Modeling Epidemics on Multi-Layer Networks

Network Modeling for Epidemics

Definition and Motivation

- Multi-layer networks are used to represent different *types* of edges in the same underlying model population
- Same node set, different edge set
- Flexibility in handling different types of relations that may vary in both formation and dissolution model
- General example for social contacts:
  - Family network in a household
    - High mean degree, complex age mixing, long persistence
  - Community network
    - Low mean degree, less complex mixing, short persistence

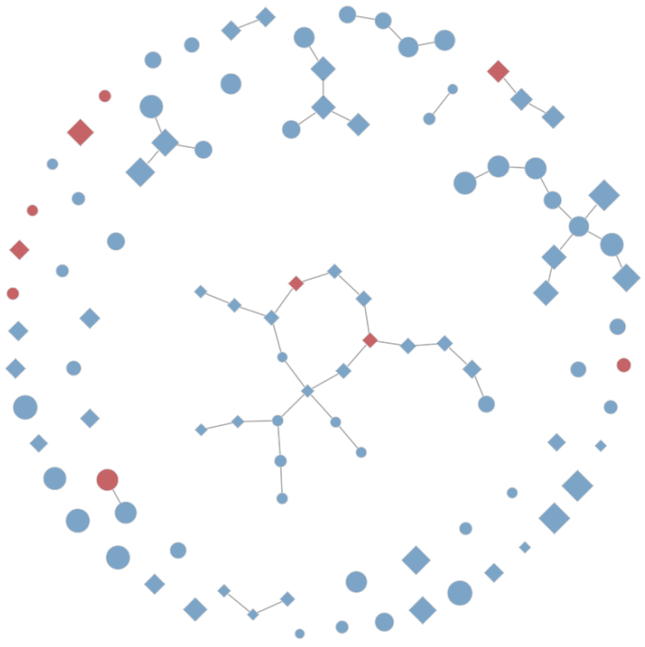
How Do Network Layers Interact?

- Network layers may be modeled independently…
- Or there may be interactions across layers:
  - Number of school contacts negatively correlated with number of work contacts
  - Number of main partners negatively correlated with number of casual partners
- Interactions can be modeled with degree in one layer as a model term in another layer
  - These cross-layer degrees can change over time and thus the network resimulations can (and should) adapt

HIV Model Example

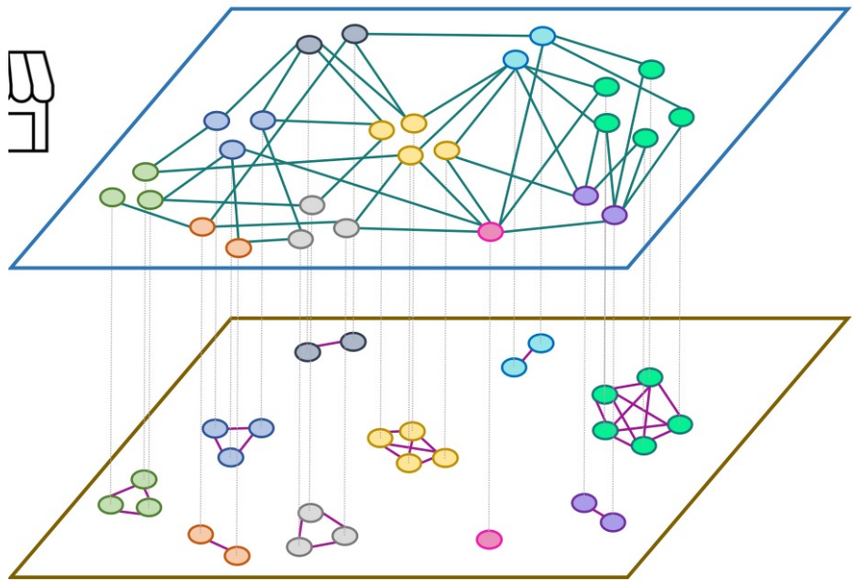
- Jenness SM, Johnson JA, Hoover KW, Smith DK, Delaney K. Modeling an Integrated HIV Prevention and Care Continuum to Achieve the Ending the HIV Epidemic Goals. *AIDS*. 2020; 34(14): 2103–2113.
  - PDF of paper: http://samueljenness.org/pdf/Jenness-2020-AIDS.pdf
  - EpiModelHIV Code: https://github.com/statnet/EpiModelHIV
  - Model scripts for paper: https://github.com/epimodel/combprev

Multi-Layer Networks for MSM Sexual Partnerships



- Three partnership networks: main, casual, one-time
  - Same node set, different edge set
- Distinguished in both their formation and dissolution model components
  - Formation formula for main network differs from other two
  - Dissolution model varies (substantially) by average duration of partnerships

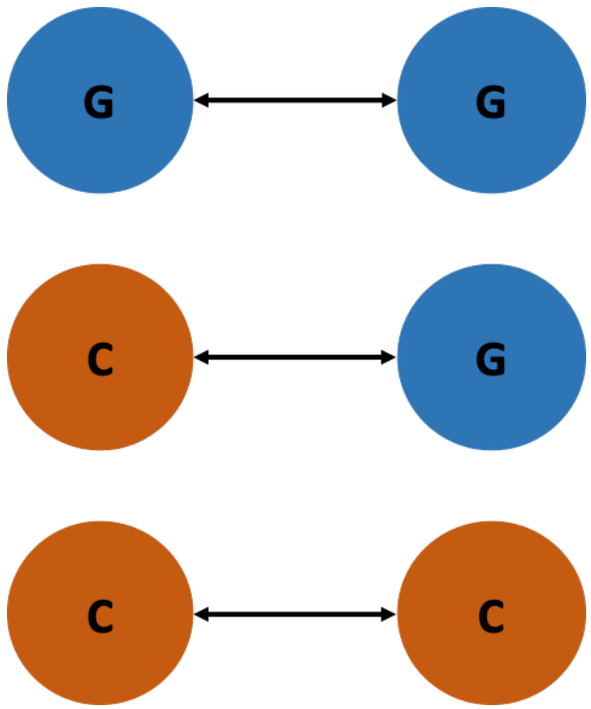
- Formation model for partnerships
  - Heterogeneity and assortative mixing by demographics, degree in other networks, sexual positioning; non-parametric degree distribution terms
- Dissolution model for partnerships
  - Mean duration of partnerships by type and age-group-specific durations (young-young partnerships shorter than old-old partnerships)



COVID Model Example

- Jenness SM, Willebrand KS, Malik AA, Lopman BA, Omer SB. Modeling Dynamic Network Strategies for SARS-CoV-2 Control on a Cruise Ship.
  - Paper: https://epimodel.github.io/sismid/0_nme_prep/pdf/Jenness-Epidemics-COVIDCruise.pdf
  - EpiModelCOVID Code: https://github.com/epimodel/epimodelcovid
  - Model scripts for paper: https://github.com/EpiModel/COVID-CruiseShip

Multi-Layer Dynamic Contact Networks



- Three overlapping ERGMs to represent guest/guest, crew/guest, and crew/crew contacts
- Multi-level structure: guests within cabins, cabins within ship sectors, crew assigned to cabins within sectors
  - x2 ERGMs, for pre-lockdown and post-lockdown network structures
- ERGMs with ship structure allow for repeated contacts with deterministic dissolution
- Scenarios focused on timing of lockdown, design of sectorization, and degree and within-cabin and within-sector mixing constraints given lockdown
  - Control-based strategies: after outbreak has started
  - Prevention-based strategies: informing future ship design

Modeling SARS-CoV-2 in Carceral Settings

Contents lists available at ScienceDirect

Epidemics

journal homepage: www.elsevier.com/locate/epidemics

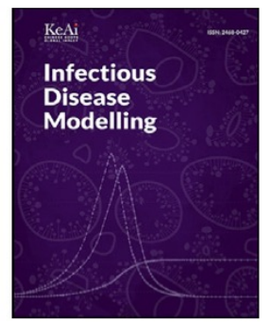
Dynamic contact networks of residents of an urban jail in the era of SARS-CoV-2

Samuel M. Jenness [a,*], Karina Wallrafen-Sam [a], Isaac Schneider [a], Shanika Kennedy [a], Matthew J. Akiyama [b], Anne C. Spaulding [a]

Contents lists available at ScienceDirect

Infectious Disease Modelling

journal homepage: www.keaipublishing.com/idm



Interventions for SARS-CoV-2 prevention among Jailed adults: A network-based modeling analysis

Isaac Schneider [a,*], Karina Wallrafen-Sam [a], Shanika Kennedy [a], Matthew J. Akiyama [b], Anne C. Spaulding [a], Samuel M. Jenness [a]

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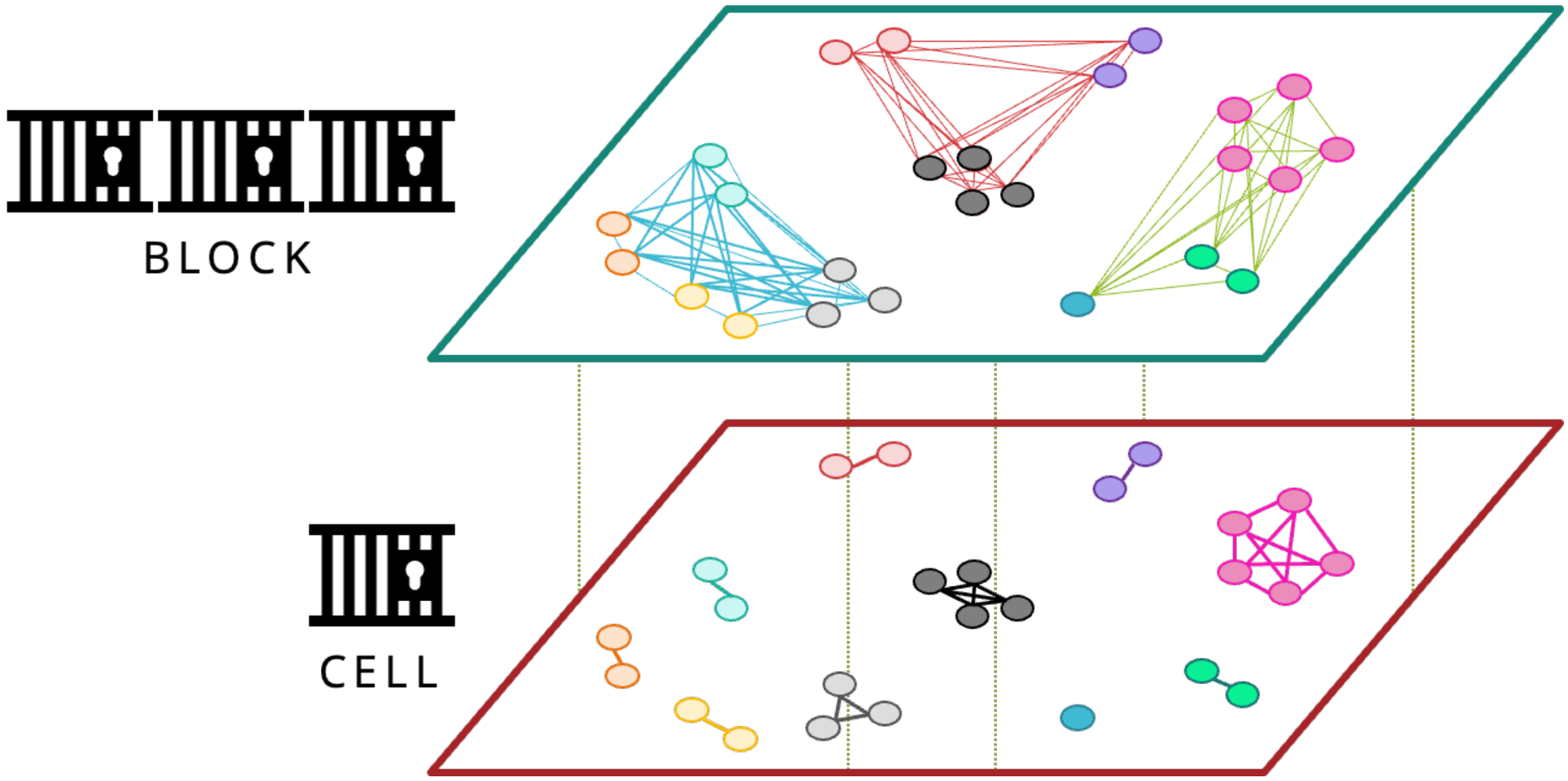
Network of Contacts within Carceral Setting



- Contact networks in cells were assumed to be saturated with strong exposures per time step
- Contact networks in blocks were assumed to be random with weaker exposures per time step

Comprehensive profiling of social mixing patterns in resource poor countries: A mixed methods research protocol

Obianuju Genevieve Aguolu[1]*, Moses Chapa Kiti[2], Kristin Nelson[2], Carol Y. Liu[2], Maria Sundaram[3], Sergio Gramacho[2], Samuel Jenness[2], Alessia Melegaro[4], Charfudin Sacoor[5], Azucena Bardaji[5,6,7], Ivalda Macicame[8], Americo Jose[8], Nilzio Cavele[8], Felizarda Amosse[5], Migdalia Uamba[8], Edgar Jamisse[5], Corssino Tchavana[5], Herberth Giovanni Maldonado Briones[9], Claudia Jarquín[9], María Ajsivinac[9], Lauren Pischel[10], Noureen Ahmed[11], Venkata Raghava Mohan[12], Rajan Srinivasan[12], Prasanna Samuel[12], Gifta John[12], Kye Ellington[2], Orvalho Augusto Joaquim[5], Alana Zelaya[2], Sara Kim[2], Holin Chen[2], Momin Kazi[13], Fauzia Malik[11], Inci Yildirim[10], Benjamin Lopman[2‡], Saad B. Omer[11‡]

- Social contact diary study of contacts rural and urban study sites in India, Pakistan, Mozambique, and Guatemala
- Fills key gap in social contact data for ID modeling in low-and-middle income countries

Cross-Layer Design

- Separate layers for home, school, work, and community contacts
- Home network represented as separated and saturated network subcomponents (no ergm needed)
- Other layers represented with degree distribution and age mixing terms in formation model and distinct mean durations for dissolution model
  - Strong cross-layer effect for school and work layers

Vaccine Prioritization on the GlobalMix India Networks

- Work in progress: a transmission-and-vaccine model built on the GlobalMix India contact networks (rural and urban Tamil Nadu), fit as dynamic TERGMs.
- Four network layers over one shared node set: household, school, work, and non-home (other community contacts).
- Household ties are permanent; the school, work, and non-home layers re-form each day, so a person's momentary degree is recounted daily across all four layers.
- A daily-timestep transmission model for COVID-19, influenza, and RSV runs on top, with age-graded severity and vaccination as a relative risk.
- Question: does prioritizing vaccine by network position (degree across the four layers) beat prioritizing by age?

Preliminary Result: Network Position vs Age

- Targeting the highest-degree people (blue) averts more infections than age in every pathogen and setting; age (red) still averts more elderly deaths, so the objectives trade off.