Developmental Systems Science: Extending Developmental Science with Systems Science Applications

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State of Developmental Science

- Cutting edge of thinking and research in the study of human development
- Developmental Systems Theories (DST)
  - Bioecological Systems Theory (Bronfenbrenner & Morris, 2006)
  - Developmental Systems Theory (Ford & Lerner, 1992)
  - Developmental Contextualism (Lerner & Kauffman, 1985)
  - Probabilistic Epigenesis (Gottlieb, 1992; 1998; Gottlieb, Wahlsten, & Lickliter, 2006)
  - Dynamic Systems Theory (Thelen & Smith, 2006)
  - Holisitic Person-Context Interaction Theory (Magnusson & Stattin, 2006)
Defining Features of Developmental Systems Theories

- Relational metatheory
- Integration of multiple levels of organization
- Bidirectional individual ↔ context interactions
- Temporality and plasticity
  - Relative plasticity
- Promotion of positive development
- Multidisciplinarity

Methodological Challenges for DST

- DST not new but gaining prominence
- Variable-oriented approaches
  - Person-oriented approaches
- Fundamental challenge = Understanding and measuring complexity
- Minimal investment in methodologies that address complex systems (with some notable exceptions)
  - Nonstationary time series modeling (e.g., Molenaar, Sinclair, Rovine, Ram, & Corneal, 2009)
  - Cognitive development & dynamic systems approaches (e.g., Fogel, 2011; Hollenstein, 2007; Lewis, 2005; Spencer & Perone, 2008; van der Maas et al., 2006; van Geert, 2011)
Developmental Science Meets Systems Science

• Shared history
  ▫ Common theoretical base but divergent methodologies (e.g., Bertalanffy, Capra)

• Systems science refers to a family of methodologies
  ▫ *Modeling and simulation* characterize much if not most of the systems science methodologies

• Systems science methods do not replace, but complement traditional linear, reductionist methods
  ▫ Hybrids are possible

• Where are systems science methodologies being implemented?
Systems science methods address developmental science challenges

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<th>Developmental Science</th>
<th>Systems Science</th>
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<tr>
<td>Relational Metatheory</td>
<td>Complement reductionist methods and capture non-linear relationships</td>
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<td>Integration of multiple levels of organization</td>
<td>Enable study of complex problems including “big picture”</td>
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<td>Bidirectional individual ↔ context interactions</td>
<td>Examine dynamic interrelationships at multiple levels simultaneously</td>
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<td>Employ causal feedback processes</td>
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<td>Examine impact of behavior on system over time</td>
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Systems science methods address developmental science challenges

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<td>Temporality and plasticity</td>
<td>Capture dynamic behavior of system over time</td>
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<td>Illuminate time delayed effects and foresee unintended consequences</td>
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<td>Allow for emergent properties</td>
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<td>Promotion of positive development</td>
<td>Simulate impact of various policy decisions</td>
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<td>Foresee unintended consequences</td>
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<td>Multidisciplinarity</td>
<td>Facilitate the integration of data and knowledge from multiple disciplines</td>
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<td>Collaborations between content experts and modelers</td>
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Systems science methods are particularly well suited for...

- Theory generation and exploration
  - Evidence synthesis
  - Heuristic tool
  - Hypothesis development

- Policy analysis
  - Evaluating policy and informing decisions
  - Scenarios and forecasting

Also occasionally used for theory testing
Specific Systems Science Methodologies

• Social Network Analysis (SNA)
  ▫ Maps and measures relationships and flows between people, groups, organizations

• Agent-Based Modeling (ABM)
  ▫ Simulates the actions and interactions of autonomous agents (individuals, organizations, or groups) to assess their effect on the system

• System Dynamics (SD)
  ▫ Models a system as a set of interrelated compartments (“stocks”) and rates of transition (“flows”) with an emphasis on feedback loops and time delays that affect the behavior of the entire system
Social Network Analysis

• Analyze *connections* across individuals, groups, or institutions

• Network methods focus on:
  ▫ Individual
  ▫ Dyads (two actors and their ties)/Triads (three actors and their ties)
  ▫ Larger systems (subgroups of individuals, or entire networks)

• Purpose of social network analysis
  ▫ Identify important actors, crucial links, subgroups, roles, network characteristics, etc, to answer substantive questions about a phenomena of interest
Social Network Analysis

• Move beyond discrete dyadic relations
• Focus on the social environment
• Uses for network analysis data
  ▫ As input in more traditional statistical models
  ▫ In combination with other systems science methods
  ▫ Detailed visualizations of data
Social Network Analysis Example

These are the **Marginal** students - totally disconnected or not receiving any friend nominations.

The **Marginal** students are those who are not connected to the network, receiving no friend nominations.

The **Accepted** group is the reference group and make up the majority of students. They are those who received 3-5 friend nominations.

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The **Peripheral** students are weakly connected to the network, with only 1 or 2 nominations.

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The **Popular** group are those with 6-7 friend nominations.

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The **Favorites** are those with the highest number of friend nominations (8+) - they are the most popular students.

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* Node size corresponds to # of friend nominations received.
Agent-Based Modeling

- One or more populations composed of individual agents
  - Agents are autonomous, interdependent, follow simple rules, and can adapt over time
- Capture interactions between individuals within populations
- Emphasizes multi-level emergence
  - How distinctive patterns can emerge at different levels of the system
Agent-Based Modeling

• When is it appropriate to use ABM?
  ▫ Dynamic problem
  ▫ Heterogeneity
  ▫ Individual-based model more appropriate
  ▫ Multiple time scales

• When is it not appropriate to use ABM?
  ▫ Lack appropriate data and expertise
  ▫ Only interested in high level understanding (SD may be more appropriate)
Agent-Based Modeling Examples

- Individual residential preferences and segregated neighborhoods (Bruch & Mare, 2006)
- Individual choice and marriage markets (Todd, Billaris, & Simao, 2005)
- Impact of child maltreatment prevention interventions (Hu & Puddy, 2010)
- Diffusion of adolescent sexual initiation (Orr & Evans, 2011)
System Dynamics

• A broad, evolving methodology to help understand & manage feedback systems
• Modeling a system as a set of interrelated compartments ("stocks") and by rates of transition between stocks ("flows")
• Considered an aggregate or compartmental technique
• Frequently used for evaluating the trade-offs and consequences of various policy interventions
System Dynamics

• When is it appropriate to use system dynamics?
  ▫ Need to achieve value early in the modeling process
  ▫ Limited to aggregate data
  ▫ Understand/describe system behavior across all possible parameter values
  ▫ Desire understanding of aggregate behavior

• When is it not appropriate to use system dynamics?
  ▫ Need to represent heterogeneity
System Dynamics Example
Future Applications of Systems Science

- Using system dynamics modeling for thinking about systems of care for adolescents with mental health problems (Lich & Urban)
- Obesity – when to intervene and who to target (ages, race/ethnicity, schools, etc.) (Rahmandad & Ammerman; Hovmand & Brennan, CompMod network)
- Understanding coordinated care for children with complex chronic conditions (Nageswaran)
- Using agent-based modeling to examine school mandates for Human Papillomavirus vaccination (Dempsey)
Toward the Union of Developmental Science and Systems Science

• Developmental Systems Science is:
  ▫ The application of systems science methodologies (such as network analysis, agent-based models, and system dynamics) to developmental science questions, particularly those derived from a developmental systems theoretical perspective
To learn more about systems science...

*Research in Human Development*


- Developmental systems science: Exploring the application of systems science methods to developmental science questions (Urban, Mabry, & Osgood)
- Estimating the relative impact of early-life infection exposure on later-life Tuberculosis outcomes in a Canadian sample (Osgood, et al.)
- Understanding long-term diffusion dynamics in the prevalence of adolescent sexual initiation: A first investigation using agent-based modeling (Orr & Evans)
- Social network status and depression among adolescents: An examination of social network influences and depressive symptoms in a Chinese sample (Okamoto, et al.)
Week-long intensive training for BSSR investigators

- Purpose: to prepare investigators to feature systems science methodologies in their NIH grant applications
- Annual course with rotating host site and faculty
- Competitive application process – all levels eligible from Ph.D. candidate through full professor
- Features three methodological tracks: system dynamics modeling, agent based modeling, and network analysis
- Call for applications is posted to the NIH BSSR-Systems Science Listserv - contact mabryp@od.nih.gov to join
Thank you!

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