Real-Time Network Science

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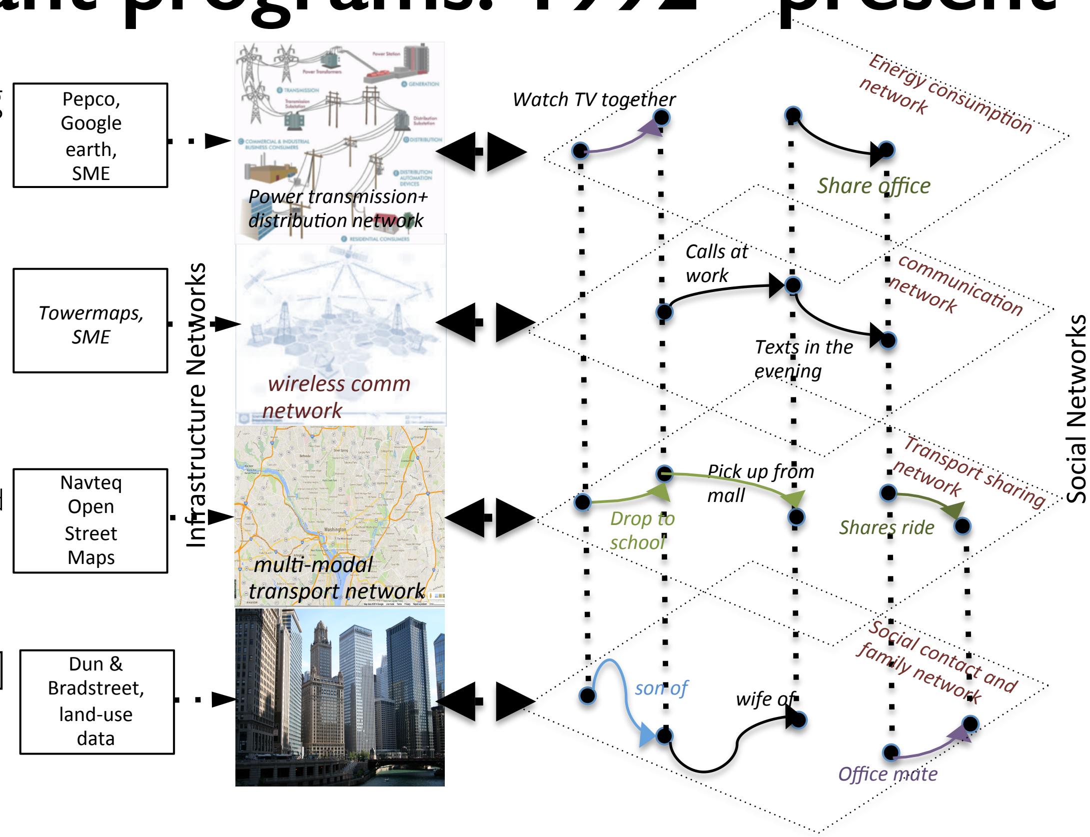
Four significant programs: 1992 - present

- TRANSIMS: Urban transport planning [1992-2001]
  - Multi-modal urban transport networks
- NISAC-UIS [2000-present]
  - Planning and response in the event of crisis. HPC based simulations, Inter-dependent infrastructures
- CNIMS: National Incident management system [2006-present]
  - Interdependent infrastructure modeling and simulation, short-term planning and response for large scale disasters
- Simdemics: Real-time epidemic planning and response [2002-present]
  - Planning and response; short time scale
  - *New technologies*: pervasive apps, real-time measurement and response,



Each application comprises of multi-scale socially coupled CP-networks

Increased sophistication and requirements from decision makers are driving real-time decision analytics

Simple lumped models

- ODE models solvable explicitly

Network models

- Realistic-networks synthesized from real data

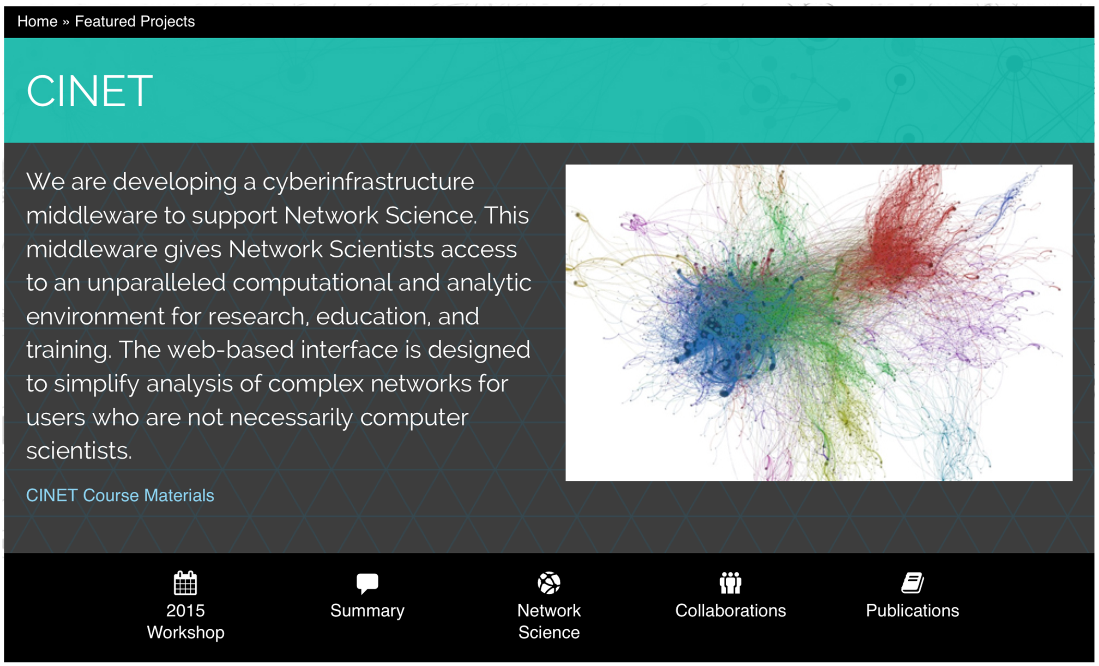
Dynamic and co-evolving Networks

- Interactive simulations and co-evolving networks

Real-time analysis and decision support

- Use of sensors (human and electronic)

CINet



- Web address

http://cinet.vbi.vt.edu or

http://ndssl.vbi.vt.edu/cinet

- Central location of CINET

Entry point to provide detailed information about *collections of network graphs and analysis measures*, and pointers to *CINET analysis tools* (Granite, GDSC, etc.)

- Portal for course materials

Portal for collecting and disseminating *course notes, presentations, videos , and research papers* related to network science

Epidemic science in real-time

Informatics for real-time integrated reasoning about situations and actions

- Vision: Real time computational networked epidemiology
- Goal: Build a flexible suite of informatics tools that
  - *Synthesize*: available data to produce consistent and meaningful representation of the underlying system
  - *Provide*: range of interpretations of incoming measurements
  - *Evaluate*: range of response actions and behaviors
  - *Monitor*: Effect of policy responses
  - Support coordination among diverse stakeholders
- Want to go beyond prediction
- Systems should be useable by analysts and not just by computing experts

EDITORIAL

Harvey V. Fineberg is president of the Institute of Medicine.

Mary Elizabeth Wilson is associate professor of Global Health and Population at the Harvard School of Public Health and associate clinical professor at Harvard Medical School, Boston, MA.

Epidemic Science in Real Time

FEW SITUATIONS MORE DRAMATICALLY ILLUSTRATE THE SALIENCE OF SCIENCE TO POLICY THAN AN epidemic. The relevant science takes place rapidly and continually, in the laboratory, clinic, and community. In facing the current swine flu (H1N1 influenza) outbreak, the world has benefited from research investment over many years, as well as from preparedness exercises and planning in many countries. The global public health enterprise has been tempered by the outbreak of severe acute respiratory syndrome (SARS) in 2002–2003, the ongoing threat of highly pathogenic avian flu, and concerns over bioterrorism. Researchers and other experts are now able to make vital contributions in real time. By conducting the right science and communicating expert judgment, scientists can enable policies to be adjusted appropriately as an epidemic scenario unfolds.

In the past, scientists and policy-makers have often failed to take advantage of the opportunity to learn and adjust policy in real time. In 1976, for example, in response to a swine flu outbreak at Fort Dix, New Jersey, a decision was made to mount a nationwide immunization program against this virus because it was deemed similar to that responsible for the 1918–1919 flu pandemic. Immunizations were initiated months later despite the fact that not a single related case of infection had appeared by that time elsewhere in the United States or the world (www.iom.edu/swinefluaffair). Decision-makers failed to take seriously a key question: What additional information could lead to a different course of action? The answer is precisely what should drive a research agenda in real time today.

In the face of a threatened pandemic, policy-makers will want real-time answers in at least five areas where science can help: pandemic risk, vulnerable populations, available interventions, implementation possibilities and pitfalls, and public understanding. Pandemic risk, for example, entails both spread and severity. In the current H1N1 influenza outbreak, the causative virus and its genetic sequence were identified in a matter of days. Within a couple of weeks, an international consortium of investigators developed preliminary assessments of cases and mortality based on epidemic modeling.*

Specific genetic markers on flu viruses have been associated with more severe outbreaks. But virulence is an incompletely understood function of host-pathogen interaction, and the absence of a known marker in the current H1N1 virus does not mean it will remain relatively benign. It may mutate or acquire new genetic material. Thus, ongoing, refined estimates of its pandemic potential will benefit from tracking epidemiological patterns in the field and viral mutations in the laboratory. If epidemic models suggest that more precise estimates on specific elements such as attack rate, case fatality rate, or duration of viral shedding will be pivotal for projecting pandemic potential, then these measurements deserve special attention. Even when more is learned, a degree of uncertainty will persist, and scientists have the responsibility to accurately convey the extent of and change in scientific uncertainty as new information emerges.

A range of laboratory, epidemiologic, and social science research will similarly be required to provide answers about vulnerable populations; interventions to prevent, treat, and mitigate disease and other consequences of a pandemic; and ways of achieving public understanding that avoid both over- and underreaction. Also, we know from past experience that planning for the implementation of such projects has often been inadequate. For example, if the United States decides to immunize twice the number of people in half the usual time, are the existing channels of vaccine distribution and administration up to the task? On a global scale, making the rapid availability and administration of vaccine possible is an order of magnitude more daunting.

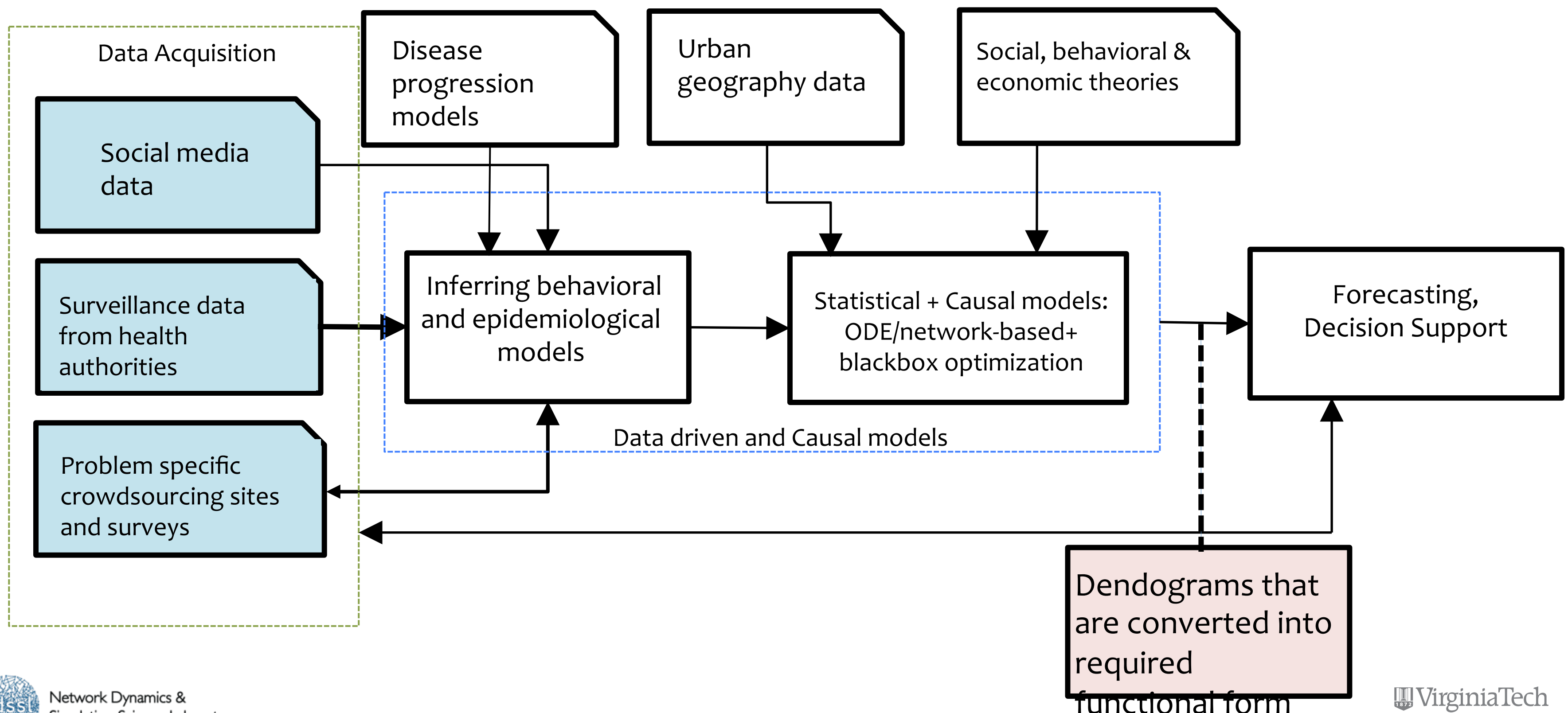
Scientists and other flu experts in the United States and around the world have much to occupy their attention. Time and resources are limited, however, and leaders in government agencies will need to ensure that the most consequential scientific questions are answered. In the meantime, scientists can discourage irrational policies, such as the banning of pork imports, and in the face of a threatened pandemic, energetically pursue science in real time.

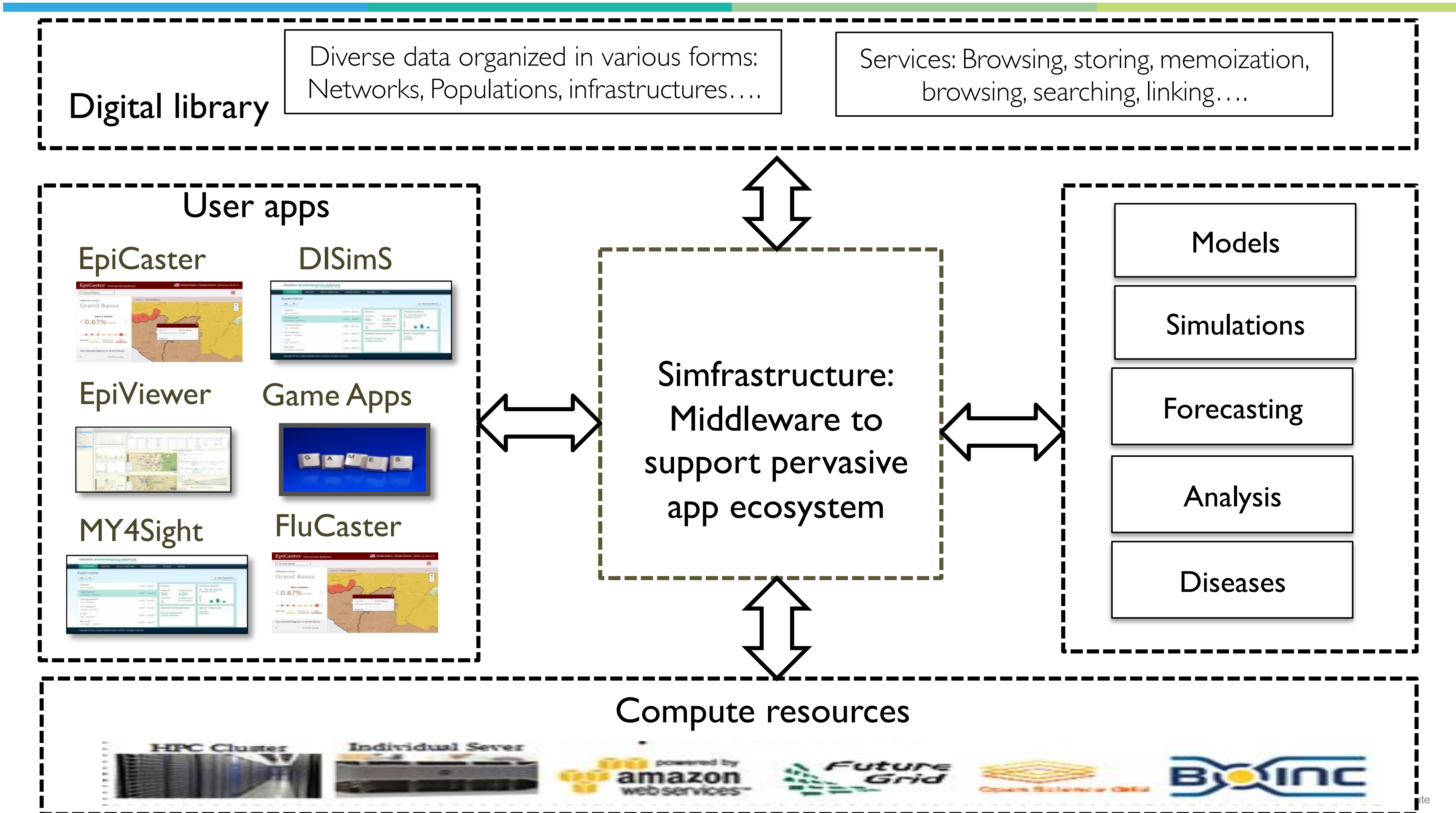
– Harvey V. Fineberg and Mary Elizabeth Wilson

10.1126/science.1176297

*C. Fraser *et al.*, *Science* 11 May 2009 (10.1126/science.1176062).

Overall pipeline: Abductive Loop for computational steering

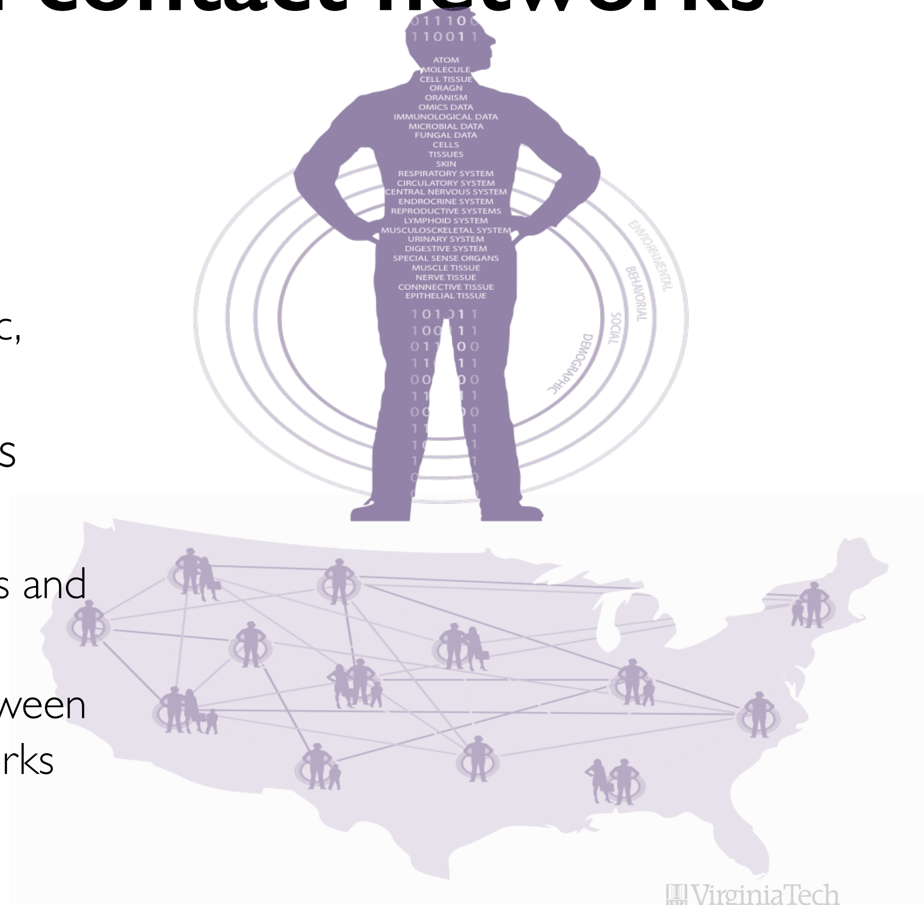




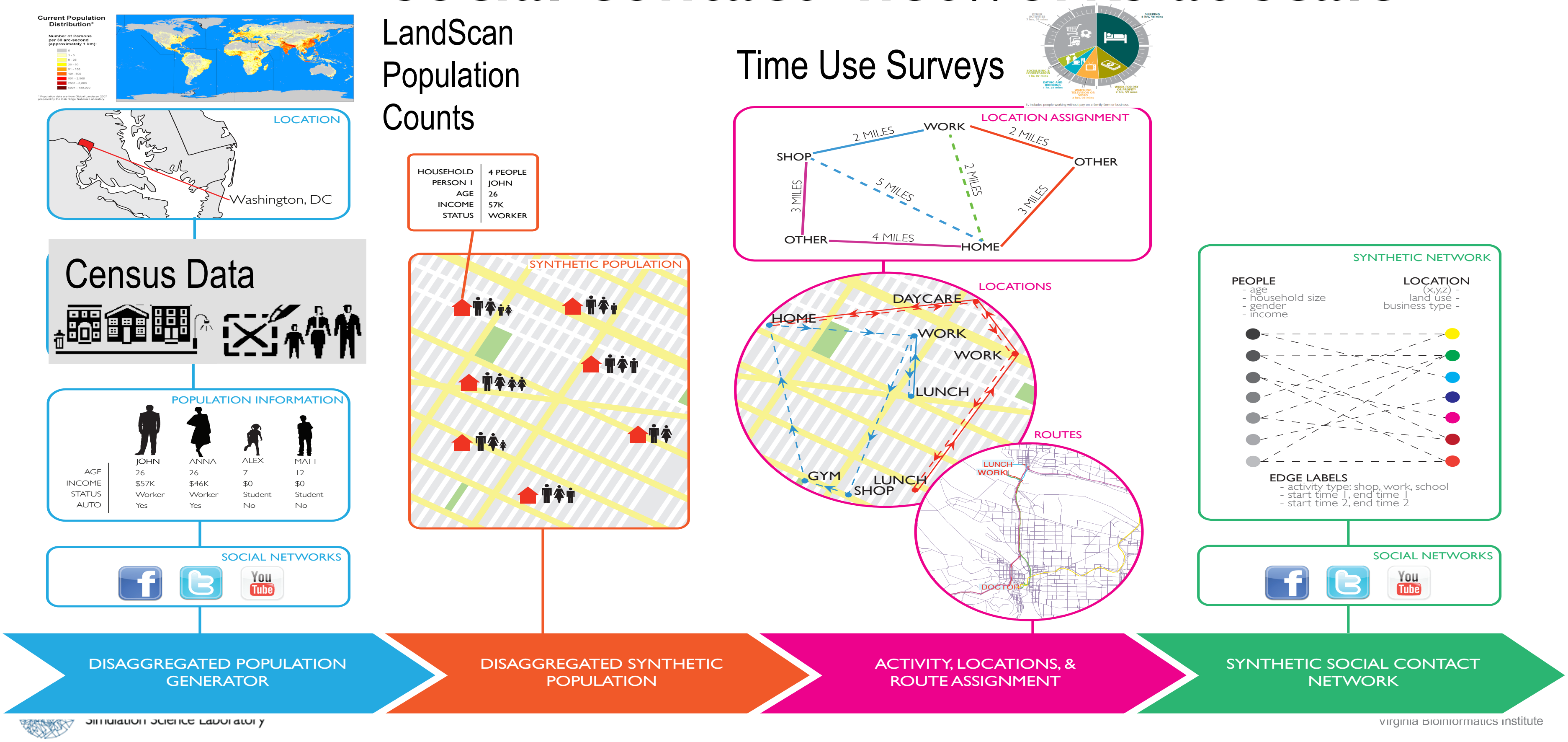
Digital library
Diverse data organized in various forms: Networks, Populations, infrastructures….
Services: Browsing, storing, memoization, browsing, searching, linking….
User apps
EpiCaster
DISimS
EpiViewer
Game Apps
MY4Sight
FluCaster
Simfrastructure: Middleware to support pervasive app ecosystem
Models
Simulations
Forecasting
Analysis
Diseases
Compute resources
HPC Cluster
Individual Server
powered by amazon web services
FutureGrid
BOINC

Synthetic social contact networks

- A statistically accurate, augmentable representation of agents (people, infrastructure elements)
  - in a given area with associated demographic, physical, social and behavioral attributes
- Synthetic infrastructure & social networks networks
  - Capture the interaction between individuals and infrastructure elements
  - Multi-networks capture the interaction between individuals and infrastructures across networks



Constructing synthetic multi-scale social contact networks at scale



Real-time epidemic science: From multi-scale networks to multi-scale, multi-layered networks

Organizational/government policies

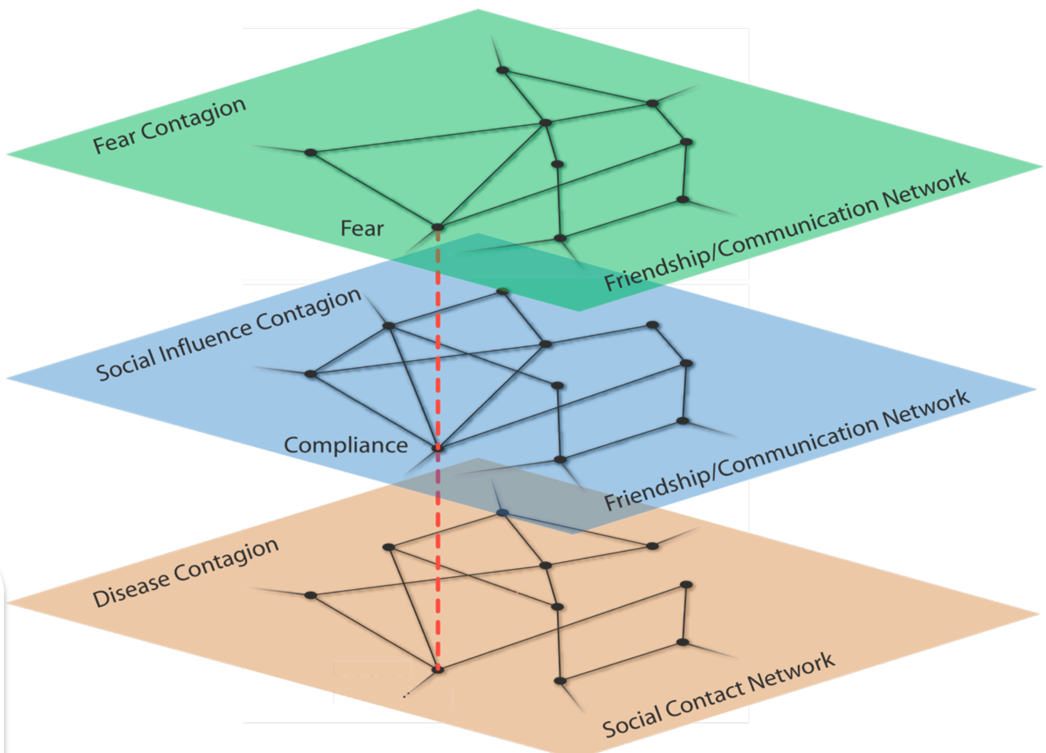
- Factors: Social and economic cost, global risk, mortality…
- Actions: Pharmaceuticals, work and school closures, building ETUs
- Time scale: days to months

Community, neighborhood actions

- Factors: unrest, ostracize, ..
- Actions: neighborhood cleaning, quarantine, funeral norms, and school closure
- Time scale: days to weeks to months

Individual behavior

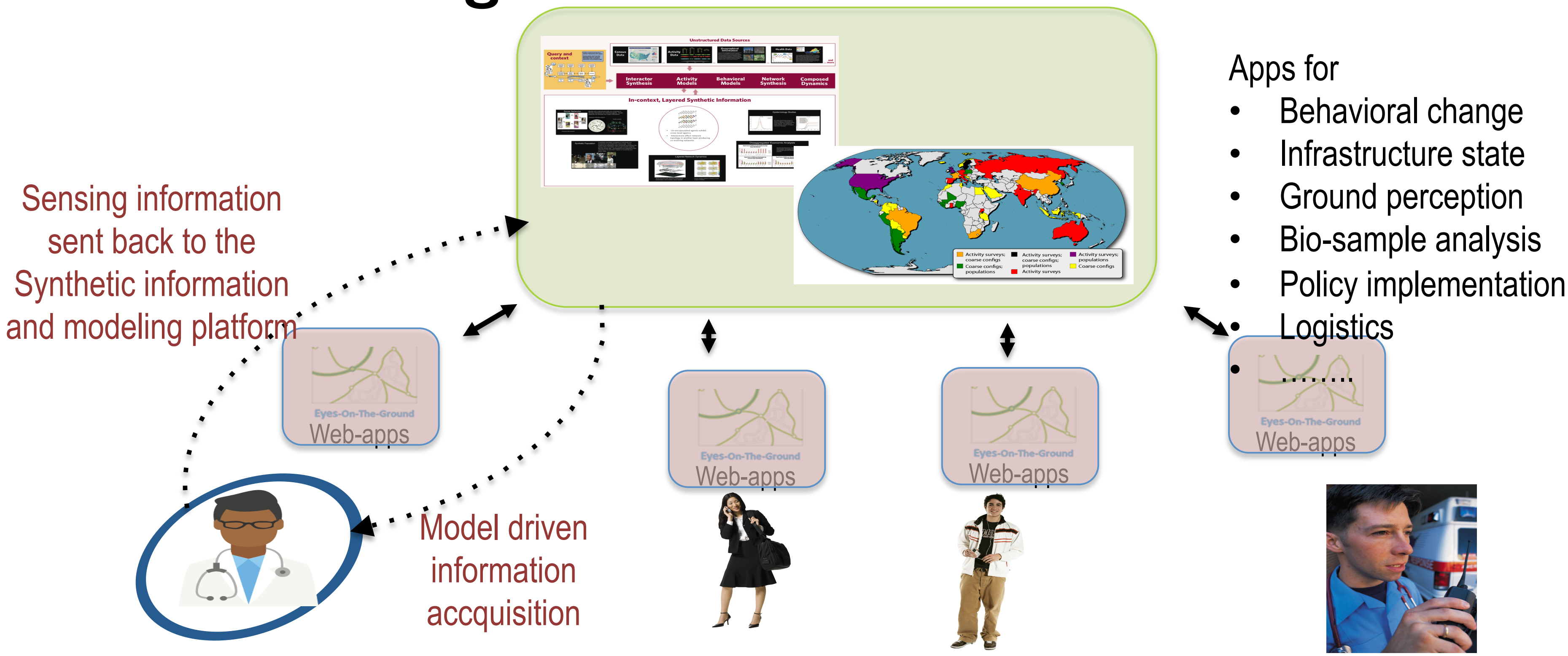
- Factors: risk perception, network information, compliance,
- Actions: self isolation, personal hygiene, antivirals
- Time scale: few minutes to days



Simulation Science Laboratory

VirginiaTech
Virginia Bioinformatics Institute

Abductive human computation for global disease surveillance



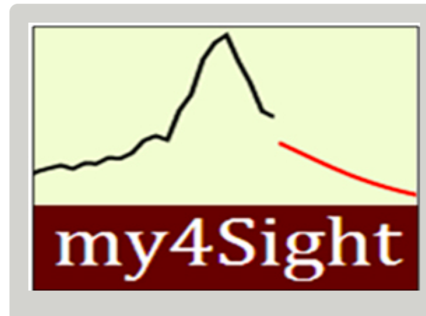
Pervasive webapps to support Ebola response
http://www.vbi.vt.edu/ndssl/tools

EpiCaster

Users can view Ebola (or Flu) activity for the past four weeks and view forecast predictions for the next two weeks. They can also view forecast trends and compare them to surveillance data. EpiCaster allows users to see what impact various strategies, such as vaccines and social distancing, have on disease spread.

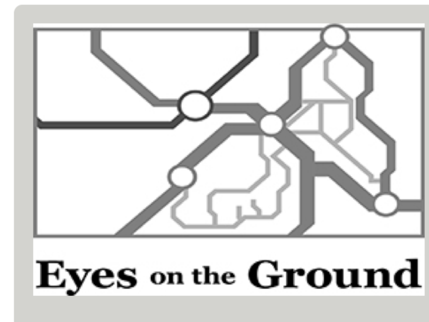
EpiViewer

EpiViewer is a data repository for epidemiologists. Users can upload and compare Ebola forecasts and surveillance data from a variety of sources and see how forecasts change over time. Users can also load and share their own forecasting predictions.



my4Sight

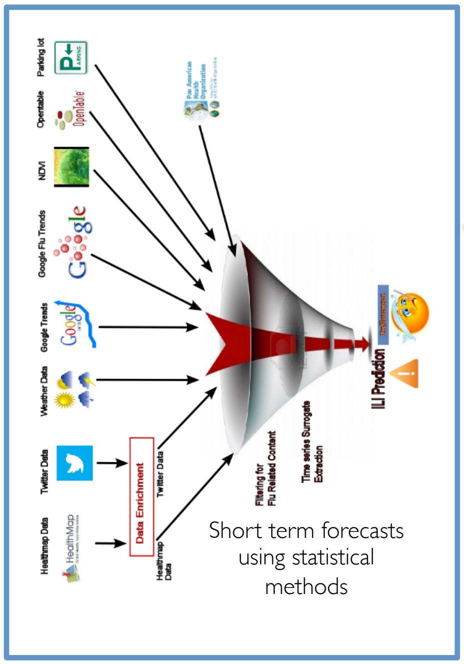
my4Sight uses human computation to enhance disease forecasting. Similar to games like Foldit, this web application allows users to assist computational models by performing tasks that humans are uniquely good at, in this case pattern matching.



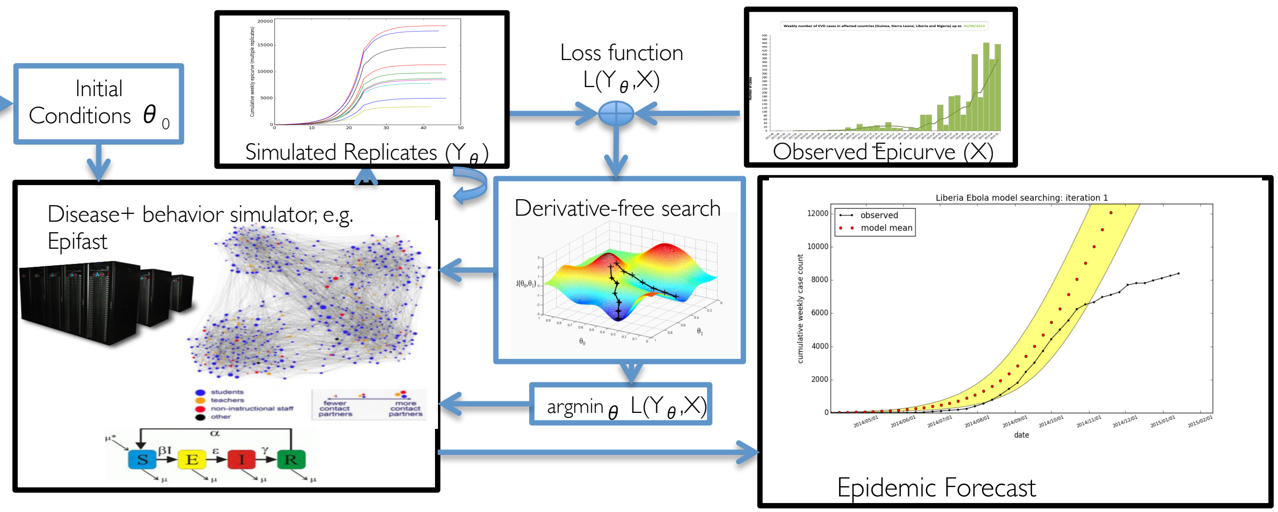
Eyes on the Ground

Road conditions can be variable in some of the rural areas in Western Africa. Eyes on the Ground allows people in affected areas to report their road conditions. Other travelers can then view these reports and plan their trips accordingly. This is especially useful when planning the delivery of patients and supplies between cities.

Combining statistical and causal methods



$$L(Y_\theta, X) = \min_\theta \frac{1}{R} \sum_{r=1}^{R} \left(\sum_{i=1}^{N} \alpha^{N-i} \left| Y_{\theta,r}(i) - X(i) \right| \right)$$



Summary

- Socially-coupled cyber-physical systems serve as an interesting class of applications for streaming research
  - Diversity of devices, human sensors and large scale simulations needed for real-time reasoning
  - Causal data driven modeling is at core: data comes from varied sources: stream processing for many steps is the key, e.g. social media, apps, PMUs, road sensors, ….
  - Certain errors are tolerated; decision cycles are slower than the rate at which data is received.
- Technical challenges
  - How does one design human-computation based abductive systems for improving streaming information foraging: *When where, what and how to collect data to improve reasoning and actions*
  - Steering is needed but is adaptive and happens at various levels from information gathering to carrying out computations locally.
  - Processing results from massive simulations for use by analysts (some on the ground)
  - These systems ***co-evolve: policies, data collection, networks and dynamics co-evolve***