Safe Learning in Unmanned and Autonomous Systems

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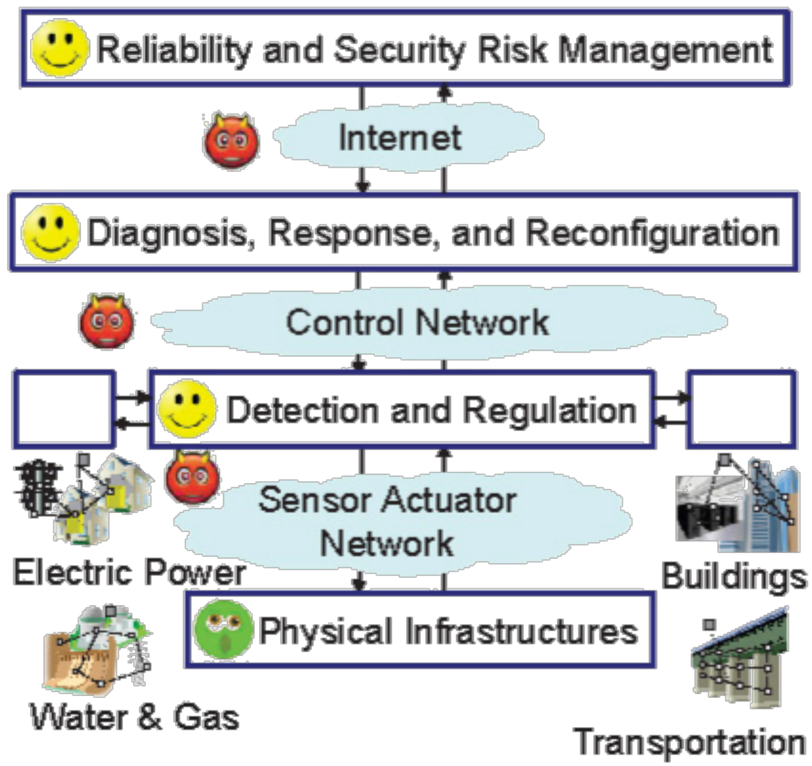
CPS PI Meeting, November 14 2017

Economic Incentives

Game theory // Mechanism design // Interdependent risk management

Resilient CPS design



Robust Control

Fault/attack diagnostics // Control of ActionWebs // Model-based design

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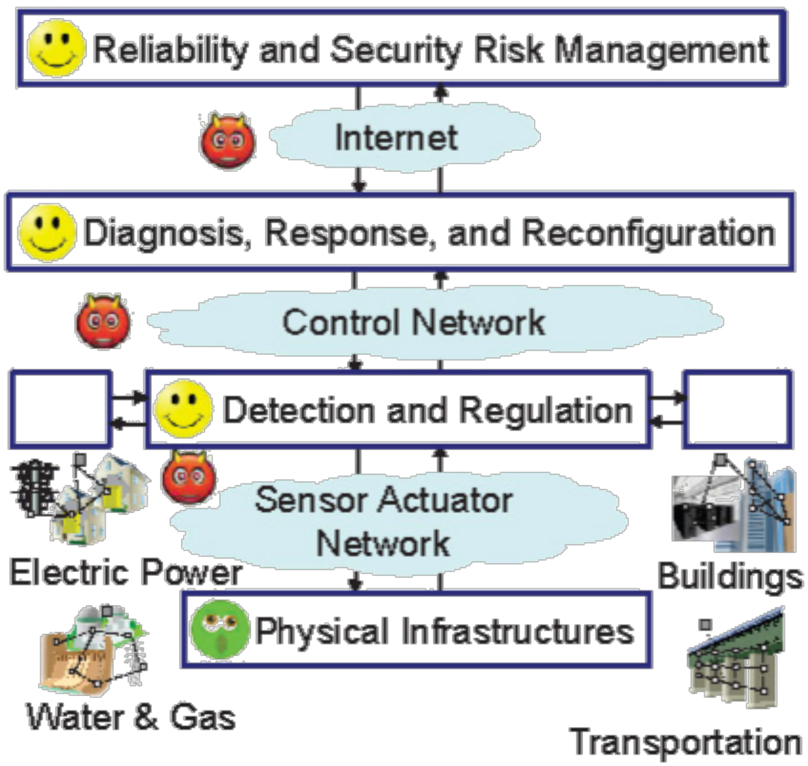
Resilient CPS design



Residential DR

Secure Estimation for CPS
Fully decentralized policies

Distributed Power
UAV networks
Resilient Stormwater Mgmt

Robust Control

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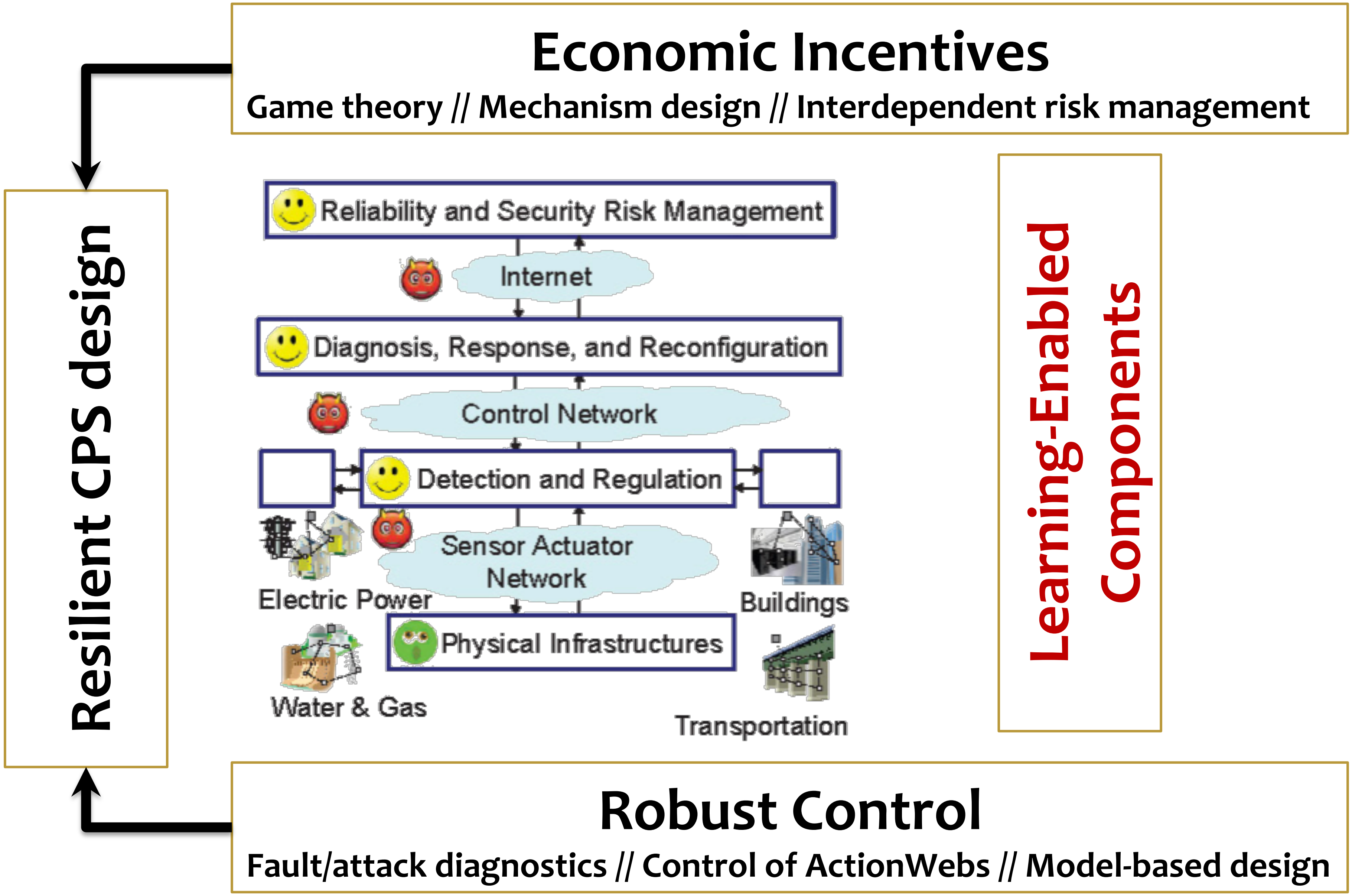
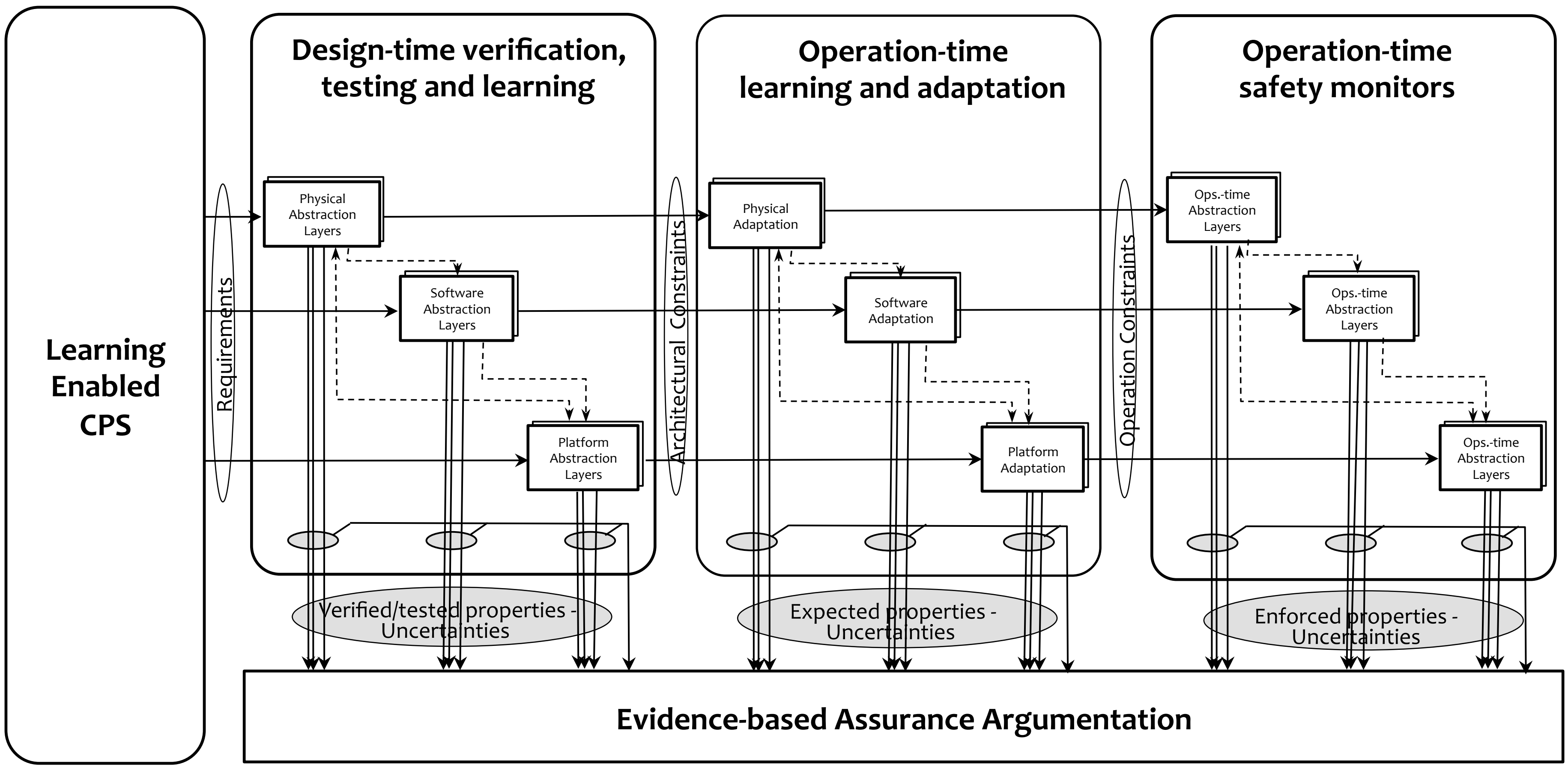


Economic Incentives
Game theory // Mechanism design // Interdependent risk management
Resilient CPS design
Reliability and Security Risk Management
Internet
Diagnosis, Response, and Reconfiguration
Control Network
Detection and Regulation
Sensor Actuator Network
Electric Power
Buildings
Physical Infrastructures
Water & Gas
Transportation
Learning-Enabled Components
Robust Control
Fault/attack diagnostics // Control of ActionWebs // Model-based design

Designing high confidence systems that can learn



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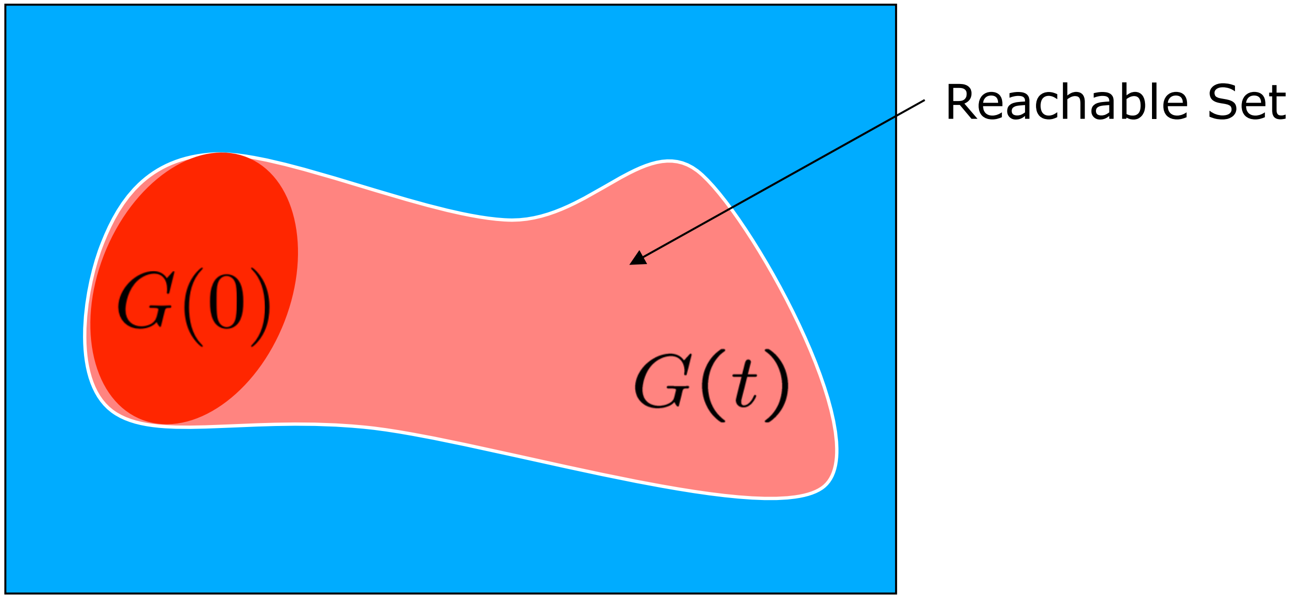
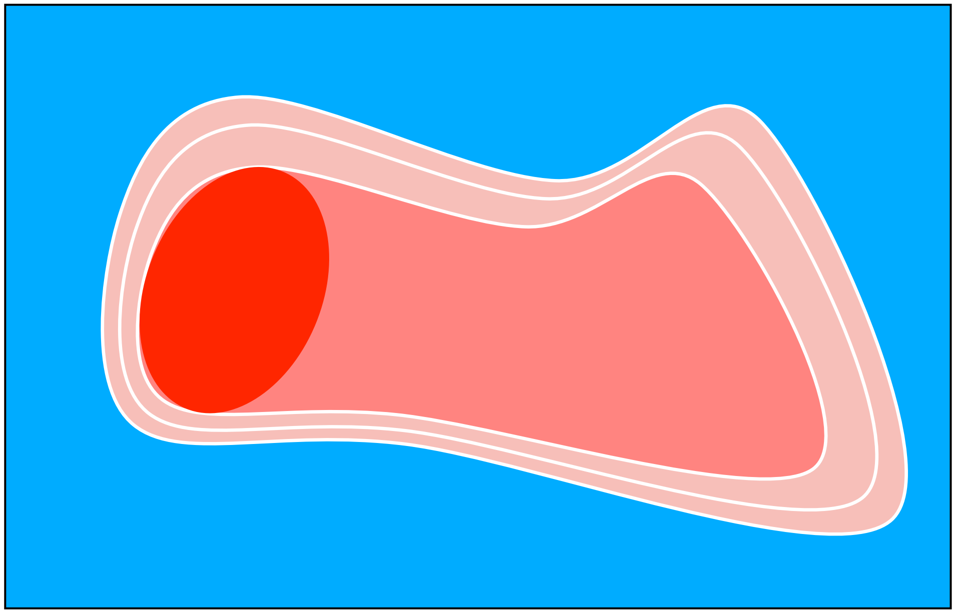
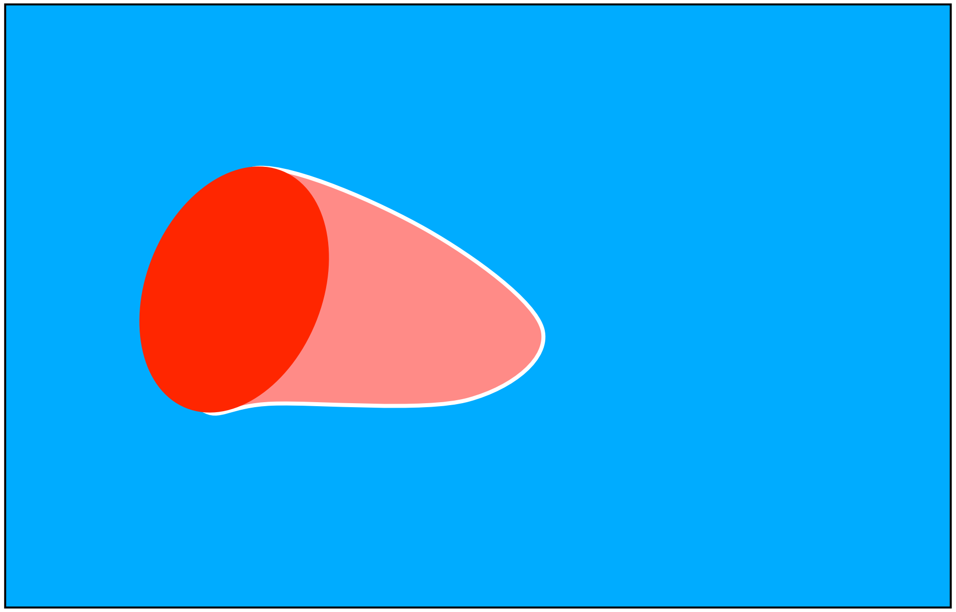
Model Checking using Reachability



Overappromixations as certificates



Learning can reduce conservatism



Scalability

- Impose practical constraints
  - Roads, highways, protocols…
- Approximations
  - Bisimulations (Girard, Pappas, Tabuada)
  - Linear, piecewise and multi-affine systems (Morari, Borrelli, Krogh, Johansson, Rantzer, Belta, Ozay, Darbon, Osher)
  - Ellipsoidal and polyhedral sets (Kurzhanski , Varaiya, Stipanovic)
  - Polynomial systems, barrier certificates (Parillo, Majumdar, Tedrake, Pappas, Papachristodoulou, Julius, Lall, Topcu, Frehse, Le Guernic, Donzé, Girard, Dang, Maler, Dreossi, Sankaranarayanan)
  - Decoupling disturbances (Chen, Herbert)
- Mathematical structure
  - Monotone systems (Sontag, Hafner, Del Vecchio, Arcak, Coogan)
  - LTL specifications (Kress-Gazit, Raman, Murray, Wongpiromsarn, Belta)
- Decompositions (Mitchell, Del Vecchio, Chen, Herbert, Grizzle, Ames, Tabuada)
- Machine learning (Lygeros, Djeridane, Niarchos, Seshia, Chen)

Learning a controller

Sinusoid + Yaw:

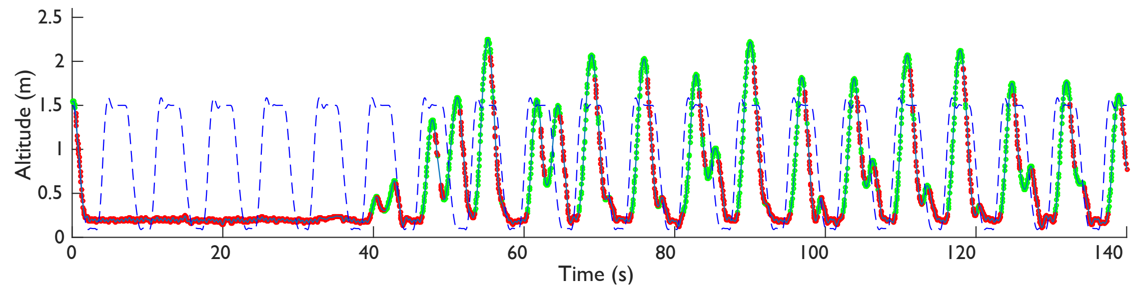
- Trained on each component separately
- Asked to fly combination
- Used Cascade FF neural net (ReLU), 2 layers, 3000 units

… but stay safe while learning

- **Safety:**
  - A nominal model with error bounds
  - Reachable sets computed to ensure safety in worst case
- **Performance:**
  - Use online learning to update model
  - Cost function used to generate control action within the safe set

Safe Policy Gradient Reinforcement Learning

The quadrotor first: drops



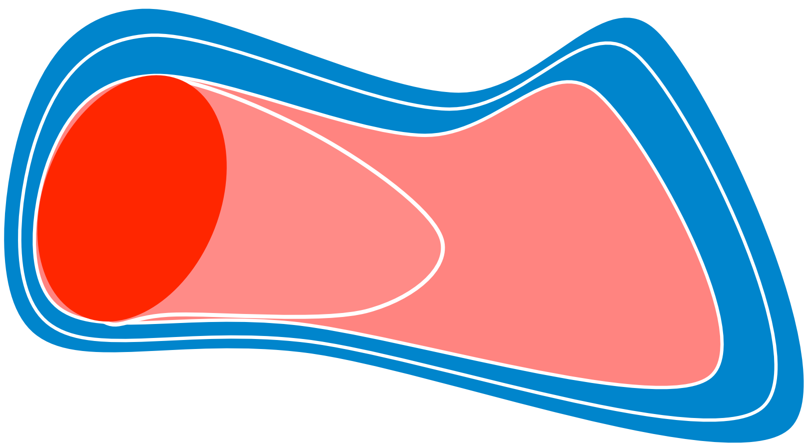
After about 1 minute,
it can roughly track the trajectory

Soon, it starts experimenting

…but the safe controller steps in

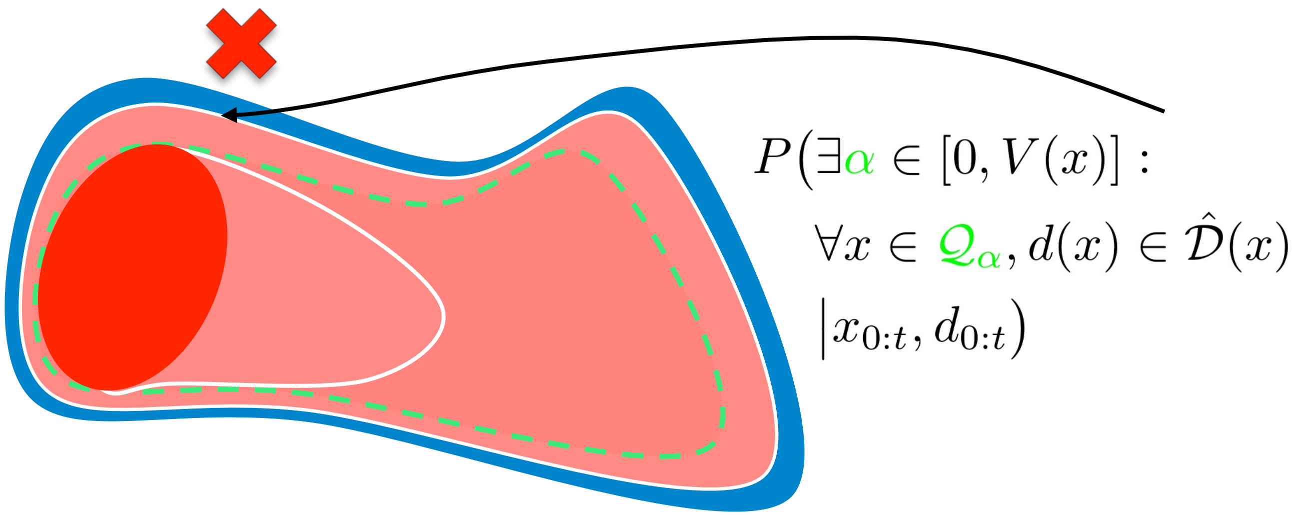
[PGSD: Kolter and Ng, 2009]

Online Safety Guarantee Validation



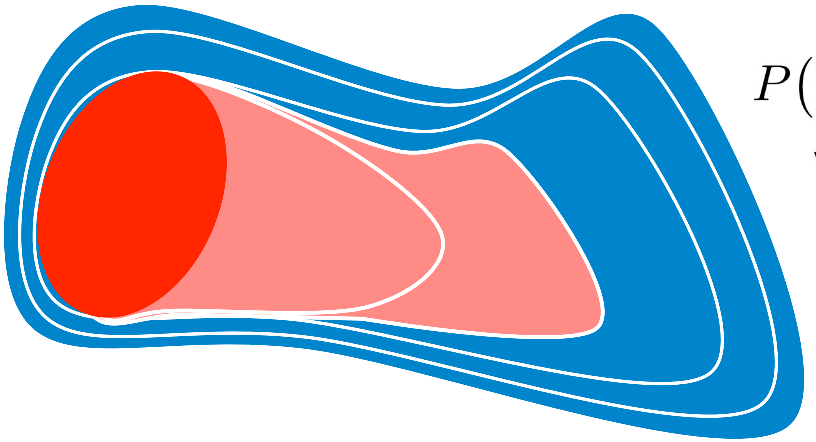
- Initialize active unsafe set = smallest candidate set

Online Safety Guarantee Validation



- Measure disturbance
- Compute Bayesian posterior on existence of a usable level set
- If posterior is low (weak safety guarantee), update unsafe set
- Update disturbance model

Online Safety Guarantee Validation



$$P\Big(\exists \alpha \in [0, V(x)] : \forall x \in \mathcal{Q}_\alpha, d(x) \in \hat{\mathcal{D}}(x) \Big| x_{0:t}, d_{0:t}\Big)$$

- Measure disturbance
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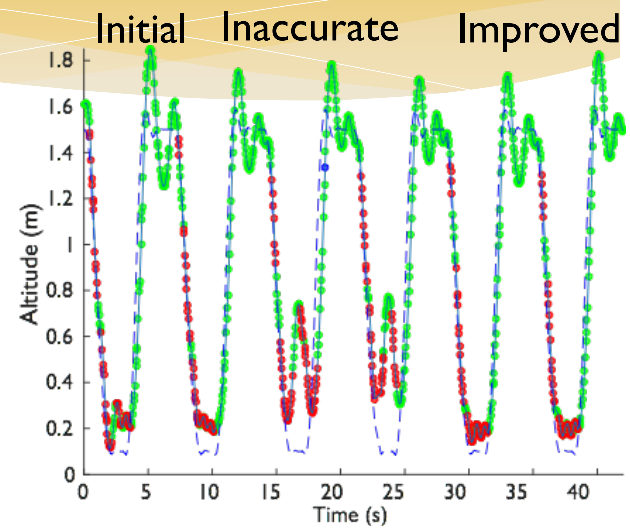
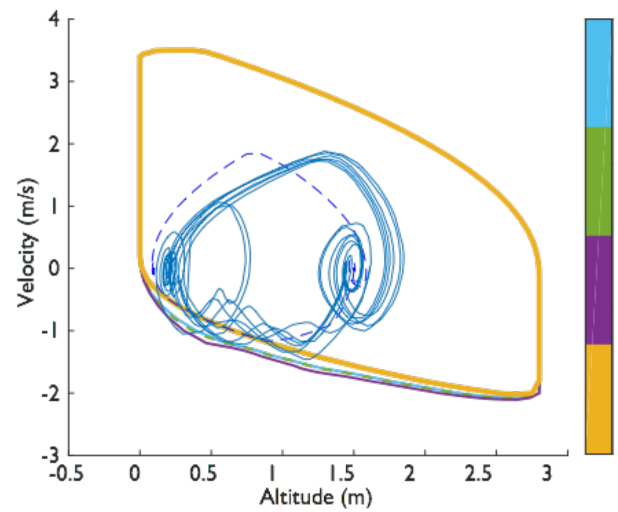
Safe Learning

First computed model is locally inaccurate

System detects inconsistency, slightly contracts safe set

Tracking resumes after a better model is computed





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Safe Learning
with online model validation
Berkeley
University of California

Research Challenges

* Models of unknown environments
* Scalability and compositional safety
* Safe exploration
* Sample efficiency: design-time vs operation-time
* Mixed initiative and collaborative learning
* Risk models

* Safe Learning: Kene Akametalu, Somil Bansal, Jaime Fisac
* **Max Balandat**, **Young Hwan Chang**, Margaret Chapman, Roel Dobbe, David Fridovich-Keil, Qie Hu, **Insoon Yang**, Datong-Paul Zhou

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