Networks – Structure and Dynamics

Nathaniel Osgood Using Modeling to Prepare for Changing Healthcare Needs Duke-NUS April 16, 2014

Announcements

This Week's Extra Office Hours

 Wednesday 3-5pm
 Friday 2:30-4pm

• Take-Home Exercise for Thursday — Please come to class having tried this



Hands on Model Use Ahead



Load your recently created SI model (provided alternative: MinimalistSIRNetworkABM)

The *Environment* defines both Spatial & Network (Topological) Context

ila Edit View Dezw Madel Taola H	lab	AnyLogic	Professional			- 1	3 ×
	× 🗟 🖓 • 🅸 • 🔳	🛷 🔯 Ϛ 100% 🗸 💡 🕶 🏢	🞦 🕞 🔹 🚫 Get Support				参 🞯
🔓 Projects 🛛 🗖 🗖	👸 Elephant 🛛 👸 Main 🛛					🙀 Palette 🖾	
 Wandering Elephants Elephant Rain Simulation: Main 	rOfElephants (3) makeUpAl (3) makeUpVe (3) placeEleph <	titudes 😚 elephants [] egetation nants 🕞 DisplacementTable	 altitudeToColor vegetationToColor altcolor 	View 80 60 40	Sand 0 20,000	Presentation Image: Presentation<	
Spatial Character	Select the agents you want Select the agents you want Space type: Space dimensions: Width: Height: Z-Height: Layout type: U Stetworktys U Enable steps	to place in the environment: Continuous O Discrete O GIS 500 500 Iser-defined V Apply on startup Iser-defined V Apply on startup		etwork	Charact	eristics	
Vandering Elephants	5	完 № ☆ ↓ ▲	Tir	ne units: days	X=74		

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 whom
 - 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

1 File Edit View Draw Model Tools H	lein			AnyLogic Profession	al				-	ð ×
🎯 - 😂 🗟 🔞 🛛 🞸 🌣 🖓 👘	X 🗟 🔿 • 🅸 •	🔳 🛷 595 95 100	0% ∨ ⊂{ (♥ • # 芯 ⊡ •	🚱 Get Support.					蓉 🞯
File Edit View Draw Model Tools F Projects S Projects S Main © Person © IncubationPeriod100: Main © IncubationPeriod5: Main © Simulation: Main	Help Main X Properties X Properties X Properties X Nain - Agent Typ Rotate vertically as v Columnent for other Select the agents you w Space type: Space type: Space dimensions: Columns: Rows: Width: Height: Neighborhood type: Layout type: Network type: M:	gress rel (along Z-axis) ragents S ant to place in the enviro Continuous O Dis 500 500 500 500 500 500 500 50	O% Q Q elect Q onment: Q screte Q GIS Q Apply on start Apply on start		Set Support.			Palette :	X entation	
	Enable steps	King lattice Small world Scale-free	*							
	5	R X A UL	8.			Time units: days	X=62			

Layout Types

File Edit View Draw Medal Tools Help		
rite cuit view braw model roots riep		(1/4)
🔞 - 😂 🖬 🔞 🛛 🔗 🗠 🖬 🖄 🗙	励 O ▼ 移 ▼ ■ ※ [3] G G 100% V G ♥ ▼ 井 范 ⊡ ▼ 發 Get Support j>	参 🙆
🔋 Projects 🛛 📃 🐻 M	Aain ∞ □	Palette 🛛 🗌 🗖
A strongers of the second	https://www.state.com/st	Presentation III X

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

🛛 Properties 🔀 🗖 P	rogress	
Main - Agent Ty	уре	
 Environment for other 	her agents	^
Select the agents you	u want to place in the environment:	
✓ Oppulation		
Space type:	Continuous O Discrete O GIS	
Space dimensions:		
Width:	500	
Height:	500	
Z-Height:	0	
Layout type:	Random 🗸 Apply on startup	
Network type:	Distance-based V Apply on startup	
Connection range:	50	
		v

Distance-Based Layout



Property for Distance-Based Layout: Distance Threshold

🛛 Properties 🔀 🛛 🖷 P	lrogress	
Main - Agent T	уре	
 Environment for other 	her agents	^
Select the agents you	u want to place in the environment:	
Space type: Space dimensions:	Continuous O Discrete O GIS	
Width:	500	
Height:	500	
Z-Height:	0	
Layout type:	Random 🗸 Apply on startup	
Network type:	Distance-based 🗸 🖌 Apply on startup	
Connection range:	100	
		*

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 (localized 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

🛛 Properties 🔀 🗖 Pr	rogress	2 - 0
Main - Agent Ty	уре	
Environment for oth	ier agents	^
Select the agents you	want to place in the environment:	
🗹 😚 population		
Space type:	© Continuous ○ Discrete ○ GIS	
Space dimensions:		
Width:	500	
Height:	500	
Z-Height:	0	
Layout type:	Ring Apply on startup	
Network type:	Random Arranged Apply on startup	
Connection range:	Spring mass	
_		~

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

🗖 Properties 🛛 🖷 Prog	ress	2 - 0
🔁 Main - Agent Typ	e	
Select the agents you wa	ant to place in the environment:	^
🗹 😚 population		
Space type:	Continuous O Discrete O GIS	
Space dimensions:		
Width:	500	
Height:	500	
Z-Height:	0	
Layout type:	Random V Apply on startup	
Network type:	Random V Apply on startup	
Connections per agent:	5	
Enable steps		
w Advanced Inve		

Connections over static Random networks can yield results very similar to what re: from continuous, dynamic random mixing in an aggregate model



With Random Connections



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!

Scale-Free Network

🗆 Properties 🔀 🗖	Progress	
🔁 Main - Agent	Туре	
Space type:	Continuous O Discrete O GIS	^
Space dimensions:		
Width:	500	
Height:	500	
Z-Height:	0	
Layout type:	Random 🗸 Apply on startup	
Network type:	Scale-free V Apply on startup	
M:	5	
Enable steps		
 Advanced Java 		
Imports section:		
		V

Intuitive Plausibility of Importance of Heterogeneity

- Someone with high # of partners is both
 - More likely to be infected by a partners
 - 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
- Chance of having k partners is proportional to $k^{-\gamma}$.
- For human sexual networks, γ is between 2 and 3.5
 - E.g. if γ=2, likelihood having 2 partner is proportional to
 ¼, of having 3 is proportional to 1/9, etc.
- We will discuss scale free networks in a separate set of lecture slides

Recall: Power Law Scaling & Log-Log Graphs

- y=x^a
- log y = a log x
- If x is negative, have something like



Scale-Free Network



Interaction Between Network & Location 2

- 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 γ 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



Hashemian, M., Stanley, K., and Osgood, N. 2010. Flunet: Automated tracking of contacts during flu season. Proceedings of the 6th International workshop on Wireless Network Measurements (WiNMee 2010), 557-562, 6pp.

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*th agent connected to agentA. Note: The first person is at index 0 (not index 1!)
- agent.getConnections()
 - Returns list (LinkedList<Agent>) of all connections of Agent *agent*. Can loop over this with e.g. a *for* loop