System Dynamics Modeling:

Population Flows, Feedback Loops, and Health

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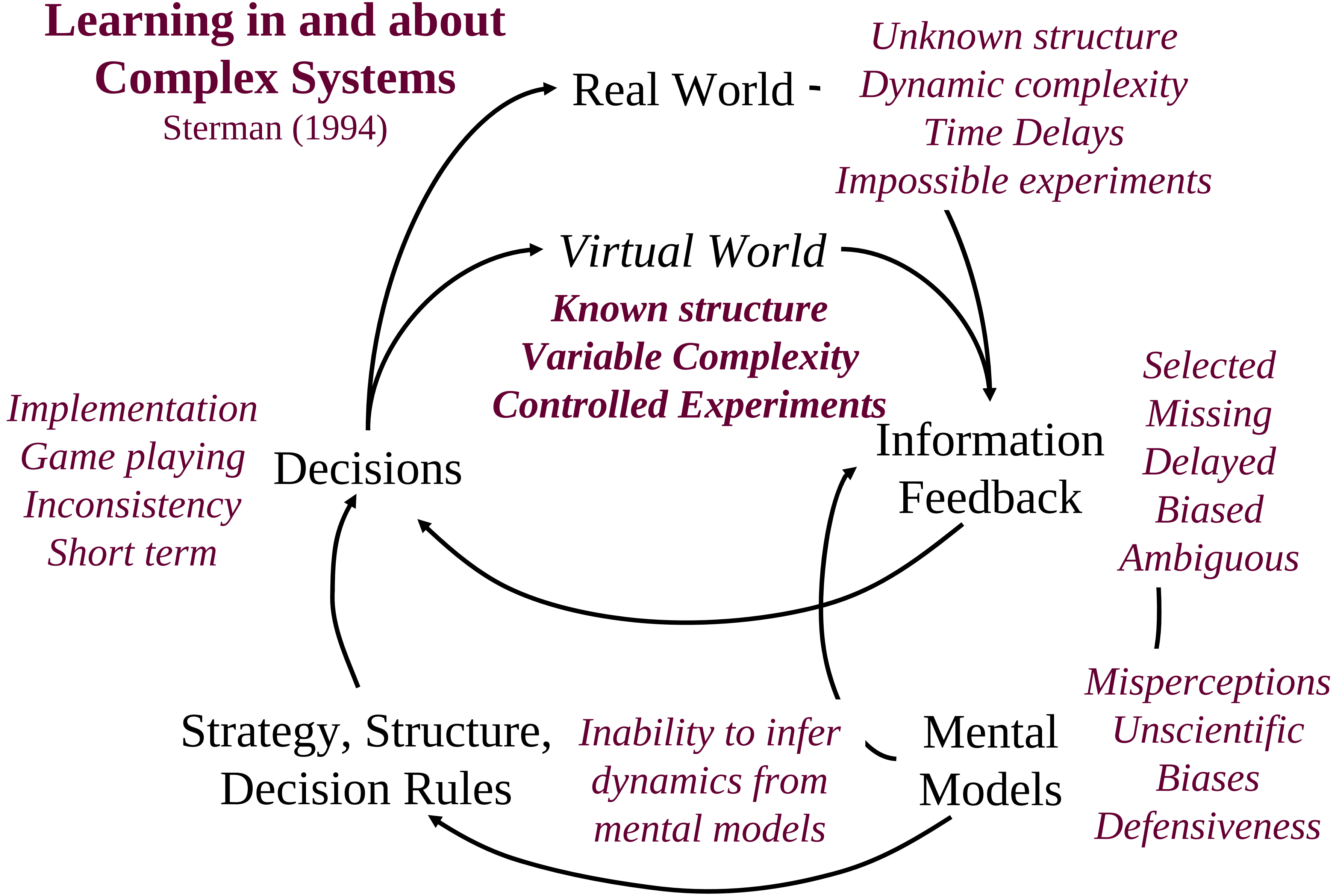
Learning in and about Complex Systems

Sterman (1994)



Dynamic Complexity arises because systems are…

- Changing over time
- Tightly coupled
- Governed by feedback
- Nonlinear: changing dominant structure
- History-dependent
- Self-organizing
- Adaptive
- Counterintuitive
- Policy resistant
- Characterized by tradeoffs

System Dynamics Contributions

- **Thinking dynamically**
  - Move from events and decisions to patterns of continuous behavior over time and policy structure
- **Thinking in circular causal / feedback patterns**
  - Self-reinforcing and self-balancing processes
  - Compensating feedback structures and policy resistance
  - Communicating complex nonlinear system structure
- **Thinking in stocks and flows**
  - Accumulations are the resources and the pressures on policy
  - Policies influence flows
- **Modeling and simulation**
  - Accumulating (and remembering) complexity
  - Rigorous (daunting) model evaluation processes
  - Controlled experiments
  - Reflection

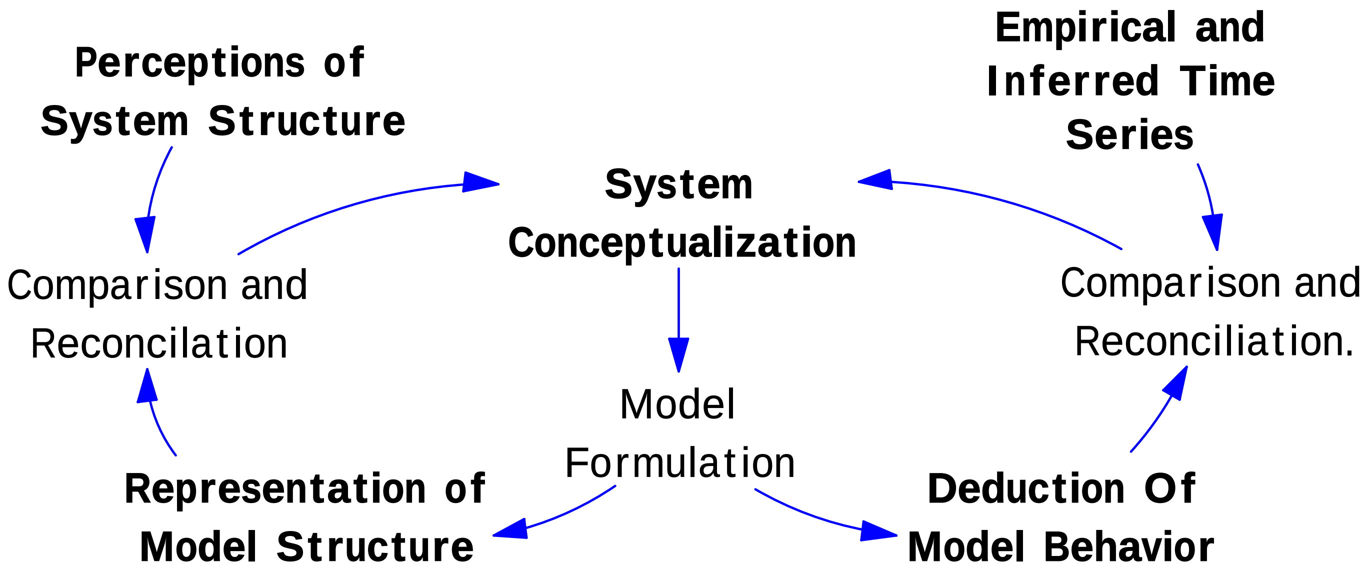
Changing Models of Population Health

What Accounts for Poor Health?

• God's will	
• Humors, miasma, ether	
• Poor living conditions, immorality (e.g., sanitation)	1840
• Single disease, single cause (e.g., germ theory)	1880
• Single disease, multiple causes (e.g., heart disease)	1950
• Single cause, multiple diseases (e.g., tobacco)	1960
• Multiple causes, multiple diseases (but no feedback dynamics) (e.g., multi-level modeling)	1980
• Dynamic feedback among afflictions, living conditions, and public strength (e.g., syndemic)	2000

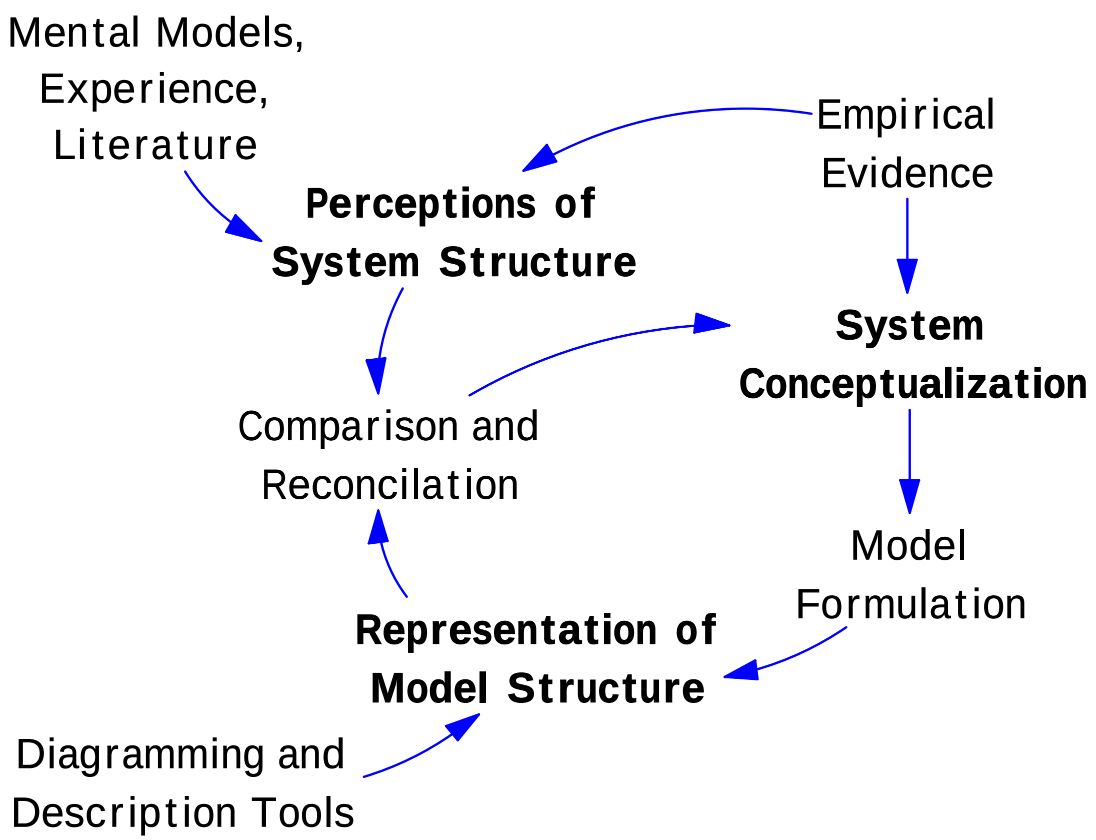
Milstein B. Hygeia's constellation: navigating health futures in a dynamic and democratic world [Doctoral Dissertation]. Cincinnati, OH: Union Institute & University; 2006.

The system dynamics modeling process

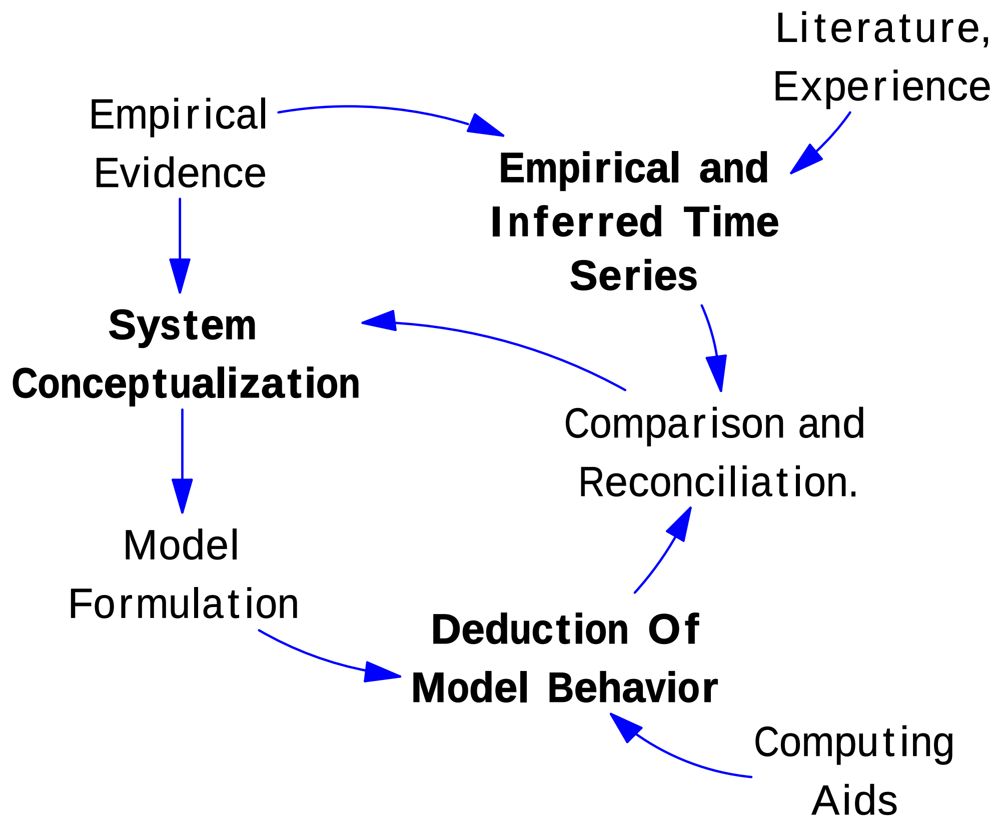


Adapted from Saeed 1992

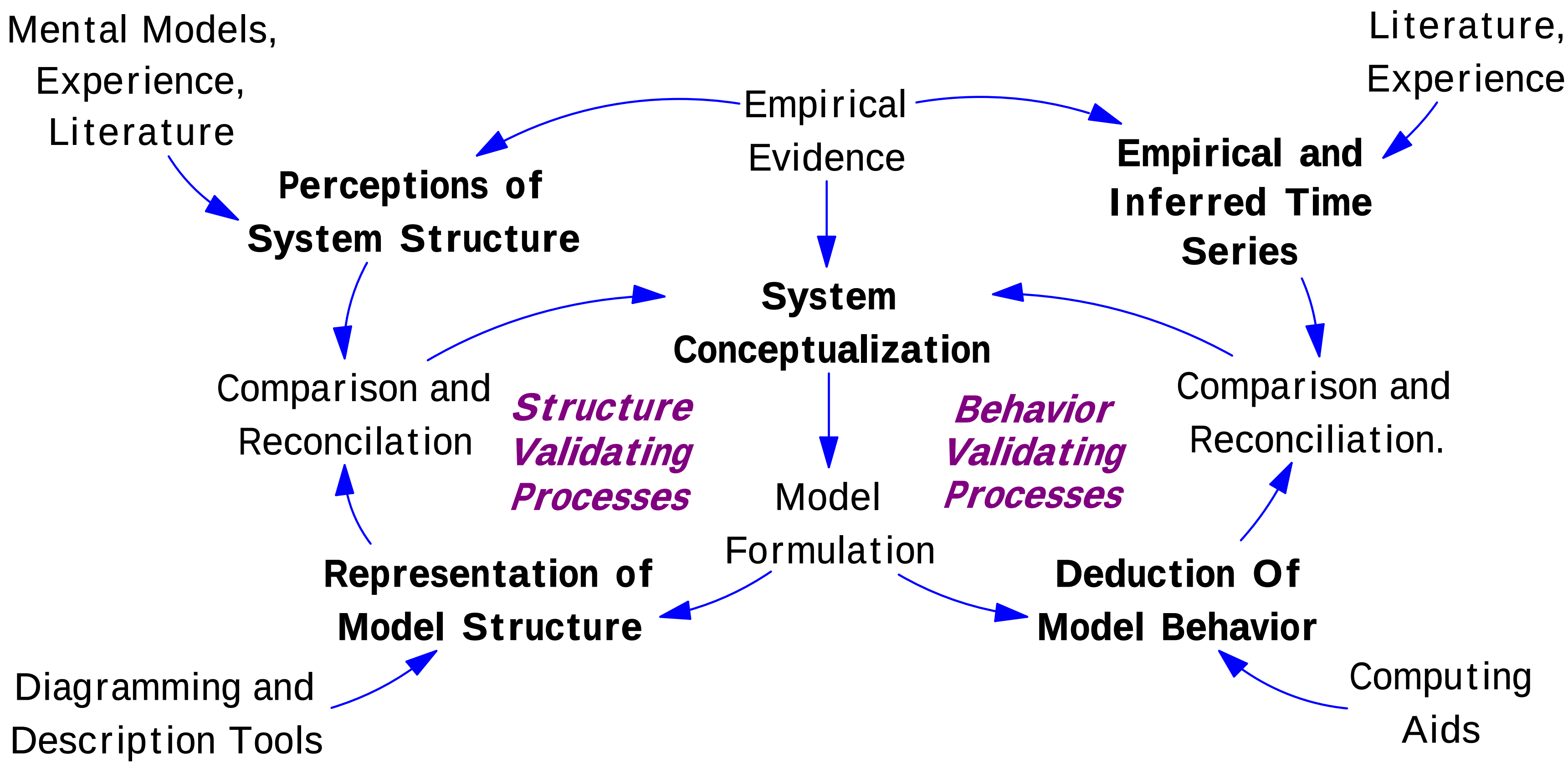
Processes focusing on system structure



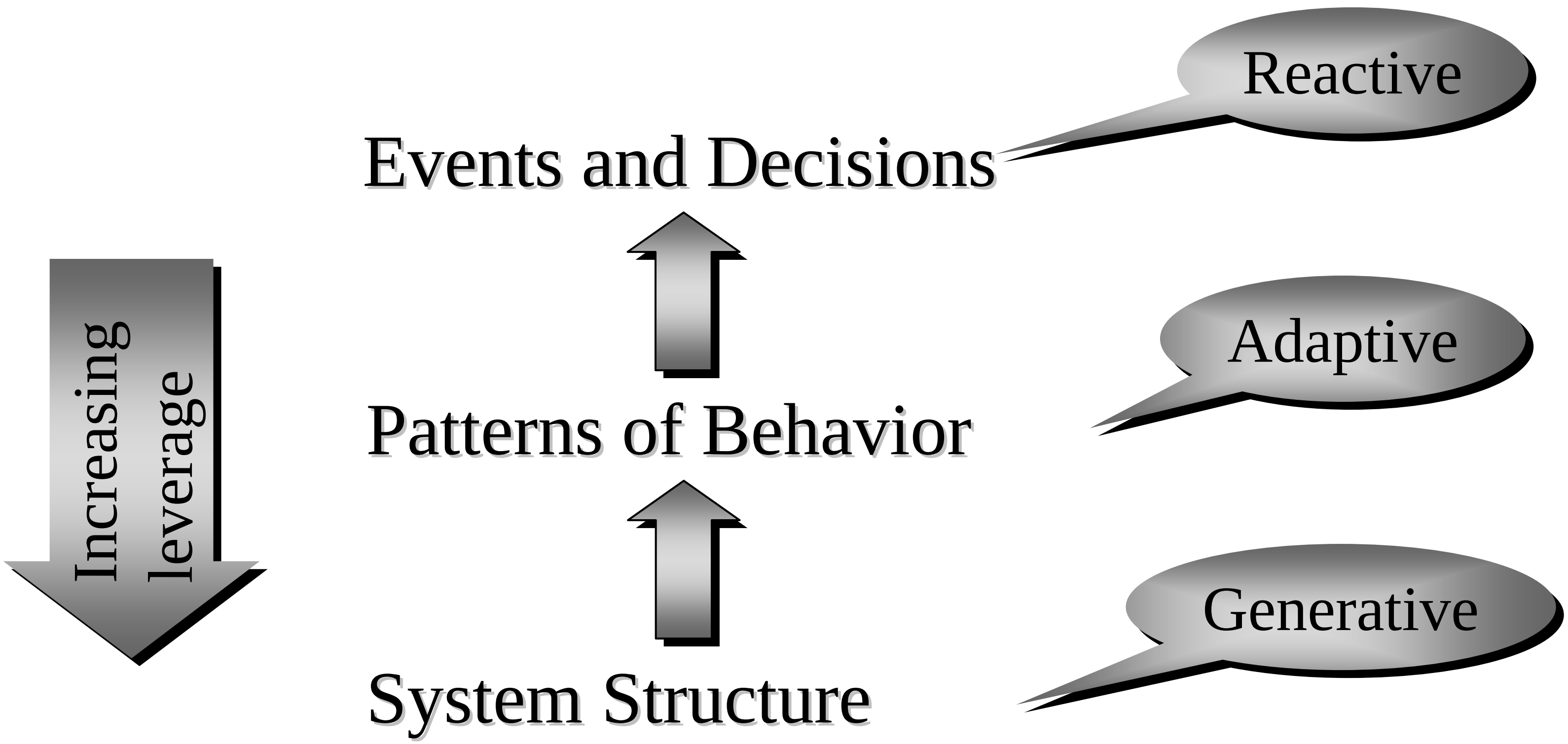
Processes focusing on system behavior



The System Dynamics Iterative Modeling Process



A Systems Perspective



What Do We Mean by Structure?

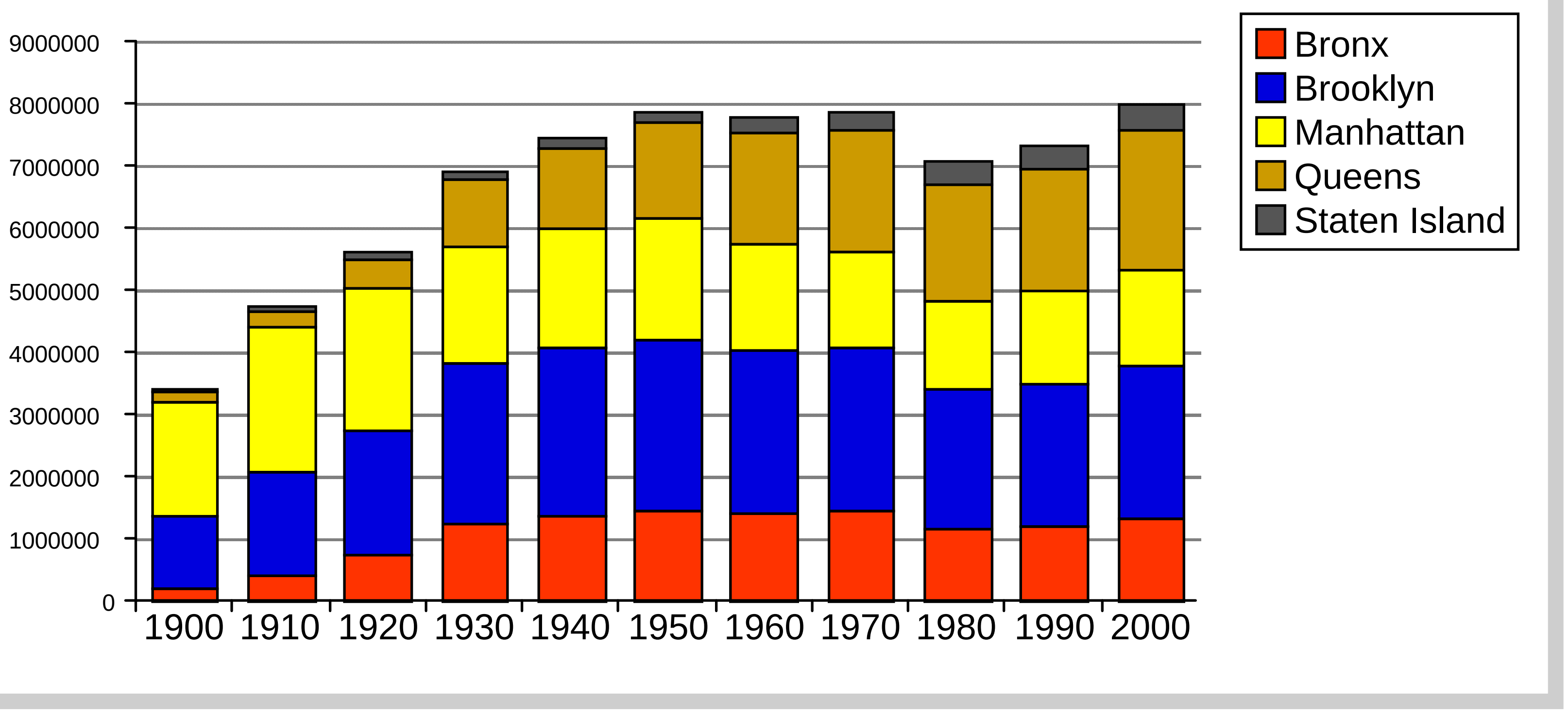
- Accumulations (populations, resources,…, ‘stocks’)
- Causal structure: ‘feedback’ loops
- Delays
- Perceptions (a kind of accumulation)
- Pressures
- Affects, emotions, (ir)rationalities
- Policies governing decisions

➢ **“Stocks and flows and feedback loops”**

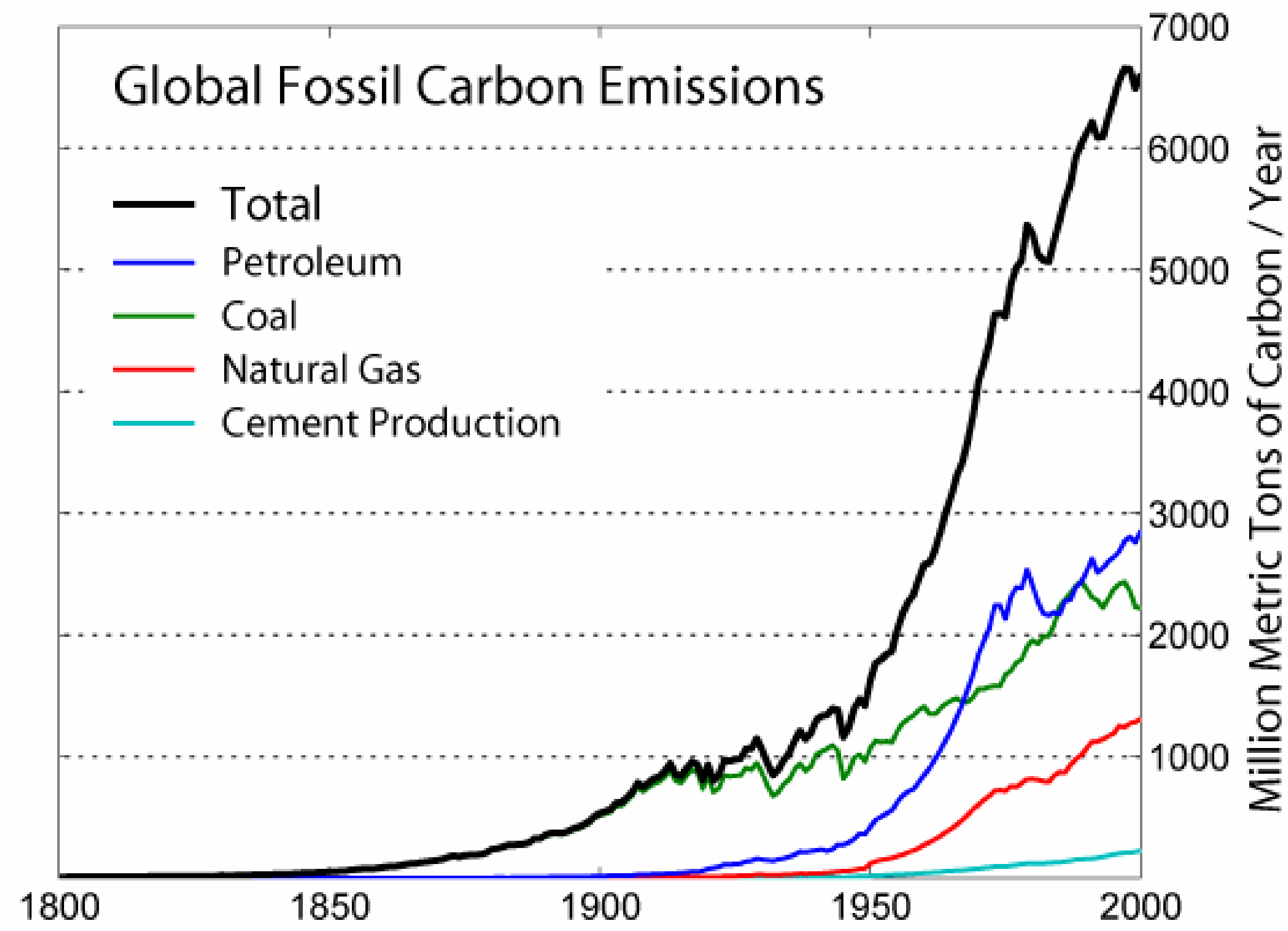
What Do We Mean by Dynamics?

- Graphs over time
- Patterns in time series data
- "Dynamic behavior"

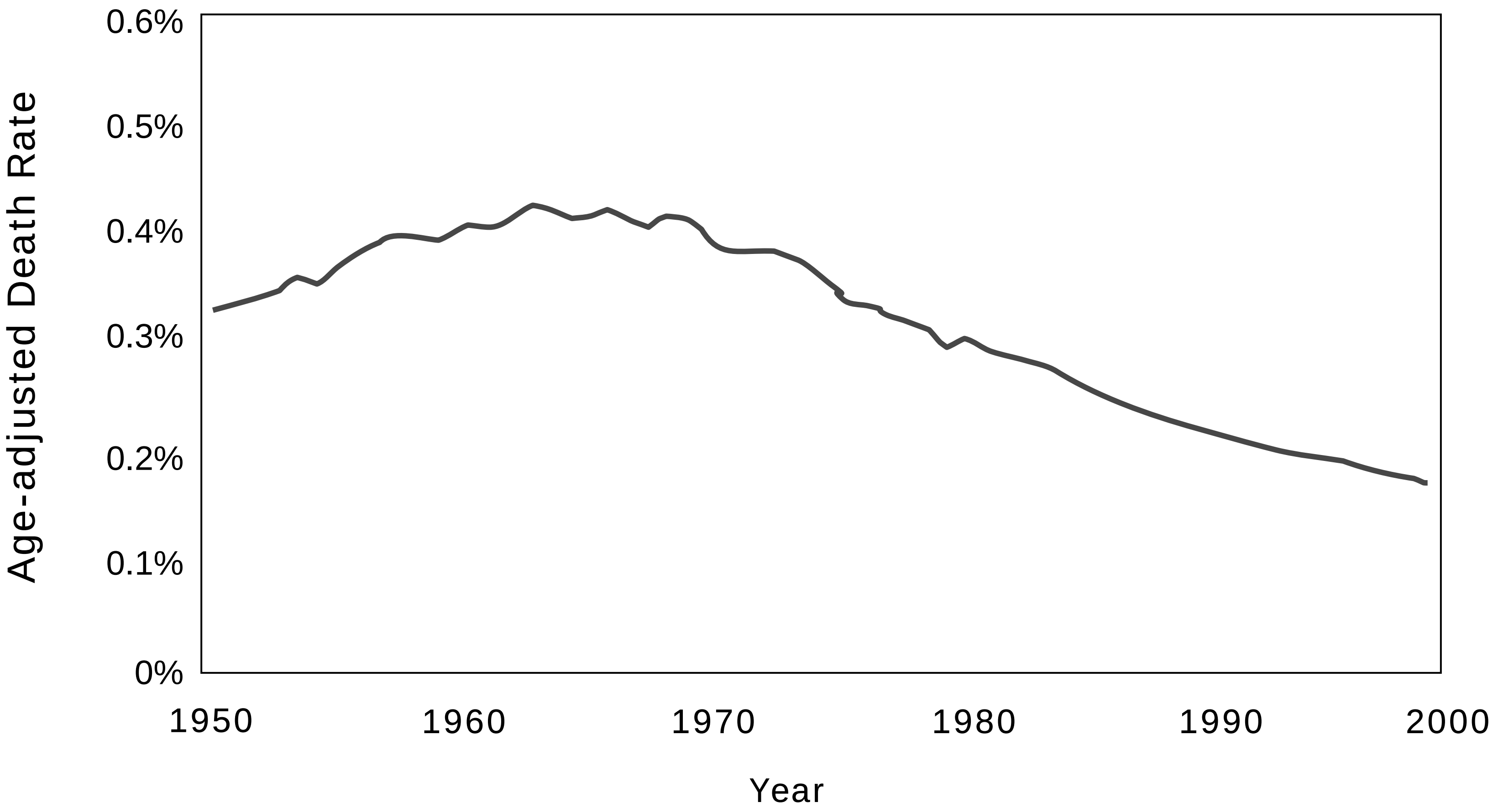
New York City Population, 1900-2000



Global Carbon Emissions (1800-2000)



Death Rate from Coronary Heart Disease, 1950-98



Poliomyelitis Before and After Vaccines

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

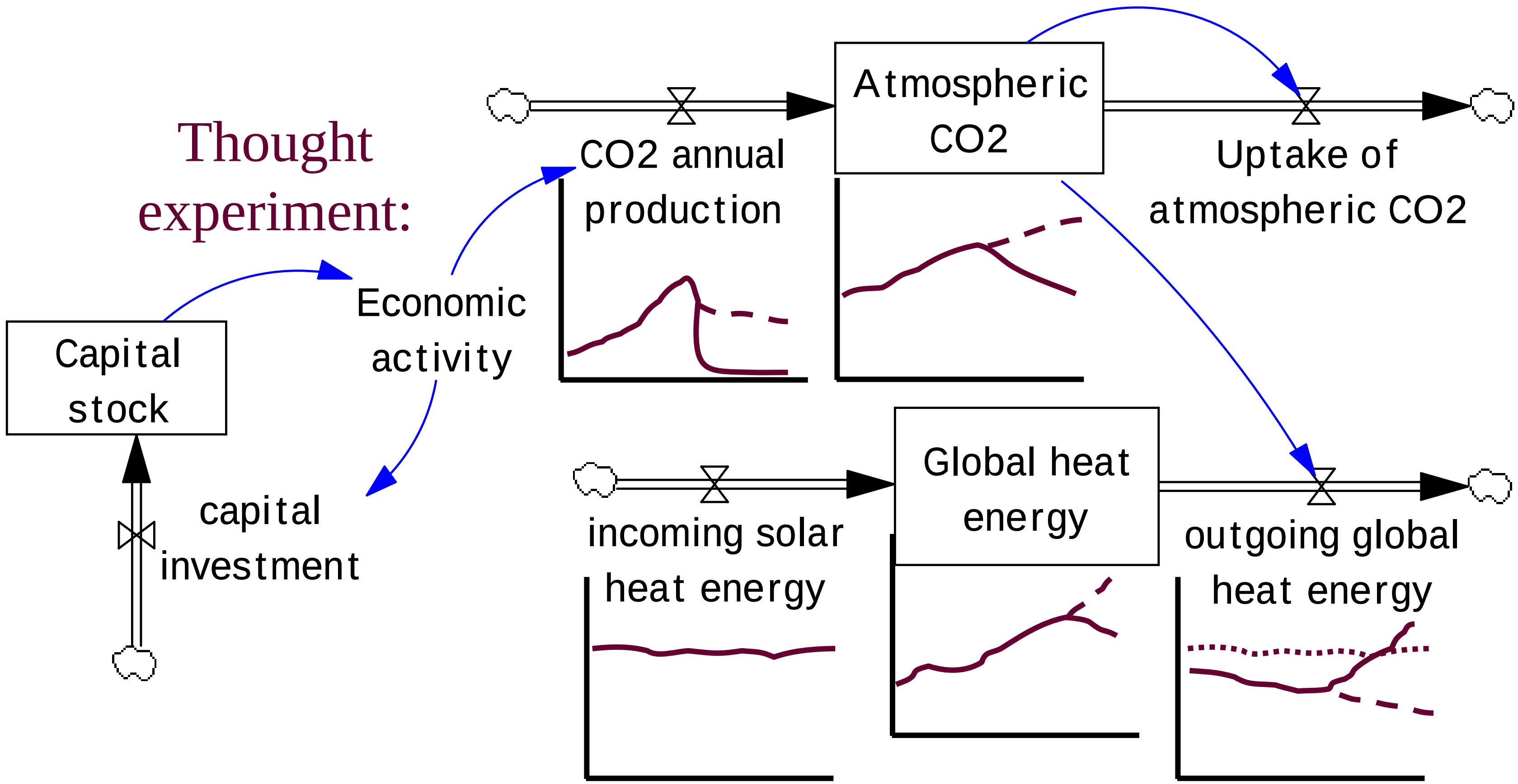
Source: Thompson and Tebbens (2006)

Tobacco Prevalence Sketches

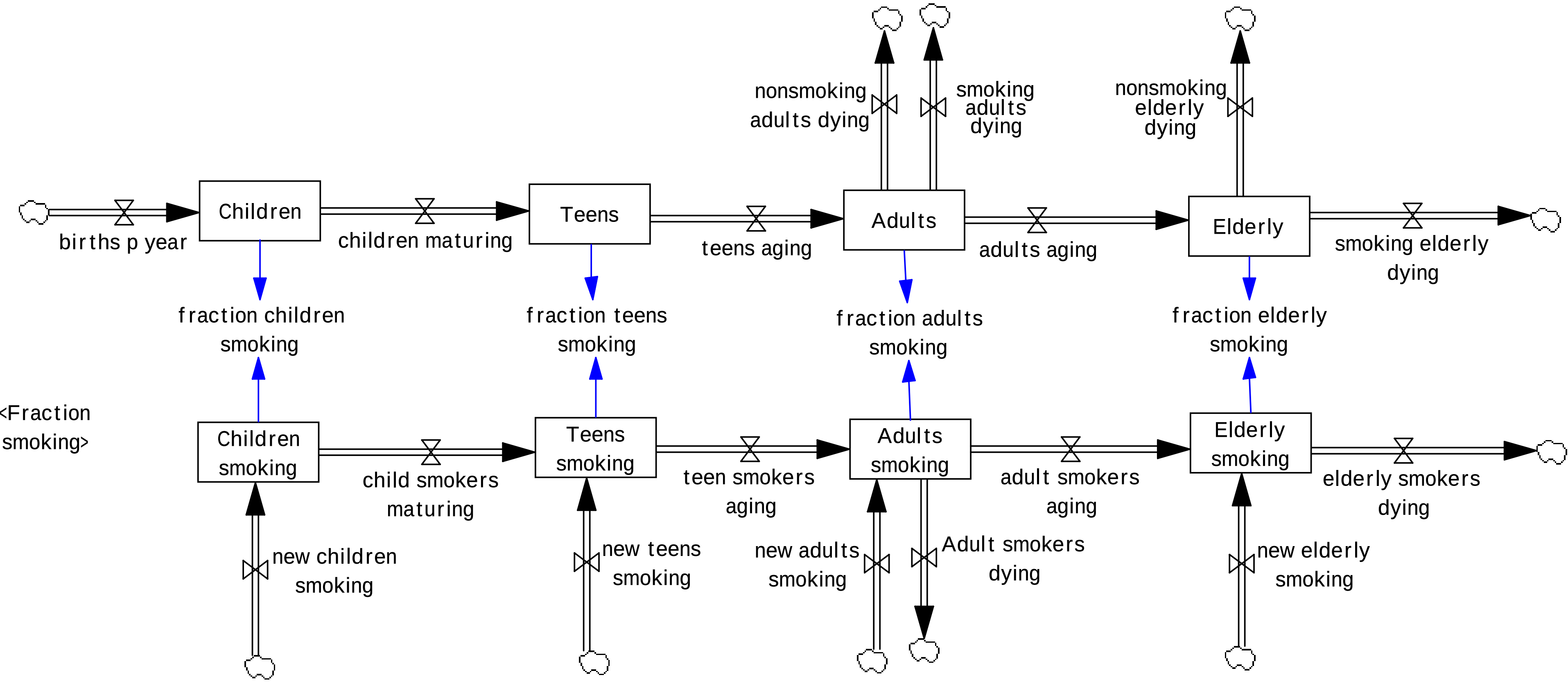
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Stocks and Flows

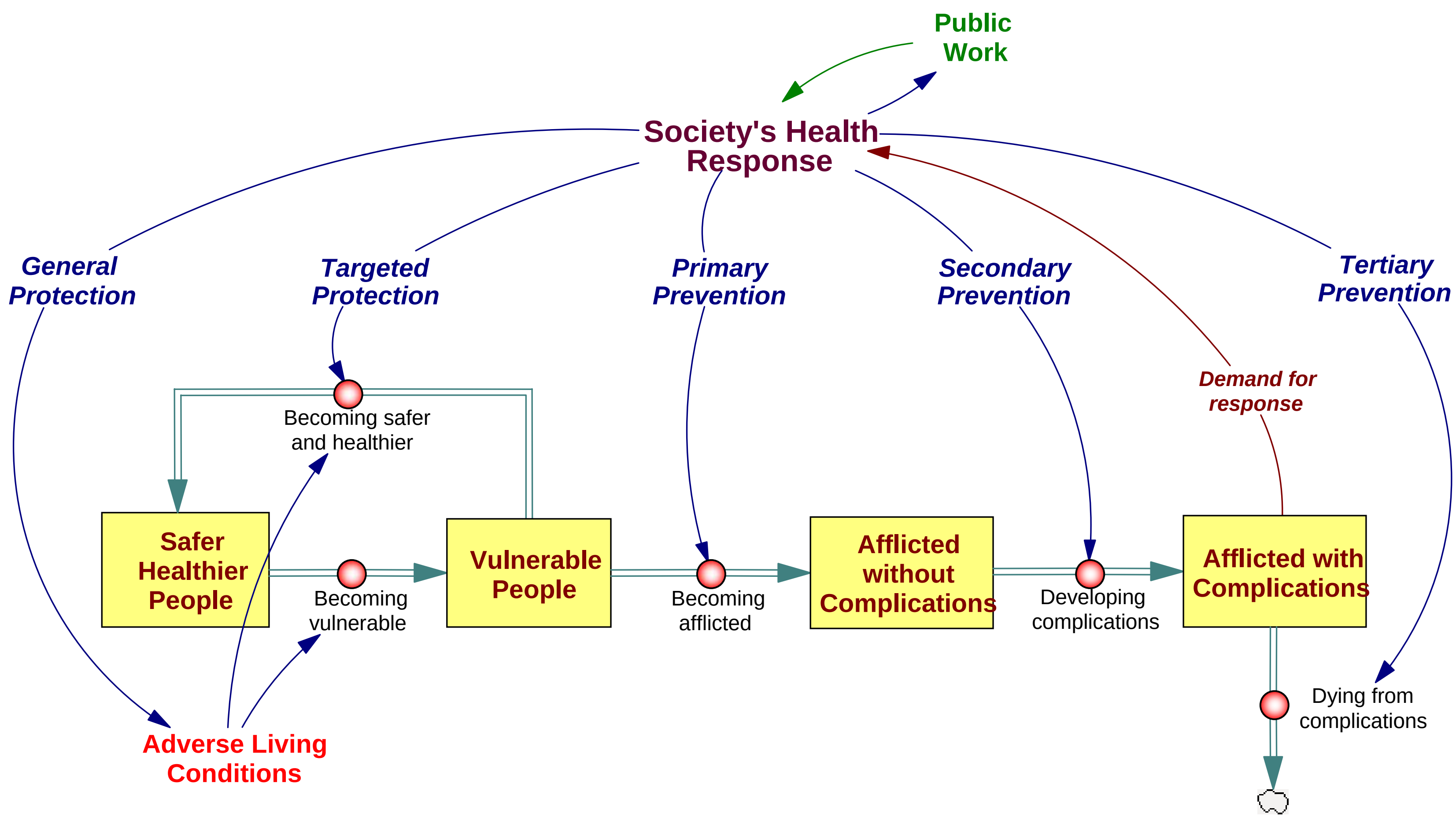
Stocks and Flows in Global Climate



Stocks and Flows in Tobacco Prevalence



Society's Health Protection Enterprise as a Stock-Flow Structure

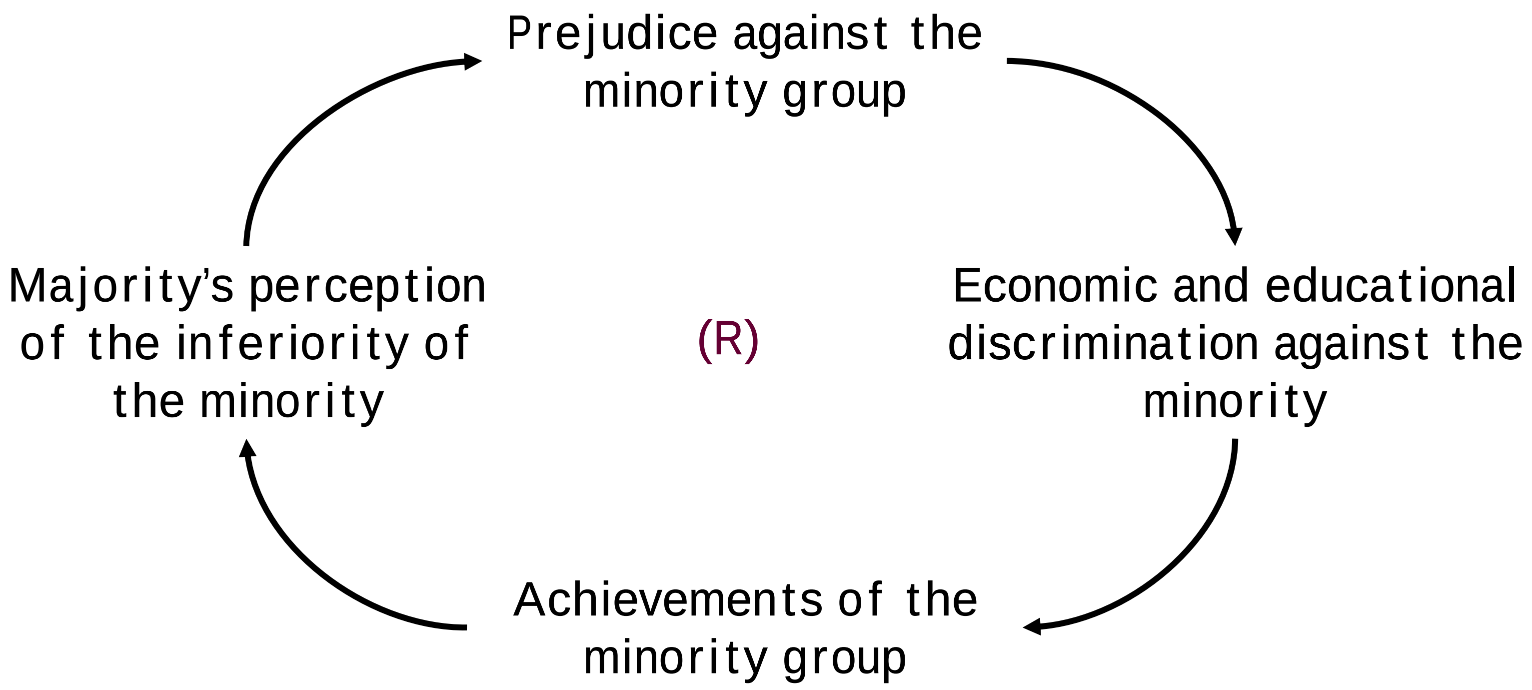


Milstein & Homer, 2003; Gerberding, 2004, 2007

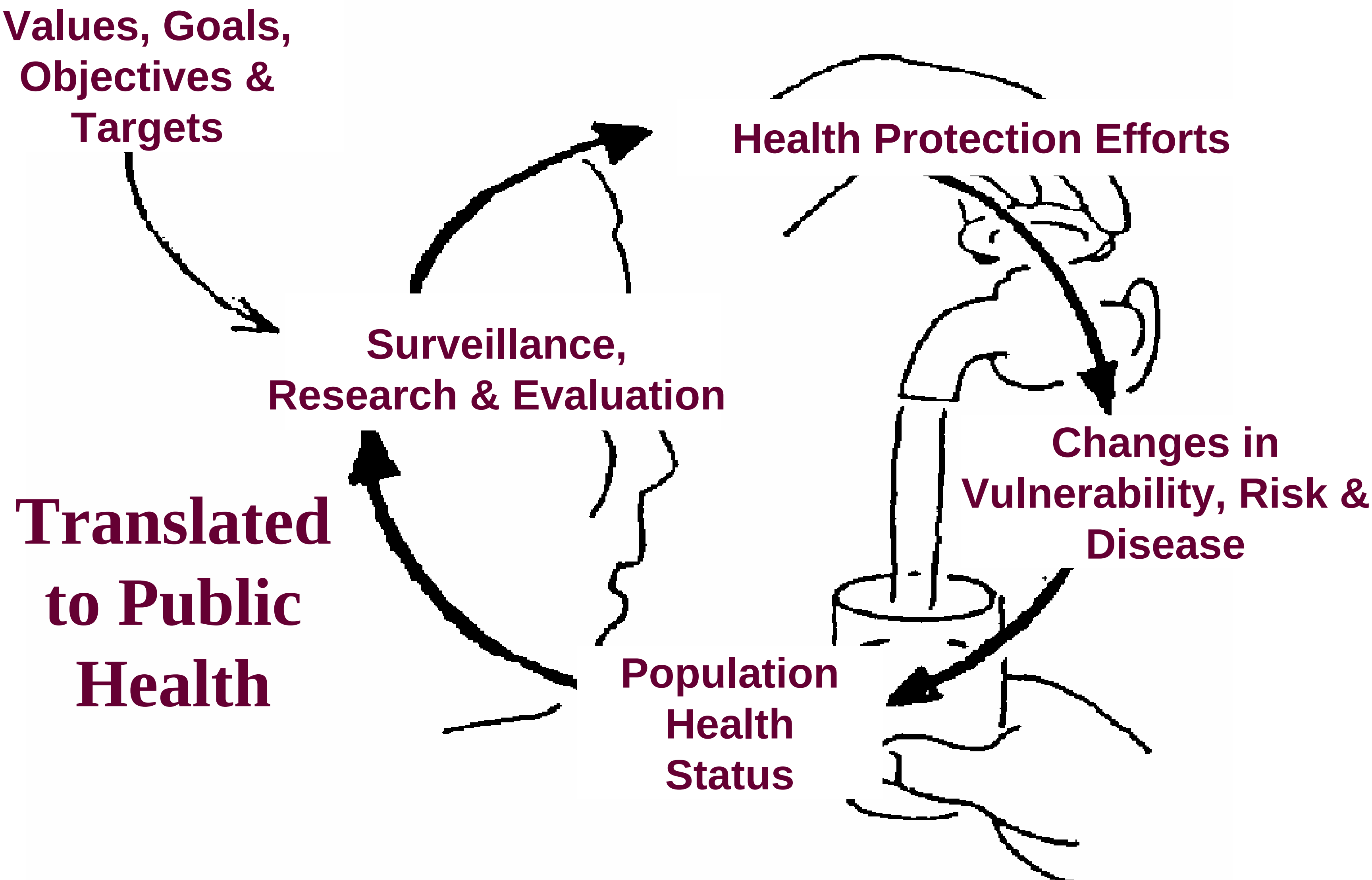
Feedback Thinking

"For one good deed leads to another good deed, and one transgression leads to another transgression." (Pirke Avot)

A Classic Reinforcing Loop
(Myrdal 1944, Merton 1948)

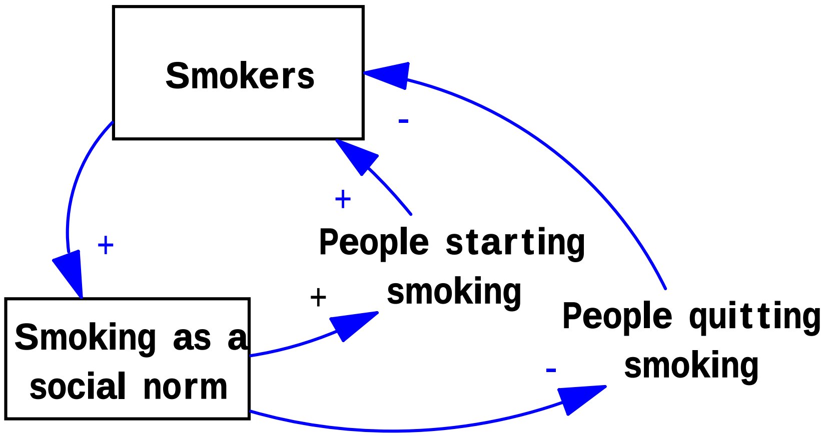


A Classic Balancing Loop

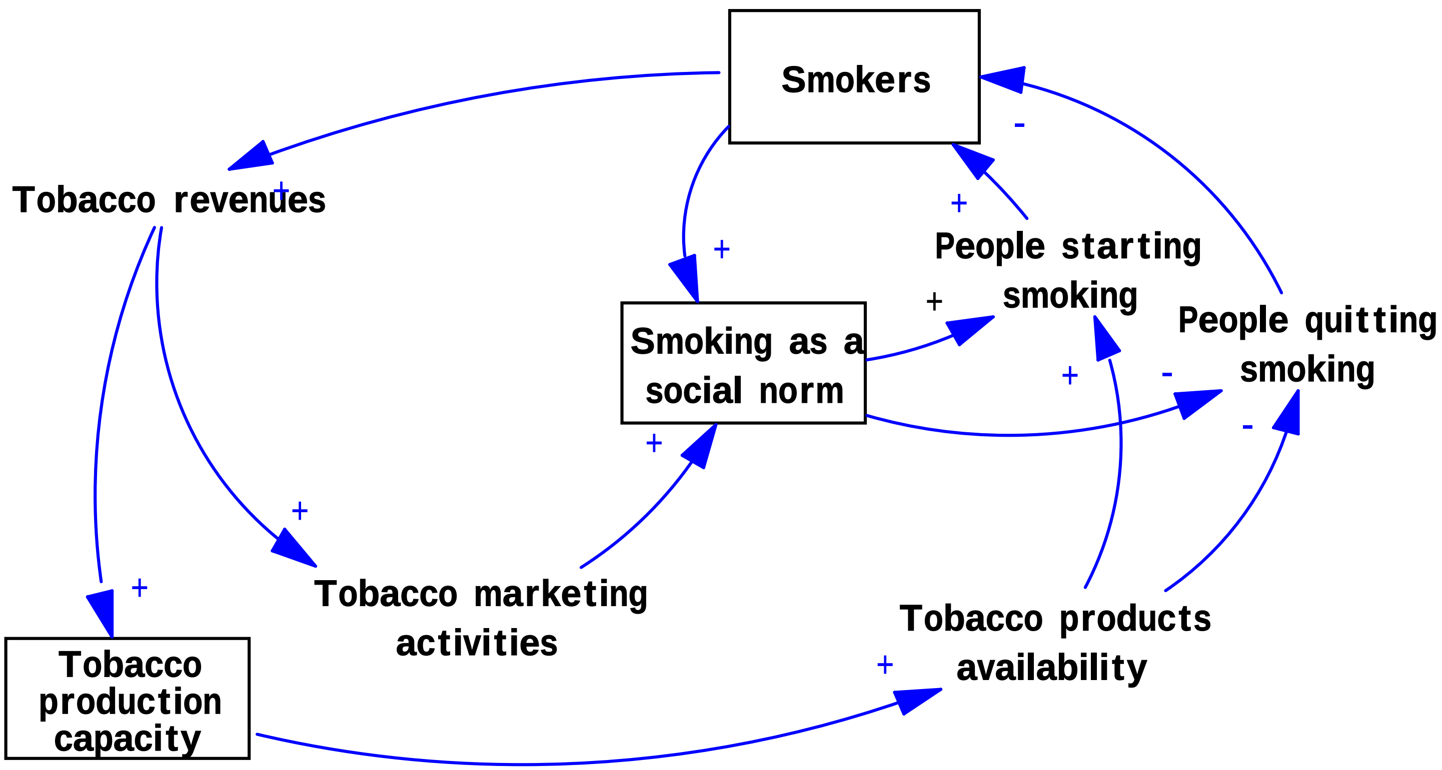


Translated to Public Health

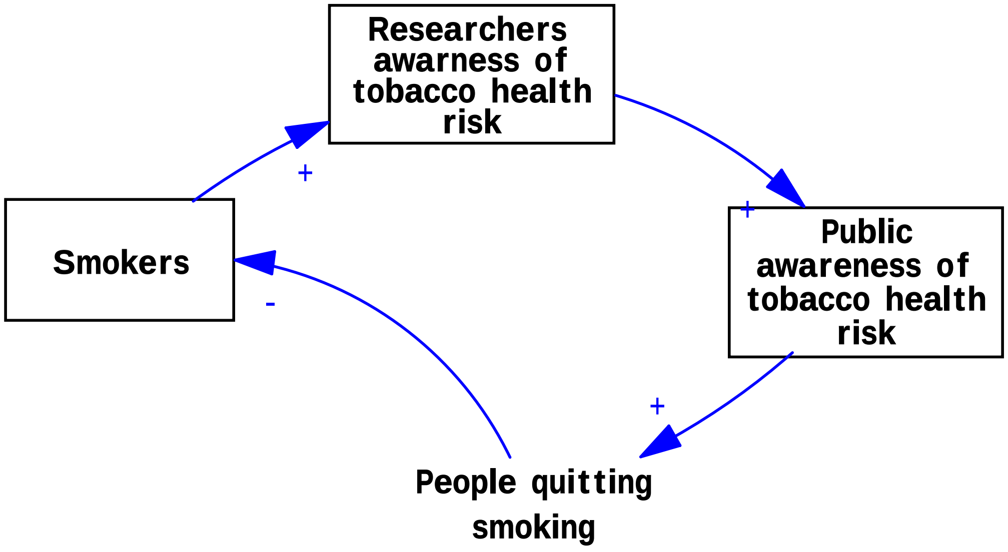
Reinforcing Loops in Tobacco Prevalence



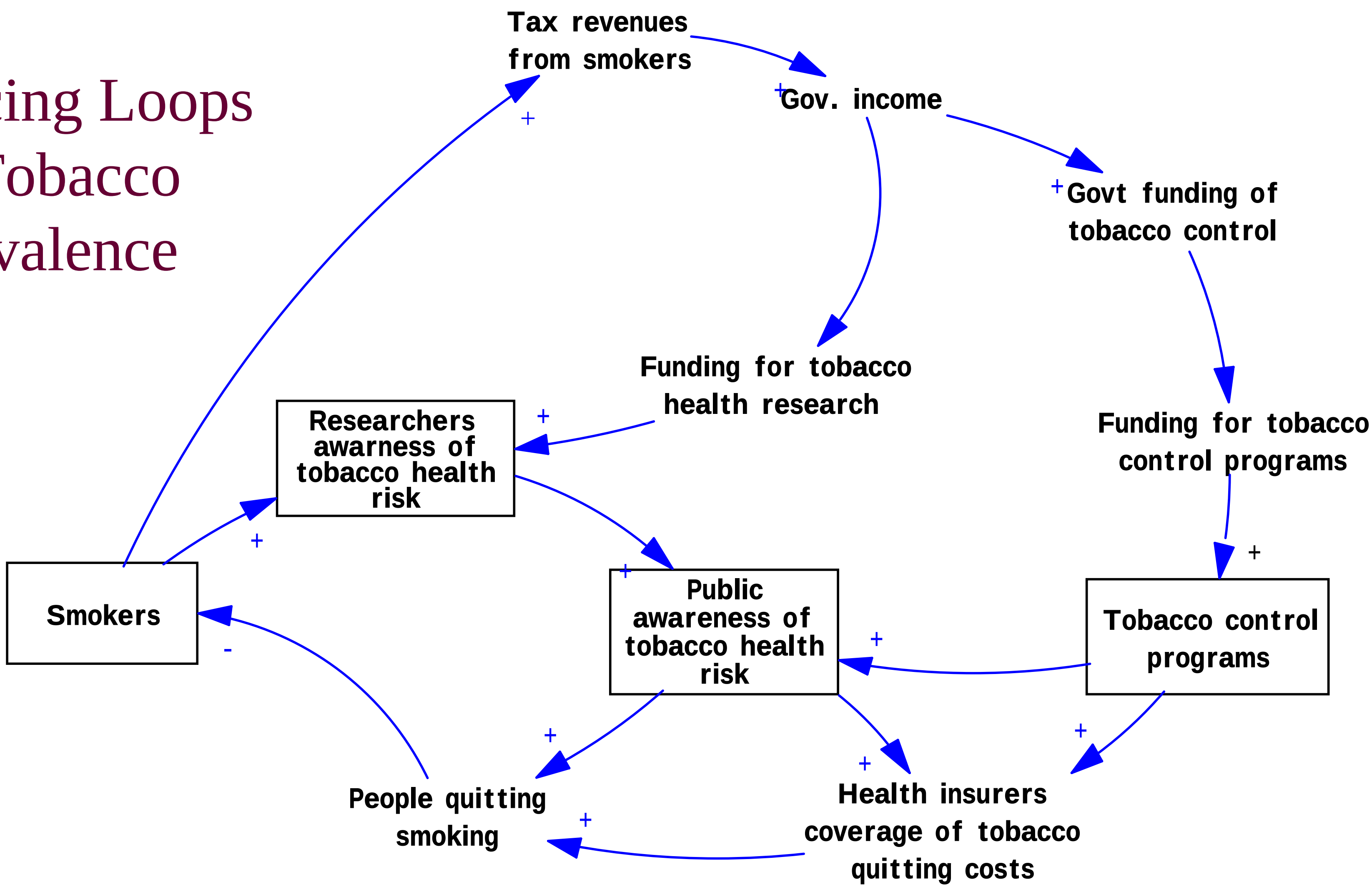
Reinforcing Loops in Tobacco Prevalence



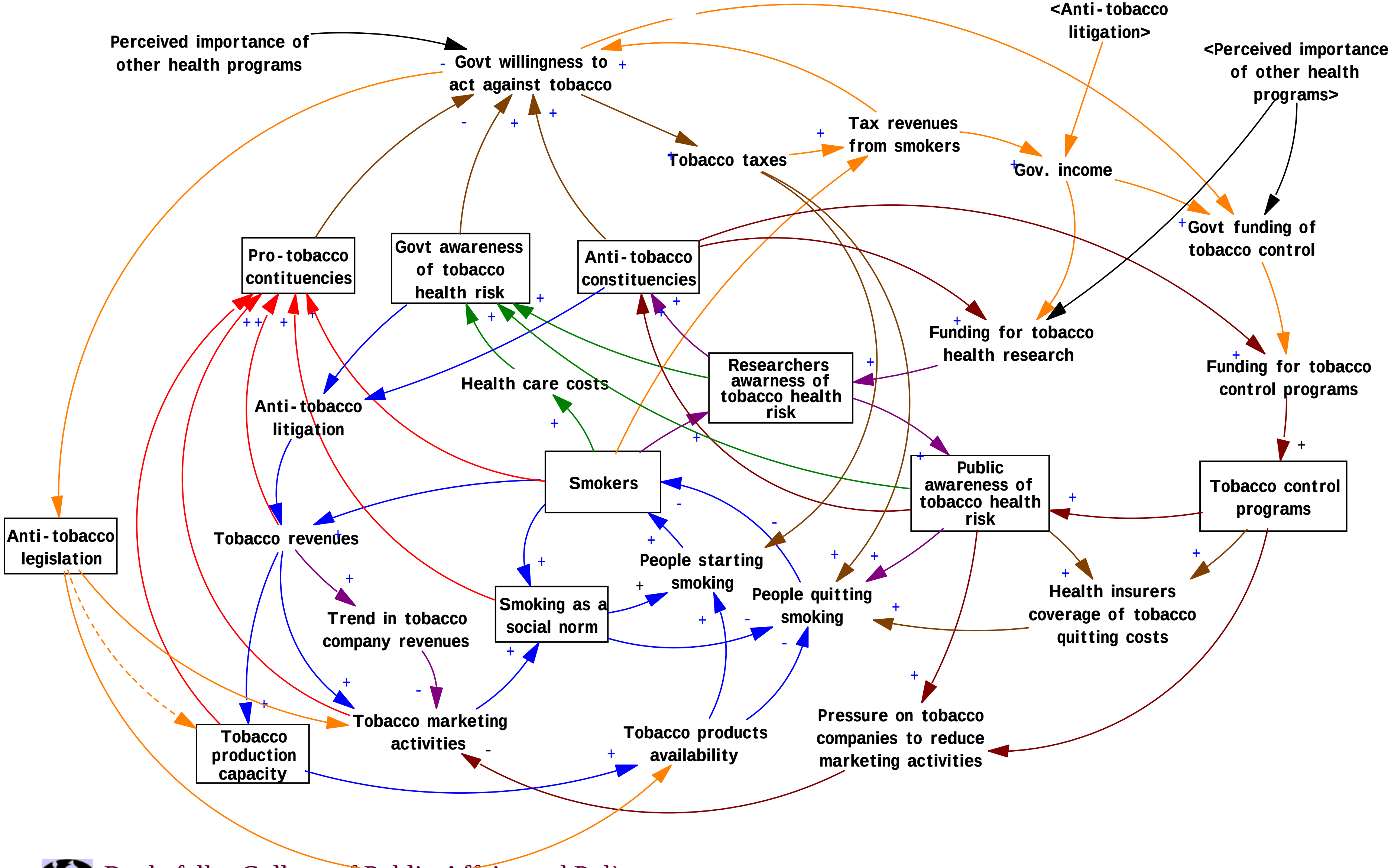
Balancing Loops in Tobacco Prevalence



Balancing Loops in Tobacco Prevalence



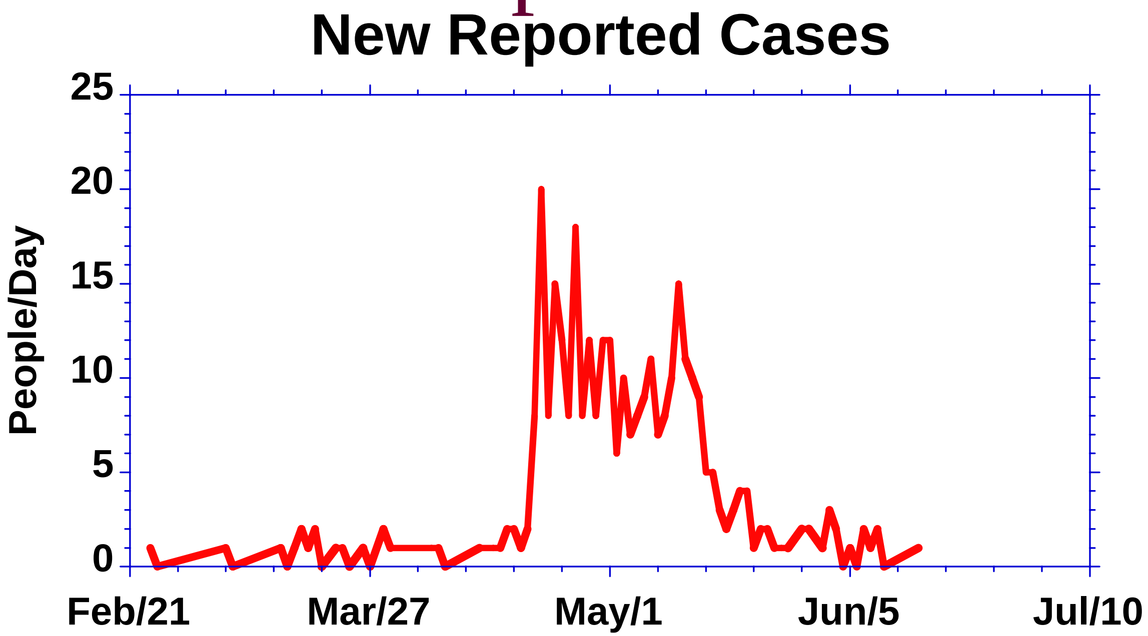
There are a lot …

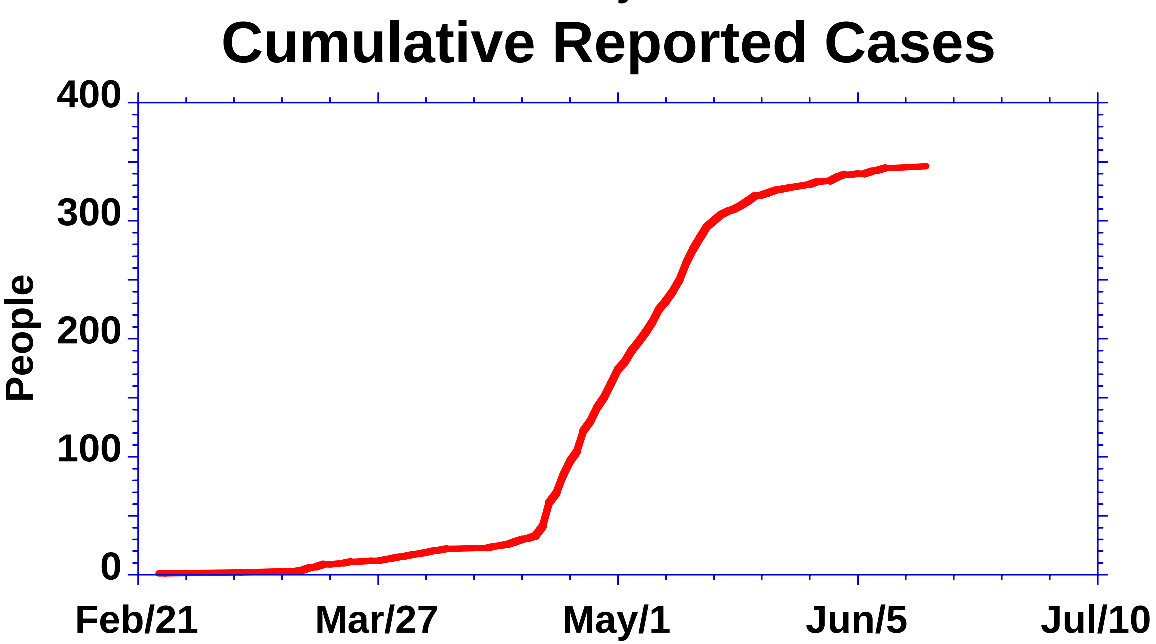


Finding the Appropriate Boundary

SARS Epidemiology

Example: SARS in Taiwan, 2003

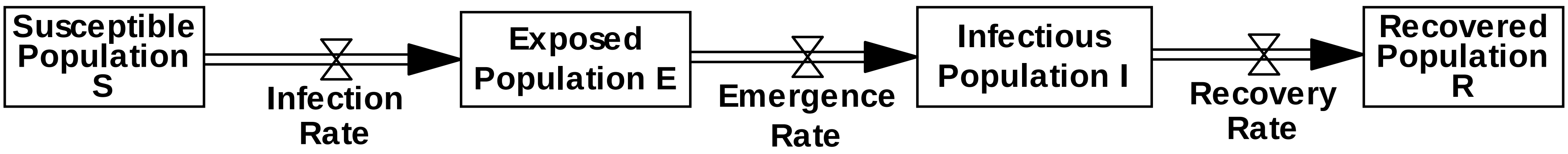




SARS displays the classic S-shaped growth pattern associated with the diffusion of infectious diseases…

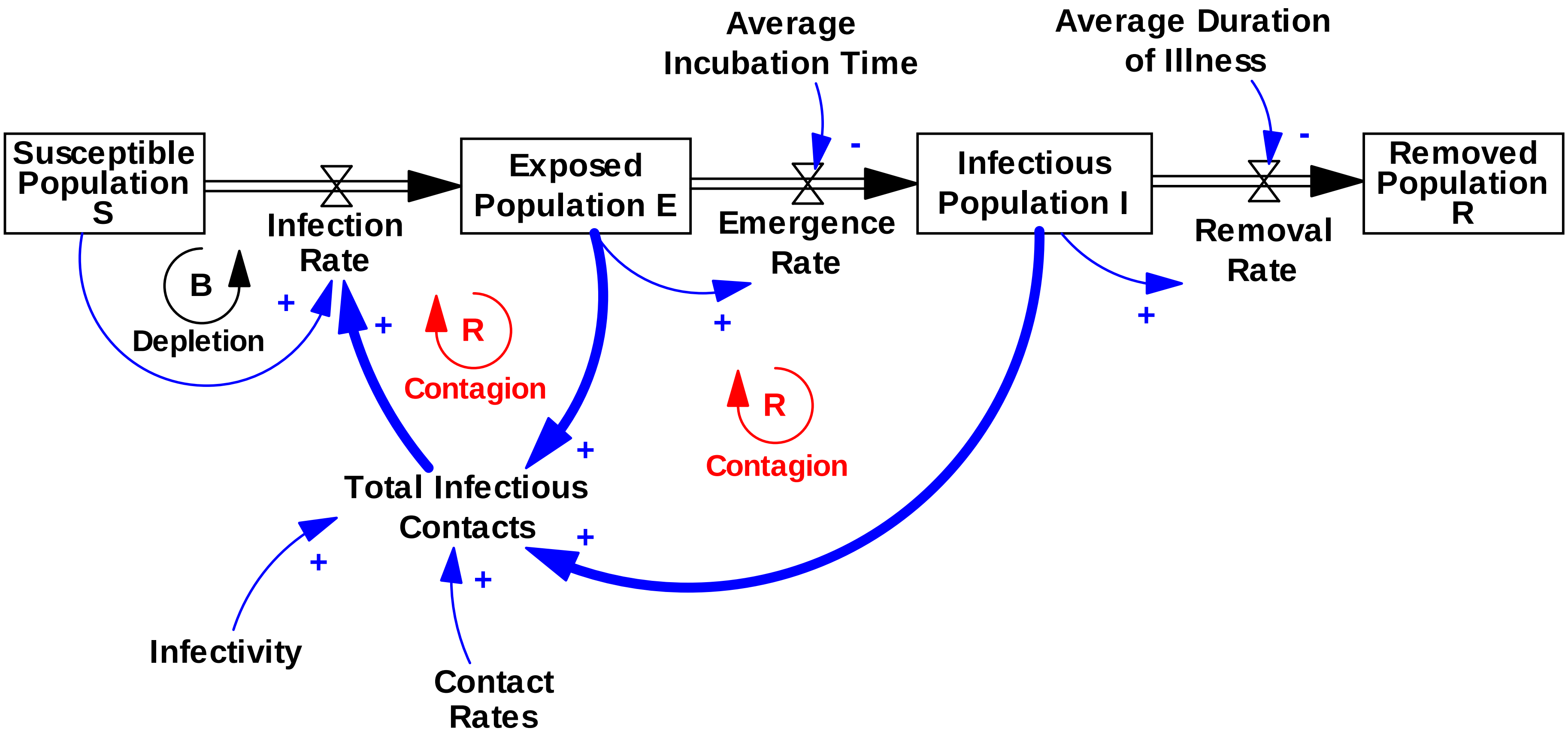
…and new products, innovations, social norms, etc.

Traditional Approach: SEIR Model

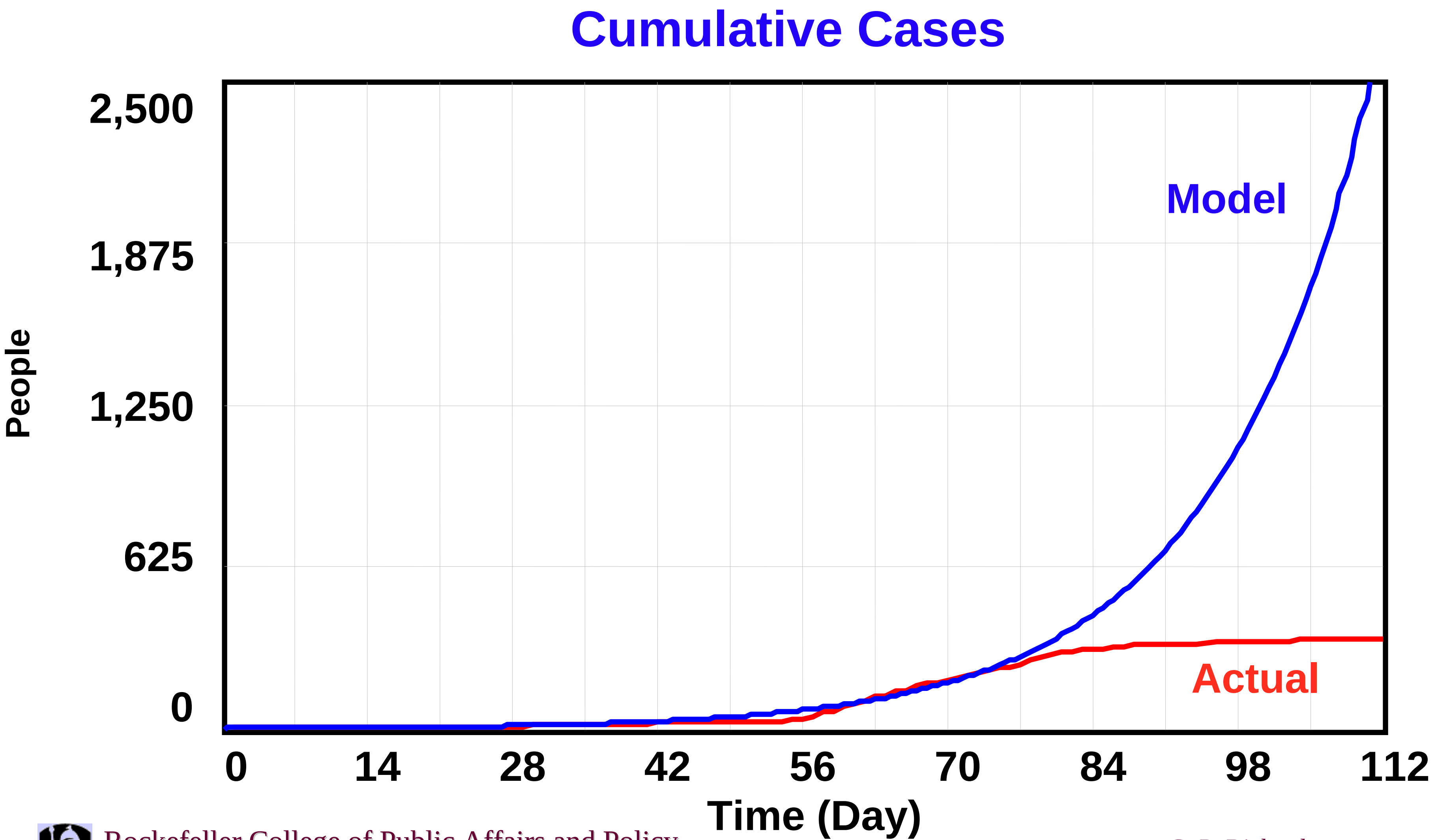


- **Most widely used paradigm in epidemiology**
- **Compartment model–individuals in given state aggregated**
- **Deterministic or stochastic**
- **Disaggregation & heterogeneity handled by adding compartments & interactions**

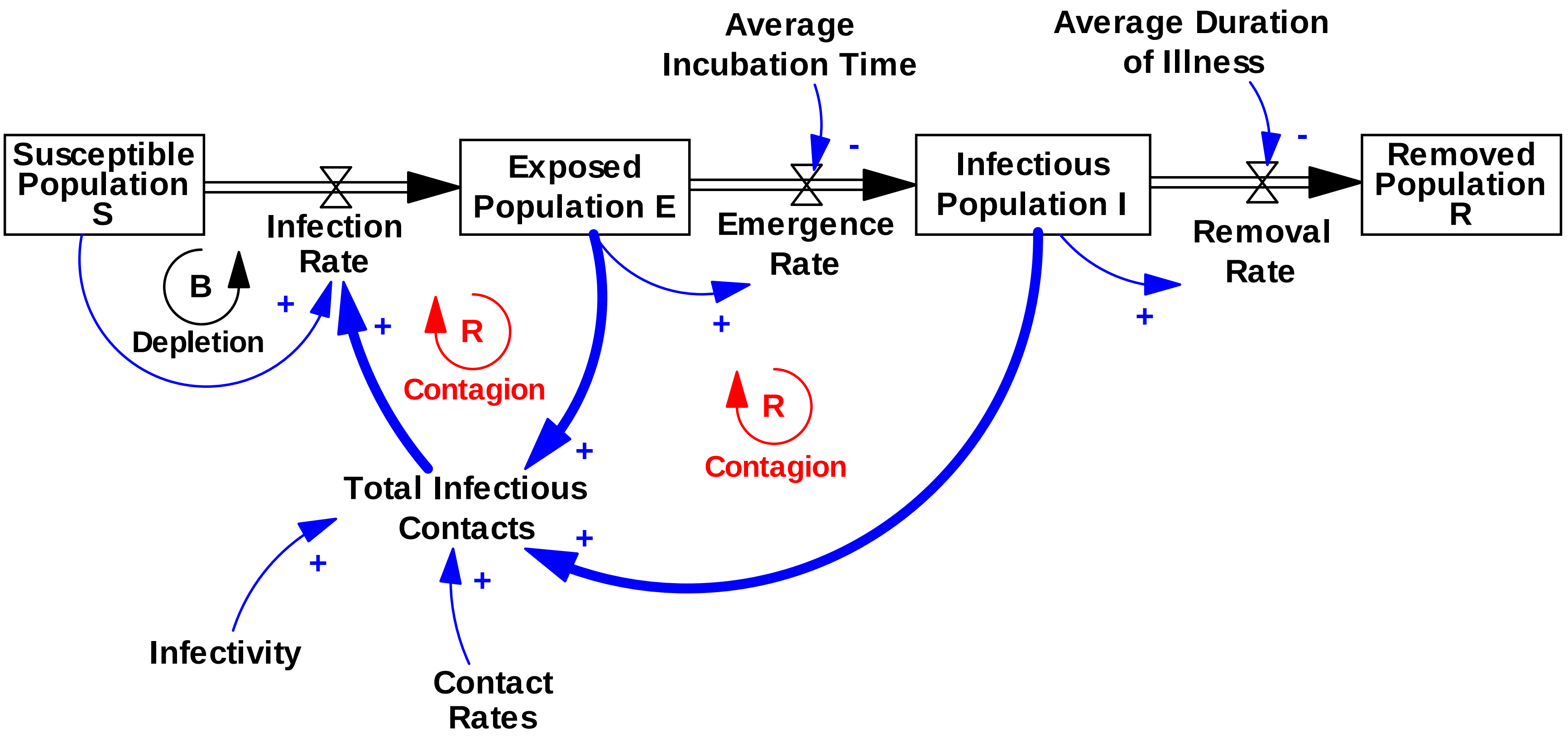
Infection in the Standard SEIR Model



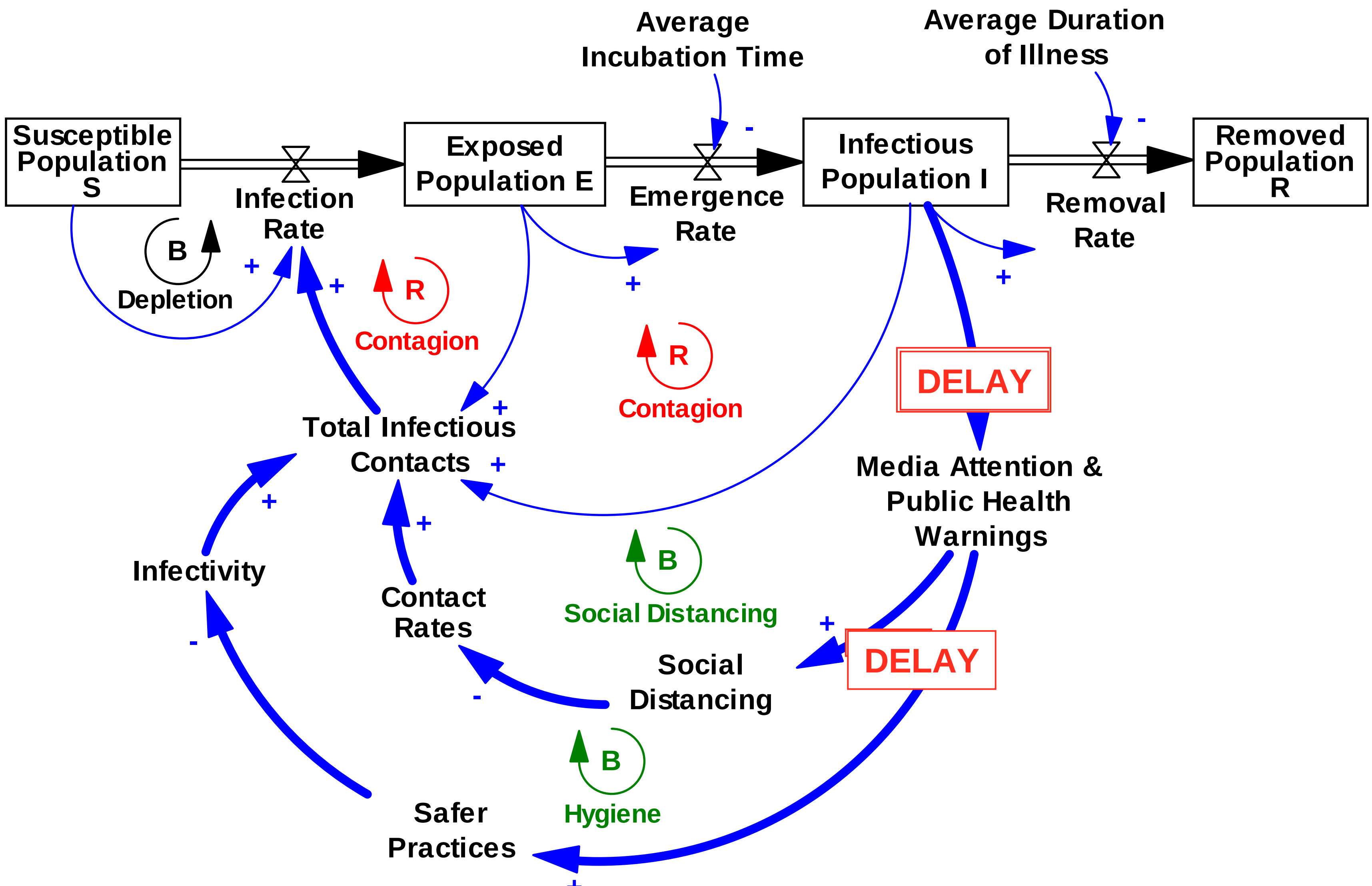
Standard SEIR Model vs. SARS Data for Taiwan



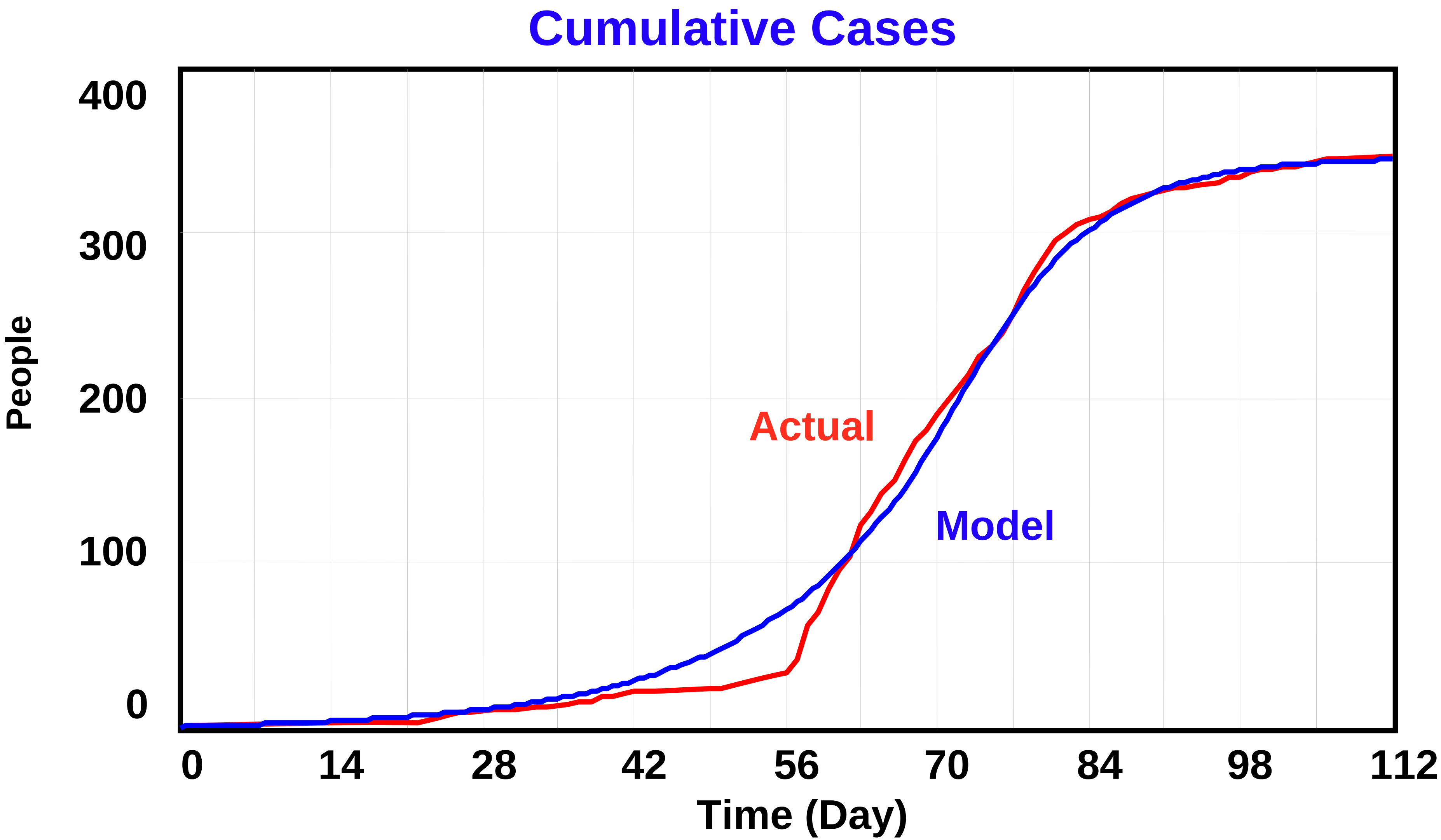
Infection in the Standard SEIR Model



Expanding the Boundary: Behavioral Feedbacks



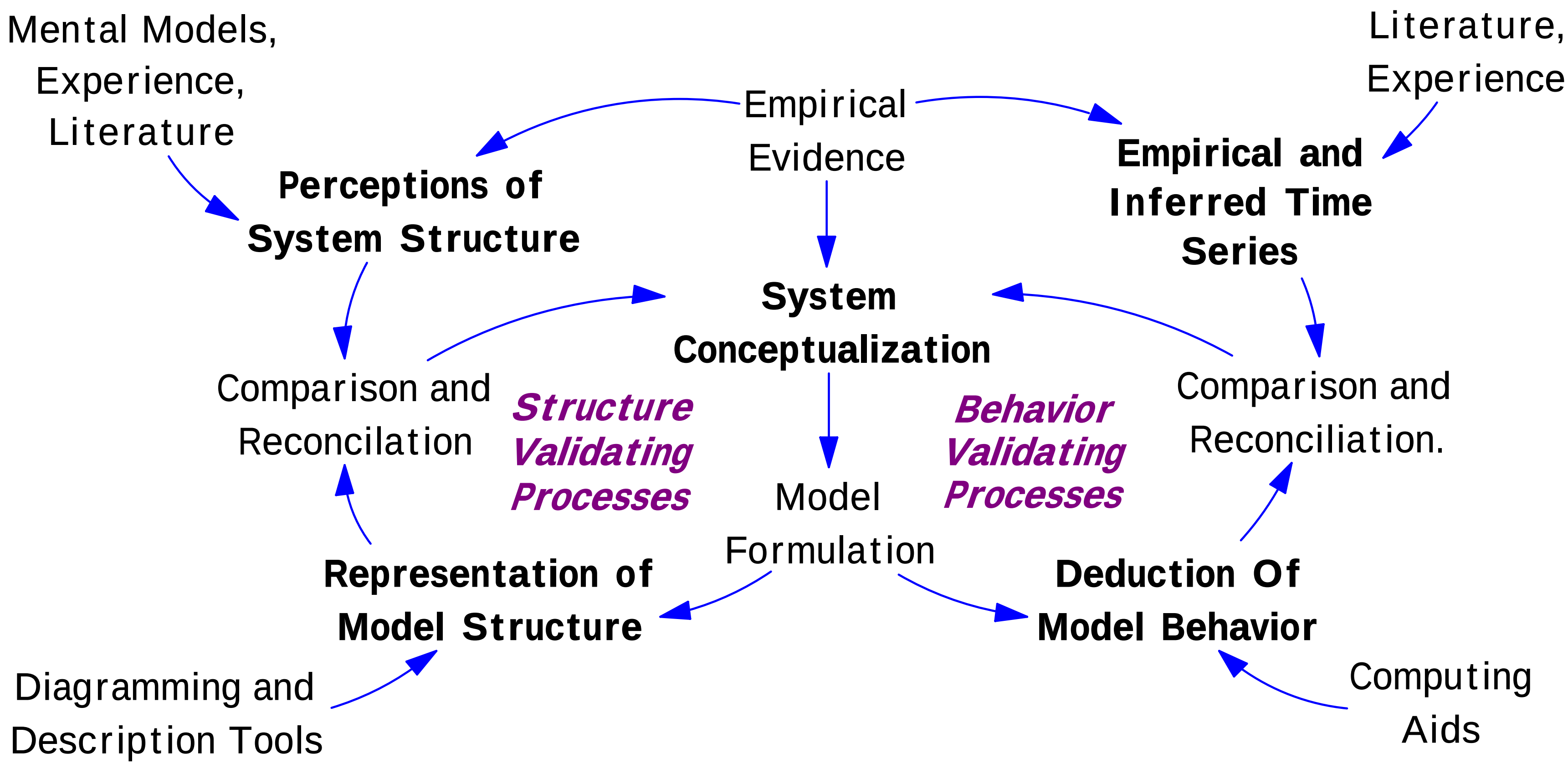
Model with Behavioral Feedbacks vs. Data



Model Evaluation (‘Validation’)

What gives us confidence to implement policy?

Two kinds of validating processes



Validation Present at Every Step

- Conceptualizing:
  - Do we have the right people?
  - The right dynamic problem definition?
  - The right level of aggregation?
- Mapping: Developing promising dynamic hypotheses
- Formulating: Clarity, logic, and extremes
- Simulating: Right behavior for right reasons
- Deciding: Implementable conclusions
- Implementing: Requires conviction!

How Much Detail is Best?

"It is obvious that a model…cannot represent every individual decision and transaction taking place in the system. In fact, we should not want to do so, any more than we should want equations that account for each molecule of water in calculating pressures and flows in a water supply system...[Appropriate] aggregation, as with other aspects of a model, depends on the purpose of the model."

-- Jay Forrester

Forrester JW. Industrial Dynamics (Chapter 11: Aggregation of Variables). Cambridge, MA: MIT Press, 1961.

The Classic Tests

	Focusing on STRUCTURE	**Focusing on BEHAVIOR**
Testing SUITABILITY for PURPOSES		
Testing CONSISTENCY with REALITY		
Contributing to UTILITY & EFFECTIVENESS		

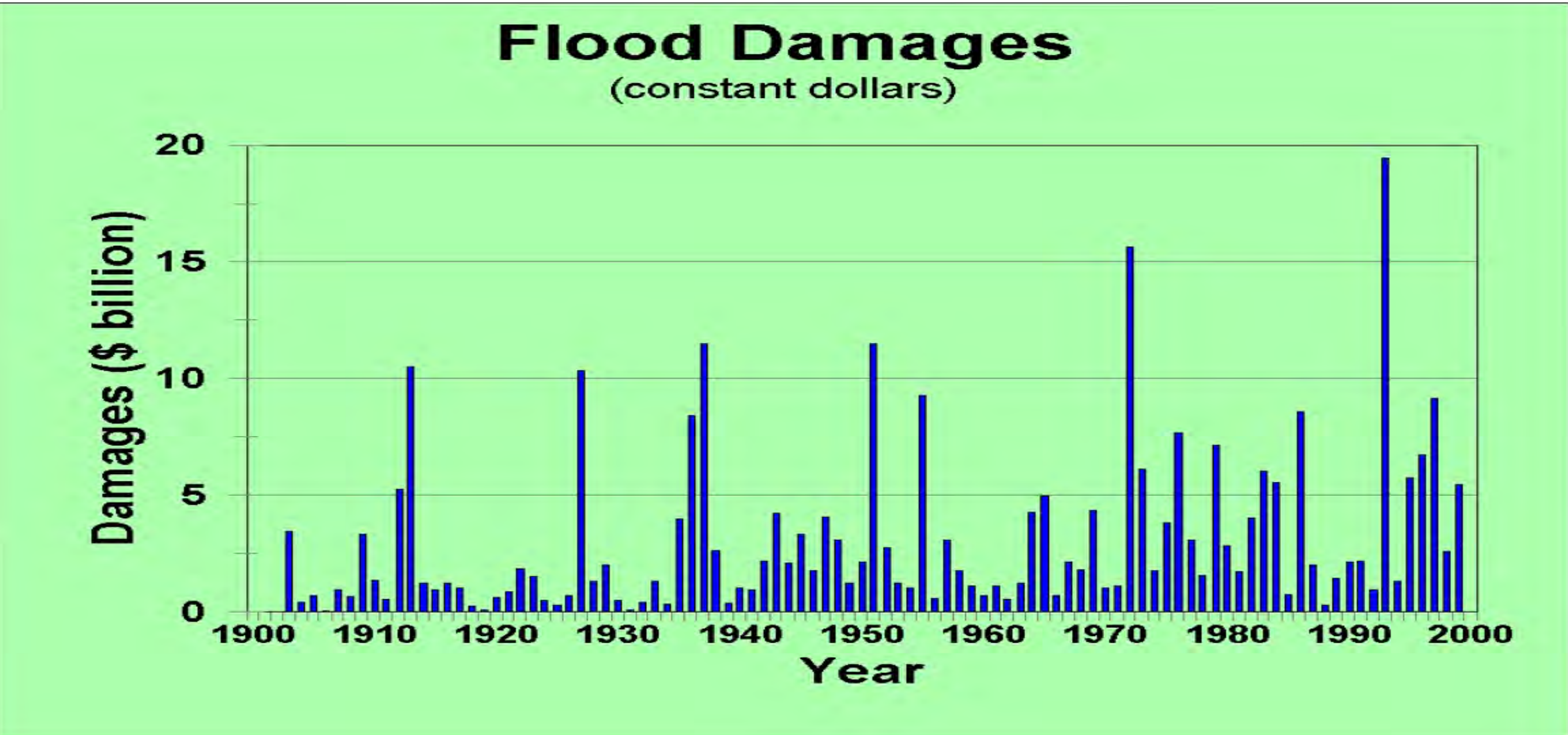
Forrester 1973, Forrester & Senge 1980, Richardson and Pugh 1981

Model-Based Policy Analysis

Helping Us to Understand
the Implications of Our Options

U.S. Flood Damages

source:http://www.nws.noaa.gov/oh/hic/flood_stats/Flood_loss_time_series.shtml



Michael Deegan,Exploring U.S. Flood Mitigation Policies: A Feedback View of System Behavior, PhD dissertation, University at Albany: Albany, NY 2007

A natural disaster occurs when <u>hazard</u> meets <u>vulnerability</u>.

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G. P. Richardson
August 2007

The Focus: Flood Mitigation

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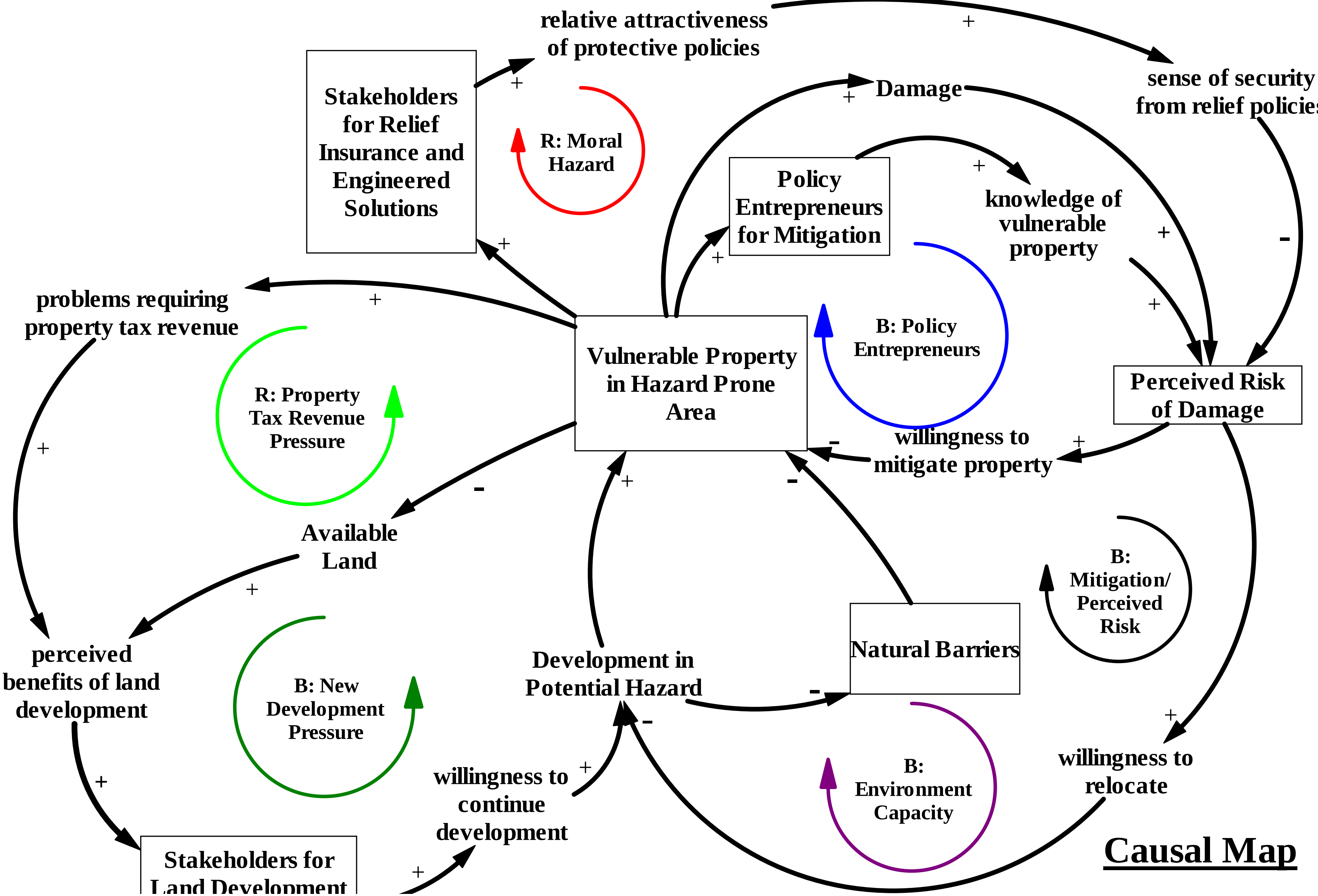

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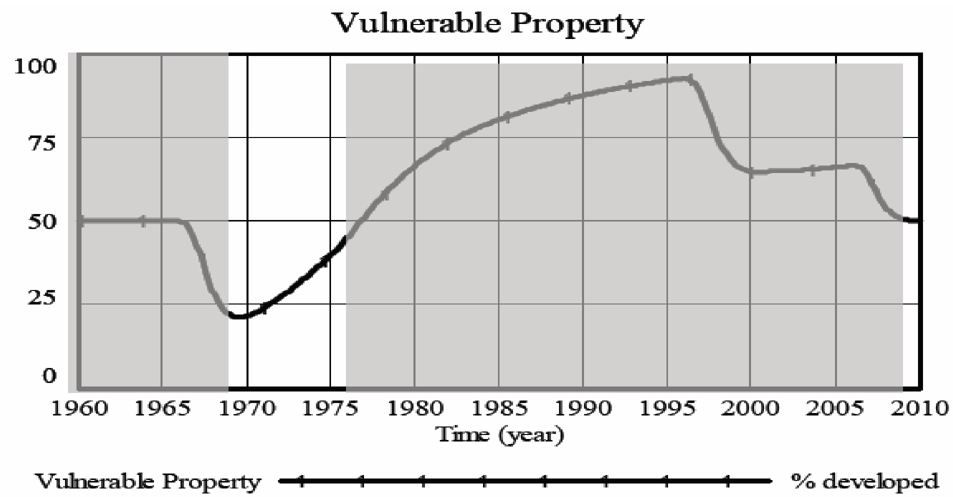
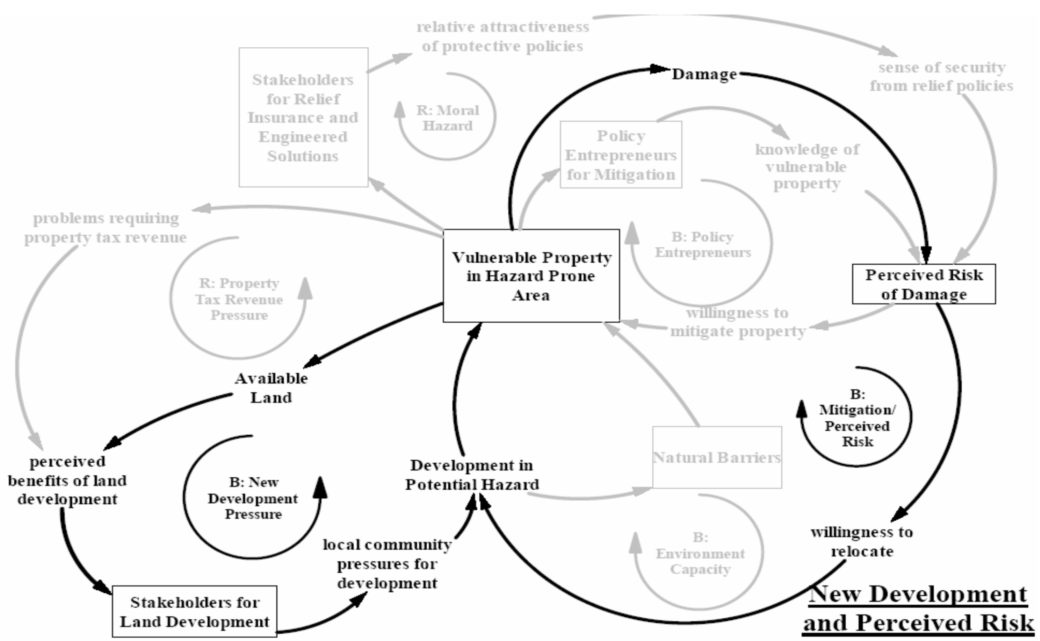
Structure explains behavior





- Period 2: recovery & development pressure
- Perceived risk leads to some floodproofing, but there are pressures to redevelop and return to normal

Defining the Policy Space

	Base	Scenario #1	Scenario #2	Scenario #3	Scenario n
Base					
Policy Mix #1					
Policy Mix #2					
Policy Mix #3					
Policy Mix m					

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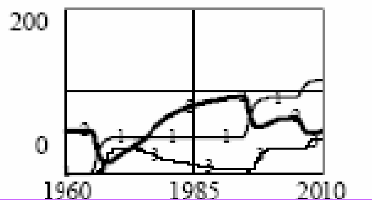
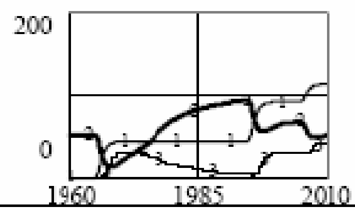
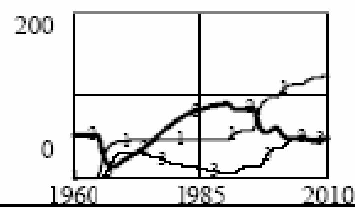
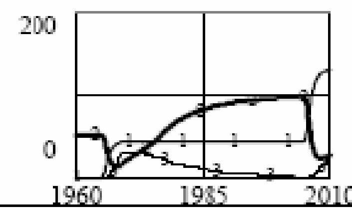
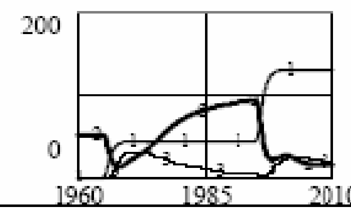
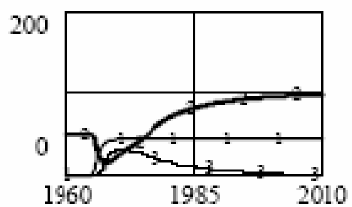
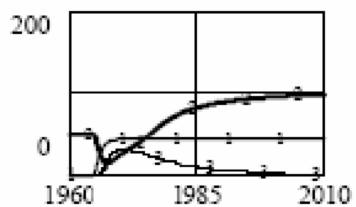
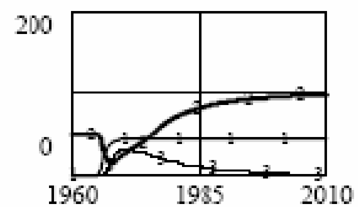
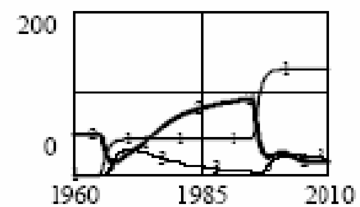
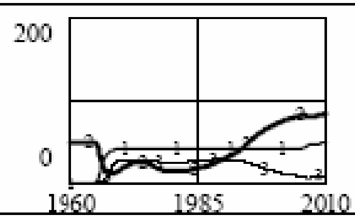
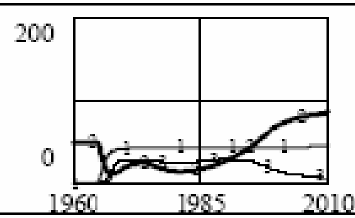
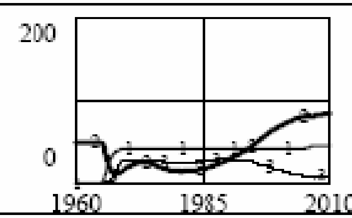
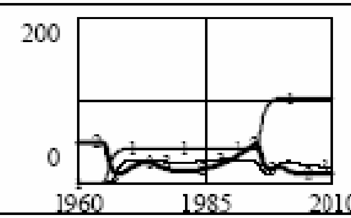
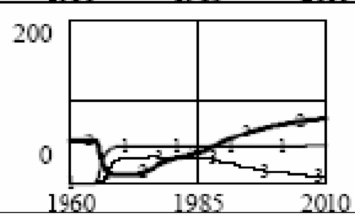
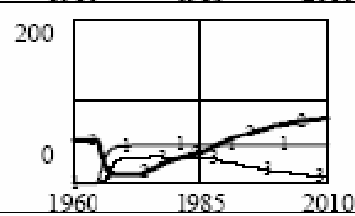
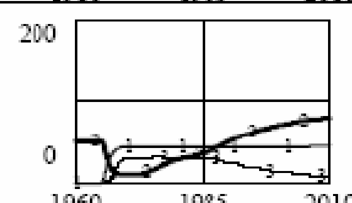
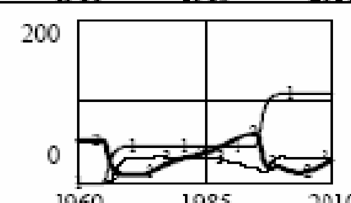
The Policy Space

1= total damage 2= vulnerable property 3= mitigated property	Base	High frequency	Low frequency	Major event
Base				
1. Structural Mitigation				
2. Public Information on Damage				
3. Policy Entrepreneurs for Mitigation				

The Policy Space

1= total damage 2= vulnerable property 3= mitigated property	Base	High frequency	Low frequency	Major event
Base				
1. Structural Mitigation				
2. Public Information on Damage				
3. Policy Entrepreneurs for Mitigation				

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The Goal: Wise Policy Consensus

References
(in addition to those on slides)

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- K. Saeed (1992). "Slicing a complex problem for systems dynamics modeling." *System Dynamics Review* 8(3): 251-262.
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