::= \forall\, v_1 \ldots v_j \bullet \varphi \mid \exists\, v_1 \ldots v_j \bullet \varphi \mid$$
$$\forall\, v_1 \ldots v_j \bullet \varphi : \psi \mid \exists\, v_1 \ldots v_j \bullet \varphi : \psi,$$

where φ is a predicate logic formula over $\mathcal{A} \cup \mathcal{S}$, ψ is an LTL formula over $\mathcal{A} \cup \mathcal{S} \cup \mathcal{R}$.

Example Analyses

Scheduling verification domain σ_{sched}



Battery verification domain σ_{batt}

Am ordering $\langle C_1 \ldots C_n \rangle$ of contract
if predecessors are not dependent o

$$\forall i \in [1, n] \bullet \forall j \in [1, i) \bullet C_j.$$

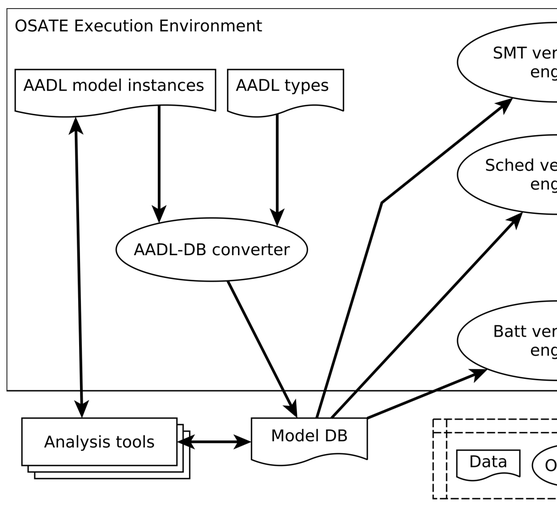
Consider a graph with vertices bein
being contract dependencies. There
ing of contracts if and only if the g
it is not cyclic, any topological orde

Contract Verification

The goal of contract verification is

For purely first-order formulas that
decide satisfiability via SMT solving
generated based on $\mathcal{A}$ and $\mathcal{S}$ menti
SMT solver is invoked on $\neg\, \varphi$ (or
tification). A universally (existential
is satisfied if and only if UNSAT (S

For formulas combining predicate f
formula ψ, we first generate an SM
find all valuations of $v_1 \ldots v_j$ that satis
valuation we call Spin on a Promela
ments $\mathcal{T}$ for **m** in the domain of ψ.
formed into an LTL property speci
universally (existentially) quantified
and only if the LTL property holds
valuations. The architecture of our
shown below:



Experimental Results

Effectiveness: we have been able to de
tion errors and verify their absence
the example.

Scalability: the results of scalability e
implementations of $\mathcal{T}$ are shown in

$\mathcal{T}_{sched}$:

Threads	(R/D)MS time*	EDF time*
3	0.01	0.01
4	0.01	0.52
5	0.07	33.4
6	0.37	2290.0
7	2.18	memlim
8	12.4	memlim
9	71.2	memlim
10	421	memlim
11	memlim	memlim

$\mathcal{T}_{ba}$

Cells
9
12
16
20
25

* All ti

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