CPS:Medium:Safe Learning-Enabled Cyberphysical Systems, CNS-2038493

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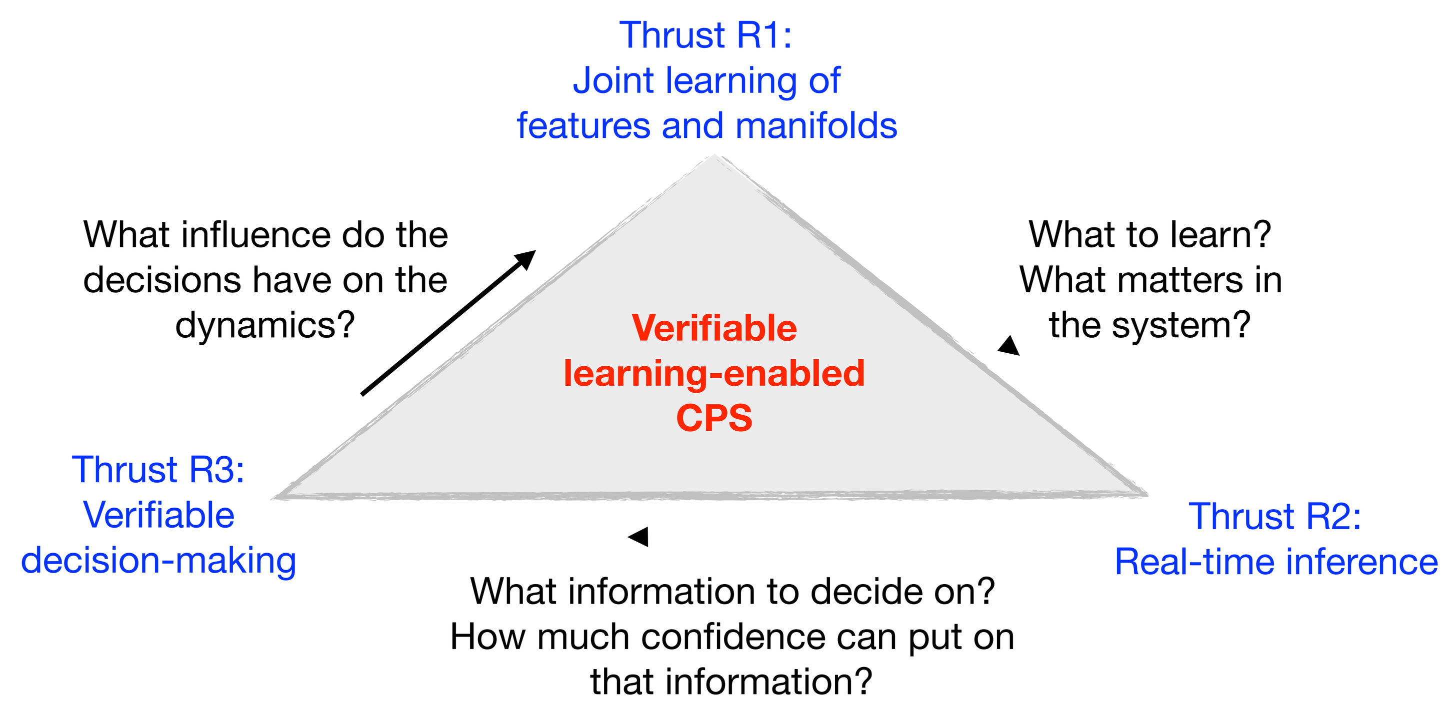
Motivation

Design autonomous CPS capable of safely operating in and adapting to previously unseen scenarios. (Humans can do it!)

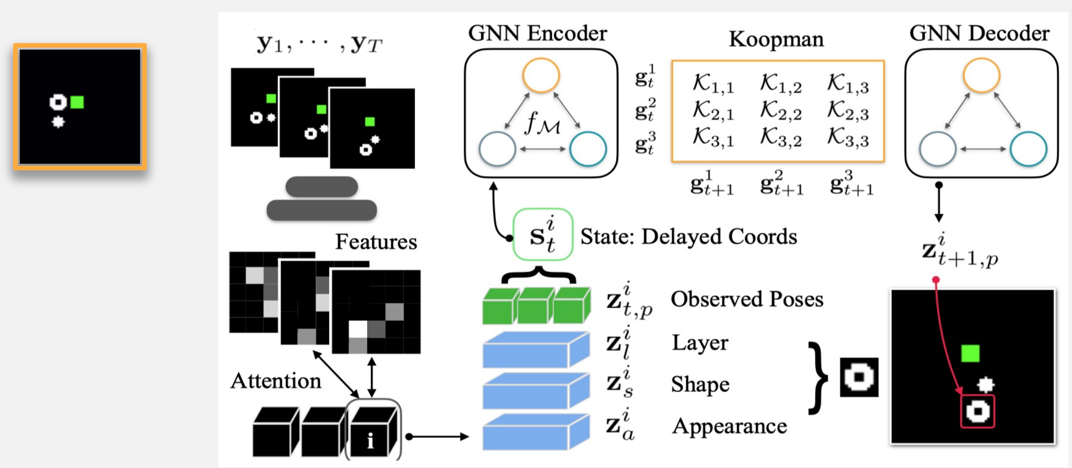
Challenges

- Lack of training data (often single execution).
- Need to act while learning (no re-do!).
- Actionable information sparsely encoded in large data sets.



Koopman-based Identification of Interacting Dynamics

- Goal: learn dynamics of multiple interacting agents.
- Main idea: Graph-based Object Centric Dynamic Mode Decomposition with Koopman Operators.
- Technical details:
  - Use delayed coordinates and attention-based tracking
  - Use a GNN to encode and decode the trajectories
  - Enforce linear manifold dynamics, with interpretable representations



2024 SYSID

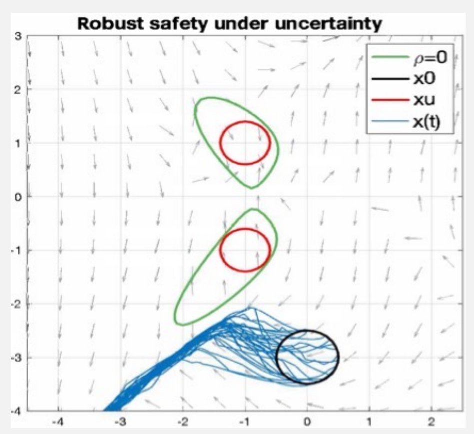
Verifiable Safe Data Driven Control

- Goal: data driven avoidance of an unsafe set.
- Main idea: enforce robust Nagumo-invariance .
- Technical details:
  - Prior: non linear dynamics of the form:
    $\dot{\mathbf{x}} = \mathbf{F}\phi(\mathbf{x}) + \mathbf{G}\gamma(\mathbf{x})\mathbf{u} + \eta \quad \mathbf{F}, \mathbf{G}$ unknown
  - Initial condition set: $\mathcal{X}_o$, bad set: $\mathcal{X}_u \doteq \{\mathbf{x} : h(\mathbf{x}) \geq 0\}$
  - Experimental data: $(\mathbf{u}(t_k), \mathbf{x}(t_k), \dot{\mathbf{x}}(t_k)),\ 0 \leq t_k \leq T$
  - Fact: bad set is avoided if there exist $\rho(x), \psi(x)$
    $\rho(\mathbf{x}) \geq 0,\ \forall \mathbf{x} \in \mathcal{X}_0,\ \rho(\mathbf{x}) < 0, \forall \mathbf{x} \in \mathcal{X}_u$ and

$$\nabla \cdot \left[\rho(\mathbf{x})\Big(\sum_i \alpha_i \mathbf{f}_i(\mathbf{x}(t)) + \mathbf{w}\Big) + \psi(\mathbf{x})\sum_j \beta_j \mathbf{g}_j(\mathbf{x})\right] - \rho(\mathbf{x})h(\mathbf{x}) > 0$$

for all plants that could have generated the data

  - Fact: reduces to a convex SDP via duality
  - Fact: only imposes $d\rho/dt < 0$ when $\rho = 0$



2024 IEEE LCSS, 2024 IEEE TAC

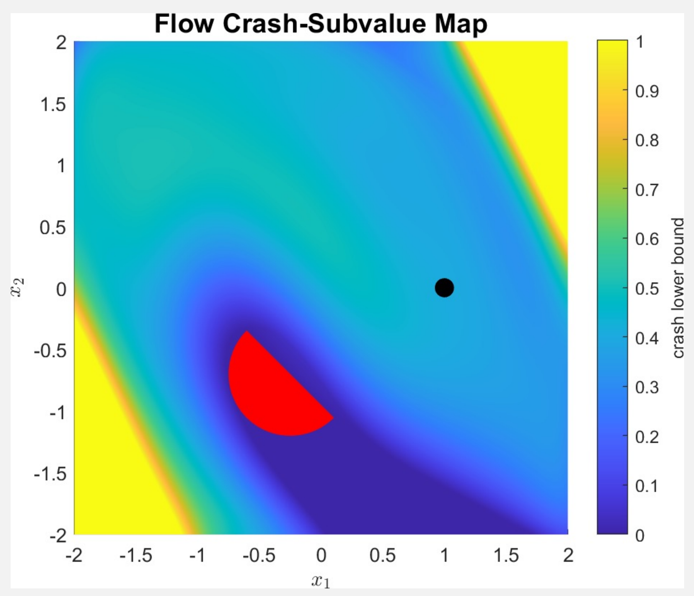
Safety Margins:

- Goal: Estimate how much uncertainty can be tolerated.
- Technical details:
  - Prior: non linear dynamics of the form:

$$\dot{x}(t) = f(t, x(t), w(t))$$
$$w(\cdot) \in \mathcal{W},\ t \in [0, T],\ x_0 \in X_0.$$

  - A reachability problem:

$$\begin{aligned} Q_z^* = \inf_{t,\ x_0,\ z,\ w}\ & z \\ & \dot{x}(t') = f(t', x(t'), w(t')), \dot{z}(t')) = 0, \quad \forall t' \in [0, T] \\ & J(w(t')) \leq z, \quad \forall t' \in [0, T] \\ & x(t \mid x_0, w(\cdot)) \in X_u \\ & w(\cdot) \in W,\ t \in [0, T],\ x_0 \in X_0, z \in [0, J_{\max}]. \end{aligned}$$



  - Reduces to convex optimization via occupation measures and SoS
  - Work in progress: extend to the data driven case

To appear, SIAM Sicon 2025

Application

- Public space monitoring to mitigate unsafe situations.


Monitoring social distancing

Active shooter scenario (joint with M. Siami)

Scientific Impact

- Rapprochement of Systems Theory, ML, Viability.
- Efficient extraction of actionable information from large data sets.
- Frugal, explainable architectures for dynamics oriented learning.

Broader Impact

- Certified safe learning enabled systems that can operate in close proximity to humans.
- Applications: safe autonomy, disaster mitigation, public space monitoring.
- Internships at Adobe, Mathworks, Google.

Award CNS-2038493