Correct-by-Construction Controller Synthesis using Gaussian Process Transfer Learning

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Research Aim

Correct-by-construction design of controllers for complex CPS with black-box models by embracing ideas from control theory, formal verification, and Gaussian processes

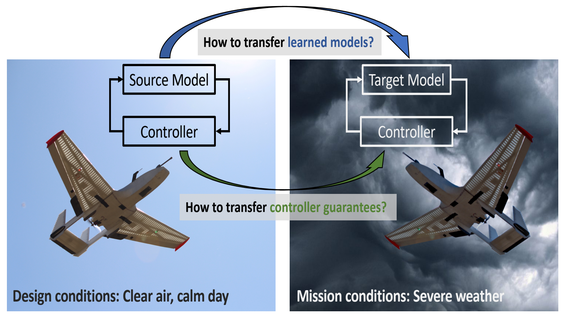
Machine Learning is powerful, yet fallible;

Formal methods are rigorous, but only as rigorous as the model.

Unmodelled Dynamics

$$x_{k+1} = f(x_k, u_k) + \overbrace{g(x_k, u_k)}^{\text{unmodelled}} + w_k$$

Using data, **efficiently** generate a control policy that is **safe**, and **reacts** to changes in the closed-loop dynamics.

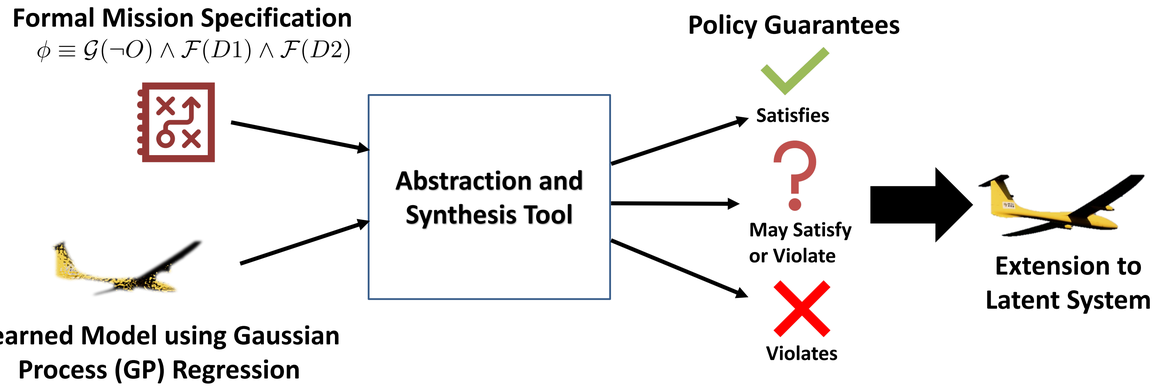


Impact Areas

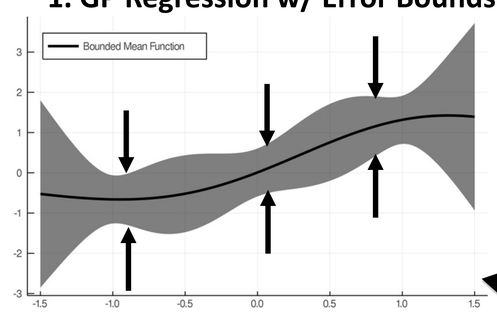
High-potential impact areas include:

- Autonomous ground vehicles, advanced air mobility applications
- Energy infrastructure – robust load balancing and forecasting
- Space exploration, extraterrestrial operations and construction

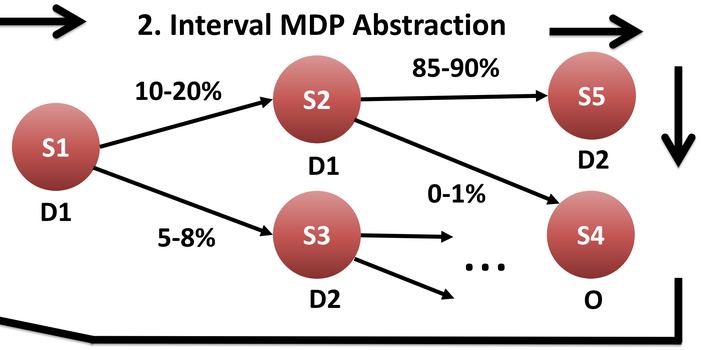
Approach Overview



1. GP Regression w/ Error Bounds



2. Interval MDP Abstraction



3. Policy Synthesis & Verification

Policy synthesis on the abstraction is posed as a value-iteration problem that is solved with convergence guarantees. Verification seeks a pessimistic policy.

4. Execution and Feedback

Data collected online is used to reduce error bounds, improve the abstraction and get a better policy.

Contributions

- Incorporating machine learning with formal methods algorithms;
- Automatically generating safe, mission-accomplishing controllers;
- Addressing scalability and feasibility challenges;
- Developing a toolbox for end-to-end verification and synthesis.

Broader Impacts

- By introducing a correct-by-construction, cost-efficient methodology for the design of CPS, this project can enable fast and reliable design of many such safety-critical systems.
- Develop courses on the integration of principles of machine learning with formal methods
- BPC/E activities focus on recruiting women into the computer science and aerospace engineering
- Initiate and mentor an engineering project course within the summer bridge session for the Engineering GoldShirt Program

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