Major Transitions in Biosphere and Anthroposphere

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We were one of the primates:
• ~ 100,000 individuals living in groups
• restricted range: E and S Africa

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How did we get here?
Where do we (and everything else) go next?

This lecture is an attempt
to look at part of the big picture

This is the Aperitif Talk, after all …
"For the purposes of this seminar, let us define ecology as the study of the Universe."
Evelyn Hutchinson (1903-1991)

This is the Aperitif Talk, after all ...

"Only then will we perceive the dignity of our science, when all the riches of nature and its great creator unfold themselves in our inner senses."
Georg Forster, 1794

This is the Aperitif Talk, after all ...
So: Stand Back!

This is the Aperitif Talk, after all …

OK!

This is the Aperitif Talk, after all …
How did we get here?

Upper Paleolithic Transition
100,000 years ago (Africa)
35,000 years ago (Europe)

Neolithic Transition
5,000 years ago (Europe)

Industrial Transition
250 years ago

Sustainability Transition
100 Years

2,500,000 Years
30,000 Years
5,000 Years
Global Climate Change
Who are we?
Who do we want to be?
What are the limitations?
What kind of nature do we want (need)?
Looking at the Change … Some Questions

Is planet-transforming life „evolution run wild“ or „evolution at work“?
Is intelligent life an unavoidable product of evolution?

Image: David A. Aguilar (CfA)
A conclusion?

Life is „easy“ / Inevitable on an earth-like planet.
(We have no idea why.) → Life is part of a planetary programme.

Or:

Earth is an extraordinary example of great luck

Basic principle of studying earth-like planets
(„How to draw conclusions from a sample the size of 1“):

• Earth is typical → conclusions can be drawn about earth-like planets
• or … Earth is untypical → not much can be said at all

→ All research rests (must rest) on the assumption that Earth is typical

Follow-up variations 1:

• Life is „hard“ and Earth a lucky place
• Life is „easy“ and earth-like conditions abound
• Life is „easy“ and earth-like conditions are rare

Follow-up variations 2:

• Once life exists, its evolution is wide open
  (S.J. Gould: „no re-running of the tape“)
• Once life exists, there aren’t that many
  (biochemical) ways of advancing it through evolution
  (S. Conway Morris: „evolution leads to human-like forms, but
  that tape runs very rarely among planets“)

... if Earth is typical ... Are humans and global change then also typical/inevitable?
How long does it take for intelligent life to evolve? … let’s look at an example (actually, the only example we have):

- **Time to evolve intelligence** $T_E \sim 4 \text{ Ga}$
- **Lifespan of the planet (central star)** $T_P \sim 10 \text{ Ga}$

which means: $T_E \sim T_P$ (for Earth)

Since $T_E$ (biochemistry) is mostly independent of $T_P$ (geology, nuclear physics), this is an astounding and unlikely coincidence!

What can generally be concluded for Earth-like planets?

Since $T_E \sim T_P$ is not likely,

- $T_E < T_P$ … but then $T_E \sim T_P$ (for Earth) is unlikely
- or: $T_E > T_P$ … then $T_E \sim T_P$ (for Earth) is quite possible

**IF** $T_E > T_P$, that is, intelligence is slow to evolve:

**How many major („hard”, unlikely) transitions in evolution are required to arrive at intelligence (humans)?**

**Poisson statistics:**

Probability for $k$ rare events happening (at small rates $\lambda$) after a long period $t$:

\[ P(t; N = k, \lambda) = \frac{e^{-\lambda t} (\lambda t)^k}{k!} \]

Probability of no event at time $t$:

\[ P(t; N = 0, \lambda) = e^{-\lambda t} \]

So: Probability for at least 1 event at $t$:

\[ P(t; N > 0, \lambda) = 1 - e^{-\lambda t} \]

**i-th Major Transition:**

$\lambda \sim 1/T_i$, where $T_i$ is the typical (very large) time for such a transition to occur; then the probability that an $i$-th rare (difficult, „major”) transition happens at time $t$ is:

\[ P_i(t) = 1 - e^{-\frac{t}{T_i}} \overset{\approx}{=} \frac{t}{T_i} \]

where $T_i > T_B$, the lifespan of the biosphere, or $T_P$ (as $T_P \sim T_B$).
P_i(t) = 1 - e^{-\frac{t}{T_i}} \approx \frac{t}{T_i}

Simplifying assumption: statistical independence of major transitions (an optimistic assumption!); then n (improbable) major transitions occur with probability:

\[ P_n(t) = \prod_{i=1}^{n} \frac{t}{T_i} \]

… in the actual case of Earth, humans have appeared within the lifetime of the biosphere \( T_B \), after n major transitions, so:

\[ P_n(t) = \left( \frac{t}{T_B} \right)^n \]

Expectance value for the time of the n-th major transition (to humans):

\[ P_n(t) = \left( \frac{t}{T_B} \right)^n \Rightarrow t(P) = T_B P(t)^{\frac{1}{n}} \]

\[ \bar{t} = \int_0^{T_B} t(P) dP = T_B \int_0^{T_B} P^{\frac{1}{n}} dP = \]

\[ = T_B \left[ \frac{1}{1/n+1} P^{\frac{1}{n+1}} \right]_0^n = T_B \frac{n}{n+1} \left[ T_B = T_B, T_B = T_B = 1 \right] = T_B \frac{n}{n+1} \]

So: expectance value for the time of the n-th major transition
(e.g. \( T_0 = 4 \) Ga, time for the transition to intelligence):

\[ \bar{t} = T_B \frac{n}{n+1} \]
Then: Time left for the future evolution of the biosphere (lifespan $T_B$) after the appearance of humans:

\[ \bar{t} = T_B \frac{n}{n + 1} \]

\[ T_B - \bar{t} = \frac{T_B}{n + 1} \]

e.g.

$T_B = 5 \text{ Ga}, \bar{t} = 4 \text{ Ga}$

$\Rightarrow n = 4 ((\text{to humans})$

$\text{or } n = 100, T_B = 5 \text{ Ga}$

$\Rightarrow T_B - \bar{t} = 50 \text{ Ma}!!$

$\text{or } n = 100, T_B - \bar{t} = 1 \text{ Ga}$

$\Rightarrow T_B = 101 \text{ Ga}!!$

**Number of major transition to humans: ~ 4!**

Contrary to expectations, the number of major transitions to humans is small! … $n<10!$

The assumptions made correspond well to knowlegde:

\[ \bar{t} = 4 \text{ Ga} \]

\[ T_B - \bar{t} = 1 \text{ Ga} \]

Prokaryotes

Eucaryotes

Complex Life

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after Carter, 1973
Major Transitions in Evolution

I. Reproducing molecules → Populations of molecules in protocells
II. Independent replicators → Chromosomes
III. RNA as gene and protein enzymes → DNA as gene and protein enzymes
IV. Bacterial cells (prokaryotes) → Cells with nuclei and organelles (eukaryotes)
V. Asexual clones → Sexual populations
VI. Single-celled organisms → Animals, plants, and fungi
VII. Solitary individuals → Colonies with non-reproductive casts (ants, bees)
VIII. Primate societies → Human societies (language)
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Slide: A. Schibalski, Potsdam, 2008
Life has not always been what it is today.

Unicellular soup to first soft-bodied animals.

Then the plant came and invaded that land.

And the vertebrates appeared, some of them got really big!
Geosphere-Biosphere Co-Evolution

And then something happened

And then another something happened
Geosphere-Biosphere Co-Evolution

And then something really happened!

Information Flow in the Biosphere

Genetic
Epigenetic
Behavioural
Symbolic
From Co-Evolution into the Anthropocene

Geosphere  Biosphere  Geosphere  Biosphere  Anthroposphere

Vegetation Effects on Climate

Bioclimatic Effects

Climate Change Impacts

Climate Change

Human Land Use

Degradation
From Co-Evolution to Self-Evolution

The Challenge:
Emergence of Conscious Global Action

What are possible paths in Earth System Phase Space?

Building on HJ Schellnhuber, Nature, 1999
Venus: too hot, too dry

Mars: too cold, too dry

State of Nature

State of Society

Our location today

Physical collapse

Social collapse

Damages

Transition

Sustainability

Climate policies

Green progress

Inaccessible domain

How do we find safe passage through the straights?
Plotting a future course for the Earth System

**Required**
to avoid cliffs & narrows

- **Good Navigation Charts**
  \(\rightarrow\) Theory-Based Models

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**State of Nature**

**State of Society**

Mars:
- too cold
- too dry

Venus:
- too hot
- too dry

Inaccessible domain

How do we find safe passage through the straights?

1. Scanning what is ahead: Theory-Based Modelling
Plotting a future course for the Earth System

Required

to avoid cliffs & narrows

• **Good Navigation Charts**
  (Theory-Based Models)

• **Constant Observation from the Crow’s Nest**
  (Earth Observations)

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How do we find safe passage through the straights?

1. Scanning what is ahead: Theory-Based Modelling
2. Checking on Reality: Earth System Observation
Sea Level Rise

Is climate changing faster than projected?

Plotting a future course for the Earth System

Required to avoid cliffs & narrows

- **Good Navigation Charts**
  (→ Theory-Based Models)

- **Constant Observation from the Crow’s Nest**
  (→ Earth Observations)

- **Be prepared!**
  (→ Expect Surprises)
Venus: too hot, too dry
Mars: too cold, too dry

State of Nature

inaccessible domain

inaccessible domain

inaccessible domain

State of Society

Tipping Points in the Earth System

Lenton et al., PNAS, 2008
Venus: too hot
too dry

Mars: too cold
too dry

State of Nature
State of Society

our location
today

beginning of the
Anthropocene

stone age

inaccessible
domain

sustainability
transition

climate policies

physical
collapse

social collapse

inaccessible
domain

inaccessible
domain

inaccessible
domain

inaccessible
domain
State of Nature

State of Society

What are the variables on this dimension?

What are the variables on this dimension?

Which institutional systems are needed?

How quickly and how strongly can paths be bent? (How much can the dimensions be decoupled?)

Will there be abrupt transitions?

What is the role of science?

Theories of Societal Development/Failure

Theories of Society-Environment Co-Evolution

Which institutional systems are needed?

What is the role of science?
30 October 2006  
Costs of Climate Change  
Benefits of Avoidance  

2 February 2007  
6 April 2007  
4 May 2007  
UN IPCC Climate Report
The Mitigation Challenge: Bridging the Emissions Gap

Scenario: O. Edenhofer and team, PIK, 2007
Growth: the current paradigm behind the debate

The Question is:
What will we do with all that energy?

The Answer is:
Remodel the world – a lot more than now

Metabolic Effects of Industrialisation

Industrialisation is a revolution in the socioeconomic metabolism and the structure of society.

Source: M. Fischer-Kowalski, iff Vienna
Human Appropriation of Photosynthetic Production

- altered land surfaces – 6.3 GtC/yr
- harvest – 8.2 GtC/yr
- fires – 1.1 GtC/yr
- backflows + 2.2 GtC/yr

Human interference and harvest:
= 23.8% of Natural Net Primary Production

Where do we (and everything else) go next?
Vergangenheit

Zukunft

Genetic to Nongenetic Information Transmission; Synaptic to Electronic Information Processing

Quelle (oben): HJ Schellnhuber, Symposium „Global Sustainability – A Nobel Cause“, Potsdam, 9 Okt 2007
Quelle (unten): W. Lucht, PIK
Maschines & Cyborgs: The next stage of evolution?
Autoevolution of the Biosphere?
Darwin: Culture is Autoevolution

But: Gene manipulation will probably have a larger, longer-lasting effect on the biosphere!

We can
• adapt to nature (green movement)
• adapt nature to us (global change, terraforming)
• detach from nature (dematerialisation)

The Question Remains:
Are there new ways forward?
Or will we suffer through collapse of the current ways?
A core question:

What will we do with our freedom?
How do we deal with our lack of freedom?

What is needed:

New cosmologies of the place of humans in the world,
- in tune with the scientific knowledge
- looking at planet Earth and humans together
- taking the form of cultural narratives and practices