



Carleton
UNIVERSITY

Advanced Real-Time Simulation Laboratory

Prof. Gabriel A. Wainer

Twitter: @ARSLab_CU

<http://youtube.com/arslab>

<http://cell-devs.sce.carleton.ca/ars/>

Carleton University Centre on Visualization and Simulation (V-Sim – CFI funding)



■ Interdisciplinary research

- Systems Engineering
- Mechanical & Aerospace
- Cognitive Science
- Architecture

– ARSLab

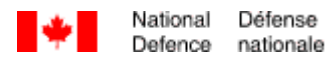
- 3 Invited Professors
- 4 Postdoctoral Fellows
- 8 Ph.D. and 4 Masters students; 5 UG

- 7 Postdocs, 16 Ph.D. and 55 Masters Students graduated since 2000
- 95 UG students supervised since 2000 (Engineering Capstone Projects)





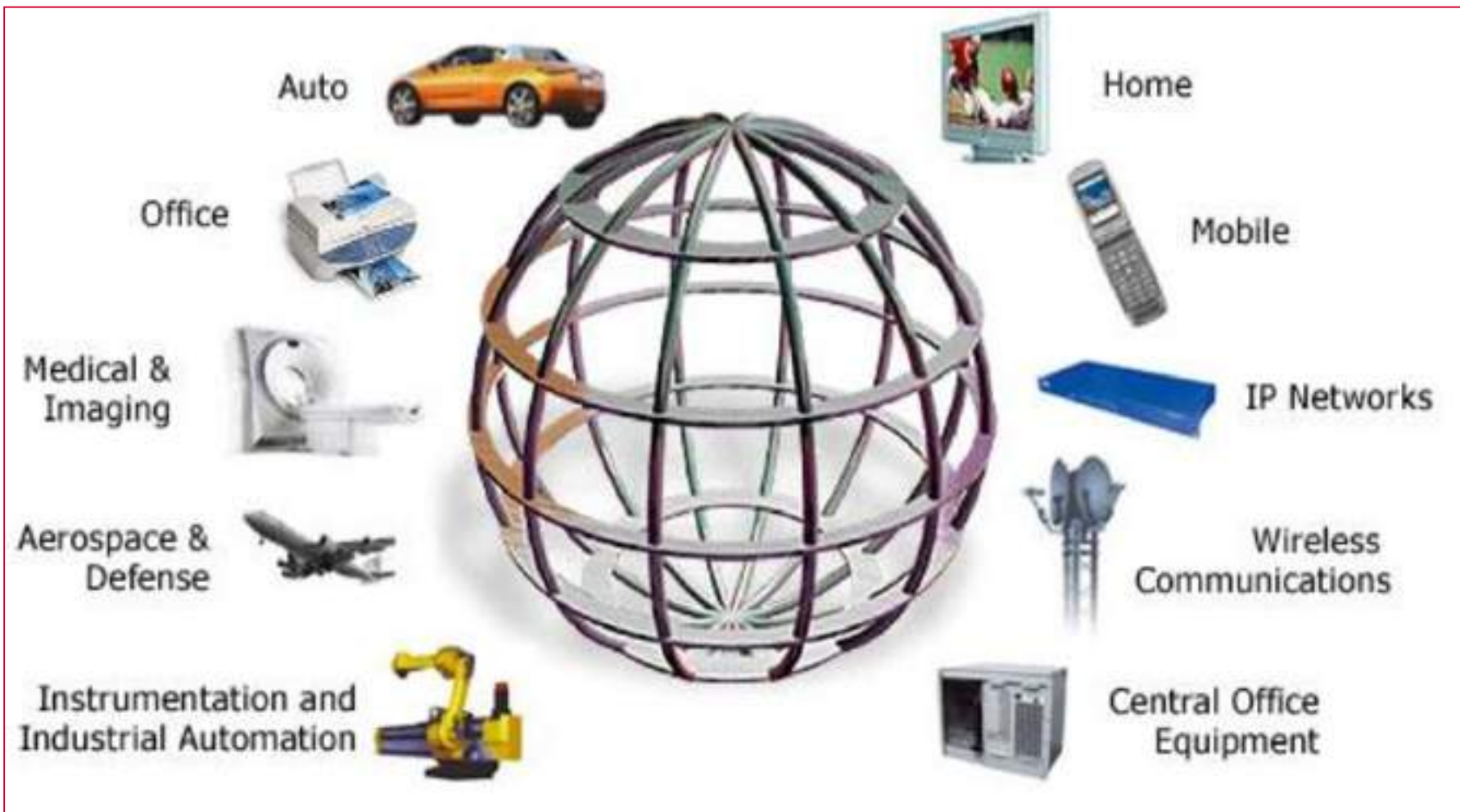
Research Support



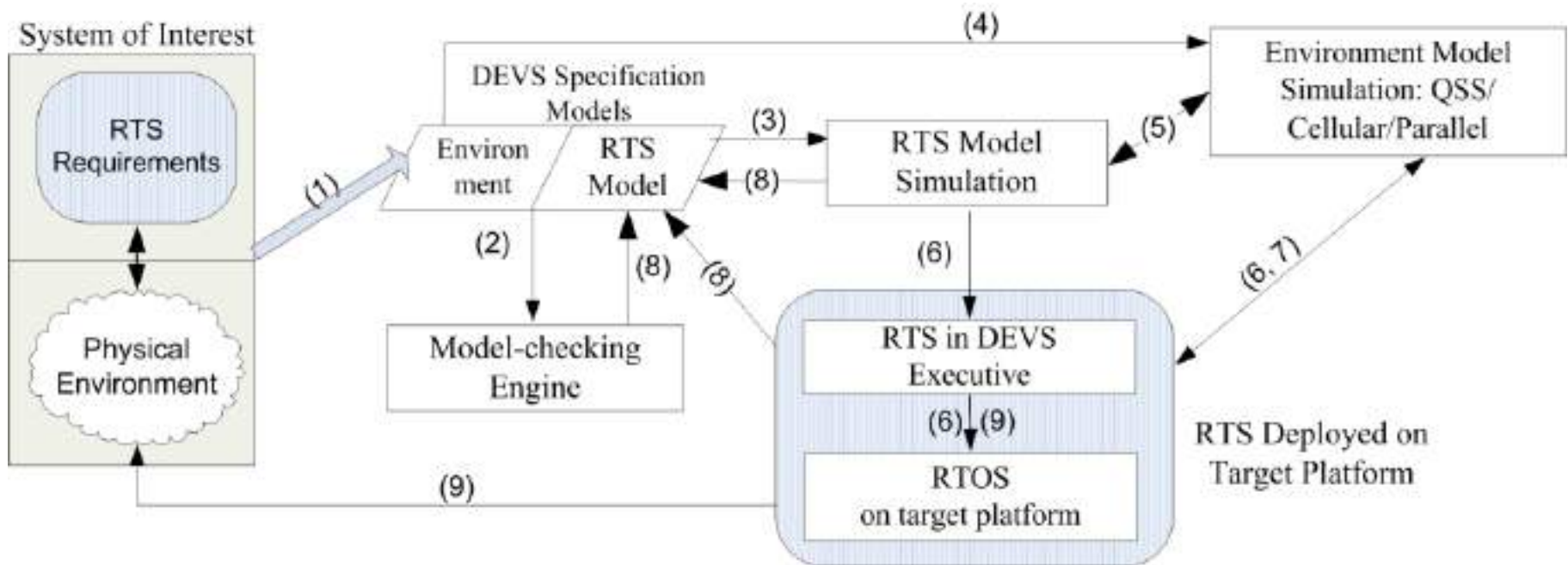
Alumni



Cyber-Physical Systems

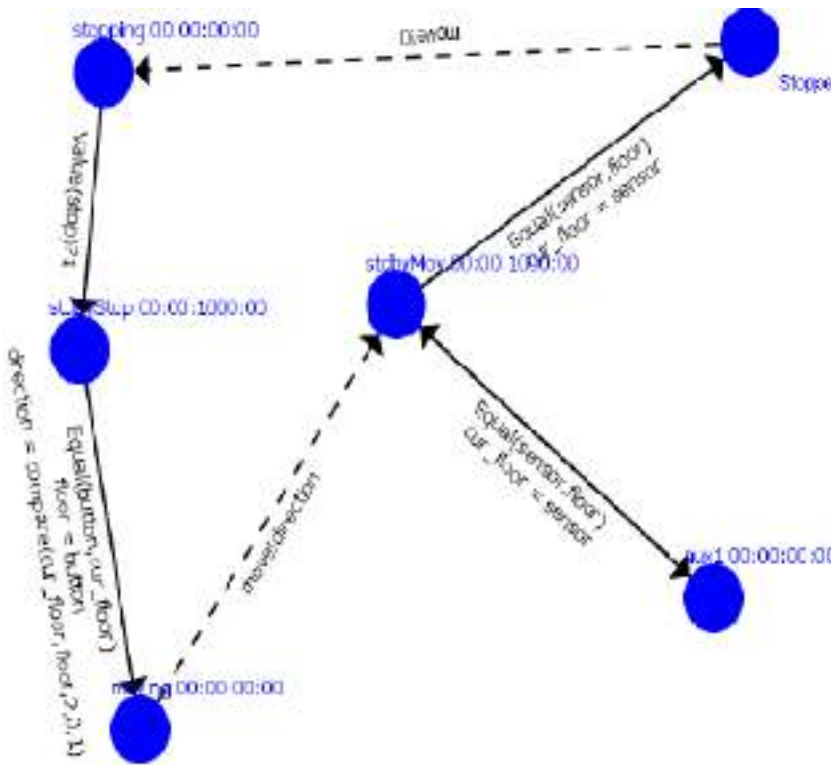


M&S for Building CPS

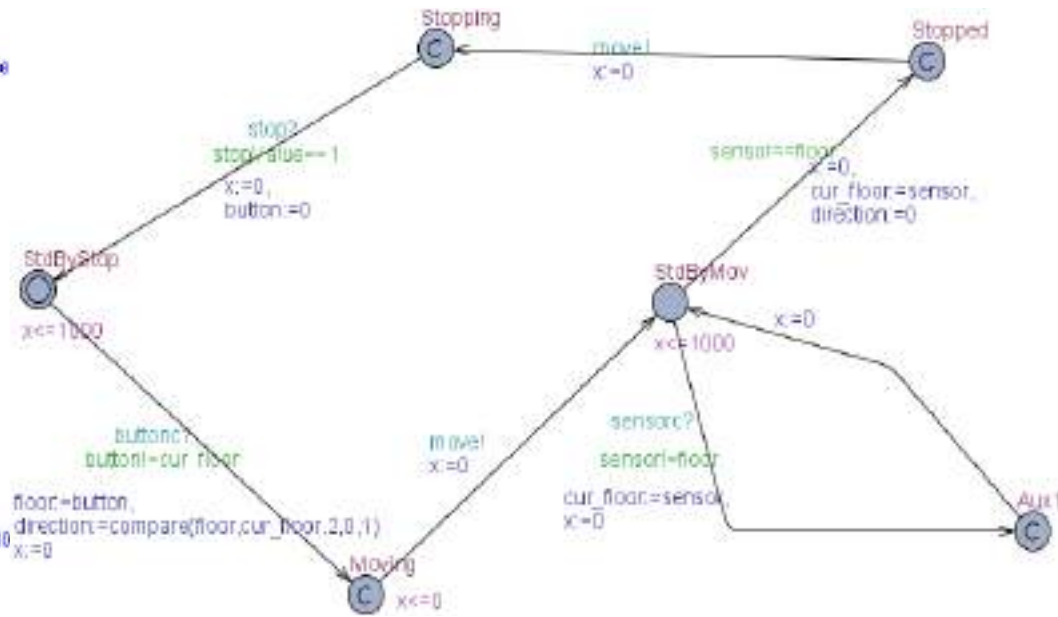




Model Transformation



Elevator Controller RTA-
DEVS Model



TA Controller model in
UPPAAL

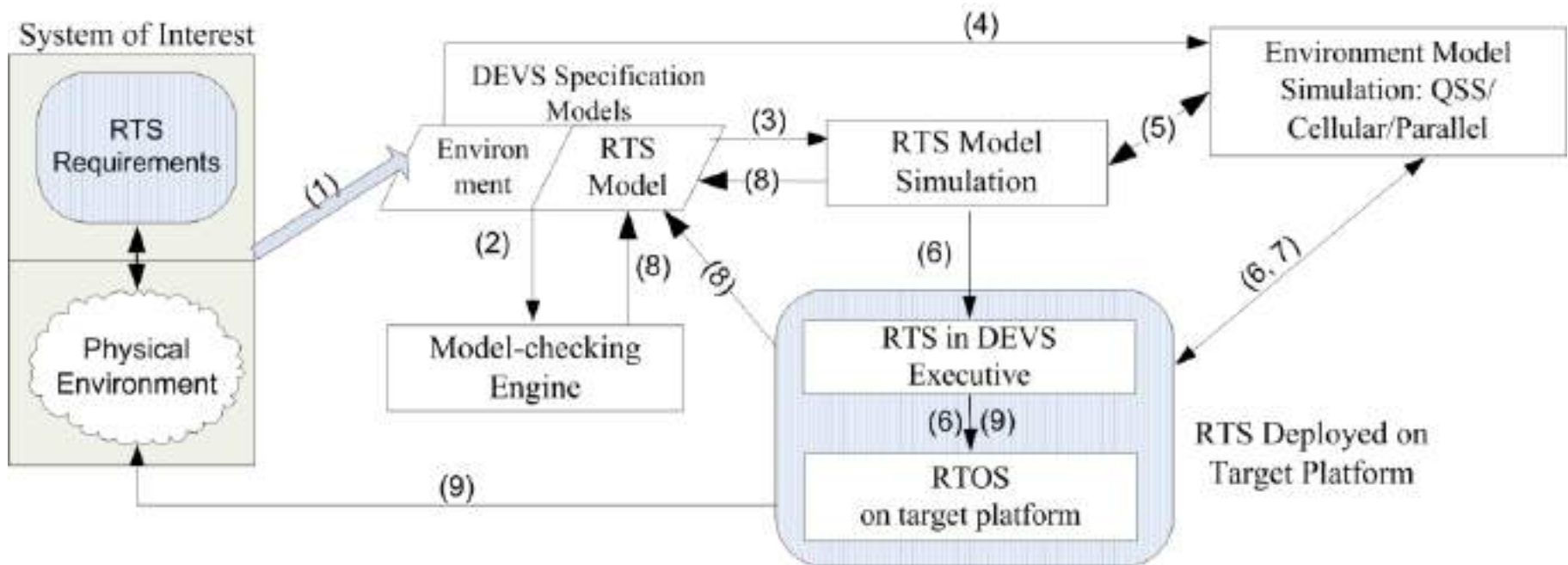
CD++ Builder Environment



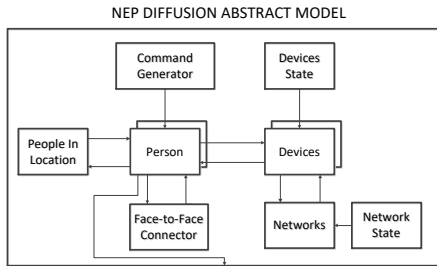
The screenshot shows the CD++ Builder interface with several key components highlighted:

- Action Buttons:** A toolbar at the top containing various icons for file operations, simulation, and editing.
- Perspectives:** A dropdown menu at the top right showing the current view mode set to "CD++ Builder".
- Project Files:** A file explorer on the left showing a project structure with files like `atomicType.cdd`, `register.cpp`, and `Top.h`.
- Graphical Editors:** The central workspace displaying a block diagram with components like "Queue", "atomic", and "coupled" connected by ports.
- Simulation Results:** A window showing a waveform plot and a network diagram.
- Modeling Tools:** A palette on the right listing components such as "Input Port", "GGAD Atomic Model", "CoupledModel", and "Link".
- Reusable Models:** A sub-section of the palette listing "Built-in Models" like "Queue", "Generator", "CPU", "Transducer", and "Traffic".
- Model Overview:** A small thumbnail view of the current model diagram.
- Autogenerated C++ Code:** A window showing the generated C++ code for a model, including comments and function definitions.
- Simulation Console:** A window at the bottom for viewing simulation logs, errors, and task lists.

M&S for Building CPS



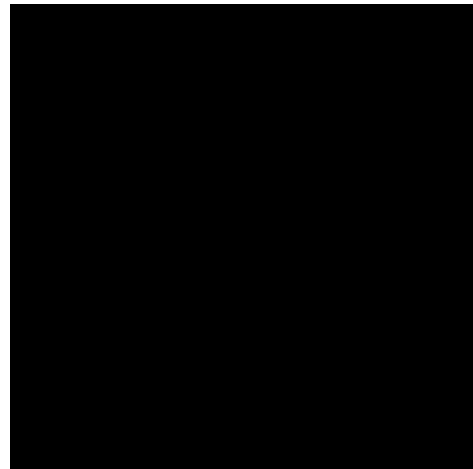
DIFFUSION COMPUTERIZED MODEL



```

1 using namespace std;
2 using namespace cadmium;
3 using namespace nep_structures;
4 using namespace nep_model_enum_types;
5
6 struct switch3Out_defst //Port definition
7 struct sendOut : public out_port<MSG> {};
8 struct answerOut : public out_port<MSG> {};
9 struct decideOut : public out_port<MSG> {};
10 struct communicationIn : public in_port<MSG> {};
11 struct setAnswerIn : public in_port<SET_STATE_SEND> {};
12 struct setDecideIn : public in_port<SET_STATE_DEC> {};
13 struct setSendIn : public in_port<SET_STATE_SEND> {};
14
15 class switch3Out { // DEVS atomic model definition
16 public:
17     DeviceType id; //Parameter
18     enum SwitchState{ANSWER, SEND, DECIDE}; //state definition
19     state_type state;
20     struct state_type;
21     vector<MSG> outMsg;
22     SwitchState state; };
    
```

x37



C++ functions
x #Coupled (8)



C++ program

DEVS Diffusion Computerized Model

```

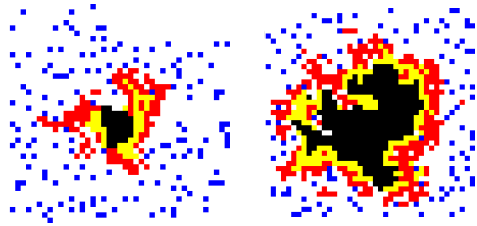
1 struct inp_generator : public cadmium::in_port<Command>{}; // SET INPUT PORTS FOR COUPLED
2 struct inp_network : public cadmium::in_port<Communication>{};
3 ...
4 outp_myLocation : public out_port<PeopleLocation>{}; // SET OUTPUT PORTS FOR COUPLED
5 outp_network : public out_port<Communication>{};
6 ...
7 template<typename TIME> // Define atomic and coupled unit devices
8 class filterDevicesNetwork1 : public filterDevicesNetwork<TIME> {
9 public: filterDevicesNetwork1(): filterDevicesNetwork<TIME>("1") {}; };
10
11 template<typename TIME>
12 class filterDevicesSetOutOrder1 : public filterDevicesSetOutOrder<TIME> {
13 public: filterDevicesSetOutOrder1(): filterDevicesSetOutOrder<TIME>("1") {}; };
14
15 template<typename TIME>
16 class phoneMOBILEPHONE1 : public phone<SetDeviceState, TIME> {
17 public: phoneMOBILEPHONE1(): phone<SetDeviceState,TIME>(DeviceId
18     (DeviceType::MOBILEPHONE, "1"),TIME("00:00:500"),TIME("00:01:000")) {}); };
19
20 template<typename TIME>
21 class phoneLANDLINEPHONE1 : public phone<SetDeviceState, TIME> {
22 public: phoneLANDLINEPHONE1(): phone<SetDeviceState, TIME>(DeviceId(DeviceType::LANDLINEPHONE,
23     "1"),TIME("00:00:500"),TIME("00:01:000")) {}); };
24//DEFINE COUPLED DEVICE
25 using iports_DEVICES1 = tuple<inp_setOutOfOrder,inp_in_com,inp_network>;
26 using oports_DEVICES1 = tuple<outp_out_com, outp_network>;
27 using submodels_DEVICES1 = models_tuple<filterDevicesSetOutOrder1, filterDevicesNetwork1,
28     filterDevicesMicroKeyboard, sinkDevices_atomic,phoneMOBILEPHONE1, phoneLANDLINEPHONE1,>
29 using eics_DEVICES1 = tuple<
30     EIC<inp_setOutOfOrder,filterDevicesSetOutOrder1,filterDevicesSetOutOrder_defs::in>,
31     EIC<inp_in_com,filterDevicesMicroKeyboard, filterDevicesMicroKeyboard_defs::in>,
32     EIC<inp_network,filterDevicesNetwork1, filterDevicesNetwork_defs::in>
33 ...
    
```

Thousands of lines of code that CDBOOST understands

CDBOOST



Bio-Medical

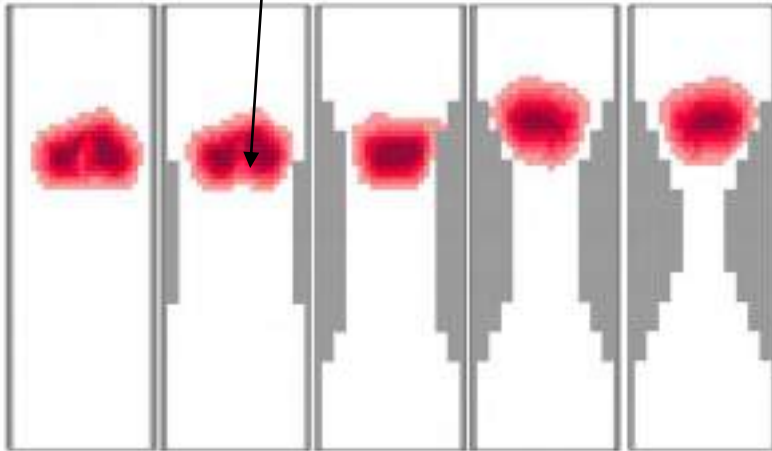


Cancer Models

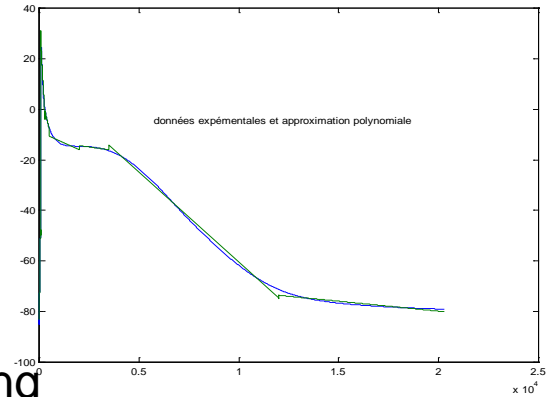
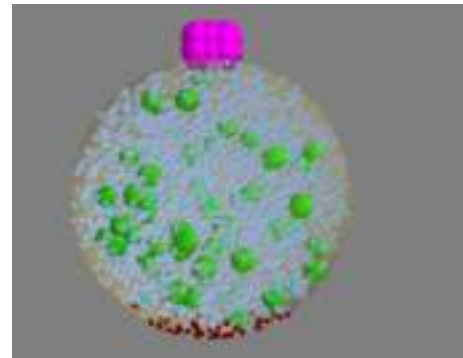


Heart tissue

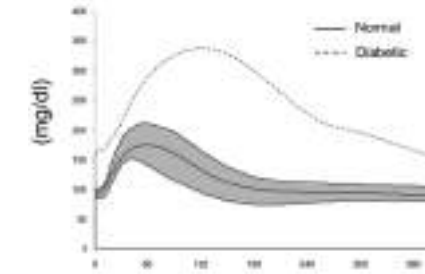
Clogging Arteries (CFD)



Nerve Terminal modeling



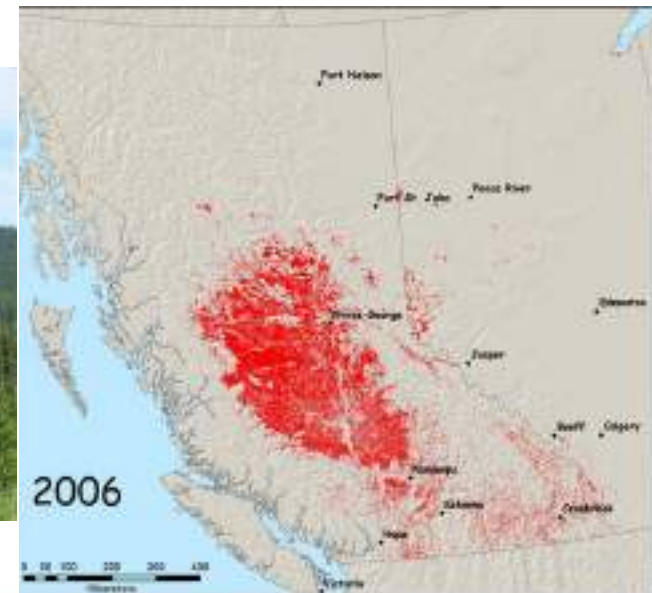
Plasma Glucose



Environmental Modeling



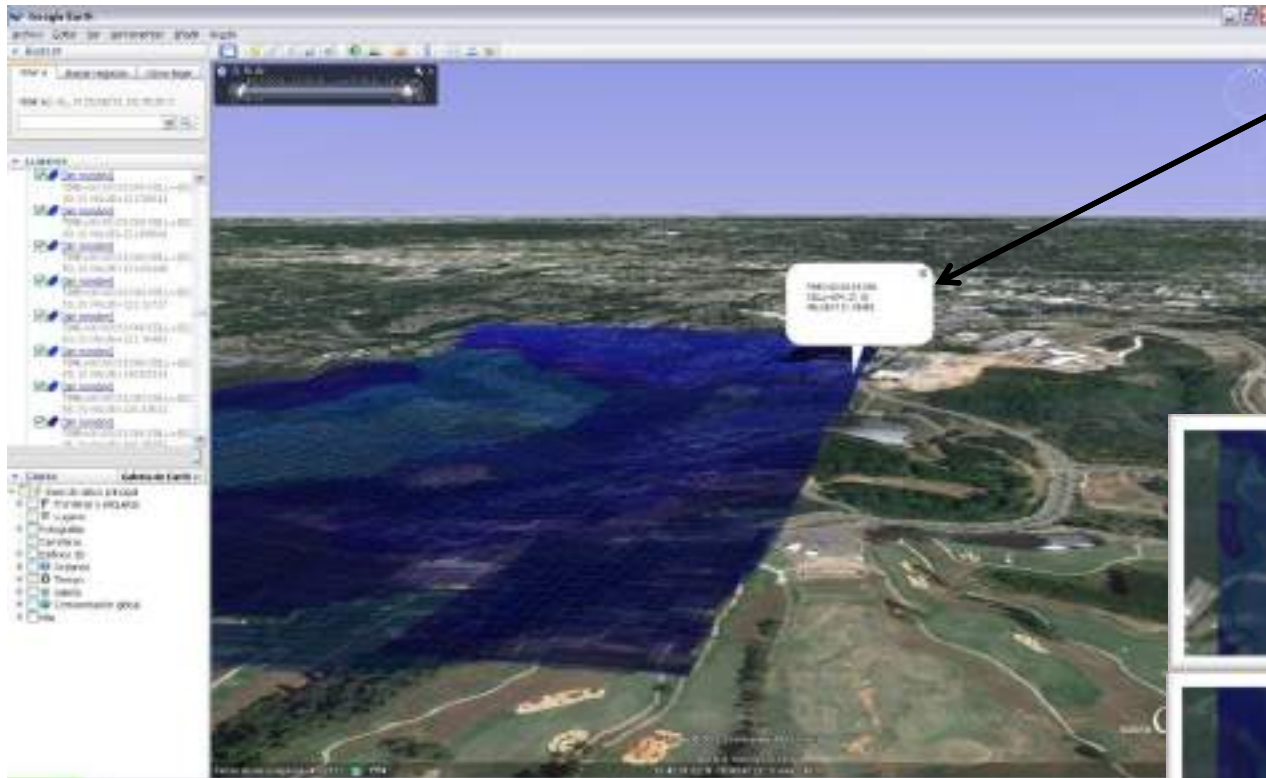
- Epidemics of mountain pine beetles in BC
- Estimation: has killed 283 million m³ of pine trees in BC
- Lodgepole Pine: important commodity
- Canadian Forestry industry issues
 - Cannot compete with growing season of South American countries



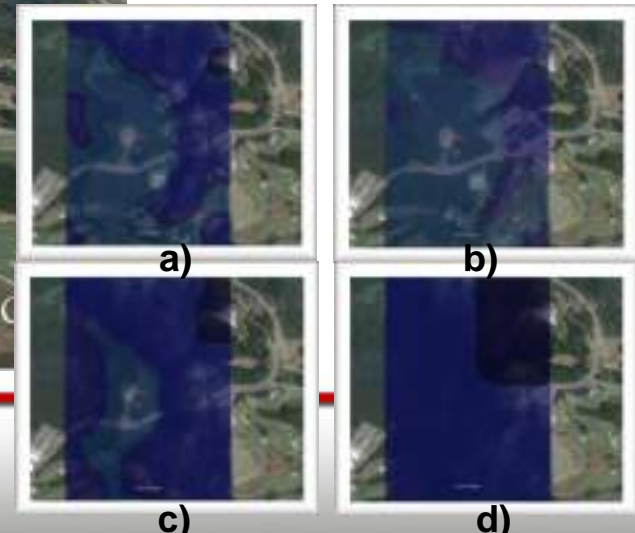
Flood Modeling



- Location-dependent experiments



Granular information available



Forest Fires



- Location-dependent experiments



a)



b)

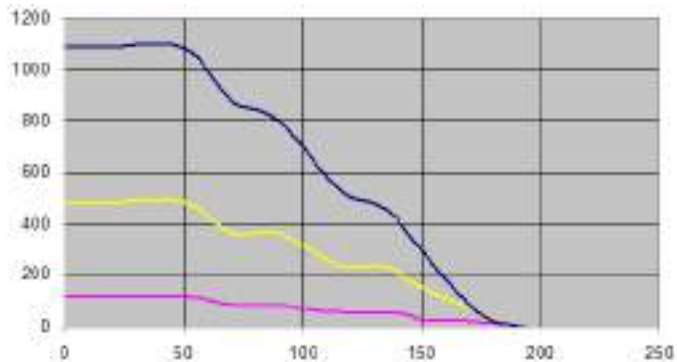


c)

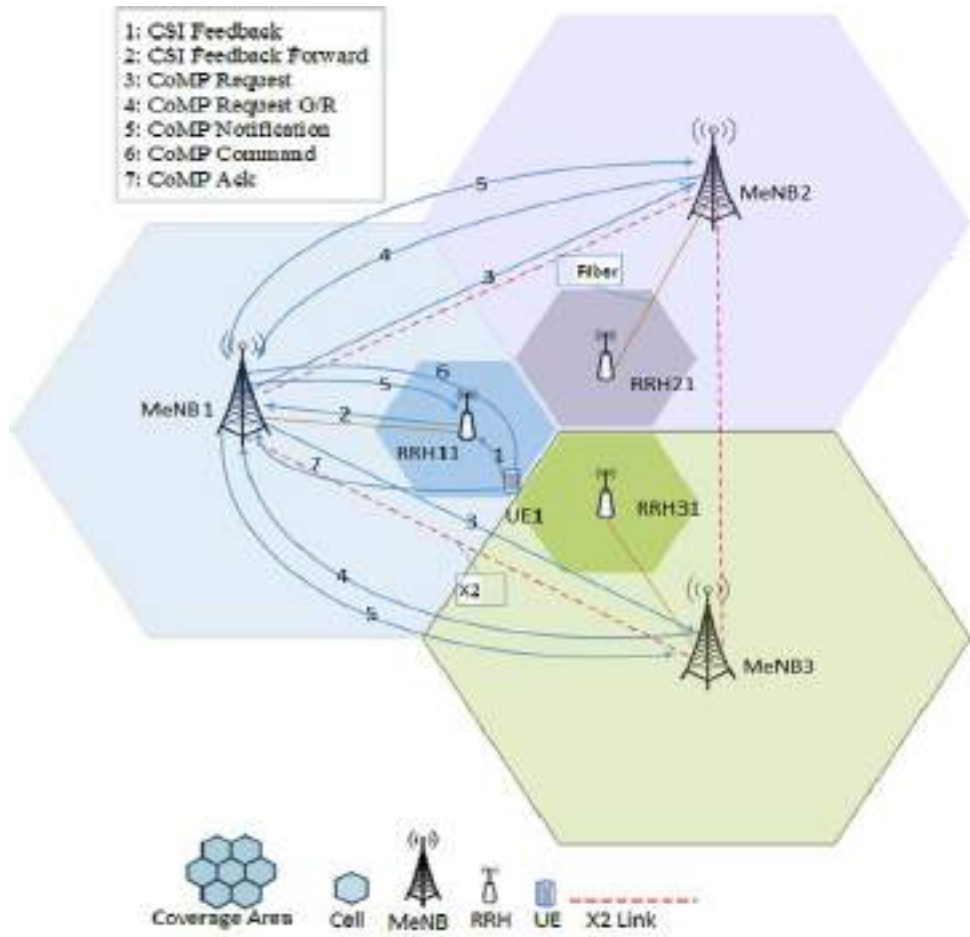


d)

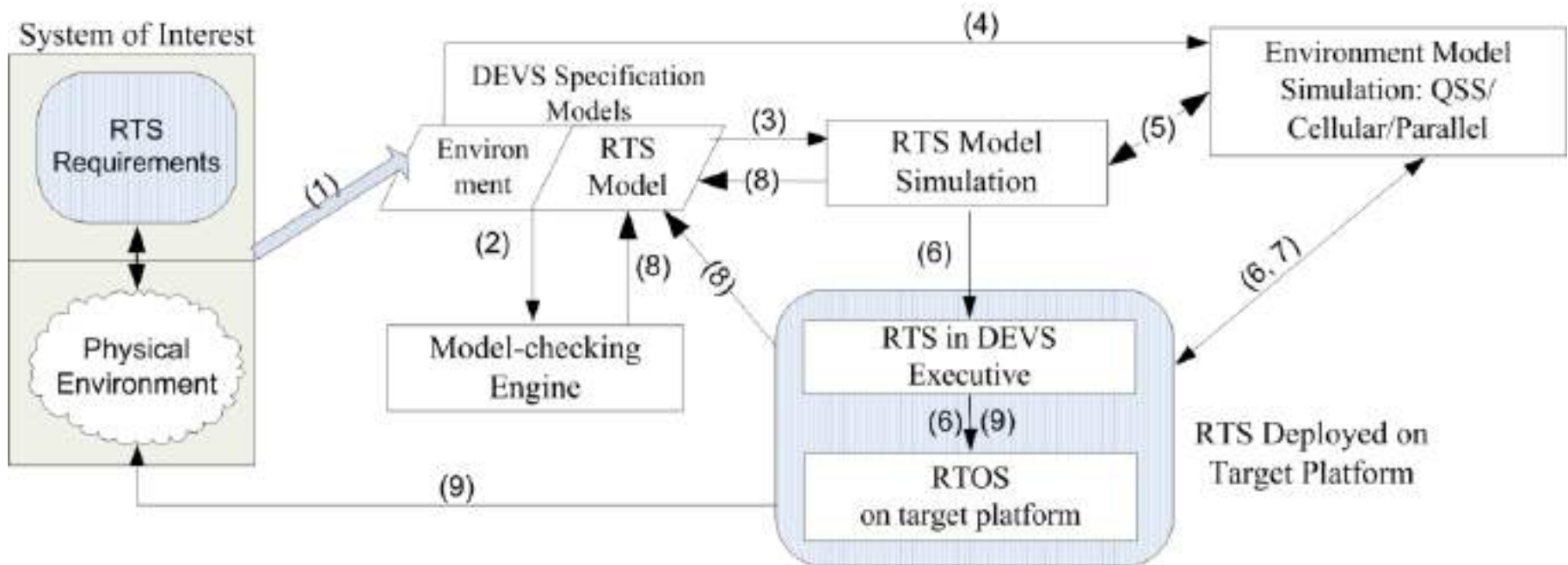
5G Cellular Communications



- 1: CSI Feedback
- 2: CSI Feedback Forward
- 3: CoMP Request
- 4: CoMP Request G/R
- 5: CoMP Notification
- 6: CoMP Command
- 7: CoMP Ack



M&S for Building CPS



Control: Sensing and Actuation



- Models → Processes
- Simulation: cost reduction for development
- Direct execution on a hardware platform



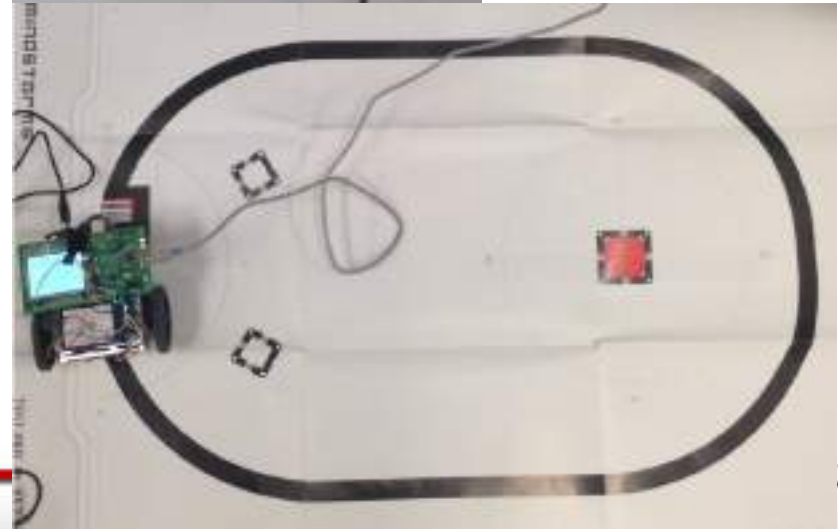
Simulation + Control



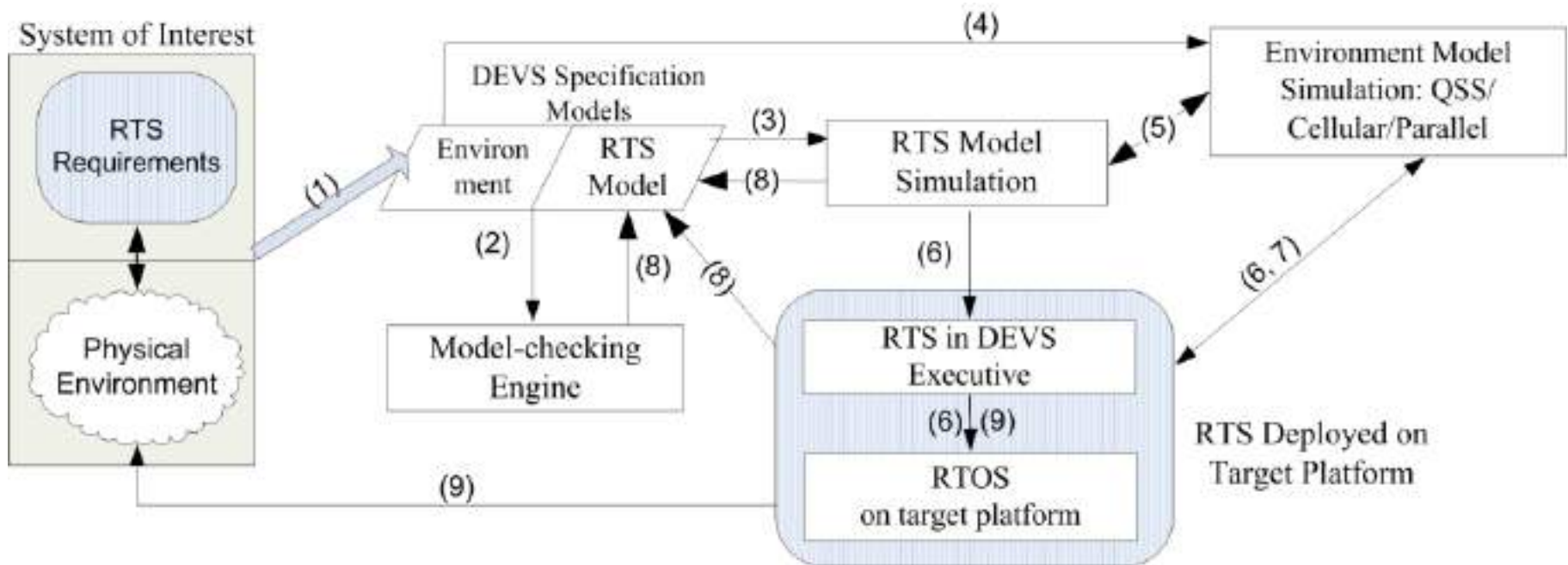
Simulation

```
1. 00:00:01:000:023 START_IN START
2. 00:00:02:000:030 LIGHT_IN DARK
   00:00:02:200:119 mover_out 1
   00:00:02:200:119 movel_out 1
3. 00:00:02:500:021 LIGHT_IN BRIGHT
   00:00:02:600:115 mover_out 0
   00:00:02:600:115 movel_out 0
   00:00:02:700:115 mover_out 1
   00:00:02:700:115 movel_out 2
4. 00:00:02:700:027 START_IN STOP
   00:00:02:700:124 mover_out 0
   00:00:02:700:124 movel_out 0
5. 00:00:03:000:019 LIGHT_IN DARK
6. 00:00:03:500:030 LIGHT_IN BRIGHT
7. 00:00:05:000:027 START_IN START
8. 00:00:05:500:021 LIGHT_IN BRIGHT
   00:00:05:700:115 mover_out 1
   00:00:05:700:115 movel_out 2
9. 00:00:06:000:028 LIGHT_IN BRIGHT
10.00:00:06:500:022 LIGHT_IN DARK
    00:00:06:650:115 mover_out 0
    00:00:06:650:115 movel_out 0
```

In the Real World



M&S for Building CPS



Carleton University

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 Ultra920 SCSI disk
- Myrinet XP PCI-X card
- NVIDIA Quadro4 980 XGL AGP graphics card
- p830 19" flat screen monitor
- Linux operating system

Development System configuration:

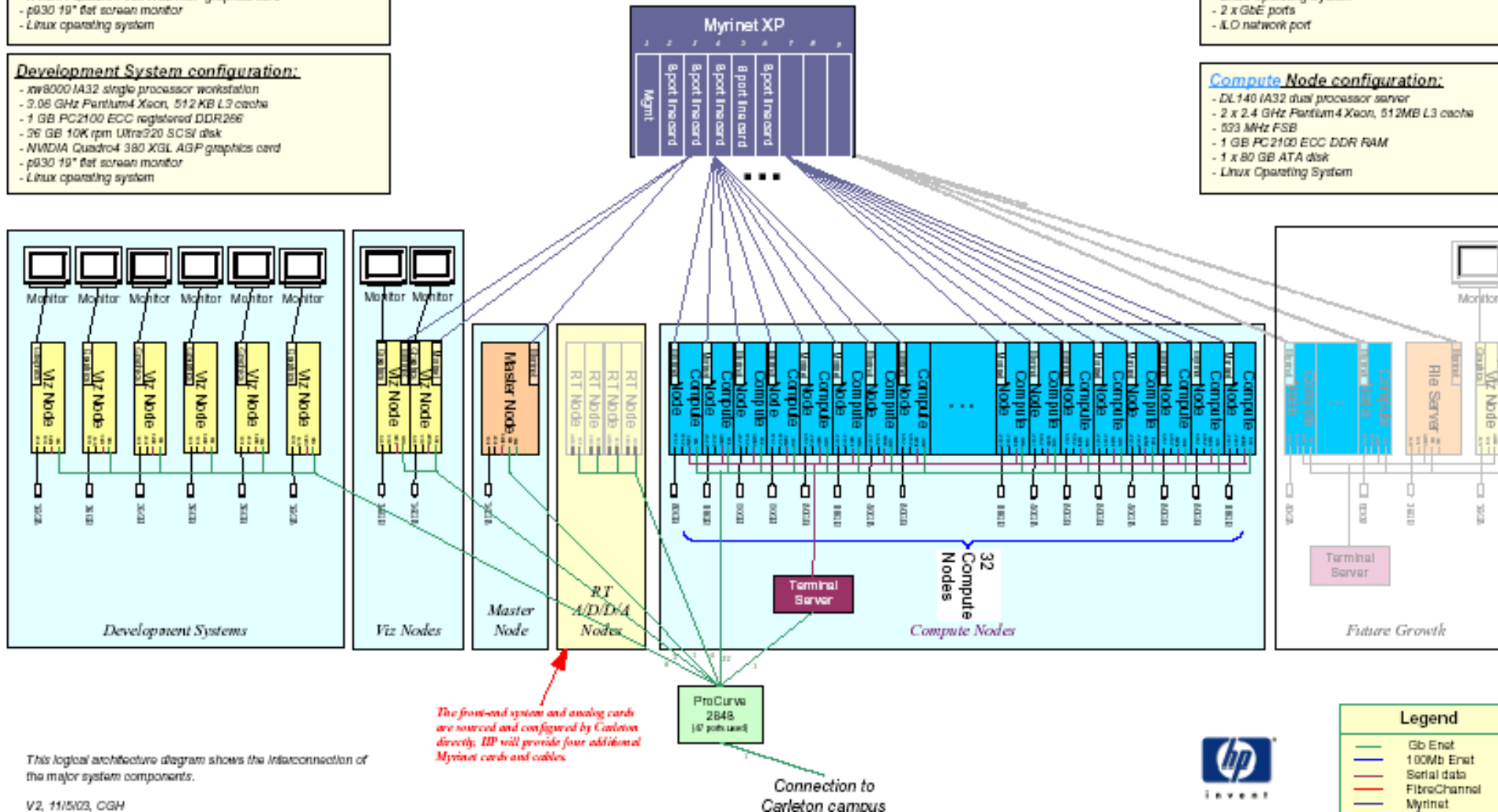
- xw8000 IA32 single processor workstation
- 3.06 GHz Pentium4 Xeon, 512 KB L3 cache
- 1 GB PC2100 ECC registered DDR266
- 36 GB 10K rpm Ultra920 SCSI disk
- NVIDIA Quadro4 380 XGL AGP graphics card
- p830 19" flat screen monitor
- Linux operating system

Master Node configuration:

- DL360-G3 IA32 2P server
- 2 x 3.06GHz Pentium4 Xeon, 512KB L3 cache
- 573 MHz FSB
- 1 GB PC2100 ECC DDR RAM
- 36 GB 10K rpm SCSI disk
- Linux Operating System
- 2 x GbE ports
- I/O network port

Compute Node configuration:

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



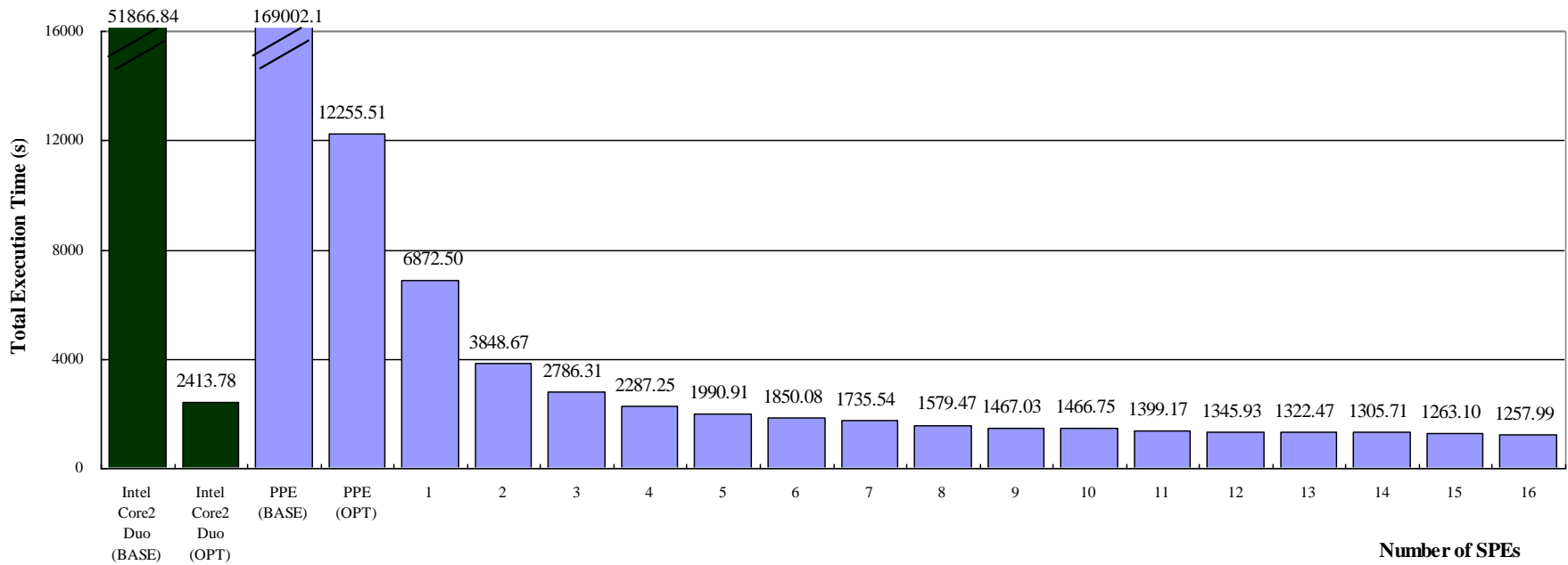
This logical architecture diagram shows the interconnection of the major system components.

Legend

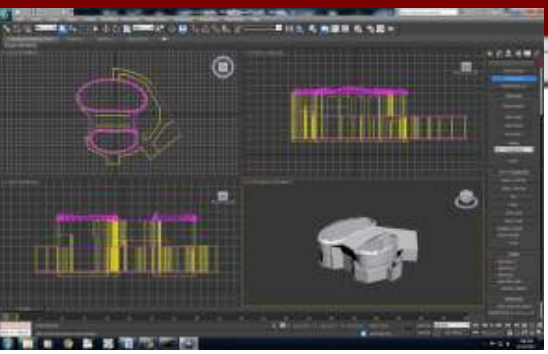
- Gb Enet
- 100Mb Enet
- Serial data
- FibreChannel
- Myrinet



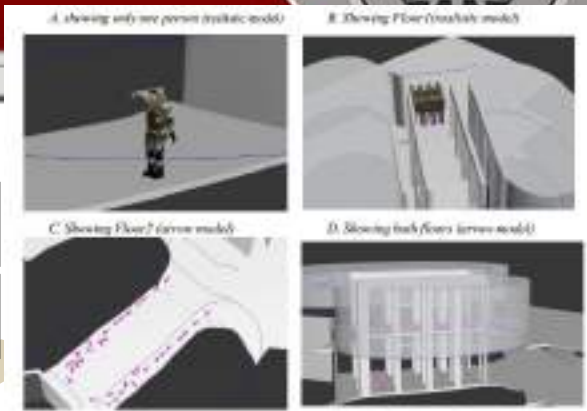
Impact on Overall Execution Time



Collaborative Environment



Rendering/Visualization (CIMS)

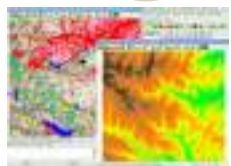


Parallel Simulation

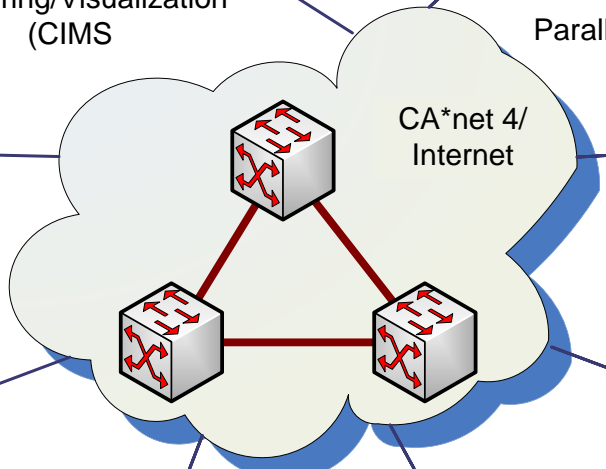
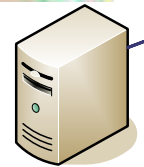
Source Data:



GIS



BIM Software



Stand-alone Simulation



Web service client



External hardware (sensors, networks, robots, etc)

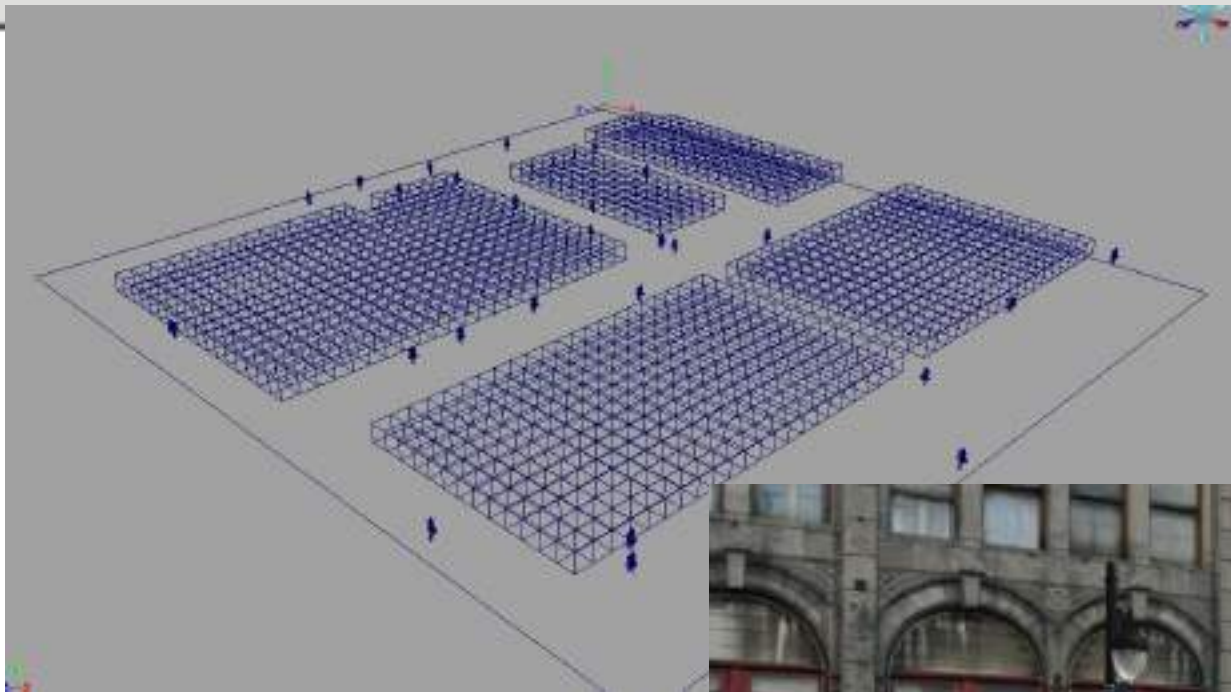
Boulevard St. Laurent (Montréal)



<http://www.cims.carleton.ca/pose>



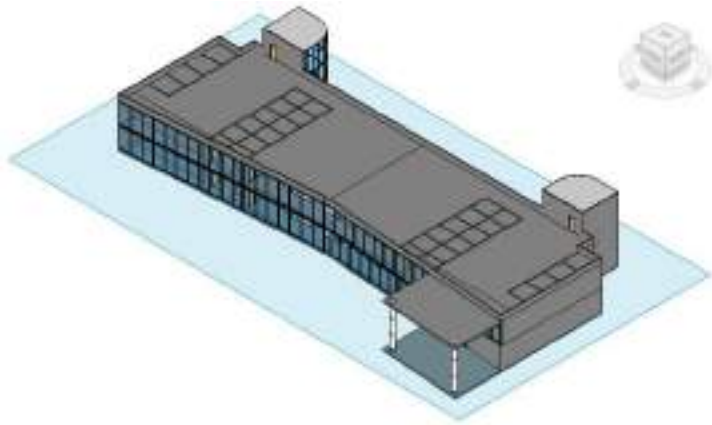
Pedestrians in St. Laurent Blvd.



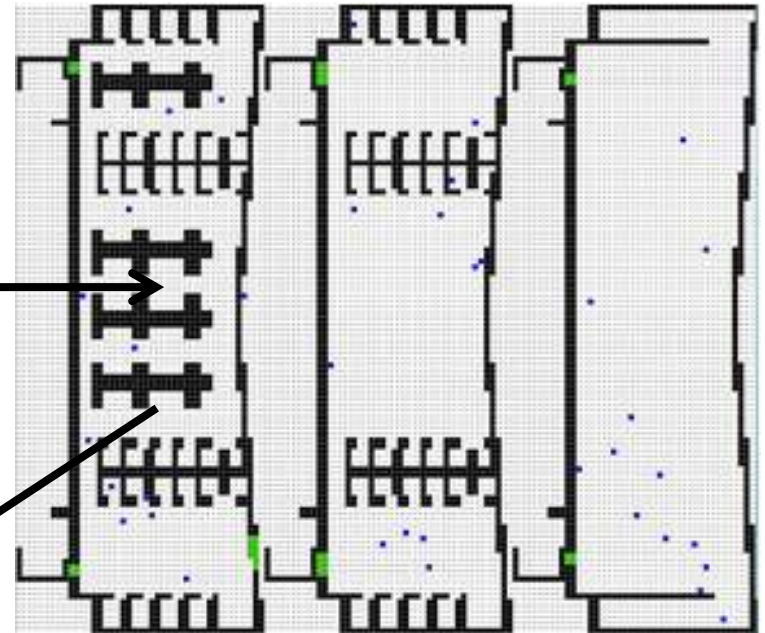
Architecture and Visualization



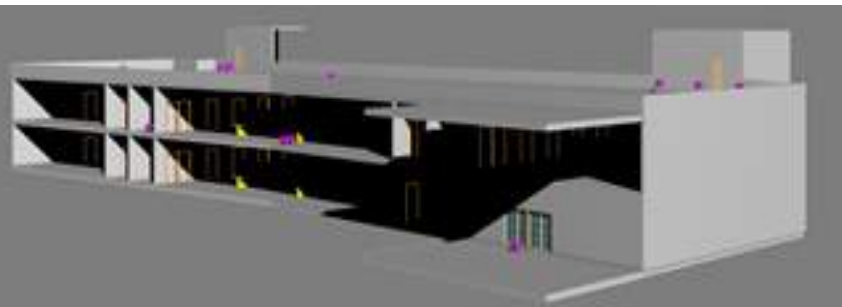
Real Building Floor Plans



Cell-DEVs model

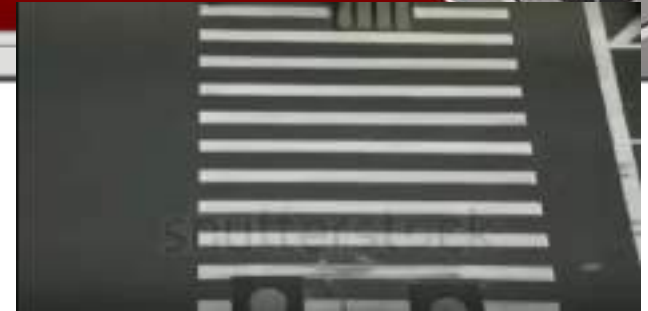


3D Visual Implementation

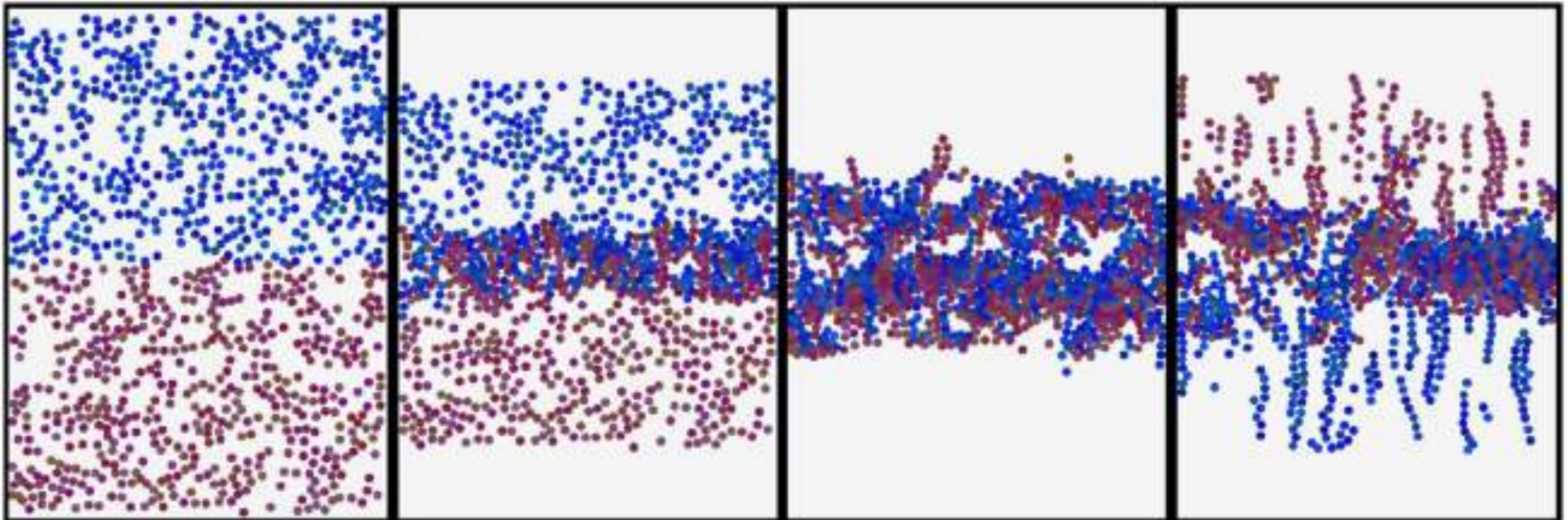




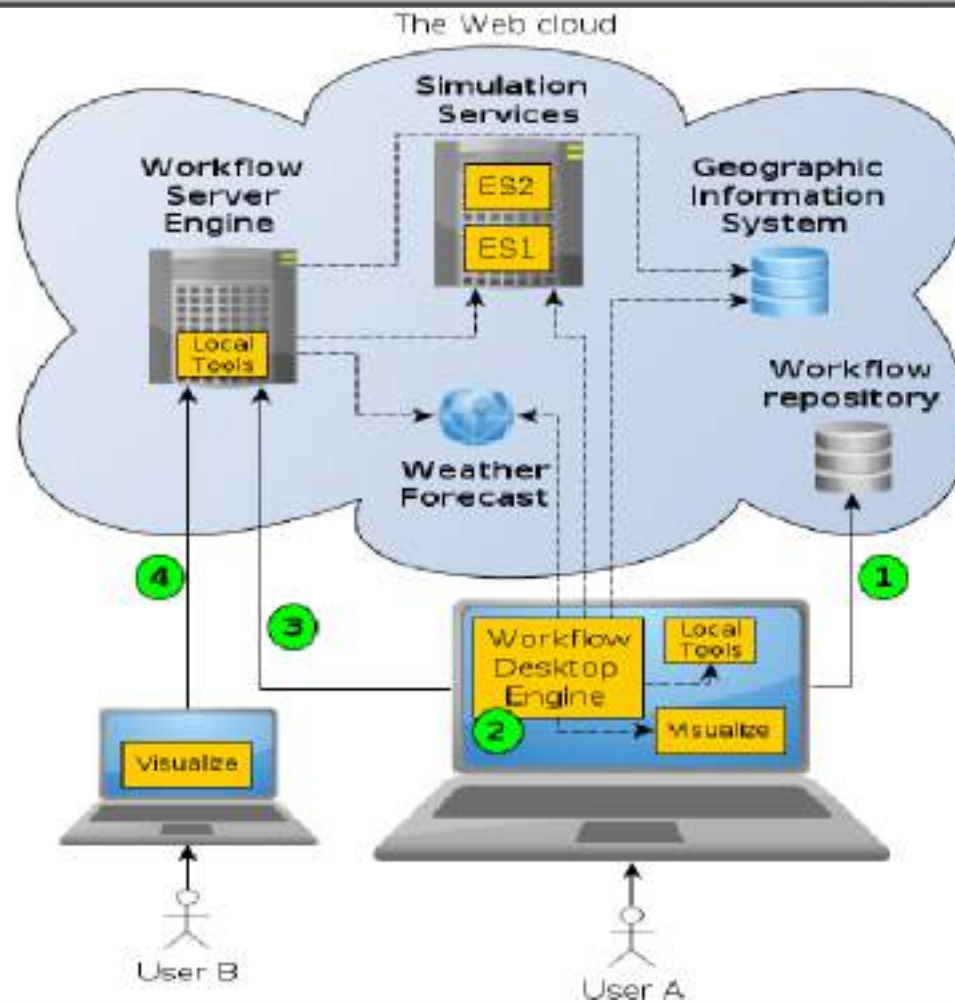
Pedestrian Modeling



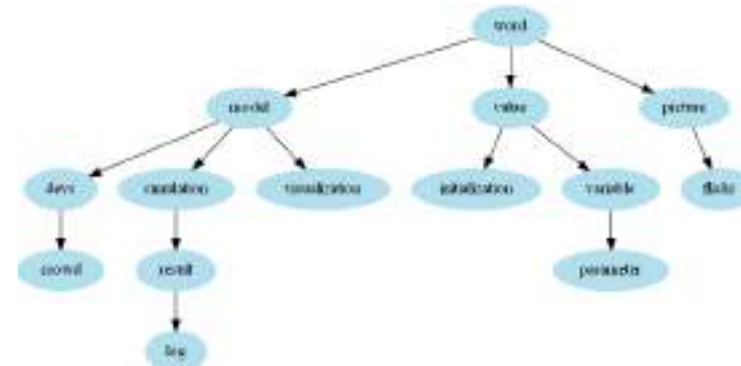
Bi-directional flow



Sharing Models? Reproducibility?



Crowd M&S





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