Ontology in Quantum Darwinism
- An Analogy to explain the Nature of Quantum States-

4th ISSPP 2016 SAIG
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**ANALOGY BETWEEN**

**Darwinian Evolution & Quantum Darwinism**

**CLAIMS**

1. **Quantum Darwinism is not a good analogy of the Darwinian evolution.** A good analogy to “explain” the quantum to classical transition could be natural selection as a sieve but it depends on the interpretation of quantum mechanics.

2. **The conundrum of the nature of quantum states in Quantum Darwinism is distorted by the use of the concept of information as a token.**
**An Analogy to Explain the Nature of Quantum States**

**Summary**

1. Analogical Reasoning in a nutshell.

2. Darwinism in a nutshell.

3. Quantum states in quantum Darwinism.

4. Conclusions
Analogical Reasoning
ANALOGICAL REASONING

Bartha, P. “By Parallel Reasoning” pp2-3

FUNCTIONS

- Heuristic tool.
- Predictive Use.
- Conceptual Unification. (Science & Maths)
- Explanation & Justification (plausibility)

APPROACHES

- Formal inference. [philosophers]
- Factual Matters. [scientists]
The Articulation Model

[Hesse’s Model]:
Vertical relations: Causal relations in acceptable scientific sense...

(Barthà’s Model):
Predictive explanatory functional correlative

<table>
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<tr>
<th>SOURCE</th>
<th>TARGET</th>
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<tbody>
<tr>
<td>DARWINIAN EVOLUTION</td>
<td>QUANTUM DARWINISM</td>
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<tr>
<td>Property P</td>
<td>Property P*</td>
</tr>
<tr>
<td>Property A</td>
<td>Property not-A*</td>
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<tr>
<td>Property not-B</td>
<td>Property B*</td>
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Explanation Q → Explanation Q*
GENERAL PRINCIPLES: Successful Analogy

SOURCE \hspace{3cm} TARGET

\textbf{Plausibility} \hspace{1cm} Q \hspace{1cm} \textbf{Explanation Q*}.

- **Prior Association:**
  explicit \textit{Vertical relation to be extended to target}.

- **Potential for generalization:**
  “No compelling reason” precludes extension of Prior Association

**Judgment of plausibility**

1. **Prima facie plausibility (prior association)**
   It is plausible that $p = \text{There are sufficient grounds for taking } p \text{ seriously.} \ [\textit{Vera causa} \text{ To be capable of confirmation, a hypothesis must stipulate a “true cause.”}]$

2. **Qualitative plausibility (strength of prior assoc.)**
What is Darwinism?
What is Darwinism?

Evolution by Natural Selection [Lewontin, 1985, p 73]

1. THE PRINCIPLE OF VARIATION

There is variation in morphological, physiological, and behavioral traits among members of a species.

2. THE PRINCIPLE OF HEREDITY

The variation is in part heritable, so that individuals resemble their relations more than they resemble unrelated individuals and, in particular, offspring resemble their parents.

3. THE PRINCIPLE OF DIFFERENTIAL FITNESS

Different variants leave different numbers of offspring either in immediate or remote generations.
Darwin’s Long Argument In Abstract


A Branching Tree of Life as an Algorithmic Process

- Exponential Growth of the Population
- Observed Stability
- Limited Resources

Through iteration in many generations

- “Struggle for Life”
- Individual level selection
- Some variation is inheritable

Natural selection (sieve)

Darwinian evolution
**Darwinian Explanation**

[Godfrey-Smith, P. “Philosophy of Biology”, 2014, pp. 30-34]

**Distribution and origin Explanation**

**Selection as a Sieve**
Immediate cause of the disappearance of some individuals & the survival of others. *(Distrib. Expla)*

**Darwin’s Natural Selection (Distrib. & Origin Exp.)**
Can have a creative role only through iteration.

**Neodarwinism Hypothesis (Williams-Dawkins-Hull)**

**Individuals** =
Interactors (Organisms) + Replicators (DNA)
Quantum Darwinism
# Quantum vs Classical States

## Non-Intuitive

**Abstract States** (wave f. or vector $|\psi\rangle \in H$)

**Physical Properties** (through measurement)

- **Fragility** – non clonable-
- **Not always distinguishable**
- **Quantum Superposition**
- **Entanglement**

## Intuitive

**States** (q, p, t.)

**Physical Properties**

- **Robustness** – clonable-
- **Distinguishable**
- **Classical Superposition**
- **Classical Correlations**

$|\Psi\rangle = \sum_n c_n |\psi_n\rangle$

• **ENVIRONMENT**
• **DECOHERENCE**
Quantum to Classical Transition


If Entanglement and Quantum Superposition are relevant in the “macroscopic” realm.

Through an Everettian Approach

We start with QM → Everyday Experience

How can the objective properties of classical systems emerge from the underlying Quantum realm?

Quantum Darwinism

Indirect Measurement of properties of the system through the redundant proliferation of information in its environment
Darwinian Analogy of Quantum Darwinism

1. “The Survival of the Fittest” : Which states can survive in the interaction with their environment?

Decoherence & Einselection through Predictability Sieve

Selection criterion:

“Some states of the system are more prone to decoherence than others and the sensitivity of a particular state is determined by the structure of the system-environment interaction. Pointer states of the system are the least entangled with the environment”.

2. Multiplication of the information in the environment. (Which states can be copied massively without being disturbed)

Quantum Darwinism
Quantum Darwinism: Replication

The environment as a communicational channel between the system and the observer.

\[ S = |\psi_s\rangle = a|0\rangle + b|1\rangle \]

\[ E = |0\rangle^{\epsilon_1} \otimes \ldots \otimes |0\rangle^{\epsilon_N} \]

States System + Environment

Dynamics

\[ |\Psi_{SE}\rangle = (a|0\rangle + b|1\rangle) \otimes |0\rangle^{\epsilon_1} \otimes \ldots \otimes |0\rangle^{\epsilon_N} \]

\[ H^{SE} = \sum_{\epsilon_k \in \epsilon} A \otimes Z^{\epsilon_k} \]

\[ \text{CNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \]

Thanks to decoherence & einselection

Pointer states preserve correlations when monitored by E: “fittest” information about S proliferates in “many copies”

Redundancy \( N^o \) of copies: each \( \epsilon_k \)-perfect copy

BUT: There’s not and cannot be iteration: Not all environments are good in this role of a communicational channel. Photons excel: They do not interact with the air or with each other, faithfully passing on information.
Observation & “Reality”: Information Transference

• INFORMATION ABOUT S (WHAT OBSERVABLE GETS REDUNDANTLY IMPRINTED IN E?) IS OBTAINED (WITHOUT DISTURBING THE SYSTEM) INDIRECTLY AND INDEPENDENTLY BY MANY OBSERVERS FROM A DISJOINT FRAGMENTIZED ENVIRONMENT,

• INTERSUBJECTIVE AGREEMENT IS IN EFFECT OBJECTIVE (AS IF IT WERE CLASSICAL)


Operational definitions

Quantum states exist

&

(THROUGH REALITY CRITERION)

Pointers States objectively Exist
What is the Ontological Status of Quantum States

1. Their “reality” is context-dependent (i.e. determined by the measurement interaction. The quantum states of isolated systems therefore not “real” but “epistemic”).

2. From epistemic to ontological through interaction with the environment. “?”

3. Not always a clear distinction between the epistemological and ontological aspects.


The problem is Zurek’s concept of information

“Quantum Darwinism accounts for the transition from quantum fragility (of information) to the effectively classical robustness. One can think of this transition as John Wheeler’s ‘It from bit’”. [Zurek, Quantum Darwinism2009 p.9]

But

Information is a type which always needs a token
Quantum Darwinism as a Sieve?

Vertical Relation: Prior Association

**Selection as a Sieve**
Immediate cause of the disappearance of some individuals & the survival of others.

Therefore: a sieve cannot transform the ontic or epistemic nature of the quantum states through the process.

Ontic Quantum states \[\xrightarrow{\text{Sieve}}\] Ontic states

Epistemic Quant states \[\xrightarrow{\text{Sieve}}\] Epistemic States

The Analogy depends on the Interpretation

Other problems (ontology)
Individuals? = Interactors (Systems or quant. States ?)
Replicators (Information) ?
Quantum Darwinism is not Darwinian Evolution

Vertical Relation
Prior Association & Extended correspondence

Natural Selection (sieve)

In Quantum Darwinism
No iteration

Darwinian Evolution

No iteration not Darwinian Evolution

General Problem:
It considers information as a reductive ontological concept.
Ontology in Quantum Darwinism
-From Analogy to the Nature of Quantum States-

Thanks!

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