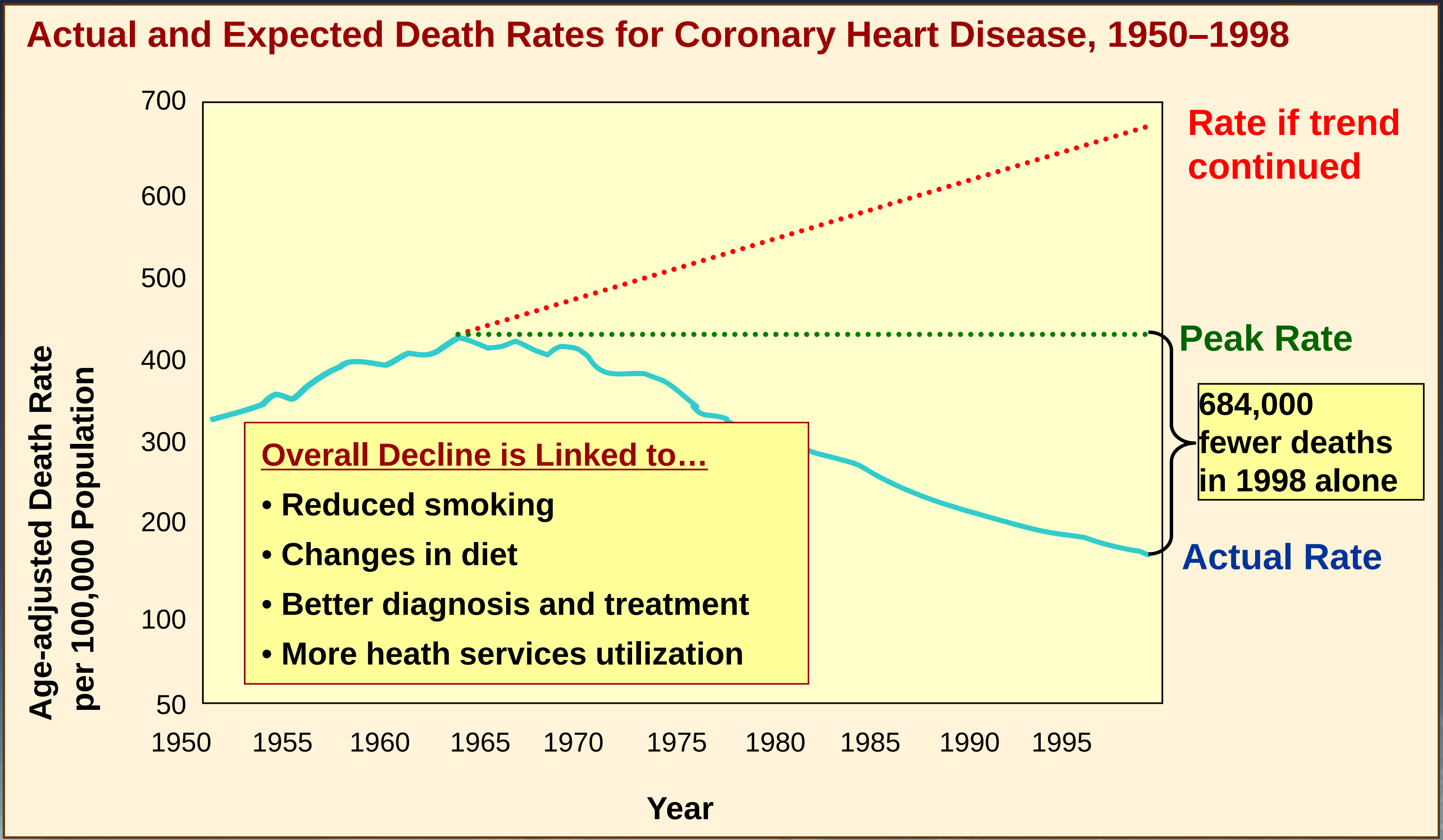
Why System Science Methods?

Nathaniel Osgood
Associate Professor
Department of Computer Science
Associate, School of Public Health
& Dept. of Community Health & Epidemiology
University of Saskatchewan
osgood@cs.usask.ca

7-23-2010

Public Health as "Redirecting the Course of Change"

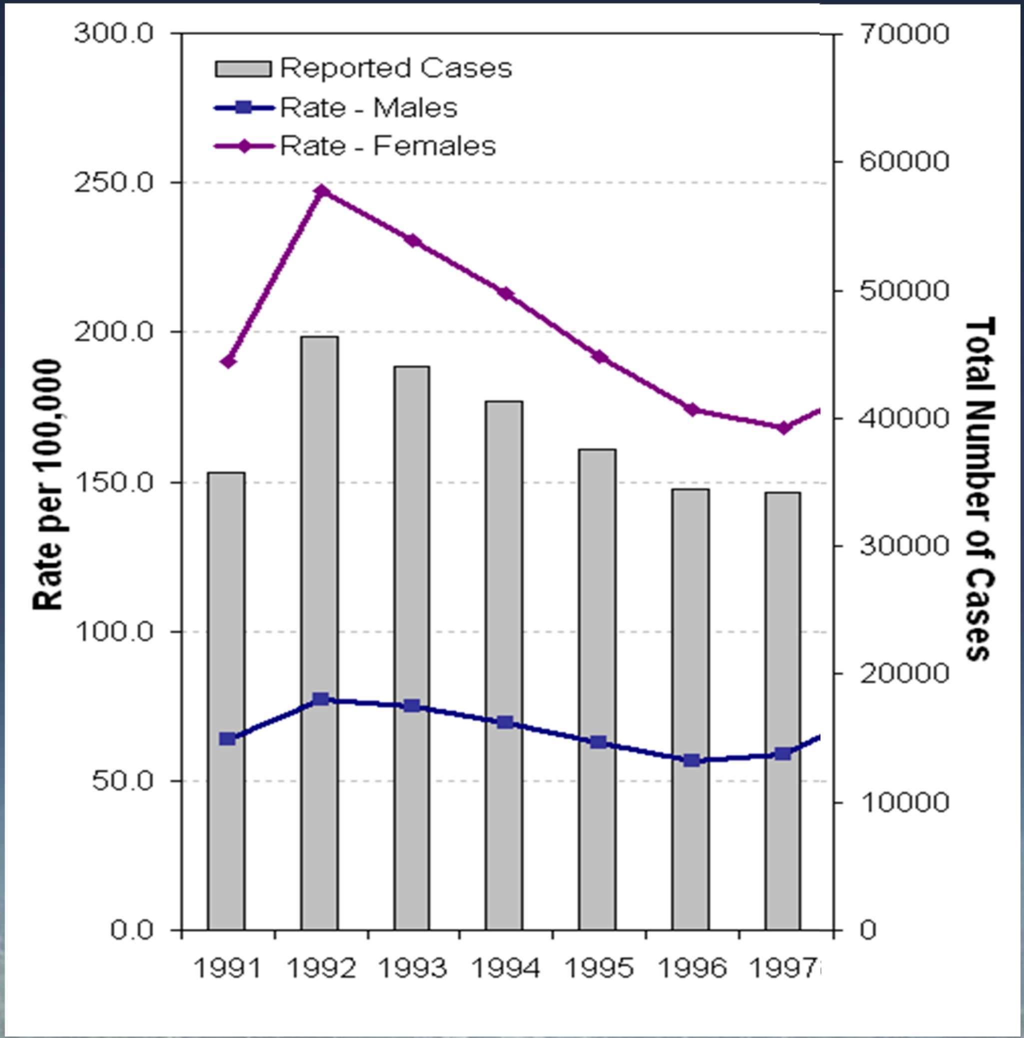


Adapted from Homer & Millstein 2007

Marks JS. The burden of chronic disease and the future of public health. CDC Information Sharing Meeting. Atlanta, GA: National Center for Chronic Disease Prevention and Health Promotion; 2003.

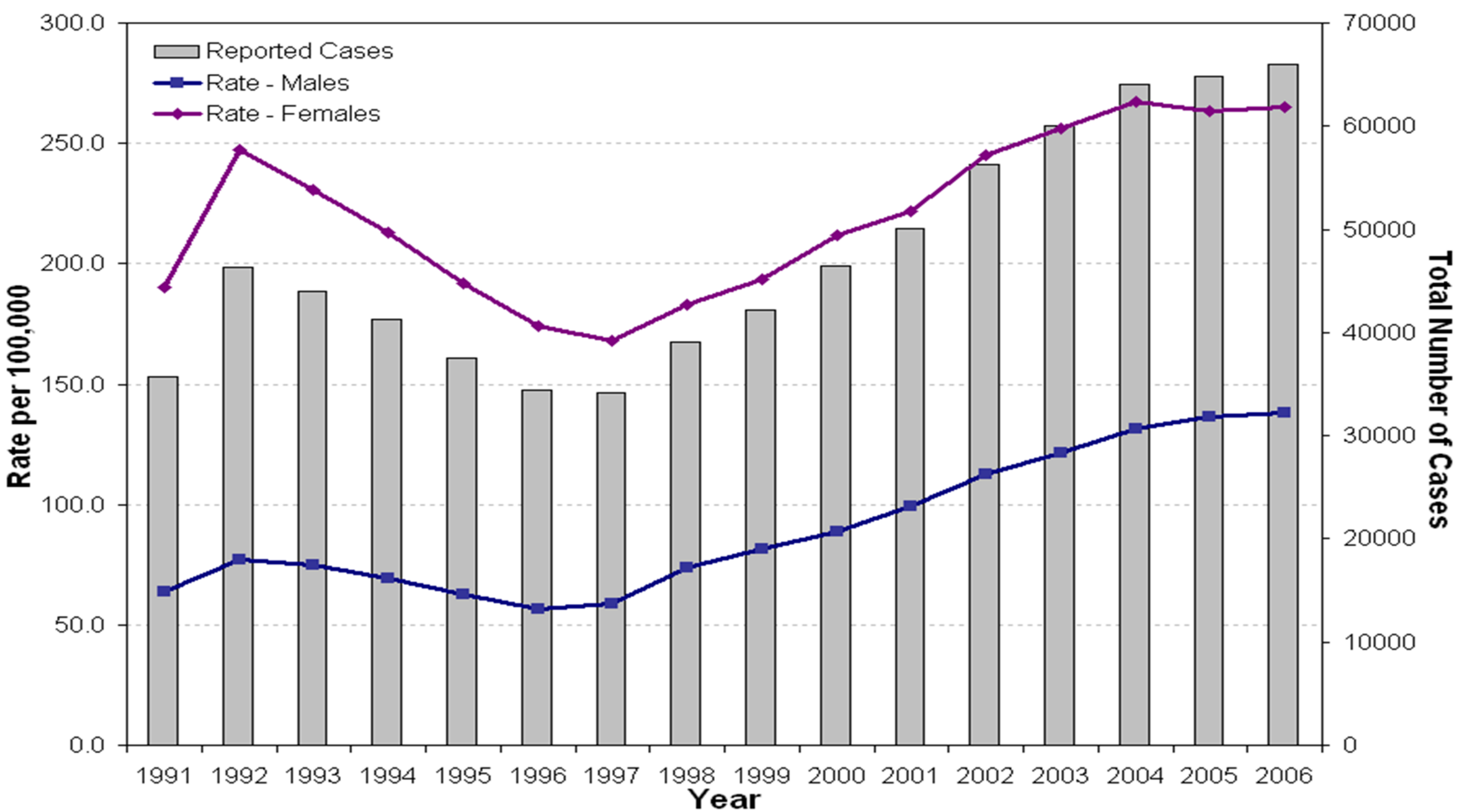
Centers for Disease Control and Prevention. Achievements in public health, 1900-1999: decline in deaths from heart disease and stroke -- United States, 1900-1999. MMWR 1999;48(30):649-656.
Available at <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm4830a1.htm>

Public Health as "Redirecting the Course of Change"



- Adapted from Tom Wong, 2007
- Data for 2005 and 2006 are preliminary and are anticipated to change
- Source: Surveillance and Epidemiology Unit, Community Acquired Infections Division, PHAC

Public Health as "Redirecting the Course of Change"



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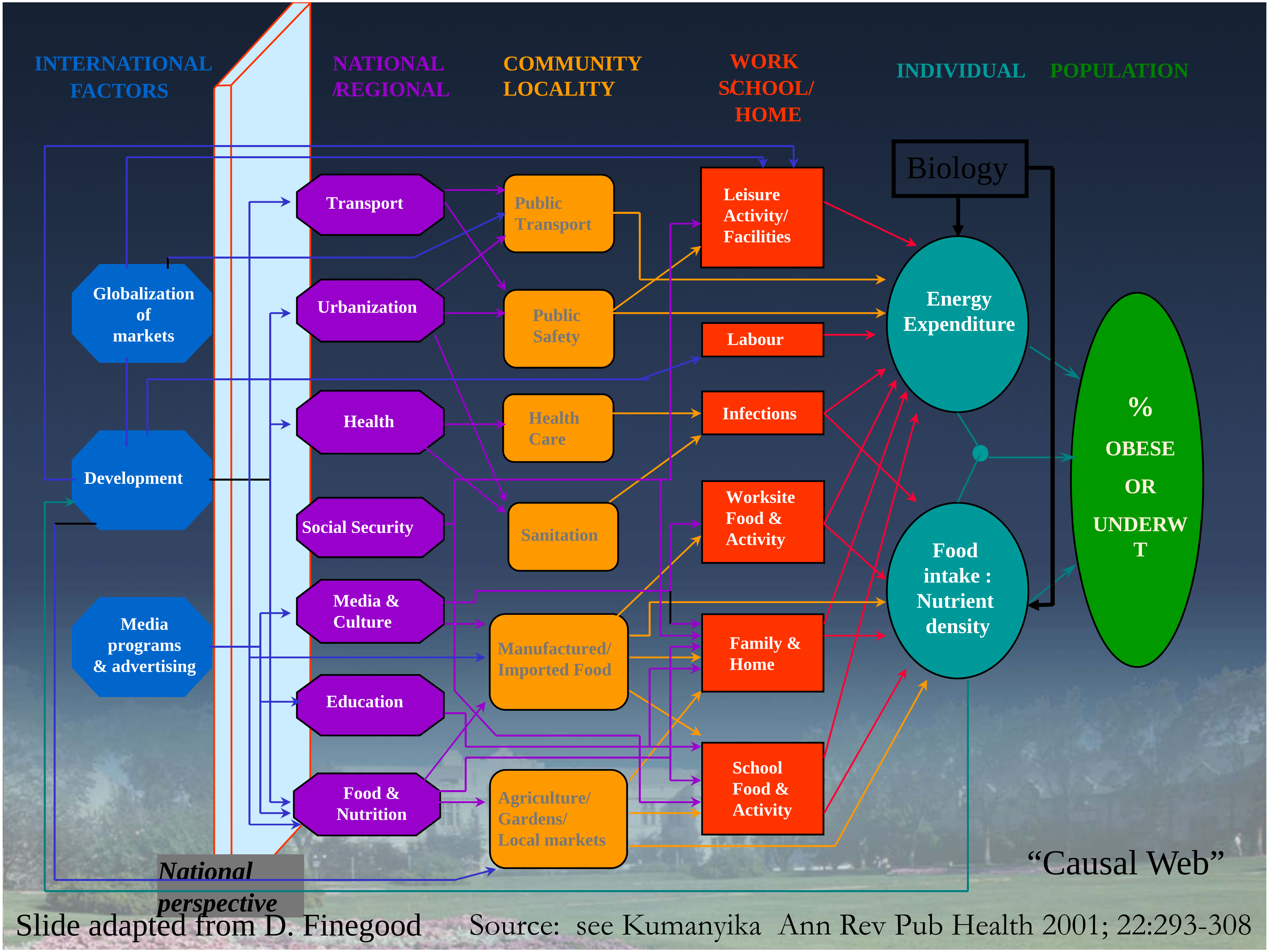
Securing Public Health Requires Grappling with Great Complexity

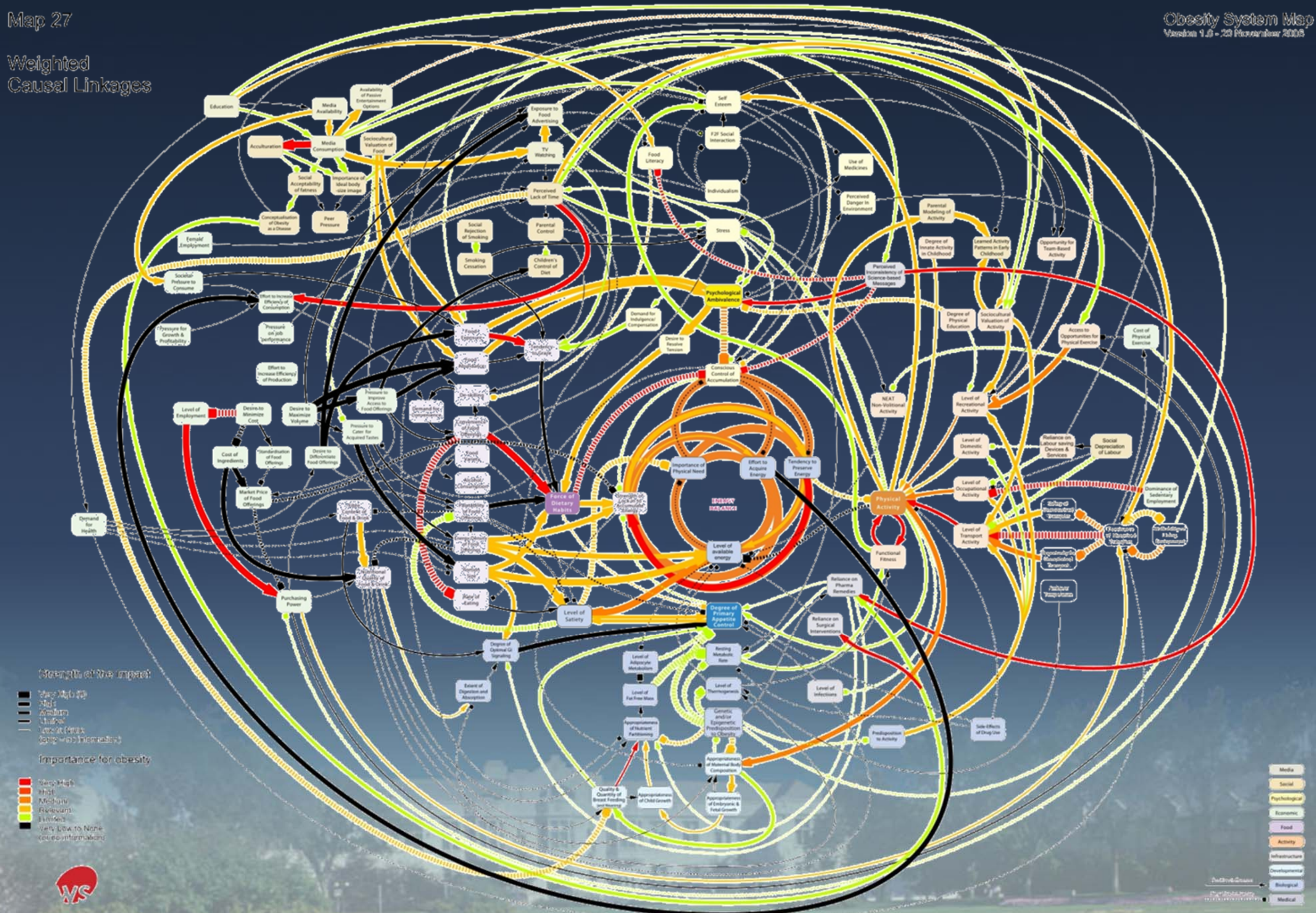
- **Structural Complexity**

- **Dynamic Complexity**

Anderson & May
Infectious Diseases of Humans


INTERNATIONAL FACTORS
NATIONAL /REGIONAL
COMMUNITY LOCALITY
WORK SCHOOL/ HOME
INDIVIDUAL
POPULATION
Biology
Globalization of markets
Development
Media programs & advertising
Transport
Urbanization
Health
Social Security
Media & Culture
Education
Food & Nutrition
Public Transport
Public Safety
Health Care
Sanitation
Manufactured/ Imported Food
Agriculture/ Gardens/ Local markets
Leisure Activity/ Facilities
Labour
Infections
Worksite Food & Activity
Family & Home
School Food & Activity
Energy Expenditure
Food intake : Nutrient density
% OBESE OR UNDERWT
"Causal Web"
National perspective
Slide adapted from D. Finegood
Source: see Kumanyika Ann Rev Pub Health 2001; 22:293-308

Obesity System Map

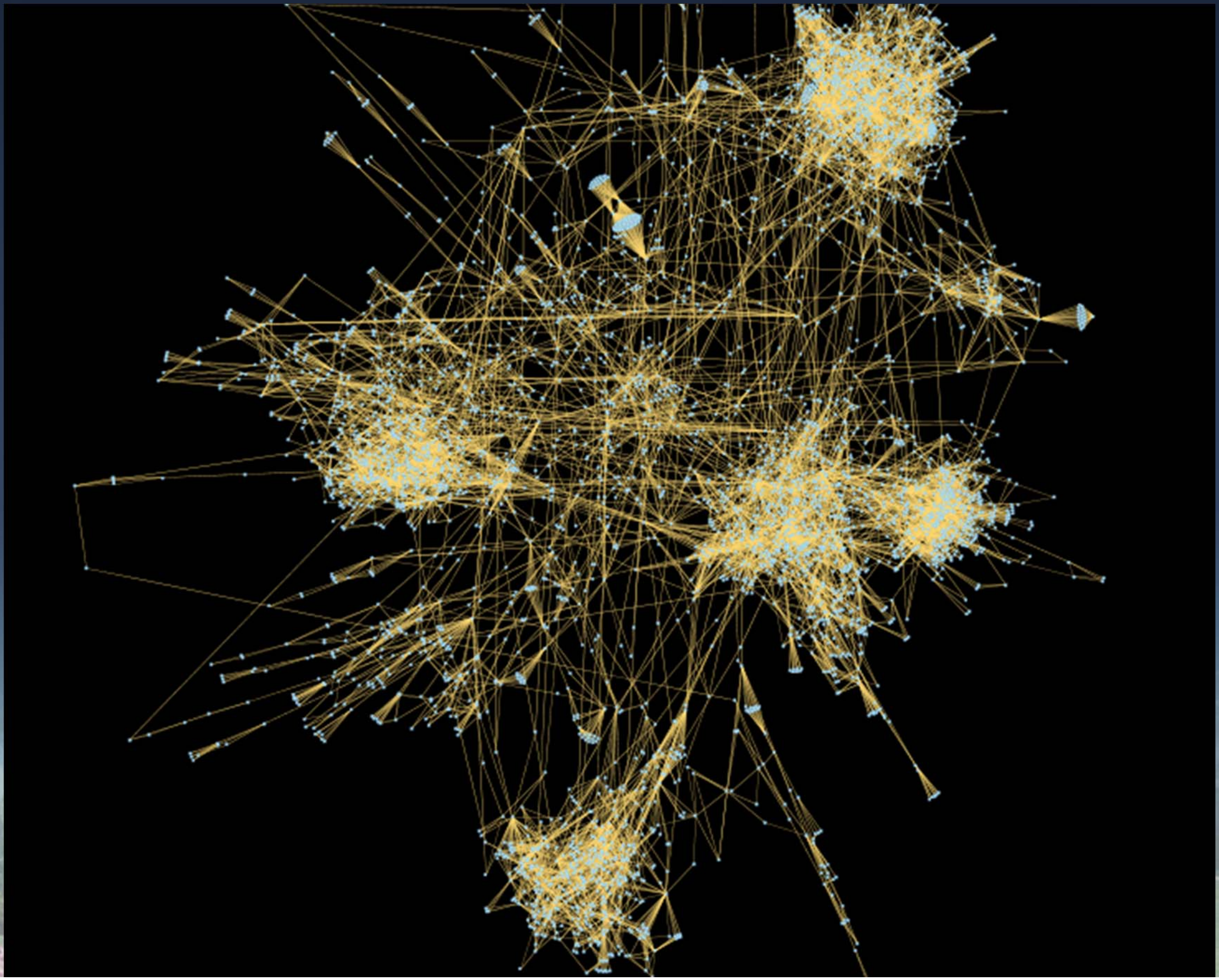


http://kim.foresight.gov.uk/Obesity/Obesity.html

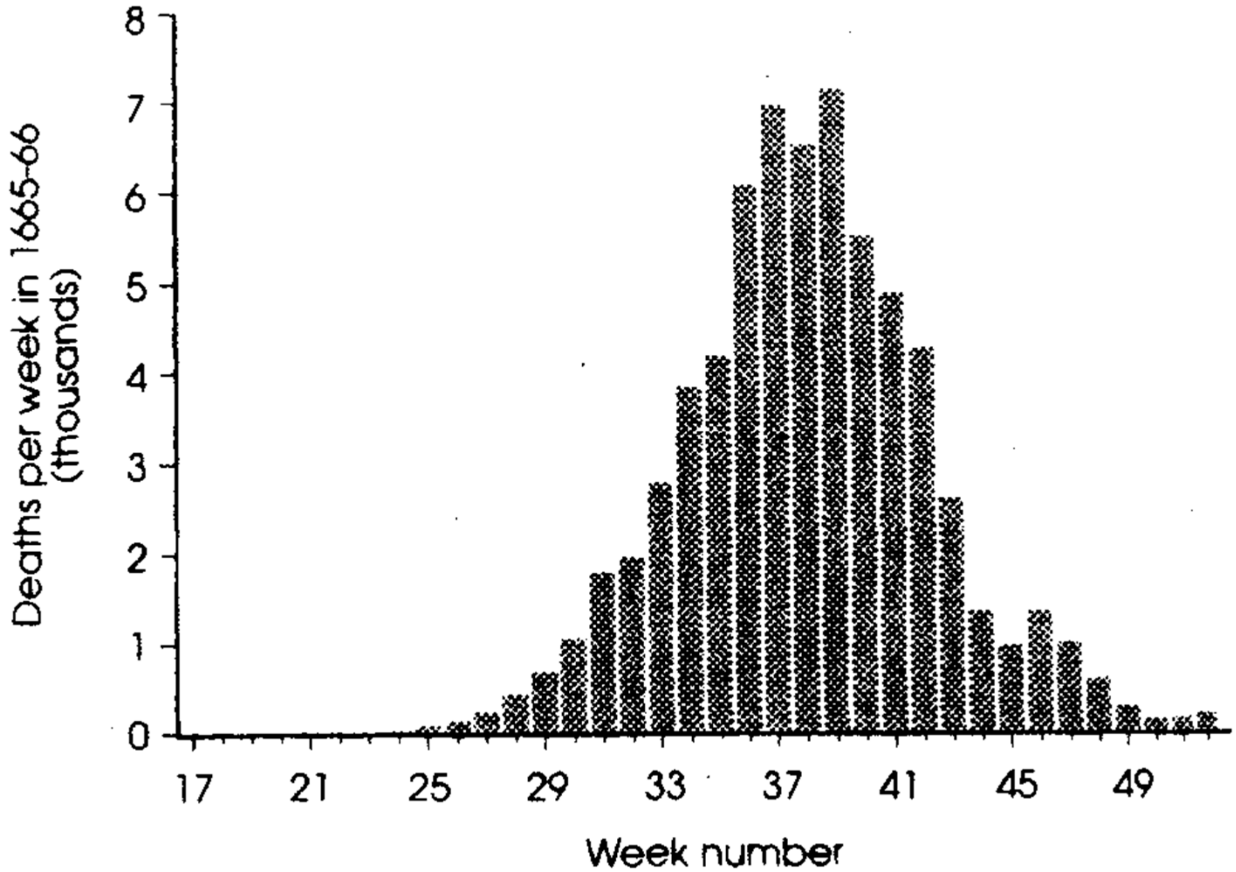
Slide adapted from D. Finegood

Importance of Bridging Individuals

TB Network Substructure



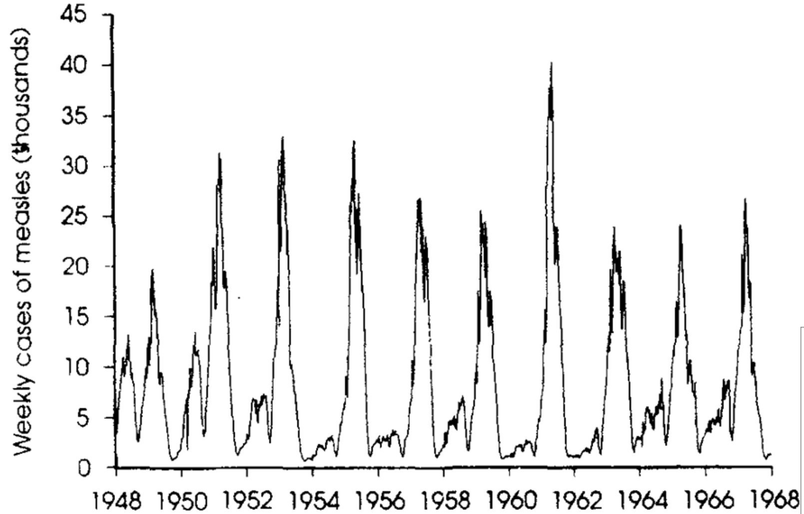
Dynamic Complexity:
Exponential Growth & Decay



Anderson & May
Infectious Diseases of Humans

Fig. 3.11. Recorded deaths from the bubonic plague in London during the year (data from Brayley 1722).

Dynamic Complexity:
Oscillations (Damped & Otherwise)



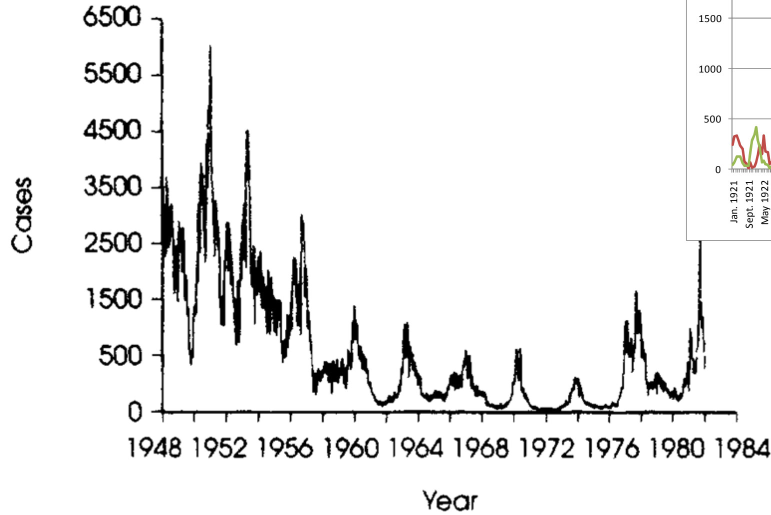
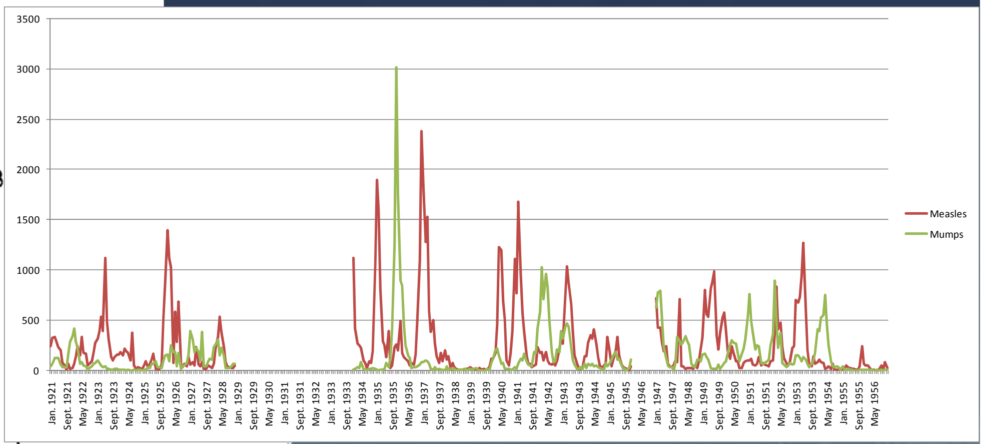


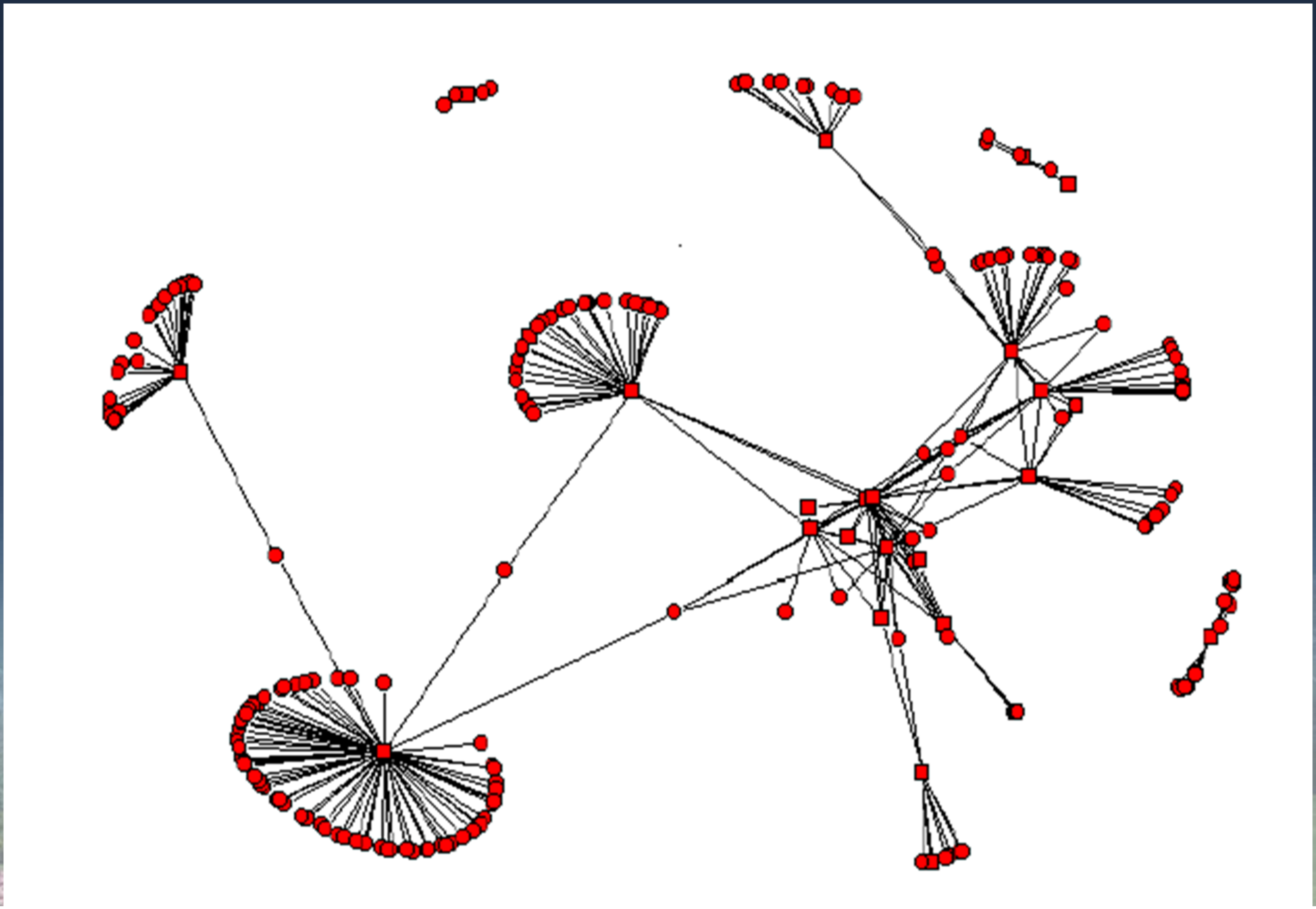
Fig. 6.8. Weekly case notifications of pertussis (whooping cough) in England and Wales for the time period 1948–82. Mass vaccination was introduced in 1956.



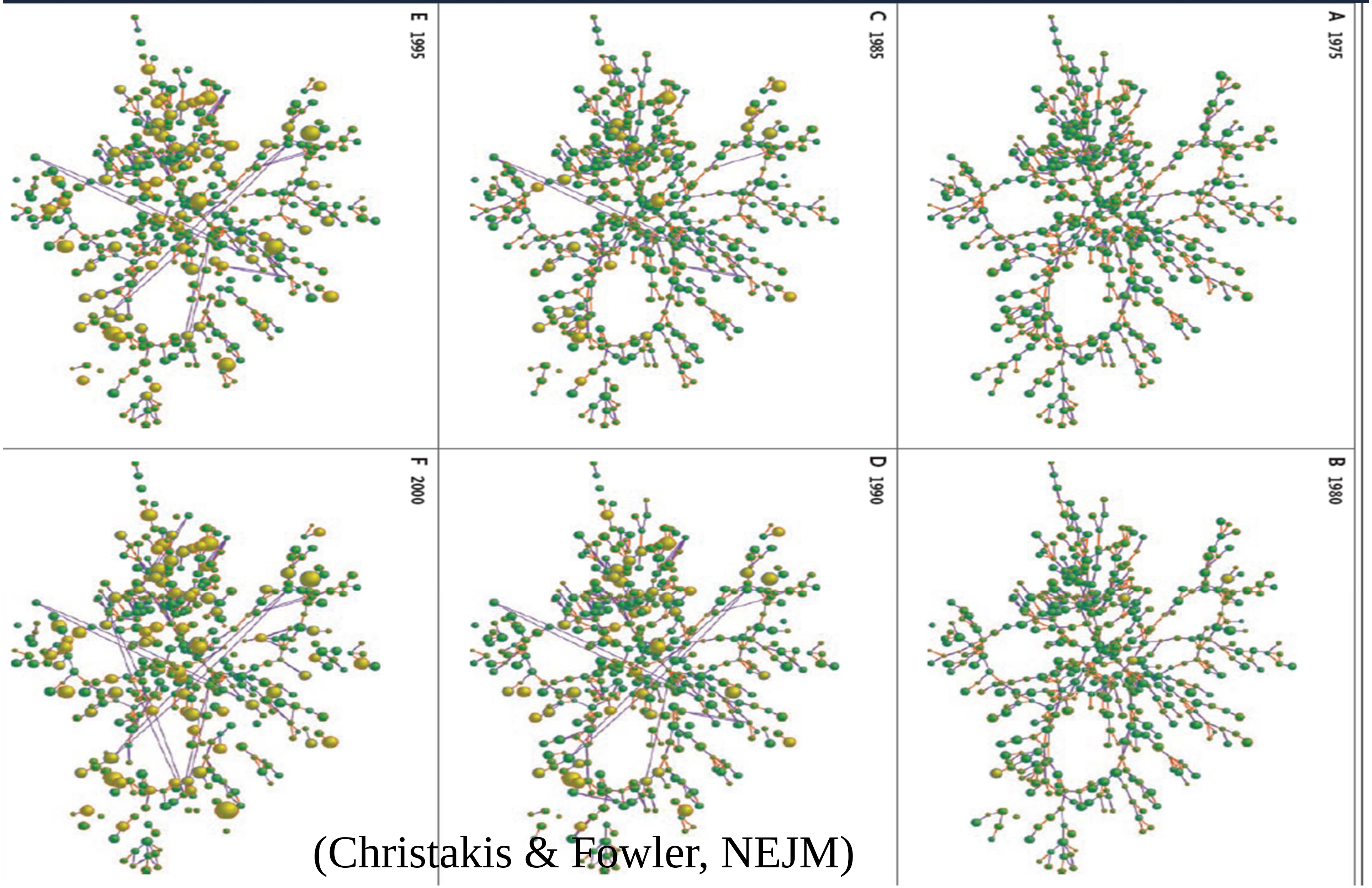
Dynamic Complexity:
Tipping Points

- **Sufficiently fast delivery of treatment or high enough vaccination rates can prevent an infection from being able to establish itself**
- **While the components of the system are the same (most individuals remain susceptible), the population as a whole is protected**
  - **This “herd immunity” is a feature of the system as a whole, not of its individual pieces**

Persistence of Endemic Infection in Network "Cores"



Network Spread of Obesity



(Christakis & Fowler, NEJM)

Emergent Patterns

- **These patterns are structured, yet are very different from what we see in *any particular component of the system***
- **These patterns reflect "emergence" from the underlying "complex system" that gives rise to them**
- **Anticipating this emergence is required to enact robust & cost-effective interventions – or to avoid doing harm**

Regularities Arise from Underlying *Processes*

- **The components of the system are tightly interrelated, not independent**
- **Many of the features of time series from a system are driven by the same underlying processes – interactions between**
  - **Natural history of infection**
  - **Demographic change of the population**
  - **Mechanisms of infection transmission**
  - **Risk behaviour & risk perception**
  - **Health system response**
- **The emergent behaviour of the system comes not from one component in isolation, but from combination of all**

Complexities & Systems Effects Matter for Intervention Selection

- Blowback, multiplier effects
- Presence of "tipping points"
- Tradeoffs of prevention vs. screening vs. contact tracing & treatment
- Interaction between infections and with chronic diseases
- Evaluation of focused intervention on different parts of system or classes of individuals
- Evaluation of intervention portfolios

Challenges of Complex Systems

- **Counter-intuitive behavior**
- **Misperceptions**
- **Policy resistance**
- **These phenomena pose problems for**
  - **Learning from experience: Painful & slow**
  - **Coordinating: Actors in 1 area of the system often have poor sense as to how actions of actors in other areas of the system affect them ⇒ risk of working at cross purposes**
  - **Deciding: Unclear tradeoffs between choices**
  - **Designing: Not clear how to best structure the roles/responsibilities of the actors, reporting,etc**

Policy Resistance

- **Development of pathogen drug resistance**
- **Cutting cigarette tar levels reduces cessation**
- **Cutting cigarette nicotine levels leads to compensatory smoking**
- **Targeted anti-tobacco interventions lead to equally targeted coupon programs by tobacco industry**
- **Charging for supplies for diabetics leads to higher overall costs by increases costs due to reduced self-management, faster disease progression**
- **ARVs prolong lives of HIV carriers, but lead to resurgent HIV epidemic due to lower risk perception**
- **Attempts to economize by understaffing STI clinics leads to long treatment wait, greater risk of transmission by infectives & bigger epidemics**
- **Antibiotic overuse worsens pathogen resistance**
- **Antilock breaks lead to more risky driving**
- **Natural feedback: Intergenerational “Vicious Cycles”**

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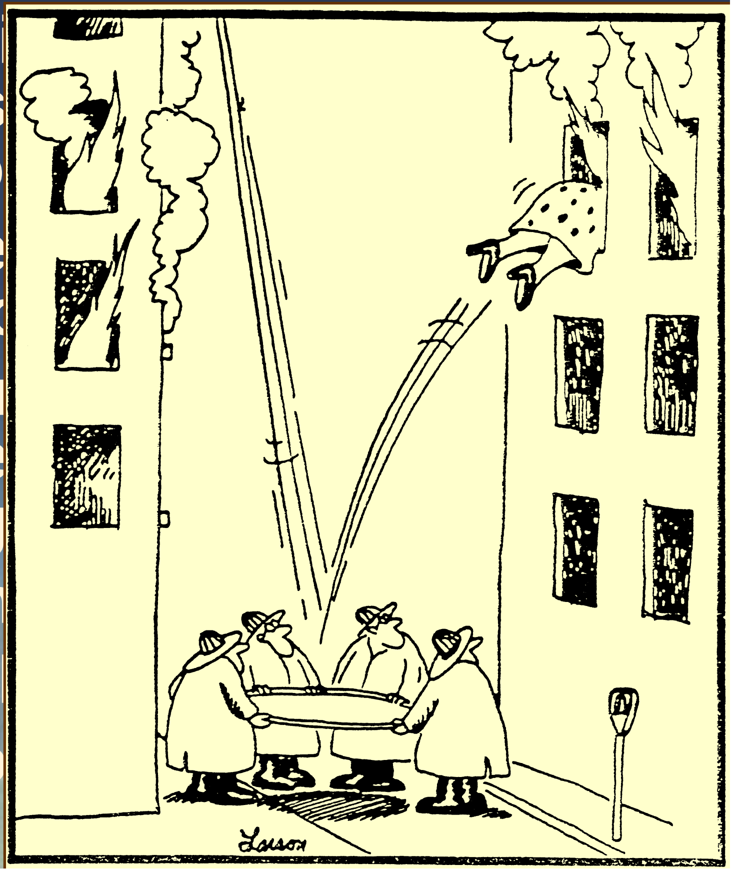


A Systems Problem

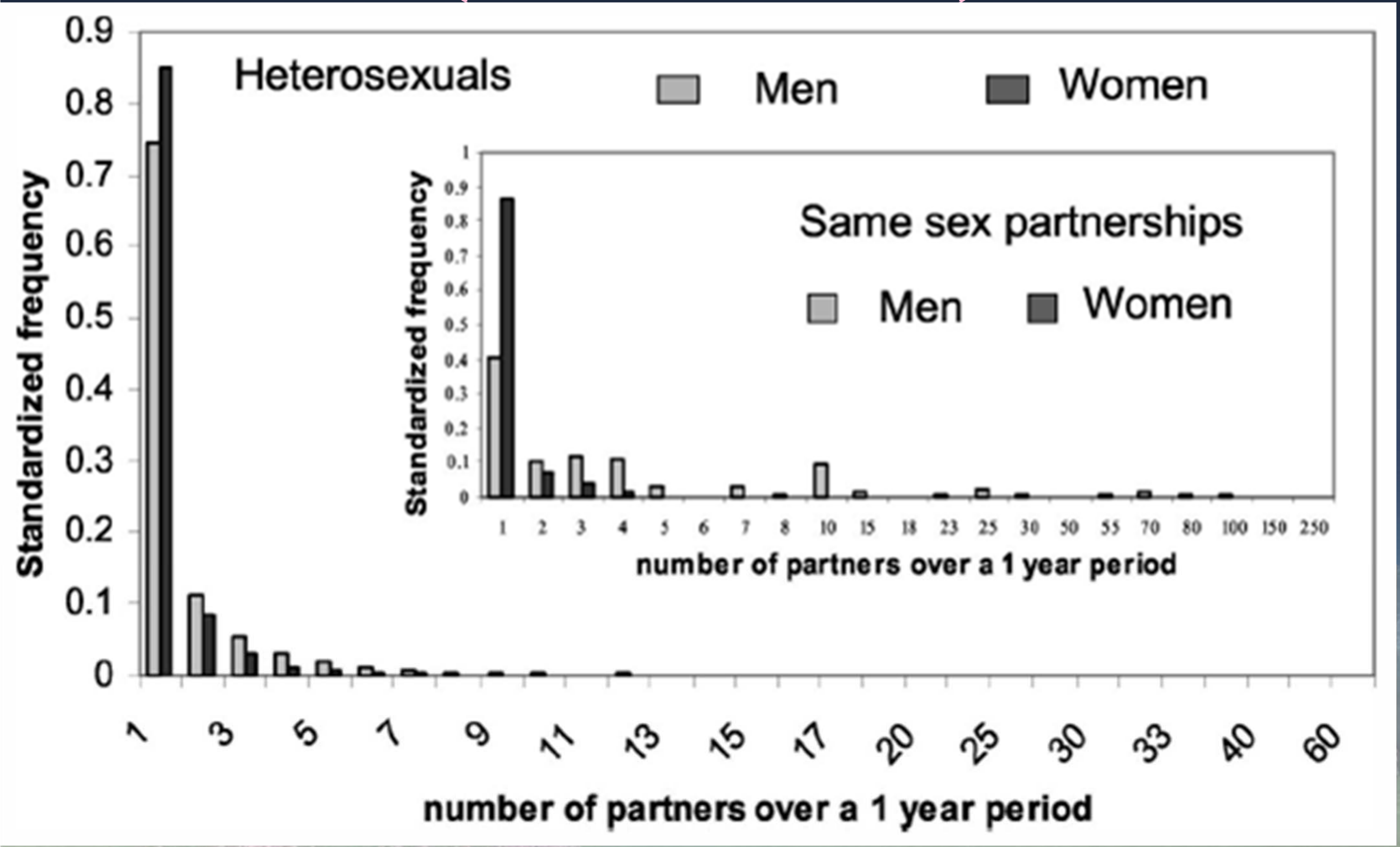
"I've got it, too, Omar … a strange feeling like we've just been going in circles."

Larson, The Far Side

Emergence Reflects Complexity of Underlying System

- Interactions
  - Interpersonal
  - Between conditions (e.g. STIs & HIV, HCV&HIV, Chronic & Infectious illness)
- Delays
  - Presentation of symptoms/Contact tracing/Identification of asymptomatic
- Feedbacks
  - Intergenerational/social network mediated
  - Immune system
  - With healthcare system
  - Behavior change after knowledge of health status
  - Risk perceptions
- Nonlinear: Risk, cost, intervention synergies
- Heterogeneity in progression, behaviour

Heterogeneities (Contact Rates)



Imperatives for Protecting Health


To Promote the Science and Art of Medicine and the Betterment of the Public Health

September 21, 2005, Vol 294, No. 11 — Pages 1297-1454

JAMA

The Journal of the American Medical Association

September 21, 2005

ORIGINAL CONTRIBUTIONS

Financial Anatomy of Biomedical Research ... 1333
H. Moses III, E. R. Dorsey, D. H. M. Matheson, S. O. Thier

The Physician-Scientist Career Pipeline in 2005: Build It, and They Will Come ... 1343
T. J. Ley, L. E. Rosenberg

Salvador Dalí (1904-19
Washington, 1950, Spa

EDITORIAL

Medical Research—
State of the Science
P. B. Fontanarosa, C. D. DeAngelis, N. Hunt

www.jama.com

COMMENTARIES

Protecting Health—
The New Research Imperative

Julie L. Gerberding, MD, MPH

The health of a people is really the foundation upon which all their happiness and all their powers as a state depend.

—Benjamin Disraeli

HEALTH IS MORE THAN THE ABSENCE OF THREATS OR disease and disability; it is a precious resource that helps to create productive satisfying lives for ourselves and our families and economic security for our nation. A very high value is placed on health, but all too often health is not protected. Indeed, the current investments in health protection are far overshadowed by expenditures to restore health once it is lost. Although the United States currently spends $1.9 trillion a year, or 15.5% of the gross domestic product, on health care, less than 1% of the $1.9 trillion is spent on protecting health and preventing the illnesses and injuries that require health care services in the first place.[1,2] A similar disequilibrium characterizes the US health research portfolio.[3]

Ordinary but critically important risks to health come in many forms—genetic predispositions, gestational factors, socioeconomic circumstances, environmental conditions, personal lifestyles and behaviors, and lack of effective medical care.[4] Individually these risks, many of which are preventable, adversely affect the health of millions of people, and collectively these risks create enormous disparities in health across the population. As a result, an alarming proportion of people are vulnerable to declining health status, and in most compelling impact than in the past. Since September 11, 2001, the Centers for Disease Control and Prevention (CDC) Emergency Operations Center has been activated to address at least 21 urgent national or international health threats. Protecting health in the context of the anthrax terrorism attacks, the global outbreak of severe acute respiratory syndrome (SARS), the emergence of avian influenza in Asia—and more importantly, preparing for new and sometimes unimaginable threats—is a daunting but essential responsibility.

From the Bench and Beside to the Frontlines of Health Protection

These unprecedented threats to health can be combated successfully, disparities can be reduced, and the nation's health and economic security can be protected, but only if bold steps are taken to rebalance the current investment portfolio. Health protection must be prioritized—through preparedness; health promotion; and disease, injury, and disability prevention—at least as much disease treatment is prioritized, and these actions must occur now. Moreover, health protection research also must be prioritized to create a solid evidence-based foundation for the policies, programs, and practices necessary for success—at least as much as biomedical research is prioritized. Enormous investments in biomedical research have created new knowledge about the causes of illness, allowed the diagnosis and treatment of an astonishing array of medical conditions, and increasingly, have identi-

Typical Current State

"Static view of problems that are studied in isolation"

Proposed Future State

"Dynamic systems and syndemic approaches"

"An imperative to shift from the typical view of static problems in isolation toward a future state in which the focus is on dynamic systems and syndemic approaches."

Currently, application of complex systems theories or syndemic science to health protection challenges is in its infancy."

Former CDC Director Julie Gerberding

Adapted from Millstein, 2007

Gerberding JL. Protecting health: the new research imperative. Journal of the American Medical Association 2005;294(11):1403-1406.

Strengths & Weaknesses of Reductionist Approaches

- **Traditional scientific approaches have pursued a primarily reductionist strategy**
- **This strategy has offered profound insights into how mechanisms work in isolation, but limited understanding how the connections between mechanisms combine to yield overall behaviour**
- **Much observed behaviour is emergent – results from the collective interaction of a set of components, rather than any component in isolation**

Missing the Forest for the Trees

- **By itself, traditional reductionist scientific approach to understanding health problems is via specialized study**
  - **Fragmented understanding**
  - **“Silos”**
- **Many complexities concerning are missed**
  - **Interactions/relationships**
  - **Context**
- **We often get a good understanding of the parts – but little understanding of the whole**

A More Holistic "Systems" Approach

- **Systems science can help us visualize understand implications of connections between model components**
- **A key way in which system science aids this is through the use of systems models**
  - **These models are simplified representations of a hypothesized situation that obtains in reality**
  - **The models help us reason about the implications of our understanding**

A Metaphor for Scientific Exploration

Complementary Model Types

- **Static Models**
  - **Models help us understand connections between system components, but don't explicitly represent time**
  - **Aid reasoning about structure of system**
- **Dynamic models**
  - **Aid in understanding dynamic implications (consequences over time) of system structure & choices**

Social Network Analysis

- **Understanding structural relationship between parties**
- **Understanding how network position influences patterns of health**
- **Identifying highly influential or critical parties**
- **An important enabler for and “synergizer” with dynamic modeling**
- **(Dynamic extensions are possible)**

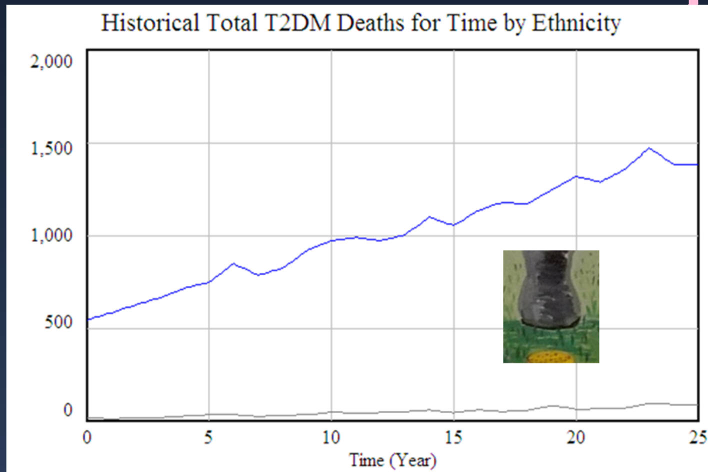
Dynamic Models

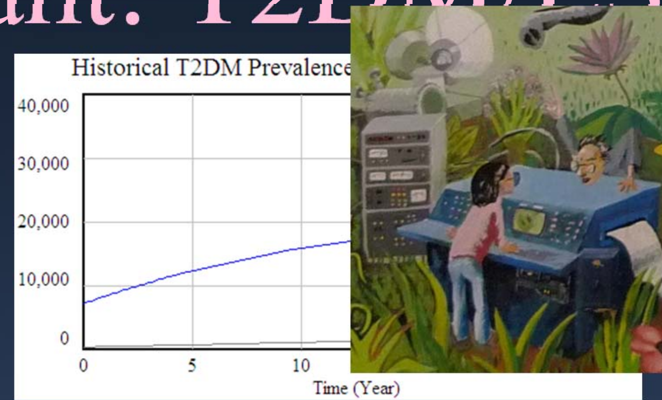
- **Simulation models represent hypothesized *causal relationships* between diverse factors**
- **Models provide a provide a way to examine diverse consequences of changes in one area of the system to the whole system**
- **Models help us and system actors to understand**
  - **System vulnerabilities, leverage points**
  - **Ways of fruitfully changing system structure**
  - **Improved ways of working together**

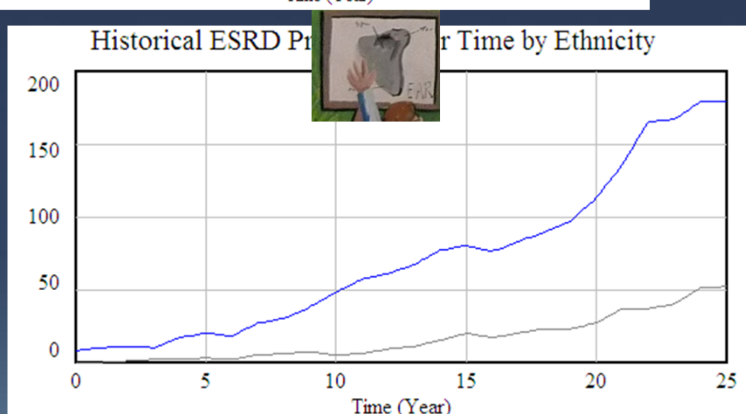
Analogy: Other Simulators to Improve Performance & Lower Risk

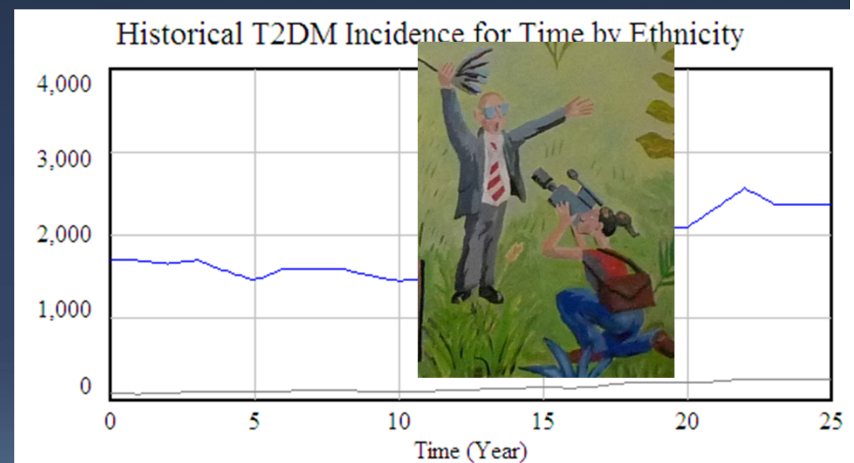
- **Pilot decision making: Flight simulators**
- **Climate policy: Climate simulators**
- **Process & power plants: Plant simulators**
- **Driver training: Vehicular simulators**
- **Street design & traffic flow regulation: Traffic simulators**
- **Construction coordination: Construction process simulators**

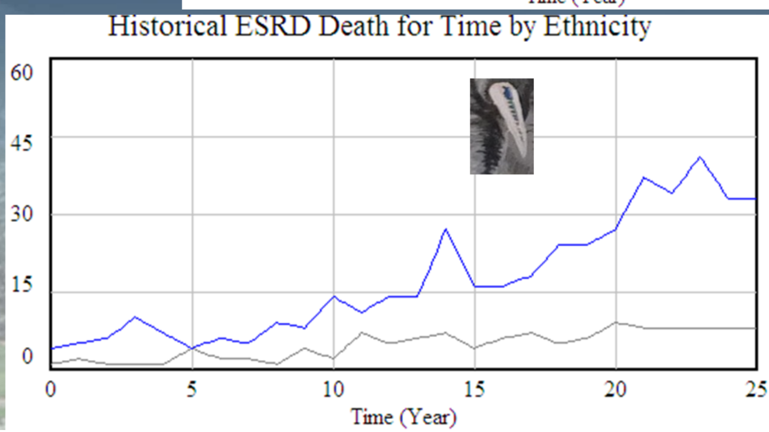
Pieces of the Elephant: T2DM/ESRD

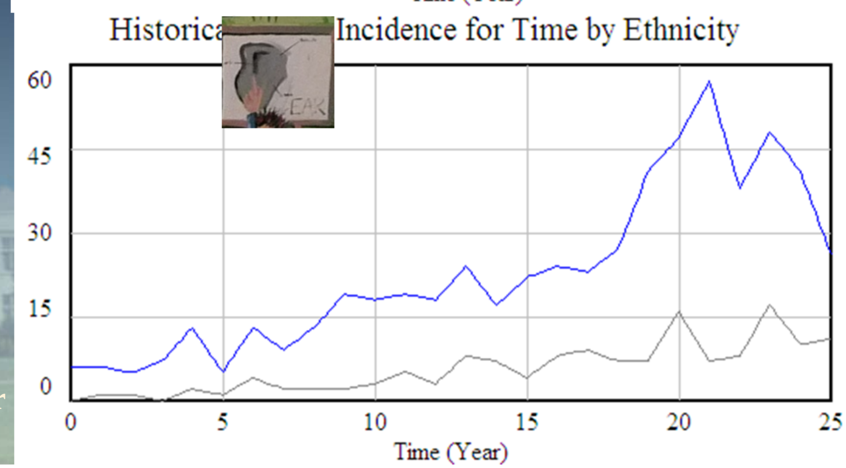












Regularities Arise from Underlying *Processes*

- **The time series shown are tightly interrelated, not independent**
- **Many of the features of the time series are driven by the same underlying processes**
  - **Natural history of infection**
  - **Demographic change of the population**
  - **Mechanisms of infection transmission**
  - **Risk behaviour & risk perception**
  - **Health system response**
- **Simulation seeks insight from characterizing *causal structure* of those processes**

Understanding Intervention Impact⇒ Seek to Understand *Causal* Relationships

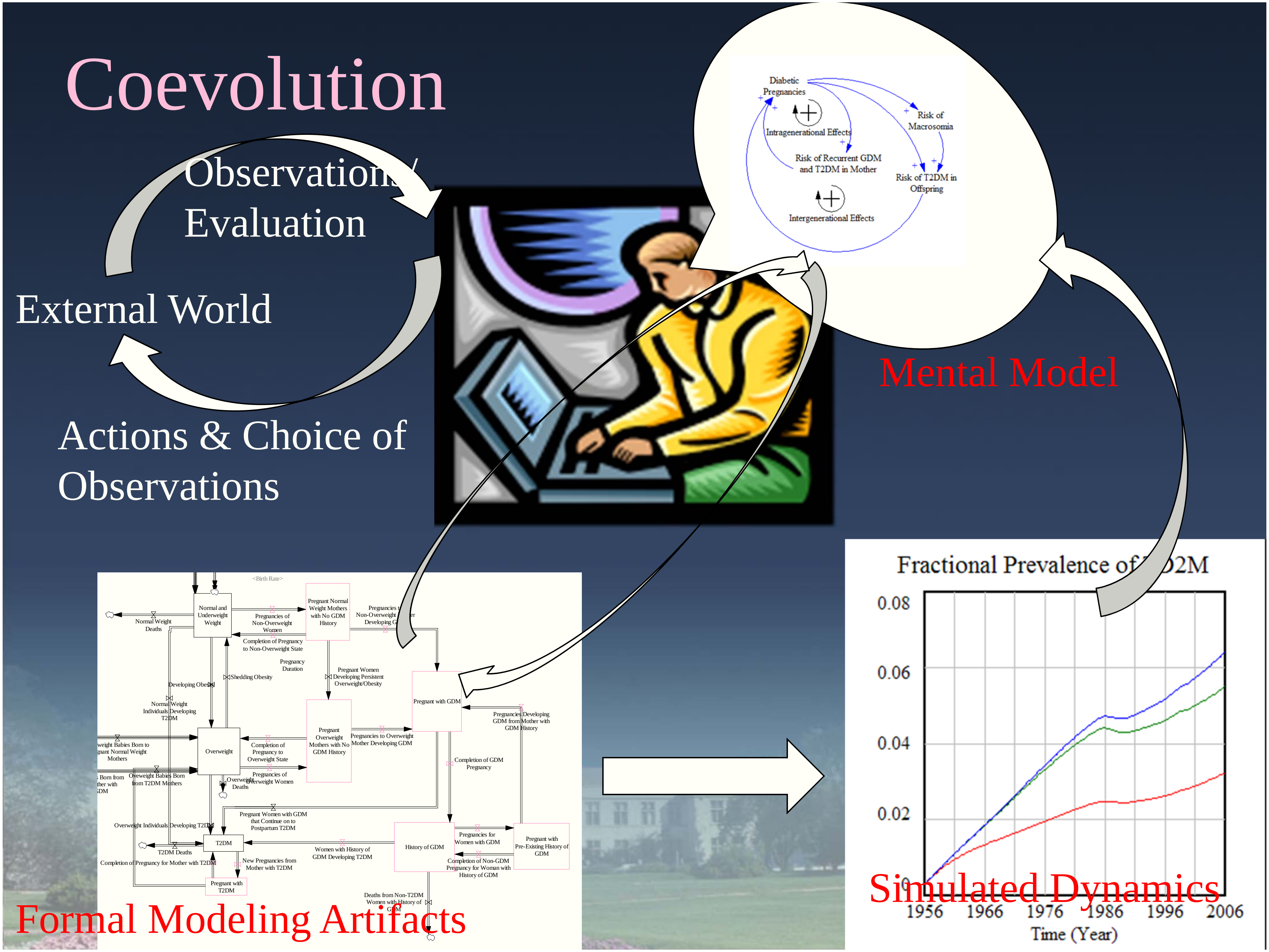
- **Progression of infection**
- **Immunity**
- **Response to treatment**
- **Mixing patterns (e.g. between communities)**
- **Intergenerational/social network mediated effects**
  - **Role modelling & Behavior change emulation**
- **Diversity in contact rates**
- **Strain interaction**
- **Diversity in symptoms**

Simulation Models: Some Uses

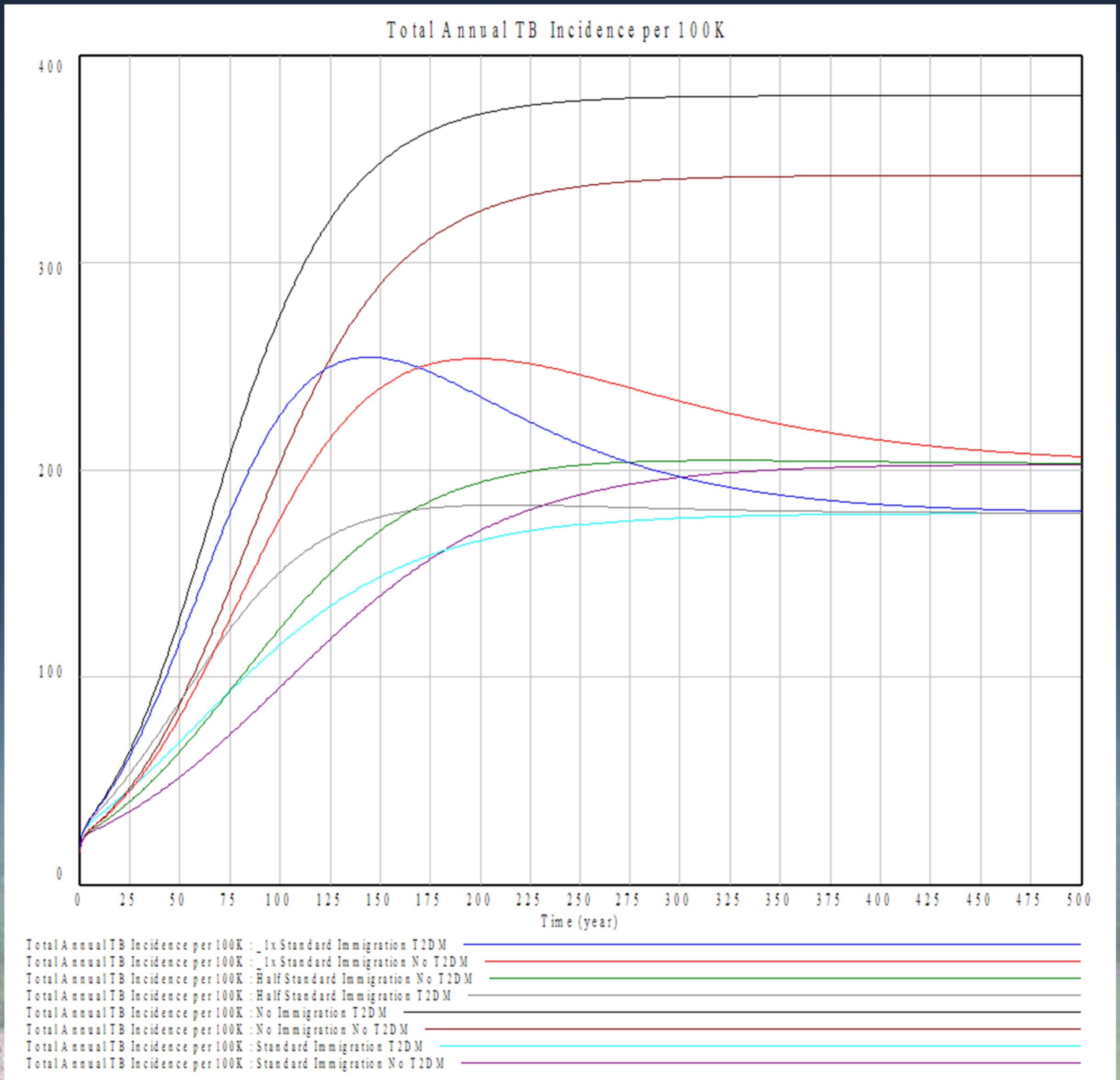
- **Make explicit mental models of causality, for discussion and collective refinement**
- **Assist in management of complex situations**
  - **Serve as "What if" tool for identifying desirable policies**
    - Cost-effective/High-leverage/Robust
  - **Understand trends & help make sense of interaction of diverse information, processes**
  - **Prioritizing research/data collection & identifying inconsistencies**
  - **Understanding commonalities between contexts, infection spread**
- **Communication (e.g. "learning labs")**

Simulation Models as Dynamic Hypotheses

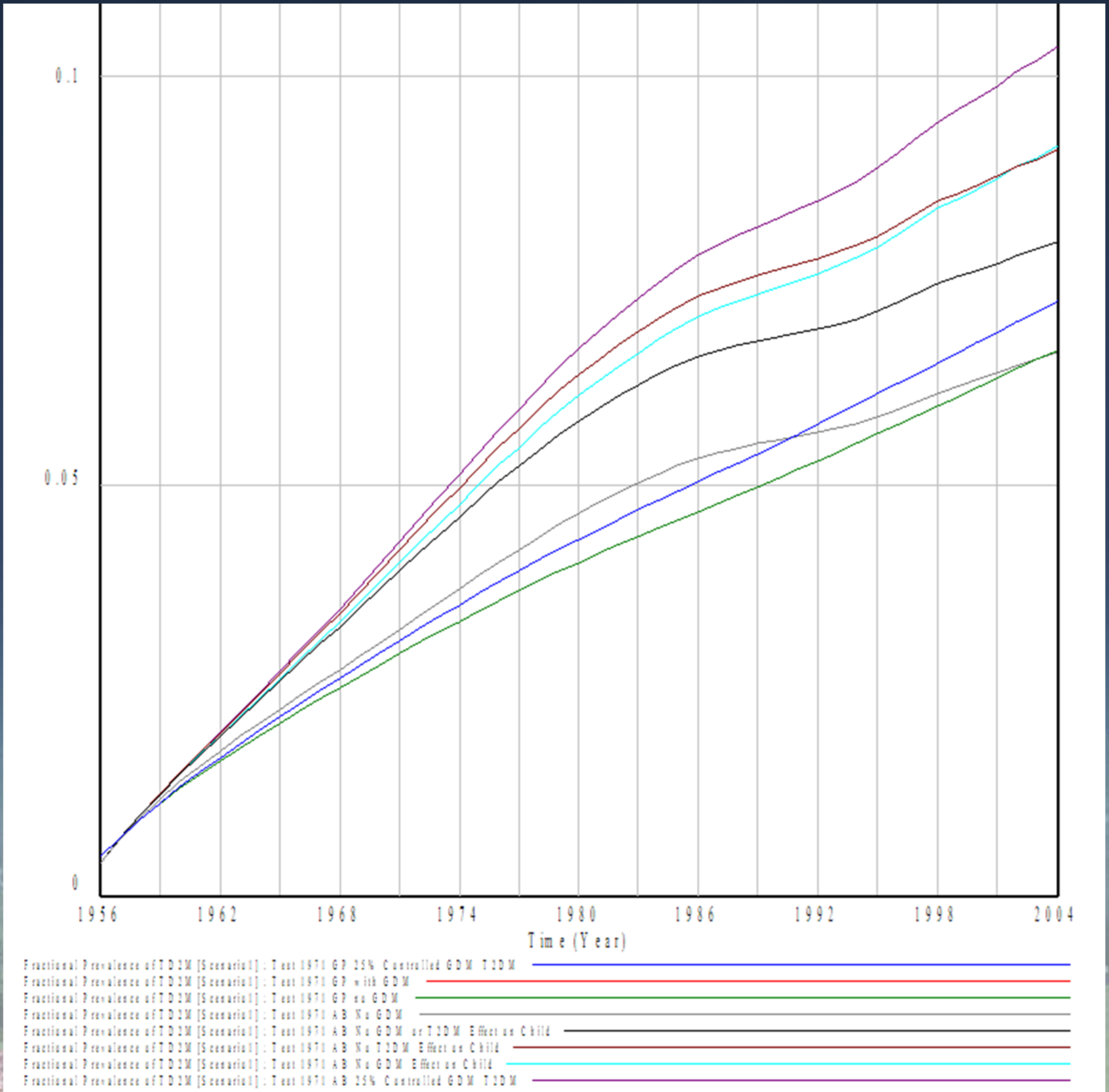
- **Explaining drivers for trends or anticipating intervention impact requires understanding processes underlying observables**
- **A model represents a hypothesis regarding the possible causal interaction of diverse factors often studied in isolation**
  - **Operationally captures a hypothesis for “how the system works” at certain level of description**
- **Model parameters: Detailed assumptions for particular epidemiological contexts**


Coevolution
Observation / Evaluation
External World
Actions & Choice of Observations
Diabetic Pregnancies
Intragenerational Effects
Risk of Macrosomia
Risk of Recurrent GDM and T2DM in Mother
Risk of T2DM in Offspring
Intergenerational Effects
Mental Model
Normal and Underweight Weight
Pregnant Normal Weight Mothers with No GDM History
Pregnant with GDM
Overweight
Pregnant Overweight Mothers with No GDM History
T2DM
History of GDM
Pregnant with Pre-Existing History of GDM
Pregnant with T2DM
Formal Modeling Artifacts
Fractional Prevalence of T2DM
0.08
0.06
0.04
0.02
0
1956
1966
1976
1986
1996
2006
Time (Year)
Simulated Dynamics

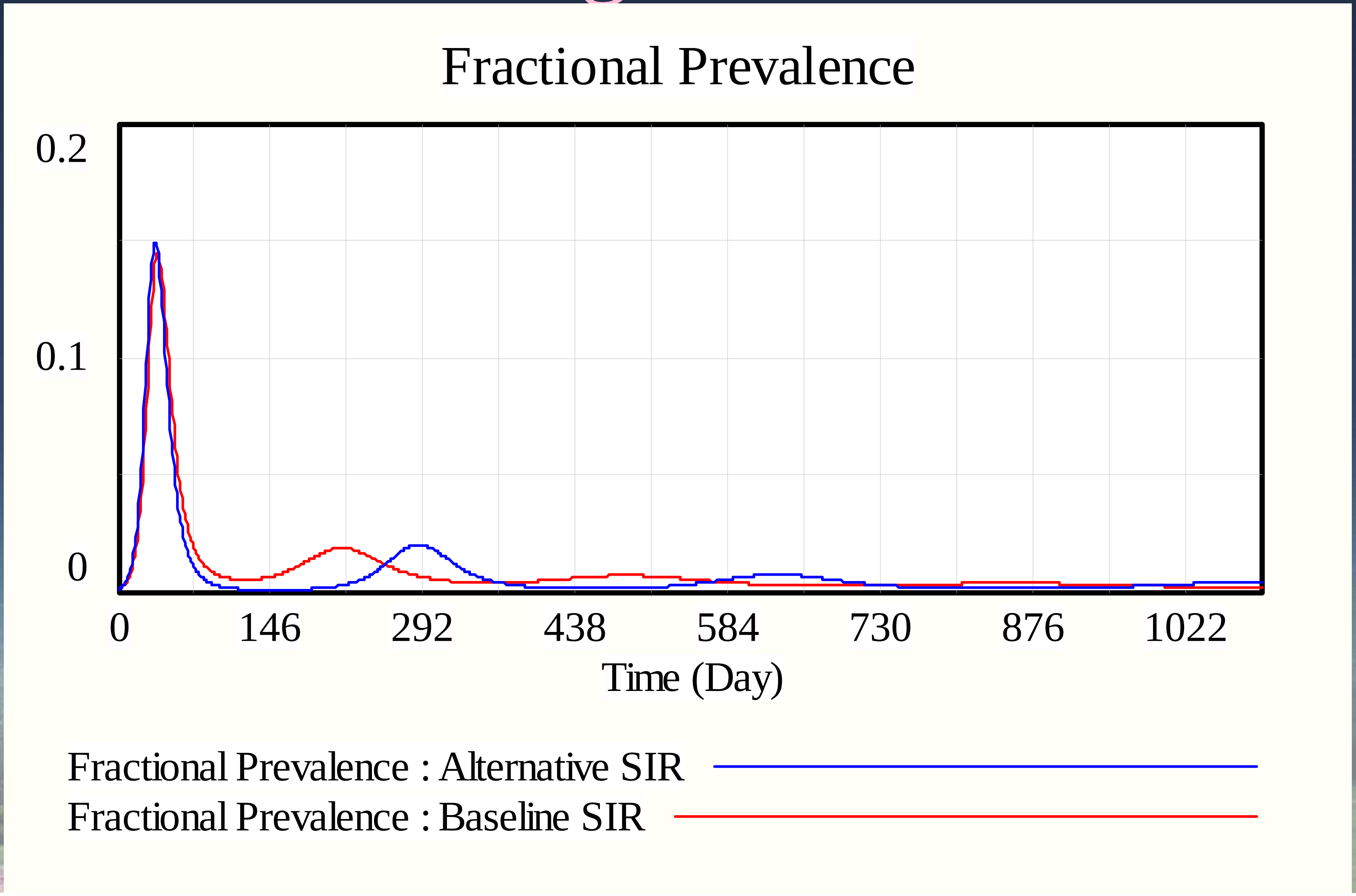
Scenarios for Understanding How Does X affect System



Policy Formulation & Evaluation



Model Can Be Used to Investigate Scenarios



Examples of Dynamic Modeling Approaches

- **System Dynamics Modeling**
  - **Feedback-centric modeling approach**
  - **Focuses on feedbacks & accumulations**
  - **Spans qualitative & quantitative methods**
  - **Supports rich mathematical analysis**
  - **Interactive model runs**

- **Agent-Based Modeling**
  - **Captures interactions between individuals within populations**
  - **Captures individual histories & trajectories**
  - **Gracefully represents network connections**
  - **Easier capturing of heterogeneity**
  - **Detailed policy planning**

Discrete Event Simulation

Simulates flow of individuals through processes

Captures resource use