Model Synthesis

New Challenges in Model Based Design

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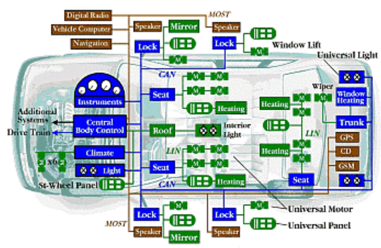
Software: Key to Embedded Revolution

Software ⇨ New features, Automation, Customization

Software ⇨ Bugs, Unpredictability, Recalls

Prius Brake Problems Blamed on Software Glitches



"Toyota officials described the problem as a "disconnect" in the vehicle's complex anti-lock brake system (ABS) that causes less than a one-second lag. With the delay, a vehicle going 60 mph will have traveled nearly another 90 feet before the brakes begin to take hold" (source: CNN Feb 4, 2010)

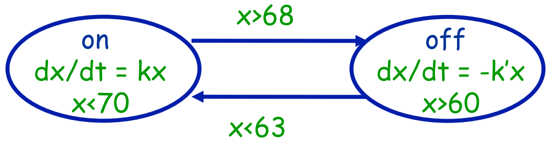
Embedded Computation

- Typical embedded program: cruise control

  Loop
  - Read the sensors;
  - Compute speed;
  - Compute pressure for brake pedal / accelerator;
  - Transmit the outputs to actuators;
- Program has (non-terminating) interaction with the outside world: Reactive computation
- Correctness depends on real-time response (does the car brake fast enough?)
- Analysis of correctness requires modeling of the dynamics of the car

Hybrid Systems

State machines + Dynamical systems



Computer Science
- Automata/Logic
- Concurrency
- Formal verification

+ Control Theory
- Optimal control
- Stability analysis
- Discrete-event system

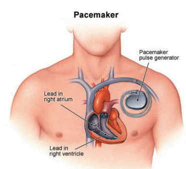
Software + Environment

Automotive

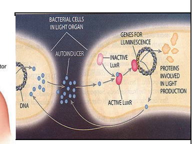
Coordination Protocols

Robotics

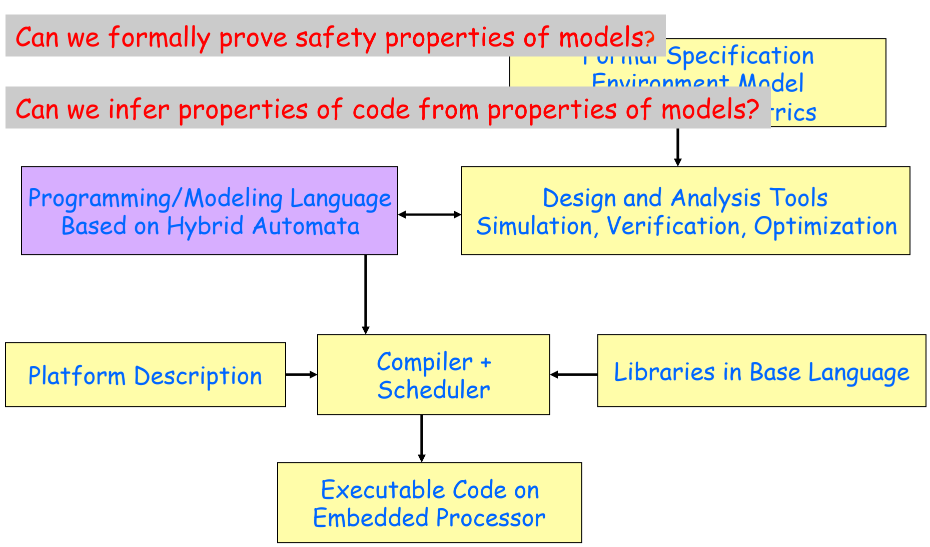
Medical Devices



Systems Biology



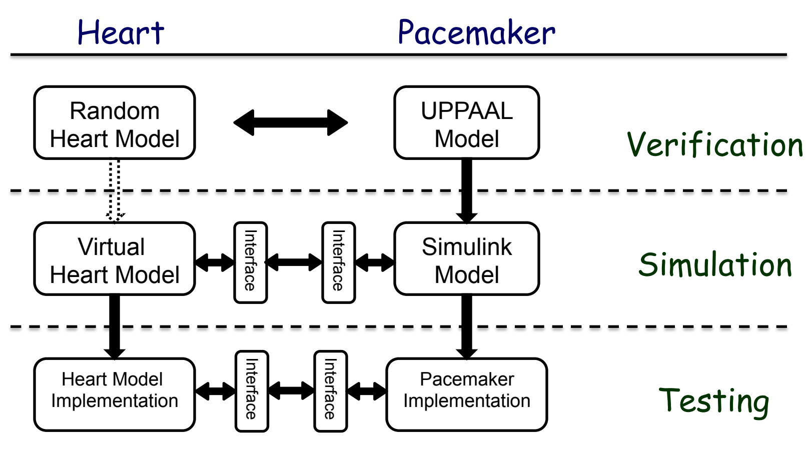
Model Based Design for Embedded Software



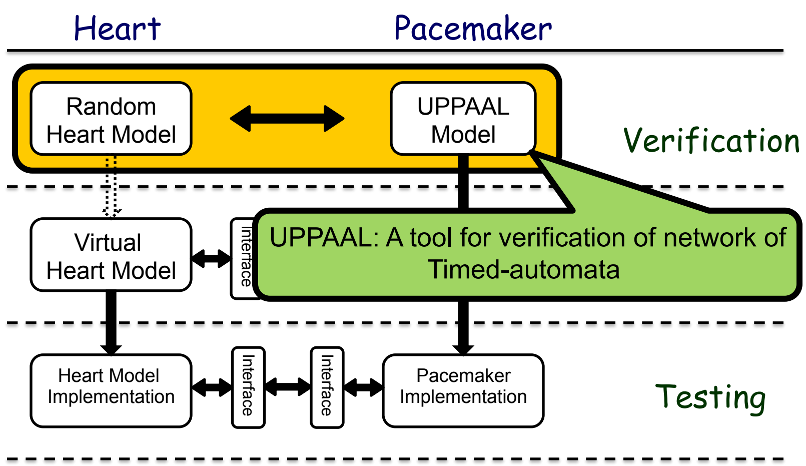
Medical Devices

- From 1985-2005, nearly 30,000 deaths and 600,000 injuries from device failures
- From 1996-2006, the percentage of software-related causes in medical device recalls have grown from 10% to 21% (Complexity ↑ → Potential safety violations ↑)
- There is currently no well-established standards for development of software for medical devices

Model-based Pacemaker Software Design

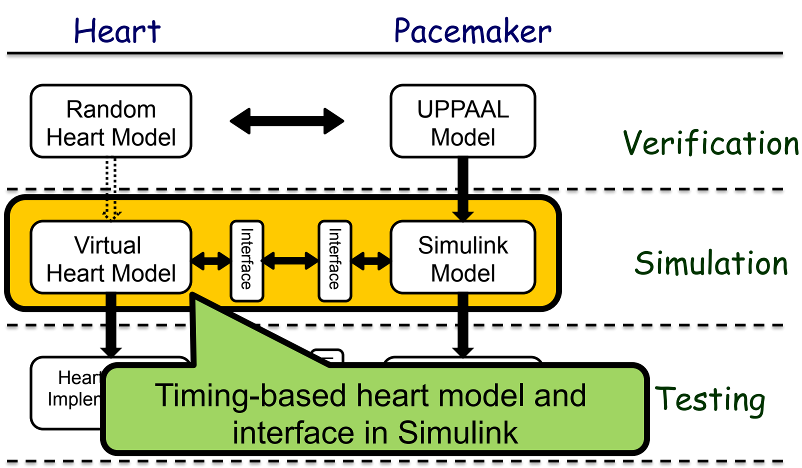


Model Verification



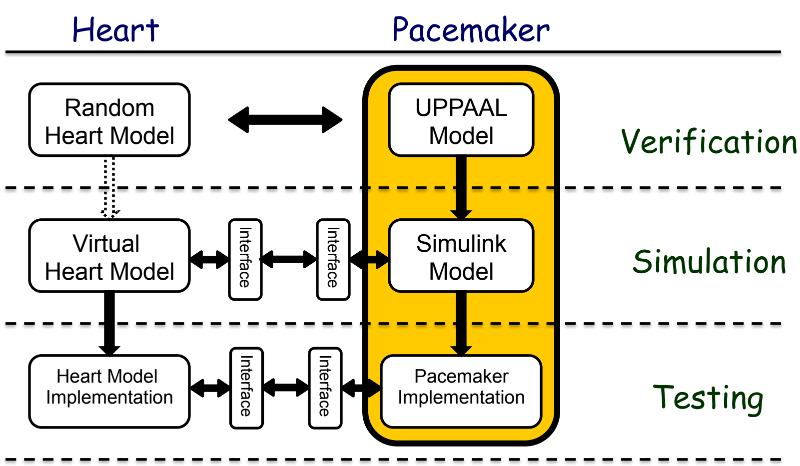
Jiang, Pajic, Moarref, Alur, Mangharam, TACAS 2012

Model Simulation



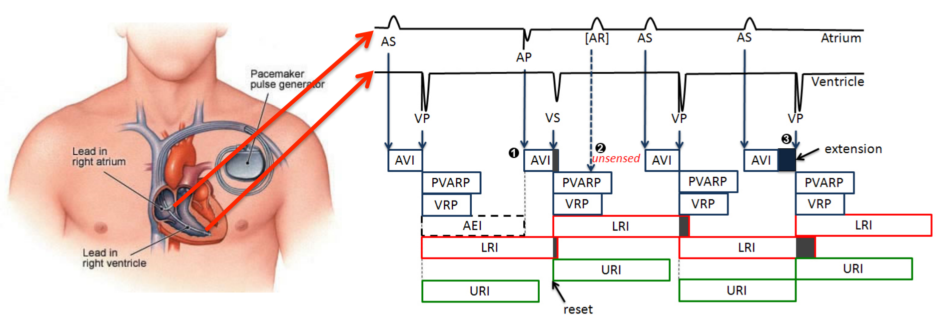
Jiang, Pajic, Mangharam, ICCPS, Proc. IEEE, 2011

Model Translation and Implementation

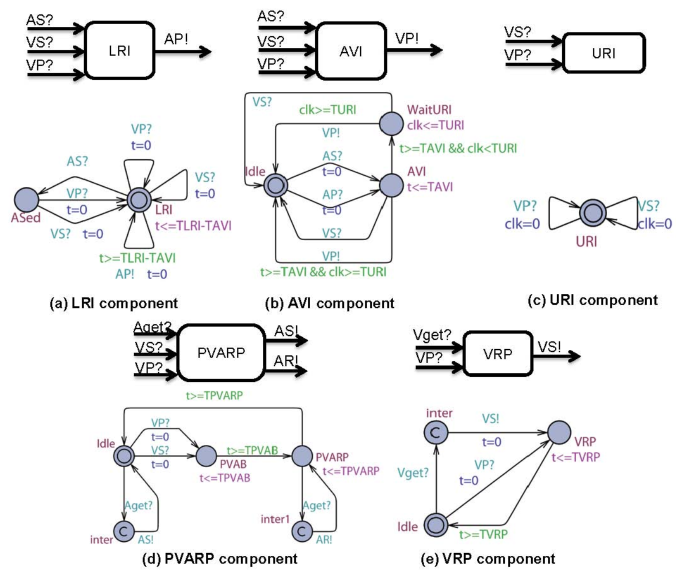


Pajic, Jiang, Lee, Mangharam, Sokolsky, RTAS 2012

Implantable Pacemaker Modeling



Uppaal Model of Dual Chamber Pacemaker



Summary of Verification Results

- ❑ Modeled and verified a dual chamber pacemaker and additional advanced functions
- ❑ Showed that adding new functions to the pacemaker may result in safety violations
- ❑ Showed that more detailed heart model is needed for more advanced safety requirements

New Challenges: Model Synthesis

1. Can we extract (controller) models from code?
2. Can we extract (plant) models from data?
3. Can we use analysis/verification technology to assist the designer to construct models?

1. From Code to Models

- What if pacemaker software is not developed using MBD
  - How to verify / certify code for pacemaker software
- Potential solution: Extract EFSM (Extended finite-state-machine) models from code
- Starting point: Predicate abstraction used for software verification
  - Challenges: Extract timing properties

Model Checking of C code

Phase 1: Given a program P, build an abstract finite-state (Boolean) model A such that set of behaviors of P is a subset of those of A (conservative abstraction)

Phase 2: Model check A wrt specification: this can prove P to be correct, or reveal a bug in P, or suggest inadequacy of A

- Shown to be effective on Windows device drivers in Microsoft Research project SLAM

```
do{
 KeAcquireSpinLock();
 nPacketsOld = nPackets;
 if(request){
    request = request->Next;
    KeReleaseSpinLock();
    nPackets++;
 }
}while(nPackets!= nPacketsOld);
KeReleaseSpinLock();
```

Do lock operations, acquire and release, strictly alternate on every program execution?

2. From Data to Models

- What's a good model of heart for verifying correctness requirements of pacemaker software?
  - Ideally, model should be patient specific
- Potential solution: Extract timed/hybrid automata models for ECG data for a patient
- Computational challenge: Can we develop suitable learning algorithms ?
  - Background: L* algorithm for learning DFA
  - Background: Learning linear constraints among variables

3. Assisting Designers in Model Construction

- How can computational tools assist designers?
  - Maturing verification technology, fast constraint solvers
  - Enormous computational power available
- Goal: Allow designer to express "model under construction" using multiple, intuitive formats
  - Synthesis tool can integrate different formats, interactively with designer to produce desired model
  - EFSMs + Example scenarios + High-level requirements
- Inspiration: Emerging research in software synthesis

Sketch: Program completion

Ref: Chaudhuri, Solar-Lezama (PLDI 2010)

```
Err = 0.0;
for(t = 0; t<T; t+=dT){
  if(stage==STRAIGHT){
    if(t > ??) stage= INTURN;
  }
  if(stage==INTURN){
    car.ang = car.ang - ??;
    if(t > ??) stage= OUTTURN;
  }
  if(stage==OUTTURN){
    car.ang = car.ang + ??;
    if(t > ??) break;
  }
  simulate_car(car);
  Err += check_collision(car);
}
Err += check_destination(car);
```

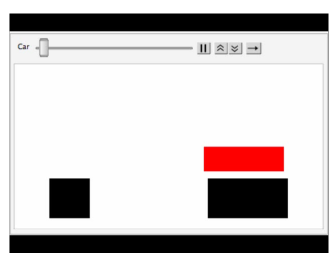
When to start turning?

Backup straight

How much to turn?

Turn

Straighten



Enables programmers to focus on high-level solution strategy

Conclusions

- Model based design (MBD) is a promising approach to design of embedded software

- Over the past year, research at Penn has demonstrated benefits of MBD for rigorous design of pacemaker software

- Synthesis has the potential to transform the way a designer can employ MBD