Seventh Annual
Cyber-Physical Systems Principal Investigators' Meeting
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Physically-Informed Assertions for CPS Development and Debugging (#1239498)

Challenges and Goals

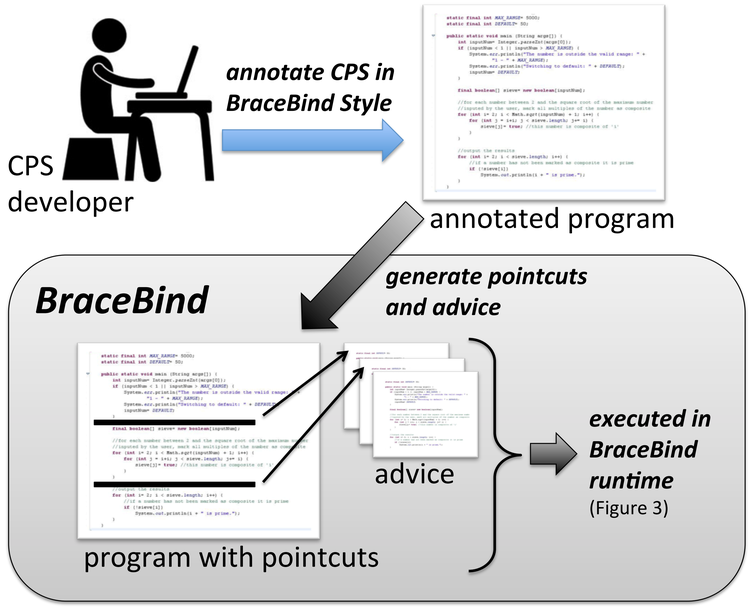
Challenge: debugging CPS requires considering the tight coupling of the cyber and the physical

- The state of the art in CPS verification and validation continues to rely heavily on "trial and error"
- Methods for CPS debugging should allow developers to seamlessly move between the two
- Developers need to be able to state (and verify, at runtime) both local and global properties

Solution: Brace framework for assertion-driven development of cyber-physical systems

- Developers annotate programs with connections to cyber or physical
- Developers write assertions of correct program behavior
- Brace automatically binds to appropriate "devices" and monitors local and global properties at runtime

Development Process



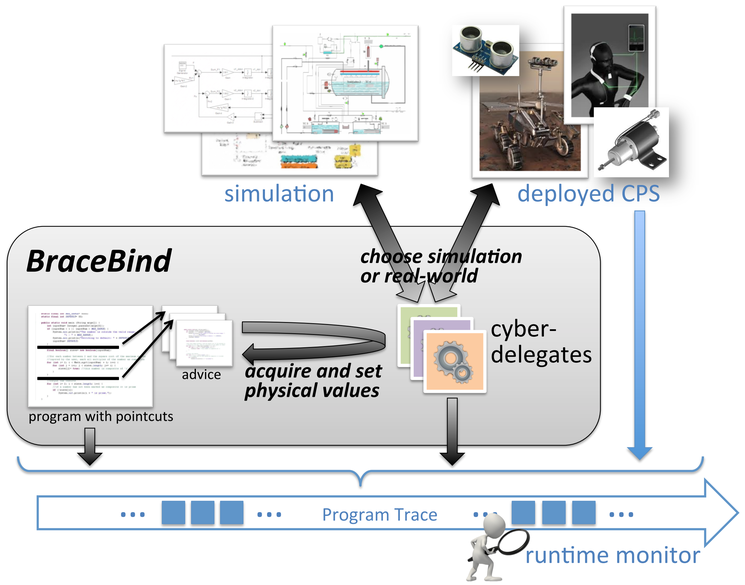
An Example Annotation

Connected (at runtime) to simulation (alternatively to a real device)

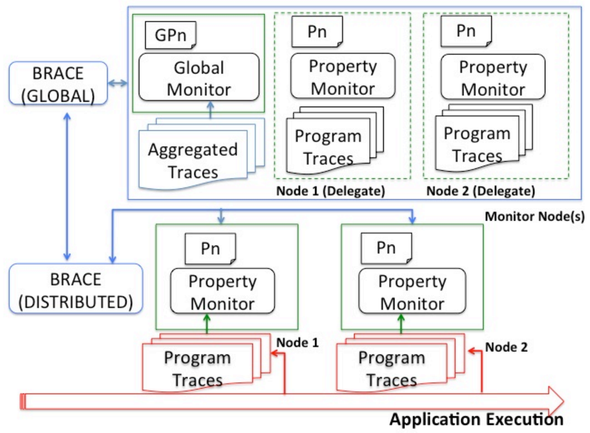
```
@PhysicalVariable(name="Angle_Change",
                  variable = "angle",
                  type="Actuator",
                  mode="Simulation")
public void onSensorChanged(SensorEvent event) {
    //... Somewhere in the function
    float orientation[] = new float[3];
    SensorManager.getOrientation(R, orientation);
    mBearing = (float)(orientation[0]*(180/Math.PI));

    //... Somewhere else in the function
    velocity = (0.15f);
    angle = ((mBearing - desiredBearing) * turn_factor);
}
```

Propagated (at runtime) to a (simulated) actuator

A Runtime Monitoring System



Monitoring Properties on Traces



Local property: the integral of absolute cross track error is bounded (the vehicle is not weaving)

Global property: the number of messages required to reach consensus on task assignment is bounded

Results

Motivated concrete need for better CPS debugging primitives[1]

Demonstrated feasibility and correctness of Brace CPS assertion framework[2]

Quantified the costs associated with runtime debugging of CPS using combined simulation and real devices[3,4]

Impact on the process of debugging CPS applications

- Resulting in a safer, more robust, and more replicable approach to verification and validation

Future impact on future *development* of CPS applications

- By enabling on-line assertion-driven program *repair*

[1] X. Zheng, C. Julien, M. Kim, and S. Khurshid. "Perceptions on the State of the Art in Verification and Validation in Cyber Physical Systems." *IEEE Systems Journal* (accepted, to appear).
[2] X. Zheng, C. Julien, R. Podorozhny, and F. Cassez. "BraceAssertion: Runtime Verification for Cyber-Physical Systems," in *Proceedings of MASS*, 2015.
[3] X. Zheng, C. Julien, R. Podorozhny, F. Cassez, and T. Rakotoarivelo. "Efficient and Scalable Runtime Monitoring for Cyber-Physical Systems." *IEEE Systems Journal* (accepted, to appear).
[4] X. Zheng, C. Julien, H. Chen, R. Podorozhny, and F. Cassez. "Real-Time Simulation Support for Runtime Verification of Cyber-Physical Systems." *ACM Ttransactions on Embedded Computing Systems* (under revision).

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