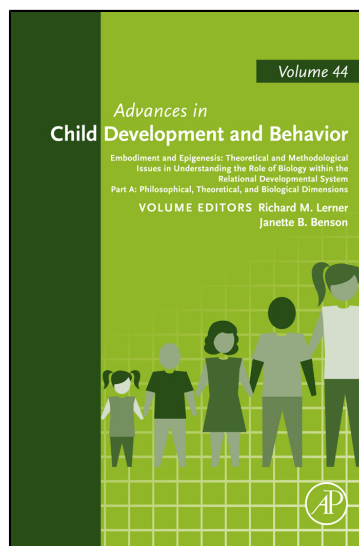


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# Emergence, Self-Organization and Developmental Science

Gary Greenberg<sup>\*,1</sup>, Kristina Schmid Callina<sup>†</sup>, Megan Kiely Mueller<sup>†</sup>

<sup>\*</sup>Department of Psychology, Wichita State University, Wichita, KS, USA

<sup>†</sup>Eliot-Pearson Department of Child Development, Tufts University, Medford, MA, USA

<sup>1</sup>Corresponding author: E-mail: Gary.Greenberg@wichita.edu

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## Abstract

Our understanding is that psychology is a biopsychosocial science as well as a developmental science. Behavioral origins stem from ontogenetic processes, behavioral as well as biological. Biological factors are simply participating factors in behavioral origins and not causal factors. Psychology is not a biological science; it is a unique psychological science, a natural science consistent and compatible with the principles of the other sciences. Accordingly, we show in this chapter how principles and ideas from other sciences play important roles in psychology. While we focus on the concepts from physics of self-organization and emergence, we also address the cosmological and evolutionary biology idea of increased complexity over time, the organizing principle of integrative levels, and the epigenetic processes that are in part responsible for transgenerational trait transmission. Our

discussion stresses the developmental science concepts of embodiment and contextualism and how they structure thinking about psychological processes. We conclude with a description of how these ideas support current postpositivist conceptions of relational processes and models in contemporary developmental science.



## 1. INTRODUCTION

While many scholars still prefer to identify psychology as a social science, we believe that this descriptor has done our science a disservice, suggesting it is a “soft science”. Indeed, a recent *New York Times* article suggested that the social sciences suffer from “physics envy”: “... the social sciences need to overcome their inferiority complex, reject hypothetico-deductivism and embrace the fact that they are mature disciplines with no need to emulate other sciences” (Clarke & Primo, 2012, p. 8). After all, there is simply science and nonscience. We come from traditions that understand psychology to be a natural science, consistent and compatible with the principles of all the other natural sciences.

From this perspective, behavior is as natural a phenomenon as rolling balls down inclined planes was for Galileo. Since adopting the methodology of science in the late nineteenth century, psychology has been influenced by ideas from the other sciences. At first, this influence manifested itself in the use of the atomistic metaphor of structuralism, the identification with positivism and the reliance on Western science’s materialism and a clockwork universe (Boring, 1950). Later, functionalism drew on ideas from Darwinian evolution (Benjamin, 2007; White, 1968). The twentieth century is understood by many to be the century of behaviorism: materialistic, positivistic, and reductionistic (e.g., Baum, 2005; Benjamin, 2007). Accordingly, B. F. Skinner has been identified as the most eminent psychologist of the period (Haggbloom *et al.*, 2002).

Just as this nineteenth and twentieth century approach in physics and the other sciences has failed to live up to its initial promise and has given way to a more holistic, field-oriented and contextual paradigm (Davies & Gribbin, 1992; Goodwin, 1994; Kauffman, 2000; Sheldrake, 1995), some in psychology too have begun to give up their adherence to an old-fashioned science in favor of this newly emerging scientific perspective (e.g., Chorover, 1990; Lerner, 2006). Thelen and Smith (1994) go so far as to suggest that we “... are in the midst of a paradigm shift” (p. 339). Overton and Lerner (2012) have made a similar claim. Indeed, Overton and Müller (2012) point

out that psychology has now taken a more postpositivist and relational stance—becoming a process-oriented rather than a substance-focused discipline—characterized by a relational developmental systems approach linking individuals to context in a nonrecursive mutually influential manner across history. That the Relational Developmental Systems model we favor in this chapter represents a paradigm shift is made abundantly clear by Overton's (2012) comprehensive review of the evolution of paradigms in science, and especially in psychology.

As Lewis and Granic (1999) point out, conceptualizations from the other sciences have often been imported into psychology. Indeed, “Modern psychology, from its inception, has been informed by ideas imported from related fields of inquiry” (Moore, 2008, p. 327). Structuralism, for example, had seeds of the atomic theory of matter and biology, and functionalism (and Freud's, 1954, psychoanalysis) drew from Darwinian evolution. It is now beyond question that principles from other sciences have relevance for understanding many of the phenomena of psychology. Early discussions of this integration include how thermodynamics and evolution affect behavior (Swenson, 1998) and how physics can help us understand aspects of locomotor behavior (Kelso, 1995; Vogel, 1998). Thelen and Smith (1994) show how “... new forms of behavior can arise during development in a self-organizing manner, consistent with the universal laws of physics...” (p. 129).

This newer perspective in science, and its extremely broad application, can be summarized as follows:

*... since the 1960s, an increasing amount of experimental data ... imposes a new attitude concerning the description of nature. Such ordinary systems as a layer of fluid or a mixture of chemical products can generate, under appropriate conditions, a multitude of self-organisation phenomena on a macroscopic scale – a scale orders of magnitude larger than the range of fundamental interactions – in the form of spatial patterns or temporal rhythms.... [Such states of matter] provide the natural archetypes for understanding a large body of phenomena in branches which traditionally were outside the realm of physics, such as turbulence, the circulation of the atmosphere and the oceans, plate tectonics, glaciations, and other forces that shape our natural environment; or, even, the emergence of self-replicating systems capable of storing and generating information, embryonic development, the electrical activity of the brain, or the behavior of populations in an ecosystem or in economic development.*

**(Nicolis, 1989, p. 316).**

While psychology comes late to a full-blown adoption of the principles associated with self-organization phenomena, there are seeds of these ideas in the writings of Z. Y. Kuo on epigenesis (1967), J. R. Kantor on interbehaviorism (1924, 1926, and 1959), T. C. Schneirla on integrated behavioral levels (Aronson, Tobach, Rosenblatt, & Lehrman, 1972; Schneirla, 1949), and Gilbert Gottlieb on probabilistic epigenesis (1984, 1992, and 1997). Biologists such as Brian Goodwin (1994) and Stuart Kauffman (1993, 1995) have elucidated the linkages between developmental psychobiology and newly emerging concepts of complex adaptive systems and self-organization (Prigogine & Stengers, 1984). This way of thinking is now even playing a role in medicine (Ahn, Tewari, Poon, & Phillips, 2006). In psychology, this integrative approach is the hallmark of developmental psychobiology (e.g., Michel and Moore, 1995), developmental systems theory (e.g., Ford & Lerner, 1992; Oyama, Griffiths, & Gray, 2001), and probabilistic epigenesis (Gottlieb, 1984, 1992, 1997). In this context, the assessment by Lewis and Granic (1999) is telling: "It is particularly fortunate that psychologists are exploring ideas of self-organization while they are still congealing in biology and the other sciences. This fulfills a long-standing wish for currency and parity with the sciences at large" (p. 369). Although these ideas originated in the physical sciences, Gell-Mann (1995) recognized their wider application: "Even more exciting is the possibility of useful contributions to the life sciences, the social and behavioral sciences, and even matters of policy for human society" (p. 322). Haken (1993, 1994) speculates that all the following can be seen to emerge from the principles of complex adaptive systems and self-organization: language, national character, ritual, form of government, public opinion, corporate identity, and social climate. As we discuss later, many other aspects of behavior also emerge from these principles.

There are three crucial linkages among the diverse components of complex adaptive systems: (1) the important organizing principle of integrative levels (e.g., Novikof, 1945), (2) the tendency toward increased complexity with evolutionary advance (Saunders & Ho, 1981), and (3) the contextual nature of behavioral events (Elder, 1974, 1980; Lerner, 1991). The synthesis of these three ideas leads to a developmental perspective in which behavior is seen to be the result of the fusion of biological and psychosocial factors, driven by probabilistic epigenetic events rather than by preprogrammed genetic or other biochemical ones (Gottlieb, 1992, 1997; Kuo, 1967). The physics model of this perspective is referred to as "nonlinear dynamic systems theory". Used in psychology, it provides a theoretically consistent language

with which to describe and analyze behavioral development (Michel & Moore, 1995; Novak, 1996).

For example, concepts of nonlinear systems from physics bear directly on our contemporary understanding of psychological development (e.g., Overton & Müller, 2012). These concepts pertain to the ideas of *system* (that the parts of organisms function interdependently and that behavior is a *process*, and not a substance or “thing” of the system), of *hierarchy or directionality* (as a fundamental principle of science that the universe exists as a family of hierarchies in which natural phenomena exist in levels of increasing organization and complexity), of *emergence and self organization*, and of *epigenesis*, described later.

One of the authors has earlier identified how the ideas of emergence and self-organization in physics and of evolution and microbiology in biology are helpful in understanding the aspects of behavioral development (Greenberg, 2011; Greenberg, Partridge, & Ablah, 2006; Partridge & Greenberg, 2010). This chapter discusses these ideas fully, especially as they relate to developmental science in general; psychology is, after all, a developmental science (Greenberg, Partridge, Mosack, & Lambdin, 2006). The significance of the idea of emergence for psychology is that “Emergentism is a form of materialism which holds that some complex natural phenomena cannot be studied using reductionist methods” (Sawyer, 2002, p. 2). For us, in this chapter, the implication is that psychological phenomena cannot be reduced to biological factors such as genes and brains (e.g., Greenberg, 2011).

Our intention in this chapter is to demonstrate, from both phylogenetic and ontogenetic perspectives, how concepts such as epigenesis and embodiment are useful in understanding the nature and course of individual development. We begin by reviewing factors that contribute to the ontological structure of psychology. We then discuss emergence, evolution, and epigenesis as means for understanding the nature of structural transformation in human development. Finally, we describe how these ideas support current postpositivist conceptions of relational processes and models in contemporary developmental science (e.g., Overton, 2010).



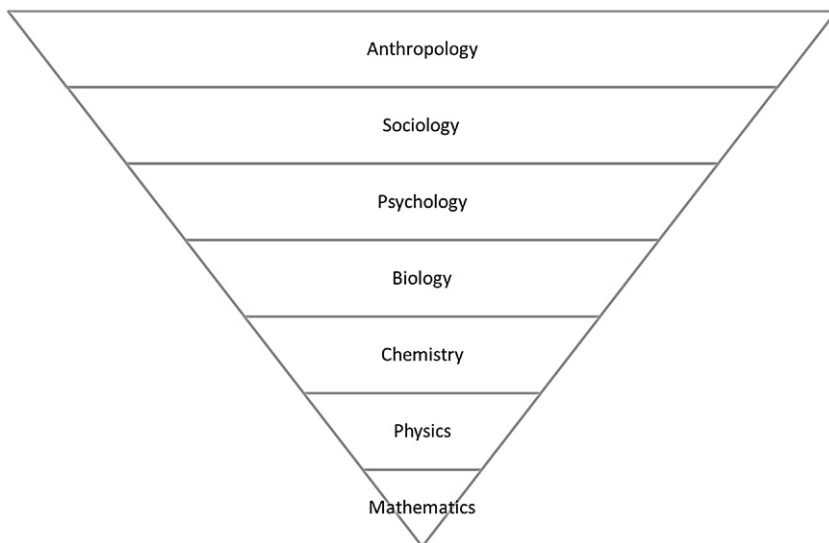
## 2. ONTOLOGICAL STRUCTURE OF PSYCHOLOGY

Our understanding of psychology is that it is a biopsychosocial science, a natural science consistent and compatible with the principles of the other natural sciences. Psychology is a unique science with its own principles that are still under development, given that it is only about 133

years since the adoption of the scientific method by Wilhelm Wundt. Psychology's principles are not those of physics, biology, or physiology. Bunge's (2003, p. 141) comment about this point summarizes our understanding very well:

*What about psychology: is it reducible to biology? Assume, for the sake of the argument, that all mental processes are brain processes.... Does this entail that psychology is a branch of biology and, in particular, of neuroscience...? Not quite, and this for the following reasons. First because brain processes are influenced by social stimuli... Now, such psychosocial processes are studied by social psychology [and its categories] are not reducible to biology. A second reason is that psychology employs concepts of its own, such as those of emotion, consciousness, and personality... that go beyond biology.*

To be sure, the ideas and principles of all sciences, are germane to psychology, but in the hierarchical arrangement of the sciences, psychology has emerged from those lower than it, as illustrated in Fig. 4.1. Gell-Mann (1995) refers to this hierarchical nature of the sciences by raising the question of which science is the fundamental one, "... science A is more fundamental than science B when... the laws of science A encompass in principle the phenomena and laws of science B..." (p. 109). Novak (1996) calls this hierarchy the "continuum of scientific disciplines" (p. 4). Psychology, then, is more complex than sciences lower



**Figure 4.1** Hierarchy of the sciences.

than it in this hierarchy; but, while more complex, it is not more difficult to comprehend.

Thus, while a student may struggle more in her physics class, that subject matter has identified variables on both sides of its equations. Psychology is still attempting to identify the myriad of variables that influence behavior, many of which are, to use Gilbert Gottlieb's (1997) term, nonobvious: "Who would have dreamed that squirrel monkeys' innate fear of snakes could derive from their experience with live insects (Matasaka, 1994)? Or that chicks' perception of mealworms as food depends on their having seen their own toes move (Wallman, 1979)?" (p. 144). This complexity is in large part due to the various factors that are responsible for psychological phenomena that can be summarized as five crucial sets of factors: phylogenetic, ontogenetic, experiential, cultural, and individual.

## 2.1. The Phylogenetic Set

The phylogenetic set reflects an organism's evolutionary status, i.e., what it is as a species, and recognizes the significance of evolution for psychological phenomena. Phylogenetic factors are embodied in Kuo's (1967) "principle of behavioral potentials," that asserts that each species has the potential to behave in species-typical ways (Haraway & Maples, 1998). There is, of course, no guarantee that these potentials will be actualized in a particular manner, another example of the probabilistic nature of behavior development (Gottlieb, 1992). Thus, Kuo asks, "Is a cat a rat killer or a rat lover?" His research shows that "it depends..." Kittens reared with rats and out of sight of cats that kill and eat rats never eat rats, even when hungry. For the cat that has never seen a rat killed or eaten, it becomes an object of "love" (Kuo's term). With respect to humans, Montagu (1952/1962) has said, "The wonderful thing about a baby... is its promise" (p. 17)—we are born *Homo sapiens*, but we have to *become* human beings (Bronfenbrenner, 2005).

## 2.2. The Ontogenetic Set

This set of factors refers to the development of an organism, from its conception to its embryonic state, to its state as an adult and to its eventual death. Once again, we underscore the probabilistic nature of this ontogeny. *Nothing in development*—embryological or behavioral—is guaranteed by biology, by genes; nothing is preformed or preordained (Gottlieb, 1992; Nieuwkoop, Johnen, & Albers, 1985). The developmental stage of an organism profoundly impacts its behavior and the way in which it reacts to stimuli. For example, a baby in its crawling period can only get under the kitchen



sink, but when she begins to walk care must be taken to fasten the kitchen drawers.

### 2.3. The Experiential Set

We adopt [Schneirla's \(1957\)](#) definition of experience as “all stimulative effects upon the organism through its life history” (1957, p. 86). As [Overton \(2006\)](#) has pointed out, the organism is not merely a passive recipient of experiences, but rather a source in that all actions initiated by the organism are also experiences; experience, then, is both what happens to the organism and what it does. [Kantor \(1959\)](#) referred to one's experiential history as the “reactional biography” (RB). RB begins at conception and continues to be built up until the organism's death. Every stimulus and each act affects the organism and changes it, although some stimulation and some acts have much more profound and obvious effects than others. Learning, for example, is an important process in behavioral change, but it is nothing more than a special set of experiences.

### 2.4. The Cultural Set

Organisms function in environments and the organism–environment relation forms a functional whole. Consequently, environments are necessary features of the organism's biological and behavioral development. This relation is most obvious in humans, who have developed cultural systems (e.g., religion, dietary practices, societal institutions) that impact behavioral development in multiple ways. But all living organisms, although perhaps at less-complex levels, function within environments of their own making. Different species may inhabit different environments, eat different foods, and so on. This important point was stressed by the ethologist [Jacob von Uexküll \(1957\)](#), who termed the behavioral environment of an animal its *Umwelt*, its sensory-perceptual world. A recent discussion of this concept is provided by [Michel \(2010\)](#). Chimpanzees, for example, display different behavioral adaptations related to their unique environments ([Matsuzawa, 1998](#)). Chimpanzees in two communities separated by only 10 km can display markedly different behaviors. These differences include nest building, ant dipping, use of leaves for water drinking, food choices, and many others. This phenomenon is so pervasive in chimpanzees that such differences are found even in groups that are in closer proximity, suggesting that this effect is not just the result of ecological factors ([Luncz, Mundry, & Boesch, 2012](#)).

A classical example of cultural traditions in nonhuman animals is that of the development of potato washing by Japanese macaques. For over 50

years, Japanese primatologists (Itani, 1961; Kawamura, 1959; Nishida, 1986) have been studying the social behavior and emergent traditions of Japanese macaque monkeys. Provisioned with novel foods—potatoes and rice—the monkeys soon began to toss handfuls of rice gathered from the sandy beach into the water where the rice would float and the sand would sink. The monkeys thus discovered a way to wash sand from their food. These practices spread throughout the colony and are now part of the animals' normal behavioral repertoire. The practice is handed down from generation to generation—a primitive form of cultural transmission. Once they began spending more time near and in the water, young macaques began playing in it. This play led to the development of new behavioral skills, such as swimming. The animals also incorporated new foods into their diets, fish for example, and may now be capable of swimming to distant islands—a type of Darwin's finches scenario.

## 2.5. The Individual Set

This set reflects the uniqueness of each individual organism and how that uniqueness relates to its development (Molenaar, 2010; Nesselroade & Molenaar, 2010). One animal may be more or less sensitive to sounds, may have a developmental abnormality that limits its interactions with its world, or may be larger or smaller than its conspecifics. This set of factors recognizes the contribution of the individual's unique genotype and how the organism's biology, in dynamic interplay with contextual influences, may render it a different behaving creature than all others. Of course, while an organism's genome plays a role in its development, the idea of genetic determinism is no longer feasible, a point we will revisit later (Charney, 2012; Greenberg, 2011; Wahlsten, 2012).

These five organizational sets provide the ontological structure of psychology. We are comforted by the use of a similar analysis by Overton (2006; Overton & Müller, 2012), one of the world's leading developmental scientists (to whom this edition of *Advances in Child Development and Behavior* is dedicated). Overton uses different labels, but is substantially in agreement that several sets of factors, at different levels of analysis and influence, play a dynamic role in human development. We are especially in agreement with respect to the significance of his discussion of the physical ideas of “fluid dynamic holism and associated concepts such as *self-organization*, system, and the synthesis of wholes” (Overton, 2006, p. 19) as they apply to understanding development. The relationship among these factors is one of fusion (Tobach & Greenberg, 1984), no one set being of more importance in

an organism's behavior development than another. Exerting their influence along the developmental trajectory, the source of many aspects of behavior cannot be identified; rather they reflect the influence of emergence.

The significance of relationism for developmental science is that development is a multicausal complex *open* system with many elements embedded within the system. Nevertheless, development proceeds in a coordinated fashion, there being no

*executive agent or ... programme that produces the organized pattern. Rather, the coherence is generated solely in the relationships between the organic components and the constraints and opportunities of the environment. This self-organization means that no single element has causal priority.*

*(Smith & Thelen, 2003, p. 344).*

We turn next to a discussion of the concepts of emergence, evolution, and epigenesis in terms of structural transformations in the process of human development.



### 3. STRUCTURAL TRANSFORMATION 1: EMERGENCE IN PSYCHOLOGY

It is always helpful to “begin at the beginning”, advice that comes from the unusual source of the Red King in *Alice and Wonderland*. In the present context, the beginning is the Big Bang (Singh, 2004) and the first elements to be formed are hydrogen and helium. Everything in the universe has come from that “simple” beginning, thus, a natural consequence of the Big Bang is that given enough time these elements have become life, and subsequently, sentient beings, a result of the natural law of increasing complexity after the Big Bang and the physical principles of self-organization and emergence. As summarized by Reid (2007), “Life emerged in a universe whose cosmology is subject to physical laws. But life, without disobeying such principles, is not predicted or contained by them” (p. 92). Across history, the continuation of the cosmic and biological evolution of the universe has resulted in increasingly more complex forms of cosmological structure and animal life. An early discussion of this process by Oparin (1961) is surprisingly contemporary in its understanding of these processes and reflects the themes of this chapter: “The facts at our disposal indicate that the origin of life was a gradual process in which organic substances became more and more complicated and formed complete systems which were in a state of complete interaction with the medium surrounding them... Following the path of the emergence of life in this way... there arose new biological laws which had not existed before... ” (pp. 36–37).

While the idea of self-organization is relatively new to physics (Prigogine & Stengers, 1984), that of emergence, that new properties come into being when old parts are arranged in new ways, has a long history in philosophy, the physical and biological sciences, and more to the point of this chapter, in psychology (Bedau & Humphreys, 2008). Sawyer (2002) notes that Wilhelm Wundt and Henry James recognized the significance of emergence in the new science they were developing. Some trace the origin of the idea of emergence to John Stuart Mill (e.g., McLaughlin, 2008), the father of British emergentism, a nineteenth century philosophical tradition. Applied to developmental science, behavior is seen to be the result of the fusion of these five sets of factors. Therefore, human behavior is a product of probabilistic epigenetic events, not a result of preprogrammed genetics (Gottlieb, 1992, 1997; Kuo, 1967). Nonlinear dynamic systems theory provides a theoretically consistent language with which to describe and analyze the development of behavior, discussed at length by Michel and Moore (1995).

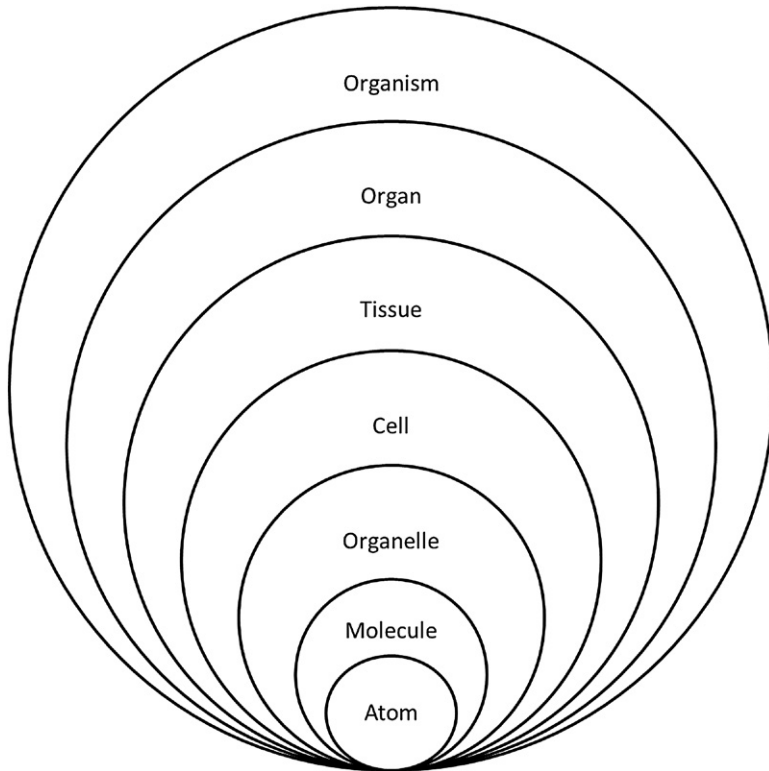
Nonlinear dynamics contains a lexicon of concepts pertaining to change processes that do not exist in any other known theoretical system. Dynamical models allow us to compare and contrast seemingly unrelated phenomena that often share common dynamical structures. Nonlinear dynamics and complex systems analysis are continuing to help revolutionize our understanding in many of the life sciences. This situation was summarized by Kauffman (1993), a leading figure in the widespread application of these ideas as follows:

*Eighteenth-century science, following the Newtonian revolution, has been characterized as developing the sciences of organized simplicity, nineteenth-century science, via statistical mechanics, as focusing on disorganized complexity, and twentieth and twenty-first-century as confronting organized complexity (p. 173).*

As Prigogine (1994) has noted, nonequilibrium physics is itself an emergent science, and has replaced certitudes (i.e., determinism) in the laws of nature with possibilities (i.e., probabilities).

As already noted, a crucial idea for understanding complex systems is the view that the universe is ordered hierarchically. This concept is illustrated in Fig. 4.2 and summarized by Aronson (1984) as follows:

*[The levels concept]... is a view of the universe as a family of hierarchies in which natural phenomena exist in levels of increasing organization and complexity. Associated with this concept is the important corollary that these successions of levels are the products of evolution (1984, p. 66).*



**Figure 4.2** Increasing complexity in nature.

As Feibleman (1954) says, referring to the hierarchy of the sciences, the levels concept places “rules” of explanation on studies of the more complex systems (e.g., biology, psychology, and sociology).

A now classical application in behavior development of dynamic systems, emergence, and self-organization is that of Thelen and Smith (1994). In acknowledging the origin of these principles in mathematics, physics, and biology, these authors substantiate the unity of the sciences and the idea that the unique principles of psychology are, as well, natural phenomena. In describing development as orderly, incremental, and progressive, Thelen and Smith point out that one may be left with the impression that such processes are guided from within the organism, or if not a result of genetic and biological determinism, surely that of the *interaction* of “nature and nurture.” However, such a formulation grants nature and nurture factors individual and independent significance in influencing behavior (Pronko, 1988). Along with Thelen and Smith, others have recognized that the dynamic interplay

between these factors is a *fusion* (Tobach & Greenberg, 1984)—one cannot therefore say how much of behavior is determined by phylogeny, how much by ontogeny, how much by nature, and how much by nurture, in much the same way that we cannot determine how much of the area of a rectangle is a function of its width or its height.

We agree with Pronko's comment that "We must not neglect genetic and other biologic factors, but, instead of treating them as causal, we regard them as *aspects* of an integrated field event or events" (1988, p. 78). This idea is, of course, the essence of the relational development systems approach to development (Overton, 2010, 2011). The prescription for development outlined by Thelen and Smith (1994) represents, "... a radical departure from current ... theory. Although behavior and development appear structured, there is no structure. Although behavior and development appear rule-driven, there are no rules. There is complexity. There is a multiple, parallel, and continuously dynamic interplay of perception and action, and a system that, by its thermodynamic nature, seeks stable solutions" (p. xix).



#### 4. STRUCTURAL TRANSFORMATION 2: EVOLUTION

It is instructive to begin our discussion of evolution with a quotation from Ernst Mayr (1979), one of twentieth century's leading evolutionary biologists:

*The most consequential change in man's view of the world, of living nature and of himself came with the introduction over a period of some 100 years beginning only in the 18th century, of the idea of change itself, of change over long periods of time: in a word, of evolution. Man's world view today is dominated by the knowledge that the universe, the stars, the earth and all living things have evolved through a long history that was not foreordained or programmed, a history of continual, gradual change shaped by more or less directional processes consistent with the laws of physics "(1979, p. 47)."*

While it was appropriate in the late twentieth century to say that "nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973), it is now the case that this idea applies as well to psychology and to the origins of behavior. This view is especially true now that evolutionary theory has once again embraced development (see our discussion of this later in the chapter).

As with all major scientific theories, Darwinism is an exemplar of simplicity. It can be summarized in five fundamental principles (Mayr, 1991): (1) evolution as such, (2) common descent, (3) multiplication of species,

(4) gradualism, and (5) natural selection. Unfortunately, as Jablonka and Lamb (2005, p. 9) point out, Mayr's summary leaves us with "... the impression that there is a tidy, well-established theory of evolution – Darwin's theory of natural selection – which all biologists accept and use in the same way. The reality is very different, of course."

Darwin knew that characteristics that permit the organisms possessing them to survive were likely to be passed on through the successful reproduction of those organisms. He knew nothing, however, about the mechanism of such inheritance. Our current understanding of genetics, which began with the work of the monk Gregor Mendel, provides this mechanism. The canonical theory of evolution, referred to as "The Modern Synthesis", combines Darwin's ideas of natural selection and Mendel's ideas of genetics (e.g., Mayr & Provine, 1980). Interestingly, Tauber (2011) recently suggested that in light of newer epigenetic thinking, the so-called Modern Synthesis, a melding of genetics and developmental biology and evolution, is likely to come to be referred to as the "Old Synthesis" i.e., a "Refreshed Synthesis". Thus, while Modern Synthesis dictates that characteristics are transmitted across generations only genetically, there is now substantial empirical support for the idea that organisms are affected genetically by experiences of their ancestors, i.e., Lamarckism, or epigenetic inheritance (Masterpasqua, 2009). Such findings challenge the idea that psychological disorders that run in families do so as a result of genetics and point instead to environmental or experiential etiologies (e.g., Greenberg, 2011). Jablonka and Lamb's (2005) summary of epigenetic inheritance is especially clear:

*But information transfer also occurs at higher levels of organization [higher than at cellular inheritance systems]. There is a good example of this in Mongolian gerbils, where the mother's uterine environment may have strong heritable effects on her offspring's development. A female embryo that develops in a uterus in which most embryos are male is inevitably exposed to a high level of the male hormone testosterone. This high level of the hormone is information for the embryo, and it affects her subsequent development. As she grows up, she develops some special characteristics, such as late sexual maturity and aggressive territorial behavior and, most remarkably, when she reproduces, her litter has more males than females. Since most of her embryos are male, her female offspring develop, just as she did, in a testosterone-rich environment, so they grow up to have the same behavioral and physiological traits as their mother. They, too, will produce more male-biased litters, and so the cycle continues. In this way the developmental legacy of the mother is transferred to her daughters – there is nongenetic inheritance of the*



mother's phenotype. Consequently, two female lineages that are genetically identical can be very different behaviorally and have different sex ratios, *simply because they transmit different nongenetic information* (pp. 145–146, *emphasis added*).

Theories in science are of necessity dynamic. All the facts are never fully collected; this is why science is characterized as a self-correcting discipline and why “truth” in science is written with a lower case “t”. New discoveries and new facts rarely result in the discarding of a strong theory, rather the course taken is to tweak the theory to accommodate the new findings (see Kuhn's 1962 book, *The Structure of Scientific Revolutions*, on this point; we appear to be on the verge of an important paradigm shift in our understanding of evolution). So it is with Darwinism, as Jablonka and Lamb (2005) point out: “Not only has opinion about the theory of natural selection as a whole changed over the years, there have also and inevitably been changes in the details” (p. 40). We address three important modifications to Darwin's original proposal.

1. While Darwin provided the fundamental law of his theory, that of Natural Selection, Saunders and Ho (1976) suggested that an increase in complexity over geological time (i.e., with evolution), can be understood to be a second law of Darwinism. One of us has discussed complexity theory and its corresponding idea of emergence in other publications (Greenberg, Partridge, & Ablah, 2006; Partridge & Greenberg, 2010). It is sufficient here to state that increases in complexity and the epigenetic emergence of novelty are the rule in evolution. This assertion should come as no surprise, for many—including Gould (1997; see also Krasny, 1997), Maynard Smith (1970), Carroll (2001) and others—have pointed out that when you begin with a single cell, with simplicity, there is only one direction to go in and that is up toward greater complexity. For instance, “... it is in some sense true that evolution has led from the simple to the complex: prokaryotes precede eukaryotes, single-celled precede many-celled organisms, taxes and kineses precede complex instinctive or learnt acts... And if the first organisms were simple, evolutionary change could only be in the direction of complexity” (Maynard Smith, 1970, p. 271).
2. A cornerstone of Darwinian theory is that evolutionary change is slow and gradual, taking millions of years. The absence of a corresponding fossil record is one source of challenge to this idea. However, Eldredge and Gould (1972) provided an explanation for these gaps in the fossil record and at the same time demonstrated the dynamism of Darwinian



theory, that it can be tweaked; their idea is referred to as *punctuated equilibrium*. The proposal, now widely accepted as another modification of Darwinian theory (Gould & Eldredge, 1993), is that species remain unchanged for long periods (i.e., in equilibrium) and that these long periods of no change are punctuated by episodes of relatively rapid (e.g., in geologic time, tens or hundreds of thousands of years) change. Thus, there is no gradual fossil record to be discovered. This is saltatory, rather than gradual, evolution and is an example of how the principle of emergence plays a role in our contemporary understanding of evolution (Reid, 2007).

3. The third major modification to Darwinian theory is that of the reintroduction of a form of Lamarckian inheritance, what Ho and Saunders refer to as the Epigenetic Theory of Evolution (Ho, 2010). While we have already discussed epigenesis in detail, it is important to emphasize the role it plays in the contemporary understanding of evolution. In this approach, natural selection is seen to play little or no role, “based on evidence suggesting on the one hand that most genetic changes are irrelevant to the evolution of organisms... ” (Ho, 2010, p. 72). As Ho explains, her theory renders evolution compatible with nonlinear dynamic systems, and to the point of this chapter, with the ideas of emergence and self-organization. Consistent with this conception, the following are now known: (1) genes are not directly responsible for phenotypic expression, but rather, the environmental context of development plays a crucial role in this process; (2) it is not only that genes work from the inside out, but rather that behavior too can influence the expression of genes (referred to as “downward causation” by Campbell, 1990); (3) not all genes of a genome get expressed; (4) natural selection is but one of the several mechanisms responsible for evolutionary change; and (5) the path from genes to physical or behavioral traits is enormously complex and indirect.

Pushing natural selection from its pedestal is not as heretical as it may seem. No less an ardent Darwinian as Stephen Jay Gould (2002, pp. 137–141) discusses its (diminished?) role in modern evolutionary biology. In criticizing those who cling to old-fashioned Darwinian fundamentalism, Gould (1997) shows that, as with all sound theories, Darwinism is dynamic, even now allowing Lamarckian ideas to be entertained (and of course Darwin, 1859; was an adherent of Lamarck’s ideas). In the words of Jablonka and Lamb (2005, p. 102), “... Darwinian evolution can include some Lamarckian processes, because the heritable variation on which selection

acts is not entirely blind to function; some of it is induced or 'acquired' in response to the conditions of life". Ho (2010, p. 62) has noted, however, that there remain some objections to the resurrection of Lamarckism: "Epigenetic inheritance, instances of Lamarckian evolution, has now been widely documented in numerous studies, and continues to get many biologists hot under the collar."



## 5. STRUCTURAL TRANSFORMATION 3: EPIGENESIS

Among the significant ideas of contemporary developmental science are those of epigenetics and epigenesis. These ideas, first introduced into modern biology by Waddington in 1957 (Haig, 2004; Waddington, 1957), supplement Darwinian evolution by showing that there are routes to inheritance other than by DNA and genetics. Genetics and developmental biology in the early part of the twentieth century were separate disciplines. Mayr (1982) noted that early progress in genetics required the banishment of development from discussions of evolution. In this context, we note that Maynard Smith and Holliday (1979) declared that, with respect to evolution, development has been safely ignored. Waddington had the foresight to join the two and in so doing coined the term epigenetics (Holliday, 2006). It took until modern times for the biological sciences to follow in Waddington's footsteps and understand the critical role that development plays in all aspects of biology, including evolution (Robert, 2004, 2008). Nevertheless, despite the renewed interest by some in studying development in an evolutionary framework (e.g., evolutionary-developmental biology, evo-devo), "The field is still dominated by the idea that genes control development" (Ho, 2010, p. 70). Of course, the present authors, along with others in this volume disagree and believe instead that development itself is an epigenetic phenomenon from which novel processes emerge. A cogent discussion of this point is provided by Moore (2003).

While epigenetics and epigenesis have similar roots, they refer to different processes. Not all authors recognize these differences and use the terms interchangeably, as even Waddington recognized as early as 1956 (Haig, 2004). While there are, as Holliday points out, different meanings of epigenetics, we are most comfortable understanding this term as referring to the developmental process in which the entire series of interactions among cells and their products results in morphogenesis and differentiation. With respect to epigenesis, we note that Overton (2011) and Overton and Müller (2012) follow in a long line of developmentally oriented scientists (e.g., Kuo,

1967; Moltz, 1965) in embracing the concept of epigenesis. Their discussion of this concept reflects the breadth of their interests and their widespread impact on this discipline. Overton (2010, p. 7) states that epigenesis:

*is the principle that the role played by any part of a relational developmental system – gene, cell, organ, organism, physical environment, culture – is a function of all of the interpenetrating and coacting parts of the system. It is through complex relational bidirectional and multidirectional reciprocal interpenetrating actions among the coacting parts that the system moves to levels of increasingly organized complexity... Epigenesis also points to a closely related feature of transformational developmental change: emergence. Transformational change results in the emergence of system novelty.*

To summarize then, in our usage, epigenetics refers to transgenerational Lamarckian-type evolutionary processes, while epigenesis refers to transformational (qualitative) changes in ontogeny, as Overton points out.

In one of his earliest theoretical papers (actually written in 1965, although not published until 1970), Gottlieb distinguished between pre-determined and probabilistic epigenesis, the former term lying firmly on the unbending nature side of the nature-nurture issue. This approach to behavior understands it to be the outcome of biology (or nature), with very little influence at all of experience (or nurture). Gottlieb's own work (1973), as well as that of others (e.g., Kuo, 1967; Smotherman & Robinson, 1988), has shown this conception to be simply wrong.

The alternative position explicated and favored by Gottlieb is that of probabilistic epigenesis, in which "behavioral development of individuals within a given species does not follow an invariant or inevitable course, and, more specifically, that the sequence and outcome of individual behavioral development is probable... rather than certain" (Gottlieb, 2001, p. 43). Indeed, this view of epigenesis is seen now to hold not just for behavior, but "is recognized in many quarters as a defining feature of development" (Gottlieb, 2003, p. 341).

Epigenesis has been described in a variety of ways, but none has been so well put as that by Moltz (1965, p. 44):

*An epigenetic approach holds that all response systems are synthesized during ontogeny and that this synthesis involves the integrative influence of both intraorganic processes and extrinsic stimulative conditions. It considers gene effects to be contingent on environmental conditions and regards the genotype as capable of entering into different classes of relationships*

*depending on the prevailing environmental context. In the epigeneticist's view, the environment is not benignly supportive, but actively implicated in determining the very structure and organization of each response system.*

We cannot overestimate the enormous influence of Gottlieb in contemporary discussions of epigenesis, more specifically of probabilistic epigenesis (Wahlsten, 2010). While he was an animal psychologist and a developmental psychobiologist, his influence as a critic of genetic determinism is widespread in the biological and behavioral sciences. Predetermined epigenesis ignores the fact that development is contextual; *all events*, from the level of the cell to those of the external environment, continuously affect development. Gottlieb illustrated this integration in a now famous diagram (1992, p. 186) of development as four interacting levels across time (i.e., genetic activity, neural activity, behavior, and the environment). Development therefore involves bidirectional processes, with events at all levels playing crucial, fused, roles in developmental outcomes.

The evidence supporting the concept of probabilistic epigenesis then, constitutes a potent argument against behavior genetics and the idea that genes alone determine all characteristics, structural and behavioral (Greenberg, 2011). Predetermined epigenesis suggests a direct one-to-one linkage between biology, genes, for example, and structure or behavior. In this formulation, biology is destiny. Having a gene for breast cancer or phenylketonuria (PKU), for example, results in the development of these diseases in the lifetime of the individual, *no matter what!* Probabilistic epigenesis, on the other hand, speaks of a probabilistic linkage between biology and both physiological structure and behavior. One may thus have a gene potentially linked to breast cancer or PKU, but as a result of diet, or other lifestyle factors, this gene may or may not be involved in such development or even express itself. Meaney (2010) provides an overview of data documenting this point.

The significance of epigenetics for developmental science and for our discussion was summed up concisely by Ho (2010, p. 61): “In the new holistic perspective, epigenetics mediates between the psychosocial and biological realms, and holds the key to how we can shape our own development.” Returning to an earlier discussion in this chapter, it is of interest here to note that the demarcations between the sciences is not as clear cut as one might expect; transitions from one level to another are not smooth. Indeed, we never really know where one level, or one science, ends and another begins. Thus, the relational holistic position we favor in this chapter takes a dramatically different perspective on the relation between biology and

psychological development. From this perspective, development is an active system of processes superordinate to biology and evolution. Thus, it is not that genes and brains explain development, but rather that the developmental system explains the functioning of the gene, the brain, and even evolution at the level of individual ontogeny. The developmental system integrates biological functions into coordinated patterns that support behavior. It is, then, the process of development that shapes biological organization and provides a temporal context for biology–behavior–ecology interrelationships (Lerner & Bush-Rossnagel, 1981; Overton & Müller, 2012).

It is appropriate to conclude this discussion of epigenetics and epigenesis with a quote from Bunge (2003), a statement that summarizes our understanding of reductionistic analysis and the role of genes and biology in behavioral origins:

*At first sight, the discovery that genetic material is composed of DNA molecules proves that genetics has been reduced to chemistry... However, chemistry only accounts for DNA chemistry: it tells us nothing about the biological functions of DNA – for instance that it controls morphogenesis and protein synthesis. In other words, DNA does not perform any such functions when outside a cell, anymore than a stray screw holds anything together. (Besides, DNA does nothing by itself: it is at the mercy of the enzymes and RNAs that determine which genes are to be expressed or silenced. In other words, the genetic code is not the prime motor it was once believed to be. This is what epigenesis is all about.) (p. 138, emphasis added).*



## 6. RELATIONAL PROCESSES AND MODELS IN DEVELOPMENTAL SCIENCE

Contemporary developmental science has successfully provided a dialectical synthesis of earlier organismic and mechanistic theories by positing that behavioral development is a function of an organism interacting with an active sociohistorical ecology (Greenberg, 2011). A family of theories has arisen that includes perspectives such as the developmental bioecological model (Bronfenbrenner, 1979), developmental contextualism (Lerner, 1998), the life-span perspective (Baltes, 1987), the person-oriented approach (Magnusson, 1996), and transactional models (Sameroff, 1975). The success of these theoretical formulations is indicated by the change in the scope and content of developmental science.

Concurrent with advances in developmental science, science in general has been revolutionized by developments in the study of nonlinear dynamic

systems, as we have discussed earlier in this chapter. Under the general rubric of nonlinear dynamics are several subfields: chaos theory, the study of complex behavior resulting from simple and deterministic processes; fractal geometry, the study of geometrical forms invariant across scale; and complex systems theory, the study of stable organized behavior resulting from complex and stochastic processes. It is the last of the three theories that seems to hold the most relevance for current formulations of developmental science. Today's developmental science is what Lerner (2006) has described as involving "the ascendancy of a developmental systems frame" (p. 5). It is relational and integrative, and the approach we will discuss represents a successful attempt at unifying the field.

Traditionally, questions that have framed the study of human development involve Cartesian split conceptions about the bases of developmental processes (see Overton, 2010; for a review). These questions ask whether behaviors, attitudes, emotions, and other aspects of psychological functioning are the result of nature (genes) versus nurture (environment), continuity versus discontinuity, stability versus instability, etc. (Lerner, 2002). According to Lerner, "This split, reductionist ontology about development meant that the epistemological route to learning about the basis of development was to identify the essential (nature or nurture) explanatory variable(s)" (Lerner, 2012, p. 5). Such split conceptions of approaching developmental science do not account for the embedded integrative nature of the developmental system (e.g., Overton, 2010).

However, beginning in the last third of the twentieth century, the field of developmental science saw a paradigmatic shift in thinking that has led to a more integrative approach to understanding human development. As is the case with paradigm shifts (Kuhn, 1962), acceptance is neither immediate nor universal. While Lerner and others (e.g., Lerner, Easterbrooks, & Mistry, 2012; Overton & Lerner, 2012) see the newer ideas about human development discussed in this chapter akin to a Kuhnian-like paradigm shift, not all agree. This difference of opinion is due to two facts: (1) because these ideas are still new, many "... have difficulty intuitively understanding the properties of complex nonlinear systems" (Singer, 2009, p. 327) and (2) because traditional psychology focuses on structures rather than processes, the clearest example of which is in the formation of cognitive models of memory located in specific parts of the brain (e.g., Friedenberg, 2009).

Nevertheless, in Overton and Müller's (2012) view, contemporary perspectives in developmental science have moved beyond the traditional linear approach to exploring development to models that view human development as dynamic and integrative. As Mascolo and Fischer (2010) note,

developmental scientists are transitioning away from thinking about psychological structures and functions as involving individual actors in isolation, independent and discrete processes, and linear movement through global stages. Instead, human development is seen as a series of dynamic relations that occur within dynamically integrated structures within developmental systems. As [Mascolo and Fischer \(2010\)](#) note, researchers now recognize the embeddedness of multiple levels of the ecology and the “profound lack of independence of the systems that make up human action as well as the systems and contexts within which human action is embedded” (p. 150).

Given the emphasis on conceptualizing human development within an embedded integrated system, there has also been a shift in how to conceptualize development in psychology. Within the embedded system, what develops and how? Instead of viewing the units of development as individual actors and independent processes, the “what” of psychological development is viewed instead as emergent systems that become integrated across the life span ([Mascolo & Fischer, 2010](#)). Therefore, development does not involve just the person in isolation, but involves integrated skills that are developed in a dynamic relationship within various contextual systems. These integrative structures are composed of appraisal-affect-action processes that promote skill building in different domains ([Mascolo & Fischer, 2010](#)).

As we previously noted, traditional theories of psychological structures describe development in terms of a linear series of steps. The Piagetian theory of cognitive development, for example, requires the individual to develop “singular, broad-based, homogeneous competencies” ([Mascolo & Fischer, 2010, p. 161](#)), within each of the four stages: sensorimotor, preoperational, concrete operational, and formal operational. [Erickson \(1959\)](#) and [Freud \(1954\)](#) held analogous theories regarding global stages of identity and personality development, respectively. However, [Mascolo and Fischer \(2010\)](#) note that evidence from several decades of research on the integration of cognition, emotion, and action indicates that changes in psychological structures are in fact the result of an “emergent developmental web” (p. 163). Rather than global stages that develop along a linear trajectory, human development involves integrative psychological structures that develop dynamically within contexts that support their construction.



## 7. NEURAL DEVELOPMENT

While we acknowledge the role of biological factors in behavioral origins, we are by no means biological reductionists. That being said, we



understand the important role played by neural factors in behavior (Greenberg, Partridge, Weiss & Haraway, 1998). It is important to point out that the core ideas we discussed here also apply to neural development. Friedenber (2009) has invoked various ideas of emergence and self-organization to attempt an explanation of how these ideas relate to brain functioning. Different aspects of neural activity perhaps underlie coding in the system: single and multiple neural firing rates and other temporal features, neural synchrony, and neural coupling represent just a sampling of the possible ways in which the nervous system represents information. The brain's complexity cannot be understood by reductionistic analysis. Thus, while the 600 electrical and 5000 chemical synapses in the nervous system of the invertebrate worm *Caenorhabditis elegans* (containing a mere 302 neurons) have been mapped, "this knowledge itself failed to provide realistic ideas about the function and dynamics of this minimal nervous system" (Koch & Laurent, 1999, p. 97). Even in the simplest nervous systems, complexity makes for the emergence of neural processes.

As Benno (1990) makes abundantly clear, the development of the brain is itself regulated by a complex set of epigenetic processes. The internal dynamics accounting for increased neural organization, however, are linked to the larger behavioral context. During the development of the embryo, animal brains grow an enormously complex web of neurons. Each of these neurons establishes connections with many other neurons by means of hundreds and thousands of dendrites. The arrangement of circuits among this tangle of neurons and dendrites, that is, the fine tuning of a brain, is the result of experiential input. Neural development involves several sets of processes, including (1) determination, the transition from totipotentiality of a nerve cell to a state of more limited fate; (2) proliferation, the production of new cells; (3) migration, the movement of neurons from where they are produced to where they eventually settle in the brain; and (4) selective cell death, more neurons are produced than the newly formed brain eventually contains. As Benno (1990) discusses, these processes are governed by probabilistic epigenetic factors. Much can go wrong in neural development, a result of environmental input. It is of interest to note that even at the time of this writing, in 2012, the mechanisms responsible for these neural changes are not yet fully understood.

Neural development is rendered even more complex by postnatal epigenetic effects. We now know that genomes remain active throughout life and are affected by many environmental stimuli (Charney, 2012). Social deprivation, contextual assets or deficits associated with socioeconomic



status, or malnutrition all have dramatic effects on development in general and on brain development in particular. Indeed, we have known for some time that pervasive and sustained negative social conditions have a profound effect not only on brain development but also on physical and behavioral development in general, a phenomenon labeled psychosocial dwarfism (Reinhart & Drash, 1969).

Of course, consistent with an embodiment model of development, biological factors are not to be ignored; they are, however, participating and not causal factors in behavioral origins (Pronko, 1988). On this point Bunge (2003, p. 52) has said, “However, far from being fully autonomous, the brain is intimately connected with the endocrine and immune systems, as well as with such support systems as the cardiovascular, digestive, and musculo-skeletal systems.” With respect to embodiment, Overton (2008) states, “embodiment [is not] about a set of genes causing behavior, or a split-off brain causing or being the mind .... Embodiment is a concept of synthesis, a bridge that joins broad areas of inquiry into a unified whole (e.g., the biological, the phenomenological, the sociocultural and environmental) as relative standpoints that together constitute the whole” (p. 3, emphasis added). He further adds that the embodiment model, i.e., a person-centered perspective, “rescues psychology generally, and developmental psychology specifically, from becoming a mere adjunct to biology” (p. 7). We will leave the discussion of the mind to another time (Greenberg & Partridge, 2010; for an interesting discussion of mind). It is suffice to say for the time being that we agree with Overton’s (2008) point that “mind and body are coconstituted, and as such, form indissociable complements” (p. 3).

Thus, we appreciate the crucial role played by neural factors in the development of complex cognitive processes. In addition, we recognize the evolutionary point that brains have increased not only in size, but also in cognitive computational power (Rumbaugh & Pate, 1984a,b). Greenberg, Partridge, Weiss and Haraway (1998) provide an introduction to the role of brain evolution and complexity in the appearance of language, complex learning, and cultural complexity, especially in humans.



## 8. CONCLUDING COMMENTS

Our goal of writing this chapter was to present psychology as a natural science, a unique science, grounded of course in biology, but not a biological science. As a natural science, the principles of psychology are consistent and compatible with those of other sciences, although not reducible to

them. Specifically, behavior cannot be reduced or understood as the product of genes and brains. Rather, psychology is a developmental science (Greenberg, Partridge, Mosack & Lambdin 2006) that is embodied. Accordingly, we discussed how concepts of development from biology and other sciences play the crucial role in behavioral origins.

A key idea in this developmental approach is that of emergence, as we discussed at length. Coming from physics, and before that from philosophy, emergence suggests that new properties simply appear when older parts are organized in new ways, i.e., they emerge. No reductionist analysis will find the reality of the new whole in the old parts. The principal thesis of emergentist theorists has been that even with a full knowledge of all the lower order parts and their potential relationships, the laws of the higher order wholes cannot be deduced. Thus, even armed with the full sequence of the human genome and a full understanding of the multiplicity of regulatory networks involved in protein synthesis, a full understanding of even morphological phenotypes, let alone behavioral phenotypes, could not be ascertained. Similarly, even if all the neural circuits of the human brain could be sketched in a grand schematic and all the probabilistic rules governing the synaptic flow of information could be cataloged, neuroscience would be no better prepared to predict behavior. This point has always been the defining claim of emergent holism, and for the better part of scientific history, it has been the Achilles heel of the position of genetic or biological reductionism.

While we present our formulations to apply across the animal spectrum, i.e., to psychology in general (Greenberg & Haraway, 2002; Greenberg, Partridge, Weiss, & Pisula, 2004), our focus here is on humans. Consistent with our definition of psychology as a biopsychosocial science, development is an embodied phenomenon (Overton, 2006, 2007). Among the implications of embodiment is that at any point in time, development cannot be understood in reference to a single variable or a single dimension, either internal or external. As we have pointed out, the study of cognitive development, brain development, personality development, or any psychological phenomenon must recognize the fusion of these processes with other internal and external dimensions of change in which they are fused. Of course, embodiment with all levels of the ecology necessarily includes the individual's embeddedness with temporality (history) that involves at the very least ontogenetic and phylogenetic time (Elder, 1998). Furthermore, embodiment is not static; that is, due to epigenesis, developmental scientists should expect qualitative discontinuities in the nature of the embodied developing individual across time and place, both ontogenetically and phylogenetically.

An important goal we had in mind in writing this chapter was to make suggestions regarding the future direction to be taken by others. Developmental scientists are advised to consider phylogenetic and ontogenetic dimensions in both time and place (Elder, 1998) in trying to understand the trajectory of an individual's life course.

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