Recall: ABMs: Larger Model Vocabulary & Needs

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

- Consensus protocol derived from panel for ABM modelers
- Primary focus: Specification protocol
  - To help understand, communicate & reproduce ABMs
- Secondary benefit: Process for ABM design
Recall: ODD: 3 Broad Components

- Overview: model goals & high level scope & design
- Design concepts: Different aspects of design being considered
- Remaining elements
ABM Modeling Process Overview

A Key Deliverable!

ODD: Overview & high-level design components

- Problem/research question articulation
- Patterns for explanation
- Model scope/boundary selection (endogenous, exogenous, ignored)
- Key entities & their relationships
  - Agents (&collectives)
  - Environment
  - Nesting hierarchy or network diagrams
- Output of interest

ODD: Design components & details

- State charts
- Parameter & state variables
- Qualitative State charts
- Influence & Causal loop diagrams
- Multi-agent interaction diagrams
- Process flow structure
- Key events
- Rough model time & spatial extent

- Specification of parameters
- Quantitative causal relations
- Decision/behavior rules
  - Transitions
  - Interactions
  - Messaging & handlers
  - Resources
  - Relationship dynamics
  - Mobility dynamics
  - Initial conditions

- Reference mode reproduction
- Matching of intermediate time series
- Matching of observed data points
- Constrain to sensible bounds
- Structural sensitivity analysis

- Parameter sensitivity analysis
- Cross-validation Formal w/Discovered Patterns
- Robustness tests
- Extreme value tests
- Unit checking
- Problem domain tests

- Specification & investigation of intervention scenarios
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- Visualizations
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Knowledge Translation
Learning environments (e.g. DISimS)
Visualizations
ODD Overview: model goals & high level scope & design

• Purpose

• Definition of key elements during operation
  – Entities
  – States (identification of both parameters & formal state)
  – Scales

• Process overview and scheduling (behavior)
ABM Modeling Process Overview

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Model Formulation

• Model formulation elaborates on problem mapping to yield a fully specified, quantitative model

• Key missing ingredients: Specifying unambiguous specification for
  • Statechart transitions
  • Flows (in terms of other variables)
  • Observer processes
  • Intermediate variables
  – Parameter values
Process Interaction & Scheduling

• In addition to specifying the processes in isolation, try to describe process interaction e.g.
  – A transmission process is not triggered until a person is sexually active
  – All reporting takes place at the very end of the day, and is done before resetting reporting counters
  – All agents first note the status of the agents around them, and only then perform updates to location

• Ask yourself on what other processes a given process depends
Concurrency

• Two or more processes may be operating concurrently (“in parallel”)
  – e.g.: Operation of different agents, agents & reporting processes, graphical interface & model
Dependencies: Synchronous vs. Asynchronous

• Suppose process A depends on information produced by process B
  – e.g. depends on knowing something produced via B

• Synchronous processes: Applied sequentially, so that A must wait for B to proceed (e.g. A calls B)

• Asynchronous processes: No “blocking” (waiting) by A for B (e.g. B sends a message to A)
  – In agent-based modeling, most interactions between agents are considered asynchronous => inter-agent communication is accomplished via asynch. messaging
ODD: 3 Broad Components

• Overview: model goals & high level scope & design
• Design concepts: Different aspects of design being considered
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ODD Design Concepts to Consciously Consider

- Origin & character of basic principles underlying model
- Emergence: To what degree are results pre-programmed vs. arising naturally out of a myriad of interactions
- Adaptation: How does system evolution lead to entity behavior change?
- Sensing: What information do entities retrieve from world?
- Objectives: Any goal seeking behavior? How interacts w/state?
- Learning: How does experience drive change in strategies?
- Prediction: How do entities anticipate the future?
- Interaction: How do entities interact directly & indirectly?
- Stochastics: Character of & motivation for stochastic effects
- Observation: What information & associated processes are required for operational use or for testing & confidence bldg
Sensing

- Information sensed from other agents & environments is key to adaptation & decisions
- Need to consider what is sensed
- May want to capture fact that entity perception is
  - Localized (e.g. risk perception, cf decision making with driver’s view of road compared to with perfect knowledge of traffic flows across city)
  - Error prone
  - Delayed
  - This can fundamentally alter dynamics: e.g.
    - Instability: Fragility of “Tit for Tat” to misunderstandings
    - Negative feedback: Sensing to correct driving path
Emergence

• To what degree are the results directly captured by assumptions? (i.e. to what degree are we presupposing what we are trying to demonstrate?)

• One ABM viewpoint: Until we can robustly *generate* a phenomenon, we don’t really understand it

• To what degree do results emerge from complex interaction of other factors where the behavior of interest is never itself described in any way
  – This is ideally what is sought
    • it allows more of a real explanation
    • Permits greater generality (anticipating system behavior under unobserved situations)
  – e.g. waves of infection in spatial SIR model
  – In CWD Model: Clustering of prions along
    • the lakeshore margin
    • High traffic corridors
Emergent Behavior: Spatial/Geographic
A Multi-Level (Dynamic) Model
Adaptation

• How does agent behavior exhibited depend on the
  – Local or global environment
  – Surrounding agents

• To what degree is agent behavior fixed based on
  predefined rules (just playing out to understand
  collective effect of rules themselves) vs. potential for
  emergence associated with inter-agent or agent-
  environment behavioral interaction, which often leads
  to correspondingly richer emergent behavior
  – Note that can still have inter-agent emergence without
    adaptation -- e.g. in an infection spread model. But the
    presence of adaptation means that the feedbacks and
    emergent phenomena can be that much richer
How Does Behavior Depend on Context?

• We have great flexibility in representing agent rules
• Some agents may be consciously objective seeking
• Just reproducing statistical patterns (likelihood changes in tobacco use over time)
  – Limited generality under counter-factuals
• Examples of ways might depend on context
  – Behavior change due to risk perception
  – Moving to a new neighborhood or hunting/gathering ground
  – Remembering insults and changing strategies (e.g. to defect) with respect to a neighbor in a connection matrix
  – By acquiring new memes or information from a neighbor
Incorporating Observed Patterns: 3 Ways

• Building patterns directly into model (likelihood of state transitions, mixing matrix per observations)
  – e.g. Fraction of time spent in different states (foraging, new lake margin, near grain bins)
  – E.g. fraction of time spends with different groups

• Building functional dependence of actions on external conditions into the model
  – E.g. mixing matrix as a function of a preference matrix and current population demographics

• Calibrating or validating to patterns
  – Making patterns emerge from lower-level “mechanics”/ “physics” of model
    • e.g. Contacts (or contact networks) emerge from myriad close-proximity spatial interactions between mobile individuals
Observed Patterns as Emergent

• Ideally, we seek to make patterns emerge from lower-level “mechanics”/“physics” of model
  – e.g. seasonal herd size emerging naturally from grouping rules in CWD model

• With *adaptation*, particularly focusing on dependence of behavioral patterns of an individual on context
  – How do varying circumstances change agent behavior?
Example of Observed Patterns as Emerging from Low-Level Interactions

- Lower food availability => Higher amount of time spent searching for food
- Higher prevalence of Gonorrhea among acquaintances => greater adherence to safer sex practices
- Higher reports of H1N1 infection or vaccination among social contacts => higher chance of getting vaccinated
- Higher risks from diabetes over age as emerging naturally from cumulative damage by glycosylation, etc.
- Greater smoking-related health complaints & sickness in peers with age => Greater likelihood of quitting with age
- Progression of substance abuse caused by underlying organic processes
- Longer infectious period, greater infection severity (peak viremia level), greater transmissibility for individuals with impaired immune functioning emerging from immune repr.
- Higher temperature => greater water seeking
One Kind of Adaptation: Objective Seeking Behavior

• Here, an entity’s behavior will depend on trying to maximize some satisfaction criteria
  – Examples of measures: Profit, Utility
  – Example application: Vehicle simulators using where driving behavior depends on consideration of perceived tradeoffs ($, time, familiarity, etc.) of different routes

• How does this vary based on agent’s state (e.g. access to resources) or environments

• Bounded rationality: For individuals, strong literature suggests that many decisions are based instead on heuristics
Learning: Changing Adaptive Behavioral Rules Based on Experience

• ABMs can support arbitrarily rich learning that may change adaptive behavior
  – Learning from experience in particular healthcare facilities
  – Trust of different parties based on
    • Direct: Treatment received
    • Indirect: Consistency of observations with claims of other party
• In some cases, this is performed using genetic programming (rules mutate and evolve)
• As a longitudinal phenomenon -- one that involves history -- support of learning & memory is a key advantage offered by ABM
Interaction

• Interaction among entities
  – Agent-agent
  – Agent-environment

• Forms
  – Direct: Agents directly interact with neighbors (e.g. via needle sharing or sexual contact)
  – Indirect: e.g. Via shared resource (depletion of vegetation for browsing by other deer, deposit of droplets with shedded pathogen on surface, or air), via risk perception

• How mediated by space & time? (e.g. transmission range of pathogen, seasonal contact dependence?)
Collectives

• Groupings are a common multi-scale feature
  – Herd, Family, Class, Office

• More than the sum of the parts:
  – Can have significant impact on agent perception or behavior
  – Agent may relocate to join new collective

• Common possibilities
  – Purely emergent phenomenon (e.g. herds in CWD example model): Not reified as agent
    • Sometimes epiphenomenal – no influence, but instead something that can be used for understanding & analysis
    • Sometimes has very material impact on system behavior
  – Reification as agent (e.g. hierarchical SIR model, gang)
    • Collective can then have own processes & state (e.g. history)
A Multi-Level (Dynamic) Model
Observer Processes

• With an agent-based model, it is often key to have access to many views of the model in operation
  – These can aid in validation (calibration, confidence building) and verification (testing), interpretation

• The data collected by such observers is typically epiphenomenal – it does not influence the model

• Often there is a significant amount of mechanism & computational effort involved in realizing these

• Detail complexity: significant investment is often further made in visualization interfaces
ODD: 3 Broad Components

• Overview: model goals & high level scope & design
• Design concepts: Different aspects of design being considered
• Details (Remaining elements)
ODD: Remaining Elements

• Initialization
  – Where does initial state come from? Are seeking to make independent of initial state? To test significance of initial state?

• Input data
  – Time series used for model (I think best put in entity specification)

• Submodels: Useful abstractions
  – Helpful to describe early on with broad abstractions (e.g. “partner change”, “go to drink”, “find food”, “stay near mother”
    • Full specification of these are delegated to submodels
  – Seeking low coupling, high cohesion
Sources for Parameter Estimates

- Surveillance data
- Controlled trials
- Outbreak data
- Clinical reports data
- Intervention outcomes studies
- Calibration to historic data
- Expert judgement
- Systematic reviews

<table>
<thead>
<tr>
<th>Parameter*</th>
<th>Description</th>
<th>Baseline value (units)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>Entry/exit of sexual activity</td>
<td>0.0056 (years$^{-1}$)</td>
<td>Garnett and Bowden, 2000</td>
</tr>
<tr>
<td>$c$</td>
<td>Partner change rate per Susceptible</td>
<td>16.08 (years$^{-1}$)</td>
<td>Approximated from Garnett and Bowden, 2000</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Probability of infection per sexual contact</td>
<td>0.70</td>
<td>Garnett and Bowden, 2000</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Fraction of Infectives who are symptomatic</td>
<td>0.20</td>
<td>Garnett and Bowden, 2000</td>
</tr>
<tr>
<td>$1/\gamma$</td>
<td>Latent period</td>
<td>0.038 (years)</td>
<td>Brunham et. al., 2005</td>
</tr>
<tr>
<td>$1/\sigma$</td>
<td>Duration of infection</td>
<td>0.25 (years)</td>
<td>Brunham et. al., 2005</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Asymptomatic recovery coefficient</td>
<td>1.5</td>
<td>Garnett and Bowden, 2000</td>
</tr>
<tr>
<td>$1/\pi$</td>
<td>Duration of naturally-acquired immunity</td>
<td>1 (year)</td>
<td>Approximated from Brunham et. al., 2005</td>
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</tbody>
</table>
These parameters must have constants specified.
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Calibration

• Often we don’t have reliable information on *some* parameters
  – Some parameters may not even be observable!
• Some parameters may implicitly capture a large set of factors not explicitly represented in model
• Often we will calibrate less well known parameters to match observed data
  – “Analytic triangulation”: Often try to match against *many* time series or pieces of data at once
• Sometimes we learn from this that our model structure just can’t produce the patterns!
Calibration: “Triangulating” from Diverse Data Sources

• Calibration involves “tuning” values of less well known parameters to best match observed data
  – Often try to match against many time series or pieces of data at once
  – Idea is trying to get the software to answer the question: “What must these (less known) parameters be in order to explain all these different sources of data I see”

• Observed data can correspond to complex combination of model variables, and exhibit “emergence”

• Frequently we learn from this that our model structure just can’t produce the patterns!
Calibration

• Calibration helps us find a reasonable (specifics for) “dynamic hypothesis” that explains the observed data
  – Not necessarily the truth, but probably a reasonably good guess – at the least, a consistent guess

• Calibration helps us leverage the large amounts of diffuse information we may have at our disposal, but which cannot be used to directly parameterize the model

• Calibration helps us falsify models
Single Model Matches Many Data Sources
Here, we are totalling up across the population
Required Information for Calibration

• Specification of what to match (and how much to care about each attempted match)
  – Involves an “error function” ( “penalty function”, “energy function”) that specifies “how far off we are” for a given run (how good the fit is)
  – Alternative: specify “payoff function” ( “objective function”)

• A statement of what parameters to vary, and over what range to vary them (the “parameter space”)

• Characteristics of desired tuning algorithm
  – Single starting point of search?
Envisioning “Parameter Space”

For each point in this space, there will be a certain “goodness of fit” of the model to the collective data.
Stochastics in Agent-Based Models

• Recall that ABMs typically exhibit significant stochastics
  – Event timing within & outside of agents
  – Inter-agent interactions

• Can have a pronounced impact on system evolution

• Such stochastics can account for observed patterns that are otherwise hard to explain

• When calibrating an ABM, we wish to avoid attributing a good match to a particular set of parameter values simply due to chance

• To reliably assess fit of a given set of parameters, we need to repeatedly run model realizations
  – We can take the mean fit of these realizations
Examples of Stochastics (Compared to Mean Field Deterministic Model)
Example

\[
\begin{align*}
\bar{x}_5 &= \left(1 + \frac{e}{100}\right) \\
\bar{x}_5 &= \sum_{r=1}^{5} \text{payoff}, \\
\bar{x}_3 &= \left(1 - \frac{e}{100}\right) \\
\end{align*}
\]

\[
\begin{align*}
\bar{x}_{10} &= \left(1 + \frac{e}{100}\right) \\
\bar{x}_{10} &= \sum_{r=1}^{10} \text{payoff}, \\
\bar{x}_{10} &= \left(1 - \frac{e}{100}\right) \\
\end{align*}
\]

\[
\begin{align*}
\bar{x}_{40} &= \left(1 + \frac{e}{100}\right) \\
\bar{x}_{40} &= \sum_{r=1}^{40} \text{payoff}, \\
\bar{x}_{40} &= \left(1 - \frac{e}{100}\right) \\
\end{align*}
\]

After 5 replications

After 10 replications

After 40 replications

Terminates

x % (e.g. 80%) confidence Interval for sample mean (average) of replications to this point

Minimum and maximum Observed values from replications

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Minimum and maximum Observed values from replications

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Minimum and maximum Observed values from replications
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**Policy Evaluation**
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Units & Dimensions

• Distance
  – Dimension: Length
  – Units: Meters/Fathoms/Li/Parsecs

• Frequency (Growth Rate, etc.)
  – Dimension: 1/Time
  – Units: 1/Year, 1/sec, etc.

• Fractions
  – Dimension: “Dimensionless” ("Unit", 1)
  – Units: 1
Dimensional Analysis

- DA exploits structure of dimensional quantities to facilitate insight into the external world
- Uses
  - Cross-checking dimensional homogeneity of model
  - Deducing form of conjectured relationship (including showing independence of particular factors)
  - Sanity check on validation of closed-form model analysis
  - Checks on simulation results
  - Derivation of scaling laws
- Construction of scale models
- Reducing dimensionality of model calibration, parameter estimation
Uncertainty Analyses

• Same relative or absolute uncertainty in different parameters may have hugely different effect on outcomes or decisions

• Help identify parameters that strongly affect
  – Key model results
  – Choice between policies

• We place more emphasis in parameter estimation into parameters exhibiting high sensitivity
Uncertainty Analysis: Initial Value

• Frequently we don’t know the exact state of the system at a certain point in time
• A very useful type of sensitivity analysis is to vary the initial value of model stocks
• In Vensim, this can be accomplished by
  – Indicating a parameter name within the “initial value” area for a stock
  – Varying the parameter value
Robustness Analysis

• To what degree are model conclusions robust under changing model structural and other large assumptions?
  – Distinguish cases where
    • Results depends on something essential about the model
    • Results depend on happenstance of simplifying assumptions
      – e.g. spatial neighborhood assumption, size or granularity of space, convenient assumptions regarding rules or what is known

• We want to rule out cases where getting “right result for wrong reasons”!

• Seek to find whether conclusions change radically when just a few assumptions are changed?

• Process is similar to what used for submodel testing, but done for entire model
Imposing a Probability Distribution
Monte Carlo Analysis

• We feed in probability distributions to reflect our uncertainty about one or more parameters
• The model is run many, many times (realizations)
  – For each realization, the model uses a different draw from those probability distribution
• What emerges is resulting probability distribution for model outputs
Example Resulting Distribution

Empirical Fractiles
Impact on cost of uncertainty regarding mortality and medical costs

Incremental Costs

Static Uncertainty
Dynamic Uncertainty: Stochastic Processes

This is a form of sensitivity analysis, but because we are capturing effects of model stochastics – rather than our lack of knowledge, we don’t term “uncertainty analysis”
Dynamic Uncertainty:
Stochastic Processes
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ODD: Overview & high-level design components

- Problem Conceptualization
- Qualitative Problem Mapping
- Model Formulation
- Model Calibration
- Model Testing
- Policy Evaluation
# Contact Tracing Simulation

*We can make it better!*

**Network type**
- ☐ Random
- ☐ Small world
- ☐ Scale free

**Network Settings**

- **Connect Per Agent**
  - Notes: Connects Per Agent is for Random and Small World Networks

- **Neighbourhood Link Prob**
  - Notes: Link Prob is for Small World Networks

- **ScaleFreeM**
  - Note: ScaleFreeM is for Scale Free Networks

**Parameter Settings**

- Simulation Fraction of RI
- Simulation Fraction of NonRI
- ✓ Enable Database

---

**Contact Tracing Policy Selection**

- ☐ No Contact Tracing Program
- ☐ Contact Tracing With Priority

**Contact Tracing Priority Settings (Weight)**

- ✓ Age Priority
- ✓ Ethnicity Priority
- ✓ RR of Count Priority

**Contact Tracing Targets**

- ☐ Tracing Infectious Active TB Cases ONLY
- ☐ Tracing All Active TB Cases
- ☐ Tracing Infectious Active TB Cases and Primary TB

**Contact Tracing Percentage on Average**

Average Percentage of Contacts to Investigate: 

---

**Scenario Information**

**Description**
Scenario Results (Means)

The graph shows the prevalence of TB infection over time (years) for different scenarios. The x-axis represents time in years, ranging from 0 to 20, and the y-axis represents the prevalence of TB infection, ranging from 0.2 to 0.45.

- **S0** (baseline = No Contact Tracing)
- **S1** (Target = Infectious & Primary TB Lost = 30 to 40%, No Priority Tracing Fraction = 90%)
- **S2** (Target = Infectious & Primary TB Lost = 10%, No Priority Tracing Fraction = 90%)
- **S9** (Target = Infectious TB Lost = 30 to 40%, No Priority Tracing Fraction = 90%)
- **S10** (Target = Infectious TB Lost = 10%, No Priority Tracing Fraction = 90%)

The graph indicates an increasing trend in the prevalence of TB infection over time for all scenarios, with **S0** showing the highest prevalence and **S2** showing the lowest.
## Variability in Results

<table>
<thead>
<tr>
<th>Scenario Id</th>
<th>Cumulative Incident Cases (Active TB)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
</tr>
<tr>
<td>$S_0$</td>
<td>425.633</td>
<td>614</td>
</tr>
<tr>
<td>$S_1$</td>
<td>311.767</td>
<td>429</td>
</tr>
<tr>
<td>$S_2$</td>
<td>279.1</td>
<td>392</td>
</tr>
<tr>
<td>$S_3$</td>
<td>318.667</td>
<td>403</td>
</tr>
<tr>
<td>$S_4$</td>
<td>283</td>
<td>364</td>
</tr>
<tr>
<td>$S_5$</td>
<td>302.233</td>
<td>486</td>
</tr>
<tr>
<td>$S_6$</td>
<td>363.2</td>
<td>508</td>
</tr>
<tr>
<td>$S_7$</td>
<td>291</td>
<td>383</td>
</tr>
<tr>
<td>$S_8$</td>
<td>265.5</td>
<td>400</td>
</tr>
<tr>
<td>$S_9$</td>
<td>315</td>
<td>438</td>
</tr>
<tr>
<td>$S_{10}$</td>
<td>271.6</td>
<td>387</td>
</tr>
</tbody>
</table>
ABM Modeling Process Overview

ODD: Overview & high-level design components

- Problem/research question articulation
- Patterns for explanation
- Model scope/boundary selection (endogenous, exogenous, ignored)
- Key entities & their relationships
  - Agents (&collectives)
  - Environment
  - Nesting hierarchy
- Output of interest

ODD: Design components & details

- State charts
- Parameter & state variables
- Qualitative State charts
- Influence & Causal loop diagrams
- Multi-agent interaction diagrams
- Process flow structure
- Key events

- Specification of:
  - Parameters
  - Quantitative causal relations
  - Decision/behavior rules
  - Transitions
  - Interactions
  - Messaging & handlers
  - Resources
  - Relationship dynamics
  - Mobility dynamics
  - Initial conditions

- Reference mode reproduction
- Matching of intermediate time series
- Matching of observed data points
- Constrain to sensible bounds
- Structural sensitivity analysis

- Model Calibration
- Model Testing
- Policy Evaluation

- Parameter sensitivity analysis
- Cross-validation Formal w/Discovered Patterns
- Robustness tests
- Extreme value tests
- Unit checking
- Problem domain tests

- Specification & investigation of intervention scenarios
- Investigation of hypothetical external conditions
- Cross-scenario comparisons (e.g. CEA)

- Knowledge Translation
- Learning environments (e.g. DISimS)
- Visualizations
Contact Tracing Simulation

We can make it better!

**Network type**
- Random
- Small world
- Scale free

**Network Settings**
- Connect Per Agent
  Notes: Connects Per Agent is for Random and Small World Networks
- Neighbourhood Link Prob
  Notes: Link Prob is for Small World Networks
- ScaleFreeM
  Note: ScaleFreeM is for Scale Free Networks

**Parameter Settings**
- Simulation Fraction of RI
- Simulation Fraction of NonRI
- **Enable Database**

**Contact Tracing Policy Selection**
- No Contact Tracing Program
- Contact Tracing With Priority

**Contact Tracing Priority Settings (Weight)**
- **Age Priority**
- **Ethnicity Priority**
- **RR of Count Priority**

**Contact Tracing Targets**
- Tracing Infectious Active TB Cases ONLY
- Tracing All Active TB Cases
- Tracing Infectious Active TB Cases and Primary TB

**Contact Tracing Percentage on Average**

Average Percentage of Contacts to Investigate: 

**Scenario Information**

Description
Key Take-Home Messages from this Lecture

• Models express dynamic hypotheses about processes underlying observed behavior

• Frequently observed behavior is “emergent” – it is qualitatively different than the behavior of any one piece of the system, or a simple combination of behavior of those pieces

• Models help understanding how diverse pieces of system work together

• ABM focus on agent interactions as the fundamental shapers of dynamics

• Models are specific to purpose