
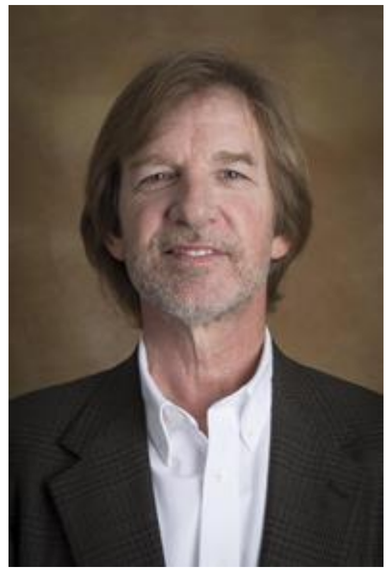

Energy and Evolution: The Systems Approach

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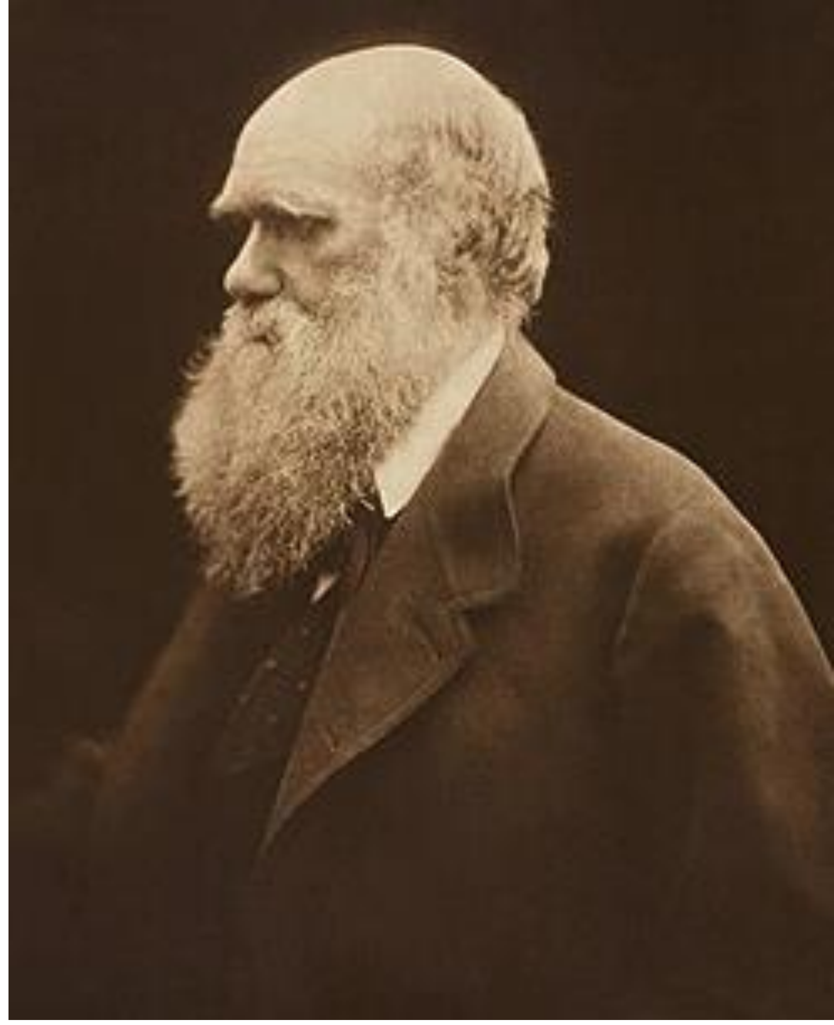
Evolution by Natural Selection

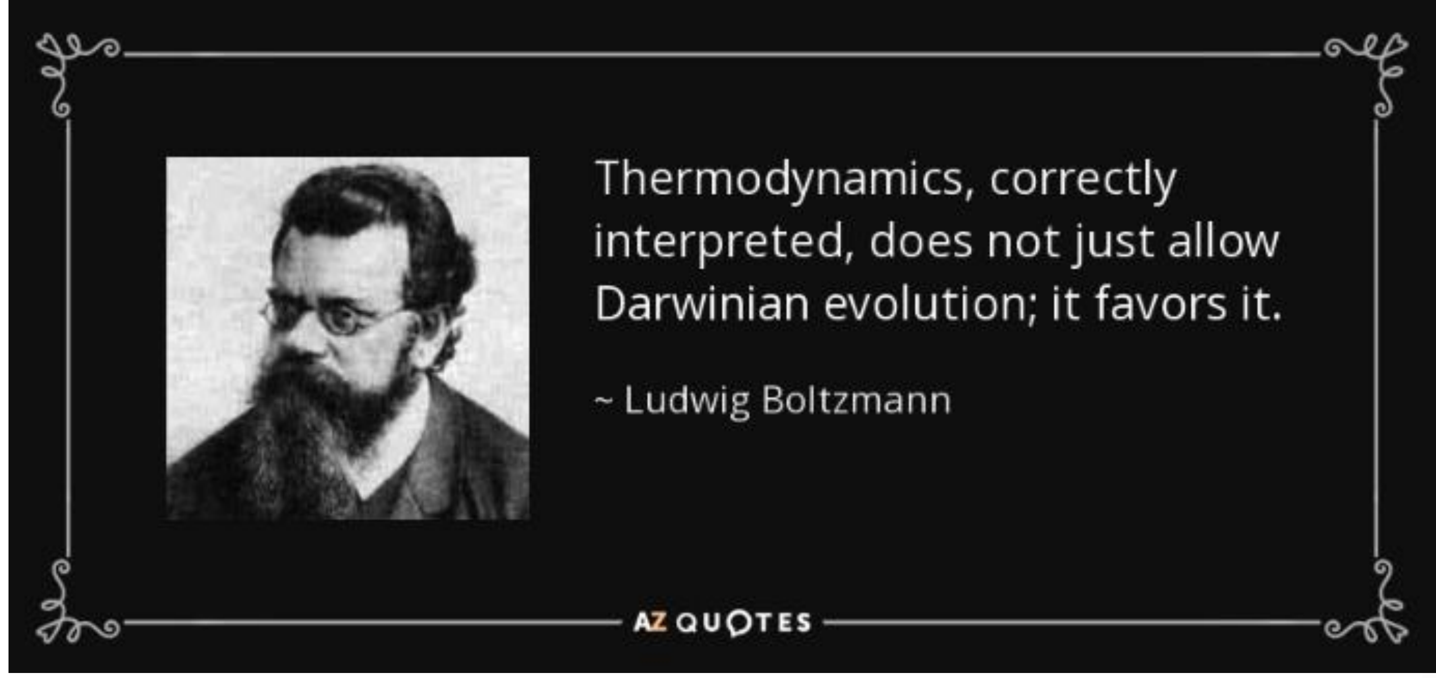


- Darwin developed the concept of evolution by natural selection from the perspective of individual organisms and populations.

- Darwin established that natural selection would operate on species in terms of what contributed to the differential survival and reproduction of individuals.

- Later investigators sought to understand evolution and natural selection in terms of energy.

    - This approach has come to be called the “thermodynamic school” of evolutionary theory (Fry 1995).



What guides thermodynamic evolution?

- Scientists have offered ***over 15*** "***Optimality Principles"*** or "***Goal Functions"*** so far.
- Collectively they have been described as being "***contradictory***," referring to "***apples and oranges,***" and "***local, and disunited***" (Bejan & Lorente 2010, 2011).
- Our central argument is that many thermodynamic optimality principles are not competing explanations of evolution. They are components of a larger systems-level pattern that Odum described using the ***Maximum Power Principle***.

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The Discussion of These Optimality Principles

- Many scientists have ***championed their principle of choice*** and argued that it is more "***accurate***" or more "***general***" than the other principles (Glazier 2024; Salthe 2010; Bejan & Lorente 2010; Brown & Burger 2024).

- In many cases, they have used ***strawman arguments*** that mischaracterize competing principles. Two factors help explain this problem:

  1. ***Complexity*** -- Many of these principles are deceptively complex (e.g., Sciubba 2011).

  2. ***Fragmentation*** -- The exponential growth of scientific research implicitly outlined by these optimality principles has made it increasingly difficult for scientists to keep up with relevant developments. Scientists describe the research as being Fragmented (Chapman et al. 2016; Martyushev et al. 2006).

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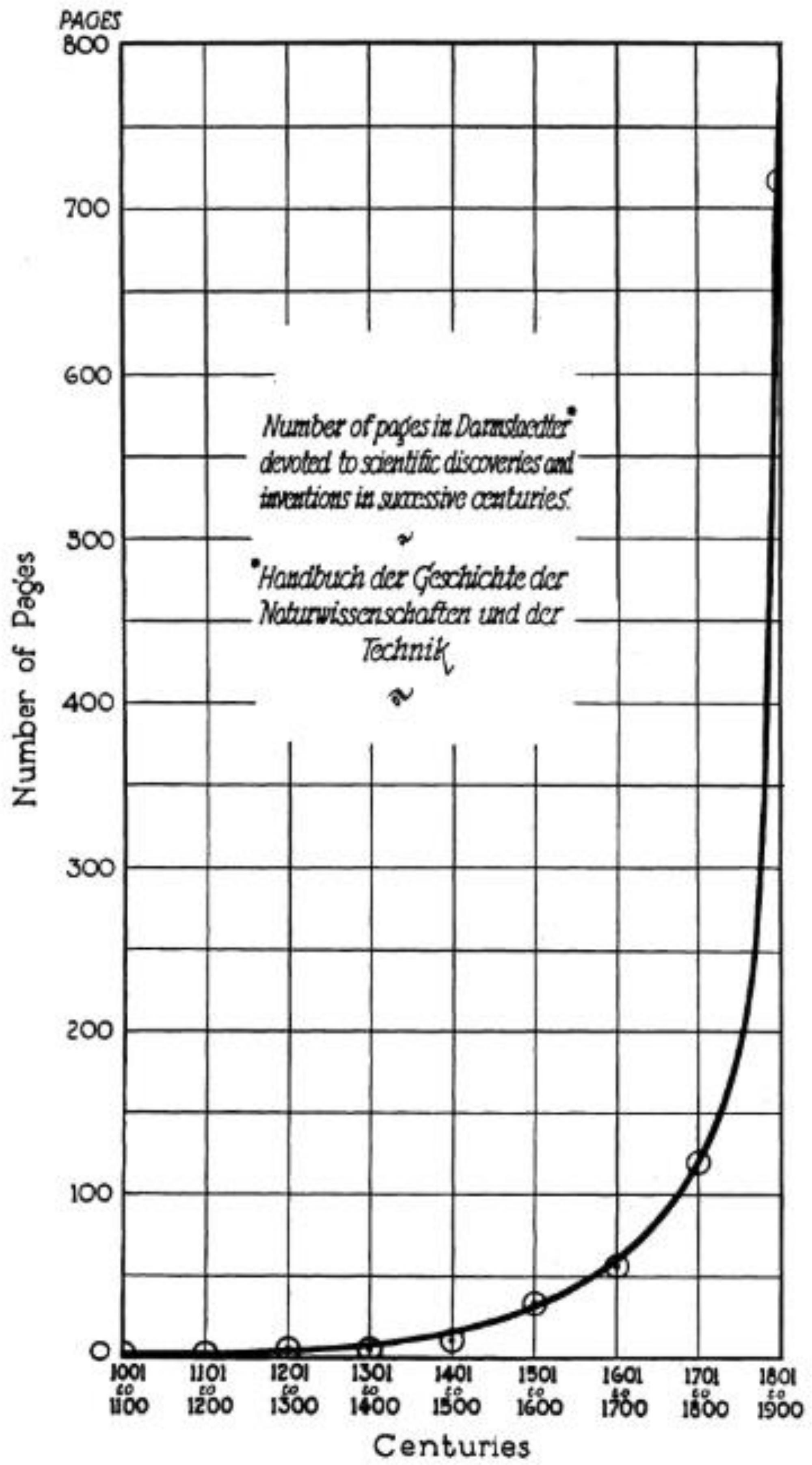
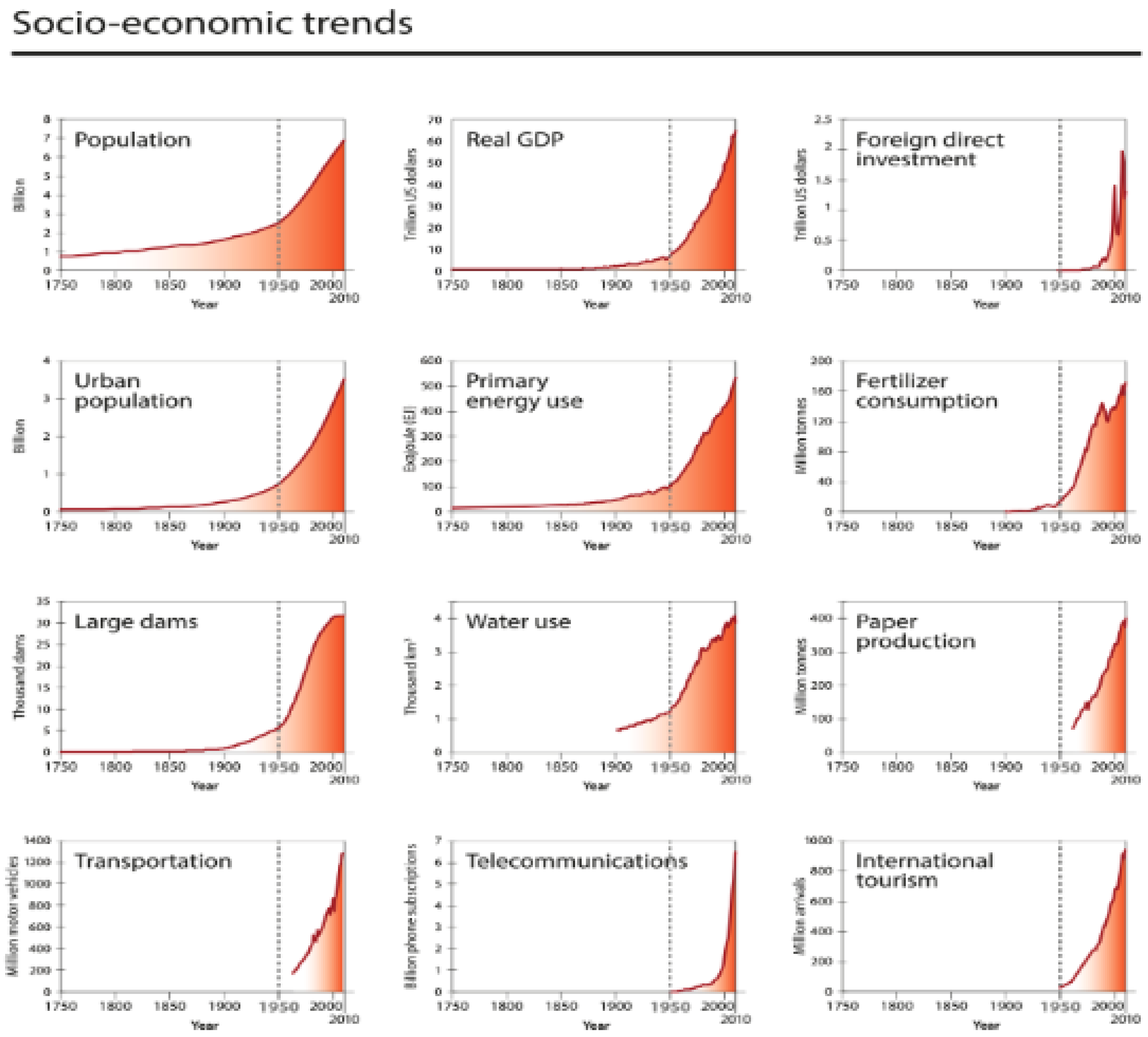


Fig. 4. Growth curve of human knowledge.

Alfred Lotka, 1939, p. 625



Will Steffen et al., 2015.

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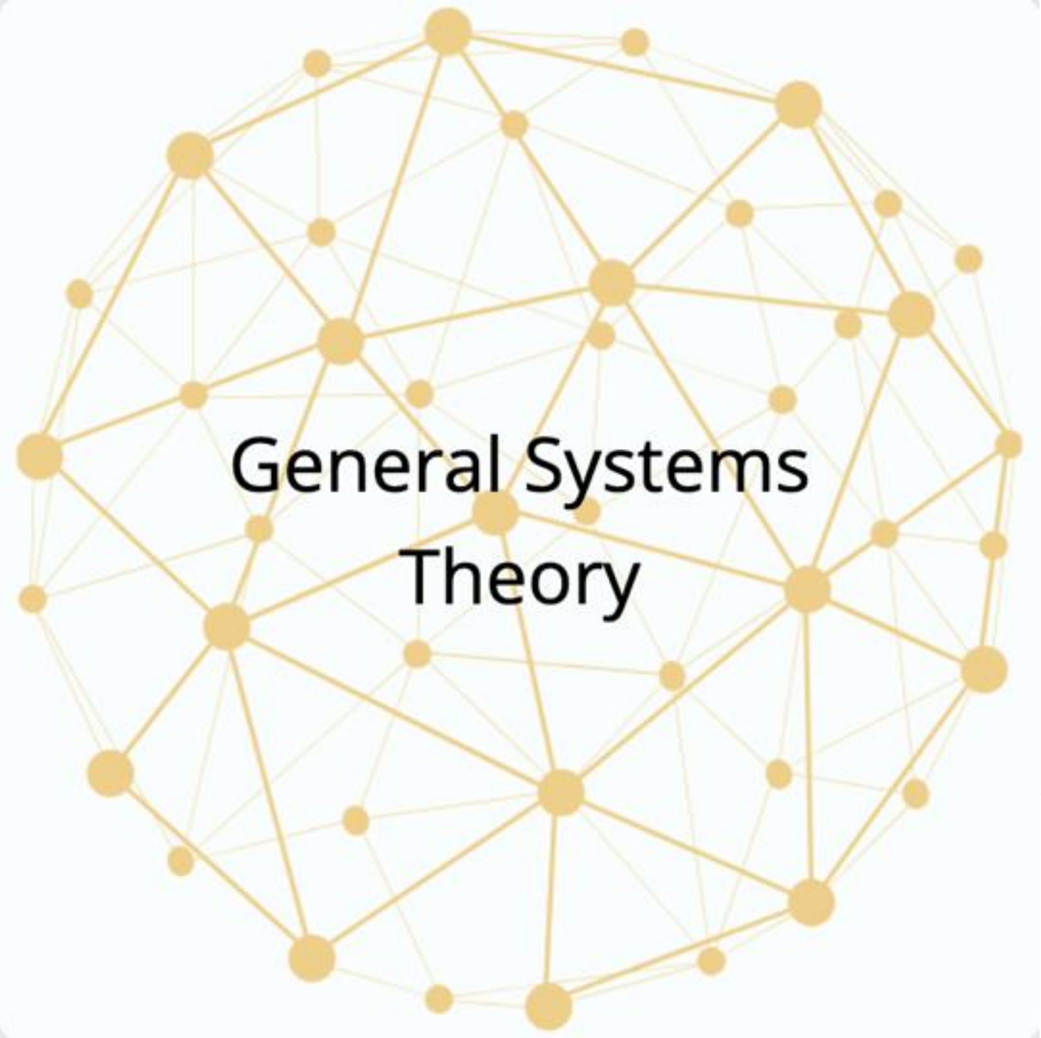
The Systems Approach

- A group of scientists has focused on illustrating how these ***optimality principles work together as a network or system***. (Jørgensen 1992, 1994, 2001; Jørgensen et al. 1998, 2007,2011, 2014, 2016, 2020; Patten 1995; Fath et al. 2001).

  - They view the evolutionary process as a complex system with many different parts that are ***connected by a web of relationships*** (Banathy 1997).

  - Jørgensen (1997) describes how the optimality principles work together in a way that forms a pattern, which he describes with his proposed ***4th law of thermodynamics***.

    - "If a system is moved away from thermodynamic equilibrium by the application of a flow of exergy, it will utilize all avenues available to build up as much dissipative structure (store as much exergy) as possible, to reduce the effects of the applied gradient" (1997, 339).

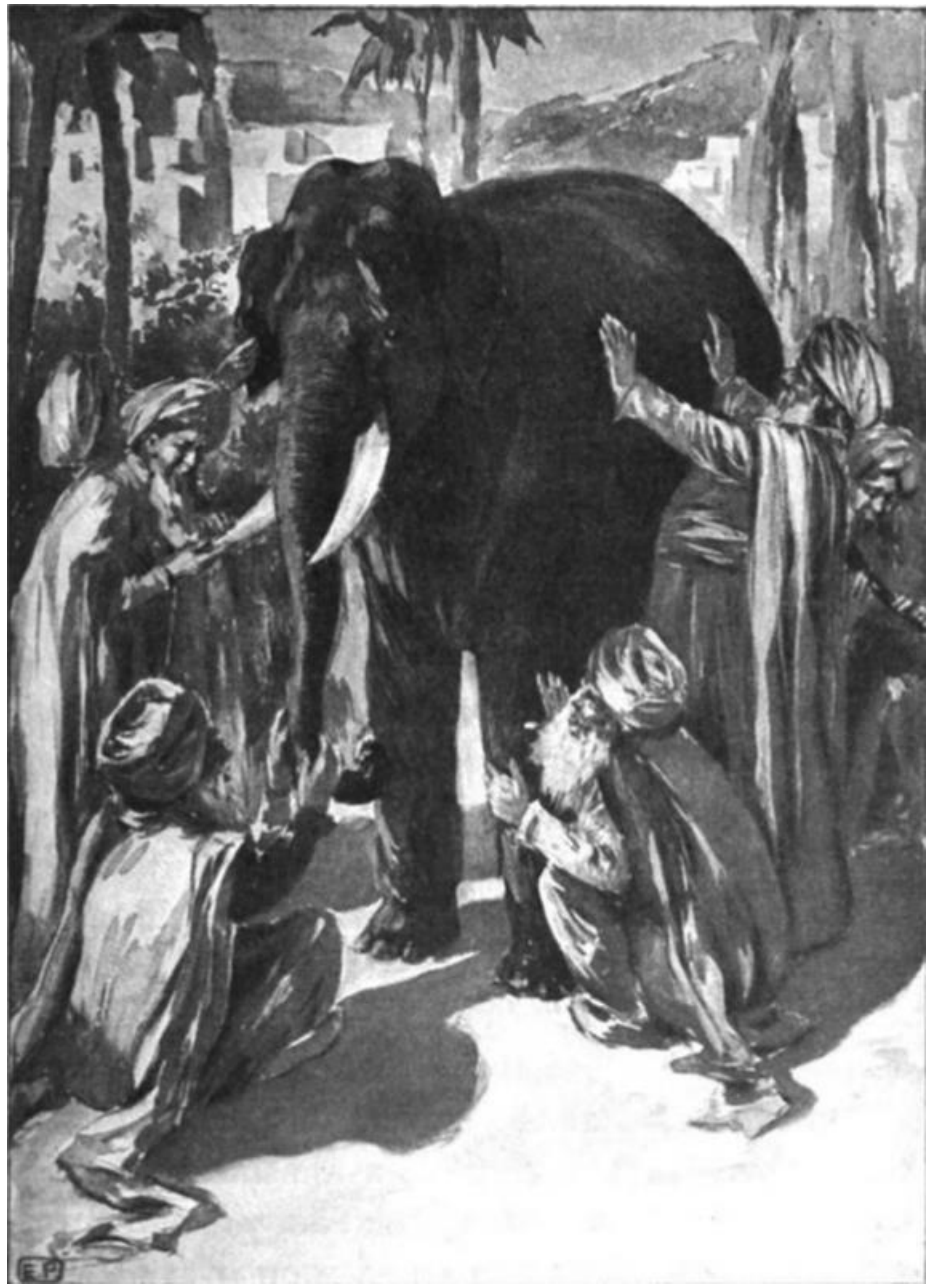


The Optimality Principles

- Focus on ***different parts*** of the process of evolutionary development:

    - The maximization of power, the production of entropy, the persistence of biodiversity, the evolution of design…

- These principles provide an ability to predict, and in some cases, explain the phenomena in these parts of the process. But each principle only provides a partial picture of the evolutionary process.



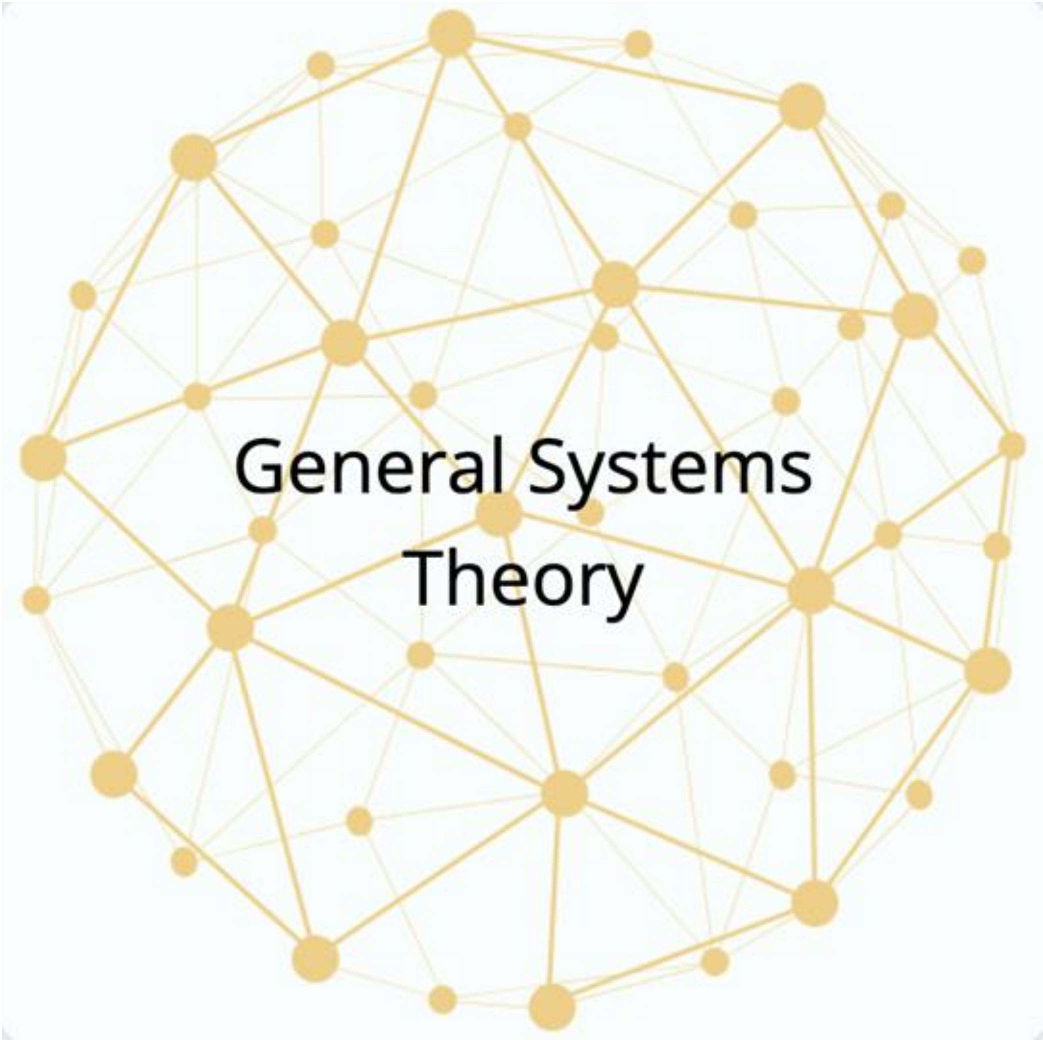
The parable of the blind men and the elephant

The Systems Approach

- Jørgensen describes H. T. Odum as a source for an optimality principle, but not as a source of a systems theory of optimality principles.

- However, Odum described optimality principles as "***special cases***" of the maximum power principle (1983a; 1983b): They align with the principle under certain conditions. They work together in a way that forms a pattern, which he describes using the ***maximum power principle***.

    - He provides information throughout his work that supports this claim, which can be used to construct a systems theory of optimality principles.



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The Principle of Maximum Energy Flux (PMEF)

Alfred Lotka (1880-1949)

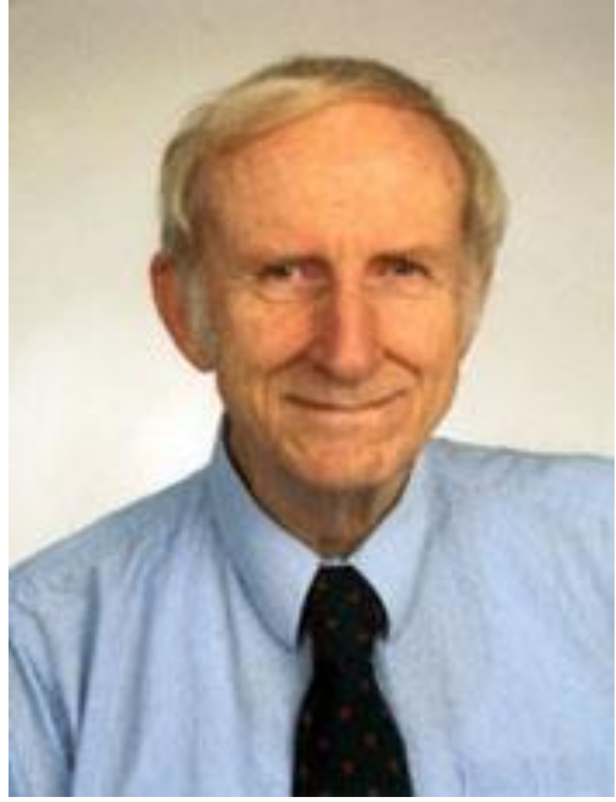
- ***Definition***: "natural selection tends to make the energy flux through the system a maximum so far as compatible with the constraints to which the system is subject" (1922a).

- He noted that the reference to the "constraints to which the system is subject" "modifies" the meaning of the PMEF.
  - Organisms with higher efficiency gain a selective advantage when energy is scarce.

- PMEF applies to ***all natural systems far from equilibrium***, both biotic and abiotic (1922b, cp. 1945).

- PMEF is discussed in terms of ***available energy*** (1922a).

The Maximum Power Principle (MPP)



H. T. Odum (1924-2002)

- Developed by H. T. Odum (and Richard Pinkerton) (1955), who attributed the principle to Alfred Lotka (1922).
    - But Odum altered the MPP in substantive ways.

- ***Definition***
    - “Lotka (1922) proposed a "law of maximum energy" for biological systems. He reasoned that what was most important to the survival of an organism was a large energetic output in the form of growth, reproduction, and maintenance … Let us make the following postulate: Under the appropriate conditions, maximum power output is the criterion for the survival of many kinds of systems, both living and non-living” (1955).

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Similarities between the PMEF and the MPP

- Both applied "so far as compatible with the ***constraints to which the system is subject***" (Lotka 1922a).

- ***Applied to All natural systems far from equilibrium***, both biotic and abiotic (Odum 2007; Lotka 1922b, cp. 1945).

- ***Utilized Feedback Loops*** (Lotka 1945; Odum & Odum 1976).

Odum's Systems Theory of Thermodynamic Evolution:
A Brief Summary

Maximum Power Principle

- ***Early succession***
  - Where energy and resources tend to be ***abundant***.
  - The MPP will be more closely aligned with:
    - The maximum biomass principle (1983b)
    - The maximum reproduction principle (2007)
    - The maximum storage principle
- ***Later succession***
  - Where energy and resources tend to be ***limited***.
  - The MPP will be closely aligned with:
    - The maximum efficiency principle (2007)
    - The maximum diversity principle (2007)
    - The equal fitness paradigm

Testing the Maximum Power Principle

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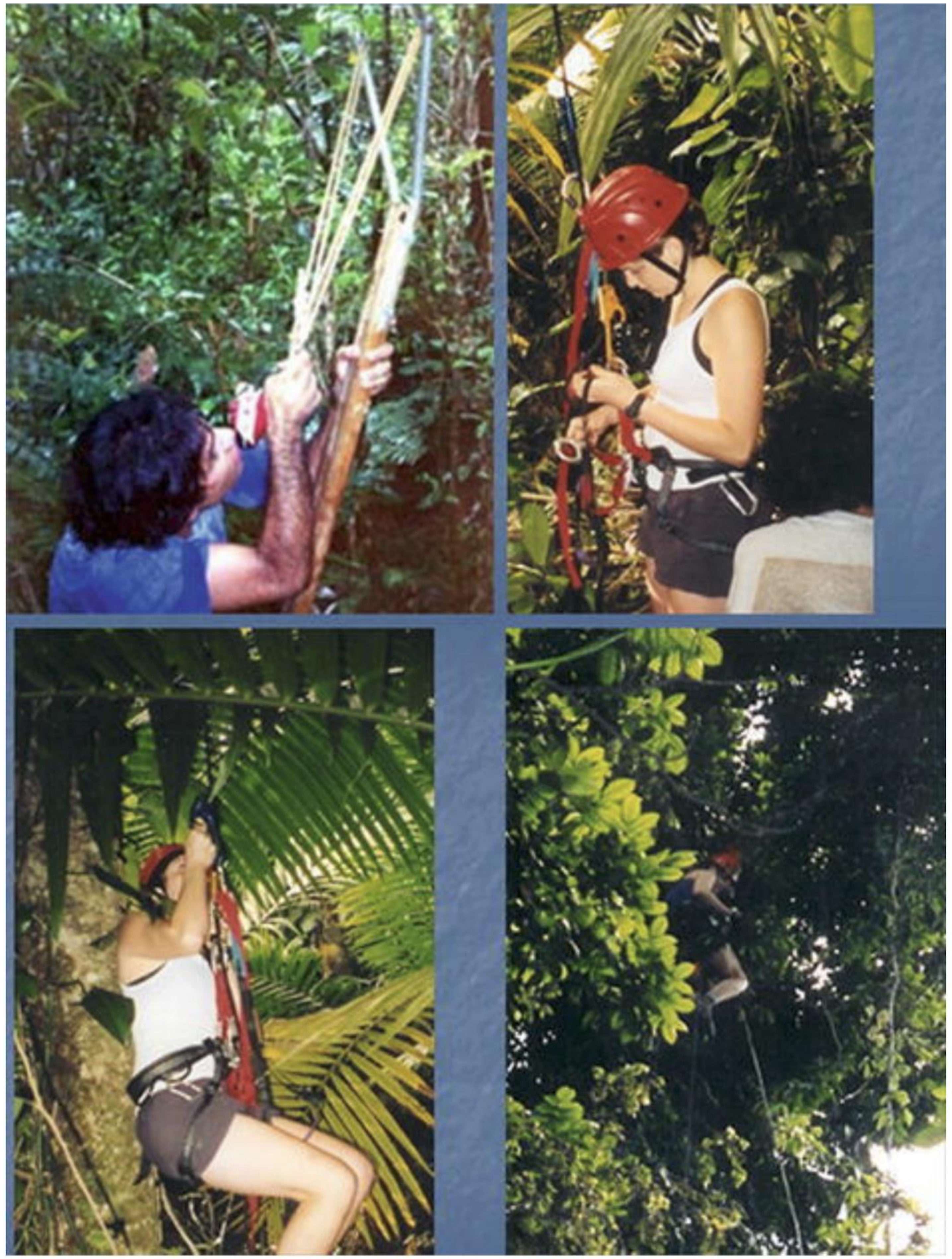

Fig. 7.15 How to access the upper leaves in a large tropical tree

We have great new tools

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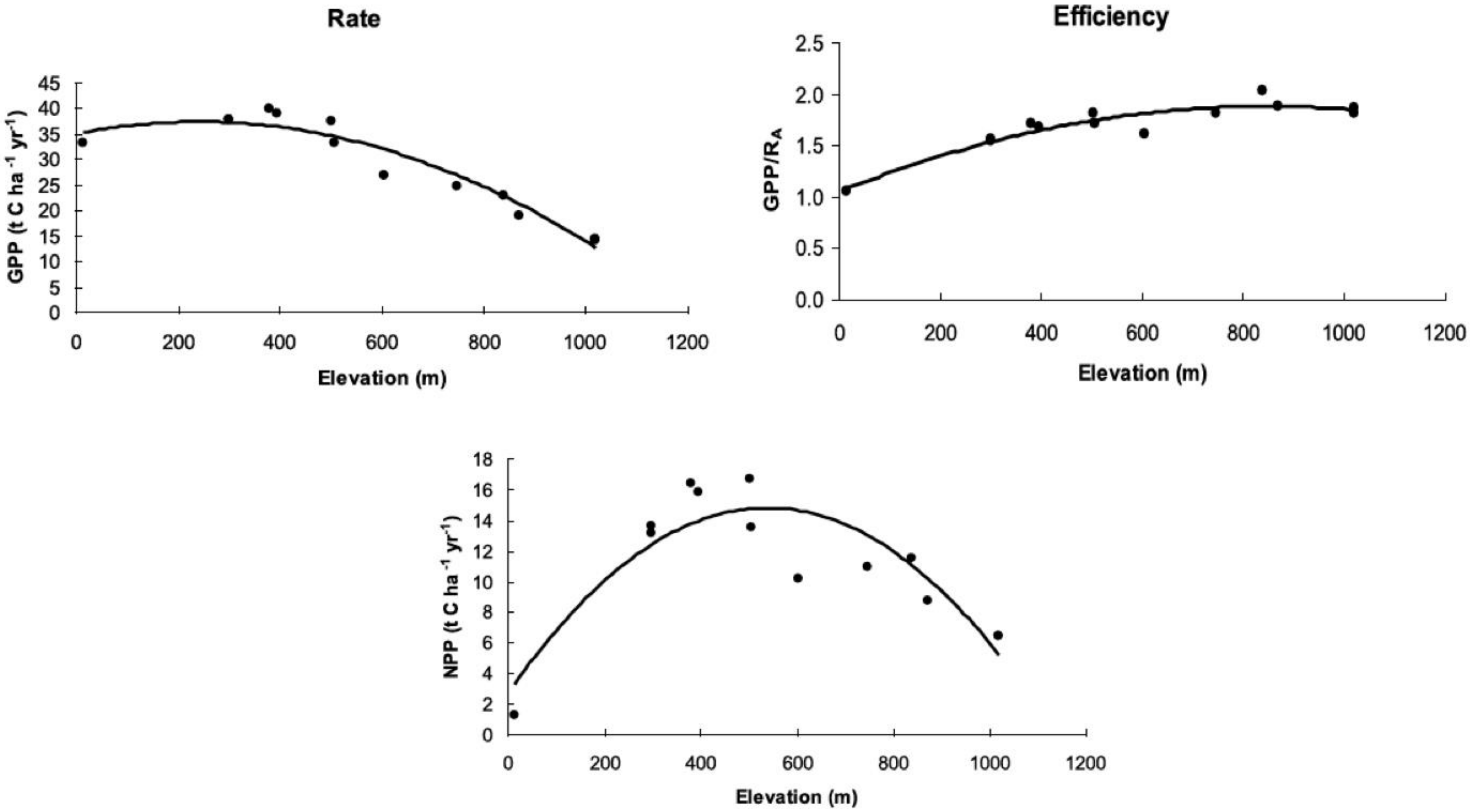

Fig. 5 Results of studies by Harris *et al.* that measured the gross photosynthesis and community respiration of a column of forest along a gradient of elevation in the Luquillo Forest, Puerto Rico. These data show a tradeoff of rate and efficiency of carbon capture, with the difference (net primary production) being maximum at an intermediate elevation, consistent with the maximum power hypothesis of Howard Odum. See Hall and McWhirter (2023).

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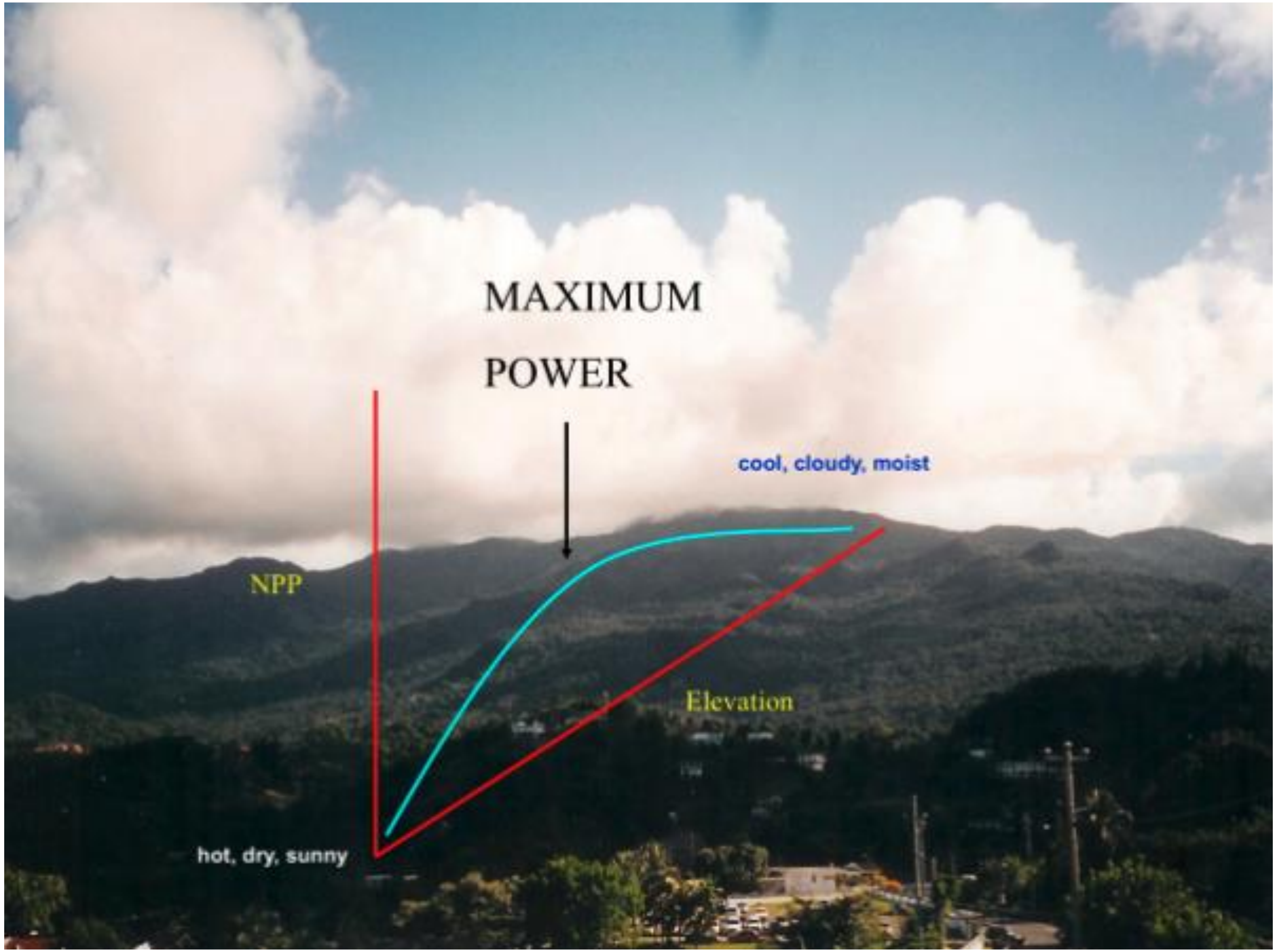
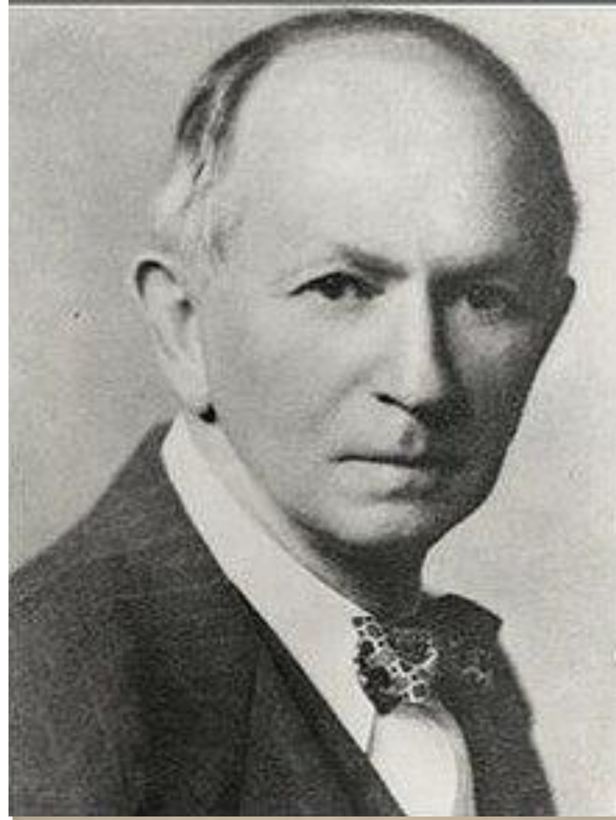

MAXIMUM
POWER
cool, cloudy, moist
NPP
Elevation
hot, dry, sunny

Studies of the MPP at the Ecosystem Scale (Chapman et al. 2016)

1. The MPP has been applied to studies that used models to optimize exergy relative to the effects on planktonic and zooplankton body size in aquatic ecosystems (Ray et al. 2001).
2. Used to constrain hydrological conceptual models (Westhoffand Zehe 2013).
3. Used to model the role of exotic species ecosystem self-organization (Campbell et al. 2009).
4. Applied to studies that simulated the role of the MPP in self-organizing forest plantation ecosystems (Li et al. 2013).
5. The MPP has been used to predict the outcomes of competitive exclusion experiments (DeLong 2008).
6. To indicate benthic ecosystem recovery following a disturbance (Libralato et al. 2006).
7. To examine microcosm ecosystem self-regulation using pH to control photoperiod (Cai et al. 2006).
8. To model the ecosystem organization of energy flows and storage (Fath et al. 2004).
9. It has been used in simulations of ecosystem responses to resource pulses (Lee 2014).
10. It has been used to predict the leaf area index in forests at different elevations (Hall et a. 2013).

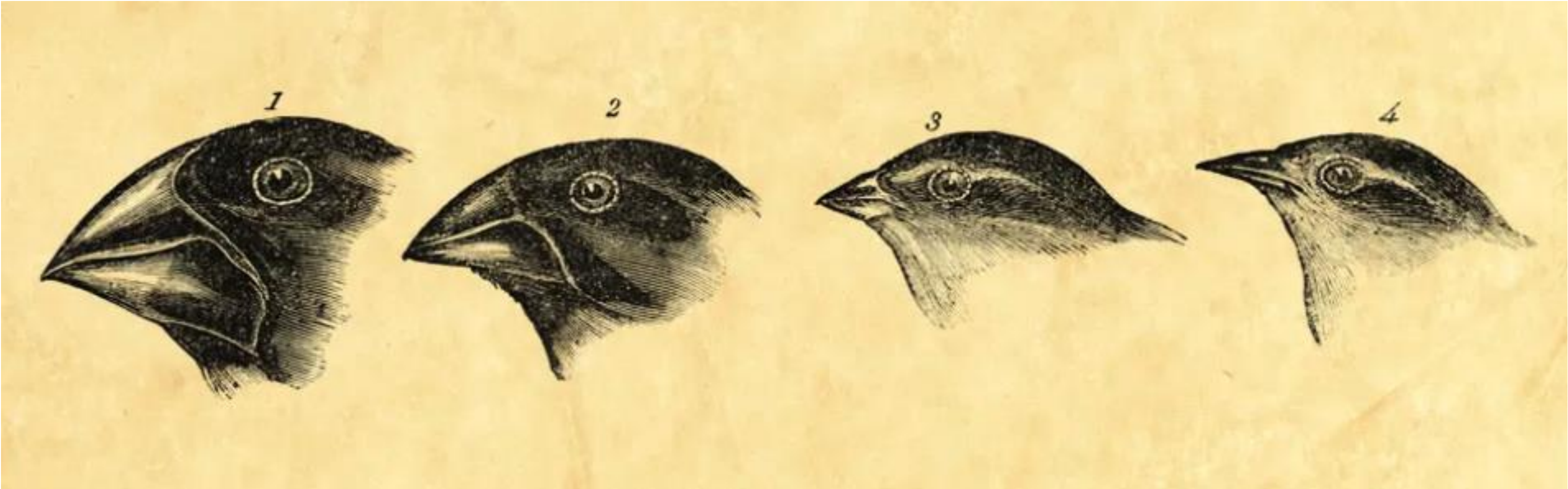
The Differences between the PMEF and the MPP



- The PMEF focuses on the ***flow of energy*** through the system; the MPP focuses on ***useful power output.***
    - Jørgensen and Fath describe the ***MPP*** in terms of the ***PMEF***.
        - They write that "Lotka's (1922) maximum power principle states that systems become organized to ***maximize their energy throughput***" (Fath et al. 2001, p. 494; Jørgensen 1997, p. 87; Jørgensen and Fath 2007, p. 190).

The MPP and the Principle of Natural Selection

- The ***MPP*** describes the maximization of the ***output of useful power***.
  - This output is defined as being in the form of "***growth, reproduction, and maintenance***." It therefore has a direct impact on the processes associated with natural selection.
  - ***The MPP is selected directly by the principle of natural selection***.
    - The PMEF, and other optimality principles, are ***selected indirectly*** because of their fundamental relation to the MPP.
    - Consequently, Jørgensen describes the relation between his ***4th Law of thermodynamics*** and the principle of natural selection as an "***open question***" (1997, 339).



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Our Book Project

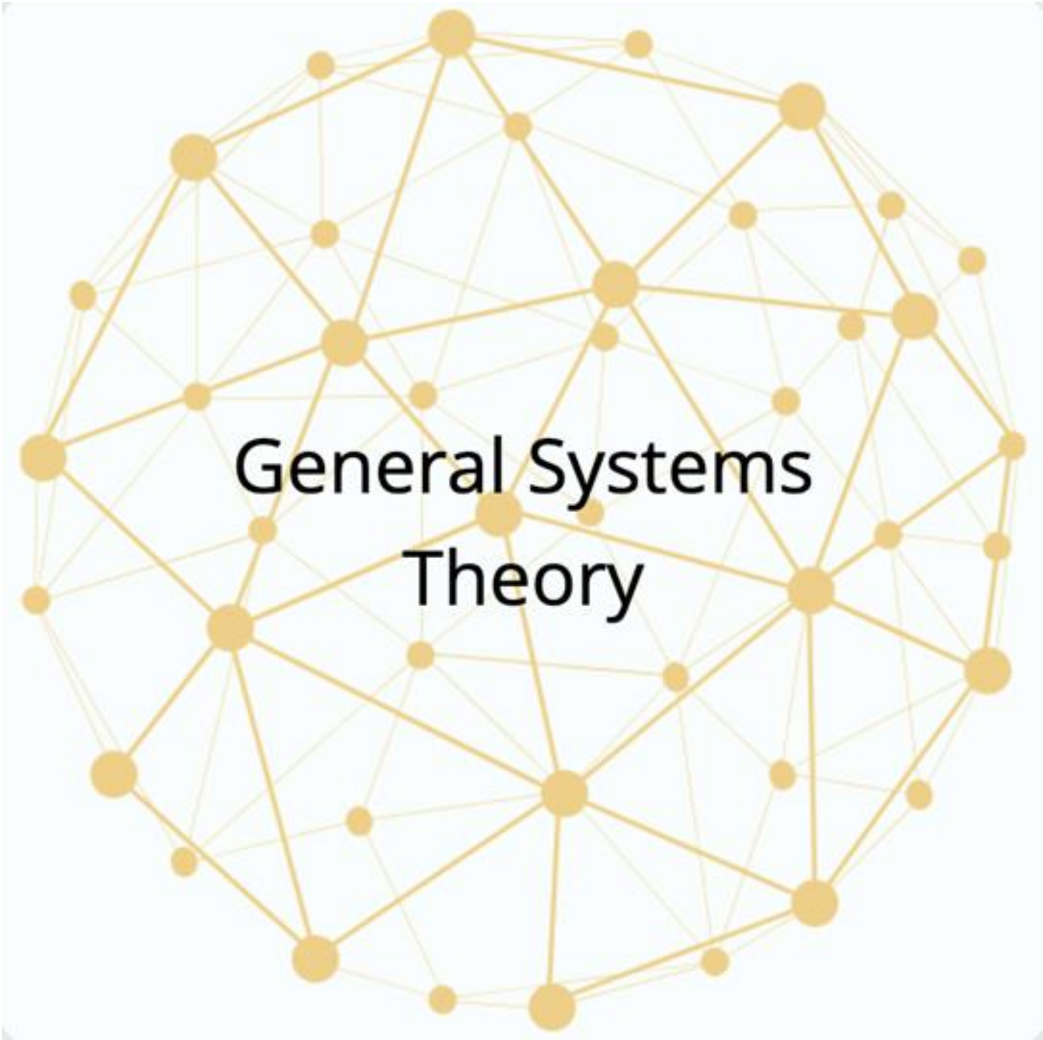
1. Describes the systems theory of optimality principles H. T. Odum outlines in his work and compares it with those that have been developed since the 1990's.

2. Extends this systems approach to other principles that have not been considered.

   - The constructal law, the equal fitness paradigm, and the maximum efficiency principle, among others.

3. Clarifies the relation between the maximum power principle and the principle of natural selection.

4. Addresses the strawman arguments that have been used against some of the optimality principles.



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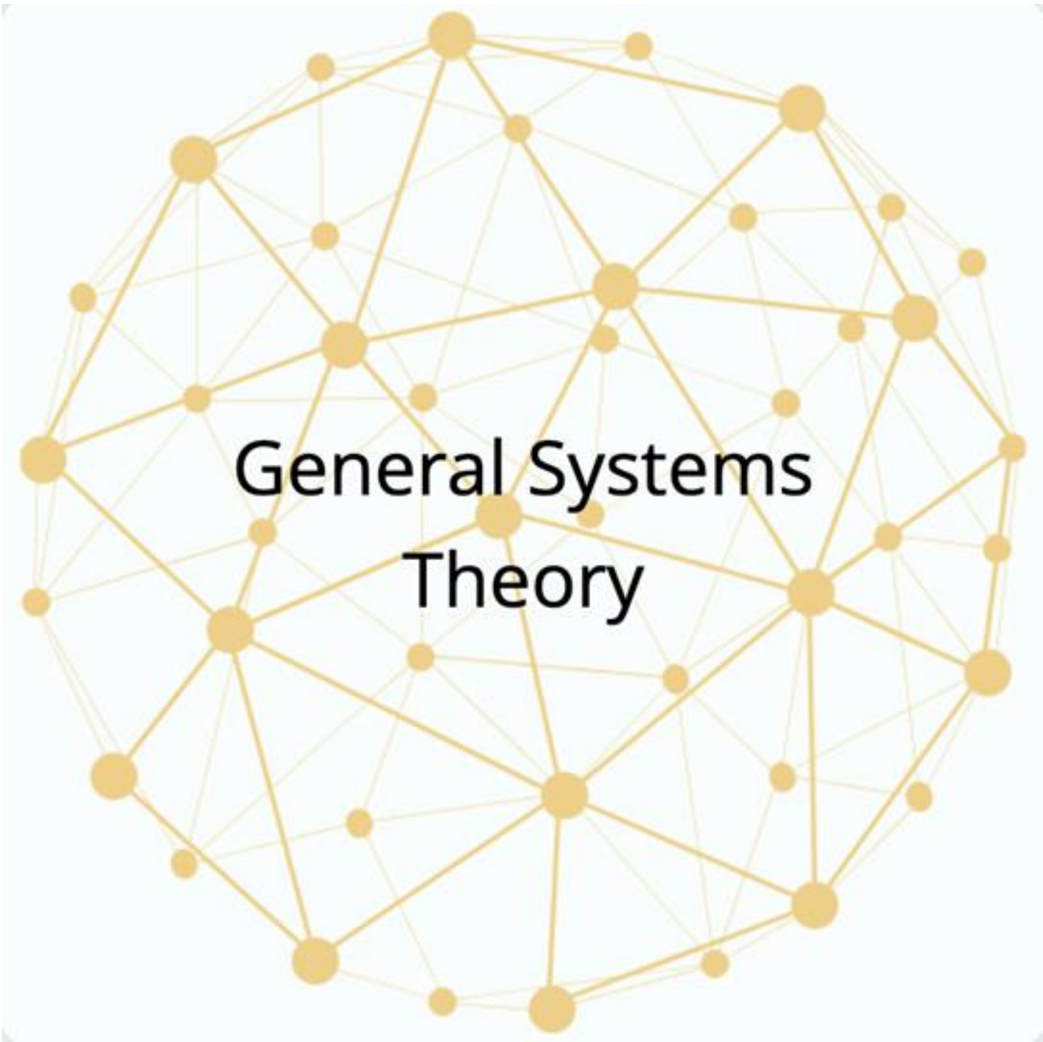
Conclusion: Our Synthetic Argument

- Our argument is not that the Maximum Power Principle replaces other thermodynamic optimality principles. Rather, it provides a framework for understanding how they relate to one another. These principles describe different aspects of a single evolutionary process operating under different constraints.

- From this perspective, thermodynamic evolution is best understood not through a single optimality principle in isolation, but through a systems approach that reveals their underlying connections.



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