A Rigorous Approach to the Design of Cyber-Physical Systems through Co-Simulation

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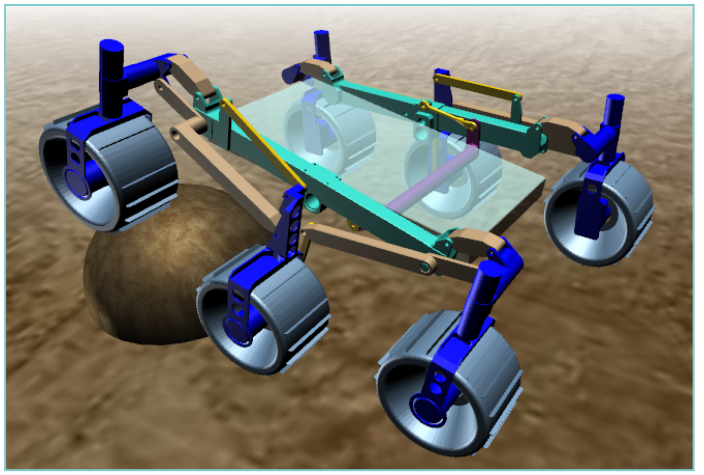
Overview

- Our view of cyber-physical systems
- DESTECS concepts
- Personal transporter case study
- Error and recovery patterns
- Conclusions and future work

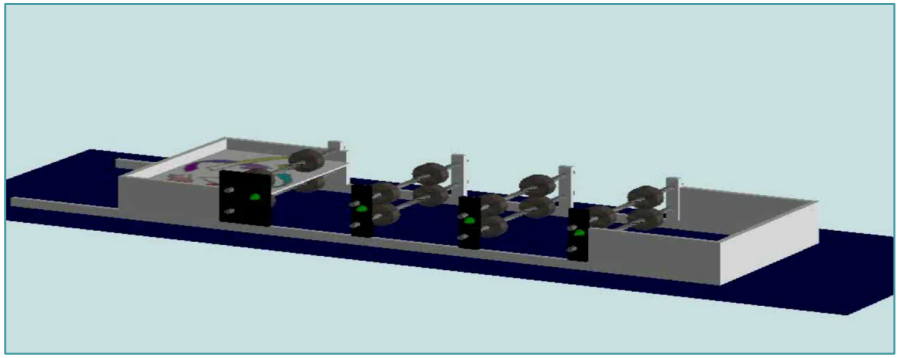
Cyber-physical Systems (1)

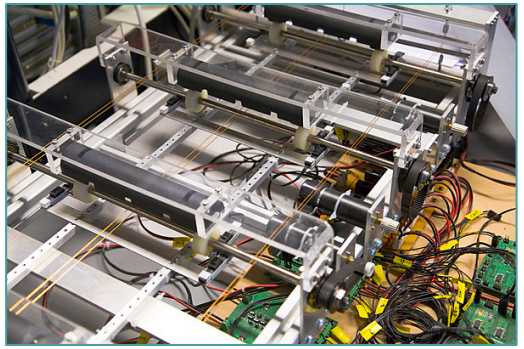
- Systems of interacting systems
  - Computing elements
  - Physical elements
  - Human interactions
- Complex, networked character
- Distributed control
- Error detection and recovery



Cyber-physical Systems (2)

- Requires collaborative development
- Analysis of models from different disciplines
  - Diverse cultures, abstractions, formalisms
- Typically tackled separately
- Require early allocation of responsibility to cyber and physical elements
- Need for **design space exploration**

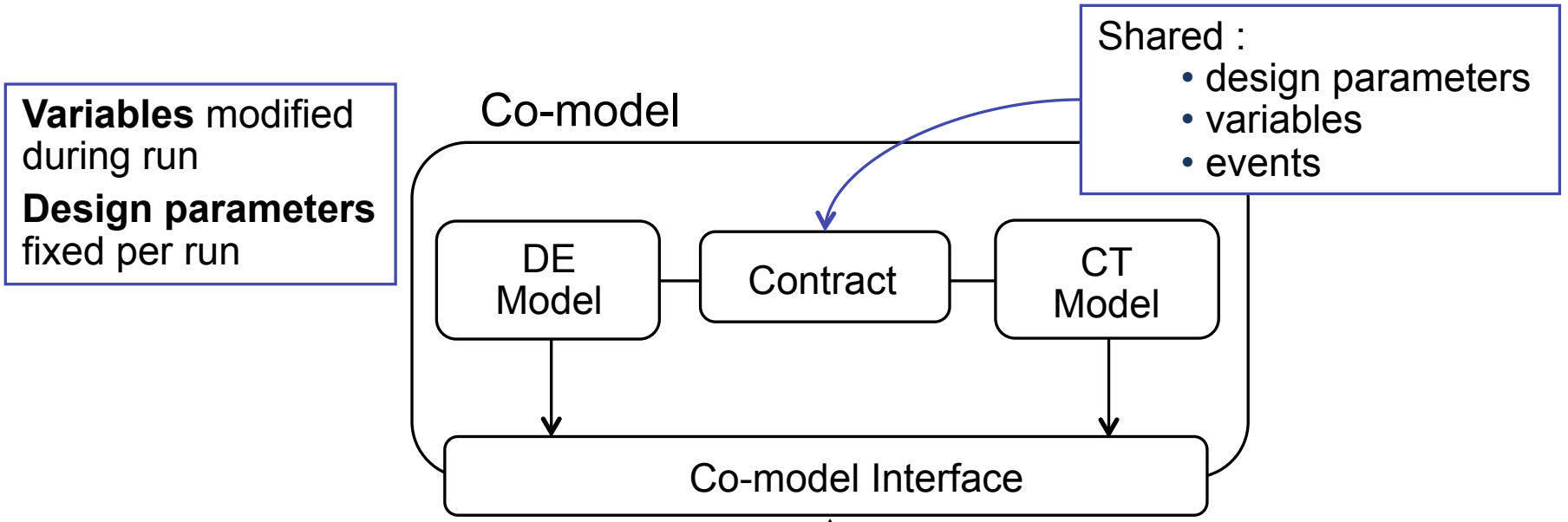




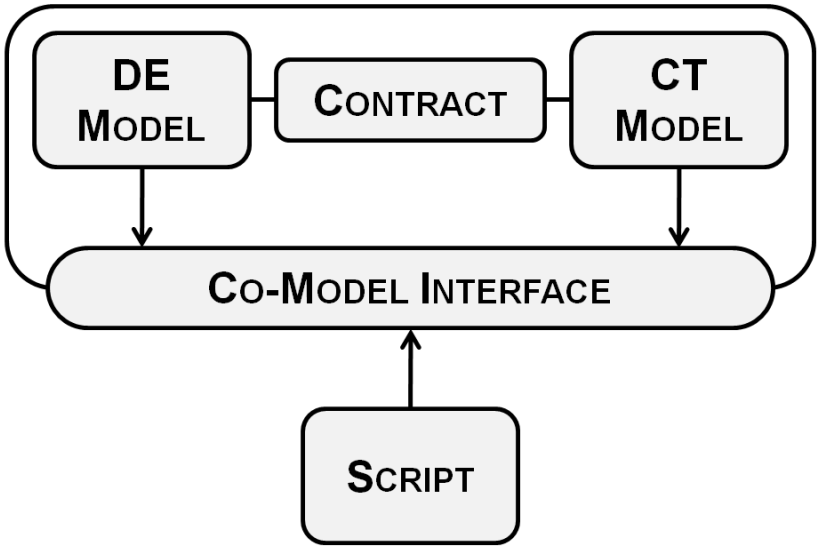
DESTECS Approach
(www.destecs.org)

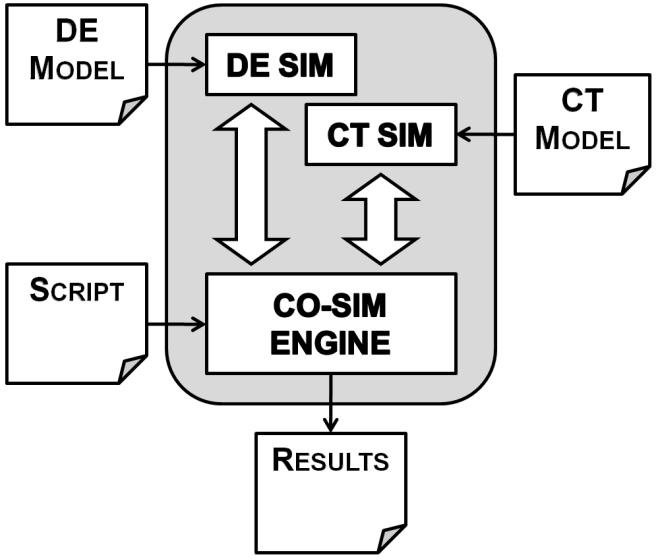
- Bridge gap between disciplines
  - Through co-simulation
  - Combine DE controller models and CT plant models
  - Collaboration while working with familiar formalism
- Developed a tool
- Developed methodological guidelines, incl. patterns
- Model failures, error detection and recovery
- Industrial partners and follow group

Basic Concepts



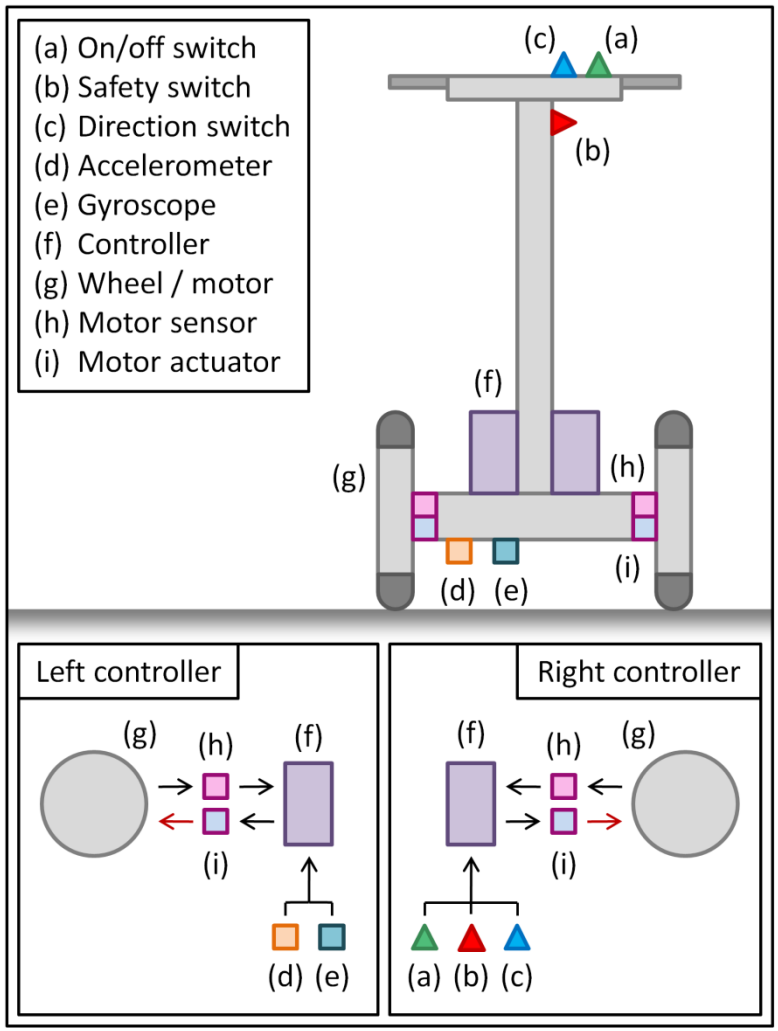
Tool Concepts



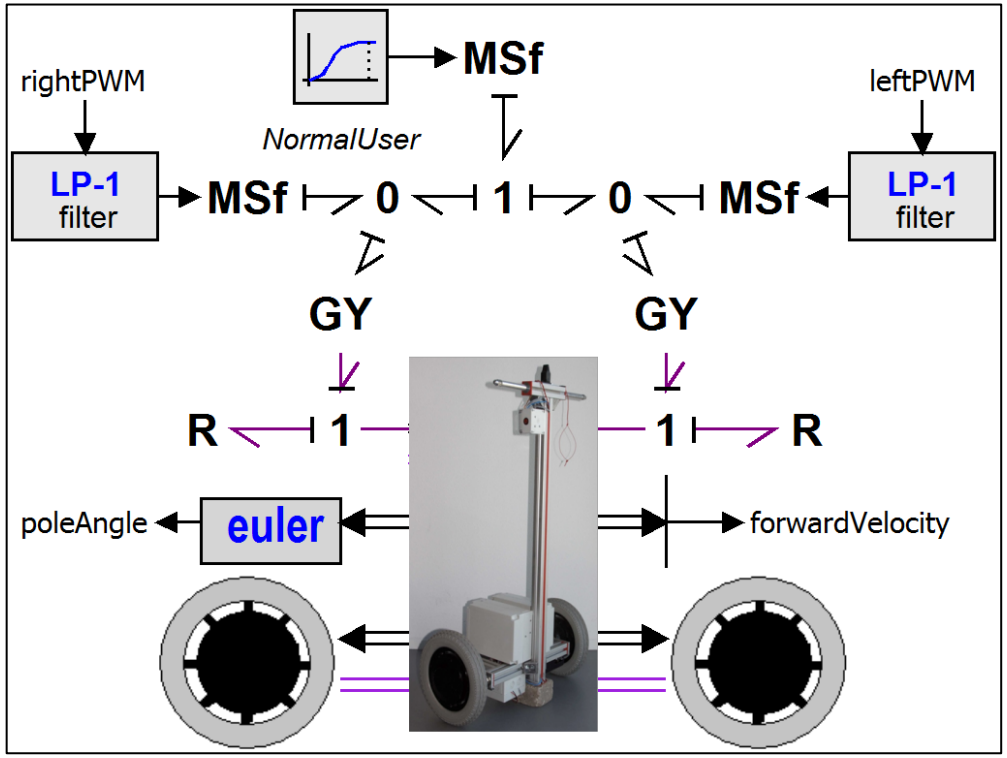


Co-model ⇨ Co-simulation

Example: Personal Transporter



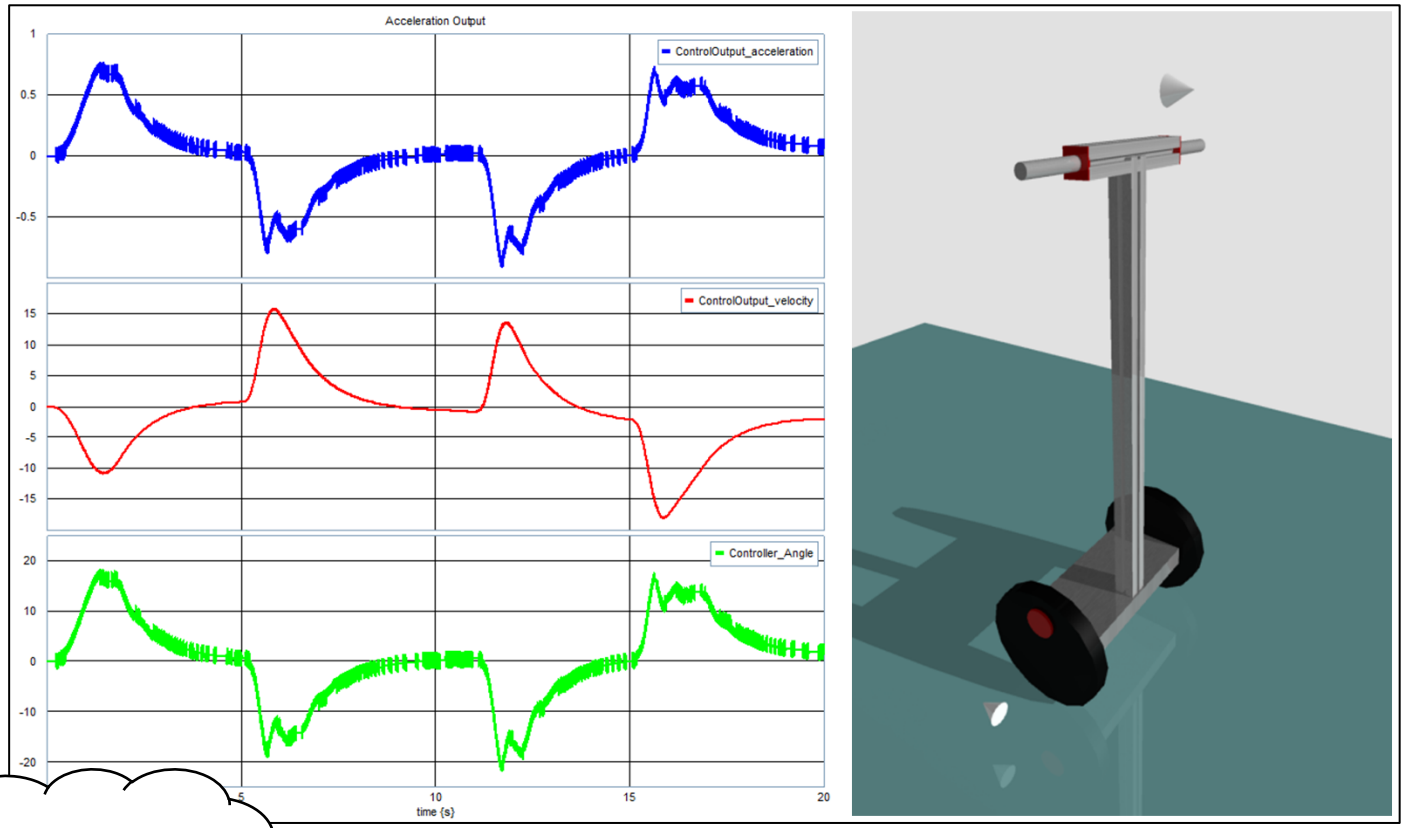
Personal Transporter (2)

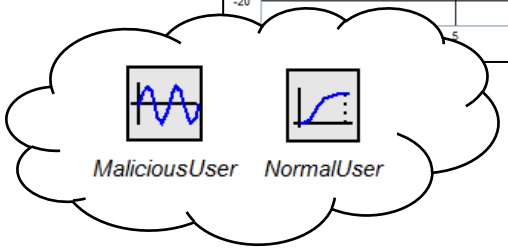


	Name	Type	Notes
controlled	leftPWM	real	range: [-1,1]
	rightPWM	real	range: [-1,1]
monitored	poleAngle	real	range: [0,2π]
	forwardVelocity	real	

```
class Controller

instance variables
  -- sensors
  private angle: real;
  private velocity: real;
  -- actuators
  private acc_out: real;
  private vel_out: real;
  -- PID controllers
  private pid1: PID;
  private pid2: PID;

operations
  public Step : () ==> ()
  Step() == duration(20) (
    dcl err: real := velocity - angle;
    vel_out.Write(pid2.Out(err));
    acc_out.Write(pid1.Out(angle));
  );

  public GoSafe : () ==> ()
  GoSafe() == (
    vel_out.Write(0);
    acc_out.Write(0);
  );

thread
  periodic(1E6,0,0,0)(Step); -- 1kHz

end Controller
```

Personal Transporter (3)





What is a Pattern?

- "Each pattern describes a problem, … then describes the core of the solution" [AIS77]
- Applied to
  - architecture [AIS77]
  - object-oriented software [GHJV95]
- Includes: name, motivation, solution, related patterns

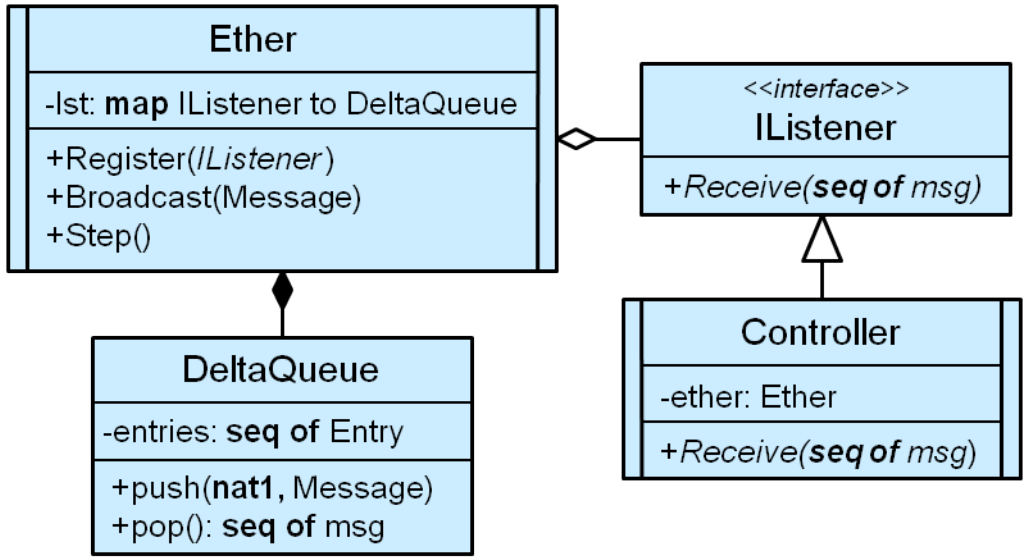
[GHJV95] Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides. *Design Patterns: Elements of Reusable Object-Oriented Software*. Addison-Wesley, 1995.

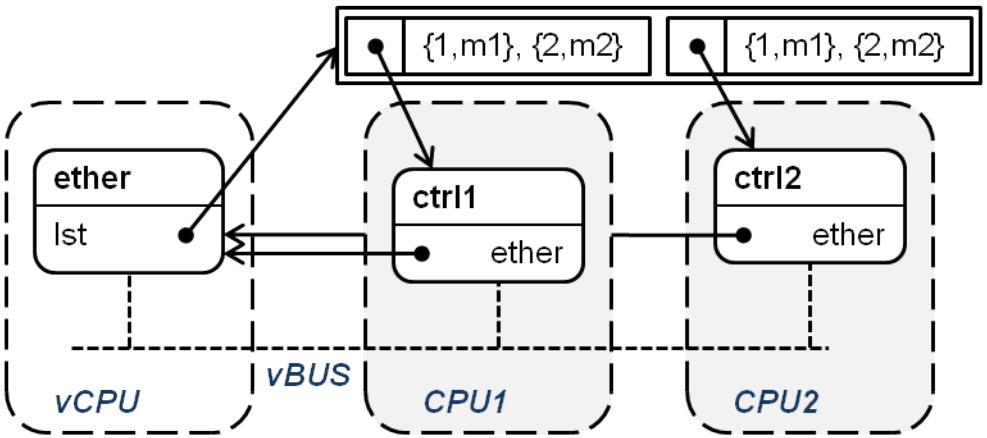
[AIS77] Christopher Alexander, Sara Ishikawa, Murray Silverstein. *A Pattern Language: Towns, Buildings, Construction*. Oxford University Press, 1977.

Ether Pattern (1)

- Model realistic communications
- Explicit model of an ***ether***
  - a medium through which data must travel
- Ether can lose, duplicate, corrupt messages
  - can be tailored to offer different guarantees representing different media

Ether Pattern (2)

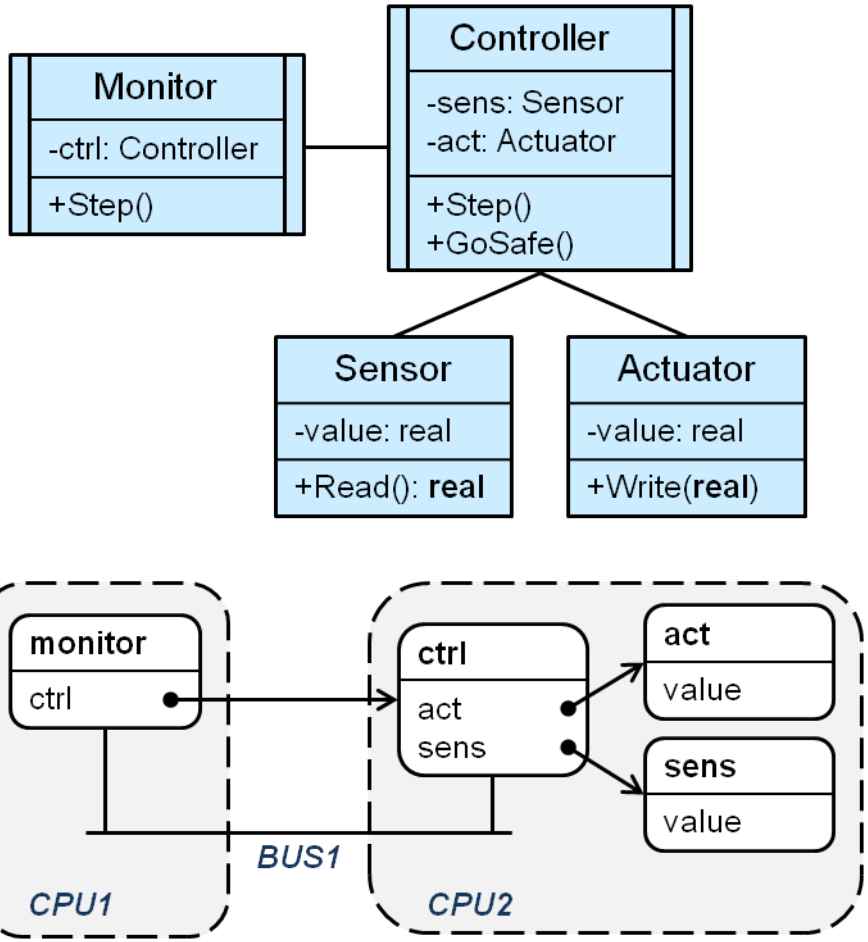




Monitor Pattern (1)

- Small, verifiable monitor that runs as a separate process
- Observes actions of the controller or other components
- Can intervene in undesirable or unsafe situations
- [See also **kernel pattern**]

Monitor Pattern (2)



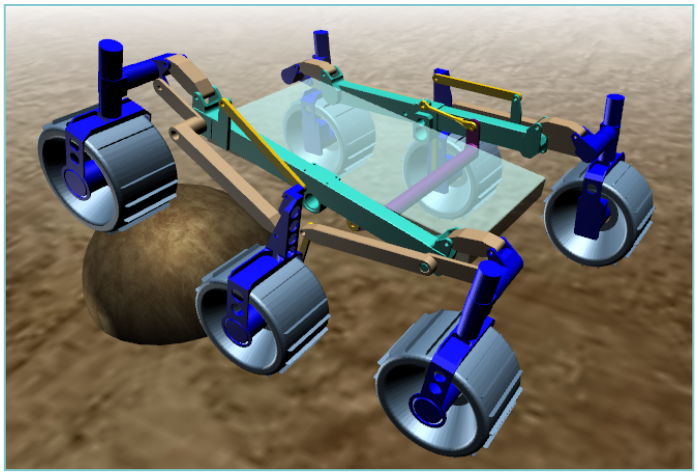

```
class Monitor

instance variables
  ctrl: Controller

operations
  private Step: () ==> ()
  Step() ==
    if not safe(ctrl) then ctrl.GoSafe()
  post safe(ctrl)

functions
  private safe: Controller -> bool
  notsafe(ctrl) == ...

thread
  periodic(1E5,1,0,0)(Step); -- 10kHz

end Monitor
```

Conclusions

- Design of resilient cyber-physical systems through:
  - the collaborative creation of heterogeneous co-models, and
  - their analysis by co-simulation
- Supported by guidelines, patterns and tools
- Small embedded systems examples

Future Work and Challenges

- From embedded systems to cyber-physical
  - increasing capability of the tool support, e.g. new scripting features, batch execution
- Simulation of multiple systems
  - Issues of abstraction, scale
- Wider range of human behaviours



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