Methodology for Embedded (Robotic) Software Development

Prof. Gabriel A. Wainer
Dept. of Systems and Computer Engineering
http://www.sce.carleton.ca/faculty/wainer

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The problem

- Development of complex software (robotic controllers):
  time consuming, **error prone**, **expensive**

- Software techniques focus on software only
  - Models of the controlled environment? (i.e., robot engines, dynamics?)
  - Decision-making: lack of good visualization tools (training?)

- Formal methods and tools (???? Experimental)

- **Model and Simulation-based solutions**: higher quality products
  - Models **discarded** in early stages of development ($$$)

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Research Proposal

- ***Using Model-Based Engineering for software development***

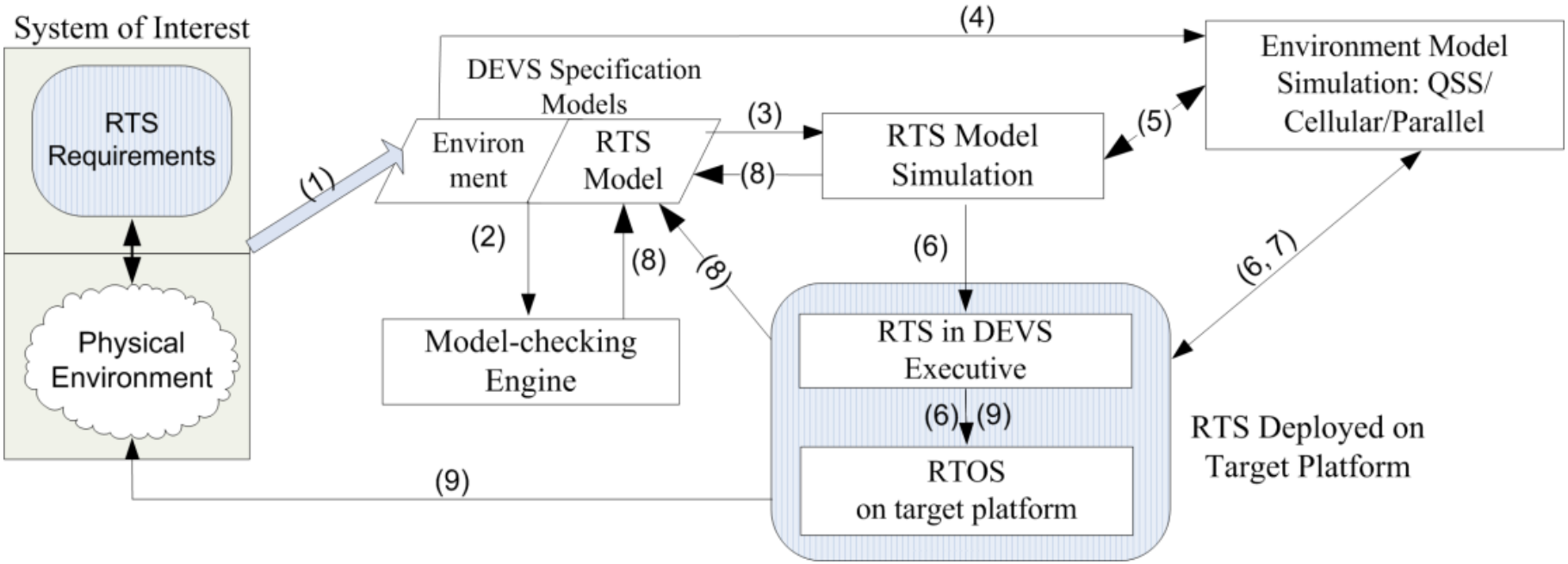
- Integrating complex applications with **varied hardware** components, software and **3D visualization**

- Models reused throughout the process (not only for exploration) => cost improved

- Truly **collaborative environment:** distributed algorithms and mashups

- Advanced visualization facilities (serious games; training)

Methodology



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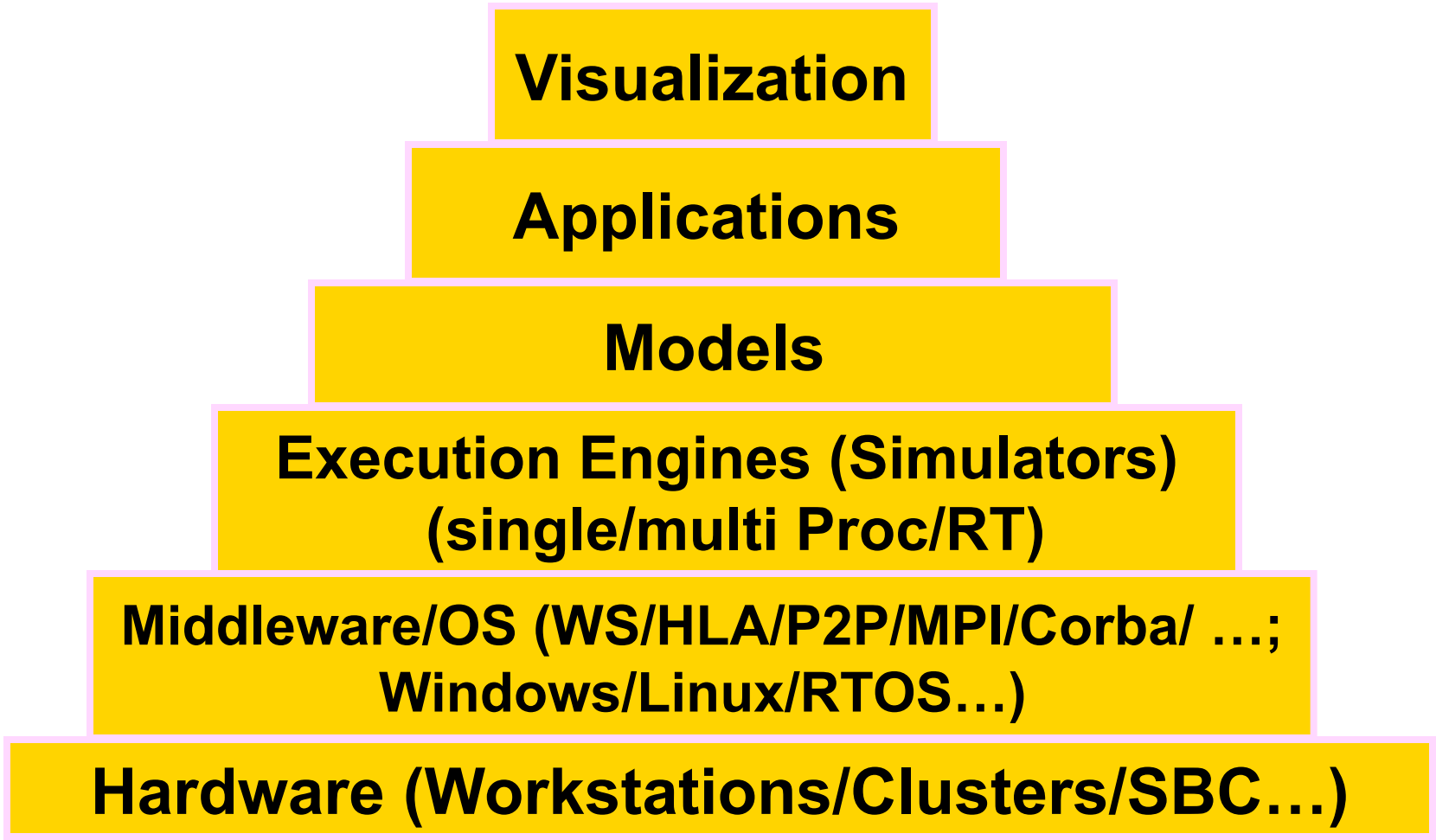
A Layered View



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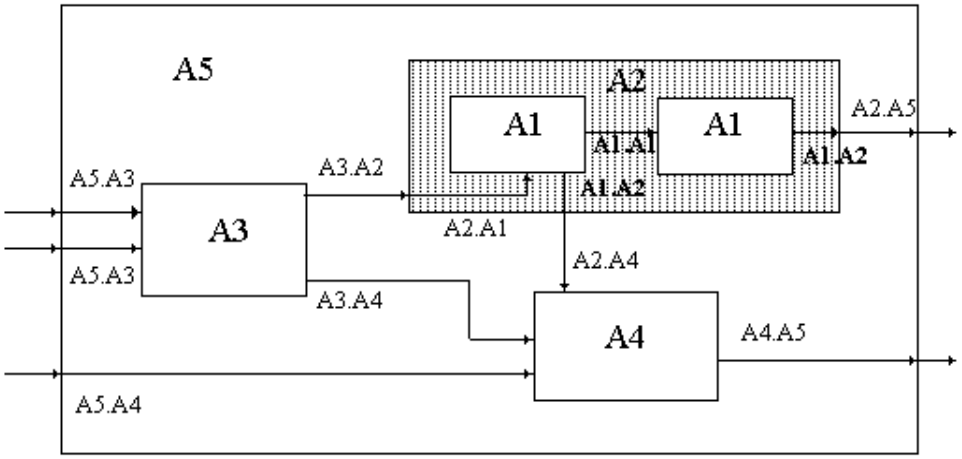
The DEVS Formalism

- Discrete-Event formalism: time advances due to occurrence of events
- Basic models that can be hierarchically coupled to build complex ones (systems theoretical approach)
- Separation of models and simulators
- Introduction to DEVS: http://en.wikipedia.org/wiki/DEVS

http://cell-devs.sce.carleton.ca ;

http://www.sce.carleton.ca/courses/sysc-5104/TutorialSpringSim.ppt

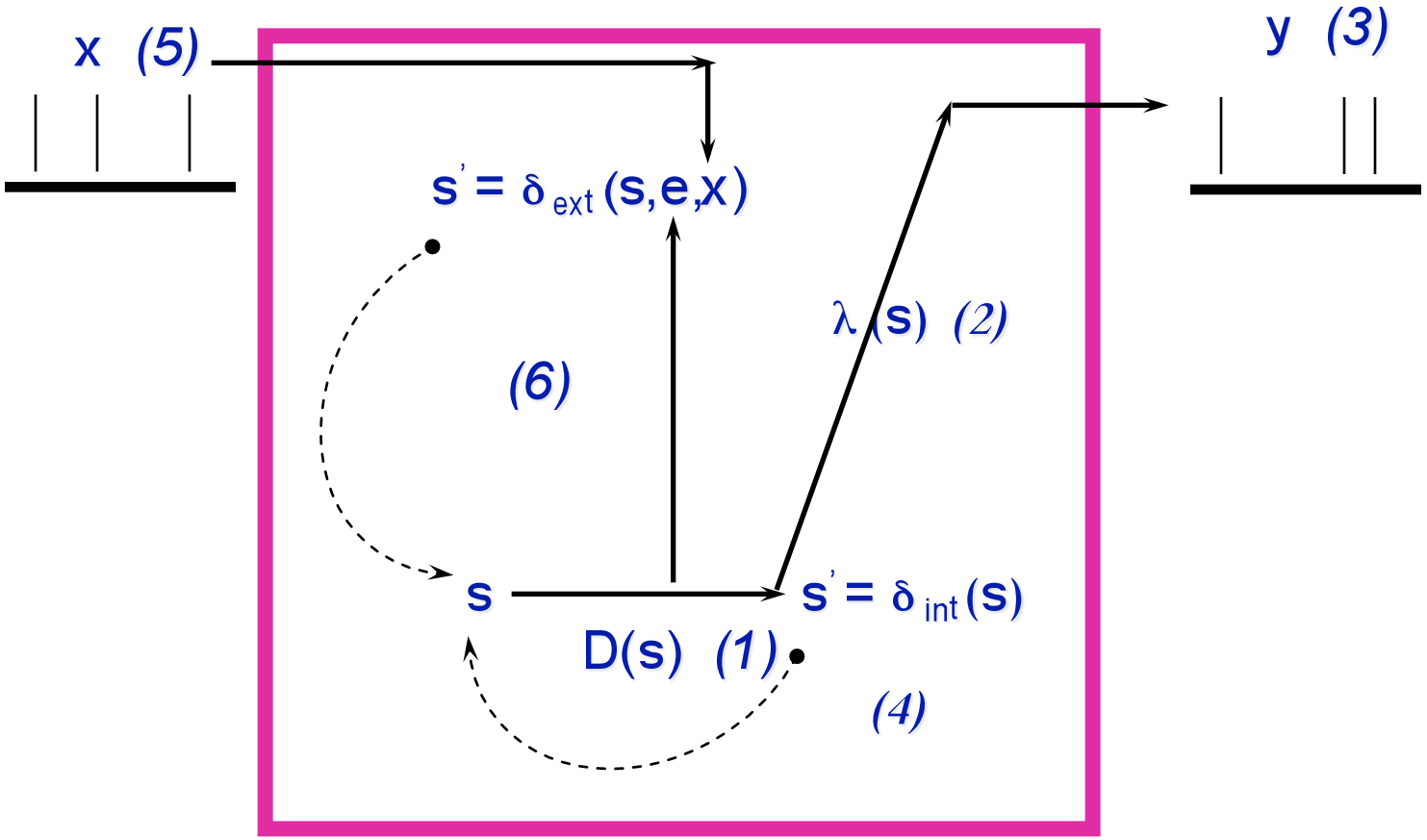


Atomic Models:

$$M = < X, S, Y, \delta_{int}, \delta_{ext}, \lambda, D >.$$

Coupled Models:

$$CM = < X, Y, D, \{M_i\}, \{I_i\}, \{Z_{ij}\}, select >$$



DEVS = $< X, S, Y, \delta_{int}, \delta_{ext}, D, \lambda >$

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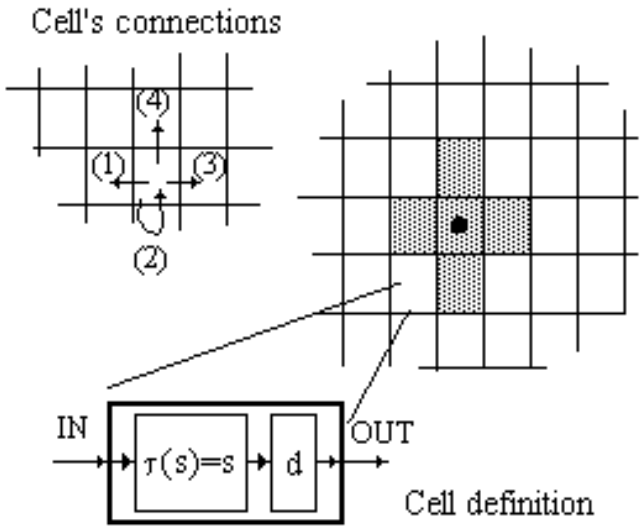
Cell-DEVS models



- Discrete-Events cell spaces
- Cells: atomic models. Automated coupling.
- Asynchronous execution using explicit delay functions
- Abstract simulation mechanism.

Introduction to Cell-DEVS: http://cell-devs.sce.carleton.ca

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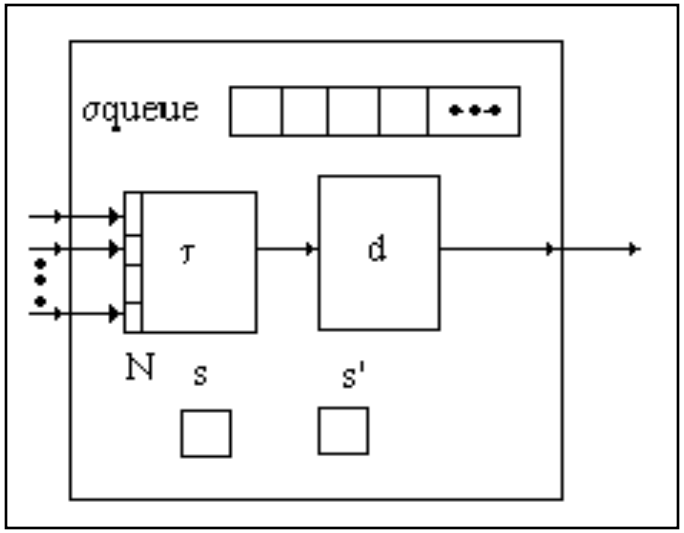
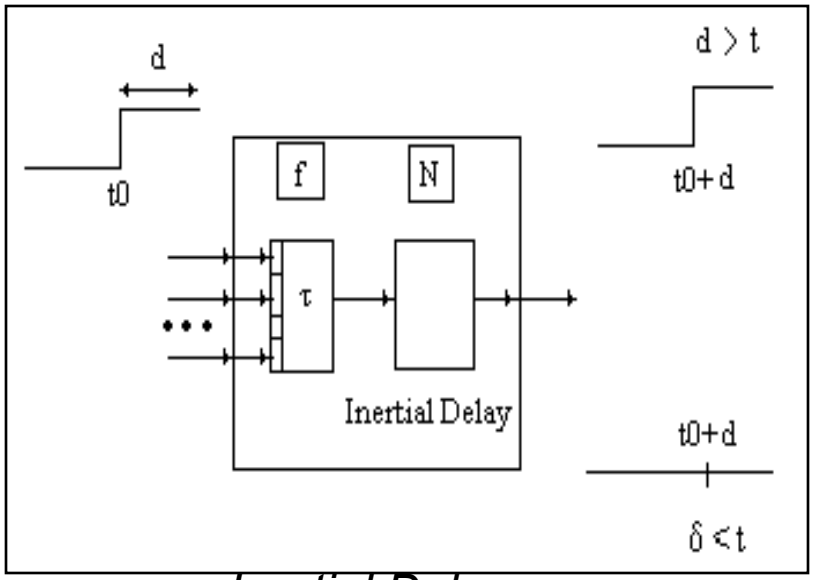
Cell-DEVS Atomic Models



Transport Delay

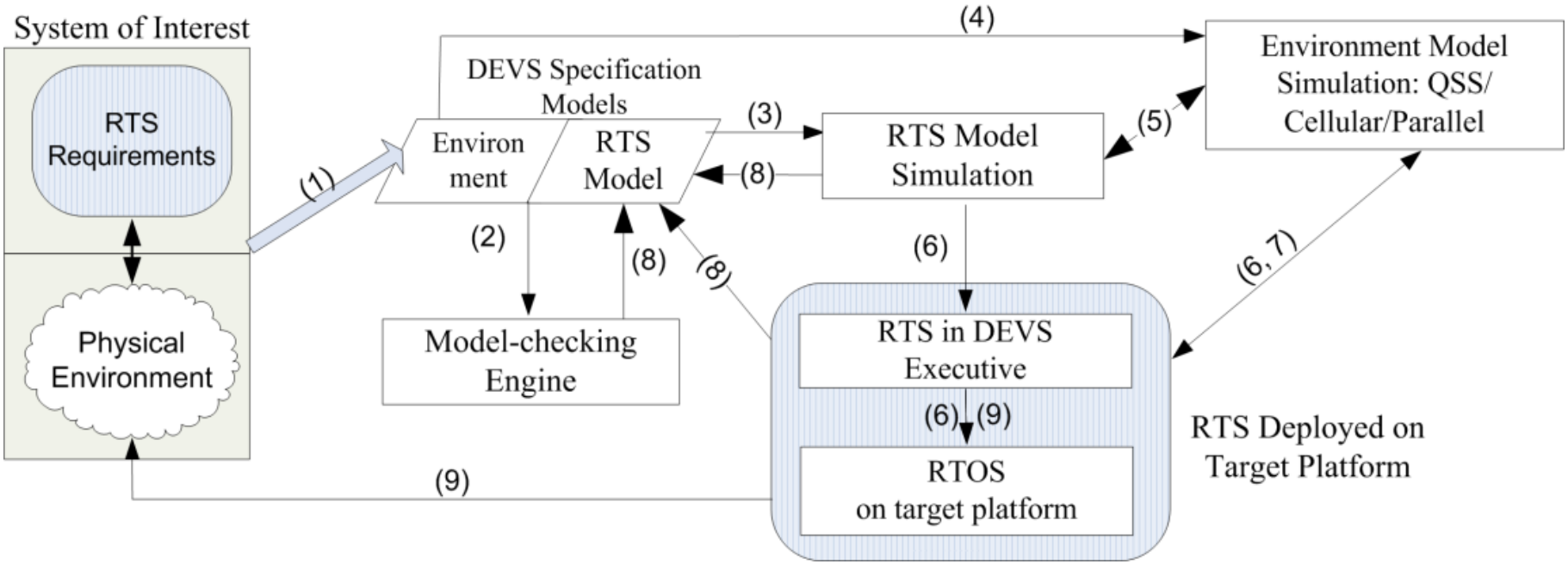


Inertial Delay

TDC= < X, Y, θ, N, **d**, τ, δ_{int}, δ_{ext}, λ, D>

- N inputs to a given cell
- Local computing function
- Inertial or Transport delays
- Outputs only if the cell state changes

Methodology (1 – Model Specification)



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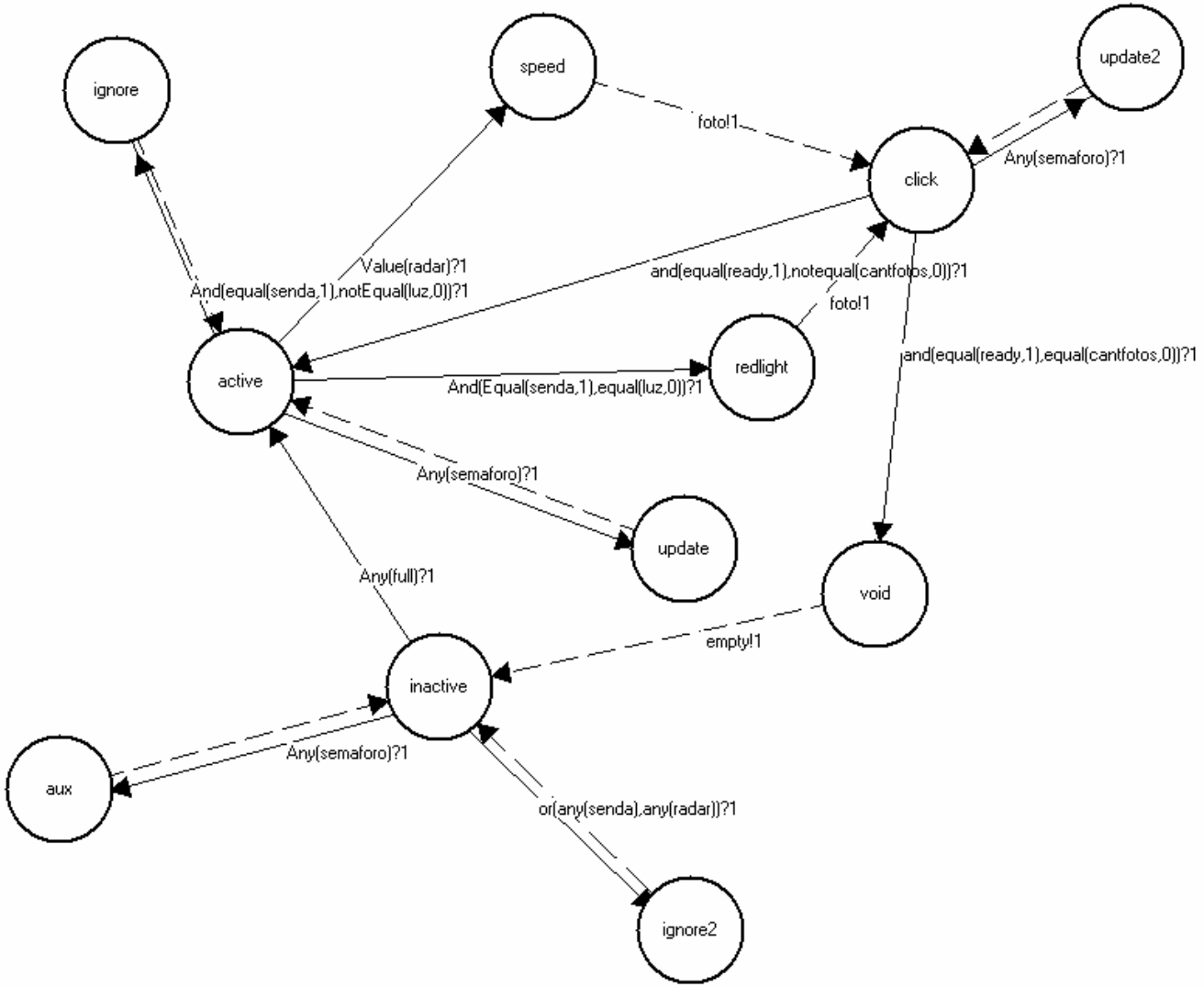
Model Specification



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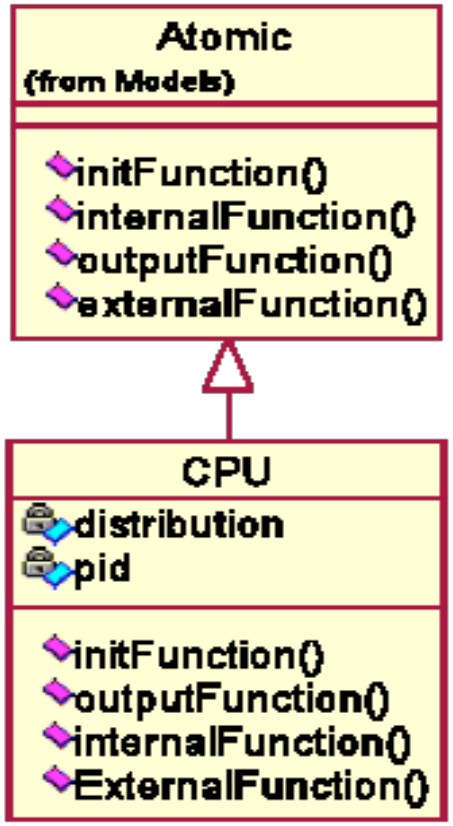
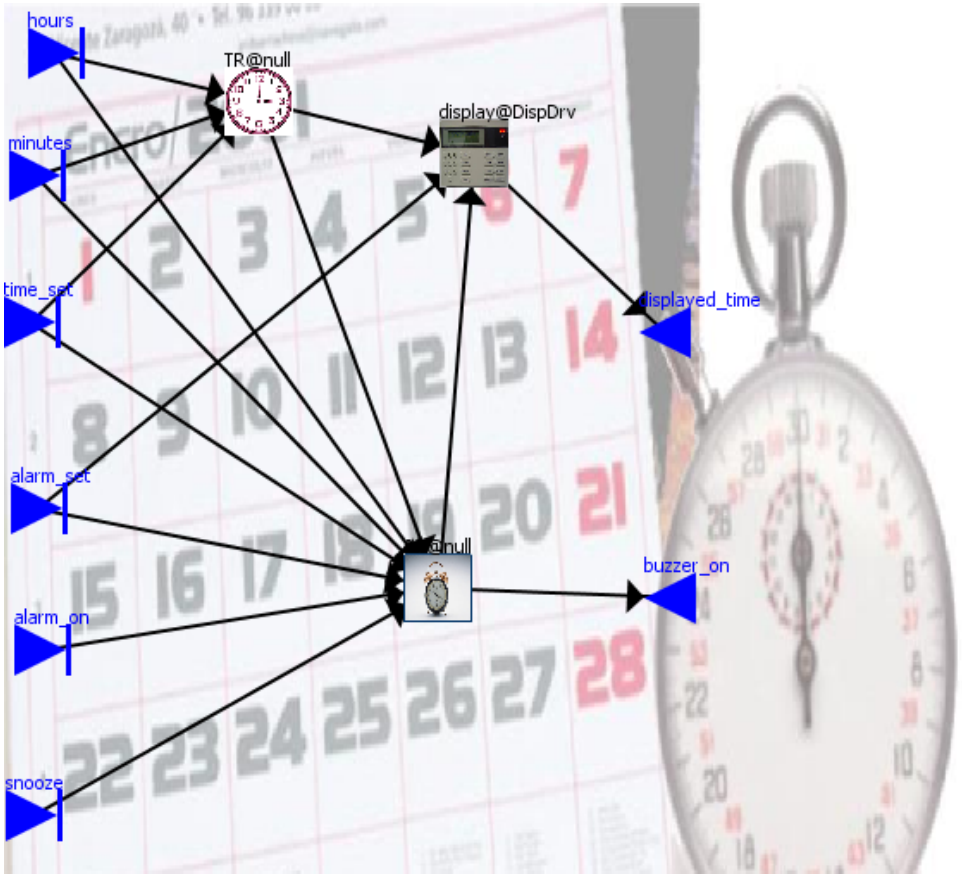
Model Specification





- High level specifications translated into executable code

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Modelling the Environment's Physics

```
model circuit
  Modelica.Electrical.Analog.Sources.PulseVoltage
          V(V=10, width=50, period=2.5);
  Modelica.Electrical.Analog.Basic.Resistor R1(R=0.001);
  Modelica.Electrical.Analog.Basic.Inductor I1(L=500);
  Modelica.Electrical.Analog.Basic.Inductor I2(L=2000);
  Modelica.Electrical.Analog.Basic.Capacitor C(C=10);
  Modelica.Electrical.Analog.Basic.Resistor R2(R=1000);
  Modelica.Electrical.Analog.Basic.Ground Gnd;
equation
  connect(V.p, R1.p);
  connect(R1.n, I1.p);
  connect(R1.n, I2.p);
  connect(I2.n, C.p);
  connect(I2.n, R2.p);
  connect(C.n, I1.n);
  connect(R2.n, C.n);
  connect(I1.n, V.n);
  connect(V.n, Gnd.p);
end circuit;
```

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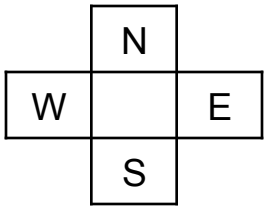
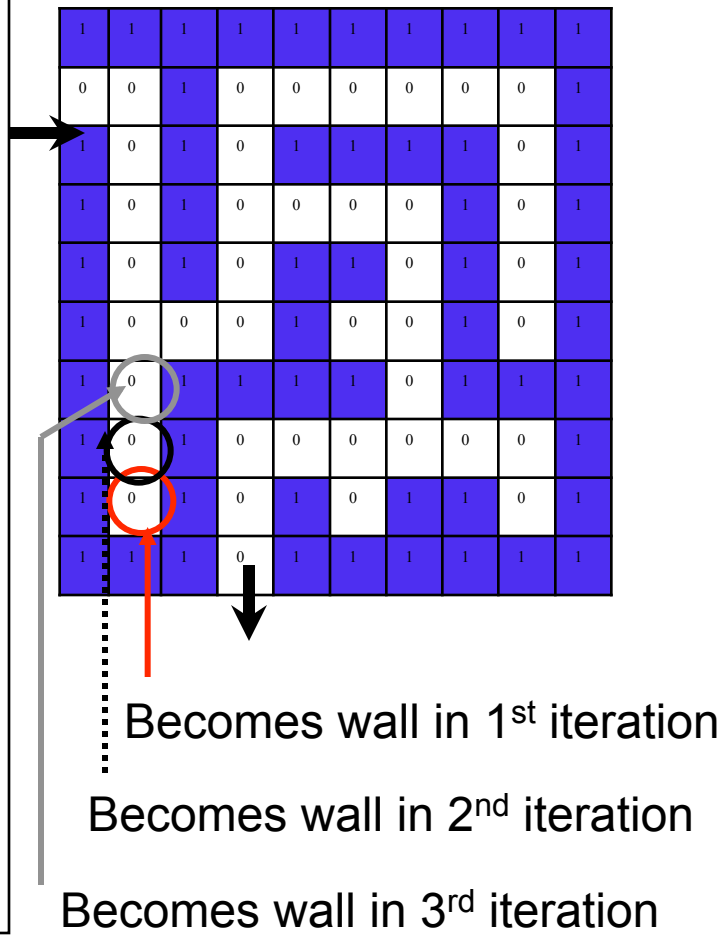
Modelling the Environment's Physics (Cellular)

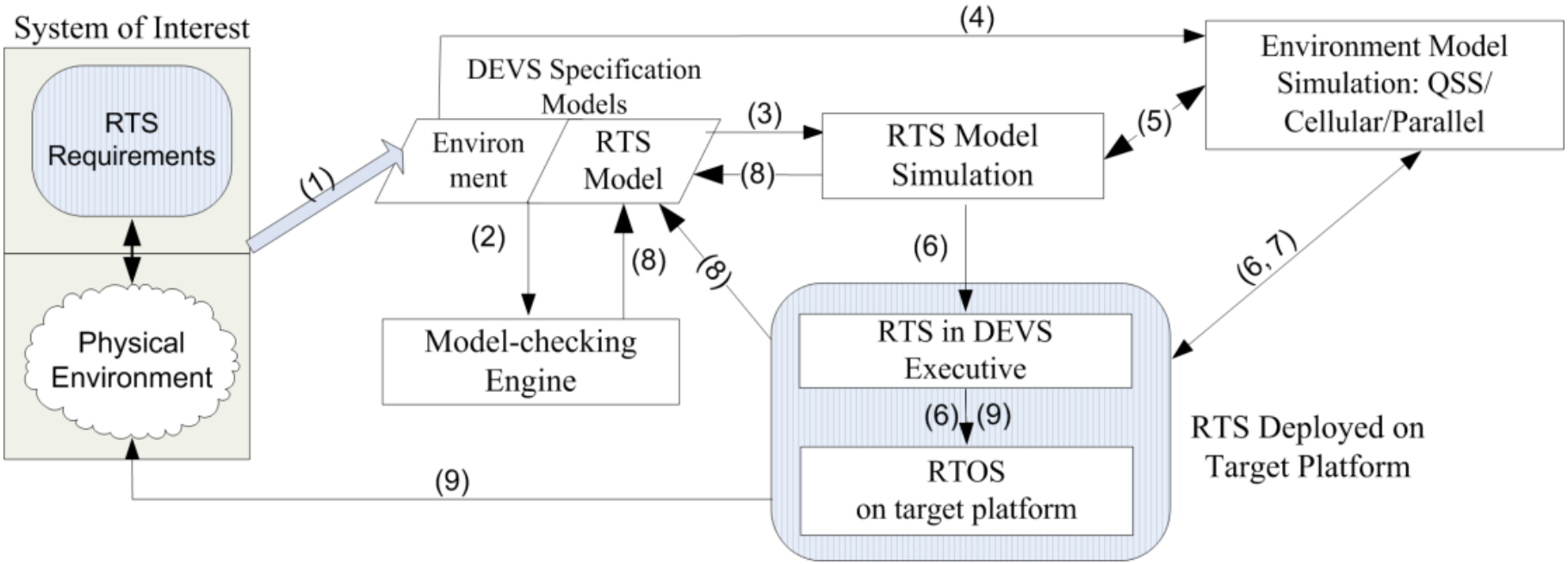
```
[maze]
type : cell
dim : (20, 20)
neighbors :                maze(-1,0)
neighbors : maze(0,-1)   maze(0,0)    maze(0,1)
neighbors :                maze(1,0)
localtransition : maze-rule
(…)


[maze-rule]
rule : 1 100 { (0,0) = 0 and (truecount = 3 or
                              truecount = 4) }
rule : 0 100 { (0,0) = 0 and truecount < 3 }
rule : 1 100 { t }
```





Methodology (2 – Model Checking)



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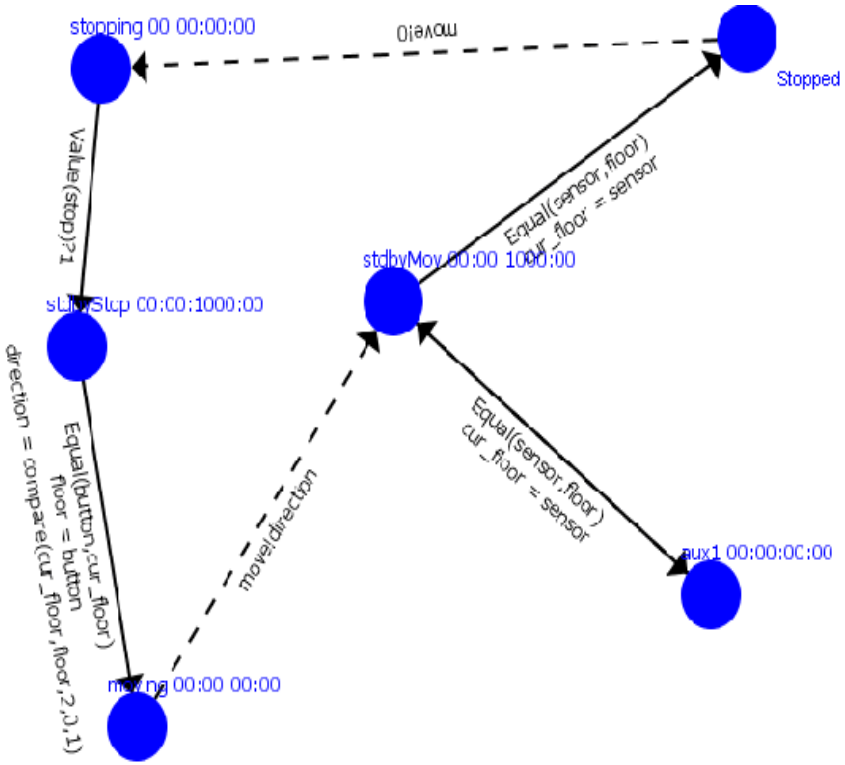
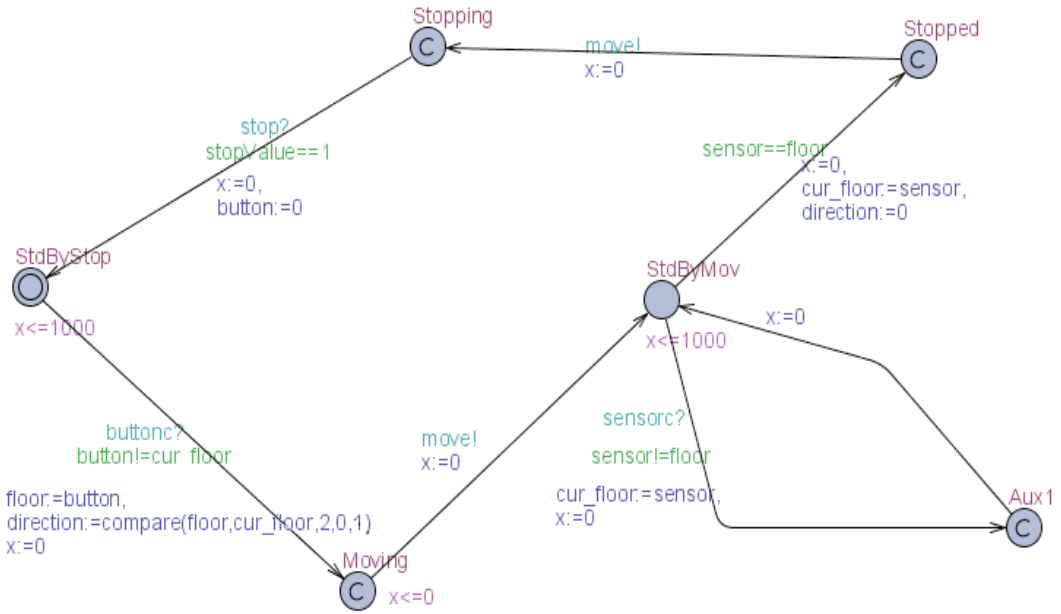
RTA-DEVS to TA Example



Elevator Controller RTA-DEVS Model



TA Controller model in UPPAAL

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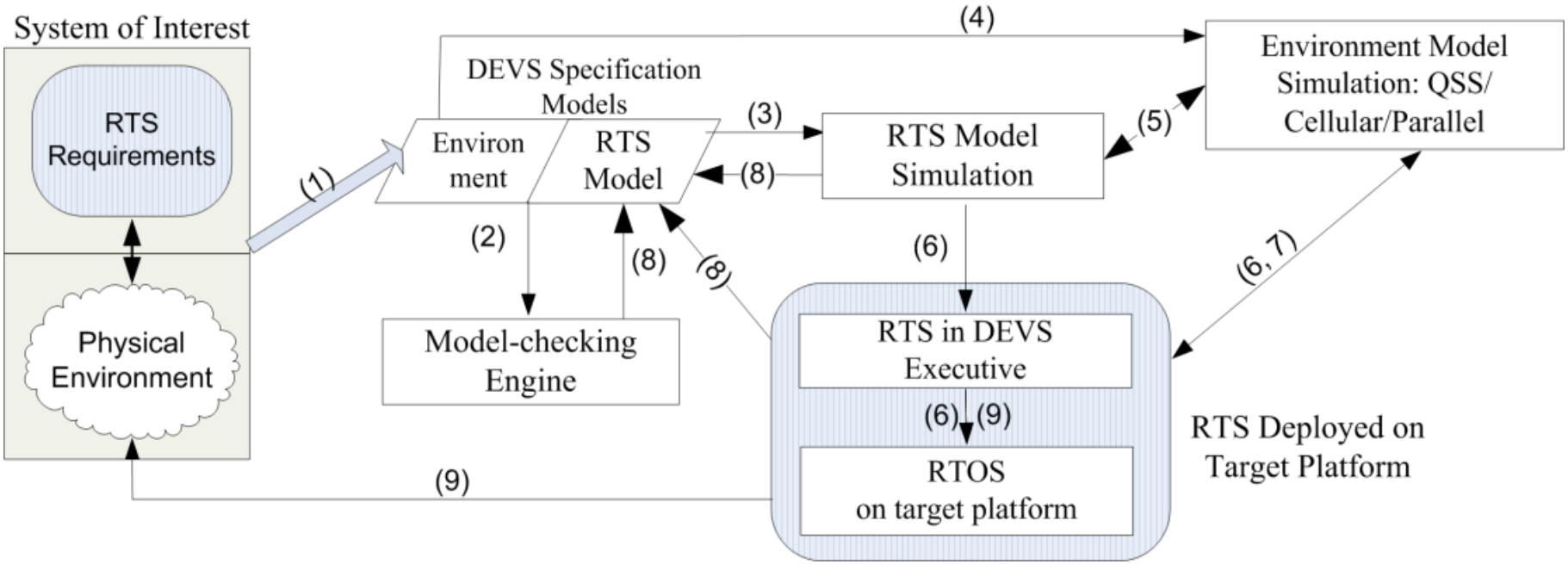
Methodology (3 – Controller simulation)



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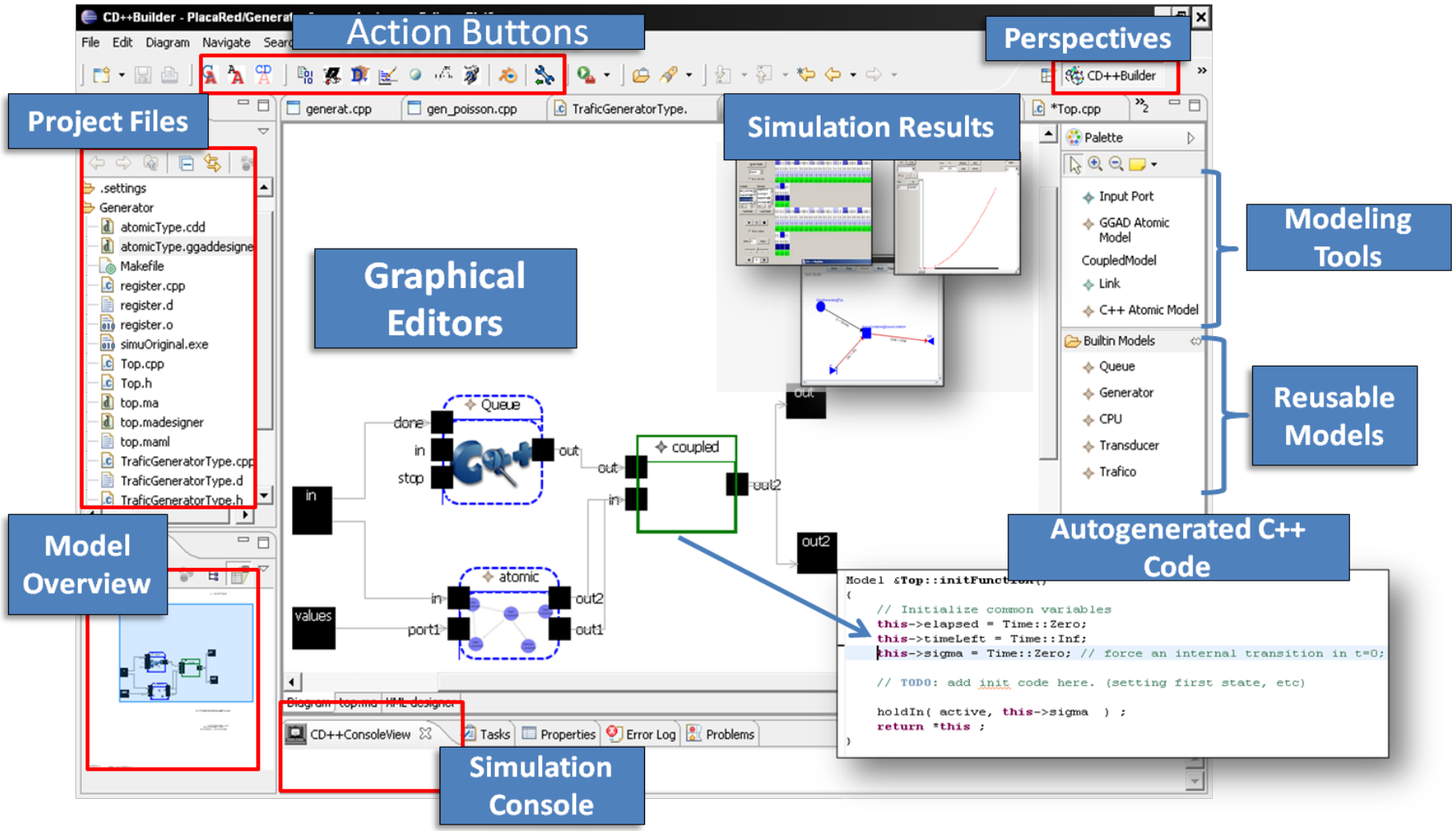
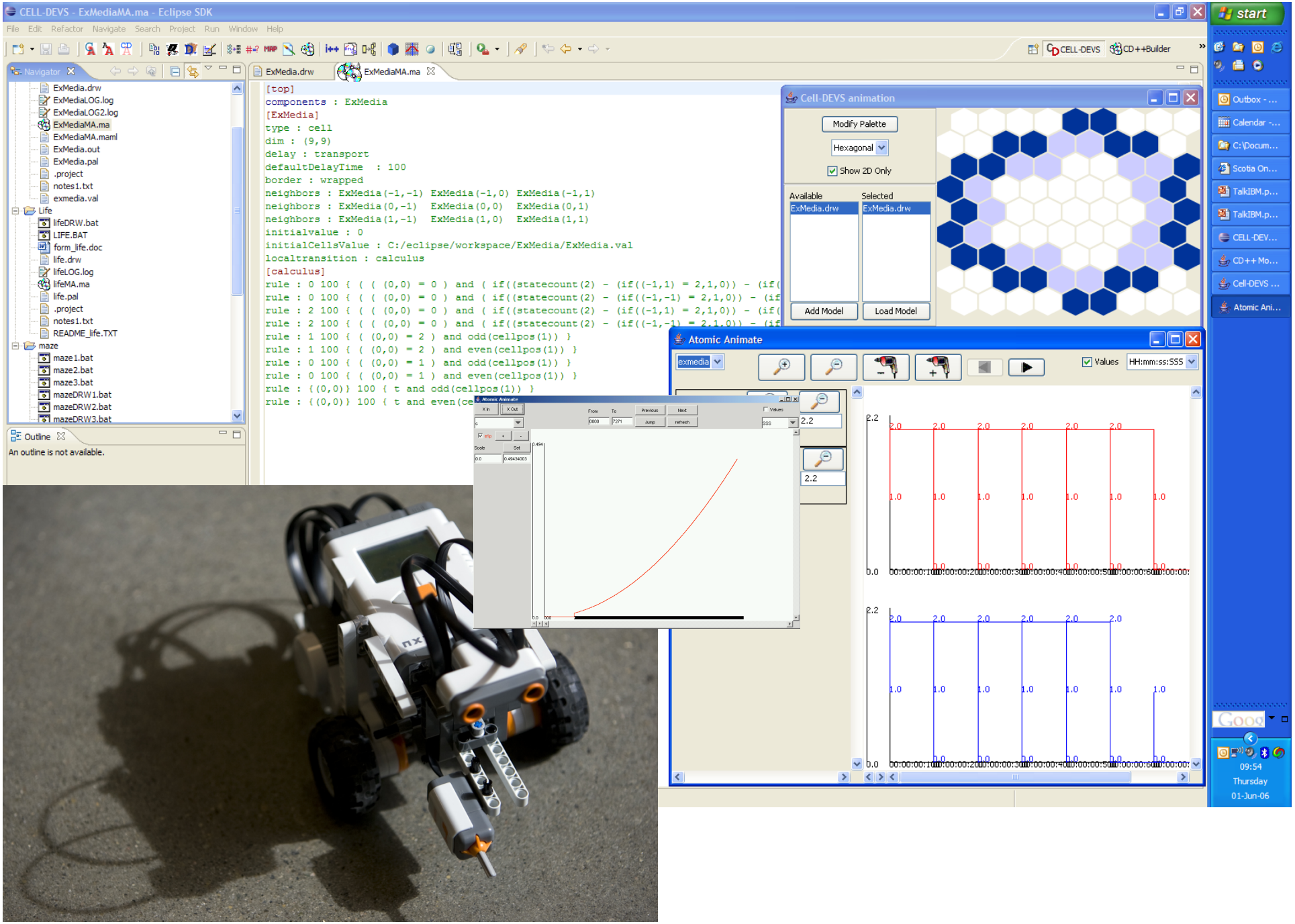
CD++ Builder Environment




CELL-DEVS - ExMediaMA.ma - Eclipse SDK
File Edit Refactor Navigate Search Project Run Window Help
CELL-DEVS
CD++Builder
Navigator
ExMedia.drw
ExMediaLOG.log
ExMediaLOG2.log
ExMediaMA.ma
ExMediaMA.maml
ExMedia.out
ExMedia.pal
.project
notes1.txt
exmedia.val
Life
lifeDRW.bat
LIFE.BAT
form_life.doc
life.drw
lifeLOG.log
lifeMA.ma
life.pal
.project
notes1.txt
README_life.TXT
maze
maze1.bat
maze2.bat
maze3.bat
mazeDRW1.bat
mazeDRW2.bat
mazeDRW3.bat
Outline
An outline is not available.
ExMedia.drw
ExMediaMA.ma
[top]
components : ExMedia
[ExMedia]
type : cell
dim : (9,9)
delay : transport
defaultDelayTime : 100
border : wrapped
neighbors : ExMedia(-1,-1) ExMedia(-1,0) ExMedia(-1,1)
neighbors : ExMedia(0,-1) ExMedia(0,0) ExMedia(0,1)
neighbors : ExMedia(1,-1) ExMedia(1,0) ExMedia(1,1)
initialvalue : 0
initialCellsValue : C:/eclipse/workspace/ExMedia/ExMedia.val
localtransition : calculus
[calculus]
rule : 0 100 { (((0,0) = 0) and (if((statecount(2) - (if((-1,1) = 2,1,0)) - (if(
rule : 0 100 { (((0,0) = 0) and (if((statecount(2) - (if((-1,-1) = 2,1,0)) - (if
rule : 2 100 { (((0,0) = 0) and (if((statecount(2) - (if((-1,1) = 2,1,0)) - (if(
rule : 2 100 { (((0,0) = 0) and (if((statecount(2) - (if((-1,-1) = 2,1,0)) - (if
rule : 1 100 { ((0,0) = 2) and odd(cellpos(1)) }
rule : 1 100 { ((0,0) = 2) and even(cellpos(1)) }
rule : 0 100 { ((0,0) = 1) and odd(cellpos(1)) }
rule : 0 100 { ((0,0) = 1) and even(cellpos(1)) }
rule : {(0,0)} 100 { t and odd(cellpos(1)) }
rule : {(0,0)} 100 { t and even(ce
Cell-DEVS animation
Modify Palette
Hexagonal
Show 2D Only
Available
Selected
ExMedia.drw
ExMedia.drw
Add Model
Load Model
Atomic Animate
exmedia
Values
HH:mm:ss:SSS
2.2
2.2
start
Outbox - ...
Calendar -...
C:\Docum...
Scotia On...
TalkIBM.p...
TalkIBM.p...
CELL-DEV...
CD++ Mo...
Cell-DEVS ...
Atomic Ani...
09:54
Thursday
01-Jun-06

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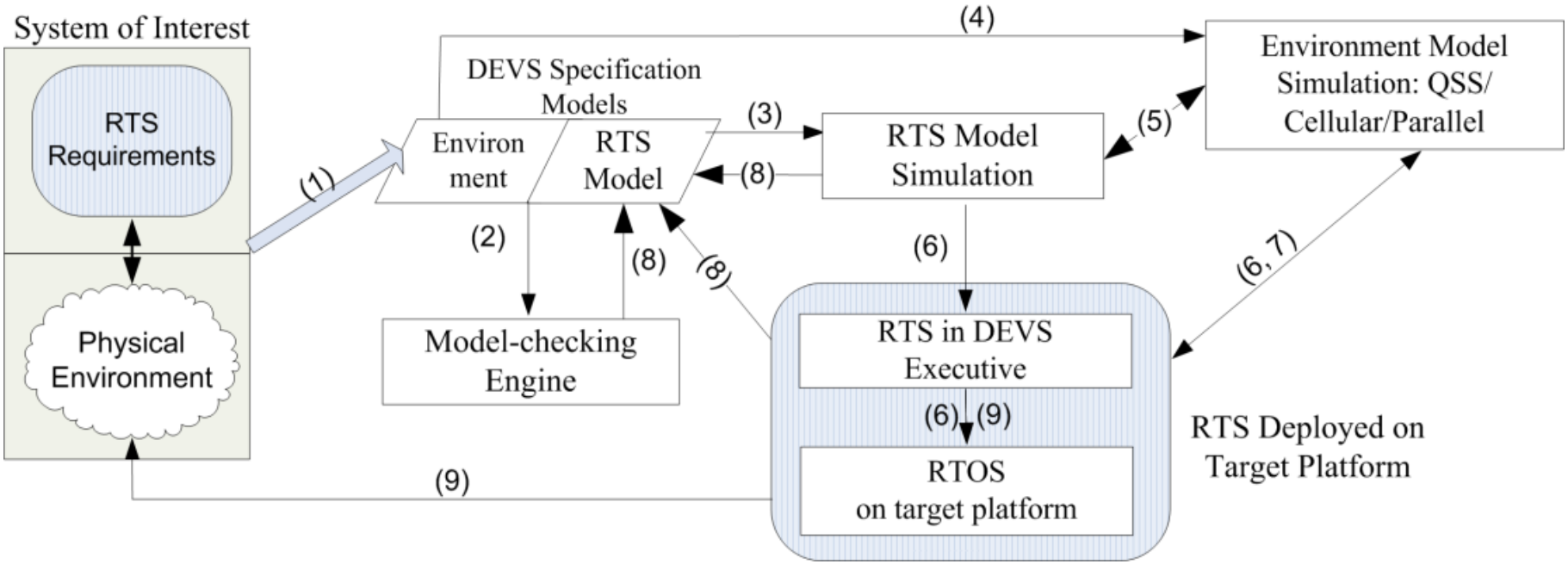
Methodology (4 – Environment Simulation)



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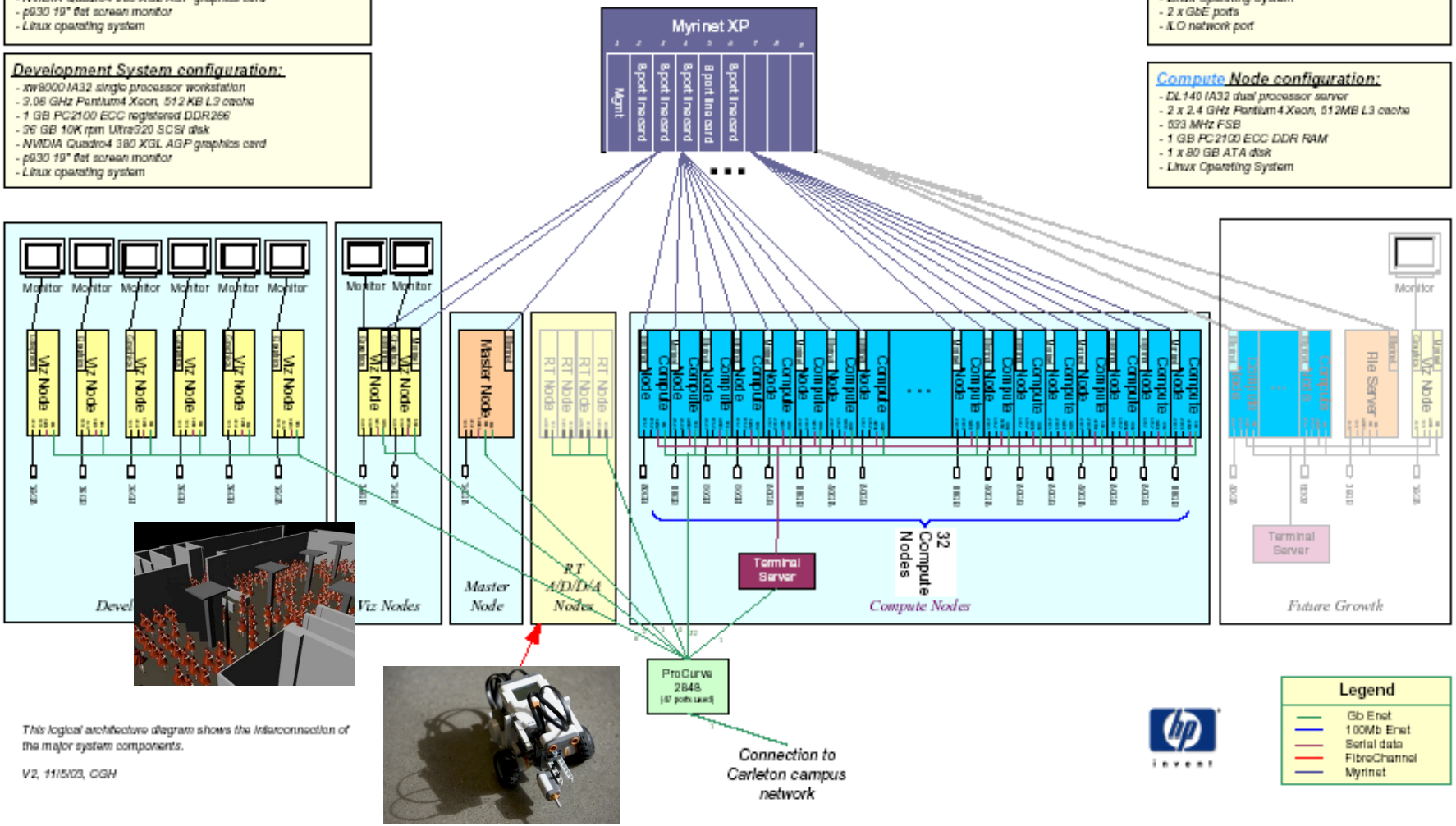
Advanced Laboratory for Real-time Simulation Cluster

Visualization Node configuration:
- xw8000 IA32 dual processor workstation
- 2 x 3.06 GHz Pentium4 Xeon, 512 KB L3 cache
- 1 GB PC2100 ECC registered DDR266
- 36 GB 10K rpm Ultra320 SCSI disk
- Myrinet XP PCI-X card
- NVIDIA Quadro4 980 XGL AGP graphics card
- p930 19" flat screen monitor
- Linux operating system

Development System configuration:
- xw8000 IA32 single processor workstation
- 3.06 GHz Pentium4 Xeon, 512 KB L3 cache
- 1 GB PC2100 ECC registered DDR266
- 36 GB 10K rpm Ultra320 SCSI disk
- NVIDIA Quadro4 380 XGL AGP graphics card
- p930 19" flat screen monitor
- Linux operating system

Master Node configuration:
- DL360-G3 IA32 2P server
- 2 x 3.06GHz Pentium4 Xeon, 512KB L3 cache
- 533 MHz FSB
- 1 GB PC2100 ECC DDR RAM
- 36 GB 10K rpm SCSI disk
- Linux Operating System
- 2 x GbE ports
- iLO network port

Compute Node configuration:
- DL140 IA32 dual processor server
- 2 x 2.4 GHz Pentium4 Xeon, 512MB L3 cache
- 533 MHz FSB
- 1 GB PC2100 ECC DDR RAM
- 1 x 80 GB ATA disk
- Linux Operating System



This logical architecture diagram shows the interconnection of the major system components.

V2, 11/5/03, CGH

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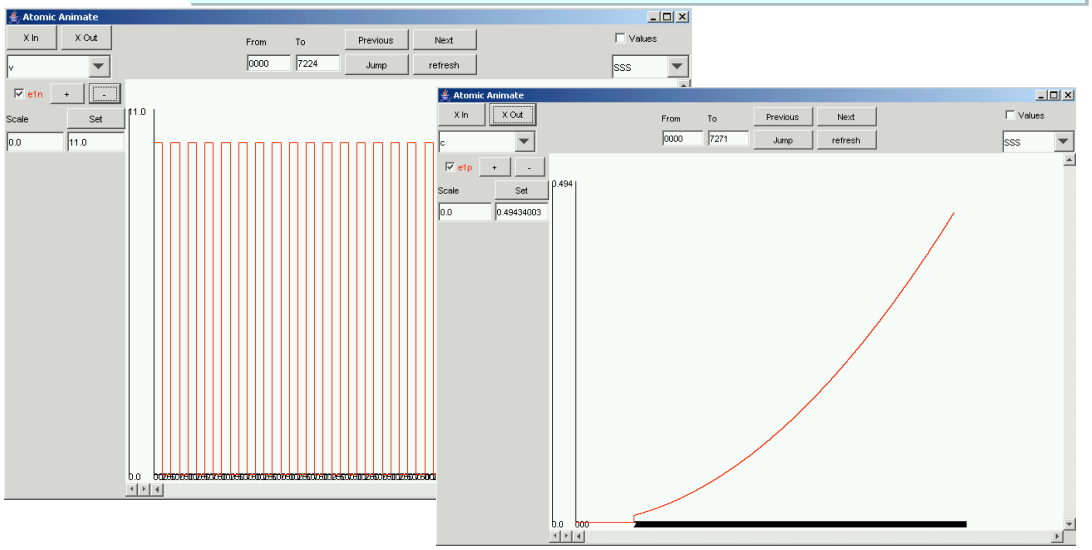
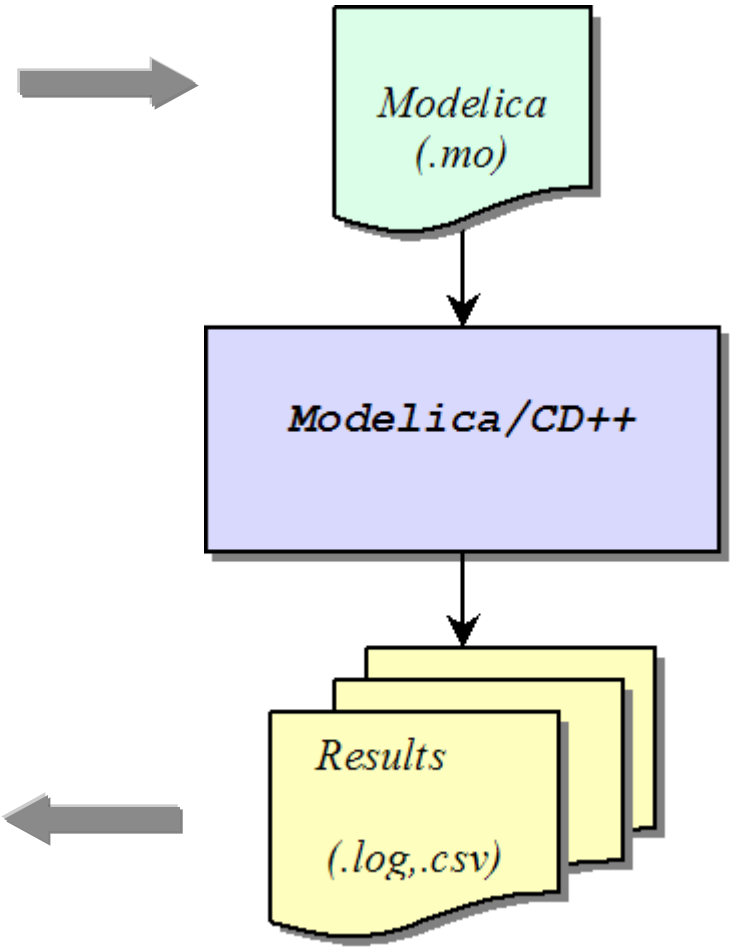
Simulating the Environment's Physics

```
model circuit
  Modelica.Electrical.Analog.Sources.PulseVoltage
                    V(V=10, width=50, period=2.5);
  Modelica.Electrical.Analog.Basic.Resistor R1(R=0.001);
  Modelica.Electrical.Analog.Basic.Inductor I1(L=500);
  Modelica.Electrical.Analog.Basic.Inductor I2(L=2000);
  Modelica.Electrical.Analog.Basic.Capacitor C(C=10);
  Modelica.Electrical.Analog.Basic.Resistor R2(R=1000);
  Modelica.Electrical.Analog.Basic.Ground Gnd;
equation
  connect(V.p, R1.p);
  connect(R1.n, I1.p);
  connect(R1.n, I2.p);
  connect(I2.n, C.p);
  connect(I2.n, R2.p);
  connect(C.n, I1.n);
  connect(R2.n, C.n);
  connect(I1.n, V.n);
  connect(V.n, Gnd.p);
end circuit;
```





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Simulating the Environment's Physics

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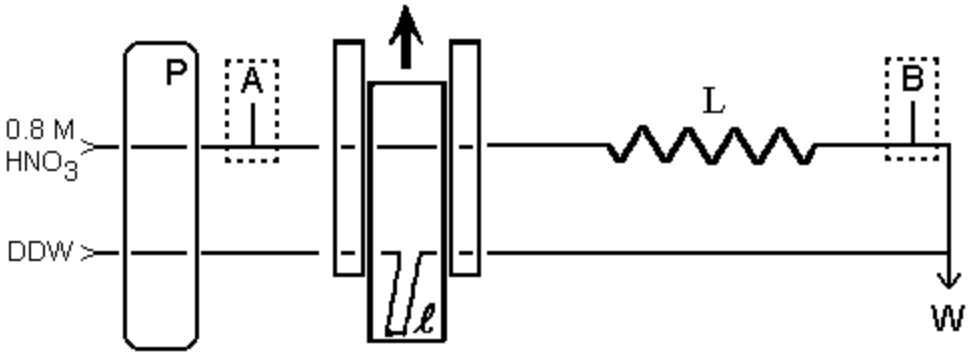
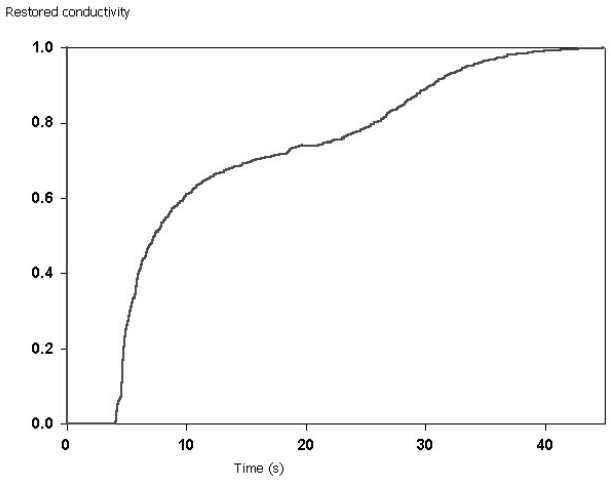
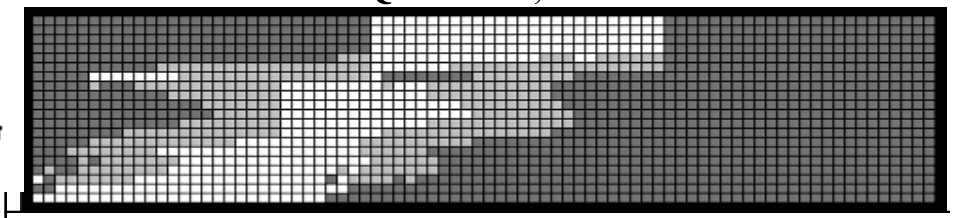
Flow Injection Analysis Model

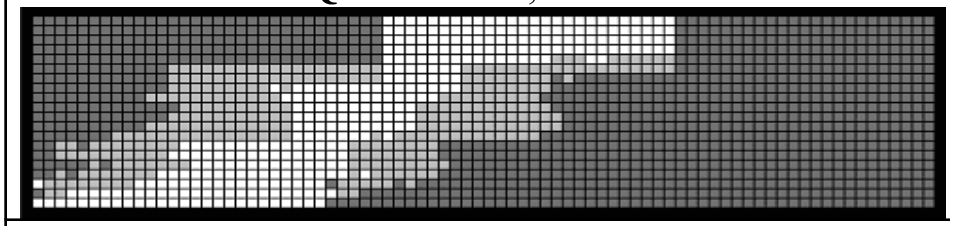




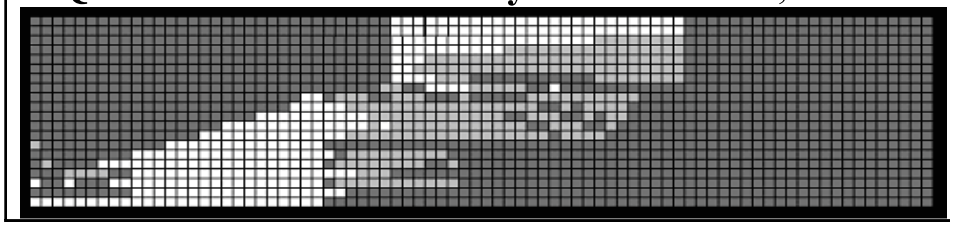
No Quantum, 120ms



Q-DEVS 0.1, 120ms



Quantum Standard 0.7 Dynamic 1 - 0.05, 120ms



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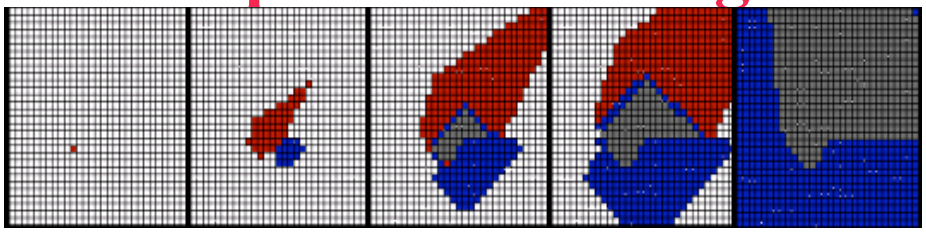
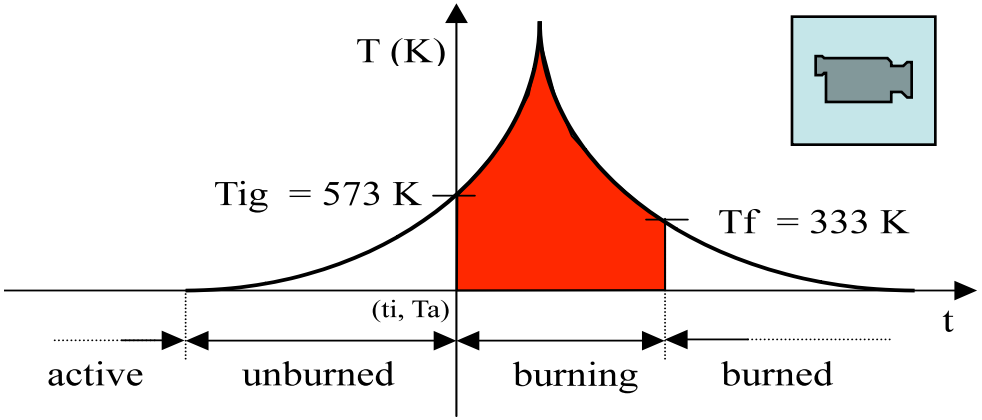
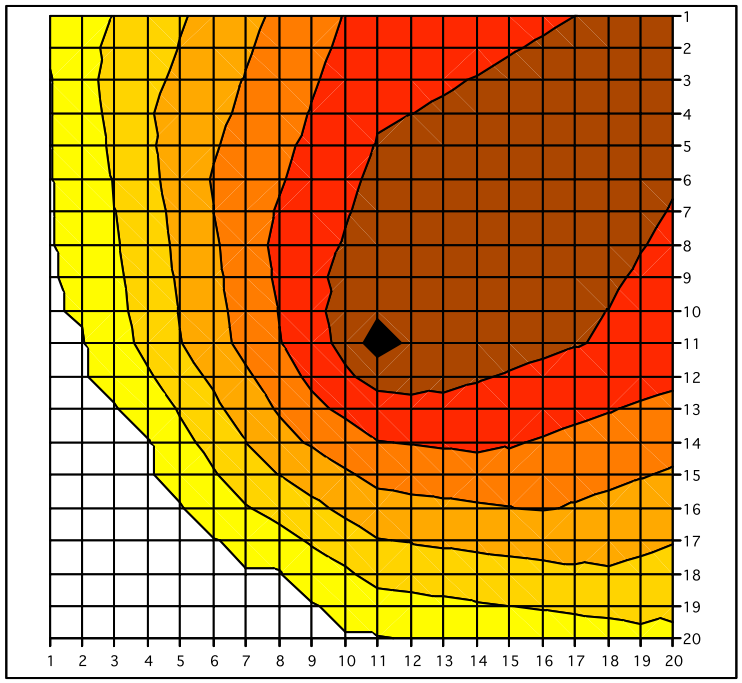
Fire Spread Modeling







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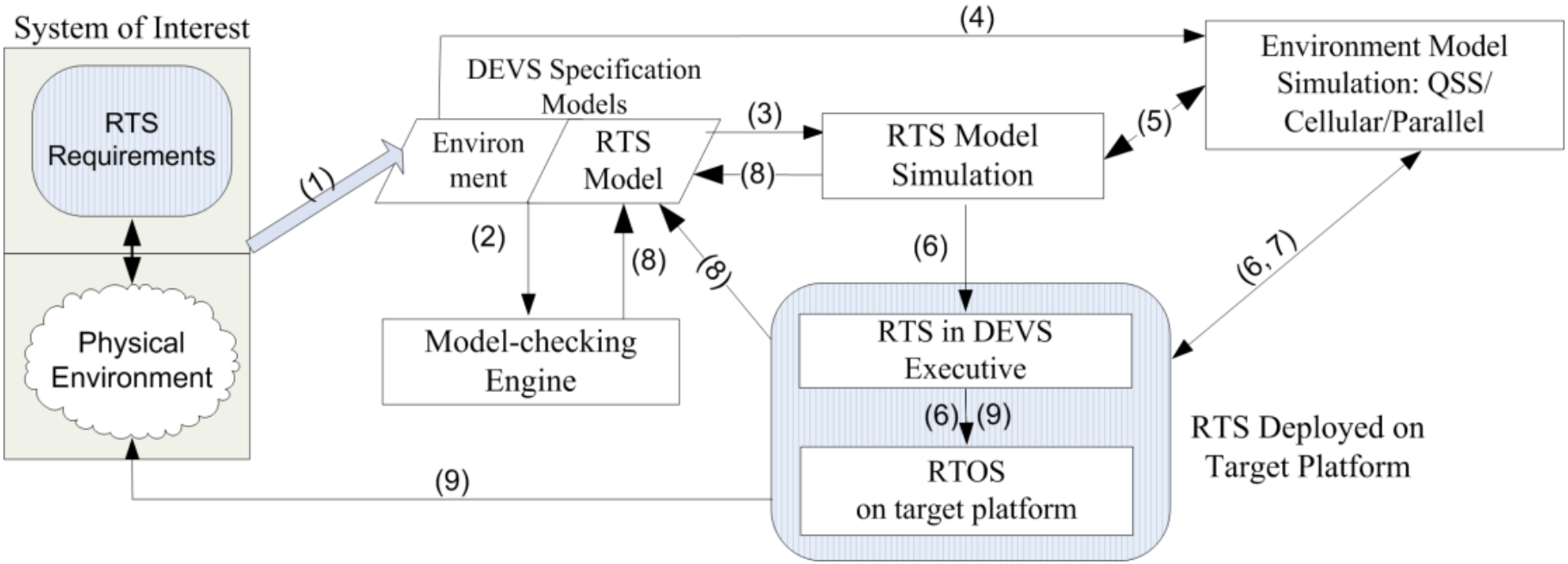
Methodology (6 – Deploying in the target platform)



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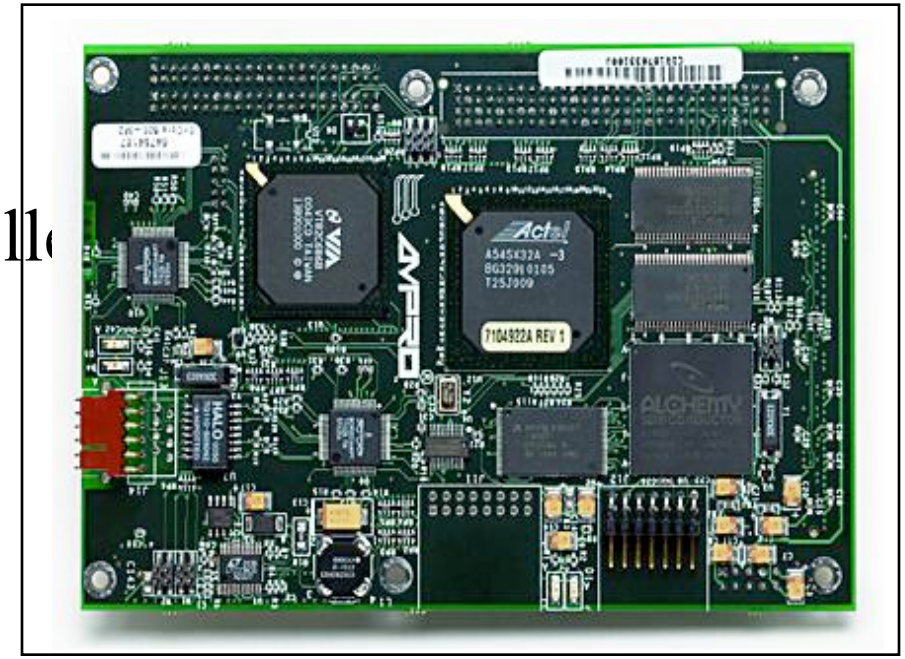
Network Prototyping

- Real time simulation on embedded microcontroll
- Rapid design and testing potential network devices



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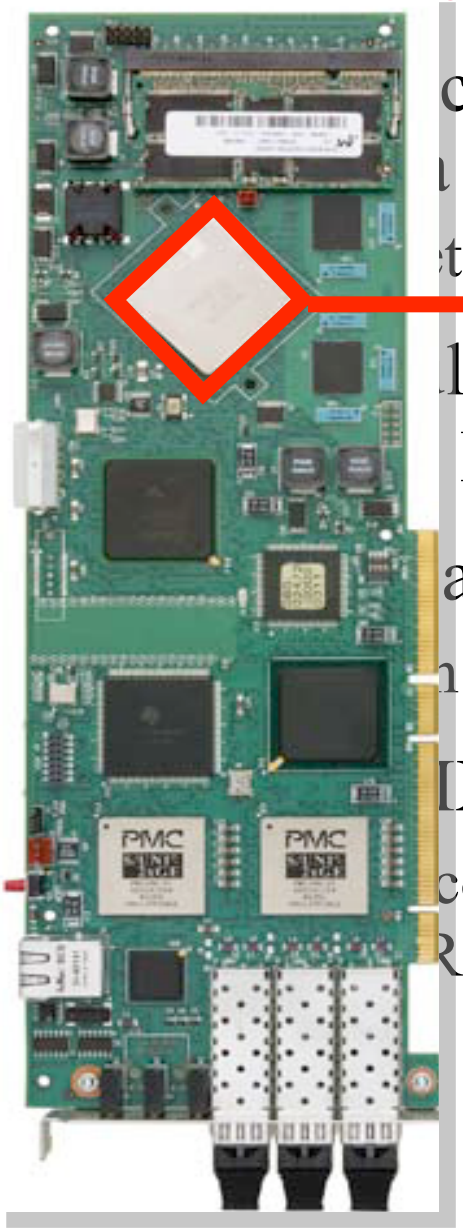
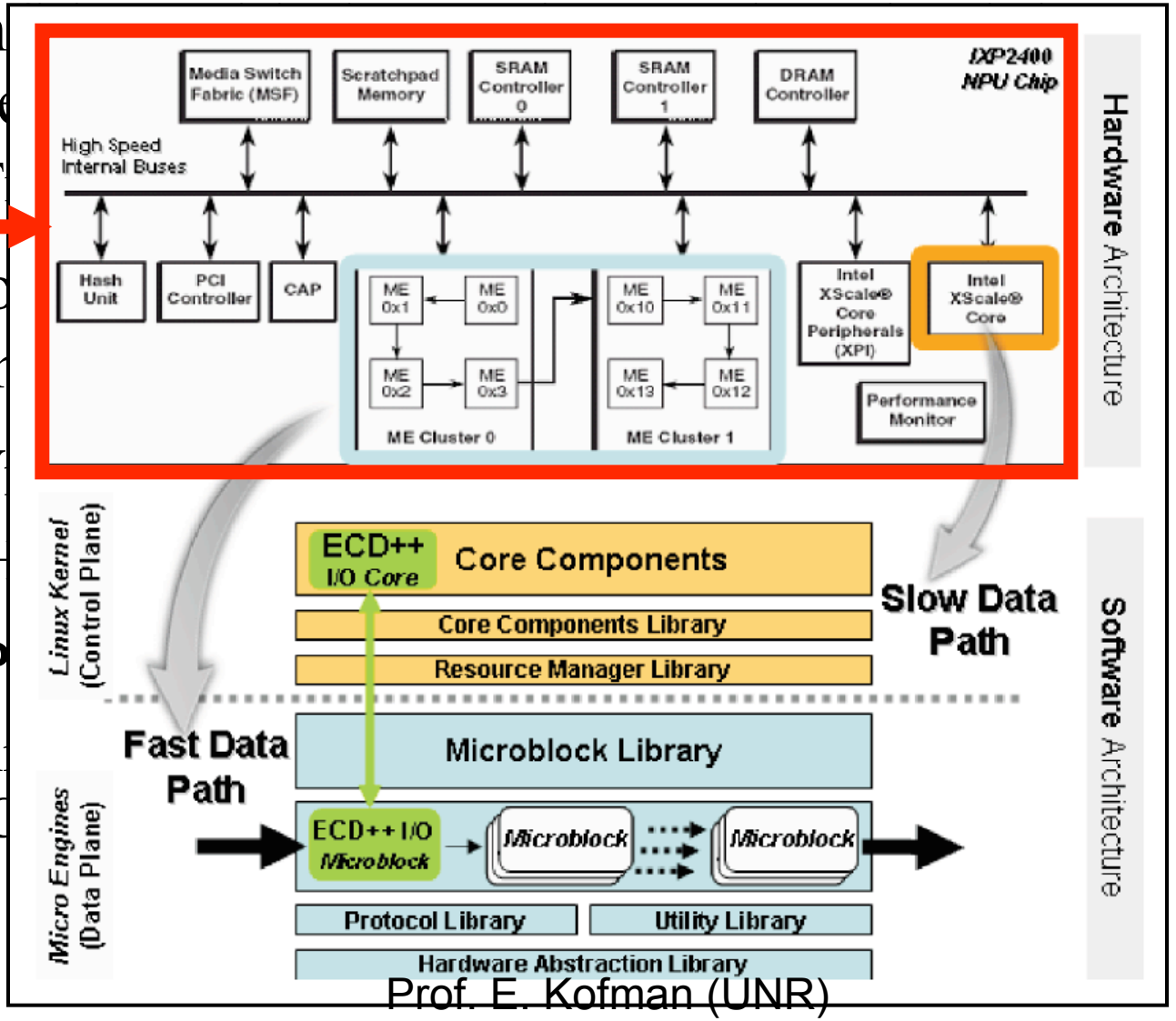
Implementation into the Embedded Target





Prof. E. Kofman (UNR)

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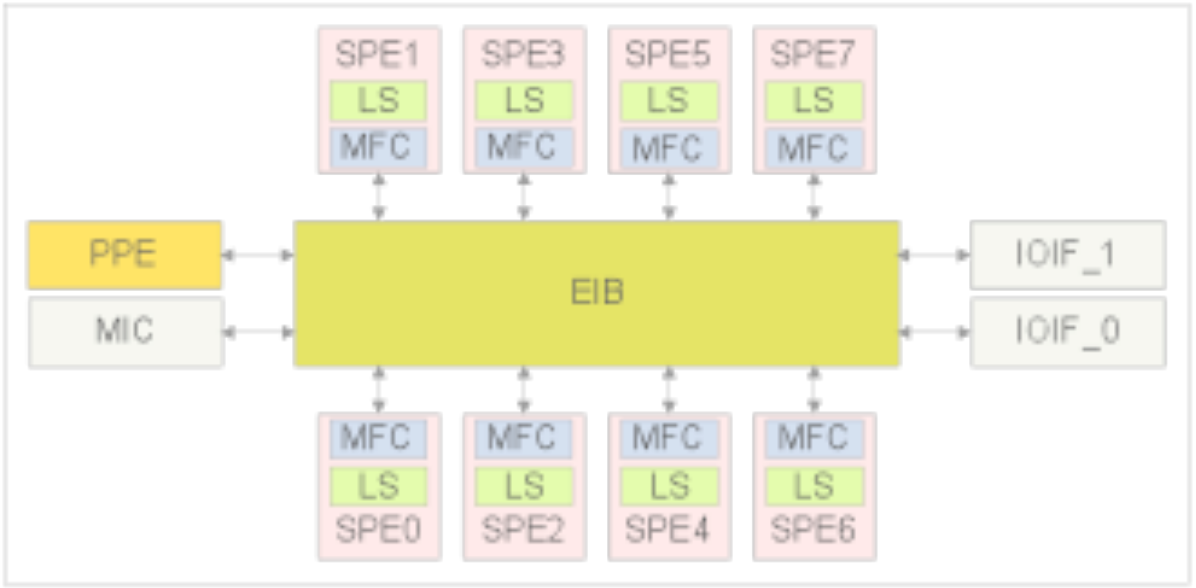
Cell Processor Overview



- Asymmetric CMP with 9 heterogeneous cores
- Software-managed LS with explicitly-addressed DMA transfers
- Low-latency EIB channels – mailbox & signal

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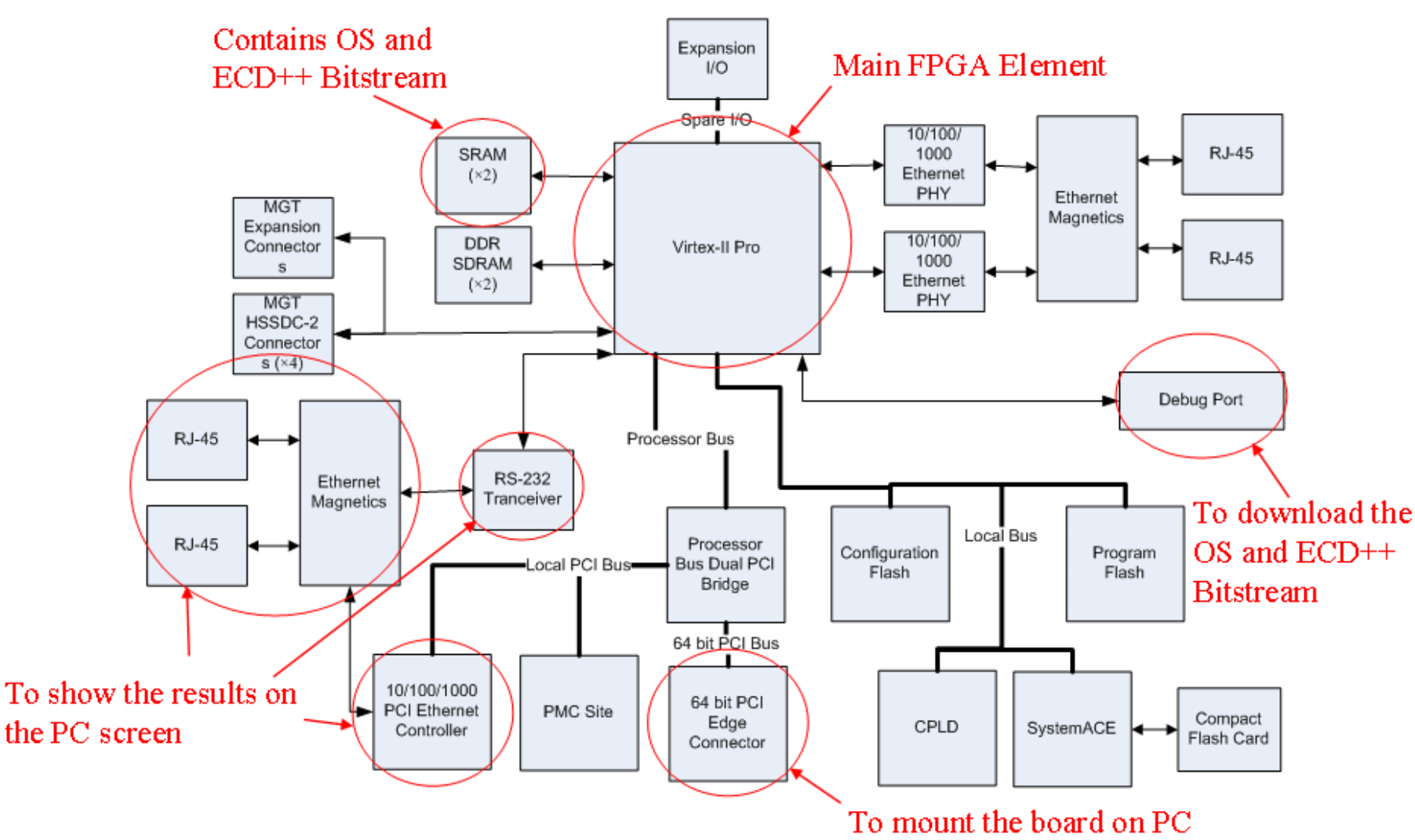
AP1000 FPGA board (Components used in our Project)



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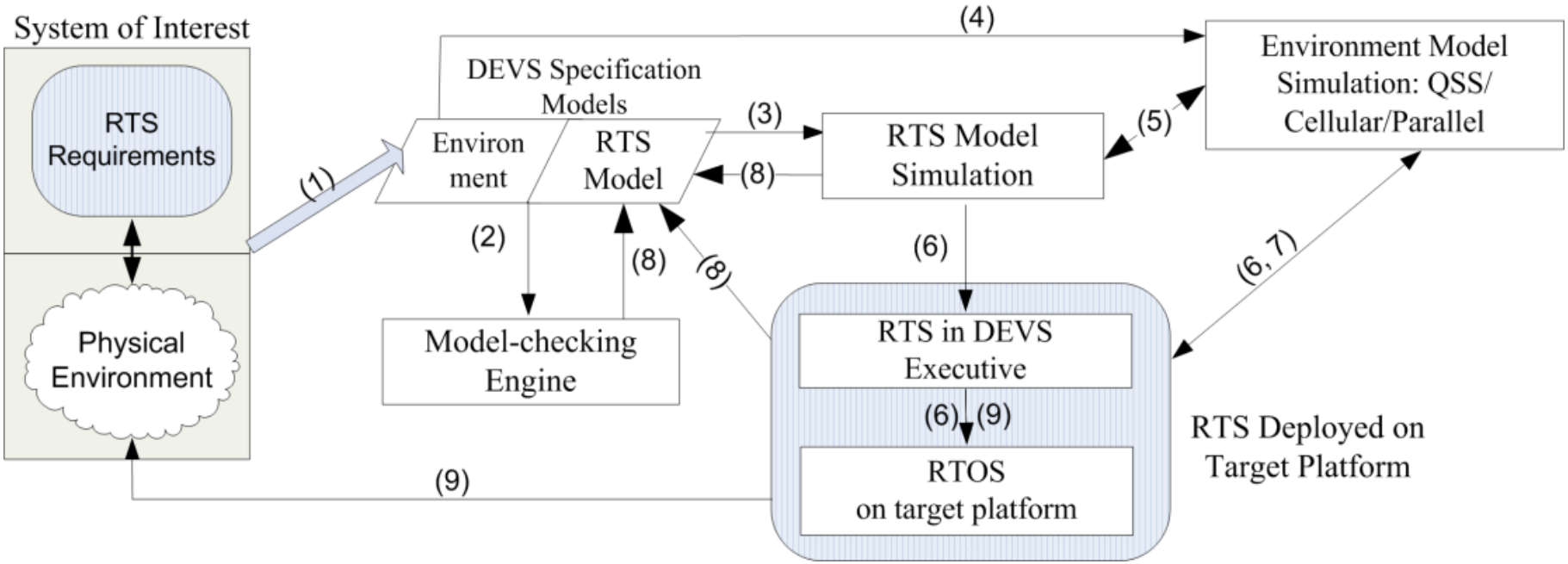
Methodology (7, 8, 9 –Validation)



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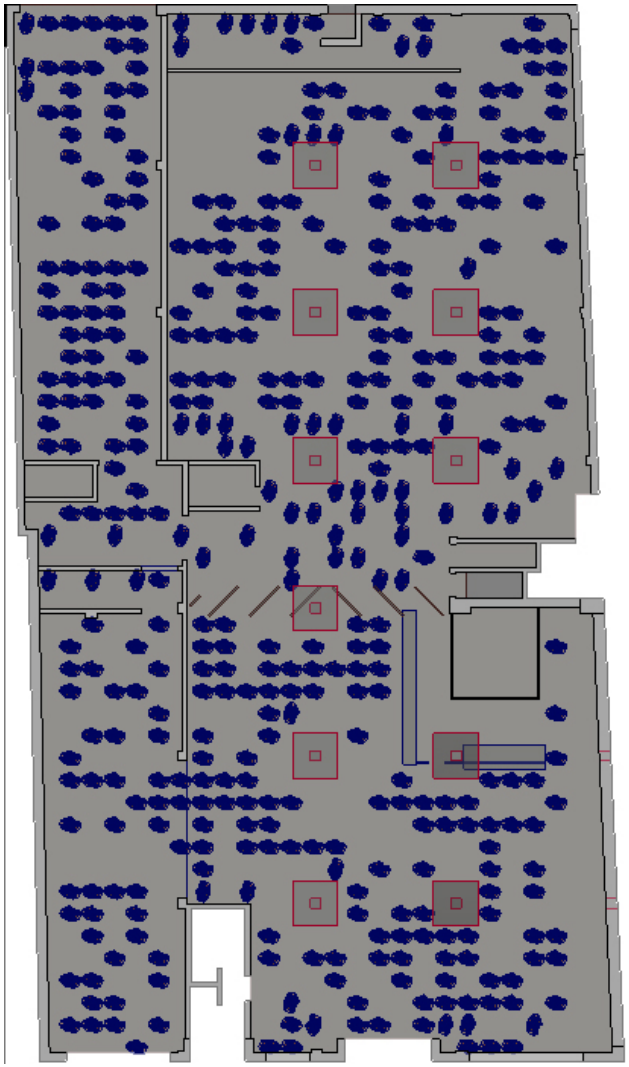
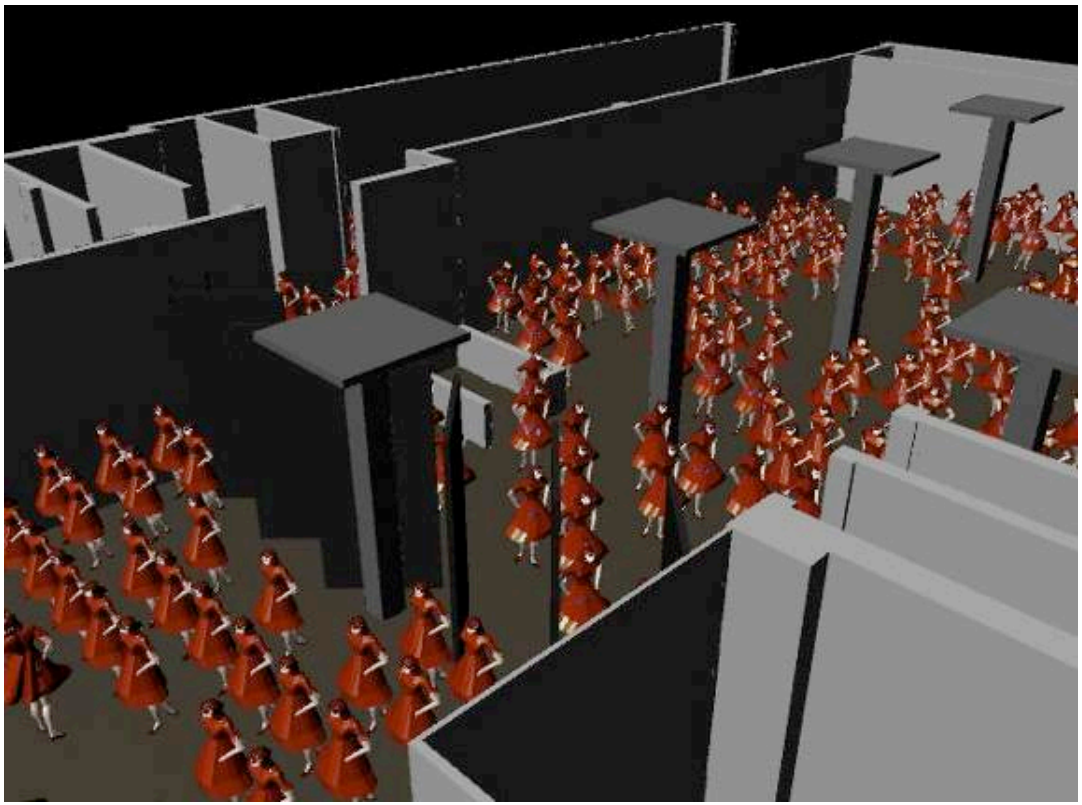
SAT Building Evacuation





Collaboration with School of Architecture (CIMS)

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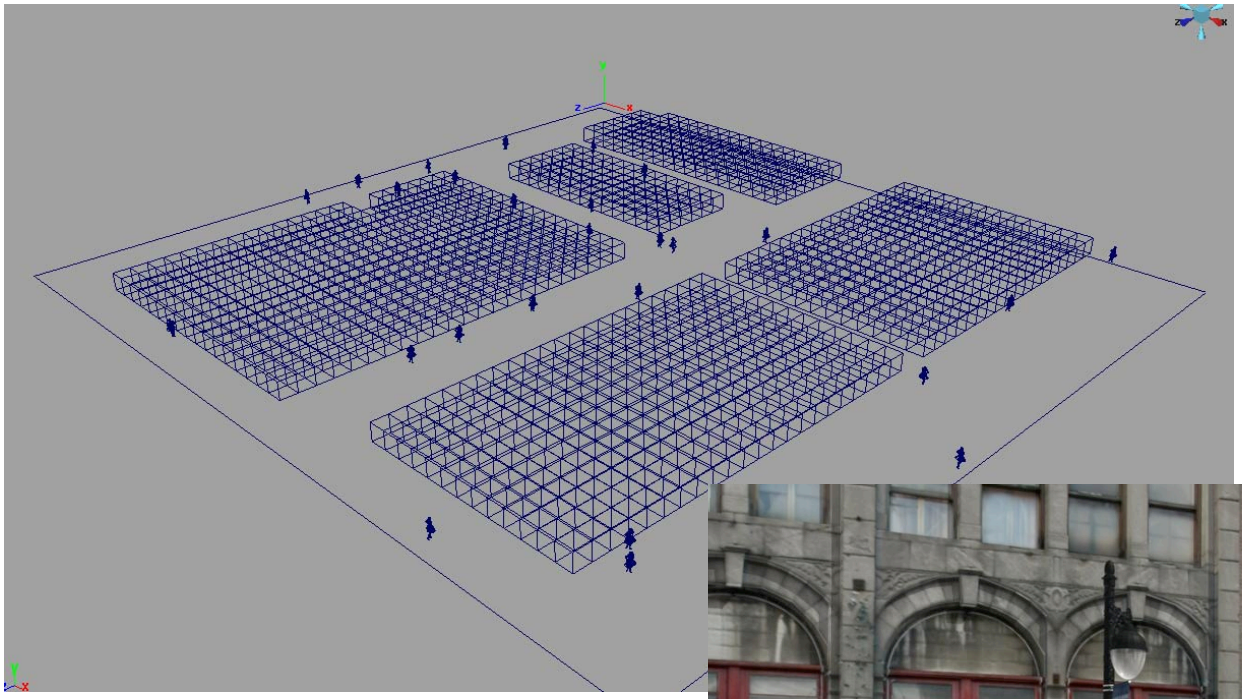

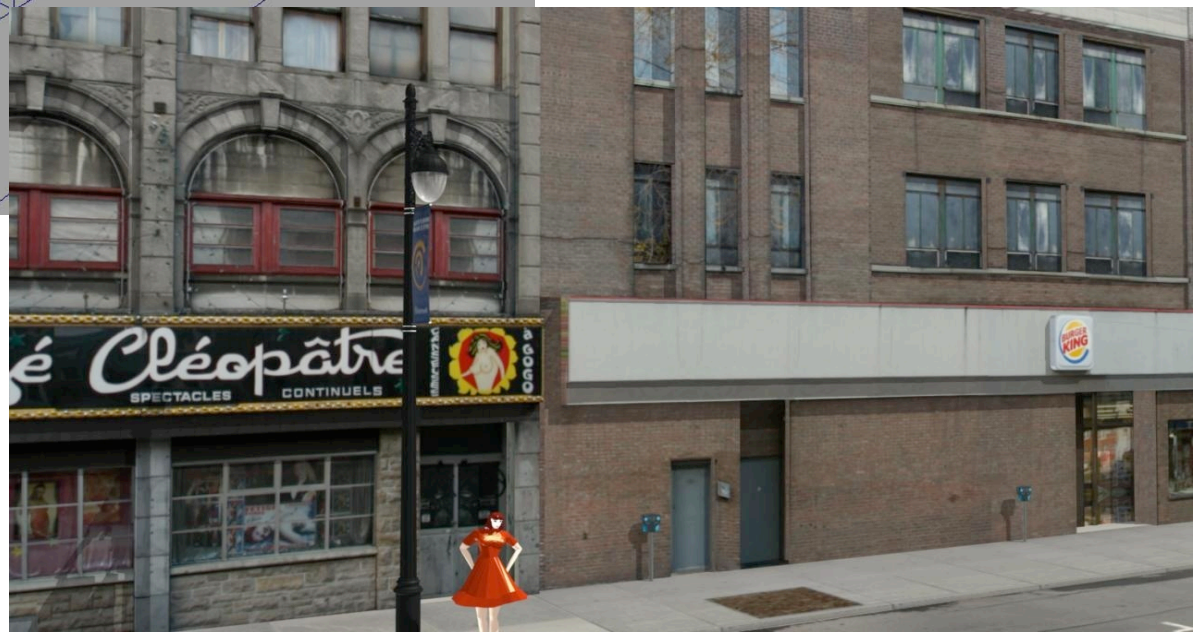

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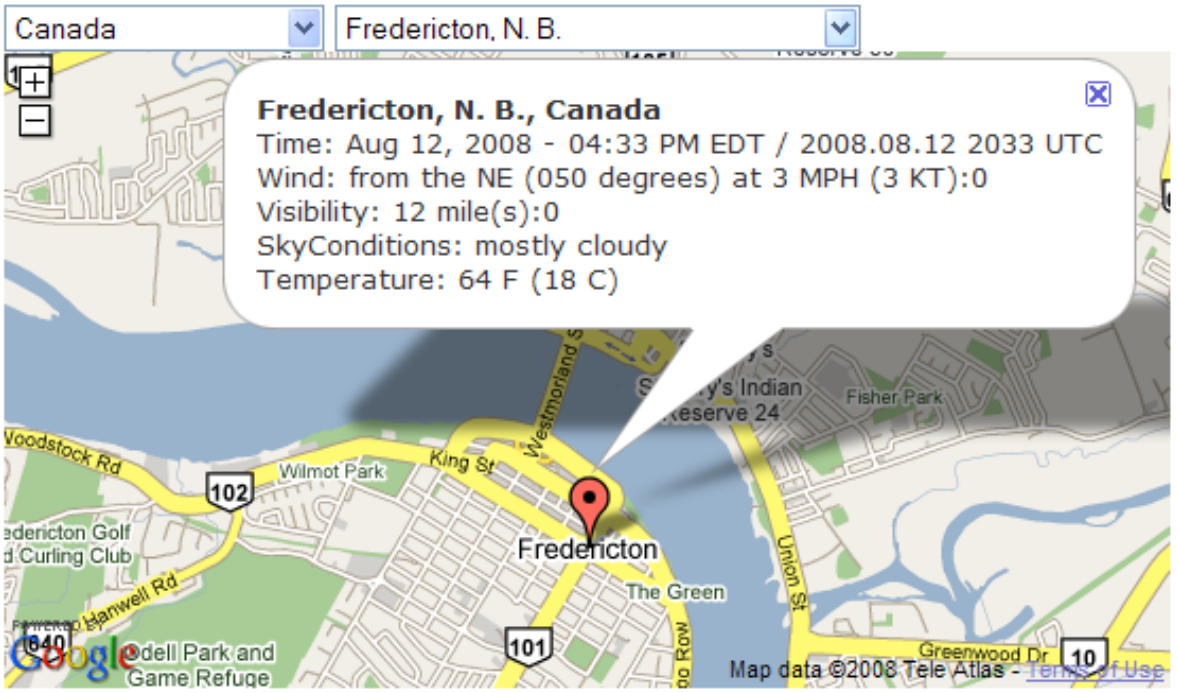
1. **Simulation location**
2. Model
3. Computer Grid
4. Simulation

Log off

Select location and check weather

Use the fields and the map above to select the country and the town where to run the simulation. If the town does not appear or is not supported, please do a manual search with the google map.



Next Step >

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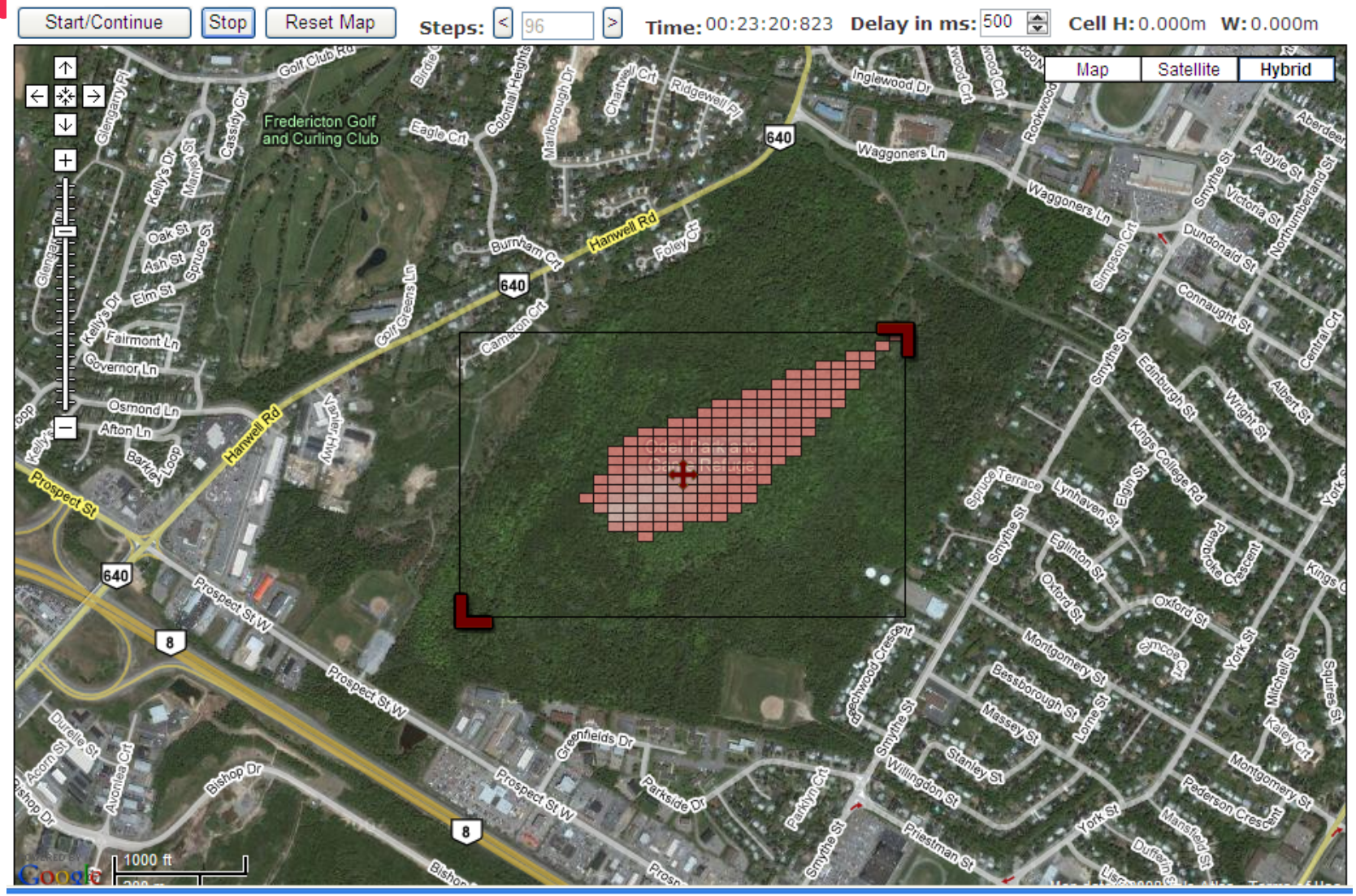
Mashup (Google Maps)



Application to Robotics

Some interesting results

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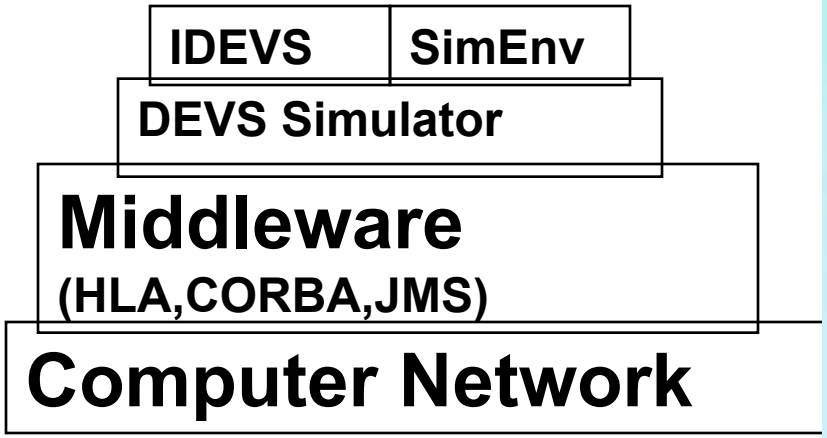
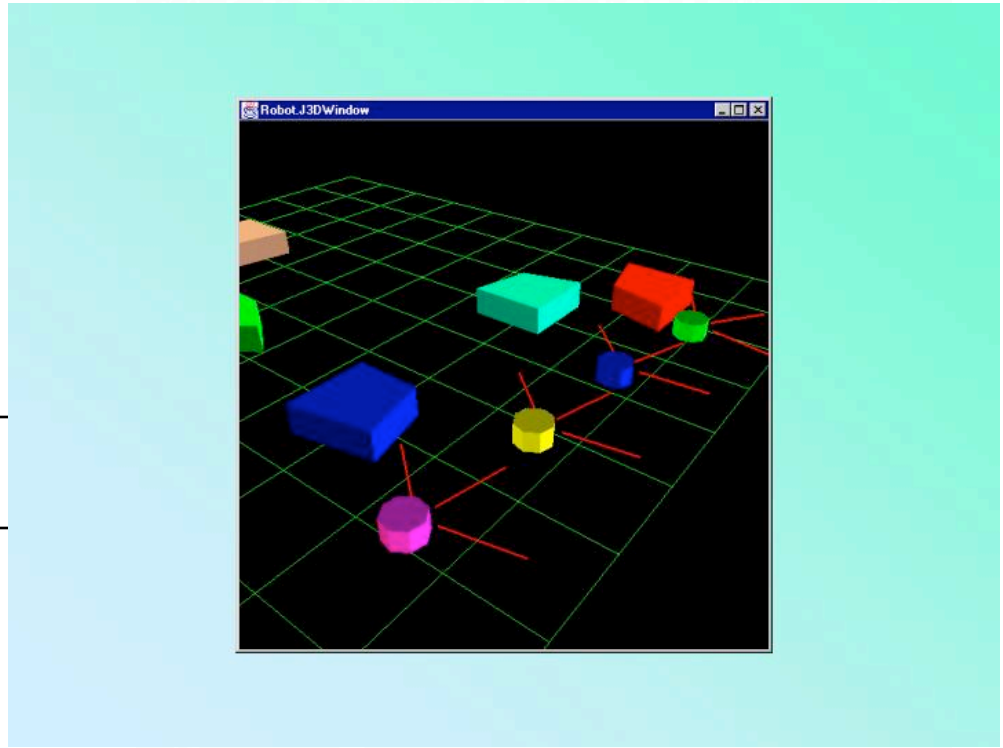
U. of New Mexico Virtual Lab for Autonomous Agents

V-Lab: DEVS M&S environment for robotic agents with physics, terrain and dynamics (Mars Pathfinders).





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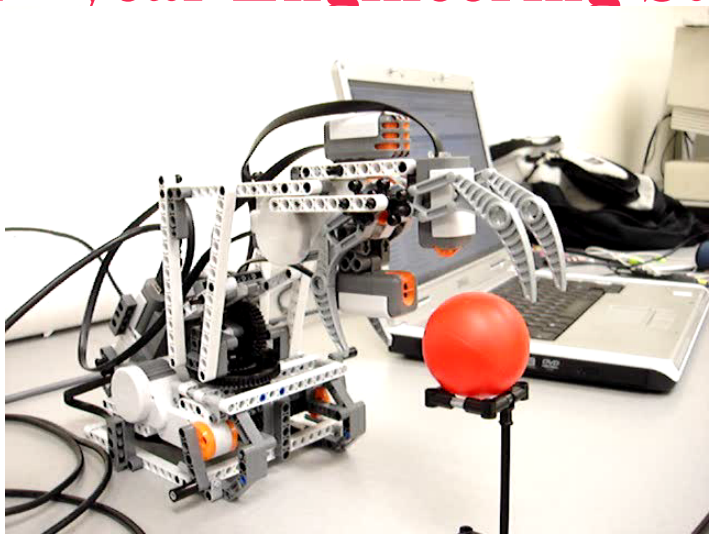
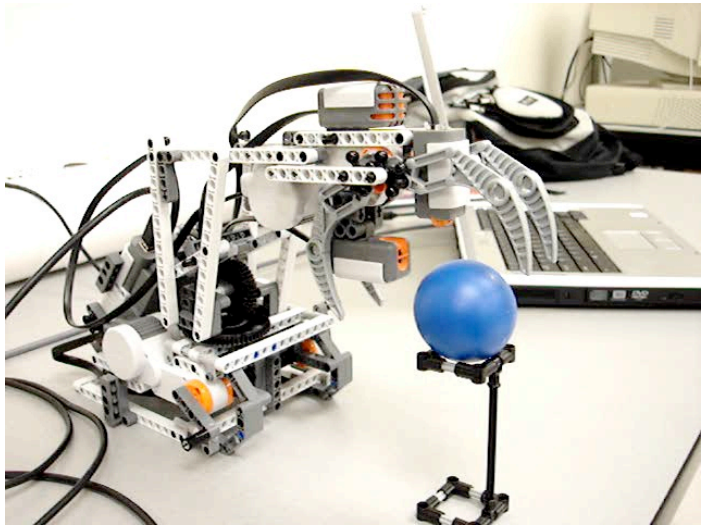
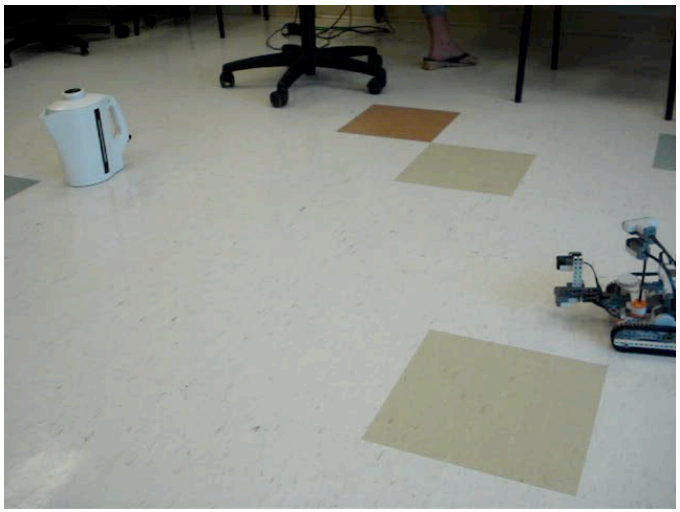
4th year Engineering Students







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Videos

- http://www.youtube.com/watch?v=R1MT8OLu8Co
- http://www.youtube.com/watch?v=j5QhX4QFER8
- http://www.youtube.com/watch?v=61vXI9qujZI
- http://www.youtube.com/watch?v=w-bwwl4CP4c
- http://www.youtube.com/watch?v=PeHO_BD46SA

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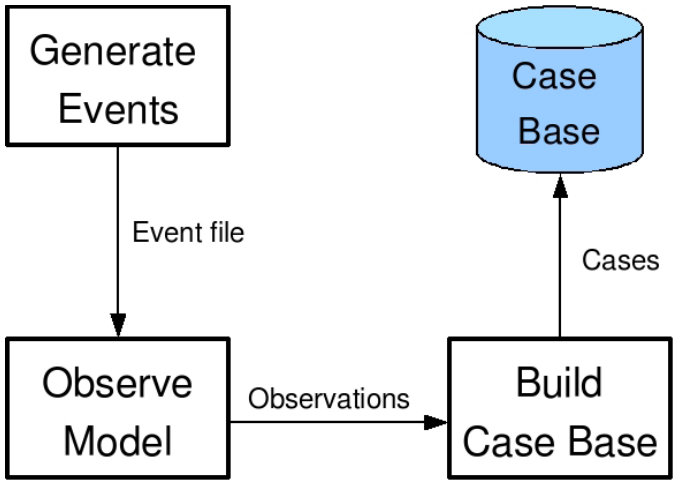
Learning by Observation

Case-Based Reasoning

a. Build Case Base

b. Imitation Model (uses Case Base)

Videos:



http://www.youtube.com/watch?v=n5wL3rBW0qo

http://www.youtube.com/watch?v=FqQuEdNAU9I

http://www.youtube.com/watch?v=4l-SC8Pi1NM

http://www.youtube.com/watch?v=_mVco23d6n4

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ePuck

http://www.youtube.com/watch?v=VoHP2kVH0Gg

http://www.youtube.com/watch?v=UFHzLk0oXyQ

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Summary

- ***Model-Based Engineering for software development***
- **Varied hardware**, software and **3D visualization**
- Models reused throughout the process => cost improved
- **Collaborative environment** based on Eclipse
- Advanced visualization facilities

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Further Information

http://cell-devs.sce.carleton.ca

http://cell-devs.sce.carleton.ca/publications