Past, Present, and Future: Directions on Automating Network Simulation

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The Past

Motivation

It started with tool building - the Simulator for Wireless Ad Hoc Networks (SWAN), created at ISTS Dartmouth College, c. 2001 and continued at Bucknell University between 2003 and 2010.

How do we validate & verify our models?

We could try to replicate experiments in the literature...

Easier said than done.

Analyses

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Steady-State Simulation of Queueing Processes:
A Survey of Problems and Solutions

Krzysztof Pawlikowski
ACM Computing Surveys, 2, 1990, pp. 123–170.

"For years computer-based stochastic simulation has been a commonly used tool in the performance evaluation of various systems. Unfortunately, the results of simulation studies quite often have little credibility, since they are presented without regard to their random nature and the need for proper statistical analysis of simulation output data.

This paper discusses the main factors that can affect the accuracy of stochastic simulations designed to give insight into the steady-state behavior of queuing processes. The problems of correctly starting and stopping such simulation experiments to obtain the required statistical accuracy of the results are addressed."

Conduct, Misconduct and Cargo Cult Science

James R. Wilson
Proceedings of the 1997 Winter Simulation Conference, pp. 1406-1413.

“For example, if you’re doing an experiment, you should report everything that you think might make it invalid—not only what you think is right about it: other causes that could possibly explain your results; and things you thought of that you’ve eliminated by some other experiment, and how they worked—to make sure the other fellow can tell they have been eliminated.”

Richard P. Feynman, “Surely you’re joking, Mr. Feynman!”, 1985.

“In summary, I claim that when individual researchers violate Feynman’s precepts of “utter honesty” and “leaning over backwards,” the cost to the scientific enterprise of policing these individuals rapidly becomes exorbitant.”

On Credibility of Simulation Studies of Communication Networks

Krzysztof Pawlikowski, Hae–Duck Joshua Jeong, and Jong–Suk Ruth Lee
IEEE Communications Magazine, vol. 40, January 2002, pp. 132-139.

Published simulation experiments must report:

- The PRNG(s) used during the simulation.
- The type of simulation (terminating or steady state).
- The method of analysis of simulation output data.
- The final statistical errors associated with the results.

Anecdote 1

"Hi there. What are you working on?"

"Coding models for a new network simulator."

"Why are you wasting your time with that? You know that it won't be able to predict what happens in the real system, anyway."

A Survey of Mobility Models for Ad Hoc Network Research

Tracy Camp, Jeff Boleng, and Vanessa Davies
Wireless Communications & Mobile Computing–Special Issue on Mobile Ad Hoc Networking: Research, Trends and Applications, vol. 2, no. 5, pp. 483–502, 2002.

"We illustrate how the performance results of an ad hoc network protocol drastically change as a result of changing the mobility model simulated."

Do Not Trust All Simulation Studies of Telecommunication Networks

Krzysztof Pawlikowski
International Conference on Information Networking, February 2003.

"This paper is focused on the issue of credibility of the final results obtained from simulation studies of telecommunication networks. Having discussed the basic conditions of credibility, we will show that, unfortunately, one cannot trust the majority of simulation results published in technical literature."

Modeling and Simulation Best Practices for Wireless Ad Hoc Networks

L. Felipe Perrone, Yougu Yuan, and David M. Nicol
Proceedings of the 2003 Winter Simulation Conference, pp. 685-693.

Empirical analysis showed that:

- Details on the composition of the protocol stack have significant importance.
- Transients in random waypoint mobility and network protocol models create a pronounced impact on run length.
- The choice of interference models matters a lot, specially when one scales up the number of nodes.

SOS: Scripts for Organizing 'Speriments (June 2002)

http://ssfnet.org/sos/index.html

"The SOS package was orginally put together to run experiments with SSFNet. Other researchers heard about it and wanted to use it to run experiments and collect data, so we made it more generic to work with any set of experiments performed on the computer (without making it any less useful for the users of SSFNet)."

Authors:
Timothy G. Griffin (AT&T Research)
Srdjan Petrovic, Anna Poplawski, BJ Premore (Dartmouth College)

Anecdote 2

Disaster 1 x 0 Good intentions

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MANET Simulation Studies: The Incredibles

Stuart Kurkowski, Tracy Camp, and Michael Colagrosso
SIGMOBILE Mob. Comput. Commun. Rev., vol. 9, no. 4, pp. 50–61, 2005.

"For our study we focused on the following four areas of credibility in research.

1. Repeatable: A fellow researcher should be able to repeat the results for his/her own satisfaction, future reviews, or further development.

2. Unbiased: The results must not be specific to the scenario used in the experiment.

3. Rigorous: The scenarios and conditions used to test the experiment must truly exercise the aspect of MANETs being studied..

4. Statistically sound: The execution and analysis of the experiment must be based on mathematical principles."

A Few Credibility Issues

Experiments published are not always **reproducible**.

- We often don’t know the version of the simulator used in the experiments. (magic numbers inside code)
- Sometimes we are not told the precise composition of the simulation model.
- We hardly ever know all the attributes for all the model components.

A Few Credibility Issues

Output data is **unavailable** or **unreliable**.

- Papers publish a thin "*slice*" of experimental results.
- Methodology to compute the statistics of output data doesn't conform to best practices.
- Plots don't have units on axes, legends on data series, or include confidence intervals.
- Data often not well organized and persistence may be a pipe dream.

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Anecdote 3

"We are in this mess because of two problems:
(1) People who design protocols and use simulation to evaluate them don't always know much about simulation methodology.

(2) People with expertise in simulation methodology and little knowledge of network protocols write models of network protocols."

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"Der Worte sind genug gewechselt,
Laβt mich auch endlich Taten sehn!"

Faust, Johann Wolfgang von Goethe

"We have enough analyses,
it's time to see deeds."

As translated by Walter Kauffmann

Deeds

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Steady-State Simulation of Queueing Processes:

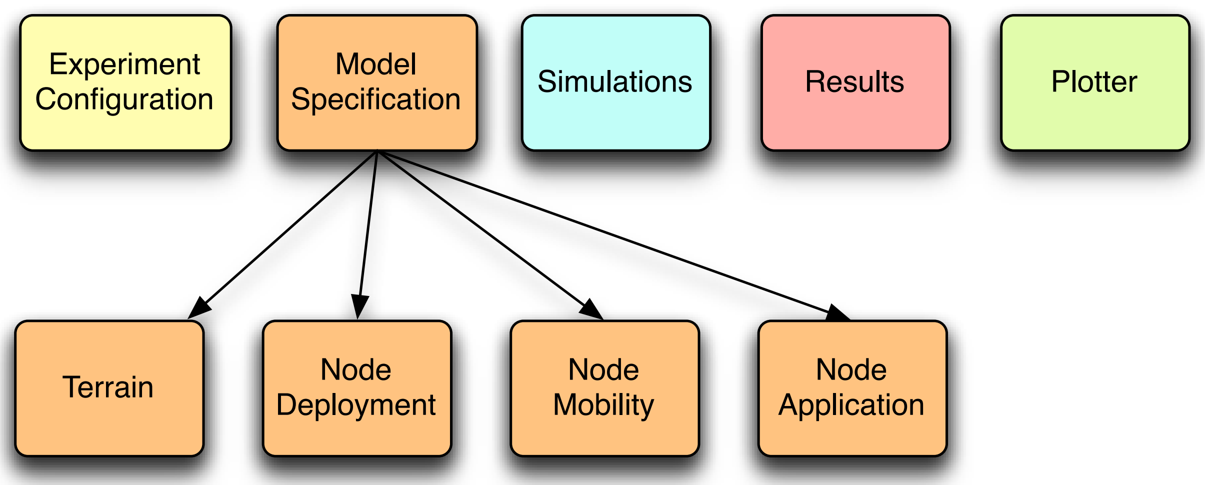
A Survey of Problems and Solutions

Krzysztof Pawlikowski
ACM Computing Surveys, 2, 1990, pp. 123–170.

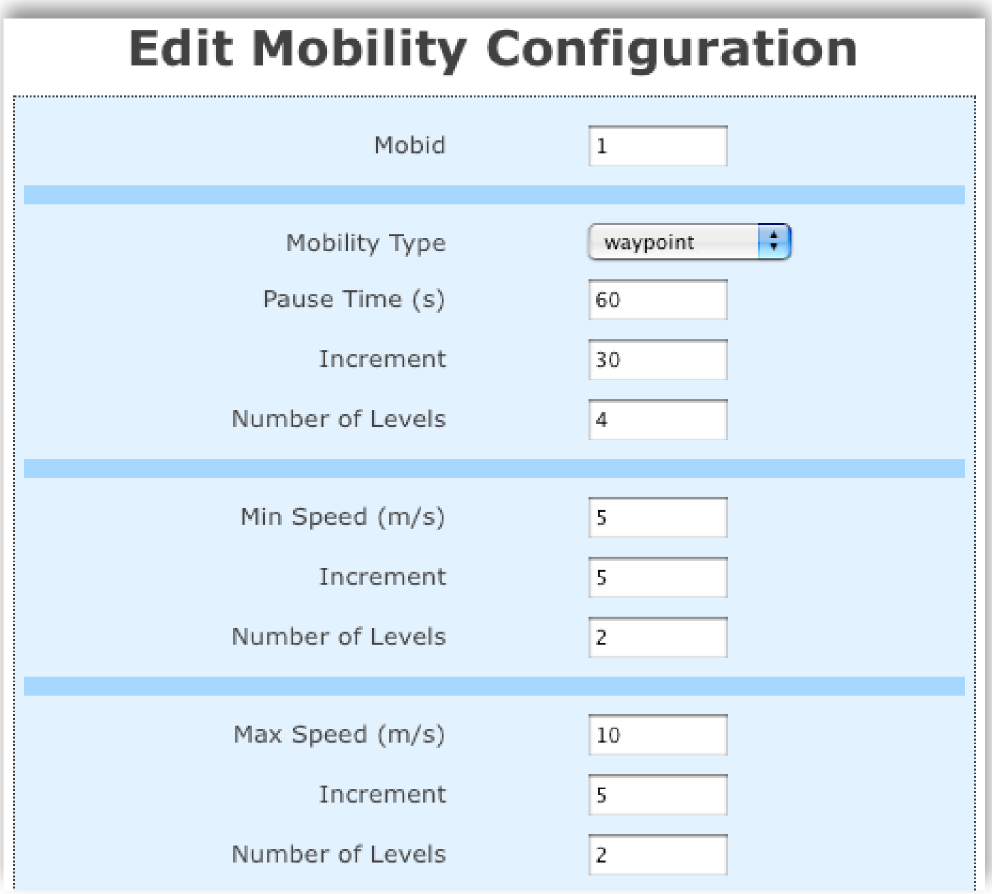
"It is hoped that further developments in the area of expert systems and applied statistics will make it possible to design fully automated, knowledge-based simulation packages."

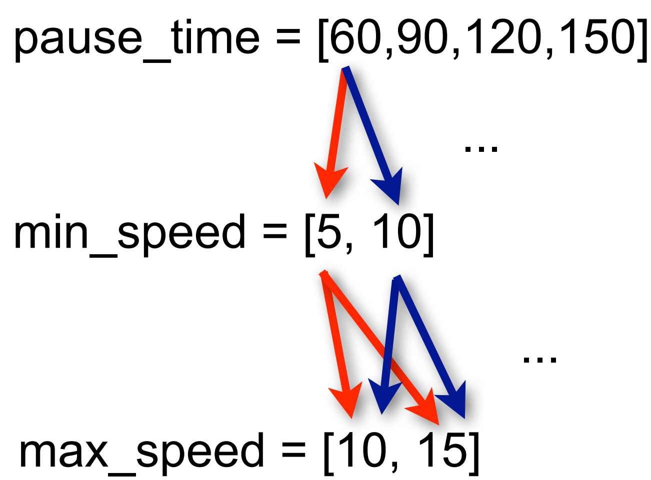
Enhancing the Credibility of Wireless Network Simulations with Experiment Automation

L. Felipe Perrone, Christopher J. Kenna, and Bryan C. Ward
IEEE International Workshop on Selected Topics in Mobile and Wireless Computing 2008.



Experiment Configuration Interface





Model Description & Composition

Radio Propagation Channel

Model: **2-ray ground reflection**

carrier_frequency	2.4 GHz
temperature	290 K
noise_figure	10.0 dB
ambient_noise_factor	0
system_loss	1.0

Wireless Node 1

Model: **Host**

packet size	512
bit rate model	CBR
bit rate	3000 bps
protocol_graph	wireless

Terrain

Model: **Flat**

xdim	5,000 m
ydim	3,000 m
zdim	5.0 m
boundary	wraparound

Mobility

Model: **Random waypoint**

min_speed	5.0 m/s
max_speed	10.0 m/s
pause_time	65 s

Node Deployment

Model: **Random**

Internally, each component is described in a configuration language (DML). Full separation of model configuration and model source code.

How does the user know what components will play nicely together?

There are dependencies and incompatibilities that must be taken into account.

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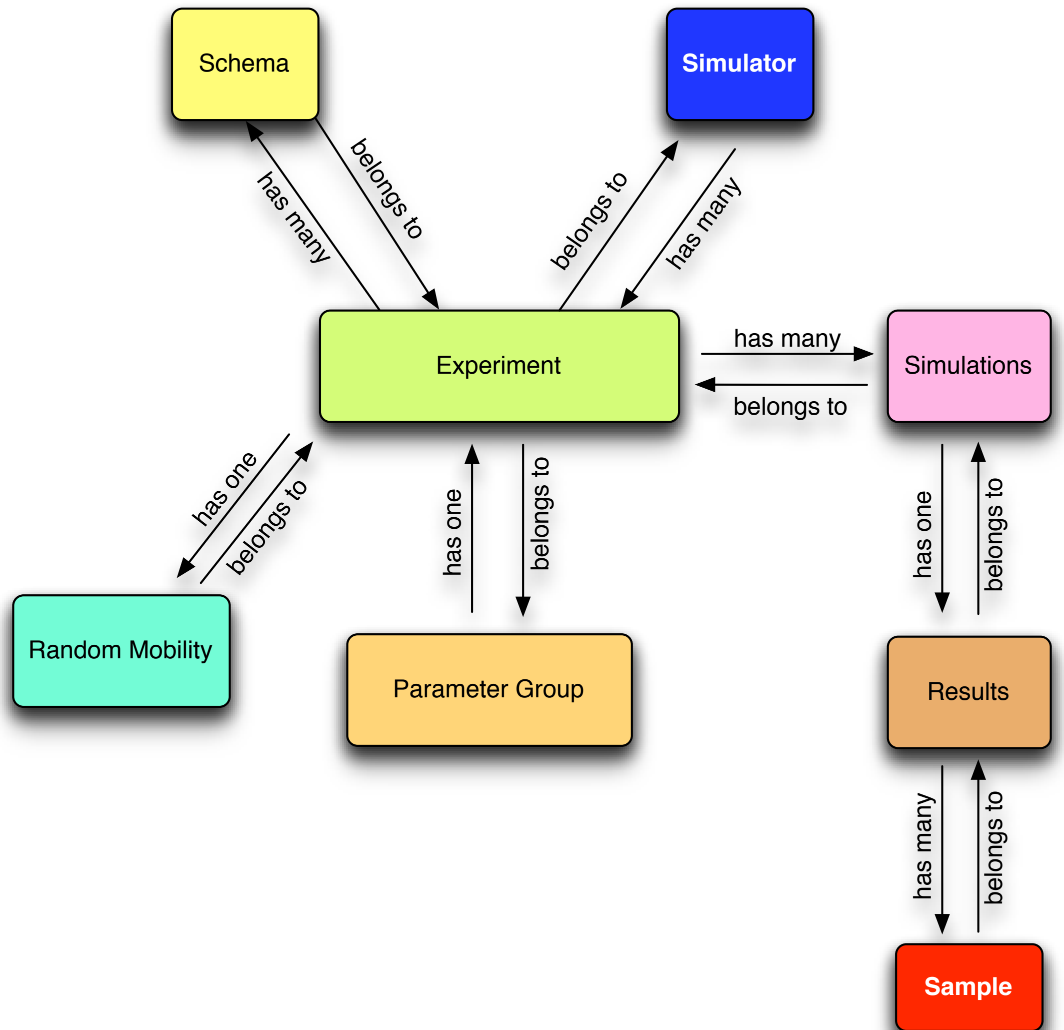
It's About the Database



Self-Documenting System

Make a request and the system returns:

- Simulation source-code (tarball)
- Model attribute settings
- Experiment definition
- Raw output data
- Processed output data
- Plots for use in reports

This simplifies the dissemination of experimental set up.

Multiple Replications in Parallel

- Exploit available systems
- Collect more samples by running more simulations
- All results reported to server process
- Statistics automatically generated
- Results stored on filesystem and in database

On the Automation of Computer Network Simulators

L. Felipe Perrone, Claudio Cicconetti, Giovanni Stea, and Bryan C. Ward.
2nd International Conference on Simulation Tools and Techniques, March 2009.

SWAN Tools is not alone: ns2measure and ANSWER, from the University of Pisa share common features; Akaroa 2, from the University of Canterbury, New Zealand, has much needed complementary features (run length control and steady-state detection).

Since SIMUTools 2009, we've learned of various similar systems developed around the world, some of which were not built for simulation (network testbeds).

The Present

Wish list for a network simulator

- Accuracy
- Detail
- Completeness
- Performance
- Scalability

Wish list for a network simulator

- Accuracy
- De
- nce
- Scalability

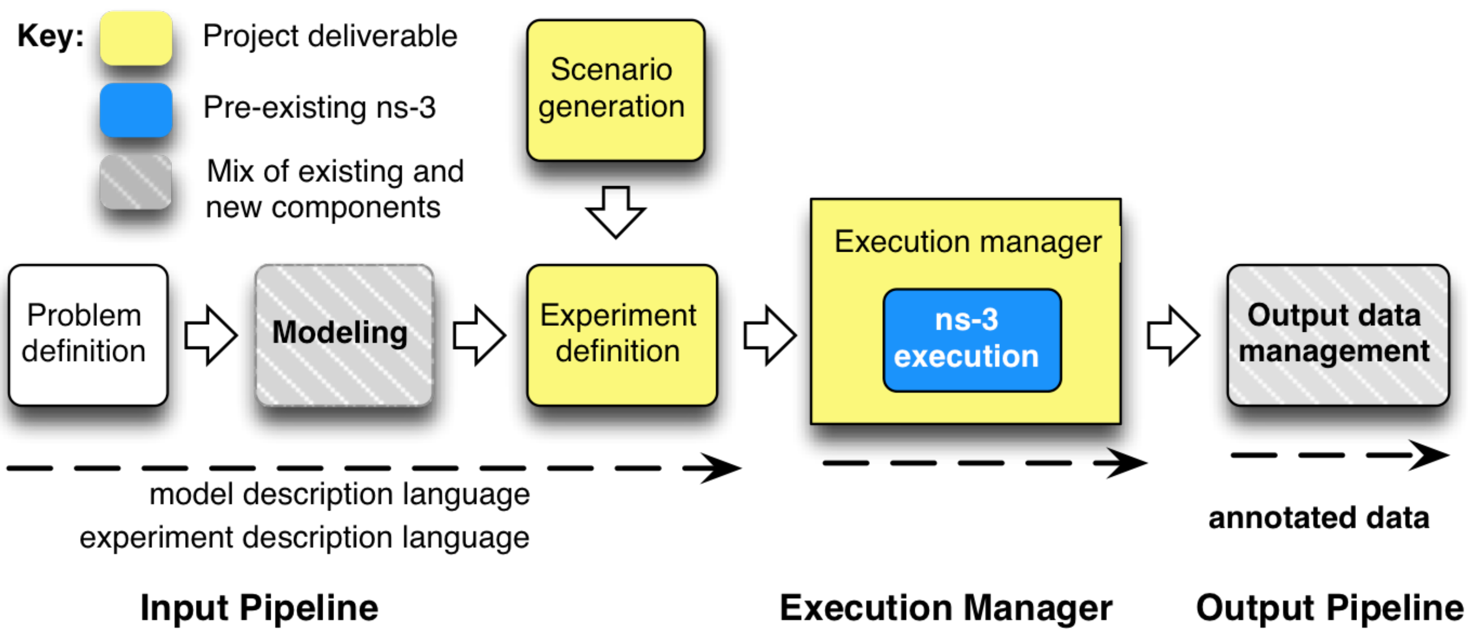
Easy to use

Easy to do science with

Frameworks for ns-3

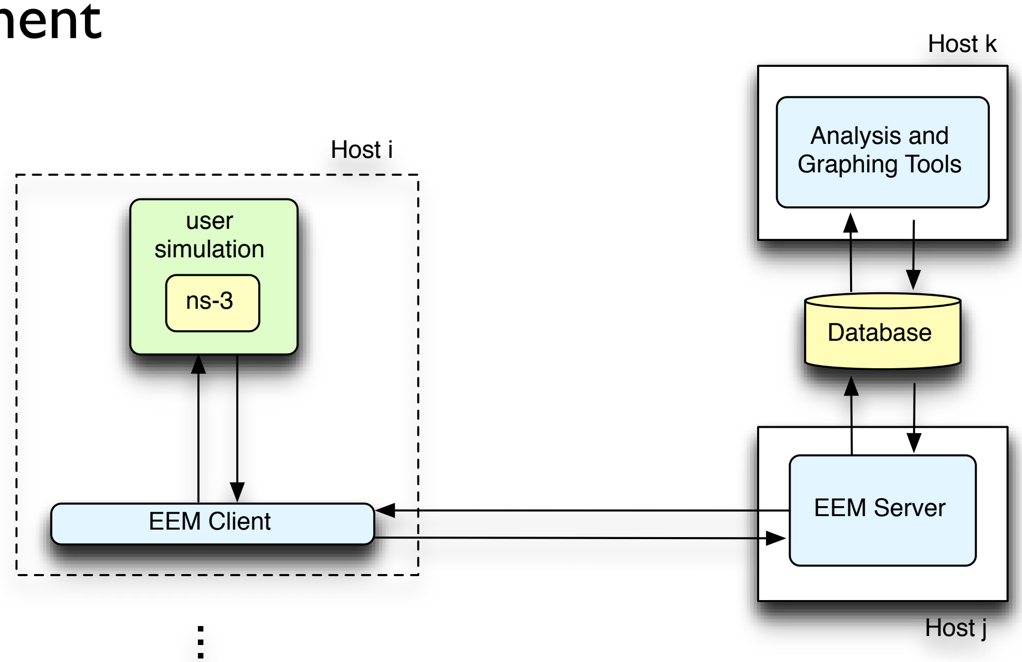
NSF CISE Community Research Infrastructure

- University of Washington (Tom Henderson), Georgia Tech (George Riley), Bucknell Univ. (Felipe Perrone)
- Project timeline: 2010-14



Simulation Automation Framework for Experiments (SAFE)

- Experiment management
- Simulation control
- Output processing
- Model verification
- Code generation

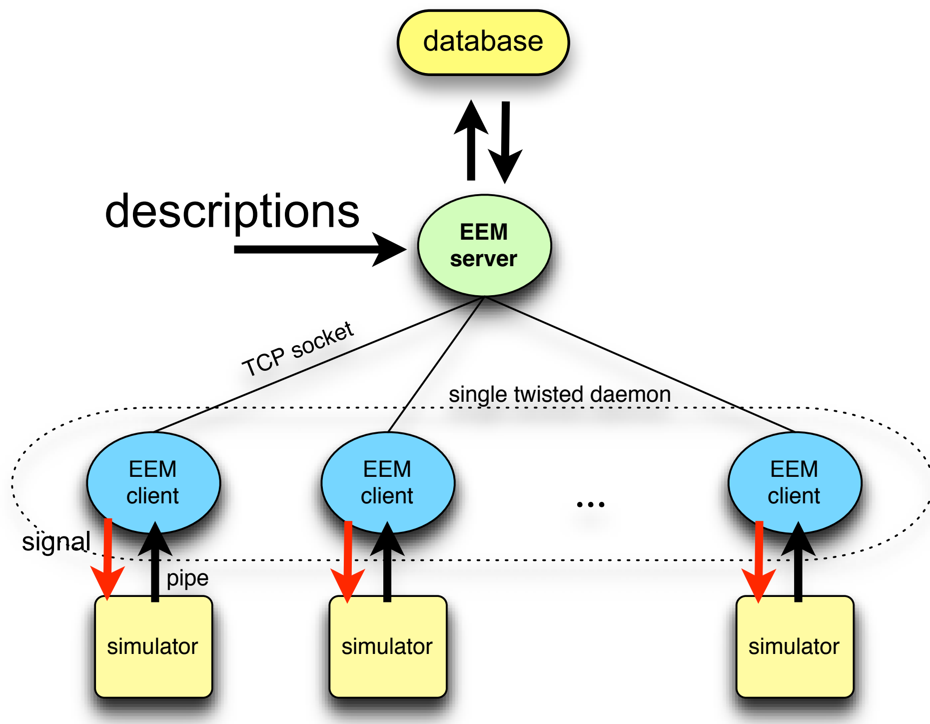


EEM: Steady state + Termination Detection

- Python based
- Built upon Twisted; http://twistedmatrix.com/

- Detects termination based on given criteria

- Detects steady-state in recorded metrics (data deletion)



Language Support

- Experiment Description: specify experiment space in a way that is intuitive, elegant and can enumerate individual design points.

- Model Description: specify model composition in a "non-programming" formalism which allows for automatic verification.

The Future

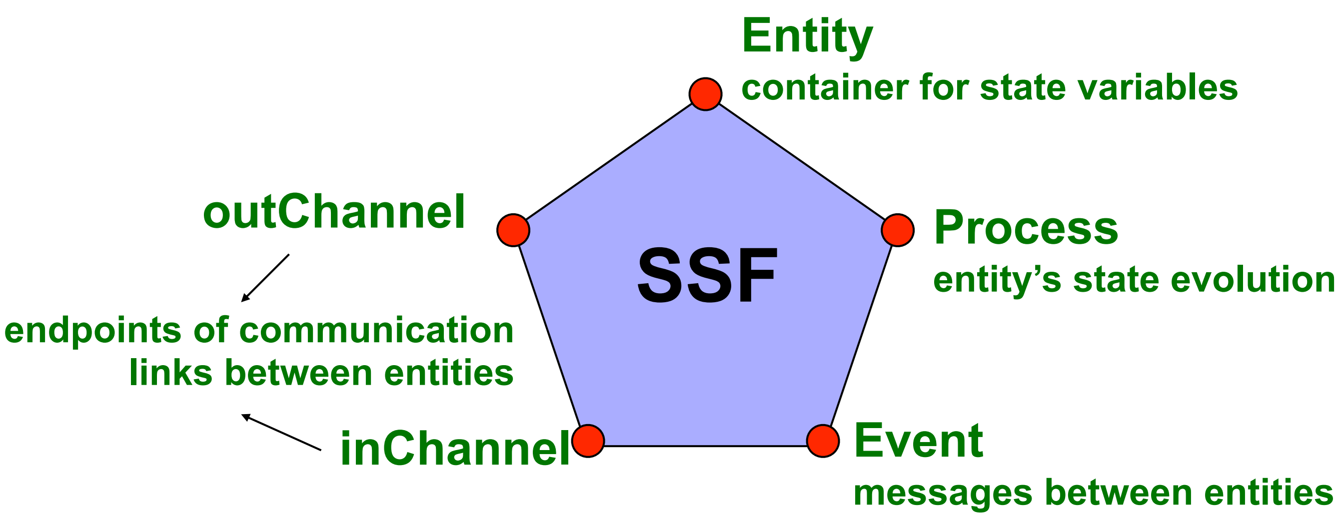
- We need valid, consistent scenarios. This is beginning to get traction (see *SCENES* workshop).
- We need to bring some formal methods back into modeling.
- Try this on Google: "ontology biological simulation". We ought to try this approach with network protocols and simulation scenarios.

Discussion

Additional material

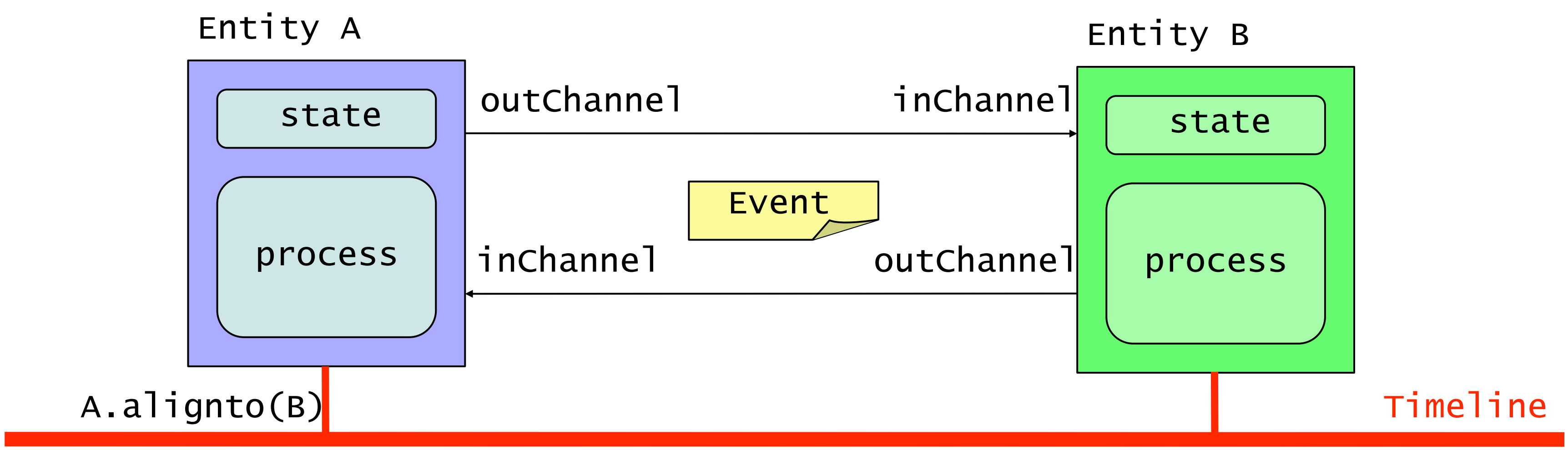
The Scalable Simulation Framework (SSF)

http://www.ssfnet.org



SSF is not a simulator: it's a specification with bindings for Java and C++.

SSF Modeling



Channels have an associated delay which is used by the kernel to determine lookahead for parallel simulation. Channels are mapped to one another.

Obviously large models would be painful to construct with this mechanism alone: enter DML (Domain Modeling Language).

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DML

The model is described by a hierarchical list of key-attribute pairs.

Each key is looked up in a database, a class is fetched, an object is constructed, and the list of attributes is passed to the "config" method of the object.

The model is constructed from the DML specification.

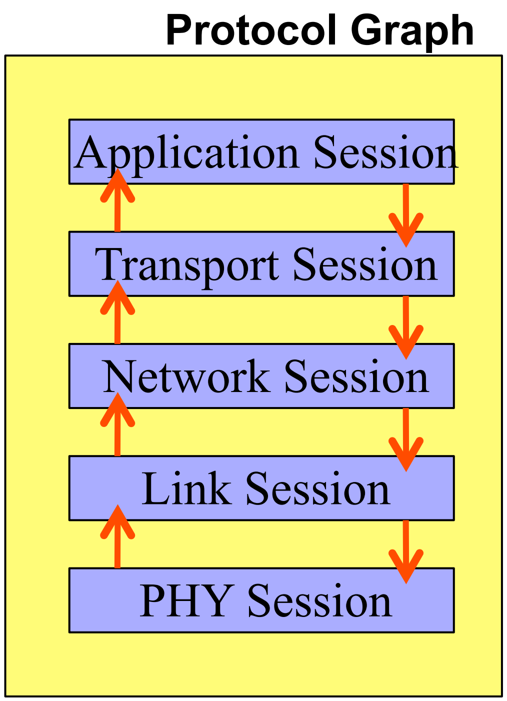
```
WIRELESS_NODE [
  ID 1
  xpos 0
 ypos 0
  battery 1000.0
  graph [
    ProtocolSession [
      name "app" use "app.sensor-session"
      inter_arrival_time 0.002400
      packet_size 100]

    ProtocolSession [
      name "net" use "net.aodv-session"]

    ProtocolSession [
      name "mac" use "mac.mac-802-11-session“]
```

Strengths of the approach

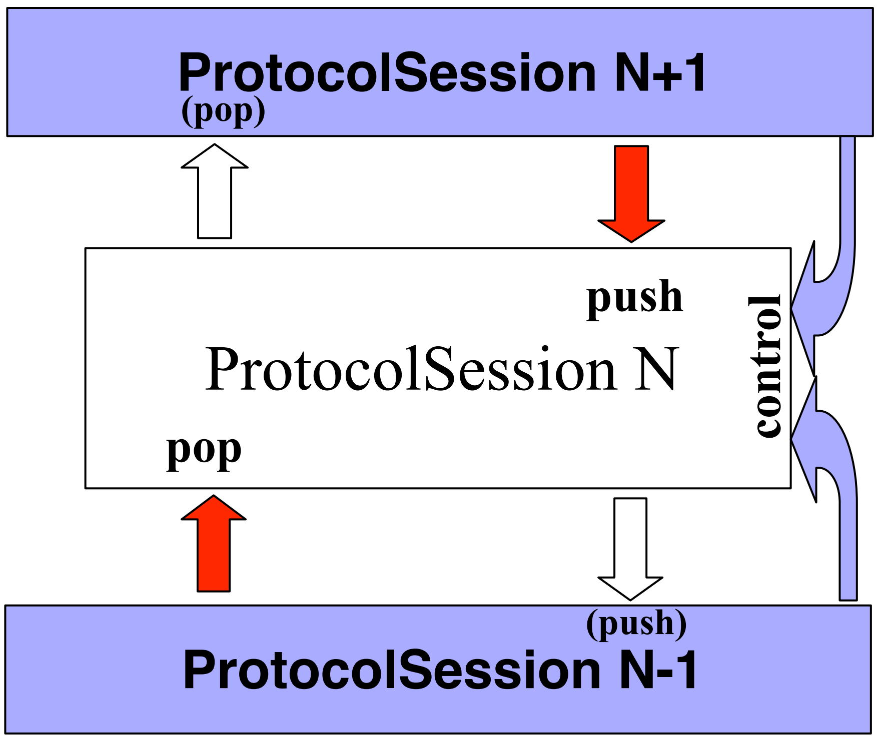
- DML is not a programming language. It allows full separation of model definition and implementation of the simulator.
- One constructs DML models by instantiating classes implemented in the simulator and passes to them levels (values) for their factors (parameters).

SSFNET-like Architecture

- A **ProtocolSession** models a protocol layer (as in the ISO/OSI reference model).
- A **ProtocolGraph** is a list of **ProtocolSessions**; it models the complete protocol stack in a host.
- Adjacent **ProtocolSessions** communicate by exchanging **ProtocolMessages**.



The ProtocolSession API

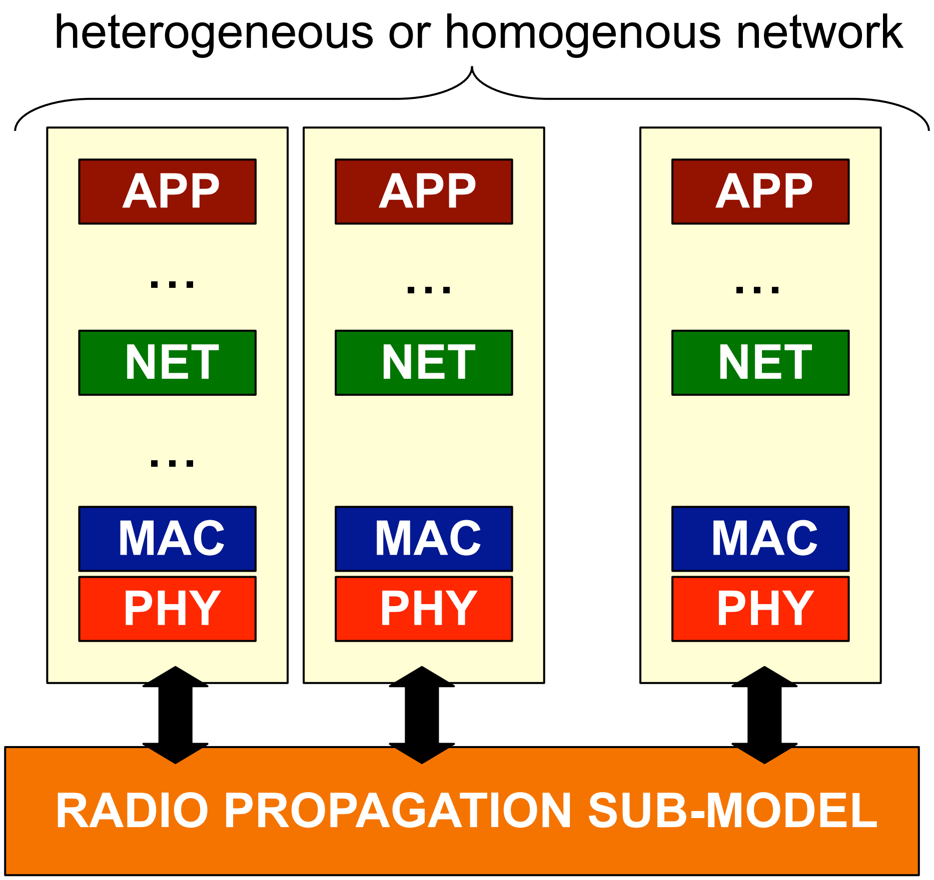


A **ProtocolSession** is a class that defines three methods: **pop**, **push** and **control**.

An element higher in the stack can send it messages invoking **push**. An element lower in the stack can send it messages invoking **pop**.

Anything that is not related to the protocol models is communicated using **control**.

Structure of a Wireless Network Model



Network Node Sub-models

Physical Layer:
radio sensing, bit transmission (SNRT, BER)

MAC Layer:
retransmissions, contention, throughput (IEEE 802.11)

Network Layer:
routing algorithms (AODV, DSR)

Application Layer:
traffic generation or "direct" execution of real application (CBR, VBR)

Strengths of the approach

- It's easy to create new protocol sessions since the API is so simple.
- The process-oriented world view of simulation is a higher-level abstraction: programmers don't think of event lists, but of the natural interactions between SSF processes.

Impact on programmers

The SWAN project was built by really strong software engineers (Jason Liu, Yougu Yuan), but…

- Several **undergraduates** were able to make contributions. The learning curve was easy on them.
- Adding a protocol model is localized operation. You just keep up with interface specs.