High Performance Computing Enabled Modeling of Coupled Co-evolving Socio-Technical Networks

Chris Barrett & Madhav Marathe
Network Dynamics and Simulation Science Laboratory
Virginia Bio-Informatics Institute & Dept. of Computer Science
Virginia Tech
cbarrett,marathe@vt.edu

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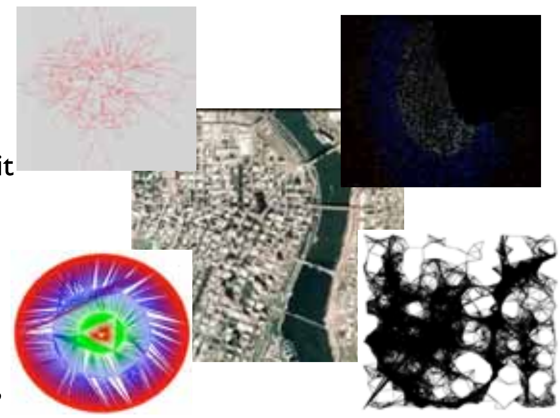
External Collaborators:

S. S. Ravi, (SUNY Albany), Hari Balakrishnan (MIT), Ravi Sundaram (Northeastern), Lukas Kroc (Cornell), Riko Jacob (ETH), Kai Nagel (Berlin), Goran Konjevod (ASU), Aravind Srinivasan, Sri Parthasarathy (U. Maryland), Nan Wang (Goldman Sachs) Stephan Eidenbenz, Sunil Thulasidasan, Gabriel Istrate, Anders Hansson, Jim Smith (LANL),

Motivation -- Very Large Complex Socio-Technical Systems (vlcs)

- Chicago Area and Population: 400 sq Miles, 12 counties, 272 townships, 9 million people
- Transportation System: ~4 million edges/nodes, ~31 million trips, every road segment, bus, transit & rail.
- Social Network for Public Health: ~20 million nodes in the temporal network with 1 sec resolution
- Telecommunication System: Million IP addresses, ~125 million calls/days



Systems Characterized by Irregular Dynamic and Heterogeneous Networks

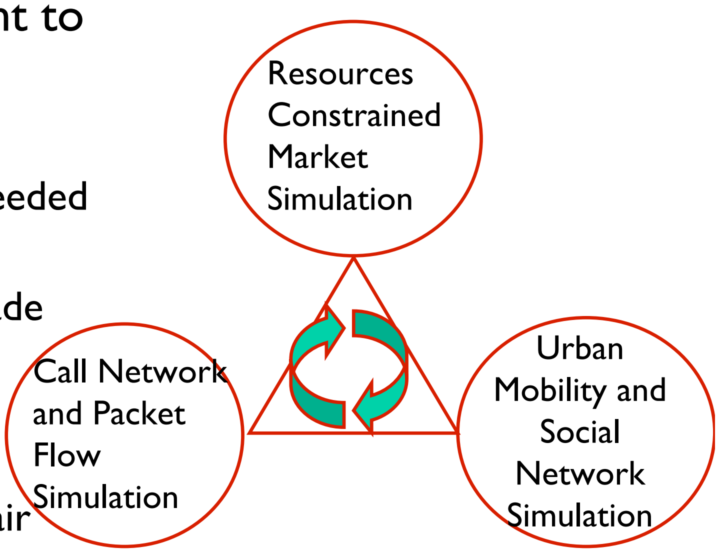
Usual Agent Based Models simply do not scale to such sizes

These networks co-evolve

- Dynamic adhoc radio networks
  - Social Networks, mobility of devices, the specific calling patterns and network protocols (e.g. power and frequency assignment) all decide the time varying adhoc radio networks
  - Conversely, the underlying network decides the performance of network protocols, and potentially calling patterns
- Epidemics
  - Social Network, public policy and individual behavior affect the disease outcome
  - Conversely, as disease spreads, behavior and thus social networks changes.

Emerging Application: Spectrum Management in Unlicensed Band

- Wireless companies want to bid for unrestricted frequency band
  - Time varying demands needed for making good bids
  - Intelligent bids can be made based on geographic call patterns
  - FCC needs to ensure no collusion and bidding is fair



Simfrastructure: Information Integration & Decision Support

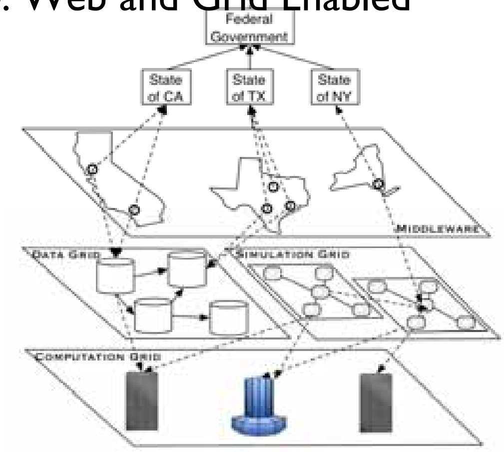
• A network centric system that replicates population activities, locations and infrastructures to create a specific urban environment.

- •Infrastructure for developing federated simulations

• Globally Scalable Cyber-Infrastructure: Web and Grid Enabled

•Varied Uses, e.g.

- •Policy Planning,
- •Situational Awareness
- •Inter-dependency Analysis
- •Economic Analysis
- •System Design and Optimization



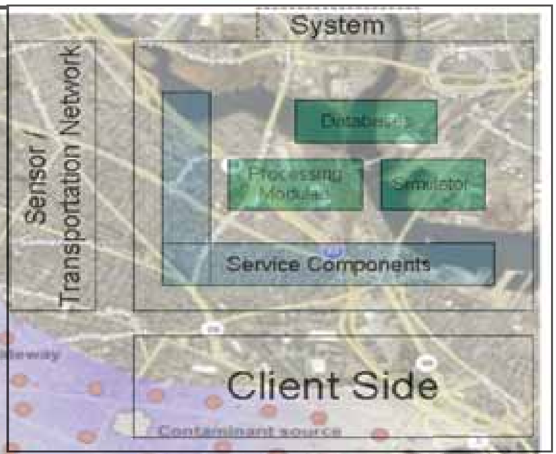
Theoretical Basis: Interaction Based Computing

- Interaction based computing viewpoint:
  - *Computation -- a result of interaction between subsystems; interaction treated as a first class object*
    - *Algorithmic Semantics: What are we computing? Traditional View: How to compute.*
    - *Computational Complexity: How hard is it to compute/design global system properties?*
- Unified approach for computing and simulations
  - *Distributed computing systems are, formally speaking, simulations*
  - *Complex systems and simulations can be viewed as computing devices*

CoSMo: Cognitively Inspired Architecture for Monitoring Urban Traffic

•A cognitively inspired internal representation for analyzing and answering queries concerning transport system

• A service oriented architecture that facilitates interaction among individual modules, of the internal representation, the observed system and the user.



Get delay on link 12 between time 8:50 A.M. and 1:20 P.M. and get the result with a Medium confidence level.

The image is a conceptual map of the CitySense deployment planned for Cambridge, MA.

What we'd like to know

For individuals in a population:

- Their demographics (Who)
- The sequences of activities they do (What)
- The times they do them (When)
- The places they do them (Where)

And sometimes (like today):

- The reasons they do them (Why)

Combined with dynamic models of processes (diseases, and packets) yield

Step 1: Synthetic Populations

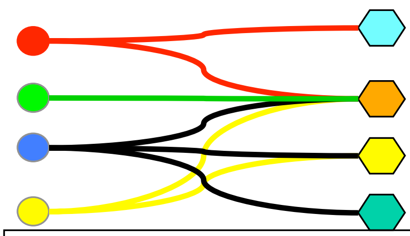
- **Who**: *People*
  - Individuals
  - Household structure
  - Statistically identical to U.S. Census
  - Assigned to Home Locations

Beckman et al. Tran. Science, NISS technical reports, Barrett et al. TRANSIMS technical reports

Step 2: Urban Dynamic Social Contact Network

- Demographically match schedules
- Assign appropriate locations by activity and distance
- Determine duration of interaction
- Generate social network

People Vertex:
- age
- household size
- gender
- income ..

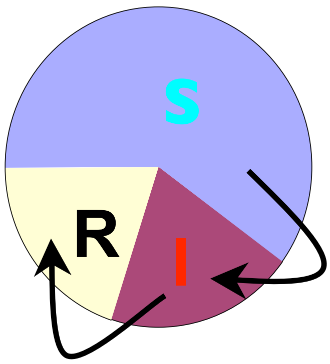


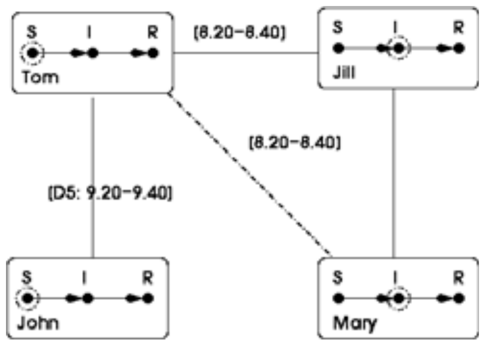
Location Vertex:
- (x,y,z)
- land use .
- Business type

Edge labels
- activity type: shop, work, school
- (start time 1, end time 1)
- (start time 2, end time 2)

Step 3: Model of Dynamical Process

- On each time step, each person's state of health can change
  - **(S)** susceptible -> infectious in t time steps with probability depending on health and duration of contacts in a social network
  - **(I)** infectious -> removed or recovered and thus susceptible after t time step (dependency is stochastic and on demographics)
  - **(R)** removed -> terminal state (could become Susceptible again)



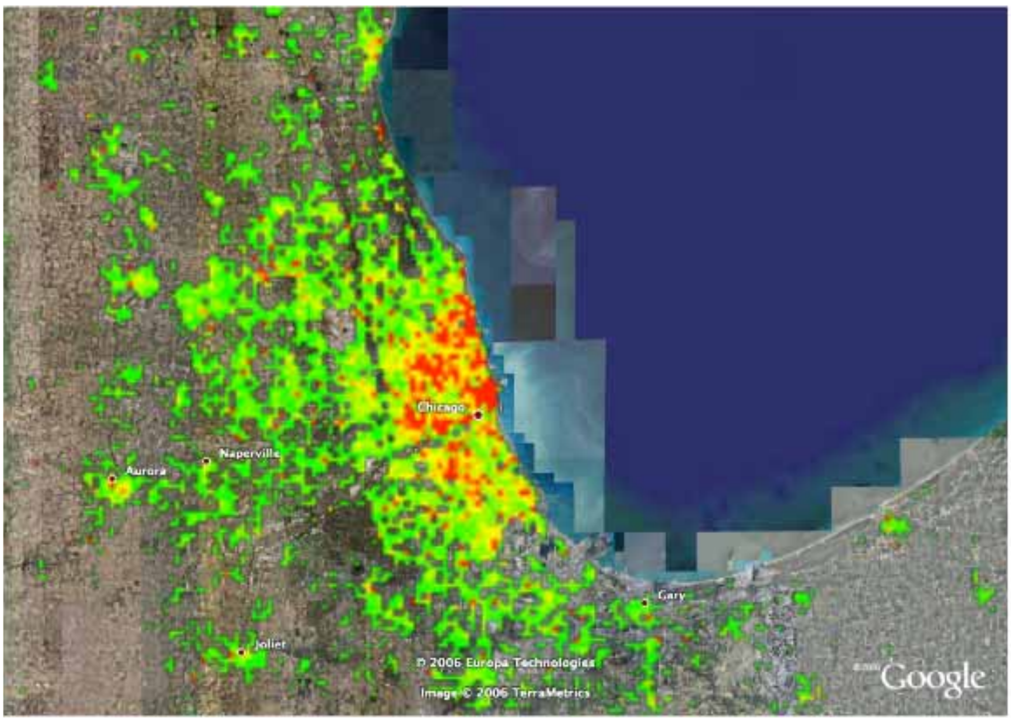


Three Simulations of Varying Strengths

	EpiSims	EpiSimdemics	EpiFast
Solution Method	Discrete Event Simulation	Hybrid Simulation	Combinatorial
Generality	Most General	Generic: time complexity depends on representation	Less General
Performance 180 days 9M hosts & 40 proc.	50 hours	2-4 hours	Few seconds to minutes
Dynamic Social Network	Can work	Works Well	Works ***only*** with restricted form
Disease transmission model	Edge as well as vertex based	Edge as well as vertex based	Edge based only
Disease Progression Latency	No restriction	Reasonable time between infection and infectious	No restriction

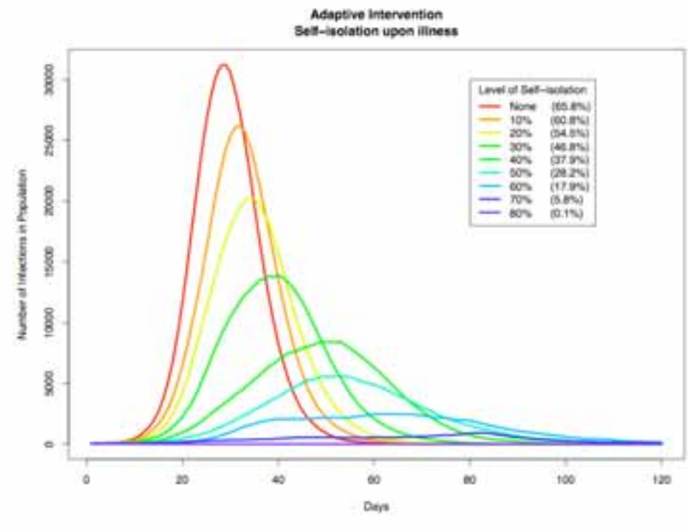
All together, gives this level of resolution …

…at this scale



Disease dependent changes

- Different proportions of the population elect to remove themselves from the wider social network



Self-isolation level	Final Attack Rate
0%	66%
10%	61%
20%	55%
30%	47%
40%	40%
50%	28%
60%	18%
70%	6%
80%	0.1%