Developmental Systems Theory and Beyond

Review

- Genic selection: the real story of evolution is told at the gene level
  - Genes are replicators and as such they compete to replicate
  - Use organisms as their interactors
  - Account for all evolutionary processes in terms of changes in gene frequency
- Weaker version of genic selection: bookkeeping only

Challenge: so, what again is a gene?

- **Evolutionary gene concept**: any reasonable short piece of DNA that is potentially immortal—will pass on copies of itself
- What about single nucleotides?
  - Dawkins—too short
  - Must have a phenotypic effect
  - That is to surrender the **evolutionary gene concept**
- How to spell out phenotypic effect?
  - **Molecular gene concept** —structure that gets expressed
  - **Functional gene concept** —difference makers

Problems with the Molecular Gene Concept

- Challenge—avoid cutting too finely so that each nucleotide becomes a gene
- But the molecular details of the gene often don't matter in terms of effects, since alternatives do just as well
  - "If we require that gene replication be robustly explained by its adaptive effects, then **it is likely that many molecular genes will be excluded**. It is not at all obvious that there is a way of formulating the notion of phenotypic effect that meets our three conditions: (1) it counts molecular genes as having phenotypic effects; (2) it excludes impostors like individual nucleotides; (3) the phenotypic effects of genes explain their replication propensity" (Sterelny and Griffiths, pp. 86-87)

Problems with the Functional Gene Concept

- Difference makers must be **context sensitive**, since in different contexts may have different effects
- Characterized in terms of the propensity, when in the right circumstances, to produce the effect
- But **will this functional role equate to any specific molecular type that forms a lineage**
  - As opposed to anything that might produce the effect
  - Objective: to be “tracking a constant underlying difference maker or set of difference makers” (p. 89).
- Further, will what it picks out be **have the same adaptive significance in all individuals**
- Faces both a conceptual and an empirical risk

If not genic selection, what then?

- Keep the focus on replicators
- What else could be a replicator?
  - Proposal: development systems

Traditional View: Bifurcate Development and Evolution

- "…when we are talking about *development* it is appropriate to emphasize non-genetic as well as genetic factors. But when we are talking about units of selection a different emphasis is called for, an emphasis on the properties of replicators. The special status of genetic factors rather than non-genetic factors is deserved for one reason only: genetic factors replicate themselves, blemishes and all, but non-genetic factors do not" (Dawkins 1982, pp. 98-99)

How special are genes?

Major part of the case for DST is a case against genes

- Program metaphor: genes are supposed to carry the information that specifies what traits an organism will have
- On their own, however, genes have limited power
  - They need enzymes just to replicate
- But are genes **in control** of the process?
  - As computer programs control what happens in a computer?

Key Claims of DST

- Emphasize the relevance of development to evolution
- Emphasize the evolutionary potential of extra-genetic inheritance

- "The fundamental unit that undergoes natural selection is neither the individual gene nor the phenotype, but the **life cycle generated through the interaction of a developing organism with its environment**." (Griffiths and Gray)

What is inherited?

- More than just genes:
  - Membranes that serve as templates for forming more membranes
  - Organelles such as mitochondria, including their DNA
  - System for gene expression
  - A physical environment?
  - A social environment?
  - Skills and information that are learned?

Environmental Dependencies

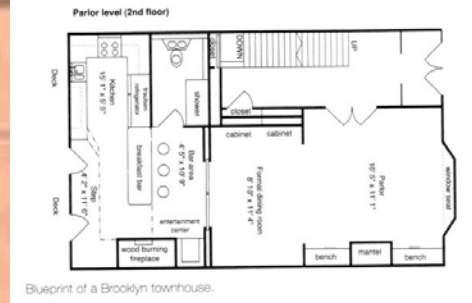
- Seeds of many eucalypt species require scorching by a bushfire in order to geminate.
  - Eucalypts help maintain the occurrence of brushfires by creating forests scattered with resinous litter and hung with bark ribbons which are carried aloft by the updraft as blazing torches and spread the fire to new areas

- "DST applies the concept of **inheritance** to any **resource that is reliably present in successive generations**, and is part of the explanation of why each generation resembles the last." (Griffiths and Gray)

Inheritance outside the organism

- Some aphid species pass on their endosymbiotic *Buchnera* bacteria to either the eggs or developing embryo.
  - The bacteria enable their aphid hosts to utilize what would otherwise be nutritionally unsuitable host plants.
- Treating aphids with antibiotics to eliminate the bacteria results in stunted growth, sterility, and early death
- Inheriting the bacteria is clearly advantageous

Genes and Information



Blueprint of a Brooklyn townhouse.

- Genes often privileged as carrying the **information** that specifies development
  - "DNA is the medium, not the message. A gene is not a DNA molecule; it is the transcribable information coded by the molecule. . . . The gene is a packet of information, not an object" (Williams, 1992, p. 11)
- Compare: blueprint and the building
  - Blueprint doesn't specify the actual materials, but the specifications they must satisfy
  - To build the building, must actually provide the materials
  - Can ask at the end—did the building satisfy the specifications in the blueprints

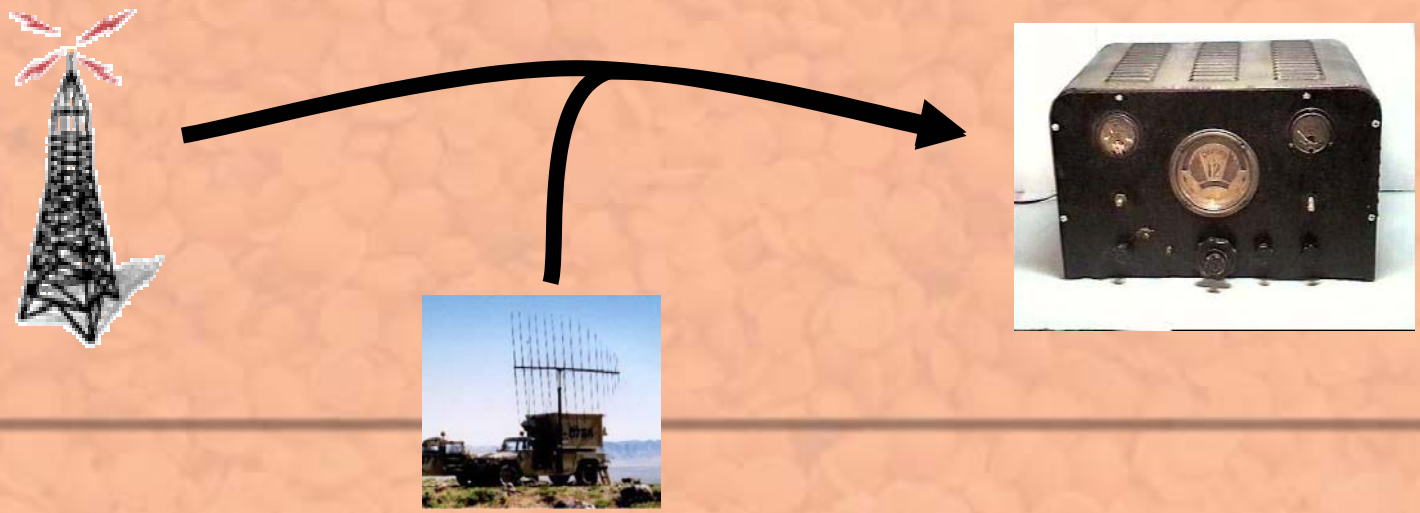
Two Senses of Information

- Mathematical information theory: **causal transmission** over a channel
- Intentional information: information ***about*** something (e.g., proteins)
  - Now it makes sense to speak of *mis*interpreting

- Does either explicate the special role of genes?

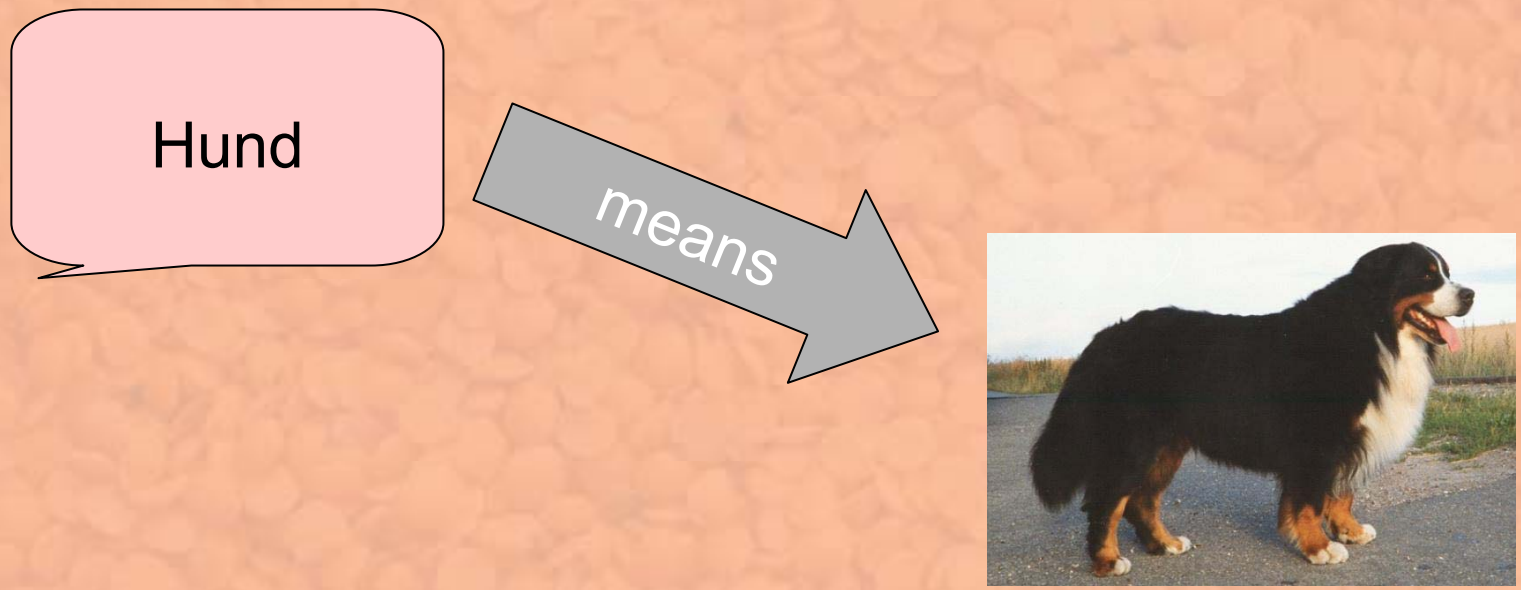
The genetic code as *information*

- In the information theory sense, a signal carries information when the state at the receiving end is correlated to the state at the sending end
  - Channel conditions affect transmission accuracy
- But source and channel conditions can be reversed so that the signal is about channel conditions instead



Intentional Information

- Information theory sense of information does not differentiate genes and channel conditions
- Does the intentional sense of information fare better?



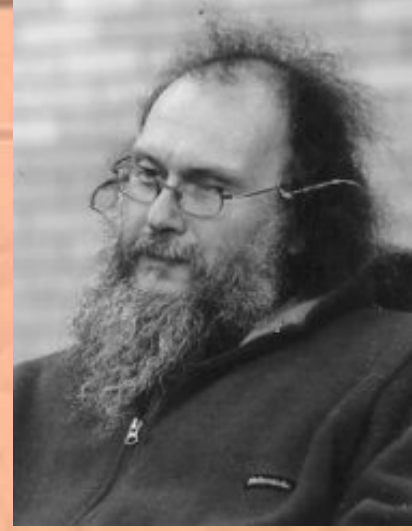
Teleosemantics and Genes

- Challenge in psychology: naturalize the sense in which languages and thoughts are intentional—specify a content
  - Teleosemantics: naturalize the content of a representation in terms of its selection history
    - “Hund” means dog because it was selected for its relation to its referent
- Genes as structures specifying a polypeptide chain are arguably selected because they designate that chain
- But so are the various other factors that help determine the trait
- Genes are not special!

DST's Positive Story: Organisms as Replicators

- "for all their biological importance, genes do not form a special class of 'master molecules' different in kind from any other developmental factor. Rather than replicators passing from one generation to the next and then building interactors, **the entire developmental process reconstructs** itself from one generation to the next via numerous interdependent causal pathways" (Sterelny and Griffiths, p. 95)

Gene Selection Fights Back



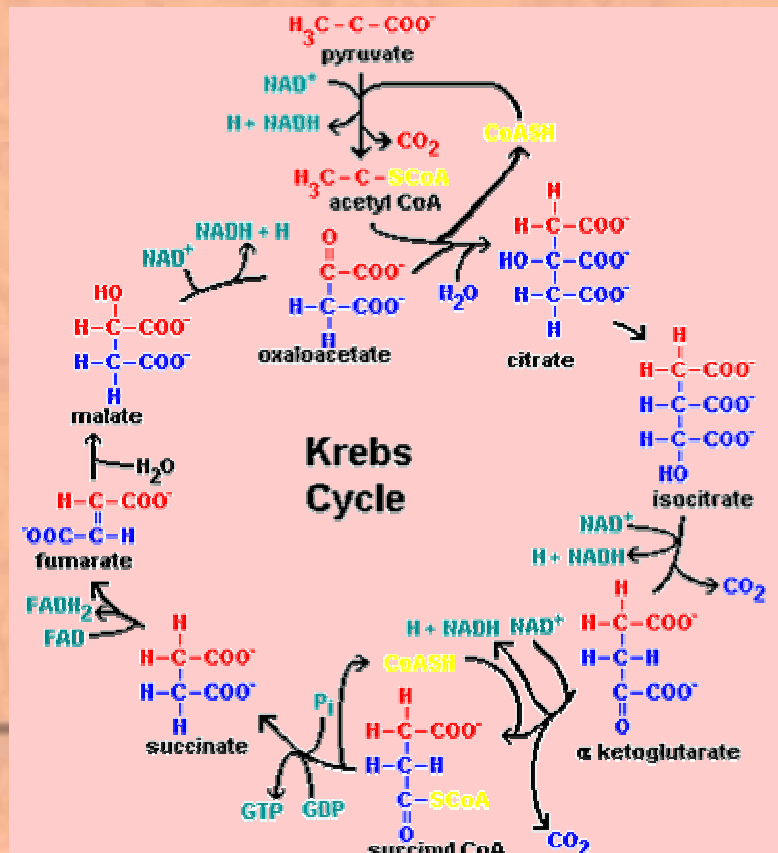
- OK, so you guys are right that more is involved than just genes, but we don't have to get all holistic and fuzzy.
  - Replicators do play a privileged role because they are designed to be copying mechanisms
  - Hold on to replicators, but recognize that they may be a bit more complex than we first thought
  - Extended replicators—incorporate extragenic copying mechanisms
- Having your cake and eating it?

Interactionist Consensus

- “it is universally accepted that all biological taits develops as a result of the interaction of genetic and nongenetic factors.
  - But perhaps some traits depend more on genes and less on the environment. It is now common to read that homosexuality, for example, is ‘substantially genetic,’ or that schizophrenia may be ‘partly genetic’. (Sterelny and Griffiths, p. 98)
- Heritability, as measured in terms of amount of variance explained, does not mean genetically controlled
- “In the interactionist view, genes are ‘context-sensitive difference makers” (p. 99).

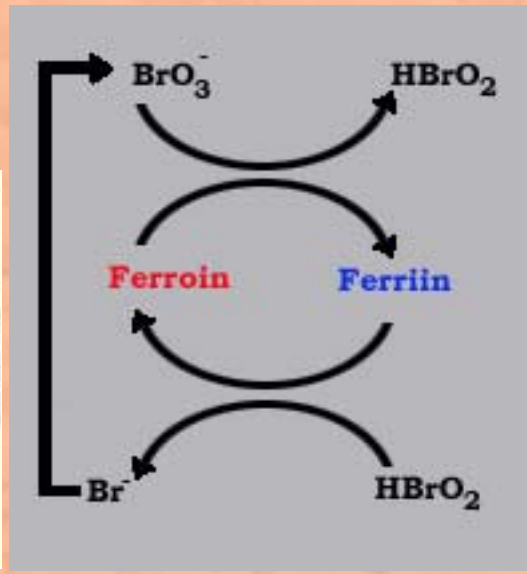
Beyond Interactionism?

- The dominance of linear models:
  - Contribution of x and y = x + y
  - Components organized serially
- But in biology
  - Cycles are common
  - Interactions are non-linear
- Cyclic organization
  - Negative feedback
  - Positive feedback
    - Autocatalytic loops
    - Self-organizing system



Start with self-organization

- Reactions such as the B-Z reaction are suggestive of how systems can self-organize and produce complex patterns



- Key elements—non-linear interactions and positive feedback
- But:
  - Require constant supply of energy
  - Is extremely dependent on boundary conditions

Autopoietic mechanisms

- "An **autopoietic machine** is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that **produces the components** which:
  - (i) through their interactions and transformations **continuously regenerate and realize** the network of processes (relations) that produced them; and
  - (ii) constitute it (the machine) as a concrete entity in the space in which they (the components) exist by **specifying the topological domain of its realization** as such a network."

Maturana & Varela (1973, pp. 78-79)

Cyclic organization: A key feature

- Needed so that the system can control its own autopoietic processes—guide the flow of energy through the system so as to generate its own components as needed
  - Kauffman: “Constraint begets work begets constraint”
  - Specific components of the system dynamically constrain other components within the system
  - Tap specific endogonic reactions as needed to support other energy consuming activities

Tibor Gánti's Chemoton

Stoichiometric coupling of three sub-systems:

a. Metabolic (A_1-$A_{5)}$ cycle which generates substances for itself and other systems
b. Membrane (boundary maintenance system) which is selective permeable
c. Control system: template consolidation system

Chemoton is self-regulating and capable of reproducing itself

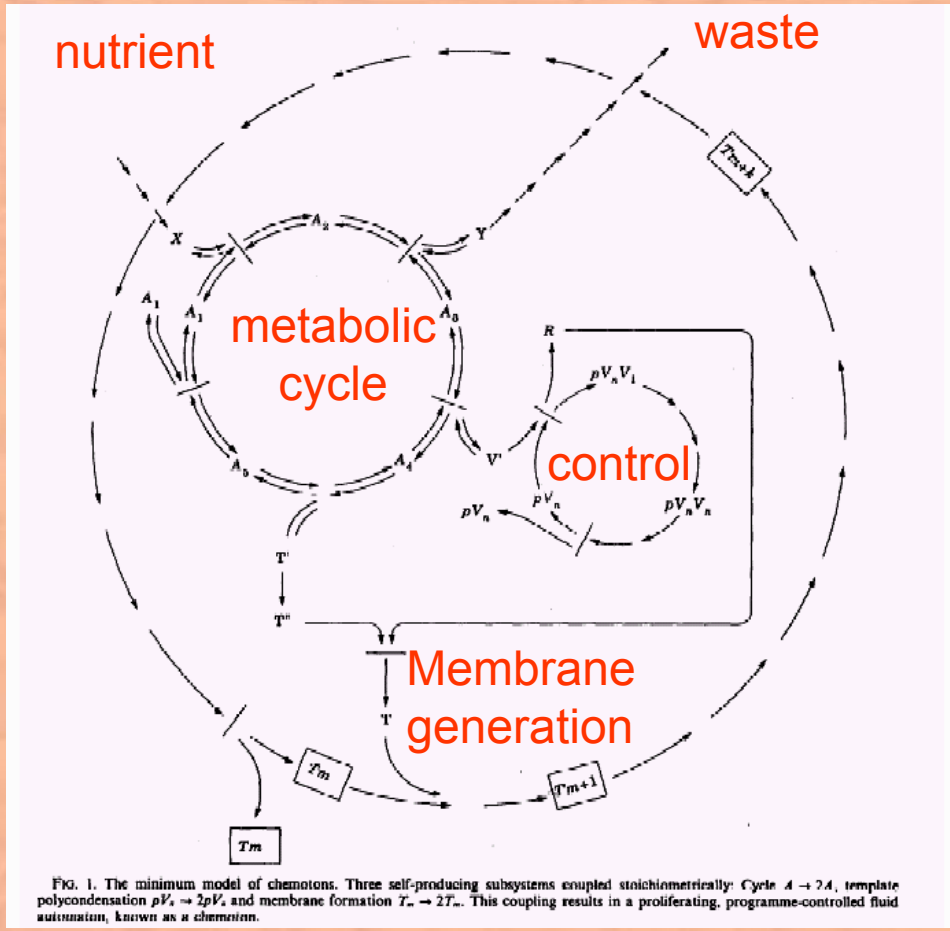


FIG. 1. The minimum model of chemotons. Three self-producing subsystems coupled stoichiometrically: Cycle $A \rightarrow 2A$, template polycondensation $pV_n \rightarrow 2pV_n$ and membrane formation $T_m \rightarrow 2T_m$. This coupling results in a proliferating, programme-controlled fluid automaton, known as a *chemoton*.

Autonomous systems

- “a far-from-equilibrium system that constitutes and maintains itself establishing an organizational identity of its own, a functionally integrated (homeostatic and active) unit based on a set of endergonic-exergonic couplings between internal self-constructing processes, as well as with other processes of interaction with its environment”

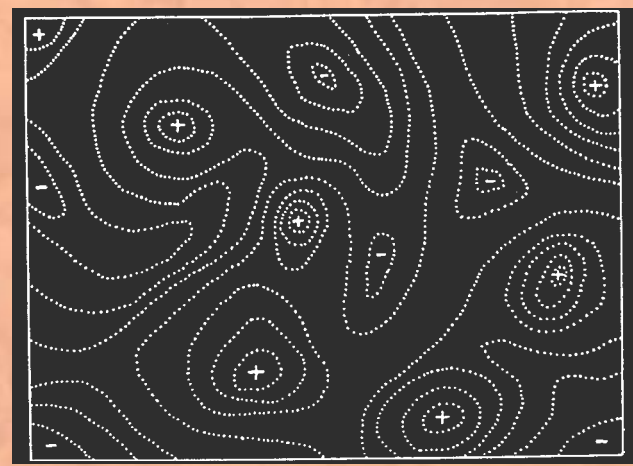
  Kepa Ruiz-Mirazo, Juli Peretó and Alvaro Moreno, A Universal Definition Of Life: Autonomy And Open-ended Evolution

Higher level units of evolution

- If organisms are in part self-organizing autopoietic dynamical systems, then what is built up in development is much more than a specification of what is in the genes
- In a strong sense, individual cells or individual organisms may be the basic unit on which selection works
- But even this may be too low a level to tell the story—if living systems engage their environment non-linearly

Adaptation and Niches

- Received view is that niches exist and organisms adapt to fit them (as a key to a lock)
- Lewontin: organisms and niches co-constructing and co-defining
- As organisms climb a hill in a fitness landscape, they change the landscape itself: construct the niche at the same time as they are constructing themselves
- Fitness landscape continuously changing as organisms develop in it



Example: Beaver Dams

- Beavers create a different environment then they encounter
- The environment in which they are being selected is in part the product of their own activity
- Selection not simply an external force operating on replicators or interactors