turning knowledge into practice

Modeling and Simulation in Social Sciences

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Modeling Approaches

Reductionist vs. Systems

Traditional Reductionist Approach

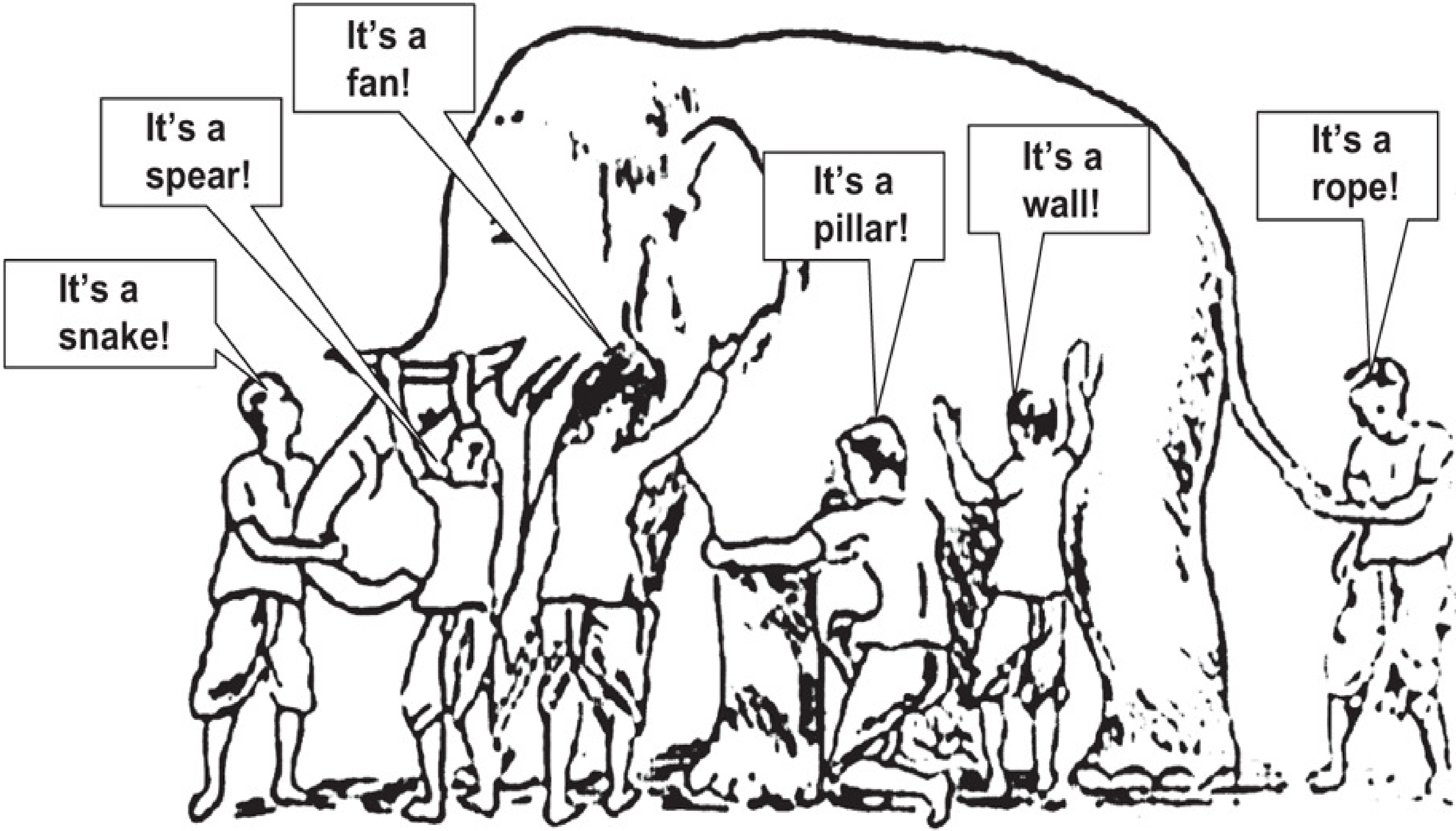
Goals

1. Understanding components
   - Assumption that certain elements are more important than the others
   - Mechanistic approach
   - Simplicity is critical
2. Finding associations. Focus on explanation
   - Traditional statistical methods (hypothesis testing)
   - Moderation and multivariate testing
3. Establishing causality. Mechanistic approach
   - Structural equation modeling, mediation
   - Control theory

Methods

- Statistical models
- Dynamical systems
  - Even simple models can produce very complex behavior
- Experimental designs
- Parameter estimation
- Predictions based on assumptions of control and consistency
  - Assumption of consistency of the model over time, i.e. if it worked last year it will work next year.

Problems


It's a snake!
It's a spear!
It's a fan!
It's a pillar!
It's a wall!
It's a rope!

Systems Modeling Approach

Goals

1. Understanding the entire system
    1. Weak predictors vs. strong predictors
    2. Complexity and adaptivity
    3. Stability vs. responsiveness butterfly effect?
2. Often a Black box approach with inputs-outputs
3. Focus on prediction rather than on explanation
    1. Practice is the criterion of truth
    2. Before predicting need to “understand”
4. Establishing feedback loops and bivariate relationships
    1. Structural equation modeling, mediation
    2. Control theory

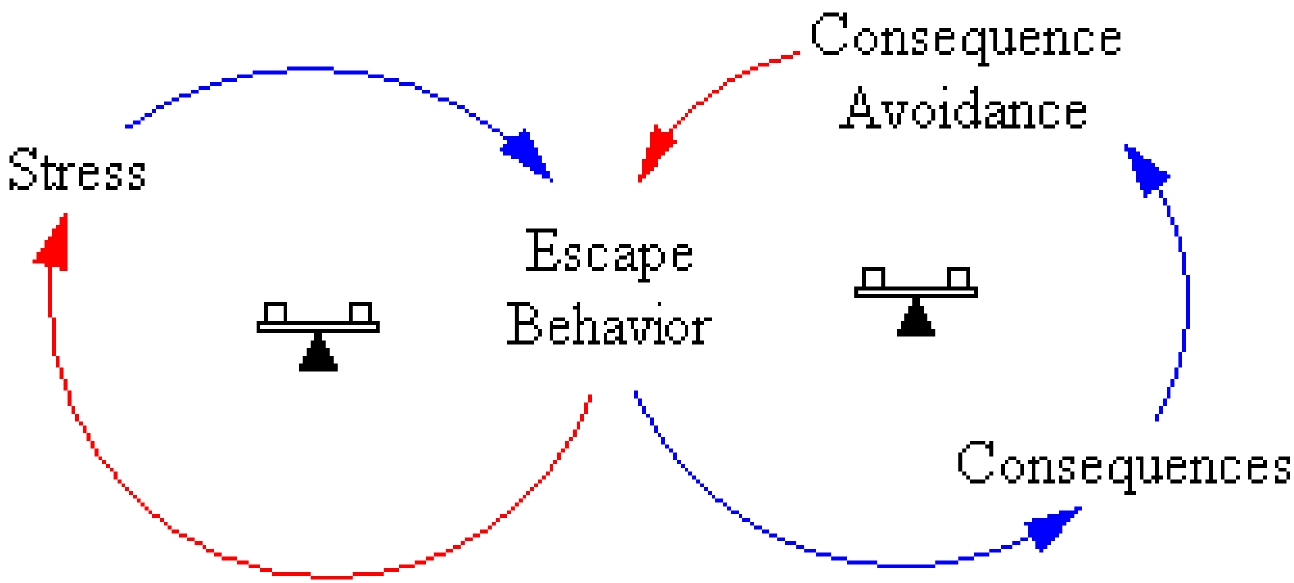
Methods

- **Mental models**
  - Implicit
  - Assumptions are hidden so ambiguities and contradictions remain undetected
  - Their structure and consistency are untested and usually, they are unsupported by data
  - Interpretations differ
- **Explicit computational models**
  - Assumptions are explicit
  - Models incorporate multiple pieces of knowledge
  - Calibration verification validation.

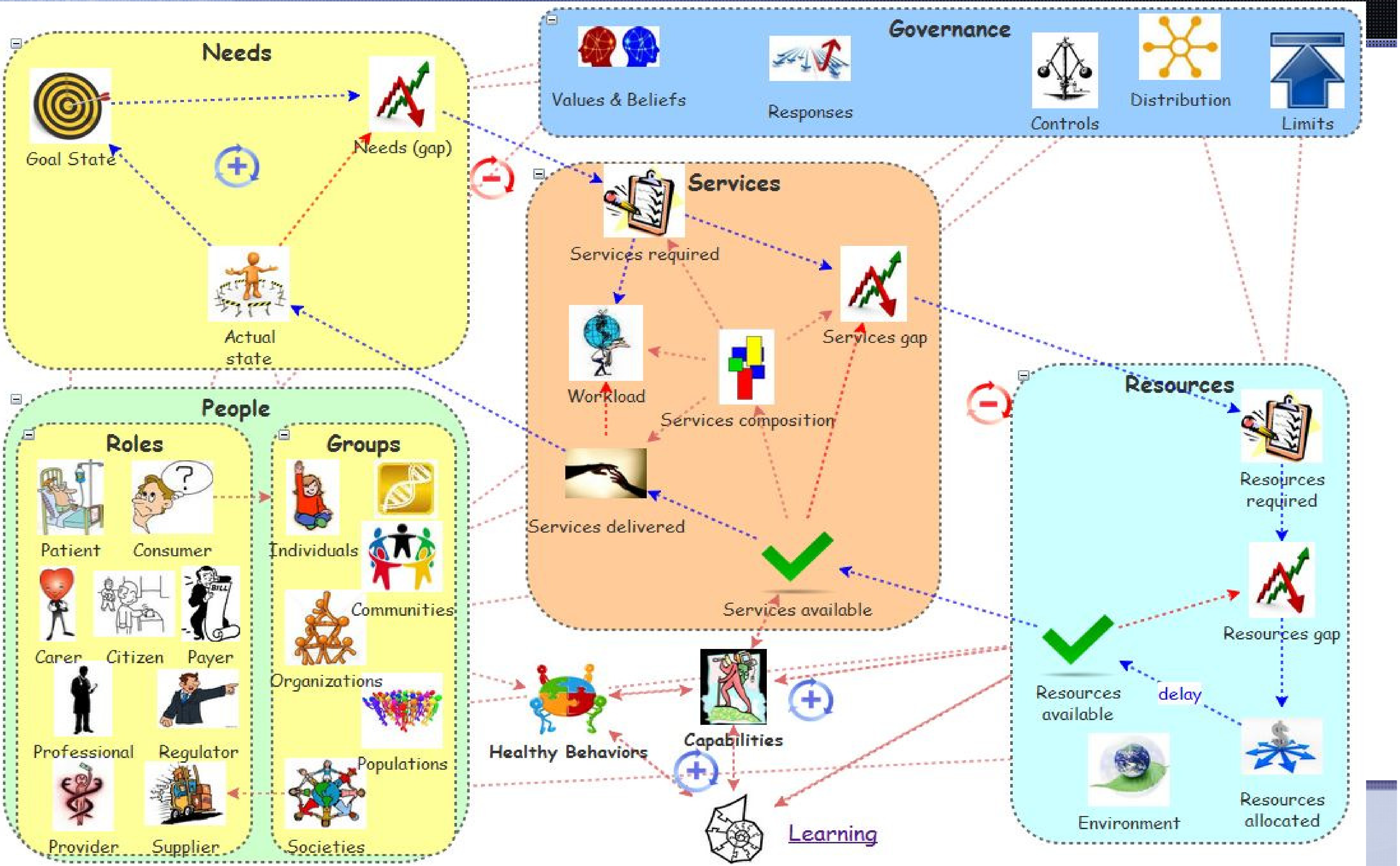
Mental Models

- Deeply ingrained filters through which we interpret our experiences, understand the world and which affect how we take action.
- Images, assumptions and stories which we carry in our minds describing every aspect of the world. They are unique to the individual and they are all flawed in some way.
- Flexible, dealing with more than just numerical data and they can be modified as new information comes to light.

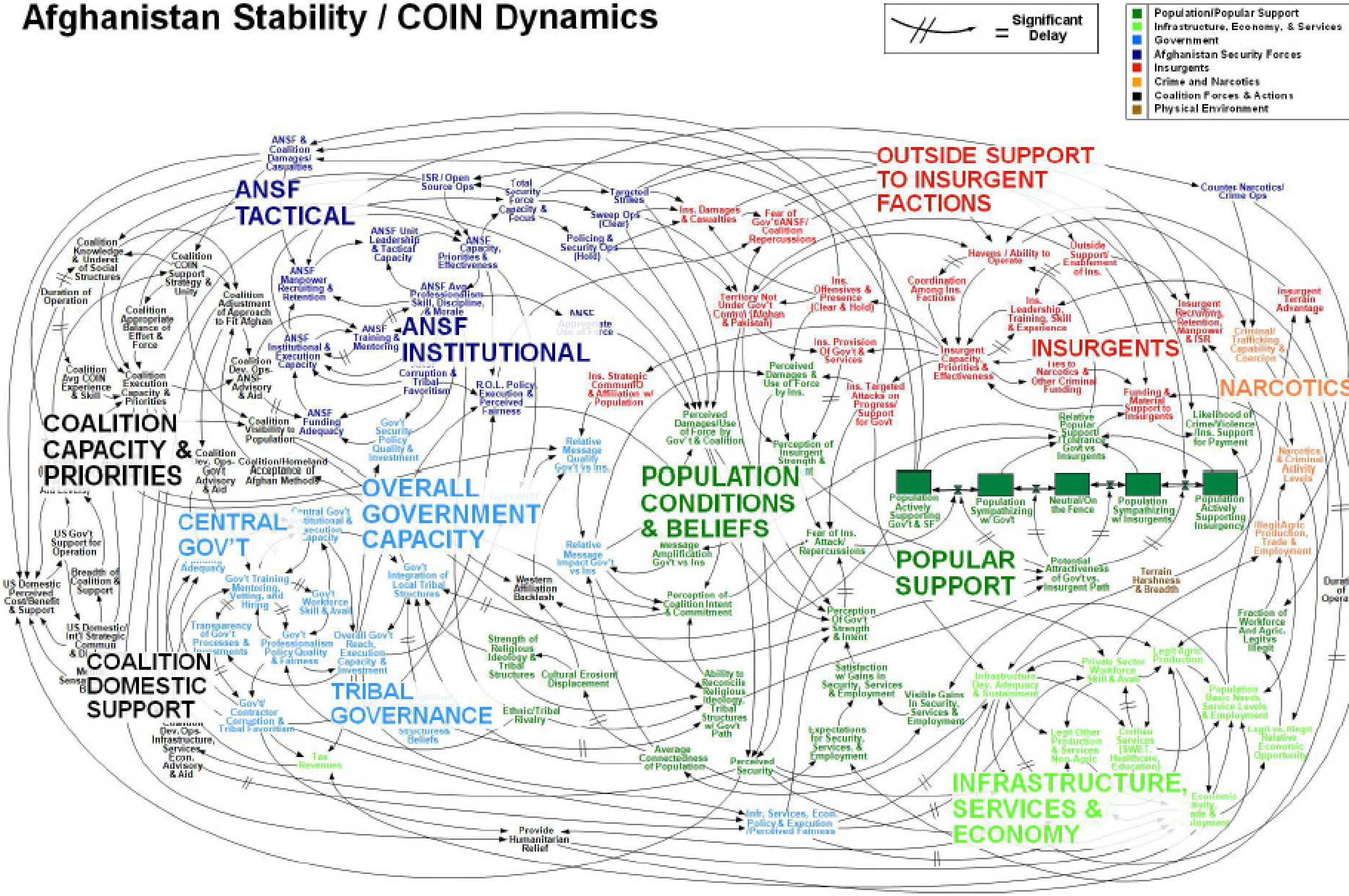
Simple Mental Model (classroom behavior) by Zachary Lawrence



Healthcare (www.systemswiki.org)



Afghanistan Stability / COIN Dynamics



WORKING DRAFT – V3

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Types of Simulation Models

By Techniques

http://www.xjtek.com/files/book/Modeling_and_simulation_modeling.pdf

Hierarchy of Simulation Models (non-consistent terminology)

Statistical → Markov → System Dynamics → Microsim e.g. Discrete Event → Agent-Based

Statistical
- Linear
- Non-linear
- Time

Markov
- Linear
- Non-linear
- Time
- States

System Dynamics
- Linear
- Non-linear
- Time
- States
- Feedback loops

Microsim (e.g. Discrete Event)
- Linear
- Non-linear
- Time
- States
- Feedback loops
- Heterogeneity

Agent-Based
- Linear
- Non-linear
- Time
- States
- Feedback loops
- Heterogeneity
- Interactions
- Non-linearity

Predictive Models Using Regression

Step 1. Fit a regression (can add nonlinearities and time)

$y=\beta_0+\beta_1 x+\varepsilon=N(\beta_0+\beta_1 x,\ \sigma^2)$

Step 2. Predict a new number

$$\hat{y}=\hat{\beta}_0+\hat{\beta}_1 x_1^{*}=\hat{\beta}_0+\hat{\beta}_1\bar{x}_1+\hat{\beta}_1\Delta x_1=y+\hat{\beta}_1\Delta x_1$$

Step 3. Estimate the variance of the prediction

$$Var(\hat{y}+\varepsilon)=Var(\hat{\beta}_0+\hat{\beta}_1 x_1^{*}+\varepsilon)=\sigma^2\left(\frac{1}{n}+\frac{(x^{*}-\bar{x})^2}{S_{xx}}\right)+\sigma^2$$

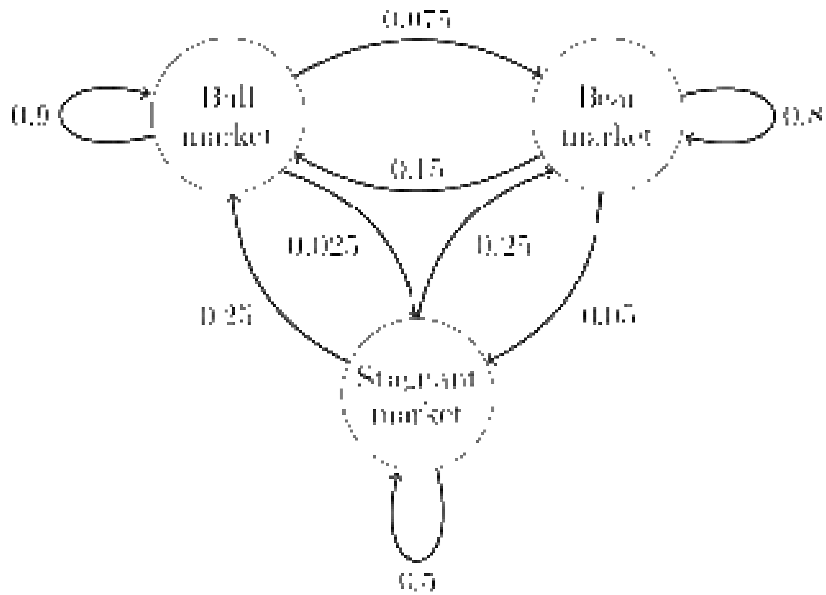
Predictive Models Using Markov Model

Step 1. Define States (e.g. Bull market, Bear market, Stagnant market)

Step 2. Define transition probabilities

Step 3. Iterate the model:

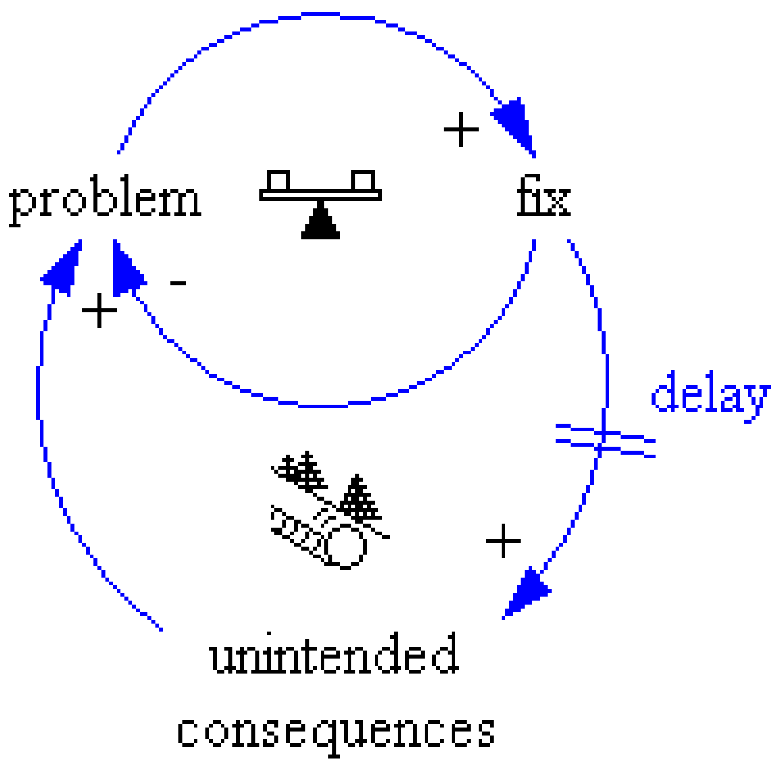
$X_{n+1}=AX_n \quad A= \begin{bmatrix} 0.9 & 0.075 & 0.025 \\ 0.15 & 0.8 & 0.05 \\ 0.25 & 0.25 & 0.5 \end{bmatrix}$



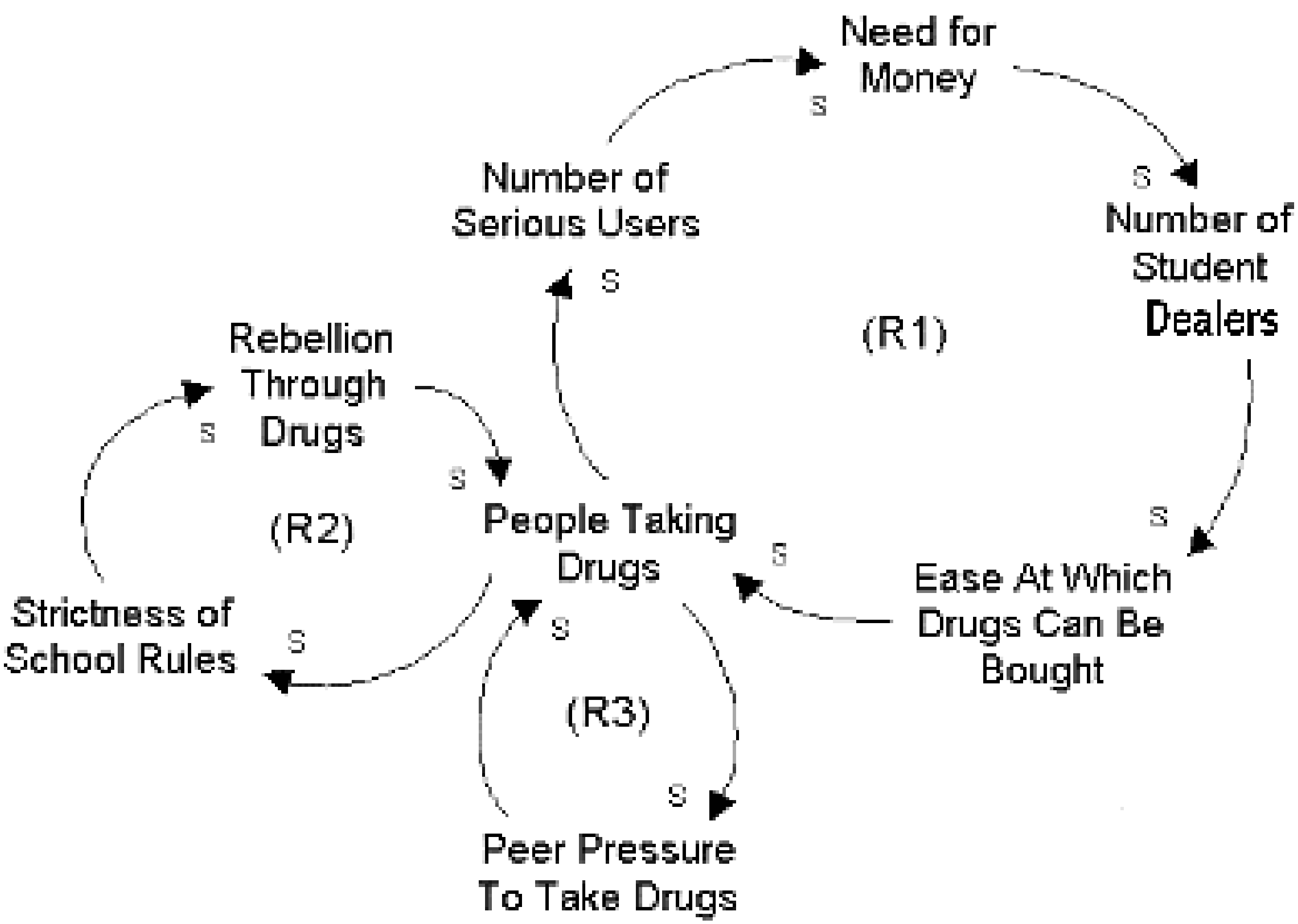
Steady state: X_∞= **[0.63, 0.31, 0.06]**

Feedback Loops in System Dynamics

Note a principal difference from statistical and Markov models



Feedback Loops in System Dynamics

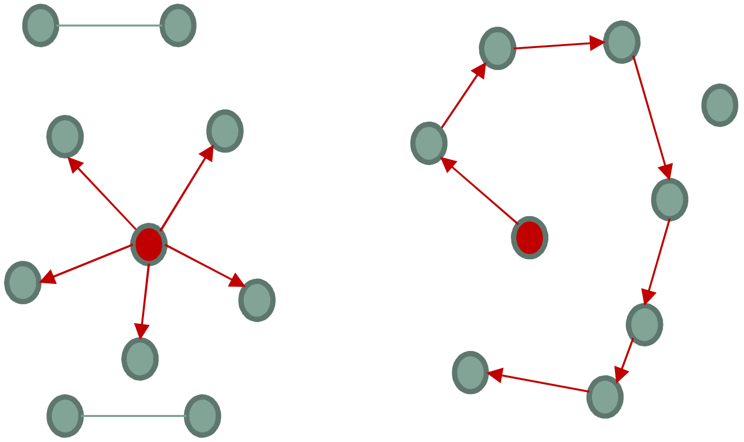


Discrete Events Model

- Individual entities are passing through certain stages or compartments
- Entities are passive
- Example: Queuing system (classic bank teller problem).
- Will customers wait?

Jensen's Inequality and the Bias of Early Averaging

- **Statistical and system dynamics models:**
  - **First average, then apply the rules.**
- **Agent-based model:**
  - **First apply the rules and then average**



Where does it matter?

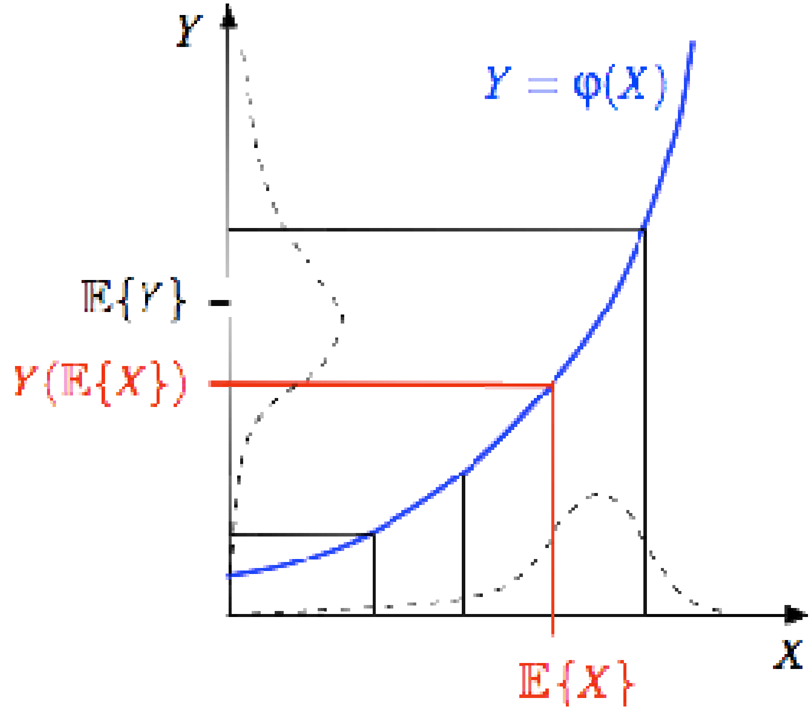
Jensen's Inequality and the Bias of Early Averaging

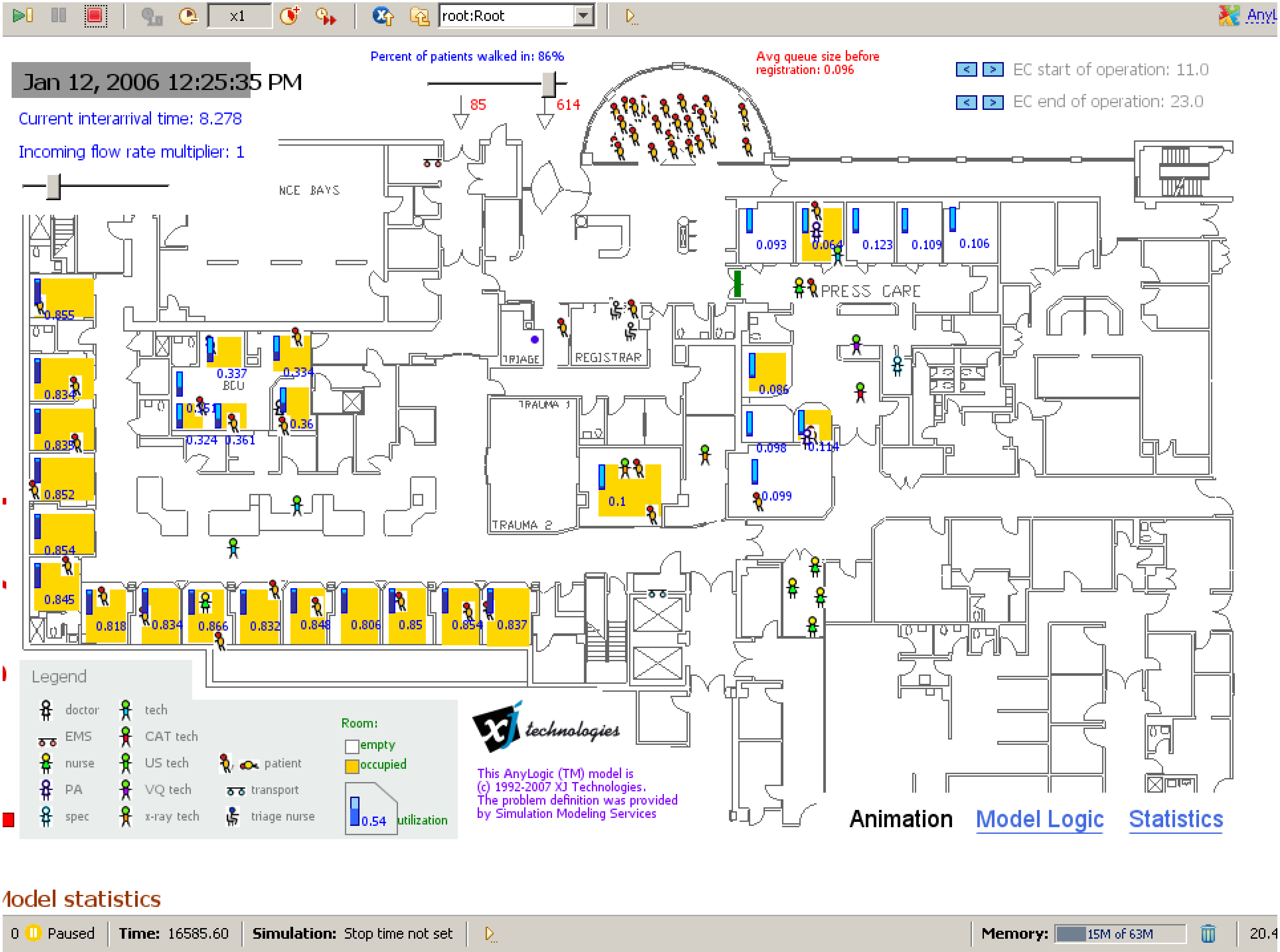
For a convex function $Y = \varphi(X)$

$$E(Y(X)) \geq Y(E(X))$$

For a concave function the relationship is reverse

$$Y(E(X)) \geq E(Y(X))$$




root:Root
x1
AnyL
Jan 12, 2006 12:25:35 PM
Current interarrival time: 8.278
Incoming flow rate multiplier: 1
Percent of patients walked in: 86%
85
614
Avg queue size before registration: 0.096
EC start of operation: 11.0
EC end of operation: 23.0
NCE BAYS
BCU
TRIAGE
REGISTRAR
PRESS CARE
TRAUMA 1
TRAUMA 2
Legend
doctor
EMS
nurse
PA
spec
tech
CAT tech
US tech
VQ tech
x-ray tech
patient
transport
triage nurse
Room:
empty
occupied
0.54
utilization
XJ technologies
This AnyLogic (TM) model is (c) 1992-2007 XJ Technologies. The problem definition was provided by Simulation Modeling Services
Animation
Model Logic
Statistics
Model statistics
Paused
Time: 16585.60
Simulation: Stop time not set
Memory: 15M of 63M

Agent-Based Models (ABMs)

Rules are defined locally

Difference from general micro-simulations when rules can be global

- **Bottom-up models**

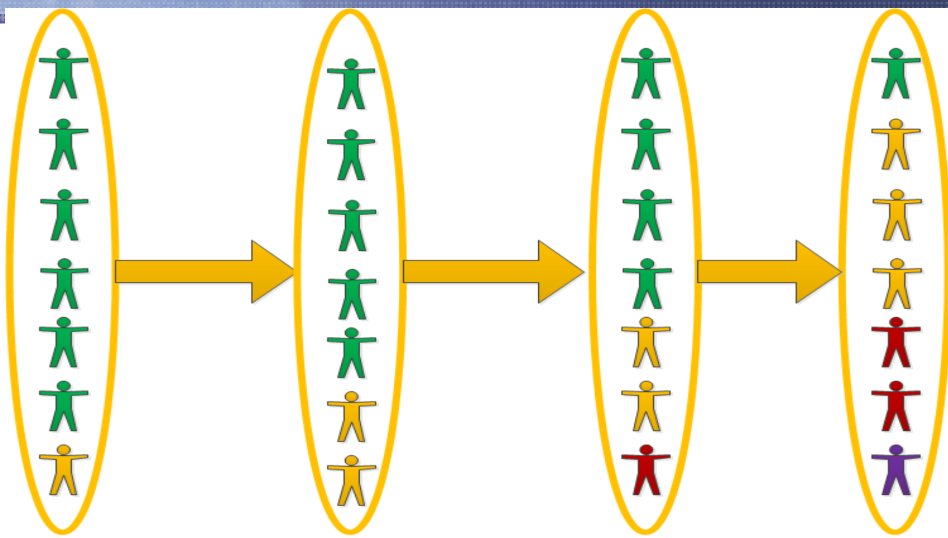
  Based on individuals, non-linear decisions, interactions, and networks

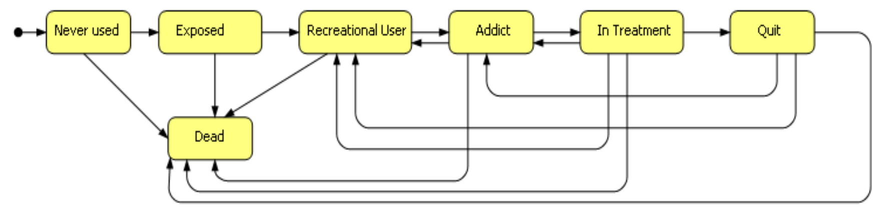
- **Agents are computer objects that are defined by states, transitions between the states and rules of interaction between each other and environment**

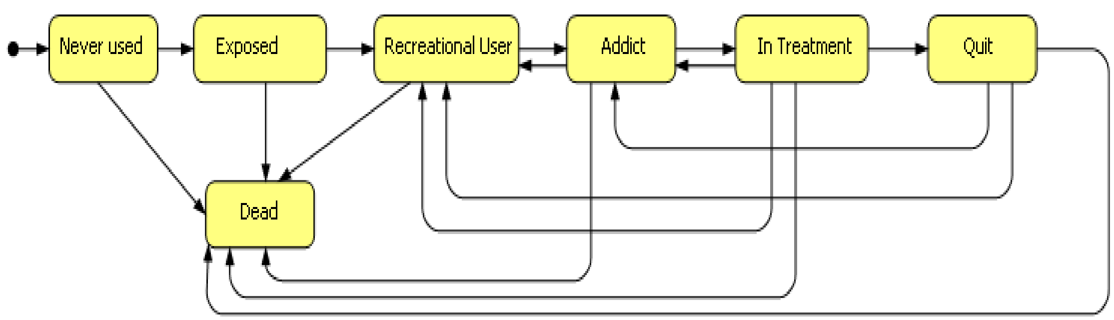
  If agents are passive the model is just a micro-simulation (a.k.a. discrete event)

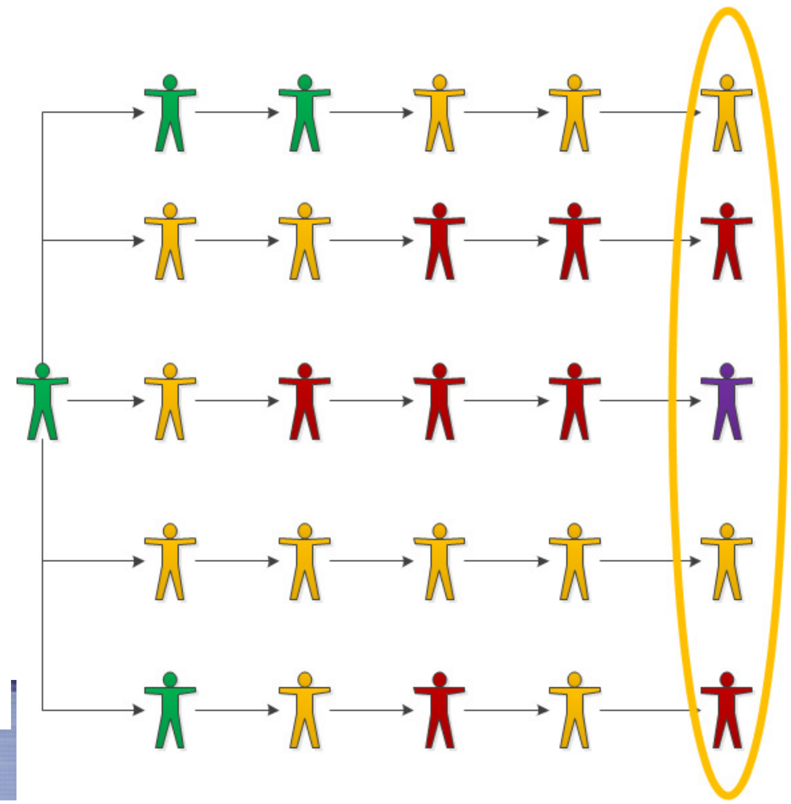
- **Hybrid models can combine, e.g., System-dynamics environments with agent-based behavioral models. Interactions between agents, not variables.**

System Dynamics and Agent-based Models

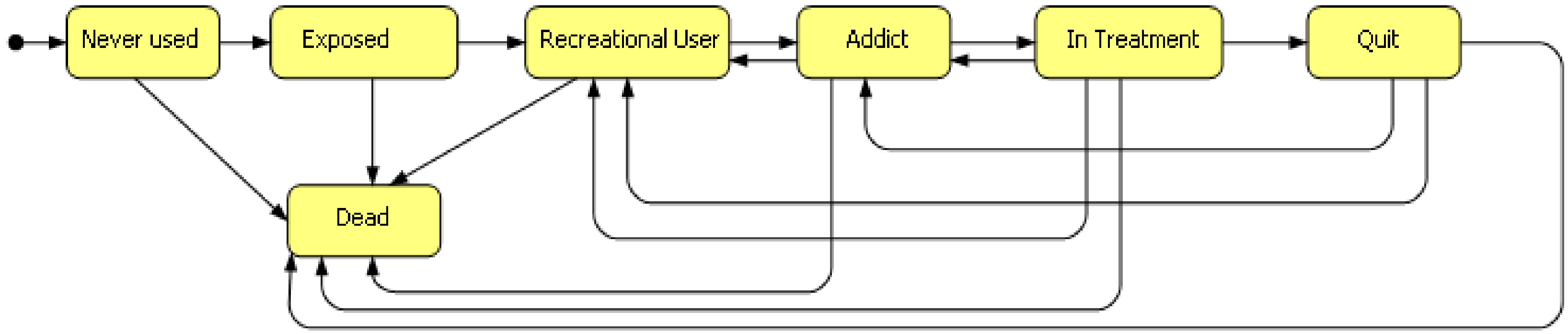






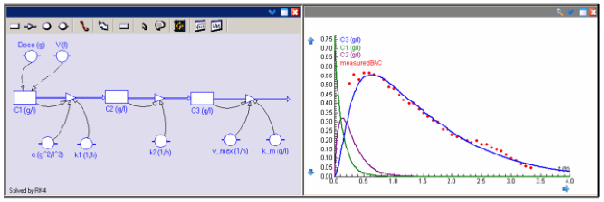


Agent-based Model



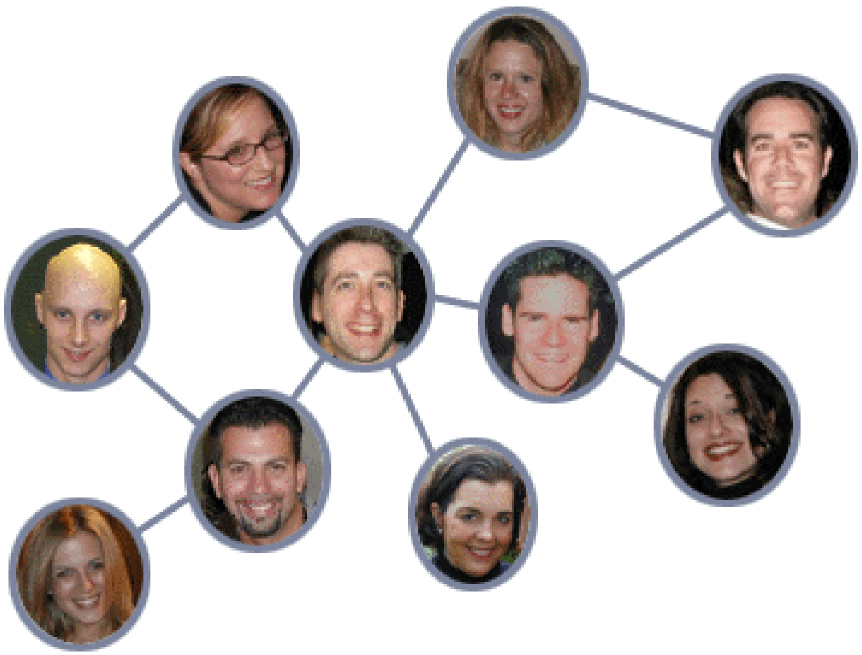
- Agents can make decisions based on rules
- Agents can be adaptive
- Agents can have several state charts and internal dynamics

Agent



- Agents can have social networks

Social Network



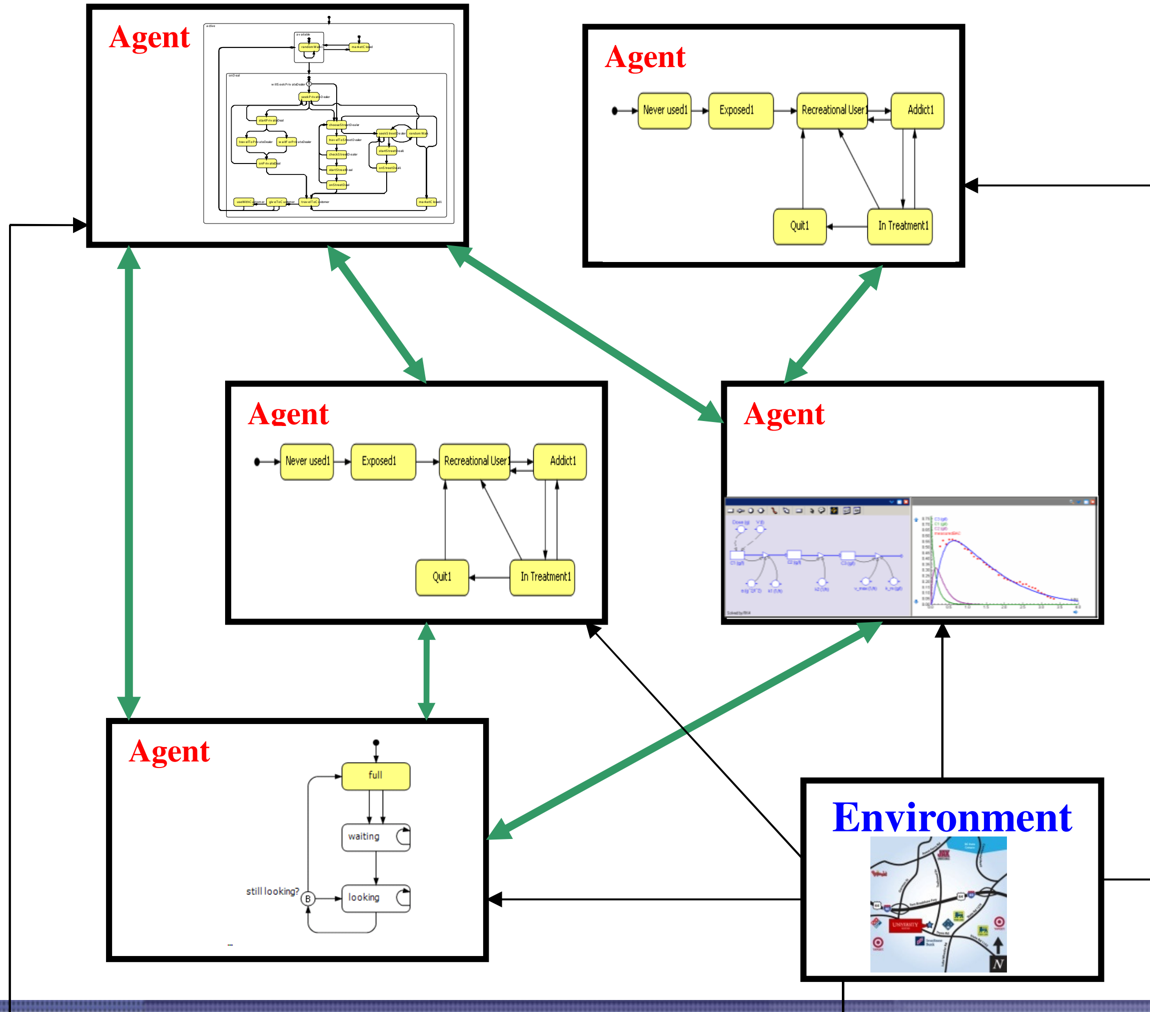
Agent-based Models

Social Networks

Behavior

Interaction

Self-organization



EXAMPLES

Flock of Birds

- **Birds have speed, and direction and fly around in on a torus**
- **A bird has vision radius and can assess birds around**
- **The birds follow three rules: "alignment", "separation", and "cohesion".**
- **Fully deterministic model! No randomness there**

Flock of Birds

- "Alignment" means that a bird tends to turn so that it is moving in the same average direction as the neighbors.
- "Cohesion" means that a bird will move towards other nearby birds
- "Separation" means that a bird will turn to avoid another bird which gets too close.
- Separation rule overrides the other two, until the minimum separation is achieved.

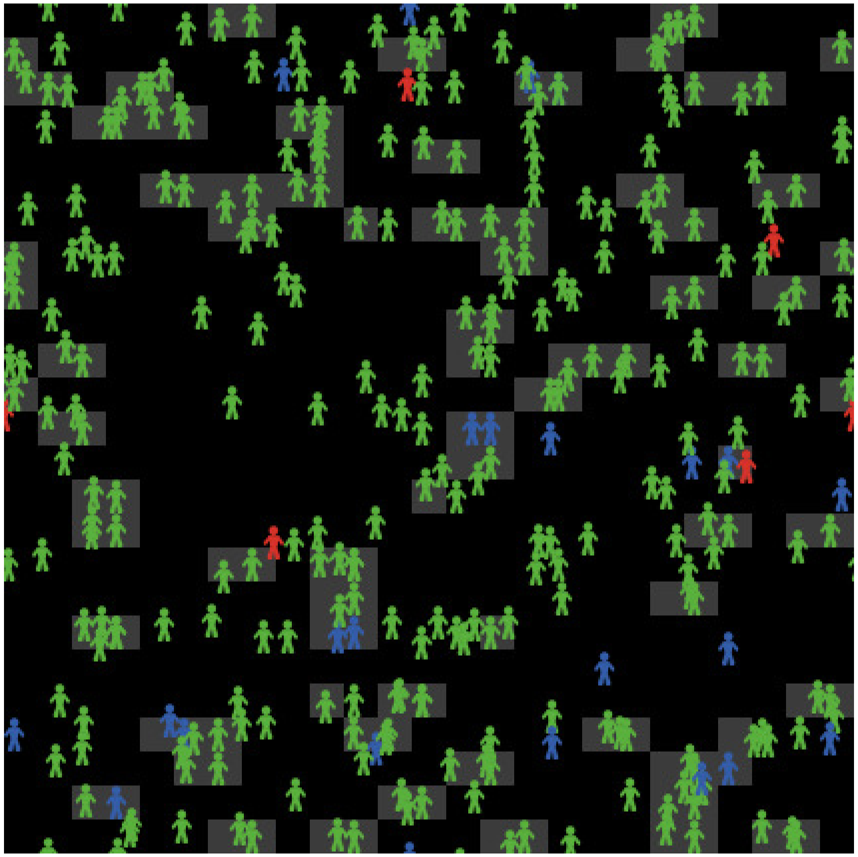
Parameter Values

- Pop 300, vis 7, sep 0.25, cohere 3 sep 1.5, align 1.5 => completely aligned
- Vis 9, sep 0.5, cohere & sep 15, align 1.5 =>circle
- Extreme cases
- Vision 10, everything else 0, cohere 20 -> 0.
- Add allign20 => all get completely aligned in a single moving packet
- Change vision to 0 lines across the screen

Predator-Pray

- Three species: wolves, sheep and grass
- When sheep eat grass they gain energy, when sheep move they lose energy
- When wolves eat sheep they gain energy , when wolves move they lose energy
- A percent of animals reproduces but loses half of energy
- Grass grows at specific rate
- Stochastic model

HIV Model



Can Models of Different Types be Equivalent to Each Other?

H. Rahmandad and J. Sterman (2004) *Heterogeneity and network structure in the dynamics of contagion: Comparing agent-based and differential equation models*

Can several types of models be compared to each other?

Compare an agent-based model with a system dynamics model. SEIR model

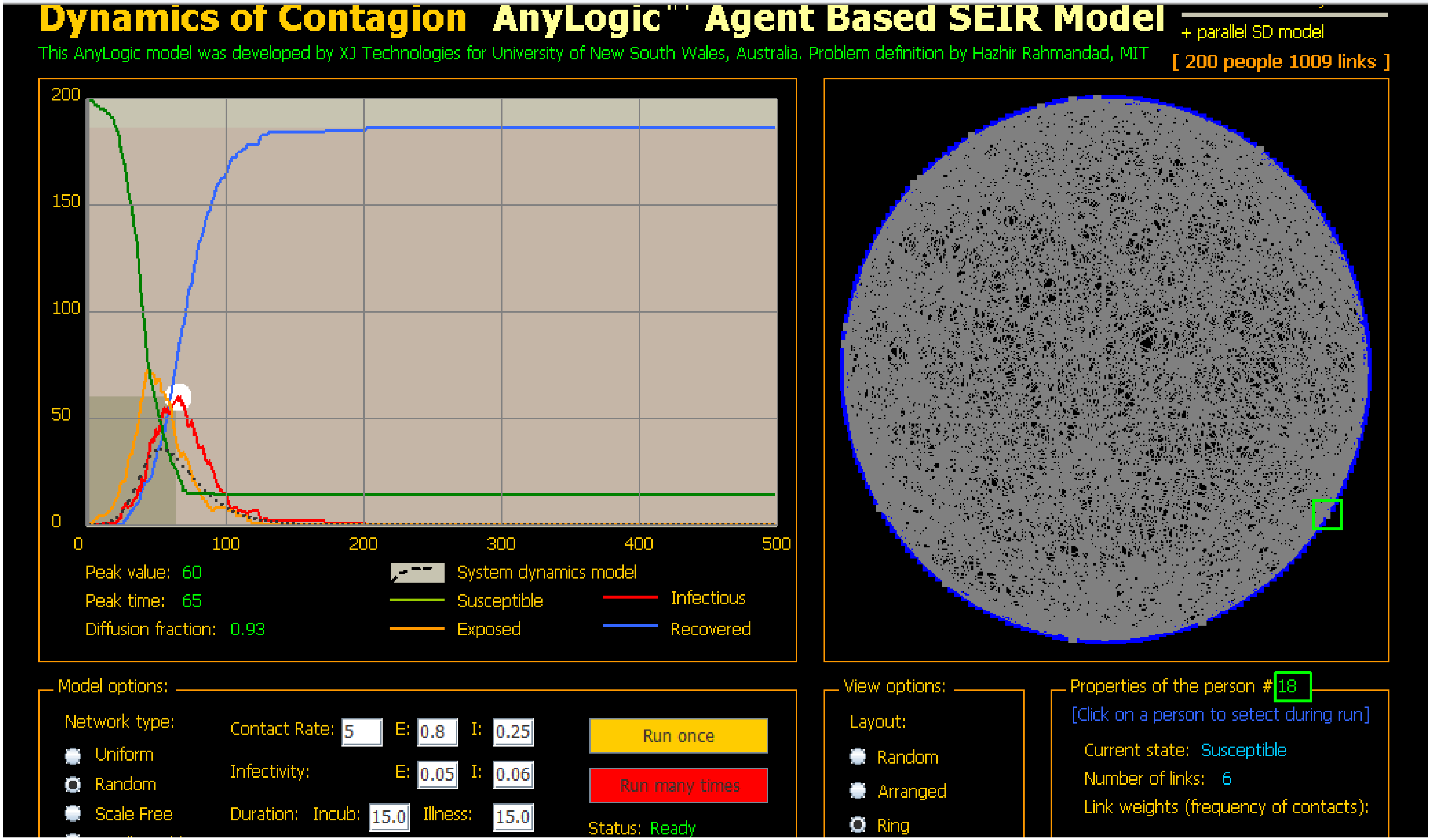
*c_{IS}*Prob(Contact with Susceptible)*Prob(Transmission|Contact with Susceptible),*

- Susceptible Change Rate: $dS/dt = -\beta SI$
- Infective Change Rate: $dI/dt = \beta SI - \gamma I$
- Removed Change Rate: $dR/dt = \gamma I$

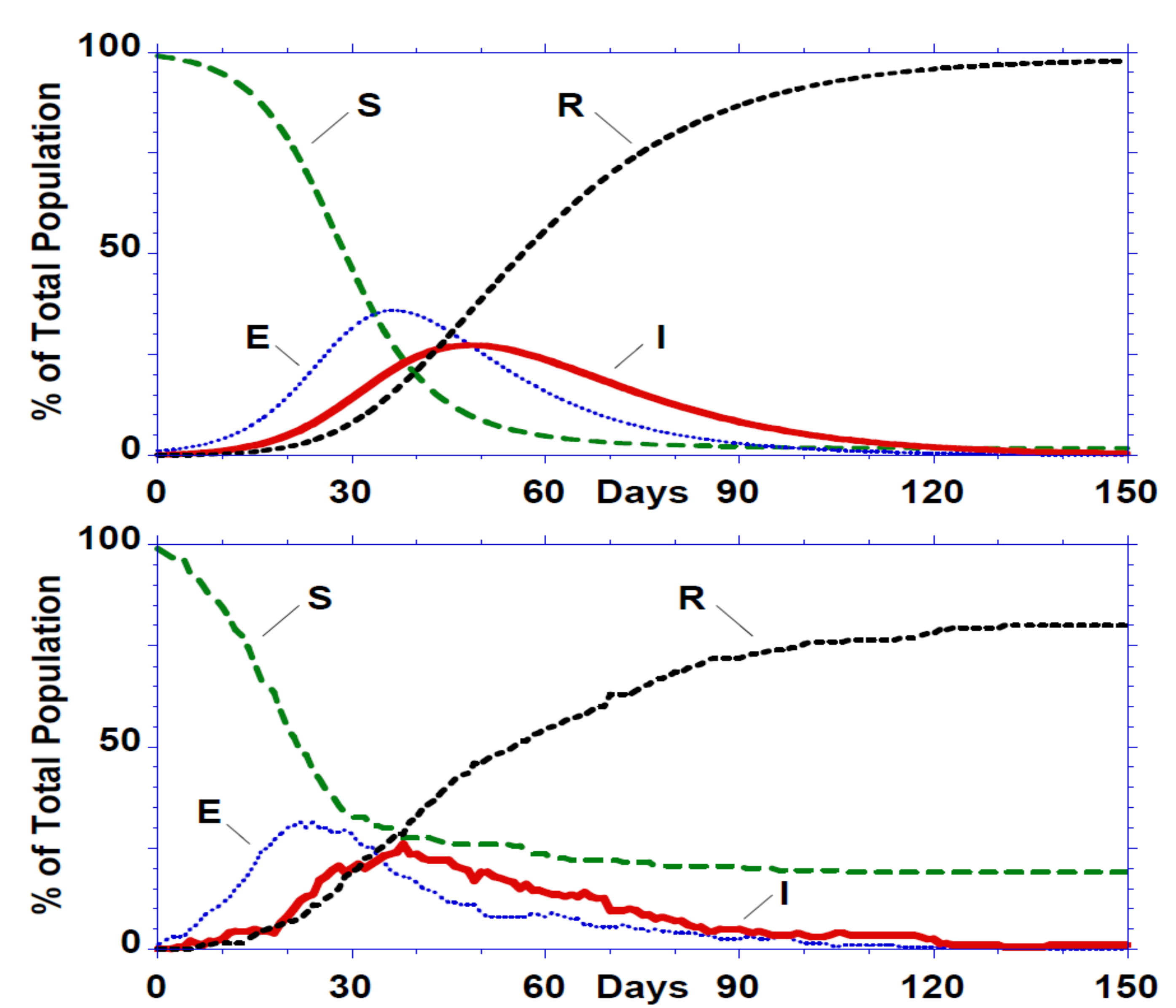
Does Network Structure Matter?

1. **Start with virus on networks and a small world network and compare with random mixing**
2. **Compare epidemic size at a particular time**
3. **Compare epidemic timing**
4. **Extend to other networks**

Comparison of Models with Different Structures



Stochastic and Deterministic Runs



How Does Network Structure Affect Transmission?

	Uniform		Random		Small World		Scale-free		Lattice	
	$H_=$	$H_{\neq}$	$H_=$	$H_{\neq}$	$H_=$	$H_{\neq}$	$H_=$	$H_{\neq}$	$H_=$	$H_{\neq}$
Infectivity of Exposed i_{ES}	0.050	0.054	0.045	0.056	0.042	0.076	0.034	0.039	0.038	0.036
Infectivity of Infectious i_{IS}	0.024	0	0	0.01	0	0.011	0.0001	0.0037	0.0074	0.0038
Average Incubation Time ε	13.8	17.4	12.5	7.4	11.7	4.5	10.0	8.3	5.6	6.5
Average Duration of Illness δ	15.3	14.3	16.6	17.2	17.1	18.3	26.4	23.7	30.0	30.0
Implied R_0 = $c_{ES}*i_{ES}*\varepsilon + c_{IS}*i_{IS}*\delta$	3.21	3.78	2.25	1.87	1.96	1.63	1.37	1.40	1.13	1.07