

INTRODUCTION TO A FEW TOPICS IN PHILOSOPHY OF BIOLOGY

John Protevi
LSU French Studies
www.protevi.com/john

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Comments welcome at protevi@lsu.edu.

INTENDED AUDIENCE

The intended audience is students who are non-specialists in philosophy of biology (as I myself am a non-specialist). Thus these are introductory lectures with a good deal of simplification and exaggeration. I wish to thank Dominique Homberger, Vince LiCata, John Larkin, Alistair Welchman and Chuck Dyke for critical and clarifying comments. They have helped immensely, and the remaining infelicities are solely my responsibility.

PLAN OF THE LECTURES

Lecture 1: a brief narrative of the development of gene-centered views of heredity and development, up through current "evo-devo."

Lecture 2: a tour of current critical issues and positions calling some aspects of the received view into question. We'll see a move from gene-centered positions to ones where genes play important but not central roles: that is, positions in which they are seen as parts of networks which include "epigenetic" elements: elements outside the genome.

OUTLINE OF LECTURE 1

INTRODUCTION

- The great questions of biology
- Some biological terminology

A BRIEF HISTORY

- Foucault on natural history and biology
- Darwin's "Copernican Revolution"
- The modern synthesis
- The molecular revolution
- Evo-devo

LECTURE 1
THE CONSTRUCTION OF THE STANDARD VIEW

INTRODUCTION

THE GREAT QUESTIONS OF BIOLOGY

The great challenges of biology are to think repetition and difference in biological processes occurring on different temporal and spatial organizational scales.

Spatial / organizational scales

Molecular	cellular	organ	organic systems	organisms	groups	ecologies
DNA	Membranes	Heart	Nervous	Bacteria	Colonies	Local
RNA	Cytoplasm	Liver	Endocrine,	Cats	Demes*	Regional
protein	Mitochondria	etc	Digestive	Dogs	Packs	Planetary
Enzymes	Ribosomes		etc	Humans	Societies	
etc	etc			etc	etc	

*Demes = reproductive communities

As the term "organizational" should alert you to, we as Deleuzeans have to be concerned as well with transformation, with the "plane of immanence" that allows change. Hence we have to think of the beings on the above spatial / organizational scale as the products of processes, or more radically, as processes themselves (which our everyday perceptions and scientific procedures freeze / reify). Thus we have to ask, what are the characteristic temporalities of these processes? How do they relate to each other?

We can identify four temporal / processual scales: developmental, organismic, reproductive, and evolutionary. What enables and polices repetition? What allows for and constrains difference? What is important difference? How do processes on the different scales interrelate?

Temporal / processual Scales

	Developmental	Organismic	Reproductive	Evolutionary
	Diachronic (months)	Synchronic (seconds, days, months)	Diachronic (generations)	Diachronic (geological)
	Embryology	Physiology	Heredity	Evolution
Repetition	Regular patterns of development	Systematic function as restoration of set points: homeostasis	Children resemble parents	Conservation of sex, body plans, species
Difference	Developmental plasticity	Multiple norms of "health"	Children differ from parents	novelty / disparity*

*Gould: diversity = number of species; disparity = difference in basic organization.

SOME BASIC TERMINOLOGY

Biological disciplines.

History-centered: classification can be called “taxonomy,” but now, after Darwin, it's also known as “*cladistics*,” that is, classification with regard to evolution; *paleontology*; *genetics*.

Organism-centered: *embryology*, *physiology*, *anatomy*, *ethology*, *ecology*. (These can be done with a gene-centered focus, but not necessarily.)

Ontogeny = development (developmental and organismic scales). Embryonic development, followed by “growth,” then “transformation” at puberty, etc.

Should best be seen as one process of change with different qualitative rhythms.

Phylogeny = descent and branching (reproductive and evolutionary scales).

You can and should see ontogeny and phylogeny together. Bergson asks us to think these processes as durational: the whole of the past accumulates and makes up the “edge” of the present. Recall Bergson's notion of the body in MM3: “the actual state of my becoming, that part of my duration in process of formation.” IOW, your body is the last stage in a continuous process of both ontogeny and phylogeny: both developmental and evolutionary history. IOW, life is continuous, from its origin: whatever it is, at whatever level of abstraction, that allows us to say the first living being was alive, enables us to say we are alive. (Autopoiesis says this is the recursive self-producing pattern in which metabolism produces a membrane that allows for metabolism.)

Speciation = appearance of new species (evolutionary scale).

Genome = set of genes for a species.

Genotype = set of genes in any one individual.

Phenotype = concrete features of the individual: anatomy, physiology, behavior.

We're NOT going to define "gene" at this point. It will become clear why not.

A BRIEF HISTORY

FOUCAULT ON NATURAL HISTORY AND BIOLOGY

According to Foucault in *The Order of Things*, 18th century natural history is the classification of natural beings by the identity and difference of their properties.

It is a putting into clear words of a constrained vision of things. Its focus is two-fold: structure (visible pattern of surfaces and lines) and character (essential nature, that which enables it to be placed in an ordered table).

The table was constructed either "systematically" by comparing a small set of features in every being, or "methodically" by exhaustively describing a key being, and then arranging all other beings in relation to the key. The table then is an ordered grid of differences.

The table expresses an ideal of continuous and fixed spatial distribution of species. Gaps in it are due only to temporal series of accidents; the goal was to reconstruct the ideal distribution from the time-battered record.

For Foucault, natural history has no idea of evolution, because time is extrinsic to the being of plants and animals: "It is ... impossible for *natural history* to conceive of *the history of nature*" (OT: 157).

Time is only a series of accidents that fouls the actual record and creates an epistemic challenge to reconstructing the true atemporal order of things. As Foucault puts it in a memorable phrase:

Finally, and memorably, Foucault will say "biology did not exist before the 19th century, because life itself did not exist; all that existed were living beings" (127-128). "Life" here means an (invisible) functional system (vs. visible structure), so Cuvier is the decisive break.

So life and time are what are introduced in the 19th century.

For us, what's important is that natural history is a system of what Deleuze calls "representation": the focus on the properties of products. By focusing on visible properties, it neglects temporal process and functional integration. It's focused on plants, whereas biology, with its historicity and dynamic organic functionality, is focused on animals (277).

The transitional figure from natural history to biology is Lamarck, who posits organic structure as the fundamental means of determining character (= essential nature of a thing). Whereas Lamarck broke with the fundamental visibility of Classical natural history to posit organic function as the key underlying reality, he still kept the notion of character as representation of place of a species in a table of identities and differences.

Cuvier is the decisive break. By positing organic function of organs as basis of taxonomy, Cuvier could relate functions (respiration, digestion, circulation, locomotion) rather than structural properties (size, shape, location, etc) of organs. Life thus becomes a functional system and a science of life, modern biology, is possible.

We'll come back to this in Lecture 3, but for Cuvier, there was a "plan of organization" (*plan d'organisation*) for the organism in which organs were hierarchically ordered according to their role in overall functional unity.

Three consequences of Cuvier's thought: 1) discontinuous forms; 2) connection w/ environment; 3) temporality.

Time is the key to Foucault's claim that Cuvier is the modern and Lamarck the Classicist, even though Cuvier is a "fixist" and Lamarck a thinker of change and development.

For Lamarck, species developed along predetermined lines in a continuous process so that a pre-established "ontological continuity" (275) is simply unfolded; thus in Foucault's view, Lamarck has time as external to the real being of living things: it's just the way in which the ideal table unfolds: the reality is pre-established.

For Cuvier, species fixism is a consequence of historical forces that have reached a stable state. The underlying reality for Cuvier was temporal. In other words, the end of history is still historical.

As with Ricardo and Marx in economics, so with Cuvier and Darwin: they both share the idea that life is fundamentally temporal: it's just that Cuvier thought that historical forces had come together to form a permanent state of stability (as Ricardo and Marx thought would happen in the future for economics, with different spins, of course -- Gutting [190] notes that Foucault allows in an interview that Marx's social theory constituted an epistemological break, but not his economics).

As we will see, Darwin is much more radical in his historicity: life is always out of balance.

DARWIN'S "COPERNICAN REVOLUTION"

BASIC CONCEPTS

Evolution is change over time. There were other “evolutionists” before Darwin, who accepted historical change in living beings.

Darwin proposed *natural selection* (NS) as the main (but not only) mechanism for organismic and ecological order. Organismic order = adaptation of organs to each other to form functioning whole. Ecological order = adaptation of organism to its fellows and to environment.

Darwin also mentions *sexual selection*, which is the topic of very interesting recent work by Elizabeth Grosz, as adding some "indetermination" to nature, that which is in excess of utility (= survival / reproduction).

There are three key concepts to NS: *variation*, *heritability* and *selection*. The concept of NS articulates organismic and reproductive / evolutionary time scales and accounts for spatial difference in distribution of organisms. It is silent on development.

Variation. The source of variation was thought by Darwin to be *accidental mutation*. Variation itself was thought to be *random* and *prevalent*. Variations are produced without reference to how they help the organism adapt to its environment, that is, without reference to “fitness” (see below).

Lamarck thought that variation was driven by adaptation; as an organism struggled in its environment, its differential use of its organs drove a variation. Thus adaptive variation was “acquired” and this acquired variation could be passed down to offspring.

Heritability. Variations have to be able to be passed on to offspring for NS to work. But Darwin did not (could not) know the *mechanism* of heredity we now accept (at least DNA, but now for many biologists, epigenetic resources as well).

Darwin held to a theory of "pangenesis," i.e., that we have "gemmules" or particles in our bodies that are modified by chance events. These modified particles allegedly migrated via blood to the reproductive cells and were then inherited by the offspring.

So even though Darwin did not accept Lamarck's (adaptive) source of variation, he did think (accidentally) acquired characteristics could be inherited.

Natural selection. According to Darwin, selection is due to population pressures relative to the carrying capacity of the environment. A species would tend to fill its “niche” to the point where the [in]famous “struggle for survival” would kick in, creating a “selection pressure” as members of the same species struggle against each other for limited resources.

Darwin will thus famously say that he has applied Malthus to the natural world. Kropotkin will say this is an English perspective: in Siberia it's clear that in many species the members co-

operate in the struggle against the environment. Darwin mentions such *intra-species co-operation*, but it's often underplayed by his successors who focus on *intra-species competition*.

Many contemporary accounts provide for other ways in which selection occurs; what counts is differential reproduction, no matter how it's achieved.

Darwin's scenario needs considerable nuancing, as it presupposes a fixed environment against the “borders” of which immobile species press (a container image). But organisms are mobile and environments are not fixed (“niche construction” [see below] would need to be discussed here). This is not to deny that populations grow. Each population tends to produce more offspring than what would be necessary to replace the parent population. In other words, in general, sexually reproducing organisms produce more than two offspring over their life time. But the response to this population growth need not be “struggle”; it's often the case that offspring move out of the core territory of their parents to find [and / or “construct”] their own niche. There are of course no guarantees; the new niche may be less favorable than the core territory, and the “emigrants” may not be successful. (Cf. the Deleuzian notion of “deterritorialization.”)

Continuing with the popular story, the “struggle” means that the “best” would survive and reproduce more; or the “worst” would be eliminated and reproduce less. The problem here is the presumed individualism. Organisms cannot “reproduce” (or even “survive” in any biologically meaningful way) in isolation. Even if you could somehow identify the “best” organism, this would have to mate with a less “perfect” individual, so that the offspring would automatically be less than “best.”

Fitness. The key to NS is the assumption that some heritable variants would affect “fitness” (= number of offspring produced per generation). The more a heritable variant helped an organism leave behind live and fertile offspring, the more that variant would accumulate across generations (or, alternatively, the more “bad” variants hurt fitness, the more those traits would disappear – although new variants are always appearing).

Biological “fitness” just measures reproductive success. Thus being the “best” doesn't measure some overall adaptation to an environment. Rather, organisms just need to be “good enough” (and not be unlucky) to interact successfully enough with the environment to survive long enough to reproduce. In other words, selection produces viability rather than optimality.

Once it reproduces, an organism's “fitness” is out of its hands, as it were: it now depends on the survival and reproduction rates of its offspring.

Grosz notes that in sexual selection traits are considered in terms of sexual “fitness” as access to partners and number of matings. Reproduction is not necessary.

Thus you could measure evolution as the change in distribution of adaptive or positively fitness-affecting heritable variants or “traits” in a population across generations. At some point in this

process a new species appeared via the accumulation of differing traits (evolution scale) and geographic isolation.

This “accumulation” need not be strictly quantitative. Theoretically, a single mutation may do the trick if it prevents interbreeding between populations that have been separated from each other and, thus, were prevented from interbreeding.

There are no inherently “bad” or “good” variants. Variants are “bad” or “good” depending on interaction with an environment. For example, a particular variant may be bad in the arctic environment, but very good in a tropical desert environment.

CONSEQUENCES OF DARWIN

Dynamicism of life: life is always out of balance due to multiplicity of beings and species all adjusting to and changing their environments (the “environment” of a species includes other species which serve as prey and predators).

Differentiation of species: constant branching and diversification. Not a Chain of Being, but a growing tree. (NOT a picture of tree, but a real, live, growing, branching, tree. AND a tree without a fixed nature, but one whose branching pattern is itself evolving!)

Multiple temporal scales: evolutionary / geological vs historical / anthropomorphic. A great displacement of the human.

Irreality of species: “species” is really just a name of a snapshot of a process of diversification. Darwin is a *nominalist* with regard to species: it’s a convenient name for a synchronic coagulation or a diachronic snapshot but it doesn’t hook on to an “essence.”

Let’s think in terms of synchronic and diachronic diversity.

With respect to *synchronic diversity*, where do you draw the line between two variants of a species and two different species? (This is somewhat analogous to the dialect vs language issue in linguistics.) Here species are like coagulations of a viscous liquid, whose spreading out on a surface you have arrested.

With regard to *diachronic diversity*, we have to remember our two temporal scales. Relative to our life span, to our *organismic* temporal scale, you might say that a species has a fixed identity (albeit with diversity of traits) – that’s if you solve the synchronic “variant vs species” problem noted above. But relative to the *evolutionary* scale, they are just snapshots of a process.

According to Gould, Darwin was a “slow gradualist” with regard to the rhythm of evolutionary change: that is, there was only a single rhythm, and speciation takes a long time. Others {Gould and Eldredge} propose “punctuated equilibrium,” that is, a variety of rhythms of speciation, some faster than others. So while speciation is a term for the

appearance of novelty, or an “event,” in some periods, there is a faster frequency of events. With this and other considerations, Sterelny and Griffiths want to recuperate reality of species.

Population thinking: Means or types are abstractions from a population of concrete individuals with a distribution of traits.

Thus there is no ideal height for a tiger; there is a distribution of heights in the tiger population. Each height is a “variant”; there might be a statistical “norm” (= “mean”) of those variants (just like there might be a statistical “mode” and “standard deviation”) but there is no “normative” norm, if you know what I mean: there is no “ideal” height that the “best” or “perfect” tiger is. And just as we can measure the distribution of variants synchronically (within the same generation), we can also track changes in that distribution diachronically (across generations). The statistical nature of means or norms entails that although the bulk of the natural distribution will approximate to the mean, no single individual need ever achieve the exact mean.

One thing I'm trying to do is to introduce population thinking into cognitive science, to replace "the" cognitive subject (even in embodied-embedded mind).

DARWIN'S UNANSWERED QUESTIONS

Darwin did not have the correct *mechanism for heredity*, nor was he able to discuss the *mechanisms of development*. So there were unanswered questions both for development (ontogeny) and for heredity (phylogeny), and for how they relate (what the new schools of evo-devo and devo-evo study).

Into this gap between heredity and development steps the concept of the *gene*. We will follow the analyses in Evelyn Fox Keller's wonderful book, *The Century of the Gene* (Harvard, 2000).

First we discuss heredity in the "modern synthesis." Then both heredity and development in the "molecular revolution." Then how they relate to each other in "evo-devo." This will complete our sketch of the standard, widely shared, view, at least of organisms. We won't be able to consider ecology and how it relates to organisms, but we will come back to this topic in lecture 3.

THE MODERN SYNTHESIS

DARWIN did not have the correct mechanism for heredity. So while Darwin could account for evolution as the selection of inherited adaptive variations (i.e., difference) on the evolutionary scale, he could not account for stability (i.e., repetition) on the reproductive scale.

WEISMANN proposed "determinants" as self-reproducing elements sequestered in a "germ-plasm" that is transferred intact between generations. Notice here two assumptions: (1) That fixed material units were passed on, and (2) that organisms are just epiphenomena of the underlying flow of germ-plasm.

KAP shows connection to Bergson, to ultra-Darwinists, and to Deleuze.

MENDEL'S LAWS of heredity were rediscovered in early 20th century. The key discovery is that each parent could transmit a trait, rather than blending with the contribution of the other parent. Here we have the famous dominant and recessive traits.

There was a big debate over continuous variation (as measured by "biometricians") vs. discrete traits in phenotype.

GENES were at first just abstract functional units thought to account for traits. They were just markers of heredity. There was no real sense of

1. what their physical structure was,
2. how they were passed on to the next generation,
3. how they conserved their structure in that passage,
4. or how they worked in development.

POPULATION GENETICS: showed how the continuous variation of traits in populations could be the result of the action of many discrete genes.

MODERN SYNTHESIS = population genetics plus Darwin's concept of evolution by NS. Evolution became thought of as the change in the distribution of genes in populations across time. But note that this is just the statistical "bookkeeping" of evolution. Evolution by NS is, in the words of Massimo Pigliucci, "a physical interaction between organisms and their environment, which partially determines the statistical patterns at the population level that biologists have access to (partially because individuals can die or reproduce for reasons independent of their physical fitness)."

(http://life.bio.sunysb.edu/ee/pigliuccilab/Lectures_files/lecture-selection.pdf).

Notice that embryology, ethology and the other organism-centered biological disciplines do not play a role in the modern synthesis.

THE MOLECULAR REVOLUTION

WATSON AND CRICK did not "discover" DNA nor even link it to genes. It had already been shown that DNA comprised the physical structure of genes.

What they did do, in their famous *double helix* 1953 breakthrough, was to deduce a chemical structure for DNA (as braided strings of nucleotides).

The combination of these two advances meant that genes were understood to be *contiguous strings of nucleotides* located on the chromosomes. And these strings of nucleotides code for protein.

STRUCTURE CONTROLS FUNCTION. So DNA's *structure* (string of nucleic acids) was supposed to account for its *function* (coding for proteins: which are strings of amino acids).

Let's see how this works. DNA is *transcribed* into RNA which is then *translated* into protein.

Here's the process:

1. DNA in nucleus is separated (two strands pull apart).
2. An enzyme (RNA polymerase) copies the bottom strand in complementary mRNA (messenger RNA). This is the process known as *transcription*.
3. The mRNA is transported out of the nucleus into the cytoplasm.
4. On the ribosome, the tRNA (transfer RNA) binds to mRNA by recognizing triplet codons on the mRNA.
5. The tRNA adds an amino acid monomer, correlative to the triplet codons of the mRNA, to the protein polymer chain under construction. This is the process known as *translation*.
6. The protein chain, when complete, drops off the ribosome and goes on to play its role in the cell.

We will see that the process is even more complex than this, as the *primary* mRNA transcript has to be *spliced and edited* to form the *mature* mRNA transcript that goes to the ribosome.

THREE OF THE FOUR SCALES. So, we can see that by controlling protein production DNA can account for cell construction and function. So it has taken care of the *organismic* scale.

Here there is a huge assumption of what we can call, for want of a better term, "methodological individualism." To have a true molecular reduction of organismic level physiology, to say nothing of ecological relations, we have to assume that we can account for organism level functions by aggregation of individual cell functions. AND that we can account for individual cell function by aggregation of individual protein functions. AND that we can account for individual protein function by aggregation of individual gene function (which is itself reducible to gene structure). All these assumptions will be challenged. More tomorrow when we discuss genetic reductionism.

What about *heredity*? DNA is passed on in sperm (cytoplasm was thought to be genetically irrelevant), so it can take care of the *reproductive* scale, and it accounts for *evolution* (as accumulation of mutations / change in distribution of alleles across generations).

Remember, heredity is repetition and difference (or "descent with modification") on the reproductive and evolutionary scales: that is, faithful reproduction of a genetic inheritance while generating mutational variability to be screened by selection.

The CENTRAL DOGMA encapsulates the structure controls function logic in a molecular reprise of Weismann's "segregation of the germ-plasm" thesis. In *development*, it said that DNA codes for RNA ("transcription") which codes for protein ("translation"). There's no influence on proteins back to DNA, so it's a one-way process of "information" flow from DNA to protein. Thus with regard to *heredity*, the source of variation can only be random genetic mutation, not mutation "directed" by "epigenetic" events (that is, mutation that comes up the wrong way on the one-way street from protein to DNA). In other words, nothing outside the genome can be passed on, so we can say the central dogma forbids epigenetic inheritance.

DEVELOPMENT: THE FINAL FRONTIER. Okay, you say, we now see how DNA can control cell construction and function (organismic scale) and how it can account for repetition and difference in phylogeny, on both reproductive and evolutionary scales. Its structure (sequence of nucleic acids) accounts for its function (coding for protein).

But what about development? It was left out of the modern synthesis. Can it be integrated with molecular biology? If it is to be, a big question must be answered: How can a linear sequence control a temporal process?

Development requires *anatomical arrangement* and *cell differentiation*: from a single cell, we develop an inside and outside, a top and bottom, a front and a back, and we develop many kinds of cells. All this spatial and qualitative change must be done in the correct order. That is, genes must be expressed (turned on and off) in the right order.

To solve this problem, JACOB AND MONOD propose a GENETIC PROGRAM: they distinguish *structural genes* (coding for protein) from *regulatory genes* (turning structural genes on and off). The actual details of their "operon model" for the regulation of gene expression in the protein synthesis of bacteria need not concern us. The important thing is that with the distinction of structural and regulatory genes, and the notion of a "genetic program," that development could be seen as genetically controlled. It's the very ambiguity of the term "genetic regulatory mechanism" that is problematic. It's really a mechanism of gene regulation in which cell conditions [e.g., the presence of lactose] play a key role. But calling it a "genetic regulatory mechanism" and talking about a "program" implies that the locus of control is genetic rather than distributed. Hence the gene-dominant reading is a misunderstanding right from the start, though one enabled by Jacob and Monod's rhetoric (Keller 2000: 79).

Keller quotes Jacob and Monod: "the discovery of regulator and operator genes ... reveals that the genome contains not only a series of blue-prints [for gene – protein coding: JP] but a coordinated program of protein synthesis and the means of controlling

its execution." Keller continues in her own words: "In Jacob and Monod's view ... genes may need to be activated, but other genes—regulator genes—were there to do the job. [even though those regulator genes are sensitive and respond to cellular conditions: JP] The net effect of Jacob and Monod's description of a gene-based mechanism of regulation was to put genes back in the driver's seat and traditional expectations of genetic control back on track" (Keller 2000: 80).

It was already known how, via the structure controls function logic (sequence determines coding), DNA accounts for repetition and difference on three of our scales: organismic, reproductive, and evolutionary. Now with the operon model and the notion of a genetic program, it could account for development as well.

EVO-DEVO

Until a series of fascinating discoveries in the 1980s, studies of genes in the evolutionary and developmental sciences were separate. Biologists knew that DNA was the basis of both evolution and development, but they didn't know how the hereditary gene and the developmental gene related to each other. How did the genes that control development evolve? And how did such evolved genes account for the difference in developmental pathways that yield both diversity of species and disparity of basic bodily plans? These were unanswered questions.

Biologists assumed that disparate biological orders had disparate developmental genes. The discovery that enabled the field of evo-devo was homeotic genes. These structure development, acting as genetic switches controlling transcription factors regulating gene expression (turning them on and off). They are essential in the development of basic body plans. They are expressed in the order in which they are found in the chromosome and they control body segmentation, for instance.

What was shocking about homeotic genes is that they are found in many different orders, conserved from before arthropod / mammal division. A famous one is "eyeless." When transplanted from a mouse into a fly, it induces an eye formation. Think about that for a minute: a mouse gene that works in a fly! A mammal gene that works in an insect! Obviously there's something very strange going on here, something that contradicts the idea that different orders have different genes. Evidently they have the same genes. But here's the catch: the eye that forms is a fly eye. It's the fly context that determines what kind of eye is formed.

So if large parts of the genome are conserved over vast periods of time and shared by widely divergent kinds of living beings, that is, if disparate organisms share developmental genes, what is the source of their disparity?

The answer is the evolution of different regulatory gene networks that change the pattern of expression of the genes and hence control developmental pathways. So evo-devo is very much gene-centered. Evolution is change in gene networks controlling development.

Sean Carroll, in his excellent popular science book, *Endless Forms Most Beautiful: The New Science of Evo-Devo* (NY: Norton, 2005), writes: "Around 3 percent of [our DNA] ... is regulatory. This DNA determines when, where, and how much of a gene's product is made.... Regulatory DNA is organized into fantastic little devices that integrate information about position in the embryo and the time of development. The output of these devices is ultimately transformed into pieces of anatomy that make up animal forms. This regulatory DNA contains the instructions for building anatomy, and evolutionary changes within this regulatory DNA lead to the diversity of form" (12).

IOW, it's all about the different developmental music (differences in rhythm and melody and harmony) that can be played on the same inherited keyboard. But who writes the score? And who does the playing?

As we will see, these are huge questions of "political physiology." Does DNA constitute a program that uses the raw materials of the cell to construct the organism? That is, is DNA the keyboard and score, and the cellular mechanisms only the paid musicians? Or should we think a more "democratic" scenario in which DNA plays an important, but not dictatorial, transcendent, role? Can we conceive a musical group in which there is no director, but the musicians rewrite the inherited score as they go along, responding to cues from each other and from the "audience" (environment), bringing out previously unexpressed potentials, forming new music as they go? (The French is better here: "audience" = ceux qui assistent.) (Hat tip to Gene Holland and his work on jazz improvisation as Deleuzean music.)

Let's end the lecture here. Tomorrow we'll see how the very progress of molecular genetics has undermined the picture of dictatorial DNA and given rise to a series of fascinating contemporary issues and positions.

Evelyn Fox Keller tells a very interesting story in *The Century of the Gene* of how advances in molecular biology of DNA has tended to undermine the very notion of the gene. In other words, as we understand more how DNA *functions* in cells and organisms, how it partakes in complex multi-level networks of gene expression (when and where genes are turned on and off), the less important becomes the notion of gene *structure*, that is, the spatial location of nucleic acids.