Assurance and Security for AI CPS

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Assurance for AI CPS (e.g., Autonomy)

Assurance of AI

- Enable ML to
  - Detect complex patterns (object recognition), handle uncertainty
- Interact with unknown environment

Cyber-Physical Systems (Most Systems in Field)

- React to physical environment
- Safe behavior: safe actions at right time (e.g., prevent crash)
- Security : ensure attacker does not make system crash

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Enforcement-based Verification

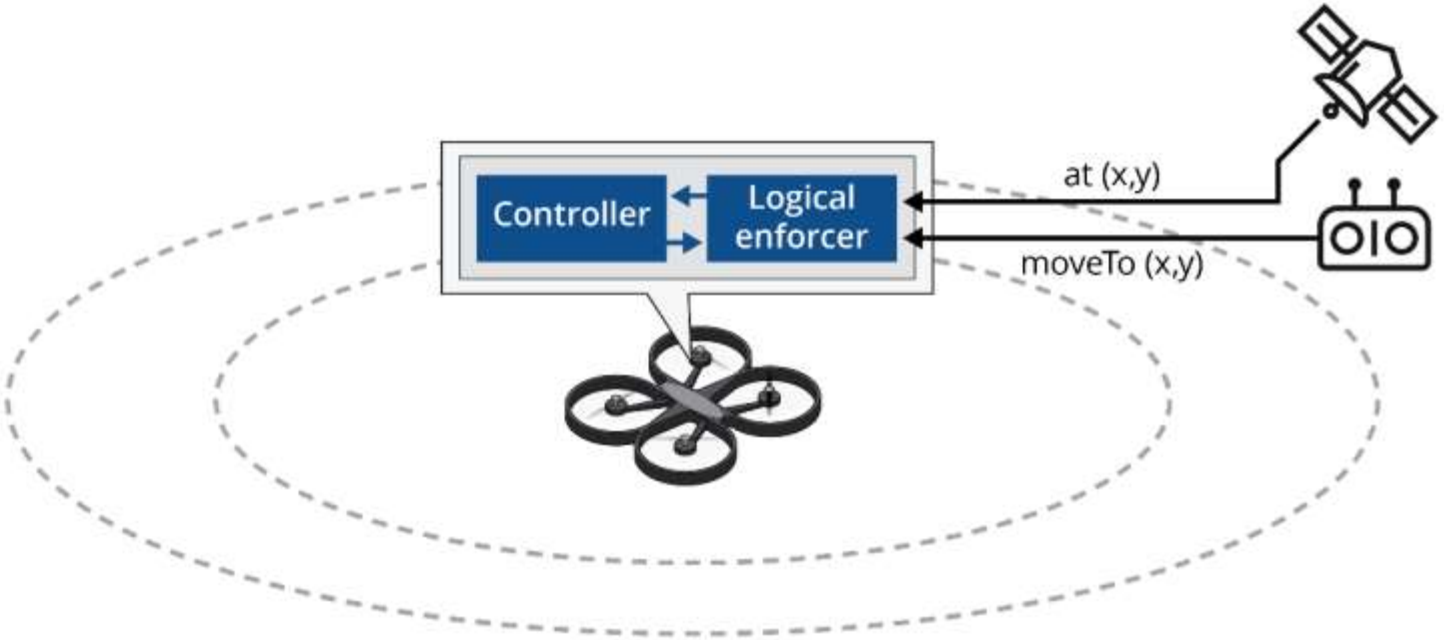
Add **simpler (verifiable)** runtime enforcer to make algorithms predictable

Formally: specify, verify, and compose multiple enforcers

- Logic: Enforcer **intercepts/ replaces** unsafe action
- Timing: at **right time**
- Physics: verified physical effects

Protect enforcers against

- Failures (Safety)
- Attacks (Security)



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Verifying Physics (Control Theory)

Recoverable Set: $\varepsilon_{SC^j}(1)$

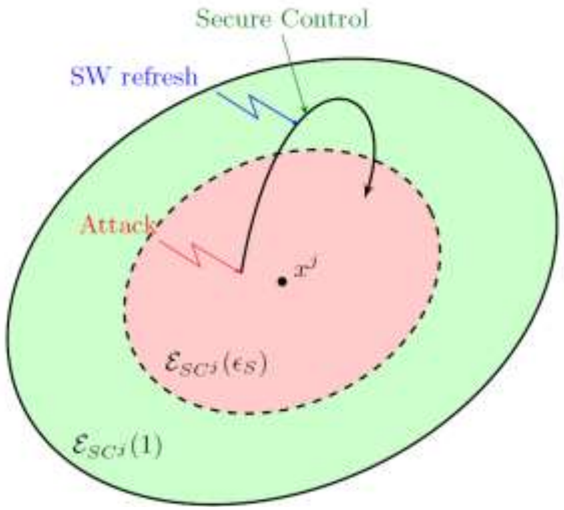
Safety Set: $\varepsilon_{SC^j}(\epsilon_s) \triangleq \epsilon_s\, \varepsilon_{SC^j}(1)$

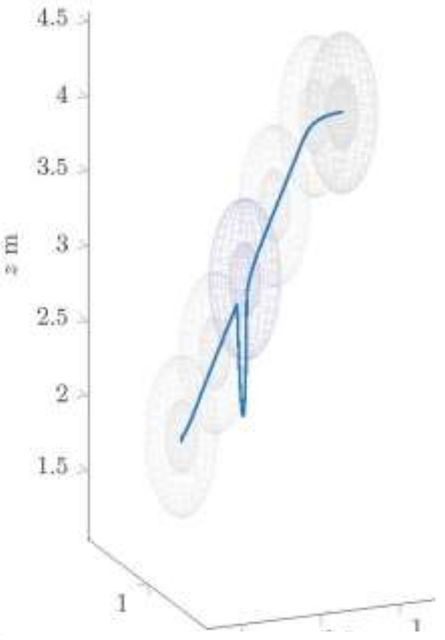
Controlled System: $\dot{x} = f_\varphi(x) \triangleq f(x, \varphi(x))$
Lyapunov Function: $V_\varphi : \mathbb{R}^n \to \mathbb{R}$, $\mathcal{N}_{V_\varphi}(x_{eq}) \subseteq \mathcal{N}_\varphi(x_{eq})$,
$V_\phi(x_{eq}) = 0$ and $\forall x \in \mathcal{N}_{V_\varphi}(x_{eq}) - \{x_{eq}\}$: (i) $V_\varphi(x) > 0$,

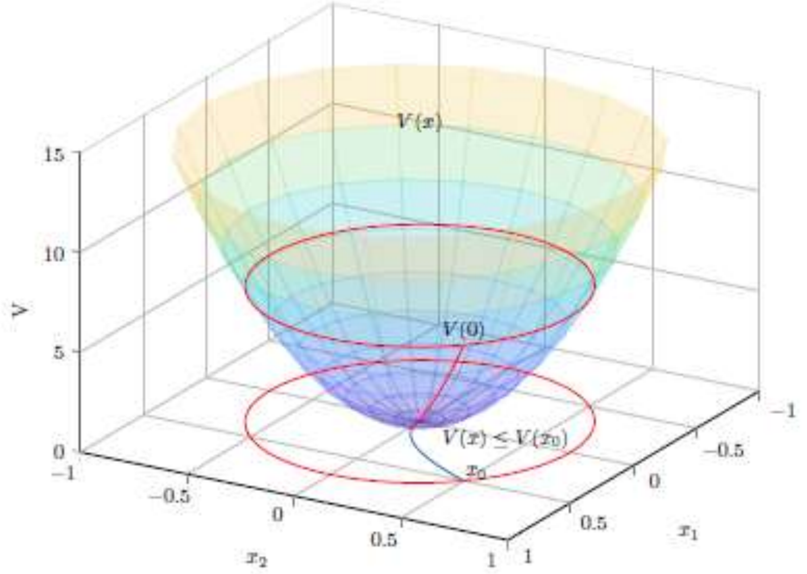
$$\dot{V}_\varphi(x) = \frac{\partial V}{\partial x} \cdot f_\varphi(x) < 0$$

Lyapunov level set: For $\epsilon > 0$,

$$\mathcal{E}_\varphi(\epsilon) = \{x \in \mathcal{N}_{V_\varphi}(x_{eq}) | V_\varphi(x) \leq \epsilon\}. \qquad \epsilon \leq 1$$







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Drone Experiment

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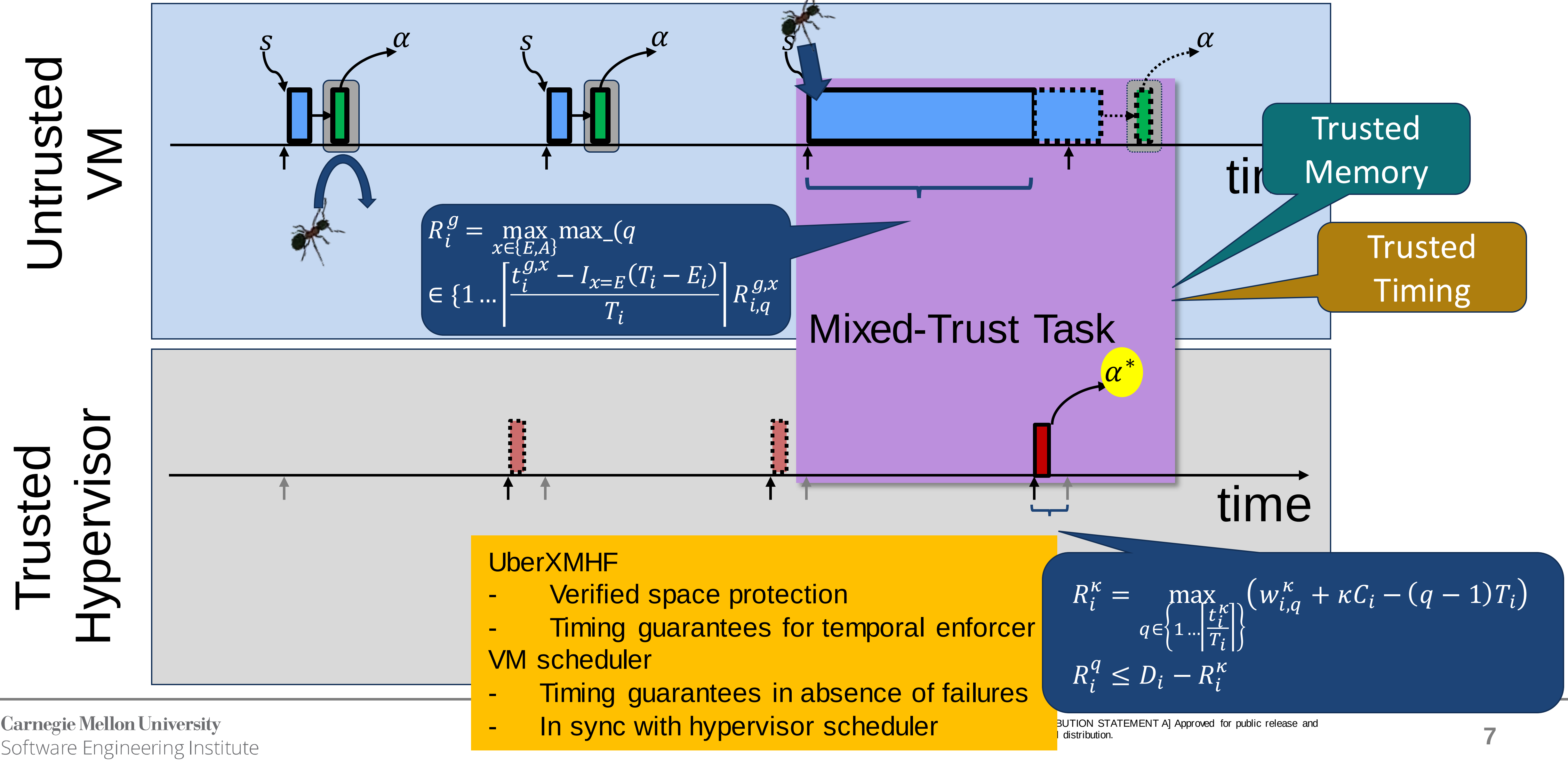
Real-Time Mixed-Trust Computation (Enforcement Protection)



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Handling Failures / Degraded Modes

LIDAR

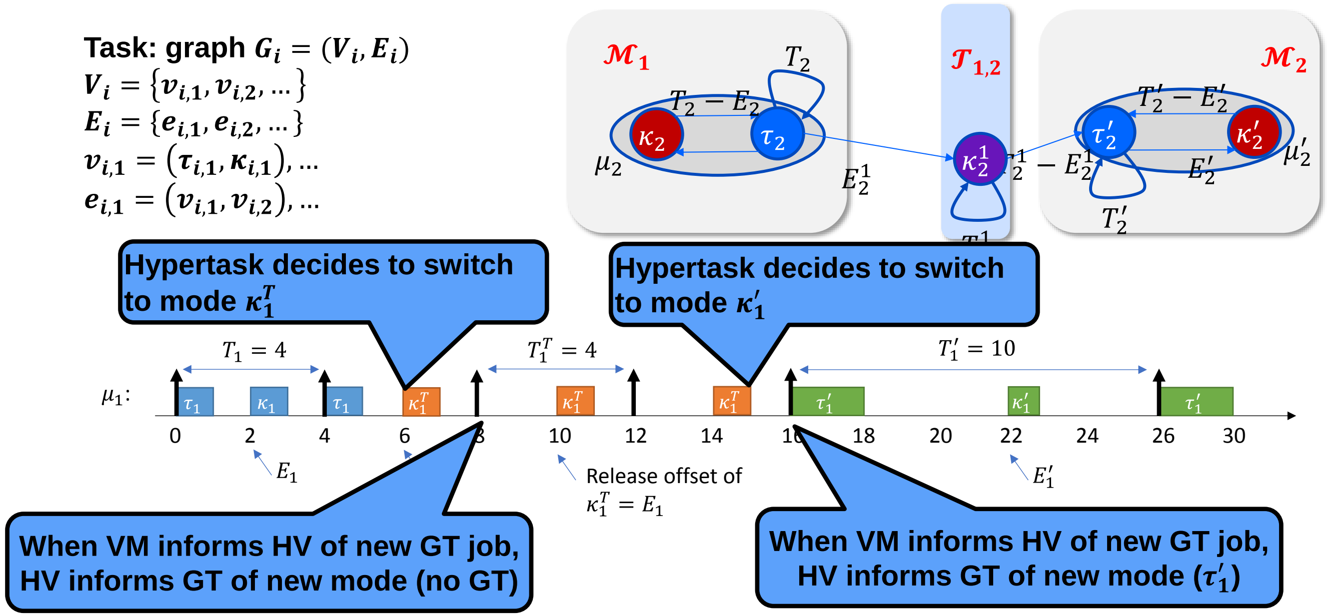
- Detection distance $20\ m$
- Max braking: $-10 \frac{m}{s^2}$
- Max speed: $20 \frac{m}{s}$

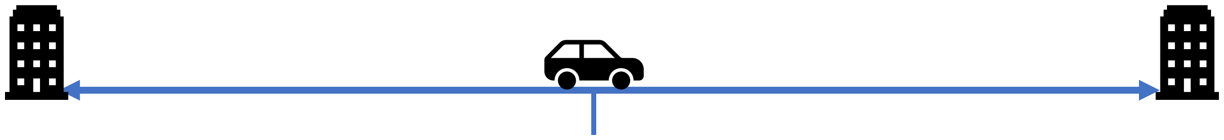
SONAR

- Detection distance $5\ m$
- Max braking: $-10\ m/s^2$
- Max speed: $10 \frac{m}{s}$

LIDAR Failure Transitioning Enforcer

- Upon failure: start braking at $-10 \frac{m}{s^2}$
- Once speed < $10 \frac{m}{s}$ Transition to SONAR enforcer





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