Reductionist and Emergentist Approaches to the Origin of Life

- Waters has argued that in order to reduce Mendelian genetics to molecular genetics, the synthesis has to be broadened to include the origin of life. More recently Rosenberg in *Darwinian Reductionism* admits that to refute Mayr's autonomy stance it is necessary to ground natural selection in the chemical and physical selection that would have occurred during the origin of life. Hence, though not admitted by Rosenberg, the reductionist program has to embrace an emergentist account of the origin of life.
- Emergentist accounts draw upon the newly developing sciences of complex systems dynamics. Such accounts, such as those of Wicken, Kauffman, Morowitz, Deamer, Deacon, Weber, Luisi, et al. are beginning to address the hard problem of the emergence of life but conceptually to explore how these insights could be incorporated into a New Modern Evolutionary Synthesis.

The Hierarchic Logic of Emergence

- First-Order Emergence: Supervenience, synchronic, macro/micro, example – wave propagation in a fluid

- Second-Order Emergence: Self-assembly, self-organization diachronic, examples – snow flakes, chemical dissipative structures (BZ reaction)

- Third-Order Emergence: Evolution and Semiosis, diachronic with biasing across iterations or generations,

  examples -- biological development and evolution, "self-referential, self-organization, an autopoiesis of autopoises"

- "So life, even in its simplest forms, is third-order emergent. This is why its products cannot be fully understood apart from either historical or functional concerns."

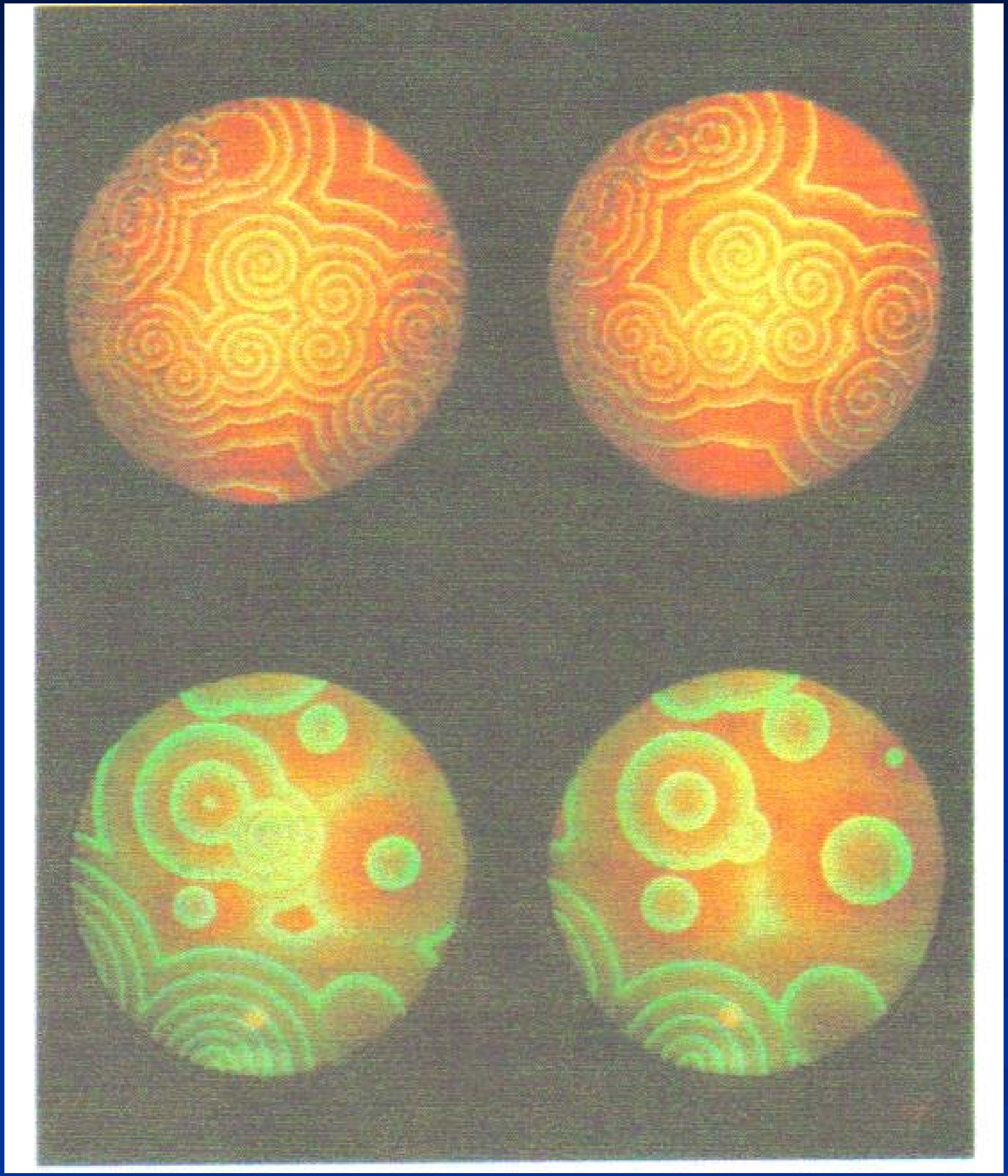
  T. Deacon (2003) in *Evolution and Learning*, B. Weber & D. Depew (eds), MIT Press, pp. 273-308.

- We might then imagine the emergence of life as a transition from second-order to third-order emergence in a complex chemical system under the right initial and boundary conditions.

Self-Organization as a Phenomenon

- **Many lines of empirical evidence demonstrate that SO is a continuing feature of cellular organization and not just a mathematical concept (Misteli [2001] *J.Cell Biol.* 155: 181-185).**
- **Patterns of cellular and subcellular order and complexity reflect constraints of chemistry and natural laws (including those being studied by complex systems dynamics) (Denton, Marshall & Legge [2002] *J. Theor. Biol.* 219: 325-342; Denton, Dearden & Sowerby [2003] *BioSystems* 71: 297-3030.**
- **In sufficiently complex systems, self-organization and selection are mutually entailing processes that work together in a parallel and distributive manner to produce emergent macroscopic organization and phenomena (Depew & Weber [1995] *Darwinism Evolving*, MIT Press; Weber & Deacon [2000] *Cybernetics and Human Knowing* 7: 21-43).**

The Belousov-Zhabotinsky Reaction



Serial Assembly of Perfected Parts is not Efficient (Or, the Importance of the Whole)

- **To design a processor (of 40 million components) it is more efficacious to have the components combined in an even minimally functional pattern than to assemble them from perfect components. A barely functioning crude whole can then have less reliable subsystems altered, removed and replaced, to improve overall function. Up to half the components in such a system can be significantly imperfect yet the system as a whole can function reliably (Challet & Johnson [2002] *Physical Review Letters* 89: 028701).**
- **With complexity comes redundancy and parallelism that can give functionality and with functionality comes pressure for improved components over time; this initial organization can be engineered in artifactual systems or arise by self-organization in natural systems (Weber & Depew [2004] in *Debating Design*, Cambridge University Press).**
- **In engineering complex systems the engineer can either work with existing self-organization or make self-organization part of the design. Self-organization and emergence are now a part of engineering (Ottino [2004] *Science* 427: 329).**
- ***The whole is defined by closure conditions: physical closure (osmotic barrier) and chemical closure (catalytic closure).***

Kauffman's Model for the Origin of Life

- Protein sequence space can be described by an NK model.
- This space can be mapped onto a catalytic-task space.
- There will be a relatively large sphere of sequences that can to some degree catalyze a given reaction.
- Such ensembles of catalytic peptides can participate in autocatalytic cycles.
- As the ensemble of such activities becomes more complex at some point catalytic closure will occur.
- Such ensembles can grow and reproduce even in the absence of central templates coding for catalysts.
- Variation in the polymer sequences explores catalytic-task space and there can be selection for catalytic efficiency.
- However, when templates emerge they stabilize information about more efficient catalysts.

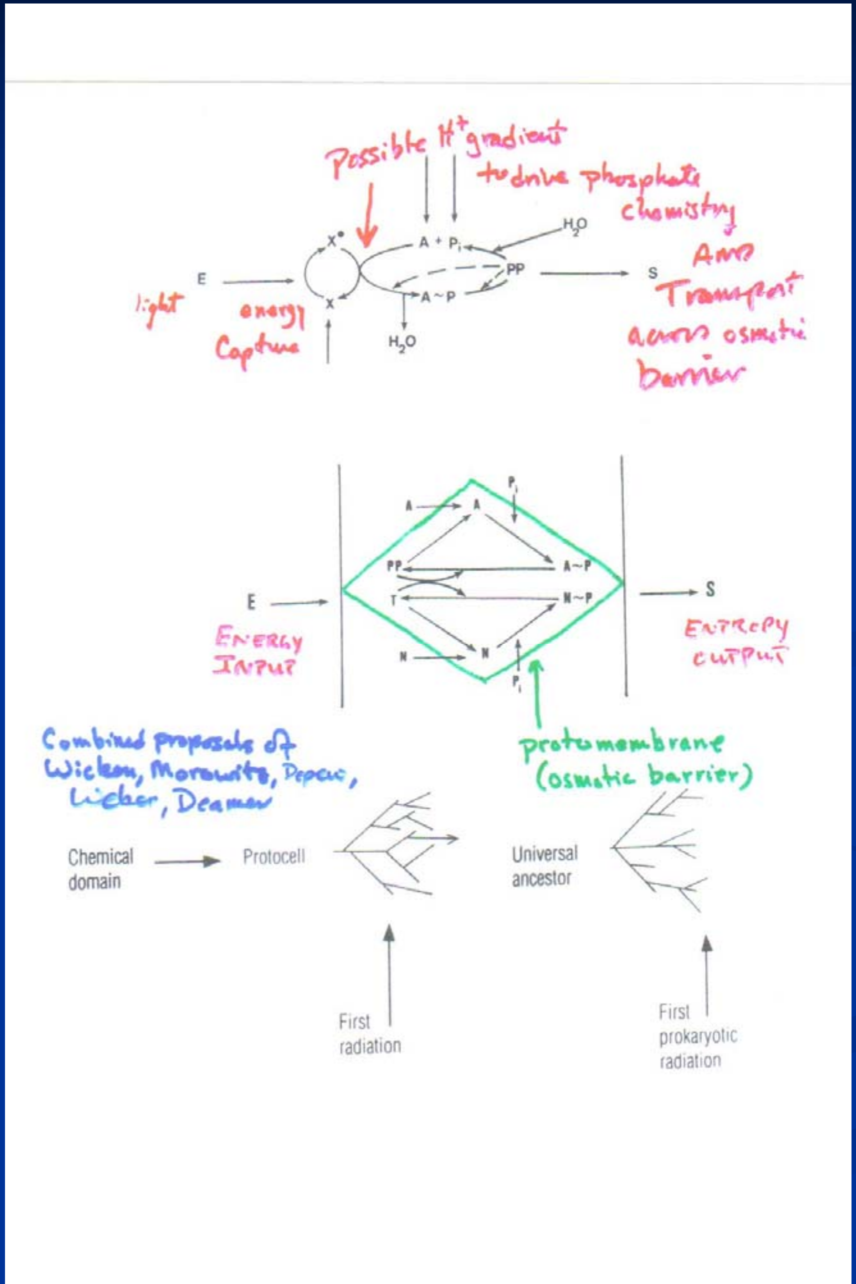
Kauffman on Origin of Life

- “We can think of the origin of life as an expected *emergent collective property* of a modestly complex mixture of catalytic polymers … which catalyze one another’s formation. I believe that the origin of life was not an enormously improbably event, but law-like and governed by new principles of self-organization in complex webs of catalysts. Such a view has many implications. Among them, the template-replicating properties of DNA and RNA are not essential to life itself (although these properties are now essential to *our* life). The fundamental order lies deeper, the routes to life are broader.”
- Stuart Kauffman (1993) *The Origins of Order: Self-Organization and Selection in Evolution*, p. xvi, emphases in original.

Transitions from Nonliving to Living Matter

- **David Deamer and Pier Luisi each have demonstrated production of lipids through photochemical reactions. Spontaneously forming vesicles used light energy also to synthesize self-replicating RNA from precursor nucleotides. Luisi further demonstrated polymerization of amino acids to proteins on the vesicle surface. Martin Hanczyc showed catalysis of vesicle formation by encapsulated clay as well as RNA polymerization (Rasmussen et al. [2004] *Science* 303: 963-965).**
- **Though thermodynamics provides the driving force for self-organization in complex chemical systems, it is the kinetic mechanisms that afford the pathways of emergence. In the transition to living systems there is a shift to an extreme expression of kinetic control in which thermodynamic requirements play a supporting rather than directing role. Replication is an instance of this extreme kinetic control. From this emerges the teleonomic character of living entities (Pross [2003] *J. Theor. Biol.* 220: 393-406).**
- **Harold Morowitz et al. view non-living chemical reactions, driven by thermodynamics, as exploring the state of space in an ergodical fashion; in contrast, living systems explore a combinatorially large space of possibilities through evolutionary processes (Rasmussen et al., *Ibid*).**

Complex Systems View of Origins



A Possible Scenario by which Life & Natural Selection Emerge

- ***Emergence of Life*** **– Ensembles of protocells are viewed as the "cradle" for the emergence of life in which mutual stabilization of 'generic' proteins & nucleic acids over time led to templating and coding. Weakly heritable analogic information about protometabolism in proteins became stabilized as digital information in nucleic acids, resulting in a chemical selection for enhanced efficiency of autocatalytic cycles of energy use and dissipation.**
- ***Emergence of Natural Selection*** **– There would be an enormous selective advantage (physical and chemical) for those entities that could "remember" information that enhances autocatalytic activity and dissipative efficiency by encoding it in RNA and later DNA. Thus natural selection of the reproductively fit would be emergent from the chemical selection of the efficient.**

Implication of Complex Systems Dynamics

In complex systems not only is the whole defined by closure conditions (physical and catalytic) but there is redundancy and parallelism. Thus even weakly incipient functional patterns of structure and interaction can persist due to greater stability and/or efficiency. With functionality comes pressure for improved structures /stability/ efficiency, through an on-going process of selection and self-organization. Thus in the origin of life, we should not expect one function to be perfected, say replication, before others appear, but that there would be an inherent holism in the process by which cellular life arose.

TAKE HOME LESSONS

- Do not expect a single narrative trajectory for the emergence of life.

- We should expect parallel distributive processes to predominate in the emergence of life.
- We should explore all possible routes of chemistry and proto-biochemistry to develop a range of plausible scenarios.
- We should not expect one function to be perfected, say replication, before others appear.
- Natural and artifactual systems should not be conflated. By anchoring emergence of life and natural selection in natural laws and processes of thermodynamics and kinetics, a conceptual wedge is driven between natural organization and design. There is no watchmaker because there is no watch.

- If there is not grandeur in this view of the emergence of life, at least there is reasonable hope for progress, through application of the tools of complex systems dynamics, towards developing a more general theory of emergence.