Toward a Unified Theory of Development

CONNECTIONISM AND DYNAMIC SYSTEMS THEORY RE-CONSIDERED

16. Dynamic Systems and the Quest for Individual-Based Models of Change and Development
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OXFORD UNIVERSITY PRESS
2009
CHAPTER 16

Dynamic Systems and the Quest for Individual-Based Models of Change and Development

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The aim of this chapter is to discuss the question of how dynamic systems theory can be fruitfully applied to the development of the kind of phenomena and variables that have interested the current authors for a long time. Examples of these phenomena are (a) the development of language, including the development of the lexicon and syntactic and grammatical knowledge and skill, (b) the development of cognition and thinking, including the emergence and acquisition of cognitive skills and knowledge in various domains, (c) the development of reflective judgment, including metacognition and social understanding, and (d) the development of social skills and behavior. Behind all these phenomena are the development of context-specific but overarching principles of skill formation, such as principles of relationships, systems of relationships, and so on.

Viewed in the context provided by the current volume, the answer to the question of how to apply dynamic systems theory to these phenomena is not trivial. Some contributors to the conference on which this book is based argued for a particular type of dynamic systems model, which both (a) is firmly rooted in a physical system, such as the body or the brain (the dynamics of which are, in principle, relatively well understood), and (b) describes a real-time interaction loop between an organism and its direct environment. Hence, psychologically relevant properties are not in the person alone, but in the person–environment dynamics.

We will argue that application of dynamic systems theory to presumed internal properties, such as the development of self-perception and identity, reflective judgment, or grammatical knowledge and skill, works with a different kind of dynamic systems model but is also built upon these two characteristics. The behaviors and cognitive properties being modeled are inherently embedded in a physical system and based on a real-time interaction loop between organism and environment. It will come as no surprise that the authors of the present chapter believe the dynamic systems view can be fruitfully applied to these subjects and topics—complex and high-end though they may be—in a way that is considerably more than metaphorical and illuminates development in important ways.

GRAND OLD VIEWS OF DEVELOPMENT AND LEARNING

Etymological Analysis of Development

Before answering the question of how dynamic systems theory can be fruitfully applied to development in the broad sense of the word, it is good to remind ourselves of what the term development actually means and how it relates to associated terms such as change, learning, acquisition, emergence, evolution, and so on.

Etymologically, the term development means un-wrapping, that is, taking something out of its original wraps, thus uncovering something
that is present at the beginning but concealed. There is a connotation of an inner logic in the term *development*, that is, the intrinsic necessity of a certain outcome. As a verb, *develop* appears in a transitive as well as in an intransitive, more precisely reflexive, form. For instance, you can develop a photo (people used to do these things before the digital camera) or develop a real estate project. However, it is a bit odd to say that a parent develops a child. One can say that the child develops grasping, for instance, or that the child develops. In the latter sense, *develop* is used as a reflexive verb, that is, a verb where the agent and patient are the same.

This historical and colloquial meaning of the term development is reflected in the structure of the classic grand theories of development, that of Piaget, for instance. These theories are implicitly based on a retrospective approach, that is, an approach that takes the properties of a final state (i.e., an outcome of development) as its conceptual starting point and reasons back, so to speak, to find the state or states that do not yet have these properties. These states must, by logical necessity, precede the final state. The properties that define each possible state are conditionally linked. For instance, Piaget’s theory explains why you cannot think about formal contents if the thinking itself is not operational; hence the emergence of operational thinking precedes the emergence of formal thinking because it is a precondition to the former. These properties and their conditional relationships define a specific temporal arrangement of possible developmental states. The first author (van Geert, 1987a, 1987b, 1987c) has analyzed various classic developmental theories in the form of generative rewrite rules that very much resemble the principles of current symbol dynamics, which is a specific branch of (formal) dynamic systems theory (Dale & Spivey, 2005; Jaeger, 1999).

The classic developmental theories tried to explain the properties of the developing person and the conditional relationships among these properties by focusing on the major developmental mechanism(s). These mechanisms were in most cases internal, driven by the developing person himself. Thus, development is an internally driven process of growing toward an end state that is, in some way, potentially present from the beginning. This is not, in any way, a form of nativism, claiming that the end state (or at least some essential core of it) is present from the beginning. Potential is derived from the Latin word for power, thus meaning that something at the beginning has the power of developing into some particular final state through transformations that unwrap the potential by making it actual.

Several chapters in this book have already discussed the main properties of dynamic systems, and we can thus ask ourselves to what extent the classic view on development relates to the notion of a dynamic system. The answer, we believe, is that there is in fact a considerable overlap or similarity, in that development is a typical example of a dynamic system—if one is prepared to condone the terminological remnants of prescientific times that may still color the use of the term development.

**Dynamic Systems and the Grand Old View of Development**

How does the dynamic systems approach relate to this unwrapping scheme and the notion of a reflexive activity (that is, something one imposes on oneself)? Dynamic systems theory has replaced this primitive notion of unwrapping by notions of emergence, self-organization, and attractors. Attractors are states to which the dynamic system is driven by internal necessity, that is, as the necessary consequence of a dynamic mechanism (the growth term) that governs the change of the system. In this sense, it has given a formal and precise meaning to the intuitive notion of potentiality—the power or possibility to move through a series of steps and transformations toward a state that has some permanence and stability. Dynamic systems theory has made the developmental notion of a self-imposed process explicit by specifying the system dynamics empirically and formally (for instance, by means of models).

The theoretical distance between the dynamic systems approach and the classic stage theories of development is perhaps smaller than that between dynamic systems and the majority
of current empirical studies in development (van Geert, 1998b). As described in the preceding section, the stages of classic theories are not trivial qualifications but result from dynamic ordering principles, based on postulated, major developmental mechanisms. This ordering of stages thus defines a sort of crude yardstick for development, the tick marks of which are the stages as distinguished by the theory at issue. In a similar vein, a dynamic system describes the change of a developing property specified in a geometric space. In a physical system, the geometric space can be the real physical space or some property such as temperature or velocity. The simplest possible space is one-dimensional, in the sense that it specifies the change in one particular dimension, such as the child's lexicon, mathematical problem solving, or popularity in a peer group. High-dimensional geometric spaces, referring to basically every relevant dimension or variable useable for describing development, are also possible and useable for dynamic modeling (van Geert, 1998a). Current dynamic systems investigations in social, dyadic interaction (e.g., between mother and child) often employ two-dimensional categorical spaces, one dimension for each participant (Hollenstein & Lewis, 2006). An important challenge for dynamic systems theory in development is to specify this geometric space and its constituting dimensions in ways that make description, explanation, and research of developmental phenomena theoretically and empirically adequate. (We will come back to this issue in section The Metric of the Dynamics and Developmental Rulers, defining the notion of developmental rulers.)

**Development, Learning, and Teaching**

Development has always been seen as different from, but at the same time intimately related to, learning and teaching. The grand old view of learning and teaching implies the notion of transmission. Thus a teacher (of whatever kind) transmits knowledge or skills to a learner. Transmission implies the bringing of something (e.g., a knowledge content) from one place to another (e.g., from an adult's brain to a child's brain). It requires the presence of a sender or transmitter and a receiver of the transmitted content. Connectionist models have considerably altered the transmission view on learning and have replaced it by a model of networks that self-organize in response to the input (as in supervised and unsupervised learning and statistical learning). However, the self-organizing formation of connections in a network is the way in which the transmission process is taking concrete shape. It is not literally transmission of content that takes place, but the formation or construction of an internal structure that in some way replicates certain structural properties or regularities of the environment.

For instance, a connectionist model of language learning explains the learning by means of networks that self-organize under the influence of linguistic inputs, resulting in a network organization that is capable of producing language itself, according to the rules that governed the language productions that were taken as input (for instance, see Plunkett & Juola, 1999). Thus, connectionist networks are capable of picking up structure from the environment, in addition to being able to build up any form of statistical regularity between the network's inputs and its outputs. Development, in its basic meaning, implies the unwrapping of an internal potential, not the mere appropriation—in whatever form—of an external content. The question is, of course, whether this distinction is anything more than an artifact. There is no process of development thinkable that does not also require the acquisition of external content. On the other hand, the initial architecture of a connectionist network greatly determines the way in which inputs affect the network's internal organization and its actual relating of inputs to outputs (for instance, see Elman et al., 1996). It is, thus, imaginable to constrain or specify a network in a way that the regularities it establishes between its actual inputs and outputs become relatively independent of the exact properties of its input and are, thus, underdetermined by the latter. This is functionally similar to saying that the network's output is innate or that inputs are no more than triggers of internally driven epigenetic processes (Chomsky, 1980; Fodor, 1975). However, in connectionist
networks, such eventual nativism makes no reference to a representationalist form of innateness and does not imply that a representation (e.g., a grammar of one’s language) is present at the start and then at some later time comes out in the form of explicit performance.

The basically constructive nature of development (i.e., using its inputs to construct its own trajectory and content), which connectionist networks imply, is also endorsed by Piagetian and neo-Piagetian theorists. They have argued that development occurs in the form of organizational/reorganizational and constructive processes, not just internally copying what is out there or incorporating what is transmitted from some outside source (Case, 1991; Fischer, 1980; Fischer & Bidell, 2006). For instance, when children start to understand the world in terms of relationships between concepts, it is not because they have somehow captured the notion of relationship as a thing present in the outside world, as if relationship were some sort of statistical regularity. In fact, the notion of relationship—whatever its actual psychological form—is constructed in an active attempt to understand and control the regularities of the world that the child encounters. In short, the distinction between development and learning is more gradual than discrete, given the fact that both learning and development rely on the working of a single underlying network structure, which is the brain. However, the gradualness of the distinction and the explanatory success of connectionist networks does not imply that it is therefore better to no longer make the distinction at all and to subsume all forms of learning and development under the same type of connectionist network operation. For instance, understanding teaching as a process of transmission requires not only an understanding of how the child processes the transmitted information, but also of how the teacher processes the information about the learning progress—or not—made by the child (van Geert & Steenbeek, 2005b). This transactional process between learner and teacher can be modeled by a dynamic system, linking the teaching of the teacher to the learning of the learner and also the other way around. The fact that the teacher and learner can be represented in the form of two interacting connectionist networks is no substitute for or reduction of the fact that teacher and learner constitute a long-term dynamic system, the properties of which can be modeled and understood (relatively) independent of the way the networks embody this dynamics.

**Dynamic Systems and Their Application to Developmental Processes**

**A General Definition of a Dynamic System**

A convenient definition of a dynamic system is “a means of describing how one state develops into another state over the course of time” (Weisstein, 1999, p. 501). It can be described by simple equations such as $x_{t+1} = f(x_t)$, with $f$ standing for some sort of function that yields a new value of $x$ given a value of $x$ at time $t$. In order to have a dynamic systems model, one thus needs three things. The first is some sort of $x$ (i.e., a description of something that changes). The second is some sort of metric describing the set of all possible states of $x$. The third is an explicit description of the form of $f$, the function that relates a preceding state of $x$ to a succeeding state of $x$.

**The Dynamic Variable: What Develops during Development?**

To begin with, $x$ can be anything that is sufficiently real to be the subject of a dynamic systems model. Thus, $x$ can be the number of carrots in a field, or the physical force exerted on a force plate, or a person’s level of skill in making reflective judgments. That is, $x$ need not

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1 In the current volume, readers are likely to encounter two different ways of representing the form of a dynamic system. The present format uses a notation where time proceeds in incremental steps (+1), where (1) can represent any convenient duration. Another format uses the notation of differential equations, with time $t$ represented by real numbers and infinitesimally small increments in $t$. The first format is customarily called a map, the other a flow. For our current purposes, the distinction between these representational formats is a matter of taste.
be a physical thing and neither does it need to be directly reducible to known physical states of a system. Take reflective judgment as an example. We do not know what happens in the brain when a person makes reflective judgments, but we would certainly not deny that people do make reflective judgments and that some people are better at it than others. We can construct tests to measure reflective judgments, and so forth, all of which is sufficient support of the fact that reflective judgment is real and not a member of the family of unicorns and other fantastic creatures. Of course, the real-ness of reflective judgment is of a different kind than the real-ness of, say, temperature or a telephone booth, but the difference in kind does not imply that reflective judgment is a metaphor, something vague, or ill defined. We shall go further into this issue in our discussion of unsolicited ontological claims (section Unsolicited Ontological Claims).

The Metric of the Dynamics and Developmental Rulers

To have a dynamic system, the metric—the second aspect of a dynamic systems model—must be something like a geometric dimension or space where the notion of distance between two states of \( x \) can be given sufficiently concrete meaning. More precisely, the dimension should be sufficiently similar to a real-number line in order to describe measurable distances and meaningful movements along the distance axis at issue. Can a property such as reflective judgment, to name but an example, be described by means of a dimension that looks like a real-number line? The assumption that psychological properties like reflective judgment or intelligence can indeed be fruitfully described by (at least a certain stretch) of the line of real numbers (or integers, for that matter) is one of the main tenets of psychometrics and dates back to the beginning of intelligence measurement.\(^2\) The point is not whether phenomena like reflective judgment or intelligence are of the kind of physical phenomena the magnitudes of which demonstrably vary in accordance with a real-number line—it is most likely they are not. What is at stake is whether variation in these phenomena can be sufficiently approximated by a real-number line to make the application of a dynamic systems model more than an empty exercise—it is most likely that this is indeed possible.

This dimension in the form of a real-number line is a mathematical object. It relates to empirically definable properties in the following way. First, it must relate to a dimension, number line, or series of ordered categorical distinctions that can be used to describe developmental processes. Dependent on one's theoretical goals, this dimension can be general and encompassing or highly context-specific. Whatever its scope, however, it must be possible to specify a person's developmental level—whatever is implied by level—as a region or point on the dimension at issue, and thus to specify a person's developmental trajectory as a temporally ordered series of such regions or points. The second author of this chapter has coined the term developmental ruler to describe such descriptive dimensions, which can function as yardsticks for specifying developmental levels (Fischer & Rose, 1999; Rose & Fischer, 1998). Developmental rulers must be linked with measurable or observable phenomena, for instance, results from a test, observations, or experiments, in some explicit way.

A developmental ruler corresponds with a sequencing of developmental stages. Instead of identifying the stage with an identifiable phase in a person's life (i.e., classic Piagetian interpretation of stage), stages should be identified as the major ticks on the developmental ruler. The question of whether these stages correspond with a real scale has been strongly supported by empirical research that shows discontinuities between levels (or stages) in both long-term development of optimal level performance and short-term variations in performance in one

\(^2\) In the behavioral and developmental sciences, the relationship between measurements and an underlying mathematical object such as a real-number dimension is often a little vague, but such relationships can fruitfully be modeled by means of fuzzy-logic descriptions (van Geert, 2002, 2004; van Geert and van Dijk, 2003).
session (Dawson-Tunik, Commons, Wilson, & Fischer, 2005; Fischer, 2008; Fischer & Bidell, 2006). For instance, Rasch analysis shows the same scale marked by discontinuities in adult speech and writing that is evident in child and adolescent development.

In addition to using developmental rulers sensu stricto, one can use simple quantitative variables, such as the number of words counted in a child’s lexicon, to specify the space of developmental dynamics, provided of course, that such quantitative variables can indeed be meaningfully linked to developmental processes.

**Dynamic Function or Growth Term and Its Level of Application**

The third aspect of a dynamic systems model concerns the form of the *f or function* in the basic dynamic systems equation. This function is called the *growth term* and consists of a fixed principle that operates on the value of any *x*, as described through its descriptive dimension(s) or developmental ruler(s), and that produces another value of *x*, given the previous value of *x* and any other influence that enters into the dynamic growth term. It must be a function that makes the value of *x* (e.g., reflective judgment at a particular moment for a particular individual) move along a specific developmental ruler (e.g., the rater for reflective judgment). Although the function itself may describe decrease, increase, or stagnation, it must be based on well-established growth mechanisms, which we will discuss later in this chapter (for instance, see, section An Example: A Dynamic Growth Model of Language Development).

The growth term applies to a specific timescale. Although we will discuss this issue further in this chapter (section Timescales and Levels of Aggregation), it is important to note that developmental issues usually invoke a distinction among the short-term timescale of real-time human action and the long-term timescale of development. These timescales are characterized by different types of phenomena and different types of dynamics. For instance, a dynamic model describing a playground interaction between two children, taking place over a short-term timescale (e.g., the course of several minutes), including processes of selection of the interaction partner (e.g., turn taking), and interacting (e.g., interpreting one’s own and the other child’s emotional expressions), differs quite considerably from a dynamic model that describes changes in peer selection and preference and emotional communication over the course of years (Steenbeek & van Geert, 2005, 2007, 2008). Events on the two timescales are related: short-term peer interactions contribute to long-term changes in, for instance, peer preference and status. Long-term changes in peer status and preference, in their turn, directly contribute to the properties and unfolding of short-term interactions (see also section Timescales and Levels of Aggregation).

Finally, although the nature of the dynamics (that is, the particular form of the growth term) depends on the timescale at issue, the use of a developmental ruler is not necessarily confined to the long-term developmental timescale. Across or within action sequences, especially those that involve more demanding problem solving, people—children and grown-ups alike—may fluctuate greatly in the developmental levels instantiated in their successive actions. For instance, they may fluctuate back and forth between a purely sensorimotor approach (with no reflection at all) and a highly abstract reflective approach. These short-term fluctuations may be described by means of the same developmental ruler or yardstick that is used to describe long-term development.

**Discussion Regarding Dynamic Systems**

To summarize this discussion, in its most general form, a dynamic systems model describes the change in a state of a variable of interest, over a space of possible states, which are described by one or more dimensions that take the form of developmental rulers. We see this general definition as a starting point for the development of many kinds of specific dynamic systems models. Examples of such more specific models are *embodied-embedded action models*, which describe the immediate online emergence of behavior that takes place in a closed loop between individual and
context, which is the sort of model put forward by Thelen, Smith, Schöner, Spencer, and others (for example, Schöner & Thelen, 2006; Smith, 2005; Smith & Thelen, 1993; Spencer, Smith, & Thelen, 2001; Thelen & Smith, 1994, 1998). Another example of a specific dynamic systems model is a connectionist model, whose description of the evolution law takes the form of connectionist networks operating under specific universes of input. Yet another type of specific dynamic systems model is the type of dynamic growth model developed by the current authors. Characteristic of this type of model is that it tries to capture the principles that govern the long-term change of any sort of variable that can be of interest to the researcher (general developmental level, size of the lexicon, popularity among peers, use of correct syntactic forms, etc.).

**UNsolicited Ontological Claims**

**Terms and Potential Confusions**

Sometimes the term *dynamic systems theory* is reserved only for the first type of model, that is, the embodied-embedded action model, with the second, connectionist type viewed as a useful extension of dynamic systems in order to explain long-term changes (for instance, see Thelen & Bates, 2003; see the special issue of Developmental Science, Spencer & Thelen, 2003). The third type, which for simplicity we refer to as the *dynamic growth model*, has been criticized as metaphorical, less grounded in actual behavior and empirical data (Spencer & Schöner, 2003; Thelen, 1996).

The most serious criticism is probably that the dynamic growth model is, in fact, implicitly representational and thus not a dynamic model at all (Thelen & Smith, 1998; van der Maas, 1995; van Geert, 1996; Witherington, 2007). The representational stance, also known as the *computational-representational understanding of mind*, or *information-processing theory*, states that thinking can best be understood in terms of representational structures in the mind and in terms of computational procedures that operate on these structures (Thagard, 1996). That is, in order to explain thinking, you need internal entities.

An important issue in Thelen and Smith's dynamic systems thinking is that it enables the researcher to get rid of the internal entities hypothesis that characterized representationalist and information-processing accounts (Smith & Thelen, 1993; Thelen & Smith, 1994, 1998). For instance, a baby's searching for hidden objects is not governed by internal computations on representations and does not involve a special representation called the *object concept* (Smith, Tzitzler, & McLin, 1999). Such explanation, according to Thelen and Smith, is typical of Piaget's theory, or of information-processing theory (see also Smith, 2005). An important part of the discussions that took place during a workshop on dynamic systems hosted by the Netherlands Royal Academy of Sciences in 1997, focused on the criticism that the approach of Dutch investigators to dynamic systems, in particular growth models and catastrophe models, was in fact a version of representationalist, information-processing-like theory that revived the notion of internal representations or structures outside the actual space–time person–environment dynamics. As participants to that discussion, the current authors' view is that the criticism was based on an unnecessary identification of certain words (for instance the *object concept* or *representation*) with a particular meaning (an internal representation featured in some sort of internal information-processing machine). We feel that such an identification or interpretation is not warranted. The next two sections will provide some background for this.

**The Unsolicited Entity Claim**

In his book, *The Concept of Mind* (Ryle, 1949/2002), the British ordinary-language philosopher Gilbert Ryle (1900–1976) warned against interpreting mental terms as referring to entities in the form of mental mechanisms. Such entities are almost automatically interpreted as little machines that cause or produce the behavior seen as an expression of these mental terms. Smith and colleagues (Smith et al., 1999) provide a detailed empirical account of the processes involved in retrieving hidden and
replaced objects by babies and thus give a concrete example of the fact that the term object concept does indeed not refer to a little representational engine in the child's head, generating solutions to object concept problems in case the baby is confronted with one. What Ryle meant to say is that a mental term (such as concept, desire, and so on) tends to invoke an association with some internal entity. However, if you believe that using a mental term such as concept automatically makes you adhere to the unproved belief that it is some internal representational engine that manufactures behavior and problem solving, you are making an unsolicited ontological claim. It is a claim about the nature and existence (hence ontological) of concepts that have not been asked for; and that claim is not necessary for justifying the use of that term in natural or scientific language. (The claim is hence unsolicited.) That is, you can perfectly say that a child has a number concept, or not, without making the unsolicited ontological claim that what the child has in this case is some sort of causal entity roaming around in his mind. (Identifying a concept or representation, for that matter, with an internal entity operated upon by computational rules is an explicit theoretical choice, which one makes if one adheres to a computational representationalist approach, as in information-processing theory.) In its most fundamental meaning, concept, coming from the Latin concepere, implies an activity, namely to take in and hold, and is directly related to an Indo-European root meaning to grasp (which is still literally visible in the translation of concept in several Germanic languages). Hence, if a mental term such as concept implies any tacit ontological claim, it is more naturally related to the notion of carrying out some sort of activity with a particular result (i.e., holding) than to a notion of a causal-mental entity.

In short, colloquial words such as concept (or representation, for that matter) are relatively undefined and vague terms. In order to be used scientifically, they require further empirically supported description. One such description, the computational-representationalist choice, entails that they are like isolaible entities that produce particular behaviors and thinking. Being such entities, they exist independent of the experiences and actions in which they serve.

Another description is that they are not entities, but processes, patterns of perception and action over time, and thus do not exist independent of the actions and experiences in which they are expressed. The latter definition is clearly the one favored by a dynamic systems approach.

However, the actual use of a term such as concept or representation in scientific discourse is in principle neutral with respect to the sort of definition or description that the user wishes to assign to the term at issue. Thus, one can very well talk about the development of representations and concepts without making the implication that representations or concepts are independent entities.

The Unsolicited Internality Claim

Just like using mental terms such as concept and representation cannot be identified with implicitly making a claim that such terms refer to entities (see section Terms and Potential Confusions), the use of such terms can neither be identified with making the claim that they are entities of an internal nature, located in a person's mind (and eventually, by implication, represented in the form of a static structure in the brain). What is the nature of concept, representation, or comparable mental terms, if they are not defined as internal entities (fixed patterns, information-processing rules, etc.)?

Various chapters in this book argue that what we tend to see as mental entities—concept, representation—are in fact deeply contextual and thus not internal at all. We agree with that point of view, but not with the eventual implication that concepts, representations, and so on, as such, do not exist. What we wish to say is that by using mental terms, such as concept or knowledge, one does not implicitly make the ontological claim that these things are in essence internal and, in essence, independent of a context. In fact, all terms referring to aspects and properties of human actions, including the covert action of thinking, are, in their very origins, deeply contextual. Take for instance the meaning of grasp in "grasping a kilo of lead"
and "grasping a kilo of feathers." The form of the grasping is entirely determined by the thing grasped, and the properties that make both movements an instance of grasping do not exist in the form of literal similarities but of resemblances in terms of form-function relationships and results. In its very origin, a mental term such as concept obeys the same implicit embedding of context. For instance, if you are saying that a child has a certain concept, you are implicitly referring to a property of a child-context system, with context being the child's characteristic environment. There is no intrinsic contradiction in saying that the development of a concept in a child is in fact the development of a child-context system. The context is not independent of the person, because the person seeks certain contexts actively, constructs certain contexts actively, and perceives certain contexts actively. (We will come back to this issue in section Can Context be an Independent Variable?) By the same token, the person is not independent of the context, since what the person does and can do, feels, perceives, and so on, depends on the person's current context.

The interplay between person and context is very intricate; it is a continuous dynamic loop (a "strange loop" in the words of Hofstadter, 2007), thus giving a clear ground to the conjecture that a person is in fact a person-context system. What we mean if we speak about the person an sich (as such, in itself) are certain similarities and regularities in the person's actions that we perceive over diverse but person-characteristic contexts and over sufficiently long stretches of time (van Geert, 2002, 2004). The question is whether the observation that development applies not to persons as isolated entities but to intricately interwoven person-context structures, also implies that there is no other way to study development than to study a particular kind of model of the dynamics of person-context interaction. The study of this person-interaction loop is the topic of dynamic systems theory as defined by Thelen, Smith, Schönner, Spencer, and others, and it makes an important contribution to our understanding of thinking, acting, and development. However, from a different perspective, it is also the topic of the dynamic growth models that the authors of this chapter have articulated, which explicitly deal with how speech, concepts, and skills involve a person interacting with contexts, based on an explicitly hierarchical view of levels of skill and levels of explanation.

Complex Systems and the Superposition of Properties

We began section Unsolicited Ontological Claims with the quibbles among Dutch and Indiana adherents of dynamic systems theory, focusing on the issue of whether dynamic growth models are implicitly representationalist, thus invoking internal, independent mental entities, and in that sense, are either not true dynamical systems or primarily metaphorical. In the preceding sections, we have explained that the use of terms such as concept, representation, and the like does not logically imply the notion of internal, independent entities, and that they can just as well be used to refer to phenomena that are local, temporal processes of organism-context loops.

The question remains, however, whether this is an issue of either—or. As far as human experience and action is concerned, we are dealing with a very complex system of brain-body-environment dynamics. Such complex systems can have surprising properties, and although the matter is highly speculative, it is likely that they can be characterized by superposition of seemingly incompatible properties and duality (van Geert & Steenbeek, 2005a, 2005b, 2008). Although the comparison is certainly somewhat immodest, the entity-versus-process distinction in psychological phenomena might be comparable to the wave-particle distinction in physics. Physical objects show a wave-particle duality, for instance, properties of particles as well as of waves, which are seemingly incompatible conceptualizations. Maybe it is a good working hypothesis to conceive of the entity-versus-process debate as an inadequate conceptualization of the complexity of experience and action, which is better served by a view that presumes a form of superposition and duality of these two aspects that, at present, are not yet sufficiently understood (for alternative
conceptualizations of this issue, see Spencer & Schöner, 2003). Accepting the assumption of such superposition, however, does not mean that one also accepts that all types of models—classic entity-based process accounts such as information-processing models, dynamics systems models, connectionist models—are thus, by definition, equally valid. Validation is a matter of empirical support in addition to theoretical coherence.

EXPLAINING PHENOMENA AND TAKING LOANS FROM OTHER EXPLANATIONS

Hierarchical Levels and the Principle of Explanatory Loans

The phenomena that developmentalists deal with are hierarchically nested all the way down. Thus, the level of human biological evolution encloses the levels of historical developments of human cultures. Cultures encompass the sequences of individual life trajectories (which consist of ontogenetic processes that entail sequences of concrete actions). Life trajectories involve close person–context interactions, which in turn are based on neurophysiological processes consisting of chemical and physical processes at atomic and subatomic scales. Any of these levels can be taken as the starting point of a dynamic model, that is, a model that describes the time evolution of some variable of interest that is characteristic of the level of aggregation chosen. These levels of aggregation, or levels of description, correspond with different timescales, and different types of dynamics. Any level of description takes a loan, so to speak, on any of the other levels. For instance, a dynamic model of a phenomenon playing on the level of historical time, takes for granted the proper working of mechanisms and phenomena at the timescale of biological evolution (the level above it) and at the timescale of ontogenesis (the level below it). Similarly, a dynamic model describing evolution of variables or properties at the ontogenetic timescale, takes for granted the proper working of phenomena at the timescale of real action (involving close interaction loops between persons and their environments) and at the historical timescale of the development of cultures and cultural artifacts. But whatever one’s target level of description, there is always an implicit loan taken on other levels.

In many cases, the loan is guaranteed, in the sense that the link with adjacent levels is well understood. For instance, a biological model of population growth in a particular species is based on a good understanding of procreation mechanisms in individual members of the species. A model of particular person–context interaction (for instance, the infant’s A-not-B error) is backed up by an understanding of the way in which the brain, in principle, processes the information involved (see for instance Schutte & Spencer, 2002; Schutte, Spencer, & Schöner, 2003; Spencer & Schöner, 2003). Models of the short-term dynamics of dyadic interaction in children (for instance, in play) can be related to long-term models of the development of social status and peer selection (Steenbeek & van Geert, 2005, 2007, 2008). Models of the long-term development of complicated thought processes (such as reflective judgment or a person’s view on the self in relationships) are based on models of mechanisms in brain development (involving the formation of new neural networks for each developmental level; see Fig. 16.1; Fischer, 2008; Fischer & Bidell, 2006).

An Example: A Dynamic Growth Model of Language Development

Although the availability of conceptual links to underlying (or, for that matter, overarching) levels of explanation, such as the brain level in models of action, significantly contributes to the explanatory value of the model at issue, the availability of such links is not a sine qua non for scientific explanation, as such. Take, for instance, the acquisition of words and the development of the lexicon. The first author of this chapter has formulated a model of long-term lexical development (and early language development, in general) based on dynamic principles of growth (for instance, see van Geert, 1991, 1993, 1994). These principles have been inspired by general biological principles of growth featured in population ecology, in which they have a firm biological basis (Kingsland, 1985). The application of these principles to developmental
psychology is thus metaphorical in the literal sense of that word, meaning that these principles have been carried over from another field. To put it differently, there is a loan from another scientific discipline, population ecology. How can the loan be paid back?

We can pay our debts by showing that the growth dynamics provide a parsimonious, spare, generic, and justifiable theory of lexical and language growth. It is a simple or parsimonious theory in that it says that the change in some linguistic variable (e.g., the lexicon) over time, \( \Delta L \), is a simple function of the level already attained, \( L \), and of a limited set of resources, \( C \), that can be treated as a constant. In the case of the lexicon, a crucial aspect of the resource constant is the lexicon used in the environment to the extent that it is accessible to the child. Finally, \( \Delta L \) depends on a set of coupled variables, \( V \), that can be of any type and that can either favor or counter the growth of \( L \).

The elementary format of the model can be written as \( L_{n+1} = L_n + \Delta L_n \) with \( \Delta L_n \) (i.e., the change in \( L \)) being equal to \( f(L_n, C, \{V_i\}) \) (with \( f \) meaning is a function of).

In the simplified condition where there are no interacting variables, \( \Delta L_t \) is calculated based on the Verhulst growth equation, which takes the form \( \Delta L_t = r L_t (1 - L_t/C) \). The effect of additional variables, e.g., variable \( V \), can be
expressed as $m L$, $V_0$. The parameters $r$ and $m$ are growth parameters, and by convention, $r$ refers to the basic growth parameter affecting $L$ (see van Geert, 1994; Fischer & Bidell, 2006).

It is a generic theory in that it offers an approach to a wide variety of phenomena (e.g., various kinds of linguistic and cognitive variables) that can be given a concrete form by specifying the variables at issue and the exact ways in which they relate to each other, by estimating the values of the interaction parameters.

Finally, it is a theory that can be justified in various ways. First, we can show that the general principle of $L - C - [V]$ dependence is supported by the available theoretical and empirical literature, for instance, on lexical acquisition or the growth of sentence length (see for instance Bassano & van Geert, 2007; van Geert, 1991, 1994; van Geert & Steenbeek, 2005a, 2005b). Second, we can link these principles to an analysis of the underlying biology; that is, a model of how the brain accomplishes the task of learning new words (Fischer, 2008; Fischer & Bidell, 2006). Third, we can show that specific models based on these general principles of growth provide good predictions of qualitative and quantitative properties of developmental processes. For instance, nonlinear dynamic growth models have predicted developmentally discontinuous trajectories at high growth rates and smooth trajectories at low growth rates, consistent with the data (Fischer & Kennedy, 1997). Another model has predicted normative developmental functions for various capacities in a domain with socioeconomic differences in the functions (Case & Okamoto, 1996). Nonlinear growth models generate patterns of stepwise growth, including temporary regressions, which are consistent with data from various academic fields (Fischer & Bidell, 2006). In particular in the field of language development, dynamic growth models explain the quantitative forms of the empirical growth curves. Examples include early lexical development (van Geert, 1991, 1993, 1994), lexical development in relation to growth of plurals (Robinson & Mervis, 1998), growth of closed-class words (Ruhland & van Geert, 1998), and pattern of growth and decline of sentences of various lengths (Bassano & van Geert, 2007; see Fig. 16.2).

By extending the growth model (which represents the level of a variable by a single vector) to a vector field model (which represents the level of a variable as a wave of levels), a variety of empirical developmental phenomena can be predicted, including discontinuous change, temporal multimodality, temporal increase in variability during a period of rapid transition, overlapping waves of development, and so forth. (For an explanation of the model and an extensive overview of the empirical data that the model explains, see van Geert, 1998b).

Description, Explanation, and the Dynamic Systems Backpack-Traveler

A possible objection against dynamic growth models is that they are basically descriptive, in spite of their claims that they explain something, for instance, trajectories of developmental variables (see the preceding section). However, it is important to note that the term explanation always has a model-specific meaning: a dynamic growth model explains a developmental trajectory through the iterative application of a transformation function, entailing the principles of growth as specified above. Like any other model, it confines its explanatory concepts to an elementary set that it sees as fundamental to its particular form of explaining. By doing so, any model takes a loan on other forms of explanation that further ground its fundamental concepts; we have already expressed this point of view in section Hierarchical Levels and the Principle of Explanatory Loans. For instance, a dynamic growth model of lexical growth takes a loan on the possibility of connectionist models explaining its principles of growth by invoking networks processing inputs (an example of such a model is given in Davis, 2003). A connectionist network takes a loan on models explaining how the brain implements the network's connectionist structure and processes. This process of taking loans continues to other disciplines.

The discussion on whether a model is explanatory in a nontrivial sense often relates to at least one of the following assumptions. The first assumption is that it matters to which deductive principle or mechanism the model is referring. A statistical regression model explaining
Figure 16.2. Dynamic growth model: Changes in word length of spontaneous sentences
This figure depicts changes in the frequencies of sentences of one, two, three, or more words in the spontaneous language production of a French-speaking girl, Pauline (after Bassano & van Geert, 2007). The frequencies relate to the emergence and eventual disappearance of three types of underlying linguistic rule systems (holophrastic, combinatorial, and syntactic rules). A dynamic growth model based on principles of conditional precursor, competitive, and supportive relationships has been fitted to the data (unmarked lines following smoothed data lines).

The development of some function by means of a polynomial of time is less theoretically convincing than a model explaining that same curve by reference to a mechanism that looks like a working brain, or, for that matter, a model that takes the preceding step as an explanation for the next step in the curve. (There are no well-established models that link pure temporal duration and the square of temporal duration directly and causally to word learning; duration matters in so far that it allows for a certain iteration of working principles, such as learning, changing of weights in a network, and so on.)

A second assumption refers to the fact that levels of explanation are hierarchically nested. (Such levels are often associated with different timescales, for instance, on the level of development, of real-time action, or of brain processes; see the preceding section and the following sections for further explanation.) According to basic reductionism, any primitive or unanalyzed element at a particular level of explanation is a thing to be explained by yet more primitive or elementary principles at some underlying level. A particularly appealing feature of the theory of complex dynamic systems, however, is its anti-reductionist nature. That is, any particular level of explanation has its own reality and cannot be reduced to the workings of lower levels. An understanding of some level of explanation—ontogeny, for instance—can be deepened, but not replaced, by an understanding of a lower level of explanation—the level of real-time action, for instance. In addition, levels are interconnected, in the sense that an understanding of one level—processes that take place on the timescale...
of ontogeny, for instance—is not only deepened by an understanding of a lower level—real-time action, for instance—but also by an understanding of a superordinate level—cultural history, for instance. In this sense, any explanation exists by virtue of leaving some things unexplained, namely things that are the topic of investigation for another level of explanation.

We have already seen that the principles featured in nonlinear dynamic growth models can be grounded on connectionist explanations. Why not replace such growth models by the connectionist models, then? The answer is that we see a dynamic systems model of long-term change and development as a traveler who travels lightly, with only the barest necessities in his small backpack. Such a person travels fast and may see a lot of the world, having the disadvantage that he can stay anywhere no longer than a little while. To put it more concretely, a dynamic systems model of long-term change may model the interactions among many components of a developing system, including the interactions and adaptations of educators and instructors. By doing so, the model builder uses a model that is relatively simple to construct to study the qualitative and quantitative properties of change, the nonlinearities and stabilities that emerge, and so forth. It is true that each and every component of that model can, in all likelihood, be replaced by a connectionist network that analyzes the working of each dynamical step in terms of changes in underlying network connections. However, building such a model will require hard labor; before doing this, the researcher might wish to study the general properties of the system through a much simpler dynamic model that captures the same general principles of change as those that emerge from the connectionist supra-model.

**TImescales and Levels of Aggregation**

**Units of Developmental Description and the Forces That Hold Them Together**

There is a wonderful book and movie called *Powers of Ten* (Morrison & Morrison, 1982; Office of Charles & Ray Eames, 1978; Office of Charles & Ray Eames, Demetrios, Mills, & Demetrios, 1990) that takes the reader on a journey through the universe, from the smallest possible levels of quantum-mechanical phenomena to the greatest possible astrophysical objects. As the reader turns the pages, as if turning a focus button of a giant microscope-telescope (or mite-scope, pronounced as "mighty-scope"), several levels of aggregation pass by the reader/viewer. The reader/viewer see clusters of galaxies and separate galaxies, held together by the long-distance forces of gravity at the cosmological level, and then moves to distinct celestial bodies, for instance our own earth, on which one can observe separate layers of organization that become ever smaller and smaller as they zoom in to the subatomic level. What is interesting is that during our journey we discover aggregations or assemblies held together by specific interaction principles that apply to the level of magnification at issue. (Well-known physical interaction principles are the fundamental forces of gravity, electromagnetism, and strong and weak forces.) At one point as we move along the magnitude scale, we discover human cities, dwellings, and human beings themselves. In order to understand aggregations at the social and behavioral level, we must take into consideration that the aggregating forces are quite complicated emergent phenomena, such as the human laws, customs, artifacts, and so forth that hold people's activities and living spaces together.

However, the principle is that throughout our journey across the universe we encounter changeable assemblies that consist of ever smaller nested assemblies. The interactions that constitute the assembly in question (pick any one you like) vary from very strong to very weak (or soft, if one prefers that word); interactions are thus, to various extents, subject to external perturbations. What matters, however, is whether the assemblies in question are sufficiently stable across time and whether the reproduction of these assemblies occurs with sufficient stability and similarity. (Think of weak assemblies such as biological organisms; think of even weaker assemblies such as human action patterns, perhaps an infant acting in an A-not-B error situation.)
DYNAMIC SYSTEMS AND THE QUEST FOR INDIVIDUAL-BASED MODELS

This basic issue raises a fundamental question about development and learning, which we have addressed in research on transient knowledge (a common state) and on how it can be transformed through dynamic growth processes into robust knowledge, which can be used with some stability across many contexts (Fischer, Bullock, Rotenberg, & Raya, 1993; Rappolt-Schlichtman, Tenenbaum, Koepke, & Fischer, 2007). In short, what emerges through development are similar to force-relationships, to put it somewhat metaphorically, that temporarily bind the components of characteristic assemblies (e.g., characteristic forms of problem solving, of acting, and so on) as they are formed in and through particular contexts.

As developmentalists, we can also look at the human life span and beyond by means of a mitescope that focuses on ever smaller (or greater) timescales, ranging from the timescales necessary to describe what happens at the level of neurons and synapses to the timescales necessary to describe what happens at the level of historical societies and human evolution. As we turn the focus button of this timescope, we will encounter aggregations, or assemblies, based on specific interactions or forces that apply to the particular timescale we are focusing on currently. These assemblies are, to various degrees, strong or weak, but again the question is how successful the assembly or aggregation is in terms of duration or reproducibility. At the timescale of concrete action, we find soft but relatively durable and reproducible assemblies that take the form of particular actions, such as the much-investigated A-not-B error action-context pattern, holding a conversation with another person, or reading the abstract of a paper in an electronic database. At longer term timescales, we are able to observe certain regularities among the actions that people perform, regularities that we can describe by means of terms such as concept, reflective judgment, understanding of relationships, personality, and so forth. The meaning of these terms applies, of course, to the level of aggregation or assembly for which they are intended, and we should be aware of making any category mistakes regarding the use and meaning of these terms as discussed in the preceding sections.

The Notion of Development as Relating to Person–Context Assemblies on Various Timescales and Levels of Aggregation

Several chapters in this book argue that psychological phenomena such as thinking and acting, if treated at the real-time level, can only be accounted for if the mutuality of person and context and the soft assembly of person–context aggregations is taken as a central feature (for a comparable discussion from the perspective of dynamic skill and dynamic growth models, see, for instance, Fischer et al., 1993; Fischer & Bidell, 2006; Van Geert, 2002). However, dynamic growth models of development focus on the growth of the lexicon, for instance, and not explicitly on word use in context. One may thus easily suspect that growth models refrain from incorporating the context by focusing on variables internal to the person. However, as we stated in the sections on unsolicited ontological claims, the implication that psychological variables such as lexical knowledge are internal entities is a theoretical choice that we do not make. Variables such as a child's level of lexical knowledge or of reflexive thinking always and by definition refer to person–context assemblies, that is, to aggregations of a person in his or her characteristic contexts.

If we then speak about the development of the child, we actually refer to long-term changes in the child and automatically also to the corresponding long-term changes in the child's contexts. These changes refer primarily to patterns of correlation over time (that is, in a single person's life trajectory) and not to identifiable entities. That is, development refers to a person–context assembly throughout the life span; contexts are no longer to be seen as independent variables or circumstances in which the person can be placed at pleasure, according to the whim of a researcher who treats such contexts as independent variables, the effect of which has to be estimated over many subjects.

The long-term assembly of person and context refers to the person in his characteristic multitude of contexts and not, as the short-term
dynamics requires for its description, the here-and-now assembly of the person and a specific temporary context. The characteristic multitude of contexts differs for a young child and an adult, for instance. For the young child, the characteristic contexts will be the family, the play relationships with peers, and a particular type of school. (In underdeveloped countries, the characteristic context of many children will not include the school, but the context of child labor, for instance.) For an adult, the family context will be an entirely different one than for the child because the adult stands in the context as caretaker and provider. A characteristic context for the adult is the professional context. Persons may differ in their characteristic contexts as they may differ in their organismic characteristics, including intelligence, temperament, and so on. The person–context assemblies over the long term are also soft assembled in the same way person–context assemblies are soft assembled in the context of short-term individual actions and thinking processes.

Can Context be an Independent Variable?

As stated earlier, the apparent softness or weakness of the association between a person and the person's characteristic contexts should not lure us into thinking that contexts are to be treated as an independent variable and not as genuine properties of the person himself. For instance, one might say that it is very easy to change a person's job (an external context) and very difficult, if not impossible, to change a person's temperament (an internal property). In reality we see that in both cases—jobs and temperaments—interactions and forces are at work that keep the associations relatively stable (although those forces are different for the job than for the temperament). Adults may change jobs, for instance, and children may change schools, but in many cases the change is relatively superficial; what remains is a very similar context as far as functionality and psychological meaning of the context for the person concerned. This idea brings us very close to the notion of Umwelt by Jakob von Uexküll (1864–1909; Von Uexküll, 1909/2001) and Thomas Sebeok (1920–2001; Sebeok, 2001; see also Kull, 2001a, 2001b, including the special issue of Semiotics, 134, 2001). Von Uexküll defined Umwelt (literally "surrounding world") as the organism's experienced environment, the qualities of which are cogenerated by the organism's senses and activities and the organism's interests and concerns. (The notion comes close to Lewin's notion of psychological life space (Lewin, 1936/1966). The notion of Umwelt implies that contexts and environments are inextricable entanglements of physical and psychological forces; and thus, context is never to be treated as independent of the organism or person.

With regard to specifying dynamic growth models, it is important to realize that persons and contexts (essentially, multitudes of contexts) are glued together in different ways. The person actively seeks certain types of contexts and by doing so actively extends the person–context association over the long term. Some persons may actively assign contexts to other persons, such as parents who send their children to a school of their choice. Contexts are dependent on the person: the context as it functions for the person is the perceived context. For instance, a book is a physical context with very special properties simply because the person has learned to read and has, thus, learned to see the physical symbols in the book as information of a very different kind than that included in the mere physicalness of the letters and words. People are bound to certain contexts through (legal) laws, ethics, customs, and so forth. People are bound to certain contexts because they need these contexts to achieve their goals. As an example, modern-day scientists have invested part of their memory into the hard disks of their computers and part of their intelligence into the processing capacities of statistical programs. As a further example, truck drivers have invested their physical carrying force into powerful trucks. Just as there are dynamic forces that keep our internal properties together—our intelligence, personality, and so on—there are dynamic forces that keep us and our characteristic contexts together. Such forces move us and our contexts along the path of development, stability, and change.
Developmental Changes in Person–Context Assemblies

The person–multiple context assemblies that form the subject of developmental statements and theories change over developmental time, but never cease to exist as person–context assemblies (with context codefined by the person's senses, skills, interests, and so on). This observation has several implications for developmental research. One implication concerns the issue of assessment or measuring a person's developmental level (or any other psychological property, for that matter). For instance, if we wish to specify a person's level of thinking or understanding at a particular moment in the person's life, we cannot do so without specifying a particular context into which this level is assessed. By definition, the assessment will refer to the person–specific-testing–context assembly. However, the person is characterized by the fact that there exists a multitude of contexts in which his thinking skills can manifest themselves. Trivially speaking, the number of such contexts is quasi-infinite; however, the number of contextual distinctions that really matter (that is, that have functional significance) is relatively limited because they are constrained by organismic properties, such as the person's senses, skills, interests, brain, impairments, and so on. Thus, we can specify the person's developmental level of thinking in a state space that reckons with the contextual dimensions that really matter. In a developmental perspective, one contextual dimension involves the support of other persons (others helping the individual person solve a particular question, giving suggestions, etc.). Another contextual dimension involves the person making use of material and physical supports and contexts in a relatively autonomous way, without apparent help by others. If we see the person and the context as an assembly, a diagnostic assessment of the person's developmental level of thinking must thus be specified in terms of a state space which is at least two-dimensional, namely his functioning with help and without help (Fischer & Bidell, 2006).

A second implication is that the nature of the relationship between person and context changes as a result of development. We already mentioned the change from transient knowledge (that relies on contextual support) to robust knowledge (that remains stable across many contexts; Fischer et al., 1993; Rappolt-Schlichtman et al., 2007). In the transition from transient to robust knowledge, the need for contextual support (perhaps from a more competent person) will gradually diminish (e.g., through diminishing scaffolding, see van Geert & Steenbeek, 2005b). On the other hand, as a consequence of developing skills, the context may gradually become more supportive. For instance, as a child learns to read; written signs available in the context become accessible to the child, giving support to more complicated forms of thinking (e.g., the use of written schemes/texts). This aspect of development has been the focus of distributed cognition approaches (e.g., Clark, 2006; Clark & Chalmers, 1998).

In summary, we must accustom ourselves to reading phrases such as “the development of the child” as shorthand for statements about the development of [child][characteristic-contexts] assemblies and about the emergence of long-term correlational patterns in the life trajectory of individual persons and their Umwelts (e.g., their continuously and dynamically constructed life spaces). These statements refer to the long-term dynamics of such assemblies and consider these assemblies as the proper units of analysis or description.

Developmental Rulers and Building Dynamic Systems Models of Developmental Change

Developmental Rulers and Contexts of Assessment

In section Can Context be an Independent Variable?, we have seen that in order to describe a process as a dynamic system, one needs a metric or dimension to describe different states of a phenomenon that one is interested in. The best possible metric is formed by the line of real numbers; this enables one to describe a process in the form of Cartesian coordinate space. Cartesian coordinates are great for describing
movement, but the most important characteristics of behavior in development and education involve cognition and emotion, not movement. A simple counting of correct or incorrect answers on a cognitive test, for instance, isn’t appropriate. What we need is a developmental scale that works across tasks and domains, that is, a developmental ruler. Research must deal with scaling issues directly, such as by testing scales under several conditions. We can get at such developmental scales by studying developmental webs.

What do we mean by developmental webs? Development and learning take place along many parallel, independent strands that have similar properties but separate structures/contents. Examples of such strands are a child’s skills in and understanding of social relationships, understanding of numerical problems, mastery of technological tools, ability to follow stories and story lines, and so forth. In a developmental web (Fig. 16.3), discontinuities may emerge that reflect new capacities emerging in common zones across strands. Clusters of discontinuities mark a universal developmental scale. That is, across disparate skills we may find one scale, for instance, a single underlying developmental ruler.

The scale or ruler not only applies to disparate skills, but also shows a developmental range, which depends on the context in which the skill at issue is put to work. As in Vygotsky’s (1978) zone of proximal development, there are differences between unsupported and supported levels of skills. In that sense, there is no single competence, not even for a domain (see also section Developmental Changes in Person–Context Assemblies). A child’s developmental level achieved under conditions of little or no external support (this we call the functional level) differs from the child’s level assessed under conditions of support that primes complex behavior (this we call the optimal level) in the following ways. First, the child’s level of growth is higher in the optimal/high support condition (Kitchener, Lynch, Fischer, & Wood, 1993). Second, optimal levels show qualitative properties that functional levels do not show, such as growth cycles and recurrent discontinuities. The distinction
From 2 to 30 years of age, 7 stages in the development of reflective judgment can be observed (see Fig. 16.4 based on studies by Kitchener & King, 1990; Kitchener et al., 1993). Briefly, the first stages entail absolute knowledge: a right or wrong judgment. Later stages involve relative knowledge, in which truth varies with perspective. Final stages imply true reflective judgment: truth depends on argument and evidence. These 7 stages are not stages in the classic developmental sense, that is, they are not identifiable discrete phases (such as being in stage 1 from age a to b, in stage 2 from age b to c, and so forth). Here, stages correspond to steps in the progression toward reflective thinking. For example, in stage 6 a person understands that although knowledge is uncertain, strong justified conclusions can be made across domains viewpoints based on evidence and argument. In high support assessment conditions, where the subjects’ more complex behavior is primed through suggestions (e.g., questions), some subjects will provide answers at stage 6, but without support, they exhibit behavior/arguments consistent with stages 4 or 5. The stage 6 knowledge is transient (that is, exists by virtue of the support given, but does not last if the support is withdrawn), while the stage 4 or 5 knowledge is more robust. Hence, the stage is not a fixed point that a person occupies, but is rather a point on a scale—a tick mark on the developmental ruler—along which the person’s skills vary in both long-term development and short-term performance. (For an example regarding changes in linguistic level across days, see van Geert & van Dijk, 2002.)

Developmental Rulers and the Space of Development

The relationship between the developmental steps—the ticks on the developmental ruler—and the geometrization of developmental space needed for the application of dynamic systems models is not trivial. The stages amount to a hierarchical growth pattern and, consequently, the scale or ruler is a hierarchical complexity scale. It can be used in different ways, to show and underlie different types of developmental patterns.
First, as we explained earlier, stages can be used as tick marks on a single developmental ruler, thus measuring the successive developmental levels found with a particular type of assessment in a particular developmental domain (e.g., support assessment of reflective judgment). A nice example of a developmentally relevant pattern captured by employing the developmental ruler in this fashion is the scalloping pattern one can observe across a series of repeated activities, where a person (or a dyad) tries to build a skill for solving a particular type of problem (Fischer, Yan, & Stewart, 2003; Granott, 2002). The person moves back and forth between widely diverging developmental skill levels. What happens, functionally, is that a person is repeatedly moving down to a low level and then rebuilding skills. This repetition contributes to the emergence of a consolidated, general skill—robust knowledge—and provides a key to the plasticity of human behavior.

Why would one need regression in development? The problem is that developmental levels show hierarchical relationships and that higher levels depend on the organization of their lower level components; for instance, representations as higher order patterns require coordination of sensorimotor patterns. If a higher level pattern (e.g., a representation, or, at a still higher level, an abstraction) does not work in a given problem context, it needs to be reworked or reorganized; in so doing, one needs to be able to move down to the lower level component patterns and reconstruct the skill (Fischer et al., 1993). In fact, what is often viewed as a critical period (that is, a period beyond which certain developments are no longer possible), arises when we cannot move down and reorganize.

Second, the stages or skill levels that are used as tick marks on a developmental ruler can also be used as developmental dimensions in their own right. Each skill level acts as a developmental grower, increasing its quantitative level over time, eventually showing temporary regressions. A series of three successive skill levels, for instance, can be represented as three growth curves, modeled in the form of a coupled system (van Geert, 1991, 1994; Fischer & Kennedy, 1997; Fischer & Bidell, 2006). Alternatively, the developing system can be seen as a single point in a state space described by the three skill levels, which function as dimensions of the state space. Based on the simplified growth equation explained in section An Example: A Dynamic Growth Model of Language Development, the relationship between the growers can be described and modeled as a dynamic system of the form \( x_{t+1} = f(x_t, C_x, y_t, z_t) \), \( y_{t+1} = g(y_t, C_y, x_t, z_t) \), and \( z_{t+1} = h(z_t, C_z, y_t, x_t) \). The symbols \( x, y, \) and \( z \) refer to the three hierarchical growers in question, and \( C_x, C_y, \) and \( C_z \) the support or resource constants for \( x, y, \) and \( z \), respectively. The functions \( f, g, \) and \( h \) are the dynamic functions that describe how a next state of a grower, for instance, \( x \), is affected by its preceding state and the preceding states of the coupled growers \( y \) and \( z \) (details have been explained in a variety of publications, see Fischer & Bidell, 2006; Fischer & Kennedy, 1997; van Geert, 1991, 1994, 2003; van Geert & Steenbeek, 2005a, 2005b). Basically, these dynamic functions imply (a) that the quantitative change in a grower over some time interval is proportional to the level already attained, (b) that it depends on limited resources and thus levels off as the resource level is approached, (c) that growers are either positively or negatively affected by the growth in other growers, and (d) that the onset of growth can depend on the presence of a precursor. These relationships can be mathematically modeled fairly easily if the growth of each variable is represented by a single vector. The modeling is more complicated if growth is represented by a vector field (van Geert, 1998a, 1998b), although the vector field models yield interesting discontinuous patterns in addition to continuous ones and can explain a host of empirical developmental phenomena.

**Conclusion: Evaluation of Dynamic Growth Models**

The patterns generated by the dynamic growth models have been repeatedly found in a variety of skills and developmental domains as well as in development of brain electrical activity. In that sense, empirical data provide good support for the underlying dynamic models. As noted earlier, we have begun to create knowledge of how
these growers—hierarchical skill levels—are physically instantiated; that is, how exactly they are represented in the brain and in the supportive, cultural contexts that make them possible. In this sense, we are moving toward founding the dynamic growth models from the bottom up; that is, we are working from the underlying physical principles up to the level of the model. In addition, the principles of support, competition, and precursors that are used in these models are firmly grounded in dynamic skill theory and various other theories of development and are, therefore, far from accidentally selected. Moreover, developments in brain research and neuroimaging provide further circumstantial evidence of the validity of the underlying principles.

In this context, dynamic growth models have one major advantage over some of their theoretical competitors, in that they are able to subsume a wide variety of developmental phenomena under a common general framework based on a small set of universal and simple principles of interaction among variables. For example, similar models explain growth patterns for reflective judgment concepts and brain activity (Fischer, 2008). As we stated earlier in this chapter, however, explanation is multi-leveled, and having an explanation on the level of, say, dynamic growth models, does not preclude the need for a different sort of explanation by means of connectionist models or neurocognitive models. The reality of development is too dynamic and nonlinear to be captured fully under a single theoretical framework. As with development itself, scientific understanding progresses by coordinating and by integrating perspectives, by decomposing and recomposing our insights in order to arrive at ever more powerful and richer explanations of the patterns of developmental change.

References


