

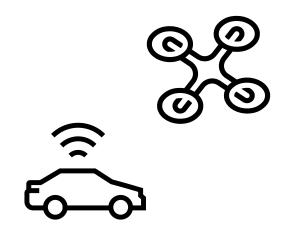


Modular Full-System Simulation for Cyber-Physical Systems



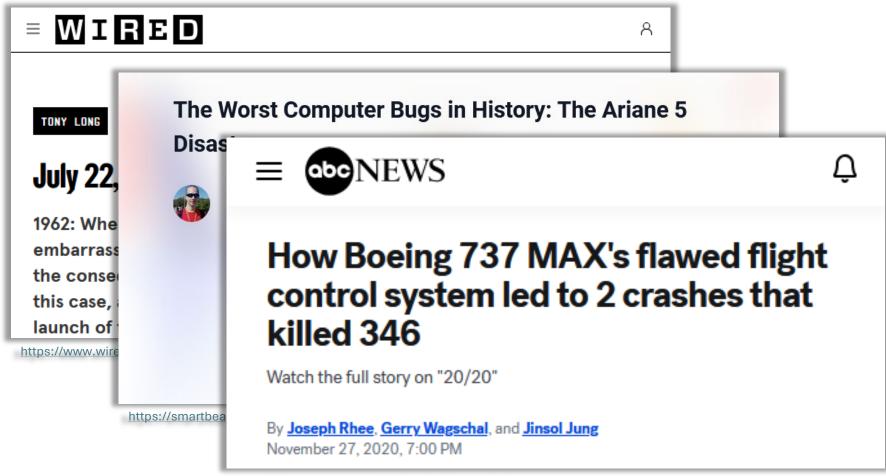
Gideon Mohr

Master Thesis





Why simulate CPS?



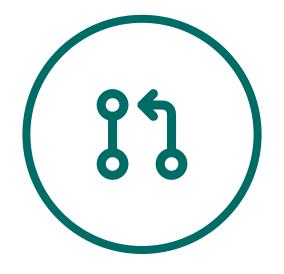
https://abcnews.go.com/US/story?id=74321424



Finding Software Bugs



Careful Design



Thorough Review



Extensive Testing



Limitations of Isolated Testing



Flawed Interfaces



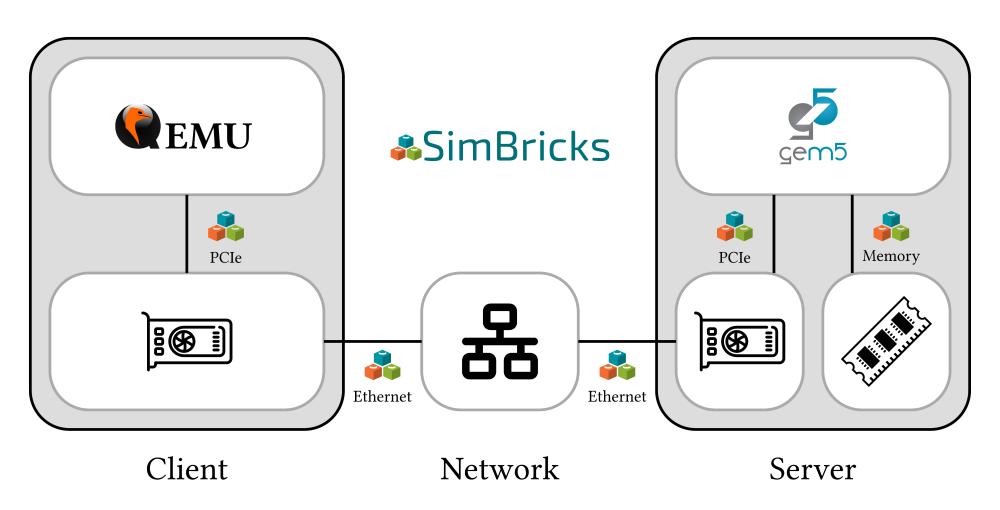
Hardware Capabilities Unknown



Different Execution Time



Full-System Simulation

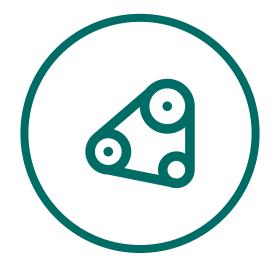




Challenges for CPS



Sensor Simulation

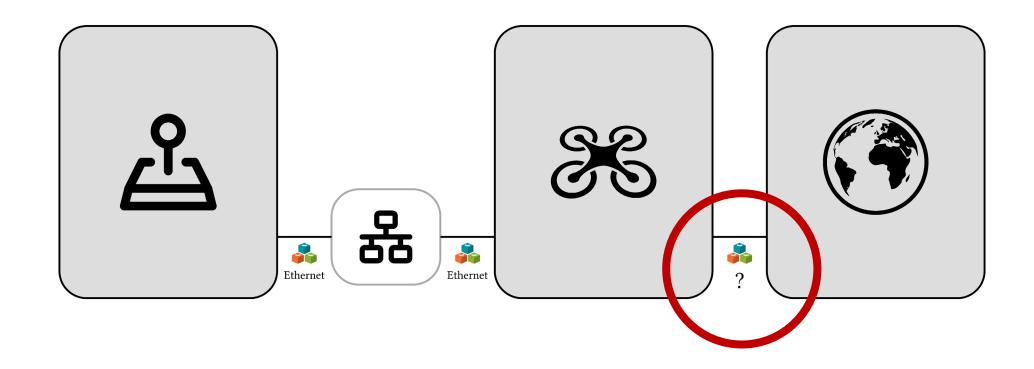


Effect of Actuators



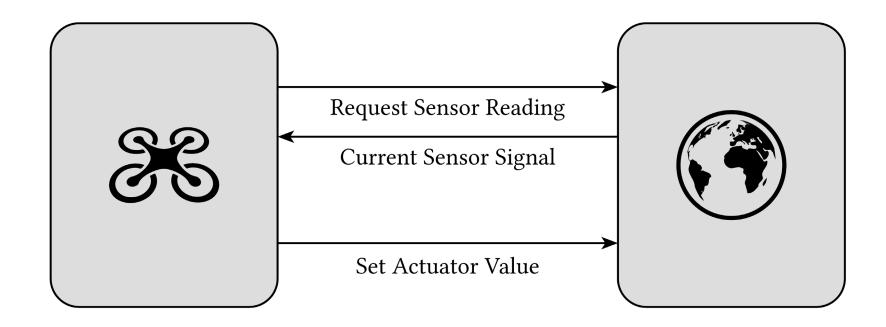
Synchronization



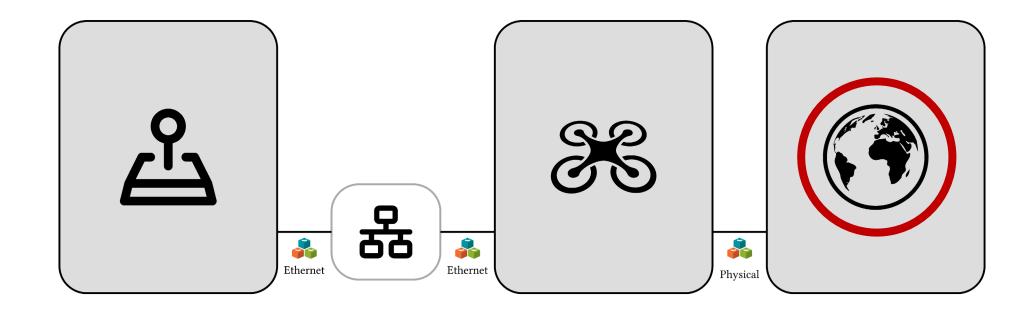




The Physical Interface





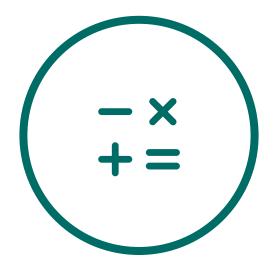




Challenges of Physical Simulation



Continuous Domains

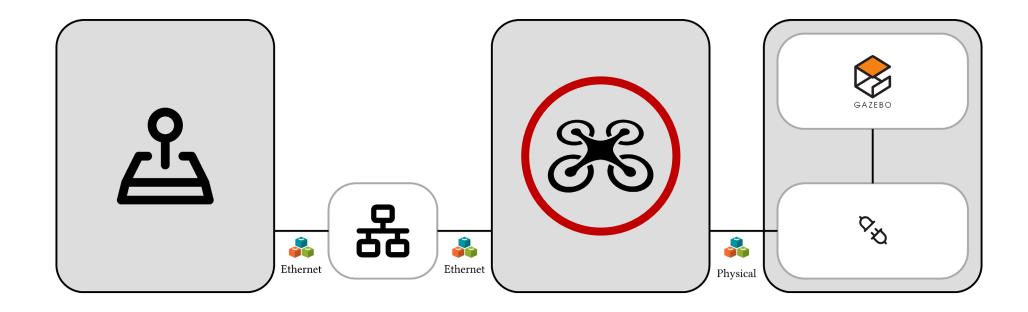


Complex Equation Systems



Modeling Problem







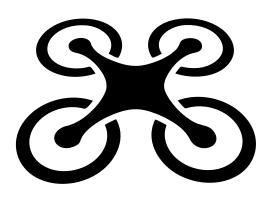


- ArduCopter is a well-known UAV Controller
- Highly configurable sensor & actuator selection
- Runs on various platforms, including Linux
- Can be executed inside gem5

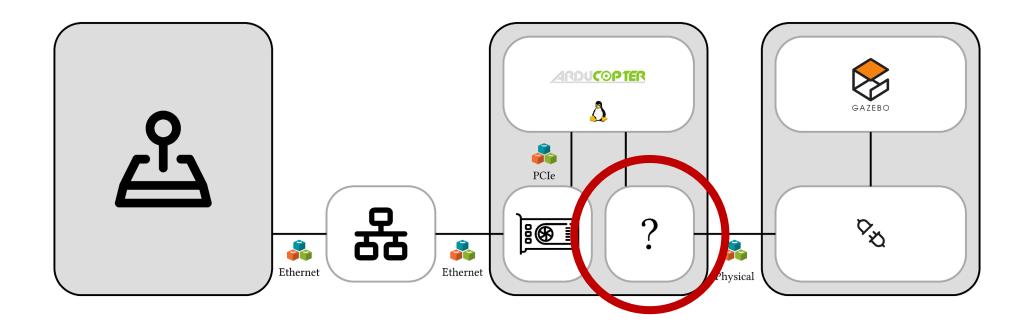














Device Emulator

- Get measurements from the physical simulation
- Check how the sensor signal relates to measurements



Invert the computation

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

Start

Barometric Pressure Sensor, with stainless steel car

		+						
Read calibration data (factory calibrated) from PROM								
Variable Description Equation Recommended Size Value								
variable	Description Equation	variable type	[bit]	min	max	Typical		
C1	Pressure sensitivity SENS _{T1}	unsigned int 16	16	0	65535	40127		
C2	Pressure offset OFF _{T1}	unsigned int 16	16	0	65535	36924		
СЗ	Temperature coefficient of pressure sensitivity TCS	unsigned int 16	16	0	65535	23317		
C4	Temperature coefficient of pressure offset TCO	unsigned int 16	16	0	65535	23282		
C5	Reference temperature T _{REF}	unsigned int 16	16	0	65535	33464		
C6	Temperature coefficient of the temperature TEMPSENS	unsigned int 16	16	0	65535	28312		

faximum values for calculation results $P_{MN} = 10$ mbar $P_{MAX} = 1200$ mbar $T_{MN} = -40$ °C $T_{MAX} = 85$ °C $T_{REF} = 20$ °C

							
Read digital pressure and temperature data							
D1	Digital pressure value	unsigned int 32	24	0	16777216	9085466	
D2	Digital temperature value	unsigned int 32	24	0	16777216	8569150	

	Difference between actual and reference temperature [2]								
a i	′	Difference b	etween actual and reference temperature in ter Got - cas 192 - TREF = D	2 <u>***</u> 65** 2	825	-16776960	16777216	2366	
TEN	1P			signed int 32 (-4085	°Ĉ۱	vith 0.01	°C reso	ution3°	广
	TEMP = 20°C + dT * TEMPSENS = 2000 + dT * C6 / 2 ²³								

		Calculate tempera	iture compensa	teu pre	ssure			
OFF	OFF OFF = OFF _{T1} + TCO * dT = $C2 * 2^{16} + (C4 * dT)/2^7$		signed int 64	41	-8589672450	12884705280	2420281617	
SENS		at actual temperature ⁽⁴⁾ (NS _{T1} + TCS * dT = C1 * 2 ¹⁵ + (C3 * dT)/2 ⁸	signed int 64	41	-4294836225	6442352640	1315097036	
Р	0.01mbar re	re compensated pressure (101200mbar with esolution) ENS - OFF = (D1 * SENS / 2 ²¹ - OFF) / 2 ¹⁵	signed int 32	58	1000	120000	100009 = 1000.09 mbar	
)

Display pressure and temperature value

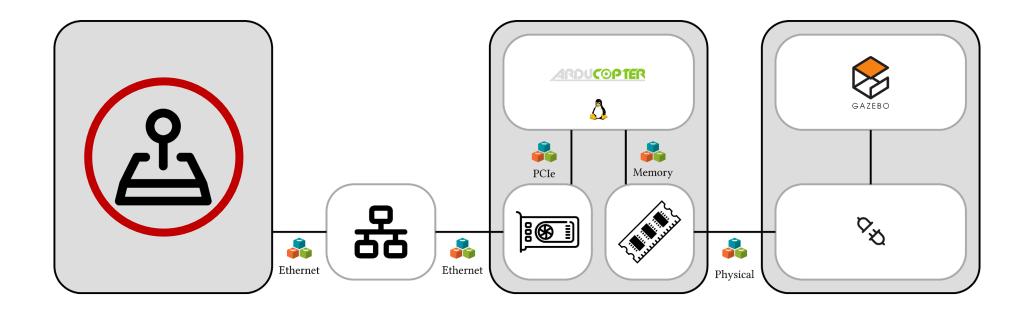
[1] Maximal size of intermediate result during evaluation of variable min and max have to be defined

[3] min and max have to be define [4] min and max have to be define

SENSOR SOLUTIONS ///MS5611-01BA03 06/2017

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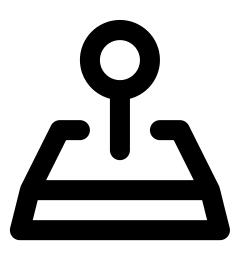




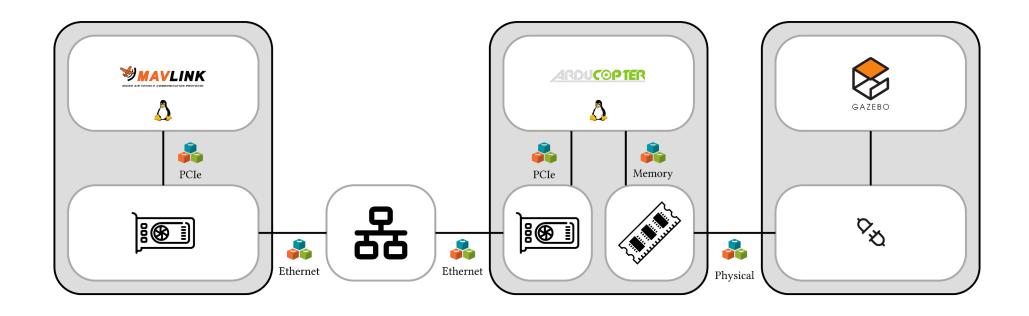




- Lightweight messaging protocol
- ArduCopter sends STATUSTEXT messages during startup
- Ground Control Station sends commands to arm & takeoff



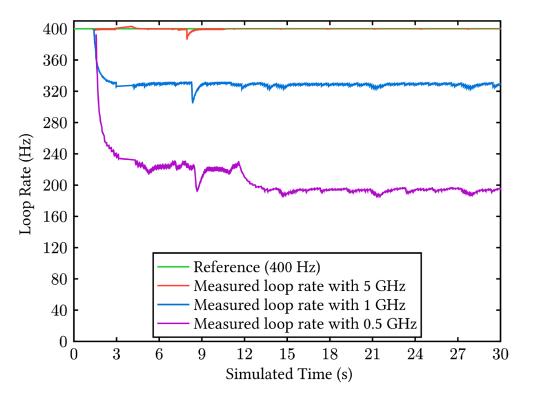


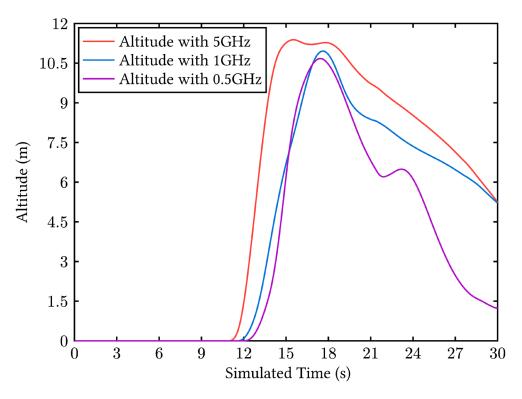




Evaluating the CPU

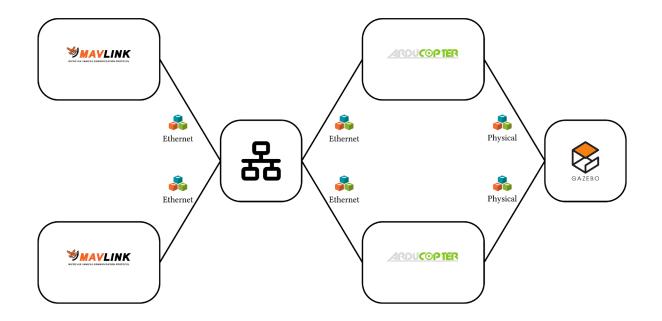
loop_rate(t') =
$$\frac{1}{0.99 \cdot \frac{1}{\text{loop_rate}(t)} + 0.01 \cdot (t' - t)}$$

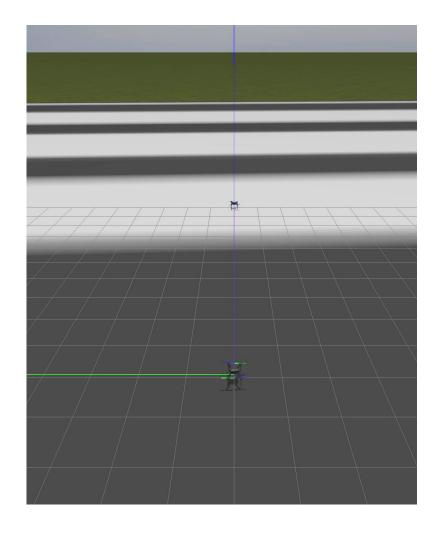




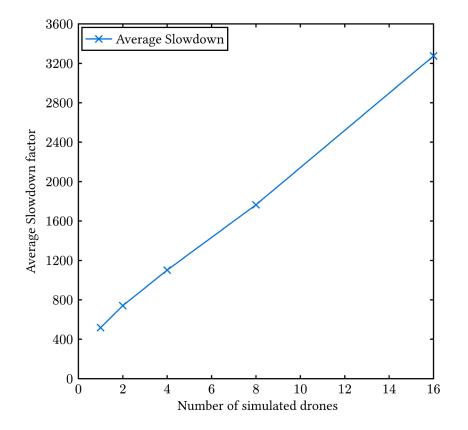


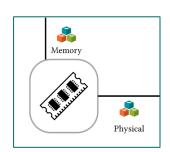
Multiple CPS



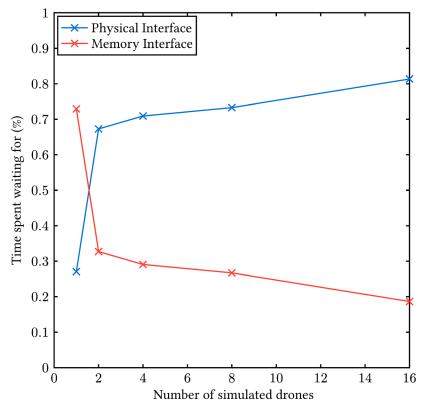


Impact on Slowdown



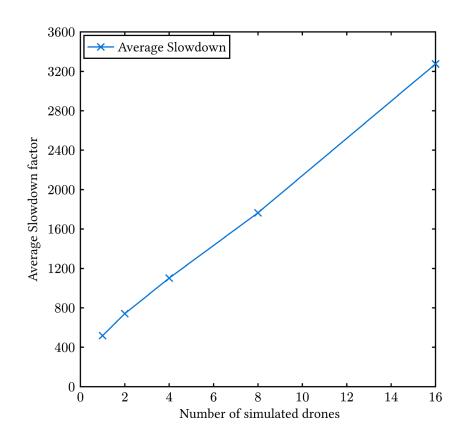


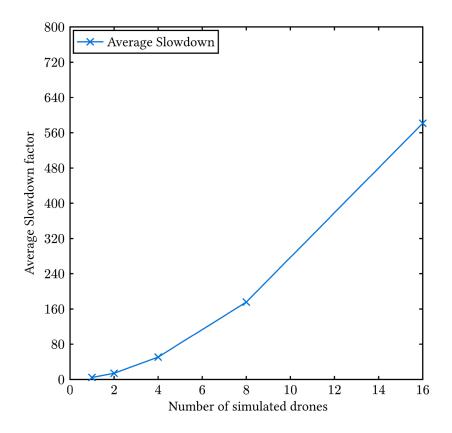






Slowdown in SITL







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?

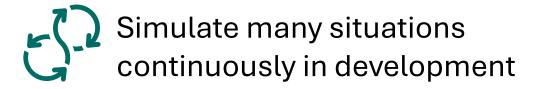


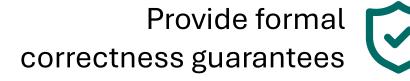


Evaluate specific edge-cases on specific configurations











Takeaway



Can help to detect issues early in development Applicable to different types of CPS

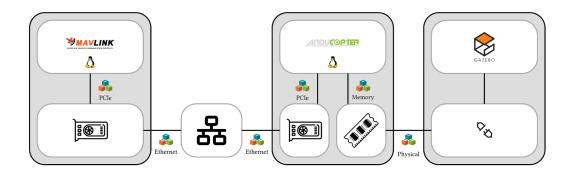


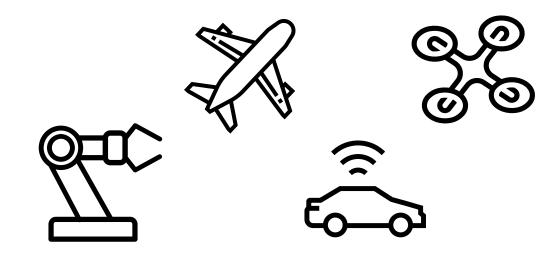
Cannot replace other simulators



High slowdown

Questions?







Lines of Code

Component	Programming Language	Lines of Code
Physical Interface Definition	C++	182
Gazebo Plugin	C++	868
Custom Kernel Module	С	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