NME

Network Modeling for Epidemics

1

Connectivity in networks

Cross-sectional (static) and Longitudinal

Connectivity thresholds
Reachable paths

How concurrency affects all of these

Why detailed partnership patterns matter

- The connectivity of the transmission network determines how an epidemic spreads

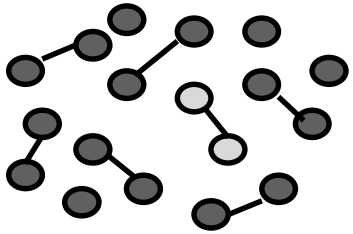
- In two ways
  - Cross-sectionally (at a moment in time)
  - Longitudinally

- And you can get connectivity even in very sparse* networks
  - With the right partnership patterns

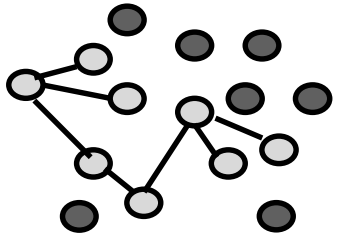
* In graph theory, a network is defined as "sparse" if tie density is less then 50%. What we mean by very sparse is profoundly lower density.

Concurrency and cross-sectional connectivity

A unique *cross-sectional* network signature:



monogamy

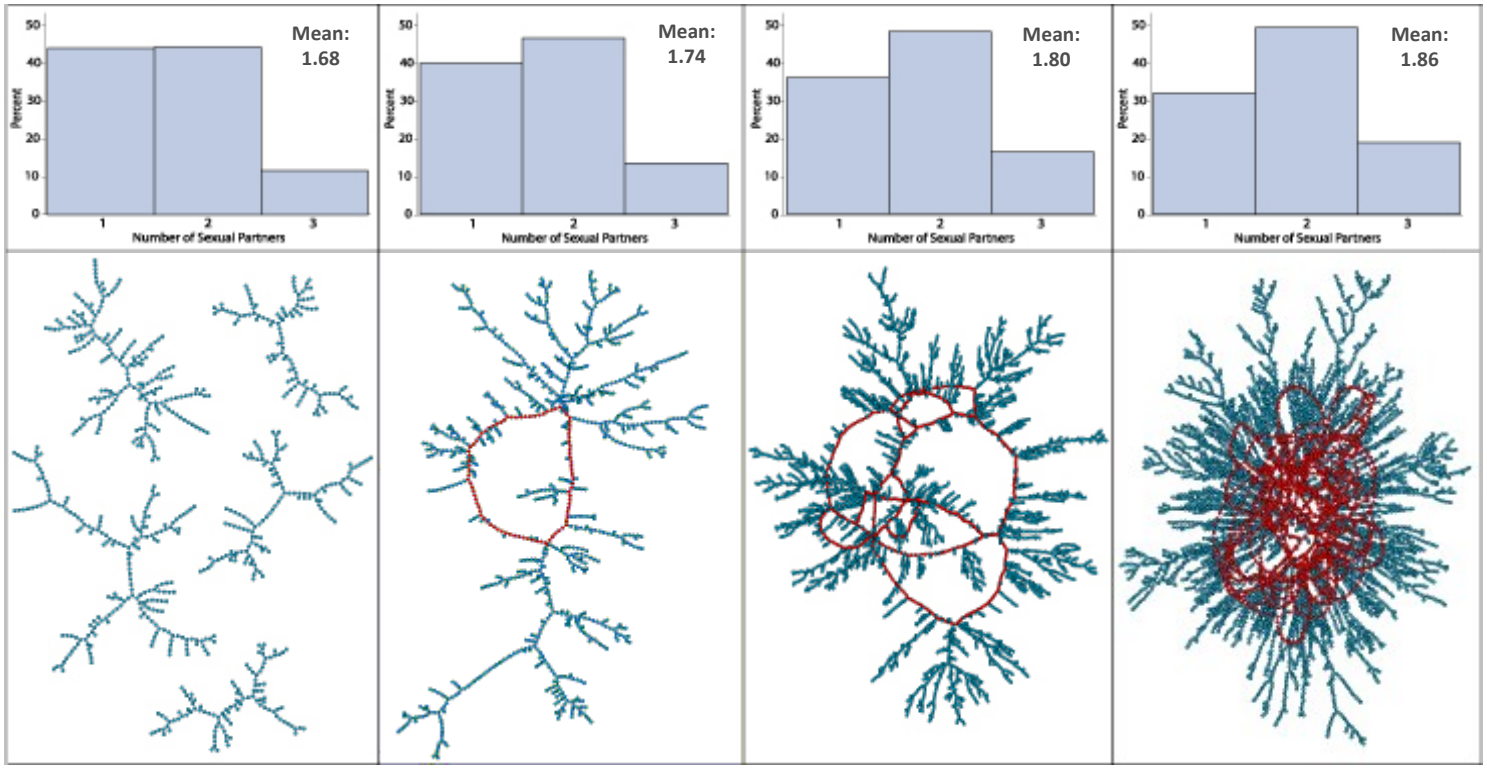


concurrency

Note: even with p(transmission=1), and an SI epidemic, there would be no spread in this network unless partnerships are dynamic

Concurrency and the connectivity threshold

Number of ongoing partners on any particular day



Largest components

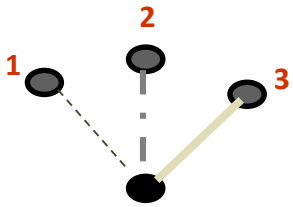
Bicomponents in red

In largest component:	**2%**	**10%**	**41%**	**64%**
In largest bicomponent:	**0**	**1%**	**5%**	**15%**

A difference of 0.2 in the mean degree causes a 60% difference in epidemic potential

Concurrency and longitudinal connectivity

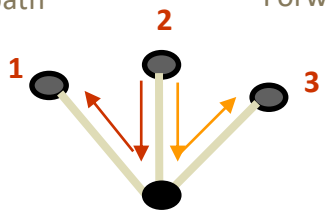
Concurrency removes the protection of sequence over time



monogamy

Backward path

Forward path



concurrency

Backward path: New chain of infection

Forward path: Shorter generation interval

This changes two features of epidemic dynamics:

The reachable path of infection

Epidemic velocity

The reachable path

- The *reachable path* in a dynamic network is
  - Not the partnerships at any single point in time
  - Nor the cumulative total over time

- But the

  cumulative time ordered sequence of partnerships

Can you observe the reachable path?

- In the real world, typically not
  - And not in any standard survey design
- So how can you study it?
  - Via simulation
- We simulated an epidemic over a dynamic network
  - Based on data from the Add Health project
  - An egocentric network study design (see the chapter on Network Study Designs)
  - Of sexual partnerships among a large sample of 18-25 year olds

Cumulative connectivity: a network collapsed over time

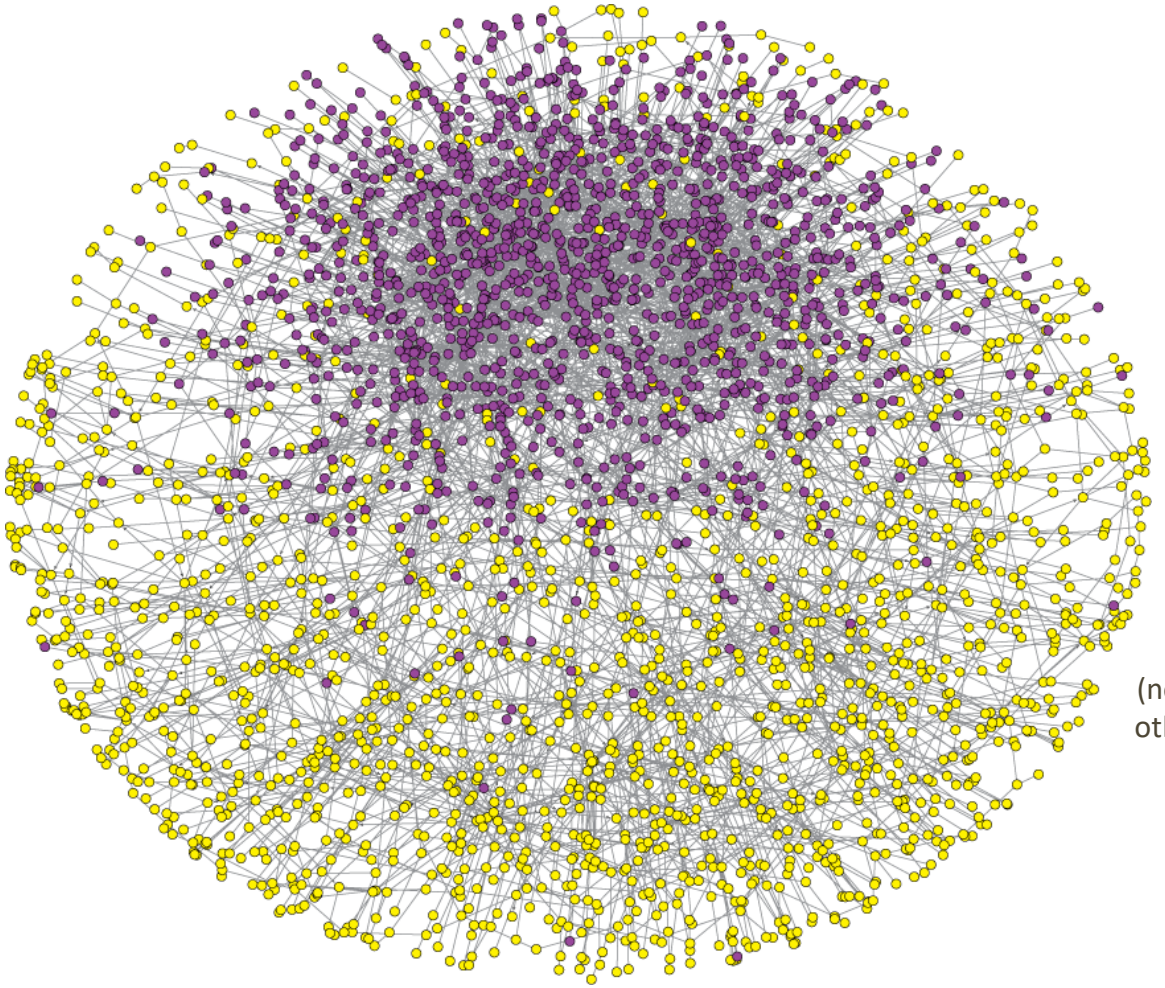
10,000 nodes

2 demographic groups

10 years of partnership activity

Average is 3 partnerships over 10 years

Typical partnership lasts just over 1 year



99.7%

Connected

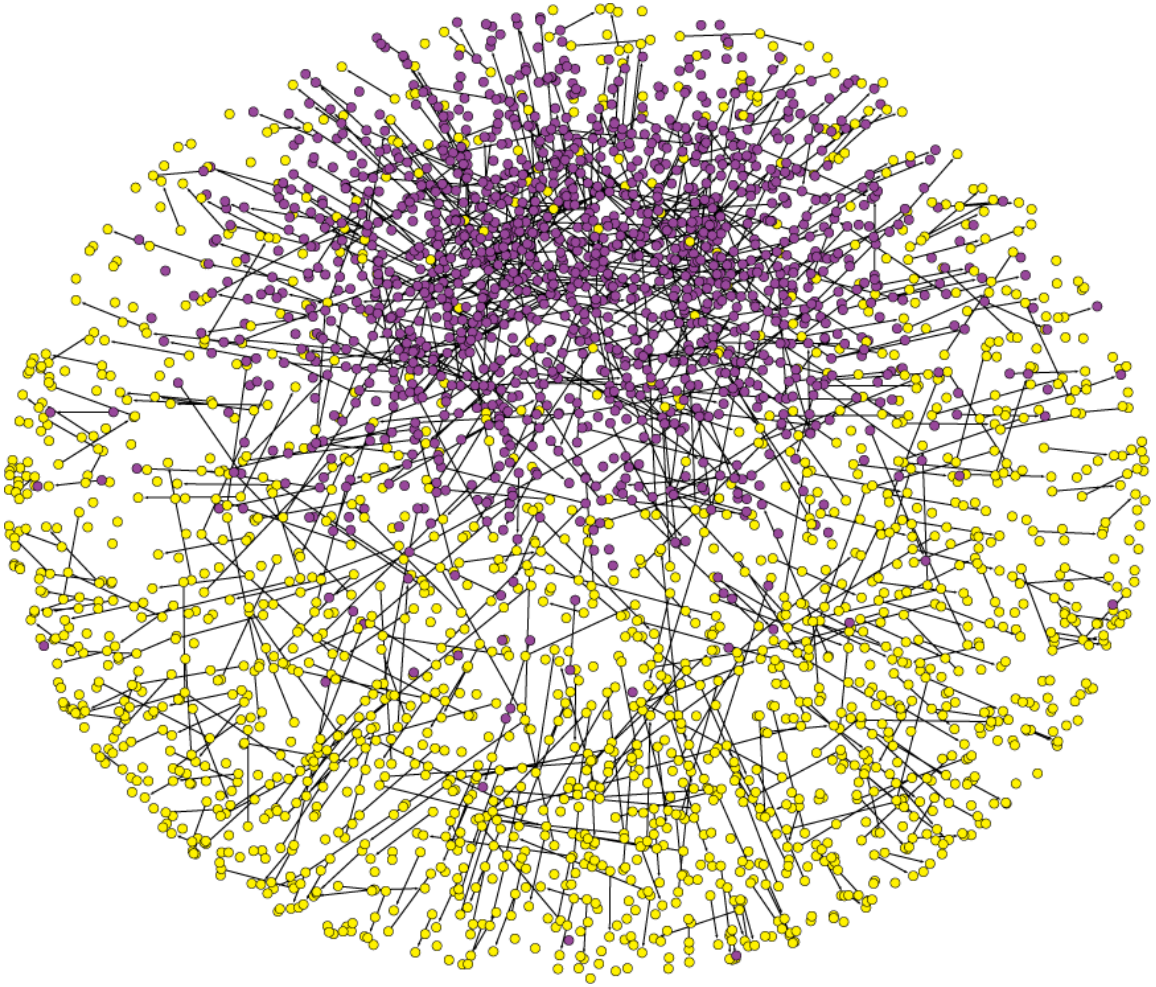
(nodes that can reach each other directly, or indirectly)

People often collapse the time dimension in static visualizations.
This gives a very misleading impression of epidemic potential

Daily connectivity: A momentary snapshot

Almost all components are size 2 or smaller

The largest components have 5-6 nodes



0.06%

connected

If you show just the active ties on the day of the survey,
this also gives a misleading impression of the potential for spread over time

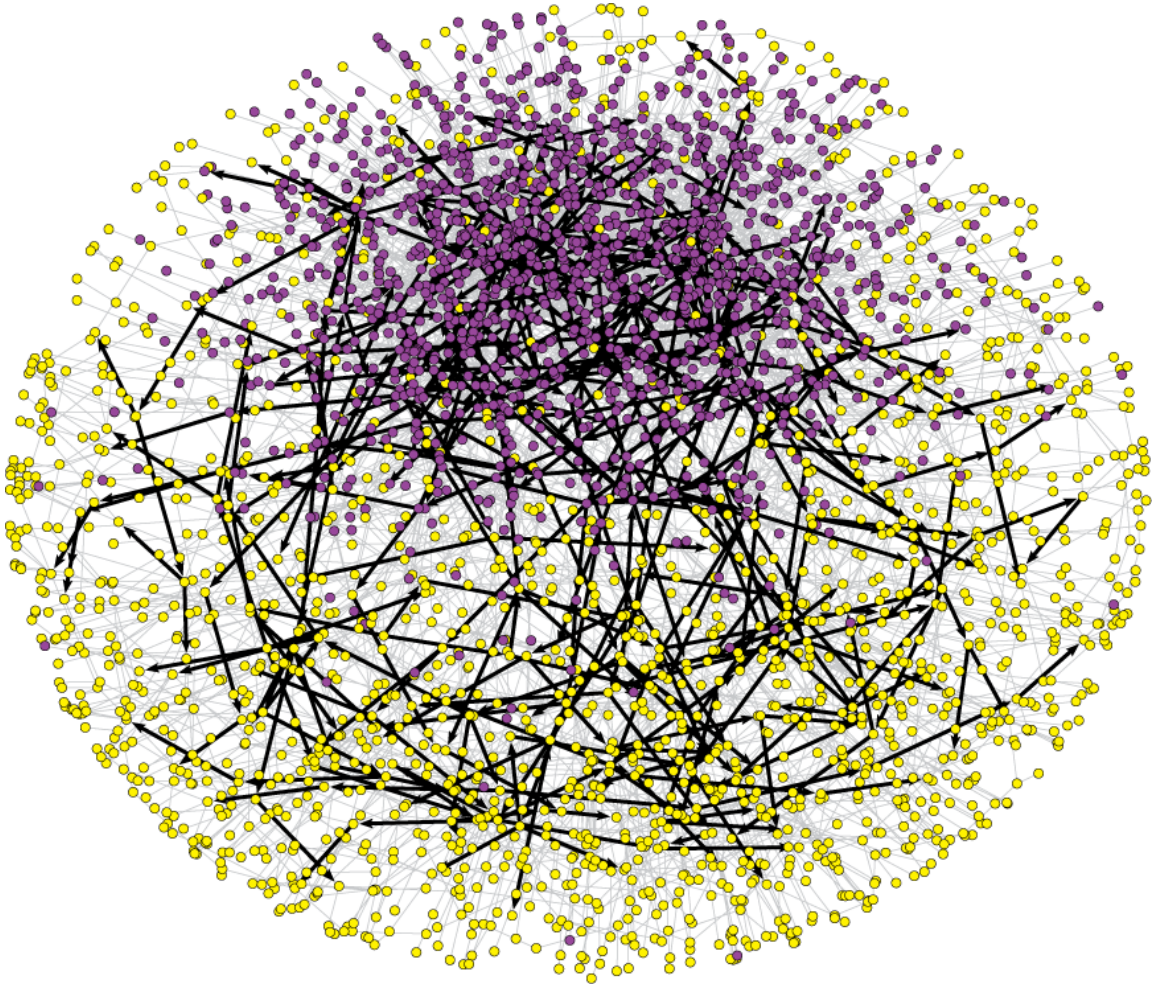
The reachable path: different than both of these

From 10 initial seeds

Trace out:

The cumulative time-ordered path of partnerships

Over 10 years



5.0%

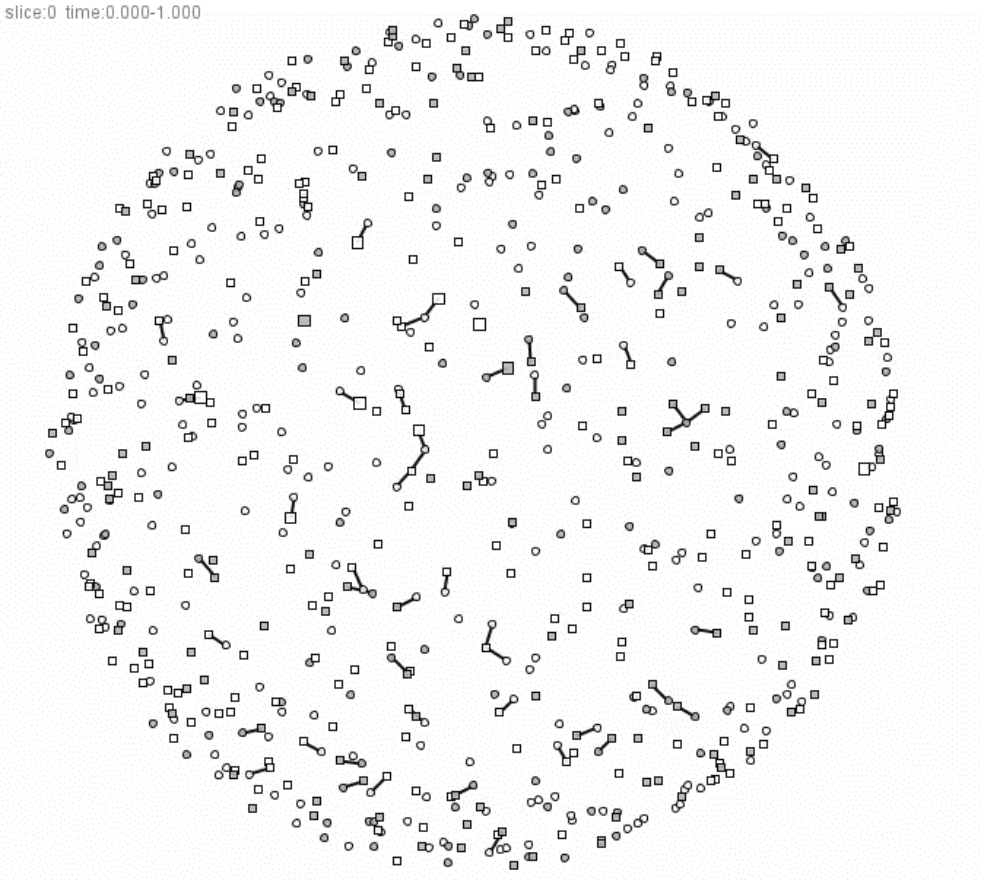
Reachable

The path of potential exposure unfolds over time;
it is not captured by either the momentary or cumulative graph

The best way to visualize this is dynamically

- We have a network movie for this
- You can view it on youtube here
  - The full movie is included in the pptx file on the next slide
  - But the pdf shows just a snapshot from the movie
- And the published paper:

Morris, M., et al., *Concurrent partnerships and HIV prevalence disparities by race: Linking science and public health practice. Amer J Pub Health, 2009.* ***99(6): p. 1023 - 1031.***



Track the growth of the forward reachable path (FRP)

- Original network: 10,000 nodes
- Focus here on the ~600 that end up in the FRP
- 10 initial seeds (slightly larger squares)
- Tie color indicates:
  - BLUE: join FRP when dyad is mutually monogamous
  - RED: join FRP when at least one node has concurrent partner
  - BLACK: active tie, but dyad not in FRP yet

Only **5%** of ties are ever concurrent

But these account for **> 50%** of the FRP

Movie online at:
https://www.youtube.com/watch?v=r3LYA5kirjA&t=214s

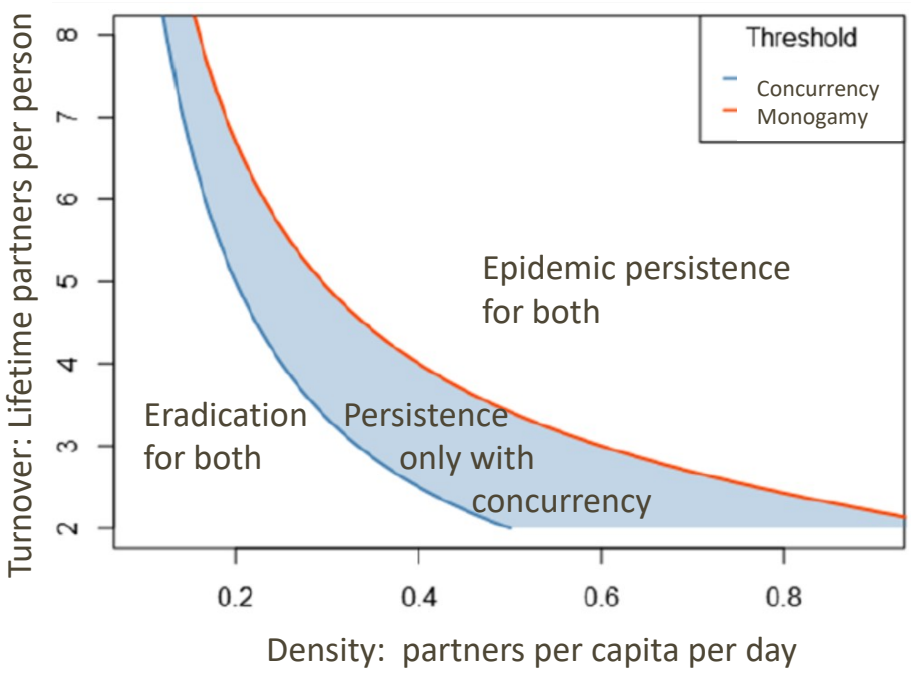
Cross-sectional + Longitudinal connectivity

- This is what gives concurrency such a powerful impact on transmission potential

- Especially in very sparse networks
  - In many real world populations, the p(tie) is too low to support persistent transmission if the ties were just randomly distributed

  - … But epidemic persistence is still observed
  - Due to the systematic structure in the tie distribution

Concurrency and epidemic persistence



- Epidemic persistence is a function of both static and temporal connectivity
  - **Density**: partners per capita on any day
  - **Turnover**: partners per capita over the lifetime
- Concurrency = more connectivity
  - Lowers the threshold for persistence
  - For the same values of density and turnover
- So there is a region where epidemics persist only if there is concurrency

Armbruster et al. (2017)