

# A CPS Approach to Robot Design

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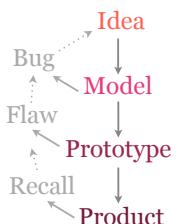
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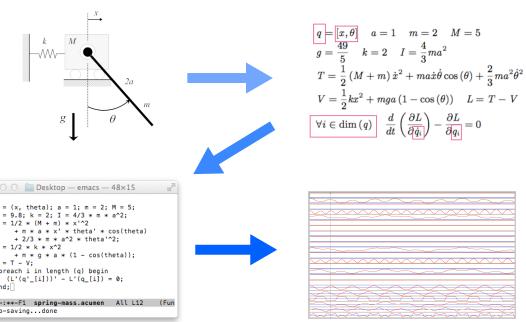
**Objective:** To accelerate innovation in robot design

## Accelerating The Innovation Process

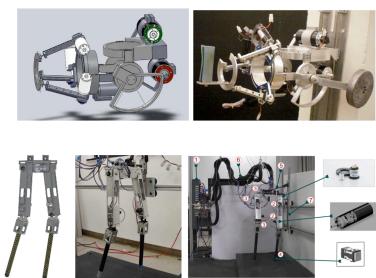
- Innovation is an iterative process
- Physical prototyping can be
  - Costly
  - Time consuming
  - Unreliable
- Explicit analysis limits to simple models
- Today's simulation tools have problems
  - Time/effort/ability to model/simulate



## Gaps Between Modeling and Simulation

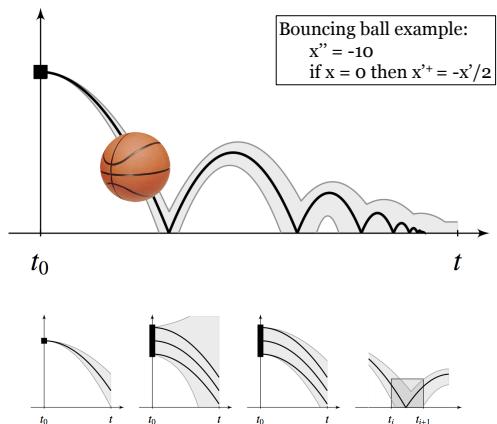


## Research Issues



- Mapping from rigid-body model to mathematical equations
- Mapping from equations to an executable form of equations (DAE or ODE)
- Modeling and simulating hybrid (continuous/discrete) models
- Defining a suitable, well-behaved executable class of mathematical equations
- Model validation

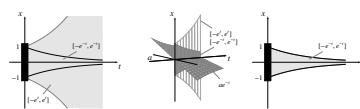
## Validated Enclosures for Hybrid Dynamic Models



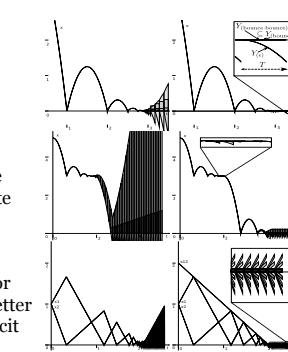
- Validated method produce enclosures *guaranteed* to contain real answer
- Challenges (and our approach): 1) Enclosing solutions to non-linear systems (Picard operator), 2) Dealing with enclosures of initial values (new generalization of Picard), 3) Dealing with events (new methods), 4) Dealing with Zeno behavior (new methods)

## Dealing with Enclosed Initial Values & Zeno Behavior

- Right: Enclosed (or "uncertain") initial values are handled solving a higher dimensional problem

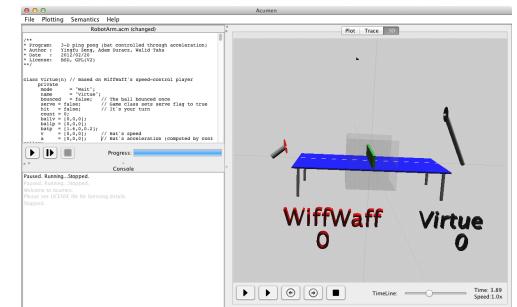


- Above: Event tree used to compute enclosures for Zeno systems in finite time
- Left: Actual enclosure computed for three Zeno systems. In all cases, better results are attained by adding explicit assertions into the model



## Prototype Test Bed: Acumen

- Core language hybrid (mixed continuous/discrete) modeling
- Support for equations and dynamic object creation/destruction
- Support for automatic 2D plotting and 3D visualization



## New Course: Introduction to Cyber-Physical System

- Emphasis on themes:
  - The need for new expertise
  - The need for hybrid models
  - Energy as a pervasive concern
- Project: Build a Ping Pong robot
  - Uses 3D physical model (above)
  - Students develop CPS players
  - Principles of communications
  - Realism gradual increased
- Course Content
  - Big picture overview of field
  - Modeling physical systems
  - Modeling computing systems
  - Principles of control theory
  - Embedded systems design
  - Principles of communications
  - Taught once at Halmstad

## Industrial Collaborators

- The MathWorks: Interest in educational aspects of project
- Volvo Technology (VTEC): Partner in a Swedish VINNOVA Foundation project focusing on Advanced Driver Assistance Systems (ADAS). Acumen is being used for developing models of vehicles, ADAS functionality, and test scenarios



Ball and Truck Images from Wikipedia Commons

## Acknowledgement

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## To Probe Further

Information about the project as well as the activities and publications of the group can be found at the Effective Modeling Group web-page ([www.effective-modeling.org](http://www.effective-modeling.org))

The Acumen language testbed is distributed under both BSD and GPL(2) licenses, and can be downloaded from the language web-page ([www.acumen-language.org](http://www.acumen-language.org))