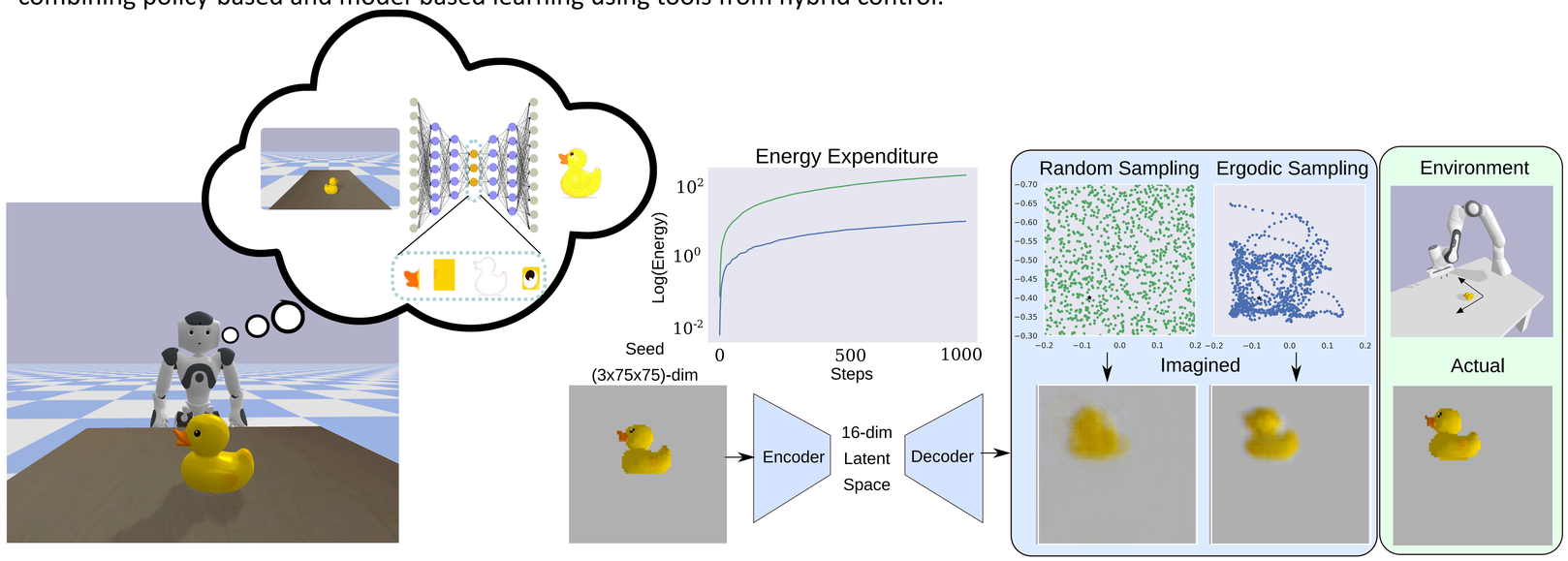
CPS: Medium: Information-Based Control of Cyber-Physical Systems Operating in Uncertain Environments

Todd Murphey (PI) and Brenna Argall (Co-PI), Northwestern University
https://murpheylab.github.io/projects/CyberPhysicalSystems

Challenge

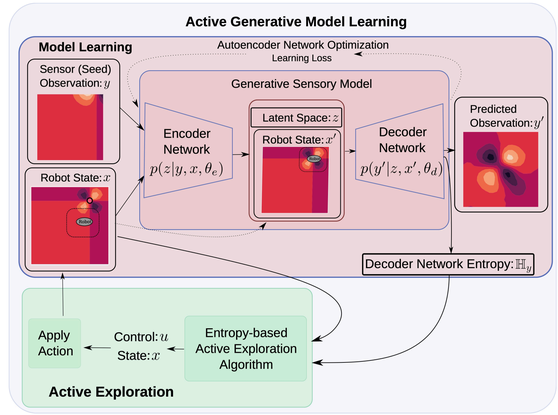
How should autonomy use control to not just reduce uncertainty, but to manage the complexity of decision-making in the context of uncertainty?

- 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.



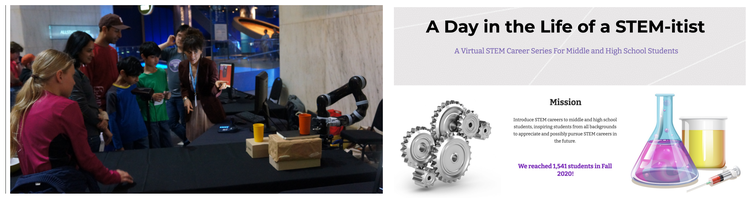
Scientific Impact

- These techniques will impact human-CPS systems that rely on learning, particularly in novel environments. In the diagram shown below, the user may need to know information that is unmodeled. In the case of this example, the robot knows neither about the sensor (in this case a camera) or the object (in this case a rubber duck) and must collect data to build a deep neural network model of the camera-duck pair.
- These structural uncertainties are common in high pressure scenarios (e.g., searching for survivors in collapsed structures) where opportunities for data collection are rare.



Impact on Society

Shared control in human-machine systems are increasingly common; these techniques seamlessly integrate people and machines. However, shared control is nearly always parameterized, assuming that both the task and the interaction are modeled ahead of time. This active learning strategy will allow a robot to use its perception system to generate a model based on general neural network representations of a task, the person, and the environment, to maintain situational awareness in the face of novel circumstances.



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.

Quantitative Impact

- This method for learning novel features is well posed for multiple sensor modalities (vision, touch, electrosense) without modification. Moreover, it significantly outperforms other active learning techniques that use entropy and entropy-like terms as the basis for exploration.
- A. Prabhakar and T. D. Murphey, “Mechanical intelligence for learning embodied sensor-object relationships,” *Nature Communications*, vol. 13, p. 4108, 2022.

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