Research Review 2017

Certifiable Distributed Runtime Assurance

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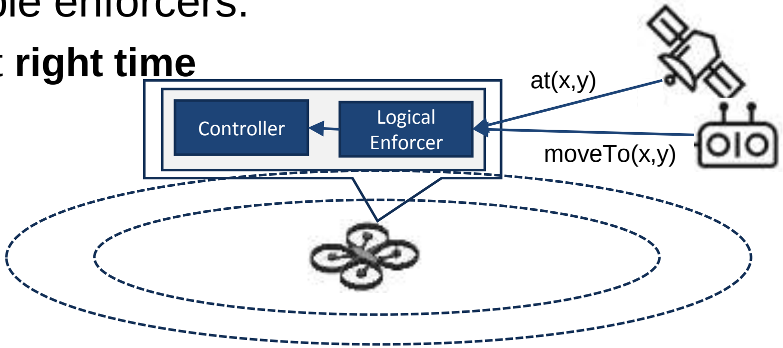
Certifiable Distributed Runtime Assurance

Challenge: Assure Safety of Distributed Cyber-Physical Systems

- Unpredictable Algorithms (Machine Learning)
- Multi-Vehicle (distributed) coordinating to achieve mission

Solution:

- Add **simpler (verifiable)** runtime enforcer to make algorithms predictable
- Formally: specify, verify, and compose multiple enforcers:
  - Enforcer **intercepts/replaces** unsafe action at **right time**



Formal Periodic Model: Representing Time-Aware Logic

<u>State of the system: values of variables</u>

State variables: V_S

Action variables: V_Σ

Variable values from **domain**: D

Location -- e.g., (x, y) position
Movement (move-to (x, y) position)
Domain specific variables

System state ≡ assignment of values to state variables: $s: V_S \mapsto D \in S$

Action ≡ assignment of values to action variables: $\alpha: V_\Sigma \mapsto D$

Add **values to quantify** position & move-to position

Behavior ≡ state transitions given actuation <u>every period</u> P: $R_P(\alpha) \subseteq S \times S$

Next state given action: $R_P(\alpha, s) = \{s' | (s, s') \in R_P(\alpha)\}$

Account for **time** & actuations

<u>Property to verify</u> subset of all possible states: $\phi \subseteq S$

Verify representative subset of ALL states
(x, y) position within region

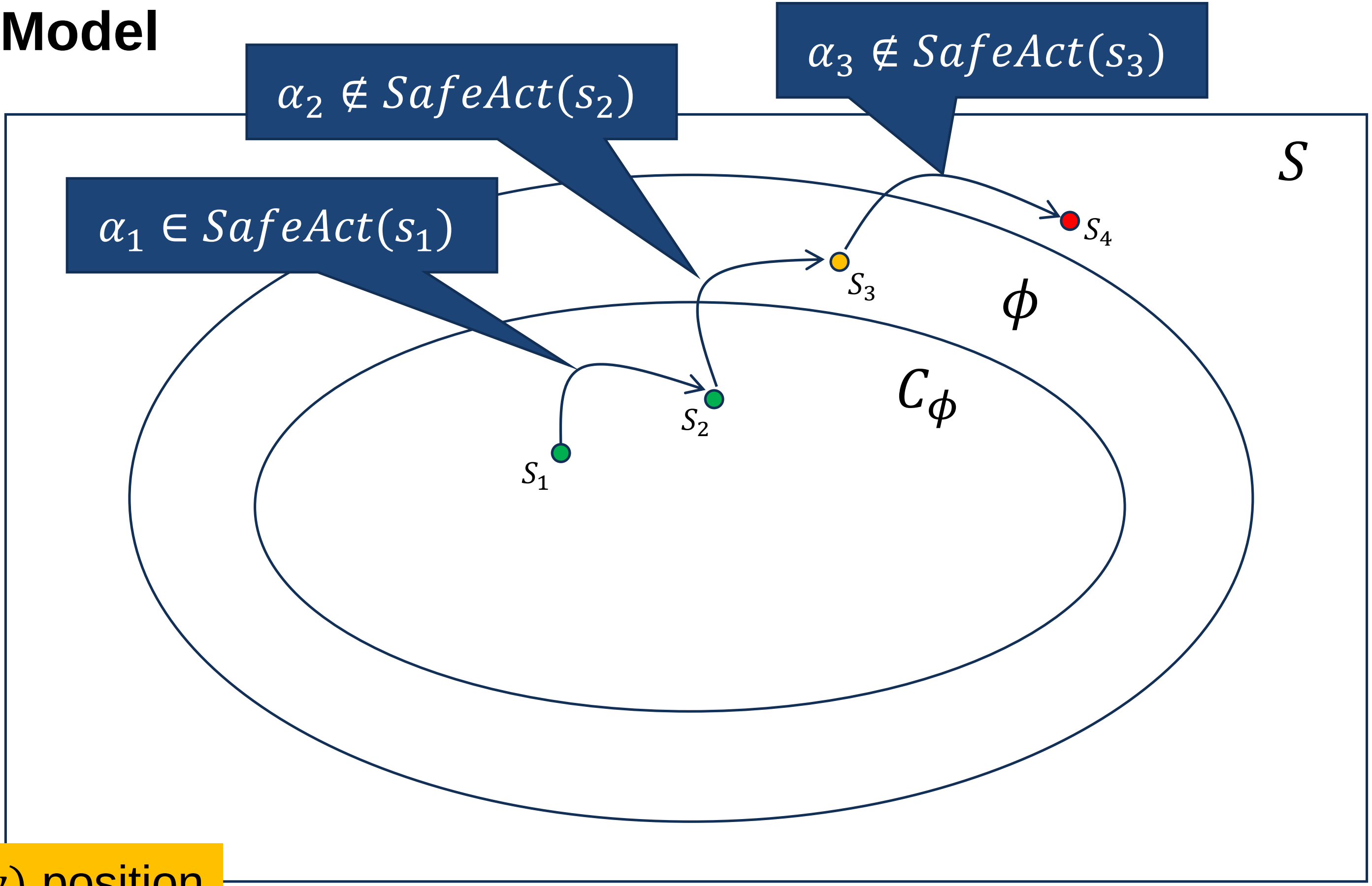
Enforceable state: $C_\phi \subseteq \phi \wedge C_\phi = \{s \mid \exists \alpha \in \Sigma: \mathrm{R_P}(\alpha, s) \in C_\phi\}$

Enforcement Mechanism
(x, y) still prevent getting out

Safe actuation : $SafeAct(s) = \{\alpha | R_P(\alpha, s) \in C_\phi\}$

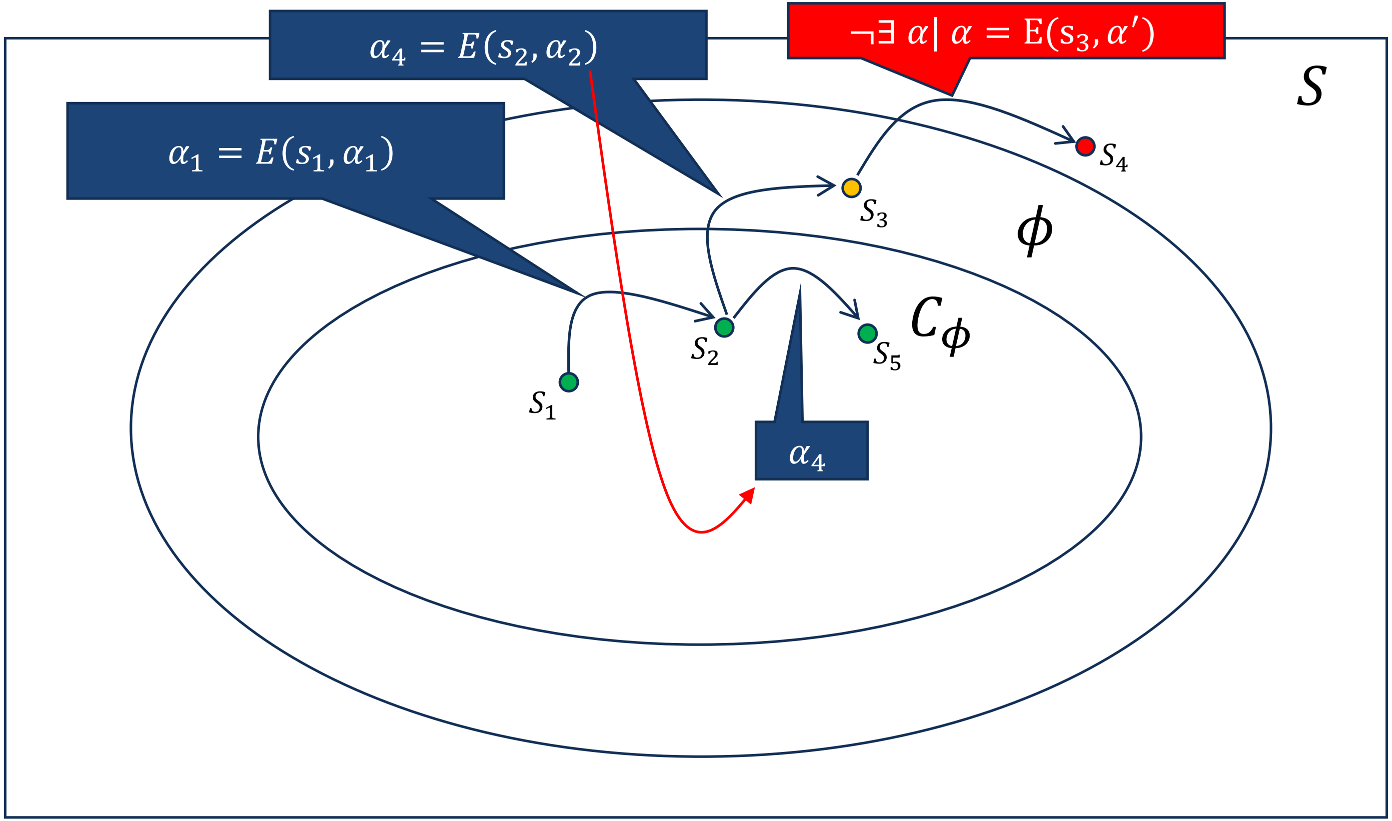
Safe actuation *AHEAD of* enforcement

Formal Model



s_i: (x, y) position

Enforcer $\mathrm{E}(s,\alpha): \alpha \in SafeAct(s)\ ?\ \alpha : \alpha' \in SafeAct(s)$



Composing Enforcers

Enforcer Details: E: $\left(P, C_\phi, \mu, U\right)$

- $\forall s \in C_\phi : \mu(s) \subseteq SafeAct(s)$
- U: utility

Composition without conflict

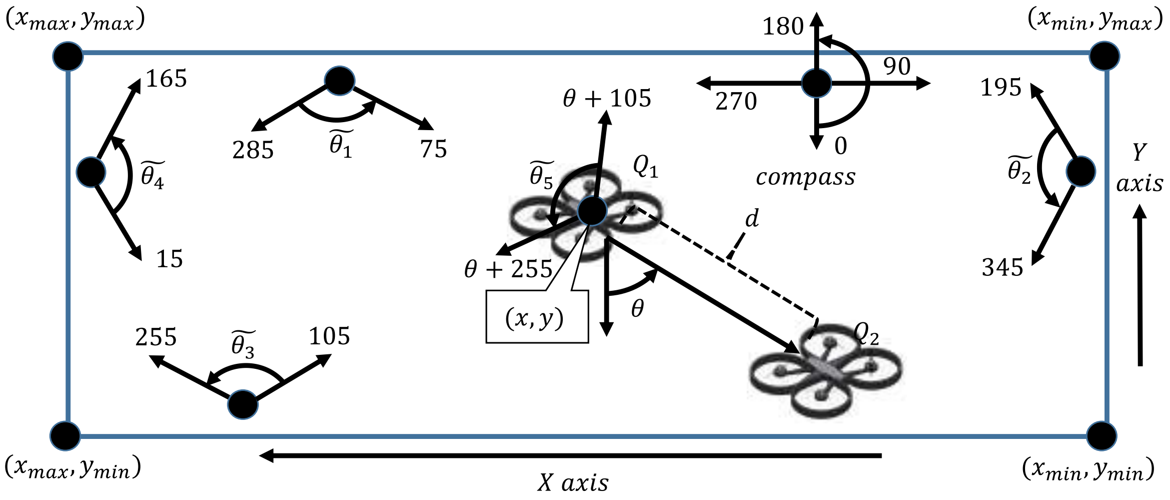
- $E_1 : \left(P_1, C_{\phi_1}, \mu_1, U_1\right)$
- $E_2 : \left(P_2, C_{\phi_2}, \mu_2, U_2\right)$
- $\mu_{1,2} : \mu_1 \cap \mu_2$

Conflicting: Priority:

- $\mu_{1,2} : \mu_1 \cap \mu_2 \neq \emptyset \, ? \, \mu_1 \cap \mu_2 : \mu_1$

Conflicting: Utility

- $\mu_{1,2} : \mu_1 \cap \mu_2 \neq \emptyset \, ? \, argmax_{\alpha \in \mu_1 \cap \mu_2} \sum U_i(s, \alpha') : argmax_{\alpha \in \mu_1} \sum U_i(s, \alpha')$



Are We Done Yet?

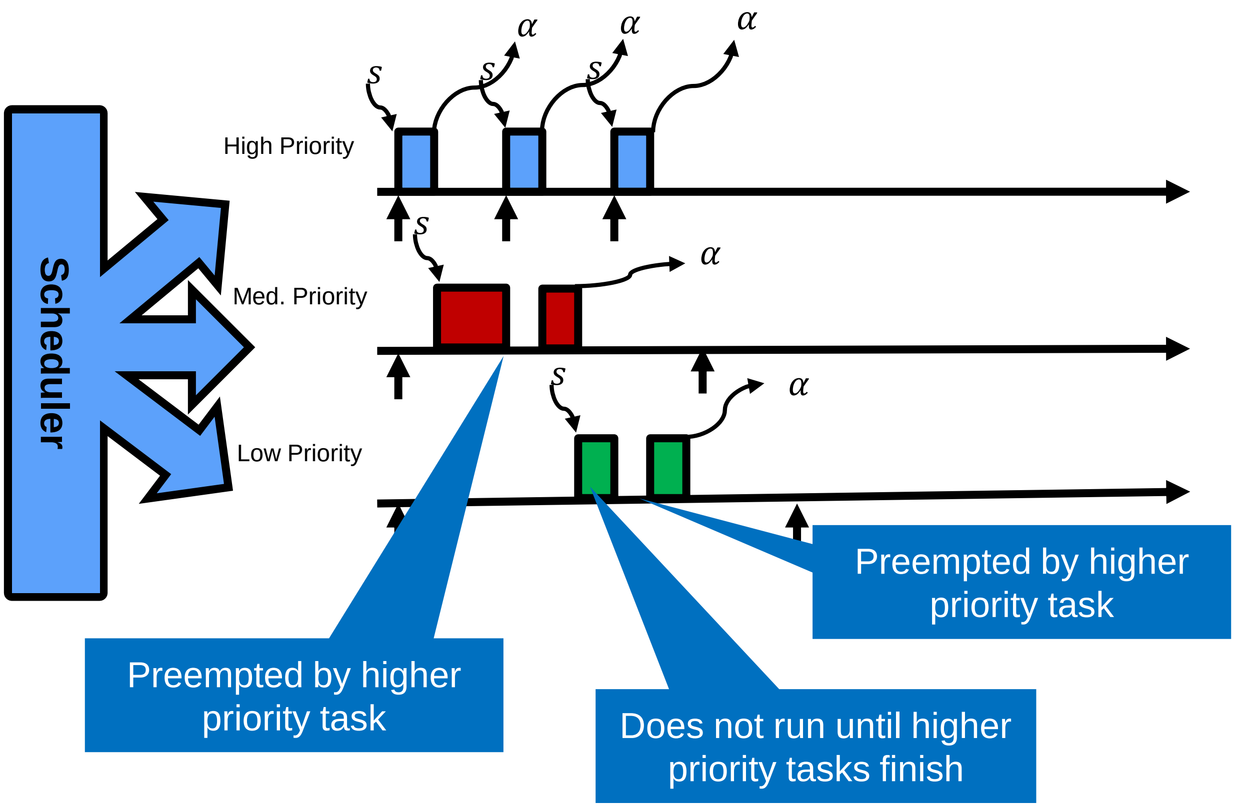
Timing Assumption:

- Unverified software finishes execution and enforcer evaluates output every P period.
- Software is guaranteed to finish executing by the next period (schedulable)
  - Unverified software executes for less than its Worst-Case Execution Time (WCET)
  - Other software running also executes for less than its WCET
  - Schedulability analysis successful

What can go wrong?

- Unverified software executes **A BIT** longer than WCET
  - Can make other software miss deadlines: late actions with old sensing
- Unverified software executes **A LOT** longer than WCET
  - Makes other miss deadline
  - Does **NOT** produce an output that can be evaluate by enforcer: late action + old sensing
    - **Inertia** takes it to **unsafe state**

Primer: Fixed-Priority Scheduling + Rate Monotonic



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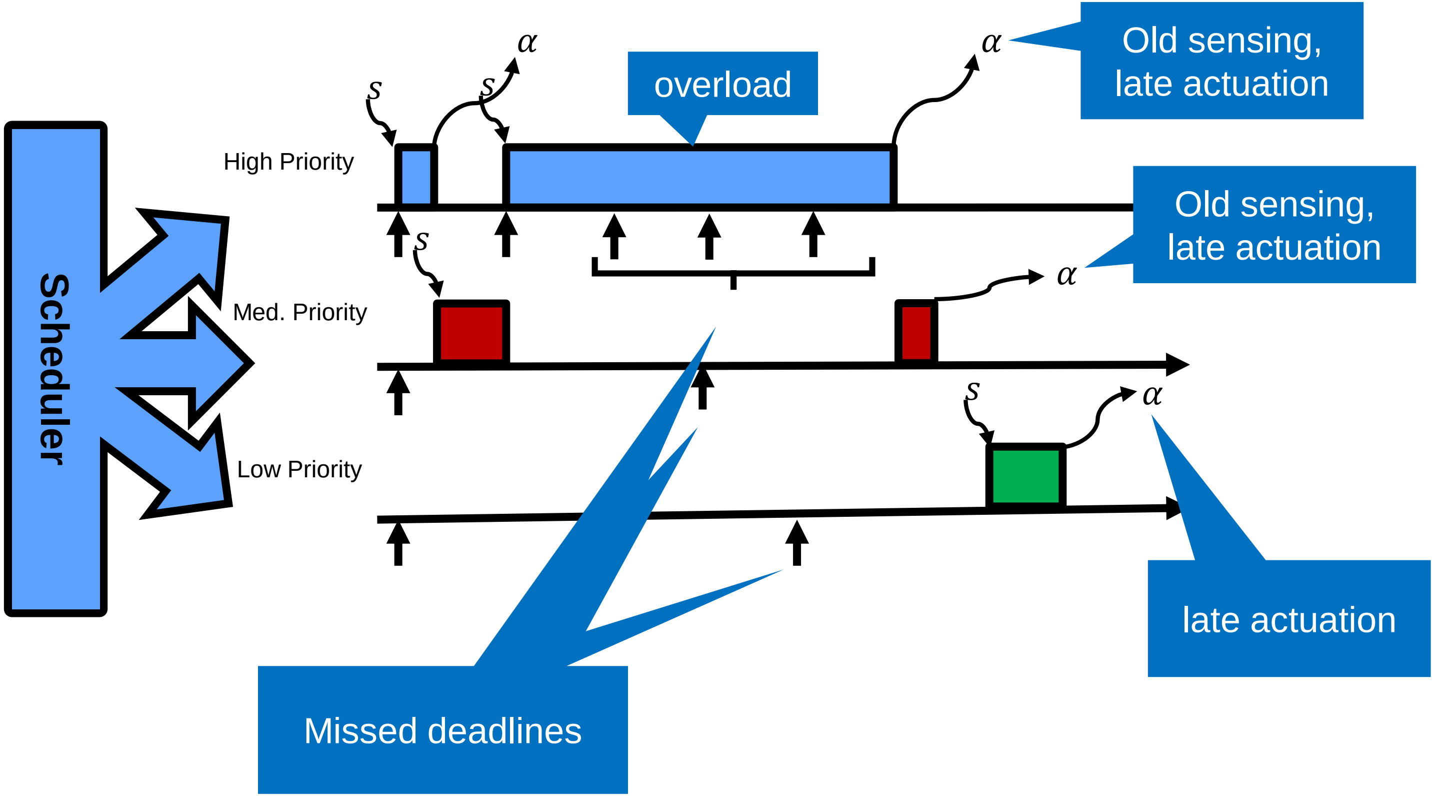
Overload -> Old Sensed Data + Late Actuation



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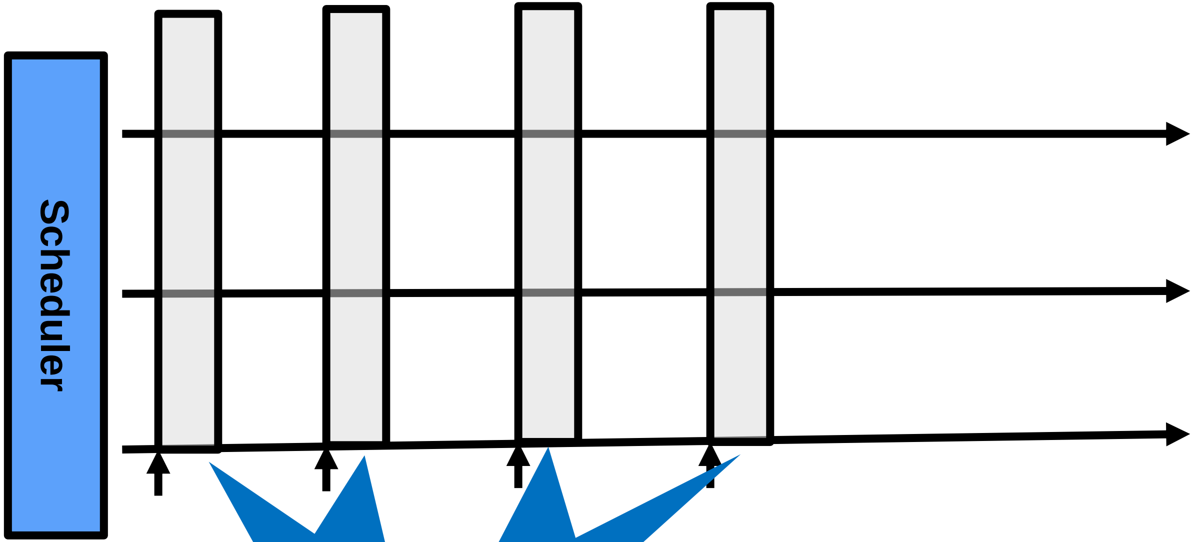
Solution: Enforce Timing Budgets (Timing Enforcement)



Only executed in given periodic time budget

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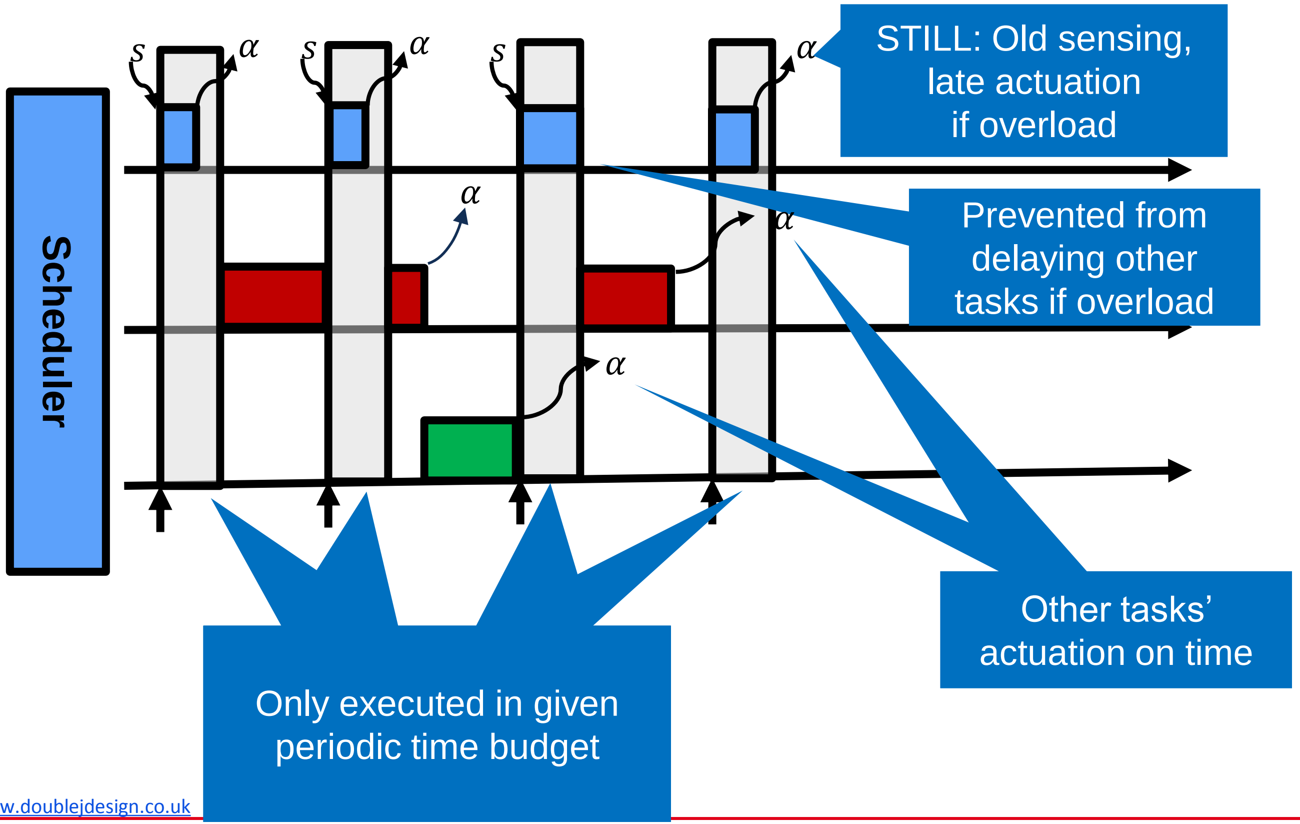
Solution Step 1: Enforce Timing Budgets (Timing Enforcement)



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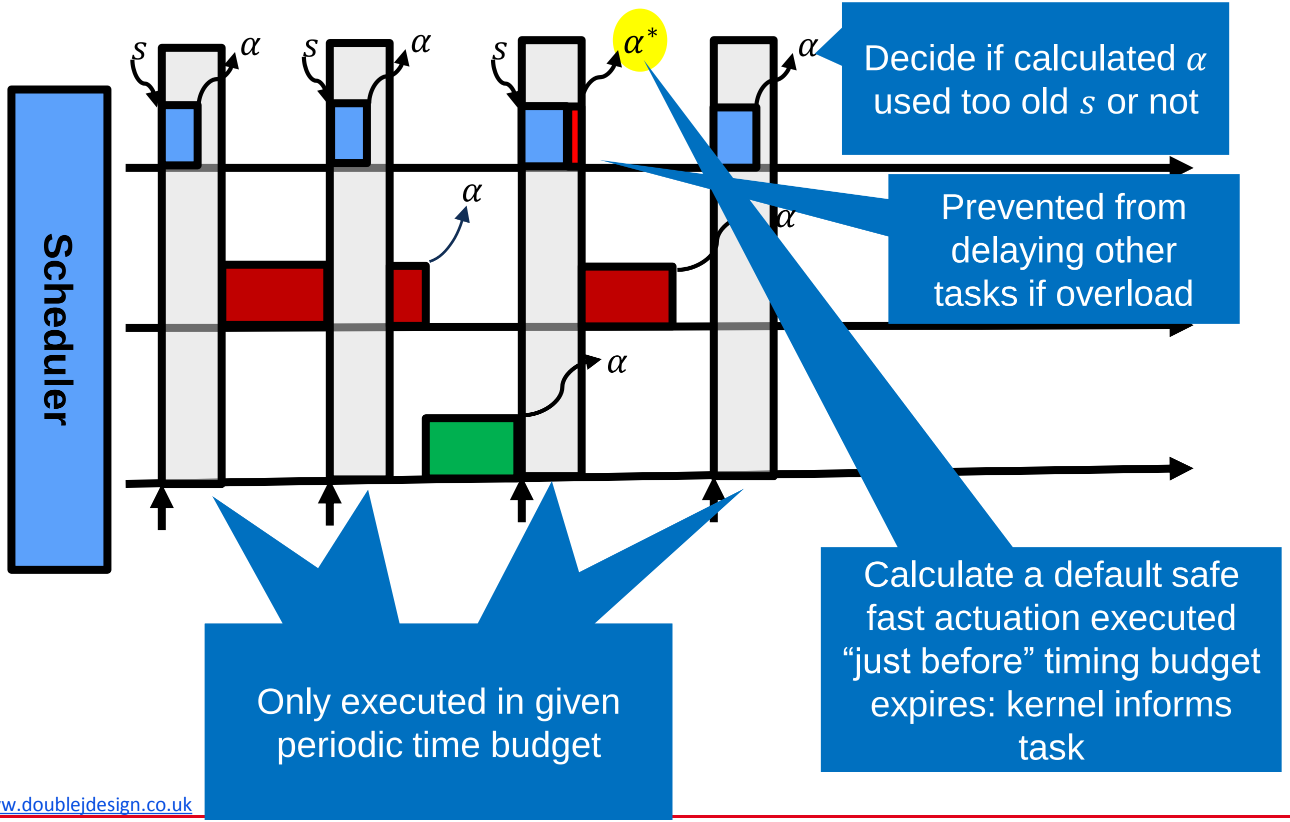
Solution Step 2: Safe Actuation on Timing Enforcement



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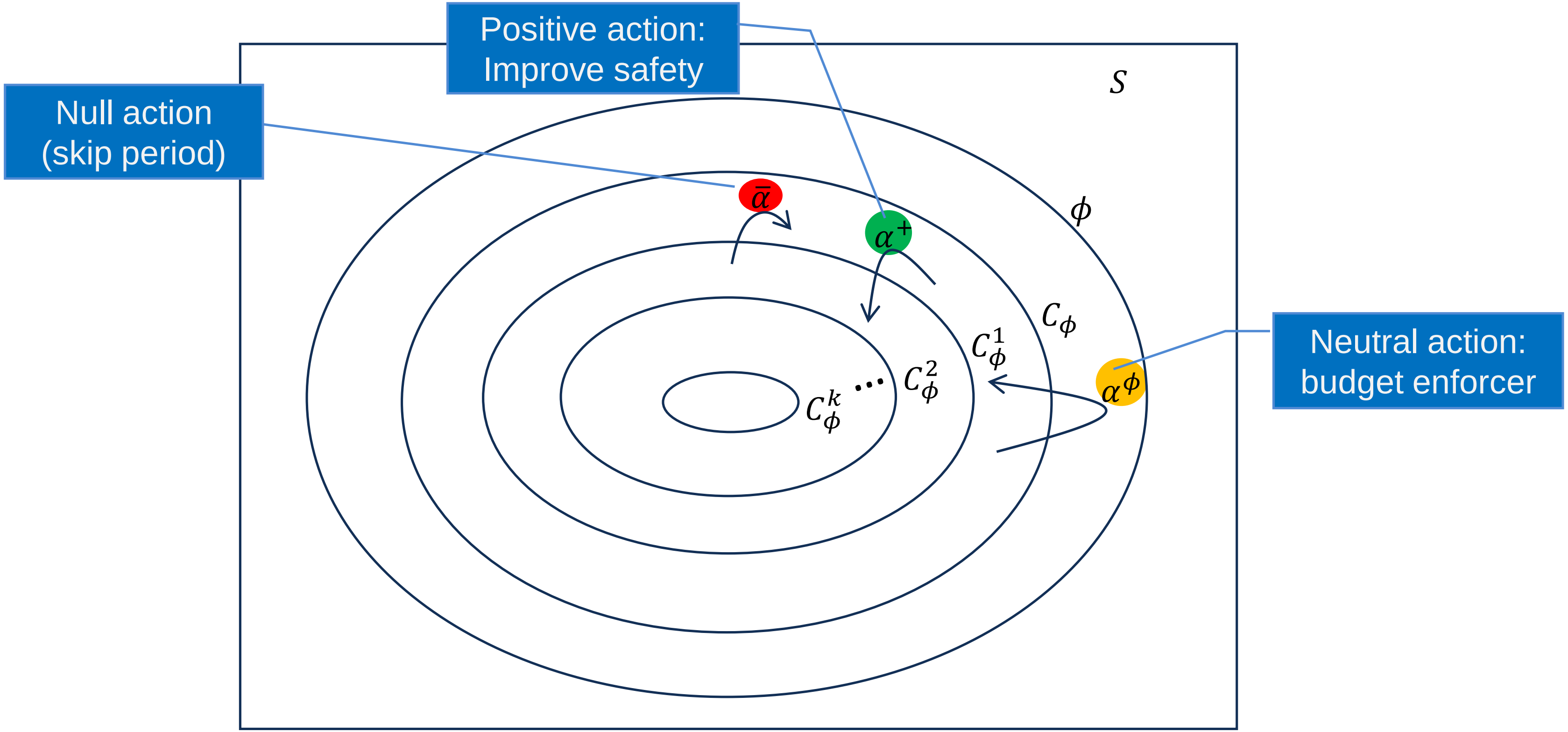
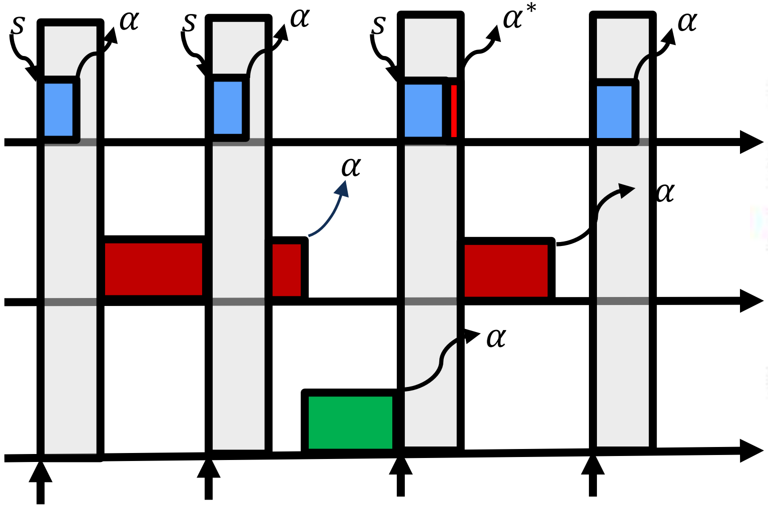
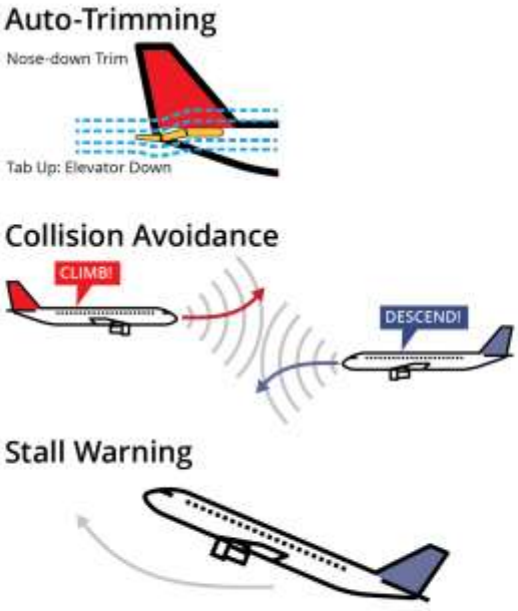
Scheduling Resilience: Tolerance To Miss Deadlines



Many Physical Processes – Many Threads





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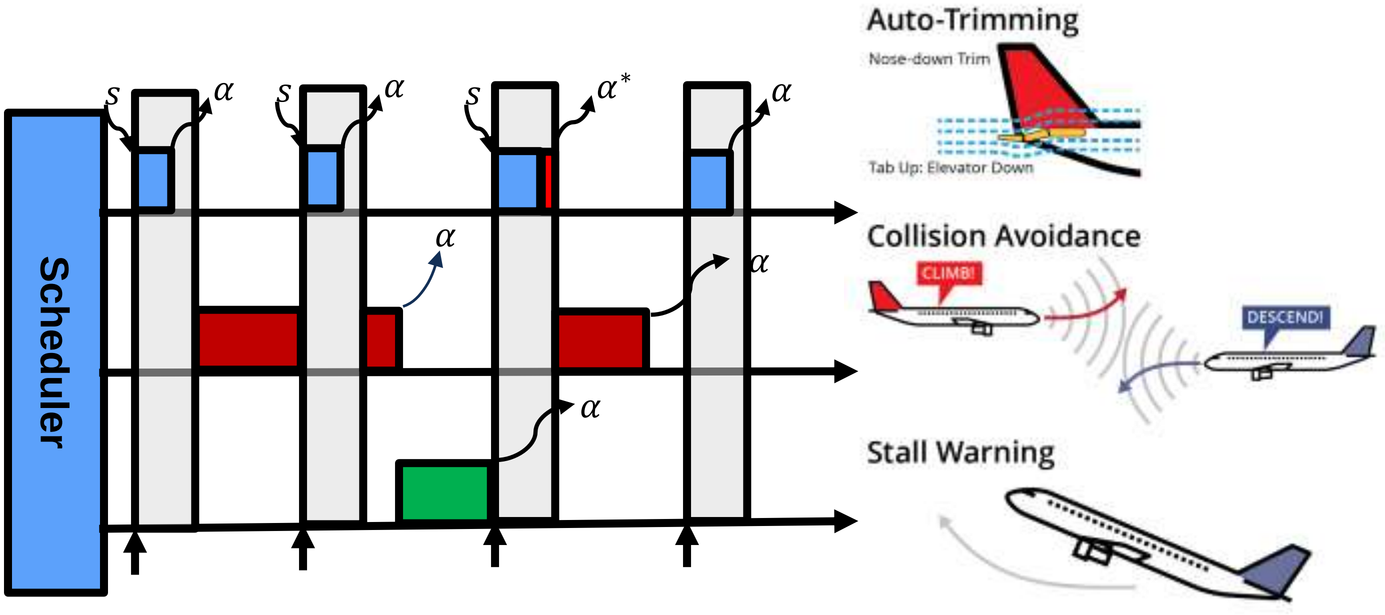
Threads Share Single Processor



Analyze Resilience to Skip Actuations

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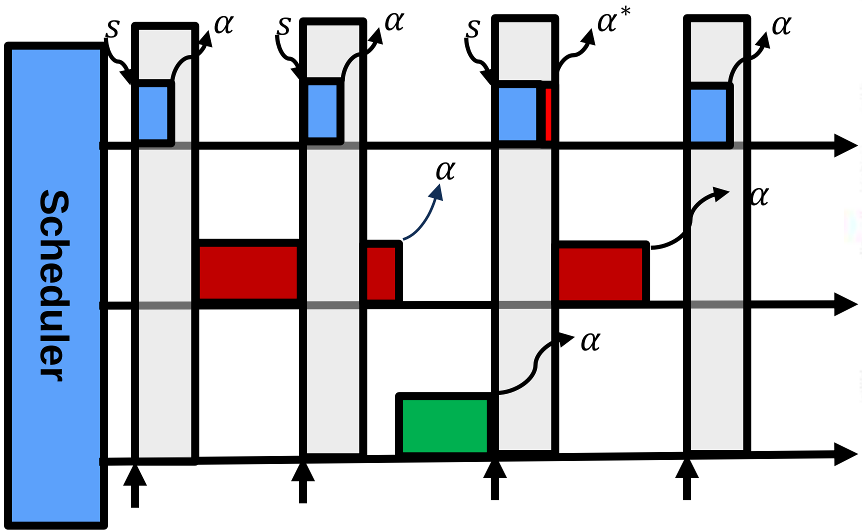
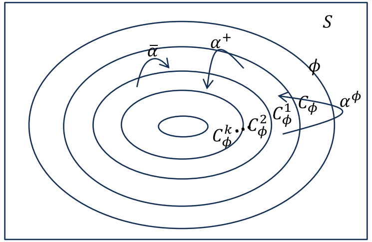
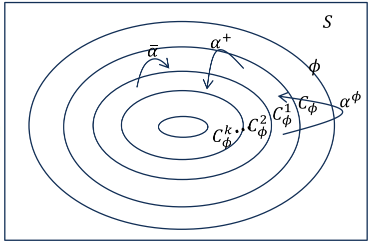
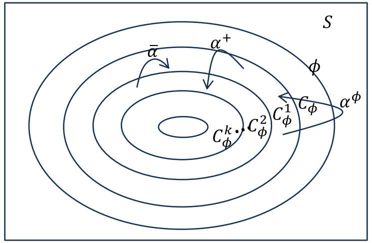
Threads Share Single Processor









Analyze Resilience to Skip Actuations

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Hypervisor Porting

Porting of XMHF Hypervisor for Drone Demos

- Raspberry Pi 3
- New Timing Infrastructure to support integration with temporal enforcer

To Support Tamper-Proof Protection

Results so Far (1)

Paper accepted on 17th International Conference on Runtime Verification 2017

- “Combining Symbolic Runtime Enforcers for Cyber-Physical Systems”
  Bjorn Andersson, Sagar Chaki, and Dionisio de Niz

Paper under submission

- “Analyzing Real-Time Scheduling of Cyber-Physical Resilience”
  Bjorn Andersson, Dionisio de Niz, and Sagar Chaki.

Results So Far (2)

Software Artifacts

- Temporal Enforcer Scheduler with default actuation
- SMT-Based Logical Enforcer Combination
- Porting of XMHF Hypervisor to Raspberry Pi 3 (to support drone demo)

Demos

- SMT-Based Parrot Mini-Drone demos
  - Logical + Temporal Enforcer

AFRL Summer of Innovation Transition

- Temporal (ZSRM) + Logical Enforcer into Drone Development Platform (UxAS)

ONR : Reuse of some core modeling ideas

Future

Second Year

- Integration of Hypervisor for Tamper-Proof Protection
  - Protect against compromised Virtual Machine
  - Coordinate temporal enforcer between hyper-visor and ZSRM
  - Logical Verification of Hypervisor Integration
- Logical Verification of Logical Enforcer and Default Actuation

Long Term

- Minimize enforcement actions: allow riskier high reward actions BUT safely
  - Require deeper understanding of risky actions and application:
    - e.g., Autonomy and Machine Learning

Contact Information

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