MAJOR EVOLUTIONARY TRANSITIONS AND CULTURAL EVOLUTION

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National Museum of Natural History
Smithsonian Institution
Outline

• Introduce Major Evolutionary Transitions
• Major Transitions in Individuality
• Nature of Individuals
• Alternative Approaches to Major Evolutionary Transitions
• Public Goods and Innovation
• Possible Implications for Cultural Evolution
Major Evolutionary Transitions

Replicating molecules → Molecules in sacks
Independent replicators → Chromosomes
RNA → DNA + protein
Prokaryotes → Eukaryotes
Protist → Cellular differentiation
Solitary individuals → Colonies
Primate societies → Human Societies (language)

From Maynard Smith & Szahmary, 1995
Major Evolutionary Transitions: Information

- After each transition previously independent individuals can only reproduce as part of a larger whole.

- These transitions involve a change in the division of labor.

- Transitions involve a change in how genetic information is transmitted.
Transitions in Individuality

• Transitions involve the emergence of cooperation among independent units, leading to a new higher-level unit.

• Transitions are associated with suppressing conflict among lower-level units.

• Emergence of new levels is contingent, not deterministic, and thus need to be explained (Griesemer, 2000; Okasha, 2005).
Evolutionary Individuals

• Traditional: spatially and temporally bounded, contiguous, physiologically discrete; genetically unique and homogeneous; division of labor between reproductive and somatic cells
  – Serve as evolutionary individuals
• Problem: most living things possess some but not all of these criteria
• Many ‘individuals’ have fuzzy boundaries
Transitions in Individuality

Focuses on suppressing conflict at lower levels and promoting cooperation

Agren, Trends Ecol. Evol 2013
## Major Transitions in Evolution and Individuality

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<thead>
<tr>
<th>From</th>
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<th>MET</th>
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*With thanks to Carl Simpson*
ALTERNATIVE VIEWS OF
MAJOR EVOLUTIONARY TRANSITIONS
Origin of Eumetazoa

Origin of Developmental Toolkit

Most signaling pathways present

Macroevolutionary lag between developmental and morphologic innovations
Invention & Innovation

- *Invention* is the creation of something new and distinct (contrast with variation on established themes)

- *Innovation* occurs when inventions become economically or ecologically significant

- *Macroevolutionary lags* emphasize the importance of this distinction

Joseph Schumpeter (1883-1950)
Alternative Views of Major Evolutionary Transitions

• Hierarchical expansion of information
• Driven by environmental drivers
• Expansion of ecospace
Alternative Views of Major Evolutionary Transitions

• Hierarchical expansion of information
• Driven by environmental drivers
• Expansion of ecospace
Simpson’s Adaptive Zones

I-IV, successive little known or unknown ancestral stages

A-E, successive known structural stages

Simpson, 1944
Niche inheritance

Next generation

$E_t$

Ecological inheritance

$E_{t+1}$

Natural selection

Niche construction

Gene pool

Populations of phenotypes

Genetic inheritance

Gene pool

Populations of phenotypes

Odling-Smee et al.
Ecosystem Engineering

Species 1
Gene pool
Genetic inheritance
Gene pool

Species 2
Gene pool
Genetic inheritance
Gene pool

\[ E_t \]
\[ E_{t+1} \]
Cambrian Ecosystem Engineering

- Archaeocyathid reefs (+)
- Sponges & other filter feeders (+)
- Burrowed sediments (+/-)
- Shelly substrates (+)
- Mesoozooplankton
Alternative Views of Major Evolutionary Transitions

• Hierarchical expansion of information
• Driven by environmental drivers
• Expansion of ecospace
• Appearance of public goods
What is a ‘Public Good’?

• Public goods are those where the use of the good does not preclude use by others (non-excludability) and the inability to prevent others from using the good (non-rivalry).

• May be local or global
Degree of Excludability

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<td>iPod</td>
<td>GPS signal</td>
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<td>low</td>
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Public Goods

Calculus
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Tragedy of the Commons
The diagram illustrates the concept of the degree of excludability and rivalry in goods. Goods are categorized into two main groups: Rivalrous and Non-rivalrous. The degree of excludability is measured on a scale from high to low.

- **Rivalrous**:
  - iPod
  - Toll Roads
  - Cable TV
  - Social/Religious clubs

- **Non-rivalrous**:
  - Club Goods
  - Fish

The diagram shows that goods with high excludability and high rivalry (iPod) are placed at the top right, while goods with low excludability and low rivalry (Fish) are placed at the bottom left. Goods with high excludability and low rivalry (Club Goods) are placed at the bottom right, indicating a transition between the two extremes.
Public/Club Goods and Major Evolutionary Transitions

- Origin of Life: sequences, replication machinery and lipid bilayers
- Early microbial life: gene sequences (HGT)
- Origin of Eukaryotes: symbionts (with ecological spillover resulting)
- Multicellularity: ecosystem engineering
Degree of Excludability

Rivalrous

- Intertidal space
- Adaptations between clades

Non-Rivalrous

- Adaptations within a clade

Positive Feedback Spillover Effects

Oxygen
REVISED “TREE” OF LIFE retains a treelike structure at the top of the eukaryotic domain and acknowledges that eukaryotes obtained mitochondria and chloroplasts from bacteria. But it also includes an extensive network of untreelike links between branches. Those links have been inserted somewhat randomly to symbolize the rampant lateral gene transfer of single or multiple genes that has always occurred between unicellular organisms. This “tree” also lacks a single cell at the root; the three major domains of life probably arose from a population of primitive cells that differed in their genes.
Gene sequences

• Network representation of vertical inheritance and lateral gene transfer among eubacteria and archaea
• Based on 539,723 protein coding genes among 181 taxa
• Infers extensive LGT
• Coding genes serve as information that has been readily transferred between lineages

Dagan & Martin, 2009, Phil. Trans R. Society B
LUCA as a diverse community

Glansdorff et al. 2008 Biology Direct
Public/Club Goods and Major Evolutionary Transitions

- Origin of Life: sequences, replication machinery and lipid bilayers
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- Origin of Eukaryotes: symbionts (with ecological spillover resulting)
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**Major Evolutionary Transitions**

- Many, and perhaps all, of the major evolutionary transitions involved the origin and spread of public goods.
- Some of these public goods involved ecological spillovers that constructed new niches for other taxa, providing positive feedback for increased diversity.
# Major Transitions in Social Evolution

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<tr>
<td>Prelinguistic culture</td>
<td>Linguistic culture</td>
</tr>
<tr>
<td>Undifferentiated cultural groups</td>
<td>‘Tribes’ (increased hierarchy and division of labor)</td>
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<td></td>
<td>Symbolic systems of information storage and transmission</td>
</tr>
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<td></td>
<td>Legal system</td>
</tr>
<tr>
<td>Protists</td>
<td>Institutionalization of science and technology</td>
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Focus on evolution of systems of information replication

*From Hodgson & Knudsen*  *Darwin’s Conjecture*
Major Transitions in Social Evolution

• Each transition generates complexity by nesting prior social adaptations within more complex structures
• Each major information transition in social evolution is accompanied by new forms of generative replicators
• Importance of ‘habits’ in the evolution of culture
Major Transitions in Social Evolution

• *Customs* as generative replicators
  – *Conditional generative mechanisms*
  – *Copied customs are similar to original*
  – *Information is transferred*
  – *As with other METs, customs require lower level functions to operate*

*From Hodgson & Knudsen, Darwin’s Conjecture*
**Key Points**

- METs involve the construction of new evolutionary individuals
- Selection happens on multiple levels: populations, species, clades,
- Multiple kinds of inheritance: genetic, epigenetic (non-DNA cellular transmission), ecologic (niche construction)

This is not ‘Universal Darwinism’ which suffers from a number of conceptual problems (not least of which is a restricted view of biological evolution)
How are new evolutionary spaces created?

- *Potentiated* by broader environmental setting (physical, genetic, ecologic)
- *Actualized* by genetic and developmental innovations leading to a new clade
- *Refined* by further developmental and ecological changes
- *Realized* as innovations by ecological expansion and evolutionary success
Evolutionary Uniformitarianism

The assumption that the evolutionary rates, mechanisms and processes that can be observed experimentally today are sufficient to explain the sweep of evolutionary patterns through geologic time.