Network Environments in AnyLogic

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Hands on Model Use Ahead

Load your recently created SI model
(provided alternative: MinimalistSIRNetworkABM)
The *Environment* defines both Spatial & Network (Topological) Context.
Network Specification in AnyLogic

• When considering networks in AnyLogic, we specify two somewhat distinct (but coupled) things
  – Network topologies
  – Spatial (and visual) Layouts
Networks & Spatial Layouts

• Distinct node attributes: Location & connections
  – Spatial layouts determine where nodes appear in space (and on the screen!)
  – Network type determines who is connected to who
  – For the most part, these characteristics are determined independently

• Network topologies (connectedness) can be defined either alternative to or in addition to spatial layouts
  – Agents will have spatial locations in either case
Network Types

Select environment
Layout Types
Layout Type

- **Random**: Uniformly distribute X and Y position of nodes
- **Arranged**: Set node locations in a regular fashion (normally in a 2D grid)
- **Ring**: Set node locations in periodically spaced intervals around a ring shape
- **Spring Mass**: Adjust node locations such that node locations that are most tightly connected tend to be closer together
  - (Sets location based on network!)
- **User-Defined**: User can set location (e.g. in initialization code)
Distance Based Networks

• Function: Capturing geographic locality in networks

• Networks may be *discontinuous* (divided into disjoint *components*) when
  – The threshold is small
  – The density of the spaces (nodes per unit area) is too small
Interaction Between Network & Location 1

• For one type of networks (Distanced Based), whether there is a connection between A and B depends on the *distance* between A & B
  – This sets connectivity based on location considerations!
Property for Distance-Based Layout: Distance Threshold
Distance-Based Layout
Property for Distance-Based Layout: Distance Threshold
Purely Local Connections: Ring Lattice

• Purely **local** connectivity
  – Agents arranged in a ring
  – Connections by a given agent to some number of agents on either side of itself in the ring

• Slow propagation of infection (no “short cuts” from one region to other regions)

• NB: Most naturally displayed with “Ring” “Layout type”
Ring Lattice – No Ring Layout
Ring Lattice – Choosing Ring Layout
Ring Lattice Topology – With Ring Layout
Global Connectivity: Poisson Random Networks

• In Poisson random networks (also called “random networks” or “Bernoulli networks”), any pair of nodes (A,B) exhibits the same chance of connection as any other pair of nodes.

• This network type has no preference for any sort of “locality” (topological or spatial).
  – There is no more overlap in the connections of two neighbors than among two arbitrary nodes in the population.
Global Random Mixing: Random Connections

Environment - Environment

General

Space type: Continuous, Discrete, GIS

Advanced

Width: 500
Height: 500
Columns: 500
Rows: 500

Neighborhood type: Euclidean

Layout type: User-defined, Apply on startup

Network: Random, Apply on startup

Connections per agent: 5
Connection range: 100
Neighbor link fraction: 0.95
M: 5
Connections over static Random networks can yield results very similar to what results from continuous, dynamic random mixing in an aggregate model.
With Random Connections
Scale-Free Network

Space type: Continuous
Width: 500
Height: 500
Columns: 500
Rows: 500
Neighborhood type: Euclidean
Layout type: User-defined
Network: Scale free
Connections per agent: 5
Connection range: 100
Neighbor link fraction: 0.95
M: 5

Apply on startup checked
Intuitive Plausibility of Importance of Heterogeneity

• Someone with high # of partners is both
  – More likely to be infected by a partner
  – More likely to pass on the infection to another person

• Via targeted interventions on high contact people, may be able to achieve great “bang for the buck”

• We may see very different infection rates in high contact-rate individuals

• How to modify classic equations to account for heterogeneity? How affects infection spread?
Scale-Free Networks

• A node’s number of connections (a person’s # of contacts) is denoted $k$
• The chance of having $k$ partners is proportional to $k^{-\gamma}$.
• For human sexual networks, $\gamma$ is between 2 and 3.5
  – E.g. if $\gamma=2$, likelihood having 2 partner is proportional to $\frac{1}{4}$, of having 3 is proportional to $1/9$, etc.
Power Law Scaling

• This frequency distribution is a “power law” that exhibits invariance to scale
• Suppose we change our scale ("zoom out") in terms of number of connections (k) by a factor of α
  Cf: \( p(k) = ck^{-\gamma} \)
  \[ p(\alpha k) = c(\alpha k)^{-\gamma} = c\alpha^{-\gamma}k^{-\gamma} = \alpha^{-\gamma}ck^{-\gamma} = dp(k) \]
  In other words, the function \( p(k) \) “looks the same” at any scale – it “zooming out” on the scale of # of connections by factor \( \alpha \) just leads it to be multiplied by a different constant

• We can get power law scaling from many sources; a key source is dimensional structure
• Power law probability distributions have “long tails” compared to e.g. an exponential or normal
The Signature of a Power Law

• Plotting a power law function on a log-log plot will yield a straight line
  – This reflects fact that \( p(k) = ck^{-\gamma} \Rightarrow \log[p(k)] = c - \gamma \log[k] \)
  – So if our axes are \( v = \log[p(k)] \) and \( h = \log[k] \), \( v = c - \gamma h \)

• This relates to the fact that the impact of scaling (scaling) is always the identical (divides the function by the same quantity)
  – e.g. if \( \gamma = 2 \), doubling \( k \) always divides \( p(k) \) by 4 (no matter what \( k \) is!)
    • In other words, no matter how many connections we may have, the fraction of people with this many connections is 4x the fraction with 2x this many connections!
  – e.g. if \( \gamma = 3 \), doubling \( k \) always divides \( p(k) \) by 8
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Scale-Free Network

High degree node

Low degree node
Small World

- Small world networks represent a sort of “weighted combination” of
  - Ring lattice network (purely local connections)
  - Random network (mostly global connections)
  - The “Neighbor link fraction” in AnyLogic dictates what fractions of the connections are to the local neighbors (per ring lattice)

- Beware of the inconsistency in the definition of “Connections per agent” for small world networks
  - Off by a factor of two!
• In a Spring-mass layout, the nodes that are highly connected will tend to be clustered
• Here, we are determining the location based on the connectivity!
Example Network Substructure
General ABM Network Caveats

• In thinking about the effects of & tradeoffs between interventions, need to recognize that networks are emergent phenomena, driven by
  – Mobility patterns
  – Relationship formulation & dissolution

• Many networks are dynamic, but traditional measures rarely yield dynamic high temporal resolution data

• We typically have only partial information on network structure

• Often collected via a non-random sampling process

• Networks specific to definition of “contact”
Example: Contact Tracing Networks

• These are produced by an asymmetric or biased contact tracing protocol
  – Uses definition of contact (e.g. needle-sharing incident, spending >8 hours in past 30 days, past or ongoing sexual relationship)
  – Perform tracing only under certain conditions

• Data at hand is likely collected over a substantial amount of time
  – The network may have changed during this time

• Unclear what this says about the network of the general population
AnyLogic Network Caveats

• Built-in networks are handy for routine tasks, but do not offer much flexibility e.g. preferential attachment, post-construction additions, etc.

• Constructing built-in networks can computationally expensive

• The “M” parameter in a Scale-Free network would not appear to be either classic parameters $\gamma$ nor $m$ (from Barabasi paper)
  – Mean # of connections/person is approximately twice this value
  – Number of connections per individual are often in discrete categories?

• NB: The “Small world” network uses a definition of connections/person inconsistent with those for other networks
  – Off by a factor of 2!
Network Dynamics in AnyLogic

• Observed networks are often dynamic over a wide range of timescales
• These dynamics can be very important to overall system dynamics.
• We can represent switching connections using
  – Removing a connection
  – Adding a new connection

Automatically Wired Connections

• Predefined built-in (i.e. non-user-defined) AnyLogic network types can take care of “wiring in” a new node into an existing network
  – Just call `environment.applyNetwork()` to get the environment to “recalculate” the network – and thereby include the new node.
AnyLogic methods for Adding & Deleting Connections

• `agentA.connectTo(agentB)`
  – Connects `agentA` to `agentB`
  – NB: Connections are assumed to be undirected and symmetric (i.e. if `agentA` is considered to be connected to `agentB`, then `agentB` is considered to be connected to `agentA`)

• `agentA.disconnectFrom(agentB)`
  – Disconnects `agentA` and `agentB` from each other

• For more details and additional methods, see the slides for the *Networks* lecture
Useful Methods for Dealing with Networks

• `agentA.getConnectionsNumber()`
  – Gets count of connections associated with `agentA`

• `agentA.isConnectedTo(agentB)`
  – Return true if `agentA` and `agentB` are connected; false otherwise

• `agent.getConnectedAgent(int index)`
  – Returns the `index`\textsuperscript{th} agent connected to `agentA`. Note: The first person is at index 0 (not index 1!)

• `agent.getConnections()`
  – Returns list (LinkedList\textlt.Agent\textrgt.) of all connections of Agent `agent`. Can loop over this with e.g. a `for` loop