Social science foundations of complex adaptive systems

Workshop on CASH: July 18, 2011
10:30-11:45
Overview

- Long historical view
- Systems analysis primer
- Systems concepts in health
Part 1: Long historical view
How we got here


- Stone age
- Enlightenment
- Game theory
- Agent based modeling

- Plato
- Republic

- Hegel
- Marx
- Engels
- Weber

- 易经
- System dynamics

Future Health Systems
Innovations for equity
Evolution of thought

- Starting point: iterative study of stimulus and response
- Intermediate point: predictive understanding of how systems will respond
- Final point: mastery and control of systems
Stone age “Homo sapiens”

- Iterative approach to systems
  - Earliest
  - Most widely used today
  - Most likely to succeed

- Steps:
  - Define desired outcome of system
  - Define a metric
  - Develop alternative solutions
  - Iterative tinkering against the metric
Examples

- **Successes:**
  - Stone tools
  - Domestication of animals and plants

- **Failures:**
  - Eradication of poverty
  - Prevention of wars
Greece and Rome

- Systematic inquiry into social and political events
- Plato’s *Republic*
  - Stakeholders as classes
    - Rulers
    - Soldiers
    - Farmers, merchants, artisans
  - Beyond iterative tinkering: models
    - Essential nature of each class
    - Relationships between stakeholders
Enlightenment

- Profound optimism
  - Scientific discoveries can make the world better

- Rousseau, Locke, Jefferson
  - Social contracts can codify and organize the social classes
  - Can imagine alternative configurations
  - Revolutions in US and France to help men in “pursuit of happiness”
Hegel, Marx, Engels, Weber

- Optimism to pessimism
- Social classes defined by the relationship to economic resources
- Materialist versions of history
  - History as “slaughterbench at which the happiness of peoples ... have been victimized” Hegel
  - Conflict between classes over social definitions of property
Social systems

- Marx/Engels: classes in a contest for property rights which are upheld by the state
  - Power of states and classes can change
  - Shifts in material base of power occur
    - Technological change
    - Ideological change
- Weber: Scientists can model these shifts in class relationships
Game theory

- Mathematical axiomatic approach to social conflict over resources
  - Define stakeholders
  - Define the rules about how they accumulate resources
  - Policy analysis
    - The policy response function
    - Tic tac toe
System dynamics

- The trouble with game theory
  - In tic tac toe: only one outcome
  - Too many games where anything can happen

- System dynamics applied simulation to social systems
  - Models of business processes
  - Tinkering in silicon
System dynamics

- Set boundary to problem
- Identify stocks and flows
- Identify information
- Identify feedback loops
- Draw a diagram
- Write equations
- Estimate parameters
- Simulate the problem and tinker
Agent based models

- In system dynamics the focus is on the physical resources of importance to the human agents.
- In agent based models the focus is on the agents:
  - Classes of agents are defined.
  - Robot agents are programmed to interact with each other in the simulation.
What is worth keeping?

- “It’s all good”
  - Stone age approach is as valid as agent based models
  - Knowledge always possible
  - Useful knowledge depends on politics
  - Progress for humanity remains rare

- Many systems that get stuck in sub-optimal equilibria
  - Knowing a better way, knowing you cannot get there, knowing why.
Summary of Part 1

- Systems analysis has a long history for human species
- Progression from
  - Iterative tinkering in real systems to
  - Mental models of systems
  - Central role of class and conflict
  - Mathematical models of systems
  - Iterative tinkering in simulated systems
Part 2: Systems analysis primer
General approach to modeling

- Eternal tasks in systems analysis
  - Define desired outcome of system
  - Define a metric
  - Develop alternative solutions
  - Iterative tinkering against the metric

- Modern features for social systems
  - Define classes
  - Define class interests
  - Define class policy options

- Choose modeling platform and structure
Task 1: Determine goals

○ Set boundaries
  ● Client problems seem unbounded
    ○ Essential drug lists linked to health insurance
  ● “The ability to ignore is a crucial component of scientific progress.” Miller and Page
Task 2: Define metrics

- Measurable and meaningful
  - Mistake 1) Measurable not meaningful
  - Mistake 2) Meaningful not measurable
- Measurable by someone
  - Sales data known by firms only
- Measurable in principle
- One metric better than many
- Consensus is difficult
Task 3: Define alternative solutions

- Institutional changes in system structure or system function
  - Technological alternatives
    - Solve traffic problems with a subway
  - Functional alternatives
    - Solve traffic problems with city entry fees
Task 4: Iterative tinkering

- Sometimes impossible to do this at full scale
- Impact of system on non-users
  - Best vs politically feasible
Classes

- Stakeholders defined by their relationship to resources
- What are resources determined by property rights
- Property rights established and maintained by formal and informal institutions
  - The role of the state
Class interests

Examples:
- Agrarian society (Land is main resource)
  - Landlords (own land)
  - Serfs (own nothing-tied to land)
  - Artisans and merchants (own rights to trade)
- Land titles are contingent on state
  - Revolutions can undo land titles
Class policy options

- What can a class do to maintain or improve the institutions that determine power?
  - Produce ideologies
    - (Academics and money can be helpful)
  - Curry favor with the state
  - Wait for technological change
Summary of part 1

- **All systems**
  - Define desired outcome of system
  - Define a metric
  - Develop alternative solutions
  - Iterative tinkering against the metric

- **Social systems**
  - Define classes by their connection to resources
  - Define class interests
  - Define class policy options
Part 3: Systems concepts in health
Basic Definitions

- **Economic Units**
  - groups of individuals brought together for a common purpose—often from a common class

- **Economic Agent**
  - an individual with a specific role in the system, e.g. a patient, a nurse, a manager

- **Institutions**
  - Norms, rules of conduct, established procedures e.g. property, corporations, paying fines, tipping waiters
Systems: Adjust, Adapt, Cohere

- **Adjustments**
  - Agents and units take the institutions and incentives that they impose as given
  - Adjust behavior according to how the incentives affect them

- **Adaptation by outsiders and insiders**
  - Work to design new institutions (vouchers, detailing)
  - Work to alter the incentives provided by existing institutions

- **Coherence**
  - The degree to which multiple units and agents coordinate their activity for common purpose
  - Harmonized incentives
Adjustment to Institutions

- Adjustment processes lead agent and principal to work within the system to their own maximal advantage
  - During adjustment both the agent and principal will exploit flaws in the contract
  - If incentives incompatible and monitoring weak
    - Agent will try to undersupply effort
    - Principal will try to undersupply the incentive
- Adjustment can try to specify better monitoring for the contract
- Coherent incentives (when both agent and principal want the same thing) monitoring is less important
Adaptation of Institutions

- Changing the structure of the institutions and norms in the system
  - Examples
    - Price regulation for essential drugs
  - Sometimes the changes are so large that they may be regarded as starting new institutions
Most Important Adaptations

- Building institutions that monitor performance
- Changing the flows of information for better contract enforcement
- Making monitoring routine
- Adapting the institutions so that there is coherence in the goals of patients, providers, payers, public health
Coherence

Coherence: the degree to which the people in the unit agree about their work (😊 = high morale, 🙁 = low morale)

High coherence

Low coherence
Importance of Coherence

- Agreement on rules or norms makes contracts work even if they are not perfect.
- If principal and agent want the same thing contracts become less important.
- Staff share in the wins and losses.
Achieving Coherence

- Leaders who can articulate and communicate the goals of the system
- Selecting individuals with incentives compatible with the system
  - Selective admission to professions
  - Selective promotion on the basis of coherent incentives
Monitoring

- If agents don’t agree on system goals, more monitoring is necessary
- Develop institutions that automatically monitor
- Develop governmental investments in monitoring and contract enforcement can improve system function
The 7 Health Subsystems (WHO building blocks +1)

1. Primary health service delivery system
2. Health workforce
3. Leadership and governance to assure quality
4. Health systems financing
5. Supplying medical products and technologies
6. Health systems information
7. Households
Reductionism: Health Systems

<table>
<thead>
<tr>
<th>Units</th>
<th>Agents</th>
<th>Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Health Subsystem</strong></td>
<td><strong>Organ Systems</strong></td>
<td><strong>Organs</strong></td>
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<tr>
<td>Health Service Delivery</td>
<td>Clinics</td>
<td>Doctors</td>
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<td></td>
<td>Hospitals</td>
<td>Nurses</td>
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<td></td>
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<td>Administrators</td>
</tr>
<tr>
<td>Supplying medical products</td>
<td>Pharma companies</td>
<td>Market rep</td>
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<tr>
<td></td>
<td>Distribution chains</td>
<td>Distributor</td>
</tr>
</tbody>
</table>
Institutional Pathology

- Human *Agents* are the “cells” in health systems
- Incentives are the “cellular metabolism” that regulate the function of human agents
  - Understanding incentives is fundamental to understanding the health system
Incentives

- Incentives are the set of motivations that compel individuals to perform roles and conduct tasks in the economy
  - Economic Incentives
    - Money (wages, benefits, revenue, promotions)
    - Comfort, Easy workload, Safe workplace
  - Psychological Incentives
    - Professionalism, autonomy, integrity, altruism
  - Social incentives
    - Approval, social status, reputation, gratitude
- “Institutions” (rules of conduct) connect agent performance to their incentives
Incentives and social cooperation

Smallest social group = 2 people. They need to cooperate
  - I will wash your car if you give me a haircut
  - I will pay you $1.00 if you give me a cup of tea

Definitions
  - “The Principal” = the one who makes the request
  - “The Agent” = the one requested
  - “A Contract” = an offer by the principal to the agent to offer incentives to perform a task

A good contract
  - Specifies the request and the reward
  - Reward/punishment is consistent with the agent’s incentives
  - Specifies criteria for fulfillment of request and proposes monitoring
  - Specifies processes in case contract is not honored by either side
Bad contracts

- Principal does not (or cannot) specify the nature of the request in sufficient detail
- Principal does not (or cannot) monitor the agent’s performance
- The incentive offered is not something that motivates the agent
- Cultural and legal environment inhibits enforcement of the contract

- Bad contracts lead to unintended consequences
  - Agent does not do exactly what principal wants
  - Principal wastes incentives
  - Agent wastes effort
Contracts in Health Care

- Contracts work better when the request is something that can be measured and monitored
  - Easy: “Deliver 1000 vials of refrigerated measles vaccine to X hospital on March 1”
  - Hard: “Provide the correct diagnosis and therapy to all of the children coming to your health post next year”

- Work best when the incentives offered are coherent with the agent’s goals
Example 1: Medical Care

Doctors are the Agents

Patients are the Principals

Patient’s contract

- “I will give you $10 if you will listen to my health complaint and tell me what to do”
- “I might buy additional drugs and services from you if you convince me they are worth it”

- Doctor emphasizes suggesting therapies that the patient thinks are valuable
  - Drugs
  - Injections
  - Follow up visits

- Low incentives to adhere to practice guidelines
Example 2: Vouchers

Households given vouchers that can be redeemed for key underutilized services

- In Uganda: attended delivery
- In Guatemala: STD treatment

Patients incentivized to seek services

Vouchers sometimes don’t specify that the patients go to good clinics
Summary of Part 3 Systems concepts in health

- Most systems we model are composed of individuals inside units
  - Units linked by institutions
  - Units linked by coherence or monitoring
  - Agents driven by incentives

- Contracts transmit incentives across units
  - Good contracts tie wanted incentives to easily measured metrics
Diagramming Systems

Workshop on CASH: July 19, 2011
10:30-11:45
Outline

- Prelude to system dynamics diagram
- Basic elements of system dynamics diagram
- Other styles of diagram
Part 1: Prelude to system dynamics
Identifying states

- A “state” is a concrete stock variable that lends itself to easy measurement
  - Number of drugs in stock
  - Number of patients in beds
  - Number of employees on payroll
Identifying flows

- Every state has at least one inflow and one outflow
  - Drugs in stock
    - Inflow from distribution chain
    - Outflow to patients
    - Other outflows?
Identifying controls

- Control variables are mostly informational facts that are used by units and agents to alter flows
Part 2: Basic diagramming
Diagramming States

State = Stock of Drugs

States are diagrammed by rectangles:
Every rectangle represents a state variable
Diagramming Flows

Rates are diagrammed by stopcocks:
Arrows inside stopcocks mean “flow”
Diagramming Controls

Controls are diagrammed by circles:
Arrows not in stop cocks are arrows of influence
Summary system dynamics notation

- Rectangles
- Stopcocks
- Circles
- Arrows inside stopcocks
- Arrows outside stopcocks
Importance of Diagram

- Can build mathematical model around each item in diagram

- Level of state X
  - $X_{t+1} = X_t + \text{Rate of Inflow}_t - \text{Rate of Outflow}_t$

- Rate of inflow
  - $\text{Rate}_{t+1} = F(\text{Control}_t) \times \text{Rate}_t$

- Control
  - $\text{Control}_{t+1} = f(\text{Controls}, \text{Levels}, \text{Rates})$
Part 3: Other diagrams
Other diagrams

- Rectangles and polygons for key concepts
- Arrows for conceptual relationships, causal influences, and resource flows
Conceptual diagrams

Model for Understanding Complex Pathways

Initiating Conditions
- Political
- Economic
- Social
- Legal
- Environmental
- Epidemiological

Complexity
- Diversity
- Connectedness
- Interdependence
- Learning

Outcomes
- Intended Outcomes
  - Health Service: Coverage, Quality, Equity, Efficiency
- Unintended Consequences
  - Marginalized populations
  - Disorganized markets
  - Narrow range of services
  - Unsustainable strategies
  - Loss of public goods

Patterns of Change
- Disorganization
- Periodic Orbits
- Linear
- Equilibrium

- Cascading
- Tipping Points
- Phase Transitions
- Path Dependence
- Emergent Structures

Future Health Systems
Innovations for equity
Diagrams of Units/Agents

- Government
- Factory 1
- Factory 2
- Distributor 1
- Distributor 2
- Hospital 1
- Hospital 2
- Hospital 3
- Patients
NetLogo Models

July 19, 2011 at 13:45
See exercise 4 handout
Applying CASH Methods

Workshop on CASH: July 20th 9AM
Outline

- Application to Chinese Health Reform
  - Define desired outcome of system
  - Define metrics
  - Define classes
  - Define class interests
  - Define policy options
Application to Essential Drug Payment Reform

○ Priorities for desired outcomes
  ● Stockouts
  ● Drug quality
  ● Government drug spending
  ● Patient out of pocket spending
  ● Government tax burden
  ● Treatment delays
  ● Volume of services
  ● Other?
Application to Essential Drug Payment Reform

- Priorities
  - Stockouts
  - Drug quality
  - Government drug spending
  - Patient out of pocket spending
  - Government tax burden
  - Treatment delays
  - Volume of services

- Metrics
Define classes

- **Resources**
  - Govt tax revenue
  - Patient care revenue

- **Units**
  - Provincial government
  - Factories
  - Distributors
  - Households
  - Patients
Define class interests

- Patients
  - Maximize health
  - Minimize spending

- Hospital
  - Maximize reputation for quality
  - Maximize political favor
  - Minimize spending

- Distributor
  - Maximize revenue, Minimize costs
Define class interests

- **Factory**
  - Maximize profit

- **Government**
  - Maximize safety of health system
  - Minimize costs for vulnerable groups
  - Protect against financial catastrophe
  - Impose reasonable taxes
## Define Policy Options

<table>
<thead>
<tr>
<th>Unit</th>
<th>Policy Options</th>
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<tbody>
<tr>
<td>Government</td>
<td>Establish criteria for winning tender</td>
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<tr>
<td></td>
<td>Collect taxes</td>
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<td></td>
<td>Budget support for hospital</td>
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<tr>
<td></td>
<td>Budget support for distributors</td>
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<td>Monitors markups and drug quality</td>
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<tr>
<td>Factories</td>
<td>Bids to supply essential drugs</td>
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<td>Contracts with distributors</td>
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<td></td>
<td>Sets drug quality</td>
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<td>Sells non-essential drugs</td>
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<tr>
<td>Distributors</td>
<td>Collects revenue (Factories, Hospitals, Govt)</td>
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<td>Expends costs to travel</td>
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<tr>
<td>Hospitals</td>
<td>Orders essential drugs</td>
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<tr>
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<td>Collects revenue (Govt, users, insurance)</td>
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<tr>
<td>Patients</td>
<td>Selects hospital</td>
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<td></td>
<td>Pays co payment, drug fee, travel costs</td>
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<td></td>
<td>Incurs health outcomes and treatment delays</td>
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</table>
Next steps

- Choose modeling platform:
  - Agent based:
    - Produce robot factories, distributors, hospitals, patients
      - Each pursues the above policies
      - Maximizes objectives
      - Tries to not go bankrupt/suffer bad outcome
  - System dynamics
    - Focus on state variables
      - Stocks of high quality drugs
      - Factory orders
      - Patient visit volumes