CHILD DEVELOPMENT PERSPECTIVES

Theoretical and Applied Dynamic Systems Research in Developmental Science

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ABSTRACT—***This article discusses some of the ways in which dynamic systems approaches have been applied to developmental science. Dynamic systems thinking suggests that (a) there is always change within stability at the level of real-time (microscopic) behavior, and (b) micro-level change provides the seeds for developmental (macroscopic) change. It is only possible to study these propositions using microgenetic designs, case-based studies of change using frequent observations across development. Normal parent–infant relationships smooth out otherwise abrupt developmental transitions using a bridging process. The absence of developmental bridging may reflect problematic or even traumatic growth patterns, suggesting that bridging, a feature of a developmental trajectory, may serve as a diagnostic individual differences variable.***

KEYWORDS—*dynamic systems; developmental change; microgenetic research; case studies*

Dynamic systems thinking has made lasting and paradigmatic changes in the past 20 years across a wide variety of fields. New branches of mathematical and statistical modeling have been applied to robotics, computing, automation, business and economics, game theory, communication, climate and climate change models, population, developmental and evolutionary biology, sports and biomechanics, medicine, neuroscience, and cognitive science. It is also possible to apply dynamic systems thinking and mathematical modeling in the understanding of complex organizations such as educational and corporate systems. This article discusses some of the ways in which researchers have applied dynamic systems approaches to developmental science.

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WHAT ARE THE GREATEST CONTRIBUTIONS OF THE DYNAMIC SYSTEMS APPROACH TO DEVELOPMENT?

Many interconnected and powerful insights arise from dynamic systems thinking, including the concepts of dynamic stability and time scales. Dynamic stability is the idea that even when something that a developmentalist might study (an action, thought, or emotion) is relatively stable—it repeats over time in more or less the same form—closer analysis always reveals that it is dynamically assembled. Thelen's work on reaching or walking (and my work on smiling) shows that each reach (or smile) is "composed" or "recreated" in that moment from its component neurophysiological processes and is dynamically coregulated with the context in that moment of being recreated (Fogel & Garvey, 2007; Fogel & Thelen, 1987; Messinger & Fogel, 2007; Thelen, Skala, & Kelso, 1987).

This idea—that action, thought, and emotion are recreated from a dynamic assemblage of elements—has two important implications: (a) there is always change within stability at the level of real-time (microscopic) behavior, and (b) microlevel change provides the seeds for developmental (macroscopic) change. This is the notion of embedded time scales: Development is not imposed on the system from the outside or preorganized by a prior code but rather emerges from sometimes subtle momentary shifts of the system in context. Often, those shifts arise in nonobvious ways, as when a motor skill change like hand-to-mouth coordination, crawling, or walking leads to developmental reorganizations in social and emotional processes (Campos, Kermoian, & Zumbahlen, 1992; Camras, 1993; Fogel, 1990; Fogel & Thelen, 1987; Witherington & Crichton, 2007).

In dynamic systems theory, the constituents of a system act together to constrain the multiple actions of other constituents so that the complex system organizes and reorganizes over time into a series of dynamically stable behavioral patterns called *attractors* (Kelso, 1995; Kugler, Kelso, & Turvey, 1982; Prigogine & Stengers, 1984). In other words, constituents change each other in the process of convergence toward an attractor. Two people in a long-term partnership change each other in the process of forming a “couple” that develops recognizable patterns and habits. Each time an attractor is reconstituted, the actions within the attractor, the microlevel activity of the system, are somewhat different from the previous occurrence of that “same” attractor (Capra, 1996; Fogel, 1993; Thelen & Smith, 1994).

These two principles of dynamic systems theory have given developmental scientists the conceptual and methodological tools to return to the fundamental question of how things change, or how something new arises in development (van Geert, 1998). Developmental researchers have applied these basic ideas of dynamic systems theory in areas such as motor development (Clark, Truly, & Phillips, 1993; Goldfield, 1993; Thelen & Smith, 1994), cognitive development (Lichtwarck-Aschoff & van Geert, 2004; Thelen & Smith, 1994; van Geert, 1993), perceptual development (Butterworth, 1993), interpersonal relationships (Eckerman, 1993; Fogel, 1993; Fogel, Garvey, Hsu, & West-Stroming, 2006; Steenbeek & van Geert, 2005), personality and temperament (Lewis, 1995), emotions (Camras, 1993; Fogel et al., 1992; Wolff, 1993), and attachment (Coleman & Watson, 2000; Labile & Thompson, 2000).

DYNAMIC-SYSTEMS-INSPIRED EMPIRICAL RESEARCH: MICROGENETIC METHODS

Just because the explicit focus of the dynamic systems approach is on change does not mean that it is easy to observe and understand how change occurs (Miller & Coyle, 1999; Siegler & Crowley, 1991). We must observe change while it is occurring (Fogel, 1990; Kuhn, 1995; Siegler, 1995), instead of simply comparing pre- and postchange behavioral patterns as in traditional cross-sectional and longitudinal designs in which the researcher can see the products of change rather than the process.

When the focus is on the change process, one can ask: How does change occur? What mechanisms produce change? What conditions are likely to promote the emergence of change? What prevents a system from changing? Microgenetic research designs are the best suited for understanding developmental change. They contain the following key characteristics, as illustrated in Figure 1:

- *Cases* (individuals, dyads, families, classrooms) are observed through a period of developmental change.
- Observations are conducted *before*, *during*, and *after* a period in which rapid change in a particular domain occurs. The change may be a spontaneous developmental change or a planned intervention.
- There is an *elevated density* of observations within the transition period. That is, observations occur at time intervals that are considerably shorter than the time required for the developmental change to occur. For instance, if a developmental change takes place over several months, then observations should take place weekly or even more frequently.

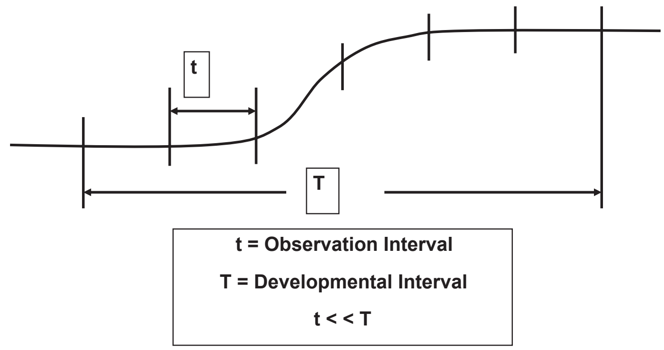

Figure 1. **Microgenetic research design in which the intervals between observations (*t*) are much shorter than the developmental interval (*T*).**

Microgenetic research has the advantage of being able to trace change over time within the same system. Studies of this kind may involve both quantitative tracking of developmental trajectories and qualitative analysis of life-history narratives that help to illuminate developmental transformation (Fogel, 1990; Fogel, Garvey, Hsu, & West-Stroming, 2006; Fogel, Greenspan, et al., 2008; Granott & Parziale, 2002; Greenspan, 1997; King, 2004; Lavelli, Pantoja, Hsu, Messinger, & Fogel, 2005; Lickliter & Honeycutt, 2003; Overton, 2002; Rosenwald & Ochberg, 1992; Shanker & King, 2002; Siegler & Crowley, 1991; Thelen & Smith, 1994; van Geert, 1998).

Recent methodological advances have given developmental scientists new tools to study change processes. Hierarchical linear models or multilevel models (Bryk & Raudenbush, 1992; Butt, Choi, & Jaeger, 2005; Prosser, Rasbach, & Goldstein, 1991) made by tracking a key measure over frequent observations, for the group as a whole and for each individual, allow researchers to examine developmental trajectories in microgenetic designs. Recent improvements in qualitative research methods have given new credibility and rigor to narrative descriptions of observed behavior and life history data (Denzin & Lincoln, 1994; Fogel, 2006; Fogel et al., 2006; Polkinghorne, 1995).

I have applied microgenetic methods to study changes in the parent–child communication system and emotional development (Fogel, 1993; Fogel & Branco, 1997; Fogel & Lyra, 1997; Fogel et al., 2006; Hsu & Fogel, 2001; Lavelli & Fogel, 2002, 2005). In this work, I have developed qualitative dynamic systems research methods in order to study the processes of meaning making that are inherent in social and emotional domains (Fogel et al., 2006).

One of the key discoveries in Fogel et al. (2006) is a developmental bridging process. We examined how mother–infant communication in the first 6 months transforms from dyadic to triadic (including toys) communication frames—dynamically stable (at least for some finite developmental period) and repeating patterns of interactive action. In this study, the primary dyadic frames were social (face-to-face play without toys), guided object (mother holds the toy and demonstrates its use but does not transfer the toy to the infant), and social–object mixed (mother uses the toy like an extension of her body to tickle or kiss the baby). We called the triadic frame the not-guided object frame, in which the mother is present and interacting but the infant may grasp the toy and play with it.

Early in the first 6 months, we primarily witnessed the first two dyadic frames (social and guided object); these gradually disappeared and the triadic not-guided object frame emerged as primary. As the two dyadic frames began to decline and the triadic frame began to increase, most dyads showed a rise and then decline of the social–object mixed frame with an inverted U-shaped trajectory. Figure 2 shows the frame trajectories for one case.

We found this inverted-U trajectory in all but three of the 13 dyads in the study. We suggested that such an inverted-U trajectory (actually a hierarchical linear model with a quadratic age term), whose peak occurred exactly at the crossover point of the declining "historical" frames and the increasing "emerging" frame, was the signature of a bridging frame. Qualitative analysis further revealed that the bridging frame existed "between" the historical and emerging frames not only in time but also in content or meaning. The social–object mixed frame had features of both dyadic social play and later object play because of the object's contact with the infant.

Our detailed qualitative analyses of these data (Fogel et al., 2006) also revealed the two principles I mentioned earlier. We found change within stability because the microlevel sequences within frames changed over the observation period. During the guided object frame, for example, the mother's demonstrations of the toy for the infant became more complex over time, culminating in shifting between showing the object and placing it into or near the infant's hand. As the object approached the infant's hand during the guided object frame, it often precipitated a real-time transition to the not-guided object frame, with the infant now holding the object and the mother looking on.

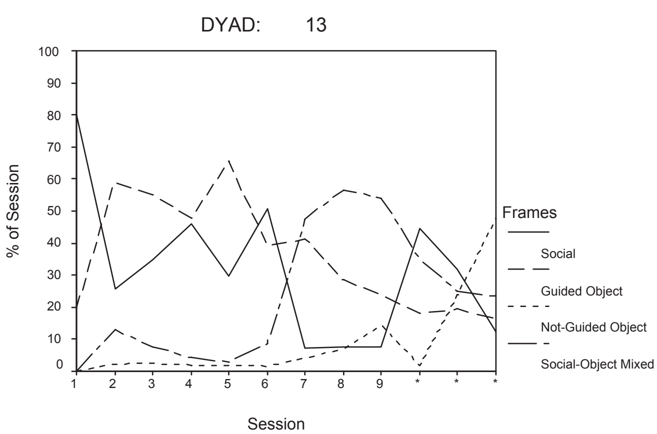

Figure 2. **The development of communication frames for mother–infant object play for one dyad observed weekly between 6 and 26 weeks (session 1 = 6 weeks).**

Note. **The developmental decrease in face-to-face (social) play and guided-object play is replaced by not-guided (solo) play with objects. During the developmental transition period, there is an increase and then a decrease of a *bridging* frame, one that uses objects for social purposes.**

These real-time transitions between frames increased during the bridging period, leading to shorter durations of the guided object frame and increasingly longer durations of the not-guided object frame. These data illustrate that microlevel change (within frames) provides the seeds for developmental change (the decline of one frame and the emergence of a new one; see Figure 2).

NEW DIRECTIONS: APPLIED DYNAMIC SYSTEMS RESEARCH AND INDIVIDUAL DIFFERENCES IN DEVELOPMENT CHANGE PROCESSES

In addition to searching for general patterns of change, microgenetic research—because it is case based rather than population based—has the potential to explain between-case variability in the developmental change process. For example, to investigate the onset of reaching, Thelen and collaborators conducted weekly observations of four infants from 3 to 30 weeks of age in a standard reaching task and in a play session with their parents—that is, before, during, and after the transition to reaching (Spencer, Vereijken, Diedrich, & Thelen, 2000; Thelen et al., 1993). This microgenetic analysis afforded opportunities for the discovery of dramatic individual differences not only in the age of reach onset—ranging from 12 to 22 weeks—but also in the strategies the infants used to get the toy that led to different developmental pathways toward reaching.

Using weekly observations of face-to-face play from birth to 3.5 months of age in 16 mother–infant dyads, hierarchical linear modeling revealed that interdyad differences in the developmental trajectories of the duration of face-to-face play emerged toward the end of the 2nd month (Lavelli & Fogel, 2002). Infants who smiled earlier and fussed less showed a trajectory of decline in face-to-face play duration compared to the group who smiled less and fussed more (see Figure 3). Apparently, the latter group did not get "enough" positive interaction and needed to extend this developmental period. These findings illustrate the importance of conducting intensive observations across developmental transition periods because individual differences arise not only in the quality and quality of behavior at a particular age but also in the shape of the developmental trajectory.

The analysis of individual differences in trajectories—when compared to individual differences in particular variables measured at a single time—has immediate relevance for applied research, including understanding developmental psychopathology and developmental disorders and the effects of therapeutic or educational interventions. Microgenetic designs inspired by dynamic systems may seek to uncover the basic principles of the change process in order to better promote desired changes and avoid undesired changes in a system. Using a dynamic systems perspective, it is possible to frame questions about the stability versus instability of new patterns that emerge (a trajectory variable) as a consequence of a naturally occurring or induced change process.

Because dynamic systems are complex, systems do not get “fixed” or “cured” in a linear cause–effect manner. Rather, it is possible to observe a dysfunctional system transforming slowly over time into a more functional system (again, a property of a developmental trajectory rather than of a fixed trait). In dynamic systems science, we seek to understand the laws of transformation. Does the emergence of new behavior patterns tend to suppress the old patterns or to coexist with them in some kind of discordant bridging frame? When warring nations negotiate peace, under what conditions will that peace remain stable, and is there any likelihood that old hostilities will reappear (incomplete bridging out of former conflict frames)?

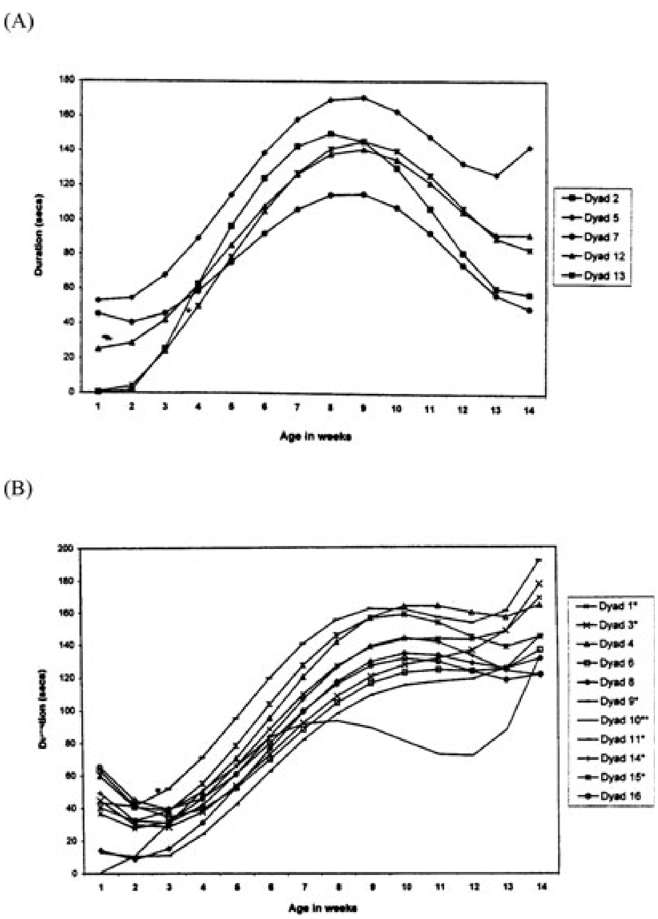

Figure 3. The duration of face-to-face play between mothers and their infants during 5 min at-home observation that occurred weekly between 1 and 14 weeks.
Note. Hierarchical linear modeling revealed two groups of dyads. In Group A, the duration of face-to-face play increases until 9 weeks and then begins to decline. This group had more girls, more infant smiling, and less fussing. Group B infants with more boys, more fussing, and less smiling did not show a similar decline in face-to-face play after 9 weeks.

As I mentioned previously, several dyads in the Fogel et al.’s (2006) data set showed no bridging frames in the dyadic-to-triadic developmental transition. Follow-up analysis is under way to investigate further differences between these groups of dyads, but a casual examination of the data suggests some communication problems in the nonbridging dyads. Unable to negotiate real-time transitions between coactivities, some dyads may be unable to manage the negotiation of bridging frames to manage developmental transitions.

We believe that one of the important developmental functions of bridging is to smooth out developmental transitions, making them less psychologically abrupt. A bridging frame in a child’s transition to a new school, for example, would involve both something from home and something from school mixed together (the teacher making home visits or the parent attending school for the first days or weeks). Without a bridging frame, developmental change may become stressful or even traumatic, as illustrated by the catastrophe theory surface in Figure 4. Given the choice, it is better to traverse a smoother change path than a more abrupt one.

Because of the ability of dynamic systems research to help us better understand change and between-system variability in the change process, and because of the advances in research methods (some of which I described here), there is a growing theoretical and empirical tool kit for unpacking critical developmental questions about a wide range of human endeavors. How do we create an educational or health care system that facilitates the emergence of new frames that are beneficial rather than detrimental? How can we better assist in the transformation of families, neighborhoods, or human service organizations from dysfunctional frames into more useful ones?

My colleagues and I on the Council of Human Development are working on dynamic systems models and methods that are readily applicable to research and intervention on any type of complex social system. Our recent effort in this domain (Fogel,

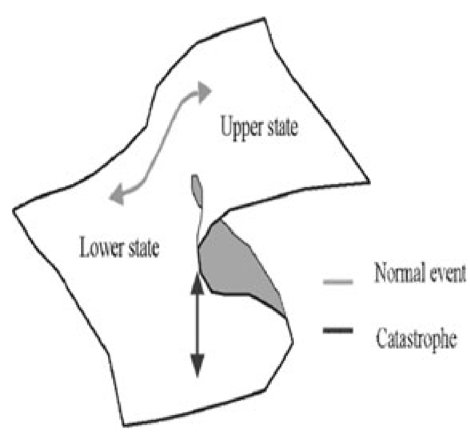

Figure 4. A catastrophe surface.
Note. The gray arrow shows a smooth developmental transition between lower and upper states, and the black arrow shows a catastrophic (nonlinear) transition.

King, & Shanker, 2008) is a collection of essays by systems scientists who write in layperson's terms a systems analysis in a wide variety of biological, sociocultural, and psychological domains. In lieu of static and linear models of people, dynamic systems thinking about change and stability can be a powerful way to approach a wide range of human problems with new possibilities for change.

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