Plasticity, Stability, and Whole-Organism Inheritance

Stephen L. Talbott

The following are excerpts from "Genes and the Central Fallacy of Evolutionary Theory," the latest article to be posted on the portion of our website entitled "What Do Organisms Mean? Toward a Biology Worthy of Life." The article looks at the ways evolutionary theory has been founded upon the gene as the fundamental element of inheritance — and how the collapse of the classical, gene-centered understanding of the organism leaves the theory without any adequate grounding. The main argument of the article, only lightly touched on here, is that inheritance is always whole-organism inheritance, and that the organism as an active agent must become fundamental to our understanding of evolution. The full article is available at http://natureinstitute.org/txt/st/org.

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 lizard — and had found the two genomes to be identical, you'd be sure I was joking. Surely such differently structured forms and behaviors could not possibly result from the same genetic instructions!

Like a phoenix rising from its pyre

Well, the fact is that *no* organisms result from genetic instructions (Talbott 2012). Moreover, there *are* flying and crawling creatures with the same genomic sequence. A monarch butterfly and its larva, for example. Nor is this an isolated case. A swimming, "water-breathing" tadpole and a leaping, air-breathing frog are creatures with the same 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, bearing the same DNA as the larva, 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 life, yet carrying around the same genetic inheritance. Isn't this a truth inviting the most profound meditation by every biologist? The picture is so dramatic that it deserves an extended sketch. I draw from a description of the goliath beetle offered by British physician and evolutionary scientist, Frank Ryan:

> 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 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 most important new role of the adult form — the sexual reproduction of a new generation. 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)

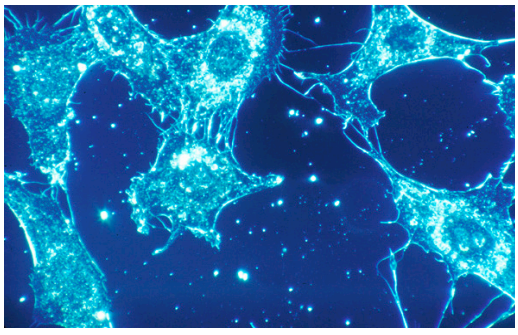
None of this is to say that DNA counts for nothing. It is no doubt as crucial in its special role as many other elements of the cell are in their roles. The larger picture may look something like this (from the DNA vantage point, at least; there are other worthy perspectives): the organism and its cells actively *play off* the genomic sequence within a huge space of creative possibility. Or, I should say (since the sequence as such is a denuded abstraction): the organism both modifies and plays off the dynamically sculpted chromosomes, thereby converting the sequence into an active, meaningful, three-dimensional structure (Talbott 2010a).

The power of differentiation

But we don't need the mystery of metamorphosis to make the point at hand. As adults we humans embody ourselves in over ten trillion cells, commonly said to exemplify at least 250 major types. Moreover,

> different parts of the body have different subtypes of the major categories of cell type . . . [Also,] many transient cell types exist in embryonic development. ... When all these cell types are enumerated, there may be 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)

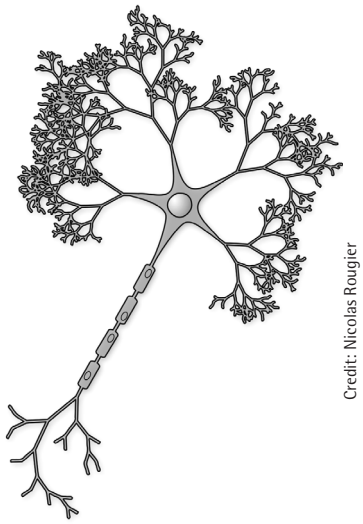
Actually, the emerging story today is even more extreme. Every cell is, to one degree or another, its own cell type. "A growing number of studies investigating cellular processes on the level of single cells revealed large heterogeneity even among genetically identical cells of the same cell type" (Loewer and Lahav 2011). For example, "identical" genomes in "identical" cells can assume altogether different three-dimensional configurations in their respective nuclei, with potentially dramatic implications for divergent gene expression (Krijger and de Laat 2013). That is, every cell is in one way or another "doing its own thing." Strikingly, however, the cell does its own thing only while heeding the "voice" of the surrounding context. It is disciplined by the needs of its immediate cellular neighborhood as well as those of the entire developing organism in its larger environment.



Credit:Cecil Fox, NCI

Connective tissue cells

The vast majority of cells in the body at all stages of development have (more or less exactly) the same DNA sequence. Yet the path from the singular zygote through the many stages of cell differentiation to a particular mature cell type is a path that, for every such type, takes a novel course. Each path of differentiation represents a distinct cellular "evolution", or active unfolding of potential.



Credit: Nicolas Rougier

Schematic drawing of a neuron

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 many other cellular organelles (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.

So the same DNA sequence sits contentedly within the unique phenotypes of hundreds or thousands of mature cell types. Some of these are as visibly and functionally different, in their own way, as the phenotypes of any two organisms known to the evolutionary biologist. And in order to reach these mature phenotypes, this DNA must have yielded itself to the finely choreographed yet flexible and adaptive sequence of transformations along each cellular path of differentiation — transformations that are "remembered"

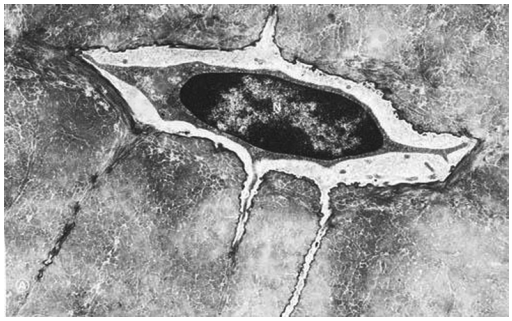
(inherited) from one cell generation to the next, yet take their place within a smooth trajectory of change.

The whole cell: stable, yet capable of elaborate change

Who, in light of all this, will dare to claim: the numerous divergent pathways from the zygote to the various cell types of the body are explained by the one thing in the cells that remains more or less the same, namely, the bare DNA sequence, unstructured by the organism's developmental processes?

Moreover, once the "end point" of differentiation of a particular cell lineage is reached, the recognizable character of that cell type can be maintained indefinitely throughout the life of the organism and through all subsequent cell divisions. Or, in some cases, it can be changed further at need. Or, as with neurons and lens fibers, a cell can remain itself without further division over the several decades of a human life.

The power of the cell to remain itself in any one of many radically different configurations signifying radically different activities and conditions, has no particular temporal limit. *Both this stable character and the power of differentiation during development are guaranteed only by the qualities of the cell as a whole in its organismal context,* rather *than by a fixed sequence of nucleic acids.*

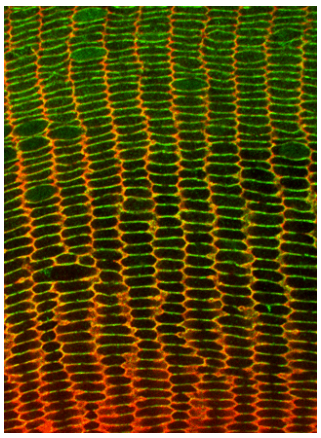


An osteocyte, the most common type of cell in bone

All these truths of development have yet to be taken with due seriousness by students of evolution. The individual organism expresses itself with almost incomprehensible eloquence, insistent aim, and aesthetic sensibility as it passes through the integral stages of unified metamorphosis or transformation — transformation involving much more than DNA. Yet this organism is somehow supposed to be rendered mute and directionless when engaged in the intricate, creative processes through which it contributes dynamic potentials to its offspring and shapes a space for their lives.

. . . . . .

The error at the core of the Genetic Dogma of Evolutionary Theory is this: it posits DNA as a clearly definable and static *thing*, a single substance that can be analyzed out of an almost infinitely complex, functioning whole and treated in this disconnected state as if it held the decisive causal explanation for the canonical form and character of that whole.



Credit: Journal of Cell Biology

Mouse lens fiber cells

But the organism does not consist of things. It is an *active agent* (Moss 2011) whose activity must be understood as such — which is to say, must be grasped as meaningful, contextualized, adaptive intent. And it would be a strange hope if we expected to comprehend the nature of this activity and its evolutionary potentials without first looking at the activity itself in the one place where we find it concretely embodied — in organisms, in their development, and in their life together. Here, then, is the position I am defending:

> **Against the Genetic Dogma of Evolutionary Theory:** The organism is an activity rather than a thing. It is a living agent whose life as a whole is a pursuit of its own ends and meanings. Its significant bequest to future generations consists of an elaborately chosen projection of its own life — not some single "controlling" molecular element — into a nascent life that is never less than a complete organism. This organism, as a physical entity, is without a beginning in any absolute sense. Its life is a continuation and transformation of the directed development of its progenitors. The heritable substance is never anything less than an entire organism.

There is nothing in actual organisms to suggest anything remotely like the standard evolutionary narrative. There is no single heritable substance as opposed to living cells or zygotes, no exclusive explanatory burden carried by DNA, and no rigid barrier separating the individual organism's life history from its contribution to evolutionary change.

. . . . . .

What is inherited?

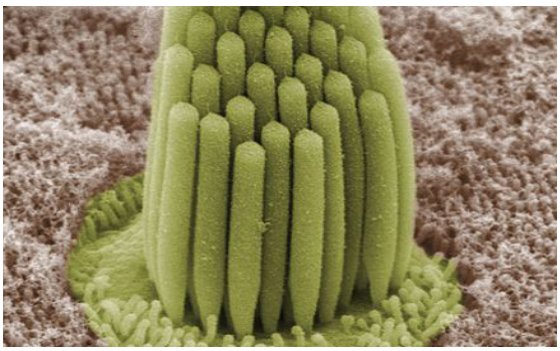
When Richard Dawkins wrote that "Bodies don't get passed down the generations; genes do" (2006, p. 79), he could not possibly have missed the truth by a wider margin. Genes, as biologically meaningful entities rather than as abstract and inherently meaningless sequences (assum-

ing, unreasonably, that they can be defined as "entities" at all) do not get passed unchanged down the generations — certainly not in the literal sense Dawkins intended. And bodies — complete organisms — are exactly what do pass from one generation to another, not indeed as precise replicas of their parents, but with the continuity of *active process* that matters for evolutionary change.

Dawkins' point, repeated in many places, is that "alterations in [the individual organism] are not passed on to subsequent generations" (1982). Taken at face value, the statement would be a monstrosity. Virtually everything in the gametes and the zygote is "custom-made" by the parents for their next-generation heir, all the way down to the detailed chromatin structure of the chromosomes. (Or, I should say, everything is custom-made in cooperation with the next-generation heir — for where, exactly, does the life of the parents end and that of the newborn begin?) Dawkins can say what he does only because he has no interest in organic change; he refuses to speak of anything other than alterations in what he imagines to be static, unlifelike structures that persist for many generations. He is interested in "replicators" that can be *acted on* by natural selection (Talbott forthcoming); he is not interested in the *agency* of an organism that is itself always responding to its environment and to its own internal imperatives — an organism "going somewhere", telling a story, even at the molecular level.

We know that the zygote is capable of all the transformations along the pathway from single, fertilized cell to mature organism, and we have seen that this maturation process is an activity of the entire cell and entire organism. Life scientists, from molecular biologists to naturalists, routinely describe the organism's life in narrative terms (Talbott 2011), and *it is the character of the narrative that must change in a coherent manner from generation to generation if evolution is to occur.* It must change in the only way an integral narrative context can change, through a continual mutual adjustment of directed activities — an adjustment that may secondarily lead to altered structures (Talbott 2010b). These structures are often where our study must begin. But they are coagulations of an ongoing activity — more like residues of that activity than causes of it, just as a spluttering cauldron of magma is continually clotting here and there into partially hardened rock.

In slightly different words: what we need is not so much the stable transmission of thing-like replicators as the *stable intention of the organism itself.* Here "stable intention" is not too mysterious for biologists to face. It refers to something like the directedness and adaptive stability we already witness in individual development. And this individual development is not separable from the processes at work in evolution. After all, the individual's physical body is potentially "immortal", inasmuch as it passes alternately through an expansionary phase of development and then a contraction into the still living germ cell, followed by another expansion. There is never anything but continuous life in this ongoing narrative. The living, directed capacities we see in the passage from adult to germ cell and zygote are not different from the capacities we see in the passage from zygote to mature adult.



Mouse stereocilia — minuscule hair-like protrusions on the surface of sensory cells (hair cells) found deep within cochlear and labyrinth structures of the inner ear

The one-celled zygote, as a whole organism, is the bearer of this narrative, and therefore is the heritable substance. It does not develop into an organism under the autocratic control of just one of the contents it effectively coordinates; it already is the whole organism. This is why it can so deftly execute the subsequent spatial re-organizations, cell divisions, normal developmental processes, and adaptations to unforeseeable disturbances, all in order to produce the orderly stages of its own existence. The passage of this directive capacity down through the generations is the essence of inheritance, and any evolutionary process must derive in the first instance from changes in the overall character of the activity.

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Light in the Dark

Henrike Holdrege

I vividly remember a visit to an art museum in the early 1980s in West Berlin, Germany. In one of the great halls a room had been built, with walls, ceiling, and well-designed entrance and exit. When I entered that room I found myself in darkness. Other people were also there. I could hear them, but I hardly saw them. Suddenly a person moving about was lit up, visible in all her colors. Moving a little further, she disappeared in the dark again. It impressed me that, when nobody occupied that magic space, we could not know it was there.

This observation has stayed with me ever since. It taught me to pay attention, in nature and in my home, to related phenomena. I often marveled at how the museum installation was done. Now, after years of studying phenomenological optics, I know how the design of such a room must look. In the summer of 2012, during a course at The Nature Institute dealing with light and color, I managed to arrange a successful demonstration akin to that in the museum in Berlin thirty years ago.

During the first morning of the weeklong course we worked in a carefully prepared classroom. Each of its three windows and three glass doors had been completely blacked out. At the beginning of the second day, I asked the course participants to come again into that dark room. They took a seat. The chairs were arranged so that everyone faced a table at one end of the room. On that table they glimpsed some black and dark-blue things. But we immediately closed the door and switched off the lights, enveloping us all in black darkness. Nothing could be seen. Nobody spoke. Suddenly a crystal glowed. Seemingly out of nowhere it hovered in the air and shone in dazzling brightness. It disappeared and then appeared again. Everyone saw it and was amazed. To some it seemed they could reach out and touch it. Others saw it a few yards away, and still others saw it so far away that it would have to have been in the yard outside the classroom.

All the materials I used for the demonstration are easy to find. However, I carefully chose a certain crystal. It was a relatively large Iceland spar with regular faces. It was colorless, translucent, but with enough irregularities to be altogether bright when illumined. The light penetrated it. In its clarity of form and its transparency such a crystal is the best object I can think of to make the light manifest in such a demonstration. Crystal and light have a kinship. When we saw it shining in the otherwise completely dark room it made a deep impression on all of us.

To prepare the demonstration I placed two cardboard tubes on a table that was covered with black poster boards. One tube was short and narrow, the other long and wide. Inside and outside, the small tube was covered with black fabric and its one end was tightly closed. Its other end was open and pointed to the opening of the second tube. That tube, covered by dark fabric, had its far end closed by layers of heavy black cloth. Between the two tubes was a space. I placed a flashlight deep inside the small tube and turned it on before everyone entered the room. Its light shone into the large tube.