Agent-Based Modeling: A Brief Glimpse

Nathaniel Osgood

Using Modeling to Prepare for Changing Healthcare Needs

April 15, 2014

Agent-Based Models

- One or more populations composed of individual agents, each associated with
  - Parameters – discrete (e.g., Gender, Ethnicity) or continuous (e.g., birthweight, income)
  - State (continuous or discrete) e.g., age, smoking status, networks, preferences
  - Rules for evolving state
  - Means of interaction with other agents via one or more environments (e.g. spatial & topological context)
- Time horizon & characteristics
- Initial state

Contrasting Organization in Aggregate Stock-Flow & ABM

Aggregate Stock & flow models

- **Within unit (e.g. city)**
  - **Subdivided according to *state and characteristics (e.g. SES)***
  - ***Each stock counts # people in associated population group***
- **State for different levels and other actors are found in stocks & flows at same "level" of the model**
  - **Summaries for entire pop. & subpops are stocks in model**
- **Relationships between units implicit in data (e.g. mixing matrix)**

Agent-based modeling

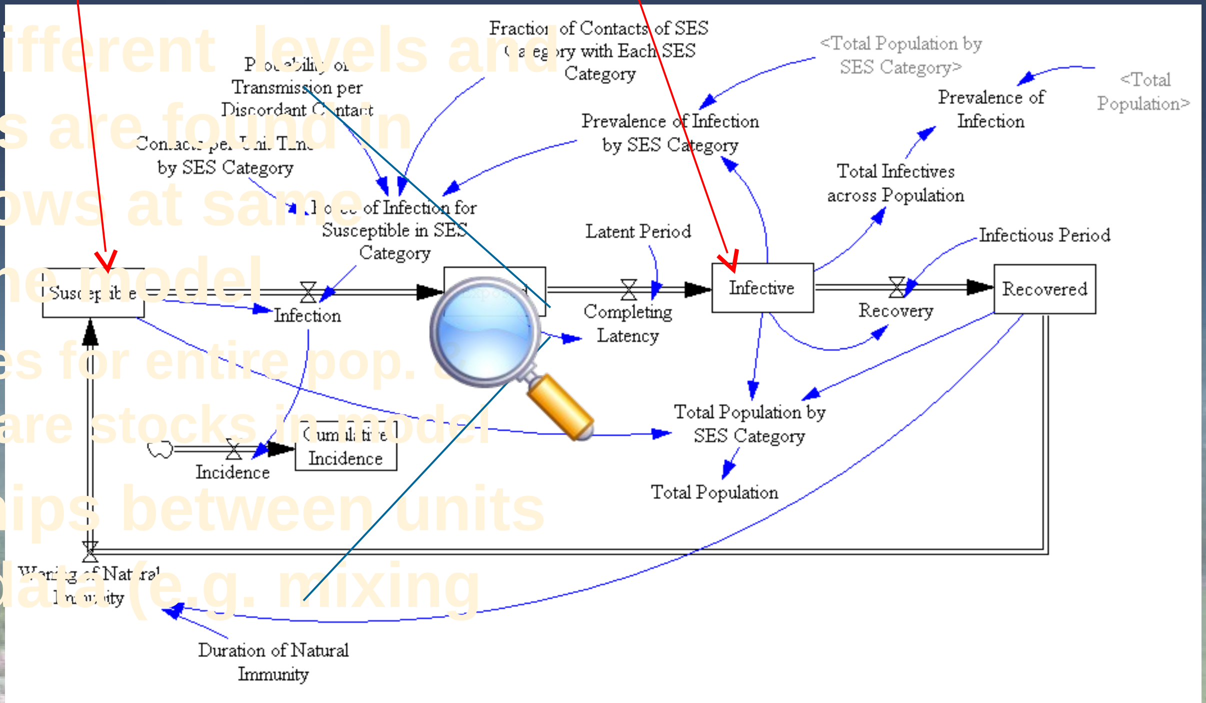
- **Within unit (e.g. city)**
  - **Subdivided according to constitutive smaller actors (e.g., individual people)**
  - **Each unit maintains its own state, attributes**
- **The nested or networked relations among actors mirror that in world**
  - **If a city "contains" people, the (references to) people appear "inside" the city**

Contrasting Organization in Aggregate Stock-Flow & ABM

Aggregate Stock & flow models

Agent-based modeling

- **Within unit (e.g. city)**
  - **Subdivided according to *state and characteristics (e.g. SES)***
  - ***Each stock counts # people in associated population group***
- **State for different levels and other actors are found in stocks & flows at same "level" of the model**
  - **Summaries for entire pop. & subpops are stocks in model**
- **Relationships between units implicit in data (e.g. mixing matrix)**



Contrasting Organization in Aggregate Stock-Flow & ABM

Aggregate Stock & flow models

- Within unit (e.g., city)
  - Subdivided according to *state and characteristics (e.g., SES)*
  - *Each stock counts # people in associated population group*
- State for different levels and other actors are f... n stocks & flows at... “level” of the mo...
  - Summaries for e... . a... subpops are sto... odel
- Relationships b... units implicit in data (e.g. mixing matrix)

Agent-based modeling

- Within unit (e.g. city)
  - Subdivided according to constitutive smaller actors (e.g., individual people)
  - Each unit maintains its own state, attributes
- The nested or networked relations among actors mirror that in world
  - If a city “contains” people, the (references to) people appear “inside” the city

Contrasting Organization in Aggregate Stock-Flow & ABM

Aggregate Stock & flow models

- Within unit (e.g. city)
  - Subdivided according to *state and characteristics (e.g. SES)*
  - *Each stock counts # people in associated population group*
- State for different levels and other actors are found in stocks & flows at same "level" of the model
  - Summaries for entire pop. & subpops are stocks in model
- Relationships between units implicit in data (e.g. mixing matrix)

Agent-based modeling

- Within unit (e.g. city)
  - Subdivided according to constitutive smaller actors (e.g., individual people)
  - Each unit maintains its own state, attributes
- The nested or networked relations among actors mirror that in world
  - If a city "contains" people, the (references to) people appear "inside" the city

Model Specification

Stock & Flow Models

- Small modeling vocabulary
- Power lies in combination of a few elements (stocks & flows)
- Analysis conducted predominantly in terms of elements of model vocabulary (values of stocks & flows)
- Directly maps onto crisp mathematical description (Ordinary Differential Equations)

Agent-Based Modeling

- Large modeling vocabulary
- Different subsets of vocabulary used for different models
- Power in flexibility & combination of elements & algorithmic specification
- Variety in analysis focus
- Mathematical underpinnings differ
- In most cases, lacks transparent mapping to mathematical formulation

ABMs: Larger Model Vocabulary & Needs

- Events
- Multiple mechanisms for describing dynamics
  - State transition diagrams
    - Multiple types of transitions
  - Stock and flow
  - Custom update code
- Inter-Agent communication (sending & receiving)
- Diverse types of agents
- Data output mechanisms
- Statistics
- Subtyping
- Mobility & movement
- Graphical interfaces
- Stochastics complicated
  - Scenario result interpretation
  - Calibration
  - Sensitivity analysis
- Synchronous & asynchronous distinction, concurrency
- Spatial & topological connectivity & patterning

Early Origins of Modern ABM

- Modern Agent-Based Modeling reflects two
  - Origins
  - Theoretical bases
- **Computer Science/Applied Mathematics**: Von Neumann's and Ulam's theory of automata
  - Interacting finite state automata
  - Cellular automata
  - Reproduction
- **Economics**: Microsimulation
  - Statistical formulation of transitions
  - Sometimes framed as challenge to neoclassical economics and rational actor theory
  - Often less central focus on direct agent interactions
- These contributions are each associated with distinct underlying theories, traditions

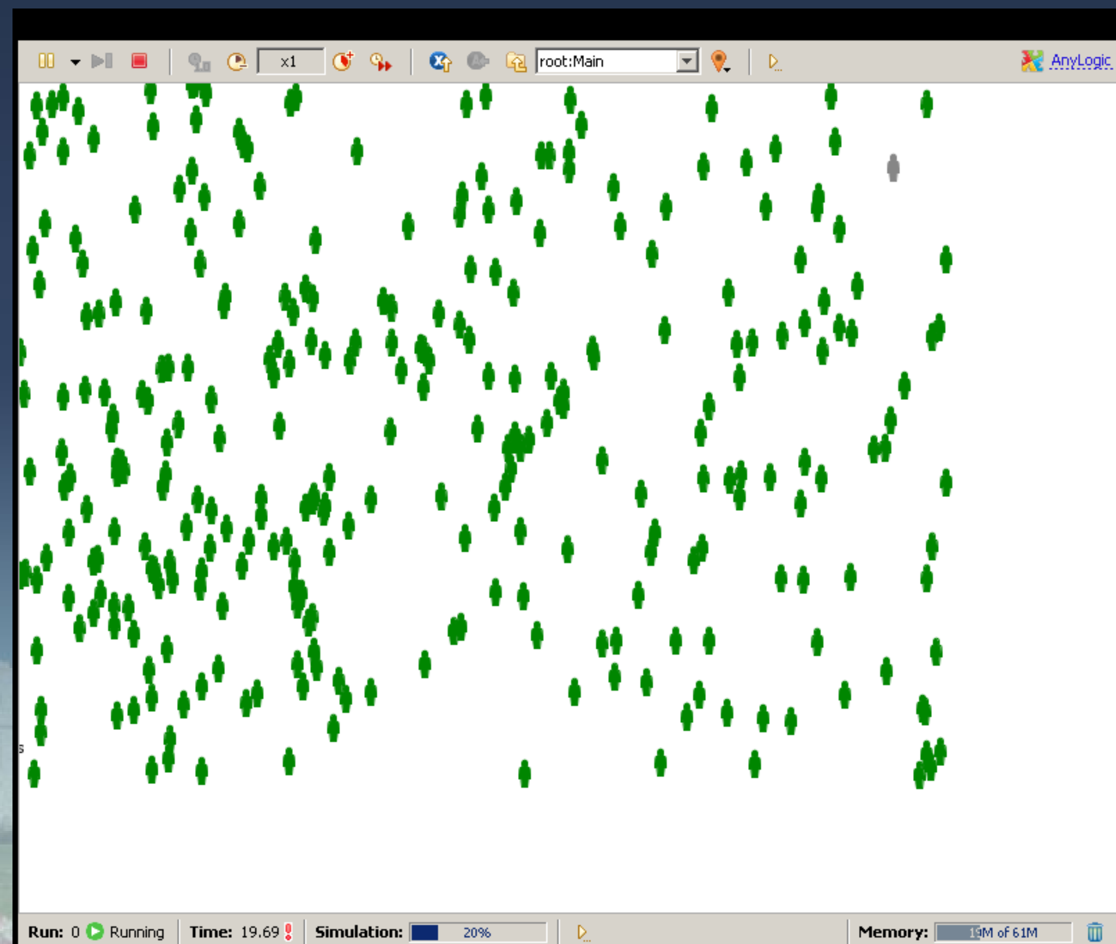
Agent-Based Models: Skill Sets

- **Construction of ABMs have traditionally required significant software engineering**
- **In recent years, ABM platforms have included increasing support for declarative specification**
  - **Such features greatly lower the programming requirements**
  - **Maintaining on-call computational consults remains important**

Model Population

In Model….

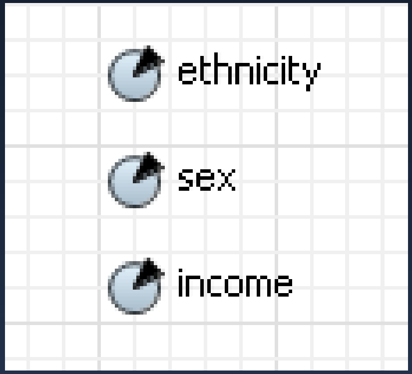
In Simulation….



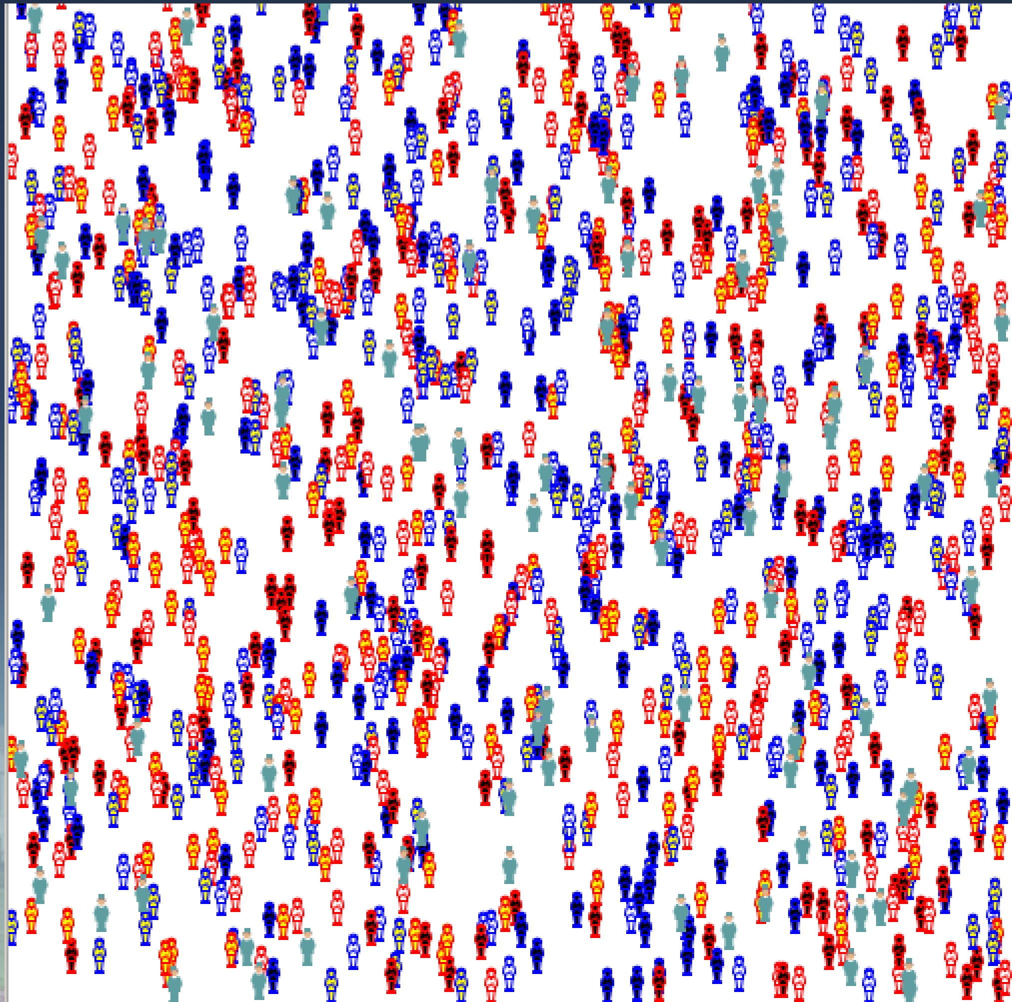
Agent-Based Models

- One or more populations composed of individual agents, each associated with
  - Parameters – discrete (e.g., Gender, Ethnicity) or continuous (e.g., birthweight, income)
  - State (continuous or discrete) e.g., age, smoking status, networks, preferences
  - Rules for evolving state
  - Means of interaction with other agents via one or more environments (e.g. spatial & topological context)
- Time horizon & characteristics
- Initial state

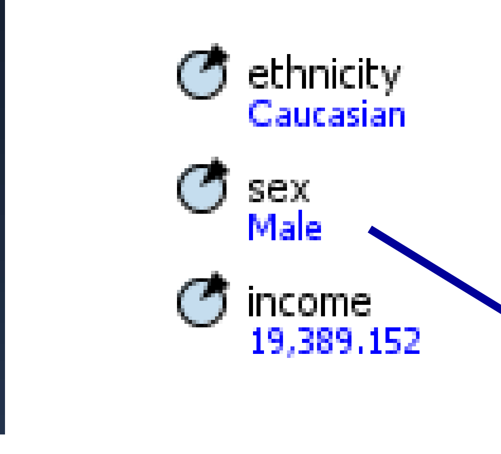
Model

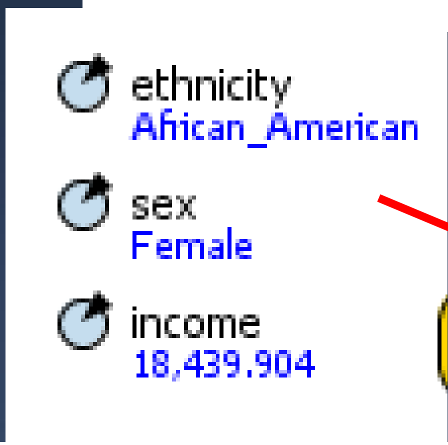


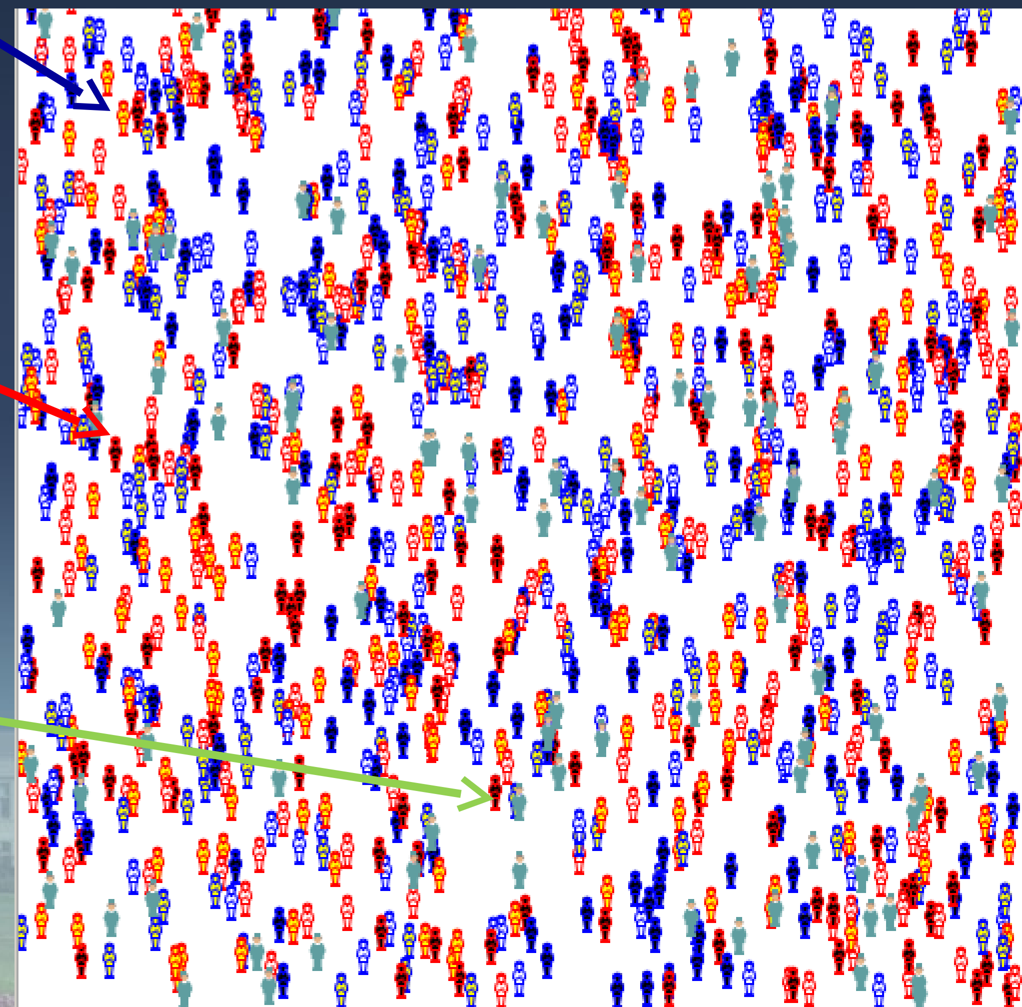
In Simulation



Properties of Individual Agents



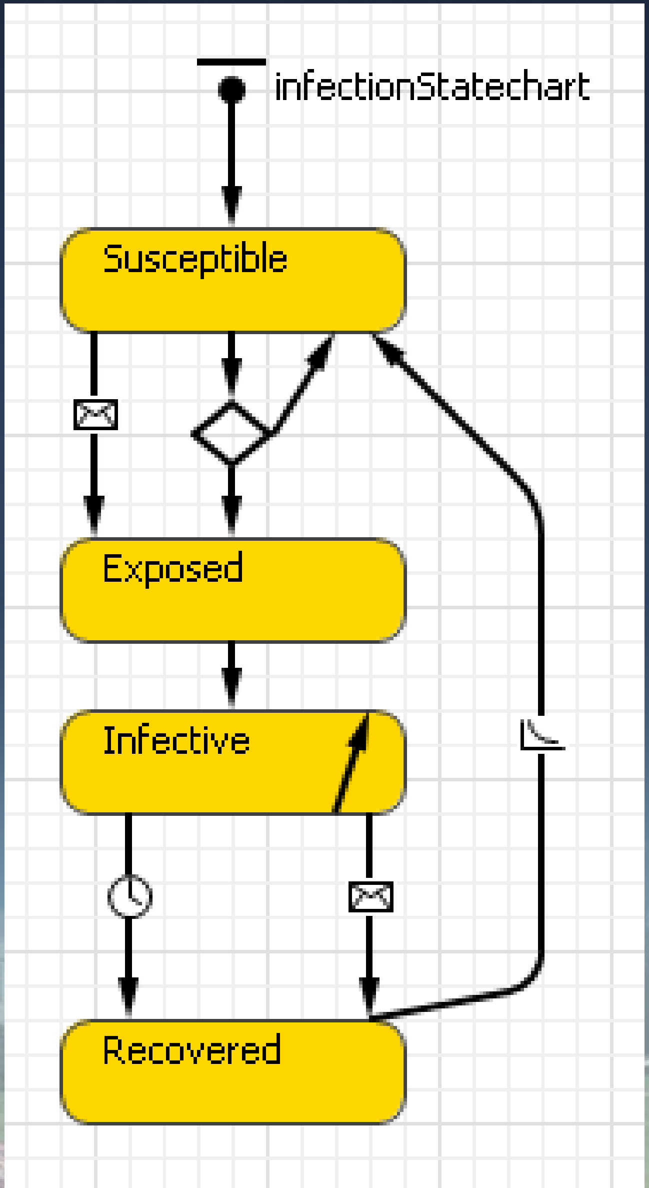




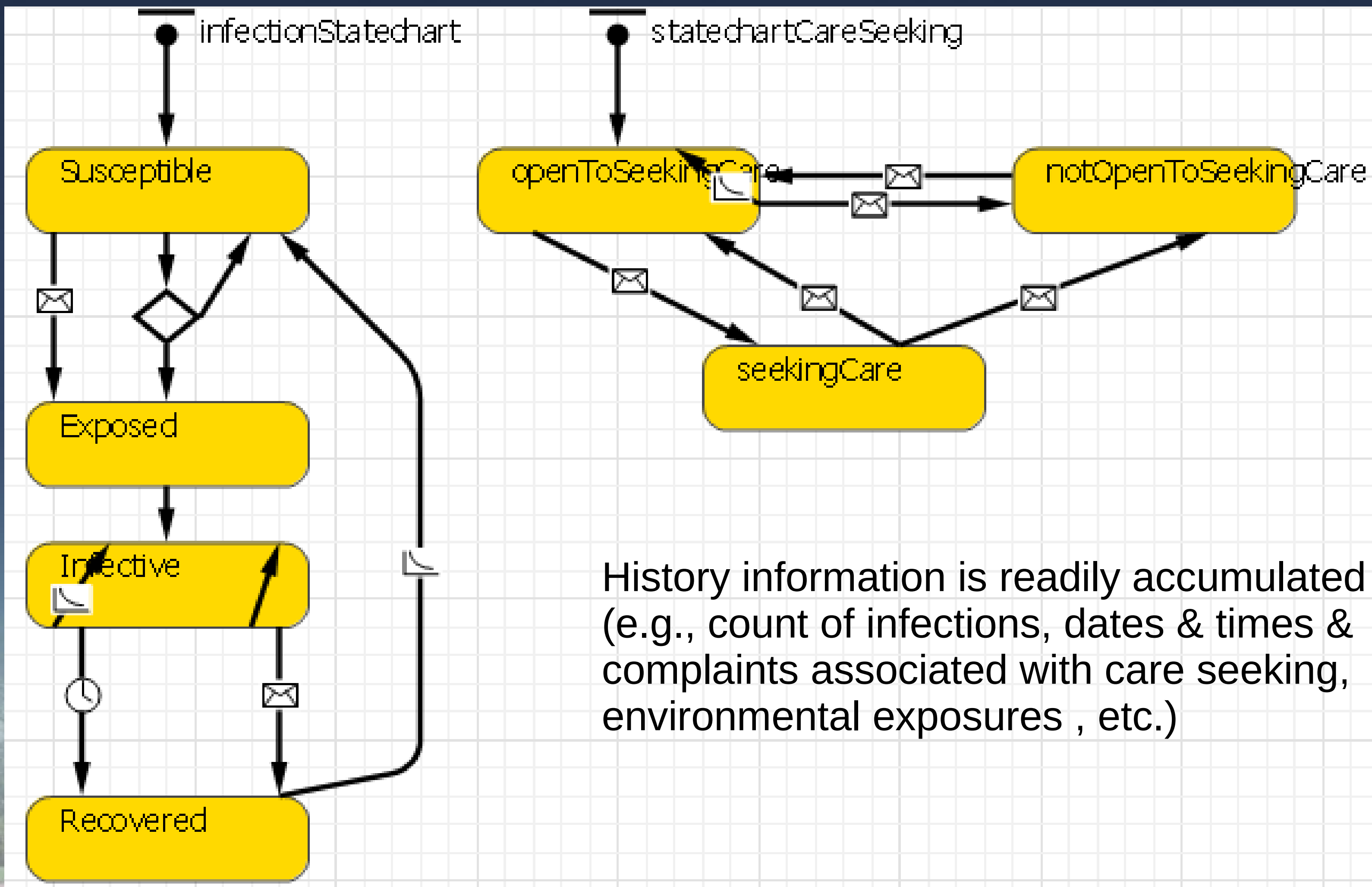
Agent-Based Models

- One or more populations composed of individual agents, each associated with
  - Parameters – discrete (e.g., Gender, Ethnicity) or continuous (e.g., birthweight, income)
  - State (continuous or discrete) e.g., age, smoking status, networks, preferences
  - Rules for evolving state
  - Means of interaction with other agents via one or more environments (e.g. spatial & topological context)
- Time horizon & characteristics
- Initial state

Example of Discrete States & Associated Transitions



Contrast to Agg. Stock & Flow Models: Adding Heterogeneity Yields No Combinatorial Explosion in Structure

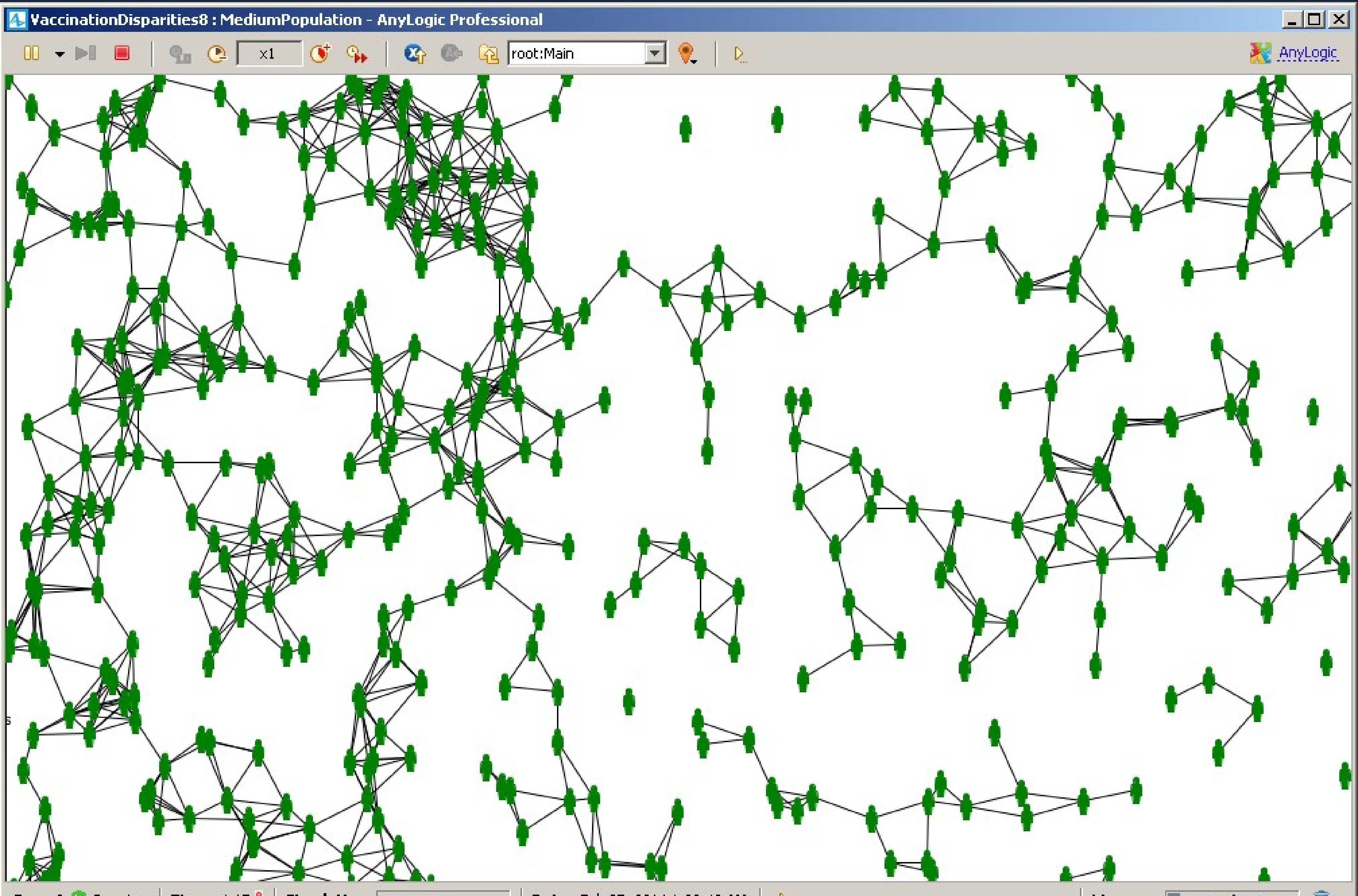


History information is readily accumulated (e.g., count of infections, dates & times & complaints associated with care seeking, environmental exposures , etc.)

Agent-Based Models

- **One or more populations composed of individual agents, each associated with**
  - **Parameters – discrete (e.g., Gender, Ethnicity) or continuous (e.g., birthweight, income)**
  - **State (continuous or discrete) e.g., age, smoking status, networks, preferences**
  - **Rules for evolving state**
  - **Means of interaction with other agents via one or more environments (e.g. spatial & topological context)**
- **Time horizon & characteristics**
- **Initial state**

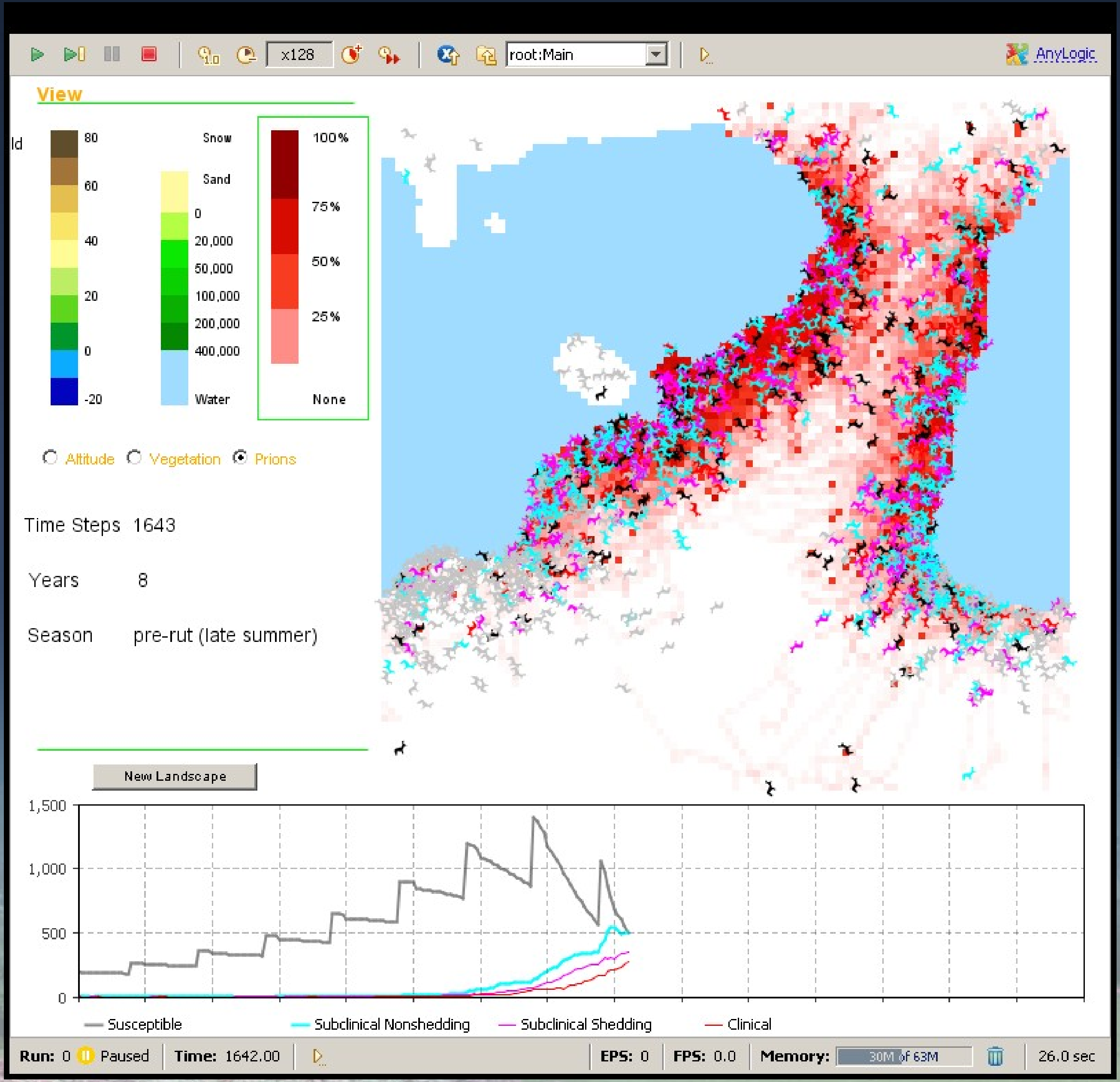
Adding Contact Network



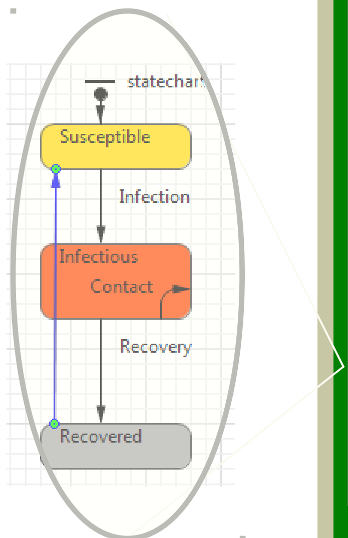
Recall: Emergent Behavior

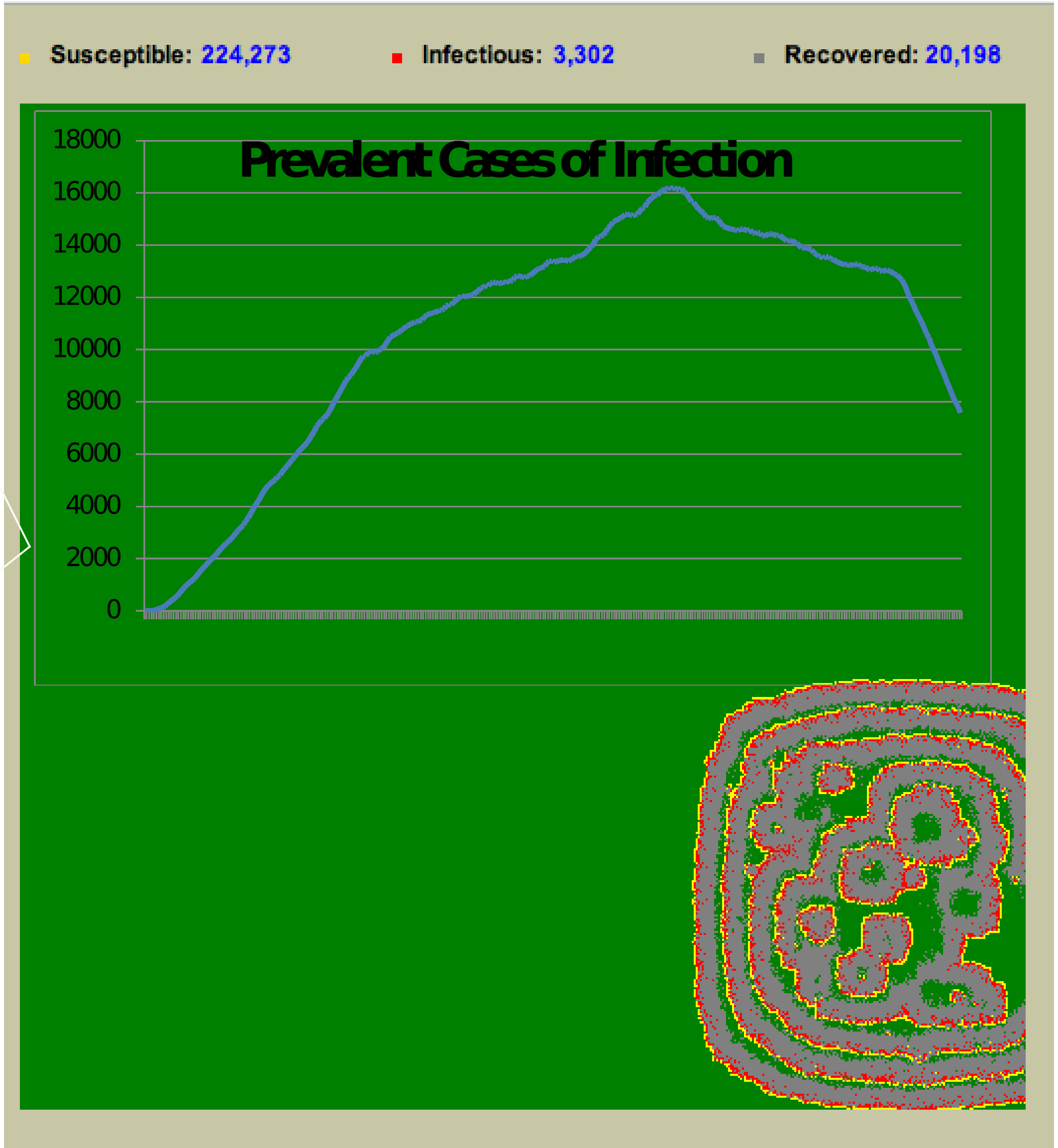
- **“Whole is greater than the sum of the parts”, “Surprise behavior”**
- **Frequently observed in stock and flow models as interaction between stocks & flows**
- **In ABMs, we see this phenomena not only at level of aggregate stocks & flows, but – most notably – *between agents***
  - ***Patterns over time***
  - ***Patterns over space***
  - **Patterns over networks**

Aggregate & Spatial Emergence

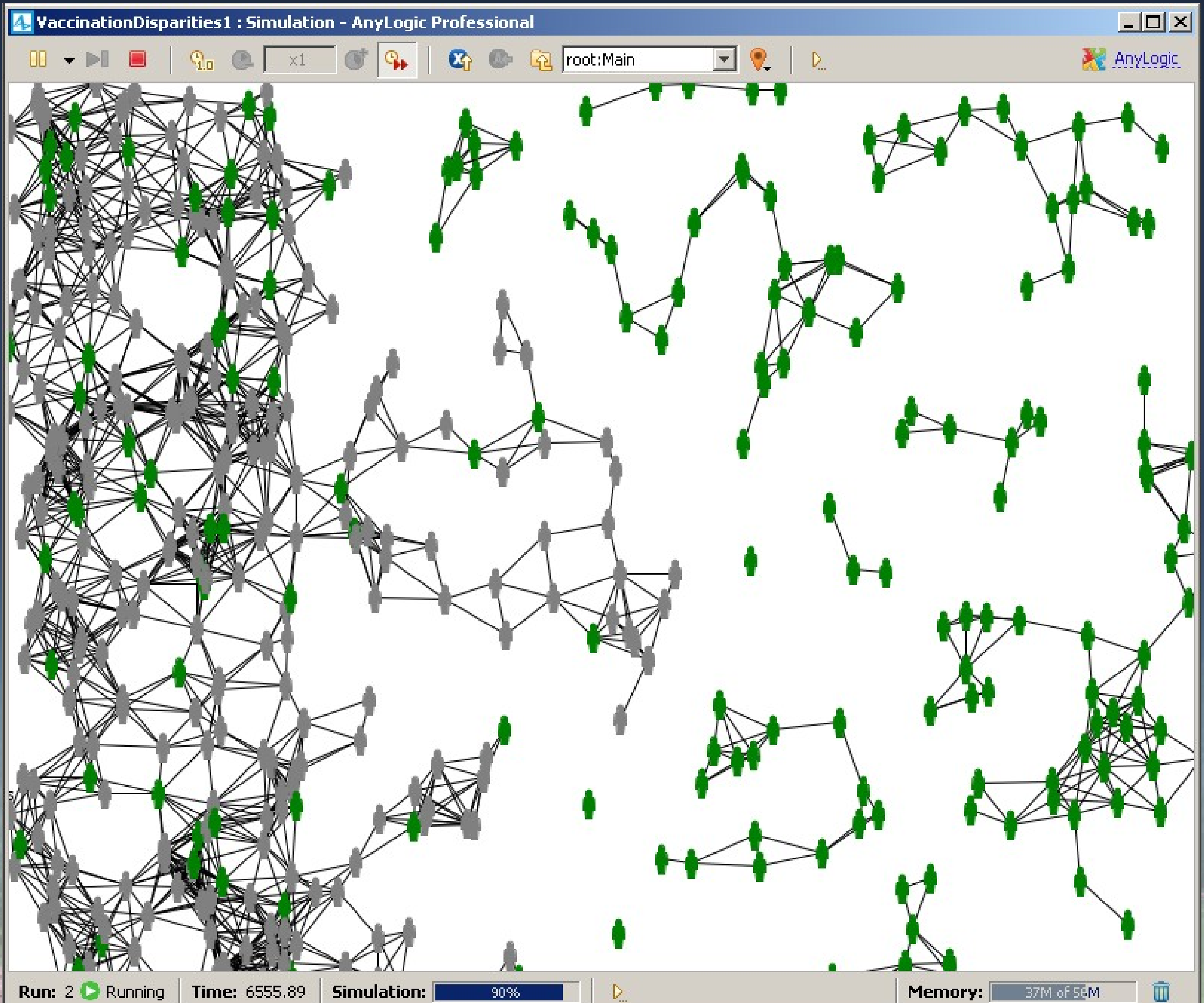


Emergent Aggregate & Spatial Dynamics





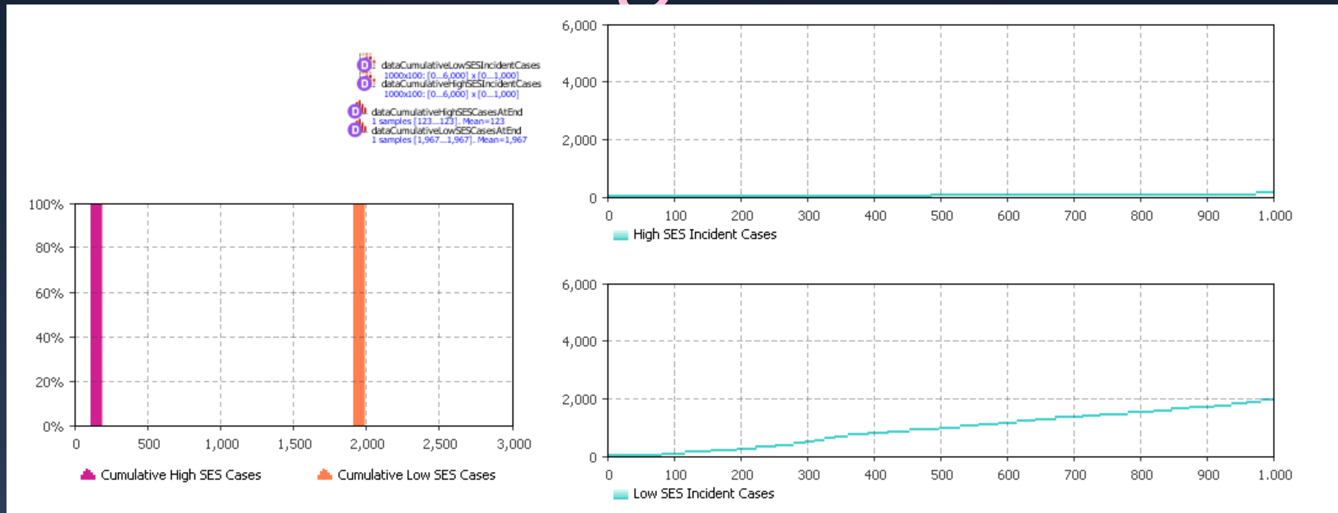
Example Model



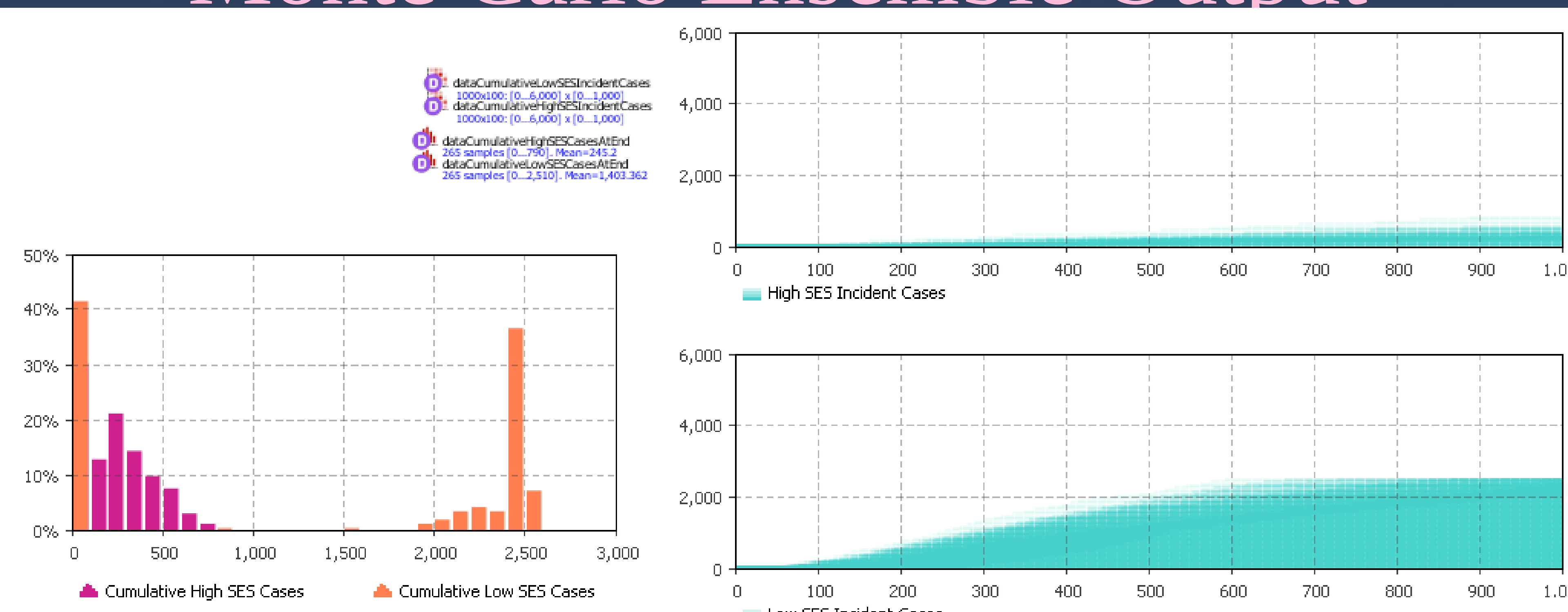
Stochastics

- In contrast to most system dynamics models, ABMs are typically stochastic
- To ensure model results are not merely flukes, a model must be run many times
  - This adds substantially to the cost associated with such models
  - This is easily parallelizable
- Stochastics as assets: Observing variability can lend insights into the variability seen in real-world data

Single Run

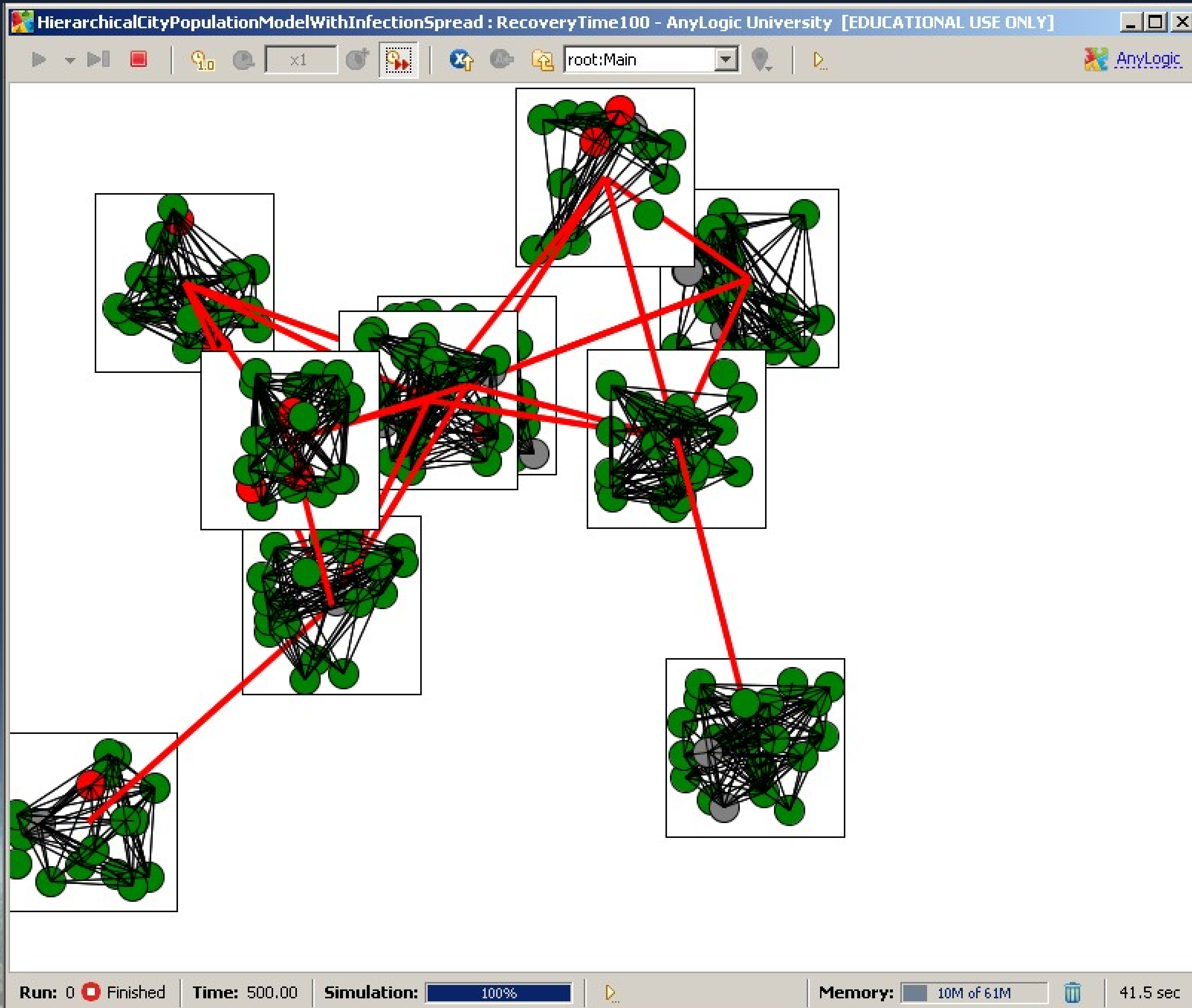


Monte Carlo Ensemble Output



Matters of Scale

- **It is straightforward to build ABMs featuring multiple (optionally nested) levels of context**
  - **Individual person / neighborhood / school / municipality / country**
  - **Individual deer / herd / ecoregion / population**
- **Emergent behavior frequently differs strikingly over different scales**


HierarchicalCityPopulationModelWithInfectionSpread : RecoveryTime100 - AnyLogic University [EDUCATIONAL USE ONLY]
x1
root:Main
AnyLogic
Run: 0 Finished
Time: 500.00
Simulation: 100%
Memory: 10M of 61M
41.5 sec

ABMs: Notable Strengths

- **Capture continuous&discrete heterogeneity**
  - **Targeted interventions**
  - **Transfer effects (vs. implicit value judgments)**
- **Representing network, spatial context, multi-level nesting**
- **Capturing situated decision making,learning**
- **Longitudinal info:intervention, calibration,…**
- **More precise, endogenous characterization of intervention effects, implementation**
- **Visualization aids communication&intuition**
- **Synthetic ground truth: Capacity for *in silico* assessment of measures & study designs**