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SEI Research Review
Contract-Based Integration of CPS Analyses

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Motivation

The development of Cyber-Physical Systems (aircrafts, cars, trains, robots, etc.) increasingly relies on many types of analyses from different disciplines for assurance purposes

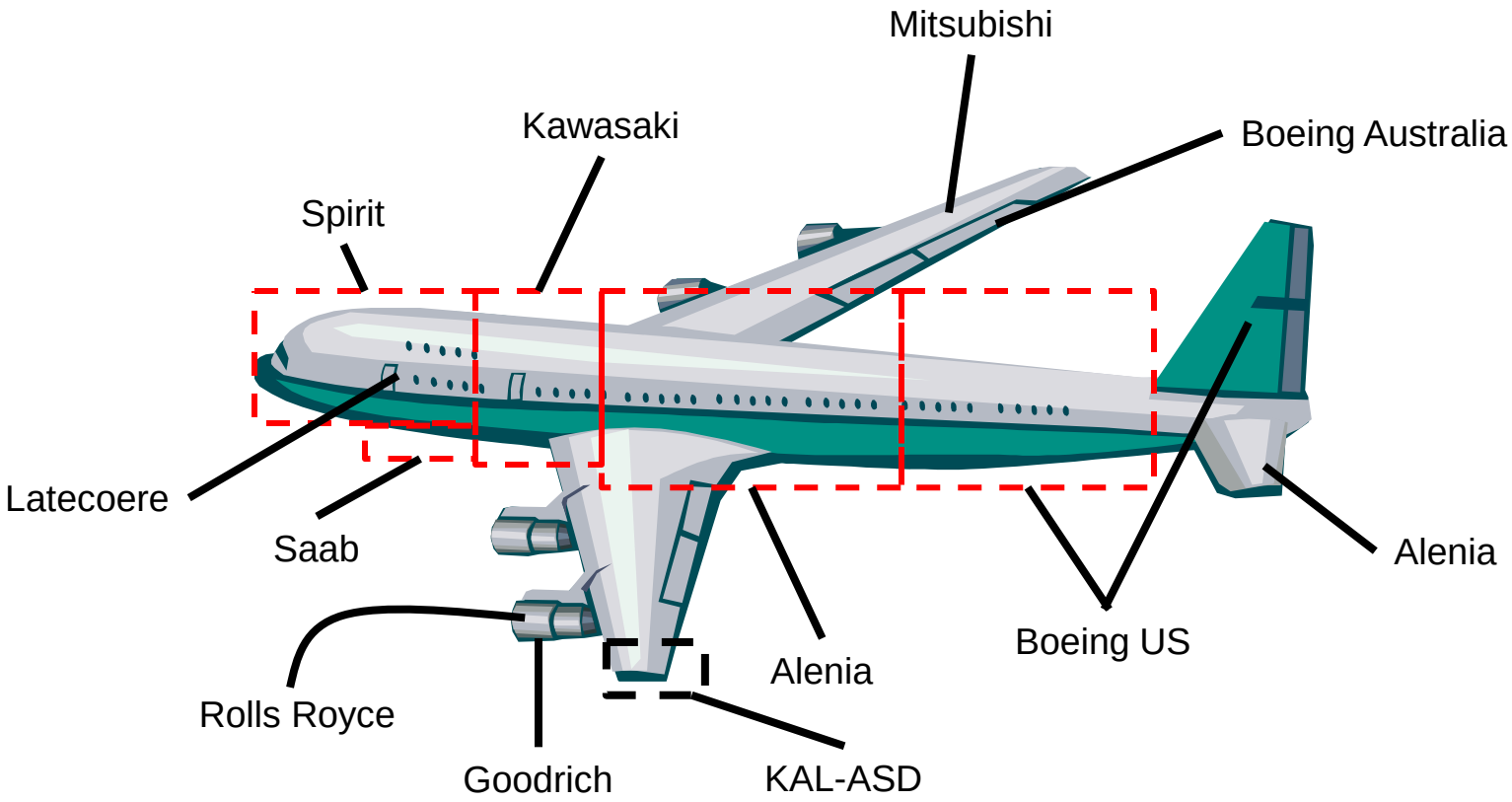
- Control stability, scheduling, logic, thermal, power, aerodynamics, etc.

Large CPS are integrated out of components developed by suppliers that use their own analysis methods and make their own assumptions

Analysis assumption mismatches are discovered late in the system integration phase

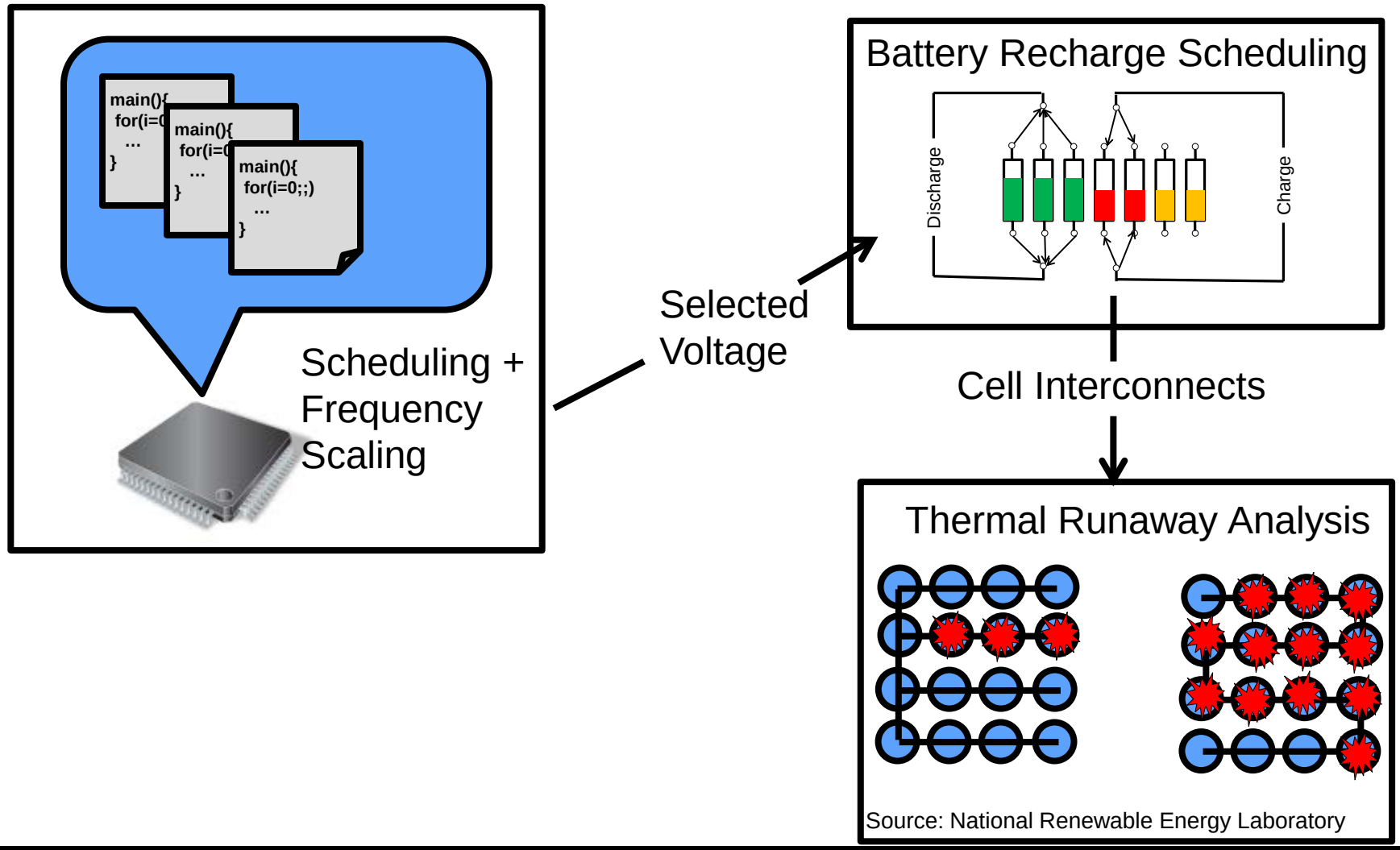
- Difficult and costly to solve

Boeing 787 Suppliers

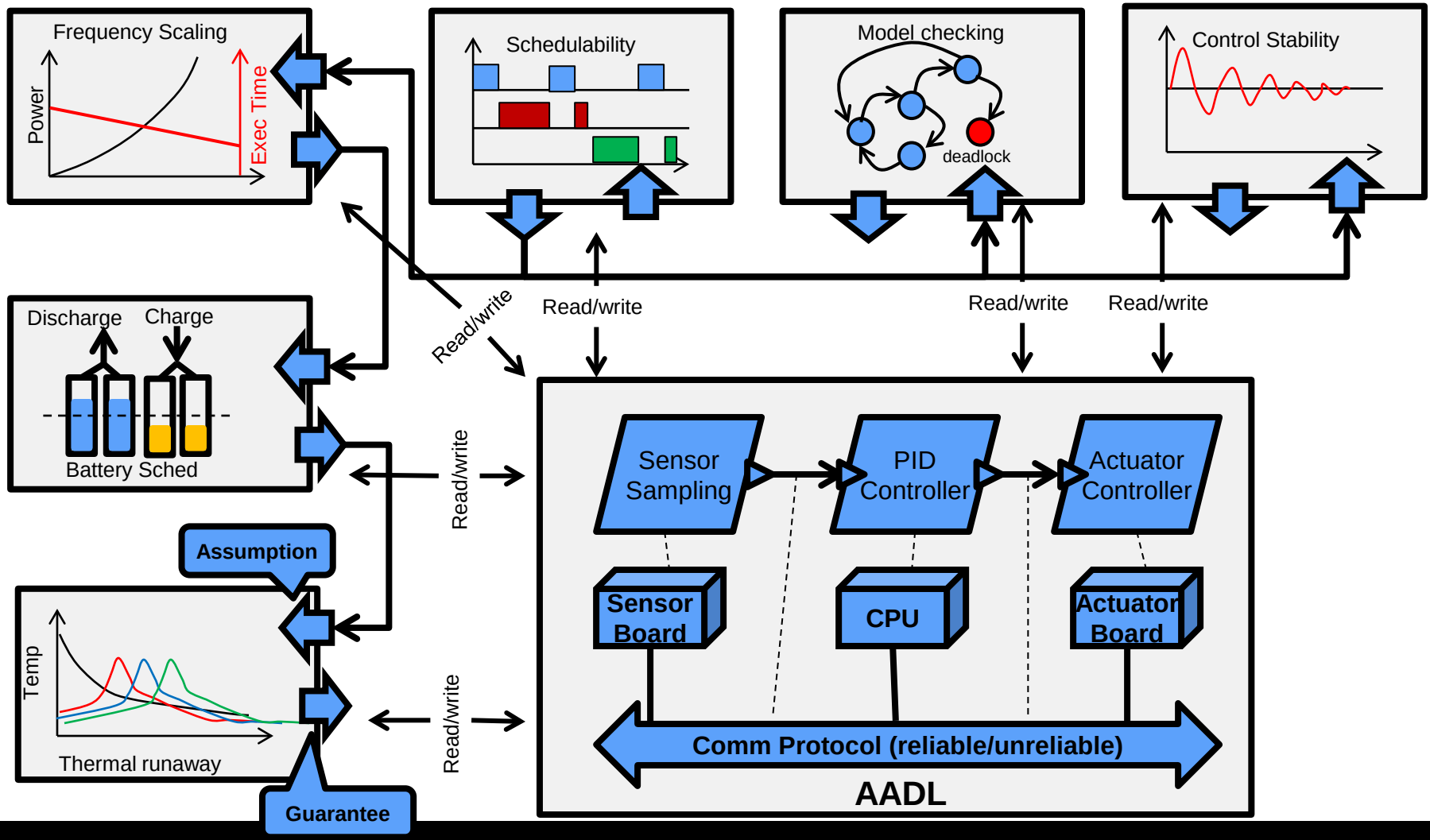


Source: Boeing / Reuters

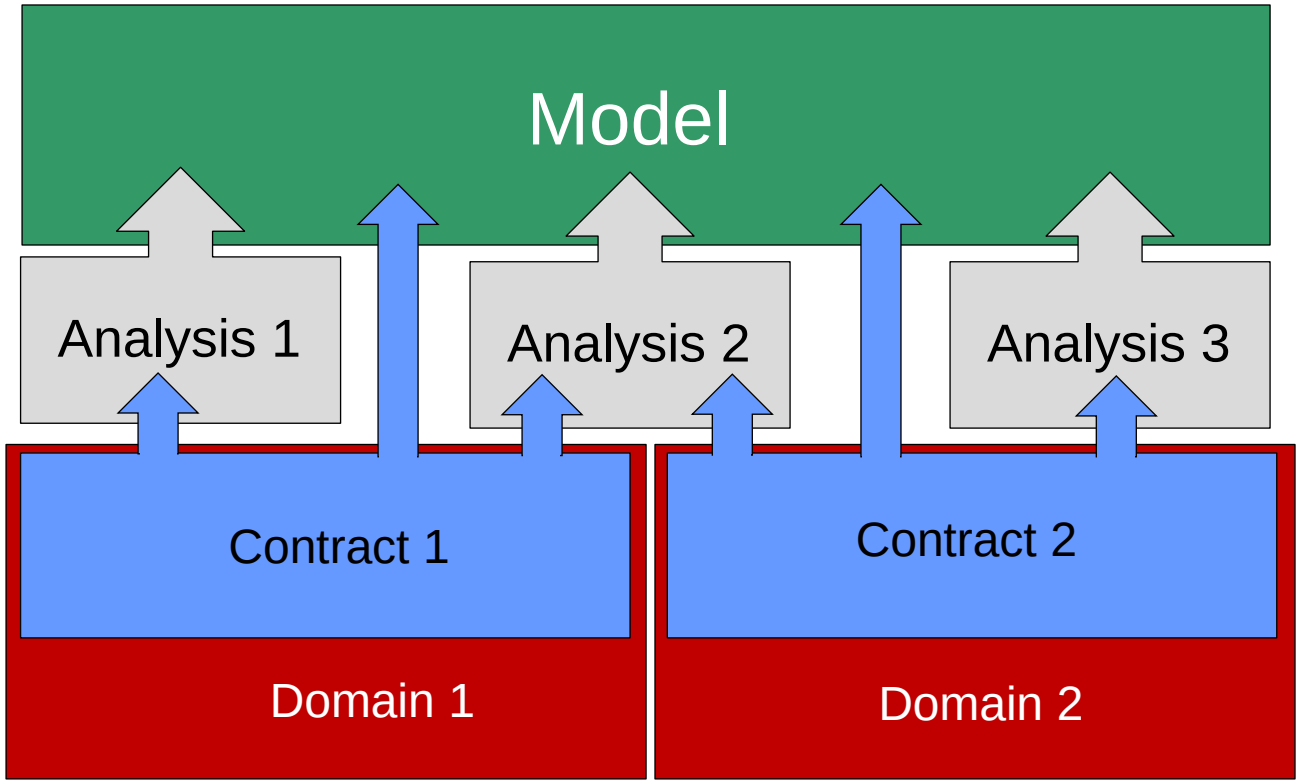
Analyses Interactions



Analysis Contracts



Analysis Contract Scheme



Contract Language & Verification

Contract formulas

- Given domain $\sigma = (\mathcal{A}, \mathcal{S}, \mathcal{R}, \mathcal{T}, [\![\cdot]\!]_\sigma)$,
- $\mathcal{F}_\sigma ::= \forall\, v_1, \ldots, v_j \cdot \phi \mid \exists\, v_1, \ldots, v_j \cdot \phi \mid \forall\, v_1, \ldots, v_j \cdot \phi : \psi \mid \exists v_1, \ldots, v_j \cdot \phi : \psi$
  - $v_i : A_i$, ϕ: static (first order) formula
  - ψ : LTL formula

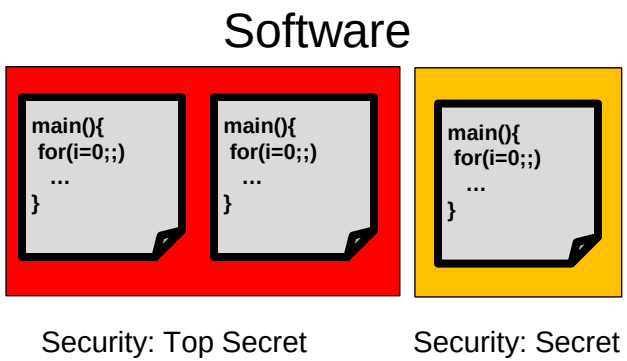
Contract $C = (I, O, A, G)$

- $I \subseteq (\mathcal{A} \cup \mathcal{S})$: Sorts and properties read by the analysis
- $O \subseteq (\mathcal{A} \cup \mathcal{S})$: Sorts and properties written by the analysis
- $A \subseteq \mathcal{F}_\sigma$: assumptions: must be true in input
- $G \subseteq \mathcal{F}_\sigma$: guarantees: must be true in output

Verification

- Contract (& analysis) dependency: $\mathrm{d}(\mathrm{C_i}, \mathrm{C_j}) : \mathrm{C_i}.\mathrm{I} \cap C_j.O \neq \emptyset$
- First order: in SMT (Z3), LTL : Model checker

Example: Surveillance Aircraft



Analysis

Security: tasks of different level to different processor

Scheduling: meet all deadlines

Freq. Scaling: minimize power

Logic: no deadlocks or race conditions

Battery scheduling: meet battery lifetime

Battery thermal: no runaways

Surveillance Aircraft Contracts

Security Analysis

- $An_{sec}.C{:}\, I = \{T, ThSecCl\}, O = \{NotColoc\}, A = \emptyset, G = \{g\}$
  - $g{:}\, \forall\, t_1, t_2 \cdot ThSecCl(t_1) \neq ThSecCl(t_2) \Rightarrow t_1 \in NotColoc(t_2)$

Multiprocessor scheduling: (Binpacking + scheduling)

- $An_{sched}.C{:}\, I = \{T, C, NotColoc, Per, WCET, Dline\}, O = \{CPUBind\}, A = \emptyset, G = \{g\}$
  - $g{:}\, \forall\, t_1, t_2 \cdot t_1 \in NotColoc(t_2) \Rightarrow CPUBind(t_1) \neq CPUBind(t_2)$

Frequency Scaling

- $An_{freqsc}.C{:}\, I = \{T, C, CPUBind, Dline\}, O = \{CPUFreq\}, G = \emptyset, A = \{a\}$
  - $a{:}\, \forall t_1, t_2 \cdot CPUBind(t_1) = CPUBind(t_2){:}\, G(CanPrmpt(t_1, t_2) \Rightarrow Dline(t_1) < Dline(t_2)$

Model checking periodic program (REK):

- $An_{rek}.C{:}\, I = \{T, C, Per, Dline, WCET, CPUBind\}, O = \{ThSafe\}, G = \emptyset, A = \{a_1, a_2\}$
- $a_1{:}\, \forall t \cdot Per(t) = Dline(t),\ a_2{:}\, \forall t_1, t_2 \cdot G(Canprmpt(t_1, t_2) \Rightarrow G\, \neg CanPrmpt(t_2, t_1))$

Thermal runaway:

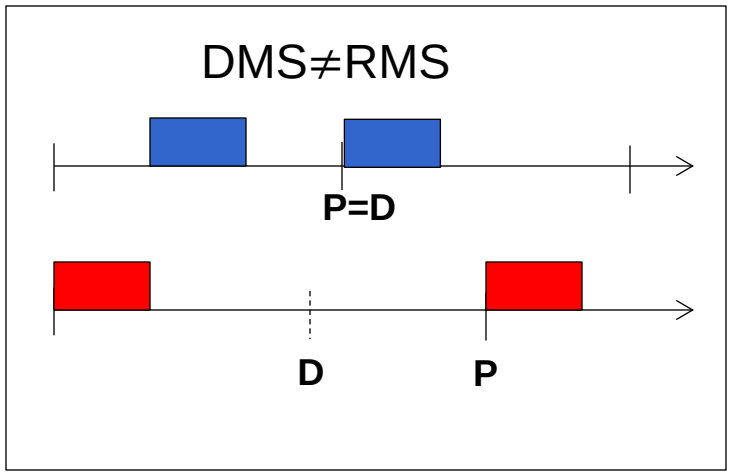
- $An_{therm}.C{:}\, I = \{B, BatRows, BatCols, Voltage\}, O = \{K\}, A = \emptyset, G = \emptyset$

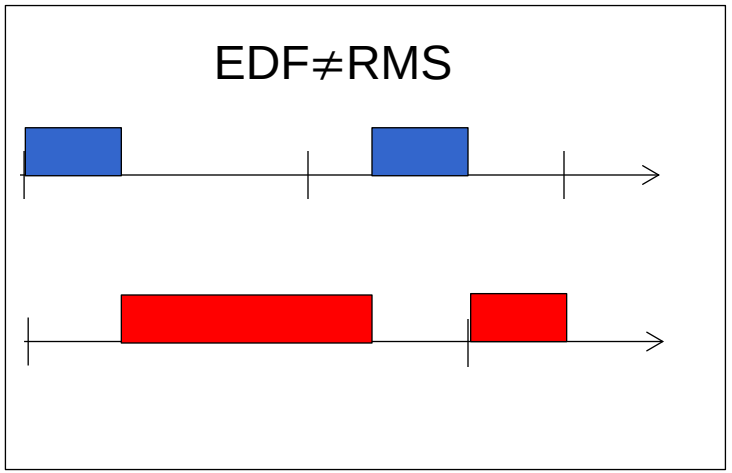
Battery Scheduling

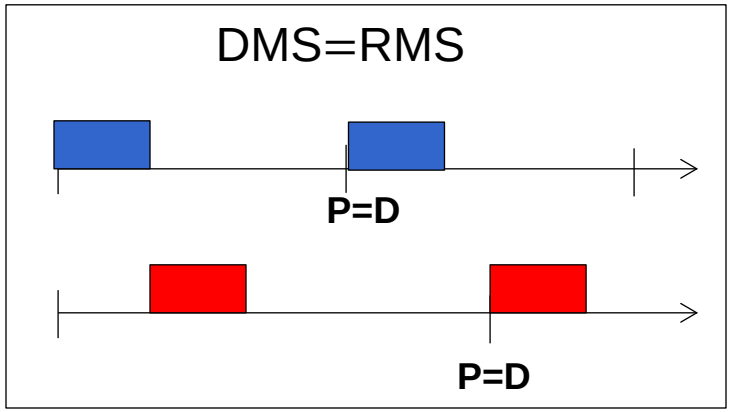
- $An_{bsched}.C{:}\, I = \{B, BatRows, BatCols\}, O = \{BatConnSchedPol, HasReqLifetime, SeriqlReq, ParalRea\}, A = \emptyset, G = \{g\}$
- $g{:}\, G(K(0) \times TN(0) + K(1) \times TN(1) + K(2) \times TN(2) + K(3) \times TN(3) \geq 0)$

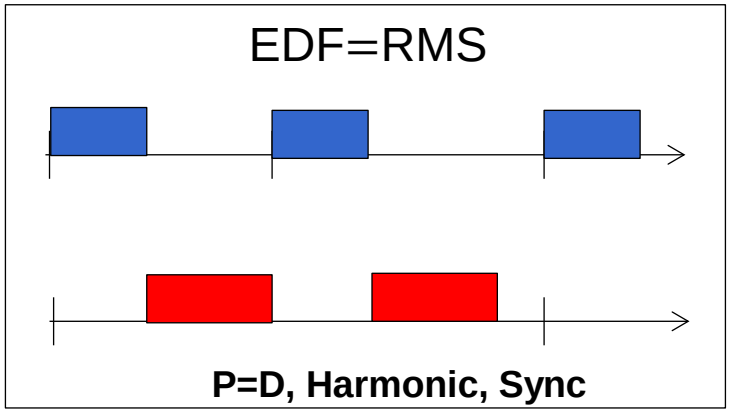
Frequency Scaling Assumption

$a: \forall t_1, t_2 \cdot CPUBind(t_1) = CPUBind(t_2): G(CanPrmpt(t_1, t_2) \Rightarrow Dline(t_1) < Dline(t_2)$









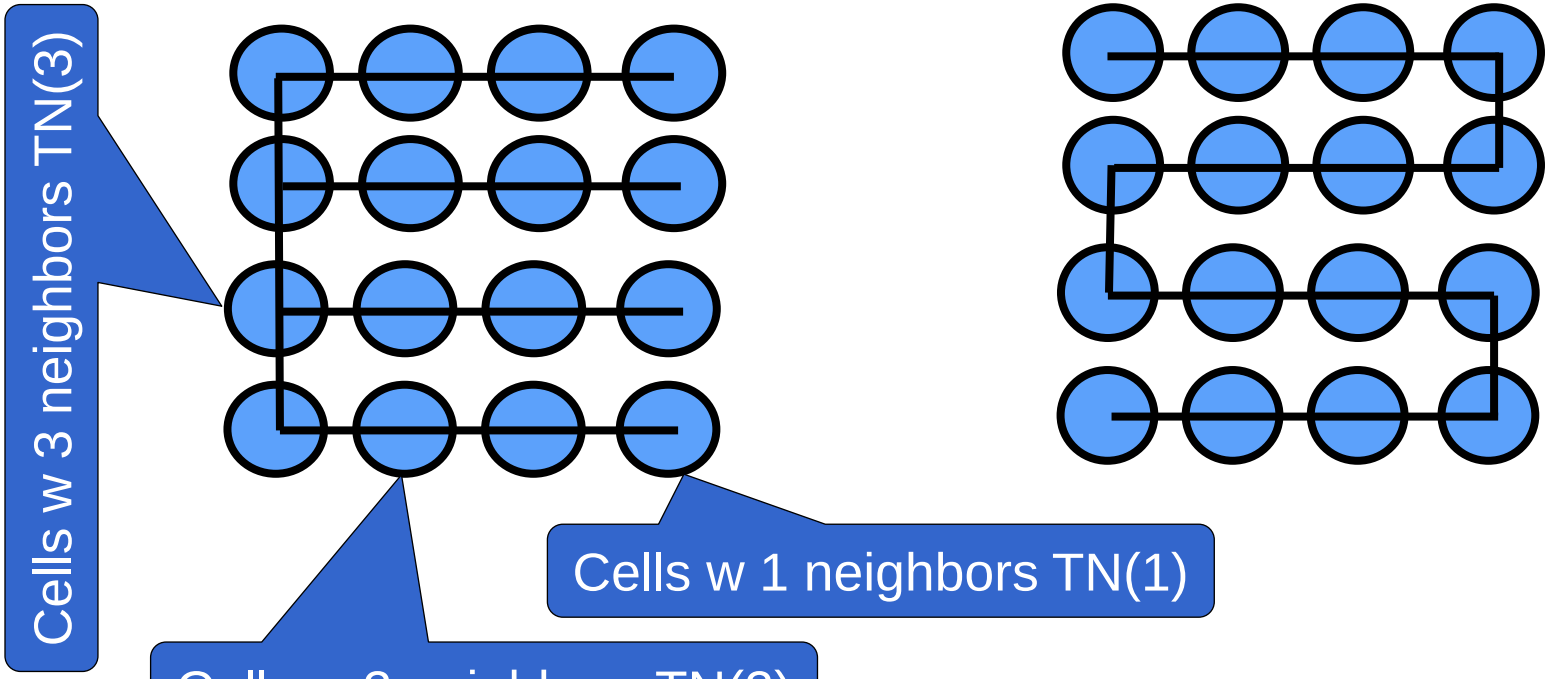
Battery Scheduling Assumption

$$g: G(K(0) \times TN(0) + K(1) \times TN(1) + K(2) \times TN(2) + K(3) \times TN(3) \geq 0)$$

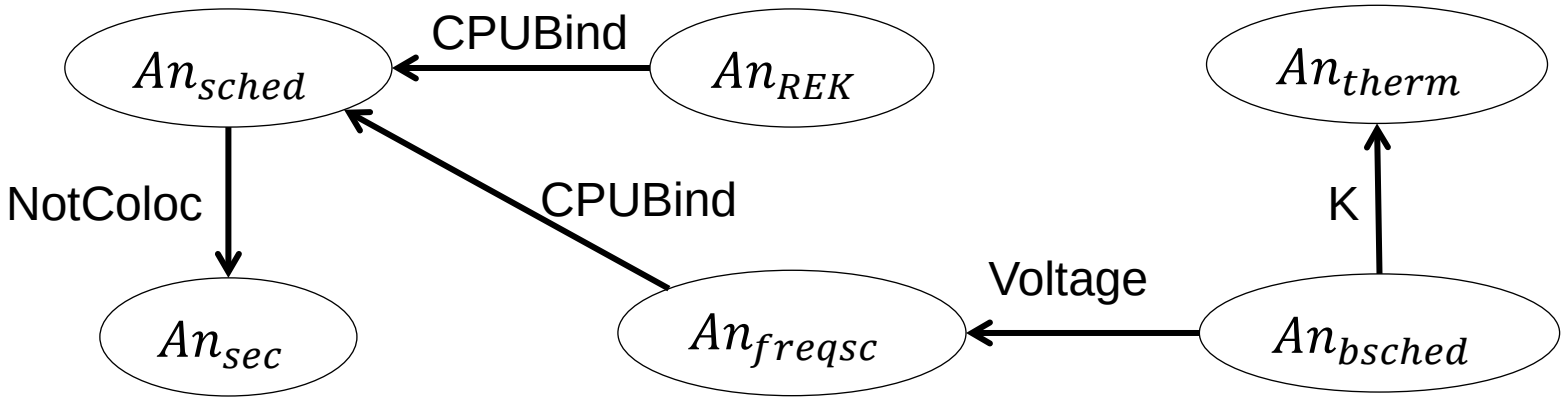
Ratio of cells with 0,1,2,3 neighbors: $1 \cdot TN(1) - 1 \cdot TN(2) + 10 \cdot TN(3) \geq 0$

$$1 \cdot 4 - 1 \cdot 10 + 10 \cdot 2 = 14 \geq 0$$

$$1 \cdot 2 - 1 \cdot 14 + 10 \cdot 0 = -12 < 0$$



Analyses Dependencies



Implementation

Models in the Architecture Analysis and Design Language (AADL)

- Supports multiple analysis
- Supports language extensions (subannexes)
- OSATE Implementation

Analysis Contract Annex

- Implement contract language
- Generates model interpretation

Contract formulas verification

- First Order Logic (Static): SMT / Z3
- LTL (Runtime): Model checking / SPIN

I. Ruchkin, D. de Niz, S. Chaki, and D. Garlan. "Contract-Based Integration of Cyber-Physical Analyses." EMSOFT 2014.

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