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## **The New Antireductionism: Its Components and Its Significance**

**Abstract:** Beginning in the 1970s and culminating in the first two decades of the 21st century, there has been a marked shift in the sciences from a predominantly reductionist and mechanistic approach to a broader and more holistic viewpoint. It goes without saying that such a shift in point of view will have significant implications, not only for the sciences but for our concepts of nature and of human beings. The present essay is an attempt to assess the significance of this change in the focus of the sciences and to describe the nature of its components. Originally, it had a far more limited scope, that of comparing two of the parts of the new nonreductionist stance: brain plasticity and biological systems theory. Unfortunately, my understanding of one of these factors (systems theory) turned out to be incorrect, while the section on brain plasticity was incomplete. The result of this dual realization is an essay of far greater scope, taking in both new developments in the sciences far beyond that of plasticity, and reassessing the content and impact of systems theory, which is greater than I had thought. I will begin with a study of systems theory, dealing first with the unexpected mathematics which made its present status possible. Then I will deal with its history, which reaches back over a century. One of the confusions into which we are liable to fall is to fail to distinguish the old systems theory from the new. This is even more likely because the two versions of the theory have many features in common.

**Keywords:** antireductionism, complexity theory, fractals, nonlinearity

## 1. The start of a new beginning: Fractals and nonlinearity

Fractal geometry dates from 1975 when the French polymath Benoit Mandelbrot first coined the word “fractal.”<sup>1</sup> Mandelbrot’s mathematics was a challenge to traditional geometry. Before Mandelbrot, mathematicians had focused their attention on objects in nature that are smooth and regular or could be taken as such. But many objects in the world have features quite different from smoothness and regularity: mountains, for example, or coastlines, clouds or rivers, Mandelbrot states:

Most of nature is very, very complicated. How could one describe a cloud? It is not a sphere. It is like a ball but very irregular. A mountain? A mountain is not a cone. If you want to speak of clouds, of mountains, of rivers, of lightning, the geometric language of school is inadequate.<sup>2</sup>

The shapes presented by Mandelbrot’s fractal geometry are far removed from the continuous accelerations of classical physics and the smoothness of parabolas, hyperbolas, and circles of classical geometry. These are nowhere to be found in fractal geometry’s menagerie of elaborate shapes. But no matter how complex or elaborate the result, fractal objects are all created by the same process: iteration.

There is nothing strange about this procedure, which consists of successive steps of addition. To cite the simplest example: if we add the number one to the number one, the result is two. Add another one and the result is three. Add another and the result is four... and so on, indefinitely?<sup>3</sup> In spite of the simplicity of this procedure, the results can turn out to be elaborate. Fractals are derived, not from the repetition of numbers, but from the iteration of shapes (i.e. triangles, squares). The result is a progression from Doric simplicity to a rococo exuberance of striking patterns.

Once constructed, fractals prove to have some very interesting and unexpected features. To this writer, the most surprising is the idea that spatial dimension does not have to be given in whole numbers. We presume that space has one, two, or three dimensions with nothing in between. For fractal geometry, this is not true. An object may exhibit half a dimension or any other fraction of a dimension: 1.685 or 2.738 for example. Thus, what it means to be spatial or extended in space is transformed.

Another fascinating aspect of fractals is their self-similarity. Fractal figures repeat their characteristic shapes at descending scales so that at any level they are similar to the whole: they repeat its pattern. To take a homely example, if one systematically breaks up a cauliflower, the resulting pieces each look like the cauliflower as a whole. If one of these pieces is broken up, it too looks like a still smaller cauliflower. And so on, down a descending but finite scale. This very precise repetition of the pattern is not limited to cauliflowers. It is found throughout nature in bone

<sup>1</sup> B. Mandelbrot. *The Fractal Geometry of Nature*. New York: Freeman, 1983, p. 2. All future references to this item will be cited in the text as FGN. For an overview of fractals cf. H.-O. Peitgen, H. Jorgens, D. Sauple, and C. Zolten. *Fractals: An Animated Discussion*. New York: Freeman, 1990, VHS/Color/63 min.

<sup>2</sup> FGN, 2.

<sup>3</sup> Fractal procedures that carry on this procedure indefinitely are termed “perfect fractals.” In nature, fractals have only a finite extent, as in the example of the cauliflower that I am about to cite. These fractals (of finite construction) are termed “imperfect fractals.”

structure, for example, and in the lungs and circulatory system where it makes possible the extreme efficiency of these systems.

As these examples demonstrate, fractal geometry is not only a fascinating mathematics—though it is that. Nor is it simply a set of aesthetically attractive shapes with implications for the arts. What is surprising is its capacity to reveal aspects of nature which, without it, remain invisible to us. It is no accident that Mandelbrot titled his magnum opus *The Fractal Geometry of Nature*. It is nature which fractals are able to reveal and make intelligible.

While Mandelbrot was developing fractal geometry, independently of him a group of researchers was developing another branch of “heretical” mathematics: the use of nonlinear equations. It had long been known that such equations existed. But since they were too complex to solve, and since they involved chaotic behavior, nonlinear equations were deemed unacceptable by most scientists. When they appeared, they were either rejected or “linearized”: transformed into linear equations. A well-thought-out article from Wikipedia on nonlinear systems makes it clear that linearization, however useful in some situations, covers up a lot.<sup>4</sup>

If the emergence of nonlinear mathematics came as a surprise to the science community, a second surprise awaited them. Nonlinearity and the equally heretical fractal geometry, far from being separate subject matters, turned out to be closely related. That is, the endpoints or culminations of the processes described by nonlinear equations turned out to be fractals. The result of this surprisingly close relationship was a new science, nonlinear dynamics. The complex configurations towards which nonlinear equations converge came to be called, as Mandelbrot notes, “strange attractors.” Strange attractors, he is quick to say, are fractal attractors.<sup>5</sup> Fractal nonlinear mathematics was quickly adopted by the newly emerging biological systems theory, a prime component of antireductionist science. To this latter theory I will now turn.

## 2. The origins of the old systems theory and the transition to the new

The term “systems theory” has a long complex history and is understood differently in its different historical contexts. There have been two versions of systems theory, one having its greatest effect in the first half of the twentieth century, the other arising in the later part of that century and extending into the present one. The first, associated particularly with the names of Paul Weiss and Ludwig von Bertalanffy, lacked the mathematics and computer power and complex molecular biology available to the current versions of the theory. Yet it possessed many of the same basic assumptions as the earlier theory so it is easy to confuse them.

To complicate matters, a little research shows that there are contrasting accounts of the history of both the older theory and the new. One writer dates the

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<sup>4</sup> “Nonlinear System.” *Wikipedia*. [https://en.wikipedia.org/wiki/Nonlinear\\_systems](https://en.wikipedia.org/wiki/Nonlinear_systems). Retrieved 4 April 2022.

<sup>5</sup> FGN, 414.

origin of the original systems theory to the work of the biologist Paul Weiss, claiming his dissertation (1912) as its founding document. Weiss's work is well known. The writer then adds to Weiss's name that of R.I. Williams, describing his work as a "classic." No other authority, however, cites Williams in their account of the early systems theory. The author, A. Trewavas, mentions Ludwig von Bertalanffy's work only in passing.<sup>6</sup>

Others, ignoring the names of Weiss and Williams, trace systems theory exclusively to the writings of Ludwig von Bertalanffy, a contemporary of Weiss.<sup>7</sup> Those who trace back systems theory to Bertalanffy term the systems approach general systems theory as he did.<sup>8</sup> Finally, there are some who trace back the history of systems theory to both Weiss and Bertalanffy.<sup>9</sup> Adding to the confusion, descriptions of just what systems theory is differ between authors. One knows that somewhere in the discussions a single viewpoint is being discussed. But what is it?

When one reads the literature of the newer systems theory, one once again finds the same sort of gappy and incomplete descriptions both of its history and contents. Take, for example, this unlikely account of its appearance on the scientific scene:

Systems biology was begun as a new field of science around 2000, when the Institute for Systems Biology was established in Seattle in an effort to lure "computational type" people who it was felt were not attracted to the academic settings of the university.<sup>10</sup>

As the account I have given of fractals and nonlinear mathematics has demonstrated, the new systems biology began at least two decades before the year 2000. Arguably, it began in the 1980s and one can trace many of the basic assumptions back even further.

It is surprising to find so many differing accounts of the history of systems theory. Equally discouraging is the discovery that historians stress different aspects of this theory in discussing its meaning. Nor is this all. When one reads the literature of the newer, current theory, the same problems arise. Writers focus on different aspects of these theories and give contrasting descriptions of how and when they arose. One should not, however, allow these discrepant accounts to confuse the basic issues. All systems theories, old or new, contain a core of common assumptions. I will sketch these here and return to them later, to deal with them in greater depth.

Among the shared assumptions of all systems theories, at least four stand out:

1. The idea of emergence, according to which the convergence of factors to create new features (cells, for example, or organs) exhibits novel, higher level elements which could not be derived deterministically from the elements themselves.

<sup>6</sup> A. Trewavas. "A Brief History of Systems Biology." *The Plant Cell*, 18(10), 2006, 2420–2430.

<sup>7</sup> L. von Bertalanffy. *General Systems Theory*. New York: Brazillier, 1969, 296.

<sup>8</sup> E.g., F. Haylinghen and C. Joslyn. "What is Systems Theory?" *Principia Cybernetica*, November 1, 1992. <http://pespmc1.vub.ac.be/SYSTHEOR.html>. Retrieved 7 April 2022; Ch.P. Cordon. "Systems Theories: An Overview of Systems Theories and its Application to Health Care." *American Journal of Systems Science*, 2(1), 2013, 13–22.

<sup>9</sup> M. Drack, O. Wolkenhauer. "Systems Approaches of Weiss and Bertalanffy and Their Relevance to Systems Biology Today." *Seminar in Cancer Biology*, 21(3), 2011, 150–155.

<sup>10</sup> "Systems Biology." *Wikipedia*. <https://en.wikipedia.org/wiki/systems-biology>. Retrieved 7 April 2022.

2. Holism: the view that living things are not simple aggregates. They contain features not evident in their parts.

3. Living things have to be described as hierarchical in nature. They consist of successive levels of organization.

4. In hierarchies, there is “top-down,” as well as the more familiar “bottom-up” causality. Higher levels of biological hierarchies can influence the lower ones.

Why so much confusion? It is because, I would argue, in the middle of the 20th century the dual assaults of behaviourist psychology and reductionist molecular biology were triumphant. Systems theories passed from acceptable science to mere relics of a past biology: metaphysical nonsense. They were thus largely if not entirely forgotten. The result was a historical gap. Prior to the prevailing reductionism, no historical antecedents of systems theory appeared on the horizon. When a new and antireductionist biology finally did appear, it was as if it appeared *ex nihilo*: suddenly and without predecessors. But, as we have seen, both perspectives were wrong. There had been a past systems theory dating from early in the twentieth century. And the new systems theory developed at least two decades before the year 2000.

There is another difficulty: that of understanding the new nonreductionist paradigm. The new mathematics, the new account of the development and structure of living things, do not fit the assumptions of common sense: at least not common sense as found in theories which reduce life quite simply to its components. A new “take” is called for, a new set of prime assumptions. This is never easy. In one of the best books on systems theory, *The Music of Life*, Denis Noble argues that this is inescapable. We are, he states:

ready to move on. Systems biology is where we are moving to. Only, it requires a quite different mindset. It is about putting together, rather than taking apart, integration rather than reduction. It starts from the reductionist approach; and then it goes further. It requires that we develop ways of thinking about integration that are as rigorous as our reductionist procedures, but different.<sup>11</sup>

This, Noble continues, is a major challenge. It means changing our philosophy, in the full sense of the term.

What does it mean to change our philosophy? It means at least this: that we are willing to give up prior assumptions and agree to understand things in terms which appear inconsistent or unreasonable. To deal with the world as nonlinear dynamics sees it is to concede that small, even minute factors can lead to big changes, while massive collections of facts in a biological system can produce only very small changes: all without our knowing what to expect in performing an experiment. Not knowing what to expect? The nonlinear dynamics that forms the conceptual foundation for systems theories contains an element of inescapable unpredictability. This is because of (to use a prevailing catchphrase) “extreme sensitivity to initial conditions.” Thus an event as minor as the flapping of a butterfly’s wing in China could cause the later appearance of a tornado in Texas: the so-called “butterfly effect.”

This is not the sort of irregularity that we have come to expect. It does not disappear when we become more precise in our mathematics or our measurements: it is, rather, fundamental. But even though theory seems at times quirky, disordered,

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<sup>11</sup> D. Noble. *The Music of Life: Biology Beyond Genes*. Oxford: Oxford University Press, 2006, 153.

odd, the fact remains that on its terms one is always dealing with a form of order: a new, unexpected form.

Having said all this, it is now possible to return to the basic assumptions of current systems theory with a fuller sense of their meaning. The first axiom we recall is that of “emergence.” It seems a simple enough term, proclaiming only that things emerge, become. But in the new systems theory emergence has a much richer meaning than this. A system in this theory is materially and energetically open; there is a continual flow of energy and matter through all aspects of living things. The behaviour of this flux is nonlinear and may include the development of new order at critical points of instability.<sup>12</sup>

The second axiom of systems theory, holism, is also subtler than the term holism suggests. It is not enough to say that the whole is greater than the sum of its parts. One must add that on the new point of view a cell, an organ, an organism is self-constructing, self-generating. It is more than the sum of its parts because it appropriates its parts and assembles them, in the process giving them characteristics the parts did not initially contain.

The third basic assumption of systems theories is that of hierarchy. This is an old idea, most famously developed in the philosophy of Aristotle. The contemporary concept of hierarchy, however, differs in at least two ways from that of the Greek philosopher. Aristotle assumed that hierarchies are eternal, and at all levels. Thus, through the millennia they will never change. The contemporary notion of hierarchy is far more dynamic, in at least two ways. First, levels of hierarchy, even the highest, can change their character. For systems theorists as for contemporary biologists in general, transformation does occur, throughout. Second, contemporary biologists often understand the differences between the levels in a hierarchy temporally: that is, the upper levels exhibit lengthier rhythms than the lower, while this lower level in the hierarchy exhibits lengthier rhythms than the next lower, and so on, indefinitely. Living things on these terms have descending levels of tempo (longer over shorter). Organs, tissues, cells, and even subcellular parts have rhythms organized as in a descending staircase. It is no wonder then that Denis Noble has titled his book *The Music of Life*. Life, like music, can only be understood through its rhythmic organization.

The fourth assumption common to all systems theories, top-down causality, also deserves some comment. For traditional reductionism, this is simply false. That is, reductionism assumes that all causal efficacy—all the forces that make a thing what it is—stem from the lowest level of the organism. Systems theory, however, bluntly denies this, contending that in biological systems any level can effect any other. It is not merely that the highest level affects the lower levels, as when we say that the mind affects the body. Causality in systems theory is therefore democratic. Any level can effect any other level.

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<sup>12</sup> For a treatment of these thoroughly dynamic factors cf. F. Capra, P.L. Luisi. *The Systems View of Life. A Unifying Vision*. Cambridge: Cambridge University Press, 2014, 498. All future references to this item will be cited in the text as SVL.

Finally, one should add to this picture the extent to which the systems theorists, like many researchers today, are compelled to deal with millions or hundreds of millions of cells, subcellular parts, organisms. This is termed “big data” and efforts to deal with it “data mining.” To find even the most minor of regularities, the biologist is forced to wade through multitudes of data.<sup>13</sup>

### 3. Autopoiesis: An extension of systems theory?

So far it has been possible to present a general and, I think, accurate account of systems theory: biological systems theory in particular. This theory, with its roots in a novel and challenging mathematics, has attracted many followers and gives promise of new and fundamental discoveries. But is it complete? There are those who do not think so. In *The Systems View of Life: A Unifying Vision*<sup>14</sup> Fritjof Capra and Pier Luigi Luisi argue that systems theories need to be extended to include yet another theory, autopoiesis. In what follows, I will outline the basic suppositions of autopoiesis. I will contend that much of what is found in autopoietic theory is already continued in systems theory. In my opinion, it is simply not clear whether the extension of systems theory to include autopoiesis is called for. The issue is problematic.

The theory of autopoiesis was developed by Chilean biologists Humberto Maturano and Francisco Varela in the 1970s—at the same time as, but entirely independent of, Benoit Mandelbrot’s creation of fractal geometry.<sup>15</sup> Essentially it is the result of a critique of Darwin’s concept of the organism—i.e. that he had no such concept—and a consequent view of the organism and its evolution as developing from within the organism and not through the actions of the organism’s environment (natural selection). With its treatment of the organism as self-creative and its demotion of natural selection, it is hard not to take autopoiesis as a challenge to Darwinism. There are alternative ways to state the fundamental assumptions of autopoietic theory.<sup>16</sup> What is presented here is a simplification but one which, I believe, goes to the point:

1. We begin with the organism, with its organization through which it is defined as a unity and structure (the organism as an operating system).<sup>17</sup>

2. The essential characteristic of an organism is its capacity to reproduce itself (literally its autopoietic character).<sup>18</sup>

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<sup>13</sup> E.O. Voigt. *The Inner Workings of Life: Vignettes in Systems Biology*. Cambridge: Cambridge University Press, 2016, 209. All future references to this work will be cited in the text as IWL. Fields which must contend with superabundant data often have the suffix “omics,” as in genomics.

<sup>14</sup> SVL, 498.

<sup>15</sup> J.M. Escobar. “Autopoiesis and Darwinism.” *Synthese*, 185, 2012, 53–72. All future references to this item will be cited in the text as AD.

<sup>16</sup> Cf. SVL, 137–143.

<sup>17</sup> AD, 59.

<sup>18</sup> H.R. Maturana, F.J. Varelo. *Autopoiesis and Cognition*. Boston: Reidel, 1980, 82.

3. Self-creating involves a coupling of the organism and its environment. The environment does not contribute to the organisms adaptation to its environment. The environment triggers but in no way determines the response of the organism.

4. Natural selection (the effect of the environment on the living thing) plays no role in evolution. In its place Maturana and Varela propose the term “drift.”

My response to autopoiesis’ rethinking of the nature of biological evolution will be threefold. First, it needs to be pointed out that the idea of autopoiesis was worked out independently of Maturana and Varela by Ilya Prigogine and his colleagues as well as by the founders of nonlinear dynamics. For both these groups the organism is seen as not merely to perpetuate itself but able, under the right conditions, to create new versions of itself and thus make possible the emergence of novel organisms. The notion of the self-creating character of organisms was hardly limited to or developed by autopoietic theorists. We are fortunate that Maturana and Varela singled it out and thought through its implications and its importance. But we are also compelled to ask whether in the extreme form they have given it, autopoiesis has to be accepted without question.

The primary difficulty of autopoiesis as its creators define it is its extreme anti-environmental stance. It is not that in this theory the environment plays no role in the evolution of life. As we have just seen, it plays a role as a necessary but not sufficient condition. Without it neither the continued survival of living things nor their transformations into new species would be possible. But is the environment really only a “spark,” an occasion in which the living thing can reassemble itself and readapt? I can think of two reasons why this cannot be so. The first is that the physical environment, via its constituents, sets limits on what directions the organism can take in its self-assembly: its creative responses to its surroundings. If plants had not begun producing oxygen, all manner of creatures could not have evolved on our planet. Can we take the world’s oxygen rich atmosphere as only a “trigger” or “spark” when its absence would have limited evolution in innumerable ways no matter what responses living things came up with to deal with the environment?

But there is one more step which autopoiesis theorists take. What is the character of the self-creating process such that it persists, reaching ever more diverse life forms? The answer, we are told, is simply, “drift.” It is not that autopoieticists do not characterize this term. There is, they contend, no underlying process which directs evolution, no purpose. Certainly, there is no antientropic force or “push” in evolution. On the other hand, life’s perpetual self-creation is not entirely random. It is based in part on the present state and present potentialities contained in its organization and structure.

It is possible that this writer has missed something in trying to understand this notion of “drift.” But he finds the concept puzzling. Beyond asserting that there is perpetual transformation in nature, drift seems to say very little. It is not equivalent to chance or randomness. Rather, it appears to be a synonym for change. As such it appears a descriptive, but not an explanatory concept. As such, I do not find it helpful.

I would like to conclude this section by noting an interesting fact. That is, while autopoietics was developed to deal with biological problems, it has been extended



far beyond its original boundaries to include social phenomena: an extension as we will see that has also occurred with systems theory enlarged by complexity theorists. In the case of autopoietic theory, this has notably been carried out by the German sociologist Niklas Luhmann, whose writings have attracted a wide following.<sup>19</sup>

#### 4. Complexity theory as broadened systems theory: Into the social world

So far the author has examined the history and basic concepts of systems theory, which represent a real change in basic conceptual schemes in all aspects of biology, from ecology to subcellular parts. In analyzing biological systems theory, the author has increasingly encountered a similar point of view termed “complex adaptive systems” or, more often, “complexity theory.” Since proponents of this latter standpoint sometimes go out of their way to distinguish their views from systems theory<sup>20</sup> and nonetheless because those theories are closely similar, a section of this paper devoted to complexity theory seems called for. The conceptual affinities of the two approaches are not the only present point of interest. Complexity theory has had in fact a large, one could almost say, massive impact on the social sciences. This fact alone would merit paying attention.

It does not take a profound reading of complexity theory to realize that one is dealing with the same set of basic assumptions one has already encountered in systems theory. For one, the terms used by complexity theorists are identical with those used by proponents of biological systems theory: nonlinearity, emergence, uncertainties in prediction, self-organization, bottom-up causality, chaos. Equally significant, complexity theorists attack the mechanistic standpoint in exactly the same way as do systems theorists. The Cartesian-Newtonian reductionism which formed the basis of the modern viewpoint, they insist, has created the problems which it cannot resolve.

This protest, which we have already found in the writings of systems theorists, is reaffirmed in a representative article by Jun Park. Park, however, aligns himself with the great majority of complexity advocates by focusing his dissatisfaction not on broadly biological factors but on problems which are fundamentally social: in his case corporate and economic. He cites four examples of this structure:

1. Organizations are owned by external parties.
2. Basic goals are formulated exclusively by management.
3. Policies are imposed by a top-down hierarchy.

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<sup>19</sup> N. Luhmann. *Theory of Society*. Vol. 1. Transl. R. Barratt. Stanford: Stanford University Press, 2012. Cf. also M. Zeleny (Ed.). *Autopoiesis, Dissipative Structures and Spontaneous Social Order*. Boulder, CO: Westview Press, 1980.

<sup>20</sup> J.R. Turner. “An Overview of Complexity Theory with Potential Applications for the Social Sciences.” *Systems*, 1(4), 2019, 4. Turner criticizes von Bertalanffy’s systems theory for its failure to be able to deal with complexity and nonlinear systems; which, as we have seen, is exactly what the newer systems theories do.

4. All procedures, even the most minimal, are routinized.<sup>21 22</sup>

But, Park insists, we now face the rapid, unpredictable development of new technologies in a highly complex and changing global economy in the context of social conditions which previous economists and sociologists could not have imagined. A new set of concepts is therefore needed to deal with a new and not exactly reassuring situation.

Interestingly, two of Park's examples mirror two of the fundamental assumptions of systems theory outlined above. The insistence of systems theorists on bottom-up causation is echoed in Park's rejection of top-down corporate hierarchies. The systems theorists' insistence on the self-creative nature of organisms is in fundamental agreement with the protest of all advocates of complexity against the dull routinization of everything.

Though this section of the present article is intended as brief, brevity here is not intended to convey some comment on the unimportance of complexity theory. Quite the contrary. In this context brevity is possible because the basic concepts of complexity theory and systems theory are the same. There is no need to repeat them, they already have been presented above. What is called for here is not an account of basic concepts, but a description of where complexity theorists have applied them and with what results.

To this writer the most striking thing about complexity theory is the number of fields to which it has been applied. Though these are found primarily in studies of corporate culture and business economics, they are by no means limited to these fields. Thus, under the heading of corporate management one finds complexity theorists' studies of organizational change, corporate innovation, economic geography, international development, leadership, theories of negotiation, to name a few. But one also finds the complexity standpoint applied to education, general psychology, applied linguistics, health services, research and nursing.<sup>23</sup> This list is not therefore intended as complete, but only as a sample of a massive literature. An idea of its extent can be seen in a list compiled by Book Authority: 55 Best Complexity Theory Books of All Time.<sup>24</sup> Complexity theory has penetrated nearly all aspects of contemporary thought.

I would like to end this section with a pair of general remarks. The first concerns a new classification of the nature of problems. Problems, complexity theorist conclude, are of three kinds: 1. Simple, 2. Complex, and 3. Wicked<sup>26</sup>. It is good, in the contemporary context, to find the hard sense of reality creeping even into the writings of theorists and intellectuals. One is impressed with the complexity theorists

<sup>21</sup> J. Park. "An Introduction to Complexity Theory." *Medium*. Medium.com/@junp01/an-introduction-to-complexity-theorysc20695725f8. Retrieved 7 April 2023.

<sup>22</sup> Cf. for example C.M. Grobman. "Complexity Theory: A New Way to Look at Organizational Change." *Public Administration Quarterly*, 29(3/4), 2005, 350–382; C.A. Hidalgo. "Economic Complexity Theory and its Applications." *Nature Reviews Physics*, 3, 2021, 92–113. All future references to this work will be cited in the text as ECT.

<sup>23</sup> ECT, 92–113.

<sup>24</sup> This is not a published volume. It is, rather, a list of writings on complexity recommended by B. Gates, Ch. Anderson, D.A. Wallach, J. O'Brien and six others.

“wicked” sense of the actual contemporary world. The second point is a footnote to the history of ideas. It is good, one would admit, that we can find concepts which help us adapt and reply to reality. But simply chanting the word practicality is not enough. If the ideas of complexity theory are capable of broadscale applications to a world of intricate international markets, technological acceleration, and global implosion it is nonetheless good to remember that the roots of complexity theory are not in corporate finance but in new forms of mathematics—a nonstandard officially unacceptable mathematics at that. We should make room for the “impractical” if we want to deal with reality.

## 5. Brain plasticity

If systems theory involves the complex interplay of mathematical, theoretical, and empirical factors, the next item in our survey of antireductionist programs, brain plasticity, arose from research with little need of theory. Even so, it represents a profound theoretical shift.

In textbooks and in popular culture, the brain is pictured as a collection of discrete regions, each dedicated to a specific task. Thus, one area is devoted to vision, another to hearing, another to language use. Each area is neatly labeled and categorized by its function. An assumption that comes along with this neat compartmentalization is that its components are “hardwired.” That is, once established, they continue unchanged from their original state. On these terms, the brain is a highly stable and conservative structure. Another prevailing assumption is that brain development is all but over and fully formed by the age of six. Changes to brain structure and function after this state are, if anything, minimal.

This picture of how the brain is constructed and how it operates has been for many decades assumed as self-evident. Alternative conceptions have been rejected out of hand. But in recent years a massive amount of evidence has accumulated showing that the reigning paradigm is inadequate. Each of the assumptions I have described as defining the older viewpoint has been shown to be false. The doctrine of the simple location of brain function has been eclipsed. We can no longer place brain functions securely at specific places. Their locations can change. Similarly, the idea that the brain is hardwired has given way to the belief that the brain and its connections are at every moment being recreated. David Eagleman suggests that the term “hardwired” be replaced by the more adequate “livewired.”<sup>25</sup> Finally, the assumption that the brain ceases developing at any point has been given up. Significant changes continue to take place in its structure well past the age of 6, reaching in some cases into old age.

For example, it has been discovered that if a part of the brain that carries on a particular function is altered whether through damage, illness, or genetic factors, another part of the brain will be able to reassemble itself internally and carry on the lost function. That is, if a part of the brain which has been devoted, for ex-

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<sup>25</sup> D. Eagleman. *Livewired: The Inside Story of the Ever-changing Brain*. New York: Vintage, 310. All future references to this work will be cited in the text as L.

ample, to language use if damaged or lost, the capacity for language use can be developed in another part of the brain and can (often through strenuous therapeutic measures) be regained.

The ability of the brain to transform itself is particularly dramatic in the case of split-brain surgery. An example is cited by David Eagleman<sup>26</sup>. A youth, Matthew, began to be affected by severe seizures. After several years his doctors diagnosed him as having Rasmussen's encephalitis, a rare inflammatory disease. The problem is that this disease afflicts an entire half of the brain and the only known treatment is to remove the afflicted half. Matthew underwent this procedure (hemispherectomy) and with the help of extensive therapy became able to think, to speak, to walk, and to pursue a normal life again<sup>27</sup>. This could only have happened if functions localized in half of the brain were transferred as a whole to the other. The same transformation occurs in people born with only half a brain. The remaining half takes over functions previously reserved for the missing half.

Another striking example of brain recovery is provided by Paul Bach-y-Rita, a pioneer in brain plasticity research. Bach-y-Rita's father, then 65 years old, was struck by a disabling stroke and left half paralyzed, unable to speak. A year of crawling and other non-standard therapy including children's games and pot washing resulted in his nearly complete rehabilitation. He was able to return to his role as a professor at the City College of New York. This dramatic recovery proved that persons with severe medical complications and abnormal behavior can, through much perseverance, recover nearly all of their normal functions. It is important to point out that his stroke caused an extensive lesion in his brainstem and damage to several brain areas. His recuperation involved the recruitment and transformation of new brain networks.<sup>28</sup>

Many other kinds of brain damage or other dysfunction showed the same potential for recuperation and have been intensively studied. Among these are autism, stress, aging, neocortical diseases (e.g. Alzheimer's), and the effects of brain surgery. These showed the same neoplastic roots to recovery as those sketched immediately above.

To put it mildly, this is daunting task for the investigator. Not only does its study take in the whole field of normal psychology.<sup>29</sup> It includes the investigation of the rich panoply of factors which support brain function, for example, cholinergic input,<sup>30</sup> Dendritic changes,<sup>31</sup> astrocyte function,<sup>32</sup> hormonal effects.<sup>33</sup> A critic would say that is only a grab bag, and the critic would be right. But at least it

<sup>26</sup> L, 310.

<sup>27</sup> L, 4–7, 15.

<sup>28</sup> N. Doidge. *The Brain that Changes Itself*. New York: Penguin, 2007, 20–23.

<sup>29</sup> Ansermet and Magistretti extend it over abnormal psychology as well: i.e. they seek to interrelate brain plasticity and Freudian psychoanalysis. Cf. F. Ansermet, P. Magistretti. *The Biology of Freedom*. New York: Routledge, 2007, 254.

<sup>30</sup> B. Kolb. *Brain Plasticity and Behavior*. New York: Routledge, 1995, 96. All future references to this work will be cited as BPB.

<sup>31</sup> BPB, 120.

<sup>32</sup> BPB, 130.

<sup>33</sup> BPB, 136.

suggests the complexity researchers face in dealing with the problems involved in brain functioning plasticity.

Brain plasticity, if it is seen most dramatically in the recovery from brain damage, turns out to be present everywhere in the functioning of the central nervous system, most prominently in the development of the brain in the embryo and extending through early childhood, but also in cognition, language use, memory, ordinary behavior, and even sleep.<sup>34</sup> One can see the very broad field that plasticity researchers are called on to investigate: namely everything. Everything involved in the plastic functioning of the brain.

Plasticity researchers do not present their achievements in axiomatic form, in statements of assumptions. Nonetheless, it is possible to outline some of their basic ideas. We have already sketched one of these: that is, that neuroplasticity is a process and largely constructive. New structures are created when called for, and these enable the brain to function normally. A very striking way of describing this activity is to say that the brain creates itself.

A second assumption common to brain plasticity research has also been described above. That is, the notion that brain functions are neatly compartmentalized must be rejected. Brain functions can relocate themselves. They are not “hard-wired,” to use the traditional term.

Brain plasticity research may include other assumptions. Some writers familiar with it add the notion of temporal hierarchy to the list of factors to be taken into account in explaining the creative activity of the brain.<sup>35</sup> But in general, brain plasticity has developed without an interest in theoretical assumptions. Rather, it has centered itself on dealing with the brain one problem area at a time. In doing so it has played an important role in the shift of opinion away from reductionism towards a more open and holistic picture of the organism.

## 6. Epigenetics: Plasticity in the genes

By stressing the word “plasticity” as a characteristic of the genes I do not mean to confuse epigenetics with brain plasticity. They are two different things in two nicely distinguishable realms. Brain plasticity is, in a broad sense perhaps extending beyond the central nervous system, a physiological phenomenon. Epigenetics involves only the genes and their expression. It is more informational than physiological.

That said, there are good reasons for linking plasticity and epigenetics. Both provide exceptions to the rule which has so far guided mainstream science: that is, the notion of “hardwiring.” The genes, like the areas of the brain which support particular functions (speech, perception...) have been assumed to be “hardwired”: except for rare mutations they remain exactly the same from generation to generation. What has happened quite recently, however, is the discovery that besides

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<sup>34</sup> P. Macquet, C. Smith, R. Stickgold (Eds.). *Sleep and Brain Plasticity*. Oxford: Oxford University Press, 2003, 379. The authors of this anthology argue that a fundamental function of sleep is that of supporting plasticity in the brain.

<sup>35</sup> L, 221; IWL, 85, 93.

the basic chemistry of the genes (DNA, RNA, proteins) there is another chemistry which allows for a flexibility over shorter time scales, a flexibility that turns out to be very useful to the organism in its interactions with its environment. What follows is a general sketch.

I will begin with a pair of examples of two well-known phenomena that have puzzled orthodox biology. One is the result of the Dutch Hunger Winter of 1944–5, in which millions of Dutch citizens were subjected to periods of starvation or near-starvation. Puzzlingly, these had an effect on the succeeding generations of Hollanders: their children and the children of their children were markedly smaller than their parents, a condition that gradually disappeared, leaving descendants of the once-starved generation less and less small until by the fifth-generation descendants were of normal stature. The other example is that of the water flea, daphnia. On perceiving one of its biological enemies it develops spikes and other defenses. These last for four generations before “washing out.”

The problem is that in these and similar cases ordinary Mendelian genetics cannot explain how these effects arise or how they persist. They are not the result of ordinary mutations. And if they were, why do they persist for only a few generations? Answers could not be found. That is, not until about the year two thousand, when epigenetics appeared abruptly on the scene. To the surprise of the majority of biologists, there are not one but two genetic systems. One is the standard Mendelian genetic systems based on the now familiar DNA–RNA chemistry. The other is the epigenetic system, which can exert control on the genes, turning them on and off, allowing them to be expressed or not expressed. This does not affect the sequences of the traditional genome. But it can make a big difference whether a gene or set of genes can be expressed, can become active.<sup>36</sup> Epigenetic changes can have negative effects not just in the womb but for an entire lifetime. They have been found in schizophrenia, asthma, multiple sclerosis and diabetes, among others.<sup>37</sup> That these discoveries have had a profound impact on the medical community is not surprising.

If epigenetics and brain plasticity involve very different systems in the body and operate very differently, they have one thing in common, which can create a broad popular following. That is, they suggest that the brain and genetic system, if they previously seemed to impose a fate from which the individual cannot escape, now appear malleable, changeable. The individual now appears able to escape biological constraints which once seemed iron clad. One thus finds books and associated medical (including psychological) programs which promise an escape from all manner of illnesses, or at least the severity of their symptoms, and more broadly, the chance to improve one’s health or even raise one’s intelligence.

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<sup>36</sup> The three fundamental epigenetic processes are: 1. DNA methylation 2. Histone modification, and 3. Non-Coding of DNA. These involve the imposition or removal of small chemical “tags”: a very simple procedure, at least in principle. Cf. P. Wigmore. “The Effect of Systematic Chemotherapy on Neurogenesis, Plasticity, and Memory.” In C. Belzug, P. Wigmore (Eds.). *Neurogenesis, and Neuroplasticity*. Berlin: Springer Verlag, 2013, 211–240.

<sup>37</sup> B. Weinhold. “Epigenetics: The Science of Change.” *Environmental Health Perspectives*, 114(3), 2006, A160–7. Ageing and Cancer are two more fields in which epigenetic effects have been found.

Epigenetics appears to offer a way for our life experiences to modify our genetic inheritance and thus alter our genetic fate,<sup>38</sup> just as the study of brain plasticity gives us the chance to escape mental illness, for example, or improve bodily functions. Nesa Carey's *The Epigenetic Revolution* thus has become a best-seller<sup>39</sup> along with self-help books offering means to self-improvement<sup>40</sup>.

It would be nice if epigenetics were a closed, stable field with basic questions answered and the effects of epigenetic processes well known, but this is not the case. As concerns human beings, much is known about the effects of epigenesis in a single generation. The effects of drug abuse, stress (especially long-term stress) or pesticide exposure, are, if not fully worked out, at least well-established in many cases. It is now well known that epigenetic effects can, for better or for worse, have marked impacts on the human organism and its genome in a single generation. When one comes to dealing with the possibility that epigenesis can be transmitted down several generations, however, certainty can be hard to find. In what follows, I will outline why this is so and make an effort to clarify a not-always-clear situation.

In effect, the problems reduce to two. There is evidence for the long-term transmission of epigenesis in human beings. The evidence is, unfortunately "indirect," giving rise to heated debate. The second problem is broadly theoretical, involving Darwin's theory of evolution. I will deal with the theoretical problem first.

According to Charles Darwin, only two factors can influence the course of evolution: genetic mutation and natural selection. Mutations supply the variations from which evolution selects. Selection in turn is a simple affair. Those organisms which are not eliminated are selected "in": being adapted to their environment, they survive. Those unable to survive are selected "out": the elimination of the unfit. To repeat the point, nothing else can direct the course of evolution.<sup>41</sup>

The contrary view was proposed prior to Darwin by a Frenchman, Jean Baptiste de Lamarck, who taught that sheer physical effort could cause traits to be passed on to descendants. This alternative is termed the inheritance of acquired characteristics. Thus, to use one of Lamarck's examples, by constantly stretching its neck to eat the leaves in the higher tree branches, could gradually lengthen its neck. This added extent could then be passed along to its descendants, who, by continuing to stretch their necks in their pursuit of leaves, could create a longer neck and pass it along to their descendants. The result would be today's giraffe: long-necked but a survivor.

Today no biologist is Lamarckian. Darwinian orthodoxy has prevailed, to the point that even a hint of Lamarckian leanings can disqualify a paper from being

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<sup>38</sup> M. Tontonez. "What is Epigenetics and Why is Everyone Talking About It?" Memorial Sloan Kettering Cancer Center, June 19, 2018. <https://www.mskcc.org/news/what-epigenetics-and-why-everyone-talking-about-it>. Retrieved 1 April 2023.

<sup>39</sup> N. Carey. *The Epigenetic Revolution: How Modern Biology is Rewriting our Understanding of Genetics, Disease, and Inheritance*. London: Icon Books, 2012, 352.

<sup>40</sup> K.L. Pelletier. *Change Your Genes, Change Your Life: Creating Optimal Health with the New Science of Epigenetics*. San Rafael, CA: Origin Press, 2018, 230.

<sup>41</sup> Darwin did attempt to make room for other sources of variation than his notion of point mutations. His admission of Lamarckian effects, under the heading of "pangenesis," then was and now is agreed to be a failure.

published or a speech from being given: that is, until the appearance of epigenetics. If epigenetic effects can be produced in one generation and passed on to succeeding generations this is a case of the heredity of acquired characteristics. It is a proof of Lamarckian inheritance, even if it is in terms that Lamarck could not have imagined. In the popular press one can find, on the basis of epigenetic generational effects, that Darwin has been refuted and a new paradigm has been proclaimed. The facts, however, are more complex than such articles suggest. More complex and more puzzling.

It is true that long-term multigenerational epigenetic effects have been established. The results, however, are not what those who proclaim a great scientific revolution suggest. Epigenetic effects have been shown to occur in plants and some animals.<sup>42</sup> What has been shown, however for mammals, including humans, is far less certain. There is a hard problem for those who believe that epigenes can be passed down the human generations. Epigenetic “mutations” in mammals are twice erased: once in the embryo and again in the early stages of development. How epigenetic information could survive this dual clearing-out is a puzzle which no one has been able to solve.

The end result is a kind of stand-off. Those who do not believe in many-generation epigeneticity protest that there is no solid proof of it. Those who believe in it insist that there is plenty of proof. It has been shown that transgenerational effects occur in a multitude of phenomena: asthma, diabetes, ageing, multiple sclerosis, trauma, child mortality, smoking...the list can be lengthened, but the puzzle remains. Yes, such phenomena demonstrate the existence of transgenerational epigenetic information. But we also have good reason to think that such phenomena are impossible. If they exist, why is it that—as one reads over and over in the scientific literature—“their exact mechanism has not been elucidated?”<sup>43</sup>

The author cannot resist offering two concluding remarks. The first seems to this observer to be obvious. In the most important respect, the survivability of the organism, whether by epigenesis or Darwinian mutation-selection are little different. Darwinian genetics—particularly when understood in Charles Darwin’s terms as comprised of minor changes<sup>44</sup> is a very slow affair. Its capacity to aid the organism in its response to rapid changes in the environment is minimal.

Epigenesis, however, operates within a brief time scale, making possible an effective adaptation of the organism to fast-moving changes. In this respect, epigenesis only adds to Darwin’s concept of evolution. Rather than parade under a banner of discredited Darwin it would be better to read and reflect on M.K. Skinner’s essay “Environmental Epigenetics and a Unified Theory of the Molecular Aspects

<sup>42</sup> R.J. Shmitz, J.R. Ecker. “Epigenetic and Epigenomic Variation in *Arabidopsis Thaliana*.” *Trends in Plant Science*, 17, 2012, 149–154; D. Weigel, V. Colot. “Epiallels in Plant Evolution.” *Genome Biology*, 13, 2012, Article 249; H.D. Madharu. “Unbelievable but True: Epigenetics and Chromatin in Fungii.” *Trends in Genetics*, 1, 2020, 12–20.

<sup>43</sup> R.R. Kanherker, N.B. Doy, A.B. Cook. “Epigenetics Across the Human Lifespan.” *Frontiers in Cell and Developmental Biology*, September 9, 2014. DOI: 10.3389/cell.2014.00049. I recommend this article as a careful and complete survey of the present literature on epigenetics.

<sup>44</sup> “Point mutations” as stated above.



of Evolution: A Neo-Lamarckian Concept That Facilitates Darwinian Evolution.”<sup>45</sup> We have good reason to expect that the future of evolutionary theory portends not so much conflict as unity.

## 7. Do animals think? Unreducing the reduction

When he established the conceptual foundations for modern science in the 17th century, René Descartes did animals a profound disservice. Human beings, he stated, think. That is their essential character. Animals, by contrast, are merely complex machines. If I injure a dog, for example, it may seem to be writhing in pain. But there is no pain, Descartes assured us. The dog, being an intricate machine, can mimic how we behave when we are injured. But pain is absent. That was the view of numerous thinkers from the 17th century to our own time. Furthermore, behaviorism in the 20th century went a step further by denying thought and feeling not only to animals but to humans. More precisely, behaviorists followed B.F. Skinner by insisting that scientists should only study outward behavior. References to feeling, consciousness, or thought must be rejected: These are illusions.

The weight of philosophical and scientific opinion combined in the early 20th century with the cultural assumptions of Western civilization, which had always placed the human mind and “soul” on a pedestal transcending the mere world. The result was a solid consensus: a stone wall. Psychologists, whether human or animal, dared not breach the wall, for fear of being labeled nonscientific; or worse, metaphysicians; or worse still, the dreaded term “mystic.”

This has changed. Exactly why it has changed and how far it has changed or something the writer finds difficult to discern. But change is in the air. Animal or comparative psychologists now feel free to talk about and investigate animals’ thoughts and feelings. The same shift in opinion has transformed scientific psychology as well, making it possible to discuss human cognition and feeling without even a blush. In this and the next section I will discuss the methods used in the new psychologies and some of their basic concepts by contrasting them with the prior approach to psychology.

Behaviorism certainly had the virtue of simplicity. But its simplicity excluded far more than consciousness and its contents. It assumed that one organism was, in its essentials, little different than another. It was not necessary to pay attention to the particular characteristics of different species. If they could be fitted into the behaviorist stimulus-response (reward-behavior) framework, that was all that was necessary. The character of the organism and its relations to its environment were excluded along with any concern over its purported thoughts or feelings. Behaviorists as a rule limited themselves to the behavior of rats and pigeons. Contemporary comparative psychologists, by contrast, insist that all of these exclusions have to be avoided. The end result was that the particular characters of an organism, includ-

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<sup>45</sup> M.K. Skinner. “Environmental Epigenetics and a Unified Theory of the Molecular Aspects of Evolution: A Neo-Lamarckian Concept that Facilitates Neo-Darwinian Evolution.” *Genome Biology and Evolution*, 7(5), 2015, 1296–1302. DOI: 10.1093/gbe/evv073.

ing its interactions with its environment, have to be taken into account. Equally important, it is a mistake for the new psychologists to limit themselves to the study of only a handful of species. The whole spectrum of living things has to be considered, as do the many features of animal awareness and behavior: environment, memory, altruistic behavior, emotions, intentions, and many others. The stark oneness of the behaviorist approach gives way to a striking but difficult to manage pluralism.

Failure to relate research to the specifics of the organism can lead to some bizarre mistakes. For example, in one experiment to discover whether elephants could recognize their reflections in a mirror (mirror recognition), the elephant was presented with a small mirror (small in relation to the elephant) which was placed at a distance from it. Needless to say the elephant took little interest in the mirror, proving that it had no capacity for mirror recognition. However, when a large mirror replaced the previous mirror and was left free standing so that the elephant could examine it front and back, the animal immediately recognized its reflection. Also, it observed a white “X” painted on its forehead and painstakingly removed the blemish. Another example of what happens when the character of the organism is ignored involves the monkey’s capacity for face recognition. Predictably, the first monkeys to be tested for this ability were tested using human faces, which the monkeys were unable to recognize. When tested using not human but simian faces, however, monkeys succeeded at facial recognition. The moral of these errors appears in the title of Frans de Waal’s *Are We Smart Enough to Know How Smart Animals Are?*<sup>46</sup> Is it animal that lacks intelligence? Or, perhaps, the problem is that the experimenters have failed to use their own intelligence.

Dealing with elephants and mirrors, monkeys and faces is relatively simple task once one has the idea of focusing on the animal *per se*. For several reasons, however, in most cases things are not so simple. It is hard, and in some instances impossible to do experiments with animals as big as elephants or whales. Studying a much more manageable animal—e.g. a chimp, a macaque, etc.— is easier. But placing them in a laboratory situation is liable to change their behavior from their actions in the wild. Hence many studies of animal empathy or cognition have to be done in the wild, with all the difficulties that involves. Equally demanding on anyone trying to understand this field is its current application to species far beyond the limited purview of pigeons and rats.<sup>47</sup> Besides these animals, recent experiments have reached out beyond elephants and monkeys to include honeybees, fish, crabs, and octopuses.<sup>48</sup>

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<sup>46</sup> F. de Waal. *Are We Smart Enough to Know How Smart Animals Are?* New York: W.W. Norton, 2016, 15–17. All future references to this work will be cited as SAA.

<sup>47</sup> For a recent publication that might help a reader interested in this, see *The Cambridge Handbook of Animal Cognition*. New York: Cambridge University Press, 2021, 328.

<sup>48</sup> See F. de Waal, K. Andrews. “The Question of Animal Emotions.” *Science*, 375(6581), March 24, 2022, 1351–1352. Also, K. Andrews. *The Animal Mind*. New York: Routledge, 2014. Andrews notes that Aristotle was wrong to hold that only human beings laugh. Rats have been shown to laugh. Finally, V.A. Braithwaite, et al. “Variation in Emotion and Cognition among Fishes.” *Journal of Agricultural and Environmental Ethics*, 26(1), 2013, 7–23.

Is paying close attention to each animal, its habitat, and its ways of coping were not enough, there is the welter of kinds of consciousness which animal psychologists have come to consider. I will list only a few, and examine only a small subset—three to be exact—of these. To do more would be to write not an article but a monograph or even a book. Today comparative psychologists study memory, communication (language use), altruistic behavior (targeted helping), emotion (distinguished from feeling), sympathy, culture, cognition, and more. Of these I will discuss only deception, sympathy, and animal culture. The discussion will be brief.

Deception turns out to be common among animals, from birds (e.g. jays, crows) to primates (monkeys, gorillas), to dogs, and squirrels.<sup>49</sup> This is extremely interesting to comparative psychologists because it is taken to demonstrate that deceivers have at least two conceptual abilities: they know the mental state of another and they are aware that they have this knowledge. The latter capacity is called “metacognition.” Martha C. Nussbaum argues:

any creature who is capable of deceiving another creature is capable of metacognition, since to deceive you must be able to think about the mental state of another. Dogs, squirrels, and many birds, and no doubt a long list of other animals, have this ability, which is crucial to survival when you have to hide your food where your competitors won't find it.<sup>50</sup>

My favorite example of animal deception, one which shows considerable social sophistication, is that of a young baboon who sounds a call of distress to get other baboons to chase away an individual who is presumably dangerous. Having made a show of pretending to ensure the safety of the pack, he then waits for the other baboons to wander off and then eats the food which the presumably dangerous baboon had gathered.<sup>51</sup> A Eurasian jay, if being watched by another, hides its food behind an opaque barrier. Old world monkeys recruit a “fall guy” to deflect aggression meant for them. Veined octopuses hide themselves behind a number of coconut shells that they carry with them to evade predators.<sup>52</sup> There is no problem about running out of examples. Scientists term the capacity to know what another individual is thinking “Theory of Mind.” It is classified as a sort of perspective taking.

Another capacity found in many animals is rendering aid: that is, helping another animal in distress. This ought not to be surprising. But it has not been long since most people in Western Civilization have seen nature, in an excess of one-sidedness, as simply “red in tooth and claw”: a violent, unending struggle not only between predator and prey but between brother and brother. This, however, is not the whole truth. For example, a baby elephant was filmed sliding into a mud hole from which

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<sup>49</sup> Cf. B.J. King. “Deception in the Animal Kingdom.” *Scientific American*, digital issue, September 1, 2019, <https://www.scientificamerican.com/article/deception-in-the-animal-kingdom/>. Retrieved 12 May 2023.

<sup>50</sup> M.C. Nussbaum. “What We Owe our Fellow Animals.” *New York Review*, 69(3), March 10, 2022, 34–36.

<sup>51</sup> J.C. Hatchett. “Intentional Deception Among Nonhuman Primates.” Senior Thesis for the University Honors College, Texas Tech University, 2001, 6.

<sup>52</sup> S. Semple, K. McComb. “Behavioral Deception.” *Trends in Ecology and Evolution*, 10, 1996, 434–437.

it could not get out. The elephants around it became thoroughly agitated. A matriarch and a nearby female elephant solved the problem:

Both females worked together placing their trunks and tusks underneath the calf until the suction was broken and the calf struggled out of the hole. When this film clip is shown to a human audience, they clap as long as the calf stands on dry land, shaking off the mud like a big floppy dog.<sup>53</sup>

Examples are not hard to find, either in the wild or under controlled conditions. There is an example of how a bonobo (a close relative of the chimp) rescued a stunned bird that had flown into a glass window or a chimp dragging a friend away from a poisonous snake. At the Primate Research Center at Kyoto University scientists set up a situation to test chimps for their willingness to share tools. They were given two ways to obtain orange juice: They could either move a container close with a rake or suck the juice through a straw. The problem was that the apes had no straws. But:

Next to them, in a separate area, sat a chimp who had a whole set of different tools. The chimp would take one look at the other's problem, then pick out the right tool for the task and hand it to the other through the small window.<sup>54</sup>

This experiment shows not only that chimps are ready to assist each other, but are willing to take their specific needs into account. There are so many examples of animals helping animals that it is almost impossible not to believe that they are aware of what they are doing, clear down to their choices of which way to render help. Note the case of the bonobo and the injured bird. There are many cases of intraspecific helping: a fascinating but puzzling fact.

Finally we come to the study of animal culture. It is now a large, very active field. Formerly, however, it was not a field at all. Not until 1952 did a Japanese researcher, Kinji Imanishi, propose that it was possible to speak of animal culture.<sup>55</sup> It was not until forty years later, in the 1990's, did animal psychologists begin to take his idea seriously. It is not hard to see why. Culture is supposed to be something only human beings have. It didn't make sense to talk about animals having it.

Today's comparative psychologists have many disagreements. But they agree on defining culture as a process involving the social transmission of behaviors among many animal species: monkeys, dogs, parrots, corvids, dolphins and others. The number of kinds of social transmission of behaviors are fascinating; reaching from backscratching, potato washing, nut cracking, and foraging techniques to bowing behaviors, song learning, and termite fishing. Within a species there will be a group that specializes in one of these socially learned behaviors while another group of the same species does not: hence we have in one species, two cultures.

Several questions crop up in publications dealing with animal culture as the social transmissions of behavior. Nutcracking or backscratching, for example, seem to be a minimal basis to define a culture. But it is not always that simple. Jane

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<sup>53</sup> F. de Waal. *The Age of Empathy*. London: Souvenir Press, 2019, 133.

<sup>54</sup> F. de Waal. *The Bonobo and the Atheist: In Search of Humanism Among the Primates*. New York: W.W. Norton, 2013, 146–147

<sup>55</sup> SAA, 51.

Goodall, famous for her lifetime study of chimpanzees, found almost forty behavior patterns in chimps that are an indication of significant cultural variation. It is interesting to note that Goodall included among these rain dances and courtship rituals.<sup>56</sup> This depicts a much more diverse, complex social system than, for example, between using sticks or chewed leaves to extract honey.

There is also the question of whether animal cultures are cumulative or if they merely change haphazardly from one learned behavior to the next. A verdict is hard to come by. Human culture seems to be far more likely to be cumulative than animal cultures. One finds no consensus as to why this might be so. Another debate encountered in the literature on animal culture involves the question of how behaviors can be socially transmitted. Is it merely a matter of stimulus and response, or is it imitation or even teaching?<sup>57</sup>

There appears to be a consensus among scientist that so long as culture is defined as the transmission of behavior in animal societies, the case for the existence of culture in both humans and nonhuman animals is, though debated on many fronts, strong. The trouble is, this is not the only way to define culture, which can be defined not as the transmission of behaviors but as fundamentally symbolic. Symbolic cultures are transmitted in terms of concepts (good and evil), mythical inventions (gods and underworlds), and constructs (promises, football games). It is not clear that animals deal in such matters, which also include, e.g., the arts, philosophy, and higher mathematics. Clearly, animals have customs. Whether they have symbolic culture, however, is a question very much up in the air. If you choose the right journal, you can find any degree of agreement/disagreement over whether or to what extent animal culture approximates symbolic status. Without wishing to dogmatize, I must admit that the gap between anything I find in the Sistine Chapel, the Fifth Symphony or, for that matter, Cantorian arithmetic largely transcends what one finds among nonhuman cultures. Chimpanzees, Jane Goodall discovered, have rain dances and mating rituals. At most one finds here a kind of approximation. But an approximation is not an identity.

## 8. Psychology in the twenty-first century: Emotion and the human body

An essay like this, since it is a broad survey, cannot escape giving brief accounts and capsule descriptions. That is its nature. This is especially true of the present section. The author does not pretend here to present a complete overview of the present state of psychology. What follows is a condensed description of the changed face of scientific psychology—so different from the psychology the author encoun-

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<sup>56</sup> M. Brunette. “Do Chimpanzees Have Culture?” *Jane Goodall Institute*, April 11, 2018. <https://janegoodall.ca/our-stories/do-chimpanzees-have-culture/>. Retrieved 18 May 2022.

<sup>57</sup> Cf. H. Taylor. “Evidence for Teaching in an Australian Songbird.” *Frontiers in Psychology*, 12, 2021, Article 593532. DOI: 10.3389/fpsyg.2021.593532. Cf. also G.L. Vale, et al. “Why do Chimpanzees Have Diverse Behavioral Repertoires Yet Lack More Complex Cultures?” *Evolution and Human Behavior*, 42(3), 2020. DOI: 10.1016/j.evolhumbehav.2020.11.003.

tered in his university education—and an effort to describe the assumptions which, from the vantage-point of neurophysiology make the emotive view of the brain possible. The author will add some criticisms and suggestions of the central figure in this paradigm shift, Antonio Damasio. They too will be brief.

As noted above, behaviorists were addicted to extreme simplicity. By leaving out any factor that might distract a researcher they hoped to make psychology purely commonsense and entirely clear. As I have said, one of the excluded factors was feeling, which was not merely excluded but roundly condemned. What is surprising about today's psychology is not that it continues to pay attention to behavior, but that it has moved feeling and emotion (i.e. "affect") from the periphery of their science to the center.<sup>58</sup> In the founding issue of *Consciousness and Emotion* Ralph D. Ellis and Nakita Newton insist:

What has been neglected, and what this journal aims to supply, is an exploration of the ways in which such conscious imagery, as well as the reasoning and action planning it supports, depends upon motivating emotional states of the organism.<sup>59</sup>

We can continue to exclude the study of the emotions, they conclude, only at the cost of excluding a significant part of what is human.

Several ways of achieving these goals are found in the literature. One is the analysis of human thought, particularly in its creative aspects, showing the central role played by the emotions in the sciences and the arts, as well as in personal decisions and goals. This is the route taken by Leonard Mlodinow in his *Emotional: How Feelings Shape our Thinking*.<sup>60</sup> One might think that since Mlodinow is a mathematician and theoretical physicist his book would be devoted to surveying emotionally-driven discoveries in the sciences. This is not so. His account of physicist P.A.M. Dirac's conversion from a despiser of emotions to a celebrator of the role emotions play in science is brief. His description of the manner in which successful stockbrokers relied on emotion ("gut instinct") in managing their portfolios while less capable brokers spoke of their distrust of emotion is lengthier. But the greater part of his book (which ends with a self-help section) deals with the course of everyday life: with the way in which our emotions guide our daily decisions, including the most important. Feelings, he argues convincingly, are necessary to our well-being and our thinking. The discoveries of recent psychology and neurophysiology, he proclaims only support this conclusion.

Far more systematic and, I think, far more profound is the work of Antonio Damasio, whose researches have dramatically shifted the way scientists describe emotion. A neurophysiologist, Damasio began with a study of patients with severe

<sup>58</sup> The description I am giving of the history of the turn towards emotion in psychology is admittedly limited. For an account reaching farther back into psychology history (and ending in 1960) cf. M. Gendren, L.F. Barren. "Reconstructing the Past: A Century of Ideas About Emotion." *Emotion Review*, 1(4), 2009, 316–339.

<sup>59</sup> R.D. Ellis, N. Newton. "The Interdependence of Consciousness and Emotion." *Consciousness and Emotion*, 1(1), 2000, 1–10.

<sup>60</sup> L. Mlodinow. *Emotional: How Feelings Shape Our Thinking*. New York: Pantheon Books, 2022, 273. One could also look at P. Ekman. *Emotions Revealed: Recognizing Faces and Feeling to Improve Communication and Emotional Life*. 2nd ed. New York: Holt Paperbacks, 2007, 320.

brain lesions. Those suffering from the lesions were essentially rational, but brain damage had impaired their emotions, making it impossible for them to make good decisions. Damasio went on to make an in-depth study of the emotions which, he concluded, far from being a detriment to rationality, are essential to our capacity to think and to manage our lives.

A prolific writer, Damasio has developed his views in a series of six books and innumerable articles. The sheer proliferation of his writings is helpful in many ways, but since he sometimes changes his opinions, can present problems of interpretation. Equally challenging is that he develops extensive terminology in the course of developing his ideas, a terminology which is not without its difficulties. I will try in what follows to stick to the main outlines of Damasio's thought, a way of proceeding that may lack nuance and skirt some difficulties. The hope is to make clear his case for the centrality and usefulness of the emotions, a case which this writer finds persuasive.

### 8.1. The protoself: First stage in a three-level world

The world of biology is for Damasio both threefold and hierarchical.<sup>61</sup> The first two levels are important in themselves and are necessary to the functioning of the third, highest level which includes human beings. The first level consists of the one-celled animals (bacteria) and plants. These have two fundamental abilities. They can both sense (a "detecting ability"). But the bacteria can do what the plants cannot. That is, they have a nonconscious intelligence which consists of exquisitely calibrated responses to their environment, responses which allow it to survive. The term protoself might be misleading. Nothing in the world of the protoself can be called a self. The organisms which make up to protoself however, possess what will be required, later in their evolutionary development, to create real selves.

### 8.2. Core consciousness: Awareness emerges

The next, second level is termed core consciousness. Core consciousness exists only in multicellular organisms which, besides being multicellular, have a nervous system. A nervous system can be simple or complex. But at any level it has a single pervasive function: to make maps which Damasio terms images.<sup>62</sup> Our strong tendency when we think of the nervous system is to think of one thing, a single web which connects us to the world and allows us to act on it. It is important to see that for Damasio our nervous system is twofold. One part maps our physical environment, picturing ordinary objects. The other conveys the viscera: heart, lungs,

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<sup>61</sup> A.R. Damasio. *Feeling and Knowing: Making Minds Conscious*. New York: Pantheon Books, 2021, 25–30. All future references to this item will be included in the text as FK. Damasio's three levels are also termed being, feeling, and extended consciousness. Extended consciousness is possessed only by human beings.

<sup>62</sup> Plants, Damasio notes, are multicellular. But they do not have a nervous system and cannot possess core consciousness.

digestive systems and much more.<sup>63</sup> As I will discuss below, the inner nervous system presents a world of images very different in their character from those of our outer world. Here it is only necessary to point out that, inner or outer, the images conveyed by our nervous systems make up the entire contents of our minds which are simply, a succession or stream of images. Damasio states:

This is the very ‘stream’ that immortalized William James and gave fame to the word ‘consciousness’ because the two words were so often paired in the phrase ‘stream of consciousness.’ But we see that the stream, to begin with, is simply made of images whose near-seamless flow constitutes a mind.<sup>64</sup>

Of course, when we do introspect what we find is not merely a succession of inner and outer images but, Damasio agrees with William James, an active process of images and consciousness, a stream that is conscious. The question thus becomes, where do we get consciousness, how does it arise? Before dealing with this most central of questions, however, I would like to make a brief stop and present some of Damasio’s core terminology which will help when we discuss his account of the emergence of feeling and consciousness.

### 8.3. Some core terminology

The two terms which need to be introduced here are emotion and feeling. These concepts flesh out Damasio’s psychology. Emotions, he holds, consist of:

collections of co-occurring and involuntary internal actions (for example, smooth muscle contractions, changes in heart rate, breathing, hormonal secretions, facial expressions, posture.<sup>65</sup>

They are the “gutsy” part of affect, which are perpetually engaged in homeostasis,<sup>66</sup> the effort to keep the body functioning by sustaining healthy states and avoiding unhealthy ones.

Feelings for Damasio are significantly different from emotions. Emotions, he states, somewhat puzzlingly, are not conscious. Feelings are.<sup>67</sup> Like emotions, feelings are involved in the struggle to maintain life.<sup>68</sup> Feelings are of two kinds, homeostatic<sup>69</sup> and emotional (such as fear, anger, and joy).<sup>70</sup> Both of these types of feeling have a practical function. We do not simply perceive them. Rather, they push and pull us. They provide us with an incentive to behave.<sup>71</sup> The behavior may be simple (like catching a basketball) or complex (like playing the piano). The former involve “primordial” feelings.<sup>72</sup> The latter involve feelings which are more developed,

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<sup>63</sup> Damasio distinguishes three kinds of perception exteroception (perception of the external world), interoception (perception of our visceral interior), and proprioception (perception of our muscular skeletal system). The third, proprioception, is not directly involved in feeling or thought.

<sup>64</sup> FK, 45.

<sup>65</sup> FK, 78.

<sup>66</sup> FK, 78.

<sup>67</sup> FK, 82.

<sup>68</sup> The actual effort to achieve homeostasis he terms “allostasis.” FK, 78.

<sup>69</sup> FK, 78.

<sup>70</sup> FK, 78–9.

<sup>71</sup> FK, 83.

<sup>72</sup> FK, 204–205.



more reflective. One more piece of terminology. With feeling we arrive at Damasio's third level of existence, "extended consciousness": that is, human consciousness.

But how does consciousness emerge from emotions? This is the very center of Damasio's problematic. We need to pause here and look again at his argument, particularly at his two nervous systems. It is the character of his inner or interoceptive nervous system which on his view explains how it is that we come to feel and think.

The external nervous system for Damasio "maps" the world in terms that we find familiar. They are geometrical, presenting us with the shapes of tables, chairs, trees. As such (that is, as images) they are passive. It is these two characteristics which allow us to act on them: at a time and at a point. The maps or images provided by the "inner" nervous system are very different from these. They do indeed give us information. But the images they transmit to us are in two ways different from those of the outer system. They are "indistinct": that is, they do not have the clear, geometrical outlines of those presented to us by outer sense. They involve "the extensive intermingling of signals,"<sup>73</sup> the "melding of contents."<sup>74</sup> They can best be understood, Damasio tells us, through the example of music.<sup>75</sup>

This is an important characteristic. But it is not as important as the fact that, as I have said, inner images not only convey information, they push us and pull us, they move us. With or without our consent, they impel us to act. This impetus to action forces us to use concepts in order to direct our behavior. It is also what requires consciousness to emerge.<sup>76</sup> It is the imperative of action, not abstract conceptual reason, which brings us to behave intelligently and to be aware of it. It is the true basis for our thoughts.

But is the inner nervous system really different than the outer? Damasio is able to show that it is different and why. The outer nervous system, like the inner, is composed of ordinary neurons, but with the following difference. The neurons of the outer system are coated with a thick sheath of a chemical called myelin, which insulates it from its bodily surroundings and allows it to transmit information with accuracy. The neurons of the inner nervous system, by contrast, lack this myelin sheath, and is thus "not really distinct from the body that hosts it."<sup>77</sup> It is, for example, not separate from the bloodstream, but registers its state directly. The inner nervous system delivers information but with a jolt. It informs us of the state of our body but forces us into the active, conscious center of our lives.

It is feeling, not only the development of the human brain, which must help us understand the emergence of extended consciousness. And it is extended consciousness which creates conceptual schemes of all kinds (art, science, religion) and the concurrent rise of complex, many-sided cultures. But cultures and their components

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<sup>73</sup> FK, 94.

<sup>74</sup> FK, 7.

<sup>75</sup> FK, 79, 142.

<sup>76</sup> A.R. Damasio. "Emotions and Feelings: A Neurobiological Perspective." In A.S.R. Manstead, N. Frijda, A. Fischer (Eds.). *Feelings and Emotions: The Amsterdam Symposium*. Cambridge: Cambridge University Press, 2004, 49–57.

<sup>77</sup> FK, 93.

are not disembodied. They remain forever “hybrids”: hybrids of body and mind, hybrids of the two nervous systems. Damasio states:

This hybrid condition may help to explain why there is a profound distinction but no opposition between feeling and reason, why we are feeling creatures that think and thinking creatures that feel.<sup>78</sup>

Feelings were and are the beginning of “an adventure called consciousness.”<sup>79</sup>

It is tempting to enter here into a detailed discussion of Damasio’s views. In an article whose purpose is to survey broad trends in current science this would be out of place. Some kind of assessment of his work, however, is called for. This will be twofold. The first concerns the question of whether he has succeeded in building concepts of the brain and peripheral nervous system which are tenable in the light of contemporary neuroscience. It seems to me—and to his many followers—that he has. That much in our lives is owed to our body hardly seems a metaphysical fancy. It is rooted in physiological and experiential (broadly phenomenological) fact. The picture Damasio draws of how our active physiology impels us into coping behavior and how this behavior must involve the utilization of concepts gives every appearance of accuracy. Damasio has succeeded in developing a plausible, scientifically<sup>80</sup> fruitful model of mind-body relations.

The second question arising from Damasio’s work concerns reductionism. In one sense he is an antireductionist, in that he refuses to limit scientific investigation to external behavior, and in that he liberates the emotions and feelings from the prison to which they had been consigned. He also, as I have reiterated, gives them a job to do: that of impelling us (or dragging) us into action. But in another sense Damasio is thoroughly reductionist. That is, he reduces or wishes to reduce emotions, feelings, and conceptual thought to the body and the body to its elemental physics and chemistry: as thoroughgoing a reductionism as one could ask for. He is, however, quite open-minded about what this might mean. As I will stress in the concluding section of this paper, what reductionism might mean depends upon what one is reducing things *to*. Damasio suggests that we might be forced in the end to reduce the matter of the nerves and bodily organs to some form of quantum physics. This would be a kind of “reductionism,” but hardly the one to which we have become accustomed.<sup>81</sup>

We have seen that Damasio has extended psychology beyond the brain, to include the two nervous systems and the body’s interior milieu. What needs to be noted here is that he is not alone in seeking to get beyond the brain-centered viewpoints which have until recently dominated both psychology and neurophysiology. Non-neurocentric theories now blossom on every hand. That is, Damasio is not alone in proposing the idea of an extended mind. Roughly contemporary with Damasio’s approach is an article which appeared in the 1998 issue of the journal *Analysis*.<sup>82</sup>

<sup>78</sup> FK, 7.

<sup>79</sup> FK, 110.

<sup>80</sup> I am not suggesting that all neurophysiologists have followed Damasio. For an alternative approach cf. J. LeDoux. *The Emotional Brain*. New York: Simon & Schuster, 1996, 384.

<sup>81</sup> FK, 61–2.

<sup>82</sup> A. Clark, D. Chalmers. “The Extended Mind.” *Analysis*, 58(1), 1998, 7–19. All further references to this work will be cited in the text as EM. Cf. A. Clark. *Supersizing the Mind: Embodiment and Cognitive Extension*. Oxford: Oxford University Press, 2011, 286.

Where does the mind stop and the rest of the world begin, Andy Clark and David Chalmers asked. Certainly not at the brain, but in the rest of the body: in hand gestures or bodily movements, or much else. Nor does intelligence stop at the human body. Computers act as extensions of our thought, but not only computers. In her clearly-argued *The Extended Mind*, Annie Murphy Paul mentions hand gestures, the influence of the physical context surrounding us, the influence of the workspace, and our capacity to work with others as components of our thought. Previous psychologies, she insists, have given us a one-sided highly abstract picture of the way we actually think, writing as if we were computers on a shelf or isolated Cartesian substances. The question which ought to guide us is how we actually think. What is actually involved? We are fortunate that psychologists, cognitive scientists, and neurologists are now able to provide a clear picture of how extra-neural inputs shape the way we think.<sup>83</sup> They make it possible to use our intelligence more effectively than we would have otherwise.

It is surprising to this writer that the extended mind hypothesis has not only attracted psychologists but has attained a truly remarkable popular following. Perhaps this is because it is a theory that can be focused on “self-help”: on how to improve one’s intellect, memory, decision-making ability or, simply, mental health. This is true of Annie Murphy Paul whose book is an “operationalization” of the extended mind hypothesis, deflecting it so as to improve our thinking on all levels. A spectacular example of this popular deflection is Daniel Goleman’s *Emotional Intelligence*<sup>84</sup> which introduces an EQ, a measurement of emotional intelligence to compete with mere IQ.

## 9. A summing up

A survey ends when it has exhausted its subject matter. This survey has examined the components of a continuing rethinking and reformulation of basic science in an effort to leave nothing essential out. Can something more be added? I think so, and on two levels. The first involves the question of whether this shift in scientific opinion constitutes a scientific revolution as we have come to think of it: a “paradigm shift” in Thomas Kuhn’s terms.<sup>85</sup> Or is it something else? The second consideration is a continuation of the first. If we are not, strictly speaking, witnessing a classical paradigm shift, how should we understand what we are seeing? The scientific transformation which started the modern age fits Thomas Kuhn’s concept of a paradigm shift perfectly. It was dramatic, and it was complete. Prior to the shift, the Aristotelian system stood supreme, with its earth-centered astronomy, its concept of qualitative substance, and its laws of motion. With the coming of the new standpoint, all this was swept away. Nature was now seen as a complex

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<sup>83</sup> EM, 14.

<sup>84</sup> D. Goleman. *Emotional Intelligence: The Extended Mind*. 10th anniversary ed. New York: Bantam Books, 2005.

<sup>85</sup> T.S. Kuhn. *The Structure of Scientific Revolutions*. 2nd ed., 50th anniversary ed. Chicago: University of Chicago Press, 2012, 217.

of hard, simply-located mass particles which perfectly obeyed three laws of motion and a gravitational law. From our viewpoint, the important thing to stress is the unity of the Newtonian standpoint and its clarity. One monolith was removed, another took its place. It was very dramatic.

Nothing of this kind has been portrayed in this essay. The prior reductionist view has in many contexts been replaced. But we can hardly say that it has been swept away, dramatically, as a whole. Its spell has been broken. But what has emerged in its place is in no sense a monolith. It would more aptly be described as a collage of similar conceptual schemes, schemes which emerged at the same time, but often independently. One can also say that the center of the new viewpoint (or viewpoints) is biological if one is very willing to take the term in a very broad sense. Beyond these two certainties, it is hard to go.

One can speculate that the factor shared by the participants in these present conceptual transformations is simply that those involved in it all found themselves forced to go beyond the limitations placed on them so categorically (and one might add, dogmatically) by the prior paradigm. Or, if this view seems unlikely, perhaps it is simply that scientists, equipped by newly developed computers and the new modular biology, began to study factors that prior science had left out. I suggest this as a plausible explanation.

Such an explanation might do for brain plasticity or epigenetics, or various features of recent animal and human psychology. But it seems that the most fundamental feature of the new biology, its mathematics, cannot profit from such an explanation. The creators of fractal geometry and nonlinear mathematics were not looking into common data which had been left out by a prevailing viewpoint. They were positing entities and relations which no scientist had imagined could exist, then demonstrating that such entities could indeed exist, not only as acceptable mathematics, but as features of the real world. These ideas represented pure conceptual creativity.

No summing up of the present situation in the sciences can be complete without a reference to the state of physics and its relations to the ferment of ideas discussed in this essay. And yet, paradoxically, there appears to be no relationship. Physics in this period in which biology and biologically relevant psychology have undergone such significant changes has gone its own way, neither influencing nor influenced by its scientific neighbors. In turn, biology, and psychology have developed independently.

We have been accustomed, since the birth of modern science, to look to physics for new worldviews, new ways of analyzing the world we experience. In the past century this seemed especially so, with physics producing two great revolutions, each in its way a challenge to our ordinary way of looking at things. We live in the shadow of quantum and relativity physics, which we feel is somehow basic to how we should see the world. But it is as I have shown: no revolution in physics stemming from relativity or quanta has influenced the emergence of the new biology-psychology. It is an independent development.

The exception to this rule is thermodynamics. As we have seen, it is thermodynamics which has provided one of the strong factors allowing biologists to reformulate the basis of their science. The science renowned for describing a universe

as an unending descent into disorder, in seeming paradox, becomes the science which helps understand the creative stirrings of nature. We get thermodynamic order out of chaos, as Prigogine showed. Nothing could be more surprising. But then, the history of science can be seen as a history of surprises.

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