Using agent-based models to investigate high-risk adolescent partner formation

Amanda D. Latimore, MA PhD
September 26, 2012
Background: Concurrency $\rightarrow$ STIs

Concurrency: the act of engaging in multiple sexual partnerships that overlap in time

Compared to serial monogamy, given the same total number of partners, **concurrency amplifies STI risk**

- Individual concurrency $\rightarrow$ increases risk of *transmission*
- Partner concurrency $\rightarrow$ increases risk of *acquisition*

Figure credit: Jim Moody and Martina Morris

Percent of people that are connected through their sexual partnerships

Morris & Kretzschmar, 1997; 2009; Aral, 2010

http://optoolkit.hivsharespace.net/index.html
Concurrency → US Racial/ethnic STI disparities

Syphilis

Highest burden in adolescents

Centers for Disease Control, 2011
Background: Black women prefer monogamous men

- 2.6 – 3.1 times the odds of concurrency in Black men (28%) vs. Whites men (13%)

- Adolescent black women express fatalism about the availability of “good” men
  - Monogamous
  - Physical attractiveness - proxy for cleanliness, faithfulness and low STI risk
  - As well as a partner with educational and career goals, that is emotionally supportive, respectful and kind

Then how and why does concurrency occur?
Background: Sex ratio → Concurrency

Proportion of men in the US, 1990

www.nationalatlas.gov

US Census Bureau
Poverty, race and sex ratio - US Census

![Chart showing the ratio of men to women in different categories: General US, Poor white, Poor black, Poor black, MD.]

- **2000**
  - General US
  - Poor white
  - Poor black
  - Poor black, MD

- **2010**
  - General US
  - Poor white
  - Poor black
  - Poor black, MD

Proportion of men (%)

- Baltimore City STD clinic-based, adolescents 15-24 years
Background: Sex ratio driven by violence and disproportionate incarceration

Male firearm homicide mortality rate per 100,000 population

Hu, Webster & Baker, 2008
Background: Sex ratio driven by birth disparity

Trends in male birth proportion by race and ethnicity
Background: Summary

Social Determinants

- Population-level

  - Partner Scarcity

  - Psychosocial Processes
    - Female Tolerance
    - Male Partner Concurrency

  - Concurrency

    - STI Prevalence

Sex Ratio theory & Demographic Opportunity theory
Overarching Goal

To understand how context (partner scarcity) interacts with individual-level partner preferences to form the empirically observed levels of male concurrency

**Population:** Sexually active, Black, inner-city adolescents

**Exposures:**
- Proportion of men at the Census tract level
- Female tolerance of male concurrency

**Outcomes:** Prevalence of men engaged in concurrency

**Method:** Agent-based modeling
Specific Aims

PART ONE

I. What is agent-based modeling?

II. What is gained by using an agent-based approach?

PART TWO

III. What is the impact of partner scarcity on concurrency relative to female tolerance and can partner scarcity explain the black-white disparity in concurrency?

IV. By what mechanisms can a female preference for monogamy lead to population-level male concurrency?
PART ONE

What do a flock of birds, a school of fish and a herd of bison have in common?
I. What is Agent-based modeling?

A multi-agent, stochastic, discrete-event simulation of individuals/components that are:

- Heuristic
- Adaptive
- Autonomous*
- Interacting
- Interdependent
- Networked

"THE SUM IS GREATER THAN THE PARTS"

Macy, 2002
I. Why Agent-based Modeling?

Health is a complex system

How do you capture using traditional experimental design?
I. Why Agent-based Modeling?

Health is a complex system
I. ABM utility in complex health systems

Agent-based is a holistic approach

- Model **heterogeneous** populations

“A POPULATION OF MODELS, NOT A MODEL OF A POPULATION”

- Understand the dynamic **cross-level feedback** of the individual and the micro/mezzo/macro environment

- Study counter-intuitive or emergent phenomenon using a **bottom-up** approach
Why simulate?

Fear-inspired flight and epidemic dynamics
Epstein, Parker Cummings, Hammond, 2008

Emergency evacuation
Dr. Paul Torrens, Dept of Geographical Sciences, University of Maryland

Adolescent partner formation?
Specific Aims

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Complexity # 1: Heterogeneity

**Advantage:** Ability to capture variation meaningful to the outcome
- More granular predictions
- Better interventions for sub-populations and hubs of risk

**Considerations:** Variation exists in partner formation strategies and risk
- Social space
- Physical space
- Relationship type and duration
- Within individuals across time and experience

**Current application:** Variations in partner number, sex ratio, change in tolerance due to experience
Complexity # 2: The interaction of individuals with each other and their environments

**Advantage:** Individuals do not act in isolation
  - Novel levels of influence for interventions
  - Better predictions

**Considerations:** Unrealistic to assume full, instantaneous or completely random access to resources in the environment
  - Network position (CONCURRENCY), size, diffusion
  - Movement of individuals through/around built/social environments
  - Error or delay in information exchange

**Current application:** Partial recognition of partner’s partners, dating network
Complexity # 3: Modeling individual processes

Advantage:

- Closer to understanding high-risk or counter-intuitive behavior

Considerations: Observation may not fully represent underlying process

- Assortative mixing: Do we seek the most attractive or the most similar?
- “Prettier at closing time” phenomenon
- Female acceptance of male concurrency despite preference for monogamy

Current application: Autonomous, locally-constrained decision-making
## Methodological Approaches

<table>
<thead>
<tr>
<th>Method</th>
<th>Level of analysis</th>
<th>Transition probabilities</th>
<th>Temporality</th>
<th>Explicit concurrency</th>
<th>Feedback</th>
<th>Heterogeneity</th>
<th>Adaptive and autonomous indiv</th>
<th>Individual-level interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Regression (LDA/MLM)</td>
<td>One (Multiple)</td>
<td>n/a</td>
<td>Static or discretely longitudinal</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Network Analysis</td>
<td>Structure &amp; relative position</td>
<td>n/a</td>
<td>Static or dynamic</td>
<td>✓</td>
<td>–</td>
<td>✓</td>
<td>–</td>
<td>✓</td>
</tr>
<tr>
<td>System Dynamics/Compartmental</td>
<td>Multiple, Aggregate</td>
<td>Differential equations</td>
<td>Dynamic and directed</td>
<td>–</td>
<td>✓</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Discrete Event Simulation</td>
<td>Multiple Queue, resource, entity</td>
<td>Adaptive, Queue logic</td>
<td>Dynamic</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Microsimulation</td>
<td>Multiple Individual</td>
<td>Mixing matrices</td>
<td>Dynamic</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>ABM</td>
<td>Multiple Individual</td>
<td>Adaptive Heuristic</td>
<td>Dynamic</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Markov Family</td>
<td>Individual or Aggregate</td>
<td>No memory Independent of history</td>
<td>Dynamic and directed</td>
<td>–</td>
<td>✓</td>
<td>–</td>
<td>✓</td>
<td>–</td>
</tr>
</tbody>
</table>

Stahl, 2008; Luke & Stamatakis, 2011; Gilbert, 2008; Chattoe-Brown, 2009
PART TWO
Specific Aims

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I. What is agent-based modeling?

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PART TWO

III. What is the impact of partner scarcity on concurrency relative to female tolerance and can partner scarcity explain the black-white disparity in concurrency?

IV. By what mechanisms can a female preference for monogamy lead to population-level male concurrency?
AIM 2: Static model (One time point)
Specific Aims

PART ONE

I. What is agent-based modeling?

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AIM 3: Dynamic model (Multiple time points with feedback)

- Social Determinants
- Psychosocial Processes
- Male Partner Concurrency
- Female Tolerance
- Concurrency
- STI Prevalence
THOUSANDS of lines of code
### Model Calibration and Validation Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRSTD II</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Black, inner-city adolescents (14-19 years) recruited from Baltimore STI clinics, 2000-2003</td>
</tr>
<tr>
<td><strong>Sexual network study</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Population-based sample adolescents (14-19), urban San Francisco neighborhood, 2000</td>
</tr>
<tr>
<td><strong>AddHealth</strong>&lt;sup&gt;3&lt;/sup&gt;</td>
<td>National school-based sample of 15-19 years, 1999</td>
</tr>
<tr>
<td><strong>US probability sample</strong>&lt;sup&gt;4&lt;/sup&gt;</td>
<td>North Carolina population-based case-control study (15-44 years), used control data only, 2002</td>
</tr>
<tr>
<td><strong>National Survey of Family Growth</strong>&lt;sup&gt;5&lt;/sup&gt;</td>
<td>Random sample of HIV negative African American state ID holders in 13 central and eastern North Carolina counties with registered HIV cases (18-59 years), 1997-2000</td>
</tr>
</tbody>
</table>

1. Raw data, Lenoir et al., 2003; Bettinger et al., 2004; Matson et al., 2012; 2. Fichtenberg et al., 2009; 3. Kelly et al., 2003; 4. Doherty et al., 2009a; 5. Doherty et al., 2009b
THE INFLUENCE OF CONTEXT AND COMPOSITION IN THE RISKY PARTNER SELECTION OF URBAN ADOLESCENTS: AN AGENT-BASED INVESTIGATION

Amanda D. Latimore, Pamela Matson, Jonathan M. Ellen, Derek Cummings and David D. Celentano

III. Static ABM

A. What are the relative cross-sectional effects of gender ratio and female tolerance on population-level concurrency?

B. Can partner scarcity explain the black-white difference we observe in male concurrency?
Hypothesized relative effects

Point prevalence of male concurrency

Female Tolerance of Male Concurrency

Partner Scarcity

Low % men

High % men

High Tolerance

Low Tolerance
Static ABM components

Gender Ratio
Female Tolerance

Partner Formation

Female degree constrained

Point prevalence of male concurrency
Other network characteristics
For an individual in a population with a given proportion of men and female tolerance...

III. Static model: Partner formation

Initialization

Seek partners from dating pool

Seek ~ P(4)  Seek 1

Available single ♂️?

Yes

Monogamous ♂

Deterministic pairing

Paired

No

Concurrent ♂

Stochastic pairing wp ∝ TOLERANCE

Single
III. Static model: Overall results

KEY FINDINGS:
• Positive association of partner scarcity and female tolerance with concurrency
• Slight advantage of female tolerance?
III. Results – Absolute change

- Change due to sex ratio when tolerance is high
- “Independent effect” of partner scarcity
- Change due to tolerance when partners are scarce
- “Independent effect” of female tolerance
III (A) Comparing relative effects

III (B) Black-white disparity

OR = 2.56 (95% CI: 1.61, 4.07)

Adjusted OR = 3.06 (95% CI: 2.27, 4.13)

Prevalence Ratio = 2.15

(Adimora et al., 2007)
III. Static ABM

A. What are the relative cross-sectional effects of gender ratio and female tolerance on population-level concurrency?
   - Interacting and difficult to compare
   - Similar in magnitude

B. Can partner scarcity explain the black-white difference we observe in male concurrency?
   - Yes. And changes in tolerance just as impactful
IV. Dynamic ABM

How/why does female tolerance develop?

A. Primary mechanism: RELAXATION hypothesis

→ What are the short- and long-term impacts of an effective tolerance intervention?

B. Alternative mechanism: MISINFORMATION hypothesis
Dynamic ABM components

**RELAXATION hypothesis**

- **Varied INPUT**
  - Gender Ratio
  - Tolerance = 0 at time\(_0\)

- **Learning**

Time

- **Output**
  - Prevalence of male concurrency
  - Other network characteristics
  - Relationship characteristics

Female degree constrained
IV. Dynamic ABM

<table>
<thead>
<tr>
<th>Relationship Duration (RD) + 1</th>
<th>Time + 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check partner status with error</td>
<td></td>
</tr>
<tr>
<td>Check RD</td>
<td></td>
</tr>
<tr>
<td>Break up</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram](image_url)

- **LEARNING**
  - “Prettier at closing time”

- **Attempts <= Threshold**
  - Attempts + 1

- **Attempts > Threshold**
  - Tolerance increase
IV. Population-level data
Change in tolerance across time

[Graph showing change in tolerance across time with data points for different age groups and thresholds.]

Average age, 50% threshold

<table>
<thead>
<tr>
<th>% Men</th>
<th>Mean (SD)</th>
<th>% populations that reach threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-40</td>
<td>16.2 (.44)</td>
<td>100%</td>
</tr>
<tr>
<td>42.5-47.5</td>
<td>18.4 (.97)</td>
<td>100%</td>
</tr>
<tr>
<td>50-60</td>
<td>21.6 (.66)</td>
<td>19%</td>
</tr>
</tbody>
</table>

RELAXATION hypothesis
IV. Population-level data
Change in effects across time
When partner scarcity exists:

- Adjusting for tolerance significantly decreases the hazard of male concurrency in a relationship
Take-home point: 2-to-1 decrease in concurrency for every %-point decrease in tolerance, on average, across levels of sex ratio
IV. Population-level data
Long-term impact of a reduction in tolerance

Populations below 50% tolerance

<table>
<thead>
<tr>
<th>% men</th>
<th>Intervention age (step)</th>
<th>N Intervention: Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-40</td>
<td>16.1 (50)</td>
<td>144:156</td>
</tr>
<tr>
<td>42.5 – 47.5</td>
<td>18.2 (75)</td>
<td>89:91</td>
</tr>
<tr>
<td>50-60</td>
<td>21.6 (116)</td>
<td>79:28</td>
</tr>
</tbody>
</table>

Average tolerance at Time_0

- 40
- 50
- 60

Age

Simulation time

0.2 0.4 0.6 0.8 1

0 50 100 150

12 14 16 18 20 22
**Key Finding:** A one-time reduction in tolerance can have long-term effects on concurrency
THE NEGATIVE IMPACT OF PARTNER SCARCITY ON CONCURRENcy IN URBAN ADOLESCENTS: Guiding interventions using an agent-based model of high-risk partner formation

Amanda D. Latimore, Derek Cummings, Pamela Matson, Jonathan M. Ellen, and David D. Celentano

IV. Dynamic ABM

How/why does female tolerance develop?

A. Primary mechanism: RELAXATION hypothesis

→ What are the **short- and long-term impacts** of an effective tolerance intervention?

**About 2 times the change in concurrency for a one-unit change in tolerance – maintained over time**
IV (B) Alternate mechanism

- **Relationship Duration (RD) + 1**
- **Check partner status with error**
- **Check RD**
- **Break up**

**MISINFORMATION hypothesis**

- **LEARNING**
  
  "Prettier at closing time"

- **Attempts <= Threshold**
  - **Attempts + 1**
- **Attempts > Threshold**
  - **Tolerance increase**
MISINFORMATION hypothesis

IV (B) Results (47.5% men)

Misinformation alone cannot explain the concurrency that we observe (66% of PRSTD sample)
IV (B) Results

35% men (7% of PRSTD sample)

55% men (2% of PRSTD sample)
IV. Dynamic ABM

How/why does female tolerance develop?

A. Main mechanism: RELAXATION hypothesis

→ What are the short- and long-term impacts of an effective tolerance intervention?

   About 2 times the change in concurrency per one-unit change in tolerance, maintained across time

B. Alternative mechanism: MISINFORMATION hypothesis

   Not likely, but a potential point of impact for those exposed to severe partner scarcity

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Guiding interventions using an agent-based model of high-risk partner formation

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AIM 2: Static ABM

1) Interacting and similar in magnitude of effect on concurrency

2) Partner scarcity can explain the black-white disparity in concurrency
AIM 3: Dynamic ABM

1) A decrease in tolerance can have short- and long-term impact on concurrency

2) What we observe is likely due to both a relaxation of preferences and misinformation
Limitations

• Need for simplifying assumptions
  • From the perspective of the female only
  • Stable sexual networks
  • Only intra-racial partner formations

• Generalizability
  • Limited data available to inform some components
  • Serious computing power needed for dynamic models
  • Insights limited by current statistical methods
  • Almost any result can be “calibrated” into a simulation
Strengths

• Systems science is the only way to address the feedback loops present in health systems
  • ABMs most appropriate for individual-level complexity
• Model was calibrated and validated with empirical data
• Ability to model concurrency
• Observe generative processes
• Examination of interdependent factors interacting across levels/time
• Ability to model process of agent learning
Innovation and public health impact

- Provides support for a common explanation for black-white disparity in concurrency and possibly STIs
- Provides insight into an empirically unobserved mechanism between partner preference and selection
- Novel application of an emerging method
- Application to a growing field that recognizes concurrency and other network-level STI risks
- Showed the potential effects of an alternative points of impact
- ~*Complexity*~
Future Directions – Where do we go from here?

Applications

- Systemic interventions for underlying causes of male scarcity
- Investigate affects of expanding female partner pool
- Groundwork for tolerance measures

ABM extensions

- Investigate individual interventions
- Multidimensional partner characteristics
- Dynamic potential partner networks
- Changes in the accuracy of partner evaluations by intimacy
- Incorporate STI transmission and condom use
- Modify for other contexts – Concurrency is a hot topic!