Individual- and Agent-Based Models: Introduction, Tradeoffs & Tools

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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

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
- *S*imulation seeks insight from characterizing *causal structure* of those processes

Understanding Intervention Impact$\Rightarrow$ 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
  - 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

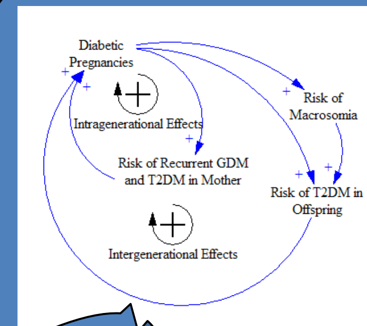
- Explaining drivers for trends or anticipating intervention impact requires understanding processes underlying observables
- A model represents a hypothesis regarding the possible causal interaction of diverse factors often studied in isolation
  - Operationally captures a hypothesis for “how the system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

Coevolution

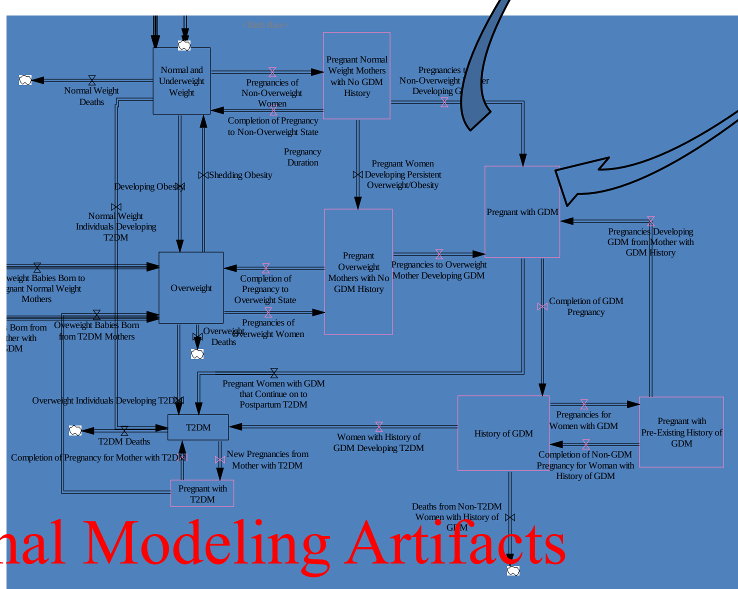
Observation / Evaluation

External World

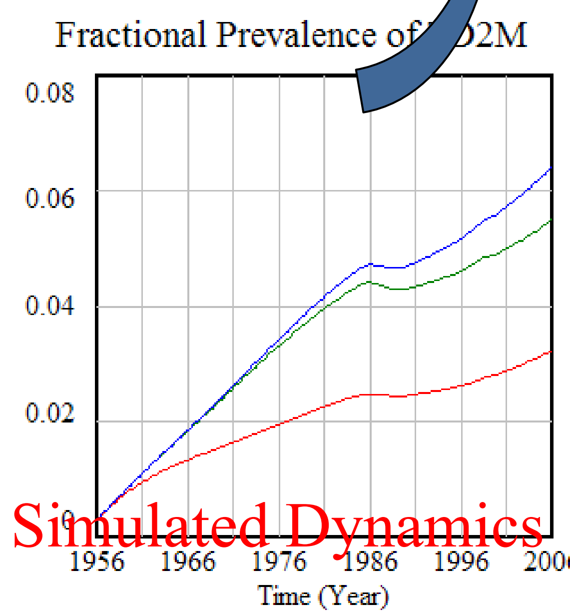
Actions & Choice of Observations



Mental Model

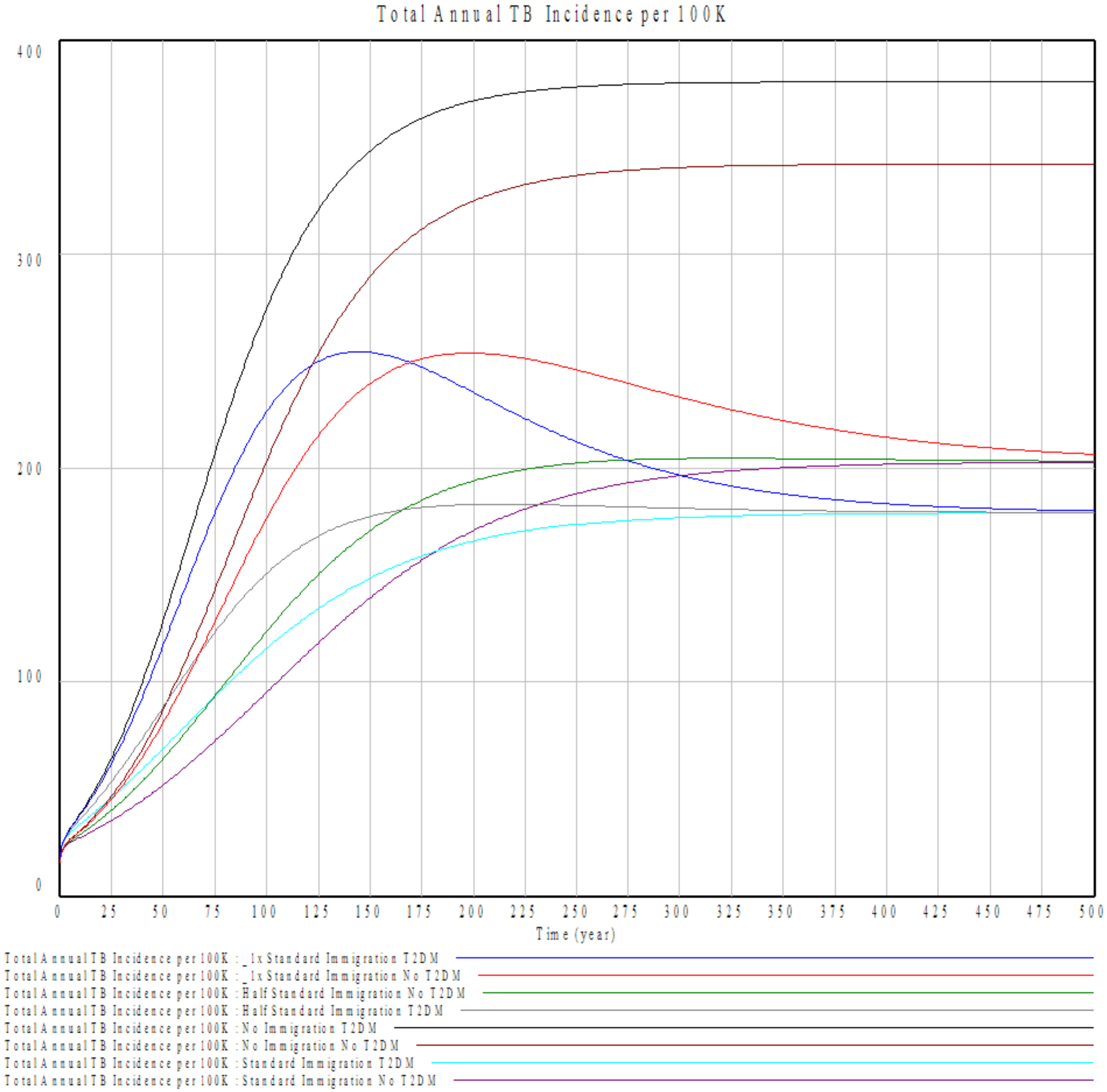


Formal Modeling Artifacts

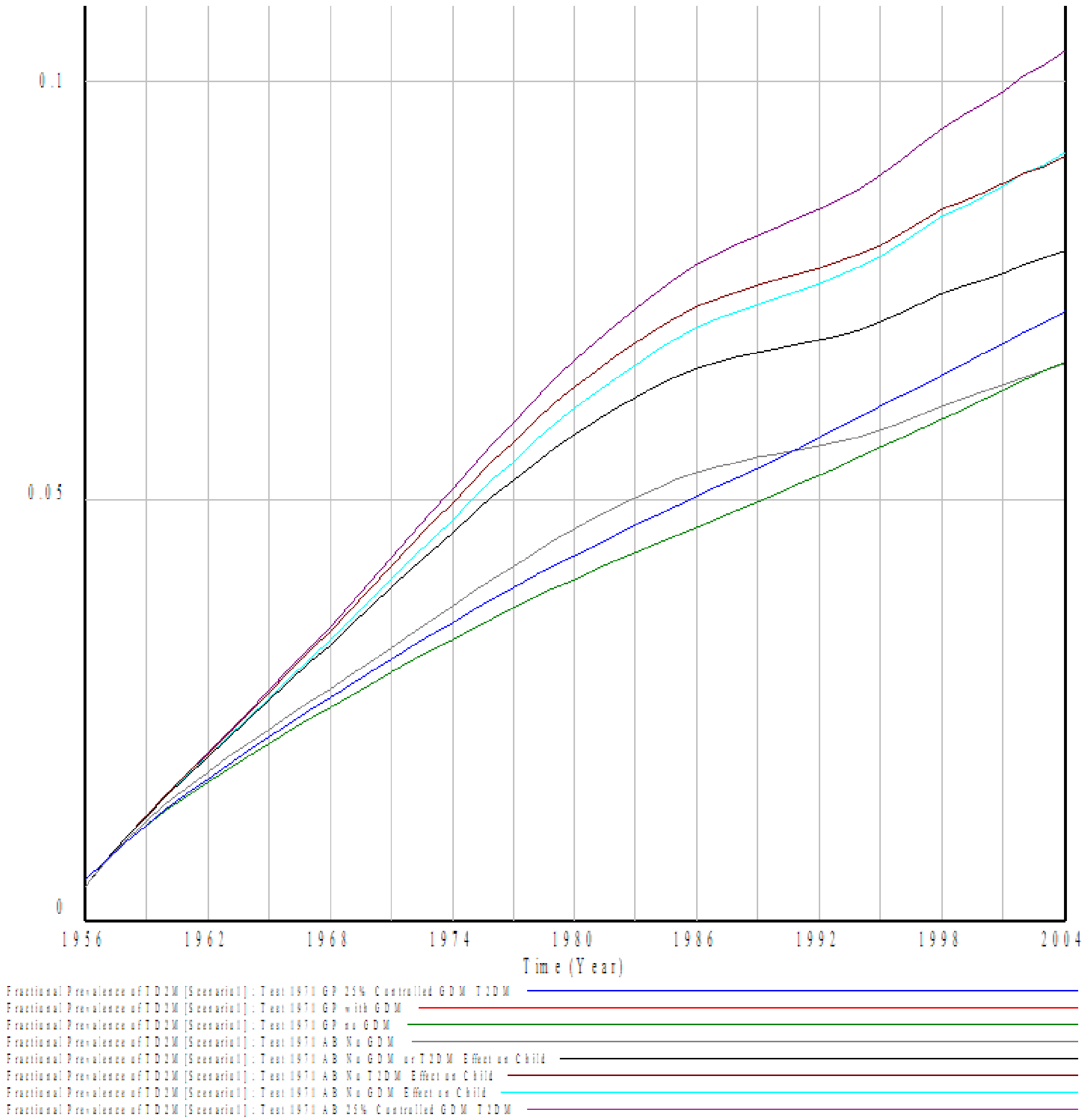


Simulated Dynamics

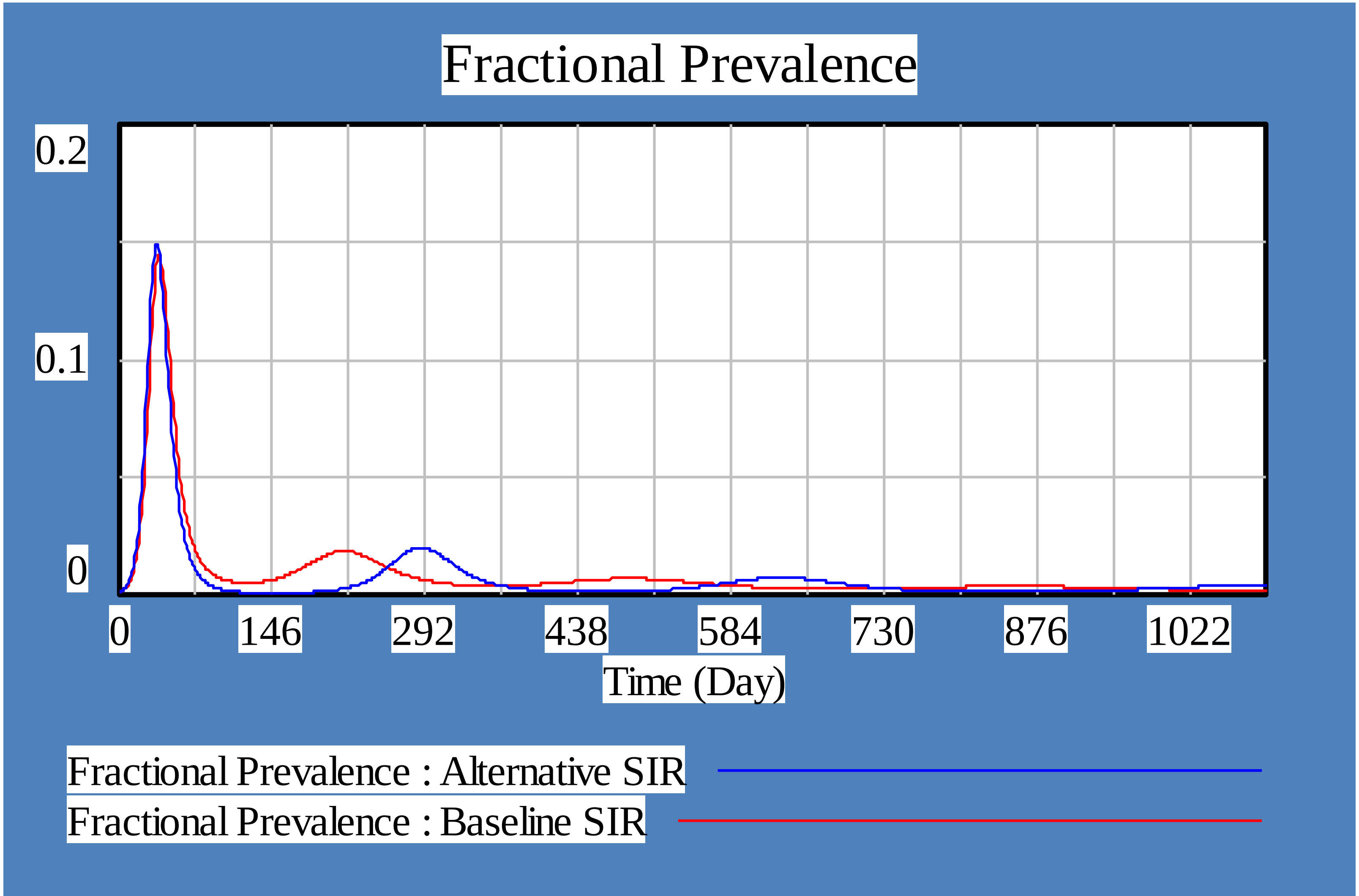
Scenarios for Understanding How Does X affect System



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**

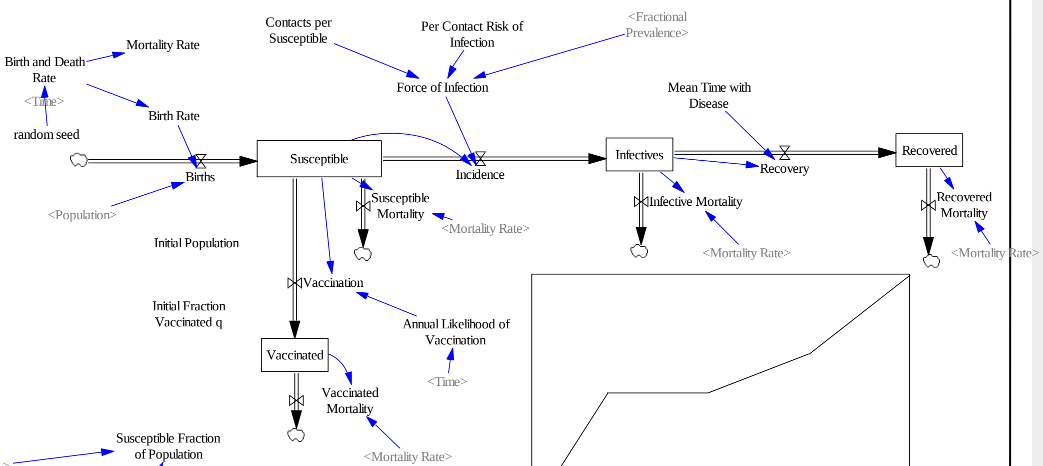
Simulates flow of individuals through processes

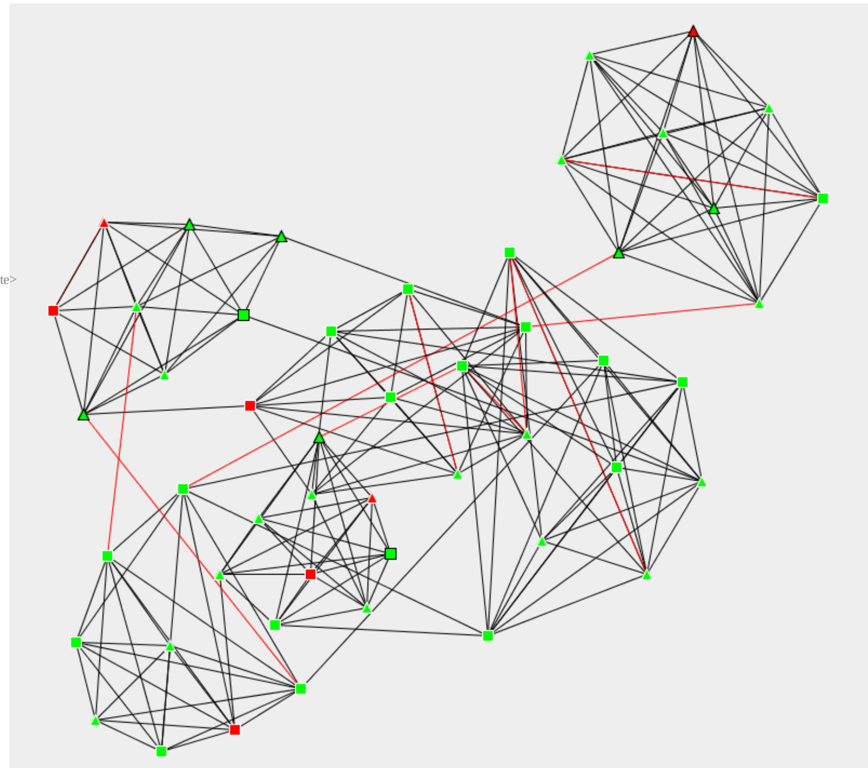
Captures resource use

Dynamic Models for Health

- Classic: Aggregate Models
  - Differential equations
  - Population classified into 2 or more state variables according to attributes
  - |State Variables|,|Parameters| << |Population|
- Recent: Individual-Based Models
  - Governing equations approach varies
  - Each individual evolves
  - |State Variables|,|Parameters| $\propto$ |Population|

Contrasting Model Granularity





Key Needs Motivating Individual-Based Modeling

- Need to calibrate against information on **agent history**
- Need to capture **progression** of agents **along multiple pathways** (e.g. co-morbidities)
- Wish to characterize **learning by and/or memory** of agents based on experience, or **strong history dependence** in agents
- Need to capture distinct **localized perception** among agents
- Seeking to intervene at points in, change behavior on, explain phenomena over or explain dynamics **across networks**
- Seek **distinct interventions for** many **heterogenous categories**
- Need to **capture impact** of intervention across **many categories**
- When it is much simpler to **describe behavior at indiv. level**
- Seek **flexibility** in exploring different **heterogeneity dimensions**
- **Needs of stakeholders** to engage with individual-based models
- Want to describe behaviour at **multiple scales**

Agent-Based Modeling

- We can capture individuals in many ways
- I view Agent based models (ABM) as a type of individual-based modeling that encapsulates a given individual as a *software object* with
  - Methods
  - Properties
- Objects provide a convenient abstraction for individuals
- Agent-based models currently require writing at least some code in programming languages
- We can formulate SD models w/i agent-based tools
  - I view such models as simultaneously SD & ABM
- We can follow an SD process to build & use agent-based models

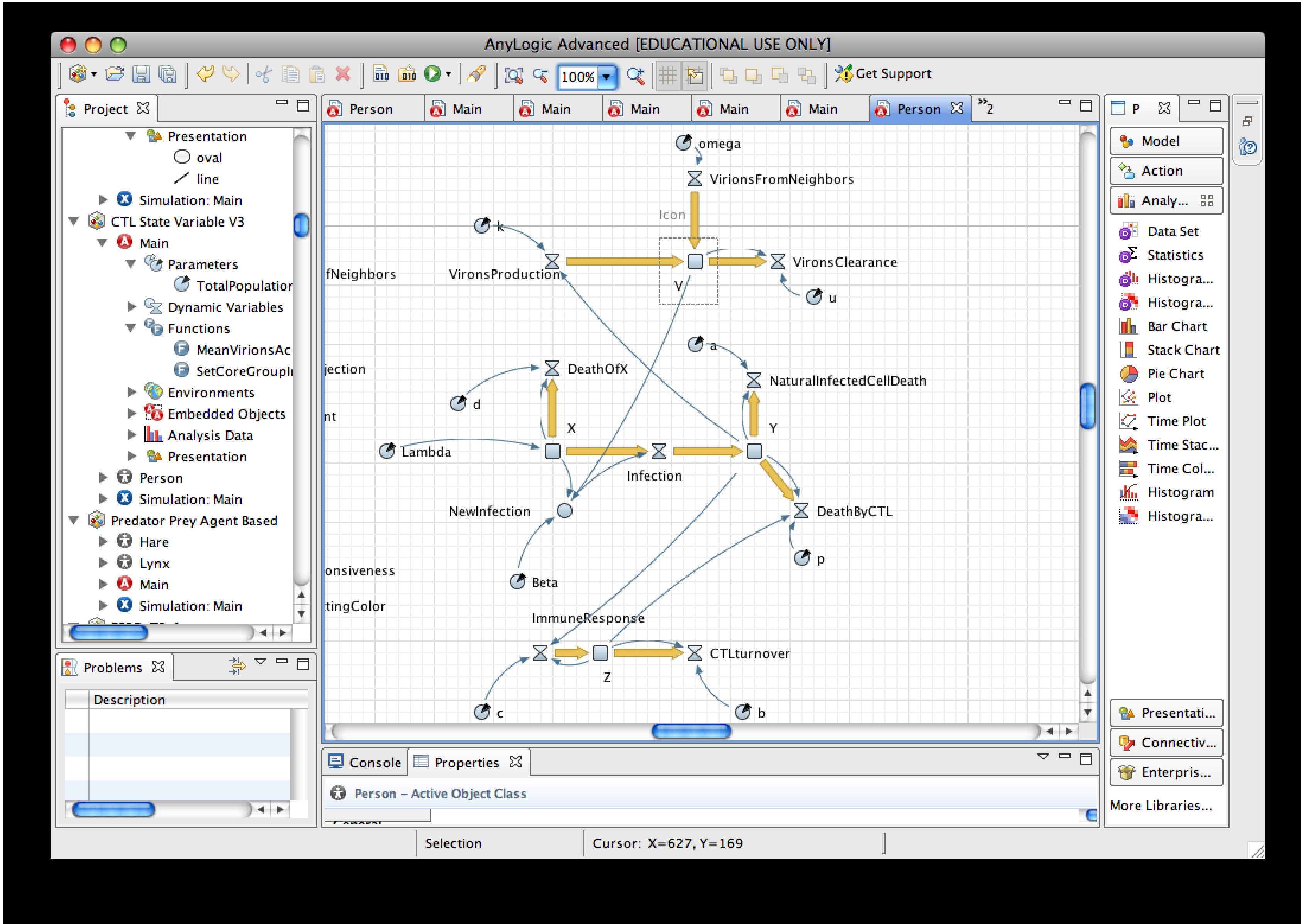
Agent-Based Systems

- Agent-based model characteristics
  - One or more populations composed of individual agents
    - Each agent is associated with some of the following
      - State (continuous or discrete e.g. age, health, smoking status, networks, beliefs)
      - Parameters (e.g. Gender, genetic composition, preference fn.)
      - Rules for interaction (traditionally specified in general purpose programming language)
    - Embedded in an environment (typically with localized perception)
    - Communicate via messaging and/or flows
  - Environment
- Emergent aggregate behavior

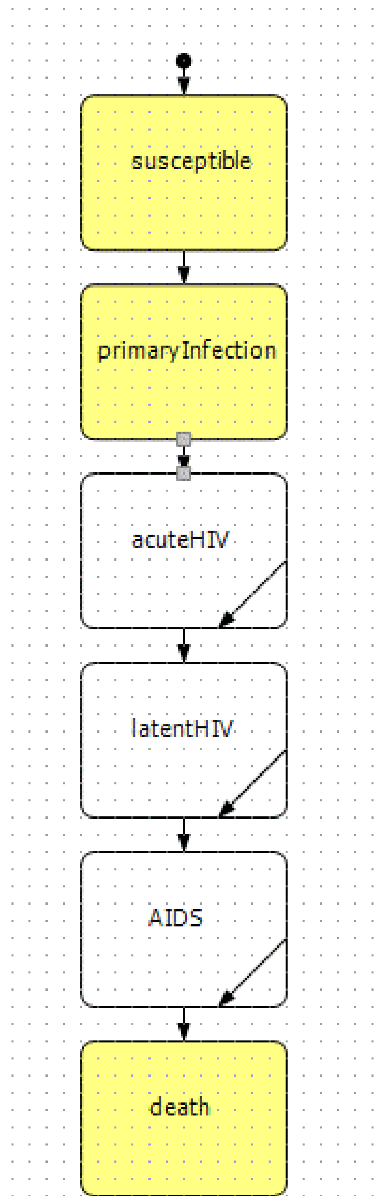
Elements of Individual State

- Example Discrete
  - Ethnicity
  - Gender
  - Categorical infection status
- Continuous
  - Age
  - Elements of body composition
  - Metabolic rate
  - Past exposure to environmental factors
  - Glycemic Level

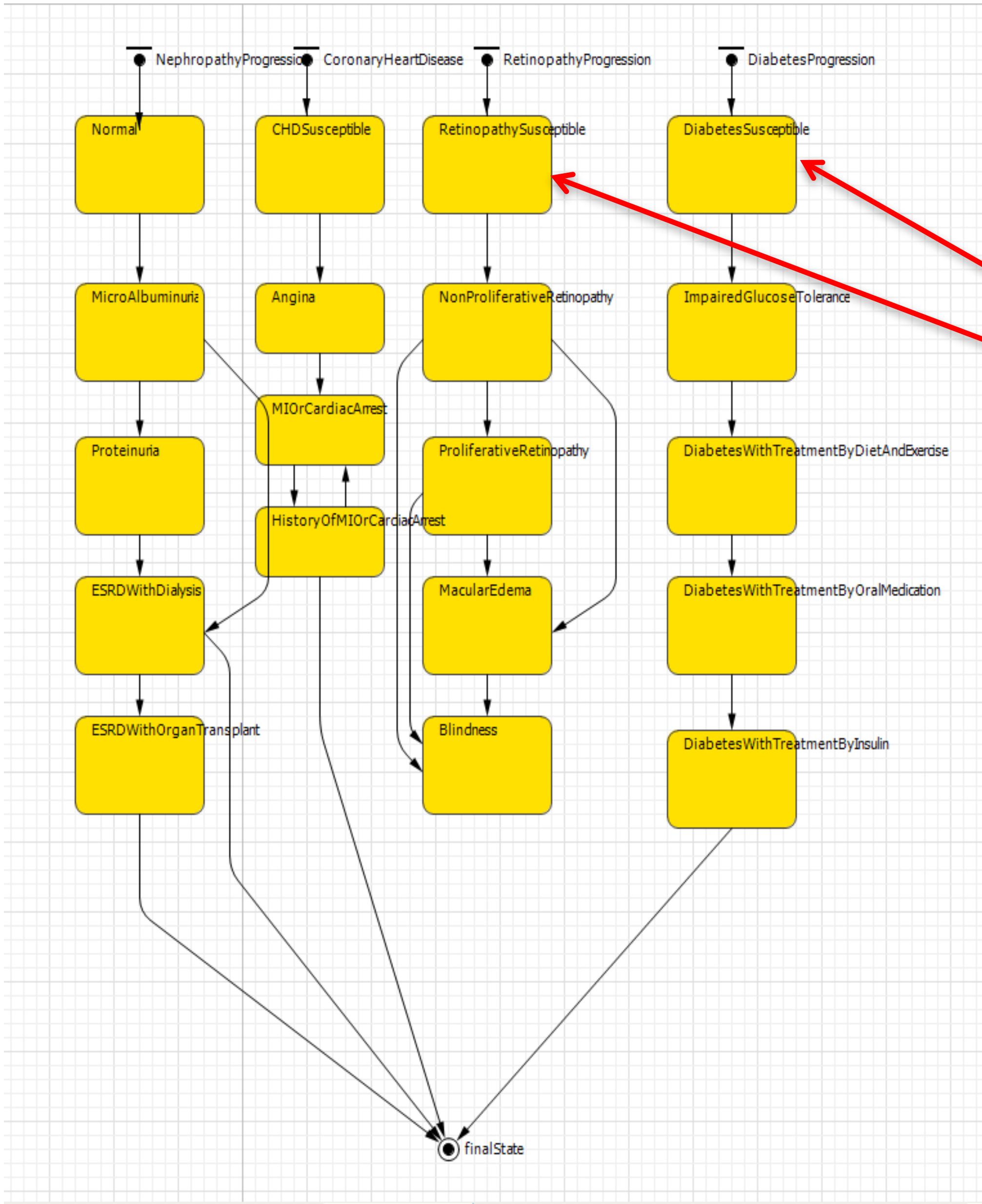
Example of Continuous Individual State



Example of Discrete States
Binary Presence in Discrete State



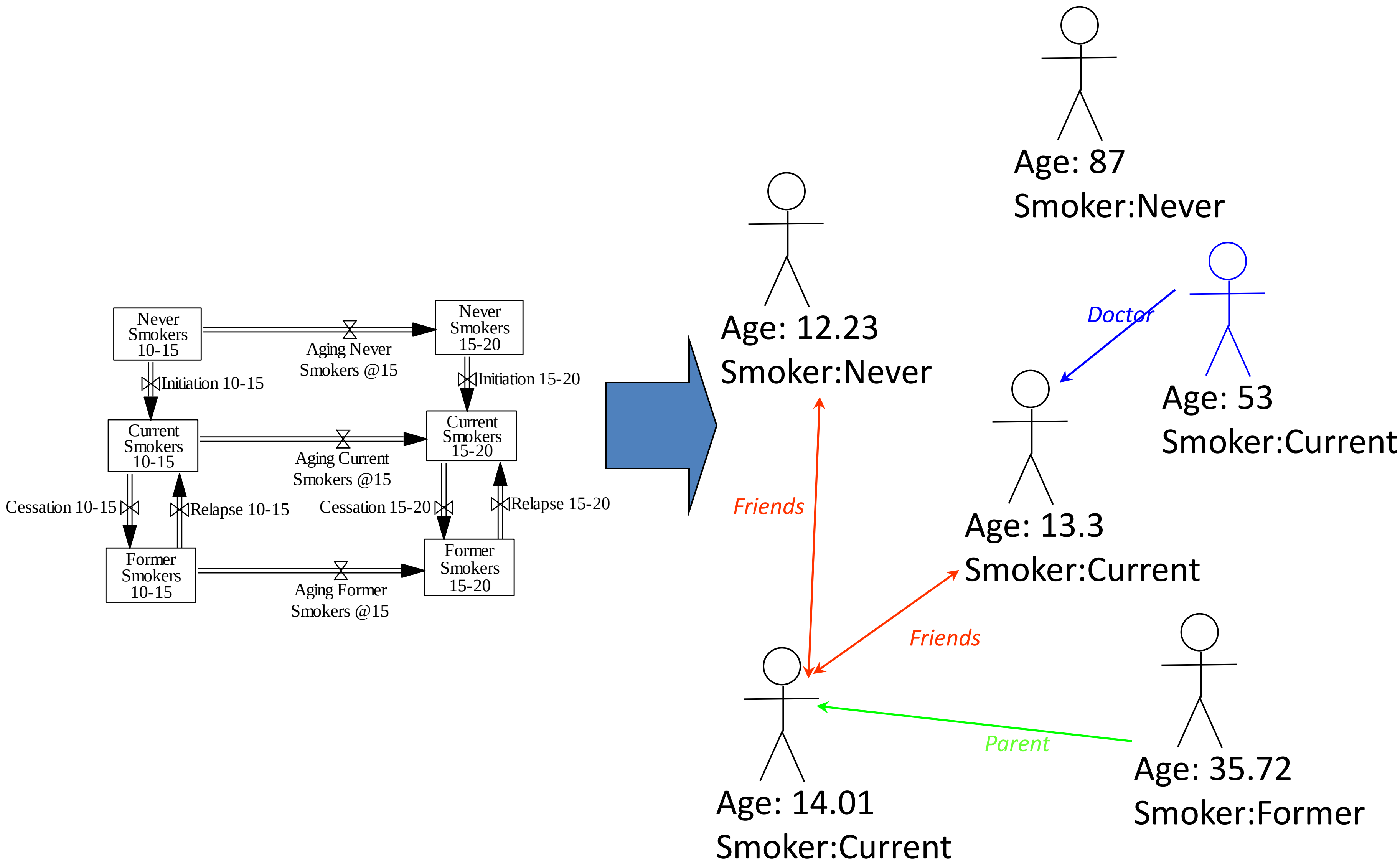
Parallel State Transition Diagrams



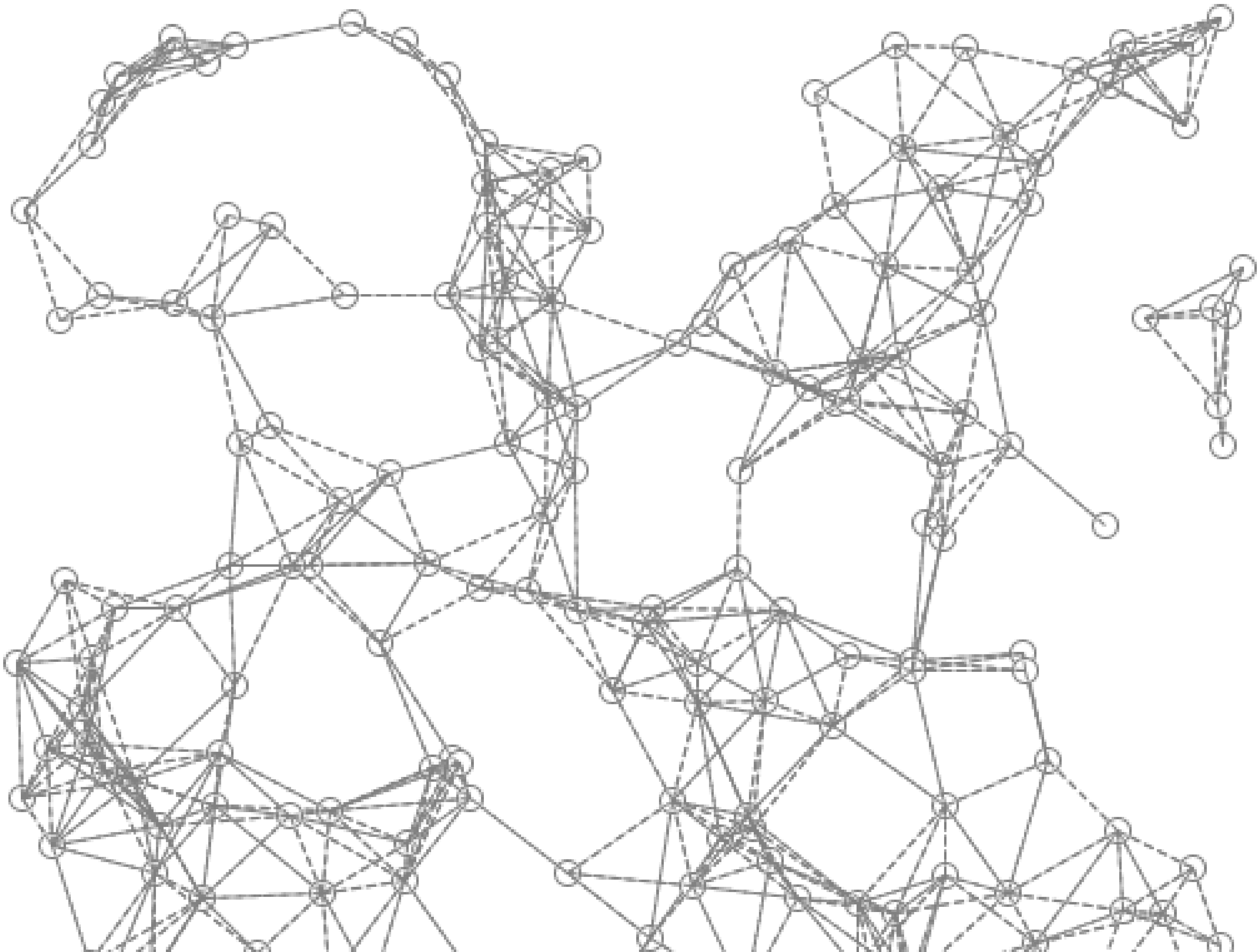
A person is in some particular state with respect to each of these (condition specific) state transition diagrams

This requires representing combinations of possibilities in an aggregate model

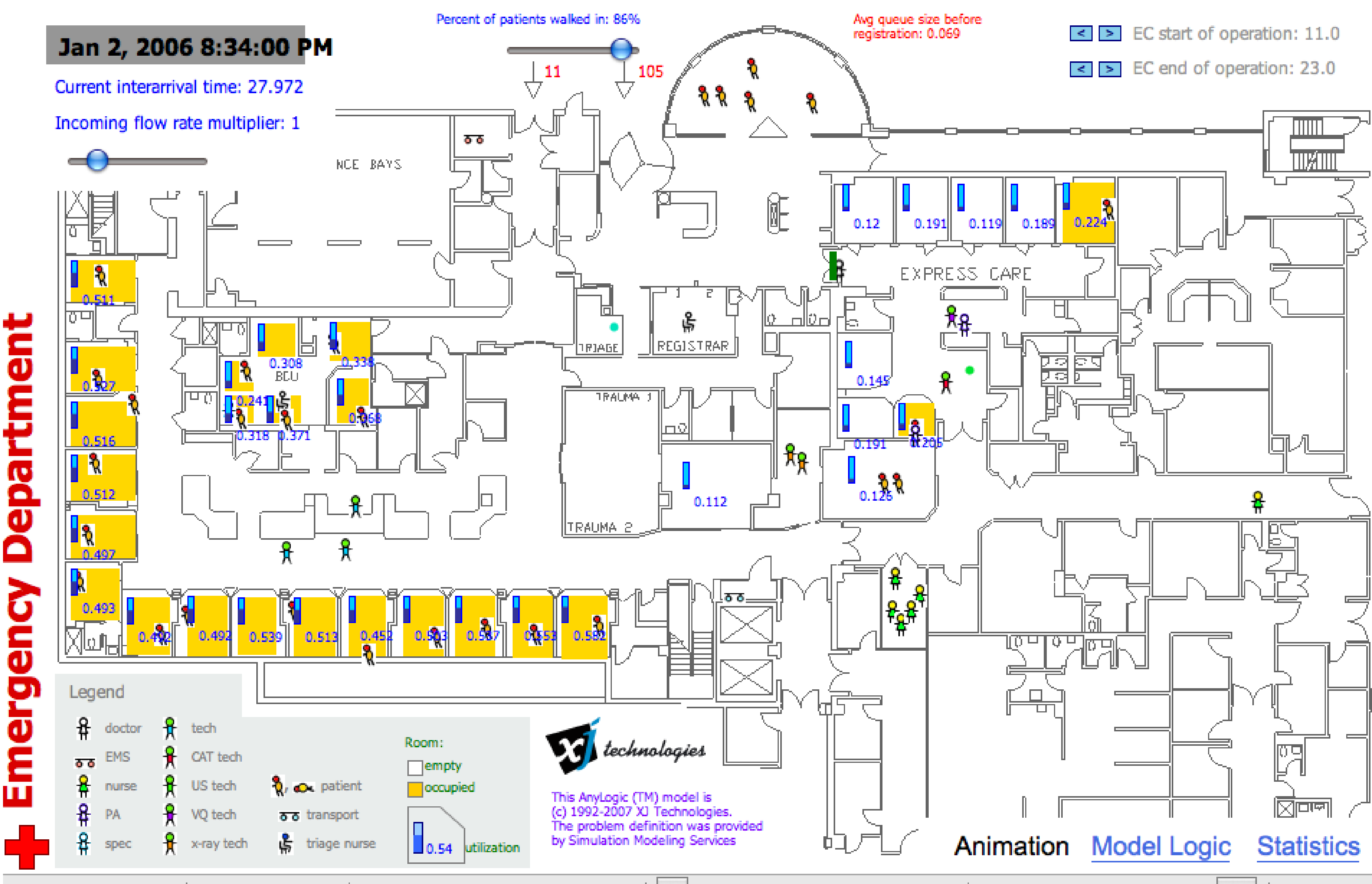
Interacting Individuals



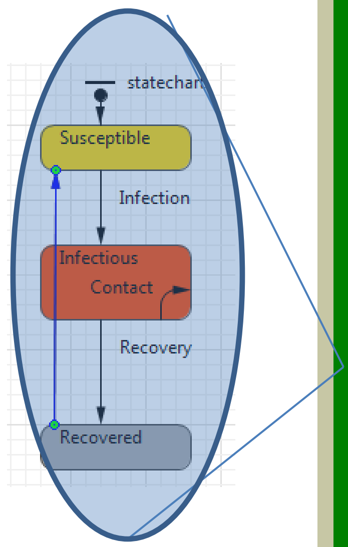
Network Embedded Individuals

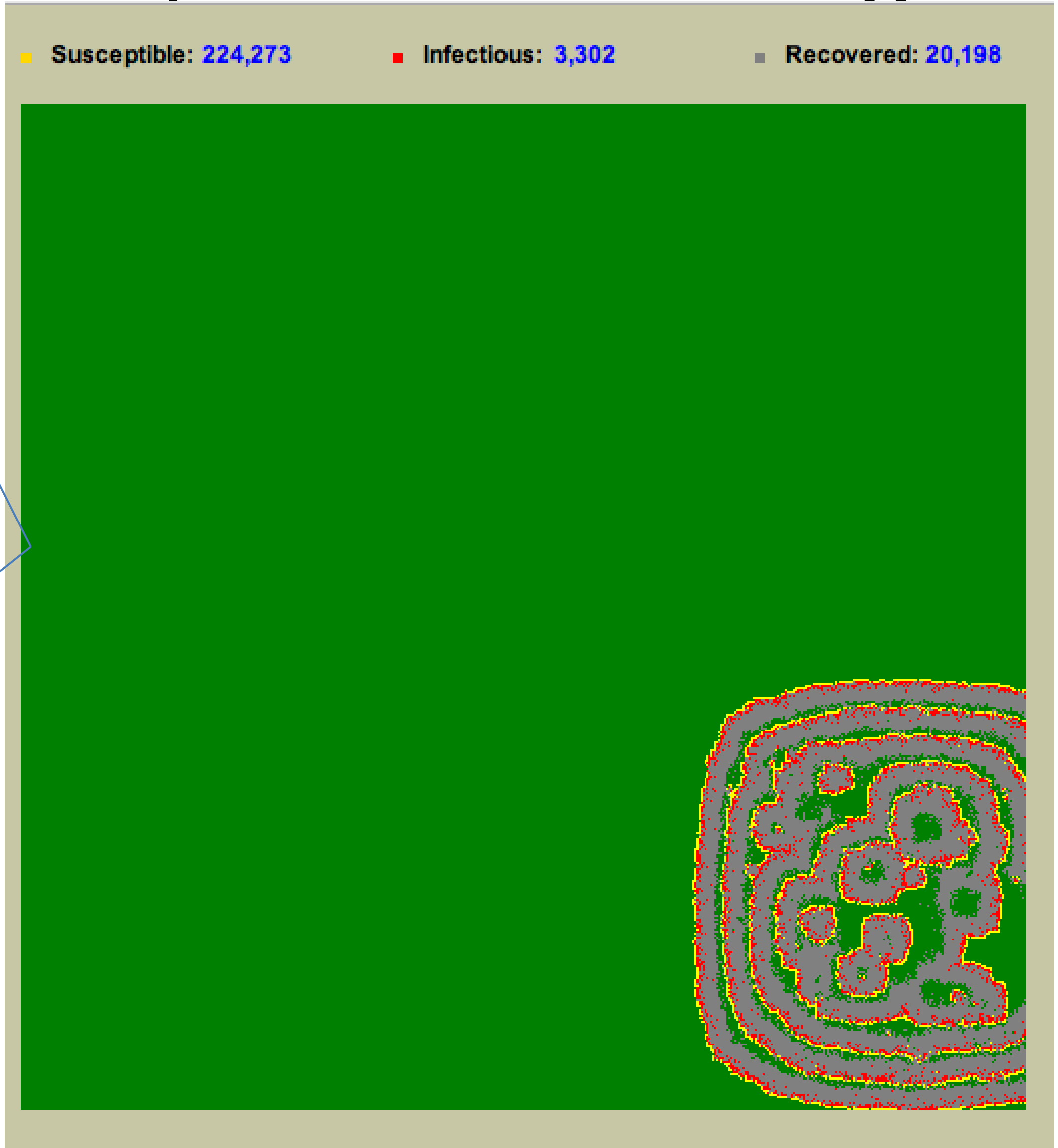


Irregular Spatial Embedding

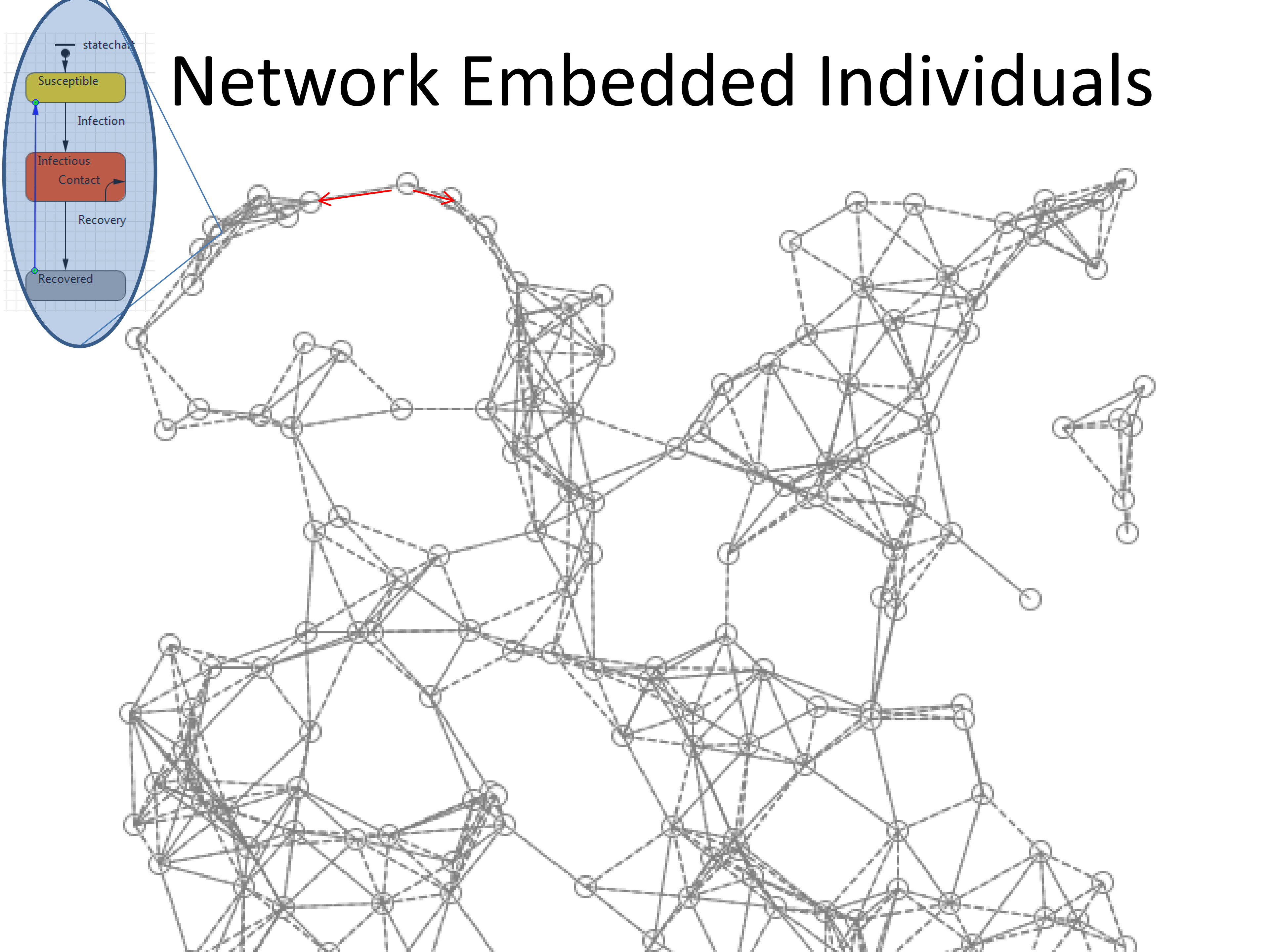


Example of Emergence: Waves in Regular Spatial Embedding

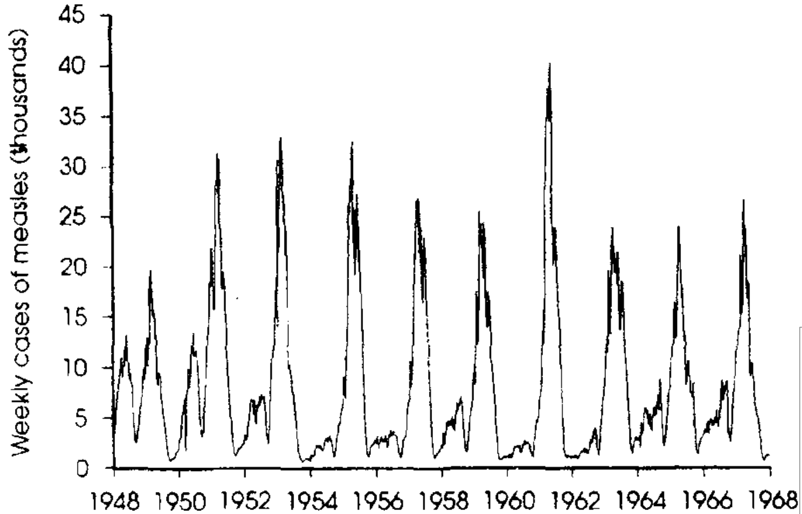


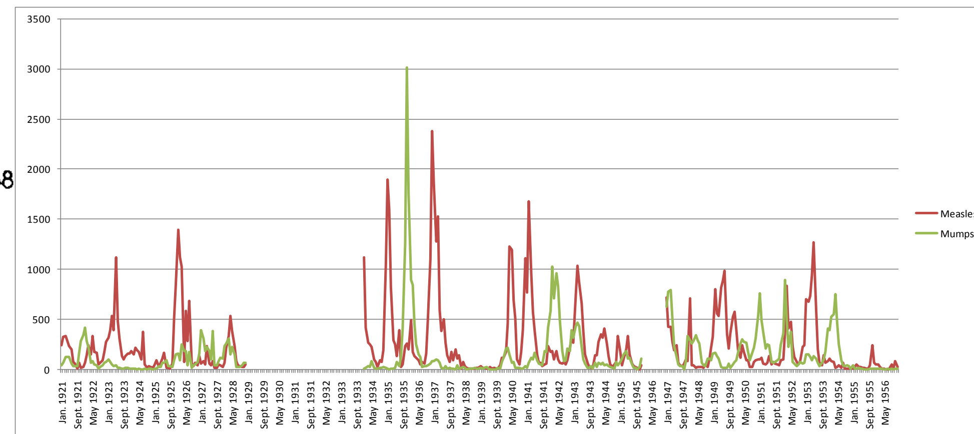


Network Embedded Individuals



Dynamic Complexity:
Oscillations (Damped & Otherwise)





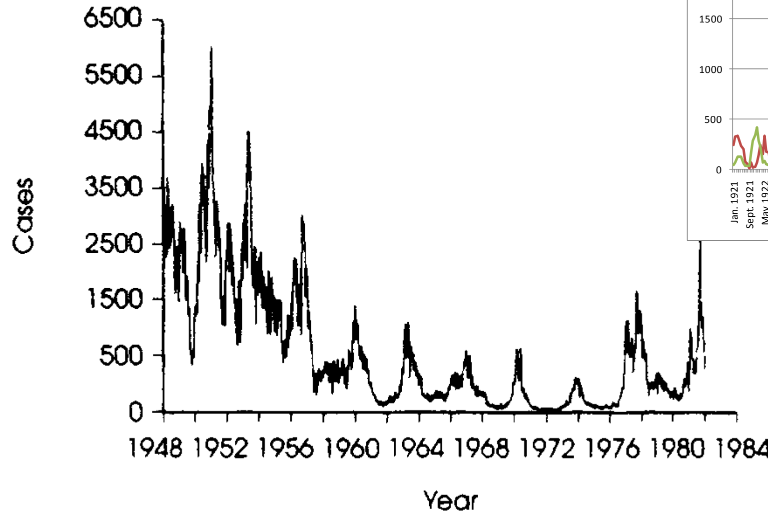


Fig. 6.8. Weekly case notifications of pertussis (whooping cough) in England and Wales for the time period 1948–82. Mass vaccination was introduced in 1956.

Emergence

- Interaction of very simple components can lead to surprising "emergent" dynamic patterns in the behaviour of a given component over time
- The patterns that are seen are quite different than what would be expected through any single component of the system
- These often relate to variables in the underlying system in complex ways

Observation & Change

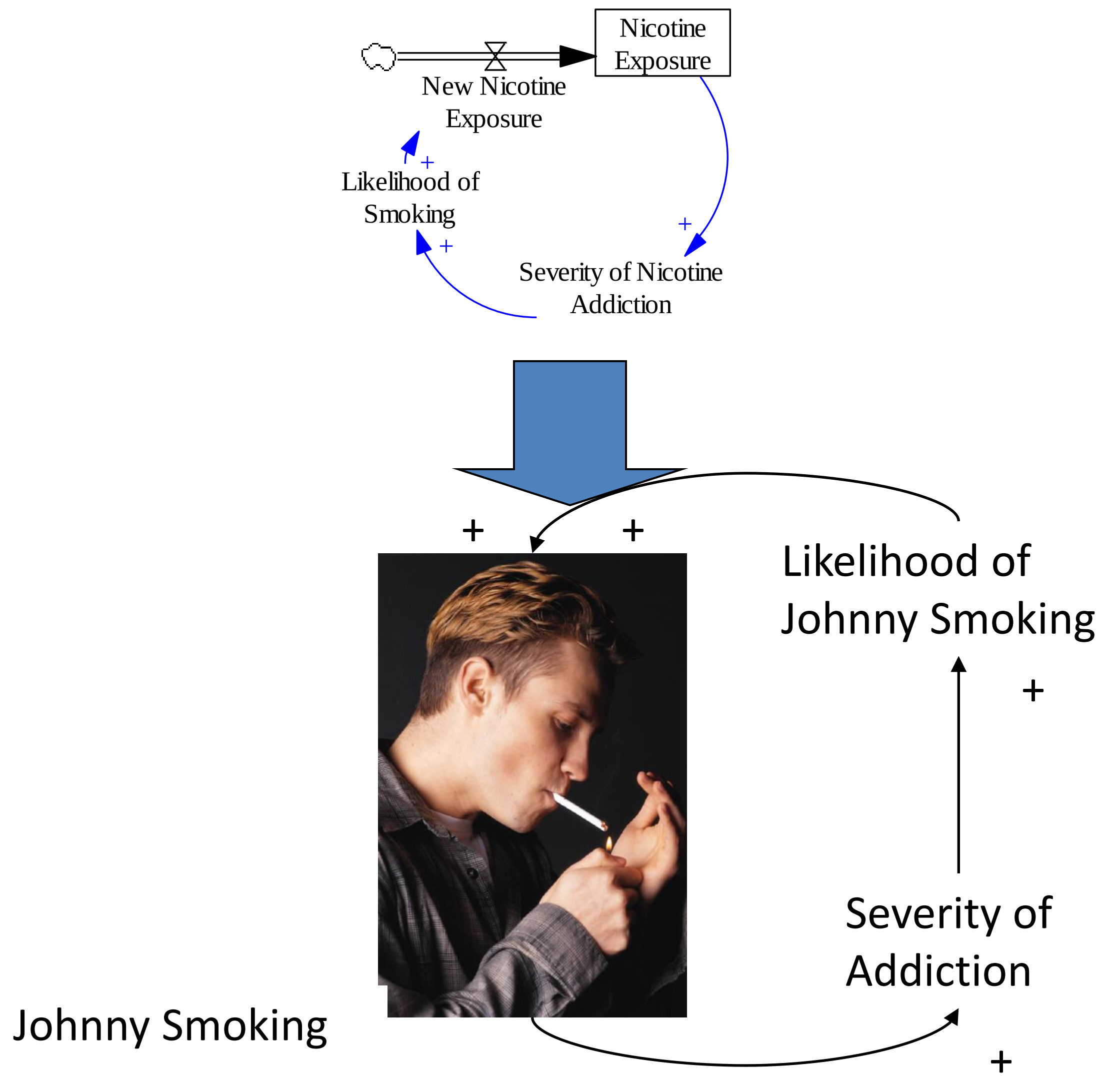
- What we observe most directly in the world are emergent properties of the system
- Changes to these emergent patterns must be accomplished by changing the underlying system
  - The emergent behaviours can change significantly with changes in model structure&parameter values
- Models help with understanding how
  - The emergent patterns reflect the characteristics of the underlying system
  - Changes in the underlying causal factors yield changes in the results

Emergent Behaviour & Modeling Types

- We see emergent behaviour in both System Dynamics and Agent-Based models
  - Agent-based models: Especially in interaction of multiple agents & higher level patterns of behaviour
  - System Dynamics: Especially in interaction of multiple stocks & flows
- Agent-based modeling particularly emphasizes multi-level emergence – how distinctive patterns can emerge at different levels of the system
  - Ability to look at high-level emergence reflects the presence of many individual agents within one model
- The emergent behaviours can change significantly with changes in model structure&parameter values

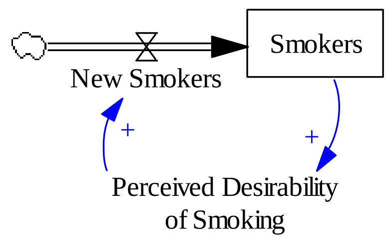
Feedbacks

- Some aggregate feedbacks lie within individual agent

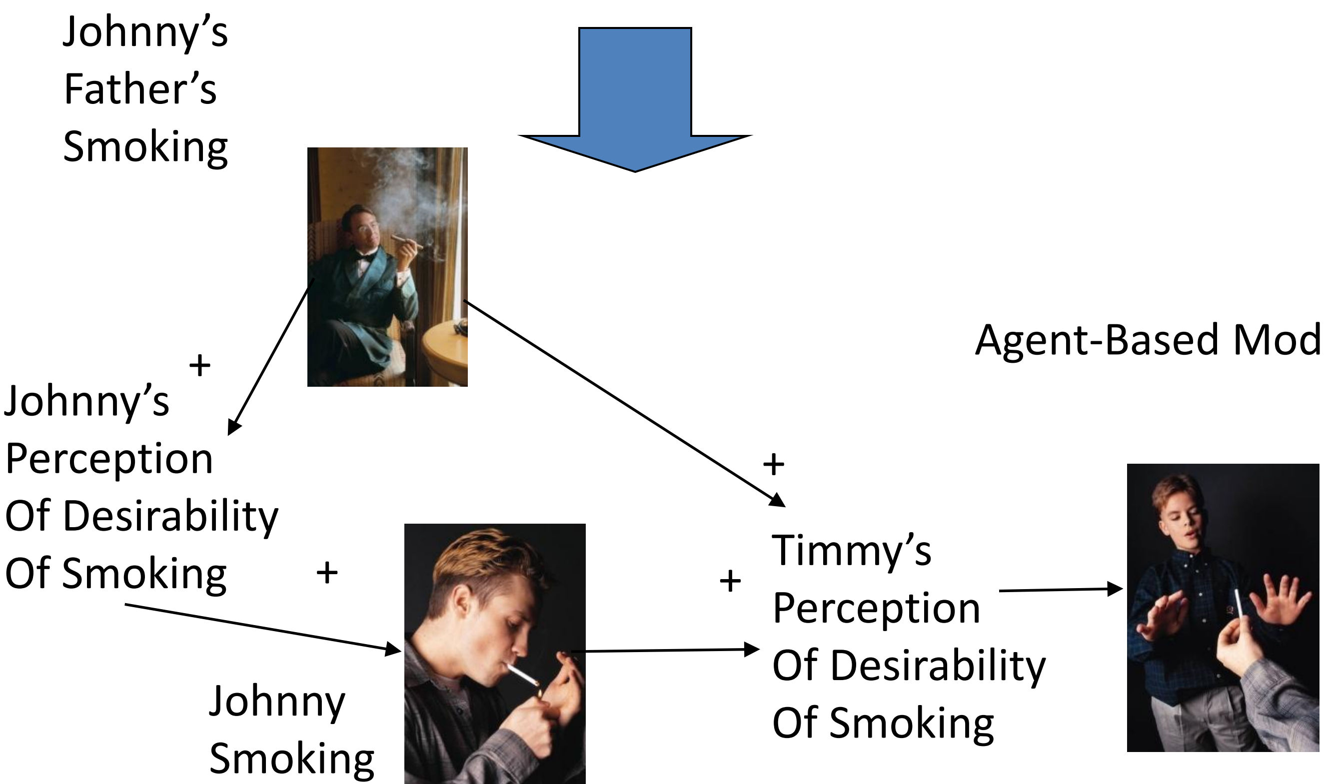


Feedbacks

- Many aggregate feedbacks are *between* agents



Aggregate Model



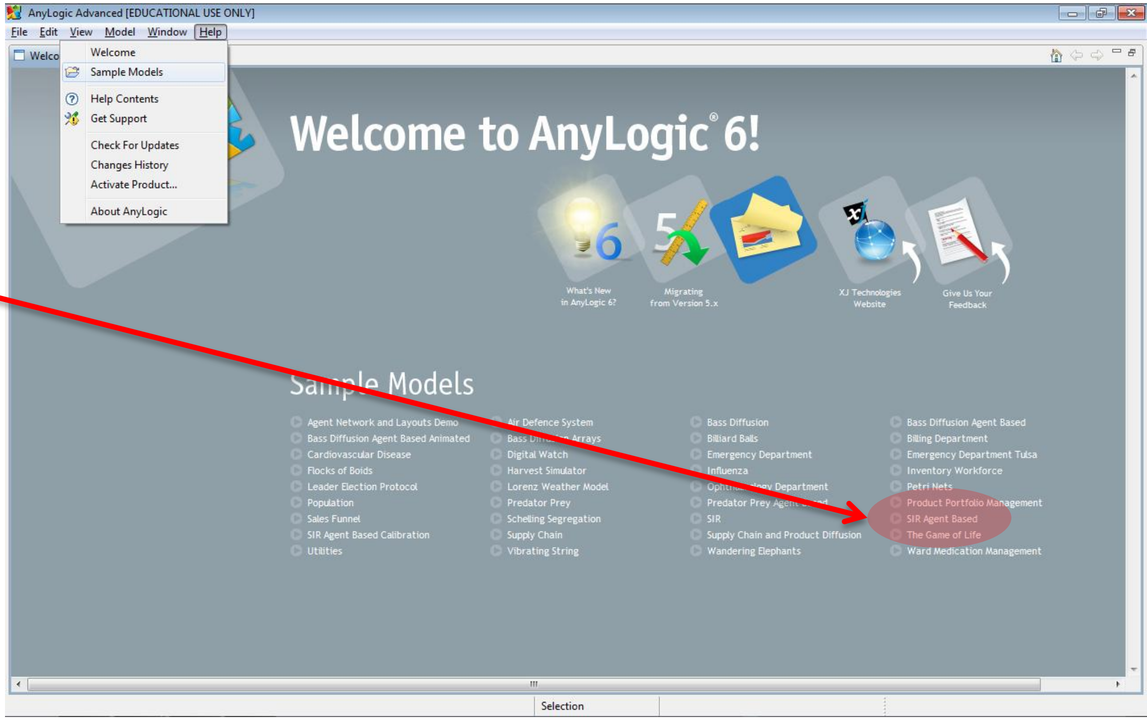
Agent-Based Model

Limitations of Agent-Based Methods

- Inability to mathematically analyze & generalize behaviour beyond a single run
- Long ensemble run times $\Rightarrow$ lack of interactivity, opportunity cost
- Calibrating yields no unique interpretation
- Requirement of some software engineering in building, modifying
- Achieving model transparency is difficulty
- Lack of defined modeling process or qualitative modeling artifacts

Hands on Model Use Ahead: First Glimpse of Agent-Based Modeling

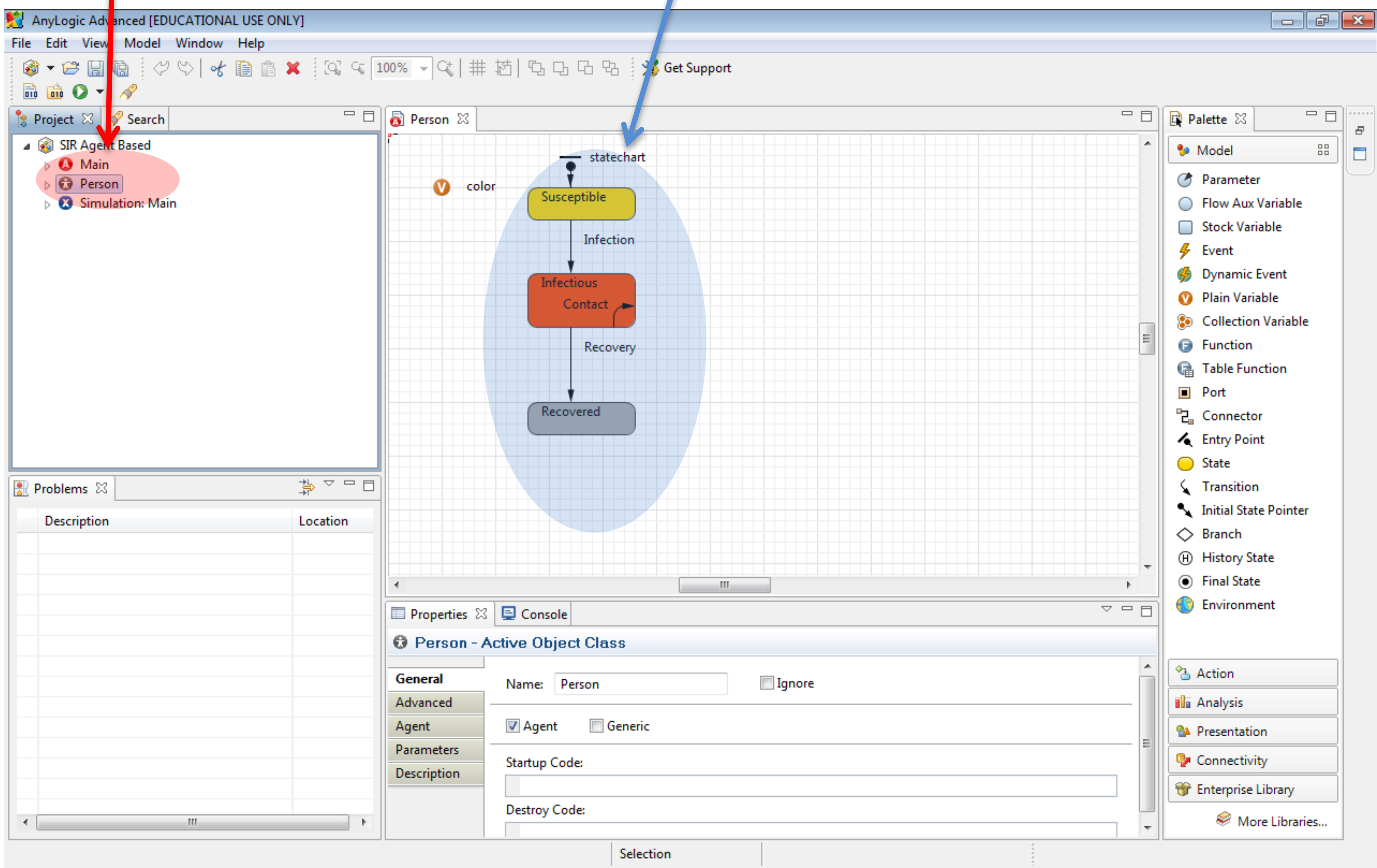
“SIR Agent-Based” is Located here



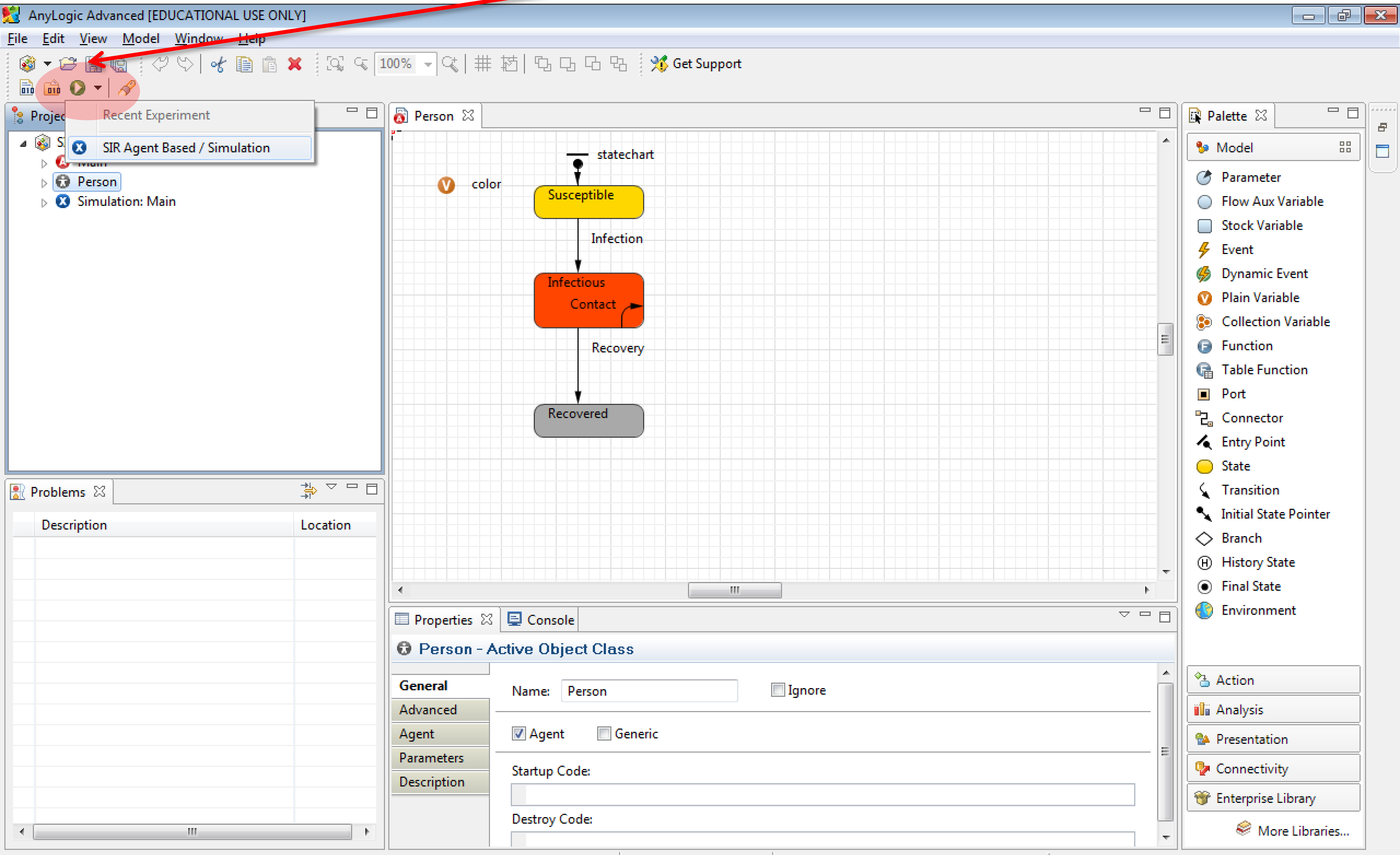
Load model: SIR Agent-Based from AnyLogic Sample Models (via “Help” menu)

Viewing the Model Structure

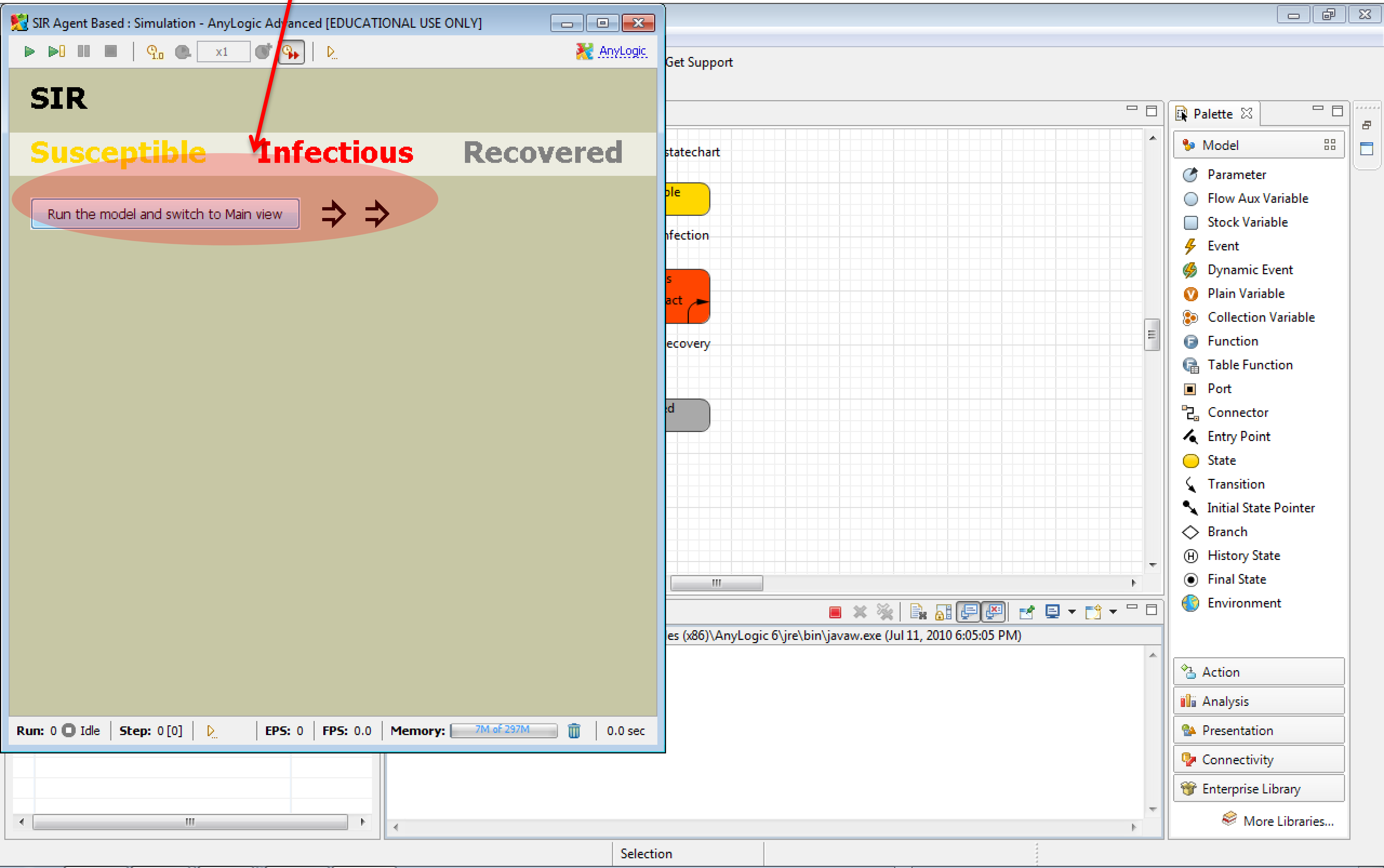
Double click on "Person" to see the associated state transition diagram



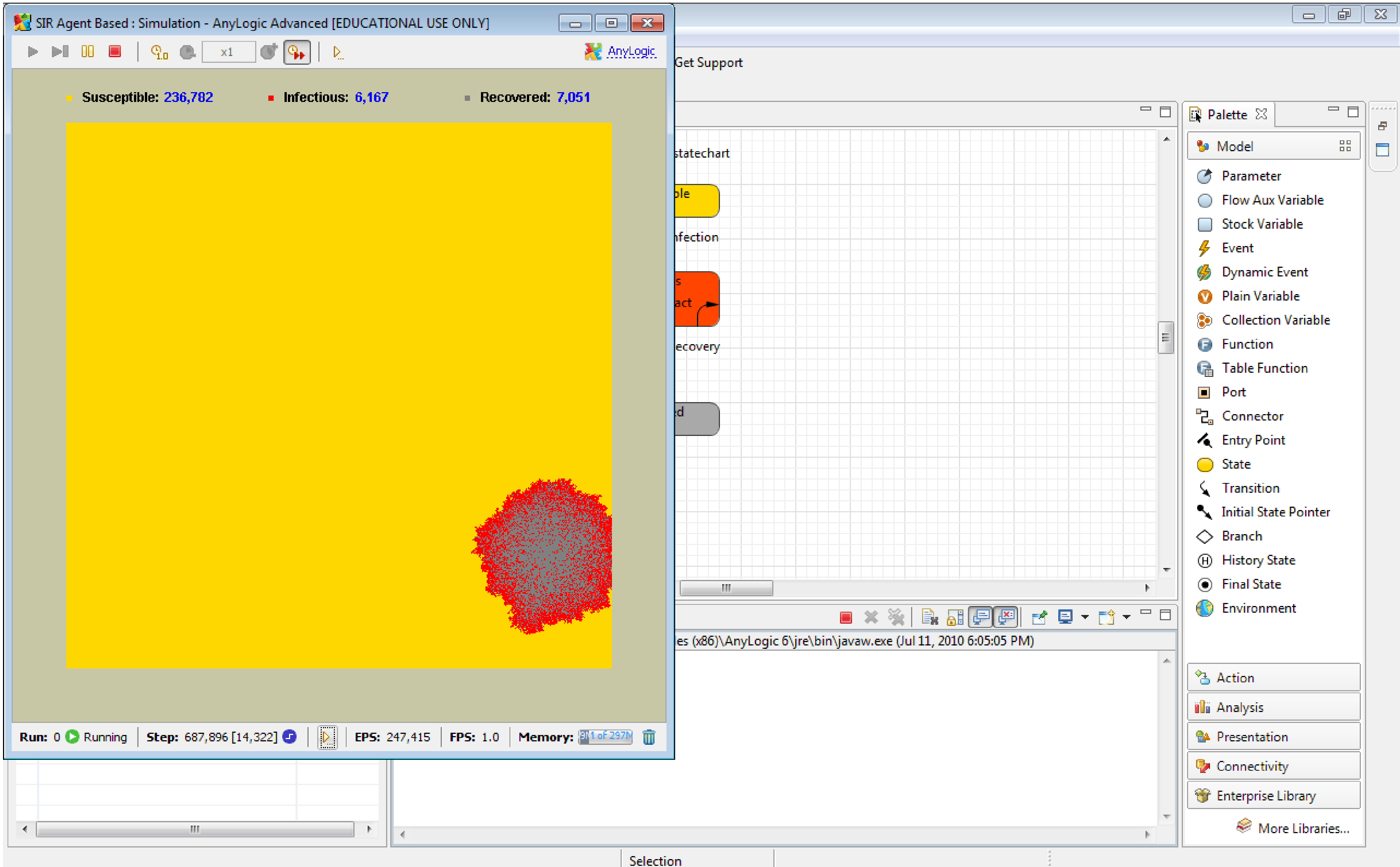
Run the Model (via the "Run" button)



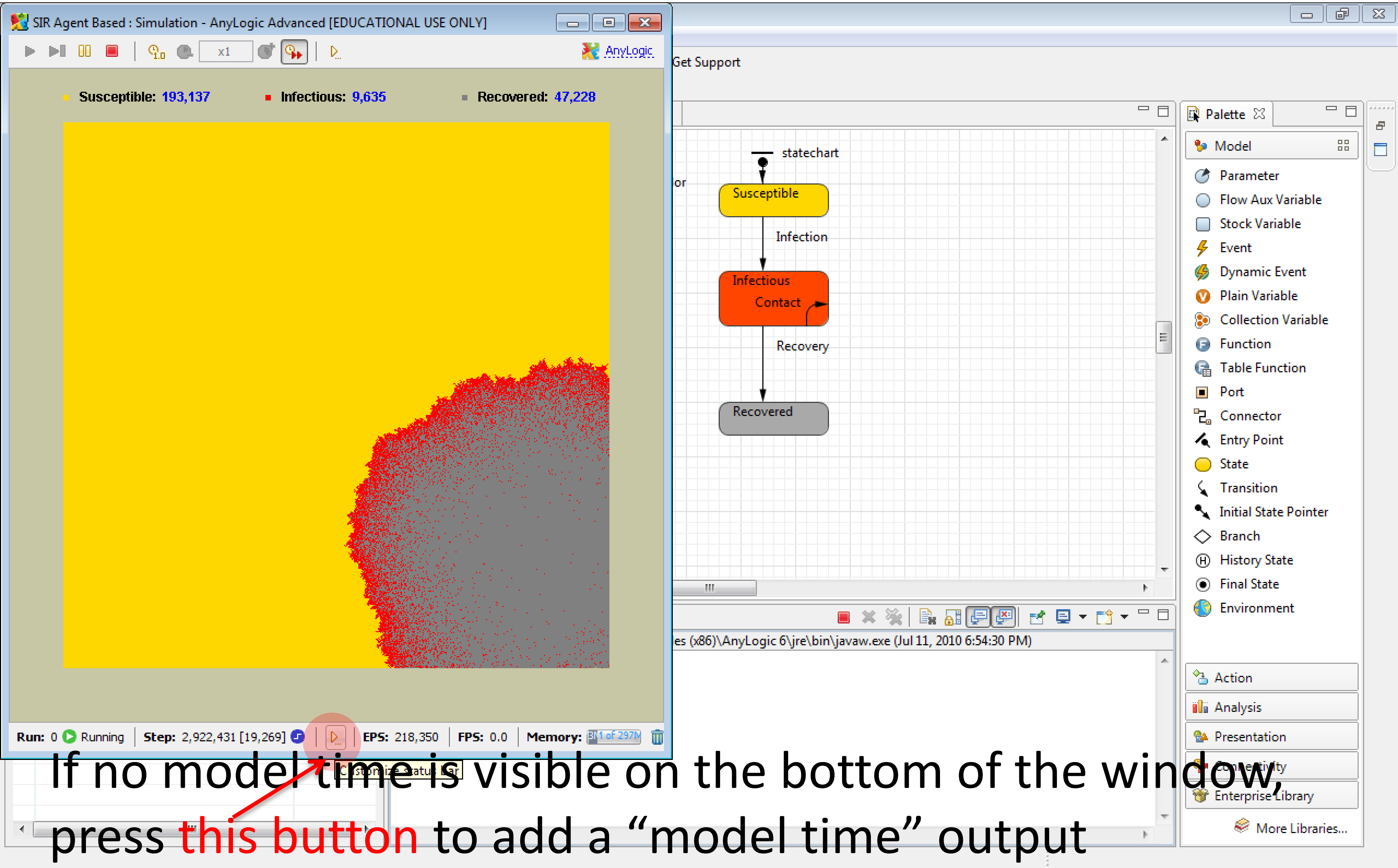
Press this button to start model execution



Example of Emergent Behaviour

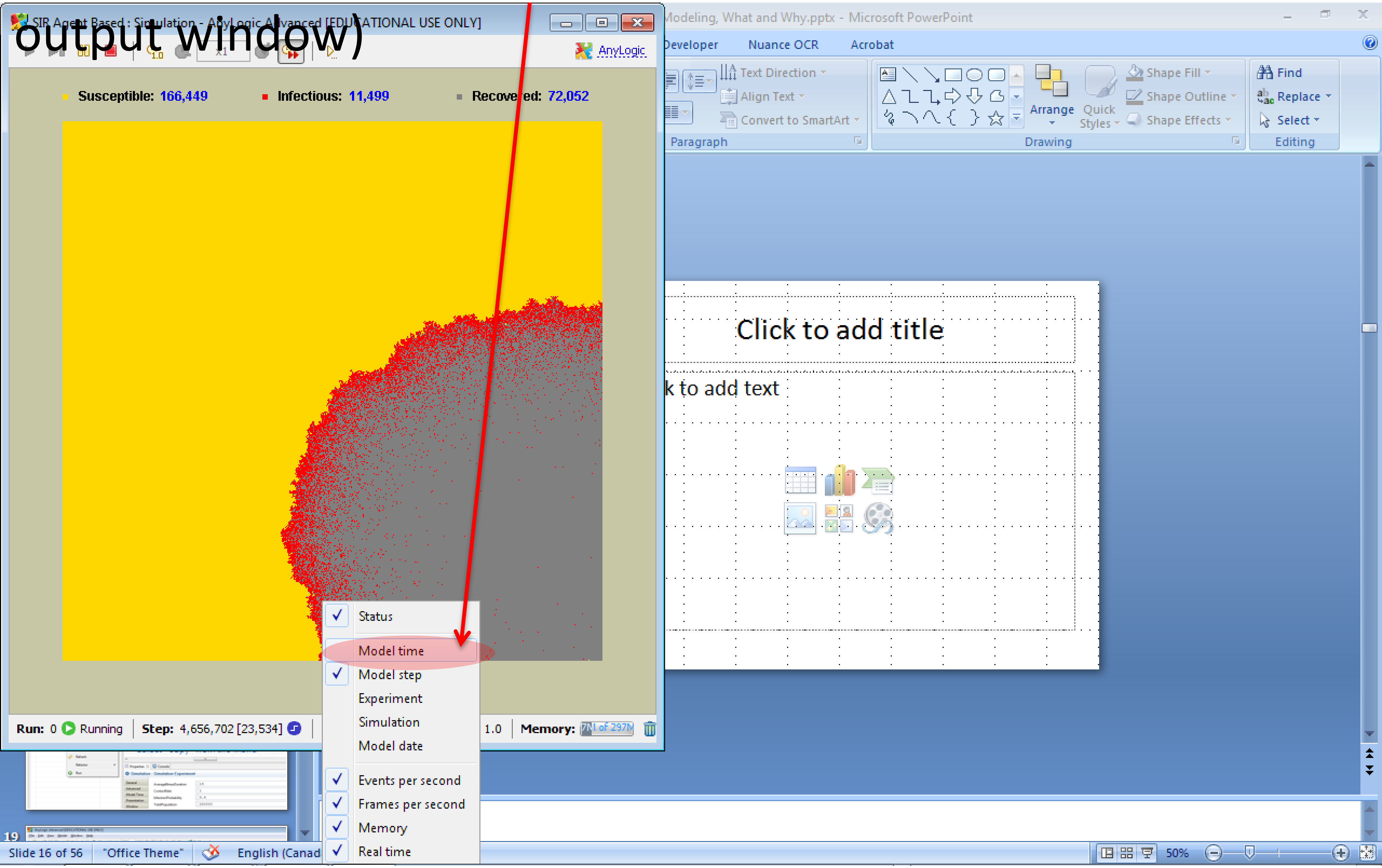


Make Sure Model Time is Visible

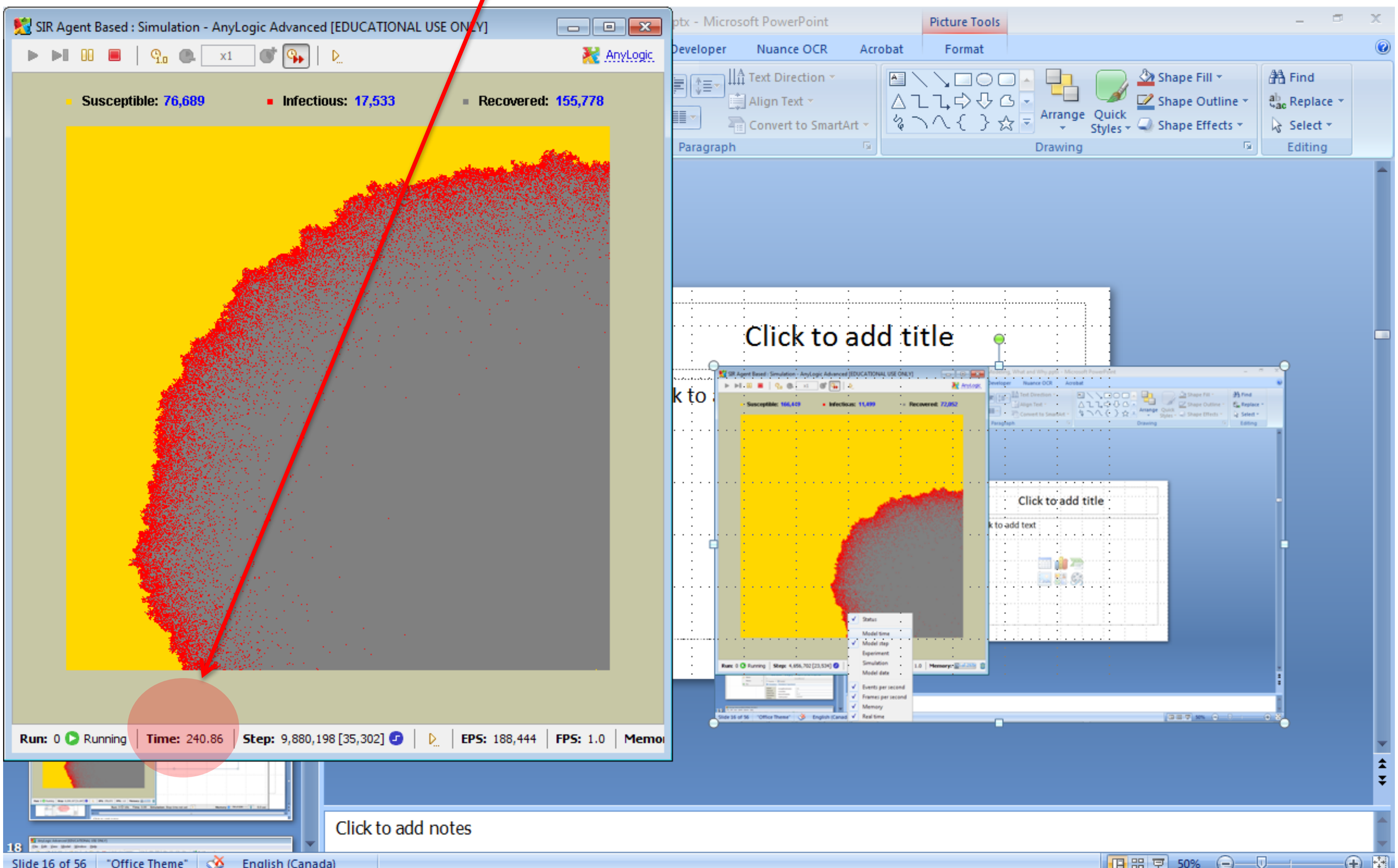


If no model time is visible on the bottom of the window, press this button to add a "model time" output

Select "Model Time" here (so a check mark appears)
(If a checkmark is already present, just click back on the output window)



The Updated Window Should Include a Model Time Output

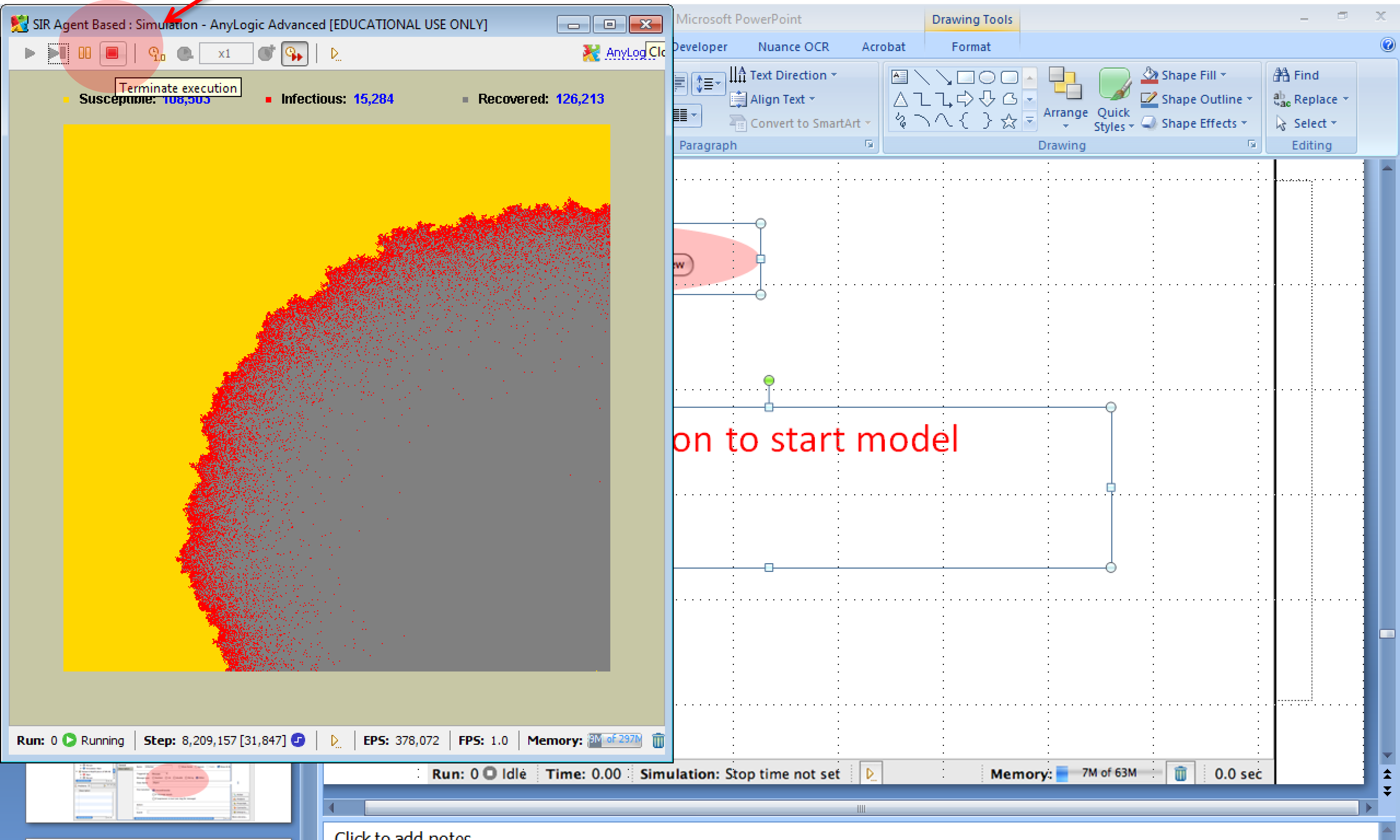


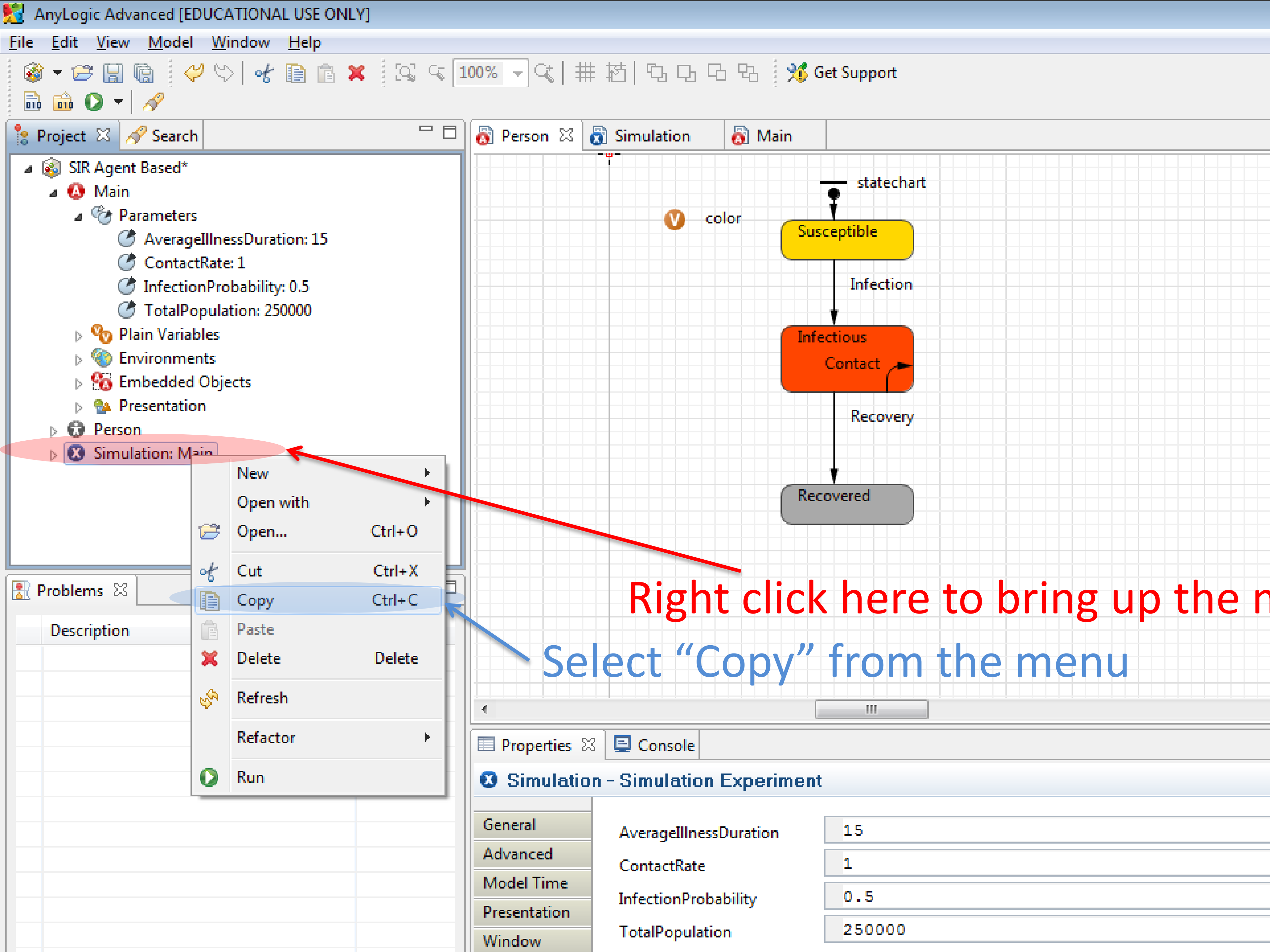
Stylized Measurement 1

- How Long Does it Take for The Infection to Reach the Top or Left Boundaries?

- We'll compare this to the situation with other parameter assumptions

Press this button to stop model execution




AnyLogic Advanced [EDUCATIONAL USE ONLY]
File Edit View Model Window Help
100%
Get Support
Project
Search
SIR Agent Based*
Main
Parameters
AverageIllnessDuration: 15
ContactRate: 1
InfectionProbability: 0.5
TotalPopulation: 250000
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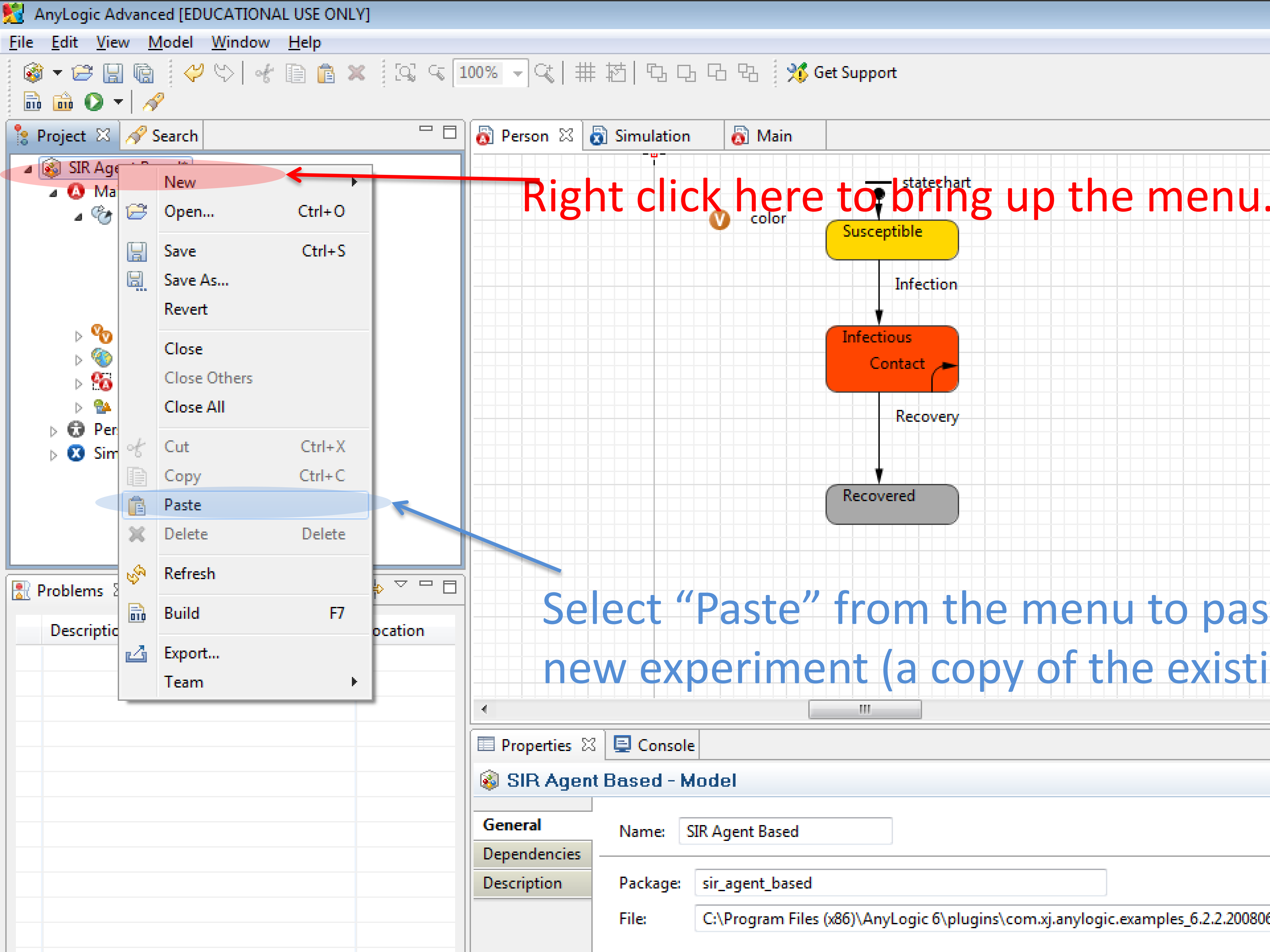

AnyLogic Advanced [EDUCATIONAL USE ONLY]
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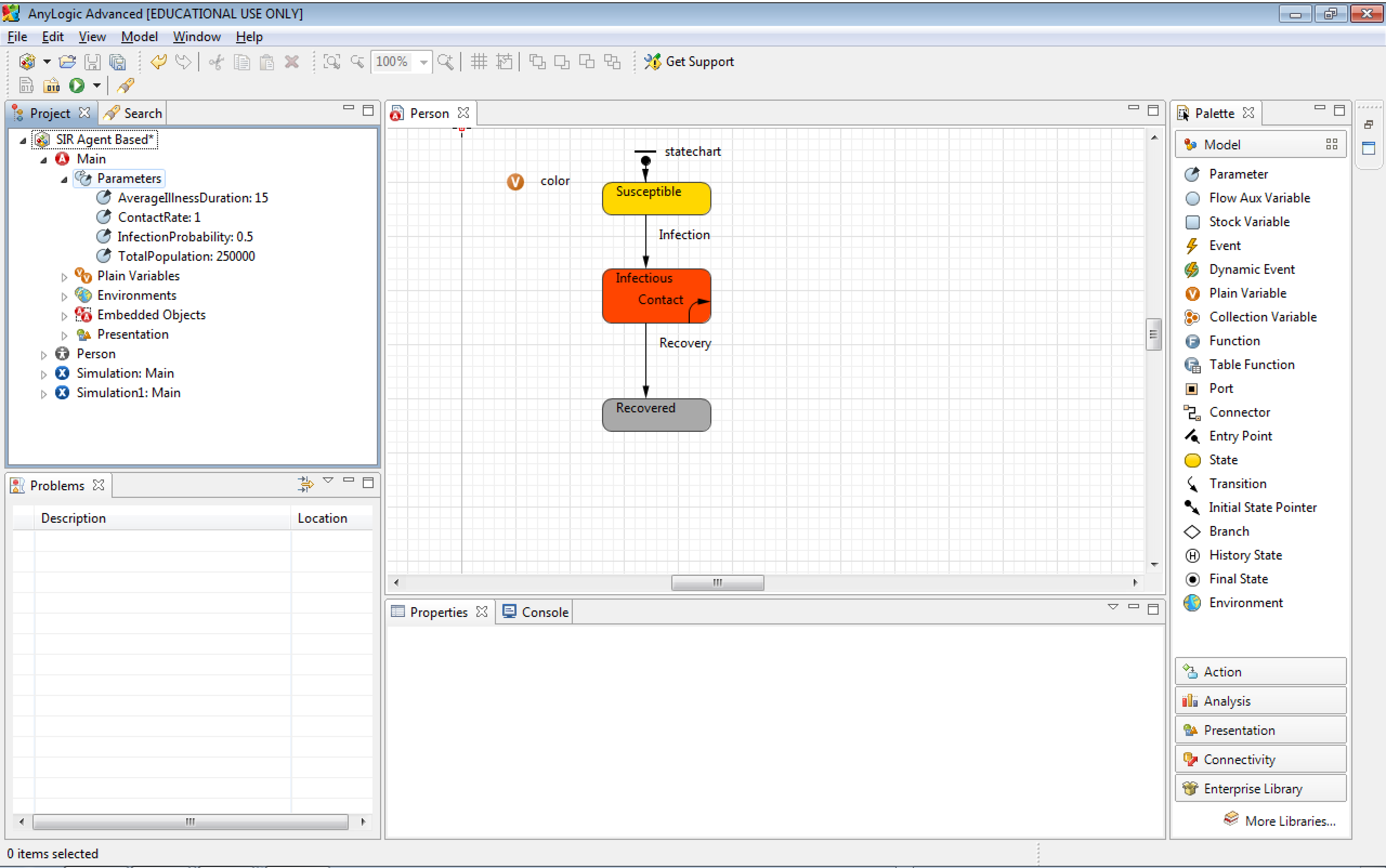
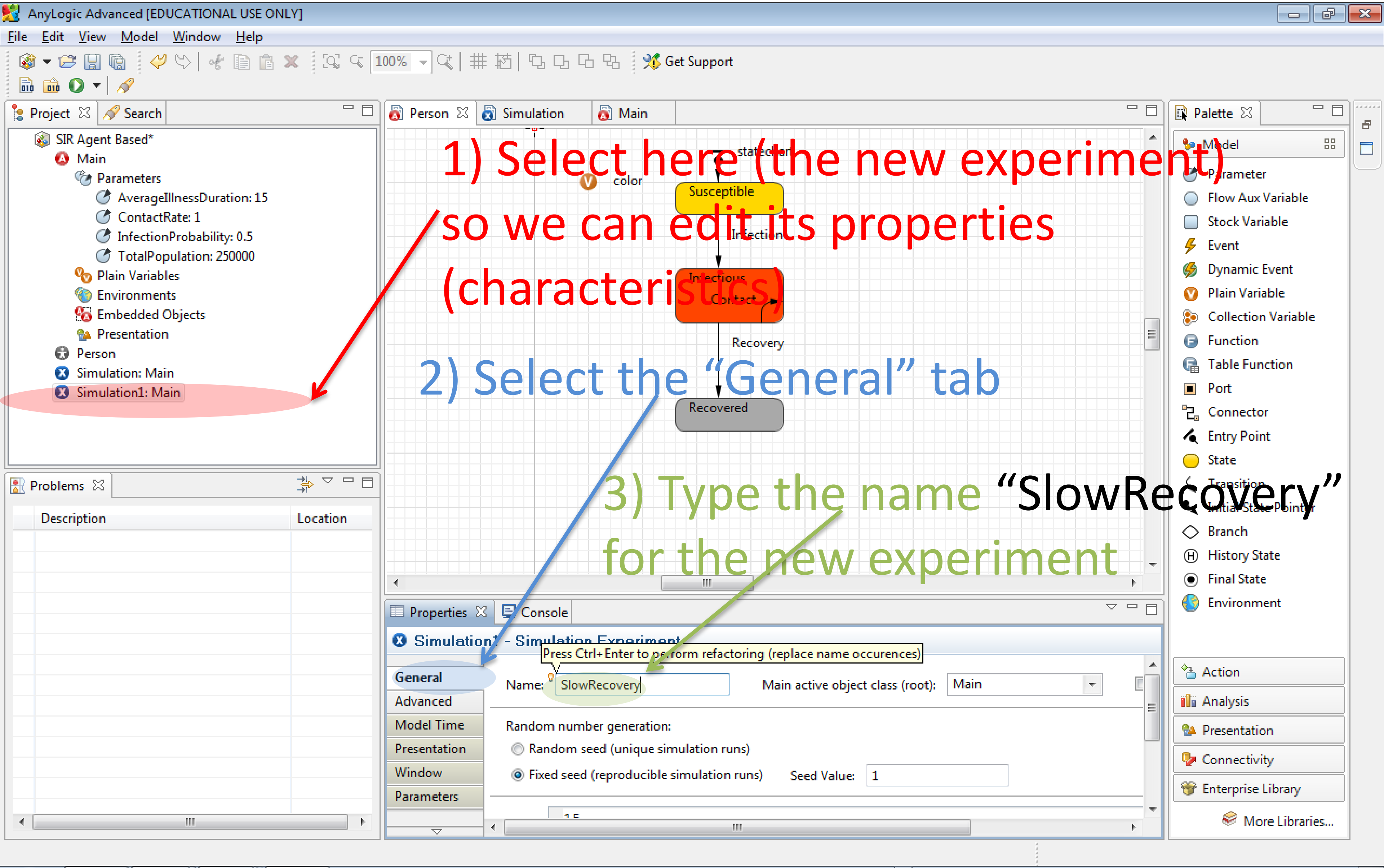
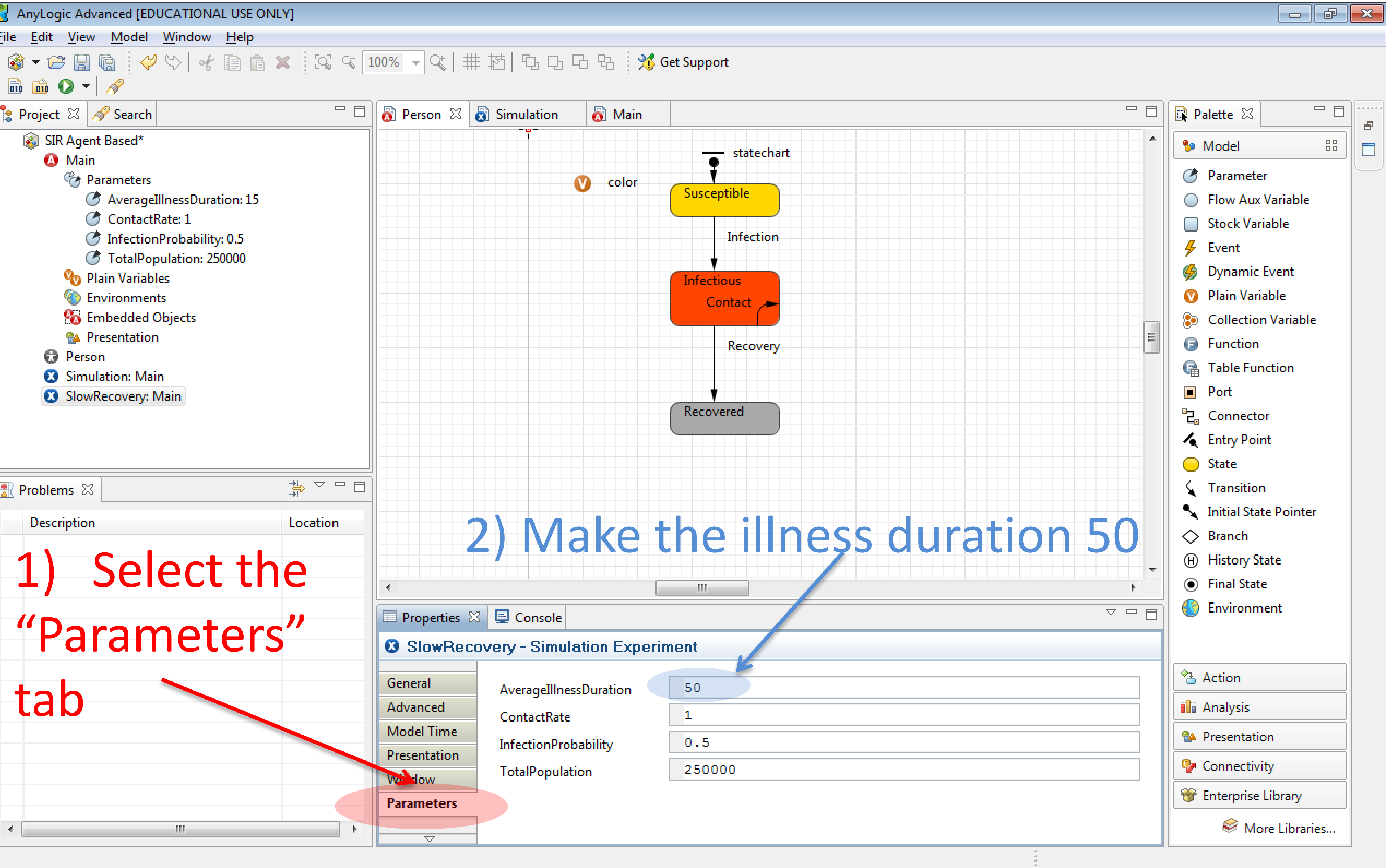
File: C:\Program Files (x86)\AnyLogic 6\plugins\com.xj.anylogic.examples_6.2.2.20080

Your Screen Should Look as Follows



Changing the Name of the Experiment

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Plain Variables
Environments
Embedded Objects
Presentation
Person
Simulation: Main
SlowRecovery: Main
Problems
Description
Location
1) Select the “Parameters” tab
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Infectious
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Recovery
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General
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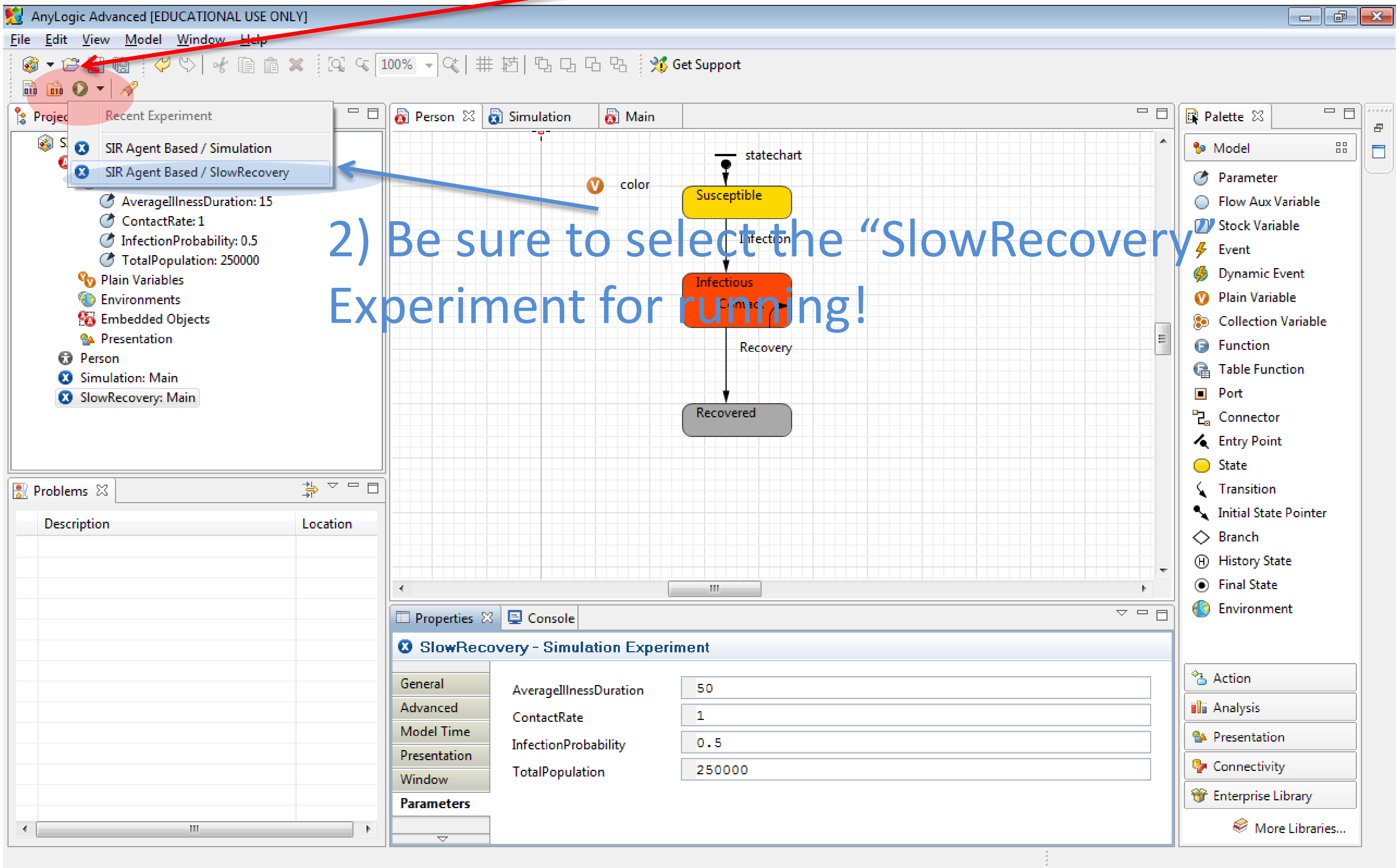
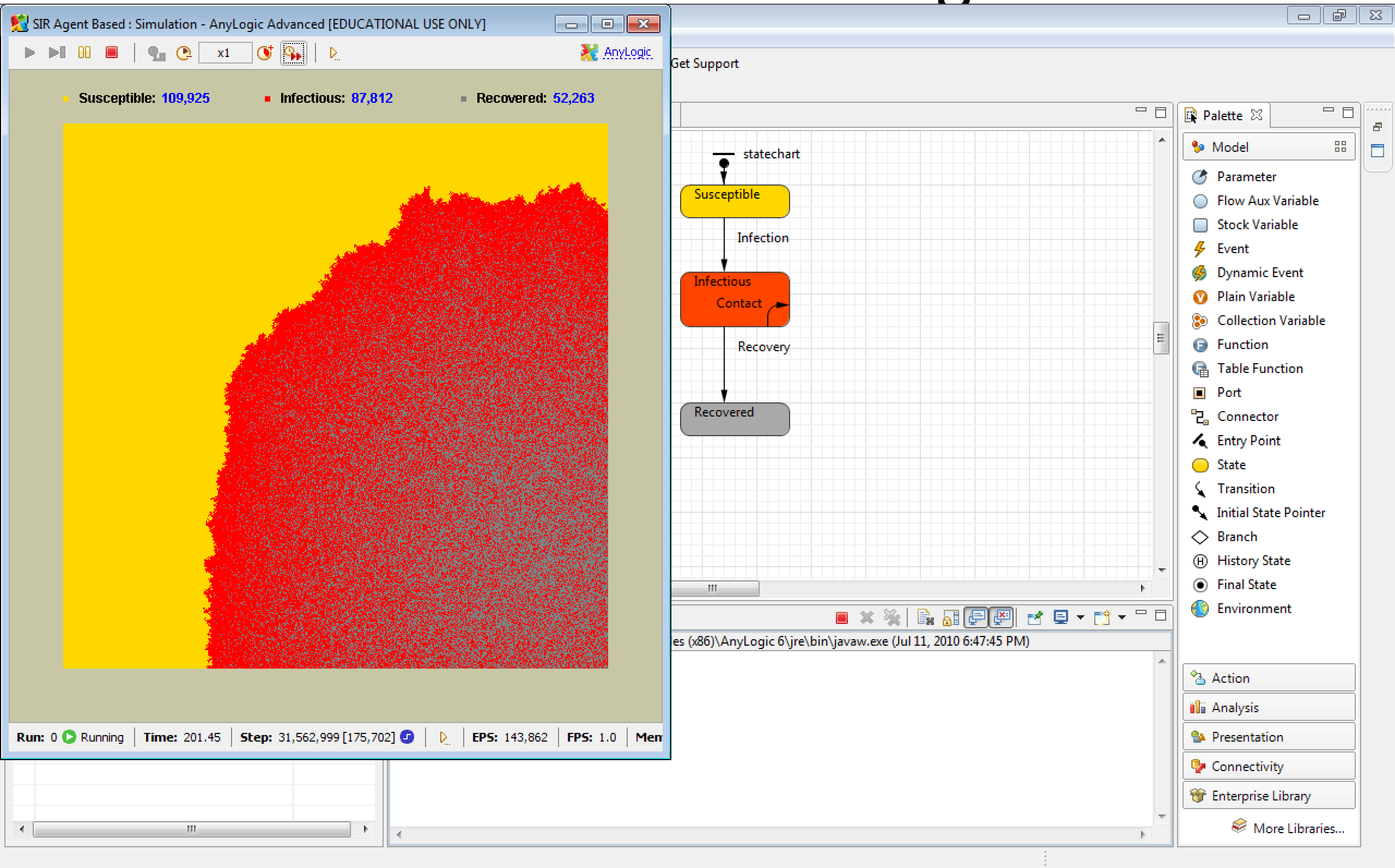
Model Time
Presentation
Window
Parameters
AverageIllnessDuration
50
ContactRate
1
InfectionProbability
0.5
TotalPopulation
250000
Palette
Model
Parameter
Flow Aux Variable
Stock Variable
Event
Dynamic Event
Plain Variable
Collection Variable
Function
Table Function
Port
Connector
Entry Point
State
Transition
Initial State Pointer
Branch
History State
Final State
Environment
Action
Analysis
Presentation
Connectivity
Enterprise Library
More Libraries...

Run the Model (via the “Run” button)

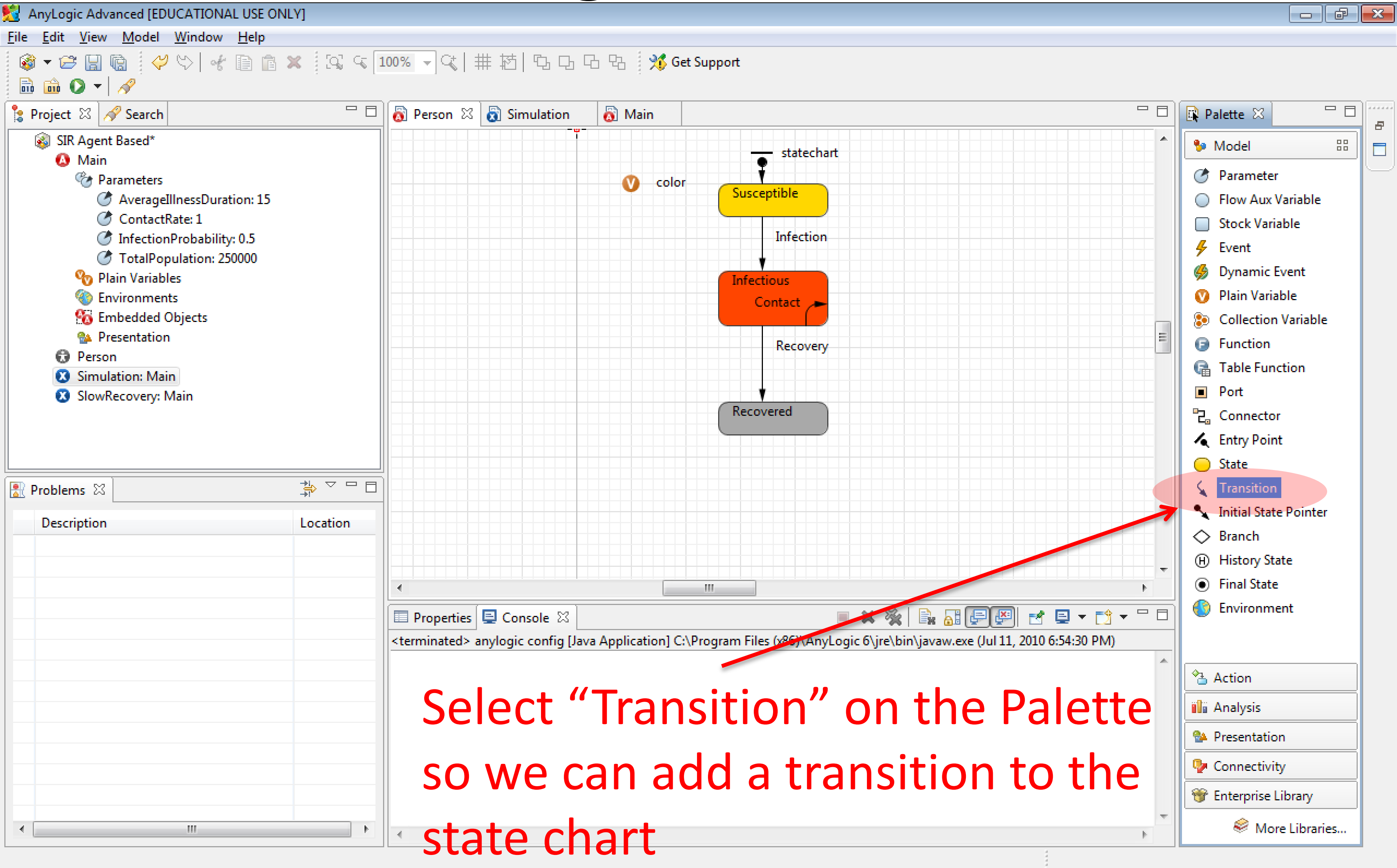


2) Be sure to select the “SlowRecovery” Experiment for running!

You Should See Something Like This

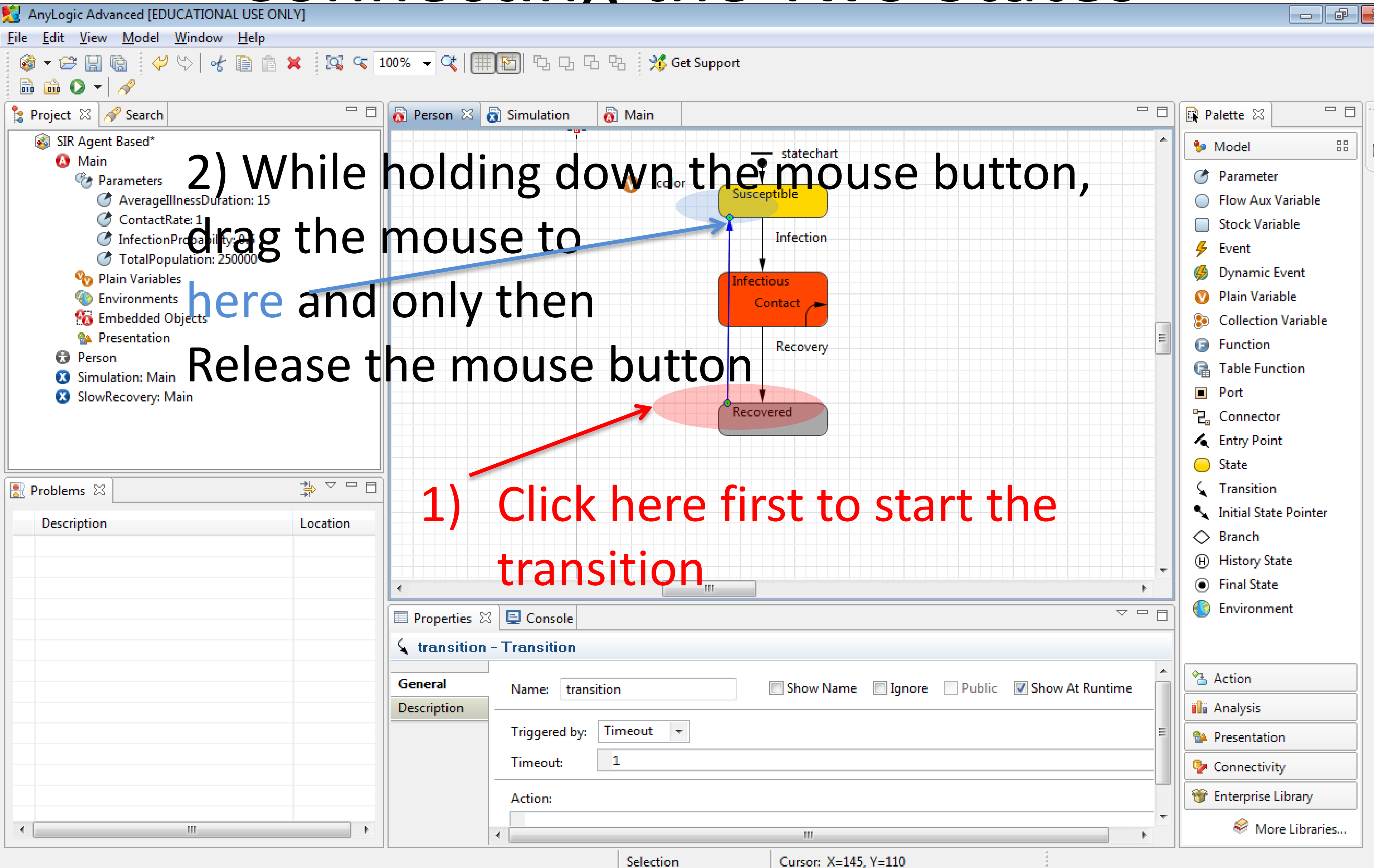


Adding a Transition



Select "Transition" on the Palette so we can add a transition to the state chart

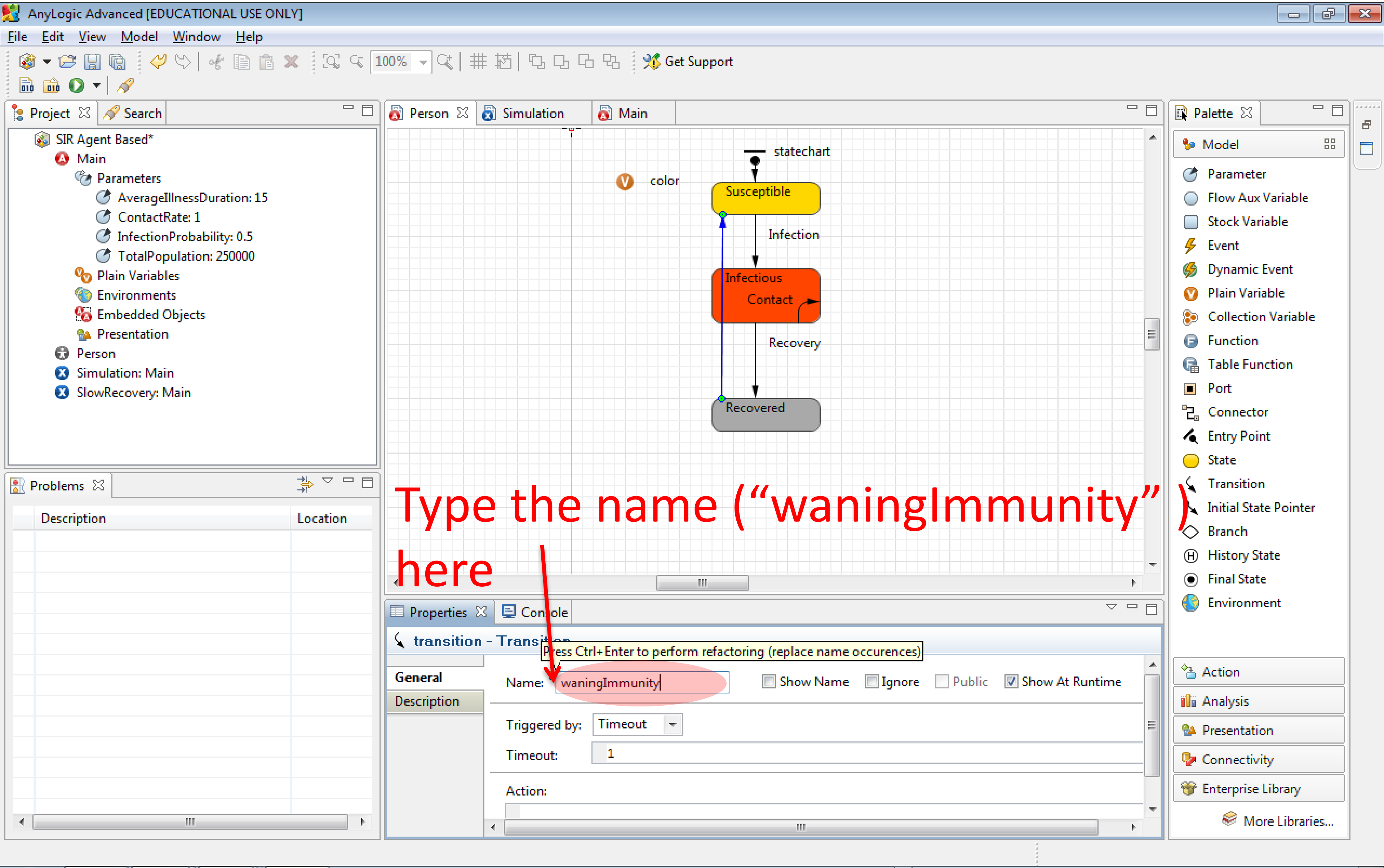
Connecting the Two States



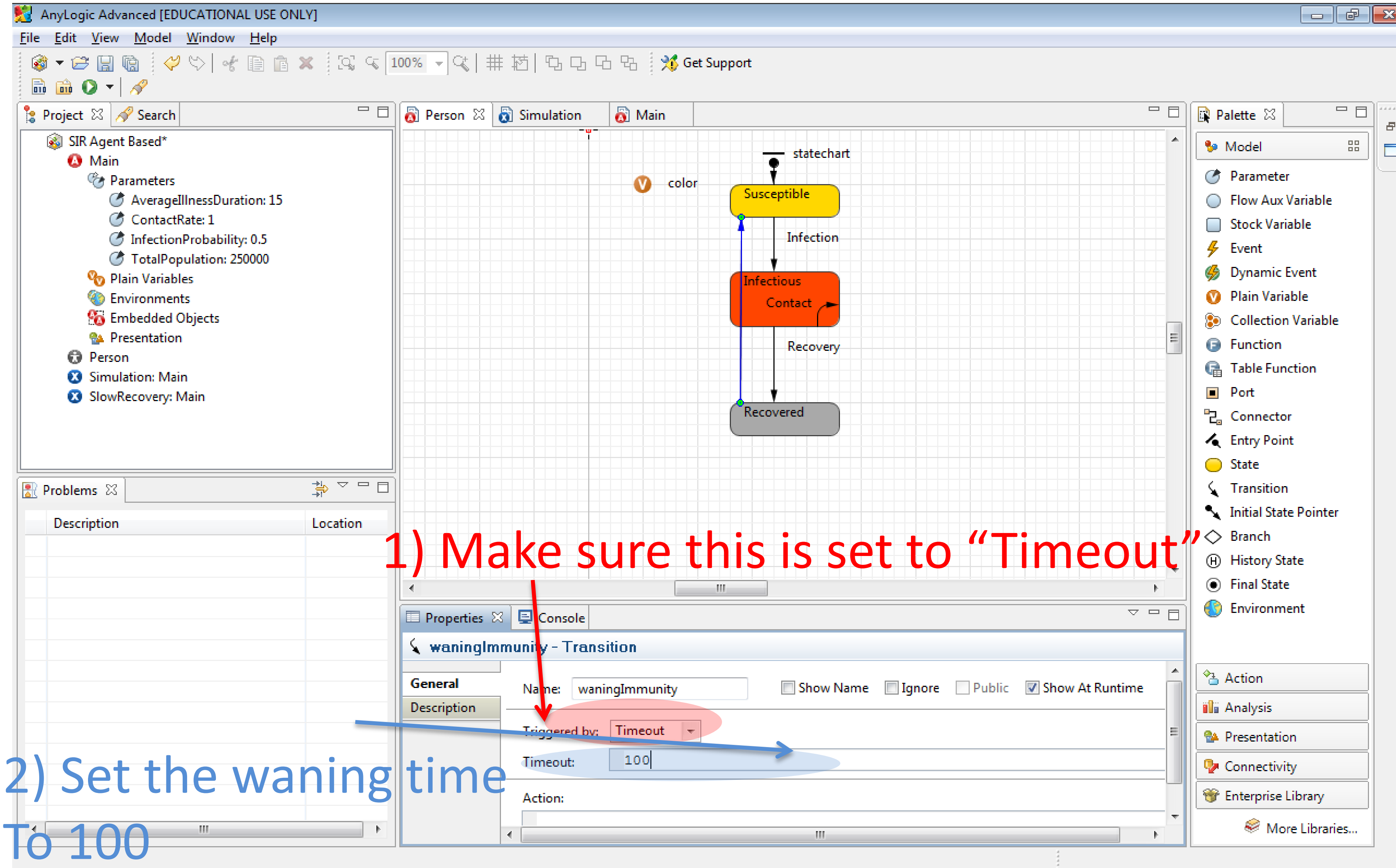
2) While holding down the mouse button, drag the mouse to here and only then Release the mouse button

1) Click here first to start the transition

Give the Transition a Name



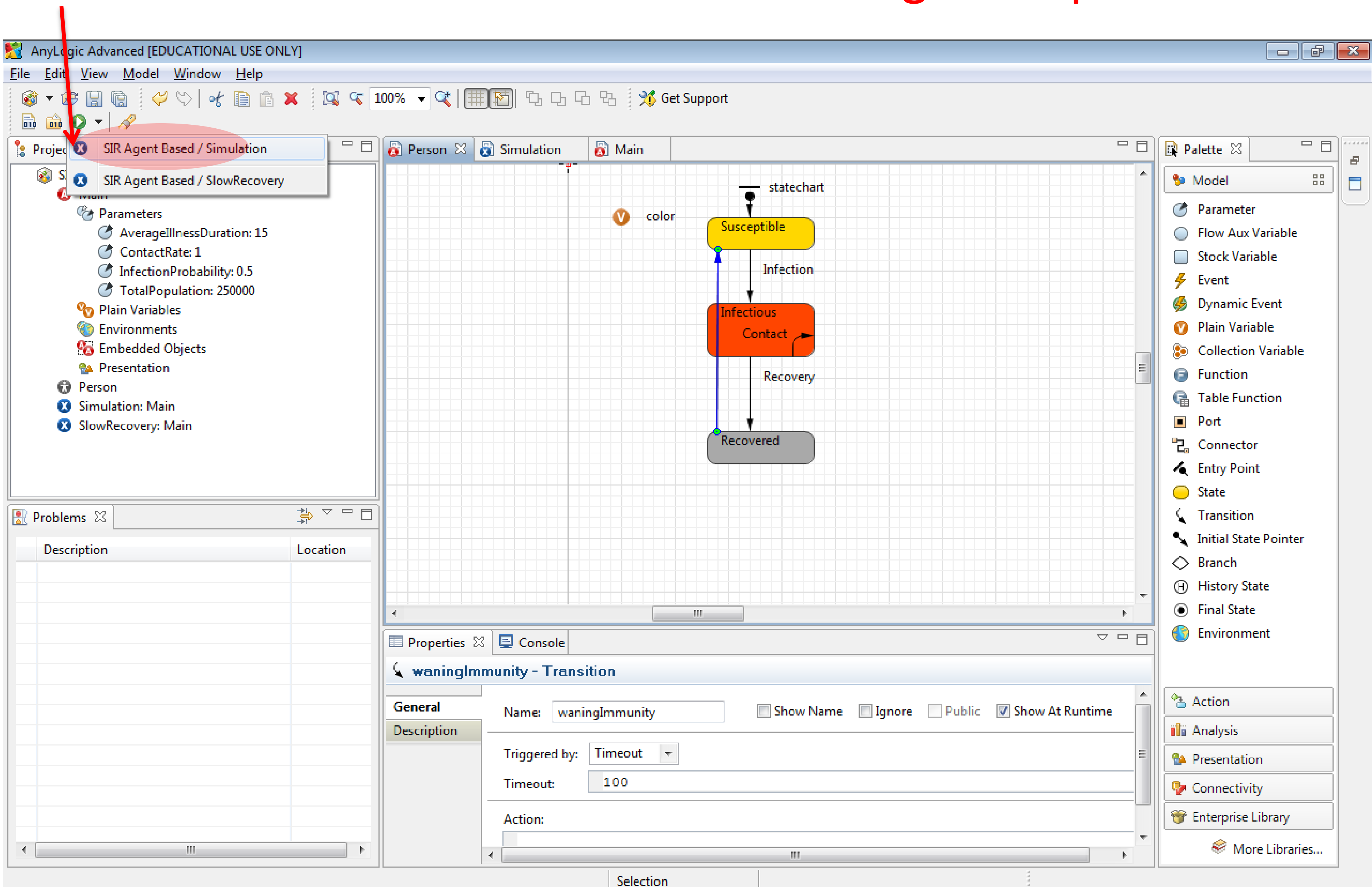
Setting the Duration Until Immunity Wanes



1) Make sure this is set to “Timeout”

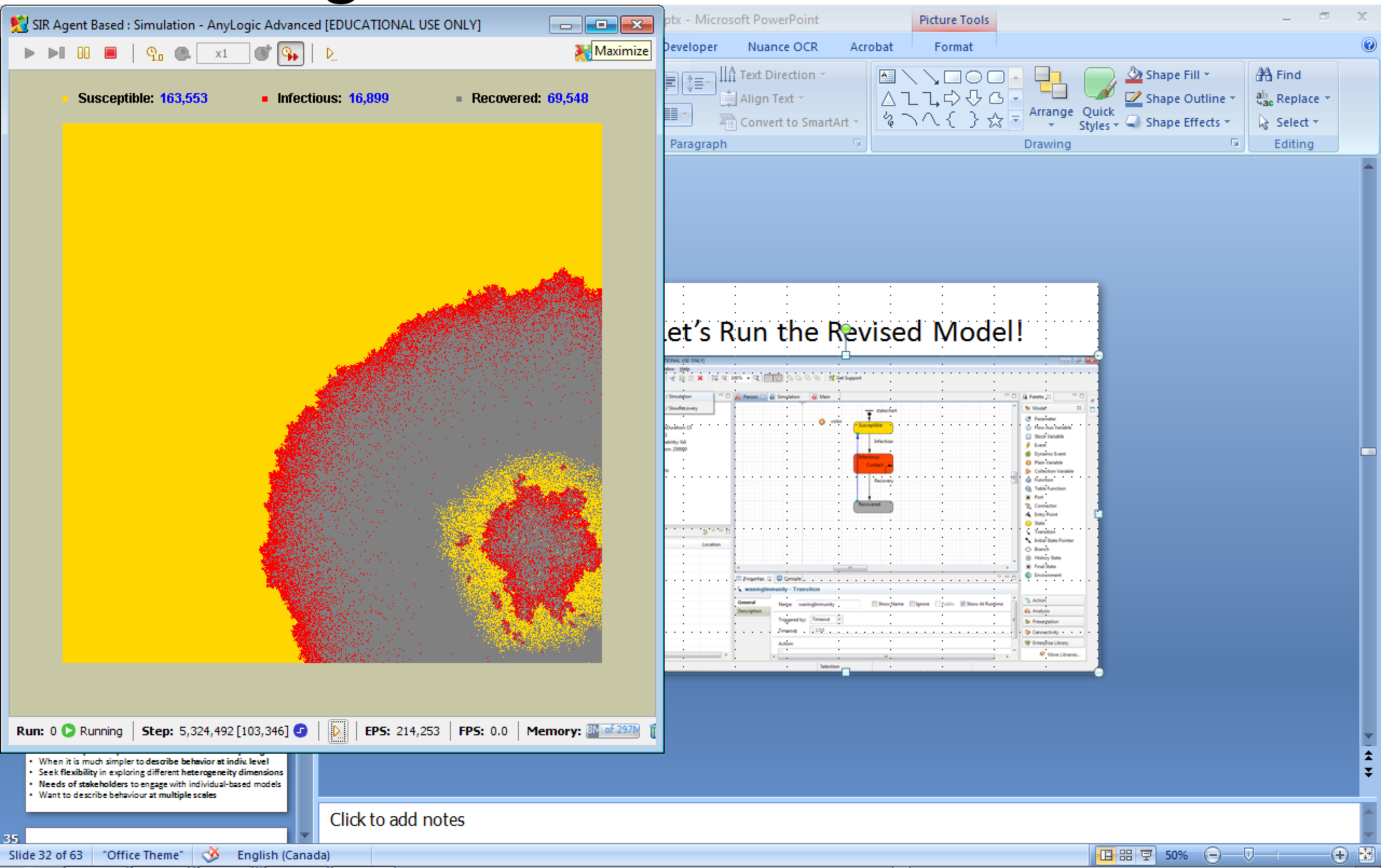
2) Set the waning time To 100

Use the Run Button and select the Original Experiment

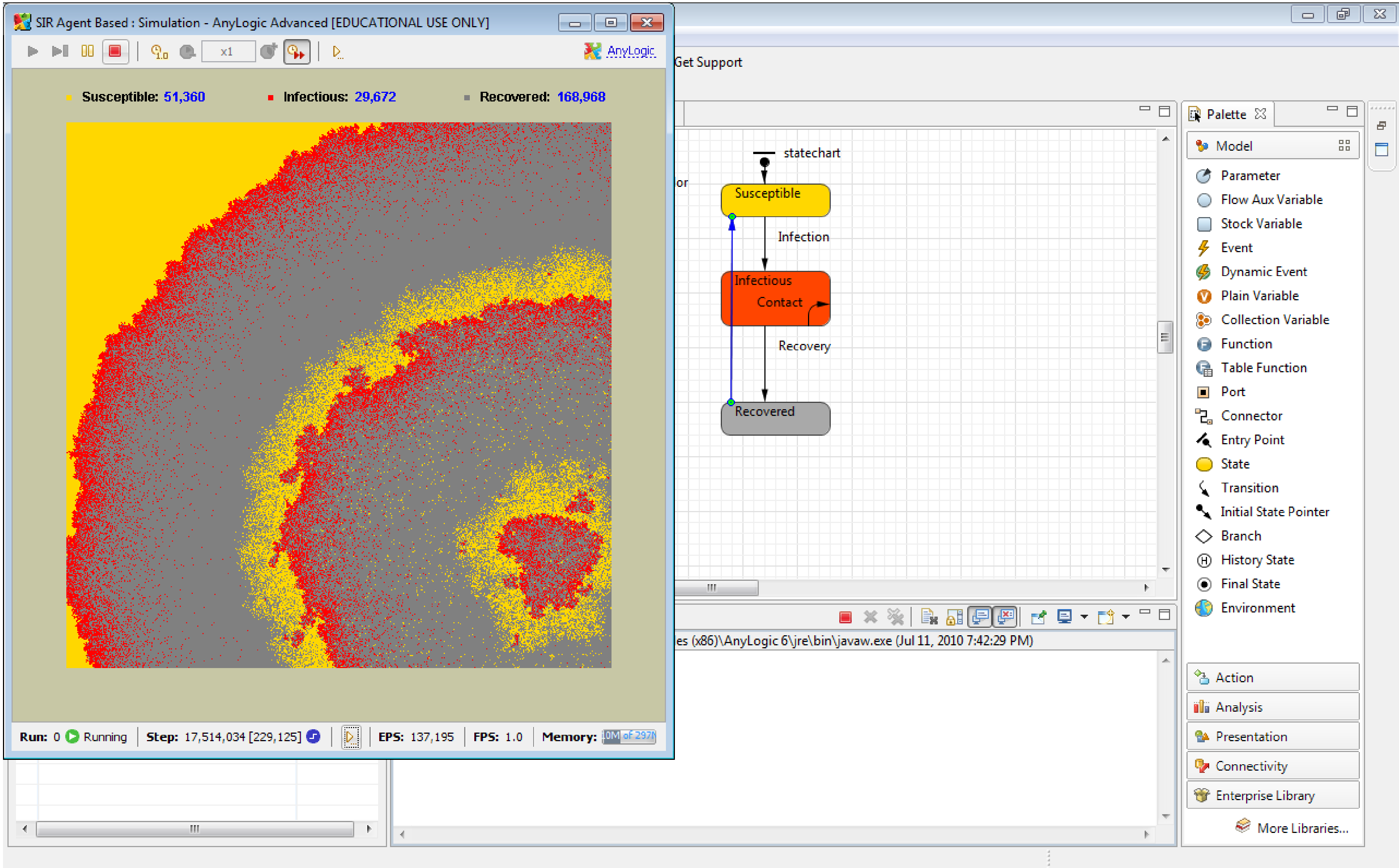


After Starting the Model, You Should See Something Like This.

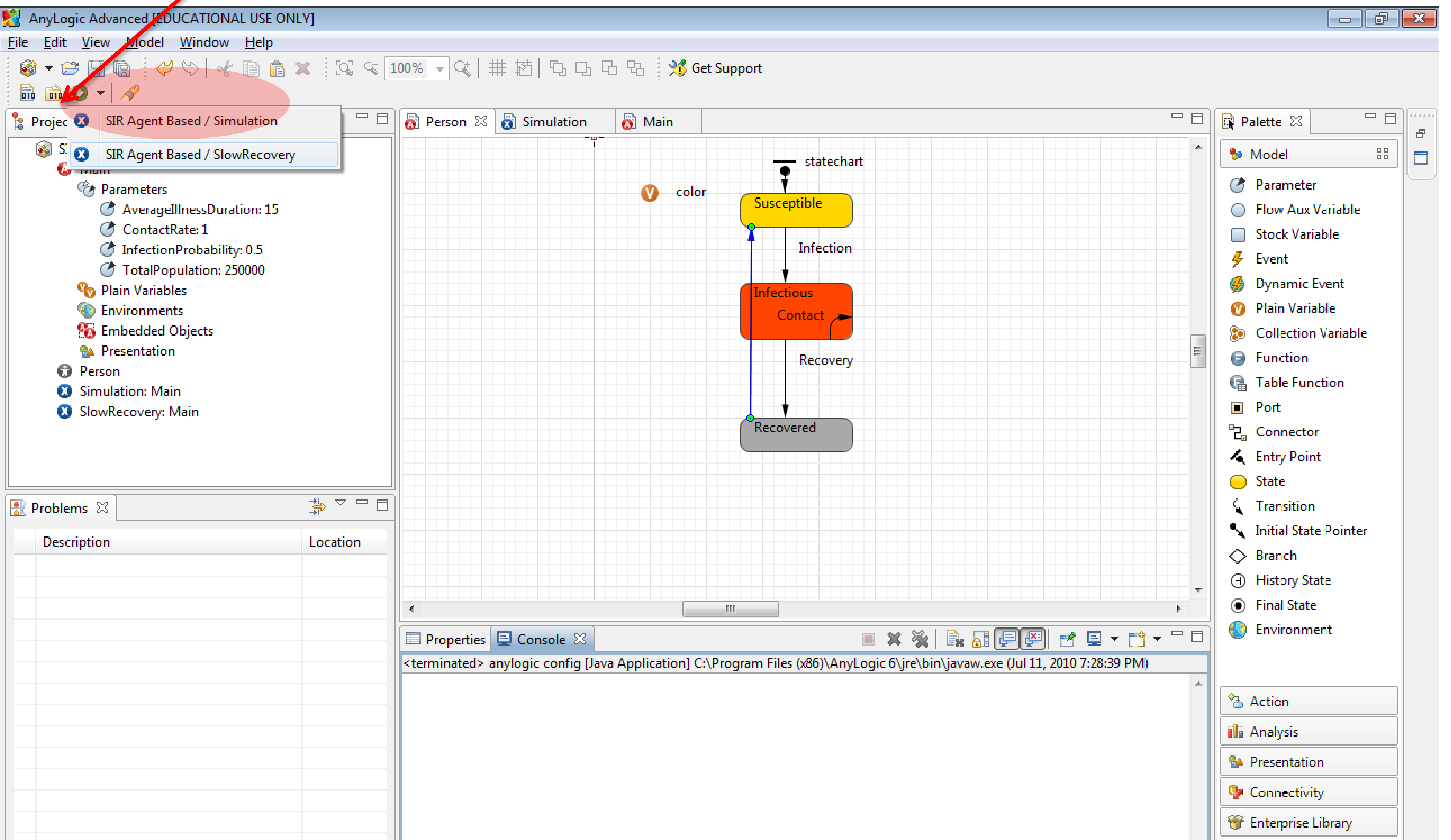
What Happens as Time Progresses?



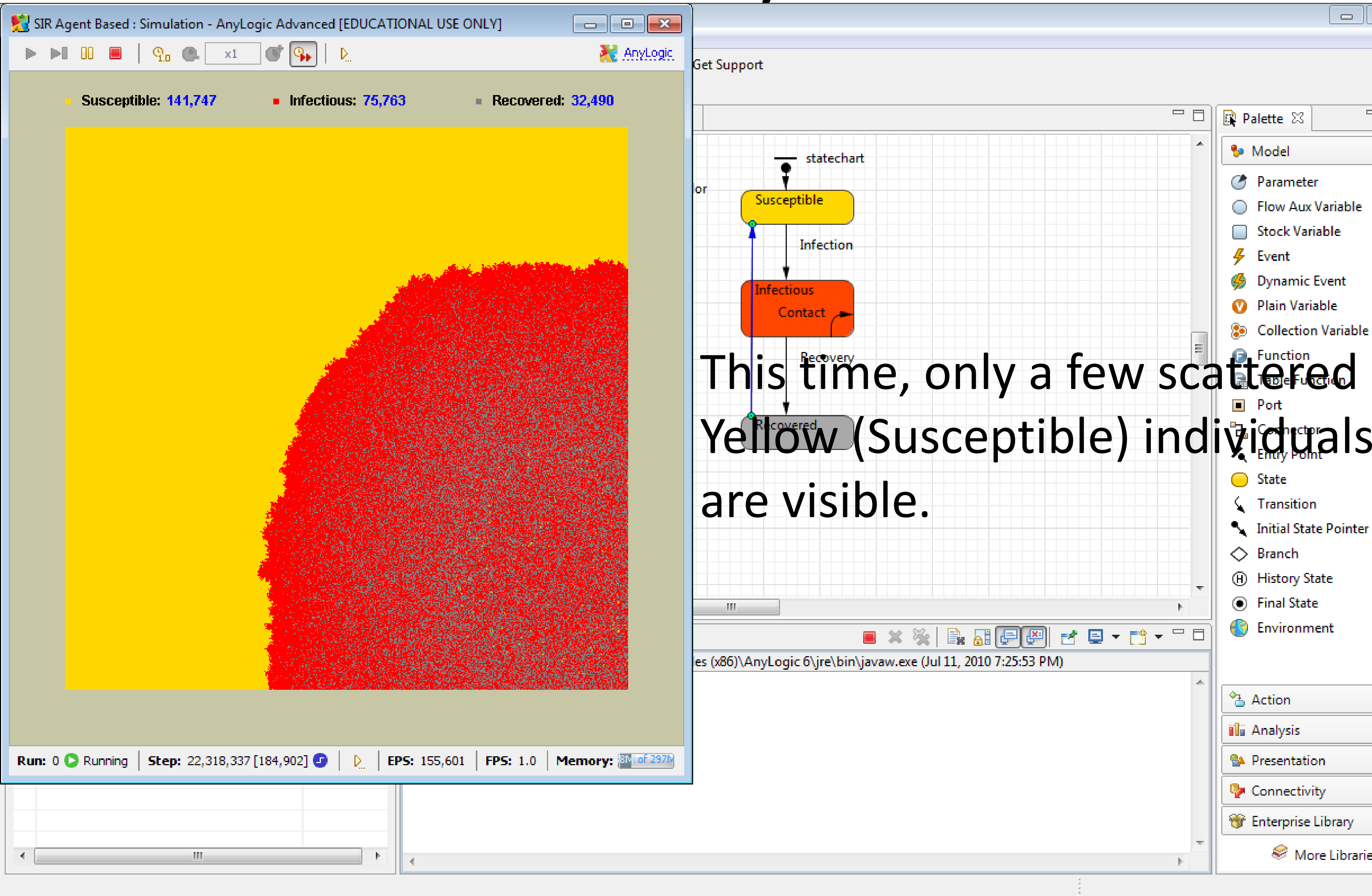
What Happens as Time Progresses?



Use the Run Button & select the “SlowRecovery” Experiment

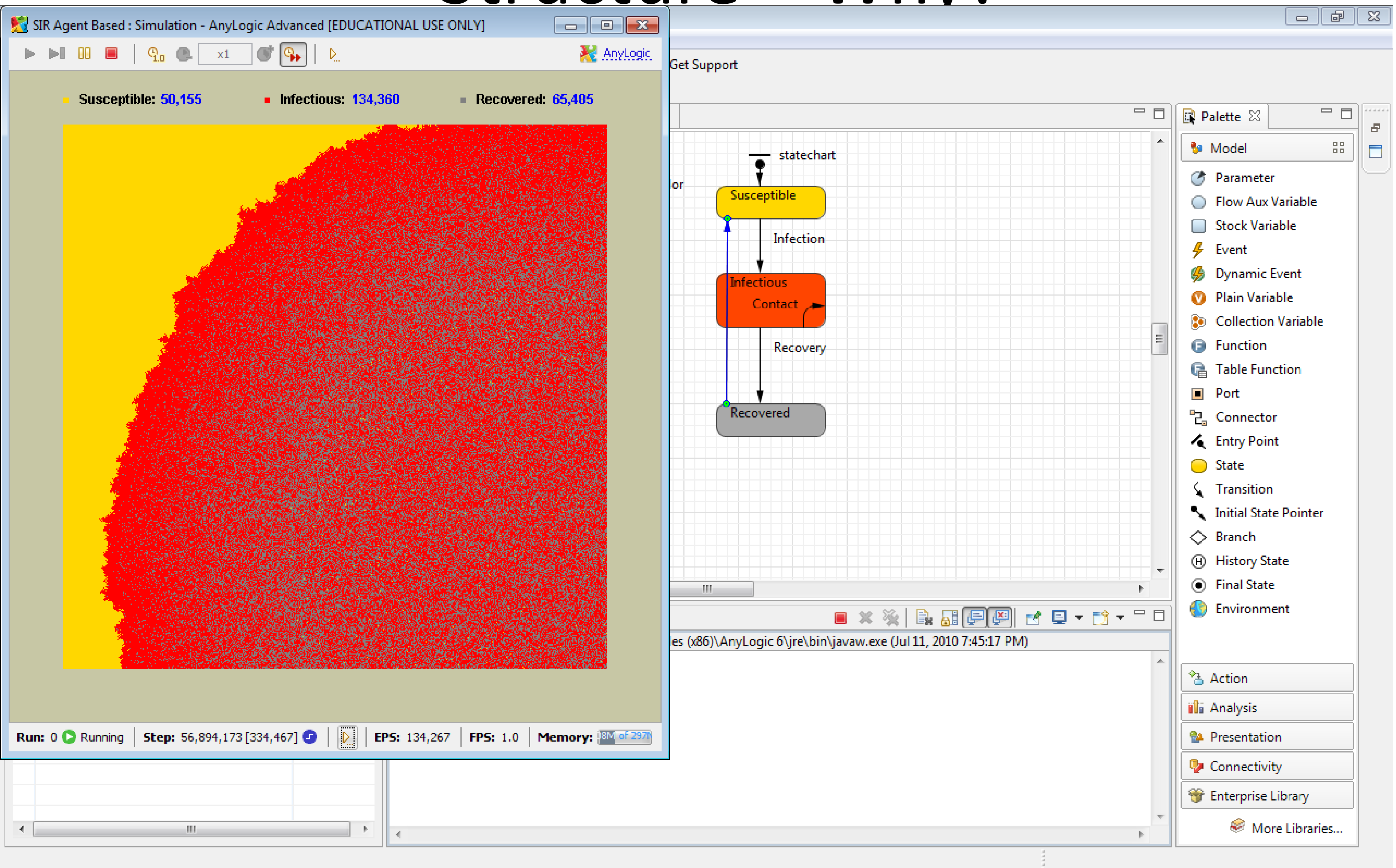


Slow Recovery Results



This time, only a few scattered Yellow (Susceptible) individuals are visible.

As Time Progresses, Little Internal Structure – Why?



Stylized Measurement 2

- How Long Does it Take for The Infection to Reach the Top or Left Boundaries?
- How does this compare with the earlier experiment with a shorter duration of immunity?
- Bonus question: What would an aggregate (random mixing) model have predicted?

Project Possibilities

- Gonorrhea
- CWD
- TB
- Diabetes & ESRD
- HPV & Smoking?
- MRSA
- Smoking