DAY 1:

MODELING ACTS AND PARTNERSHIPS: the building blocks of the transmission network

NME WORKSHOP 2017

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Objectives

- Delve deeper into how compartmental, agent-based, and network models represent partnership dynamics
    - How are sex partners selected?
    - Can persistent partnerships be represented?
        - How (if at all) is temporal overlap in partnerships represented?
        - How are partnerships dissolved?
    - What are the implications for representation of observed network features and how those features evolve over time?

Compartmental models

- The population is divided into discrete states or “compartments”
- Simplest division: susceptible and infected (SI model)

$$\boxed{\text{Susceptible}} \longrightarrow \boxed{\text{Infected}}$$

$$Incidence(t) = S(t)\frac{I(t)}{N(t)}\alpha\tau$$

Number susceptible

prevalence

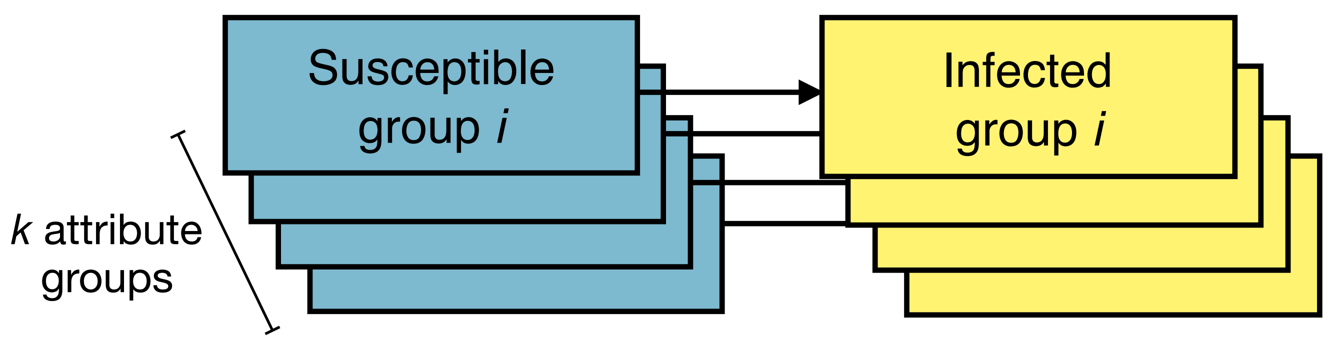
act rate

transmission probability
per S-I act

- In this simple model:
  - Partner selection: **random**
  - Persistent partnerships: **no**

Compartmental models

- Representing patterns of selective sexual mixing
  - Define mixing matrices for discrete attributes (e.g. race, sex, disease state, marital status, sexual activity class)



$$Incidence_i(t) = S_i(t)\sum_{j=1}^{k}\frac{I_j(t)}{N(t)}\alpha_{ij}\tau_{ij}$$

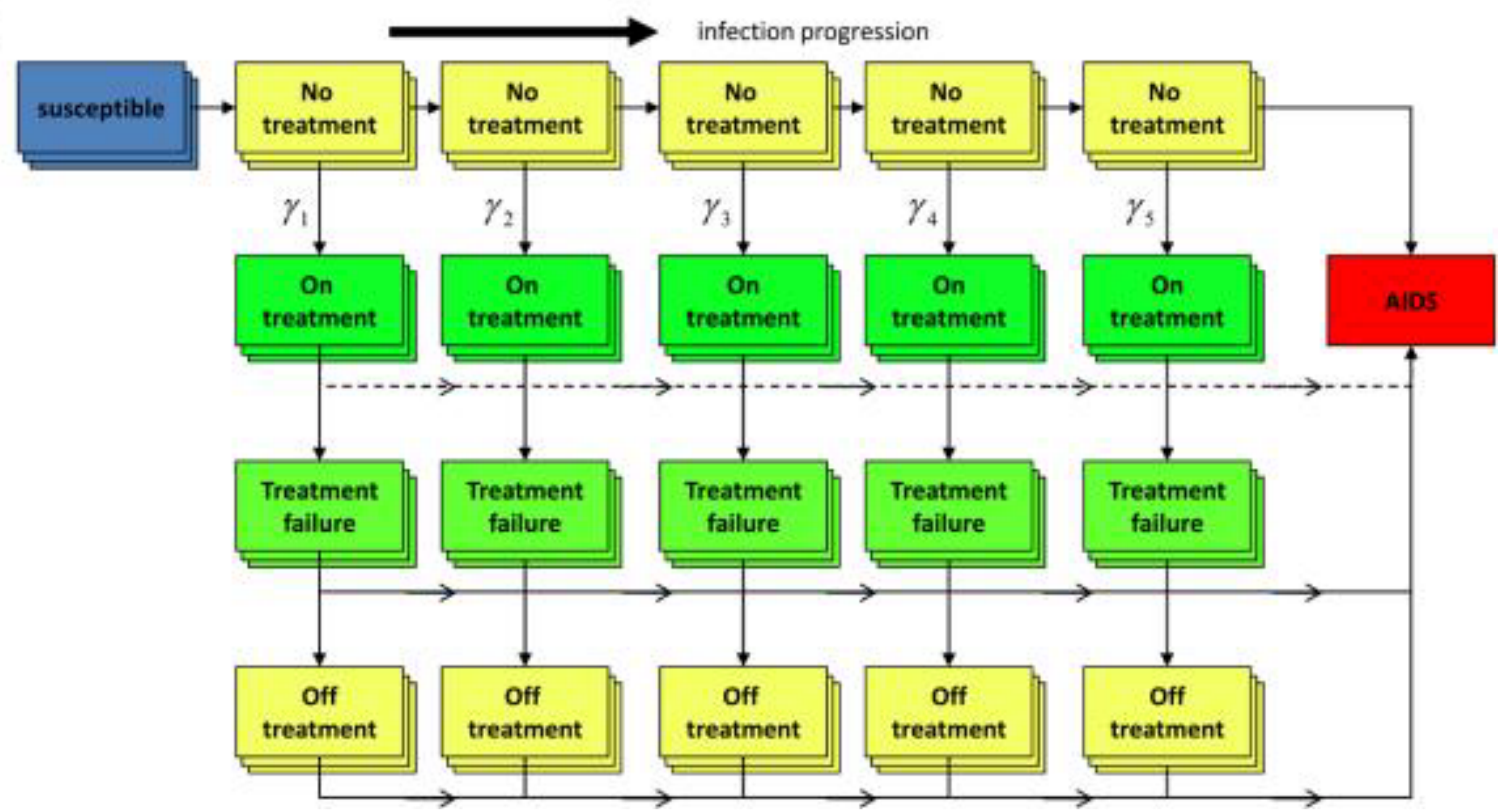
Number susceptible of group *i*

prevalence of infected persons of group j

propensity for acts between *i* and *j*

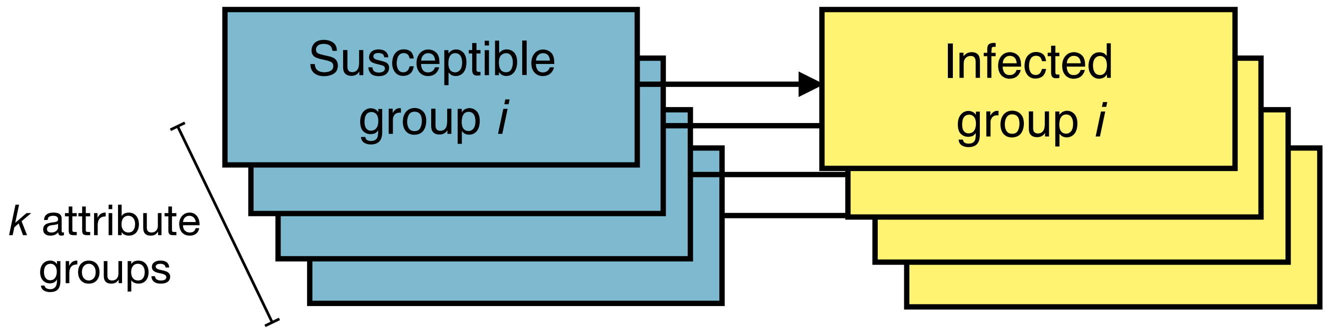
transmission probability per S-I act between *i and* j

Compartmental models



Baggaley, R. F., & Fraser, C. (2010). *Curr Opin HIV AIDS,* doi:10.1097/COH.0b013e32833a51b2

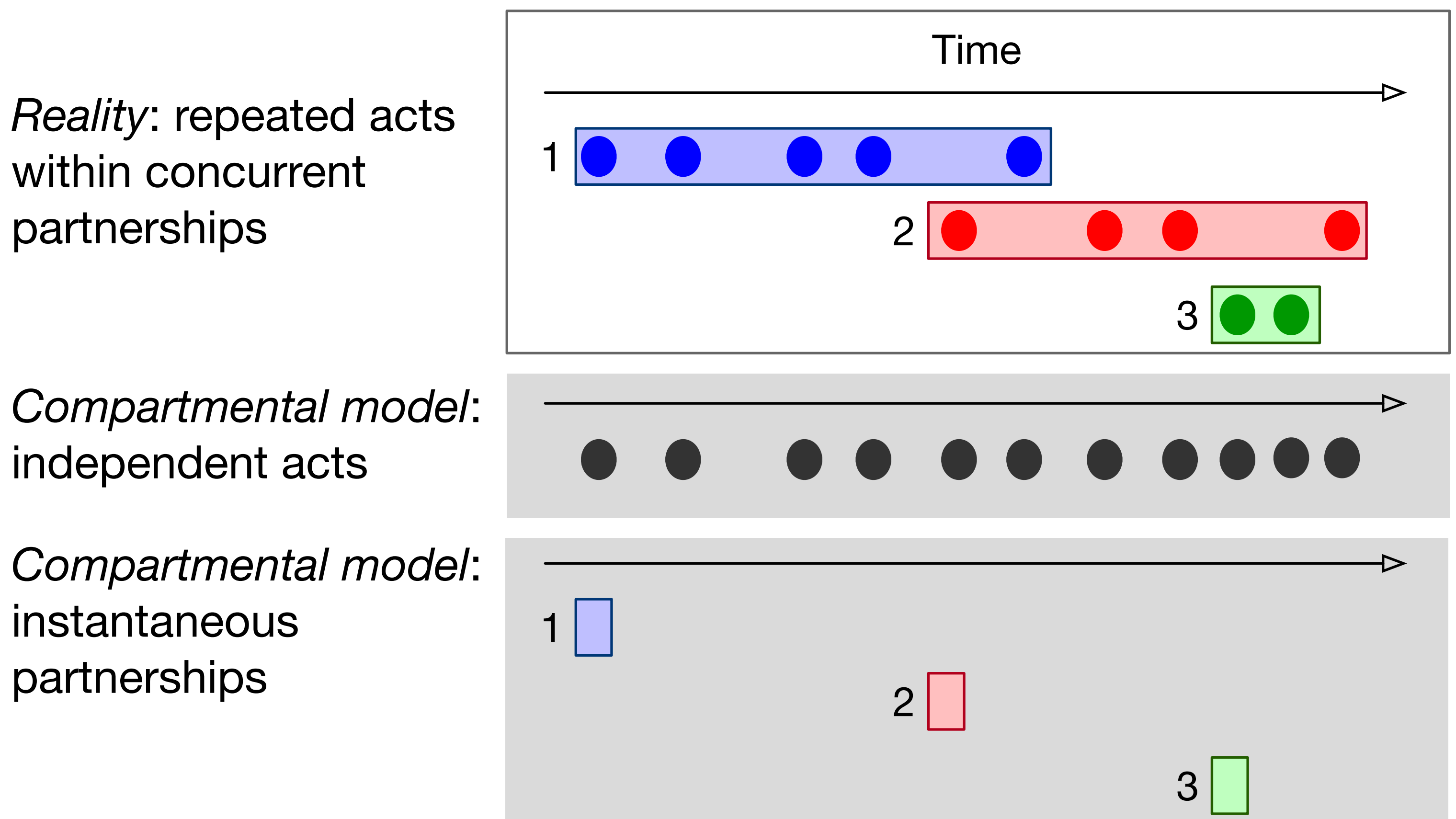
Compartmental models



- In this more complex model:
  - Partner selection: **selective (limited to discrete attributes)**
    - With each additional attribute group, need to define:
      - transitions between states for time-varying attributes (i.e. age, sexual risk group, CD4 count)
      - mixing patterns between each combination of attributes
      - transitions from susceptible to infected states
  - Persistent partnerships: **no**

Compartmental models

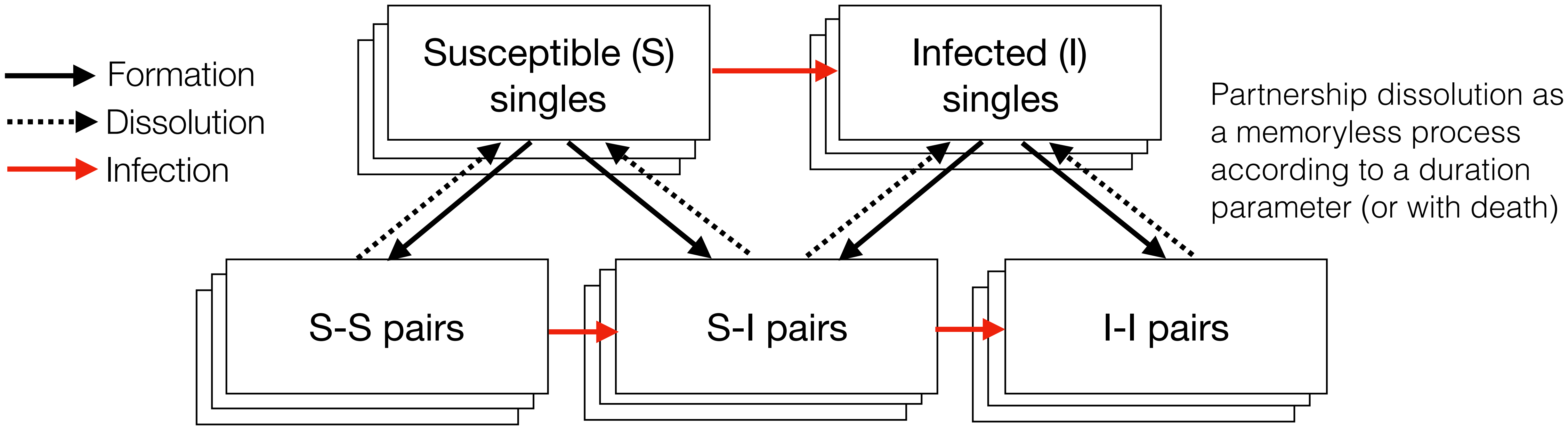
- In the standard compartmental framework, sexual contact is modeled as independent acts or instantaneous partnerships



- Neither approach captures temporal overlap in partnerships (concurrency) or multiple acts within partnerships

Pair formation models

- States are defined for each partnership configuration

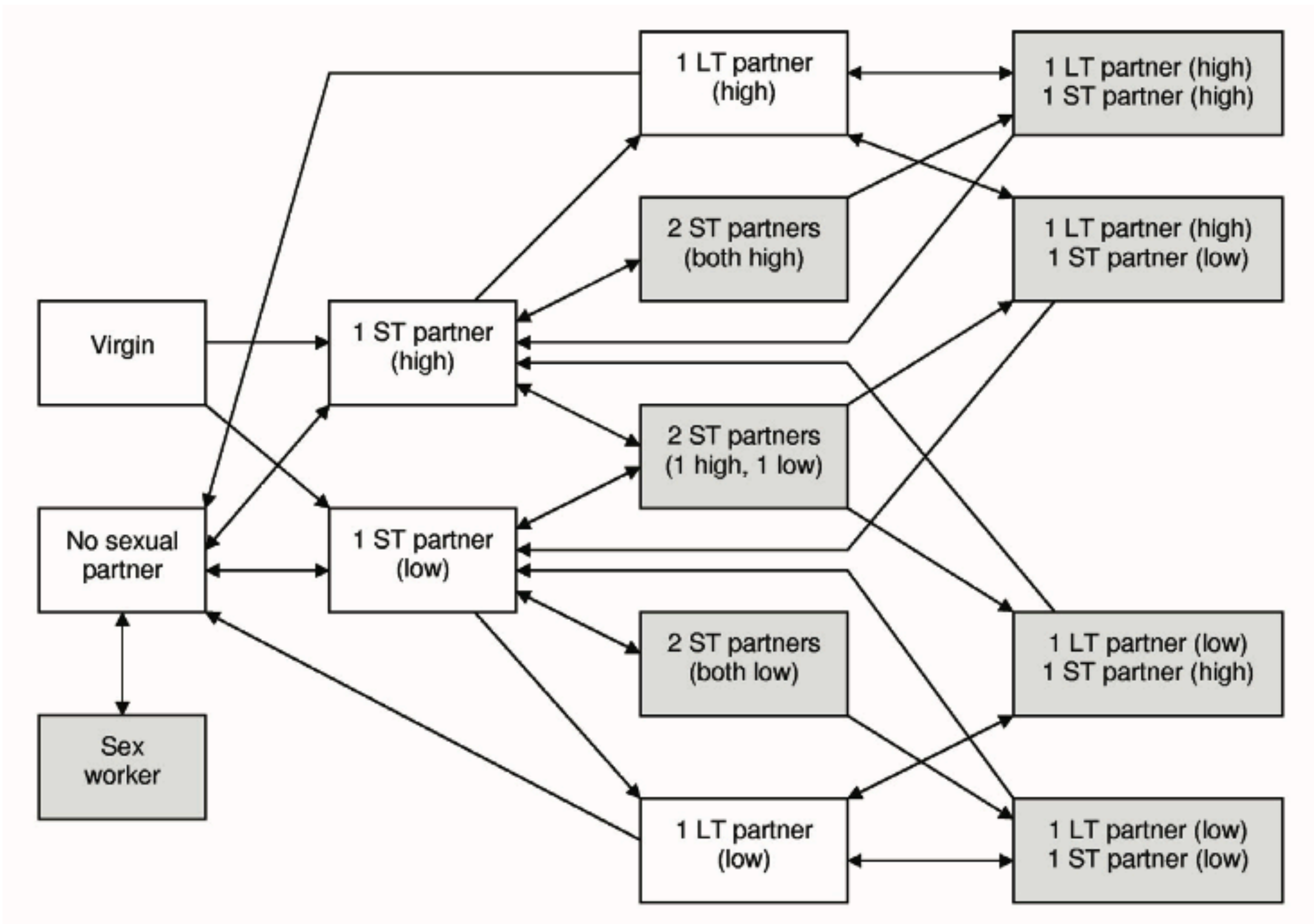


Adapted from Kretzschmar, M. (2000). *Sex Transm Dis, 27*(10), 627-635
and Powers K.A. et al. (2011). *Lancet, 378*(9787), 256-68

- In this model:
  - Partner selection: **random** **or** **selective**
  - Persistent partnerships: **yes**
  - Overlapping persistent partnerships: **no**

Example: Johnson et al. (2009)

Figure 1: Multi-state model of sexual behaviour of 'high risk' females



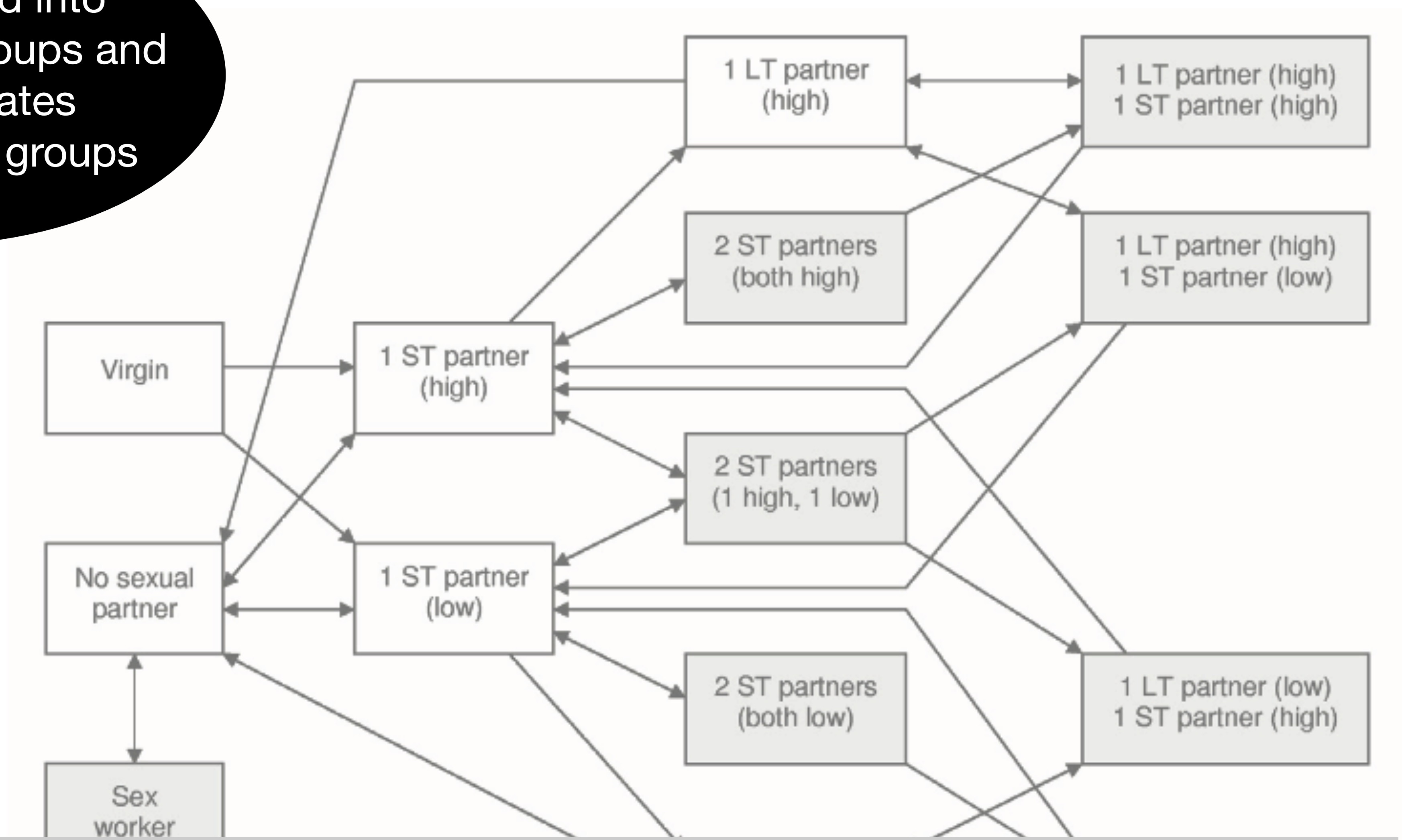
LT = long-term (spousal); ST=short-term (non-spousal)
"High" and "low" refer to the risk group of the sexual partner

Johnson et al. (2009)

Example: Johnson et al. (2009)

Further divided into
16 5-year age groups and
6 disease states
k = 96 attribute groups

Multi-state model of sexual behaviour of 'high risk' females



Control over the resulting network statistics (i.e. number of individuals who are single, degree distribution…)? **No**

"High" and "low" refer to the risk group of the sexual partner

Johnson et al. (2009)

Stochastic agent-based models

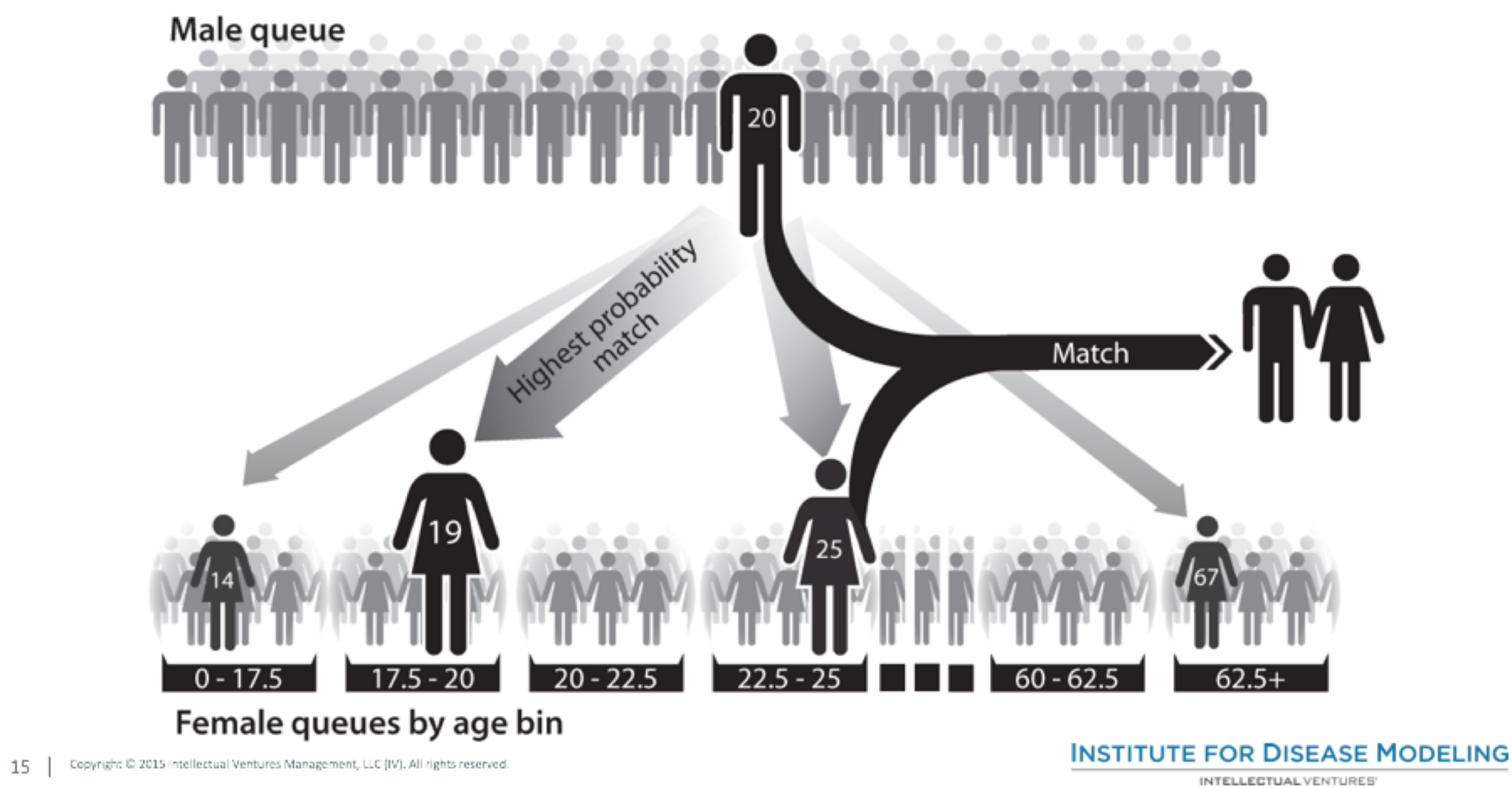
Individuals are explicitly modeled

- Easier to incorporate heterogeneity

Partnership formation and dissolution

- Simple models (*poker chips and lecture 4*):
  - Partner selection: **random**
  - Persistent partnerships: **no**
- Complex models (*more common in the literature)*:
  - Define mixing matrices
  - Calculate each individual's propensity for partnership formation at time *t*
  - Select new partners
  - Update partnership status attribute
  - Simulate acts within partnerships
  - Dissolve partnership according to specified duration parameters, or with death or migration (EMOD-HIV)

Example: EMOD-HIV

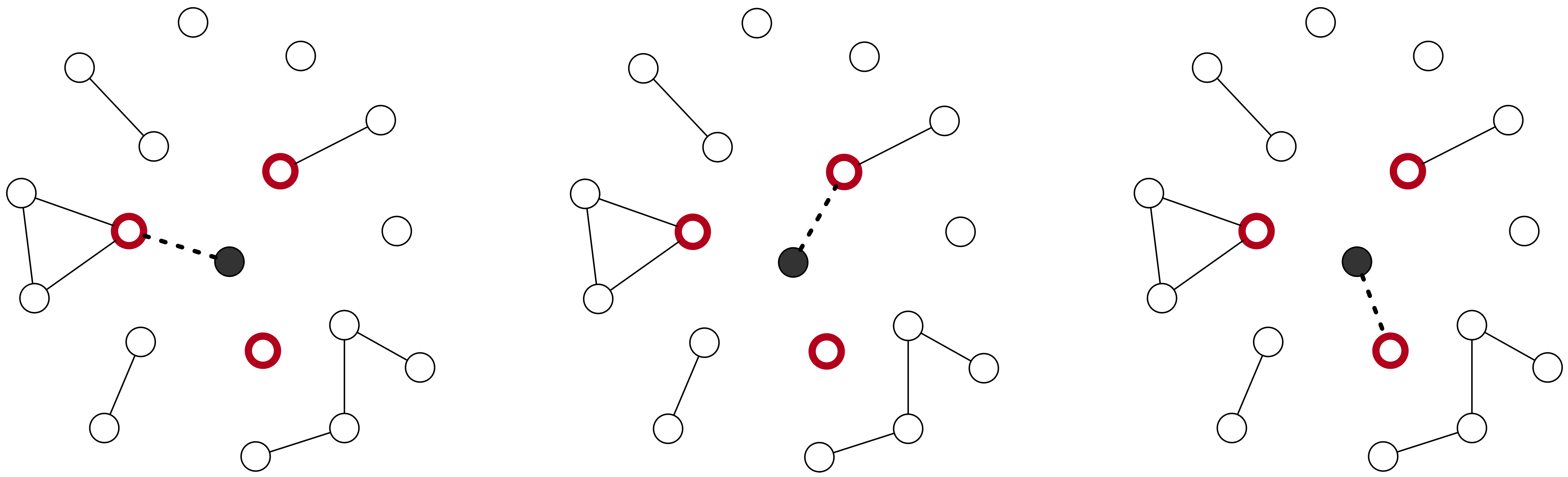


Daniel Klein, lecture in EPI 554 on October 15, 2015

More on EMOD-HIV: https://institutefordiseasemodeling.github.io/EMOD/STI_and_HIV_Tutorials.pdf

Stochastic agent-based models

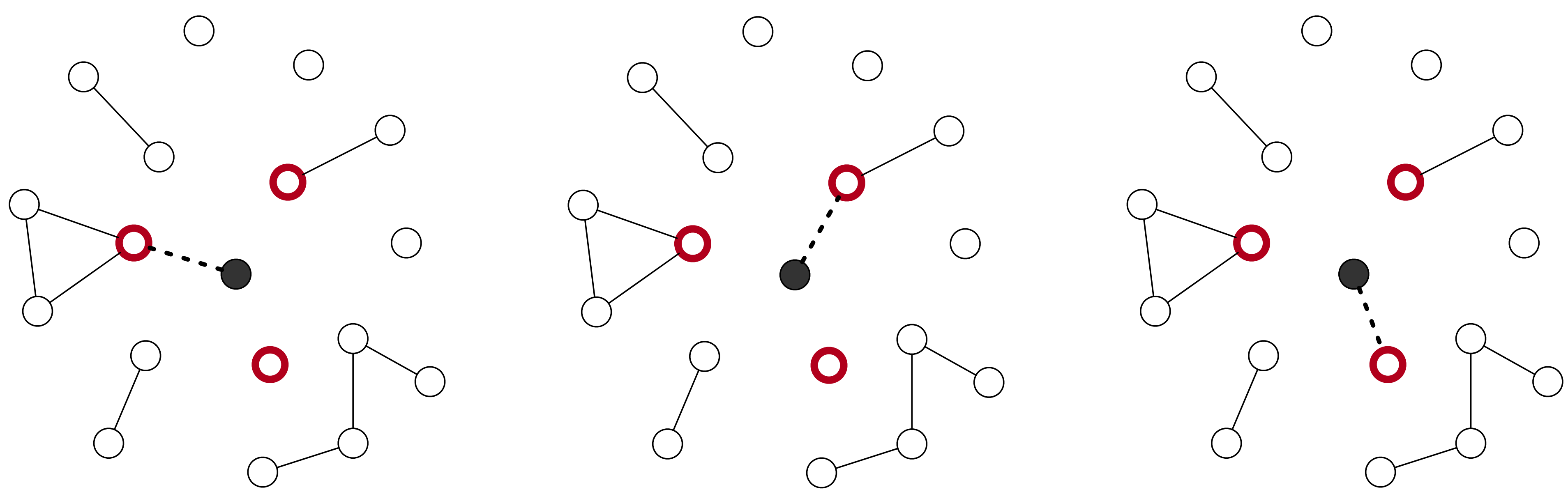
Individual models from a network perspective…



Individual at the head of the queue

High probability matches

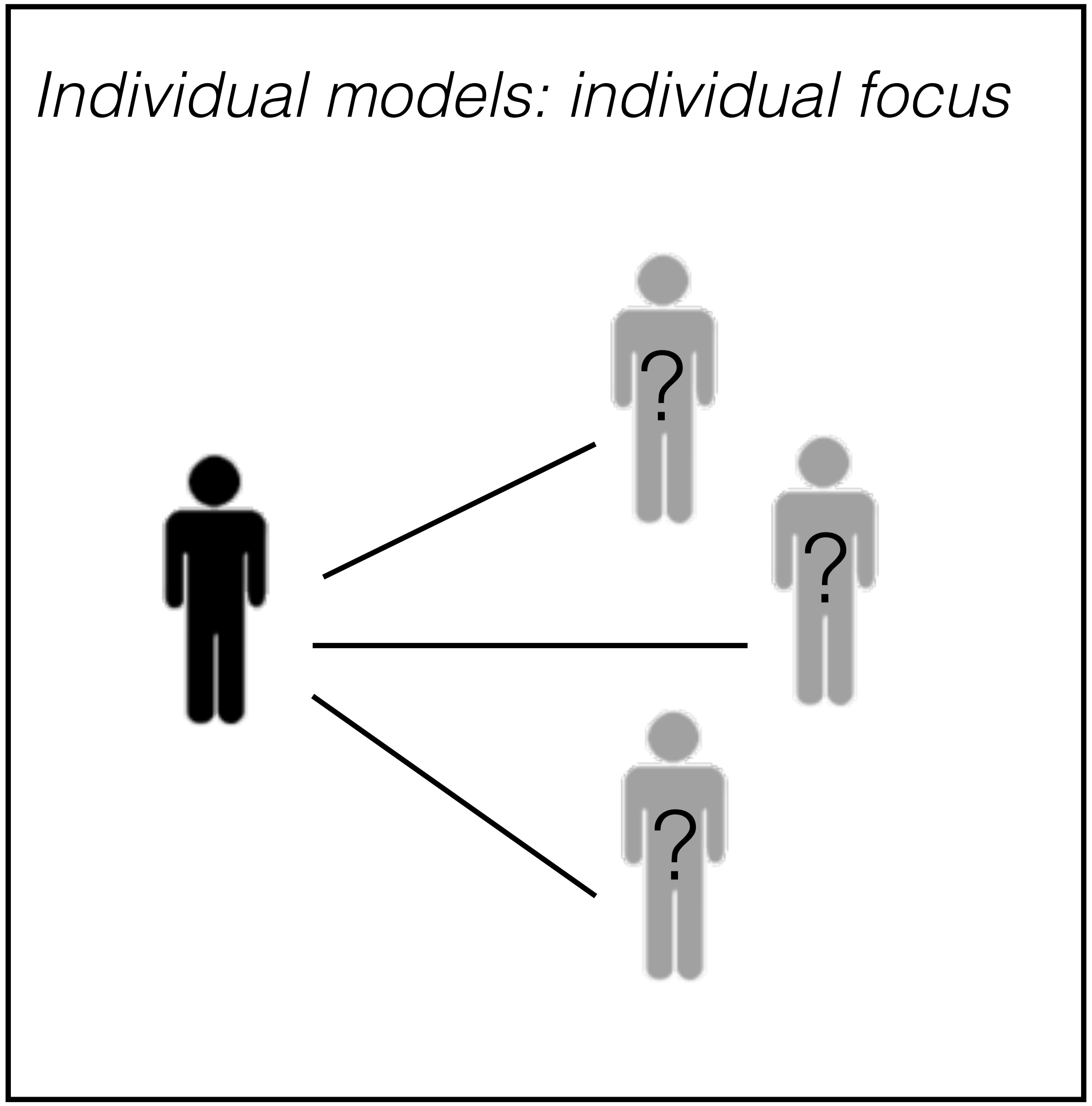
Stochastic agent-based models

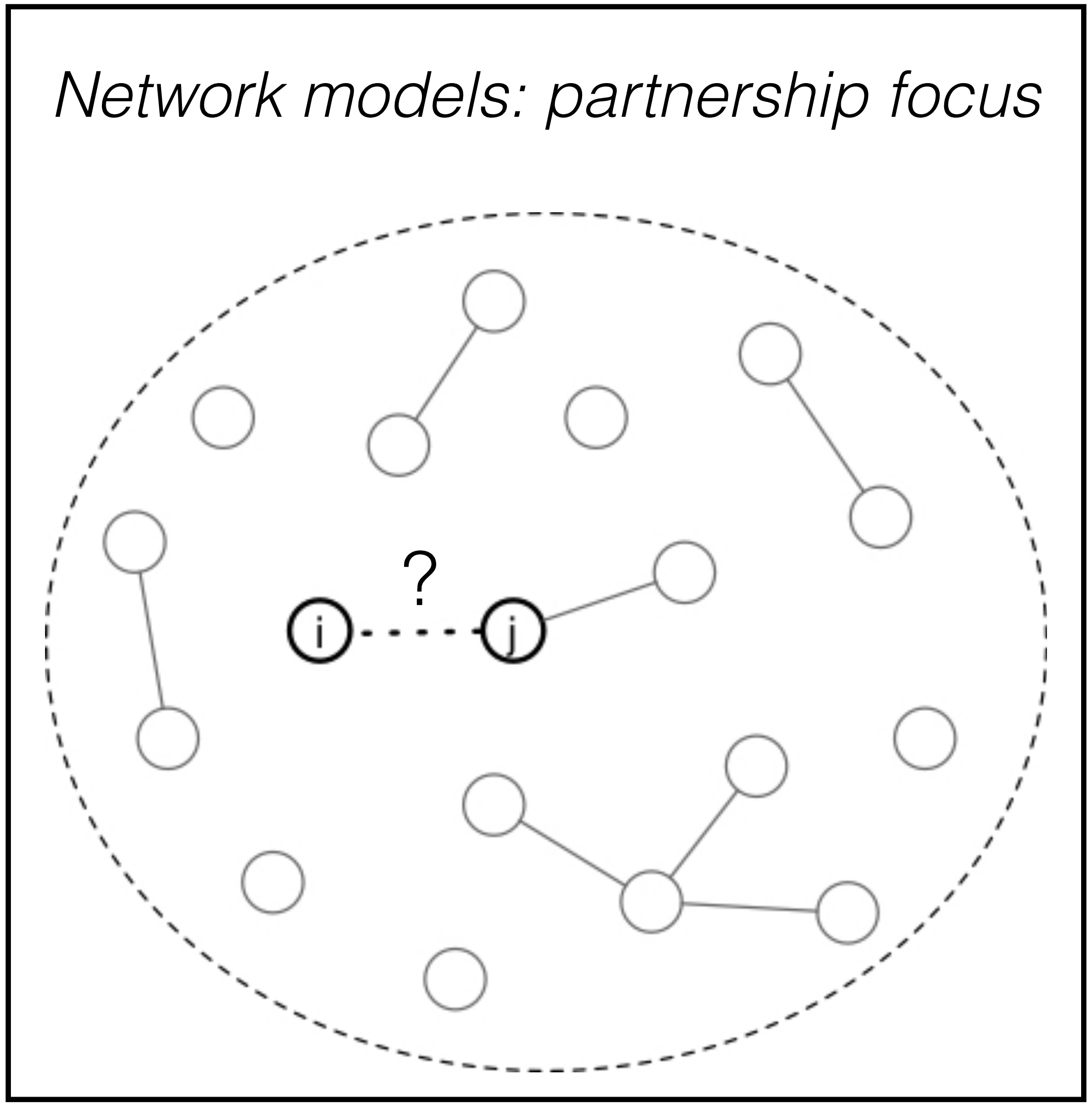


- Complex agent-based models
  - Partner selection: **selective**
  - Persistent partnerships: **yes**
  - Overlapping persistent partnerships: **yes (some)**
  - Control over resulting network statistics: **Limited**

Stochastic network models

- Partnerships are the unit of analysis





Stochastic network models

- Calculate network statistics from sampled data
  - Joint distribution of sexual mixing by attributes (age, race, sex, dyadic age difference, etc.)
  - Degree distribution
  - Partnership duration
- Feed network statistics into a statistical model to estimate parameter coefficients
- Simulate stochastic networks from the statistical model
- Simulate stochastic epidemic processes within the simulated network
  - Simulations will preserve the joint distribution of the observed network statistics in expectation and allow them to evolve with changes in demographic and epidemic conditions

Stochastic network models

- Partner selection: **selective**
- Persistent partnerships: **yes**
- Overlapping persistent partnerships: **yes**
- Control over resulting network statistics: **yes**

More details on how all this works in the coming days!

Summary

Deterministic compartmental models

- Assume homogeneity within compartments
- Selective mixing can be specified by a limited set of discrete attributes
- Limited ability to represent partnerships with duration and dynamic network structures

Stochastic individual models

- Can represent persistent concurrent partnerships
- Easier to incorporate individual and partnership heterogeneity
- Network structures emerge as a byproduct of individual level processes

Stochastic network models

- Statistically principled representation of partnership formation and dissolution processes and resulting network structures
- Network, demographic, and epidemic dynamics as dependent processes

Examples

- Deterministic compartmental models

Johnson, L. F., Hallett, T. B., Rehle, T. M., & Dorrington, R. E. (2012). The effect of changes in condom usage and antiretroviral treatment coverage on human immunodeficiency virus incidence in South Africa: a model-based analysis. *J R Soc Interface, 9*(72), 1544-1554. doi:10.1098/rsif.2011.0826

Cremin, I., McKinnon, L., Kimani, J., Cherutich, P., Gakii, G., Muriuki, F., . . . Hallett, T. B. (2017). PrEP for key populations in combination HIV prevention in Narobi: a mathematical modelling study. *Lancet HIV*. doi:10.1016/s2352-3018(17)30021-8

Smith, J. A., Anderson, S. J., Harris, K. L., McGillen, J. B., Lee, E., Garnett, G. P., & Hallett, T. B. (2016). Maximising HIV prevention by balancing the opportunities of today with the promises of tomorrow: a modelling study. *Lancet HIV, 3*(7), e289-296. doi:10.1016/s2352-3018(16)30036-4

- Pair formation models

Ferguson, N. M., & Garnett, G. P. (2000). More realistic models of sexually transmitted disease transmission dynamics: sexual partnership networks, pair models, and moment closure. *Sex Transm Dis, 27*(10), 600-609. Agent-based models

Powers, K. A., Ghani, A. C., Miller, W. C., Hoffman, I. F., Pettifor, A. E., Kamanga, G., . . . Cohen, M. S. (2011). The role of acute and early HIV infection in the spread of HIV and implications for transmission prevention strategies in Lilongwe, Malawi: a modelling study. *Lancet, 378*(9787), 256-268. doi:10.1016/s0140-6736(11)60842-8

Johnson, L., Dorrington, R., Bradshaw, D., Pillay-Van Wyk, V., & Rehle, T. (2009). Sexual behaviour patterns in South Africa and their association with the spread of HIV: insights from a mathematical model. *Demographic Research, 21*(11), 289-340.

- Stochastic agent-based models

Bershteyn, A., Klein, D. J., & Eckhoff, P. A. (2016). Age-targeted HIV treatment and primary prevention as a ‘ring fence’ to efficiently interrupt the age patterns of transmission in generalized epidemic settings in South Africa. *International Health, 8*(4), 277-285. doi:10.1093/inthealth/ihw010

Johnson, L. F., & Geffen, N. (2016). A Comparison of Two Mathematical Modeling Frameworks for Evaluating Sexually Transmitted Infection Epidemiology. *Sex Transm Dis, 43*(3), 139-146. doi:10.1097/olq.0000000000000412

- Stochastic network models

Jenness, S. M., Goodreau, S. M., Morris, M., & Cassels, S. (2016). Effectiveness of combination packages for HIV-1 prevention in sub-Saharan Africa depends on partnership network structure: a mathematical modelling study. *Sex Transm Infect, 92*(8), 619-624. doi:10.1136/sextrans-2015-052476

Jenness, S. M., Sharma, A., Goodreau, S. M., Rosenberg, E. S., Weiss, K. M., Hoover, K. W., . . . Sullivan, P. (2017). Individual HIV Risk versus Population Impact of Risk Compensation after HIV Preexposure Prophylaxis Initiation among Men Who Have Sex with Men. *PLoS One, 12*(1), e0169484. doi:10.1371/journal.pone.0169484

Goodreau, S. M., Rosenberg, E. S., Jenness, S. M., Luisi, N., Stansfield, S. E., Millett, G. A., & Sullivan, P. S. (2017). Sources of racial disparities in HIV prevalence in men who have sex with men in Atlanta, GA, USA: a modelling study. *Lancet HIV, 4*(7), e311-e320. doi:10.1016/s2352-3018(17)30067-x