INTRODUCTION TO A FEW TOPICS IN PHILOSOPHY OF BIOLOGY

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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.

LECTURE 2

CONTEMPORARY ISSUES AND POSITIONS

OUTLINE OF LECTURE 2

- Issues
  - Physiology and Development
    - Genetic determinism and reductionism
    - Genetic reductionism in physiology: structure dictates function
    - Genetic reductionism in development: the genetic program
  - Heredity and Evolution
    - Unit of selection
    - Adaptation
    - Niche-construction and "co-evolution"
- Contemporary Stances
  - Standard positions

Ultra-Darwinism
Evo-devo
Critical positions
Devo-evo (developmental evolutionary biology)
DST (Developmental Systems Theory)
Autopoiesis / enaction
Process structuralism
Serial endosymbiosis

ISSUES

PHYSIOLOGY AND DEVELOPMENT

GENETIC DETERMINISM AND REDUCTIONISM

First, we have to remember that the model I'm presenting of genetic determinism / reductionism is indeed a straw man for biologists, but unfortunately, and for many social-political reasons, has become -- and remains -- the standard popular view in mainstream media and in the minds of most educated but not specialized people. It may be that the crude ideas presented here never existed in the writings of real biologists, as opposed to being popular misconceptions right from the start. Just as, for example, nothing like "post-modernism" as some scary nihilism about the impossibility of meaning or reference ever existed except as a misunderstanding right from the start.

In any event, here we go.

Determinism is an *ontological* thesis: genes are the sole source of order of (they determine) physiological and developmental processes.

> No one has ever upheld such an absolute position if by that one means epigenetic conditions have no influence whatsoever, that they are determined the way a stone is determined to fall by gravity. The real target of critique is what Susan Oyama and the DST crowd call "interactionism," that is, the idea that there are two classes of developmental resources, genetic and epigenetic, and that genes provide the information or blue-print or plan or program, and that the epigenetic resources are the materials or background upon which or in which genes act. The real question is locus of control rather than absolute determination. Thus the DST critical position is to uphold a "parity thesis" in which genes are considered one among many developmental resources; they are an important, indeed essential, part of physiological and developmental processes, but they are immanent to those processes and cannot be said to "control" them in any transcendent way. At stake is a deep question of "political physiology."

Reductionism is an *epistemological* issue: can the discourse about physiology and development be reduced to (or translated into) discourse about genes? Also, can Mendelian genetics be

reduced to molecular biology? That is, can we translate talk about traits and genes into talk about DNA?

> My LSU colleague John Larkin writes that practicing biologists think of reductionism as asking the question: can the portion of physiology and development due to genetic control be considered separately from the portion due to environmental / outside influences? A point of clarification: molecular processes always include genetic (DNA / RNA) and epigenetic (intranuclear and cytoplasmic) factors. However, many biologists will limit the extent of inherited epigenetic factors (they have to be inherited to play a role in evolution and development considered together) to intranuclear and cytoplasmic factors, and consider extra-cellular and extra-somatic factors to be "outside." The most radical DST position will be to include the extra-cellular and extra-somatic factors as epigenetic inheritance in a maximally extended "developmental system" (hence the name) or "life-cycle."
>
> Now however one stands on the question of the extent of epigenetic inheritance, the key question is the separation and control question, which is a matter of "interactionism" as defined above. That is, a DST question would be: all biologists today admit epigenetic factors play a role, but, whatever their extent, are they controlled by epistemologically separable genetic factors?

We're going to see that determinism / reductionism is in trouble.

GENETIC REDUCTIONISM IN PHYSIOLOGY
STRUCTURE DICTATES FUNCTION

We remember the structure dictates function logic: a contiguous string of DNA (structure) codes for a string of amino acids in protein (function).

Well, not so fast. As we're going to see, following Keller's presentation in *The Century of the Gene*, the very progress of molecular biology has undermined that early picture. (In the last lecture we'll see the way Deleuze can help us make sense of this progress / undermining.)

For now, let's see why the process of transcription and translation is no longer thought to be linear and under the sole control of the genome (via regulator genes).

Here's the transcription / translation process at the time of the central dogma:

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.

Extra steps. However, between steps 3 and 4, complex processes of splicing and editing go on. Thus the *primary* mRNA transcript at step 3 has to be *edited and spliced* to form the *mature* mRNA transcript that goes to the ribosome in step 4.

Why these extra steps? Well, it turns out that proteins sometimes need separated strands of DNA for their synthesis. Often there are big chunks of inactive or "junk" DNA (technically, "introns" for "intragenic region" or "intervening sequence") between the strings of active DNA ("exons" or "expressed DNA"). So the introns have to be cut out (edited) from the primary mRNA transcript and the exons have to be strung together (spliced) to form the mature mRNA transcript.

> Note that unexpressed DNA can evolve by drift (mutation) and other processes, independent of natural selection. This is because NS only works on phenotypes. (NS is about real world interactions, even if they can be tracked by gene shifts.) The variation in unexpressed DNA can be a reservoir for developmental plasticity, as we will see in discussing West-Eberhard.

Another twist: exons can be spliced together in different orders! This is called "alternative splicing." It means you can get more than one mature mRNA transcript from the same primary mRNA transcript (that is, from the same DNA string).

So here's *the real process*:

1. DNA in nucleus is separated (two strands pull apart).
2. An enzyme (RNA polymerase) *transcribes* the bottom strand in complementary mRNA (messenger RNA).
3. The primary mRNA transcript is transported out of the nucleus into the cytoplasm.
    a. The introns are excised
    b. The exons are spliced together
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.

Thus there is no longer a one-to-one correspondence of DNA sequence and synthesized protein. We have now one gene (DNA string) = many (mRNA transcripts) = many proteins.

Control of editing and splicing. And here's the important point: what controls the editing and splicing? *It depends on the state of the cell at any one time*. Thus control has migrated from

DNA (structural plus regulatory genes) to the complex system in which DNA plays a (certainly very important) role, but no longer a controlling role.

> We can call this something like "functional dynamics of gene expression," though in one sense, you could also call it "dynamics of gene formation and expression," since the process of editing and splicing "forms" the gene as functional part of the system from the gene as string of DNA.

Separating the concepts of structural and functional genes. Think of it this way: we have to learn to separate the *heredity gene* or *structural gene* (as contiguous string of DNA passed down in reproduction) from the *functional gene* (end-product of transcription processes "forming," from separated strings of DNA, a gene which plays a role in protein synthesis).

> If you want to be dialectical about it, you could say that now function determines structure. That is, the function of the protein to be formed dictates the formation of the mature mRNA transcript. That is, the structure of the mature mRNA transcript, the structure of the functional gene, is dictated by the function of the protein to be formed. As you can no doubt anticipate a daring person might say that there's a teleology or even intentionality at work here. Obviously there are big philosophical issues in saying that!

Regulation of protein function. But the story is not over yet. Not only are different proteins formed from the "same" gene (that is, to repeat, different mature mRNA transcripts can be formed from the same primary mRNA transcript), but *proteins function in different ways, according to the cellular context in which they find themselves*. This change in protein function is due to changes in their structure; this is known as "allostery." So now we have, instead of "one protein = one function," the case that "one protein = many functions."

Consequences. So we've gone from "one string of DNA = one gene = one protein = one function" to "one string of DNA (structural / hereditary gene) = many (functional) genes (many mature mRNA transcripts) = many proteins = many functions."

> Of course the first equation is an ideal case: everyone always acknowledged the possibility of errors at each stage (i.e., errors in transmission of DNA in heredity, then transcription or translation errors). Still, the point is that the classic reference point was always a linear, self-contained process by which cell function (and further on, phenotypic traits) could be understood as reducible to proteins produced by genes as DNA strings.
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> Mike Wheeler puts it this way: we have to give up the idea that "genes code for traits," and be satisfied with the notion that individual mature mRNA transcripts code for individual proteins. But we can't go simply from hereditary genes (DNA strings) to functional genes (individual mature mRNA transcripts), nor can we go from proteins to traits.
>
> That's because there's a big assumption here that we can account for individual cell function by aggregation of individual protein functions (in other words, a denial of emergent cell function).

> We've seen the disappointment of all those determinist / reductionist assumptions, since we've seen how gene formation and expression depends on cell dynamics which are part of larger networks. (In fact, even the stability of the hereditary gene or DNA sequence is influenced by external events in what's called "stress-induced mutagenesis": in crisis situations, mutation rates increase. This capacity has itself evolved in what's called the "evolution of evolvability.")
>
> But let's talk about development before we talk any more about heredity – anticipating West-Eberhard's views on developmental plasticity as inducing genetic variation.

GENETIC REDUCTIONISM IN DEVELOPMENT
THE GENETIC PROGRAM

So far we have spoken about individual cell metabolism. But the process of development includes cell differenciation: we have lots of different types of mature cells. Thus gene expression has to follow a temporal pattern.

At first, hopes were high that Jacob and Monod's operon model, which depended on the regulatory vs structural gene distinction, meant that gene expression and hence development could be controlled from inside the genome, by a "genetic program." But now biologists acknowledge the role that *epigenetic* factors play in development.

What are these epigenetic factors? Working our way outward from DNA, we note that it is packaged and coiled on the chromosomes. This packaging, DNA and chromosomal proteins together, is called *chromatin*. Chromatin plays an important role in gene expression.

Next we find the *cytoplasm*. In earliest development, the fertilized egg. The chemical gradients in the egg turn out to be very important in development. There are also lots of connections between cytoplasm and chromatin. Control is being dispersed.

> One of the keys to this new view of the importance of the cytoplasm is nuclear transplantation. It used to be thought that you couldn't clone from an adult nucleus because the genome copy carried in an adult cell was irrevocably changed by the process of cell differenciation so that it lost its "totipotency." But after Dolly the sheep, we can now see definitively that what counts is the relationship of nucleus and cytoplasm, not the (allegedly changed) state of the nucleus.

This is the most conservative position to take, that epigenetic factors are limited to chromatin and cytoplasm. As we'll see in discussing DST, some people propose other factors, extracellular and even extrasomatic.

But even if we stick to intracellular elements as the limits of our epigenetic factors, we have to recognize that cell position in development plays a role in cell differenciation. Hence gene

regulation networks are dynamic and multifactorial; they are no longer simply genomic. Hence development is key to seeing limits of genetic determinism / reductionism.

So here we have critically examined the assumption behind genetic determinism / reductionism 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 supposedly reducible to gene structure). AND that a genetic program has to control the development of all these mature structures.

All these assumptions have been challenged. Instead of DNA as master molecule (as localized and transcendent to the process) it plays a functional role (as immanent to the distributed process). DNA is part of networks that are dynamic and that themselves change over time throughout the development process (which we can see as lifelong, as involving different rhythms).

HEREDITY AND EVOLUTION

UNIT OF SELECTION

What is it that is targeted by NS?

Gene centered selection: Darwin thought it was the organism. But with the molecular revolution, genetic selectionism came to the fore, popularized by Richard Dawkins (*Selfish Gene*, 1976; *Extended Phenotype*, 1982).

Here we find Dawkins' famous distinction of replicators and vehicles, with all his famous phrases: organisms as "lumbering robots," etc. Dawkins is after "active germ-line replicators": genes as units of heredity and development. The replicator has to be "active" because it has to have a phenotypic effect, since that organism-level trait will be the proximate target of NS – though genes as chunks of DNA ("germ-line") are the ultimate target. In this way, Dawkins is promoting a "molecular Weismannism."

David Hull substitutes the term "interactor" for "vehicle": "interactor" doesn't imply subordination to replicator and can be used in discussing higher levels of interaction (Sterelny and Griffiths 1999: 56).

Genetic selectionism does not imply that organisms qua interactors are irrelevant. In fact, they are the ways in which genes are selected: phenotypic effects cause differential replication of genes via survival and reproduction of organisms. Nor are organisms mere epiphenomena of genes. However, it is a "gene's eye view" of evolution.

Criticisms of genetic selectionism. (Relying here on Sterelny and Griffiths 1999.) There's a key assumption of a simple path to gene expression in genetic selectionism. That is, phenotypes are what are screened in NS, and via their phenotypic effects, genes are the ultimate target.

But we have seen that gene expression is anything but simple. We have seen that once put into functional networks in developmental processes, structure no longer dictates function. In other words, there is a separation of the hereditary gene as string of DNA and the functional gene as end product of transcription process of editing and splicing. So even if gene structure as chunk of DNA is passed on in heredity, gene function in development is not equal to a contiguous string of DNA.

So if phenotype is what is selected for (and gene selectionists agree with this), then any complexity or multiplicity, any deviation from one gene – one phenotype expression, will derail gene selectionism.

It's no good to shift the target and say that the functional gene is the target of selection because it has no stable molecular base that is inherited. There's no sense in saying that the end products of complex cellular processes are "replicators."

So while the hereditary gene as string of DNA is a replicator, it has such variable phenotypic effects that it is invisible to selection and cannot be the target of selection. And the functional gene that does have reliable phenotypic effects is not a replicator.

> As if the multiplicity of gene expression argument weren't enough, genetic selectionism also has to deal with *gene interaction* and with *piggy-back genes*.
>
> Gene interaction is a big problem for genetic selection since genes never work in isolation: they work together in groups. How is a gene's effect on phenotype to be isolated so it can be targeted by selection?
>
> Another problem is "piggy-back" genes: selection *for* organisms with certain traits (a phenotype) will cause selection *of* genes *correlated* with those phenotypes, even if there is very little or no causal contribution of those carried along genes to the selected for phenotypes. This means that a lot of genetic variation will be "invisible" to selection. But the thesis of genetic selectionism is that genes are the ultimate target of selection.

We'll deal with two other problems for genetic selectionism in the next section, on contemporary postions. These problems are *epigenetic inheritance* [in the DST section] and *organism level selection* [in the "phenotypic and developmental plasticity" section].

Group selection. Here there are two issues: emergence and altruism.

A big question here is emergence. If groups can have functional organization in the same way individuals do, that is, if groups can be emergent individuals, then groups can also be "vehicles" for selection. For example, groups that cooperate better may have out-reproduced those which did not.

With co-operation, we get lots of debates about *altruism* here. Some see it as the key to groups functioning as emergent individuals and hence allowing for group selection.

But the gene-centered folks talk about "kin selection": If you sacrifice yourself for a kin, at least part of your genotype, the "altruistic" part that determines or at least influences self-sacrifice and that is [probably] shared with that kin, is passed on.

On the other hand, the organism folks talk about "inclusive fitness," which is individual fitness plus the effect the organism's behavior has on other organisms' fitness.

> Dominique Homberger writes: "Altruism has rarely anything to do with the macho notion of "self-sacrifice". Some biologists maintain that what we call altruism is actually fairly common and can be seen in motherly (of fatherly) behavior towards offspring and young animals in general (adoption and even trans-specific adoptions of deserted youngsters are observed fairly regularly, and herding animals can be seen eating side by side (in contrast to hummingbirds who will chase away other hummingbirds from a feeder even if they themselves cannot eaten more). Most animals are to some degree social beings and as such, they feel good about pleasant interactions (e.g., reproduction, raising young, playing, feeling safe in company, etc.). Altruism, of course, is very important for the survival of highly social animals, such as social insects, naked moles, hyraxes, prairie dogs, and most of all human beings. Given their very precarious anatomy and physiology, human beings are very vulnerable as individuals (i.e., without tools and alone by themselves, human beings are unlikely to survive for very long in any truly wild environment). For human beings, hence, becoming one of the most "successful" species was possible only because of their highly developed social skills and altruistic interactions, which have been documented early on, such as the presence of handicapped and chronically sick individuals in graves of Neanderthals."

There's a lot to talk about in altruism and co-operation with Kropotkin and political physiology and naturalism. We'll come back to these in the third lecture.

ADAPTATION

Probably the most famous critique of *complete* adaptationism is Gould and Lewontin's "Spandrels of San Marco" article: some traits we see today were never selected for, but are just the accidental product of other selected traits.

In general, the "genealogical" strain in philosophy (Nietzsche, Foucault, Deleuze) would say that the current function of something is no absolute or foolproof clue to its origin, or in other words, that a structure can assume different functions over the course of its history, as it is subsumed in different "assemblages." This would hold for both biological and social history according to these thinkers. (In our talk about "genealogy," it is important to distinguish "function" (i.e., property) of a structure from the "biological role" of a structure within a natural environment. IOW, "functions" are relational, not substantial.

My colleague Dominique Homberger confirms the prior existence of this idea in biology. She writes “It is actually known under the concept of *Funktionswechsel*, which was formulated first by Anton Dohrn in 1881 and which states that evolutionary changes of particular structures always entail changes of function.”

However, another colleague, Vince LiCata reminds us to be cautious here. While the phenomenon of spandrels certainly occurs at many levels of biological organization, we should not unlink current function from origin *in general*, since all life forms are so strongly related that using current function as a clue to origin has been very successful in many, many cases. Thus we have to remember that Gould and Lewontin’s argument carries only against rampant or complete adaptationism, not adaptationism *per se*. (We also have to remember the debates about the role such a complete adaptationism plays in Gould and Lewontin’s *bête noir*, Evolutionary Psychology.)

NICHE-CONSTRUCTION AND "CO-EVOLUTION"

In all these adaptation debates there are also very interesting questions about “niche construction.” The theory of niche-construction proposes that an organism does not passively submit to the pressures of a pre-existing environment, but actively constructs its niche: its own activity will change the environment and hence affect the selection pressure. The notion of “niche construction” is closely related to the notion of “co-evolution” in which the activity of one species will affect the fitness of another species, and vice versa. The two (or more!) species then “co-evolve.” The simplest example of this is the “arms race” of predator-prey, but there are other modes of co-evolution.

CONTEMPORARY CRITICAL STANCES

STANDARD POSITIONS

ULTRA-DARWINISTS

Dawkins / Dennett / EO Wilson (sociobiology) / Pinker (Evolutionary Psychology). We have dealt with this in the above treatment of genetic selectionism.

EVO-DEVO

We spoke of this yesterday. To recap: evo-devo is the study of molecular development and its evolution. A big discovery is homeotic genes. These structure development, acting as genetic switches controlling transcription factors regulating gene expression (turning them on and off). They are essential in body plans. They are expressed in the order in which they are found in the chromosome and they control body segmentation, for instance. 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. 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.

Evo-devo is still gene-centered. Let's move beyond the gene. First stop: the organism and its developmental plasticity.

CRITICAL POSITIONS

DEVO-EVO
DEVELOPMENTAL / PHENOTYPIC PLASTICITY

Mary Jane West-Eberhard, *Developmental Plasticity and Evolution* (Oxford, 2003). West-Eberhard calls her work "developmental evolutionary biology," which we can call "devo-evo."

Evo-devo to date has a genetic / molecular focus: how have regulatory gene networks evolved? But what about the organism? After all, there are many ways to skin the developmental cat: organisms are plastic, meaning that they can produce many different phenotypic expressions in response to different environments even with same genetic makeup. In other words, development is *flexible*. But it is also *robust*: even with different genetic makeup, organisms still follow similar developmental pathways.

Now evo-devo found that large parts of the genome are conserved over vast periods of time and shared by widely divergent phyla. So if diverse organisms share genes, what is the source of their diversity? The answer is different developmental networks that change the pattern of expression of the genes. But how do those different developmental networks evolve?

W-E proposes that genetic control mechanisms can be exposed to selection by the phenotypic adaptation of organisms to new kinds of environment. For her, this phenotypic adaptation, what she calls "plasticity," ultimately drives evolution.

W-E has three points to make:

1. Environmental induction is a major initiator of evolutionary change (genes are followers, not leaders.)
2. Evolutionary novelties result from reorganization of preexisting phenotypes and incorporation of environmental elements (novel traits are not de novo results of mutation).
3. Phenotypic plasticity can facilitate evolution by immediate accommodation and exaggeration of change (phenotypic plasticity is not mere noise obscuring genetic patterns).

In other words, DPE is a book on developmental evolutionary biology – that is, evolutionary biology with reference to development – thus paying attention to "variation and selection w/in populations, speciation, developmental plasticity, and the origin of behavioral, physiological and life history traits." Rather than evo-devo as developmental biology with an evolutionary reference, that is, concerned with "regulatory genes, body plans and morphology, as seen in a few model organisms."

> For W-E, there is a restricted sense of development today: lab science (marriage of embryology and molecular biology) where development means "gene expression and tissue differentiation, primarily during early development, and primarily in multicellular organisms." For W-E, development must include "the ontogeny of all aspects of the phenotype, at all levels of organization, and in all organisms." Thus we have to look to "the environment as agent of development, not just selection, in the evolution of all forms of life."

W-E does not deny NS, but claims it will favor the spread of a particular environmentally-induced phenotypic variant when it has positive effects on individual fitness, that is, when it is adaptive.

Now you may want me to stop right here, because this sounds Lamarckian. It's not though, W-E emphasizes, because there is no direct influence of environment on genotype. In other words, Lamarck thought that adaptive phenotypic changes were the source of variants that could be inherited (in contemporary terms, adaptive phenotypic changes produce genetic variation). But that's not West-Eberhard's scheme. What she says is that some adaptive phenotypic change is the result of developmental plasticity calling upon previously hidden, i.e., unexpressed, genetic variation. In other words, neither the phenotype nor the environment produces genetic variation.

> The key concept for West-Eberhard is "genetic accommodation."
>
> The process goes like this: a new phenotype develops (developmental plasticity) by being induced via a genetic mutation or an environmental difference. What has happened here

is that the new environment has brought forth an untapped potential of the pre-existing genetic variation.

This is a key assumption of W-E's argument: unexpressed genetic variation that was previously screened from selection by developmental robustness, that is, the fact that there are many genetic pathways to the same phenotypic expression. It makes sense given our previous discussion that not all genetic variation is expressed; remember that genetic expression depends on cellular / environmental conditions. We have to also remember that such unexpressed genetic variation can be inherited, but that's okay, given gene interaction and piggy-back genes: lots of genes can get inherited without being selected for – this is only a problem for gene selectionists.

The key and controversial assumption is that this new phenotype is adaptive. The notion of adaptive phenotypic accommodation is called the "two-legged goat effect" from the example of a goat born with two legs which changed lots of things in its phenotype to survive to reproductive age (though it didn't, in fact, reproduce). The principle is that organisms can adaptively change in response to mutations or environmental changes, and that these adaptive changes can become genetically accommodated (again, this sounds Lamarckian, but really isn't).

This change in phenotype creates new selection pressures (because selection is all about interaction of phenotypes; remember, genetic changes simply keep track of real world interactions). The new phenotype starts to spread (as long as, in the case of environmentally induced change, the new environmental conditions reliably recur).

Then the new selection pressures go to work on the regulatory gene networks of the pre-existing unexpressed genetic variation (this is why it's not Lamarckian). The new selection pressures can cause the spread of phenotypes which rely upon the expression of the previously unexpressed genes, so that it (the new phenotype) can eventually become a fixed expression (that is, the regulatory gene networks can be selected for), even when the original environmental novelty is no longer present. If the trait appears without recurrence of the environmental stimulus, there is "genetic assimilation" (going back to Waddington's work). "Genetic accommodation" is the general case in which the trait appears with or without the environmental stimulus. If it occurs only with the environmental stimulus, it's said to be an "environmentally sensitive" trait expression. In this latter case, what gets selected for is, conservatively speaking, the regulatory gene network, or, radically speaking, the life cycle that includes the extended network encompassing the recurrent environmental stimulus and the regulatory gene network.

So, to recap, when an adaptive phenotypic change has a genetic component, the regulator gene networks (or more radically, the life cyle) for this adaptive phenotypic variant (gene networks that were only "virtual," that is, only potentials of the pre-existing but unexpressed genetic variation) will now be selected (if the environmental change reliably recurs), so these gene networks are thus "followers", as opposed to "leaders" in evolution. Instead of being the sole causal factors, they are often just "bookkeeping."

DEVOLOPMENTAL SYSTEMS THEORY (DST)

Anti-genetic determinism: the "parity principle" of DST states that there are *multiple developmental resources of which DNA is only one*. Genes are certainly important, but they are immanent parts of networks.

> No one has ever upheld an absolute determinist position if by that one means epigenetic conditions have no influence whatsoever, that they are determined the way a stone is determined to fall by gravity. The real target of critique is what Susan Oyama and the DST crowd call "interactionism," that is, the idea that there are two classes of developmental resources, genetic and epigenetic, and that genes provide the information or blue-print or plan or program, and that the epigenetic resources are the materials or background upon which or in which genes act. The real question is locus of control rather than absolute determination. Thus the DST critical position is to uphold a "parity thesis" in which genes are considered one among many developmental resources; they are an important, indeed essential, part of a developmental process, but they are immanent to the process and cannot be said to "control" it in any transcendent way. At stake is a deep question of "political physiology."
>
> A crucial point is "information." Oyama holds that the idea the DNA contains pre-existing information as bundles of physically encoded meaning able to direct development is false; instead, "information" has to be seen as a process (in-formation:) in which the direction of developmental stages emerges in that very process. Thus the title of her book, *The Ontogeny of Information*. Francisco Varela expresses this idea with the phrase "laying down a path in walking." We can consult Simondon in *L'Individu et sa genèse physico-biologique* for in-formation as a process vs information as a unit.

DST proposes *the life cycle* as at least one of the units of selection (pluralist position) or as the unit of selection (strong position). They are also big proponents of niche-construction as providing a robust sense of extra-somatic inheritance (i.e., epigenetic inheritance very widely construed).

With the emphasis on *niche-construction* as part of epigenetic inheritance, DST brings ecology into direct relation with development and with evolution, that is, with evo-devo and devo-evo. We might even call a DST and devo-evo synthesis "eco-devo-evo."

> Many practicing biologists reject the DST position as unworkable, as getting too close to an unmanageable holism -- where do you draw the line once you're extra-somatic? Sure, in principle, the entire universe is reflected in each Whiteheadean "organism" or Leibnizian monad, but you can't do science that way -- science is about extracting a few factors and measuring their interaction as dependent and independent variables. So a key question is: is DST "just philosophy"? Or can you operationalize it, render it scientific? Can you form testable hypotheses from it? The DST people will point to already ongoing research projects following their principles.

Some key DST books: Richard Lewontin: *The Triple Helix* (niche-construction); Susan Oyama: *The Ontogeny of Information* (multiple developmental resources); Jablonka and Lamb: *Evolution in Four Dimensions* (genetic, epigenetic, behavioral, symbolic inheritance).

AUTOPOIESIS / ENACTION

Maturana and Varela. Combined with DST in Evan Thompson, *Mind in Life* (Harvard, 2007). Sense-making. Autonomous systems. Jonas / Spinoza connection.

Varela is perhaps best known for his early collaboration with Humberto Maturana in developing the concept of autopoiesis. This work, published in Spanish in 1973, and made known to the Anglophone community by a 1974 article and then by a 1980 monograph, is a classic of "second-order" or "neo" cybernetics. In our terms, it is marked by a notion of "synchronic emergence," which is conducted in static part / whole terms. The concept of autopoiesis was developed to provide a horizon of unity for thinking living entities, rather than the haphazard empiricism of the "list of properties" model usually adopted ("reproduction, metabolism, growth …"). In other words, Maturana and Varela were trying to isolate an essence of life, an essence which would provide a viewpoint on life that is "history independent" (Varela, Maturana and Uribe 1974: 187).

To produce the concept of the essence of life, Varela and his colleagues distinguish organization (essence) and structure (historical accident). Organization is the set of all possible relationships of the autopoietic processes of an organism; it thus forms the autopoietic 'space' of that organism (Maturana and Varela 1980: 88 [scare quotes in original]). Structure is that selection from the organizational set that is actually at work at any one moment (Maturana and Varela 1980: xx, 77, 137-38; see also Hayles 1999: 138 and Rudrauf et al, 2003: 31). Changes in the environment with which the system interacts are known as "perturbations" of the system. The system interacts only with those events with which it has an "interest" in interacting, that is, those events that are relevant to its continued maintenance of autopoietic organization (e.g., nutrients). These events of interaction form a process of "structural coupling" that leads to structural changes in the system. These changes, as reactions to the perturbation, either re-establish the baseline state of the system (they re-establish the homeostasis of the system) or result in the destruction of the system qua living (Maturana and Varela 1980: 81). Homeostatic restoration thus results in conservation of autopoietic organization. From this essentialist viewpoint, the origin of life must be a leap into another register, a *metabasis eis allo genos* ("the establishment of an autopoietic system cannot be a gradual process; either a system is an autopoietic system or it is not" [Maturana and Varela 1980: 94]). From the autopoietic perspective, questions of diachronic emergence have to be thought in terms of "natural drift," whose relation to autopoietic essential organization is problematic, as we will see. In any event, clearly autopoietic organization is synchronic emergence in which the whole arises from a "network of interactions of components" (Varela, Maturana and Uribe 1974: 187).

For Maturana and Varela, autonomous systems have sufficient internal complexity and feedback that "coupling" with their environment "triggers" internally-directed action. This means that only those external environmental differences capable of being sensed and made sense of by an autonomous system can be said to exist for that system, can be said to make up the world of that

system (Maturana and Varela 1980: 119). The positing of a causal relation between external and internal events is only possible from the perspective of an "observer," a system that itself must be capable of sensing and making sense of such events in its environment (81).

The biological basis of the judgments "good" and "bad." This basic value polarity is well noted in affective neuroscience, and is in fact grounded in basic organic capacities for affective cognition. Witness the single-celled organism's ability to make sense. "Sense" has, perhaps fittingly, a three-fold sense: sensibility, signification, and direction. (There is an archaic sense of the English word "sense" meaning "direction," as in "the sense of the river." This sense is still present in French, as in, among other uses, the expression sens unique for "one-way street.")

A single-celled organism can sense food gradients (it possesses sensibility as openness to the environment), can make sense of this difference in terms of its own needs (it can establish the signification "good" or "bad"), and can turn itself in the right sense for addressing its needs (it orients itself in the right direction of movement). This fundamental biological property of sense-making is one reason why the Cartesian distinction of mental and material has no purchase in discussions of sense-making. There is no "mental" property (in the sense of full-blown reflective consciousness) attributable to the single-celled organism, but since there is spontaneous and autonomous sense-making, there is no purely "material" realm either in these organisms either. Affective cognition in humans is simply a development of this basic biological capacity of sense-making.

PROCESS STRUCTURALISM

Goodwin, Kauffman: self-organizing physical processes in development (morphogenesis) constrain NS by providing another source of order. Key notion is a phase space of body plans and organ development. Much of it is off-limits due to constraints imposed by self-organizing physical processes.

> Kauffman also talks about the properties of regulatory gene networks for cell differentiation (DeLanda ISVP 54-55). K can predict surrounding transformation space for any one cell based on its history / neighborhood by looking at nearby attractors in gene network model. Note that DeLanda overestimates the "open space" for evolution this creates (58).

SERIAL ENDOSYMBIOSIS

Macro-evolution: Margulis: mutation not the only source of creativity / innovation in evolution. The most important source is symbiosis. Most famous example: Mitochondria as previously independent aerobic bacteria engulfed by anaerobic (proto-nucleated) bacteria. Needed because of the "oxygen holocaust" produced by spread of blue-green algae which produced oxygen as by-product of their metabolism. Oxygen is highly corrosive: it combines with anything and "burns" it. The ingested aerobic bacterium received nutrients from the host while the host received energy from the aerobic activity of the bacterium. Symbiosis short-circuits the strict Darwinist doctrine of mutation and selection of slight adaptations.