

## CHAPTER 11

# Why We Cannot Explain the Form of Organisms

Questions of form have seemed oddly resistant to the biologist's quest for explanation. Darwin himself seemed to sense the difficulty in that famous instance where he recoiled from contemplating the subtle perfections in the form of the eye: "To suppose that the eye with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest degree" (Darwin 1859, chapter 6).

Of course, as Darwin quickly added, his theory convinced him that he was merely suffering from a lack of imagination. All that was really needed were the creative powers of natural selection acting through eons upon an endless supply of small, helpful changes. But his underlying malaise was not so easily vanquished: "It is curious", he wrote to the American botanist Asa Gray in the year following publication of the *Origin*, "that I remember well [the] time when the thought of the eye made me cold all over, but I have got over this stage of the complaint, and

now small trifling particulars of structure often make me very uncomfortable. The sight of a feather in a peacock's tail, whenever I gaze at it, makes me sick!" (Darwin 1860).

We can assume that Darwin got over that stage of the complaint as well. But, thankfully, the biologist is still now and then allowed, if not a complaint, at least an honest expression of wonder. The great twentieth-century student of animal form, Adolf Portmann, writing not of the peacock, but of another bird with a remarkable pattern of coloration on its wings, helps us to share in his own wonder:

If ... we look at the speculum on a duck's wing, we might imagine that an artist had drawn his brush across some ten blank feathers, which overlap sideways — making white, bluey-green, and black lines — so that the stroke of the brush touched only the exposed part of each feather. The pattern is a single whole, superimposed on the individual feathers, so that the design on each, seen by itself, no longer appears symmetrical. We realize the astonishing nature of such a combined pattern only when we consider that it develops inside several or many feather sheaths completely separated from one another; and that in

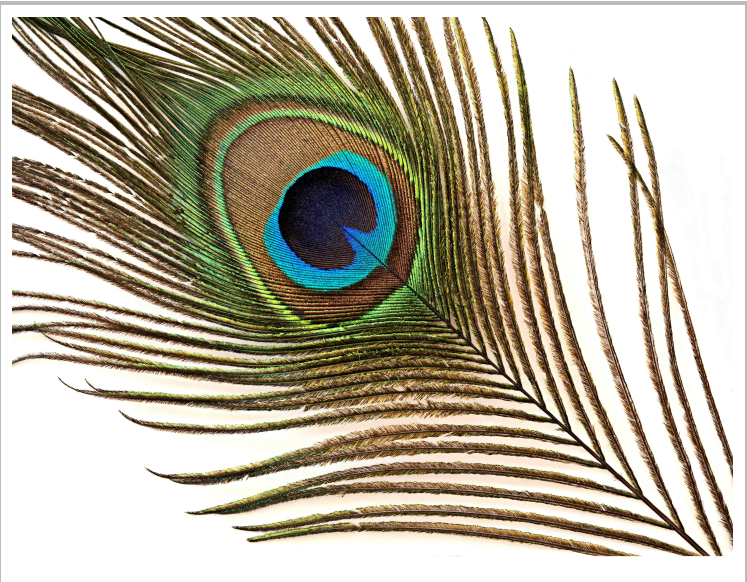


Figure 11.1. An eyespot in a peacock feather.

each individual feather it appears at an early stage while it is still tightly rolled up, the joint pattern not being produced until these feathers are unfolded. What sort of unknown forces direct the constructional work in the “painting” of these feather germs? (Portmann 1967, p. 22).

Whatever Portmann’s “unknown forces” may be, they seem to work to perfection. But how are we to understand this perfection? What sort of explanation are we looking for when we want to make *sense* of form? In the case of that patch of color on the duck’s wings, surely we will eventually be able to trace exhaustively the processes and connections by which each molecule of pigment seems lawfully “compelled” to take up its proper place in the various feathers. But where, amid the innumerable, widely dispersed molecular jiggings, transits, collisions, interactions, and chemical transformations, will we glimpse the global *coordinating* power that guarantees the overall, aesthetically satisfying outcome in the face of all the degrees of freedom (Chapter 6, “Context: Dare We Call It Holism?”) possessed by the interacting molecules in all the individual and separate feathers?



**Figure 11.2.** A mallard duck with a speculum on each of its wings (left); and an individual speculum feather (right).<sup>1</sup>

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### ***Looking for physical explanations of form***

Sean Carroll thinks he has an answer to this question. A geneticist and developmental biologist, Carroll tells the story of the rising discipline of evolutionary developmental biology in a widely read and beautifully illustrated book, *Endless Forms Most Beautiful: The New Science of Evo Devo* (Carroll 2005). Inspired by work in the relatively young discipline of evolutionary developmental biology (“evo devo”), he aims to explain “the invisible genes and some simple rules that shape animal form and evolution” (p. x).

Carroll's triumphalist narrative focuses heavily on the role of "tool kit" or "master" genes. (On "master" controllers in general, see [Chapter 9](#), "A Mess of Causes".) Until the discovery of these genes, he tells us, biologists had known that "evolution is due to changes in genes, but this was a principle without an example. No gene that affected the form and evolution of any animal had been characterized" (p. 8).

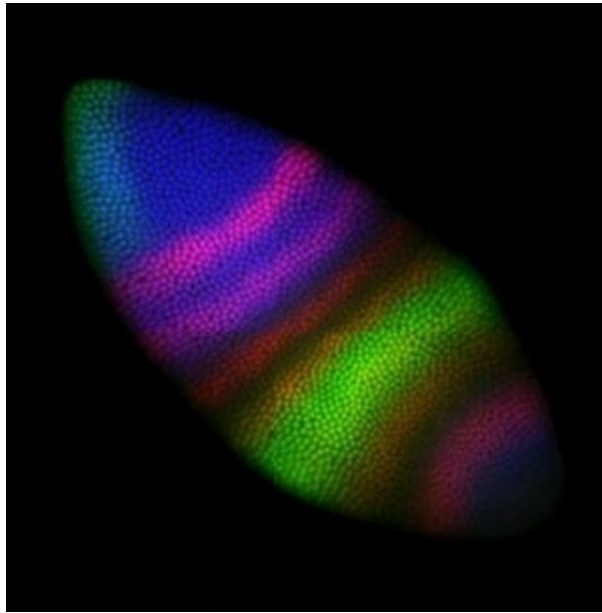
That state of affairs apparently ended with the identification of a relatively small number of genes whose presence, absence, or mutation turned out to be associated with the formation (or malformation) of large-scale, discrete features of an organism — and they were often associated with similar features in widely differing organisms. These tool kit genes may, for example, produce proteins that are distributed in bands, stripes, lines, or spots in a young insect embryo. This geographical distribution turns out to be a kind of map of certain features that will develop later.

Carroll reproduces beautiful photographs of fly embryos showing (by means of technical manipulation) brightly colored regions, where each region — blue, green, red, yellow — corresponds to the activity of a particular collection of genes. A couple of hours after fertilization, the oblong embryo is about one hundred cells in length from end to end (or from "west" to "east", as the researchers prefer to say, with west corresponding to the future head pole). Thanks to the differentiated activity of tool kit genes, the western, middle, and eastern sections of the embryo clearly reveal themselves as separate bands.

As these bands fade, they are replaced by seven stripes over the eastern two-thirds of the embryo. Each stripe, together with the neighboring darker band, marks out a pair of future segments of the fly larva. Then these stripes, too, under the influence of yet another group of genes, give way to fourteen stripes indicating the fourteen segments of the larva individually. Most of these latter stripes persist throughout development, and they lead rapidly to actual segmentation of the embryo.

The photographs are spectacular, and leave no doubt in one's mind that the early embryo, uniform and undistinguished as it might appear under ordinary light, is in fact an embodiment of order and form. There is a head and tail, with degrees of longitude between them, and likewise a top and bottom (dorsal and ventral regions), with degrees of latitude. And different "modules" (as Carroll calls them) are already marked out for the development of specific organs and appendages.

Carroll's own work has focused on butterflies. Here again the design to come is signaled by the distribution of tool kit proteins. Carroll produces photographs showing these proteins in the developing wing, occupying exactly those locations where the beautifully decorative spots and stripes and rings will eventually appear. *It's as if the future design were in some way already there.*



**Figure 11.3.** Artificially colored bands on a fruit fly embryo, showing the location of particular proteins, which in turn result from differential gene expression and signal the future location of fly segments.<sup>2</sup>

## The mastery of genetic switches

But tool kit genes are only part of the picture. It's true that the protein bands in the early embryo are associated with genes that are activated in those bands so as to produce ("express") the proteins. Certain genes that are "on" or "off" within the band, will be in the opposite state outside the band. But what is supposed to coordinate this activation and deactivation of genes?

Carroll's answer is at the same time his central theme: the tool kit genes are systematically turned on and off by a computer-like "operating system" — a vast network of switches residing in those portions of DNA that do not "code" for proteins. Acting, according to Carroll, like a global positioning system (GPS), these switches "integrate positional information in the embryo with respect to longitude,

latitude, altitude, and depth, and then dictate the places where genes are turned on and off".

Each switch, as Carroll describes it, is actually a short stretch of DNA controlling a particular tool kit gene. Often there are multiple switches controlling a single gene. Proteins (produced by yet other tool kit genes) can bind to these switches, altering their state. The overall pattern of switch states for a particular gene then determines whether that gene will be activated or repressed. This allows a single gene to be used in many different ways at different times and places — for example, in the development of our own heart, eyes, and fingers. Everything depends on the states of its associated switches. "The entire show", writes Carroll, "involves tens of thousands of switches being thrown in sequence and in parallel" (p. 114).

The governing image in all this is that of the computer. He refers to DNA switches as "fantastic devices [that] translate embryo geography into genetic instructions for making three-dimensional form" (p. 111). The computational powers of the controlling network of switches, he tells us, allow fine-grained management of the expression of individual genes. But at the same time the switches are the key to a software-like modularization of the organism, making it possible for entire features (a spot on a wing, an insect's eye, a digit on a mammal's foot) to come or go — or be modified in dramatic ways — with the flip of a few switches.

## Can we trace form to something other than earlier form?

All this raises an obvious question, which, in a way, Carroll himself acknowledges. Suppose we have a fly embryo divided into three regions marked out by proteins A, B, and C.



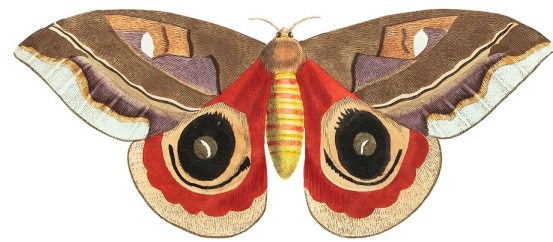
You might ask, where do these patterns of tool kit proteins A, B, and C come from? Good question. These patterns are themselves controlled by switches in [the associated] genes A, B, and C, respectively, that integrate inputs from other tool kit proteins acting a bit earlier in the embryo. And where do those inputs come from? Still earlier-acting inputs. I know this is beginning to sound like the old chicken-and-the-egg riddle. Ultimately, the beginning of spatial information in the embryo often traces back to asymmetrically distributed molecules deposited in the egg during its production in the ovary that initiate the formation of the two main axes of the embryo ... I'm not going to trace these steps — the important point to know is that the throwing of every switch is set up by preceding events, and that a switch, by turning on its gene in a new pattern, in turn sets up the next set of patterns and events in development. (p. 116)

Here, then, is the general thrust of Carroll's attempt to elaborate “the simple rules that shape animal form”. But perhaps we may be forgiven a certain unease at this point — a discomfort, first of all, with a claim of simplicity applied to “tens of thousands of switches being thrown in sequence and in parallel”. Before we can see the exquisitely detailed and aesthetically satisfying spatial pattern of pigments on the butterfly's wings (or the peacock's feathers), there must be a correspondingly exquisite and detailed pattern of flipped genetic switches. The form at the later stage must in some way be foreshadowed by the form at the earlier stage.

It is no wonder that Carroll says “I'm not going to trace these steps”. For it appears that the tracing would not give us an *explanation* for the form of development of an organism — not in the usual causal sense of “explanation”. It would simply trace the form through successive manifestations, one snapshot of which might be given in an image such as that of the fruit fly embryo's colored bands.

The problem with the usual sort of causal explanation is that, as we saw in [Chapter 7](#) (“Epigenetics: A Brief Introduction”), and will see much more fully in [Chapter 14](#) (“How Our Genes Come to Expression”), the “causal factors” elucidated in studies of gene expression end up converging upon each other in endlessly varying patterns — patterns extending throughout the entire cell and organism.

So we might wonder whether the effort to define unambiguous biological causes always resists a final resolution in terms other than those of form — that is, resists our attempts to *explain* form. If in fact a biological performance always involves an intentional, directed coordination of physically lawful interactions, then explanation in terms of the physical interactions alone will never rise to the level of biological understanding. It is the *pattern* — the thought-infused, aesthetic, and qualitative aspect of the coordination — the meaning of it all — that we really want to lay hold of. The form of an organism's body and behavior just is this meaning put on display.



**Figure 11.4.** The moth, *Automeris janus*, illustrated by George Shaw (1751-1813) in *The Naturalist's Miscellany*.

Perhaps, in other words, we never are, at any stage of our investigation, tracing physical mechanisms that *explain* observed form. Perhaps apprehending form in its own terms — and doing so as perceptively as possible — is how we make sense of biological phenomena, because form is itself the decisive explanatory principle. It seems worth considering whether form is what every material phenomenon most essentially *is* for our understanding. After all, the form of a thing is not just a particular feature that can be pasted onto the thing. It belongs to the creative, interior aspect that makes the thing *this sort of appearance* and not *that sort*.

A second source of our unease with Carroll's supposedly explanatory genetic tools and switches is the casual assumption that something in fluid, ever-transforming cells operates in meaningful analogy to a computer's precisely machined, rigidly fixed, transistor-based hardware. No specific support is offered for this critical and wholly improbable fundament of Carroll's argument.

Moreover, we do know that his language at this point is misdirected. He speaks as if particular switches "control" genes or "dictate" such-and-such an outcome. But, as we saw in [Chapter 9](#) ("A Mess of Causes"), such straightforward, machine-like causes are foreign to the life of organisms. The ever-expanding sciences of genetics and epigenetics have shown us that influences flow toward genes from just about every corner of the cell and organism — and they do so as all those corners are themselves caught up in the overall developmental transformation of the whole organism. Contrary to any picture of neat controlling causes, we are forced to understand the entire organism as itself the fundamental, rock-bottom, metamorphosing "cause" of its own development.

Discomfort also arises when we contemplate Carroll's ever-receding series of "inputs" that, as we look further and further into the past, finally peters out in the vagueness of "asymmetrically distributed molecules" in the earliest stages of an egg's development.<sup>3</sup> These randomly disposed, "primordial" molecules in the egg hardly seem the ultimate, revelatory basis for explaining the not yet realized form of the mature organism. So what is the explanation Carroll claims to possess?

Such vagueness at the decisive beginning of the entire developmental process, when all the organism's still-to-unfold features lie potent in the egg, does not say much for our present understanding of the supposedly "simple rules" that explain the observed complexity and seamless unity of every unique life form.

Carroll's whole approach raises one other concern, perhaps the most fundamental of all. All form seems to be essentially qualitative. To apprehend an appearance is to grasp at least part of its *meaning*. We see directly, perceptually — not only through technical analysis — what constitutes it a *this* rather than a *that*, a redwood rather than a willow, a squirrel rather than a chipmunk, a virtuous act rather than a dastardly one. When we try to capture such differences in words, we always slip into a qualitative language — for example, the language of art (Carroll's "sculpting") — even if we immediately obscure that language behind the terminology of mechanism.

This brings us to the underlying difficulty that Carroll (and biologists generally) run up against. Their physical world has, in the style of nineteenth-century classical physics, finally been reduced to inert, mindless, and therefore qualityless, particles. These particles can have nothing to do with the reality of inherently qualitative form. And so, in order to make sense of

Carroll's non-explanatory explanations, readers must superimpose upon his toolbox language whatever pictures of form they have gained from his illustrations. And then all they have is form related to form. But *this* form — true form — qualitative as it inevitably is, remains wholly disconnected from Carroll's tools, switches, and networks. There is, from the standpoint of contemporary science, no bridge from a mechanistic to a qualitative understanding.

So, then, returning to our central question: where in the entire developmental sequence can we honestly say, "Here we are *explaining* the form itself, as opposed to simply *describing* a continuous manifestation and transfiguration of form, which can be understood in its own terms?"

If the arrangement of an insect's body segments is prefigured by various patterns of protein deposition, and if the protein patterns are prefigured by patterns of gene expression, and if the patterns of gene expression are prefigured by precisely arranged spatial patterns of switches being turned on and off, then we may be describing a play of form over time and at specific levels of observation. But if we try to see this as an explanation of how significant form arises from the supposedly unformed, we can hardly help noticing that we have merely pushed the problem of form backward in time and downward in scale, until it vanishes from sight, still unexplained.

Every stage of the most complex animal, starting from the single-celled zygote and extending all the way to maturity, is in fact the proper and complete form of the animal at that particular stage. To understand the form of an organism is to enter as fully as possible with our imagination (which is itself a power of forming and transforming) into the power manifested in the continuous metamorphosis of form from the beginning to the end of that organism's life.

## Endless transformations most beautiful

All processes of development and growth are *metamorphoses*. If we were able to view a three-dimensional movie showing the magnified interior of our own developing bodies, the significance of the proceedings would be overwhelming. We would watch a single zygotic cell reproduce and diversify, yielding eventually a trillion or more cells proceeding along hundreds or thousands of distinct trajectories of differentiation.

It would almost be as if we were watching a vast menagerie of wildly different, single-celled organisms, multiplying, writhing, dancing, and contorting themselves in different rhythms and patterns in countless niches or compartments throughout all the tissues and organs of the body. Each of those "organisms" has its own intricate form, changing from cell generation to cell generation, and yet it all happens under the "discipline" of the larger and unfathomably complex, developing form of the whole organism.

Every organ would have its own distinct story to tell. In our developing brains, for example, we would see not only the differentiation of the many unique cellular lineages in that organ, but also the forming of significant functional connections and patterns of interaction as the brain shaped itself (or was shaped) to the form of our cognitive experience and motor activity. The lungs would likewise be shaped for and by the air and our eyes for and by the light, just as our bones are shaped for mobile support under the influence of gravity and our habits of

movement.

And, of course, the picture is just as lively and striking when we step back and look at any organism as a whole. Here is the well-known description by Thomas Huxley, Darwin's pre-eminent apologist during the latter part of the nineteenth century:

Examine the recently laid egg of some common animal, such as a salamander or newt. It is a minute spheroid in which the best microscope will reveal nothing but a structureless sac, enclosing a glairy fluid, holding granules in suspension. But strange possibilities lie dormant in that semi-fluid globule. Let a moderate supply of warmth reach its watery cradle, and the plastic matter undergoes changes so rapid, yet so steady and purpose-like in their succession, that one can only compare them to those operated by a skilled modeller upon a formless lump of clay. As with an invisible trowel, the mass is divided and subdivided into smaller and smaller portions, until it is reduced to an aggregation of granules not too large to build withal the finest fabrics of the nascent organism. And, then, it is as if a delicate finger traced out the line to be occupied by the spinal column, and moulded the contour of the body; pinching up the head at one end, the tail at the other, and fashioning flank and limb into due salamandrine proportions, in so artistic a way, that, after watching the process hour by hour, one is almost involuntarily possessed by the notion, that some more subtle aid to vision than an achromatic, would show the hidden artist, with his plan before him, striving with skillful manipulation to perfect his work<sup>4</sup> (Huxley 1860).

Do we really need some still more subtle instrument that will reveal a hidden artist working from outside — which, of course, Huxley didn't believe in — or do we need rather to credit the capacity of our own, educated eyes to see, as Huxley did, the *inherent artistry* that informs the processes right there in front of us? The embryo plainly and objectively manifests a power of unified expression, of metamorphosing organic form — something a child can recognize. Why should we not accept this power exactly as and where we observe it — as a living *power* — just as we accept the very different power of gravity in exactly the terms of *its* manifestations?

And, despite Huxley's reference to "a formless lump of clay", never in all this drama of transfiguration do we witness a cell or any other element being constructed from formless substance (if such substance could even be imagined) — or being built from preexisting, "plug-and-play" parts. The parts undergo transformation simultaneously with the whole, and only as expressions of the whole.

The starting point of it all is the living zygote, and in its flourishing and wonderfully structured context-embeddedness, its life "overflows" and multiplies. The zygote's original, one-celled unity is never lost, but rather is subdivided and differentiated. It is worked on from within and influenced from without (that is, from the environment), according to the unfolding of its governing principles of form.

These principles — those of the type, or species — are regarded by every embryologist as telling *one, unified story* from zygote to maturity and senescence. Further, the informing power that is characteristic of that story remains "in force", as far as circumstances allow, regardless of drastically different nurturing environments, and even in the face of disfiguring insults inflicted by laboratory technicians. The organism responds to every insult by bending it, as far as possible, toward the normal pattern of development.

The existence of this governing pattern, or form, in every different sort of organism is a decisive truth of biology. No matter how far down toward the molecular we go in trying to explain



form, we find our explanations themselves, so far as they are biological and not merely physical or chemical, to be always based on considerations of form. We never seem able to get beneath or behind these considerations so as to grasp something more fundamentally explanatory than form itself.

Even the classic efforts to explain everything based on genes have now become ever more vividly an elucidation of form — form that is already in play at the level of genes and chromosomes. For example, some geneticists speak of “genomic origami”, while others refer to the three-dimensional “dance” of chromosomes in the nucleus — a spatially significant performance essential to the expression of the right genes in the right amounts at the right times ([Chapter 3](#), “What Brings Our Genome Alive?”).

Apparently Carroll, and all the other biologists who in one way or another employ the same language, have come to the (perhaps unconscious) conclusion that we really do need to find Huxley’s “invisible artist” — but that we must do so mechanistically, re-imagining the artist as a designer-engineer (often working in the guise of natural selection). It somehow seems too distasteful to take seriously the transformative artistry we can observe actively at work in the organism itself.

This is a good place to return to the wisdom of the twentieth-century cell biologist, Paul Weiss, who once remarked:

There would be less room for misconception if instead of referring to developmental dynamics as “formative”, we were to designate them as “transformative”, for then the notion that order or organization as such are created *de novo* [anew] within a totally random pool of unit elements could not arise (Weiss 1971, p. 39).

## Is Form a Primary and Irreducible Feature of the Organism?

In the chapter introduction, I asked where we might glimpse the global, coordinating power that guarantees the infinitely detailed and aesthetically satisfying form of organisms — for example, the pattern of color in a duck's speculum — given that physical laws by themselves know nothing of the sustained and meaningful coordination required.

In both [Chapter 10](#) ("What Is the Problem of Form?") and this one I have argued that mechanisms do not give us workable models for the play of form in organisms. In this chapter I have suggested further that the attempt to explain form seems misconceived in the first place, since we can never get "behind" form to an explanatory principle more basic. I have also pointed out that an appeal to form is usually an appeal to some part of the qualitative thinking through which we discover a phenomenon to be understandable.

If the effort to explain form is misdirected, does this mean that the idea of explanatory causes has no place in our understanding of biological form? Not at all. Maybe we will be reminded here of the fact that *formal causes* have long been recognized as essential for our understanding, going back to Aristotle. Perhaps the apprehension of principles of form yields understanding precisely because those principles are themselves causal, although in a crucial sense differing from our usual understanding of causes.

The conclusions of this chapter will, I suspect, seem rather anemic to conventionally minded biologists. This is because we still need to illustrate as vividly as possible what it means to gain a profound grasp of an organism's form, and also because we need a fuller reckoning with the *causal* role of form. These topics will be touched upon in [Chapter 12](#) ("Is a Qualitative Biology Possible?"), where we will look at three research efforts aimed at elucidating form in the phenomena of life. These efforts are irreducibly qualitative, and in their light we may begin to understand that form is not so much a result of causes (as causes are commonly understood in biology), but rather is itself a too-long-neglected kind of cause.

## Notes

1. Figure 11.2 credits (left): Krista Lundgren, United States Fish and Wildlife Service ([CC By 2.0](#)); (right): The Feather Factory, <https://thefeatherfactory.co.uk>.

2. Figure 11.3 credit: FlyEx data base.

3. The origin of this asymmetry is often assigned by biologists to the “random movements” of some number of molecules. But such randomness does not contribute much, if anything at all, to scientific understanding. If we consider the eggs, or germ cells, of species with radically different forms — say, anteaters and eagles — random movements in the developing germ cells cannot meaningfully explain the specific and differing character of those forms.

4. This, quite evidently, was written during a period of much greater intellectual freedom and honesty than we see today — that is, before the veil of blindsight began to hinder the eyes of biologists, preventing them from explicitly acknowledging, or even being conscious of, the purposive dimensions of organic activity. It is worth asking: What is the fear underlying this blindsight?

Today it certainly seems that, at least in part, it is fear of what intelligent design [ID] advocates might do with “injudicious” language about purpose and design. And what makes the situation so difficult is the fact that ID so closely reflects conventional biology. In the battle between ID proponents and establishment biologists, it is very hard for the antagonists to distinguish themselves from each other. There is, above all, the mutual insistence by both sides that organisms are machine-like. Machines, of course, are designed entities — designed from without by humans. So conventional biologists have the “devil” of a time distinguishing their version of science from that of ID theories holding that organisms are designed from without by some supernatural power.

The argument over ID is easily resolved through scientific observation — by showing that both sides are wrong in conceiving the organism mechanistically (a project to which I have tried to contribute in this book). The essential question is the following (as I put it in [Chapter 10](#), “What Is the Problem of Form?”): Do organisms show evidence of being designed and tinkered with from without, or are they enlivened from within? The fact is that we never see a designing power or force that acts other than through what appears to be the living agency of the organism itself. Or, as philosopher Ronald Brady has put it: “We cannot detect, in [organic] phenomena, the distinction between ‘that which is to be vitalized’ and ‘that which vitalizes’” ([Brady 1987](#)).

And so, despite common assumption, the argument between the two camps has no bearing on the tenets of true religion. I know of no religion that does not view divine power, such as it may be, as immanent in the world as well as transcendent — at least, no religion that I can easily imagine a spiritually minded person today being tempted to profess. The reigning conviction of machine-like design in biology is a conviction governed by materialist and anthropomorphic thought, whether it is pro- or anti-intelligent design. This thought is capable of conceiving organisms only as if they were built up through a human-like process of manufacture — an external assembly of discrete and unliving physical parts — rather than growing by means

of a living power within.

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