Parallel and Distributed Simulation Systems

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Outline

- Intelligent Transportation Systems
  - Interoperable Distributed Simulations
  - Data and Field Experiments
- Large-Scale Simulation of Communication Networks
  - Parallel Simulation on Clusters and Supercomputers
  - Client/Server Architecture and On-Line Simulation
- Earth Magnetosphere Simulation
  - Discrete Event Simulation Approach
  - Parallel Simulation Using Reverse Computation
- Underlying Themes
  - Interdisciplinary Research
  - Parallel and Distributed Simulation Systems

Intelligent Transportation Systems Research

Richard Fujimoto Karsten Schwan	Computing
Randall Guensler Michael Hunter, John Leonard	Civil & Environmental Engineering
Chris Paredis	Mechanical Engineering

Georgia Institute of Technology

Intelligent Transportation Systems

www.lewrockwell.com/

- **Safety**: 40,000 fatalities in 6 million crashes per year in U.S. alone[1]
  - $150 billion in economic loss
- **Congestion**: Delays cost $69.5 billion per year in 75 urban areas in the U.S. in 2001[1]
  - 3.5 Billion hours delay, 5.7 Billion gallons of fuel
- **Environment**: Major source of air pollution
  - > 50% hazardous air pollutants in U.S.[2]
  - Up to 90% of the carbon monoxide in urban air[2]

[1] The 2003 Annual Urban Mobility Report (http://mobility.tamu.edu)
[2] Texas Natural Resource Conservation Commission (http://www.tnrcc.state.tx.us/air)

ITS Today

- Largely centralized, disseminate travel information, emergency vehicles
- Infrastructure heavy
  - Expensive to deploy and maintain
  - Limited information of individual travelers
  - Limited ability to customize services for individual travelers

www.georgia-navigator.com

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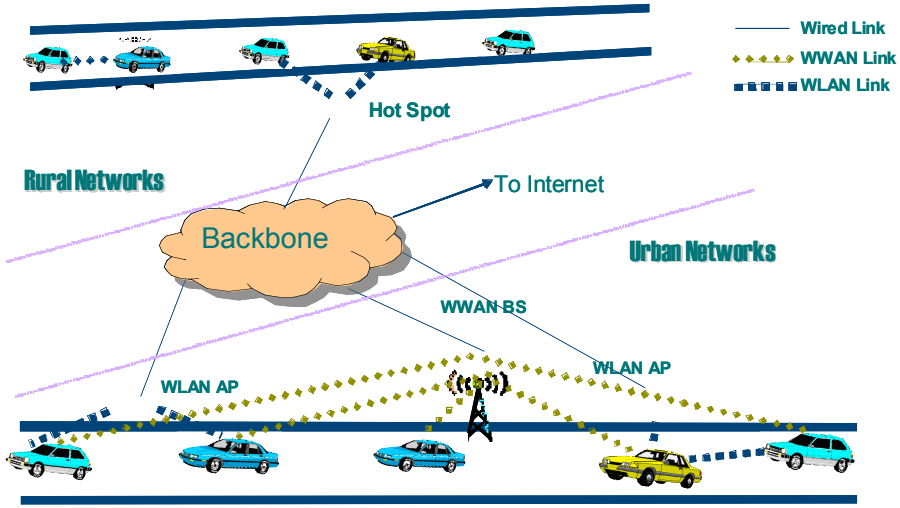
Future

- Emerging Technologies
  - Sophisticated in-vehicle computing
  - Hi-speed wireless communications
- Vision: sophisticated distributed computing systems on the road
  - Improved Safety
  - Transportation system mgt.
  - Commercial services



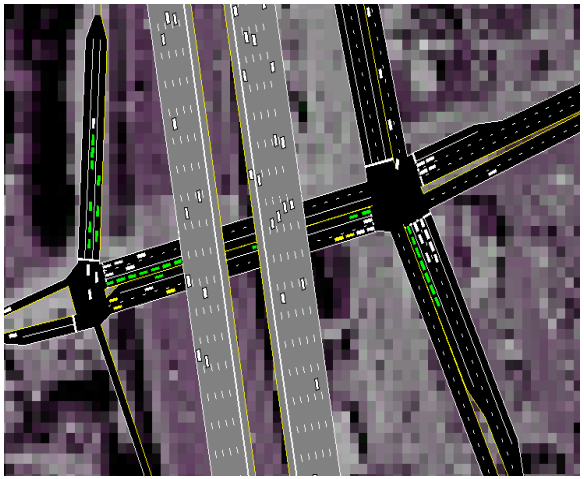
Current Research

- Develop technologies and tools to integrate disparate simulators
  - Interoperable transportation and communication network simulations
  - Efficient distributed execution on cluster computers, LAN, WAN
  - Run Time Infrastructure (backplane) software
  - Semantic technologies (Paredis)
- Develop, populate, and calibrate simulations with models and data on traffic in the Atlanta metropolitan area (Guensler, Hunter)
  - State and local government partners
  - Vehicle monitoring project
- Apply tools to develop and evaluate communication architectures and algorithms for transportation system
  - V2V data dissemination algorithms, models for data propagation
  - Communication architectures: WWAN (e.g., cellular), WLAN (802.11), V2V
- In-vehicle computer systems
  - Virtualization technologies (Schwan)
- Demonstrate feasibility through prototypes, field experiments

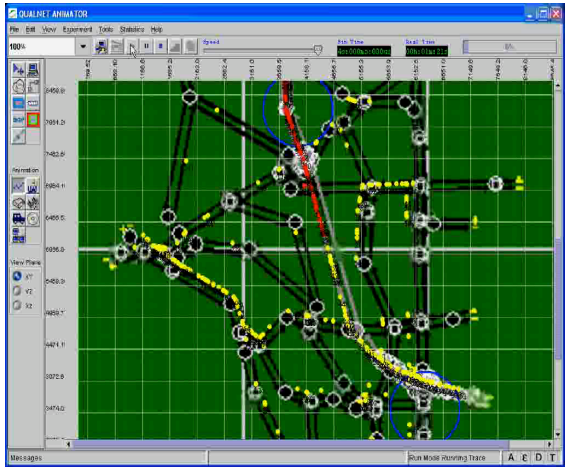
Integrated Distributed Simulations

- Microscopic traffic simulation
- Vehicle-to-vehicle and vehicle-to-infrastructure wireless communication
- Validation
- Distributed simulation over wide area networks
- Distributed simulation over grid/web services

CORSIM



QualNet



Traffic Simulator

Comm. Simulator

Run Time Infrastructure Software

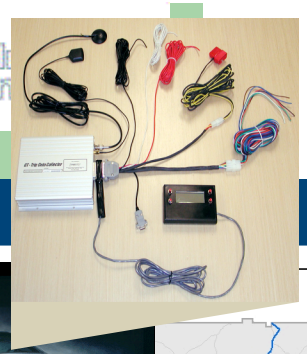
Federation management

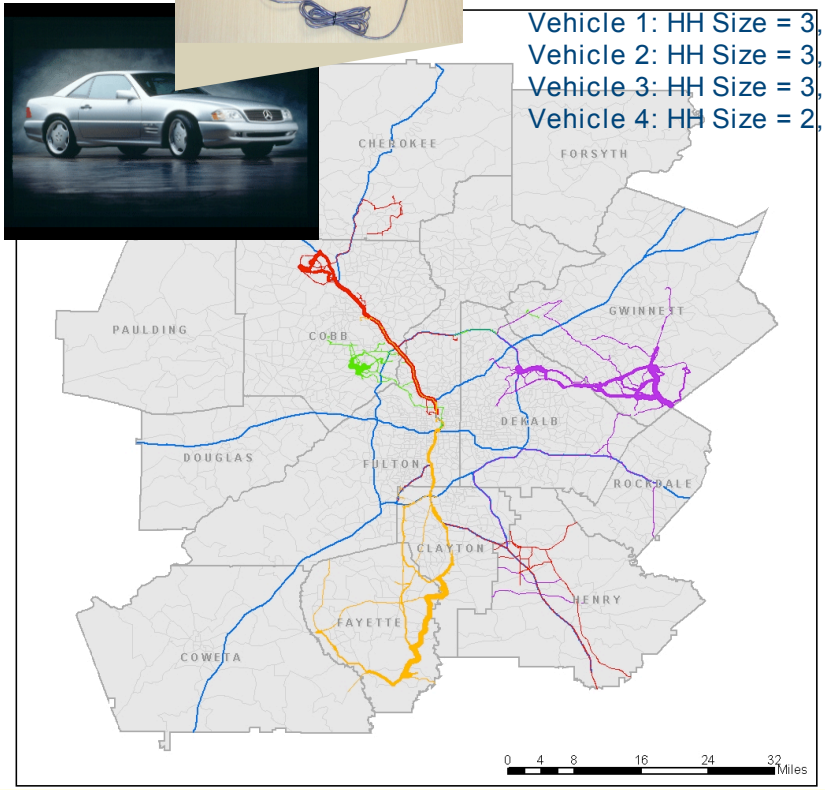
Pub/Sub Communication

Synchronization (Time Management)

LAN/Internet

Transportation System Data (Guensler, Hunter)





In-vehicle computers/sensors deployed in 500 vehicles in Atlanta area (FHWA funded)

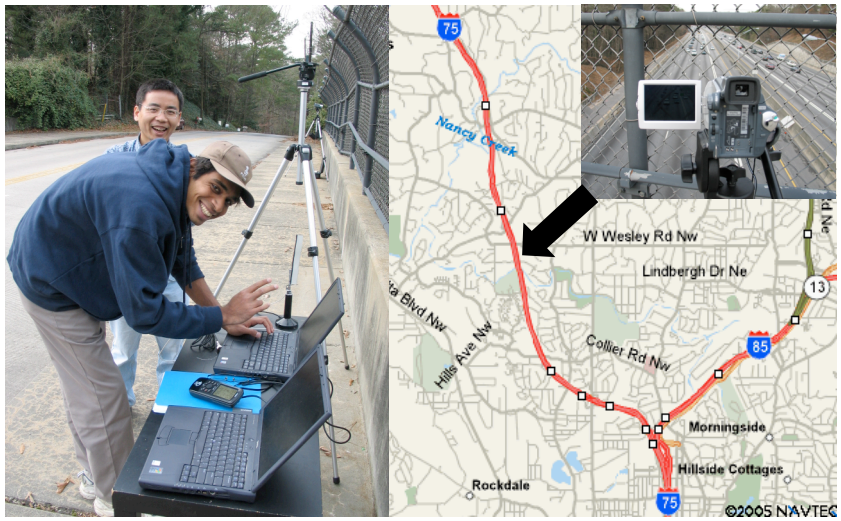
Data Collection: Second-by-second vehicle activity

- Position, speed, acceleration
- Engine operating parameters

Other Federal, State, Local Government Data Sharing

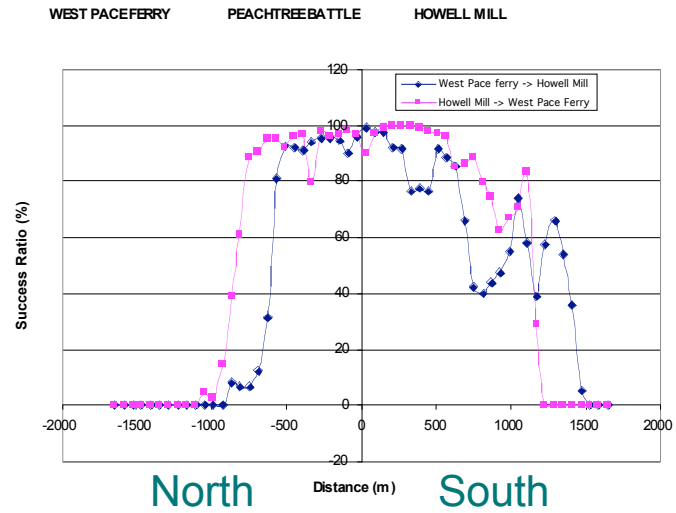
- City of Atlanta, Cobb County: Signal timing data
- Georgia Department of Transportation (GDOT) and Georgia Road and Tollway Authority: Traffic volume data
- Georgia Regional Transportation Authority: Traffic impact study data

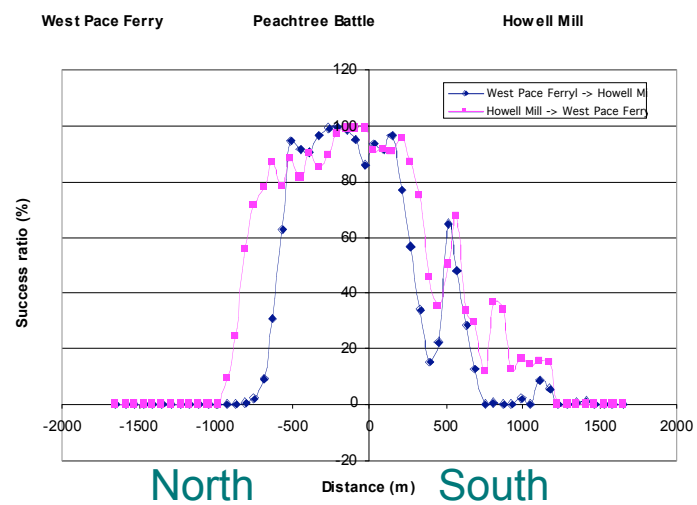
Field Measurements



- Fixed-position base station mounted on I-75 overpass
- In-vehicle computer traveling at freeway speeds
- Measure wireless communication performance (802.11b)
- Reliable communication of at least 250 meters, typically much more
- Physical obstructions degrade communication significantly

Base station on south side of bridge





Base station on north side of bridge

Parallel Simulation of Large-Scale Communication Networks

Mostafa Ammar
Steve Ferenci
Richard Fujimoto
Kalyan Perumalla

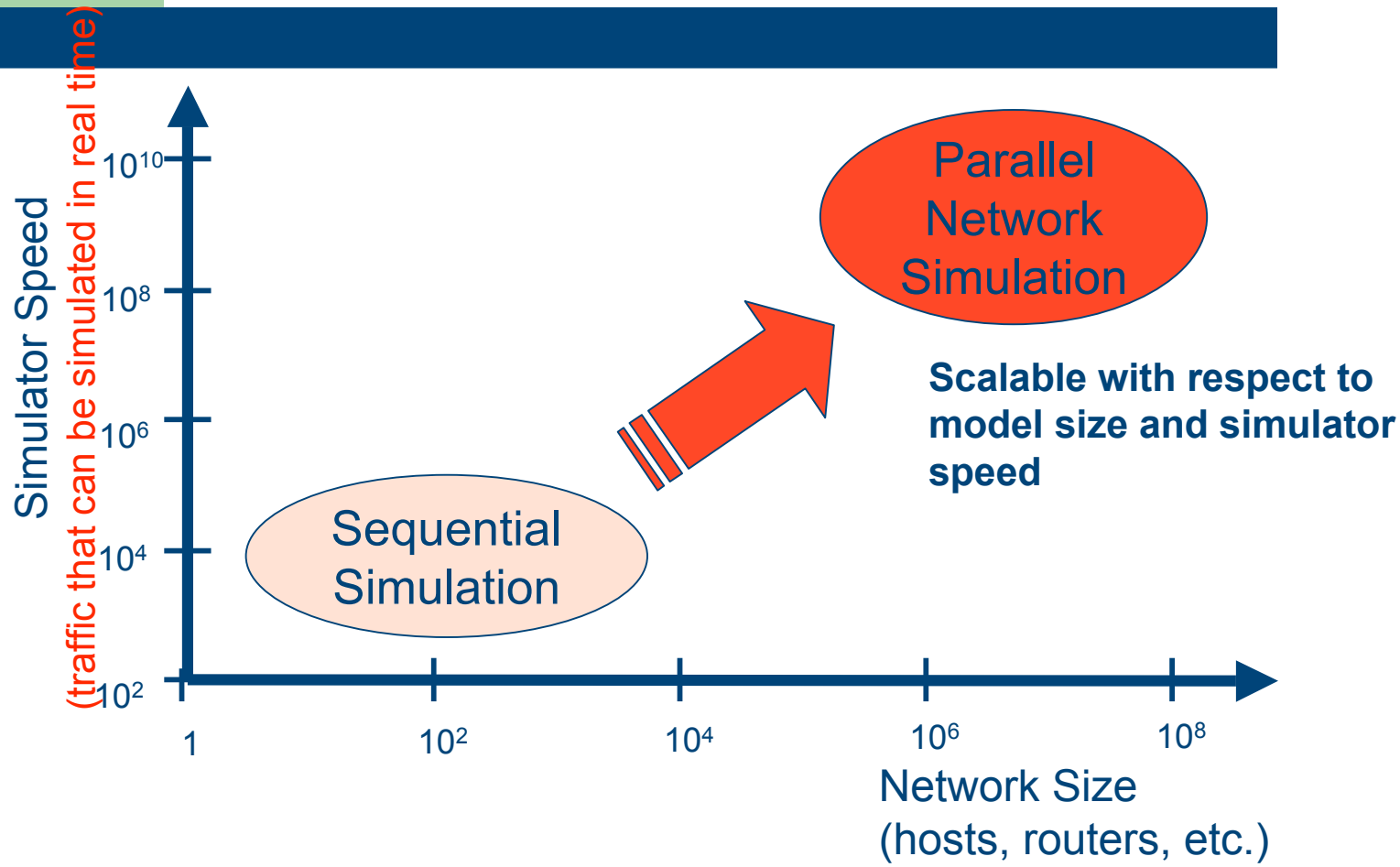
Computing

George Riley

Electrical & Computer Eng.

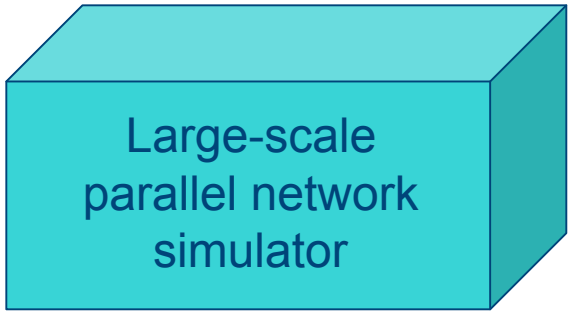
Georgia Institute of Technology

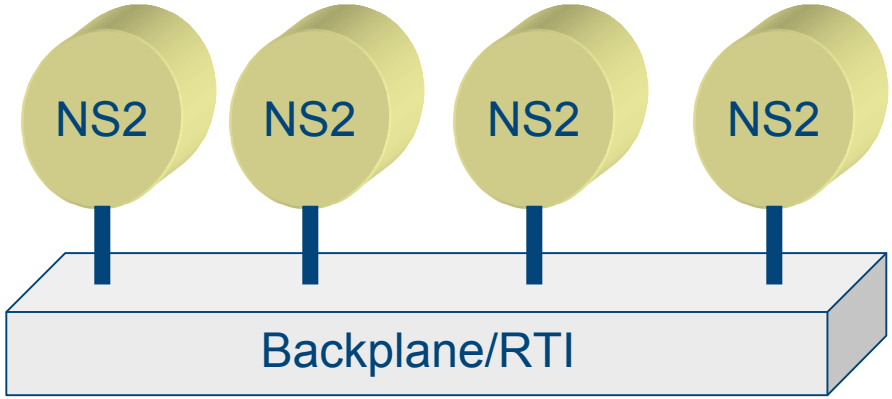
Large-Scale Network Simulation



- Sequential sims limited to modeling hundreds, thousands of network nodes
- Develop technologies/tools to enable detailed (packet-level) simulation of very large communication networks (many millions of nodes)
  - Protocol scalability, cyber-attacks, QoS in mobile networks, infrastructure simulations, etc.

Parallel Network Simulation





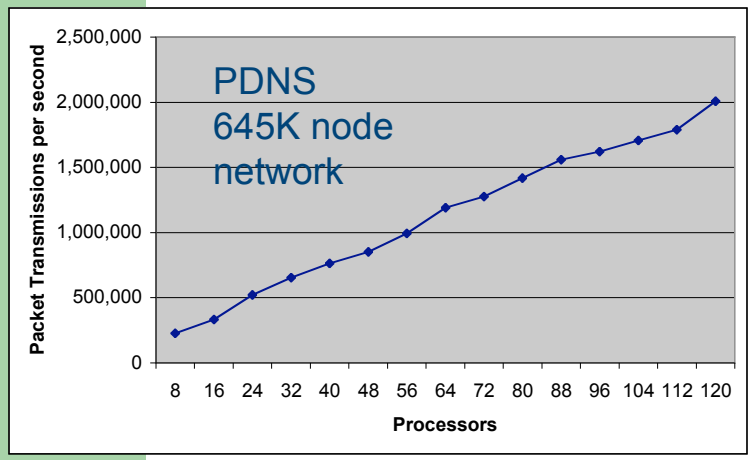
Build "from scratch" approach:

- Substantial effort to build & validate new models
- Users must learn a new simulator
- SSFNet, TeD, Qualnet, ROSS, Javasim, Warped, TeleSim…

Federated simulation approach:

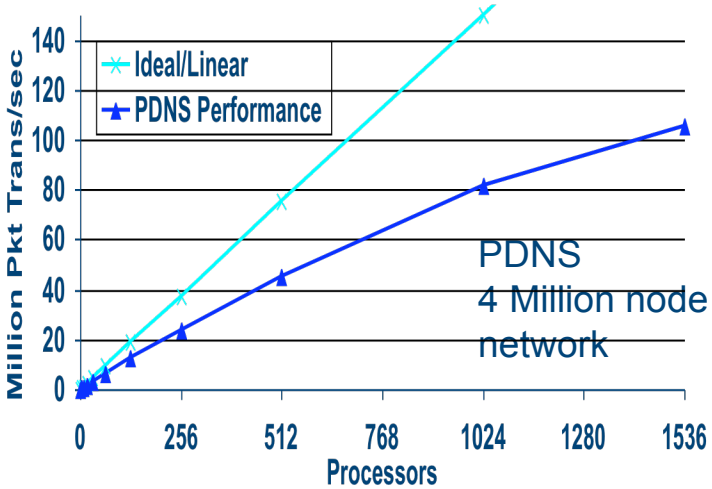
- Simulators integrated via a software backplane/RTI
- Exploit existing software & validated model & user base
- Heterogenous simulations
- PDNS, GTNets

Large-Scale Network Simulation Performance



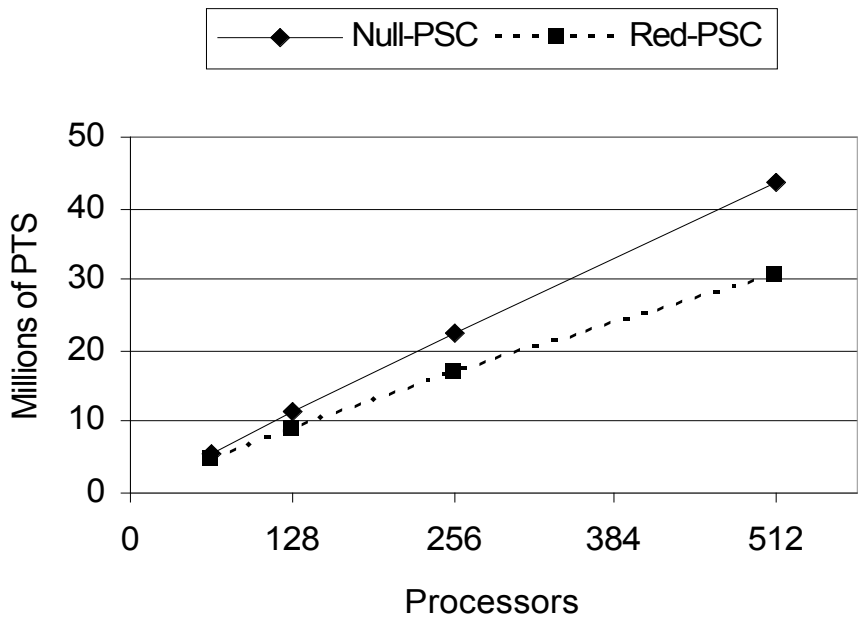
Georgia Tech Cluster
- Pentium III XEON servers
- 8 550 MHz CPUs / server
- 4Gbytes memory / server
- Gigabit Ethernet LAN

Pittsburgh Supercomputing Center
- HP-Alpha ES45 servers
- 4 1.0 GHz CPUs / server
- 4Gbytes memory / server
- *Quadrics* interconnect



- Denial of Service Attacks
- Worm simulations
- FTP traffic
- Web traffic

Optimized Time Management



- **Synchronous** – Global Reductions
  - Distributed snapshot algorithm
  - Computation and synchronization steps
  - Butterfly interconnect
- **Asynchronous -** Chandy/Misra/Bryant
  - Null message algorithm
  - Synchronization with neighbors
  - Deadlock avoidance

- Asynchronous, local synchronization
- Theoretically, better performance properties for this application

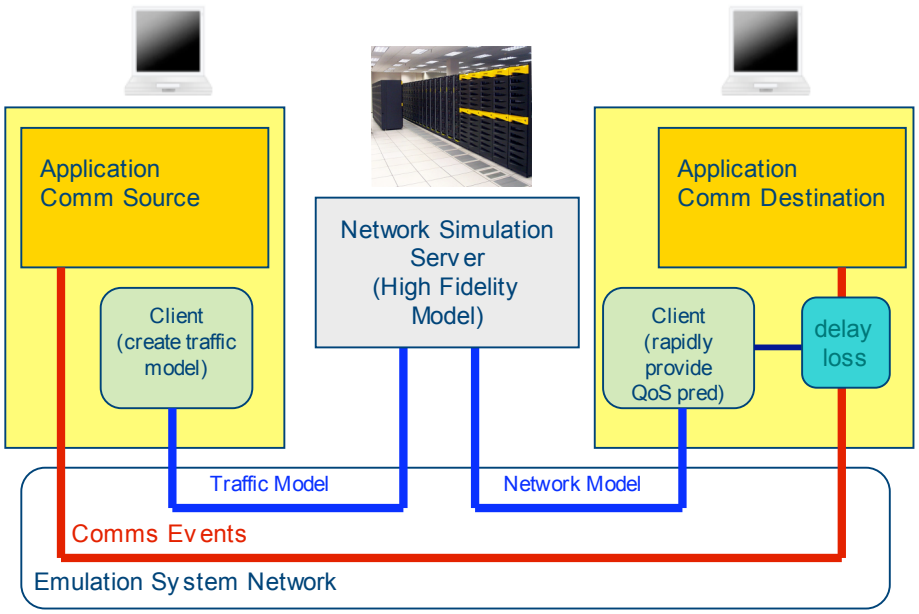
Remote Network Simulation: Client/Server Architecture

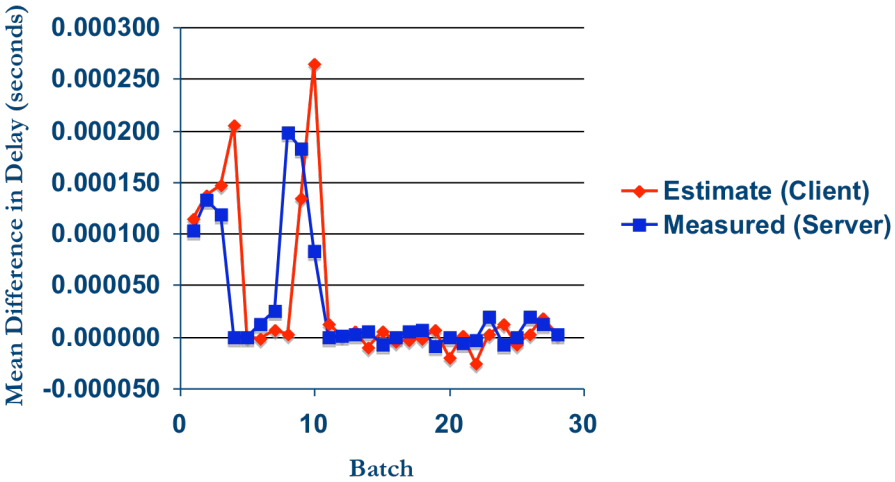
Objective

Enable exploitation of remote large-scale parallel simulations for real-time distributed applications

Client/Server architecture

- Client (local): Provide network QoS predictions rapidly on demand to applications
- Server (remote): High fidelity large-scale network simulation dynamically calibrates client to provide high accuracy





Experiment

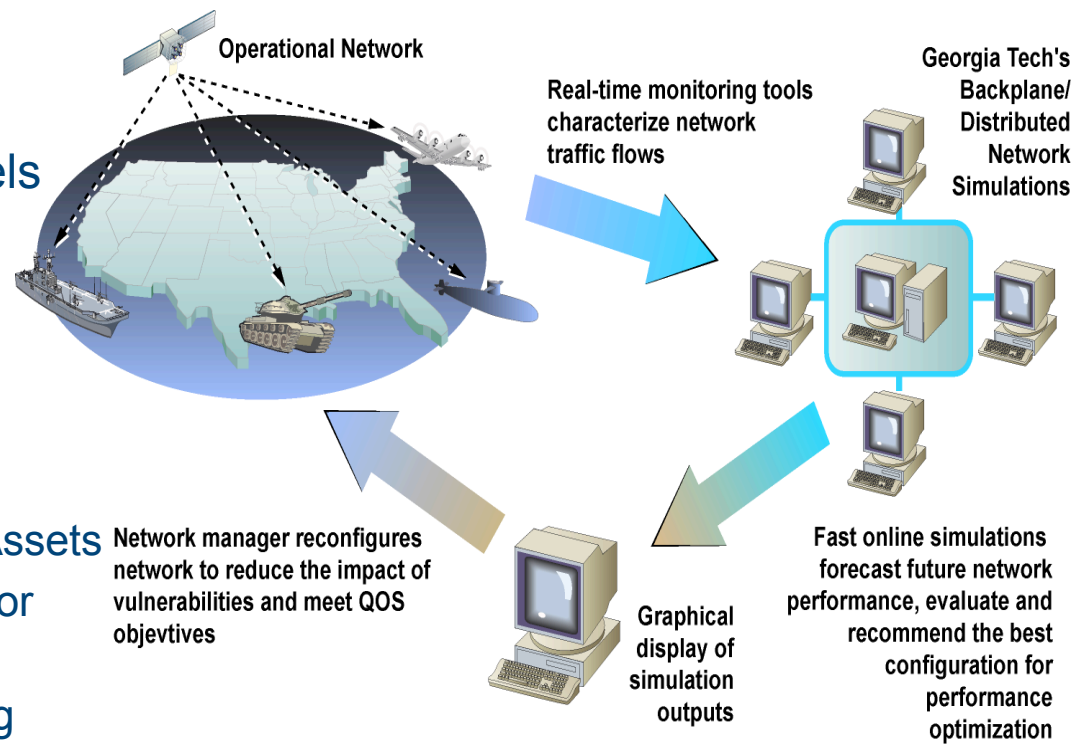
- Server: High Fidelity worm propagation simulation using GTNetS
- Client Simulation: System identification model

Results

- Client closely tracks remote server predictions
- Software being transitioned to JFCOM JUO experiments to add realistic communication models to experiments

On-Line Network Simulation

- On-Line Monitoring and Simulation of Operational Networks
- Populate Simulation Models with Measured Network Demand
- Predict Future Network Performance
  - Link or Node Failures
  - Additional or Reduced Assets
  - Modified Flow Priorities or QoS Assignments
  - Modified Packet Shaping Parameters
    - –Packeteer



Goal: on-line analysis, prediction and control for faster, better decision-making for intelligent, interoperable, networks.

Parallel Discrete Event Simulation of the Earth's Magnetosphere

Richard Fujimoto
Steve Ferenci, Santosh Pande
Kalyan Perumalla

Computing (Georgia Tech)

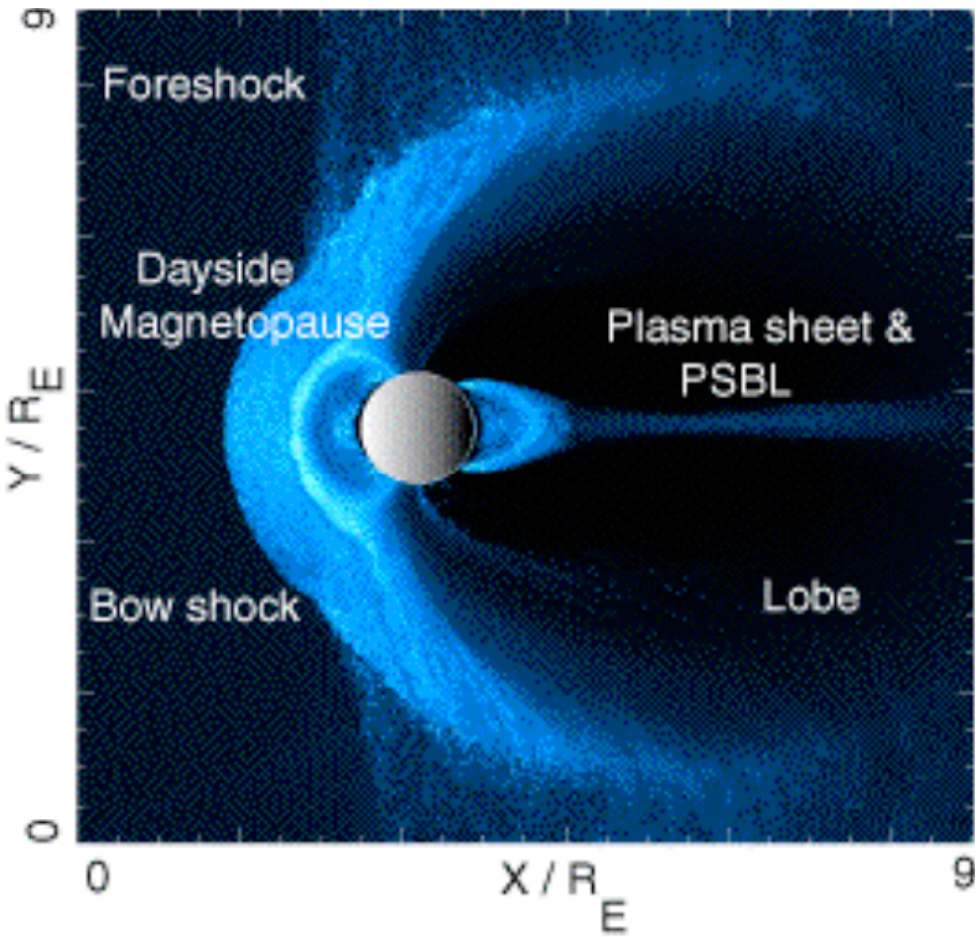
Homa Karimabadi
Yuri Omelchenko

Space Physics (SciberNet)

Georgia Institute of Technology
and
SciberNet Inc.

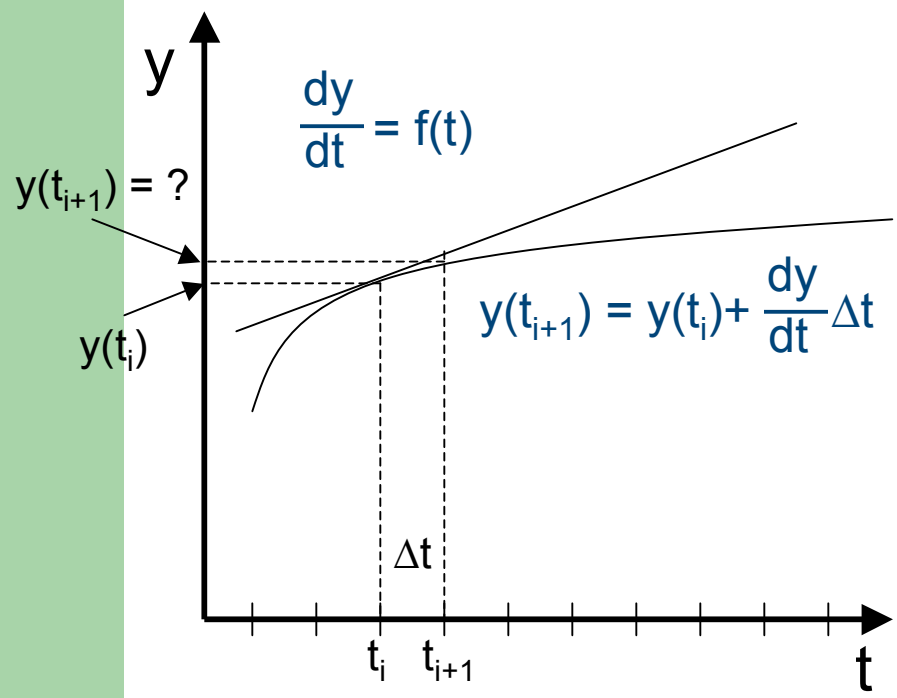
Earth Magnetosphere Simulation

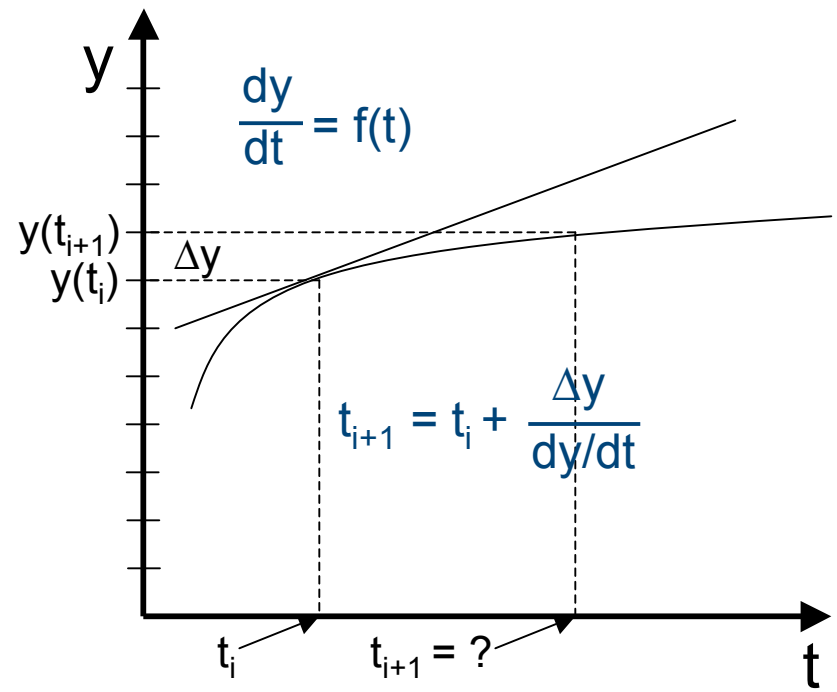
- Global Multi-Scale Kinetic Simulations of the Earth's Magnetosphere
  - Multi-physics; multi-scale
- Goal: understand how solar wind interacts with the Earth's magnetosphere (space weather)
- Challenge: prohibitive computation time
- Approach: parallel discrete event simulation



Courtesy of H. Karimabadi

Discrete Event Simulation of Physical Systems (SciberNet)





- Update at each time step
- Time step size limited by Courant-Friedrichs-Levy condition
- Adaptive Mesh Refinement (AMR) techniques

- DES: update if significant change
- Potentially much less work esp. for irregular computations
- Particle in Cell (PIC) simulation: 300x speedup [Karimabadi et al.]

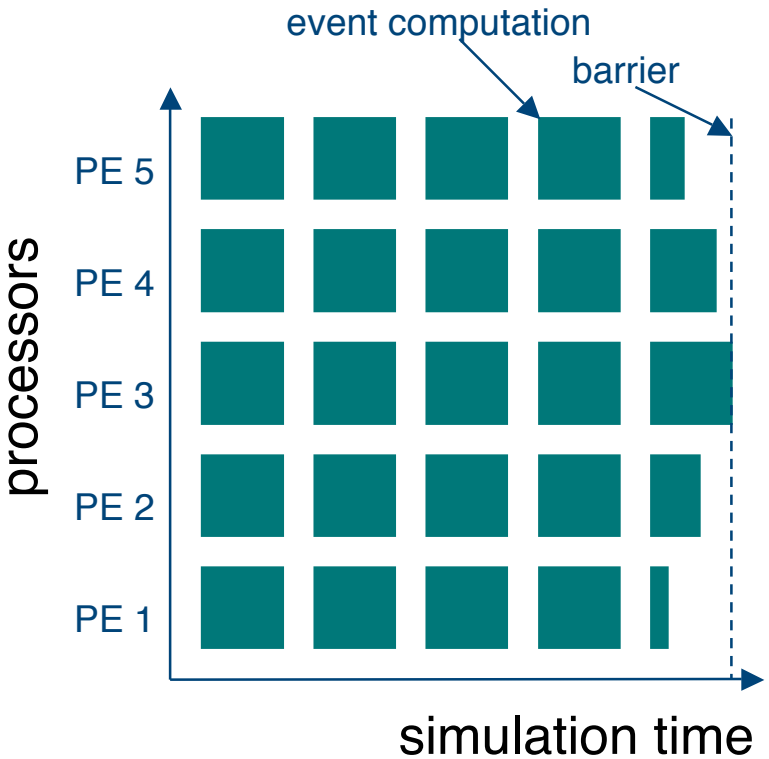
Karimabadi, H. et al., "A New Asynchronous Methodology for Modeling Physical Systems: Breaking the Curse of the Courant Condition." *J. Computational Physics,* **205**(2): 755-775, 2005.

Zeigler, Praehofer, Kim, Theory of Modeling and Simulation, Academic Press, 2000.

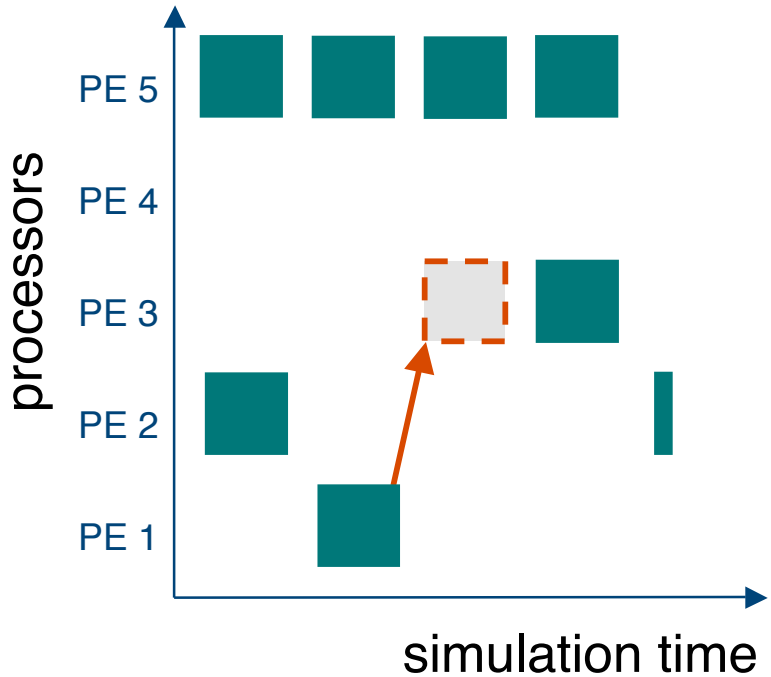
The Synchronization Problem

Parallel execution introduces synchronization problems

Time stepped execution



Event driven execution

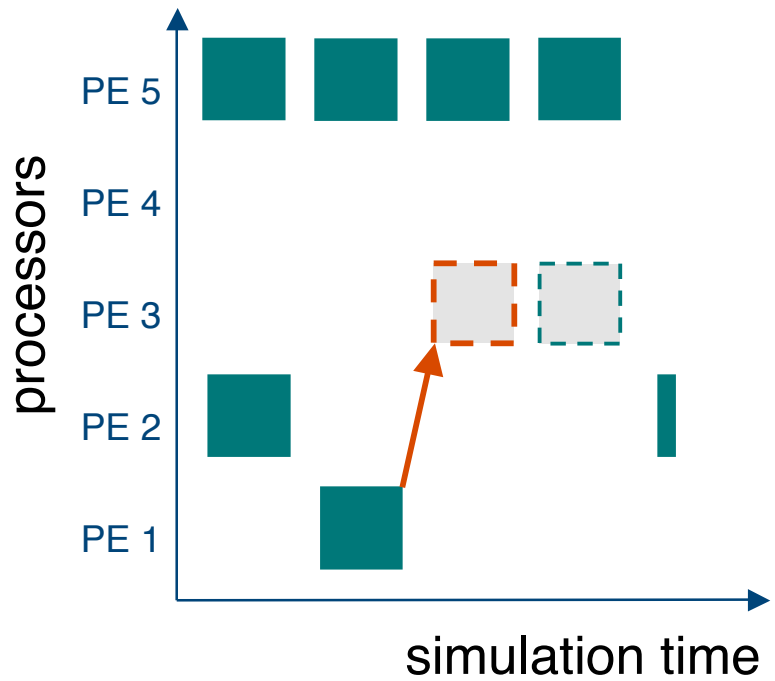


All processors complete simulation for the current time step before advancing to the next time step.

Processors must be allowed to execute ahead of other processors

What if one processor affects the "past" of another?

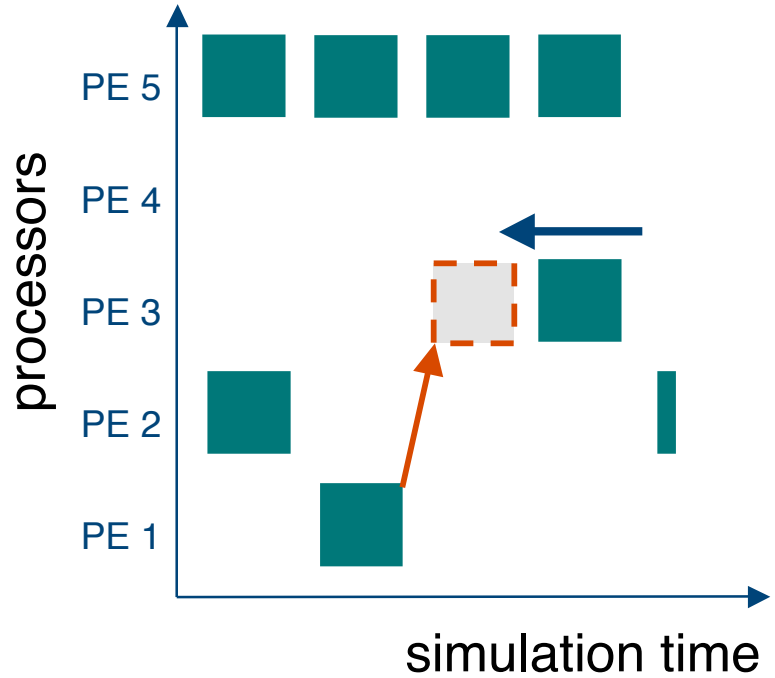
Conservative Synchronization



- Basic idea
  - Do not allow causality errors (out of order event processing) to occur
  - Block computations if it is possible an event may arrive in a simulation process's "past"
  - Several algorithms exist (e.g., Chandy/Misra/Bryant)

- Requires "lookahead" to yield efficient execution, i.e., an ability to predict possible dependencies among future events
- In general, this may be quite difficult to do!

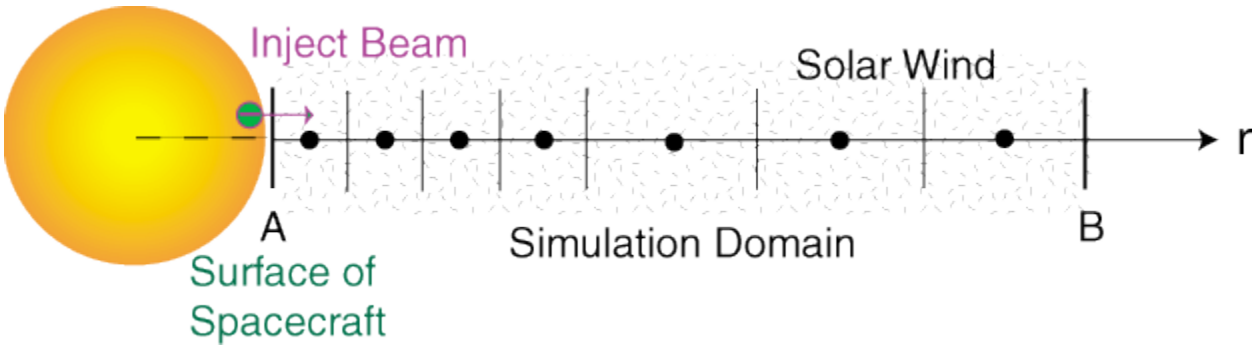
Optimistic Synchronization



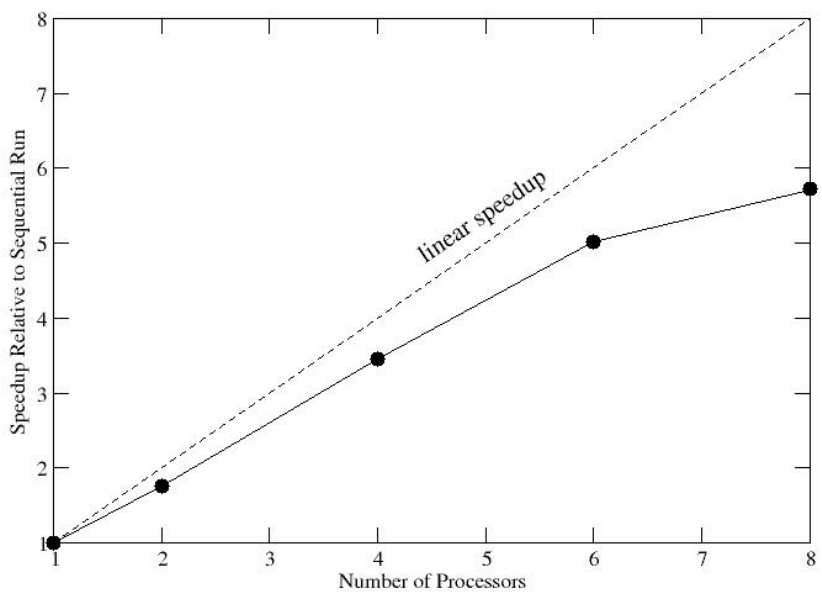
- Basic Idea
  - Allow causality errors to occur
  - Recover using rollback mechanism
  - Time Warp (Jefferson)

- Rollback mechanism
  - Traditional approach to rollback is to use state saving (checkpointing)
  - Can consume much memory
- Reverse computation
  - Rollback by performing the inverse of the event computation
  - Reduces both memory and time needed for state saving

Particle-in-Cell (PIC) Model



- Charging a spacecraft due to periodical beam injection from its surface
- Conceptually simple, yet sufficiently complex to capture characteristics of plasma dynamics



Summary: Research Interests

- Distributed simulation
  - Interoperability issues
  - Execution over wide area networks
  - Grid/Web services
- Parallel discrete event simulation
  - Synchronization algorithms
  - Efficient execution on clusters, supercomputers
- Software
  - Federated Simulations Development Kit (FDK)
  - Interoperable Distributed Simulations (IDSim)
  - μsik parallel discrete event simulation engine