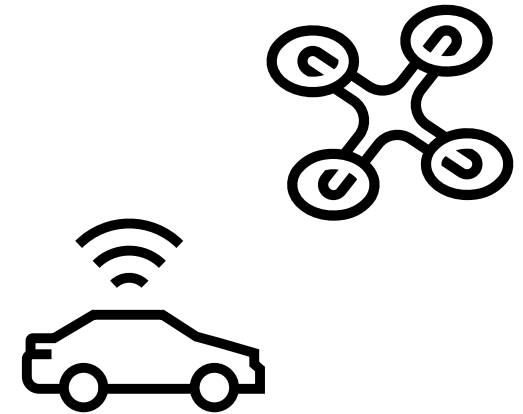
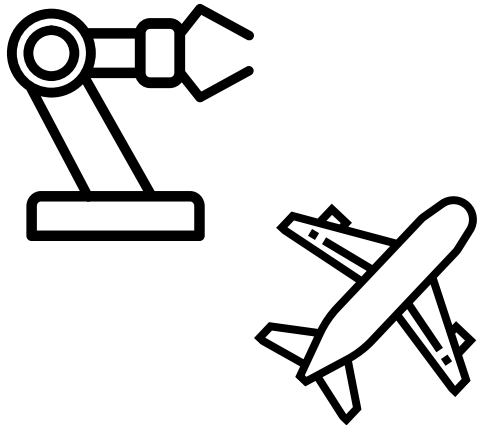


Modular Full-System Simulation for Cyber-Physical Systems

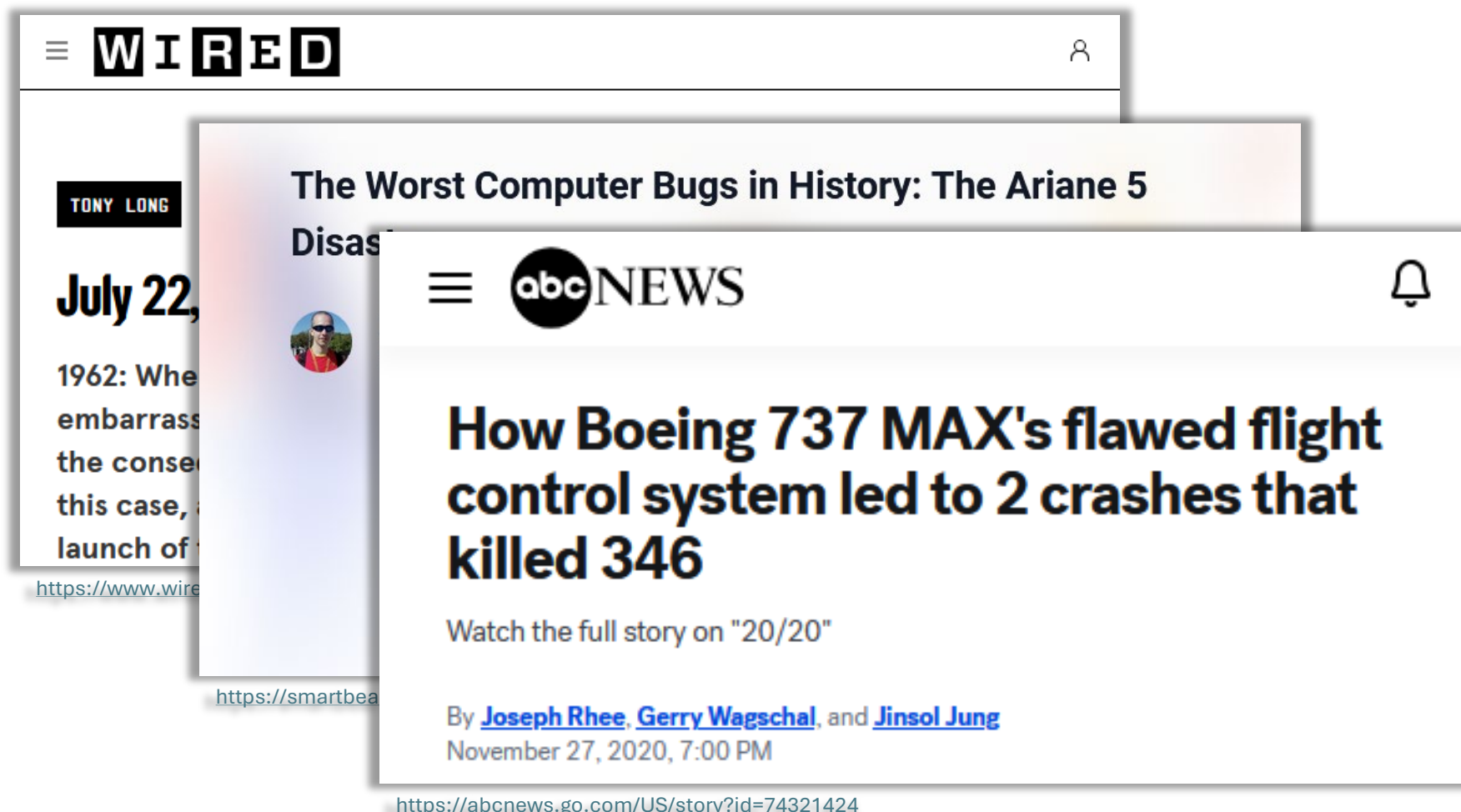
Gideon Mohr

Master Thesis





Why simulate CPS?

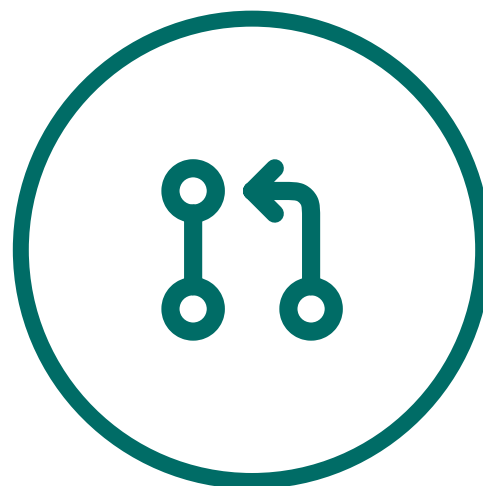




Finding Software Bugs



Careful
Design



Thorough
Review



Extensive
Testing

Limitations of Isolated Testing



Flawed
Interfaces



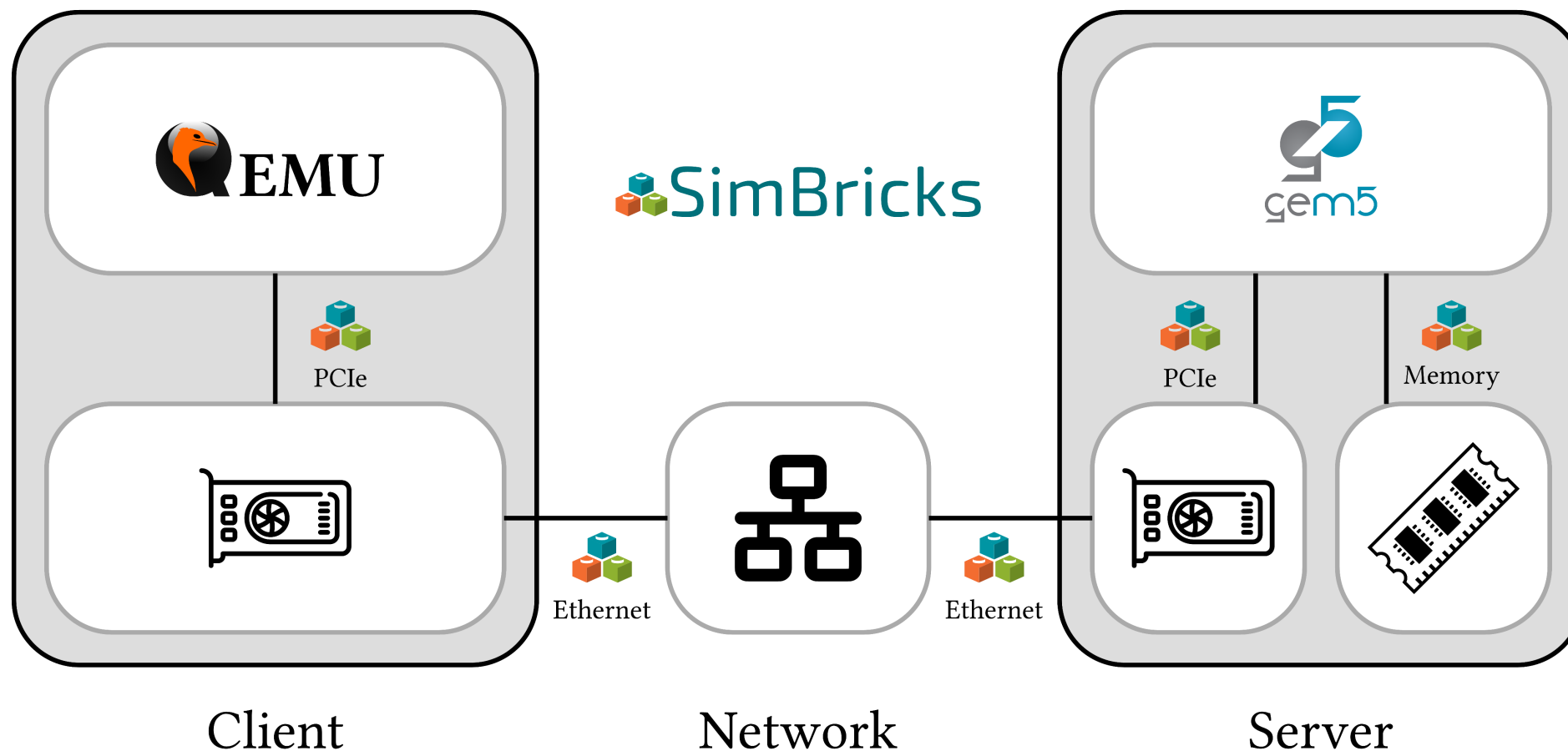
Hardware
Capabilities
Unknown



Different
Execution
Time



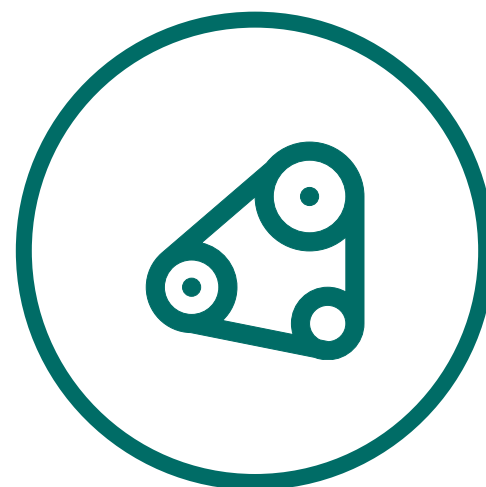
Full-System Simulation



Challenges for CPS



Sensor
Simulation



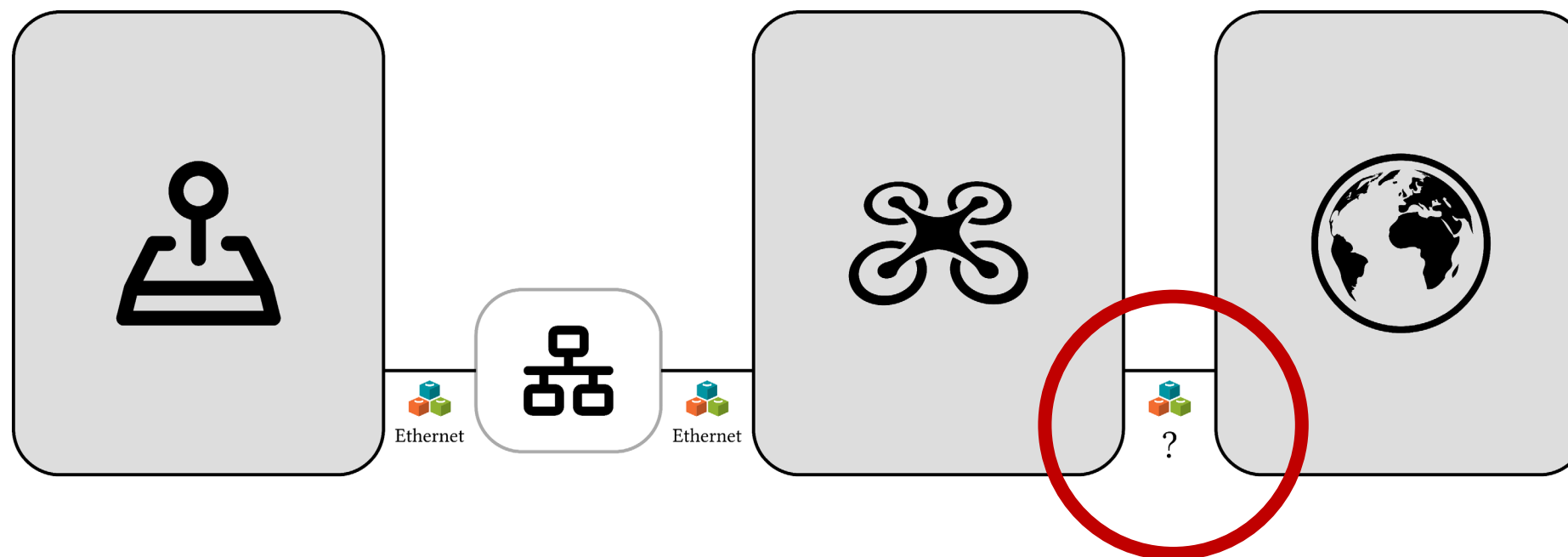
Effect of
Actuators



Synchronization

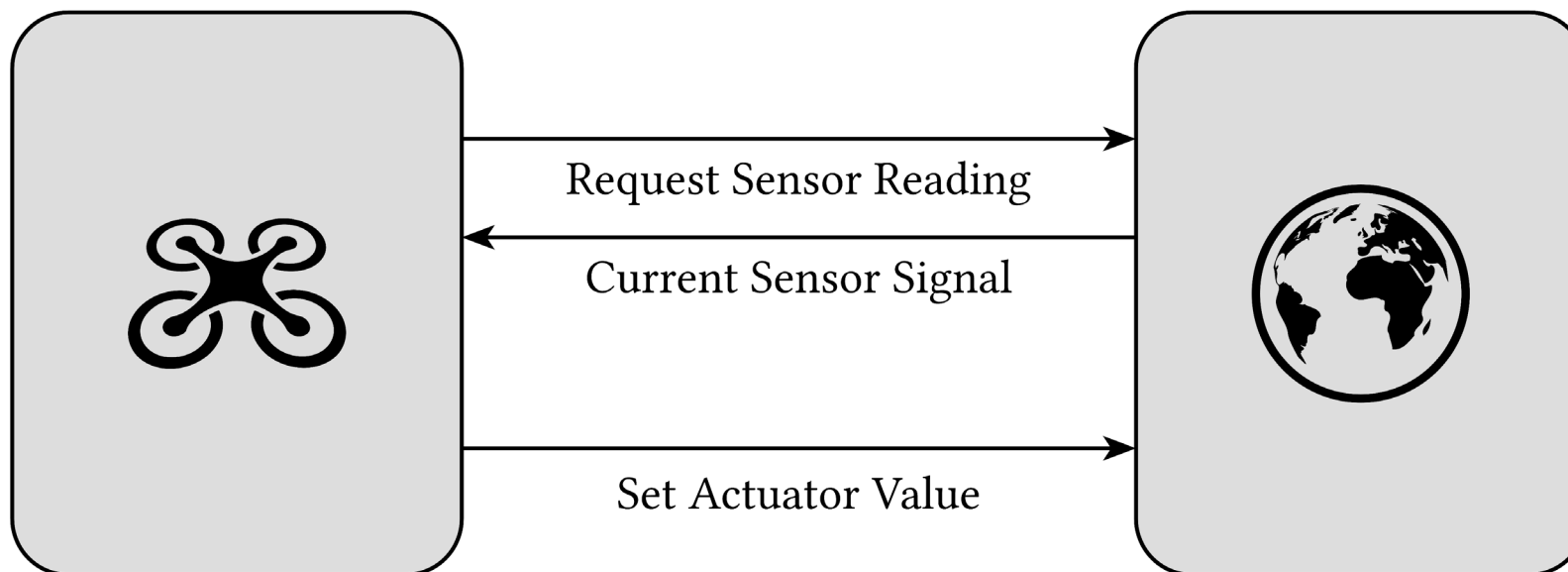


Simulating CPS



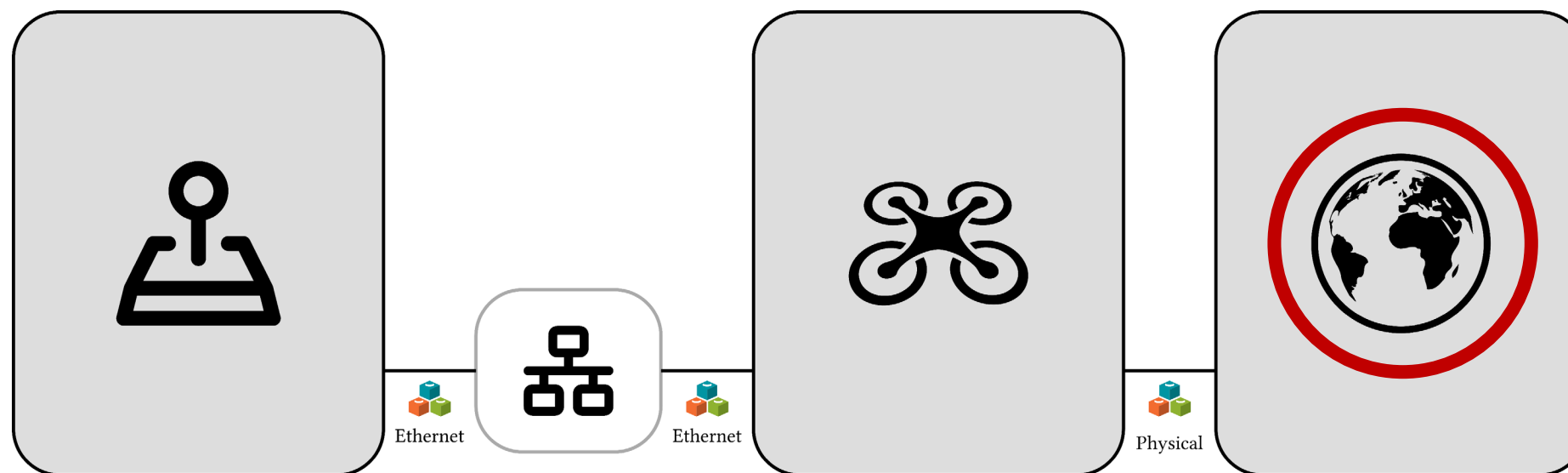


The Physical Interface





Simulating CPS

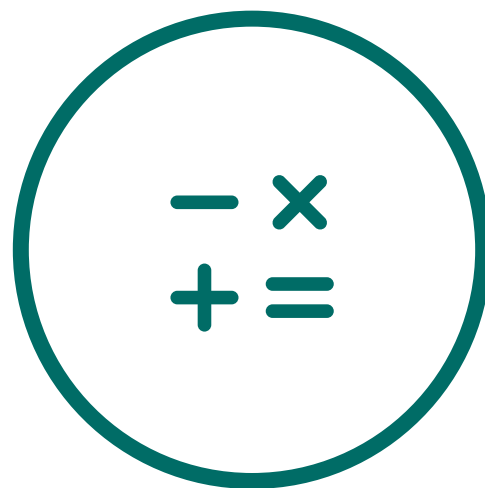




Challenges of Physical Simulation



Continuous
Domains



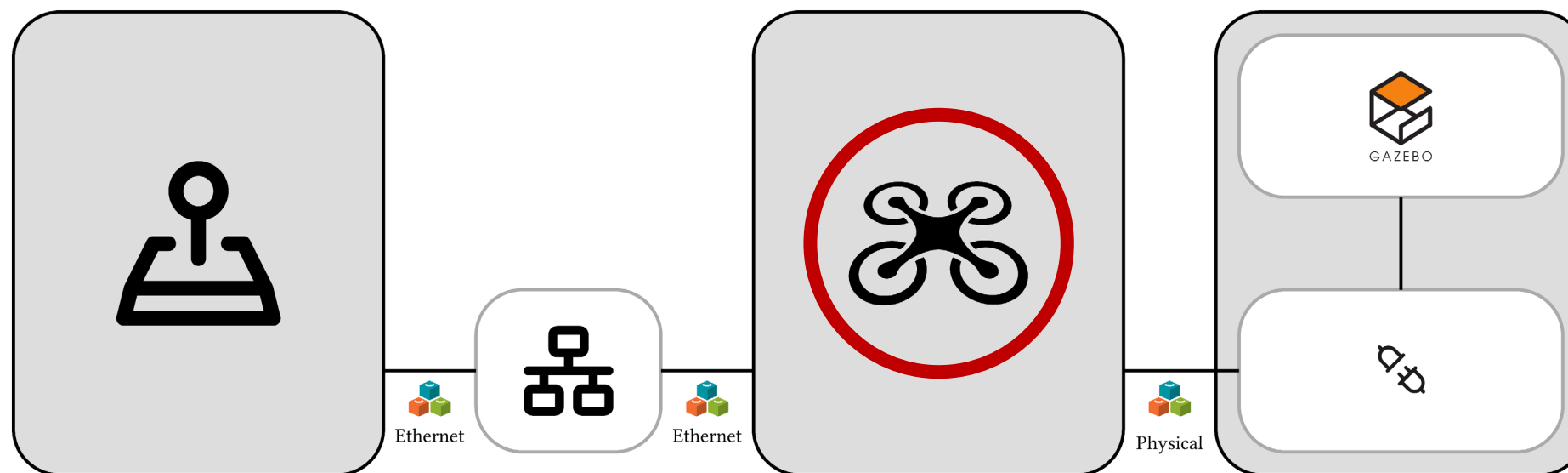
Complex
Equation
Systems



Modeling
Problem

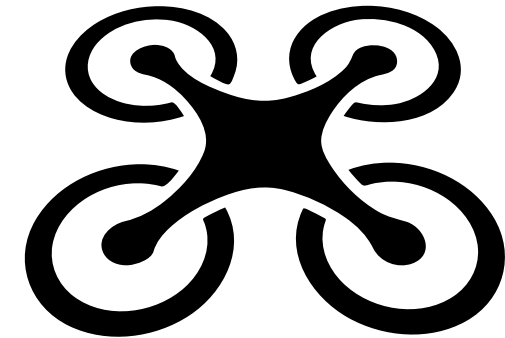


Simulating CPS



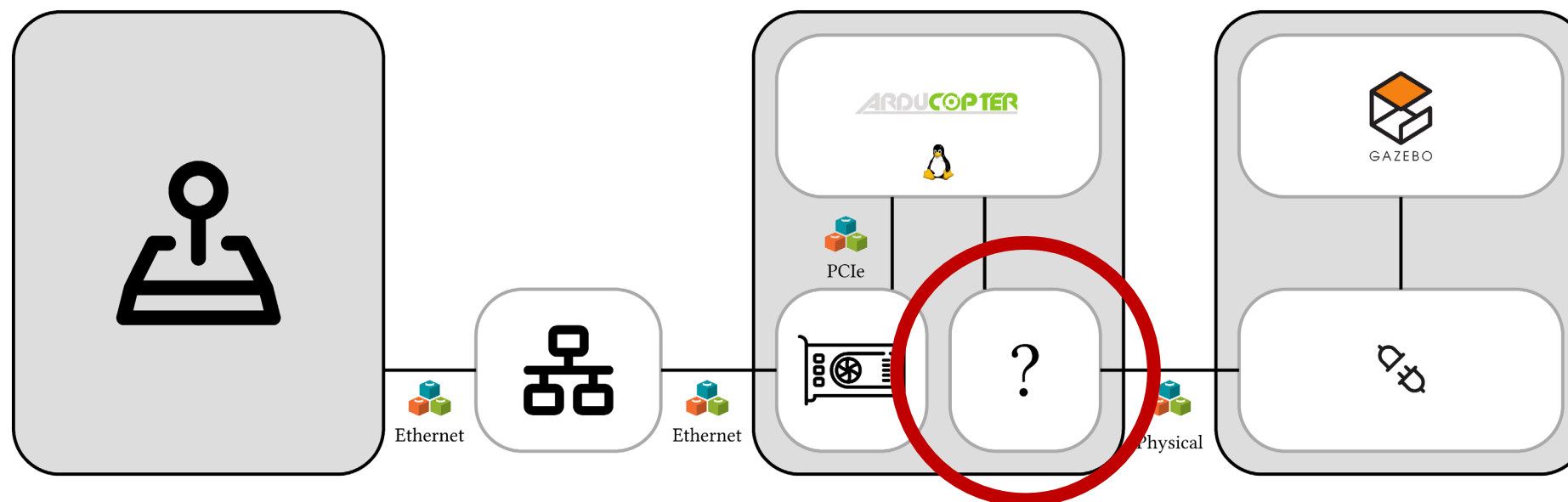


- ArduCopter is a well-known UAV Controller
- Highly configurable sensor & actuator selection
- Runs on various platforms, including Linux
- Can be executed inside gem5





Simulating CPS





MS5611-01BA03

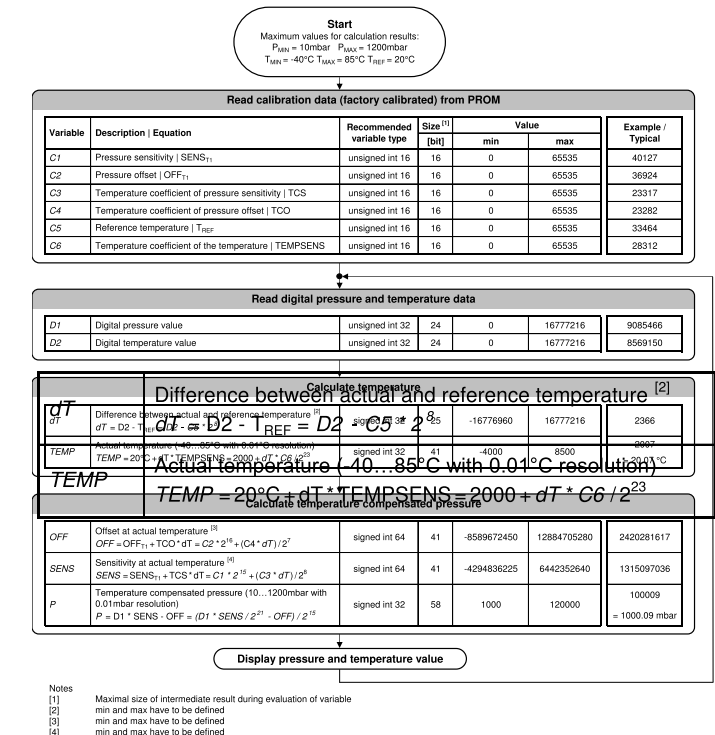
Barometric Pressure Sensor, with stainless steel cap

Device Emulator

- 1 Get measurements from the physical simulation
- 2 Check how the sensor signal relates to measurements
- 3 Invert the computation

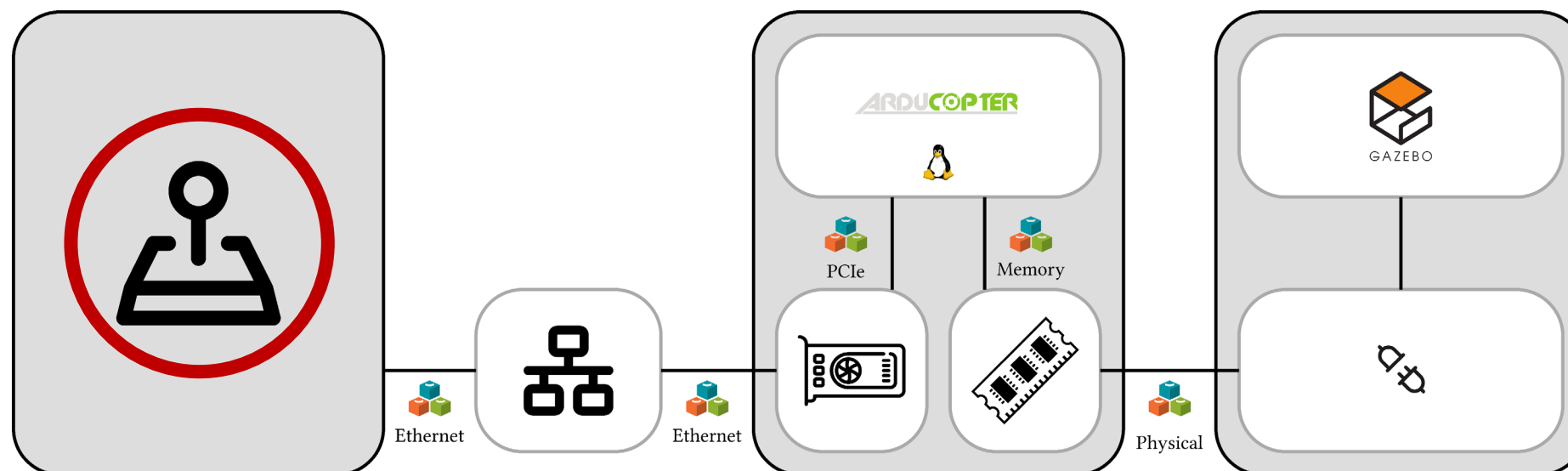


$$D_2 = \left((t - 2000) \cdot \frac{2^{23}}{C_6} \right) + C_5 \cdot 2^8$$

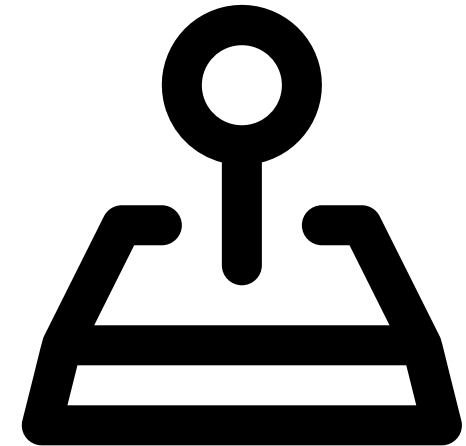




Simulating CPS

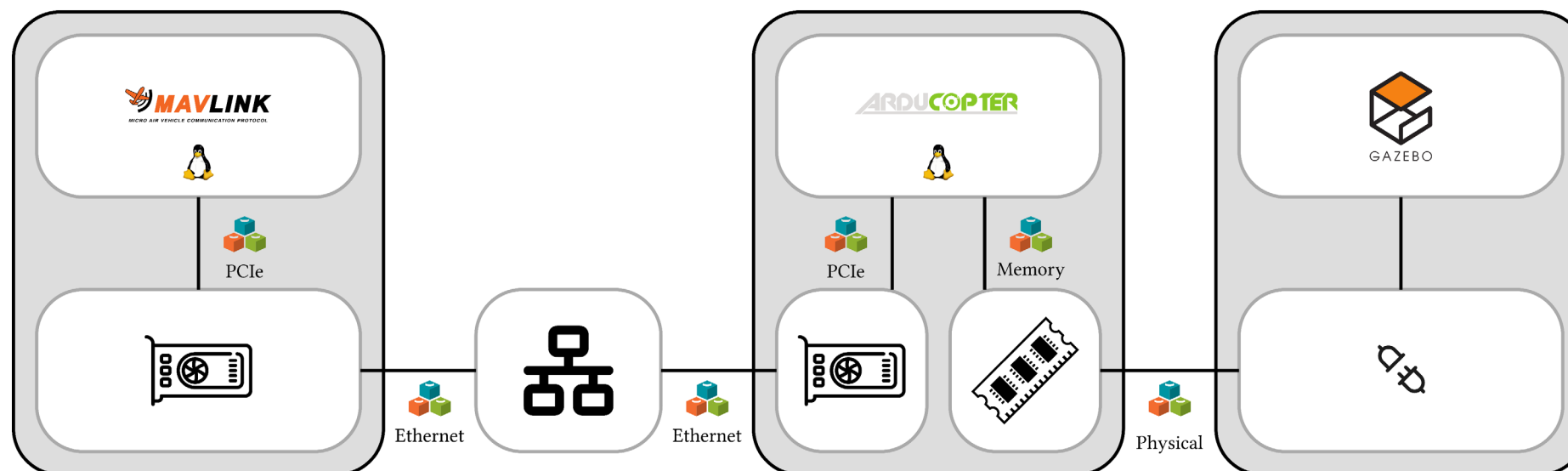


- Lightweight messaging protocol
- ArduCopter sends STATUSTEXT messages during startup
- Ground Control Station sends commands to arm & takeoff



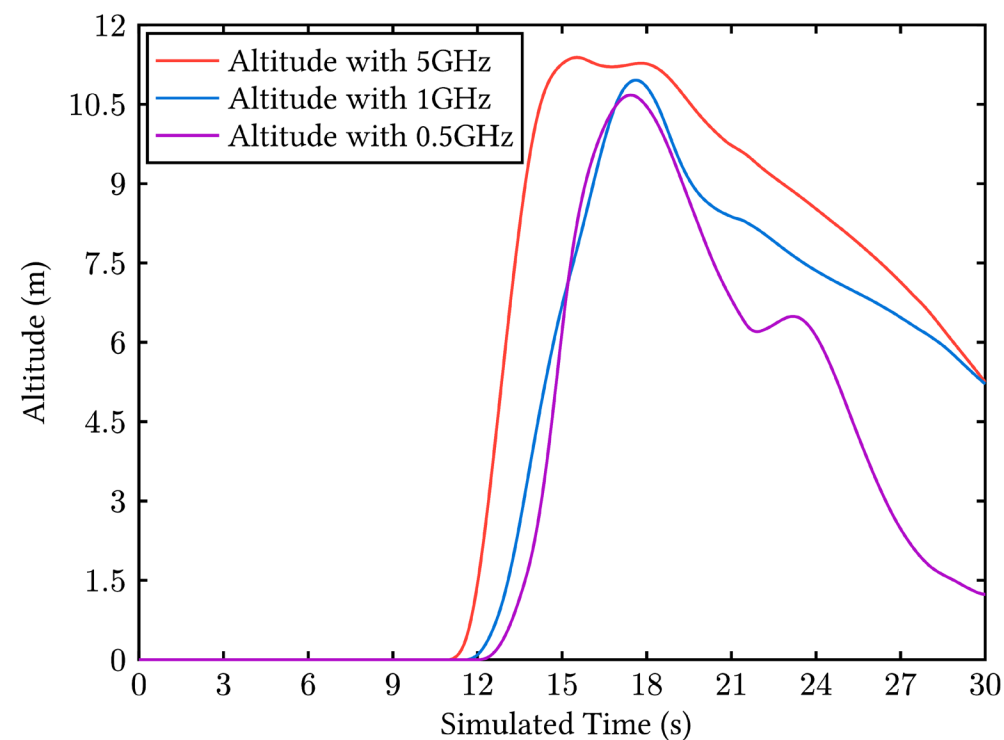
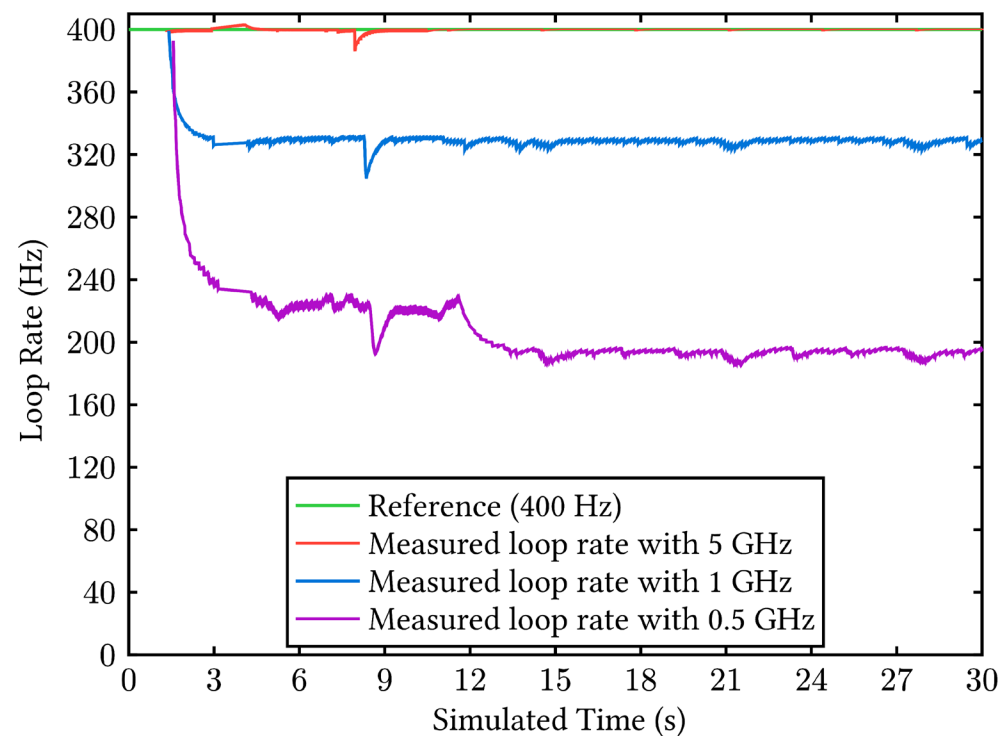


Simulating CPS

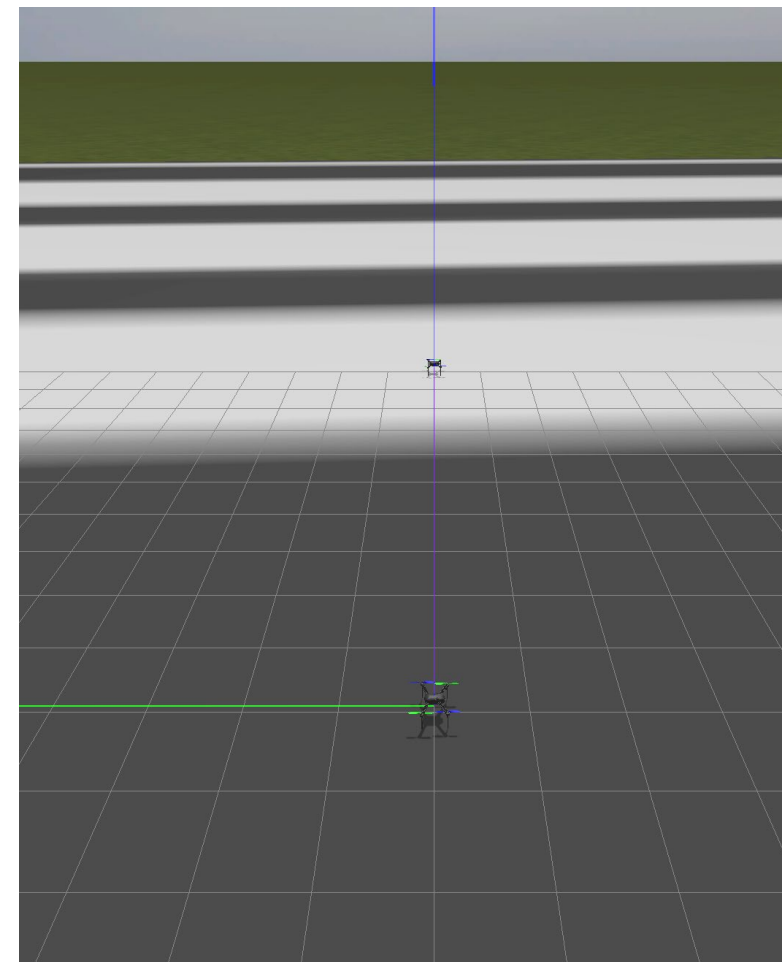
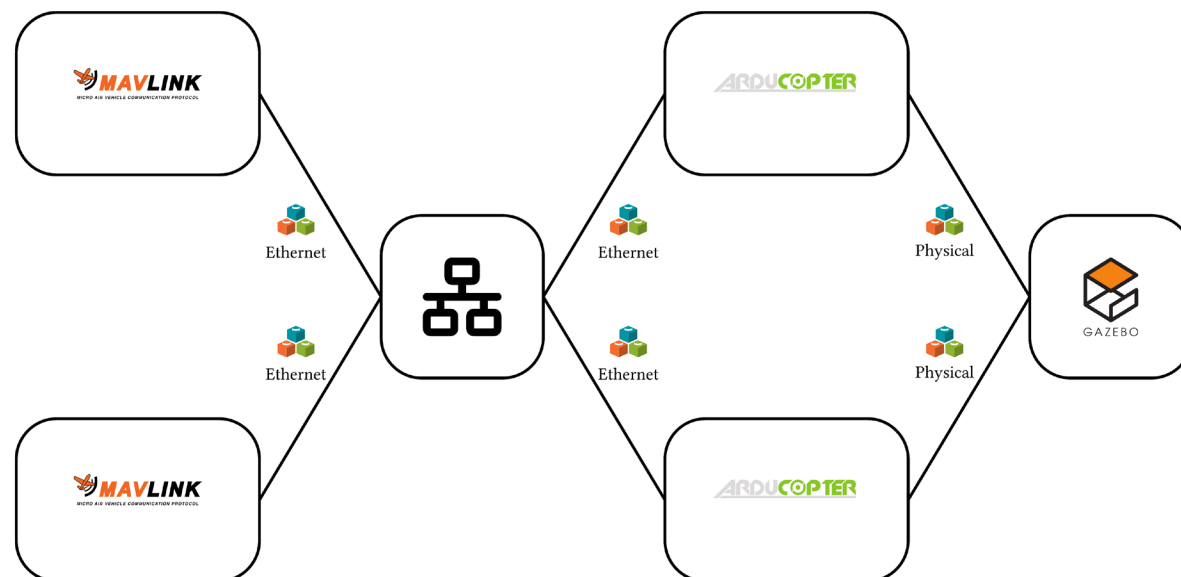


Evaluating the CPU

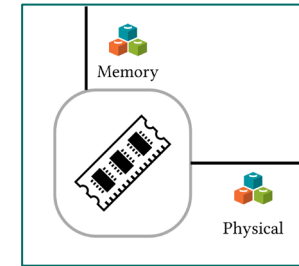
$$\text{loop_rate}(t') = \frac{1}{0.99 \cdot \frac{1}{\text{loop_rate}(t)} + 0.01 \cdot (t' - t)}$$



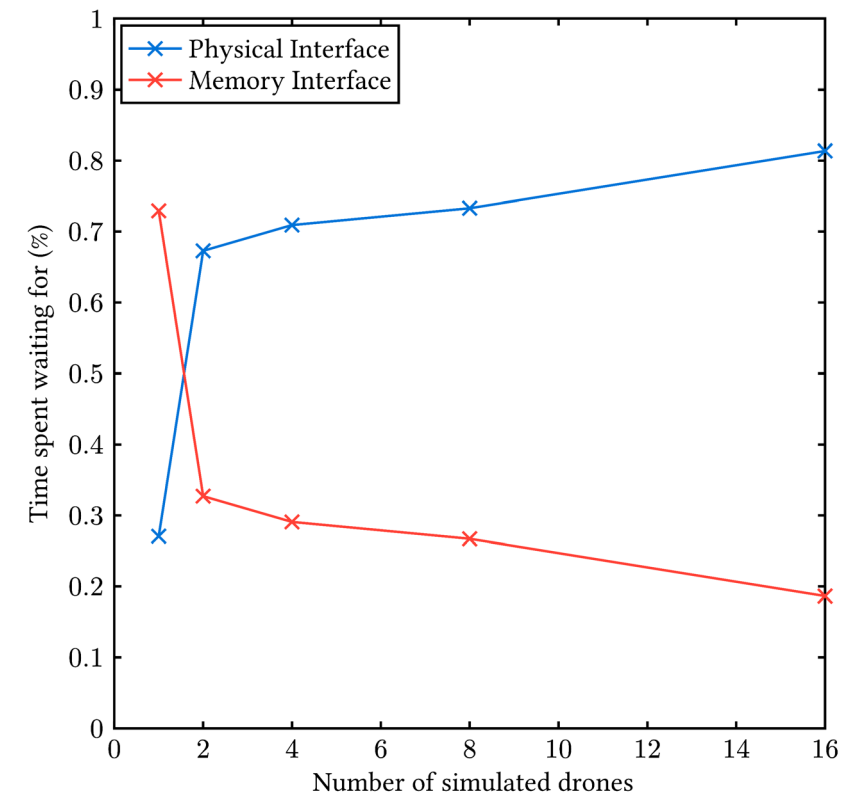
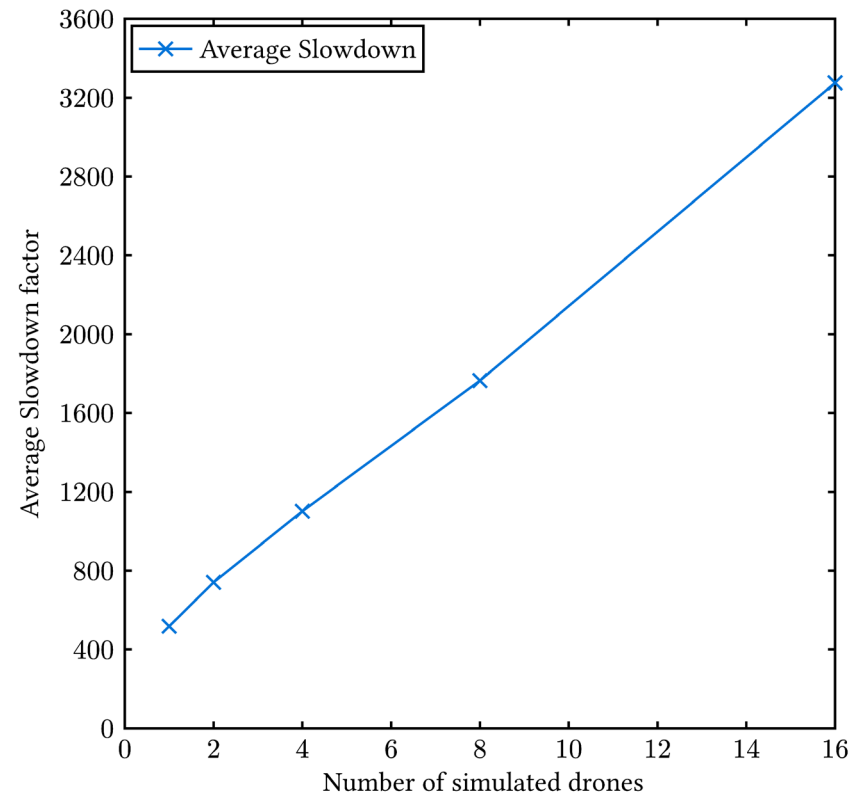
Multiple CPS



Impact on Slowdown

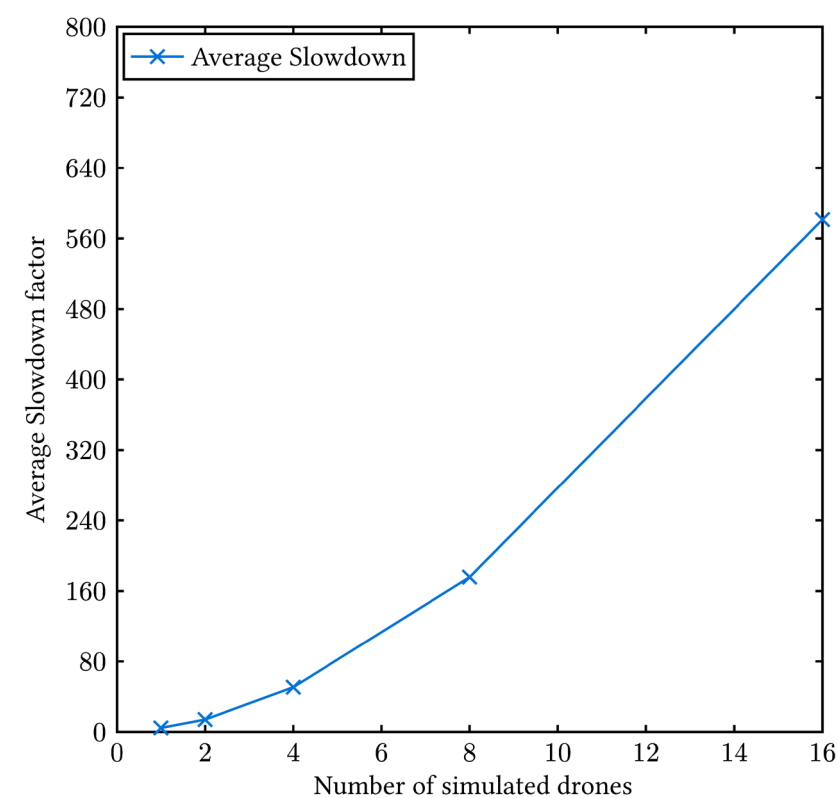
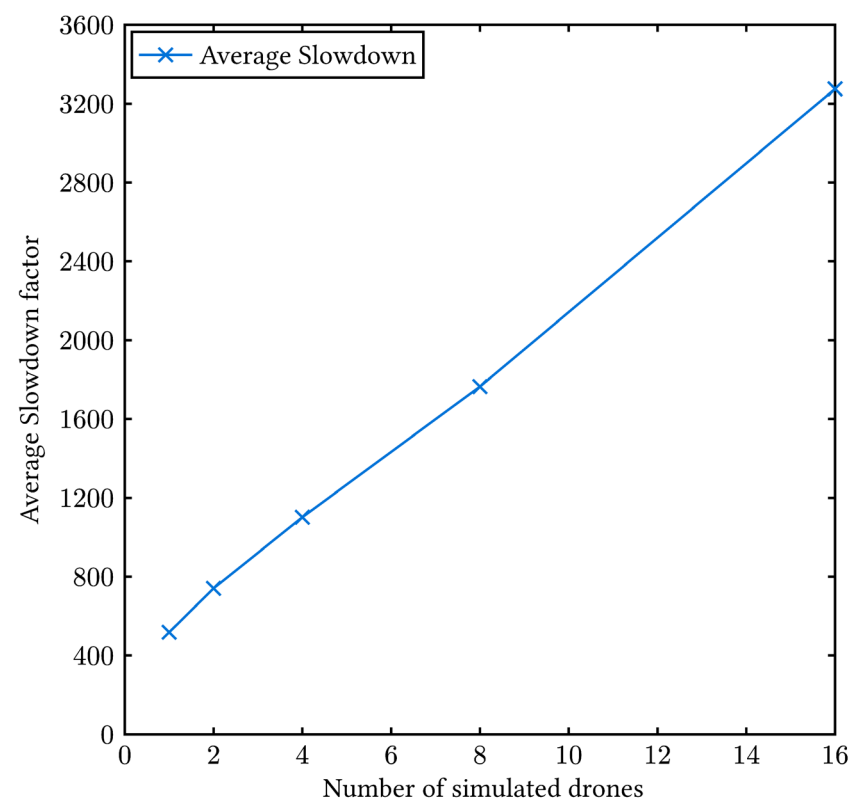


MAX PLANCK INSTITUTE
FOR SOFTWARE SYSTEMS





Slowdown in SITL





Limitations



No support for
manual inputs



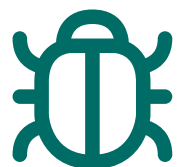
Limited message size



Sensors and actuators are
assumed to be the only point of
interaction with the environment

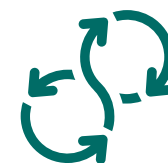


The Perfect Solution?



Reproduce issues
reported by users

Evaluate specific edge-cases
on specific configurations



Simulate many situations
continuously in development

Provide formal
correctness guarantees



Takeaway



Can help to detect issues
early in development

Applicable to different
types of CPS

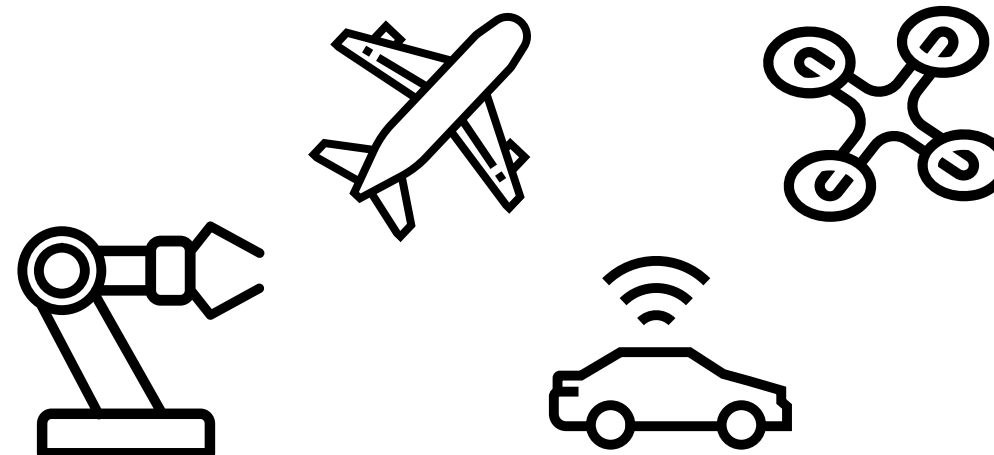
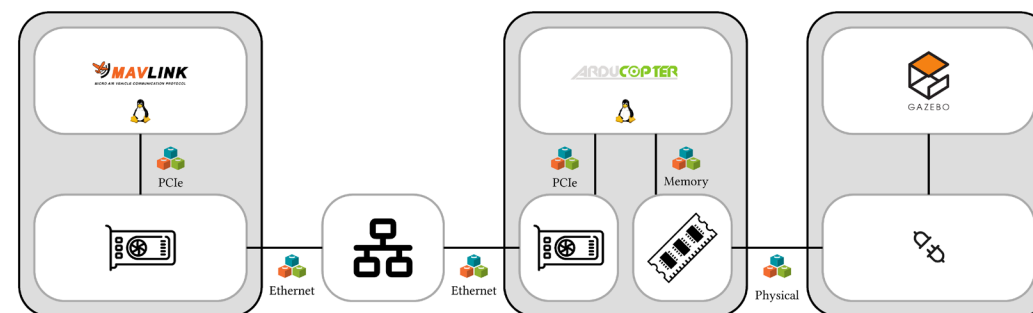


Cannot replace
other simulators



High slowdown

Questions?





Lines of Code

Component	Programming Language	Lines of Code
Physical Interface Definition	C++	182
Gazebo Plugin	C++	868
Custom Kernel Module	C	547
Device Emulator	C++	2778
Drone Definition	XML/SDF	794
World Definition	XML/SDF	174
Simulator Definition	Python	98
Experiment Script	Python	92
Gazebo Logger	C++	331