Chapter 17
Evolution Writ Small

One might think that the natural place to look for an understanding adequate to the evolutionary history of life would be the powers of self-transformation we observe in the evolving organisms themselves. But it can be dangerous to look in a clear-eyed manner at the creative potentials of living beings. One risks having to acknowledge the evident wisdom and agency so vividly on display. In an era of institutionalized materialism, any suggestion that these inner powers are vital to the entire evolutionary story can only produce the sort of discomfort associated with a taboo.

On the other hand, Stephen Jay Gould ran afoul of no taboo when he effectively ascribed this same wisdom and agency to natural selection. Countering the questions we heard voiced in Chapter 16 about what sort of creative principle could explain the "arrival of the fittest", he asked (referring to several giants of twentieth-century evolutionary biology), "Why was natural selection compared to a composer by Dobzhansky; to a poet by Simpson; to a sculptor by Mayr; and to, of all people, Mr. Shakespeare by Julian Huxley?"

The answer, Gould said, is that the allusions to poetry, musical composition, and sculpture helpfully underscore the "creativity of natural selection":

> The essence of Darwinism lies in its claim that natural selection creates the fit. Variation is ubiquitous and random in direction. It supplies the raw material only. Natural selection directs the course of evolutionary change. It preserves favorable variants and builds fitness gradually.[1]

On its face, this argument for Darwinism was a puzzling one. Its answer to the question how variation arises amounted to saying nothing more than "It is everywhere" ("variation is ubiquitous") — which, one might have thought, only added urgency to the need for an explanation. The suggestion seems to be that, because organisms are so expert and prolific at producing new possibilities of life, the evolutionist can simply take their powers of achievement for granted without actually *looking* at them. Because *organisms* so abundantly provide what is needed ("raw materials") for the transformation of life, we are somehow free to declare *natural selection* the transforming agent. It need only preserve all those wonderfully effective new variants, and they will somehow integrate themselves into the almost infinitely differentiated unity of a living being. We need not concern ourselves with those powers of integration and unity. After all, what could they have to do with evolution?

How easy it is, apparently, to forget that the so-called "raw materials" being preserved are never merely raw materials! At the first appearance of any substantive change, the creative work has already been accomplished — if indeed the change is truly beneficial to a living being. We find ourselves looking, not at random raw materials, but at a whole harmoniously transforming itself *as a whole*, where everything tends to affect everything else.

In this way, whatever we may have falsely isolated in our minds as a "new feature" is incorporated into the tightly interwoven complexity of an organism's life. The only power we know to be capable of such incorporation is that of the organism telling its own story, a story always reflecting the qualitative, unified character and dynamic developmental potentials of a particular species.

This harmonious incorporation of new features, founded upon whole-cell inheritance and manifested in whole-organism processes of development, is where we see creative evolutionary change originating. The spreading of an already-existing change through a population is an entirely different matter.

So Gould's response shows us that one of the evolutionist's strategies for coping with taboo agency is immediately to turn the question, "How does creative change arise?" into the different question, "How does creative change, once arisen, spread through a population?" The switch of topics is not hidden, but occurs in plain sight. Only a habit of blindsight relative to the organism's agency seems able to explain such an obvious evasion of a real biological question.

None of this means we need to doubt whatever is true in the idea of natural selection (which may be very little that bears directly on evolution). Selective mortality certainly occurs throughout all domains of life. Not every organism lives out a full life. But the mere elimination of problematic traits (or defective organisms) through mortality is not the same thing as positively and viably transforming the integral unity that a particular organism is.

The point is not terribly subtle. There is simply nothing in the idea of natural selection itself that points to the creative capacities necessary for producing new adaptive features — for producing, say, a four-chambered heart (with all its organism-wide implications) from a three-chambered one. There is only the living being whose agency and activity natural selection necessarily assumes and which evolutionists have unconsciously transferred to a mystical "mechanism" of selection somehow operated by the inanimate world.

So, if we do not accept this subterfuge, we are left with the main question for this chapter: What do organisms show us, directly, compellingly, and uncontroversially, about their own powers of organic transformation? Much of the first half of this book contributes to an answer, especially at the physiological and molecular levels of observation. But in the present, evolutionary context, it will be well to look at the organism from a new angle.

A 'magical' power of self-transformation

If I were to tell you that scientists have sequenced the genomes of two entirely distinct organisms — say, a flying creature such as a bird or bat, and a crawling one such as an earthworm or snake — and had found the two genomes to be identical, you would probably think I was joking. Surely such differently structured forms and behaviors could not possibly result from the same genetic instructions! A genome, we've been told time and again, comprises a blueprint for, or otherwise corresponds to, a phenotype — that is, the manifest form and functions of an organism. And what could be more different than the phenotypes of a snake and bird?

And yet a good reason for jettisoning the entire notion of a genetic "blueprint" is that there *are* flying and crawling creatures with the same genome. A monarch butterfly and its larva, for example. Nor is this kind of thing rare. A swimming, “water-breathing” tadpole and a leaping, air-breathing frog are creatures with the same inherited DNA. Then there is the starfish: its bilaterally symmetric larva swims freely by means of cilia, after which it settles onto the ocean floor and metamorphoses into the familiar form of the adult. This adult, carrying the genome passed on from its larval stage, exhibits an altogether different, radially symmetric (star-like) body plan.

Millions of species consist of such improbably distinct creatures, organized in completely different ways at different stages of their lives, yet carrying around the same genetic inheritance. (See Box 17.1.) This is something to reflect on. How could the transformation possibly be orchestrated, and where lies the power of orchestration?

To speak of the “power of orchestration” will perhaps trigger accusations of “mysticism”. And yet the expression of *some* power is right there before our eyes. It is hardly anti-science to let ourselves come up against questions

Box 17.1

Metamorphosis of an Insect

The British physician and evolutionary scientist, Frank Ryan, described the goliath beetle’s metamorphosis this way:

“Rather than a den of repose, we see now that the enclosed chamber of the goliath’s pupa really is a crucible tantamount to the mythic pyre of the phoenix, where the organic being is broken down into its primordial elements before being created anew. The immolation is not through flame but a voracious chemical digestion, yet the end result is much the same, with the emergence of the new being, equipped with complex wings, multifaceted compound eyes, and the many other changes necessary for its very different lifestyle and purpose.

The goliath beetle (*Goliathus goliatus*), larva and adult. The photos are not printed at the same scale.[2]

“The emerging adult needs an elaborate musculature to drive the wings. These muscles must be created anew since they are unlike any seen in the larva, and they demand a new respiratory system — in effect new lungs — to oxygenate them, with new breathing tubes, or tracheae, to feed their massive oxygen needs. The same high energy needs are supplied by changes in the structure of the heart, with a new nervous supply to drive the adult circulation and a new blood to make that circulation work.

“We only have to consider the dramatic difference between a feeding grub or caterpillar and a flying butterfly or a beetle to grasp that the old mouth is rendered useless and must be replaced with new mouthparts, new salivary glands, new gut, new rectum. New legs must replace the creepy-crawly locomotion of the grub or caterpillar, and all must be clothed in a complex new skin, which in turn will manufacture the tough new external skeleton of the adult. Nowhere is the challenge of the new more demanding than in the nervous system — where a new brain is born. And no change is more practical to the new life-form than the newly constructed genitals essential for the we cannot yet answer. They are what science is for.

One way or another we must come to terms with the fact that the organism and its cells actively *play off* the genomic sequence and all the other available resources within a huge space of profoundly creative possibility. No identifiable physical force compels or directs the cell-by-cell and molecule-by-molecule dissolution and refashioning described in Box 17.1. It is only healthy that such difficulties for our understanding should be acknowledged.

> most important new role of the adult form — the sexual reproduction of a new generation.
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> "The overwhelming destruction and reconstruction extends to the very cells that make up the individual tissues, where the larval tissues and organs are broken up and dissolved into an autodigested mush … To all intents and purposes, life has returned to the embryonic state with the constituent cells in an undifferentiated form" (Ryan 2011, pp. 104-5).

Looking at the pupal case of a fly, the developmental biologist and evolutionary theorist, Wallace Arthur, asked: "What on earth is going on in there to turn one animal into another? If we didn't know better, we might venture 'magic' as our best attempt at an answer" (Arthur 2004, p. 45). Arthur's wonder is justified. And he surely expects, as we must, that a more satisfactory answer than "magic" will be forthcoming. Meanwhile, it is worth keeping in mind that the "magical" impression made by a phenomenon increases in direct proportion to the inadequacy of our current explanatory resources.

Metamorphosis of cells

Frogs and beetles aside, we are brought up against the same perplexities even when we consider the more "routine" developmental processes in complex organisms. Take, for example, the radical cellular transformations following from a single, fertilized human egg cell. As adults, we incarnate ourselves in trillions of cells, commonly said to exemplify at least 250 major types. And when we count subtypes and transient types, we may well find that — as cell biologists Marc Kirschner and John Gerhart tell us — there are "thousands or tens of thousands of kinds representing different stable expression states of the genome, called forth at different times and places in development" (Kirschner and Gerhart 2005, pp. 179-81).

As researchers hone their ability to investigate single cells, they are finding that even neighboring cells, "identical" in type and occupying the same tissue or niche, reveal great heterogeneity. Every cell is, in whatever degree, "doing its own thing".

Strikingly, however, the cell is not *only* doing its own thing; it is also heeding the "voice" of the surrounding context, which is in turn an expression of the unity of a particular kind of organism. So each cell is disciplined by the needs of its immediate cellular neighborhood as well as those of the entire developing organism, which in turn is conditioned by the larger environment. Every organism — even a single-celled one — is a remarkable diversity within an overall, integral unity.

In humans there are, for example, cells (neurons) that send out extensions of themselves up to a meter or more in length, while being efficient at passing electrical pulses through the body. There are contractile cells that give us our muscle power. There are the crystalline-transparent fiber cells of the lens of the eye; their special proteins must last a lifetime because the nucleus and some other subcellular entities (prerequisites for protein production) are discarded when the fibers reach maturity. There are cells that become hard as bone; as easily replaceable as skin; as permeable as the endothelial cells lining capillaries; and as delicately sensitive as the various hair cells extending into the fluids of the inner ear, where they play a role in our hearing, balance, and spatial orientation.

Many of these cells are as visibly and functionally different, in their own way, as the phenotypes of any two organisms known to us. This, you might think, would interest the evolutionary biologist. It *has* drawn the attention of a few who — if they do venture to comment about it — tend to be widely ignored on the point. One such is the much-awarded biochemist, cell biologist, and cancer researcher, Mina Bissell, who remarked in an interview with *Cell* magazine, "Your nose and mouth are completely different and yet they have the same DNA. So what on earth is telling the DNA what to do?" (Bissell 2020).

The question is as old as it is decisive. A hundred years ago, as we heard in Chapter 7 ("Epigenetics: A Brief Introduction"), the pre-eminent biologist, Frank Lillie, who served as president of the National Academy of Sciences, said that "those who desire to make genetics the basis of physiology of development will have to explain how an unchanging complex [DNA] can direct the course of an ordered developmental stream" (Lillie 1927, pp. 367-68). I can't say there's much evidence yet that evolutionary biologists feel they should bother with the question.

Organisms manage their own germlines expertly

Of all the cellular phenotypes, it would be hard to find one whose differentiation and specialization is more distinctive, or more expertly and intricately contrived, or more purposively managed, than the germ cells of sexually reproducing organisms. We can hardly help acknowledging that parental organisms, in carrying out meiosis, genetic recombination, and mating, play a massive role, not only in preserving the genome, but also in re-purposing and transforming it. Deeply embedded in time like all organisms, and therefore *always facing the future* in every aspect of their being, sexually reproducing animals express their future orientation most immediately and vividly in the gametes whose full "self-expression" belongs to the next generation.

A gamete is at least as specialized as any other cell of the body. At the same time, this gamete, along with the entire lineage leading up to it, must retain the potential to yield the totipotent zygote. That is, despite its commitment to a highly specialized, reproductive function unlike that of any other cell type in the body, the germline cell must at the same time preserve within itself the flexibility and freedom that will be required for its role as progenitor for every cellular lineage of a new organism.

It is an extraordinary mandate, and our bodies must focus extraordinary powers of development upon it. For example, the chromosomes of both sperm and egg will have been modified by epigenetic “marks” (Chapter 7, “Epigenetics: A Brief Introduction”), ensuring that certain genes in the offspring will be active, or repressed, depending on which parent the gene was inherited from. Other widespread marks imposed by the parents will (for the most part) be erased immediately after fertilization. This leaves space for the new organism to structure the spatial, electrical, and chemical characteristics of its chromosomes (and therefore also its gene expression) according to its own way of being and developmental potentials.

And, of course, there is the elaborately orchestrated “meiotic ballet” (Page and Hawley 2003) that produces both sperm and egg, each with only half the number of chromosomes found in somatic cells, and with those chromosomes reshuffled and otherwise modified according to a logic and via activities that are still largely beyond any comprehensive understanding. But one thing is sure: the body’s rearrangement (“recombination”) of its germ-cell chromosomes during meiosis is now showing itself to be highly regulated. Multiple protein complexes and epigenetic modifications of chromosomes function combinatorially, with synergism, antagonism, and redundancy: “The new-found multiplicity, functional redundancy and [evolutionary] conservation” of these regulatory factors “constitute a paradigm shift with broad implications” (Wahls and Davidson 2012).

So we are given no choice but to think of the germline as an expression of that same agency — that same, end-directed transformative power — through which our bodies subtly, elaborately, and adaptively direct each of their other cell lineages toward a distinctive form and functioning within the unity of the whole. We have seen that this power of transformation comes to intense expression in entire differentiating cells, quite apart from any mutations in their DNA. And it is just a fact that an entire cell is what each parent passes on as an inheritance to its offspring.

It would be strange indeed if the organism’s ability to proceed adaptively and creatively along paths of whole-cell developmental transformation were to become frozen at the very point where, via the most sophisticated activity imaginable, it prepares its whole-cell bequest for the next generation. Can we reasonably claim that this is the one cell lineage in which the organism’s normal, future-oriented activity goes silent? Or that, with all the organism’s expertise at producing and stably maintaining diverse phenotypes even without changes in DNA sequence, it “refuses” to employ this expertise when it comes to the preparation of inheritances? Or that the power with which the organism adapts all its cells, tissues, and organs as far as possible to new or unexpected conditions is a power lost to it in the management of its own germline?

If every organism is a living agent and power of becoming, as we know it to be, then surely that power of agency — whatever its nature, and however conditioned and constrained by the material results of its previous activity — is the decisive thing preparing the way for a new life. And yet our science has not even addressed the problem of this species-specific formative power, let alone asked about its source or about what role its unfolding expression and its development of its own potentials might play in evolution.

The questions we do ask — and ask compulsively — have to do with how an organism’s genes mutate, not how, say, a mammal directs its single, inherited genome toward the radically different fates of a lens cell and a liver cell. Such cellular fates (not unlike the whole-organism fates of larva and beetle or tadpole and frog we also discussed above) are repeatedly and stably achieved before our eyes and with apparently casual ease, despite their being more complexly divergent over the space of a few weeks or months than the changes accomplished in a million years within many an evolutionary lineage.[3]

Another question we *could* wonder about is how all this creative potential of the organism bears upon the question of genetic mutation itself. And here we would have to reckon with the same future-oriented aspect we see in every cellular lineage during an organism's development, and indeed in all biological activity. Which is to say that the real question hasn't yet even been posed.

That question is not "How does a mutation affect this organism's fitness", but rather "How does it relate to where the species is going evolutionarily?" It cannot be emphasized enough that this latter question differs radically from that of fitness. After all, a tadpole in the process of transforming into a frog — having lost its tadpole organs for feeding and digestion, but not yet having completed the formation of the corresponding frog organs — is presumably not as fit as the fully mature frog. But this temporary "unfitness" is exactly what is required for the sake of the future.

Where are we now?

Does the Organism's Life Have a Bearing on Evolution?

The powerful adaptive plasticity whereby organisms undergo concerted developmental change looks like exactly the sort of change that might translate, upon a wider stage, into the diverse organic transformations of evolution. But, oddly enough, the bare logic, or algorithm, of natural selection makes no reference to any specific potentials for organic transformation. On the other hand, we do discover such potentials playing out in the distinctive developmental trajectories leading from a single-celled zygote to osteoblast and endothelium, neuron and neutrophil. And we see them also when we watch the goliath beetle larva (or human embryo) metamorphosing into the adult form.

Only because we ignore the *living powers* required for such transformations do we subconsciously transfer our ineradicable sense of these powers to the working of a blind evolutionary algorithm — something we looked at in Chapter 16 ("Let's Not Begin With Natural Selection").

But the discussion of evolutionary issues and questions in the previous chapter and this one has so far been sketched on far too narrow a canvas. After all, it is not organisms individually that evolve, but populations or species or even larger groups. Furthermore, there is a very real sense in which we cannot even say that a *collection* of organisms evolves. The analogous truth would be this: we cannot say that it is a collection of cells that develops ("evolves") from a zygote to a human adult. That's not what we see. Starting with the zygote, and all along the trajectory, it is a whole, an undivided unity, that develops, and the cells come to be and gain their identity by being differentiated out of that unity. They are produced by the developing whole; they do not produce it.

There is no reason not to think similarly about the evolution of a population or species. What prevents us from doing so is our reluctance to recognize biological agency as the interior power of activity it is. But once we do recognize this — once we understand that the agency playing through a developing organism informs and governs perhaps trillions of cells with their relatively independent lives — we have no ground left for thinking it odd that something like this agency must play through a honey bee colony or school of fish or wolf pack or an entire species with countless individual members.

Just as individual cells participate in the life of a complex organism, so, too individual organisms participate in the life of a population, or species. In neither case is it always easy to distinguish what is individual from what is collective. And this suggests that the agency we recognize in individual organisms cannot be cleanly separated from the agency at work in the species — surely an idea the evolutionary theorist might run with.

But these remarks are only a kind of "advance warning" to brace you for some (I hope stimulating) intellectual turbulence ahead. Our task now is to keep our eyes open to the reality of organic transformation as we shift our focus from the development of individual organisms to the evolution of populations. We will begin to take up the issues in the next chapter.

Notes

1. Gould 1976. By the time Gould completed his 2002 masterwork, *The Structure of Evolutionary Theory*, he would offer a richly nuanced qualification of these statements. But his fundamental belief in the creative role of natural selection — or, as he would say, its "efficacy" — remained.

2. Goliath beetle larva and adult photo credit: Frantisek Bacovsky.

3. The organism's ability to transform its cells (that is, to transform itself) independently of genetic mutations during development becomes especially significant when we consider those evolutionary lineages where change seems to occur at an unexpected, almost preternaturally rapid pace. See, for example, the discussion of cichlid fish evolution in the lake region of East Africa (Chapter 19, "Development Writ Large"). But we would expect germline DNA, over generations, to be caught up in a species' self-transformation, just as are all other available resources. The main point is that DNA would not be the sole or leading factor in the change. It would, in its own way and like all the other parts, express the evolving whole, not govern it.

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