CPS: Medium: Information-Based Control of Cyber-Physical Systems Operating in Uncertain Environments

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https://murpheylab.github.io/projects/CyberPhysicalSystems

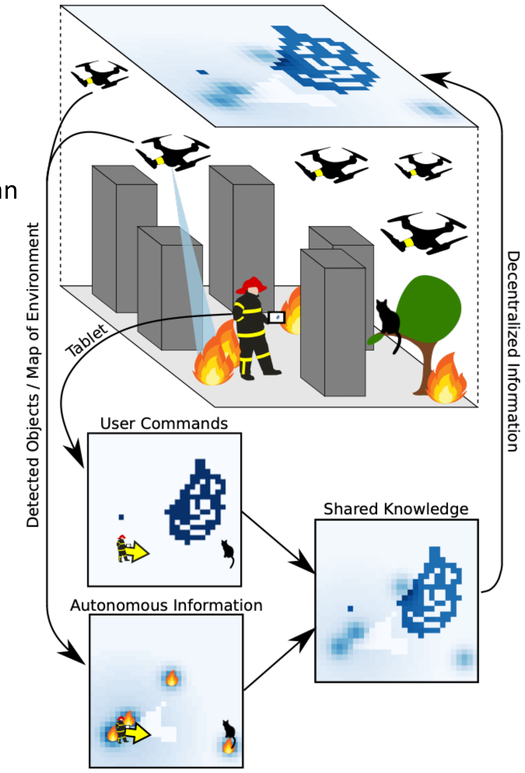
Challenge

How should autonomy use control to not just reduce uncertainty, but to manage the complexity of decision-making in the context of uncertainty?

- We are creating control synthesis techniques for acquiring data to help support decision-making.
- We use distributions for specification, enabling the user to specify what they want the autonomy to do without worrying about the type or number of agents available. Moreover, if the user is unable to engage, these techniques enable the autonomy to provide environmental feedback without requiring the user to provide commands.
- The key outcomes of this work include improving machine learning techniques by automating high quality data collection and combining policy-based and model-based learning using tools from hybrid control.

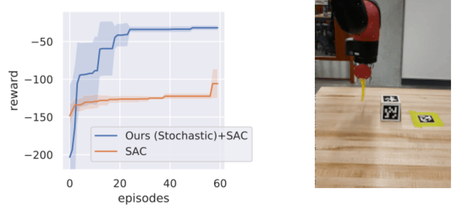
Scientific Impact

- These techniques will impact human-CPS systems. In the diagram shown to the right, the user may need to know information outside of visual range or occluded by buildings. The autonomy, in this case a fleet of drones, can respond to the user's explicit commands as well as a model of the user's needs.
- These results are useful for automating data collection in environments likely to change quickly and where pre-existing datasets do not exist; these environments naturally include disaster response, but the same techniques can be applied to other applications such as handling novel materials in manufacturing.



Autonomy searches an environment to help an operator under time pressure

Block pushing to target location

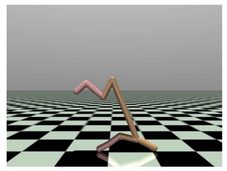


Block stacking

Ant walking task

Half Cheetah Running Task

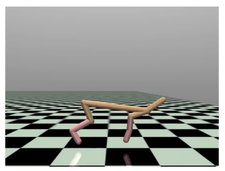
Model-based



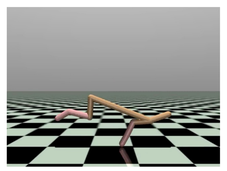
Short-lived success

Unable to recover once it falls

Hybrid Learning



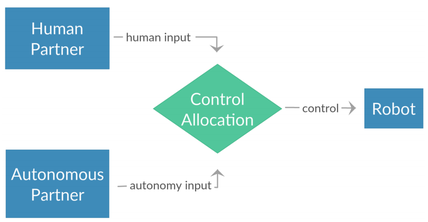
Model-free



Never gains enough useful experience to learn to run

Using tools from hybrid optimal control to switch between policies and model-based policies, we combine policies based on human demonstrations and model-based reasoning to provide superior performance in a range of tasks including manipulation and locomotion.

Impact on Society



Shared control in human-machine systems are increasingly common; these techniques seamlessly integrate people and machines.

Outreach

Our outreach efforts have included exhibits at the Museum of Science and Industry in Chicago. Moreover, we created online content for middle school students during the pandemic.

Quantifying Broader Impact

- In a simulated example of an aerial vehicle arresting its descent after a rotor failure, active learning cut the distance required to learn the new dynamics by 50%, dramatically improving safety. Responding quickly to unmodeled events will enable safer systems that can reason about the future.
- When operators used information-based control for a swarm in a simulated game, their total number of commands was cut by nearly 50% while their game performance improved, indicating that these information-based techniques improve human-machine teaming.

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