Beyond Darwin: General Theory of Evolution of Everything

From the origin of life to the market economy

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Short title: The Theory of Evolution of Everything

If you don't have a theory, you might just as well count the stones on Brighton beach

Charles Darwin[1]

There is nothing so practical as a good theory.

Kurt Lewin[2]

[1] Cited in (Penny 2009)

[2] Cited in (Lewin 1951)

Abstract

The basic concern of the general theory of evolution is to understand the entire evolution from the origin of life to the biological, technological, social, and economic structures of the present from a unified point of view and structure.

The general theory of evolution can be seen as a comprehensive generalization and extension of Darwin's theory of evolution. It goes far beyond conventional extensions of Darwinian theory, such as synthetic evolutionary theory or multistage selection or evo-devo or epigenetics. Essentially, it views evolution from the perspective of the evolution of information. It expands the Darwinian terms of "biological species," "genotype," "phenotype," "mutation," and "selection" and replaces them with much more general terms. These conceptual extensions make it possible to describe evolutionary developments in quite different areas from a unified point of view and within a unified time frame.

The basic idea is to understand the evolution of everything as the emergence of new information types and new information technologies in the following sense:

- A new type of information is associated with the emergence of a new storage technology

- For each new type of information, 3 information technologies emerge one after the other:

Storage technology, Duplication technology, processing technology.

With this concept, the chronology of the entire evolution can be divided in a natural way into 7 ages with 3 sub-ages each, which correspond to the 7 information types with their corresponding 3 information technologies. Better and better information technologies are the basis for the fact that more and better targeted variation mechanisms could be formed. This explains the exponential increase in the speed of development and why development is probably heading for a singular point.

The following topics represent a selection of new ideas presented in detail in the paper:

- Evolutionary theory of information

- Link between the evolutionary theory of information and the general theory of evolution.

- Megatrends of evolution

- Evolution of the driving forces

- Targeted variation mechanisms as essential elements of evolution

- Constraints as essential elements of evolution

- The illusion of free will as an evolutionary trait of success

- The documentation of debt relationships (especially in the form of money) as a catalyst for win-win and cooperation mechanisms

- The difference between individual utility optimization and total utility maximization

- From Artificial Intelligence 1.0 to Artificial Intelligence 2.0

Keywords: evolutionary theory, evolution of information, variation mechanisms, evolutionary systems, chronology, megatrends, driving forces, win-win mechanisms, evolution of cooperation, singular point, artificial intelligence 2.0

Contents

1. Introduction

1.1. So why is the world the way it is?

The central purpose of this paper is to understand the essential mechanisms of evolution that have led to the world being the way it is.

In order to understand developments, to recognize essential correlations and to be able to shape the future based on them, **5 principles must be** observed in any case:

1. The long-term development of living systems is determined by the **theory of evolution:**
   The behavior of living individuals is determined by environmental influences and stored information in the general sense. Information in the general sense is information that is passed on directly or indirectly to other individuals or subsequent generations. At the simplest stage of evolution, this information consists of the genetic information laid down in genes. In higher evolutionary stages, the information that is passed on also consists of information that is stored, for example, in the cerebrum or in "external" information stores. This information is qualitatively changed by various influences such as mutation, sexual reproduction, experience, scientific knowledge, etc., and its frequency is altered by various mechanisms such as selection and gene drift. In this altered form, they are in turn passed on to others. That information which has a survival advantage over other information can either prevail over the others in competition or occupy new life niches without displacing the old ones

2. The **evolutionary theory of information** describes in which order and in which time periods new information types (data types) with in each case new storage technologies, new duplication and new processing technologies for the information have developed in the course of the evolution. As a rule, the new technologies did not displace the other technologies in the sense of competition, but the new technologies were only possible on the basis of the existing technologies and were newly added.

3. If we want to understand the present and shape the future, we have to **look into the past**. Only if we have understood the principles of evolution in the past, we have a chance to estimate if and how these principles might change in the future and how these principles might determine the future.

4. The essential developments and structures are determined by **positive feedbacks**, i.e. by self-reinforcing forces. This leads to exponential developments.

5. If you want to recognize the essential regularities and interrelationships, you have to choose the **right scale** for this when looking at things and simplify them accordingly, otherwise "you can't see the forest for the trees."

1.2. The general theory of evolution of everything

The general theory of evolution we develop in this paper is a theory of the evolution of everything. The basic concern is to understand the entire evolution from the origin of life to the biological, technological, social, and economic structures of the present from a unified point of view and structure.

The **general theory of evolution** can be seen as a **comprehensive generalization and extension of Darwin's theory** of evolution. It does not involve modifications of Darwinian theory (see e.g. (Lange 2020)) in the sense of synthetic evolutionary theory or the extension of the concept of selection to include multilevel selection (Wilson und Sober 1994) or new insights from evolutionary developmental biology (Evo-Devo) (Müller und Newman 2003) or epigenetic research. The general theory of evolution goes far beyond this. It extends the terms "biological species", "genotype", "phenotype", "mutation" and "selection" corresponding to the Darwinian theory and replaces them with much more general terms:

Darwinian theory of evolution	→	**general theory of evolution**
biological species	→	species (in a broader sense)
genetic information, genotype	→	general information
phenotype	→	form
mutation mechanism, mutation	→	variation mechanism, variation
selection dynamics	→	evolutionary dynamics

These conceptual extensions allow evolutionary developments in quite different fields to be described from a unified point of view and within a unified time frame. Some examples:

Biology	hominins → homo → homo sapiens
Data types	RNA → DNA → electrochemical potential
Targeted variation mechanisms	Imitating→learning→teaching
Technologies	writing → letterpress → computing
Monetary systems	commodity money → coinage money → paper money → electronic money
Economic systems	exchange → division of labor → investment
Economic regimes	market economy → capitalist market economy →global capitalist market economy

Cooperation	group coop. → direct coop. → debt coop. →indirect coop. → norms coop
Driving forces	gradient of concentration →gradient of electrochemical potential →gradient of utility

Just as a biological species is characterized by its genetic information (genotype) and the organism formed by the genotype and its biological traits(phenotype), a "species in a broader sense" is characterized by general information and by the particular form formed by the information and its properties.

Just as mutation mechanisms lead to mutations (=changes in genetic information), variation mechanisms lead to variations (=changes in general information). Selection dynamics describes the survival of the best adapted individuals, biological species and their genetic information. Evolutionary dynamics (dynamics of evolutionary systems) describes the development of the frequencies of species in a broader sense, of forms and of the underlying general information. Typically, dynamics and therefore selection dynamics and evolutionary dynamics (dynamics of evolutionary systems) are formally described by differential equations.

These terms are explained in more detail using 3 examples:

1. Example from Darwin's theory of evolution:

DNA is a technology for storing **genetic information**. The DNA leads to a biological traitin an individual A, e.g. a reproduction rate b_A . This genetic information can be changed into a new (genetic) information by a **mutation mechanism** (coincidence, chemical substances, radiation, etc.). This new changed information is called a **mutation**. It leads to an organism B with a changed biological trait, e.g. a reproduction rate b_B . The temporal develop-ments (**evolution dynamics**) of the frequencies of A and B are described by a differential equation system (**evolutionary system**). If the reproduction rate b_B is greater than the reproduction rate b_A , the offspring of B will reproduce faster than the offspring of A and the relative proportion of A will become smaller and smaller over time ("survival of the fittest"). This particular dynamic is called **selection dynamics**.

2. Example from the general theory of evolution (on the concept of general information and form):

Each special **biological species** of mammals is characterized by its special genetic information (**genotype**), from which the special organism with its traits (**phenotype**) results. Analogously, a market economy occurs in different **species (in a broader sense).** Each particular type of market economy is shaped by a variety of different **general information**, such as technological knowledge, governmental norms of behavior, genetic traits of people, and so on. From this special general information, a special **form of** economic activity with all its traits emerges in each case, e.g. the capitalist market economy or one of its special forms.

3. Example from the general theory of evolution (on the concept of variation mechanism, variation, evolutionary system and evolution dynamics):

The **neural network** in a person's cerebrum is a technology for storing **general information**, such as complex causal relationships, e.g.: "If you look for wild grain, you will have food". This information leads to a certain behavior. This general information stored in the cerebrum as a causal relation, can be changed into a new causal relation by the **variation mechanism** "**learning**", e.g..: "If you do not eat all the cereal grains, but sow some of the cereal grains, you will not have to search for cereal grains anymore, but you will be able to harvest more cereal grains". This new causal relation stored in the cerebrum (grow grain → eat more food) thus represents a **variation of** the old causal relation (seek grain → eat).

The old causal relation leads to a dynamic system (**evolutionary system**), which describes the temporal development (**evolution dynamics**) of the frequencies of the gatherer. Through the variation mechanism "learning" the old general information (the old causal relation) is transformed into a variation (the new causal relation). The new causal relation leads to a new dynamic system (evolutionary system), which describes the temporal development (evolution dynamics) of the frequencies of the sower and its food.

Note on terminology: The term "learning" or other terms such as "norm" or "exchange" are often used for the sake of simplicity for the entire mechanism consisting of variation mechanism, variation, evolutionary system and evolution dynamics, or for individual parts of it in the same way. As a rule, however, this does not lead to any problems of understanding, because it is clear from the context what is meant.

The **basic idea** of the general theory of evolution is to understand the "evolution of everything" as the emergence of new types of information and new information technologies in the following sense:

- A new type of information is associated with the emergence of a new storage technology.

- For each new type of information, 3 information technologies emerge in succession:

Storage technology, duplication technology, processing technology.

With this concept, the chronology of the whole evolution can be naturally divided into 7 or 8 ages:

Age	**Start Years ago**	**Storage medium**
[0]	4,6 10^9	Crystal
[1]	4,4 10^9	RNA
[2]	3,7 10^9	DNA
[3]	6,3 10^8	Nervous system
[4]	6,0 10^6	Cerebrum
[5]	5,0 10^3	External local memory
[6]	1,0 10^1	Cloud (Internet, networked memory)
[7]	*future*	Man-machine symbiosis

Each of the 7 ages can typically be divided into 3 sub-ages corresponding to the 7 information types with their corresponding 3 information technologies. Better and better information technologies are the basis for the fact that more and better targeted variation mechanisms could be formed. This explains the exponential increase in the speed of development and why development is probably heading for a singular point.

The course of evolution can be understood by the **following diagram**, which describes the evolution of evolutionary systems and variation mechanisms.

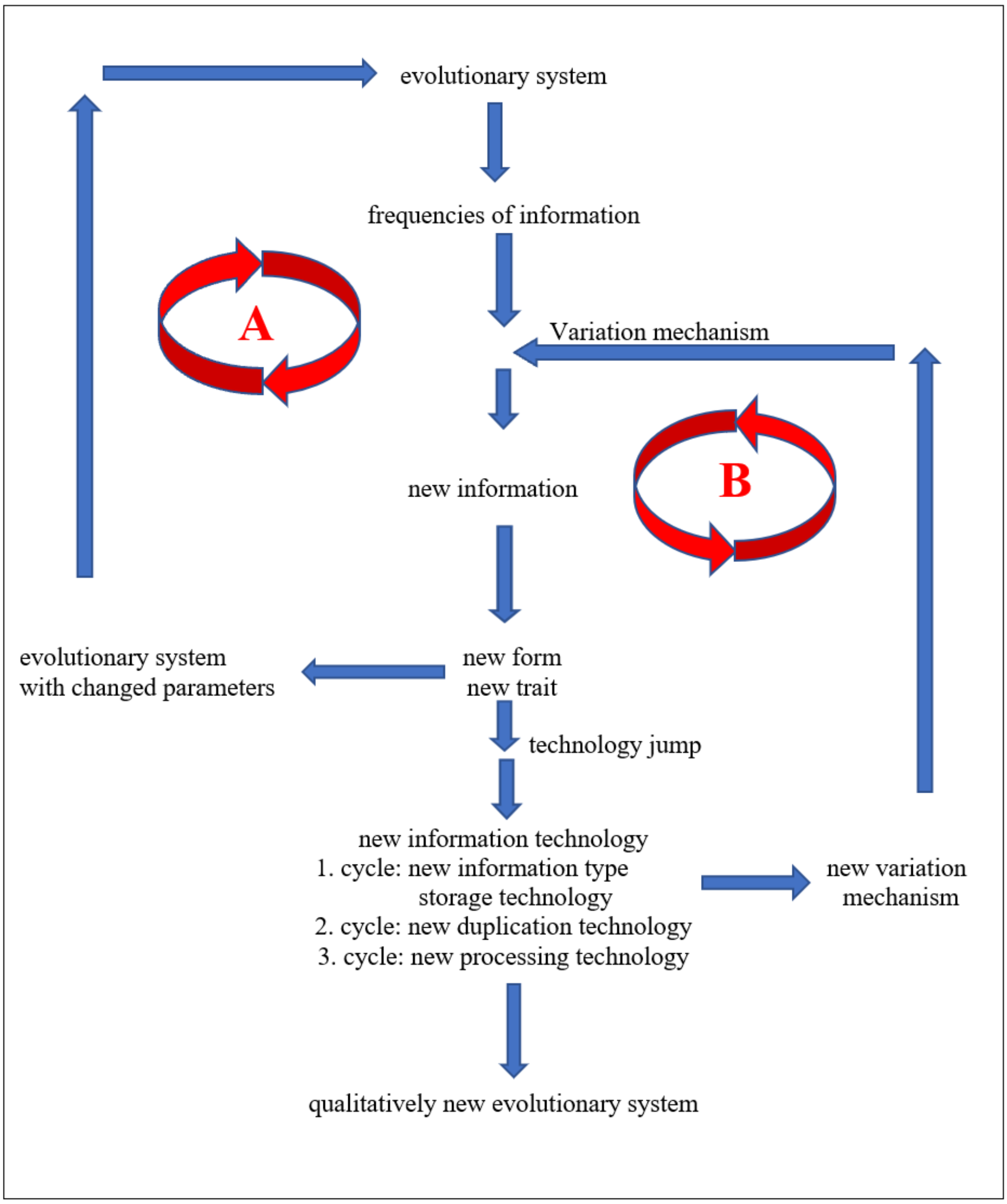


Diagramm:

Cycle A *represents essentially the Darwinian theory for terms of the general theory*
Cycle B *represents an essential extension of the Darwinian theory to the general theory*

Cycle A essentially describes the **Darwinian theory**, which also applies to the new terms of the general theory of evolution. We write the respective Darwinian terms in brackets in the following. An evolutionary system (selection system) determines the dynamics of the frequencies of information (genetic information). A variation mechanism (mutation) leads to a new information (genetic information), from which a new form (phenotype) is formed. The new traits of the form (phenotype) lead to a new evolutionary system (selection system) with new parameters and the cycle A starts again from the beginning.

Cycle B describes one of the most important **extensions of Darwin's theory to the general theory of evolution**. Cycle A is run until a new trait appears in a new form that corresponds to a technological leap in an information technology. This technological leap may result from a new type of information with associated storage technology, a new duplication technology, or a new processing technology. It leads on the one hand to a qualitatively new evolution system and on the other hand to a new variation mechanism. This new variation mechanism influences in the consequence quite substantially the cycle A. In the sequence the cycle A is run through as long as until it comes to the next technology jump. Then again a qualitative new evolutionary system and a new variation mechanism emerges.

Examples of variations are all "random" mutations but also "targeted" variations that arise from **targeted variation mechanisms**. Such targeted variation mechanisms include: "imitating, learning, teaching", cooperation mechanisms, documentation of debt relationships by money, logical thinking, utility optimization, animal and plant breeding, genetic manipulation, etc.

Targeted variation mechanisms have a particularly high influence on the speed of evolution, because thereby detours of the evolution are shortened as it were and "wrong developments" are avoided.

The structure of the diagram and the emergence of more and targeted variations makes it possible to understand the exponential increase in the rate of evolution and why evolution is likely heading toward a singular point.

The general evolution theory describes in the above sense in a systematic way all developments as they have proceeded on the earth under the given chemical-physical conditions since about 4 billion years. The essential considerations to it are, however, of such fundamental nature that the hypothesis is put forward that the evolution on other planets develops necessarily after the same 3 principles:

(1) that evolution inevitably produces new types of information, each with new storage technologies, new duplication technologies and new processing technologies,
(2) that the evolution is moving from simple systems to more and more complex systems, and
(3) that once evolution gets going, it proceeds at an exponentially increasing rate.

However, this does not at all lead to the conclusion that evolution always leads to the same result. The mechanisms of evolution are typically characterized by self-reinforcing mechanisms. Therefore, random changes in individual cases can lead to completely different processes of evolution. Even if evolution always proceeded according to the same principles, it would therefore lead to different results and traits in individual cases, even if the chemical-physical conditions were the same.

The following topics represent a selection of further new ideas presented in detail in the paper:

- Evolutionary theory of information
- Link between the evolutionary theory of information and the general theory of evolution.
- Megatrends of evolution
- Evolution of the driving forces
- Targeted variation mechanisms as essential elements of evolution
- Constraints as essential elements of evolution
- The illusion of free will as an evolutionary trait of success
- The documentation of debt relationships (especially in the form of money) as a catalyst for win-win and cooperation mechanisms
- The difference between individual utility optimization and total utility maximization
- From Artificial Intelligence 1.0 to Artificial Intelligence 2.0

1.3. A short literature overview

For books with similar claims and thoughts on evolution as a whole, see also (Dawkins 1989; Wright 2001; Kurzweil 2005; Eigen 2013). In (Stewart 2020), John E. Stewart outlines a general theory of the major cooperative evolutionary transitions.

For books with similar claims and thoughts on the evolution of humanity, see also (Sumner 2010; Graeber 2011; Harari 2011; Nowak und Highfield 2012; Elsner 2015; Ridley 2015; Wilson 2019; Villmoare 2021).

For books with similar claims and thoughts especially about the future evolution of mankind see also (Lange 2021)

For books with similar claims and thoughts on the evolution of economics and technology, see also (W. B. Arthur u. a. 1997; W. B. Arthur 2011). The terms "evolutionary economics" (Nelson und Winter 2004) and "evonomics" (Shermer 2008) stand for the insight that economic systems basically evolve in the same way as biological systems.

As a basic structure for the general theory of evolution, an "evolutionary theory of information" is developed in this book (see section A). Other concepts in which general basic structures for understanding evolutionary principles are developed are e.g.:

- the concept of "character, modularity, or homology" see (Wagner 2001; Schlosser und Wagner 2004; Wagner 2014),
- the concept of the "constructal law" see (Bejan 2016),
- the concept of "dynamic kinetic stability" see (Pross 2011), which tries to integrate the evolution of inanimate matter (in form of molecular replicating systems) and the evolution of animate matter within a single conceptual framework.

An overview of the explanatory structure of evolutionary theories and their stable laws can be found in (Pásztor und Meszéna 2022)

An overview of the multiple interconnections of evolutionary research in the narrow sense with a variety of non-biological disciplines can be found in Part IV of (Sarasin and Sommer 2010).

1.4. Contents overview

The paper is divided into 2 parts: The first part (sections A, B, C) describes the general theory of evolution largely verbally and can be understood by the interested non-expert without any significant prior knowledge. The 2nd part (section D, E) brings theoretical deepening and addresses itself rather to specialists (for section D physical and chemical previous knowledge is of advantage and for section E knowledge of the formal evolution theory is of advantage). Sections D, E provide for many terms and relationships formal physical and mathematical formulations and shows among other things

- the evolution of the physico-chemical driving forces of the dynamic processes of life and the rate of evolution (section D).
- The relationship of the "general theory of evolution" to the description of evolution using evolutionary games (section E).

An overview of the contents of the evolutionary theory of information (section A), the general evolution theory (section B) and the evolution of the physico-chemical driving forces (section D) can be obtained most easily by using the table in chapter 1.4.

Section A describes the **evolutionary theory of information**. The evolution theory of the information is no theory which can be derived compellingly from the natural science, but it describes regularities with which the course of the evolution can be understood better. Temporally the bow spans itself thereby from the emergence of the earth up to today. These regularities are in accordance with the empirical facts of the course of the evolution and are well founded in the following sense:

- Each data type can have relevance for the evolution only if there is a storage technology for this data type.
- Without storage technology a duplication technology is ineffective, which has the consequence that every duplication technology belonging to a data type could develop temporally only after the development of a storage technology.
- A processing technology usually produces a single new piece of information at first. However, this new information cannot become significant for evolution until a duplication technology exists. Therefore, new processing technologies for the respective data type can evolve temporally only after the emergence of a duplication technology.
- Each of the new technologies was more complex and powerful than the previous technologies and built upon them. Thus, due to the positive feedbacks in this process, there is an exponential development of the system's performance and an exponential increase in the speed at which the new information technologies emerge.

The core statements of the evolutionary theory of information are:

- A new type of information is always linked to the appearance of a new storage technology
- For each new type of information, information technologies emerge in sequence:

    - Storage technology
    - Duplication technology
    - Change technology or processing technology
- The speed at which new technologies have emerged has accelerated extremely.

Because the principles of the evolutionary theory of information obviously apply independently of the special physical-chemical conditions on Earth, it is hypothesized that evolution on other planets also proceeds according to the same principles.

The easiest way to get an overview of the contents of the evolutionary theory of information (section A) is to refer to the table in chapter 2.3.

In **section B** it is shown how the evolution of living beings from the beginnings of life to the present time can be better structured and understood as evolution of variation mechanisms and evolution of evolutionary systems with the help of the evolutionary theory of information. As **evolutionary systems** we call dynamic systems, which describe the dynamics of the interaction of the species (in the broader sense) and as **variation mechanisms** we call mechanisms, which lead to a substantial change of the evolutionary systems.

The **central thesis of** section B is that each new information technology (in the sense of the evolutionary theory of information of section A) leads to characteristic new biological or technological properties. These enable new mechanisms of variation and thus lead to new evolutionary systems. It follows that the temporal evolution of the variation mechanisms and the evolutionary systems is closely linked to the temporal evolution of the information technologies. The temporal arc spanned here therefore reaches again from the formation of the earth up to the present time.

An overview of the general theory of evolution (Section B), i.e., the evolution of variation mechanisms and evolutionary systems and their relation to the evolutionary theory of information, can be most easily obtained from the table in chap. 2.3.

Section C summarizes the **"megatrends" of evolution** that have occurred in the past. The basic process of evolution, namely the development of increasingly complex information types and information technologies in terms of the evolutionary theory of information, is largely determined by the laws of nature. Evolution would therefore lead to a similar sequence of such complex structures on another planet. In each individual case, however, very different sequences and structures could result because of the randomness in the details of the variation mechanisms. The result of the evolution would have to result by no means always something what could be called human being, which is however by no means a contradiction to the general development sequences of the evolution. Biological and philosophical considerations can also be found in the essay by Jaques Monod "Chance and Necessity" (Monod, Eigen 1983).

Another central thesis deals with the possible future developments: Because everything has changed so far with exponentially increasing speed and is still changing, we are obviously facing a singular point in the development or evolution of mankind. However, at a singular point in a dynamic system, there are typically unpredictable, fundamental qualitative changes in the behavior of the dynamic system. Although the fundamental concern and motive is to understand the past precisely in order to make predictions about the future, the only viable insight that remains is that it is extremely problematic to make predictions about the future because of the expected singularity in evolutionary development. Nevertheless, some basically conceivable scenarios for the near future will be discussed.

In the **second part of the paper,** many concepts and relationships that have been largely described verbally in the first part are made more precise by formal physical and mathematical formulations. **Section D** explains the evolution of the driving forces which, from the scientific point of view, are behind all dynamic processes of life and shows that the evolution of these driving forces is closely related to the appearance of the various new types of information over time. In addition, it justifies why the rate of evolution at which the number of species and the complexity of species have evolved has increased in an exponential manner.

In **Section E, the** key concepts and principles describing evolutionary systems and variation mechanisms are clarified with more formal mathematical formulations.

1.5. Tabular overview of section A, B and D

The table can be read approximately in the following sense:

(1) In the age **column 1**,

(2) that started **column 2** years ago**,**

(3) evolved the living creatures **column 3**,

(4) equipped with the storage medium **column 4**,

(5) which enabled the storage of the information type **column 5.**

(6) The biological-technological trait **column 6** (of the living creatures column 3).

(7) corresponds to information technology **column 7**

(8) and leads to the social form **column 8**.

(9) The biological-technological trait column 6 enables the variation mechanism **column** 9

(10) and this leads to the evolutionary system with the evolution dynamics **column 10**.

(11) The driving force of the evolutionary dynamics is given by **column 11**.

Age			Section A Evolutionary theory of information					Section B general theory of evolution		Paragraph D Evolutionary theory of driving forces
1	2	3	4	5	6	7	8	9	10	11
Designation	**Start years ago**	**Living being Form**	**Storage medium**	**Information type**	**Biological-technological trait**	**Information technology**	**Leads to social form**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**	**Driving force**
[0]	$4{,}6.10^9$ Chaoticum	Inanimate matter	Crystal	Crystal	Self-organization due to decreasing temperature	**Emergence of** information	--	Temperature Pressure	Crystallization	Decreasing **temperature**
[1.1]	$4{,}4.10^9$ Zirconium	RNA molecules	RNA	Digital single strand	Self-organization at crystal surfaces	Information **storage**		Environmental change	Creation Destruction	Decreasing **temperature**
[1.2]	$4{,}0.10^9$ Eoarchaikum	Ribocytes			Autocatalysis of RNA creation	**Duplication of** information		Mutation mechanism	Genotype selection (survival of the fittest genotype)	
[2.1]	$3{,}7.10^9$ Paleoarchaic	Single-celled organism	DNA	Gene (digital, double strand)	Genetic code Phenotype formation	**Storage of** genetic hereditary information	Organism	Constraint, Epigenetics	Phenotype selection (survival of the fittest phenotype)	Minimization of free enthalpy along the **chemical gradient** (which is built up by supplying energy from the outside).
[2.2]	$2{,}1.10^9$ Paleoprotero-zoic	"Simple" multicellular			Cell division Cell association	Intraindividual **duplication of** genetic hereditary information		Network formation Horizontal gene transfer	Network-Win-Win	
[2.3]	$1{,}0.10^9$ Neoprotero-zoic	"Higher" multicellular organisms (with sexual reproduction)			Sexual reproduction	Interindividual **processing of** genetic hereditary information,		Sexual reproduction	Variety of very complex dynamics	

1	2	3	4	5	6	7	8	9	10	11
[3.1]	6,3. 10^8 Ediacarium	"Predatory" animals (predatory plankton, bilateria, chordate, etc.)	Electrochemical potential in nervous systems	External and internal analog information	Nerve cells (sensors, nerves, neural tube, spinal cord)	Perception and **storage of** external and internal information, "monosynaptic reflex arc" (passing on the information to **one** organ)	Individuals and ecosystems	General interactions (eating, altruism, selfishness, etc.) Networking	Predator-prey system Prisoner's dilemma Network collaboration	Minimization of free enthalpy along the **electrochemical gradient** (which is built up by supplying energy from the outside).
[3.2]	5,5. 10^8 Cambrian explosion to Ordovician 4,85. 10^8	Apterygota Insects Fish Amphibians Reptiles Early birds Early mammals			Brainstem	**Reproduction of** the information, "polysynaptic reflex arc" (Passing on the information to **several** organs)		Imitating Group formation	Group cooperation	
[3.3]	6,6. 10^7 Tertiary	Higher mammals Higher birds			Cerebellum, Diencephalon (limbic system)	Information **processing** (passing on the **processed** internal and external information to several bodies).		Emotions direct reciprocity ("Tit for Tat")	Direct cooperation	
[4.1]	6. 10^6	Hominine (human-like)	Cerebrum	Complex contents of consciousness	Associative neural network	Recognition and **saving** of causal relationships ("learn": if A→ then B)	Social society	Learning 2-sided obligations	Debt cooperation	Minimization of free enthalpy in the neuronal **network of electrochemical potentials** of the cerebrum by **non-linear** processes, because the system is driven far away from equilibrium by the supply of a lot of energy from outside
[4.2]	9. 10^5	Homo			Simple language	Interindividual **duplication of** experiences (communication)		Teaching Reputation, Indirect reciprocity, Social debt, Exchange	Indirect cooperation Exchange	
[4.3]	7. 10^4	Homo sapiens			Cognitive revolution: abstract language, logical thinking, consciousness, immaterial realities, individual utility optimization	Intra/interindividual **processing of** experiences into causal relationships (Why B? Then if A)		Logical thinking, Social norms (constraints), Individual utility optimization, Commodity debts, Division of labor	Norms cooperation Division of labor	

1	2	3	4	5	6	7	8	9	10	11
[5.1]	5.10^3	Market economy	External local storage	External data	Writing Coin money	External **storage** of digital data	Cultural and economic society	Written religious norms, Individual contracts, Quantitative individual utility optimization, Monetary debts, Purchase, Animal and plant breeding	Cooperation based on religious norm systems, Regional trade	Individual monetary economic utility optimization Dynamics along the resultants of the **individual utility gradients** (GCD General Constrained Dynamic)
[5.2]	5.10^2	Capitalist market economy			Letterpress Paper money	External **duplication of** data		National norms, Investment in real capital	Cooperation based on national systems of norms, National trade	
[5.3]	5.10^1	Global capitalist market economy			EDP Electronic fiat money	External **processing of** data into new data		International norms, Investment in human capita	Cooperation based on international norm system World Trade, Globalization	
[6.1]	10	Internet-market economy	External crosslinked storage Cloud	Knowledge	Internet International payment systems	Networked **Storage** / **Duplication** of data/knowledge	Globally networked Society	Attempt at overall utility optimization by global standards with sanctions, Investment in sustainability	Promoting cooperation based on global sanctions	Attempt to achieve global overall utility optimization through **individual utility optimization with constraints** (internationally sanctioned norms)
[6.2]	Present	AI-based economy			AI 1.0 based knowledge processing, Blockchain, SOWL (Synthetic optimized world language)	**Processing** knowledge into new knowledge and virtual reality (=production of knowledge and virtual reality)		Stabilization through AI-based automatic sanctions, Investment in stability, genetic manipulation	Enforcing global cooperation based on automatic global sanctions	
[7]	Future	Humanity as a single individual Cyborg	Quantum Computer	Comprehensive understanding	AI 2.0 based knowledge production, Direct human-machine communication, Fusion of real and virtual world	Direct man-machine **storage** / **duplication** / **processing** (production of comprehensive understanding by AI 2.0)	Universe-society	AI 2.0 based production of knowledge and comprehensive understanding, Direct human-machine communication, Merging real and virtual reality, Overall utility maximization	Completely new form of social organization	**Overall utility maximization** (dynamics along the overall utility gradient).

A. The evolutionary theory of information

2. Overview and clarifications

2.1. Motivation

Writing was invented 5000 years ago, letterpress printing 500 years ago, and electronic data processing (EDP) 50 years ago. Until the invention of writing, man was only able to store information in the cerebrum, to pass it on to others (to duplicate it) with language and to process it using logical thinking.

With the invention of writing, a new storage technology was invented that made it possible to store numbers, words and sentences externally. Numbers, words and sentences are a new type of information, namely digital data that could be stored externally (on clay tablets, papyrus, etc.). With the invention of letterpress printing, (efficient) duplication of this digital data was made possible for the first time. With the invention of electronic data processing, (efficient) processing of this data and thus the formation of new data from existing data was made possible for the first time.

The following features of this sequence are noteworthy:

- A new type of information was possible through the invention of a new storage technology
- The new information technologies emerged in the following sequence:
    - Storage technology
    - Duplication technology
    - Change technology or processing technology
- The speed at which new technologies have emerged has accelerated extremely.

The question arises whether these features are characteristic for the course of the entire evolution and which consequences for the future result from it. In the "evolutionary theory of information" it is tried to show exactly that, namely

- that the evolution of life is based on the development of ever new types of information,
- that the new technologies for these new types of information have always been in the order of storage, duplication and processing technology,
- that the speed at which new types of information or their storage, duplication and processing technologies have appeared has increased exponentially,
- that due to the exponentially increasing speed of the emergence of new developments we are today facing a singular or a critical point in evolution, and
- that it is characteristic for singular (critical) points that unpredictable qualitative changes of the system occur at them.

The evolution theory of the information is no theory which can be derived compellingly from the natural science, but it describes regularities with which the course of the evolution can be understood better. Temporally the bow spans itself thereby from the emergence of the earth up to today. These regularities are in accordance with the empirical facts of the course of the evolution and are well founded in the following sense:

- Each data type can have relevance for the evolution only if there is a storage technology for this data type.
- Without storage technology a duplication technology is ineffective, which has the consequence that every duplication technology belonging to a data type could develop temporally only after the development of a storage technology.
- A processing technology usually produces a single new piece of information at first. However, this new information cannot become significant for evolution until a duplication technology exists. Therefore, new processing technologies for the respective data type can evolve temporally only after the emergence of a duplication technology.
- Each of the new technologies was more complex and powerful than the previous technologies and built upon them. Thus, due to the positive feedbacks in this process, there is an exponential development of the system's performance and an exponential increase in the speed at which the new information technologies emerge.

Because the principles of the evolutionary theory of information obviously apply independently of the special physico-chemical conditions on Earth, it is hypothesized that evolution on other planets also proceeds according to the same principles.

2.2. Structure of the evolutionary theory of information

Each new age[3] is characterized by the appearance of an additional new storage medium with an associated information type:

Age	Storage medium	Information type
[1]	RNA	
[2]	DNA	Genes
[3]	Nervous system	Information about the outside world
[4]	Cerebrum	Complex contents of consciousness
[5]	External local memory	External data
[6]	Internet (networked memory)	Knowledge (networked data)
[7]	Quantum computer	Comprehensive understanding

[3] Note on the notation of the different ages: The numbering of an age is written in square brackets in each case

Each age is characterized by 3 new information technologies: a new storage technology, a new duplication technology, and a new processing technology.[4] These new technologies each correspond to a new biological-technological trait. It is plausible that a duplication technology presupposes a storage technology and that a processing technology presupposes a duplication technology. Thus, it is also plausible that they each developed in this temporal order.

In the sequel, we build on this evolutionary theory of information and show in section B that the new information technology with its biological-technological properties enables new variation mechanisms that lead to new evolutionary systems. Therefore, the evolutionary theory of information is the basis for understanding the evolution of variation mechanisms and evolutionary systems and the timing of the whole evolution.

When we speak of a point in time when a technology first appeared, we actually mean more precisely,

- that, firstly, this technology has become established for the first time in an **efficient** form and
- secondly, that it has led to **far-reaching changes**.

Thus, of course, even when characters were first stored on a clay tablet or on papyrus, it was possible to reproduce this clay tablet or papyrus by hand. There was also letterpress printing with fixed letters before letterpress printing with movable letters. So, when we talk about duplication technology for writing, we mean only letterpress printing with movable type, because it was this technology that was efficient and had a correspondingly large impact on society. Also, mechanical calculating machines existed long before electronic data processing. But when we talk about a new processing technology in this context, we mean electronic data processing, because it was the only one that was firstly efficient and secondly had far-reaching effects on society.

In each age, each of these new information technologies corresponds to a new biological trait and thus a new type of living being such as e.g.: RNA complex, unicellular, multicellular, chordate, reptilian, mammalian, hominid, Homo, Homo sapiens 70,000 years ago.

The new technologies have led to the fact that the development of new types of living beings in the above sense has continued. The various economic forms of mankind with the technologies of writing, printing, computing, the Internet, and the economic form of today's man, who is able to process knowledge into new knowledge with artificial intelligence and create virtual realities, represent new types of living beings from the point of view of the general theory of evolution. We do not know where evolution will take us in the future, but one of the possibilities is the fusion of humans and machines into a cyborg.

Each of the new technologies was more complex and powerful than the previous technologies and built upon them. Thus, due to the positive feedbacks in this process, there is an exponential development of the performance of the system and an exponential increase in the speed at which the new information technologies emerge. Humanity is therefore today facing a singular, critical point in evolution. As a result, there will be a qualitative break in

[4] Notation: The numbering of the (sub)ages characterized by the storage, duplication and processing technologies is also placed in square brackets in each case.

evolution, which may range from the destruction of human beings to the merging of real human beings with the virtual world.

2.3. Tabular overview about the evolutionary theory of information

Age			Section A Evolutionary theory of information				
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Designation	**Start years ago**	**Living being Form**	**Storage medium**	**Information type**	**Biological-technological trait**	**Information technology**	**Leads to social form**
[0]	$4,6.10^9$ Chaoticum	Inanimate matter	Crystal	Crystal	Self-organization due to decreasing temperature	**Emergence of** information	--
[1.1]	$4,4.10^9$ Zirconium	RNA molecules	RNA	Digital single strand	Self-organization at crystal surfaces	Information **storage**	
[1.2]	$4,0.10^9$ Eoarchaikum	Ribocytes			Autocatalysis of RNA creation	**Duplication of** information	
[2.1]	$3,7.10^9$ Paleoarchaic	Single-celled organism	DNA	Gene (digital, double strand)	Genetic code Phenotype formation	**Storage of** genetic hereditary information	Organism
[2.2]	$2,1.10^9$ Paleoprotero-zoic	"Simple" multicellular			Cell division Cell association	Intraindividual **duplication of** genetic hereditary information	
[2.3]	$1,0.10^9$ Neoprotero-zoic	"Higher" multicellular organisms (with sexual reproduction)			Sexual reproduction	Interindividual **processing of** genetic hereditary information,	

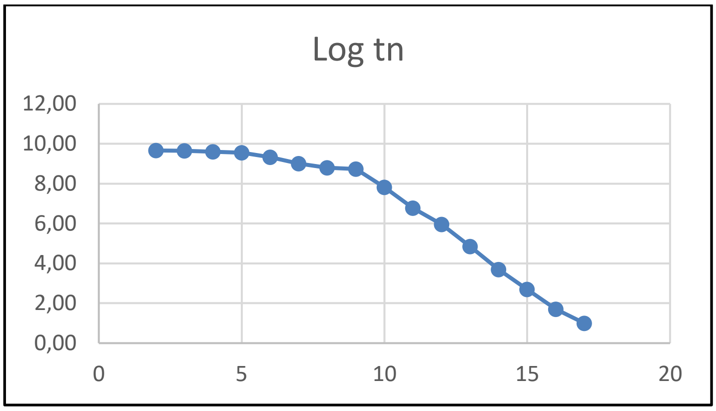
1	2	3	4	5	6	7	8
[3.1]	6,3. 10^{8} Ediacarium	"Predatory" animals (predatory plankton, bilateria, chordate, etc.)			Nerve cells (sensors, nerves, neural tube, spinal cord)	Perception and **storage of** external and internal information, "monosynaptic reflex arc" (passing on the information to **one** organ)	
[3.2]	5,5. 10^{8} Cambrian explosion to Ordovician 4,85. 10^{8}	Apterygota Insects Fish Amphibians Reptiles Early birds Early mammals	Electro-chemical potential in nervous systems	External and internal analog information	Brainstem	**Reproduction of** the information, "polysynaptic reflex arc" (Passing on the information to **several** organs)	Individuals and ecosystems
[3.3]	6,6. 10^{7} Tertiary	Higher mammals Higher birds			Cerebellum, Diencephalon (limbic system)	Information **processing** (passing on the **processed** internal and external information to several bodies)	
[4.1]	6. 10^{6}	Hominine (human-like)			Associative neural network	Recognition and **saving** of causal relationships ("learn": if A→ then B)	
[4.2]	9. 10^{5}	Homo		Complex contents of consciousness	Simple language	Interindividual **duplication of** experiences (communication)	Social society
[4.3]	7. 10^{4}	Homo sapiens	Cerebrum		Cognitive revolution: abstract language, logical thinking, consciousness, immaterial realities, individual utility optimization	Intra/interindividual **processing of** experiences into causal relationships (Why B? Then if A)	

1	2	3	4	5	6	7	8
[5.1]	$5.\,10^{3}$	Market economy	External local storage	External data	Writing Coin money	External **storage** of digital data	Cultural and economic society
[5.2]	$5.\,10^{2}$	Capitalist market economy			Letterpress Paper money	External **duplication of** data	
[5.3]	$5.\,10^{1}$	Global capitalist market economy			EDP Electronic fiat money	External **processing of** data into new data	
[6.1]	10	Internet- market economy	External crosslinked storage Cloud	Knowledge	Internet International payment systems	Networked **Storage** / **Duplication** of data/knowledge	Globally networked Society
[6.2]	Present	AI-based economy			AI 1.0 based knowledge processing, Blockchain, SOWL (Synthetic optimized world language	**Processing** knowledge into new knowledge and virtual reality (=production of knowledge and virtual reality)	
[7]	Future	Humanity as a single individual Cyborg	Quantum Computer	Comprehensive understanding	AI 2.0 based knowledge production, Direct human-machine communication, Fusion of real and virtual world	Direct man-machine **storage** / **Duplication** / **Processing** (production of comprehensive understanding)	Universe- Society

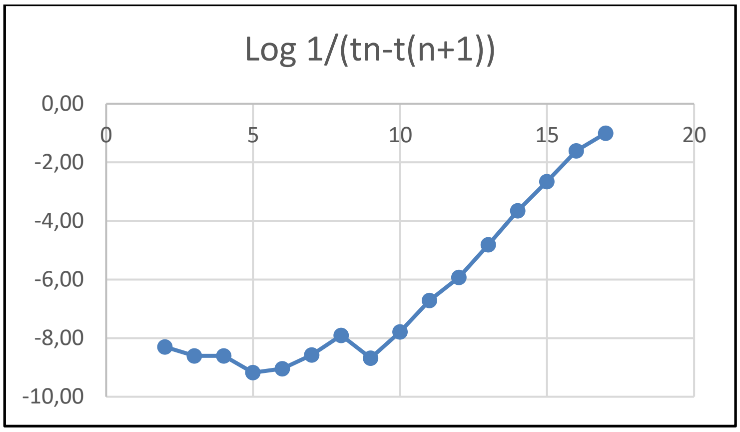
2.4. Tables and graphs showing the development over time

n	Age	Name	Years ago t_n	Log t_n	Log $1/(t_n - t_{n+1})$
1	[0]	Chaoticum	4 600 000 000	9,66	-8,30
2	[1.1]	Zirconium	4 400 000 000	9,64	-8,60
3	[1.2]	Eoarchaic	4 000 000 000	9,60	-8,60
4	[2.1]	Paleoarchaic	3 600 000 000	9,56	-9,30
5	[2.2]	Mesoproterozoic	2 100 000 000	9,32	-9,18
6	[2.3]	Neoproterozoic	1 000 000 000	9,00	-8,57
7	[3.1]	Ediacarium	630 000 000	8,80	-7,90
8	[3.2]	Cambrian explosion	550 000 000	8,74	-8,68
9	[3.3]	Tertiary	66 000 000	7,82	-7,78
10	[4.1]		6 000 000	6,78	-6,71
11	[4.2]		900 000	5,95	-5,92
12	[4.3]		70 000	4,85	-4,81
13	[5.1]		5 000	3,70	-3,65
14	[5.2]		500	2,70	-2,65
15	[5.31]		50	1,70	-1,60
16	[6.1]		10	1,00	-1,00
17	[6.2]		1	0,00	0,00

The occurrence of a new age signifies a qualitative leap in evolution through the appearance of a new information technology. Since the Cambrian, the rate at which qualitative leaps in evolution occur has been increasing exponentially (See the previous table and following graphs)



Graph 1: The course of the logarithm of the time of the beginning of the ages shows a largely linear course between the age [3.2] (Cambrian) and the age [6.2] (present). This means an exponential course of the evolution.

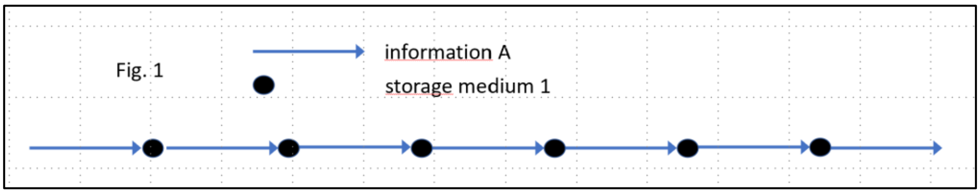


Graph 2: $t_n - t_{n+1}$ describes the duration of an age. $\frac{1}{t_n - t_{n+1}}$ therefore, describes the speed with which a new age occurs. The logarithm of this speed shows also between the age [3.2] (Cambrian) and the age [6.2] (present) a largely linear course. This means an exponential increase of the speed of the evolution.

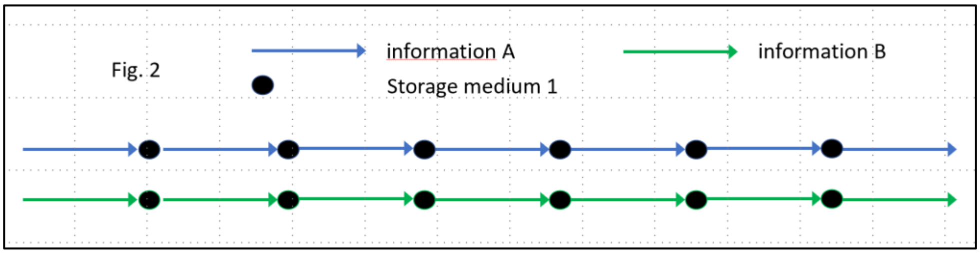
2.5. Clarification of the terms storage technology, duplication technology, processing technology

The sequence of the terms storage technology, duplication technology and processing technology is intended to characterize, more precisely, the qualitative difference in the graphs of information flow.

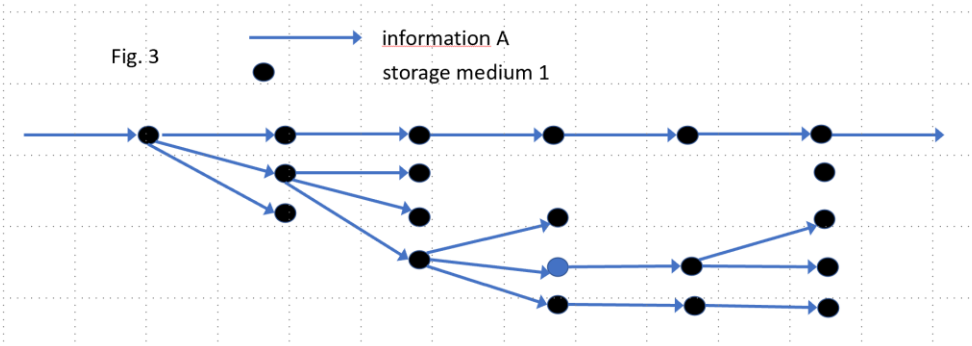
The information flow of an information A in a system with only one information type and one associated storage technology can be symbolically represented by Fig. 1:



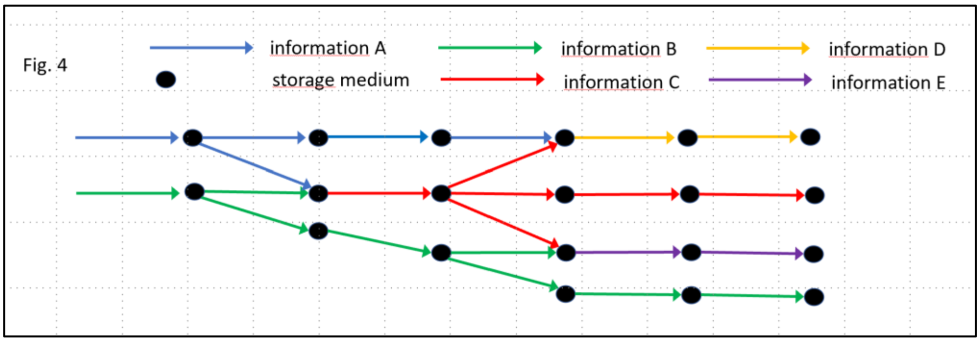
If a second piece of information is added, which is stored using the same storage technology, the result is:



A qualitatively new picture emerges when the information can be "multiplied" or, to put it more precisely, distributed not only to one memory but also "simultaneously" to several memories:



Again, a qualitatively completely new picture emerges when 2 or more different pieces of information can be processed into a third piece of information (i.e., when a new processing technology has evolved) and the duplication technology continues to come into play.



If a second new storage technology is then added, e.g. symbolized by ◆, then there is obviously again a qualitative leap in the complexity of the information flow graph.

The sequence of storage technology 1, duplication technology 1, processing technology 1, new storage technology 2, duplication technology 2, processing technology 2, new storage technology 3, and so on, is, precisely speaking, not meant to describe anything other than the qualitative increase in the complexity of the information flow graph.

Once again, it should also be pointed out that a single duplication of information does not yet constitute a real qualitative leap in complexity (e.g. printing with rigid type). Only when the frequency exceeds a certain threshold (in analogy to the exceeding of a critical temperature in physics), i.e. only when an efficient duplication technology is available which is used correspondingly frequently (such as letterpress printing with movable type), only then does a leap in complexity occur and thus a new period in evolution.

2.6. Causes of the big shifts in the biological-technological properties in the transition to a new age

In the theory of evolution, there has long been debate (Chouard 2010) as to whether big shifts in evolution were caused by single mutations with far-reaching consequences or by a large number of mutations with small effects that added up to large effects. It is becoming increasingly clear that both mechanisms probably play a role. On the one hand, evolutionary developmental biology (evo-devo for short) (Müller und Newman 2003; Theissen 2019; W. Arthur 2021) has shown that single mutations in the developmental control genes responsible for the individual development of individuals can lead to big shifts (see also chap. 5.8.1); on the other hand, mutations with small effects are important because they provide the necessary fine-tuning and sometimes pave the way for subsequent explosive evolution.

The general theory of evolution itself does not make any specific statements about individual stages of concrete variation mechanisms which have led to the individual qualitative big shifts in the transition to a new age. However, the central statements of the general theory of evolution (see chap. 6) are independent of the exact course of these mechanisms.

Again, it is to be pointed out

- that the general theory of evolution wants to recognize the essential regularities and connections and therefore things must be simplified accordingly, because otherwise "one does not see the forest for the trees".

- that biological-technological properties may have developed over a longer period of time, but that we only speak of a new property when it has become established in an efficient form and has led to far-reaching changes.

3. Evolutionary theory of information in the chronological sequence

3.0. The age of inanimate matter [0]

Information was first created in the Chaoticum about 4.6 billion years ago by self-organization in the form of crystal growth due to decreasing temperature of the Earth's surface.

3.1. The age of RNA [1]

3.1.1. RNA as a storage technology [1.1]

Ribonucleic acids (RNA) have formed more or less by chance or possibly by catalysis on inorganic crystal surfaces.[5] An RNA molecule is a single chain of the 4 bases adenine (A), guanine (G), cytosine (C) and uracil (U) and thus carries digital information.

RNA probably first appeared in zirconium 4.4 billion years ago.

3.1.2. Autocatalysis as a duplication technology [1.2]

The outstanding property of RNA is that some RNA molecules not only carry information, but also have the ability to promote the production of the same RNA molecules through self-catalysis[6]. This is described by the theory of hypercycles (Eigen und Schuster 1979). This form of autocatalysis results in the duplication of information. The RNA complexes formed in this way are called ribocytes. They can be regarded as the first precursors of living organisms. It is assumed that these first precursors of life were formed in the Eoarchaic period about 4.0 billion years ago (Stone 2013).

3.2. The age of DNA and the first living organisms [2].

3.2.1. DNA and genetic code as a storage technology [2.1]

A DNA molecule (deoxyribonucleic acid) consists of a double helix with 2 complementary chains of the 4 bases adenine (A), guanine (G), cytosine (C) and thymine (T). It thus carries digital information in the same way as an RNA molecule. Each DNA molecule represents a gene because it carries the genetic information for the synthesis of a protein molecule, which consists of a corresponding chain of 20 amino acids. The so-called genetic code specifies how a sequence of the 4 bases A, U, G, C is translated into a sequence of amino acids. DNA as a carrier of genetic information and the proteins formed from it were the components of the first living unicellular organisms. One-celled organisms can be regarded as the first living organisms.

The first single-celled organisms formed in the Paleoarchaic era about 3.7 billion (Dodd u. a. 2017) years ago.

3.2.2. Intraindividual cell division as a duplication technology [2.2].

The technology of cell division, in which 2 cells are formed from 1 cell by cell division, was the basis for the fact that unicellular organisms could survive and thus developed at the same time as the unicellular organisms. However, this did not yet create a new structure. New structures were only created by multicellular organisms. The technological progress consisted in the fact that these cells remained in a common cell association. It therefore corresponds to an intraindividual duplication of genetic information. Above all, however, it consisted in the fact that the cells could develop into different cells with different tasks and properties by "switching on" or "switching off" parts of the genetic information despite having the same genetic information.

This led to the formation of the first simple multicellular organisms in the Paleoproterozoic, about 2.1 billion years ago (Veyrieras 2019; Sánchez-Baracaldo u. a. 2017).

[5] According to more recent theories, it was not RNA but chemical hybrids between RNA and DNA and/or proteins that were the precursor of both RNA and DNA. For the sake of simplicity, however, we will speak only of RNA in this context.

[6] Sidney Altman and Thomas R. Cech Nobel Prize 1989

3.2.3. Sexual reproduction as a processing technology [2.3]

The technology of sexual reproduction can be seen as the first technology for the systematic processing of information. From 2 different cells with different hereditary information a new cell with a new hereditary information arises thereby, which developed by processing the hereditary information of the original cells.

The precursors of sexual reproduction were horizontal gene transfer and endosymbiotic gene transfer. Horizontal gene transfer involves the transfer of genetic material from one organism into an existing organism. It is particularly important in prokaryotes (cells without a nucleus). A second important precursor form was endosymbiotic gene transfer, which played an important role in the development of eukaryotes (cells with a cell nucleus) about 1.5 billion years ago. (French u. a. 2015) years ago. In this process, various unicellular organisms entered into an endosymbiosis, i.e. one continued to live in the other for mutual utility. Among other things, the mitrochondria were formed in this way.

In both precursor forms, however, there is no systematic processing of genetic information into new genetic information. This only occurred during sexual reproduction. Whereas previously changes in the genetic information of individuals were only possible through mutations and horizontal gene transfer, sexual reproduction resulted in a new mixture of the parents' genes in each new individual and thus a substantial increase in genetic diversity. Therefore, sexual reproduction led to a dramatic acceleration of evolution and the formation of the first higher multicellular organisms.

Sexual reproduction (Droser und Gehling 2008; Fraune u. a. 2012) could be proven already 565 million (Droser 2008) years ago. However, it probably already developed about 1 billion years ago.

3.3. The age of the nervous system [3]

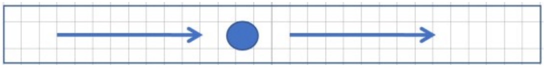
In the age of DNA [2], genes were the type of information for which a new storage technology, duplication technology and processing technology has emerged. The genes are information that is passed from generation to generation. The genes provide the information for the production of the protein that makes up the organisms.

In the age of the nervous system [3], on the other hand, it is information about the environment (external information) for which new storage, duplication and processing technologies have developed. The nervous system leads to closely communicating and cooperating cells. We call such a group of cells an individual. However, unlike genes, information about the environment is not passed from an individual of one generation to an individual of the next generation, but is stored, duplicated, and processed within an individual. Once this external information has been stored, duplicated or processed into new information within an individual, this information can then also be seen as internal information.

Particularly in connection with information on the environment, attention is drawn once again to the more precise meaning of the terms storage, duplication and processing technology as defined in chap. 2.5 pointed out. These terms actually refer to the increasing qualitative complexity of the information flow graph.

3.3.1. Sensors and spinal cord as a storage technology for information about the environment [3.1]

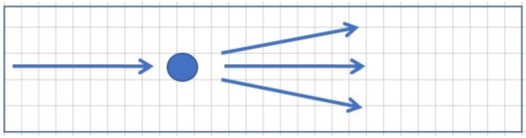
Sensors and the most primitive forms of the nervous system co-evolved in the form of neurons (nerve cells) in the Ediacarium about 630 million (Rigos 2008; Podbregar 2019) years ago. The first and simplest basic type is found in coelenterates (hollow animals) (Roth 2000). A central nervous system is first found in the simplest bilaterally symmetrical animals (Bilateria) (Roth 2000). Here, information about the environment is detected by sensors and transmitted, with or without intermediate storage, to a cell association or organ in which it triggers a single corresponding response ("monosynaptic reflex arc"). This is symbolically expressed by the following picture:



The technology with which this environmental information is stored and transmitted is widely known. It takes place via the change in concentration of ions in the nerve cells or, more precisely, via changes in the chemical potential.

3.3.2. The brainstem as an intraindividual duplication technology of information about the environment [3.2].

To put it simply, the brainstem in its evolutionary original form has been the trigger of reflexes. It is therefore often descriptively referred to as the reptilian brain. It has developed in the course of the so-called Cambrian explosion about 500 million („Der Hirnstamm oder das ‚Reptiliengehirn'", o. J.) years ago.[7] The difference between the simple nervous system (or spinal cord) and the original brainstem is that a reflex usually does not represent a single reaction of a single cell association, but corresponds to **several** simultaneously triggered activities of several organs or cell associations ("polysynaptic reflex arc"). This is symbolically expressed by the following picture:



Typical reflex-controlled activities are the important vital functions such as heartbeat, respiration, digestion, etc. but also protective reflexes such as eyelid blink reflex, escape reflex, etc.

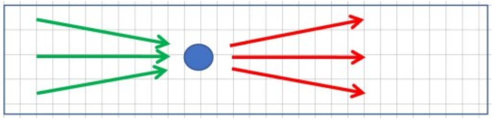
3.3.3. The cerebellum and diencephalon (limbic system) as the processing technology of information [3.3].

In its original form, the cerebellum is the integration center for learning, coordination and fine-tuning of movements.[8] It first developed in fish about 400 million years ago („Rätsel Kleinhirn" 2003). Input information is primarily visual, haptic, balance, and sensory

[7] Of course, the brainstem has evolved over the course of evolution to include more functions in its mammalian form than in its original form. In mammals, it includes the midbrain, the bridge, and the medulla oblongata. In this form, it not only triggers reflexes, but it also transmits all signals from the cerebrum to the organs, for example.

[8] Like the brainstem, the cerebellum has evolved over time to include more functions in its mammalian form than in its original form.

impressions. These are first processed in the cerebellum and then deliver motor commands to various muscle groups.



To process more complex information, the diencephalon (limbic system) developed later in evolution in the first mammals. However, the diencephalon only gained full importance with the explosive development of mammals in the Tertiary period 60 million years ago. This is why it is also called the mammalian brain („Das limbische System oder das „Säugergehirn"“)[9] because it is common to all mammals. It regulates sensations typical of the social nature of mammals, such as concern for offspring, fear, play instinct, and learning by imitation. All kinds of external sensory input and internal information serve as input information. These are processed into emotions such as fear, anger, love, or sadness. These emotions in turn trigger a variety of reactions. This is symbolically expressed by the following picture

3.4. The age of the cerebrum and social societies [4].

In the age of the cerebrum, it is not (only) the genes that are passed on from generation to generation as information, but above all individual complex contents of consciousness such as thoughts or behaviors that are stored in the cerebrum and processed there. Of crucial importance is that this information can not only be passed on (like genes) from parents to offspring, but that it can be passed on from any individual to any other individual e.g. via different forms of language. This leads to close relationships between individuals and thus to the formation of social societies, which are characterized precisely by close relationships between individuals.

3.4.1. The neural network of the cerebrum as a storage technology for individual experiences [4.1]

Although the cerebrum has existed for a much longer time from a purely physiological point of view, it only acquired its outstanding importance about 6 million years ago with the emergence of the first precursors of man, the hominins. The exact chemical, physical, mathematical form of how the complex contents of consciousness and thoughts are stored or processed in the brain is still not known. More or less clear is only that the basis for it are associative neuronal networks and the information is stored therefore not locally, but delocalized.

The special significance of the cerebrum lies in the fact that individual perceptions can be compressed into experiences and stored in this form. In particular, the recognition of possible causal connections is to be understood as experience: "Whenever event A can be determined, event B (probably) also occurs". This recognition of causal connections and the long-term storage possibility of many such causal connections in the cerebrum of an individual has led to a great survival advantage for the respective individual.

[9] https://www.gehirnlernen.de/gehirn/das-limbische-system-oder-das-s%C3%A4ugergehirn/

3.4.2. Simple language as a duplication technology for individual experiences [4 .2]

The next qualitative leap in evolution has come through the possibility of duplication of these experiences in the form of transmission to other individuals. The basis for the transmission was the development of simple languages, both in the form of sign languages and simple spoken languages, i.e. languages without sentence structure, abstract words and grammar. Simple language as a technology of reproduction developed about 900,000 years ago and is the most important characteristic feature of the genus Homo.

Of course, language was not only used to pass on experiences in the narrower sense. As a general means of communication, language naturally also had a great social influence.

3.4.3. Abstract language and reasoning as a processing technology [4.3]

The most essential characteristic feature of Homo sapiens is the abstract language with sentence structure, abstract words and grammar. It has probably developed together and simultaneously with the possibility of abstract thinking and logical reasoning. Abstraction and logical reasoning are the most important ways of processing the contents of consciousness. Abstract language therefore led to the so-called great cognitive revolution about 70,000 years ago[10] . (See also chap. 5.13)

In addition to the knowledge of causal relationships, it was thus also possible to search for the causes of events. I.e. in addition to knowledge in the form of the statement "if A, then B" it was now possible to think about the causes of B with the question "why B?”. This possibility was so fundamental that one could also characterize Homo sapiens by the fact that he is not only able to ask the question "Why?", but that he is virtually genetically conditioned to ask the question "Why?" for everything and to want to find an answer for everything. In this sense it is a tracing of the transition from the Homo to the Homo sapiens if children at the age of approx. 2-3 years incessantly ask the question "Why?

With good reason, therefore, one can also consider the concept of God as an abstraction of the answer to all those questions to which one has not found an answer. The **emergence of religions** can therefore be plausibly explained in the following way:

1. The question "Why?" resulted in an evolutionary advantage, because logical connections could be recognized with it and thus the future consequences of actions could be better estimated.

2 The concept of God arose naturally from this as an abstraction of the answer to all those questions for which no other answer could be found.

3 With the concept of God, the formation of religions was also possible, which led to an evolutionary advantage as a means of enforcing social norms.

[10] The term was introduced by Y.Harari (A Brief History of Mankind).

3.5. The age of local external storage and cultural and economic societies [5].

With the help of abstract language, it was initially only possible to pass on consciousness contents stored in the cerebrum in analogue form from one individual to another. In the age of local external storage, on the other hand, there is the additional possibility of storing, duplicating and processing information in the form of digital data. This leads to the formation of cultural and economic societies characterized by the fact that information could be accumulated and used over time.

3.5.1. Writing as an external storage technology for external data [5.1]

The invention of writing about 5000 years ago led to a technological leap in the quality of information storage, characterized by 2 technological innovations: first, writing made it possible to convert information into a digital form and, second, to store it in an external medium, i.e. outside living beings.

3.5.2. Letterpress printing as a duplication technology of external data [5.2]

Of course, records on clay tablets or papyrus and thus information stored in writing could always be reproduced by copying. However, the reproduction of information stored in writing only gained full social significance with the invention of letterpress printing with movable type around 500 years ago.

3.5.3. Electronic data processing (EDP) as a processing technology of external data [5.3]

From today's perspective (i.e., from the perspective of the year 2022), the triumphant run of electronic data processing began around 50 years ago. This made it possible for the first time not only to store and duplicate digital data efficiently and on a large scale, but also to process it.

3.6. The age of the Internet (age of delocalized networked external storage) and the globally networked cultural and economic society [6].

Some may be surprised that the Internet is not regarded simply as one of the many technological innovations in electronic data processing, but even as a new stage in its evolution. But the Internet represents a leap in quality that is still (dramatically) underestimated today. It is the basis for the fact that not only data, but above all information can be stored, duplicated and processed in a new form, namely in the form of knowledge. Knowledge in this context means data that are related to each other in a comprehensive sense. Of crucial importance here is that this information is available to practically everyone, leading to a globally networked cultural and economic society.

3.6.1. The Internet as a storage technology for knowledge [6.1]

In its original form, the Internet was conceived as a technology for data exchange. In this form, it was still to be understood more as a particularly efficient duplication technology for data. For about 10 years (from the perspective of the year 2022), however, the Internet has evolved dramatically in terms of quality.

The development of the Internet into a huge delocalized networked storage medium that can be accessed from anywhere at any time will lead to a fundamental upheaval of human society similar to what the development of the cerebrum or the development of external local data storage has done. It would be presumptuous to think that we can even begin to estimate the impact of this technological quantum leap today. Rather, our ignorance of the consequences today is comparable to the inability of human ancestors (hominins) to estimate the impact of the cerebrum. In the same way, at the time of the invention of writing, it was impossible to estimate the impact of the digitization of data.

Since access to the "cloud" is basically possible at any time and for everyone, the step to a duplication technology, which was still necessary in the previous periods, is no longer required.

3.6.2. Knowledge processing and artificial intelligence as processing technology to create new knowledge and virtual reality [6.2]

Today we are in the middle of the development of new information processing technologies. Until yesterday, intelligent action and creation of new knowledge was reserved for humans. Today, however, "artificial intelligence" is explosively permeating the whole society and we are on the threshold of technologies capable of creating new knowledge and virtual realities from existing knowledge scattered all over the Internet.

3.7. The future: the age of man-machine symbiosis? Mankind as a universe individual [7].

3.7.1. We are at a singular point in evolution

Summarizing the main characteristics of the evolutionary process so far, the following findings emerge:

- Evolution is quite significantly determined by the development of new information technologies in nature.
- Each new technology builds on the preceding technologies.
- Thus, through positive feedback, there is an exponential increase in the performance of technologies on the one hand, and an exponential increase in the speed at which new technologies develop in each case on the other.

Exponential developments cannot in principle be continued arbitrarily in real systems, but lead to a singular (critical) point. When such a critical point is crossed, there is usually a far-reaching qualitative break between the properties of the old and the new system. There are countless examples of this in physics, such as the transition from one state of matter to another.

What can we conclude from this for the future of evolution? Today we are probably standing before a critical point in the evolution. It is therefore very probable that it comes to a qualitative upheaval in the evolution, of which it is hardly assessable, however, in which direction it will run. In any case, it is conceivable that this upheaval could range from the destruction of mankind to the fusion of real people with the virtual world.

In any case, however, this will lead to such a close interconnectedness and interdependence of the individual human beings as is the case for the individual cells of an individual. The whole mankind on earth will therefore represent a single "universe individual" from the point of view of the universe and one can legitimately assume that there are numerous other such universe individuals in the universe.

3.7.2. Direct human-machine communication and symbiosis of real and virtual world as storage, duplication and processing technology for comprehensive understanding

On the horizon, the coming era could be characterized by quantum memory systems, quantum computers, by direct human-machine communication, and by other previously unimaginable technologies. A "comprehensive understanding" could take over the role that "knowledge" has today.

The only conclusion from the past of evolution that can be drawn with great certainty is that future developments can hardly be guessed at and are beyond any imagination.

B. The evolution of variational mechanisms and evolutionary systems

To review section B, we show in chap. 4.8 in a table the relation of the evolution of evolutionary systems and variation mechanisms to the evolutionary theory of information. In chap. 5 we describe the development of evolution leading from the inorganic world to the mechanisms of economy.

4. Overview

4.1. Outline

After the overview in chap. 4, we show in detail in chap. 5 how the general theory of evolution builds on the evolutionary theory of information and how the temporal evolution of variation mechanisms and evolutionary systems results from it.

The formal foundations of the general theory of evolution are presented at the end of the paper in section E (chap. 11 - 16).

We give a formal definition and examples of possible important evolutionary systems and variation mechanisms in chap. 11.1.

In the chapters 12 and 13, we describe the basic structure of **evolutionary systems**, the different types of evolutionary systems, and their qualitative behavior.

In chapters 14 we build the bridge between biological systems and economic systems. We show that they can be described methodically in the same formal form as so-called "General Constrained Dynamic Models".

In chap. 15 we classify the variation mechanisms according to their biological or economic causes, and in chap. 16 we classify them according to their effects.

4.2. Basics

The **general theory of evolution** can be seen as a **comprehensive generalization and extension of Darwin's theory** of evolution. It is not about modifications of Darwin's theory in the sense of the synthetic theory of evolution since 1930 or an extension of mutation mechanisms to include epigenetic changes in phenotypes, as they have been intensively researched since about 2000. The general theory of evolution goes far beyond this. It extends the terms "biological species", "genotype", "phenotype", "mutation" and "selection" corresponding to the Darwinian theory and replaces them with much more general terms:

Darwinian theory of evolution	→	general theory of evolution
biological species	→	species (in the broader sense)
genetic information, genotype	→	general information
phenotype	→	form
mutation mechanism, mutation	→	variation mechanism, variation
selection dynamics	→	evolutionary dynamics

In Darwin's sense, a biological species is determined by its genetic information. The genetic information (genotype) determines the biological traits and behavior of the corresponding individuals (phenotypes). The temporal evolution of the frequencies of the individuals and thus of the frequency genetic information is described by selection dynamics, which is determined by the different traits (fitness) of the species. Mutations lead to changes in the genetic information and thus to changes in the biological traits of the individuals (phenotypes), which in turn leads to a change in fitness and selection dynamics.

In the sense of the general theory of evolution, a **species (in a broader sense)** is determined by general information. This general information determines the biological or technological traits and the behavior of the corresponding forms. This results in an evolutionary system, which describes the temporal development of the frequencies of the different forms and thus of the frequencies of the different information. Different variation mechanisms lead to changes of the underlying information and thus to changes of the traits of the forms and consequently to changes of the evolutionary systems and their dynamics.

The general information relevant to the general theory of evolution is, as shown in the evolutionary theory of information in section A, not only the genetic hereditary information laid down in the DNA, but also all the other information mentioned.

As an **example of a form** serve today's capitalist market economy. This special form of economic activity emerges from a multitude of associated information (such as technological knowledge, governmental behavioral norms, genetic characteristics of people, etc.) in an analogous way as a special organism emerges from its associated DNA. The "way" of doing business is thus characterized by the underlying "information" and the resulting actual "form" of doing business.

Crucially for evolution, the general information and subsequently the evolutionary systems are modified by a wide variety of mechanisms. We therefore use the broader terms **variation mechanism** and **variation** instead of the narrow terms mutation mechanism and mutation. Examples of variations are all "random" mutations but also "targeted" variations that arise from targeted variation mechanisms. Such targeted variation mechanisms include: "imitating, learning, teaching", cooperation mechanisms, documentation of debt relationships by money, logical thinking, utility optimization, animal and plant breeding, genetic manipulation, etc.

When we speak of mutation, we mean in particular only the random change of DNA during replication, sexual reproduction or due to environmental influences. But this is only one of the possible mechanisms of changing a special information. For example, poor linguistic communication can also lead to a random change in the message transmitted. Furthermore, a message can not only arrive at the addressee altered by an accidental error, but can also be passed on "intentionally" incorrectly (e.g. "fake news"). Therefore, it remains to be investigated in the following whether and in which sense and to what extent and from when in the course of evolution targeted variation mechanisms of information have acquired a relevance.

The temporal evolution of the frequencies of the different species (in the broader sense) can usually be modeled by systems of differential equations. We refer to these differential equation systems as **evolutionary systems** and the temporal behavior they describe as **evolutionary dynamics.**

These **evolutionary systems** and the corresponding **evolutionary dynamics** are modified by a wide variety of variation mechanisms. Of particular importance is the qualitative behavior of the different evolutionary systems. The dynamics can lead to linear, exponential or interaction growth. In the same way stable equilibria between the different species are possible, but also cyclic or even too chaotic developments are possible. Evolutionary systems can not only describe the survival of species at the expense of the extinction of other species, i.e. selection in the narrow sense. They can also describe, for example, predator-prey behavior, Prisoner’s Dilemma behavior, cooperation, exchange, division of labor, investment, and so on.

The following 2 examples will be used to illustrate once again how the general theory of evolution can be understood as an extension of Darwin's theory of evolution.

1. **Example from Darwin's theory of evolution:**

DNA is a technology for storing genetic information. The DNA leads to a biological trait in an individual A, e.g. a reproduction rate b_A . This genetic information can be changed into a new (genetic) information by a mutation mechanism (random, chemical substances, radiation, etc.). This new changed information is called mutation. It leads to an individual B with an altered biological trait, e.g., a reproduction rate b_B . If the reproduction rate b_B is larger than the reproduction rate b_A , the offspring of B will reproduce faster than the offspring of A and the relative proportion of A will become smaller and smaller over time. This dynamic system is called selection dynamics.

2. **Example from the general theory of evolution:**

The **neural network** in a person's cerebrum is a technology for storing general information, such as complex causal relationships, e.g.: "If you look for wild grain, you will have food". This information leads to a certain behavior. This general information stored in the cerebrum as a causal relation, can be changed into a new causal relation by the **variation mechanism** "**learning**", e.g.: "If you do not eat all the cereal grains, but sow some of the cereal grains, you will not have to search for cereal grains anymore, but you will be able to harvest more cereal grains". This new causal relation stored in the cerebrum (grow grain → eat more) leads to a new dynamic system (**evolutionary system)** in which the frequencies of the gatherer on the one hand and the sower on the other develop in different ways.

The general theory of evolution describes in the above sense in a systematic way all developments as they have proceeded on the earth under the given physico-chemical conditions since about 4 billion years. The essential considerations about it are, however, of such fundamental nature that the hypothesis is put forward that the evolution on other planets necessarily develops according to the same principles:

(1) that evolution inevitably produces new types of information, each with new storage technologies, new duplication technologies and new processing technologies,
(2) that the evolution is moving from simple systems to more and more complex systems, and
(3) that once evolution gets going, it proceeds at an exponentially increasing rate.

However, this does not at all lead to the conclusion that evolution always leads to the same result. The mechanisms of evolution are typically characterized by self-reinforcing mechanisms. Therefore, random changes in individual cases can lead to completely different processes of evolution. Even if evolution always proceeded according to the same principles, it would therefore lead to different results and forms in individual cases, even if the physico-chemical conditions were the same.

4.3. The relationship between evolutionary theory of information and general evolutionary theory (evolution of evolutionary systems and variation mechanisms).

The Darwinian theory of evolution describes the emergence of new species on the basis of genetic information, mutation and selection. The general theory of evolution goes far beyond this. It not only tries to explain the emergence of new species, but it tries to understand the entire evolution from the origin of life to the biological and social structures of the present from a unified point of view.

It turns out that there is a very close relationship between the evolutionary theory of information and the evolution of biological and social structures, and that therefore the evolutionary theory of information is the theoretical key to understanding evolution in a very general sense.

The evolutionary theory of information not only describes the development over time of the various types of information and information technologies, but it also describes in which species they first appeared in the course of evolution. The respective information technologies are to be understood as characteristic biological traits of these species. They typically represent the preconditions for the formation of the variation mechanisms and evolutionary systems which are characteristic of the species. Therefore, the temporal sequence of the different variation mechanisms and evolutionary systems results directly from the temporal sequence of the information technologies as described in the evolutionary theory of information.

4.4. The relationship between the general theory of evolution and the theory of the main evolutionary transitions of John E. Stewart and other evolutionary theories.

The general theory of evolution explains the major evolutionary breaks on the basis of the evolutionary theory of information by the appearance of new information technologies. These enable the formation of new increasingly efficient cooperation mechanisms (see table 3 chap. 5.7.7 and columns 9 and 10 from the tabular overview in chap. 4.8), which subsequently prevail in the sense of the game-theoretic evolutionary games.

As an example of a theory that attempts to describe evolution on the basis of a unified explanation, consider John E. Stewart's theory of major evolutionary transitions (Stewart 2020). This explains the major evolutionary upheavals in cooperation not on the basis of evolutionary games, but on the basis of a management theory. It assumes that the emergence of higher-level "managers" and selection at the level of managers plays a far more important role than selection in terms of evolutionary games at the level of all individuals. This leads to increasing cooperation at increasingly higher levels.

All evolutionary theories assume that the emergence of cooperation is fundamental to evolution (Nowak und Highfield 2012). John E. Stewart's theory also assumes this. However, the general theory of evolution provides a clue as to why cooperation is such an essential element of evolution. Namely, it shows that from age [3.1] onward, a new form of cooperation emerges in each age, which impressively explains the central role of cooperation for evolution.

The general theory of evolution goes beyond Stewart's theory and other theories especially in the following:

- The general theory of evolution shows,
    - that the new cooperation mechanisms could develop only by the appearance of new information technologies
    - that much more cooperation mechanisms play an essential role than the usually discussed cooperation mechanisms (network cooperation, group cooperation, direct cooperation, indirect cooperation, kin selection (for kin selection see chapter 16.4.7)): e.g. all different forms of norm cooperation, all different forms of debt cooperation including the importance of money.
- The general evolution theory gives a chronological classification of the new cooperation mechanisms.
- The general theory of evolution can describe and explain the evolution of many other areas besides cooperation: e.g. information technologies (see section A), directed variation (see 4.7.3), driving forces of dynamical systems (see section D).

4.5. Explanation of the terms variation mechanism, evolutionary system and their relation to the evolutionary theory of information using 3 examples.

The concepts of variation mechanism and evolutionary system and their close relationship to the evolutionary theory of information are exemplified by the following 3 examples:

4.5.1. Example 1: The genetic code, phenotype selection (survival of the fittest phenotype)

We use this simple case to explain the underlying differential equation system (evolutionary system), the 2 variation mechanisms "constraint condition" and "mutation" and their relation to the evolutionary theory of information.

About 3.7 billion years ago, the technology developed to store genetic information in the form of DNA. The so-called genetic code indicates how the genes (genotype), i.e. how the special sequences of the 4 bases A, U, G, C of the DNA, is translated into a sequence of amino acids and thus used to produce the proteins of the corresponding individuals (phenotypes).

4.5.1.1. Constraint as a variation mechanism

The time course of the quantity $n^A(t), n^B(t)$ of 2 phenotypes A and B is first determined by their reproduction rates r^A, r^B and described by the differential equation system (evolutionary system)

$$\begin{aligned}\frac{dn^A(t)}{dt} &= r^A\, n^A(t) \\ \frac{dn^B(t)}{dt} &= r^B\, n^B(t)\end{aligned} \qquad \text{<4.1>}$$

Typically, the quantity of A and B cannot evolve independently because resources (food, habitat, etc.) are limited. This leads, for example, to the constraint

$$n^A(t) + n^B(t) = N \qquad z.B. \quad N = 1000$$

i.e. that in sum only $N = 1000$ individuals can live. This leads for the relative frequencies of A and B

$$x^A(t) = \frac{n^A(t)}{N} \qquad x^B(t) = \frac{n^B(t)}{N}$$

to the so-called replicator equation (for details see Chap. 13.3)

$$\begin{aligned}\frac{dx_A}{dt} &= \left(r^A - r^B\right) x_A x_B \\ \frac{dx_B}{dt} &= -\left(r^A - r^B\right) x_A x_B\end{aligned} \qquad \text{<4.2>}$$

Thus, the occurrence of a constraint corresponds to a variation mechanism that changes the evolutionary system <4.1> into the evolutionary system <4.2>. Constraint conditions limit the temporal evolution of phenotypes and therefore first appeared in the age [2.1].

4.5.1.2. Mutation as a mechanism of variation

If the growth rates r^A, r^B are equal, the result is

$$
\begin{aligned}
\frac{dx_A(t)}{dt} &= \left(r^A - r^B\right) x_A(t)\ x_B(t) && r^B = r^A \\
\frac{dx_B(t)}{dt} &= -\left(r^A - r^B\right) x_A(t)\ x_B(t) && r^B = r^A
\end{aligned}
\qquad \text{<4.3>}
$$

i.e. that the temporal change of the relative frequencies x^A, x^B is zero or that the relative frequencies x^A, x^B remain constant. If a mutation occurs in B that causes the reproduction rate to become larger, i.e., that

$$r^B > r^A$$

the evolutionary system <4.3> changes to the more general evolutionary system

$$
\begin{aligned}
\frac{dx_A(t)}{dt} &= \left(r^A - r^B\right) x_A(t)\ x_B(t) && r^B > r^A \\
\frac{dx_B(t)}{dt} &= -\left(r^A - r^B\right) x_A(t)\ x_B(t) && r^B > r^A
\end{aligned}
\qquad \text{<4.4>}
$$

with the result that the relative frequency of A approaches 0 and the relative frequency of B approaches 1. Exactly this behavior is called selection.

Mutations thus represent a special mechanism of variation because, for example, they change the evolutionary system <4.3> into the evolutionary system <4.4> change.

Mutations in the narrower sense were possible for the first time when information was stored as a sequence of bases in an RNA and autocatalytic replication of RNA strands was possible in ribocytes. Mutations as variation mechanisms therefore occurred for the first time in the age [1.2].

4.5.2. Example 2: electrochemically stored information

About 635 million years ago with the beginning of the age [3.1], the technology to store information in the form of electrochemical potentials in nerve cells has developed. This led to the formation of the first efficient direction-sensitive sensors that could detect environmental information from a larger distance[11] . Most notable among these were light-sensitive sensors that ultimately converted light signals into electrochemical potentials. These efficient sensors were in turn the precondition for predatory (actively eating) animals to evolve. These were then no longer dependent only on food with which they came into contact by chance, but they could actively seek food. This was obviously a major evolutionary advantage that allowed predatory (actively eating) animals to evolve in the first place. This new behavior has led to completely new dynamic systems (evolutionary systems) in the age [3.1], which involve the interaction between these animals and other individuals (animals and plants) or their environment, e.g. the predator-prey system:

$$
\begin{aligned}
\frac{dn_A}{dt} &= -b_{AA} n_A + c_{AB} n_A n_B && A\ \textit{predator} \\
\frac{dn_B}{dt} &= +b_{BB} n_B - c_{BA} n_B n_A && B\ \textit{prey}
\end{aligned}
$$

[11] Before that, in the age [2], there were only sensors that reacted to chemical substances and their concentration gradients, which was particularly important, for example, in sexual reproduction for finding sexual partners.

For details see Chap. 12.7.2.

4.5.2.1. Example 3: Digitally stored information

Around 5000 years ago, writing first developed as a storage technology for digital information. Coins subsequently developed as a further technology for storing digital information. Coins are the simplest form of money. The essential function of money in any form is the ability to store claims or debts efficiently. The ability to store debt efficiently, acts like a catalyst in a chemical reaction. It increases the speed of commodity exchange, since instead of exchanging commodity 1 for commodity 2, it becomes possible to exchange any commodity for money as a universal medium of exchange. Only money has made efficient trade in the form of a market economy possible. When someone gives away a good and receives money in return, the money he then has documents his demand to receive goods again in exchange.

Money changes the parameters of a pure exchange system in such a way that everything happens much faster. Only through money, therefore, the evolutionary system of an efficient market economy is made possible. In this sense, the storage technology for digital information in the form of money in the age [5.1] leads to a new evolutionary system, namely the market economy, which is quite essentially based on the variation mechanism of using money to document debt relationships.

These relationships are discussed and justified in detail in chap. 16.3.3

4.6. Types of variation mechanisms classified by effects

4.6.1. Unilateral effects versus multiple effects

Typically, a mutation leads to an improvement or deterioration of the evolutionary fitness of the affected individual and the fitness of all other individuals is not affected. However, if there is a strong interaction between individuals, a mutation in one individual may improve or worsen the fitness of the other individuals.

Variation mechanisms that provide both a fitness utility to themselves and a utility to others are called win-win mechanisms.

So-called Prisoner’s Dilemma situations lead to a fitness disadvantage for both agents. A mechanism that leads to both agents cooperating with each other in a Prisoner’s Dilemma situation is called a cooperation mechanism. Because of the cooperation, it leads to the fitness being higher for both. Thus, a cooperation mechanism is a special win-win mechanism.

All win-win mechanisms, and especially cooperative mechanisms, have a paramount importance for evolution.

4.6.2. Win-win mechanisms

The majority of the biomass consists of win-win systems. This is understandable due to the relatively higher utility and thus the relatively higher survival advantage of individuals in win-win systems. In biology, the formation of win-win systems is usually purely genetically determined, so to speak, in terms of hardware. Examples are:

- Systems with the same or similar genetic material e.g.
    - Cells from multicellular organisms
    - Individuals of an ant colony
    - Swarm behavior
- Systems with different genetic material ("symbiosis") e.g.
    - Lichens as symbiosis of fungi with algae
    - Animals and their gut bacteria
    - Flowering plants with their pollinators
    - Ants and aphids, etc.

In an economy, the formation of win-win systems is determined by individual utility functions. Examples are:

- Exchange
- Division of labor
- Trade
- Investment

4.6.3. Cooperation mechanisms: variation mechanisms to overcome the prisoner's dilemma.

A Prisoner’s Dilemma situation results in the overall worst evolutionary fitness (utility, survival advantage) for both agents, namely the "altruistic" cooperators and the "selfish" defectors. Mechanisms that lead both agents to cooperate with each other in a Prisoner’s Dilemma situation, resulting in better evolutionary fitness for both, are called cooperation mechanisms. The simplest cooperation mechanism is the mechanism of punishing non-cooperative behavior.

All cooperation mechanisms presuppose corresponding biological-technological properties of the individuals so that they can be realized. The different cooperation mechanisms have therefore arisen in different ages. We will discuss them in detail at these ages:

Network cooperation[12]	age [3.1]
Group cooperation[13]	age [3.2]
Direct cooperation[14]	age [3.3]
Cooperation based on 2-sided debt relationships	age [4.1]

[12] often also called network selection

[13] often also called group selection

[14] often also called direct reciprocity

Indirect cooperation[15] (Cooperation based on social debt)	age [4.2]
Cooperation based on social norms	age [4.3]
Cooperation based on religious norm systems	age [5.1]
Cooperation based on national norm systems	age [5.2]
Cooperation based on international norm systems	age [5.3]
Cooperation based on global sanctions	age [6.1]
Cooperation based on automatic global sanctions	age [6.2]

4.7. Types of variation mechanisms classified according to their influence on the speed of evolution

Different variation mechanisms have different degrees of influence on the rate of evolution. In the course of evolution, evolutionary mechanisms have developed that have led to an ever-increasing rate of evolution. It is useful to distinguish the following 3 types:

- VM1: Variational mechanisms that lead to **random** variations with **random** effects on fitness.
- VM2: Variational mechanisms that lead to **random** variations with a **tendency to have positive effects** on fitness
- VM3: Variational mechanisms leading to **targeted** variations with **predominantly positive effects** on fitness.

4.7.1. VM1: Variational mechanisms leading to random variations with random effects on fitness.

This type includes mainly those mechanisms that lead to a random change of a single base in RNA or DNA, i.e., that lead to the simplest form of a mutation. Mechanisms for such a mutation include random errors in reproduction, chemical substances, energy-intensive radiation, and other environmental influences.

Characteristic of these types of mechanisms is that the effects on fitness are completely random. Whether a particular mutation leads to a higher or a lower fitness is decided only afterwards by selection dynamics. Thus, they lead only to a low rate of evolution. At the beginning of evolution in the age [1.1] 4.4 billion years ago, these were the only variation mechanisms. This is the reason for the slow evolution speed at the beginning of evolution (see graphs 1 and 2 in chapter 10.1).

4.7.2. VM2: Variational mechanisms leading to random variations with a tendency to positive effects on fitness.

This type mainly includes horizontal gene transfer and, in particular, sexual reproduction. In both mechanisms, a gene segment or an entire gene is transferred from one individual to

[15] often also called indirect reciprocity

another. Which gene or gene segment is transferred is random, but the following is crucial. The gene or gene segment is not random information, but genetic information that has already proven advantageous in a previous evolutionary dynamic. The probability that this genetic information also contributes to an advantageous fitness in the other individual is therefore greater than for a purely random information. In a sense, these variation mechanisms shortcut the path of evolution by using already proven genetic information instead of random information.

The importance of sexual reproduction for the rate of evolution is even much greater than horizontal gene transfer, because it does not occur at random times, but systematically at each reproductive step.

Horizontal gene transfer has existed since the age [2.2] 2.1 billion years ago. Sexual reproduction is thought to exist since the age [2.3] probably 1 billion years ago. Since sexual reproduction became established, the rate of evolution has accelerated exponentially (see graphs 1 and 2 in chap. 10.1).

4.7.3. VM3: Variational mechanisms leading to targeted variations with predominantly positive effects on fitness.

Epigenetic variations can be considered as the first beginnings of targeted variations. They probably developed for the first time in the age [2.1].

Above all, however, the following variation mechanisms belong to this type:

- "**Imitating, learning, teaching**" that evolved in ages [3.2], [4.1], [4.2]. In this process, an already evolutionarily successful general information is passed on.
- "**Logical thinking**" developed in the age of Homo sapiens [4.3]. Thereby a presumably successful new general information is created.
- **Individual utility optimization, overall utility maximization**, which developed in the ages [5.1], [6.1], [6.2]. In this process, as a rule, the evolutionary success of a general information is further improved.
- **Investment in real capital and human capital** developed in the ages [5.2], [5.3]. Thus, an exponential development of evolutionarily advantageous general information is sought, which usually - but not always in the case of individual utility optimization because of the possible Prisoner’s Dilemma situations - leads to an actual evolutionary advantage.

Similarly, but even much more efficiently than in the case of VM2 mechanisms, this very much shortens the path of evolution. Therefore, by these VM3 mechanisms, the speed of evolution was accelerated even more.

All these 3 types of variation mechanisms have therefore contributed quite substantially to the exponential development of evolutionary speeds (see graphs 1 and 2 in chap. 10.1).

For thoughts on targeted evolution and targeted variation mechanisms, especially with respect to humans, see (Lange 2021).

4.8. Tabular overview of the relationship between evolutionary theory of information and general

Age		Section A Evolutionary theory of information		Section B general theory of evolution	
1	**3**	**5**	**6**	**9**	**10**
Designation	**Living being Form**	**Information type**	**Biological-technological trait**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[0]	Inanimate matter	Crystal	Self-organization due to decreasing temperature	Temperature Pressure	Crystallization
[1.1]	RNA molecules	Digital single strand	Self-organization at crystal surfaces	nvironmental Change	Creation Destruction
[1.2]	Ribocytes		Autocatalysis of RNA formation	Iutation mechanism	Genotype selection (survival of the fittest genotype)
[2.1]	Single-celled organism	Gene (digital, double strand)	Genetic code Phenotype formation	Constraint, Epigenetics	Phenotype selection (survival of the fittest phenotype)
[2.2]	"Simple" multicellular		Cell division Cell association	Networking Horizontal gene transfer	Network-Win-Win
[2.3]	"Higher" multicellular organisms (with sexual reproduction)		Sexual reproduction	Sexual reproduction	Variety of very complex dynamics

1	3	5	6	9	10
[3.1]	"Predatory" animals (predatory plankton, bilateria, chordate, etc.)		Nerve cells (Sensors, nerves, neural tube, spinal cord)	General interactions (Eating, altruism, selfishness, etc.) Networking	Predator-prey system Prisoner's dilemma Network collaboration
[3.2]	Apterygota Insects Fish Amphibians Reptiles Early birds Early mammals	External and internal analog information	Brainstem	Imitation Group formation	Group cooperation
[3.3]	Higher mammals Higher birds		Cerebellum, Diencephalon (limbic system)	Emotions direct reciprocity ("Tit for Tat")	Direct cooperation

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[4.1]	Hominine (human-like)	Complex contents of consciousness	Associative neural network	learn 2-sided obligations	Debt cooperation
[4.2]	Homo		Simple language	teach Reputation, indirect reciprocity, social debt, Exchange	Indirect cooperation Exchange
[4.3]	Homo sapiens		Cognitive revolution: abstract language, logical thinking, consciousness, immaterial realities, individual utility optimization	logical thinking, social norms (constraints), individual utility optimization, commodity debts, Division of labor	Norms cooperation Division of labor

1	3	5	6	9	10
[5.1]	Market economy	External data	Writing Coin money	Written religious norms, Individual contracts, Quantitative individual utility optimization, Monetary debts, Purchase, Animal and plant breeding	Cooperation based on religious norm systems, Regional trade
[5.2]	Capitalist market economy		Letterpress Paper money	National norms, Investment in real capital	Cooperation based on national systems of norms, National trade
[5.3]	Global capitalist market economy		EDP Electronic fiat money	International norms, Investment in human capital	Cooperation based on international norm systems, World Trade, Globalization

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[6.1]	Internet- market economy	Knowledge	Internet International payment systems	Attempt at overall utility optimization by global standards with sanctions, Investment in sustainability	Promoting cooperation based on global sanctions
[6.2]	AI-based economy		Knowledge processing, Artificial intelligence, Blockchain, SOWL (synthetic optimized world language)	Stabilization through AI-based automatic sanctions, Investment in stability, genetic manipulation	Enforcing global cooperation based on automatic global sanctions
[7]	Humanity as a single individual Cyborg	Comprehensive understanding	Direct human-machine communication Fusion of real and virtual world	Direct human-machine communication, Merging real and virtual reality, Overall utility maximization	Completely new form of social organization

5. Evolutionary systems and variation mechanisms in temporal sequence

5.1. The age of inanimate matter [0]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[0]	Inanimate matter	Self-organization due to decreasing temperature	**Emergence of** information	Temperature Pressure	Crystallization

Information has originated for the first time about 4.6 billion years ago by self-organization in the form of crystal growth on the basis of decreasing temperature of the earth's surface. The evolutionary system belonging to the age of the inorganic world, describes therefore nothing else than the crystallization process. A change of temperature or pressure, can lead to other crystal forms. Temperature and pressure can change the crystallization process and can therefore be considered as variation mechanisms.

5.2. The age of RNA molecules [1.1]

1	3	6	7	9	10
Age	**Living-being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[1.1]	RNA molecules	Self-organization at crystal surfaces	Information **storage**	Environmental change	Creation, Destruction

5.2.1. Biological-technological trait of RNA molecules: self-assembly at crystal surfaces.

An RNA molecule is a chain of the 4 bases adenine (A), guanine (G), cytosine (C) and uracil (U). It is thus a storage medium for a digital information. Ribonucleic acids (RNA) first formed in zirconium about 4.4 billion years ago possibly by catalysis on inorganic crystalline surfaces.

5.2.2. Evolutionary system: creation and destruction

The evolutionary system

$$\frac{dn_A}{dt} = a_A \qquad a_A > 0$$

describes the creation of RNA. The creation and destruction of RNA is described by the evolutionary system

$$\frac{dn_A}{dt} = a_A - b_{AA}n_A \qquad a_A > 0 \text{ and } b_{AA} > 0$$

This evolutionary system describes nothing else than a simple form of creation and death and thus elementary dynamics of life.

5.2.3. Variation mechanism: environmental change

Changes in environmental conditions, e.g. an increase in temperature or a change in pH, can very easily lead to a different rate of creation or a different rate of destruction.

Therefore, the change of environmental conditions can be formally considered as a mechanism of variation because they change the rate of creation and the rate of destruction of RNA.

5.3. The age of ribocytes [1.2]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[1.2]	Ribocytes	Autocatalysis of RNA creation	**Duplication of** information	Mutation mechanism	Genotype selection (survival of the fittest genotype)

5.3.1. Biological trait of ribocytes: autocatalysis of RNA creation.

The outstanding property of RNA is that some RNA molecules not only carry information, but also have the ability to promote the production of the same RNA molecules through autocatalysis[16] . Autocatalysis is described by the differential equation

$$\frac{dn_A}{dt} = b_{AA} n_A$$

and always leads to exponential growth. This also leads to a corresponding exponentially growing duplication of information. The RNA complexes formed in this way are called ribocytes. They evolved about 4 billion years ago and can be considered as the first types of living organisms.

5.3.2. Variation mechanism: mutation

The mechanism of duplication of information by autocatalysis was the precondition for the occurrence of the mutation mechanism. Random duplication errors of individual bases, high-energy radiation or chemical substances can cause RNA A to give rise to RNA B with an altered growth rate.

$$\frac{dn_A}{dt} = b_{AA} n_A \quad \rightarrow \quad \begin{matrix} \frac{dn_A}{dt} = b_{AA} n_A \\ \frac{dn_B}{dt} = b_{BB} n_B \end{matrix}$$

<5.1>

Thus, the mutation mechanism changes the evolutionary system and is therefore a special variation mechanism.

[16] SIDNEY ALTMAN and THOMAS R. CECH, NOBEL PRIZE 1989

5.3.3. Evolutionary system: genotype selection

If the growth rate (fitness) of A is greater than the growth rate (fitness) of B, i.e., $b_{AA} > b_{BB}$, the evolutionary system

$$\frac{dn_A}{dt} = b_{AA} n_A$$
$$\frac{dn_B}{dt} = b_{BB} n_B$$

leads to the relative frequency of B approaching 0 and the relative frequency of A approaching 1 over time (see Chap. 13.2, example b.). This is exactly the formal description of what is meant by selection.

Ribocytes consist only of RNA, i.e. the carriers of genetic information. Selection therefore results directly from the traits (e.g. growth rate) of the RNA and therefore takes place directly at the level of genetic information. It can therefore also be called genotype selection ("survival of the fittest genotype"). In contrast, from the subsequent age of unicellular organisms [2.1], selection takes place at the level of phenotypes, i.e. at the level of organisms and their traits (phenotype selection, "survival of the fittest phenotype"). Organisms no longer consist only of genetic information (genotype) but also of the associated proteins, which determine the phenotype, i.e. the traits (e.g. growth rate) of the organisms.

5.4. The age of the protozoa [2.1]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[2.1]	Single-celled organism	Genetic code, Phenotype creation	**Storage of** genetic hereditary information	Constraint, Epigenetics	Phenotype selection (survival of the fittest phenotype)

5.4.1. Biological trait of unicellular organisms: creation of phenotypes

A DNA molecule (deoxyribonucleic acid) consists of a double helix with 2 complementary chains of the 4 bases adenine (A), guanine (G), cytosine (C) and thymine (T). It thus carries digital information in the same way as an RNA molecule. Each DNA molecule represents a gene, because it carries the genetic information for the synthesis of a protein molecule, which consists of a corresponding chain of 20 amino acids. The so-called genetic code indicates how a sequence of the 4 bases A, G, C, T is translated into a sequence of amino acids during the synthesis of proteins. The totality of the genes of an organism is called genotype. The organism built from the associated proteins with all its physiological and behavioral traits is called phenotype.

The first organisms were single-celled organisms that formed in the Paleoarchaic Age about 3.7 billion years ago.

5.4.2. Evolutionary system: phenotype selection

The frequency of the genes (genotype) is determined by the growth rate of the organisms corresponding to the genes and their traits (phenotype). The evolutionary system "survival of the fittest" , no longer takes place directly at the level of genes, but at the level of organisms. The creation of organisms was therefore the precondition for the creation of the evolutionary system phenotype selection ("survival of the fittest phenotype").

The evolutionary system survival of the fittest phenotype is described in principle by the same differential equation system as <5.1> described:

$$\frac{dn_A}{dt} = b_{AA}\, n_A$$
$$\frac{dn_B}{dt} = b_{BB}\, n_B$$

If the growth rate of A is greater than the growth rate of B, i.e. $b_{AA} > b_{BB}$ or A is fitter than B, this leads to the relative frequency of B approaching 0 and the relative frequency of A approaching 1 over time. This is exactly the formal description of what is meant by selection.

5.4.3. Variation mechanism: constraints

The first mechanism that led to the evolutionary system of phenotype selection ("survival of the fittest phenotype") besides mutation was the struggle for limited resources such as habitats or food. Limited resources represent a constraint on the sum of individuals that can survive. They lead to the reduction of birth rates and the formation or increase of death rates and thus represent a variation mechanism. A detailed formal description of this is given in chap. 11.3 formula <11.3> - <11.7> and chap.15.4 formula <15.2> - <15.4>.

5.4.4. Variation mechanism: epigenetics

Epigenetic variation is a heritable phenotypic variation that is not based on a change in DNA sequence, but can nevertheless be inherited over several generations. Examples of epigenetic modification mechanisms are DNA methylation and histone modification, which change the way genes are expressed without changing the underlying DNA sequence.

The prerequisite for the possibility of epigenetic modification mechanisms was obviously the formation of phenotypes. Epigenetic mechanisms have therefore been able to form at the earliest in the age [2.1]. Epigenetic variations have a particularly important function in cell differentiation, as they appeared for the first time in the age of higher multicellular organisms [2.3].

5.5. The age of simple multicellulars [2.2] -Network formation

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[2.2]	"Simple" multicellular	Cell division, Cell association	Intraindividual **duplication of** genetic hereditary information	Network formation, Horizontal gene transfer	Network-Win-Win

5.5.1. Biological trait of simple multicellular organisms: cell association

The biological trait that cells can adhere to each other formed in the Mesoproterozoic 1.6 billion years ago and leads to 2 consequences:

If the cells are of the same type, this leads to simple multicellular organisms. The remaining of new cells created by cell division in the common cell complex corresponds to an intraindividual duplication of genetic information.

If the cells are different, the cohesion of the cells allows horizontal gene transfer.

5.5.2. Variation mechanism: network formation, evolutionary system: network win-win

If a random mutation results in a positive win-win interaction ($c_{AA} > 0$) when 2 cells of species A meet, and μ_{AA} denotes a measure of the frequency with which a cell of species A meets another cell of species A, this results in

$$\frac{dn_A}{dt} = b_{AA} n_A \quad \rightarrow \quad \frac{dn_A}{dt} = b_{AA} n_A + c_{AA}\mu_{AA} n_A n_A$$

This leads to a fitness advantage for A because it increases A's growth rate. This increases the more often the cells of A interact with each other, which is obviously the case when they remain connected in a spatial network. The biological trait that cells remain in a common spatial network over a longer period of time thus enables the formation of positive interactions (win-win interactions) to a particularly high degree. Network formation thus represents a variation mechanism. The resulting evolutionary system can be called a network win-win. This explains the frequent occurrence of multicellular organisms in nature.

5.5.3. Variation mechanism: horizontal gene transfer

The biological trait that cells adhere to each other is not only possible for cells with the same genetic properties, but it can also occur for cells with different genetic properties. If such cells remain spatially attached to each other for a greater or lesser length of time, the exchange of genetic information between these cells can occur. This leads to a change in genetic information, which is called horizontal gene transfer. The difference to a mutation is that not only one base is changed, but many bases are changed at the same time.

Horizontal gene transfer plays a particularly important role in prokaryotes (cells without a cell nucleus). Evolution is accelerated by this mechanism (see chap. 4.6.2).

5.6. The age of higher multicellular organisms [2.3]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[2.3]	"higher" multicellular organisms (with sexual reproduction)	sexual reproduction	interindividual **processing of** genetic hereditary information,	sexual reproduction	Variety of very complex dynamics

5.6.1. Biological trait of higher multicellular organisms: sexual reproduction

In terms of the evolutionary theory of information, sexual reproduction by fusion and division of cell nuclei represents a systematic processing of genetic information from father and mother into new genetic information for the offspring. Sexual reproduction could already be proven 565 million years ago. However, it probably developed about 1 billion years ago.

5.6.2. Sexual reproduction as a variation mechanism for genetic information

Until the emergence of sexual reproduction, change in fitness or growth rates was limited to the variational mechanisms of environmental change, random mutation, and random horizontal gene transfer.

From the point of view of information theory, the precursor of sexual reproduction was horizontal gene transfer, i.e. the random exchange of entire partial chains of DNA between individuals (with a random result), which plays a role especially in cells without a cell nucleus (prokaryotes). Horizontal gene transfer has greatly increased the frequency and breadth of genetic changes (see chap. 4.6.2).

In cells with nuclei (eukaryotes), sexual reproduction has evolved. The essential feature of sexual reproduction over horizontal gene transfer is that the exchange of DNA does not occur at a random time, but systematically with each new generation. Sexual reproduction has dramatically increased the number and breadth of genetic changes, which has dramatically accelerated the emergence of new species through alteration of genetic information and selection, and thus evolution (see chap. 4.6.3). Species with sexual reproduction had a great evolutionary advantage due to the tremendously increased adaptability, which explains the frequency of sexual reproduction in living nature.

5.6.3. Evolutionary system: sexual reproduction

Sexual reproduction proceeds in detail in very many different, complex expressions. Accordingly, the associated evolutionary systems are also complex. They reflect the individual advantages and disadvantages of sexual reproduction. As essential examples are mentioned:

Advantage: enormously increased adaptability

Disadvantage: the sexual partners must find each other. This could be achieved either by a very high number of offspring, so that the probability of the sexual partners meeting was high enough, or the development of sensors that made it easier to find the sexual partners. The first such sensors were based on the possibility of detecting concentration gradients of special chemical molecules (e.g. pheromones).

5.7. The age of the first predatory animals [3.1]

1	**3**	**6**	**7**	**9**	**10**
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[3.1]	Predatory animals (predatory plankton, bilateria, Chordatiere, etc.)	Nerve cells (Sensors, nerves, neural tube, Spinal cord)	Perception and **storage of** external and internal information, "monosynaptic reflex arc" (passing on the information to **one** organ)	General interactions (eating, altruism, selfishness, etc.)	Predator-prey system, Prisoner's dilemma, Network collaboration,

5.7.1. Biological trait of predatory animals: nerve cells

Until now, there were only technologies for storing, duplicating and processing genetic information, i.e. information that was passed on to the next generation.

In the age [3.1] - [3.3], on the other hand, information about the environment outside an individual plays a major role for the first time. For this purpose, about 630 million years ago, the technology developed to detect this information with the help of sensors, to store it in the form of electrochemical potentials in nerve cells (neurons) and to pass it on directly to another organ without modification or duplication. This form of transmission is called monosynaptic reflex arc.

This has led to the formation of the first efficient direction-sensitive sensors that could detect environmental information from a greater distance[17] . Most notable among these were light-sensitive sensors that ultimately converted light signals into electrochemical potentials. These efficient sensors were in turn the precondition for predatory (actively eating) animals to evolve. These then no longer relied solely on food (animals or plants) with which they came into contact by chance, but were able to actively seek out food. This was obviously a major evolutionary advantage that made the development of predatory animals possible in the first place.

5.7.2. Variation mechanism: interaction

Of particular importance in information about the environment are contact and interaction with other individuals. This applies to individuals of the same species as well as to individuals of another species. Important examples of interaction between individuals are: Eating, altruism, selfishness. This has led to the fact that in the evolutionary systems the growth rate of the frequency of a species A or B was no longer only proportional to the frequency of A or B respectively

$$\frac{dn_A}{dt} = b_{AA} n_A \qquad \frac{dn_B}{dt} = b_{BB} n_B$$

but that also so-called interaction elements

$$c_{AA} n_A n_A, \qquad c_{BB} n_B n_B, \qquad c_{AB} n_A n_B \qquad c_{BA} n_B n_A$$

could occur:

$$\frac{dn_A}{dt} = b_{AA} n_A \quad \rightarrow$$
$$\rightarrow \frac{dn_A}{dt} = b_{AA} n_A + c_{AA} n_A n_A + c_{AB} n_A n_B + c_{BA} n_B n_A + c_{BB} n_B n_B$$

$n_A n_A$ describes the frequency with which 2 individuals A meet, $n_A n_B$ describes the frequency with which an individual A and an individual B meet, and so on. If the respective factor $c > 0$, this describes a positive interaction between the individuals, i.e. that a meeting leads to an increase in the growth rate. In the case of $c < 0$, that a clash leads to a decrease in the growth rate.

More generally, interactions are an important variation mechanism that leads to substantial changes in an evolutionary system.

5.7.3. Evolutionary systems: predator-prey system, prisoner's dilemma, network cooperation

Particularly important such evolutionary systems are:

The predator-prey system

[17] Before that, in the age [2], there were only sensors that reacted to chemical substances and their concentration gradients, which was particularly important, for example, in sexual reproduction for finding sexual partners.

$$\frac{dn_A}{dt} = -b_{AA}^{-} n_A + c_{AB} n_A n_B \qquad A\ predator$$
$$\frac{dn_B}{dt} = +b_{BB}^{+} n_B - c_{BA} n_B n_A \qquad B\ prey$$

the prisoner's dilemma

$$\frac{dn_K}{dt} = c_{KK} n_K n_K + c_{KD} n_K n_D \qquad K\ cooperator$$
$$\frac{dn_D}{dt} = c_{DK} n_D n_K + c_{DD} n_D n_D \qquad D\ defector$$
$$mit\ c_{DK} > c_{KK} > c_{DD} > c_{KD} \qquad und \qquad 2c_{KK} > c_{DK} + c_{KD}$$

and the special cooperation form of network cooperation, which was the first of the cooperation forms in the development of evolution to overcome Prisoner's Dilemma situations

$$\frac{dn_K}{dt} = c_{KK} n_K n_K + c_{KD} n_K n_D$$
$$\frac{dn_D}{dt} = c_{DK} n_D n_K + c_{DD} n_D n_D$$
$$mit\ c_{DK} < c_{KK}$$

We describe these in detail in the following chapters.

5.7.4. The predator-prey system

5.7.4.1. On the concept of predatory animals

Eukaryotes (cells with nuclei) are divided into plants (energy supply via photosynthesis), fungi, and animals (energy supply via ingestion of organic matter ultimately derived from photosynthesis). The first predatory animals, i.e. those that specifically used other individuals as food, probably appeared after the end of the Cryogenium about 630 million years ago (van Maldegem u. a. 2019; Hallmann, 2019). As food and thus as "prey" other animals as well as plants come into question.

5.7.4.2. Eating as a variation mechanism

The evolutionary system of a species A, that reproduces at the birth rate b_{AA}^{+} and dies at the death rate b_{AA}^{-}, together with a species B that reproduces at the birth rate b_{BB}^{+} and dies at the death rate b_{BB}^{-} is as follows.

$$\frac{dn_A}{dt} = (b_{AA}^{+} - b_{AA}^{-}) n_A$$
$$\frac{dn_B}{dt} = (b_{BB}^{+} - b_{BB}^{-}) n_B$$

The variation mechanism of interaction in the form of "eating" causes the birth rate of predator A to become proportional to the frequency of prey B and the death rate of prey B to become proportional to the frequency of predator A:

$$\begin{aligned} \frac{dn_A}{dt} &= (b^+_{AA} - b^-_{AA})n_A \\ \frac{dn_B}{dt} &= (b^+_{BB} - b^-_{BB})n_B \end{aligned} \rightarrow \begin{aligned} \frac{dn_A}{dt} &= (c_{AB}n_B - b^-_{AA})n_A = -b^-_{AA}n_A + c_{AB}n_A n_B \\ \frac{dn_B}{dt} &= (b^+_{BB} - c_{BA}n_A)n_B = +b^+_{BB}n_B - c_{BA}n_B n_A \end{aligned}$$

The resulting evolutionary system

$$\begin{aligned} \frac{dn_A}{dt} &= -b^-_{AA}n_A + c_{AB}n_A n_B & \quad A\ \textit{predator} \\ \frac{dn_B}{dt} &= +b^+_{BB}n_B - c_{BA}n_B n_A & \quad B\ \textit{prey} \end{aligned}$$

is called **predator-prey system** (see also chap. 12.7.2).

Both animals and plants can be the prey.

5.7.4.3. Stable predator-prey balance

A predator-prey system with constant coefficients b^+, b^-, c typically exhibits cyclic behavior.

If the coefficients change because both predator and prey have high adaptability, the system tends to the stable fixed point of the predator-prey cycle, where both the number of predators and the number of preys remain constant. The reason for this lies in the following mechanism:

The evolutionary pressure on the prey to adapt is particularly great when their numbers decrease, i.e. when the difference between birth rates minus death rates is negative. Selection then favor those mutants that increase their birth rates or decrease their death rates because, for example, they can hide better or defend themselves better. In contrast, selection pressure on prey decreases toward high birth rates and low death rates as the number of prey increases. The same is true, mutatis mutandis, for the predators. It can be shown that such a predator-prey system tends toward the stable fixed point with the appropriate mutation rates.

In nature, adaptation rates are usually high enough that relatively stable stationary predator-prey equilibria usually develop as long as there are no external disturbances. Pronounced predator-prey cycles are rather rare in nature.

5.7.4.4. Biological cognitive preconditions, first appearance of predator-prey systems.

The biological-cognitive preconditions for the variational mechanism of eating, and thus for the existence of predator-prey systems, are that predators can recognize their prey and actively eat. The minimum precondition for this is the existence of a rudimentary nervous system with sensors capable of detecting prey and a monosynaptic reflex arc that triggers an eating reflex.

These conditions, in terms of the evolutionary theory of information, were present for the first time in the age of the first eating animals (predatory plankton, bilateria, and chordates) (age [3.1]) after the end of the Cryogenian, 630 million years ago.

The existence of predatory animals has dramatically increased the pressure to adapt in general. This has resulted in species complexity evolving at an exponentially increasing rate following this age (see chap. 10).

5.7.5. The Prisoner's Dilemma as an evolutionary system

An evolutionary system of the type

$$\frac{dn_K}{dt} = c_{KK} n_K n_K + c_{KD} n_K n_D \qquad K \text{ cooperator}$$
$$\frac{dn_D}{dt} = c_{DK} n_D n_K + c_{DD} n_D n_D \qquad D \text{ defector}$$

is called a prisoner's dilemma system when the case that seems paradoxical at first sight occurs,

1. that the fitness (reproductive rate) of the pure species K (cooperators) is greater than the fitness (reproductive rate) of the pure species D (defectors), and
2. nevertheless, K is not evolutionarily stable with respect to D, i.e., an arbitrarily small set of defectors finally displaces all cooperators.

This is generally the case when

$$c_{DK} > c_{KK} > c_{DD} > c_{KD} \;\; und \quad 2c_{KK} > c_{DK} + c_{KD}$$

In the **language of evolution,** this "dilemma" means that cooperators ("altruistic" individuals) are displaced by defectors ("selfish" individuals), although they alone have a higher fitness than defectors. That is, in Prisoner’s Dilemma situations, the overall fitness (reproductive rate) of the population of K and D decreases over time.

Or expressed for the behavior of people: In a Prisoner’s Dilemma situation, if everyone behaves selfishly, this leads to a worse solution for everyone than if everyone behaves altruistically.

5.7.6. Overview of cooperation mechanisms and cooperation systems

Variational mechanisms that change the evolutionary system of a Prisoner’s Dilemma situation in such a way that the "paradoxical" situation of the Prisoner’s Dilemma just does not occur anymore are called cooperation mechanisms. The resulting evolutionary systems are called cooperation systems. There are 2 types of cooperation mechanisms (see also chap. 16.4.3)

Type a): The mechanism causes $c_{KK} > c_{DK}$ to apply instead of $c_{KK} < c_{DK}$ (for details see Chap. 16.4.2, note <5.2> and chap. 16.4.4)

Type b): The mechanism causes the frequency of the encounter of D and K to no longer be purely random, and thus no longer proportional to $n_D n_K$, but to be reduced by a mechanism (see also chap. 16.4.5)

The simplest cooperation mechanism of type a) is the mechanism of punishment of non-cooperative behavior. A punishment formally leads to the fact that the advantage c_{DK} of the defector from non-cooperative behavior against the cooperator is reduced by a penalty s , so that then no longer $c_{KK} < c_{DK}$ but $c_{KK} > c_{DK} - s$ applies.

However, this mechanism of punishment presupposes very high cognitive abilities, which were not yet given in the age [3.1]. The precondition for this was the cognitive revolution in the age [4.3], which made the formation of social norms (or religions) possible.

The simplest case of a type b) cooperation mechanism is network formation in the form that in the network cooperators are more often surrounded by cooperators and defectors are more often surrounded by defectors, whereas cooperators and defectors are rarely neighbors of each other. If the network formation in this sense is high enough, the Prisoner’s Dilemma is overcome, i.e., the cooperators can no longer be displaced by defectors. The biological-technological properties for network formation were already given in the age [2.2], but at that time Prisoner’s Dilemma systems were not yet possible because of the lack of interactions. Therefore, the evolutionary system of network cooperation appears only first in the age [3.1].

All other possible cooperation mechanisms and cooperation systems also require corresponding biological-technological properties in order to be realized. The different cooperation mechanisms and cooperation systems have therefore arisen in different ages. We will discuss them in detail at these ages (see the following table 3).

The term "kin cooperation" or "kin selection" is also frequently used. We avoid this term because kin cooperation occurs either as a special case of network cooperation or as a special case of group cooperation. Put simply, "I help my relatives not because we share genes, but I help my relatives because I am connected to them through a social network or because I feel I belong to the group of my relatives". We discuss this issue in detail in chap. 16.4.7.

5.7.7. Network cooperation

The simplest case of a type b) cooperation mechanism is network formation in the form that in the network cooperators are more often surrounded by cooperators and defectors are more often surrounded by defectors, whereas cooperators and defectors are rarely neighbors of each other. If the network formation in this sense is high enough, the Prisoner’s Dilemma is overcome, i.e., the cooperators cannot be displaced by defectors.

Age	Cooperation mechanism	Cooperation system
1	9	10
[3.1]	Network formation	Network cooperation[18]
[3.2]	Group formation	Group cooperation[19]
[3.3]	Tit for tat, "direct reciprocity"	Direct cooperation[20]
[4.1]	2-sided obligations	Debt cooperation
[4.2]	Reputation, "indirect reciprocity" social debt	Indirect cooperation[21]
[4.3]	Social norms	Norm cooperation
[5.1]	Monetary debts, written religious norms,	Cooperation via religious norm systems
[5.2]	National standards	Cooperation via nation-state standards systems
[5.3]	International standards	Cooperation via international standards systems
[6.1]	Overall utility Optimization through global standards with global sanctions	Cooperation via sanctions
[6.2]	Stabilization through AI-based automated sanctions	Cooperation via automatic sanctions

Table 3: Cooperation mechanisms and Cooperation systems

[18] often also called network selection
[19] often also called group selection
[20] often also called direct reciprocity
[21] often also called indirect reciprocity

5.8. The age of the higher animals [3.2]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[3.2]	Apterygota Insects Fish Amphibians Reptiles Early birds Early mammals	Brainstem	**Reproduction of** the information, "polysynaptic reflex arc" (Passing on the information to **several** organs)	Imitating Group formation	Group cooperation

5.8.1. Biological trait of higher animals: polysynaptic reflex arc in the brainstem as a duplication technology

During the Cambrian, 541 - 485 million years ago, the first explosion of biodiversity occurred. During this time, the essential structural elements of all insects and all early vertebrates (fish, amphibians, reptiles, dinosaurs including early birds and early mammals) also evolved. The cause of this species explosion is attributed to mutations in the developmental control genes responsible for individual development (Theissen 2019). How the control of individual development of living organisms (ontogeny) has evolved in evolutionary history is now intensively studied in the context of evolutionary developmental biology (called evo-devo for short) (Müller und Newman 2003; W. Arthur 2021)

In the monosynaptic reflex arc of the first predators of the preceding age [3.1] (see chap. 5.7), a single reflex response of a single organ occurred. In contrast, in all new creatures of the age [3.2], a more complex nervous system evolved with a polysynaptic reflex arc, meaning that an incoming piece of information was multiplied and triggered multiple reflexes. This more complex nervous system subsequently evolved into what is now called the brainstem (Truncus cerebri or colloquially, the reptilian brain). The brainstem controls vital functions such as reflexes, breathing, heartbeat, eating, fighting, fleeing, etc.

5.8.2. Variation mechanism: imitating

The biological cognitive preconditions for the possibility to imitate the behavior of other individuals and thus to duplicate information consist at least in a polysynaptic reflex arc. This enables a single sensory impression (e.g., perceiving a smile) to trigger a complex reflex (smiling oneself) that imitates the sensory impression. Presumably, mirror neurons or precursors of mirror neurons also play an essential role in this process.

The ability to imitate also enables the biological phenomenon of swarm formation, as seen in fish, birds, and (state-forming) insects.

The variation mechanism of imitation can be considered as the **first targeted variation mechanism** following sense (see also chapter 4.6.3 for more details): A random mutation changes the parameters of an evolutionary system. However, it is not foreseeable from the very beginning whether the mutation is positive, i.e. increases the reproductive rate, or whether it is negative. This is only decided by the long temporal process of survival of the fittest. With an imitation however a certain behavior - thus formally a certain information - is taken over. Nothing else happens formally, than that certain parameters of the evolutionary system are changed. However, with imitation only such parameters are taken over, which turned out already as evolutionary advantageous, because otherwise they would rather not have occurred with the individual that is being imitated. In this sense, imitation leads to a high acceleration of evolution, because only positive behaviors are adopted and not, as in the case of mutation, only random behaviors.

5.8.3. Variation mechanism: group formation

The biological cognitive preconditions for the possibility of group formation are that

- the individuals must be complex enough to be able to form appropriate group recognition traits (e.g., smell, song, visual traits),
- the individuals must have sensors to perceive these recognition features,
- individuals must have (presumably at least) a polysynaptic reflex arc to respond to group members and non-group members differentially in terms of interaction frequency and quality of interaction.

These preconditions have developed with the brain stem for the first time during the Cambrian species explosion about 542-485 million years ago. Therefore, in the sense of the evolutionary theory of information, the variation mechanism of group formation and consequently the evolutionary system of group cooperation has existed since the age of insects and early vertebrates (age [3.2]).

5.8.4. Evolutionary system: group cooperation

Group formation can lead to overcoming a Prisoner's Dilemma situation, i.e., cooperators K become evolutionarily stable with respect to defectors D (for details see Chap. 16.4).

A more or less strong grouping of the cooperators among themselves or of the defectors among themselves ensures that cooperators rarely meet with defectors. The advantage that defectors can gain over cooperators through non-cooperative behavior thus becomes less important. This makes it easier for cooperators to prevail over defectors.

5.9. The age of higher mammals [3.3]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[3.3]	Higher mammals, Higher birds	Cerebellum, Diencephalon (limbic system)	Information **processing** (passing on the **processed** internal and external information to several bodies).	Emotions, Direct reciprocity ("Tit for Tat")	Direct cooperation

5.9.1. Biological trait: cerebellum and diencephalon (limbic system) as processing technology.

In its original form, the cerebellum is the integration center for learning, coordinating, and fine-tuning movements.[22] It first developed in fish about 400 million years ago. („Rätsel Kleinhirn“ 2003; „Das limbische System oder das „Säugergehirn"“) years ago in fish. Input information is primarily visual, haptic, balance, and sensory impressions. These are processed and deliver motor commands to the most diverse muscle groups.

To process more complex information, the diencephalon (limbic system) developed later in evolution in the first mammals. However, the diencephalon only gained full importance with the explosive development of mammals in the Tertiary period 60 million years ago. This is why it is also called the mammalian brain („Das limbische System oder das „Säugergehirn"“)[23] because it is common to all mammals.

The most important parts of the limbic system are the amygdala, hypothalamus, cerebellum, and hippocampus.

The limbic system is a system for simple processing of external and internal information. Complex information is reduced to the most important content. Explained by an abstract example, the information about a temporally changing object is reduced to the information "big" or "small". The additional information contents e.g. about the change of the size ("becomes bigger" or "becomes smaller") or whether the size changes fast or slowly is not analyzed. From an information-theoretical point of view, similar things happen as in the approximation of a function by the first member of a series expansion of this function. This mechanism runs in the amygdala and makes it possible to categorize complex information according to a few classes.

[22] Like the brainstem, the cerebellum has evolved over time to include more functions in its mammalian form than in its original form.

[23] **https://www.gehirnlernen.de/gehirn/das-limbische-system-oder-das-s%C3%A4ugergehirn/**

All information that is thereby reduced to the same class subsequently leads to the same reaction of the body (feelings, emotions, behavior). The hypothalamus triggers the release of corresponding hormones, which are often also subjectively perceived as feelings, e.g. anger, fear, love etc.. The cerebellum triggers corresponding motor movements, such as flight, attack, sexual behavior, etc. The interaction of the parts of the limbic system thus controls libidinal behavior.

The hippocampus, in turn, is involved in the storage and memory of such events.

The limbic system is the biological cognitive precondition for the following important behavior or variation mechanism that evolved in higher mammals and higher birds:

- "Direct reciprocity" (tit for tat, you me so me you)

5.9.2. Variation mechanism and evolutionary system: direct reciprocity, direct cooperation.

In both previously occurring cooperation mechanisms (network cooperation and group cooperation), the 2 species, namely cooperators and defectors, are initially in a Prisoner’s Dilemma system. Here, the fitness of the species is determined from the sum of the effects when exactly one interaction occurs between all individuals. The cooperation mechanisms network cooperation and group cooperation lead to such a change of parameters that cooperators prevail over defectors.

If the fitness of the species is not determined by a one-time encounter of the individuals alone, but only results from a multiple, e.g. an N-time, encounter, one speaks of an iterated Prisoner's Dilemma. Here, the behavior of the respective species (cooperate or defect) is determined by a strategy that depends on the past behavior of the other individual and on the past own behavior.

A strategy is called direct reciprocity if it essentially[24] follows the tit-for-tat principle. One could also consider this response behavior as special imitation behavior controlled by emotions. The strategy that always defeats is called "AllD."

Without going into the details, the following applies in essence (for details, see Chap. 16.4.5):

In a pure species that always executes the directly reciprocal strategy Tit for Tat, all individuals will always cooperate. It therefore has a higher fitness than a pure species with the strategy "AllD", where all individuals always defect.

Nevertheless, the "AllD" strategy prevails over the directly reciprocal Tit for Tat strategy when the number of encounters N after which fitness is decided is small.

On the other hand, if the number of encounters N is large enough, the direct reciprocal strategy prevails against "AllD".

That strategies can develop which depend on past behavior in such a way requires that the behavior of the other individual could be categorized, e.g., into "good" or "bad" or "it cooperates" or "it defects" and that it could be stored. This was possible for the first time in an efficient form through the limbic system.

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[24] This also includes, for example, the Tit-for-Tat, Generous-Tit-for-Tat, Win-Stay-Lose-Shift strategies.

Direct reciprocity is thus, in addition to network formation and group formation, another cooperation mechanism, a mechanism, in other words, that leads to the Prisoner's Dilemma being overcome. We can therefore call the resulting cooperation direct cooperation.

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5.10. Comparison of the ages [3.1] - [3.3] with the coming ages, the fundamental importance of debt

5.10.1. Basic difference

A key characteristic of the biological traits of the ages [3.1] - [3.3] was that an event often triggered an immediate, temporally instantaneous response to that event:

3.1. information about environment→ monosynaptic reflex

3.2. information about environment (or other body parts)→ polysynaptic (complex) reflex (e.g. fight, imitation)

3.3. information about complex process in the environment→ processing and categorization in the limbic system→ complex process (emotion, Tit for Tat)

An essential characteristic of the following ages, on the other hand, is the possibility that an event does not have to lead to an immediate reaction, but that the reaction to this event can also occur with a significant time delay.

A key characteristic is therefore also the possibility of debt creation, because the event of a debt formation triggers a debt repayment only at a much later point in time as a subsequent reaction. Debts arise from services that are initially not matched by any direct compensation. The possibility of storing debt is not only the precondition, but is virtually the core element for the formation and cohesion of social communities.

As we show in the following chapter, the fundamental importance of debt is that the possibility of debt formation greatly facilitates the formation of cooperation, which is a major survival advantage for both individuals. The development of ways to document debt relationships has therefore had a dramatic impact on evolution. We refer to this mechanism as cooperation through debt.

An essential element of debt is the documentation of debt. It is this documentation of debt that makes it possible to maintain the debt over a longer period of time and to repay the debt at a later date. Therefore, the more efficient a mechanism for documenting debt is, the easier it is for win-win situations to develop.

5.10.2. The fundamental importance of documenting debt relationships for the creation of win-win systems

5.10.2.1. The documentation of debt relationships as a catalyst for the formation of win-win systems

We first show why mechanisms for documenting debt relationships are of such fundamental importance for the emergence of win-win systems.

Assume that a specific variation (change in the evolutionary system) leads to an additional utility for both species and thus to a win-win situation. This is described by

$$\frac{dn_A}{dt} = f_A(t) \quad \rightarrow \quad \frac{dn_A}{dt} = f_A(t) + z_A(t)$$
$$\textit{with added utility } z_A(t) > 0 \textit{ for } A$$
$$\frac{dn_B}{dt} = f_B(t) \quad \rightarrow \quad \frac{dn_B}{dt} = f_B(t) + z_B(t)$$
$$\textit{with added utility } z_A(t) > 0 \textit{ for } B$$

$f_A(t)$ and $f_B(t)$ are arbitrary growth functions describing the growth before variation.

We call a variation in which the additional utility arises for both species at the same time or place Case 1 variation. As an example of a Case 1 variation, consider, for example, a variation that allows for the exchange of goods. A variation where the additional utility arises at a different time or place, we call Case 2 variation. As an example of a case 2 variation, consider, for example, a variation that enables the purchase and later sale of goods.

Because there are many more opportunities for a variation to produce an additional utility at some other time or place than there are opportunities for a variation to produce an immediate additional utility at the same place, Case 2 variations arise more easily and thus more frequently than Case 1 variations. On the other hand, a Case 1 variation leads more quickly and without detours to an additional utility for both individuals. Therefore, once the variation has occurred, Case 1 variations prevail more easily than Case 2 variations.

Therefore, a mechanism which transforms a case 2 win-win situation into a case 1 win-win situation (or a sequence of case 1 win-win situations) is of particular importance. Indeed, this obviously leads to a beneficial variation not only occurring more frequently, but also to a more rapid implementation of this variation. The most important mechanism for this is the **documentation of debt relationships**. Documentation of debt relationships is, as it were, a catalyst for the formation of win-win situations.

This is illustrated by the following example. B gives A a good that represents a value of 3 for B and a value of 5 for A. At a later point in time, A gives a good to B that represents a value of 3 to A and a value of 5 to B. This corresponds to a case 2 cooperation. For the time evolution of the utility of A and B then holds:

Case 2 Cooperation (without documentation of the debt relationship with money):	Utility A	Utility B
Initial situation	**0**	**0**
Utility change at time 1 due to goods	**+5**	**-3**
Overall utility change at time 1	**+5**	**-3**
Utility change at time 2 due to goods	**-3**	**+5**
Overall utility change at time 2	**+2**	**+2**

A variation that allows the use of money or promissory bills to document debt relationships converts the case 2 cooperation into the sequence of two case 1 cooperations. Buying the good for 4 monetary units gives A a utility of 5 - 4 = 1 and B a utility of 4 - 3 = 1. The utility arises for both at the same time and place. It is therefore a case 1 cooperation. At a later point in time, there may be a sale of a good from A to B, i.e. a second case 1 cooperation. For the temporal development of the utility of A and B then applies:

Sequence of case 1 cooperations through documentation of the debt with money	Utility A	Utility B
Initial situation	**0**	**0**
Utility change at time 1 due to goods	**+5**	**-3**
Utility change at time 1 due to money	**-4**	**+4**
Overall utility at time 1	**+1**	**+1**
Utility change at time 2 due to goods	**-3**	**+5**
Utility change at time 2 due to money	**+4**	**-4**
Overall utility at time 2	**+2**	**+2**

By documenting debt relationships, there is obviously a continuous growth of utility over time for both parties, which makes the enforcement of this variation much easier and thus faster.

5.10.2.2. The development over time of the various technologies for documenting debt relationships

Social communities are created through interdependencies. Debt relationships of all forms are the most important mutual dependencies. Thus, debt relationships are the most important basis on which social communities are formed. When we teach children to say "please and thank you," the social community is strengthened. Because with the word “please”, someone indicates that he is willing to go into debt. With the word “thank you”, the social debt that has been incurred is acknowledged. Thus, saying the words please and thank you contributes to the fact that social debt occurs more easily and more often, and therefore social communities are strengthened by this behavior. Therefore, saying please and thank you has become an evolutionary practice.

More formally, the precondition for the possibility of documenting debt relationships is the existence of a storage technology. Since the documentation of debt relationships requires a storage technology for information, the evolution of win-win mechanisms is therefore closely related to the evolutionary theory of information.

For the formation of direct cooperation through the behavior of direct reciprocity (tit for tat, you me so me you) in the age [3.3], documentation of the debt relationships over a longer period of time was not yet necessary, since the reactions usually took place in immediate temporal proximity.

Over a longer period of time, debt relations were only possible by an efficient cerebrum in the age [4.1], which also had the ability to store complex information. As a rule, the first debt relations were characterized by 2-sided debt relations ("I helped you").

The emergence of cooperation through the mechanism of indirect reciprocity in age [4.2] (see chap. 16.4.5 and 5.12.2) is based on the formation of a high reputation for cooperators. The reputation of a cooperator can be seen as the documentation of the cooperator's achievements towards many other individuals without direct reciprocation. Reputation thus represents, as it were, the documentation of a social debt owed by the general public to a cooperator.

The emergence of a high reputation of an individual requires not only the ability to store complex information, but also the ability to communicate in the form of a simple language to spread knowledge about the reputation of the cooperator in the community. Therefore, indirect reciprocity was made possible in the course of evolution only in the genus Homo in the age [4.2], who were able to use a simple language for communication.

The next evolutionary step in the formation of debt relations was the possibility of forming commodity debts in the age [4.3] of Homo sapiens. As a special form of it can also be considered the tradition of providing gifts, which contributed to the stabilization of human societies by consciously producing debt relations through gifts.

The next major breakthrough in the age [5.1] was the ability and method to describe or value different debts with a single symbol. This one symbol is called money. Money has subsequently itself been subject to major technological change that has had far-reaching effects on the development of humanity. The technology of money and with it the documentation of debt relationships became more and more efficient: From coin money (Age [5.1]), to paper money [5.2], fiat money [5.3]), electronic money [6.1], to blockchain technology [6.2]. Money is the root cause of the huge extent of win-win mechanisms in humans, an extent found nowhere else in nature (Nowak und Highfield 2012). Money as an efficient documentation mechanism for debt relationships is thus also the actual cause for the dominance of humans on earth.

5.11. The age of hominins (human-like) [4.1]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[4.1]	Hominine (human-like)	Associative neural network	Recognize and **saving** causal relationships ("learning": if A→ then B)	Learning 2-sided obligations	Debt Cooperation

5.11.1. Biological trait of hominins: the cerebrum as a memory for complex consciousness content

Hominins (human-like) are the direct ancestors of humans who split off from hominids (apes) about 6 million years ago. To put it simply, the decisive characteristic was that the cerebrum reached a size and a capacity such that it was able to store complex contents of consciousness and to recognize causal relationships. The storage technology of the brain is based on associative neuronal networks..

One of the most important features of the fully developed cerebrum was the ability to assume or recognize a causal relationship from the frequent successive occurrence of events X and Y and to learn and store it as information in the form "whenever X, then also Y".

In this context it should be pointed out again that although also higher birds and higher mammals have a larger cerebrum and occasionally also causal action can be observed with them, the cerebrum was still of subordinate importance for the overall behavior. When we speak of a point in time when a technology (in this case the cerebrum) has shown itself "for the first time", it is actually more precisely meant that this technology

- firstly, has prevailed in an efficient form and
- secondly, that this technology has led to far-reaching changes.

This developmental stage of the cerebrum was the biological cognitive precondition for 2 variation mechanisms or evolutionary systems.

- Learning (= recognizing and storing) causal relationships from own experiences
- 2-sided social debt relationships, cooperation through debt.

5.11.2. Variation mechanism and evolutionary system: learning causal relations from own experiences

The ability to learn causal relationships from one's own experiences, i.e. to recognize and store them, is the biological-cognitive precondition for the targeted influencing of the course of events and a targeted emergence of new information. This ability does not lead to a random variation, but to a **targeted variation** of information.

5.11.3. Variation mechanism and evolutionary system: debt cooperation through 2-sided social debt relations.

Cooperation between two persons can also occur when debt relationships are formed and documented, as described in Chapters 5.10.2 and 16.3.3.

Sequence of case 1 cooperations through documentation of the debt with money	Utility A	Utility B
Initial situation	**0**	**0**
Utility change at time 1 due to goods	**+5**	**-3**
Utility change at time 1 due to money	**-4**	**+4**
Overall utility at time 1	**+1**	**+1**
Utility change at time 2 due to goods	**-3**	**+5**
Utility change at time 2 due to money	**+4**	**-4**
Overall utility at time 2	**+2**	**+2**

Obviously, by documenting debt relationships, there is a continuous growth of utility for both parties over time, which has greatly facilitated and thus accelerated the enforcement of this cooperation mechanism.

The precondition for this was only given by the ability of the cerebrum to store complex contents of consciousness.

5.12. The age of Homo [4.2]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[4.2]	Homo	Simple language	Interindividual **duplication** of experiences (communicate)	Teaching, Reputation, Indirect reciprocity, Social debt, Exchange	Indirect cooperation, Exchange

5.12.1. Biological trait of Homo: the simple language as a duplication mechanism of information

The language of animals in the form of acoustic, optical and chemical signals is essentially limited to the communication of e.g. warning, fear, sexual luring signals and indications of food occurrence. However, it is not able to communicate experiences such as causal relationships or to pass on (teach) complex skills. This was only possible through the development of a simple language, which probably evolved in Homo about 900,000 years ago.

5.12.2. Variation mechanism and evolutionary system: teaching causation and complex behavior.

While the cerebrum of the human ancestors initially only enabled the recognition of causal connections through their own experiences, the simple language of the first humans also enabled the teaching of experiences, i.e. the passing on of experiences and in particular causal connections from one individual to another. If already the recognition of causal connections was a great evolutionary advantage, this was obviously increased considerably by the possibility to share such experiences among each other.

If B adapts his behavior when meeting A to A's behavior, the result is e.g. $c_{BA} \rightarrow \tilde{c}_{BA} = c_{AB}$ i.e.

$$\begin{matrix} \dot{n}_A = a_A + b_A n_A + c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B = a_B + b_B n_A + c_{BA} n_B n_A + c_{BB} n_B n_B \end{matrix} \rightarrow \begin{matrix} \dot{n}_A = a_A + b_A n_A + c_{AA} n_A n_A + c_{BA} n_A n_B \\ \dot{n}_B = a_B + b_B n_A + c_{BA} n_B n_A + c_{BB} n_B n_B \end{matrix}$$

The change of the evolutionary system for imitation (see chap. 5.8.2), learning (see chap. 5.11.2) and teaching are formal the same. The difference, however, is in efficiency. Adaptation is more rapid and better via teaching than via learning, and better and more rapid via learning than via imitation. Moreover, only a behavior can be imitated, whereas the knowledge of a causal relationship cannot be gained by imitation.

Moreover, the even more essential difference between imitating, learning and teaching is that the respective cognitive preconditions for them differ very much. This is the reason that the variation mechanisms imitating, learning and teaching have developed one after the other in the course of evolution, namely in the ages [3.3], [4.1] and [4.2].

Until the development of the variation mechanism teaching in the age [4.2] of Homo, the use of tools has played only a minor role. The recognition of causal connections and their transmission by teachings is the precondition for the efficient construction and the extensive use of **tools**. If one regards plants and animals as certain information, which formed due to random changes, then consciously built tools are the first information, which formed by **targeted variation**.

5.12.3. Variation mechanism and evolutionary system: social debt, reputation, indirect reciprocity, evolutionary system: indirect cooperation

Without language, presumably only 2-sided social debt relationships were possible. Only the development of a simple language as an efficient duplication technology of information has made the formation of more complex debt relations possible. These include, above all, social debt relationships vis-à-vis an entire social community. Social debt relations towards the whole social community play an important role especially in the cooperation mechanism of indirect reciprocity.

Direct reciprocity (see chap. 5.9.2) is described in simplified terms by the principle "I help you so that you help me" . The variation mechanism of indirect reciprocity, on the other hand, is described in simplified terms by the principle "I help you so that someone else helps me".

The basic idea of indirect reciprocity is,

(1) that cooperative behavior of an individual increases the standing (reputation) of that individual in the community and that defecting decreases his reputation,
(2) that an individual's reputation can be seen by all others and spread through language,
(3) that an individual is more likely to cooperate with an individual with high reputation because it can assume that an individual with high reputation is likely to cooperate, which increases its fitness relative to defective behavior,
(4) that an individual is more likely to defect with a low-reputation individual because it can assume that a low-reputation individual is likely to defect, which increases its fitness relative to a cooperating behavior.

The existence of a simple language as a technology for the duplication of information, is because of (2) therefore obviously the precondition for reputation and thus indirect reciprocity to form.

Reputation, because of (3) and (4), leads to an increase in the probability of both mutual cooperative behavior and mutual defective behavior, and a decrease in the probability of cooperators encountering defectors. This leads, in the sense of chap. 16.4.5 formally, that $\mu_{KK} \uparrow$ and $\mu_{DK} \downarrow$, which leads to the enforcement of cooperation, namely indirect cooperation.

If an individual provides a service without direct compensation, this can lead to an increase in the reputation of this individual in the community. Reputation can be interpreted as a debt owed by the community to that individual or as a credit (claim) owed by the individual to the community. In the sense of chap. 5.10.2.1 debt relationships act as catalysts to accelerate the enforcement of win-win mechanisms. Since cooperation mechanisms are special win-win mechanisms, the debt relationship described by reputation leads to the rapid spread of indirect cooperation.

5.12.4. Variation mechanism and evolutionary system: exchange

The exchange of goods is a win-win mechanism. It arises from a case 1 variation (see chap. 5.10.2.1 and chap. 16.3.3.1) and requires elementary communication skills such as simple language. However, to form it, unlike case 2 variations such as division of labor and purchase (see chap. 5.13.5) no documentation of debt relationships is necessary.

5.13. The age of Homo sapiens [4.3]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[4.3]	Homo sapiens	Cognitive revolution: abstract language, logical thinking, consciousness, immaterial realities, individual utility optimization	Intra/interindividual processing of experiences into causal relationships (Why B? Then if A), Intangible realities	Logical thinking, Social norms (religion), Individual utility Optimization, Commodity debts	Norm-Cooperation, Division of labor

5.13.1. Biological traits of Homo sapiens: the cognitive revolution

The abundance of new biological features of Homo sapiens that evolved about 70,000 years ago are collectively referred to as the cognitive revolution[25] .

This includes above all:

- The abstract language
- The logical thinking
- The question "Why?"
- The understanding of causal relationships
- The consciousness
- The development of intangible realities
- Religion

[25] The term was introduced by Y. Harari (A Brief History of Mankind).

- The illusion of free will
- Individual utility optimization

The most essential characteristic feature of Homo Sapiens is the **abstract language** with sentence structure from abstract words and grammar. It has probably developed together and simultaneously with the possibility of abstract thinking and logical reasoning. Abstraction and **logical thinking** are the most important forms of processing of consciousness contents. Abstract language was thus the basis for the cognitive revolution.

Whereas previously it was only possible to recognize causal relationships, with logical thinking it was also possible to search for the causes of events. That means in addition to knowledge in the form of the statement "if X, then Y" it was now possible with the question "why Y?" to think about the causes of Y. This possibility was so fundamental that one could also characterize Homo sapiens by the fact that he is not only able to ask the question **"why?"**, but that he is virtually genetically conditioned to ask the question "why?" for everything and to want to find an answer for everything. In this sense it is a tracing of the transition from the Homo to the Homo sapiens if children at the age of approx. 2-3 years incessantly ask the question "Why?".

With good reason, therefore, one can also consider the concept of God as an abstraction of the answer to all those questions to which one has not found an answer. The evolution of **religion** can therefore be plausibly explained in the following way.

1. the question "Why?" resulted in an evolutionary advantage, because logical connections could be recognized with it and thus the future consequences of actions could be better estimated.

2. The concept of God arose naturally from this as an abstraction of the answer to all those questions for which no other answer could be found.

3. With the concept of God, the formation of religions was also possible, which led to an evolutionary advantage as a means of enforcing social norms.

Whereas the information processing technology of the limbic system is essentially only capable of reducing complex information to its essential content, the processing technology of the cerebrum is characterized by its ability to produce fundamentally new information from complex input information, e.g., in response to the question "Why?" This new information originates in parts of the cerebrum and becomes input information for other cerebral cortical areas through the communication of the different cerebral cortical areas with each other. This input information is perceived by these brain areas as "external" information in the same way as the information they receive from the actual external real world through the sense organs. Thus, a new **immaterial reality** is added to the perceptions about the real world, which is taken to be as real as the external environment. It is through these complex feedbacks in the flow of information that what is called **consciousness** ultimately occurs. Immaterial social realities include, above all, moral systems and religion and the concepts of intentionality and free will (Singer 2019) or more precisely, the **illusion of free will.** (Roth 1998).

In scientific terms, individuals are nothing more than physico-chemical systems. The behavior ("output") of all individuals at a certain point in time is determined exclusively by their genetically determined traits ("hardware"), their traits acquired in the course of life ("software") and the respective environmental situation ("input"). The selection of which behavior an individual actually exhibits is therefore always determined by physico-chemical processes. Only because this physico-chemical selection process, which leads to a certain behavior, is much more complex in humans in most situations than in all other living beings, it is misleadingly called "free will" by humans.

The possibility of the emergence of these immaterial realities has as a precondition the development of an abstract language and the ability for logical thinking. Without abstract language only a communication of the people about the real environment is possible. Only the abstract language has also made possible a communication about these immaterial realities.

Of particular importance for evolution is the possibility of the evolution of the intentionality of decision mechanisms and thus the possibility of the evolution of the variational mechanism of **targeted variation** through **individual utility optimization** (see Chap. 5.13.4)

It was not until the cognitive revolution that the biological cognitive conditions were also in place for the development of cooperation through systems of norms and the strengthening of a social society through the division of labor and commodity debts.

5.13.2. Variation mechanism: logical thinking

Logical thinking does not lead to random changes of information, but is a particularly efficient **targeted** variation mechanism. In this mechanism, already existing successful information is not adopted by imitating, learning or teaching, but new information successful for evolution is created. Logical thinking causes a change of almost all evolutionary systems and leads to a substantial **acceleration of** evolution (see also 4.7.3).

5.13.3. Variation mechanism: social norms, evolutionary system: norms cooperation

In principle, in a Prisoner’s Dilemma situation, the variation mechanism of a punishment for defective behavior and/or a reward for cooperative behavior can always lead to cooperation prevailing (see Chap. 16.4.4). This may have played a role already sporadically before the time of Homo sapiens. But this became of formative importance only when Homo sapiens, due to the abilities described above, had the preconditions for the formation of immaterial realities. Only then the establishment of simple social norms by simple religions was possible. From a social point of view, religions - apart from the enforcement of individual claims to power - have ultimately always had the enforcement of cooperation through punishment and reward as their goal.

Punishments and rewards do not completely prevent noncooperative behavior; in a sense, they only exert pressure to behave cooperatively. When the pressure of a norm is so strong that noncooperative behavior does not occur at all, that norm formally acts as a constraint. (See also chap. 11.3 and chap. 15.4). Cooperative behavior is then no longer encouraged by punishments and rewards, but enforced by a constraint.

5.13.4. Variation mechanism: individual utility optimization and the need for cooperation mechanisms.

Of particular importance is the variation mechanism of individual utility optimization (for a formal description see chap. 15.5.6). It obviously requires that an immaterial concept like individual utility can form at all. This was only possible by the cognitive revolution in Homo sapiens.

The variation mechanism of individual utility optimization leads to **targeted** variation.

In the case of an untargeted variation, e.g. a random mutation, it only becomes apparent in **retrospect** whether this change represents a fitness advantage. Suppose, for example, that the mutation leads to the behavior "stop when the traffic light shows red". It is then not foreseeable from the outset whether this mutation is positive, i.e. whether it increases the reproductive rate (because one cannot be run over by a car), or whether it is negative (because one loses a lot of time if one waits forever in front of the traffic light although no car is coming). This is only decided by the long temporal process of survival of the fittest.

The situation is completely different when behavior is determined by a decision mechanism that evaluates the individual utility and selects the behavior that brings the best individual utility. Then, the brain **immediately** decides whether the behavior "Stay put when the traffic light shows red" comes into play. For example, an additional check is made to see if cars are actually coming, and if none are coming, to cross the street even when the light is red. The individual utility that is optimized would be, for example, to reach the destination as quickly as possible on average. A species (like e.g. Homo sapiens), in which such decision mechanisms have developed, in which decisions are made on the basis of the estimation of an individual utility, obviously has an overall fitness advantage, compared to a species that always waits "forever" before the red light, even if this decision mechanism can end badly in the individual case, because the mechanism can also be error-prone in the individual case.

Obviously, the ability to optimize individual utility is a major evolutionary advantage overall. In many cases, individual utility optimization can lead to high overall utility, although in some situations it can also be a disadvantage. This is true not only in some individual cases (e.g., when one overlooks an approaching car), but especially in Prisoner's Dilemma situations individual utility optimization almost systematically leads to the worst solution for all. In all Prisoner's Dilemma situations, an increase of utility for all can only be ensured by cooperation mechanisms. Therefore, cooperation mechanisms, i.e. mechanisms that overcome Prisoner's Dilemma situations, are of particular importance in these situations.

Important for understanding the difference between individual utility optimization and overall utility maximization is the following fact: If several agents influence each other in their behavior and each of the agents tries to behave in such a way that his own utility is as high as possible, this need not at all lead to maximizing his own utility or the utility of another agent or a overall utility, however defined. We therefore always speak of individual utility optimization as opposed to overall utility maximization**.** For the formal connection between individual utility optimization and overall utility maximization, see Chap. 15.7.3.

5.13.5. Variation mechanism and evolutionary system: commodity debt and division of labor

For division of labor to be efficient, it must be possible to produce the outputs and the compensations at different times and to balance them at different times. Division of labor therefore arises through a case 2 variation (see chap. 16.3.3.1) and is therefore promoted quite substantially by the possibility of efficiently documenting debts. In the simplest case, these debts are commodity debts. Only in Homo sapiens with its ability to think logically and to form immaterial realities was it possible to document debts objectively (independent of the subject). This was possible in particular only by the ability to count. The emergence of a clear number concept is again very closely connected with the existence of an abstract language (Wiese 2004). All this explains why an efficient division of labor developed only with Homo sapiens.

5.14. The age of the market economy [5.1]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[5.1]	Market economy	Font, Coinage	External **storage** From digital data	Written religious norms, Individual contracts, Quantitative individual utility optimization, Monetary debts, Purchase, Animal and plant breeding	Cooperation via religious norm systems, Regional trade

5.14.1. Technological trait: writing and coinage as storage technology

The invention of writing made it possible to store information externally with the help of symbols. Information about debt relationships is nothing other than special information. Debt relationships were therefore initially stored in the form of symbols at about the same time as the invention of writing. For example, a clay tablet with 1 circle carved on it could mean that you owe me 1 goat, a clay tablet with 3 squares carved on it could mean that you owe me 3 buckets of wheat, and a clay tablet with 6 dashes could mean that you owe me 6 jugs of oil.

Any documentation of debt relationships is, as it were, a catalyst for the formation of win-win situations (see Chap. 16.3.3)

The great qualitative leap in the documentation of debt relationships was the invention of money. Money is nothing more than a uniform standard for evaluating all debt relationships. One of the first important symbols that served as money were metallic coins.

5.14.2. Variation mechanism and evolutionary system: cooperation through written religious norm systems (high religions) and individual contracts.

Writing was the precondition for the formation of written religious norm systems, which are often referred to as high religions. The essential function of norm systems is to enforce cooperation (see chap. 16.4.4) or the avoidance of market failure. In formal terms, norm systems ultimately represent nothing more than constraint conditions that lead to cooperation prevailing (see chap.16.4.6).

However, cooperation need not always derive directly from general norms. It can also result from the insight of two individual partners that they are in a Prisoner’s Dilemma and that it is therefore better for both partners to conclude a cooperation agreement. Such behavior, however, requires a high degree of cognitive ability on the part of the contracting parties and a correspondingly highly developed system of norms for enforcing contracts. Formally, such a cooperation contract also leads to constraints that cause cooperation to prevail (see chap.16.4.6).

5.14.3. Variation mechanism: quantitative individual utility optimization as a characteristic of a market economy

In the sense of K.H. Brodbeck, money appears next to human language as the second central form of socialization (Brodbeck 2009). This is because money has not only brought a great qualitative leap in the documentation and valuation of debt relations, but also because money, above all, enables the quantification of individual utility on a uniform scale. Since then, money and individual utility optimization have permeated all areas of human life, with all the advantages and disadvantages that this entails. Individual utility measured in money becomes the determining force for wide areas of human society.

The principle of a market economy is virtually defined by the fact that each participant tries to achieve the highest possible individual utility through his behavior. In economics, the assumption of the "invisible hand" (by Adam Smith) means that individual utility-optimizing behavior usually leads to an overall utility maximum or at least to an increase in utility for each individual. If this is not the case, economists speak of market failure.

Prisoner's dilemma situations are typical cases in which market failures occur. A particularly important mechanism for overcoming a Prisoner’s Dilemma situation is the introduction of constraints in the form of social norms by which cooperating behavior is enforced over non-cooperating (defective) behavior.

5.14.4. Variation mechanism: purchase as individual utility optimization, evolutionary system: trade

A purchase is the exchange of a good for money. A purchase between two market participants usually occurs when the individual utility (measured in money) of both trading partners increases. It is therefore driven by the individual utility optimization of the market participants.

Money is the precondition for efficient trade in a market economy. It enabled the transformation of relative prices between all possible goods (1 goat against 3 buckets of wheat, 1 bucket of wheat against 2 jugs of oil) into "absolute" prices, i.e. relative prices against money or money in the form of coins (1 goat against 6 coins, 1 bucket of wheat against 2 coins, 1 jug of oil against 1 coin).

Money in its function as a uniform standard, as a generally recognized, uniform medium of exchange and as a means of storage was a highly efficient catalyst for trade and thus also for an efficient division of labor.

5.14.5. Variation mechanism: animal and plant breeding

Animal husbandry, arable farming and the "bookkeeping" (storage of digital data) of animal and plant productivity have provided the preconditions for animal and plant breeding as a **targeted variation** mechanism.

5.15. The age of the capitalist market economy [5.2]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[5.2]	Capitalist market economy	Letterpress, Paper money	External **duplication of** data	Nation norms, Investment in real capital	Cooperation across national systems of norms, National trade

5.15.1. Technological trait: letterpress printing and paper money as duplication technologies

Letterpress printing is the first efficient mechanism for reproducing external digital information. The technology of letterpress printing also made the efficient production of paper money possible. Paper money was the first efficient mechanism to be able to produce money in any units (denominations) and in any quantity, taking into account appropriate backing. The quantity of paper money was limited only by the fact that it either had to be backed by real goods such as gold or silver or, in the form of "credit money" (i.e. money created when loans were granted), it had to be backed at least by claims on real goods such as investments or real estate.

Paper money was therefore a precondition for the financing of large-scale investments and for transactions involving large amounts of money.

5.15.2. Variation mechanism: investment in realcapital as a duplication mechanism

As explained in the previous chap. 5.15.1 printing and thus paper money were the preconditions for the financing of large-scale investments and thus made them possible. Investment in productive real capital is the first efficient mechanism for multiplying the production of goods.

As explained in chap. 16.3.4.4 capital can be regarded as a separate species. Humans and capital are basically related to each other in the same way as 2 different species. (see also chap.12.7.5).

By autocatalysis, the variation mechanism investing generally leads to approximately exponential economic growth, i.e. exponential growth in the production of capital goods and consumer goods, at least in the longer run.

However, to ensure that investments also lead to a win-win result for everyone in the long term, many constraints are usually necessary.

5.15.3. Variation mechanism and evolutionary system: cooperation through national norm systems

The normative systems of the high religions were initially stored in written form but reproduced in oral form.

Only the printing press made possible the efficient reproduction of these reli-gious norms (keyword: Luther's Bible). However, book printing was ultimately also the precondition for the formation and dissemination of such complex systems of norms as the national systems of norms laid down in laws.

Like any system of norms, state systems of norms formally represent constraints that are intended to lead to the enforcement of cooperation.

5.15.4. Policy concepts for overall utility maximization

Overall utility can usually be defined in any way for multiple agents. Regardless of how overall utility is defined in a particular case, the problem is how to enforce a behavior of all agents involved that leads to overall utility. Theoretically, there are various policy approaches to achieve this goal:In the economy of a small tribal group, it should be possible, in principle, to identify what behavior all members must exhibit in order to achieve maximum overall utility for all. In such a small community, this behavior can be enforced by the chief. But the larger, and thus the more complex, an economy is, the more difficult it becomes, even through the use of supercomputers, to identify and enforce the optimal behavior for all agents. This is, in essence, why every major centrally planned economy has failed.

But if a planned overall utility maximization fails, the only option left is to organize it through individual utility optimization strategies of its members. This is precisely the central organizing principle of the free market economy. However, the assumption or axiom of the free market economy that this individual optimization strategy always leads to an overall optimum due to Adam Smith's invisible hand is fundamentally wrong.

The big question of political economy is therefore to analyze which additional measures (constraints) could guarantee that the individual optimization strategies of the participants lead to an overall optimum for all. From this point of view, the different economic theories can be characterized in terms of which measures they assume to be sufficient to guarantee an overall optimum without abandoning the principle of individual optimization.

Neoliberalism:

The fundamental axiom of neoliberalism is the assumption that competition (i.e. individual utility optimization) may be restricted only to the extent that the rules of the game must be the same for everyone. Beyond that, however, more stringent measures (constraints) should generally not be required to ensure an overall optimum. This assumption is fundamentally wrong, because Prisoner's Dilemma situations are not the exceptional case, but the normal case when individuals live together.

Social market economy:

Indeed, the social market economy rejects the fundamental axiom of neoliberalism, but assumes that interventions in the distribution of welfare are sufficient to guarantee that individual optimization leads to an overall optimum.

Real - socialism (planned economy, communism):

The goal of real socialism was to achieve equality in society. But obviously one can learn from the Prisoner's Dilemma that a constraint in the sense of equal utility for all individuals does not necessarily lead to an overall optimum, since in the Prisoner's Dilemma even the worst solution can satisfy the equality condition.

The basic axiom of real socialism is that it is impossible to achieve an overall optimum by an individual optimization strategy, no matter how strict the constraints are set. The logical conclusion of real socialism is therefore that only a planned economy can achieve an overall optimum. As mentioned above, this assumption underestimates the complexity of a large economy and that is why every form of real -socialism has failed in the past.

Keynes:

In a sense, Keynesian economic theory is a compromise. On the one hand, it accepts that due to the complexity of the economy, an individual optimization strategy is unavoidable as a starting point. On the other hand, Keynesians recognize that strong constraints are necessary to guide the economy toward an overall optimum.

For example, the following is proposed:

- A control of the core parameters of the macroeconomy
- A wide range of strong government regulations, e.g., prohibiting or taxing non-cooperative behavior.
- Measures to equalize the political power and economic power of economic entities.
- A balancing distribution policy

Common Good Economy

The common good economy (Felber 2021), leaves the extremes of neoliberalism and socialism behind. It is based predominantly on private enterprises, but these do not strive for financial gain in competition with each other, but cooperate with the goal of the greatest possible common good.

5.16. The era of the global capitalist market economy [5.3]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[5.3]	Global capitalist market economy	EDP, Electronic fiat money	External **processing of** data into new data	International norms, Investment in human capital	Cooperation based on internation norm systems, World trade

5.16.1. Technological property: electronic data processing as a processing technology and electronic fiat money.

The development of COBOL in 1960 can be considered as the moment of the beginning of the wider use of electronic data processing in business. COBOL (Common Business Oriented Language) was the first standardized computer language. Electronic data processing was the most important technical precondition for the explosive growth in international world trade that began around 1975.

Until 1971, the U.S. dollar and thus all other major currencies were at least in essence (i.e. partially) backed by gold. In 1971, the Bretton Woods Agreement was terminated by Richard Nixon, thus abolishing the gold backing of the U.S. dollar. This was the birth of the so-called "fiat" money, a money that no longer directly represents a real tangible asset or can be exchanged for a tangible asset. This form of money has since prevailed worldwide. The fact that such a "fiat" money system actually works and does not lead to hyperinflation is ensured solely by the actions of the various central banks. Money in the form of coinage or paper money is becoming less and less important, while the proportion of electronically documented money is increasing. The electronic documentation of money is an essential facilitator for the prompt transaction of any amount of money over any distance. Electronically documented money is thus a precondition for efficient international trade.

5.16.2. Variation mechanism: international norms, evolutionary system: world trade and globalization as (supposed?) win-win system

World trade agreements under the WTO can be seen as constraints with the aim of strengthening international trade.

The UN and human rights can be seen as international normative systems to promote cooperation at the international level in all areas of society.

Global statistically recorded exports of goods increased more than 19-fold between 1960 and 2017; in contrast, statistically documented production of goods grew only 7-fold („Entwicklung des grenzüberschreitenden Warenhandels“ 2021). The sharp increase in international interdependence and dependency through international trade are key traits of what is now commonly called "globalization".

At the same time, this globalization was accompanied by a fundamental change in the most important value and norm systems, characterized by the concept of neoliberalism or, more precisely, by the concepts of liberalization, privatization and deregulation. In light of the theory of individual utility optimization, overall utility maximization, general constrained dynamics (GCD models), and constrained conditions (see chap. 15.6, chap. 14, chap. 16.4.6), this development can be interpreted as follows:

In principle, democracy can be seen as a system of norms which has pushed back the power of the "strong" and strengthened cooperation in society. However, neoliberalism is leading to a shift of power back to the strong in all social issues of the present and the future, and thus to a repression of cooperation. Norms that promote cooperation are abolished and competition is seen as the most important element of social action. The state's financial resources are reduced in order to reduce its ability to limit the power of the strong through norms. Democracy is undermined as the strong take control of the media. Thus, the variational mechanism of individual utility optimization becomes more and more widespread. In a system with individual utility optimization, however, those whose power factors μ are large are the ones who prevail in the sense of the GCD models. This is tantamount to saying that in a system that is largely subject to competition, the strongest will always prevail.

I.e. ultimately, this evolutionary system is moving further and further away from a mechanism for overall utility maximization, regardless of how overall utility is socially defined. I.e. that neoliberalism ultimately represents a win mechanism for a few strong and not at all a win-win mechanism for all.

5.16.3. Variation mechanism: investment in human capital

"Since 2005, expenditure per pupil in Germany has increased from 4700 euros to 6000 euros in 2011. This corresponds to a nominal increase of 26% and a real increase of 19.1%. This increase can be attributed to expenditure increases in recent years and declining pupil numbers" (Schmidt 2014). Or, for example, from about 1970 there was an exponential expansion of universities (Haller, o. J.). Both are indications that investment in education has risen very sharply in recent years. Similar figures can be found for the development of total investment in research and development.

Investments in research, development and education lead to the creation and accumulation of intangible capital, often also referred to as human capital, in the economy as a whole. Like real capital, this intangible capital leads to higher production efficiency and thus, via autocatalysis, to economic growth.

The same as for investments in real capital, however, also applies to investments in human capital. To ensure that these investments also lead to a win-win result for all in the long term, many constraints are certainly still missing at present.

5.17. The age of the Internet-based market economy [6.1]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[6.1]	Internet-market economy	Internet, International payment systems	Networked **storage** / **duplication** from data/knowledge	Attempt at overall utility optimization by global norms with global sanctions, Investment in sustainability	Cooperation based on global sanctions

5.17.1. Technological traits: internet, international payment systems

The development of the Internet into a huge delocalized, networked storage and communication medium (cloud) that can be accessed from anywhere and at any time will lead to a fundamental upheaval of human society similar to that caused by the invention of the cerebrum or the invention of external local data storage. The decisive characteristic of the Internet is that it is not only a data store of enormous size and that the volume of data expands almost automatically every day, but it consists above all in this,

- that a separate duplication technology is unnecessary, because theoretically everyone has access to all stored data at any time
- that the data are not stored in isolation, but that the data are stored with their mutual interrelationships (knowledge = data with their interrelationships)

The Internet is therefore by no means just a continuous improvement in electronic data processing, but represents a fundamental leap in the quality of information technology, the longer-term effects of which are still completely underestimated today.

If we define knowledge as logically linked and networked data, the Internet represents more than a data store, namely a knowledge store. In this sense, the Internet is also the technical precondition for the possibility of overall utility maximization.

The Internet is leading to a leap in quality and speed not only in commerce, but also in the production of knowledge through research and development and dissemination of knowledge through education.

5.17.2. Variation mechanism: attempt to maximize overall utility for future generations and the environment based on global norms with global sanctions

The Internet has an enormous impact on the economy. The essential characteristic of online trade is that the competitive mechanism of the market economy is dramatically intensified and trade is extremely accelerated because it is enormously easier for buyers to select products and compare prices. As a result, people's behavior is having an increasingly rapid impact on the environment, and this impact is becoming increasingly uncontrollable.

The previous international norm systems such as human rights or world trade agreements refer solely to people and in particular to the people of the present. Because of the dramatically increasing general interconnectedness, the specific interconnectedness of mankind with the environment is also moving into general awareness. Because of the dramatic increase in the speed of all social and economic processes, however, the consequences for future generations are also moving more and more into general awareness. As a consequence, there are first tentative attempts to solve these problems by new global norm systems in such a way that there is cooperation with all species in nature beyond the present. For the first time, for example, there are also international norms linked to financial sanctions with the International Climate Protection Agreements.

Whether global norm systems with selective financial sanctions for the protection of the environment and future generations will be developed and politically enforced quickly enough and, above all, whether they will be sufficient to avoid negative feedbacks for the entire system of living nature is, from today's perspective at least, highly questionable.

5.17.3. Variation mechanism: investing in sustainability

If in age [5.2] it was investment in real capital and in age [5.3] investment in human capital to increase production, age [6.1] is characterized by an beginning investment in the long-term sustainability of the economy and the longer-term survival of humanity.

5.18. The age of the AI-based market economy [6.2]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[6.2]	AI-based market-economy	AI 1.0 based knowledge processing, Blockchain, SOWL (Synthetic optimized world language	**Processing** knowledge into new knowledge and virtual reality (=production of knowledge and virtual reality)	Stabilization through AI-based automatic sanctions, Investment in stability	Cooperation via automatic sanctions

5.18.1. Technological trait: knowledge processing with artificial intelligence

The Internet has greatly facilitated the production of new knowledge by enabling all people to access existing knowledge at any time. However, artificial intelligence will also mean that new knowledge will no longer be created only by people, but that new knowledge will also be created directly by computers, which will have access to all existing knowledge via the Internet. This will revolutionize the speed and quality with which new knowledge is produced.

Artificial intelligence is in its infancy today. It will very quickly develop far beyond what is commonly considered artificial intelligence today (autonomous driving, expert systems, machine learning, pattern recognition, etc.). Artificial intelligence will very quickly establish itself in society as a comprehensive and indispensable tool and subject society to a dramatic qualitative change.

We therefore understand artificial intelligence in a very broad sense as a machine processing mechanism to create new knowledge from old knowledge.

Currently, artificial intelligence is methodologically based on the statistical analysis of large amounts of data. This form of artificial intelligence could be called artificial intelligence 1.0.

Artificial intelligence 2.0 will deliver a completely new quality. This will no longer be based on statistical analysis of large amounts of data, but will produce new information from the logical combination of existing information. We can expect this development in the future (see Ch. 7.1).

5.18.2. Technological trait: blockchain technology

Blockchain technology is a decentralized database management system for storing, controlling, duplicating and processing complex information. "Tokens" for describing complex rights or debt relationships play an essential role in blockchain technology. They can be regarded as tradable rights and thus represent a qualitatively new addition to money.

Just as money as a uniform means of documenting debt relationships has facilitated commerce and the economy as a whole and can thus be viewed as a win-win mechanism, blockchain technology can also be viewed as a means of documenting and processing debt relationships. In particular, blockchain technology can also be used to document and process very complex debt relationships. Thus, blockchain technology represents a new win-win mechanism in addition to money.

5.18.3. Technological trait: synthetic optimized world language (SOWL)

According to the current directory of Ethnologue (Andersen, 2010) there are 6900 different languages worldwide (Isabelle, 2016). Approximately 3 billion people speak one of the 10 most common languages as their mother tongue. 4.5 billion people speak a less common language as their mother tongue.

When the world was not yet as interconnected as it is today, this fact was still of secondary importance and could therefore be mastered more or less well, but still with reasonable effort, with the efforts of translation and with the help of interpreters.

However, in today's world, which is completely networked via the Internet, this state of affairs is extremely problematic. In particular, it is important to remember that a large proportion of interpersonal problems occur because of misunderstandings due to faulty communication. If it is already difficult for 2 individuals with the same mother tongue to avoid misunderstandings in communication, then when people with different mother tongues communicate with each other, misunderstandings are almost inevitable and thus often lead to conflicts with serious consequences.

A first idealistic attempt to overcome this problem was the invention of the synthetic language Esperanto in 1887 by Ludwig Zamenhof.

This is not the place to go into why English, Chinese or Esperanto are not particularly suitable as world languages. Rather, the future solution to this problem will be considered from the perspective of information processing.

The ever-growing need for translations in the increasingly networked world is obvious. It is increasingly being met today with ever more powerful artificial intelligence-based programs. A self-learning translation program that needs to translate many languages into each other will certainly develop an internal language into which all languages can be translated for reasons of efficiency. However, this does not mean that this internal language is also suitable as a human language. Therefore, only 3 possible further developments remain:

1. The technology for communication with powerful translation programs becomes so user-friendly that different mother tongues practically do not hinder communication between people.

2. The internal translation language is transferred into a human language by artificial intelligence and optimized in such a way that it can be learned and understood as easily as possible by all people with the most diverse native languages.

3. The linguistic deficiencies of English[26] or Chinese are continuously corrected by the ongoing communication with the translation program with the help of artificial intelligence.

In any case, this development will give rise to a Synthetic Optimized World Language ("SOWL") that will influence communication between people as fundamentally as it was once influenced by the invention of writing.

5.18.4. Variation mechanism: stabilization through automated sanctions, investment in stability and resilience

Investments in sustainability alone (as in age [6.1]) cannot guarantee that this sustainability will be achieved. For this goal to actually be achieved, the dynamic system must above all also be stable. To put it vividly: A car that is properly programmed to go to Paris will not arrive in Paris if, on the way there, it skids because of self-reinforcing oscillations. In this sense, the age [6.2] will be characterized by investments in the stability and resilience of humanity's social and economic system. A key mechanism for this will be AI-based sanctions automated via blockchain technology, which will be effective in the event of a foreseeable threat to overall utility and system stability. This will ultimately enforce global cooperation.

5.18.5. Variation mechanism: gene manipulation

Just as new knowledge and thus information is created in the general sense, new genetic information will also be created in the specific sense by targeted genetic manipulation. Genetic manipulation therefore corresponds to a targeted variation mechanism that will further accelerate evolution dramatically. The effects on society and evolution as a whole are hardly predictable at present.

[26] Spelling is not phonematic (each letter should have only one pronunciation). Many phrases, which leads to misunderstanding (meaning of words should not depend heavily on context). Too little redundancy in the spoken word (different things should sound sufficiently different), etc.

C. "Megatrends" of evolution as a basis for understanding future developments

6. Megatrends of Evolution

6.1. The regular sequence of new storage technology, duplication technology and processing technology.

The evolutionary theory of information is not a theory that can be derived from natural science, but it describes regularities with which the course of evolution can be structured and better understood. These regularities are well founded and are in accordance with the empirical facts of the course of the evolution.

The core statements of the evolutionary theory of information are:

- A new type of information is always linked to the appearance of a new storage technology
- For each new type of information, information technologies emerge in sequence:
    - Storage technology
    - Duplication technology
    - Change technology or processing technology
- Each new information technology enables a new variation mechanism. Through this, the evolutionary systems describing the dynamic development of the frequency of species (in a broader sense) can be changed.
- The speed at which new technologies have emerged has accelerated extremely.

6.2. The development of increasingly efficient cooperation and win-win mechanisms

Cooperation mechanisms (such as direct and indirect reciprocity, group formation, etc.) and win-win mechanisms (such as symbiosis, barter, purchase, investment, etc.) cause the evolutionary fitness (i.e., reproductive rate) of a species to increase. This leads not only to the reproduction of these species, but also to the development of increasingly efficient cooperation and win-win mechanisms.

An important role in the development of win-win mechanisms is played by the possibility of documenting debt relationships. The most efficient form of documenting debt relationships is through money. The development of ever more efficient forms of money has led to the development of ever more efficient forms of win-win mechanisms. These, in turn, are the deeper cause of man's dominance in nature.

6.3. From random variation to targeted variation

At the beginning of evolution there are random variations (mutations). In the course of evolution, however, targeted variation mechanisms become more and more important. Epigenetic variations can be regarded as the first precursor of targeted variation. Horizontal gene transfer and sexual reproduction do not lead to the transmission of random mutations, but to the random transmission of mutations that have already successfully prevailed evolutionarily (see chap. 4.7.2) and can therefore be seen as simplified targeted variation mechanisms. Important true targeted variation mechanisms are (see chap 4.7.3):

- imitating, learning, teaching
- logical thinking
- individual utility optimization
- overall utility maximization
- animal and plant breeding
- genetic manipulation

These lead to an enormous increase of the evolutionary speed, because presumably evolutionary unsuccessful "misdevelopments" are avoided and thereby, as it were, detours of the evolution are shortened.

6.4. Values and norms as a result of evolution

Value attitudes and their formalization as religious or state norms are the result of evolutionary processes. The dynamics of evolutionary systems decide which value attitude prevails, just as they decide which species prevails.

There is no such thing as "good" or "bad" behavior in absolute terms. It is not clear from the beginning whether the norm "you should kill your enemies" or the norm "you must not kill anyone" will prevail. Which norm prevails, or in other words, which norm is "good" for the survival of a species, is usually difficult to judge in advance, but can often only be judged in retrospect.

The norm " you shall kill your enemies" could also well prevail or have prevailed, if it leads to the fact that for the survival in the fight against enemies abilities have developed, which represent an overall fitness advantage. Or, to put it simply, for the gazelle the norm of "eating grass and running away from enemies" has prevailed, for lions the norm of "eating meat and killing gazelles" has prevailed.

The question also arises whether strict adherence to a norm is overall evolutionarily advantageous. Or whether, due to the basic principle of evolution in the sense of mutation and selection, it is not downright necessary that existing norms are repeatedly deviated from or, in extreme cases, revolutions against norms are initiated.

The answers to these questions are very closely related to the image of man that we have built up as an immaterial reality:

- Is man (and the human order) a creature of God? (religious image of man)
- Is man (and his various human societies) a living being like any other in the world that has emerged as a product of evolution? (Social Darwinist view of man)[27]
- Or is man a product of evolution that differs from other creatures precisely because he has a mind that enables him to estimate the effects of his actions on the future? (humanistic view of man)[28]

These images of man have acquired a corresponding importance in the chronological order as religious, social Darwinist, humanist world view. Which view of man prevails will have a great impact on the future development of mankind.

Norms restrict the possible dynamic developments. Therefore, norms always formally correspond to constraints in dynamic systems.

6.5. The interplay between overall utility maximization (cooperation) and individual utility optimization (competition)

Ignoring the evolutionary development of new changes, cooperation in the sense of overall utility maximization in Prisoner’s Dilemma situations leads to an increase in the weighted total fitness of the system relative to individual utility optimization (see Theorem <16.3> in chap. 16.4.2).

However, taking into account the evolutionary development of new changes, it is quite possible that competition in individual utility optimization will cause "stronger" species to prevail, so that overall fitness, taking into account the newly evolved species, will increase over time.

Thus, it may well be that, taking into account the emerging species, a balance of overall utility maximization and individual utility optimization over time leads to the fastest increase in the overall fitness of the system.

Thus, it does not seem surprising that in economic systems, too, a balance between cooperation and competition leads to the "best" outcome.

6.6. The exponential developments in evolution and the nature of exponential growth

The analysis so far shows exponential developments in many areas of evolution:

- the speed with which new types of information or their storage, duplication and processing technologies have appeared
- the speed with which the complexity of species has increased

[27] A social Darwinist view of man in the sense of "the right of the strongest" has existed long before Darwin

[28] Humanism in the sense of

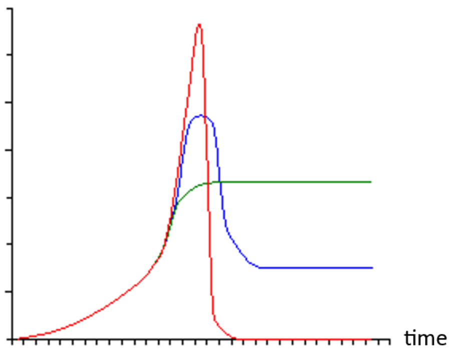
- "socio-political program designed to meet present challenges and shape the future." On the modern use of the term in a non-traditional sense, see the detailed article Humanismus in: Hans Schulz, Otto Basler: Deutsches Fremdwörterbuch, 2nd edition, vol. 7, Berlin 2010, pp. 459-465, here: 460f. and the evidence compiled there.
- "an optimistic assessment of humanity's ability to find its way to a better form of existence." https://www.wikiwand.com/de/Humanismus

- the speed with which new variation mechanisms have evolved
- The speed with which new drivers of dynamics have developed

Basically, exponential growth of real quantities in a bounded system is not possible in the long run, because the growth must reach its limits at some point due to the boundedness of the system. Therefore, there must always be a point in time when the behavior of such a exponentially growing dynamic system changes qualitatively in a fundamental way. This point in time is called a singular or critical point. That we are facing such a singular point in the course of evolution was also predicted, for example, by Ray Kurzweil, the head of technical development at Google. (Kurzweil 2005). How qualitative behavior will evolve at such a singular point cannot be deduced from knowledge of past behavior alone. A typical behavior is, for example,

(1) that the system overshoots strongly and then collapse
(2) that the system overshoots slightly and then stabilize at a lower level or
(3) That the system stabilizes at a higher level without overshooting

Exponential growth and its consequences



The only thing we can predict with certainty from the analysis of the past of evolution is the fact that we will soon come to a singular moment in evolution when the qualitative behavior of the dynamics of evolution will change fundamentally.

6.7. Generalizability

The general theory of evolution describes the developments as they have proceeded on earth under the given chemical-physical conditions for about 4 billion years. However, the essential considerations are of such a fundamental nature that we hypothesize that evolution necessarily develops according to the same principles on other stars as well.

However, this does not at all lead to the conclusion that evolution always leads to the same result. The mechanisms of evolution are typically characterized by self-reinforcing mechanisms. Therefore, random changes in individual cases can lead to completely different processes of evolution. Even if evolution always proceeds according to the same principles, it will therefore lead to different results and expressions in individual cases, even if the chemical-physical conditions are the same.

7. Possible future scenarios

7.1. The distant future: the age of humanity as an individual (cyborg) [7]

1	3	6	7	9	10
Age	**Living being form**	**Biological-technological trait**	**Information technology**	**Variation mechanism**	**Evolutionary system describes evolution dynamics**
[7]	Humanity as a single individual, Cyborg	Direct human-machine communication, Fusion of real and virtual world	Direct man-machine **storage** / **duplication** / **processing** (Production of comprehensive understanding)	Direct human-machine communication, Merging real and virtual reality, Overall utility maximization	Completely new form of social organization

Our analysis of evolution so far shows:

Even if "catastrophic" events have occurred again and again in the course of evolution, which have led to a mass extinction of species for a wide variety of reasons, evolution has nevertheless developed in the long term towards an ever higher diversity of species with increasingly complex individuals. The assumption is therefore justified that this development will continue in the future, at least in the long term.

In terms of the evolutionary theory of information, the following scenario is conceivable:

Over many periods, technological development has always occurred in the succession of new storage technology, new duplication technology and new processing technology. Only in the last age, with the Internet, has an information technology developed that combines storage technology and duplication technology.

We therefore hypothesize that the next age, whenever it comes, will be characterized by an information type and technology that combines storage technology, duplication technology, and processing technology. We assume that this technology will be characterized by direct human-machine communication and will lead to a merging of the real and virtual worlds.

In particular, this age will also be characterized by the development of artificial intelligence 2.0. Unlike artificial intelligence 1.0, this will no longer be based on a statistical analysis of large volumes of data, but will be able to produce new information from the logical combination of existing information. The logical combination and linking of all information stored on the Internet will result in a qualitatively completely new production of new information. On the one hand, this will result in a qualitative evaluation and selection of the data on the Internet into "true" (trustworthy) information and false information. On the other hand, the production of new information by AI 2.0 goes far beyond the stage of producing "knowledge" and can be understood as the production of comprehensive understanding.

The technical preconditions for this could possibly be provided by quantum computers.

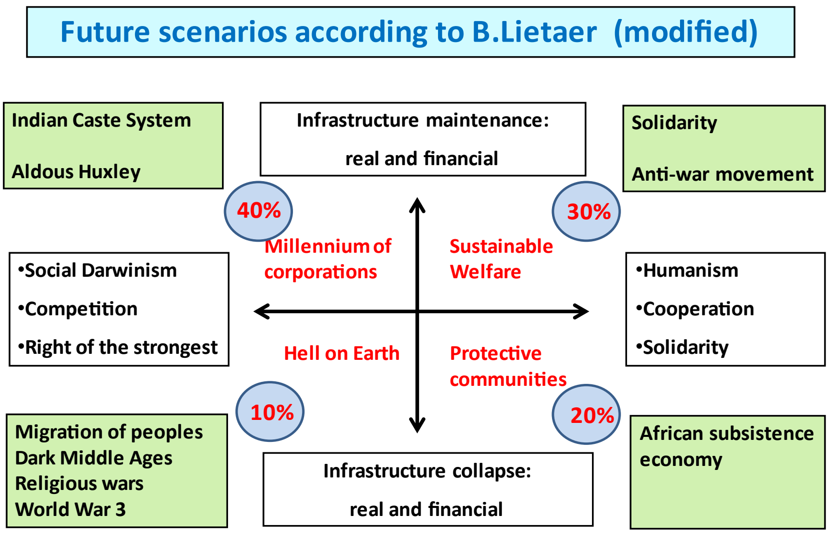
This will result in a networking of people (and the environment) that corresponds to the networking of the individual cells of a present-day individual. Just as the cells of an individual have no meaning on their own and are not capable of surviving on their own because they are all interdependent, the single human individuals will also lose their meaning. In a word: mankind as a whole will have to be regarded as a single life unit consisting of human individuals, just as the individuals today are to be regarded as a single life unit consisting of cells.

It is obvious that this will have a serious impact on the behavior of individuals, on the relationships between people and on the whole human society, culture and economy.

Just as evolution has driven cells to generally behave in a way that leads their behavior to maximize utility (i.e., evolutionary fitness) for the entire individual, so too will humanity be primarily driven by maximizing overall utility. However, this will then no longer result from norms and sanctions, but from a completely new kind of organization of society. However, this does not necessarily have to result. Because if cells do not behave in the sense of overall utility optimization, but in the sense of individual utility optimization, then they multiply without "consideration" of the total individual, i.e. they behave exactly like cancer cells. Just as the development of cancer in the course of evolution cannot be excluded, a behavior of individuals in mankind determined by individual utility optimization cannot be excluded either. Just as cancer usually leads to the death of the individual, a behavior of individuals characterized by individual utility optimization can also lead to the extinction of the entire human race because of the profound interconnectedness and interdependence.

7.2. The near future

Because exponential growth is not permanently possible (see chap. 6.6) and we are therefore on the verge of a singular point in evolution, a serious change in evolution will occur in the near future, whereby 4 different scenarios are conceivable. Regardless of which of the 4 scenarios will result in the near future, in the long run the scenario of the whole mankind as one individual in the sense of chap. 7.1 result.



Quelle: B. Lietaer, Das Geld der Zukunft, 1999

The quality of these future scenarios will essentially depend on 2 factors:

(1) Does the technical infrastructure based on the division of labor collapse due to wars or other disasters, or can the infrastructure be maintained?
(2) Is the prevailing value system characterized by the social Darwinist right of the strongest or by a cooperative humanistic basic attitude?

According to this, there are 4 basic types for a possible future:

7.2.1. The apocalypse

A collapse of the real und financial infrastructure and the social Darwinist fight of everyone against everyone leads to the apocalypse, comparable to the times of the migration of peoples and the ever-repeating wars.

Subjective probability of occurrence: 10%.

7.2.2. The relapse into small-scale structures

If society is characterized by a cooperative humanistic value system, but if the infrastructure collapses due to a serious environmental disaster, for example, society will revert to a subsistence economy with small-scale protective communities in which everyone helps everyone else.

Subjective probability of occurrence: 20%.

7.2.3. The fascist takeover by the state or by international social media groups

It is rather unlikely that there will be extensive destruction of the infrastructure as in the two previous scenarios. However, it is to be feared that society will continue to be characterized by a social Darwinist value system for a long time to come. The most likely scenario is therefore that there will be a fascist takeover by the state or by international social media corporations. The current and future technical possibilities for monitoring people and influencing or probably even determining their opinions will be so enormous that they will be used by the powerful in the future in any case.

If in the past it was religion that the powerful used to enforce their interests, in the future it will be the unforeseeable developments in surveillance and manipulation techniques. The efforts of China in this direction have become known in recent years, but it is also to be feared that Google or Facebook or other new corporations will develop in this direction in the future.

Subjective probability of occurrence: 40%.

7.2.4. Sustainable prosperity for all in a humanist society based on solidarity

Even if it seems to some, or perhaps to many today, an idealistic, unrealizable pipe dream that future generations will live in a solidary, cooperative, peaceful, humanistic society characterized by the common good, a glance at the past of human society is enough to realize that profound positive changes in human society have very much occurred over time, although very often only after very painful experiences. Just think of the introduction of democracy or the welfare state. Subjective probability of occurrence: 30%.

D. The evolution of the driving forces of the dynamic processes of life

An overview is given in chap. 9.1

8. All life is chemistry

All life is chemistry. Therefore, the driving forces of evolution are the same forces that drive chemical and physical reactions. (The importance of energy supply for evolution is described by Nick Lane. (Lane 2015))

Simplified, the following 3 basic laws apply:

8.1. The direction is determined by the Gibbs-Helmholtz equation

Chemical-physical processes proceed in the direction in which the free enthalpy (Gibbs energy) G decreases, i.e. ΔG is negative. For ΔG , the change of G, the Gibbs-Helmholtz equation applies

$$\Delta G = \Delta H - T\Delta S$$

where ΔH is the change in enthalpy (Helmholtz energy), T is the absolute temperature, and ΔS is the change in entropy.

The characteristic of the evolution is that structures (DNA, cells, individuals etc.) are formed. Generally formulated this means that order or information is formed. In these cases, the entropy decreases (locally), i.e. that

$$\Delta S < 0 \text{ or } -T\Delta S > 0$$

According to the Gibbs-Helmholtz equation, structures can therefore only form if the enthalpy change ΔH is negative enough. A process like evolution can therefore only produce structures permanently if the process is supplied with enough (Helmholtz) energy from outside permanently.

8.2. The speed is determined by the amount of activation energy

The activation energy E_A is an energetic barrier that must be overcome by the reaction partners during a chemical reaction. The lower the activation energy, the faster the reaction proceeds. The rate of a chemical reaction is characterized by the rate constant k . According to the Arrhenius equation, the following applies (E_A activation energy, R gas constant, T absolute temperature)

$$k \text{ ist proportional zu } e^{-\frac{E_A}{RT}}$$

i.e. the lower the activation energy E_A is, the faster the reaction proceeds.

A catalyst is a substance that lowers the activation energy and therefore increases the reaction rate accordingly.

8.3. The 2nd law of thermodynamics, the formation of local structures in reactions far from equilibrium

The 2nd law of thermodynamics states that in a closed system the entropy always increases

$$\Delta S > 0$$

and thus the order always decreases. This does not exclude that locally (in a subsystem) the order increases ($\Delta S < 0$) as long as considered over the whole system the order decreases ($\Delta S > 0$).

Typically, the farther a system is from thermodynamic equilibrium (i.e., the more negative ΔG or ΔH are), the higher the reaction rates and the more likely is the local occurrence of order phenomena, i.e., a local decrease in entropy. The reason is that driving forces tend to be small and approximately linear near equilibrium, but that the farther the system is from equilibrium, the higher the nonlinearity and strength of the forces become. Nonlinear processes tend to produce feedback phenomena in the dynamics and thus a corresponding formation of structure in the dynamics of the system.

As an example: the transition from laminar flow in a pipe, which shows practically no structures, to turbulent flow, which is very strongly structured via vortex formation. In the vicinity of a pressure equilibrium, low forces are present, therefore there is a low flow velocity and thus no structure formation The flow is laminar in this case. However, when the pressure exceeds a critical point, the forces become nonlinear and vortex formation occurs via mechanisms of self-organization of the dynamics, i.e. the flow becomes turbulent. Locally, very high velocities occur in the vortices, even if the overall flow velocity decreases.

9. The evolution of the driving forces of dynamics and its consequences

9.1. Tabular overview

1	3	5	11
Age	**Living being form**	**Information type**	**Driving force**
[0]	Inanimate matter	**Information type**	Decreasing **temperature**
[1.1]	RNA molecules	Crystal Digital single strand	Decreasing **temperature**
[1.2]	Ribocytes		
[2.1]	Single-celled organism	Gene (digital, double strand)	Minimization of free enthalpy along the **chemical gradient** **(**which is built up by supplying energy from the outside).
[2.2]	"Simple" multicellular		
[2.3]	"Higher" multicellular organisms (with sexual reproduction)		

[3.1]	"Predatory" animals (predatory plankton, bilateria, chordate, etc.)	External and internal analog information	Minimization of free enthalpy along the **electrochemical gradient** (which is built up by supplying energy from the outside).
[3.2]	Apterygota Insects Fish Amphibians Reptiles Early birds Early mammals		
[3.3]	Higher mammals Higher birds		

[4.1]	Hominine (human-like)	Complex consciousness contents	Minimization of free enthalpy in the neuronal **network of electrochemical potentials of** the cerebrum, by **non-linear** processes, because the system is driven far away from equilibrium by supplying a lot of energy from outside
[4.2]	Homo		
[4.3]	Homo sapiens		
[5.1]	Market economy	External data	Individual monetary economic utility optimization Dynamics along the resultants of the **individual utility gradients** **(**GCD General Constrained Dynamic)
[5.2]	Capitalist market economy		
[5.3]	Global capitalist market economy		
[6.1]	Internet- market economy	Knowledge	Attempt to achieve global overall utility optimization based on **individual utility optimization with constraints** (internationally sanctioned standards)
[6.2]	AI-based economy		
[7]	Humanity as a single individual, Cyborg	Comprehensive understanding	**Overall utility maximization** (dynamics along the overall utility gradient).

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9.2. Decreasing temperature as driving force in the age [0] - [1.2] (crystal and RNA)

The formation of crystals and RNA molecules is primarily an (exothermic) crystallization process with $\Delta H < 0$ and an increase in order, i.e. $\Delta S < 0$, which can be described with equilibrium thermodynamics and the Gibbs-Helmholtz equation. At high temperatures, the (positive) entropy term $T\Delta S$ outweighs the negative enthalpy term ΔH , so that $\Delta G > 0$ and therefore crystallization does not occur. If the **temperature** falls below a critical threshold, $\Delta G < 0$ and crystallization occurs.

The formation of RNA is favored or accelerated by the catalytic effect of inorganic crystals and the autocatalytic effect of RNA complexes.

9.3. The chemical potential as a driving force in the age [2.1] - [2.3] (DNA, unicellular and multicellular organisms)

The formation of crystals results in the formation of a static structure. In contrast to this, the structure of living organisms consists in particular of a dynamic structure. This dynamic structure is basically comparable with the vortices in turbulent flow, only it is much more complex. It cannot be described with the equilibrium thermodynamics, but only with the thermodynamics of irreversible processes.

As described in chapter 8.1, a sufficient continuous energy supply is the precondition for the system to be permanently far enough from equilibrium and for dynamic structures to build up permanently as a result. In single- and multicellular organisms, chemical energy absorbed from the environment in the form of food substances or light energy is used for this purpose to build up concentration gradients of chemical substances. These different concentrations correspond to a **chemical potential**. The course of the dynamics is determined by the (negative) direction of the gradient of the chemical potential. By permanently supplying energy, the gradient and thus the dynamic structure can be permanently maintained.

9.4. The electrochemical potential as driving force in the age [3.1] - [3.3] (nervous system)

The driving force for the performances of the nervous systems is based on the (negative) gradient of the **electrochemical potential**. The electrochemical potential results not only from different substance concentrations but also from additional differences in the concentration of electric charges. This requires a permanently higher energy input than for the maintenance of purely material concentration differences. The essential evolutionary precondition to provide this higher energy supply was first provided by the development of the variation mechanism of "eating" in animals. They no longer had to wait for what food happened to float by, but were able to meet this increased energy demand through the mechanism of eating on plants or other animals. Thereby, the development of the nervous system and the corresponding sensors, which could perceive food or prey, further improved the coverage of the necessary energy demand.

The direction of the dynamics is determined by the (negative) direction of the gradient of the electrochemical potential. Due to the fact that the necessary high energy demand can be supplied permanently, the gradient and thus the dynamic structure can be maintained permanently.

9.5. The networked electrochemical potential far from equilibrium as a driving force in the age [4.1] - [4.3] (cerebrum).

The cerebrum has by far the highest energy demand of all organs relative to its organic mass. The biological reason for this is obviously that the maintenance of an electrochemical potential in a network requires an even much higher energy demand than the maintenance of an electrochemical potential in an essentially linear nervous system.

It is well known that the biological preconditions for the development of a powerful cerebrum in hominins was (Czichos 2017) only given with the possibility of ingesting more energy-rich food (fruits, tubers, meat) and by the fact that the use of fire made food more easily digestible. The further development of the cerebrum contributed in a feedback loop to further increase the energy content of the food.

Although the biophysical processes involved in the storage and processing of complex information in the cerebrum are not yet entirely clear, it can be surmised,

- that a very high interconnected electrochemical potential is built up in the cerebrum,
- that maintaining the electrochemical potential requires a very high amount of energy,
- that the processes in the cerebrum correspond to a dynamic that is very far from equilibrium,
- that high distance from equilibrium and interconnectedness are the preconditions for the emergence and maintenance of the dynamic structures in the cerebrum, which in turn are the basis for all cognitive performances of the brain,
- that ultimately all processes take place along the gradient of the electrochemical potential (which is extremely complex due to the enormous interconnectedness)

9.6. Individual utility optimization in the age [5.1] - [5.3] (GCD General Constrained Dynamics).

The biological cognitive preconditions for the evolution of the variational mechanism of individual utility optimization were first present in Homo sapiens (see Chap. 5.13.4). However, individual utility optimization did not acquire its profound significance until the age of the market economy, when people were able to quantify utility with the invention of money and numbers. Market economy is virtually characterized by the fact that all participants strive to maximize their individual utility quantitatively.

The essential difference between all physical-chemical systems and the mechanism of individual utility optimization is that the force and thus the dynamics in physical-chemical systems are determined by the **gradient of a single quantity**, namely by the gradient of free enthalpy (Gibbs energy of the chemical, electrochemical, or networked electrochemical potential). In contrast, individual utility optimization in a market economy initially results in many different forces arising from the gradients of each individual utility function. Typically, however, these forces each point in a different direction for all individuals. The direction of the force that determines the actual dynamics can therefore only result as the **resultant** (possibly weighted by power factors) of **all individual forces.** This is exactly what is described by the modeling approach of the "General Constrained Dynamic GCD" models (see chap. 14 and (Glötzl, Glötzl, und Richters 2019))

Without additional measures, overall utility maximization does not automatically occur in a market economy because utility functions cannot always be "aggregated" into a overall utility function. Such situations lead to what in economics is called the "fallacy of aggregation". They are also one reason why situations called "market failures" can occur again and again in a market economy. For the theoretical relationship between individual utility optimization and overall utility maximization, see section 15.7.

9.7. Overall utility maximization in age [6.1] - [6.2]

Individual utility optimization can be transformed into overall utility maximization by appropriate constraints (see chap. 15.4). First approaches to global overall utility maximization are global norms with financial sanctions in time [6.1] and automated sanctions in time [6.2].

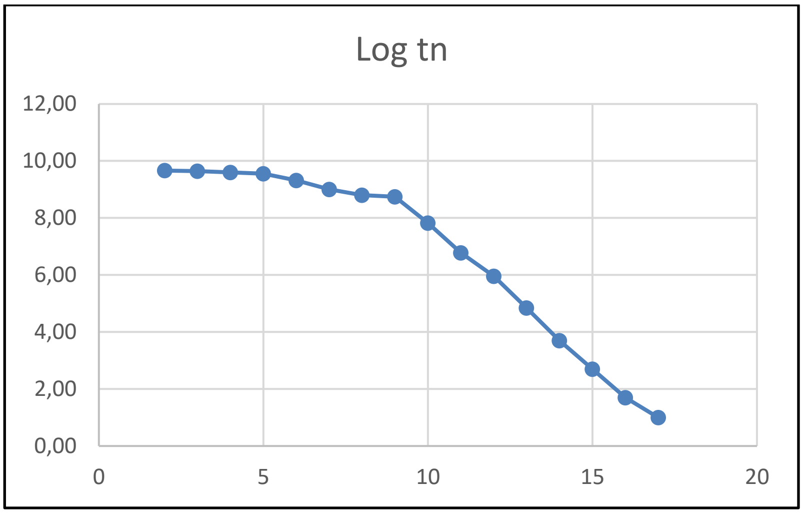
10. The speed of evolution of evolutionary leaps, the evolution of the number of species and complexity

10.1. The speed of evolution of the evolutionary leaps (new ages)

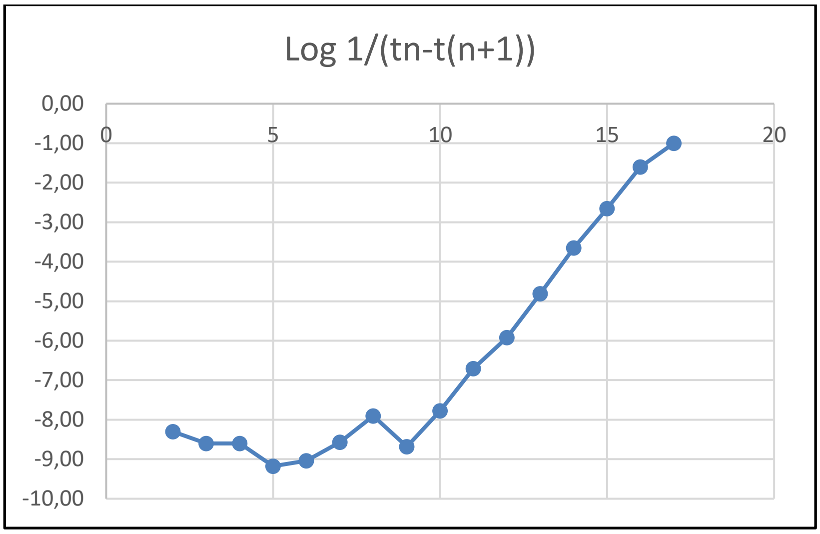
The occurrence of a new age signifies a qualitative leap in evolution through the appearance of a new information technology. Since the Cambrian, the rate at which qualitative leaps in evolution occur has been increasing exponentially (See the following table and graphs):

n	Age	Name	Years ago t_n	Log t_n	Log $1/(t_n - t_{n+1})$
1	[0]	Chaoticum	4 600 000 000	9,66	-8,30
2	[1.1]	Zirconium	4 400 000 000	9,64	-8,60
3	[1.2]	Eoarchaic	4 000 000 000	9,60	-8,60
4	[2.1]	Paleoarchaic	3 600 000 000	9,56	-9,30
5	[2.2]	Mesoproterozoic	2 100 000 000	9,32	-9,18
6	[2.3]	Neoproterozoic	1 000 000 000	9,00	-8,57
7	[3.1]	Ediacarium	630 000 000	8,80	-7,90
8	[3.2]	Cambrian explosion	550 000 000	8,74	-8,68
9	[3.3]	Tertiary	66 000 000	7,82	-7,78
10	[4.1]		6 000 000	6,78	-6,71
11	[4.2]		900 000	5,95	-5,92
12	[4.3]		70 000	4,85	-4,81
13	[5.1]		5 000	3,70	-3,65
14	[5.2]		500	2,70	-2,65
15	[5.31]		50	1,70	-1,60
16	[6.1]		10	1,00	-1,00
17	[6.2]		1	0,00	0,00

The occurrence of a new age signifies a qualitative leap in evolution through the appearance of a new information technology. Since the Cambrian, the rate at which qualitative leaps in evolution occur has been increasing exponentially (See the previous table and following graphs):



Graph 1: The course of the logarithm of the time of the beginning of the ages shows a largely linear course between the age [3.2] (Cambrian) and the age [6.2] (present). This means an exponential course of the evolution.



Graph 2: $t_n - t_{n+1}$ describes the duration of an age. $\frac{1}{t_n - t_{n+1}}$ therefore describes the speed with which a new age occurs. The logarithm of this speed shows also between the age [3.2] (Cambrian) and the age [6.2] (present) a largely linear course. This means an exponential increase of the speed of the evolution.

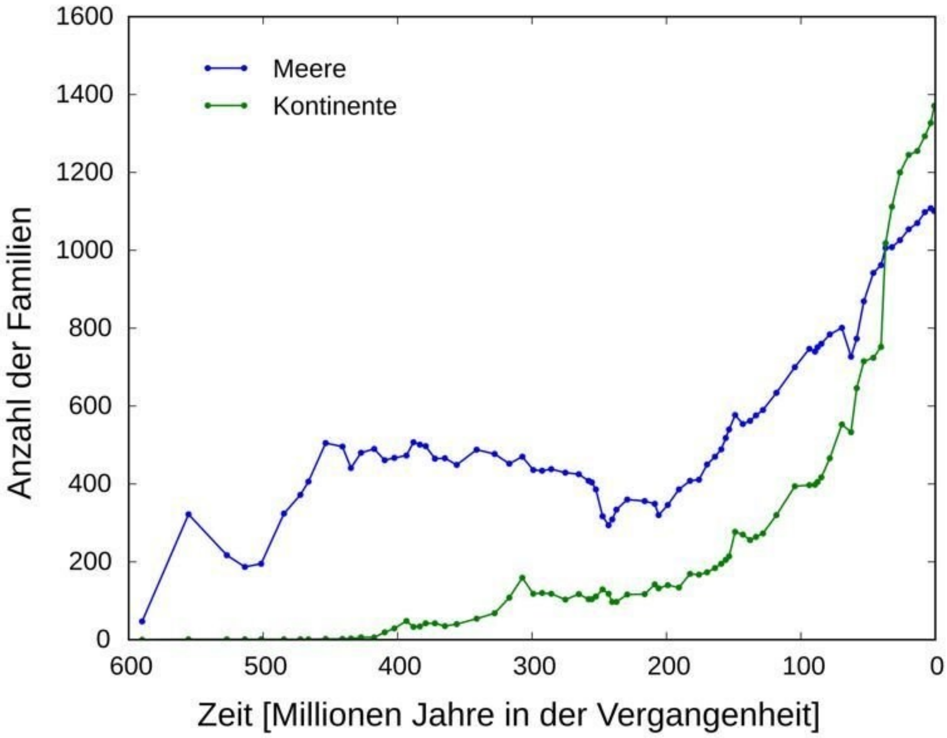
10.2. Evolution of the number of species

The constant rapid emergence of new species is promoted by:

(1) **A high rate and range of variation**: This was achieved primarily through sexual reproduction about 1 billion years ago.

(2) **A high level of evolution or complexity**: the larger the underlying genetic information, the more possibilities there are for change. This necessary level of complexity was reached with the emergence of the higher multicellular organisms after the Cryogenium 630 million years ago.

(3) **A high diversity of habitats**: this is higher on land than in the sea and has increased over time due to geological changes in the Earth's surface. This explains why the number of species on land has developed exponentially since the Cambrian. Likewise, it can be used to understand the slower development of the number of species in the oceans, which deviates from this. See the graph below (Stollmeier, 2014).
(4) **A low pressure to adapt**: because this also means a low rate of species extinction.
(5) A particularly high influence on the speed of evolution has the emergence of variation mechanisms of **targeted variation**, because thereby detours of the evolution are shortened as it were and "wrong developments" are avoided.



10.3. Evolution of the complexity of the most evolved species

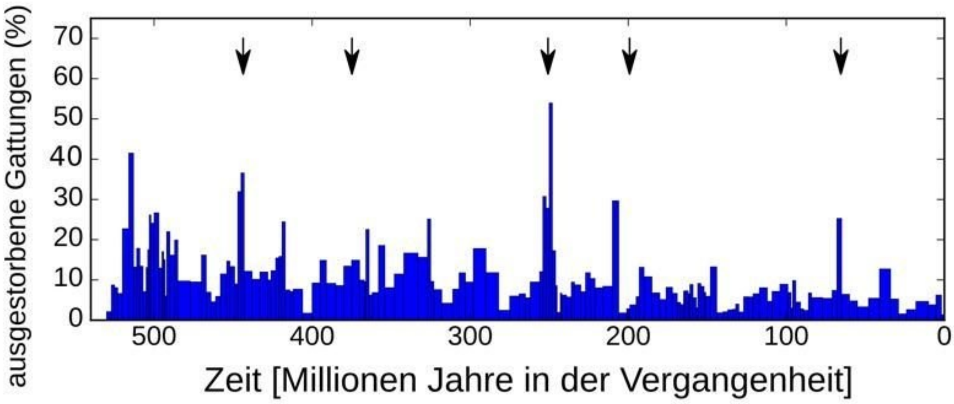
On the one hand, high adaptation pressure tends to lead to a higher extinction rate of species but it leads to a more rapid formation of more complex structures.

A permanent high pressure to adapt is given by the existence of predatory animals. These first appeared after the end of the Cryogenian, 630 million years ago. This is one reason why subsequently, from the time when predators became widely established, the complexity of species evolved exponentially. See the graphs on the time course in chap. 10.1.

10.4. The influence of environmental changes and environmental disasters

Environmental changes lead to adaptation pressures that tend to reduce the number of species on the one hand, but increase their complexity on the other.

Over time, environmental disasters have repeatedly led to the extinction of up to 60% of species (Stollmeier 2014).



At the same time, however, the reduced number of individuals subsequently eliminates many constraints in the form of limited resources, which facilitates the formation of new species.

10.5. Summary

The occurrence of a new age signifies a qualitative leap in evolution through the appearance of a new information technology. Since the Cambrian, the speed at which qualitative leaps in evolution occur has been increasing exponentially.

Since the beginning of the Cambrian period 541 million years ago, the complexity of species has been growing exponentially.

Likewise, the number of species grows largely exponentially. Repeatedly occurring catastrophes have always reduced the number of species only in the short term.

E. Formal bases for the evolution of evolutionary systems and variation mechanisms

In Section E, we explain the formal basis of the key concepts and principles used to describe evolutionary systems and of variation mechanisms.

11. General

11.1. Basics

A biological species is characterized both by its genetic information in the form of DNA (genotype) and by the traits of the organism (or individual) that emerge from that DNA.

Since Darwin, the origin of species has been described by the interaction of mutation and selection. Mutation is usually understood as the random change of DNA. Selection, on the other hand, does not take place at the level of the DNA, but at the level of the organisms (or individuals) formed by the respective DNA. Selection is usually understood to mean the survival of the species that has produced the best adapted organism ("survival of the fittest"), which at the same time leads to the survival of the respective associated DNA.

The **general theory of evolution** can be seen as a **comprehensive generalization and extension of Darwin's theory** of evolution. It is not about modifications of Darwin's theory in the sense of the synthetic theory of evolution since 1930 or an extension of mutation mechanisms to include epigenetic changes in phenotypes, as they have been intensively researched since about 2000. The general theory of evolution goes far beyond this. It extends the terms "biological species", "genotype", "phenotype", "mutation" and "selection" corresponding to the Darwinian theory and replaces them with much more general terms:

Darwinian theory of evolution	→	**general theory of evolution**
biological species	→	species (in the broader sense)
genetic information, genotype	→	general information
phenotype	→	form
mutation mechanism, mutation	→	variation mechanism, variation
selection dynamics	→	evolutionary dynamics

Just as a biological species is characterized by its genetic information (genotype) and the organism formed by the genotype and its biological traits (phenotype), a **species (in a broader sense)** is characterized by **general information** and by the particular **form** formed by the information and its properties.

This can be explained by the following example: Each special biological species of mammals is characterized by its special genetic information (genotype), from which the special organism with its traits (phenotype) results. Analogously, a market economy occurs in different species (in a broader sense). Each particular type of market economy is shaped by a variety of different general information, such as technological knowledge, governmental norms of behavior, genetic traits of people, and so on. From this special general information, a special form of economic activity with all its traits emerges in each case, e.g. the capitalist market economy or one of its special forms.

The information relevant for the general theory of evolution is, as shown in section A, not only the genetic hereditary information laid down in the DNA, but also all the other information mentioned. Crucially for evolution, this information is modified by a wide variety of mechanisms. Therefore, instead of the narrow terms mutation and mutation mechanism, we use the broader terms **variation** and **variation mechanism**. When we speak of mutation, we are referring specifically only to the random change of DNA during replication or by environmental influences. But this is only one of the possible mechanisms of variation of a piece of information.

For example, the variation mechanism of poor linguistic communication can also lead to a random variation of the transmitted message. Furthermore, a message may not only arrive at the addressee changed by chance, but may also be passed on incorrectly "on purpose" (e.g., "fake news"). Therefore, it remains to be investigated in the following whether and in which sense and to what extent and from when in the course of evolution targeted variations of information have acquired a relevance.

Another example is the variation mechanism "learning": The neural network in a person's cerebrum is a technology for storing general information, such as complex causal relationships, e.g.: "If you look for wild grain, you will have food". This information leads to a certain behavior. This general information stored in the cerebrum as a causal relation, can be changed into a new causal relation by the variation mechanism "learning", e.g..: "If you do not eat all the cereal grains, but sow some of the cereal grains, you will not have to search for cereal grains anymore, but you will be able to harvest more cereal grains". This new causal relation stored in the cerebrum (grow grain → eat more food) thus represents a variation of the old causal relation (seek grain → eat).

Other examples of variation mechanisms are all "random" mutations but also "targeted" variations that result from targeted variation mechanisms. Such targeted variation mechanisms include: "imitation, learning, teaching", cooperation mechanisms, barter, documentation of debt relationships by money, investment, logical thinking, utility optimization, animal and plant breeding, genetic manipulation etc. These variation mechanisms can lead to various immediate biological effects such as: Death, facilitation of cooperation, linear, exponential or interaction growth, etc. We give a formal definition and examples of possible important evolutionary systems and variation mechanisms in the following chap. 11.1.

The concept of selection refers in a narrow sense to the survival of the best adapted or to the extinction of the less well adapted species (or their information and form). However, we want to consider the whole **dynamic evolution** of the absolute or relative frequencies of the different species (or their information and forms). These dynamics may not only lead to selection in the strict sense, i.e. to survival of species at the expense of extinction of other species. The dynamics can equally lead to stable equilibria between the different species, but also to a cyclic or even chaotic development of the frequencies of the different species.

The dynamics describing these temporal evolutions are usually modeled by systems of differential equations. We refer to these differential equation systems as **evolutionary systems**. Thus, mechanisms of variation are precisely mechanisms that lead to a change in these evolutionary systems. Of particular importance is the qualitative behavior of the different evolutionary systems.

In the chapters 12 and 13, we describe the basic structure of **evolutionary systems**, the different types of evolutionary systems, and their qualitative behavior.

In chapters 0 we build the bridge between biological systems and economic systems. We show that they can be described methodically in the same formal form as so-called "general constrained dynamic models" (GCD models).

In chap. 15 we classify the variation mechanisms according to their biological or economic causes, and in chap. 16 we classify them according to their effects.

11.2. Formal definition and typical examples of evolutionary systems and variation mechanisms.

Formally, the time evolution of the absolute frequency $n = (n_1, n_2, ...)$ (or also of the relative abundance $x = (x_1, x_2, ...)$) of different species can usually be modeled in general by a differential equation system[29] with functions $f = (f_1, f_2, ...)$ and parameters $q = (q_{11}, q_{12}, ..., q_{21}, q_{22}, ..., ...)$ .The parameter q_{ij} describes the *j-th* property of the species *i. For* simplicity, we always assume that neither f nor q explicitly depend on t.

$$\dot{n}_i(t) = f_i(n(t), q) \qquad\qquad i = 1, 2, ...$$ <11.1>

Furthermore, for simplicity, we initially always assume,

- that the system consists of only two types A and B
- and that the functions f_A, f_B are polynomials of at most 2nd degree in n_A, n_B and are of the following simple form:

$$\begin{aligned} \dot{n}_A &= a_A + b_{AA} n_A + b_{AB} n_B + c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= a_B + b_{BA} n_A + b_{BB} n_B + c_{BA} n_B n_A + c_{BB} n_B n_B \end{aligned}$$ <11.2>

Some of the factors a, b, c may also be zero.

---

[29] Note on notation: in Section E, when formulating differential equations, we use the abbreviated notation for the time derivatives by a superscript dot for simplicity, i.e., e.g., $\dot{n}(t) := \frac{dn(t)}{dt}$

We refer to such a differential equation system describing the dynamics of absolute frequencies as a **standard evolutionary system**.

The parameters $a_A, b_{AA}, b_{AB}, c_{AA}, c_{AB}, a_B, b_{BA}, b_{BB}, c_{BA}, c_{BB}$ describe biological-technological properties of species A and B.

Variational mechanisms are biological or economic mechanisms that typically result in a change (variation) in these parameters from

$$
\begin{aligned}
a,b,c &\rightarrow \tilde{a},\tilde{b},\tilde{c} \\
\nu,\mu &\rightarrow \tilde{\nu},\tilde{\mu}
\end{aligned}
$$

The change of these parameters can lead not only to a quantitative but also to a qualitative change of the solutions of the evolutionary system.

These changes can be temporally

- discrete, i.e., occur in a single step, e.g., by random mutation or, in the case of overall utility maximization,
- quasi-continuous, i.e., e.g., in a sequence of mutations and selection mechanisms, each of which leads to a small change in a biological trait in the sense of "adaptive dynamics" (Dieckmann, 2019),
- continuous, e.g., by utility optimization along the gradient of a utility function or by individual utility optimization along the resultant of individual forces.

Examples of different **evolutionary systems** are:

Let $n_i = n_i(t),\ a_i = const,\ b_i = const,\ c_{ij} = const,\ x_i := \frac{n_i}{\sum_j n_j}$

(1) linear growth

$$\dot{n}_1 = a_1$$

(2) autocatalysis, exponential growth

$$\dot{n}_1 = b_{11} n_1$$

(3) evolutionary 2-person game

$$
\begin{aligned}
\dot{n}_1 &= c_{11} n_1 n_1 + c_{12} n_1 n_2 \\
\dot{n}_2 &= c_{21} n_1 n_2 + c_{22} n_2 n_2
\end{aligned}
$$

(4) replicator equation

$$
\begin{aligned}
\dot{x}_1 &= \left(c_{11} x_1 + c_{12} x_2 - \phi(x_1, x_2)\right) x_1 \\
\dot{x}_2 &= \left(c_{21} x_1 + c_{22} x_2 - \phi(x_1, x_2)\right) x_2
\end{aligned}
$$

(5) predator-prey equation

$$
\begin{aligned}
\dot{x}_1 &= \left(c_{11} x_1 + c_{12} x_2 - \phi(x_1, x_2)\right) x_1 \\
\dot{x}_2 &= \left(c_{21} x_1 + c_{22} x_2 - \phi(x_1, x_2)\right) x_2
\end{aligned}
$$

Examples of different **variation mechanisms** include:

(1) Random mutations

lead to random changes in properties. Randomness is modeled by a quantity ω. This leads to

$$
\begin{aligned}
&n(t) && \rightarrow n(t,\omega) \\
&q && \rightarrow q(\omega) \\
&\textit{differential equation} && \rightarrow \textit{stochastic differential equation}
\end{aligned}
$$

(2) Targeted Variation

$$q_A = constant \quad \rightarrow \dot{q}_A = \frac{\partial U(q_A, q_B)}{\partial q_A} \qquad \qquad U \; utility, \; fitness \; etc.$$

(3) Punishment/Reward

Let $c_{ij} \geq 0$. The differential equation system

$$
\begin{aligned}
\dot{n}_C &= c_{CC}\, n_C n_C - c_{CD}\, n_C n_D \\
\dot{n}_D &= c_{DC}\, n_D n_C + c_{DD}\, n_D n_D
\end{aligned}
$$

describes the evolutionary system consisting of a cooperator C and a defector D. The evolution mechanism "reward/punishment" with reward $b > 0$ and penalty $s > 0$ leads to a new evolutionary system and thus to a new dynamic, namely "cooperator/defector with reward b and penalty s"

$$
\begin{aligned}
\dot{n}_C &= (c_{CC} + b)\, n_C n_C - c_{CD} n_C n_D \\
\dot{n}_D &= (c_{DC} - s)\, n_D n_C + c_{DD}\, n_D n_D
\end{aligned}
$$

bzw.

$$
\begin{aligned}
\dot{n}_C &= (c_{CC} + b)\, n_C n_C - (c_{CD} - b) n_C n_D \\
\dot{n}_D &= (c_{DC} - s)\, n_D n_C + (c_{DD} - s)\, n_D n_D
\end{aligned}
$$

which leads to a higher frequency of the cooperator n_C and to a lower frequency of the defector n_D.

Variation mechanisms can be considered on the one hand from the point of view by which biological or economic mechanisms they are caused and on the other hand which direct effects they have. For example, through the mechanism of random mutation or the mechanism of breeding as an effect the size or the reproduction rate can be changed.

Variation mechanisms structured according to causes, i.e. structured according to the underlying biological or economic mechanisms:

- Random mutation or variation
- Change of the environmental situation
- Long-term variation through adaptive dynamics
- Targeted variation such as
    - Imitate, learn, teach
    - Logical thinking
    - Investment
    - Breeding
    - Genetic manipulation and targeted modification of information

    - Individual utility optimization
    - Overall utility maximization
- Constraints by
    - Limited resources (in terms of food, space, raw materials, money supply) or based on
    - Norms of behavior (moral, religious, or governmental norms).

Variation mechanisms classified by immediate effects:

- Quantitative changes of properties
- Qualitative change of growth type:
    - Linear growth (0th order)
    - Exponential growth (1st order)
    - Interaction growth (2nd order)
        - Interaction with other individuals: altruism, egoism
        - Interaction with commodities: investment, capitalism
- Death such as
    - Death due to environmental change
    - Death by competition for limited goods
    - Old age death
    - Death as prey
- Win-win mechanisms, i.e. measures that form an advantage for both species
    - Symbiosis
    - Documentation of debt relations by e.g. money
    - Exchange
    - Division of labor
    - Purchase
- Cooperation mechanisms, i.e., measures that favor cooperation in Prisoner's Dilemma situations, making cooperation evolutionarily stable. (cooperation mechanisms are precisely win-win mechanisms in Prisoner's Dilemma situations)
    - Network formation
    - Group formation
    - Direct reciprocity (tit for tat)
    - Indirect reciprocity (reputation)
    - Reward/punishment
- Other mechanisms favoring fitness
    - Imitate, learn, teach
    - Individual utility optimization
    - Overall utility maximization
- Mechanisms favoring growth or even compulsion to grow
    - Investment, interaction with raw materials

11.3. Evolutionary systems with constraints

In the classical mechanics of physics, the dynamics according to Newton's laws is described by the differential equation system

$$\dot{v}_i(t) = \frac{1}{m} F_i(x, v)$$

$$(F \;\; \textit{force vector},\; x \;\; \textit{position vector},\; v := \dot{x} \;\; \textit{velocity vector},\; i = 1,2,3)$$

For example, if the motion is constrained by an additional holonomic[30] constraint of the form

$$Z(x) = Z(x_1, x_2, x_3) = 0$$

an additional constraint force $F^Z = (F_1^Z, F_2^Z, F_3^Z)$ occurs and the dynamics is governed by the differential algebraic equation system

$$\begin{aligned} &\dot{v}_i(t) = \frac{1}{m} F_i(x, v) + \lambda(t) F_i^Z(x, v) \qquad\qquad i = 1,2,3 \\ &Z(x) = 0 \end{aligned}$$

In physics, the so-called d'Alembert's axiom applies to the constraint forces (in addition to Newton's axioms), which states that the constraint force vector F^Z is always perpendicular to the surface defined by the constraint condition. This is equivalent to the constraint force being in the direction of the gradient of the constraint. This results in the so-called Lagrange equations of the 1st kind for the dynamics under constraints in physics

$$\begin{aligned} &\dot{v}_i(t) = \frac{1}{m} F_i(x, v) + \lambda(t) \frac{\partial Z(x)}{\partial x_i} \qquad\qquad i = 1,2,3 \\ &Z(x) = 0 \end{aligned}$$

The gradient $\frac{\partial Z(x)}{\partial x_i}$ indicates the direction of the constraint force, its absolute magnitude is determined by the so-called Lagrange multiplier $\lambda(t)$

Constraints, however, play a major role not only in physics but also in other fields such as biology and economics. An essential difference to physics is that d'Alembert's axiom does not necessarily hold, i.e. the constraint force vector does not necessarily have to be perpendicular to the plane spanned by the constraint force. The direction in which it is directed results from the particular circumstances in each case. Furthermore, the dimension of the problem does not have to be 3, but can be arbitrary.

[30] A constraint is called holonomic if it depends only on the position coordinates

In biology, the constraint force vector is often directed towards or away from the origin, i.e. the constraint force vector at the point $x = (x_1, x_2, ...)$ is directed towards $x = (x_1, x_2, ...)$ or $-x = (-x_1, -x_2, ...)$, respectively. Which sign is used is meaningless in terms of content, but is only a matter of convention. In biology, this model assumption is equivalent to the assumption that in the struggle for limited resources, equally high death rates are triggered for all species.

We want to explain this with an example. A typical dynamic for biology is the initially independent exponential growth of 2 species A and B.

$$\begin{aligned} \dot{n}_A &= b_{AA}\, n_A \qquad && b_{AA} \ \textit{growth rate von A} \\ \dot{n}_B &= b_{BB}\, n_B \qquad && b_{BB} \ \textit{growth rate von B} \end{aligned} \qquad <11.3>$$

If a growth rate is greater than 0, it is called a birth rate; if it is less than 0, it is called a death rate. We assume $b_A > 0,\ b_B > 0$ to be birth rates.

A constraint typical for biology is e.g. the assumption of limited resources. This can be given e.g. by a limitation of the food supply or also by a limitation of the habitat. This leads to the fact that the sum of the number of absolute frequencies of the different species i remains constant. This is formally described by the constraint

$$Z(n_1, n_2, ...) = \sum_i n_i - constant = 0$$

Assuming that equal death rates ϕ are triggered by the constraint in both species, the differential algebraic equation system is as follows

$$\begin{aligned} \dot{n}_A &= b_{AA}\, n_A - \phi\, n_A \\ \dot{n}_B &= b_{BB} n_B - \phi\, n_b \\ Z(n_A, n_B) &= n_A + n_B - n = 0 \qquad && n \ \textit{constant} \end{aligned} \qquad <11.4>$$

Assuming that A is twice as successful ("powerful") in the struggle for resources, A would have half the death rate and thus the system of equations

$$\begin{aligned} \dot{n}_A &= b_{AA}\, n_A - \phi \frac{1}{2} n_A \\ \dot{n}_B &= b_{BB}\, n_B - \phi\, n_b \\ Z(n_A, n_B) &= n_A + n_B - n = 0 \end{aligned}$$

We use the symbol λ for the Lagrange multiplier only if the d'Alembert axiom holds. Otherwise we use the symbol ϕ for the Lagrange multiplier.

This system of equations <11.4> can be solved in the following way. Because of the constraint Z the condition also applies to the time derivatives

$$\dot{n}_A + \dot{n}_B = 0$$

From the system of equations

$$\dot{n}_A = b_{AA}\, n_A - \phi\, n_A$$
$$\dot{n}_B = b_{BB}\, n_B - \phi\, n_b$$
$$n_A + n_B = n$$
$$\dot{n}_A + \dot{n}_B = 0$$

results by simple transformation

$$\begin{aligned} \dot{n}_A &= \frac{1}{n}(b_{AA} - b_{BB}) n_A n_B \\ \dot{n}_B &= \frac{1}{n}(-b_{AA} + b_{BB}) n_A n_B \\ \phi &= \frac{1}{n}(b_{AA} n_A + b_{BB} n_B) \end{aligned} \qquad \text{<11.5>}$$

or with the relative frequencies $x_A = \frac{n_A}{n}$, $x_B = \frac{n_B}{n}$

$$\begin{aligned} \dot{n}_A &= n(b_{AA} - b_{BB}) x_A x_B \\ \dot{n}_B &= n(-b_{AA} + b_{BB}) x_A x_B \\ \phi &= (b_{AA} x_A + b_{BB} x_B) \end{aligned} \qquad \text{<11.6>}$$

Conclusion:

The limitedness of resources leads to 2 main mechanisms of variation through the corresponding constraint:

(1) The occurrence of death rates (see chap.16.2)

$$\textit{death rate for } A = -\frac{b_{BB} n_B}{n} \qquad \textit{death rate for } B = -\frac{b_{AA} n_A}{n}$$

This results from a simple transformation of <11.5>:

$$\begin{aligned} \dot{n}_A &= \frac{1}{n}(b_{AA} - b_{BB}) n_A n_B = \left(\frac{b_{AA} n_B}{n} - \frac{b_{BB} n_B}{n} \right) n_A \\ \dot{n}_B &= \frac{1}{n}(-b_{AA} + b_{BB}) n_A n_B = \left(\frac{b_{BB} n_A}{n} - \frac{b_{AA} n_A}{n} \right) n_B \end{aligned} \qquad \text{<11.7>}$$

(2) The occurrence of interactions. The interaction is described by the term $n_A n_B$. Because of the term $n_A n_B$ the 2 differential equations are no longer independent of each other. In economics, constraints are of particular importance. See the detailed discussion in (Glötzl, Glötzl, und Richters 2019). In particular, all balance sheet identities constitute such constraints. These include, for example.

- that in a closed system the sum of all debts is always equal to the sum of all credits ("1st law of economics") (Glötzl 1999)) or
- that imports to one country are equal to the sum of exports from the other countries, or
- that the change in a household's money supply is equal to the difference between revenues and expenditures.

11.4. The qualitative behavior of evolutionary systems

The solutions of the differential equations (evolutionary systems) describe the temporal development of the frequencies. As a rule, the differential equations cannot be solved analytically, but only numerically.

In particular, one is interested in the qualitative behavior of the solutions of the differential equations as a function of the special parameters. This is described by terms like e.g.

- A dominates B: the dynamic always leads to B becoming extinct
- A and B coexist in a stable equilibrium
- A and B are bistable (whether A or B dies out depends on the initial state).
- A is ESS (A is evolutionarily stable against mutant invasion).
- Gene diversity within a species
- Emergence of new species through bifurcation

•

12. Types of evolutionary systems

Note: We describe below the systems without constraints. But all the systems mentioned may also contain additional constraints to describe limited resources. We give examples with constraints in chap. 12.7.1 and 13.2. In 12.1 we give a tabular overview of important growth equations and replicator equations.

12.1. Tabular overview of growth equations and associated replicator equations.

Evolutionary Systems	**Growth equation for absolute frequencies** $n_A(t), n_B(t)$	**Replicator equation for relative frequencies** $x_A(t), x_B(t)$
0 th order growth, linear growth	$\dot{n}_A = a_A$ $\dot{n}_B = a_B$	$\dot{x}_A = \frac{1}{(n_A + n_B)}(a_A x_B - x_A a_B))$ $\dot{x}_B = -\dot{x}_A$
1st order growth, exponential growth	$\dot{n}_A = b_{AA} n_A + b_{AB} n_B$ $\dot{n}_B = b_{BA} n_A + b_{BB} n_B$	$\dot{x}_A = x_A(b_{AA} x_B - b_{BA} x_A) +$ $+ x_B(b_{AB} x_B - b_{BB} x_A)$ $\dot{x}_B = -x_A(b_{AA} x_B - b_{BA} x_A) -$ $- x_B(b_{AB} x_B - b_{BB} x_A)$
2 nd order growth, interaction growth, evolutionary games, results from exponential growth with frequency-dependent growth rates	$\dot{n}_A = c_{AA} n_A n_A + c_{AB} n_A n_B$ $\dot{n}_B = c_{BA} n_B n_A + c_{BB} n_B n_B$ *results from* $b_{AA} = (c_{AA} n_A + c_{AB} n_B)$ $b_{AB} = 0$ $b_{BA} = 0$ $b_{BB} = (c_{BA} n_A + c_{BB} n_B)$	$\dot{x}_A = (n_A + n_B) x_A x_B \left((c_{AA} - c_{BA}) x_A + (c_{AB} - c_{BB}) x_B \right)$ $\dot{x}_B = -(n_A + n_B) x_A x_B \left((c_{AA} - c_{BA}) x_A + (c_{AB} - c_{BB}) x_B \right)$
General interaction growth	$\dot{n}_A = c_{AA} \mu_{AA}(n_A, n_B) +$ $+ c_{AB} \mu_{AB}(n_A, n_B)$ $\dot{n}_B = c_{BA} \mu_{BA}(n_A, n_B) +$ $+ c_{BB} \mu_{BB}(n_A, n_B)$	
Time-dependent growth factors	$a(t)$ $b(t)$ $c(t)$	
Mixed evolutionary systems	Growth of 0 th order +1st order +2nd order.	

12.2. Growth 0. order (linear growth)

The linear growth for a species A is described by

$$\dot{n}_A = a_A$$

With the solution

$$n_A(t) = n_A(0) + at$$

Linear growth for 2 species A, B without mutual influence:

$$\begin{aligned} \dot{n}_A &= a_A \\ \dot{n}_B &= a_B \end{aligned}$$

<12.1>

Definition: The **replicator equation** is the growth equation for relative frequencies.

For the meaning of the replicator equation, see in particular chap. 13.3.

The replicator equation for linear growth for 2 species A, B without mutual influence is

$$\begin{aligned} \dot{x}_A &= \frac{1}{(n_A + n_B)}\left(a_A x_B - a_B x_A)\right) \\ \dot{x}_B &= -\frac{1}{(n_A + n_B)}\left(a_A x_B - a_B x_A)\right) \end{aligned}$$

<12.2>

Proof:

$$\begin{aligned}
&\dot{n}_A = a_A \\
&\dot{n}_B = a_B \\
&x_A := \frac{n_A}{n_A + n_B} \qquad x_B := \frac{n_B}{n_A + n_B} \\
&\Rightarrow \\
&\dot{x}_A = \frac{\dot{n}_A(n_A + n_B) - n_A(\dot{n}_A + \dot{n}_B)}{(n_A + n_B)^2} = \frac{a_A(n_A + n_B) - n_A(a_A + a_B)}{(n_A + n_B)^2} = \\
&\quad = \frac{1}{(n_A + n_B)}\left(a_A\left(\frac{n_A}{(n_A + n_B)} + \frac{n_B}{(n_A + n_B)}\right) - \frac{n_A}{(n_A + n_B)}(a_A + a_B) \right) = \\
&\quad = \frac{1}{(n_A + n_B)}\left(a_A(x_A + x_B) - x_A(a_A + a_B)\right) = \\
&\quad = \frac{1}{(n_A + n_B)}\left(a_A - x_A(a_A + a_B)\right) = \qquad \text{wegen } (x_A + x_B) = 1 \\
&\quad = \frac{1}{(n_A + n_B)}\left(a_A(1 - x_A) - x_A a_B)\right) = \\
&\quad = \frac{1}{(n_A + n_B)}\left(a_A x_B - x_A a_B)\right) \qquad \text{wegen } (1 - x_A) = x_B
\end{aligned}$$

$$\Rightarrow \dot{x}_B = -\frac{1}{(n_A + n_B)}\left(a_A x_B - x_A a_B)\right) \qquad \text{wegen } \dot{x}_A + \dot{x}_B = 0$$

12.3. 1st order growth (exponential growth with constant growth rates, growth by autocatalysis)

However, one speaks of life in the narrower sense only from the time when individuals have produced offspring of the same kind. This represents an autocatalytic process. Autocatalytic processes represent, as it were, the foundation of all life processes. Autocatalysis means that the change of the absolute frequency is proportional to the absolute frequency:

$$\dot{n}_A = b_A n_A$$

If the growth rate b_A is greater than 0, it is called a birth rate; if it is less than 0, it is called a death rate.

We first assume that the growth rate b_A is constant.

Autocatalysis thus describes positive feedbacks or self-reinforcing mechanisms. We have already pointed out in the introduction that the essential developments and structures are determined precisely by such mechanisms, because they lead to exponential growth:

$$n_A(t) = n_A(0)e^{b_A t}$$

The exponential growth for 2 species A, B with mutual influence results in the differential equation (evolutionary system)

$$\begin{aligned} \dot{n}_A &= b_{AA}n_A + b_{AB}n_B \\ \dot{n}_B &= b_{BA}n_A + b_{BA}n_B \end{aligned} \qquad \text{<12.3>}$$

The corresponding replicator equation (equation for relative frequencies) is:

$$\begin{aligned} \dot{x}_A &= x_A(b_{AA}x_B - b_{BA}x_A) + x_B(b_{AB}x_B - b_{BB}x_A) \\ \dot{x}_B &= -\left(x_A(b_{AA}x_B - b_{BA}x_A) + x_B(b_{AB}x_B - b_{BB}x_A)\right) \end{aligned} \qquad \text{<12.4>}$$

Proof:[31]

$$\begin{aligned} \dot{n}_A &= b_{AA}n_A + b_{AB}n_B \\ \dot{n}_B &= b_{BA}n_A + b_{BB}n_B \end{aligned}$$

$$x_A := \frac{n_A}{n_A + n_B} \qquad x_B := \frac{n_B}{n_A + n_B}$$

$\Rightarrow$

$$\dot{x}_A = \frac{\dot{n}_A(n_A + n_B) - n_A(\dot{n}_A + \dot{n}_B)}{(n_A + n_B)^2} =$$

$$= \frac{(b_{AA}n_A + b_{AB}n_B)(n_A + n_B) - n_A(b_{AA}n_A + b_{AB}n_B + (b_{BA}n_A + b_{BB}n_B))}{(n_A + n_B)^2} =$$

[31] https://www.dropbox.com/s/eay373g2y9dnjs5/Replikatorgl.%20f%C3%BCr%20exponentielles%20Wachstum.nb?dl=0

$$= \left((b_{AA}x_A + b_{AB}x_B)(x_A + x_B) - x_A((b_{AA}x_A + b_{AB}x_B) + (b_{BA}x_A + b_{BB}x_B))\right) =$$
$$= \left((b_{AA}x_A + b_{AB}x_B) - x_A((b_{AA}x_A + b_{AB}x_B) + (b_{BA}x_A + b_{BB}x_B))\right) =$$
$$\textit{wegen } (x_A + x_B) = 1$$
$$= \left(b_{AA}x_A(1 - x_A) + b_{AB}x_B(1 - x_A) - x_A(b_{BA}x_A + b_{BB}x_B)\right) =$$
$$= \left(b_{AA}x_A x_B + b_{AB}x_B x_B - b_{BA}x_A x_A - b_{BB}x_A x_B)\right) =$$
$$\textit{wegen } (1 - x_A) = x_B$$
$$= x_A(b_{AA}x_B - b_{BA}x_A) + x_B(b_{AB}x_B - b_{BB}x_A)$$

$$\Rightarrow \dot{x}_B = -\left(x_A(b_{AA}x_B - b_{BA}x_A) + x_B(b_{AB}x_B - b_{BB}x_A)\right)$$
$$\textit{wegen } \dot{x}_A + \dot{x}_B = 0$$

Note:

The growth rates $b_{AA}, b_{AB}, b_{BA}, b_{BB}$ do not have to be constant. A distinction is made between 2 important cases:

- **(frequency-dependent) evolutionary games** (see chap.12.4): The growth rates b_{AA} and b_{BB} are functions that depend linearly on the absolute frequencies n_A, n_B and $b_{AB} = b_{BA} = 0$:

$$b_{AA} = c_{AA}n_A + c_{AB}n_B$$
$$b_{BB} = c_{BA}n_A + c_{BB}n_B$$

This leads to the evolutionary system

$$\dot{n}_A = b_{AA}n_A = (c_{AA}n_A + c_{AB}n_B)n_A = c_{AA}n_A n_A + c_{AB}n_A n_B$$
$$\dot{n}_B = b_{BA}n_B = (c_{BA}n_A + c_{BB}n_B)n_B = c_{BA}n_A n_B + c_{BB}n_B n_B$$

So this leads to interaction growth.

- **Economy** (see chap.12.5): The growth rates b_{AA} and b_{BB} are functions that do not depend on n_A, n_B but depend on (time-dependent) parameters. In the simplest case, these parameters are the quantities $m_A^1, m_A^2, m_B^1, m_B^2$ that A, B possess of the two goods 1 and 2, e.g.:

$$b_{AA} = (m_A^1)^{\alpha}(m_A^2)^{(1-\alpha)} \qquad 0 \le \alpha \le 1$$
$$b_{BB} = (m_B^1)^{\beta}(m_B^2)^{(1-\beta)} \qquad 0 \le \beta \le 1$$

(For simplicity, we usually set proportionality factors equal to 1).
This leads to well-known economic processes.
The special cases $\alpha = 1$ and $\beta = 1$ respectively express that growth rates depend only on good 1 and not on good 2:

$$b_{AA} = m_A^1$$
$$b_{BB} = m_B^1$$

12.4. 2nd order growth (interaction growth, evolutionary games)

Just as 0th order growth (linear growth) and 1st order growth (exponential growth) are qualitatively fundamentally different from each other, 2nd order growth (growth by interaction) is qualitatively fundamentally different from these two forms of growth. Growth by interaction between individuals of the own kind is described by

$$\dot{n}_A = c_{AA}\, n_A n_A$$ <12.5>

and growth by interaction with individuals of another species is described by

$$\begin{aligned}\dot{n}_A &= c_{AB}\, n_A n_B \\ \dot{n}_B &= c_{BA}\, n_B n_A\end{aligned}$$ <12.6>

The factor c_{AA} describes how the number of individuals n_A changes when two individuals of species A meet. Assuming that the meeting of the individuals is purely random, the factor $n_A n_B$ is proportional to the probability of the meeting of an individual of the species A with an individual of the species B. The factor c_{AB} describes how the number of individuals n_A changes when two different individuals meet. (This applies analogously to the 2nd equation).

In general, a differential equation for a species can consist of all factors (linear, exponential, interaction). But especially important is the case of **"evolutionary games"**(Sigmund 1993; Maynard Smith 1982), where there are simultaneous interactions between individuals of the own and the other species, but neither linear nor exponential links occur:

$$\begin{aligned}\dot{n}_A &= c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= c_{BA} n_B n_A + c_{BB} n_B n_B\end{aligned}$$ <12.7>

We refer to this evolutionary system as the **standard interaction system**. It can also be interpreted as exponential growth in the sense of <12.3>

$$\begin{aligned}\dot{n}_A &= b_{AA} n_A + b_{AB} n_B \\ \dot{n}_B &= b_{BA} n_A + b_{BB} n_B\end{aligned}$$

with the (non-constant) growth rates

$$\begin{aligned}b_{AA} &= (c_{AA} n_A + c_{AB} n_B), \qquad & b_{AB} &= 0 \\ b_{BA} &= 0, & b_{BB} &= (c_{BA} n_A + c_{BB} n_B)\end{aligned}$$

because this leads again to <12.7>:

$$\begin{aligned}\dot{n}_A &= b_{AA} n_A + b_{AB} n_B = (c_{AA} n_A + c_{AB} n_B) n_A + 0.n_B = c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= b_{BA} n_A + b_{BA} n_B = 0.n_A + (c_{BA} n_A + c_{BB} n_B) n_B = c_{BA} n_B n_A + c_{BB} n_B n_B\end{aligned}$$ <12.8>

This relationship reflects the basic idea of evolutionary games, in which a player of strategy A receives a payoff of c_{AA} for each encounter with a player of strategy A and receives a payoff of c_{AB} for each encounter with a player of strategy B. With a number of n_A players of strategy A and a number of n_B players of strategy B, in a round in which everyone plays against everyone, he receives a total payoff of

$$(c_{AA}n_A + c_{AB}n_B)$$

This payoff is interpreted as evolutionary fitness or evolutionary utility U_A and is therefore equated to the growth rate b_{AA}. The same applies analogously to the growth rate b_{BB} .

$$\begin{aligned}(c_{AA}n_A + c_{AB}n_B) &= U_A = b_{AA}\\(c_{BA}n_A + c_{BB}n_B) &= U_B = b_{BB}\end{aligned}$$

<12.9>

If the individuals of A and B meet by chance, the frequency of meeting is described by $n_A n_B$. If the individuals do not meet by chance, the frequency of encounter is increased or decreased by factors $\mu_{AA}, \mu_{AB}, \mu_{BA}, \mu_{BB}$ (usually $\mu_{AB} = \mu_{BA}$). This leads to the **generalized interaction system**

$$\begin{aligned}\dot{n}_A &= c_{AA}\mu_{AA}n_A n_A + c_{AB}\mu_{AB}n_A n_B\\\dot{n}_B &= c_{BA}\mu_{BA}n_B n_A + c_{BB}\mu_{BB}n_B n_B\end{aligned}$$

<12.10>

Here, the factors $c_{AA}, c_{AB}, c_{BA}, c_{BB}$ describe the effects of the encounter of A on B and $\mu_{AA}, \mu_{AB}, \mu_{BA}, \mu_{BB}$ the frequencies of the encounter.

In chap. 16.4 we will consider this general system in order to understand cooperation mechanisms. All of the above systems may still contain additional constraints to describe limited resources.

As the **replicator equation** (i.e., equation for the relative frequencies) for evolutionary games in the sense of <12.7> it follows:

$$\begin{aligned}\dot{x}_A &= (n_A + n_B)x_A x_B\left((c_{AA} - c_{BA})x_A + (c_{AB} - c_{BB})x_B\right)\\\dot{x}_B &= -(n_A + n_B)x_A x_B\left((c_{AA} - c_{BA})x_A + (c_{AB} - c_{BB})x_B\right)\end{aligned}$$

Proof:

$$\begin{aligned}\dot{n}_A &= c_{AA}n_A n_A + c_{AB}n_A n_B\\\dot{n}_B &= c_{BA}n_B n_A + c_{BB}n_B n_B\end{aligned}$$

$$x_A := \frac{n_A}{n_A + n_B} \qquad x_B := \frac{n_B}{n_A + n_B}$$

$$\Rightarrow \dot{x}_A = \frac{\dot{n}_A(n_A + n_B) - n_A(\dot{n}_A + \dot{n}_B)}{(n_A + n_B)^2} =$$

$$= \frac{(c_{AA}n_A n_A + c_{AB}n_A n_B)(n_A + n_B) - n_A((c_{AA}n_A n_A + c_{AB}n_A n_B) + (c_{BA}n_B n_A + c_{BB}n_B n_B))}{(n_A + n_B)^2} =$$

$$= (n_A + n_B)\frac{(c_{AA}n_An_A + c_{AB}n_An_B)(n_A + n_B) - n_A((c_{AA}n_An_A + c_{AB}n_An_B) + (c_{BA}n_Bn_A + c_{BB}n_Bn_B))}{(n_A + n_B)^3} =$$

$$= (n_A + n_B)\big((c_{AA}x_Ax_A + c_{AB}x_Ax_B)(x_A + x_B) - x_A((c_{AA}x_Ax_A + c_{AB}x_Ax_B) + (c_{BA}x_Bx_A + c_{BB}x_Bx_B))\big) =$$

$$= (n_A + n_B)\big((c_{AA}x_Ax_A + c_{AB}x_Ax_B) - x_A((c_{AA}x_Ax_A + c_{AB}x_Ax_B) + (c_{BA}x_Bx_A + c_{BB}x_Bx_B))\big) =$$

$$\textit{because } (x_A + x_B) = 1$$

$$= (n_A + n_B)\big(c_{AA}x_Ax_A(1 - x_A) + c_{AB}x_Ax_B(1 - x_A) - x_A(c_{BA}x_Bx_A + c_{BB}x_Bx_B)\big) =$$

$$\textit{because } (1 - x_A) = x_B$$

$$= (n_A + n_B)\big(c_{AA}x_Ax_Ax_B + c_{AB}x_Ax_Bx_B - c_{BA}x_Ax_Bx_A - c_{BB}x_Ax_Bx_B)\big) =$$

$$= (n_A + n_B)x_Ax_B\big(c_{AA}x_A + c_{AB}x_B - c_{BA}x_A - c_{BB}x_B)\big) =$$

$$= (n_A + n_B)x_Ax_B\big((c_{AA} - c_{BA})x_A + (c_{AB} - c_{BB})x_B\big)$$

$$\Rightarrow \dot{x}_B = -(n_A + n_B)x_Ax_B\big((c_{AA} - c_{BA})x_A + (c_{AB} - c_{BB})x_B\big)$$

$$\textit{because } \dot{x}_A + \dot{x}_B = 0$$

12.5. Biological and economic utility functions

As was already discussed with the special case of evolutionary games (chap. 12.4, <12.9>), in evolutionary systems of the type

$$\dot{n}_A = b_{AA}n_A$$
$$\dot{n}_B = b_{BB}n_B$$

in general, the (non-constant) growth rates b_{AA}, b_{BB} can be equated with the respective utility U_A, U_B that species A, B have in certain situations. In evolutionary games, the utility depends linearly on the absolute frequencies n_A, n_B

$$U_A = (c_{AA}n_A + c_{AB}n_B) = b_{AA}$$
$$U_B = (c_{BA}n_A + c_{BB}n_B) = b_{BB}$$
<12.11>

This results in the evolutionary system

$$\dot{n}_A = b_{AA}n_A = U_An_A = (c_{AA}n_A + c_{AB}n_B)n_A$$
$$\dot{n}_B = b_{BB}n_B = U_Bn_B = (c_{BA}n_A + c_{BB}n_B)n_B$$
<12.12>

In economic systems, the utility of an "agent" A does not depend on n_A, n_B, but typically on the quantity of two (or more) goods, namely good 1 and good 2 (e.g. potatoes and shirts). If m_A^1, m_A^2 denotes the quantities of good 1 and good 2 that A has at its disposal, then the utility of A, B is typically described by a function of the following kind (we set the proportionality factor equal to 1 in each case):

$$U^A = (m_A^1)^{\alpha}(m_A^2)^{(1-\alpha)} \qquad 0 \le \alpha \le 1$$
$$U^B = (m_B^1)^{\beta}(m_B^2)^{(1-\beta)} \qquad 0 \le \beta \le 1$$
<12.13>

This results in the evolutionary system

$$\dot{n}_A = b_{AA} n_A = U_A n_A = (m_A^1)^{\alpha} (m_A^2)^{(1-\alpha)} n_A$$
$$\dot{n}_B = b_{BB} n_B = U_B n_B = (m_B^1)^{\beta} (m_B^2)^{(1-\beta)} n_B$$
<12.14>

The functions according to <12.13> are examples of so-called self-referential functions, because U^A (the utility for A) depends only on the quantities at A's disposal and does not depend on the quantities at B's disposal. In contrast, the utility functions <12.11> in evolutionary games are precisely not self-referential, because the utility functions depend not only on n_A but also on n_B, i.e., they depend on properties concerning both A and B. But non-self-referential utility functions can also play a role in economic systems. We will discuss this in chap.15.6 when we discuss the theoretical foundations and the importance of overall utility maximization and individual utility optimization in the context of the question about the aggregability of utility functions.

12.6. The relationship between single-particle, multi-particle and many-particle systems.

In physics, a distinction is made between single-particle, multi-particle and many-particle systems, and with good reason, because not only the complexity increases, but above all qualitatively large differences can arise. More recently, in analogy to many-particle physics, one also tries to describe phenomena (so-called emergent phenomena) in economics, which only arise during the transition from finitely many agents to infinitely many agents. However, we will not go into this in detail.

12.7. Examples of important evolutionary systems

12.7.1. Limited exponential growth

The exponential growth of A

$$\dot{n}_A = b_{AA} n_A$$

is restricted by limited resources N_{max}. This leads to the fact that the growth rate is proportional to the proportion of individuals still possible $\frac{N_{max} - n_A}{N_{max}}$. This results in the so-called sigmoid curve:

$$\dot{n}_A = b_{AA} \frac{N_{max} - n_A}{N_{max}} n_A = b_{AA} (1 - \frac{n_A}{N_{max}}) n_A$$

Characteristic of the sigmoid curve is $\lim_{t \to \infty} n_A(t) = N_{max}$

12.7.2. Predator prey system

An example where the behavior of a species is described by both exponential and interaction links is the **predator-prey system.**

$$\dot{n}_A = (-b_{AA} + c_{AB} n_B) n_A = -b_{AA} n_A + c_{AB} n_A n_B \qquad A \text{ predator}$$
$$n_B = (+b_{BB} - c_{BA} n_A) n_B = +b_{BB} n_B - c_{BA} n_B n_A \qquad B \text{ prey}$$

mit

b_{AA} *death rate of A*

$c_{AB} n_B$ *death rate of A*

b_{BB} *death rate of B*

$c_{BA} n_A$ *death rate of B*

Characteristic: With constant coefficients, the system typically behaves cyclically. No permanent exponential growth occurs even in the absence of resource constraints. In the long run, a predator-prey system typically evolves to a stable equilibrium through adaptive dynamics (successive mutations and selection processes). (see chap. 5.7.4.3)

12.7.3. Symbiosis

Case 1: A increases growth of B and vice versa

$$\dot{n}_A = b_{AA} n_A + b_{AB} n_B$$
$$\dot{n}_B = b_{BA} n_A + b_{BB} n_B$$

Case 2: A increases growth **rate** of B and vice versa

$$\dot{n}_A = (b_{AA} + c_{AB} n_B) n_A = b_{AA} n_A + c_{AB} n_A n_B$$
$$\dot{n}_B = (c_{BA} n_A + b_{BB}) n_B = b_{BB} n_B + c_{BA} n_A n_B$$

Characteristic: Without limiting constraint, the system grows in case 1 for $t \to \infty$ towards ∞, in case 2 it grows already after finite time towards ∞. With limited resources a stable equilibrium is formed.

12.7.4. Simple Prisoner's Dilemma System

A cooperator

B defector

$$\dot{n}_A = (c_{AA} n_A + c_{AB} n_B) n_A = c_{AA} n_A n_A + c_{AB} n_A n_B = (v - k) n_A n_A - k\, n_A n_B$$
$$\dot{n}_B = (c_{BA} n_A + c_{BB} n_B) n_B = c_{BA} n_B n_A + c_{BB} n_B n_B = v\, n_B n_A + 0.n_B n_B$$

$v > 0$ *benefit of individual* (A *oder* B), *if it encounters cooperator A*

$k > 0$ cos*t of cooperator A, if it encounters an individual* (A *oder* B)

Characteristic: Without special cooperation mechanisms, cooperators are even displaced by an arbitrarily small set of defectors (Cooperators are said to be "evolutionarily unstable" with respect to defectors, cf. chap. 16.3).

12.7.5. Man and capital

$$\dot{n}_A = -b_{AA} n_A + b_{AB} n_B \qquad A \text{ man}$$
$$\dot{n}_B = b_{BB} n_B \qquad B \text{ capital}$$

Capital can be considered as an own special species (in a broader sense). Man and capital are basically related to each other in the same way as 2 different species. (For details, see chap.16.3.4.4). The basic problem is mainly that capital is not subject to restrictions as long as there are resources in surplus. Capital in this case grows essentially exponentially. Furthermore, a comparison with the predator-prey system shows,

$$\begin{aligned} \dot{n}_A &= -b_{AA} n_A + c_{AB} n_A n_B \qquad && A \text{ predator} \\ n_B &= +b_{BB} n_B - c_{BA} n_B n_A && B \text{ prey} \end{aligned}$$

that the man-capital system differs from the predator-prey system (besides $b_{AB} n_B$ instead of $c_{AB} n_A n_B$) in particular by the fact that for capital the negative feedback $-c_{BA} n_B n_A$ is missing. Therefore, in contrast to the predator-prey system, the human-capital system does not lead to a cyclical but to an exponentially growing dynamic.

13. Qualitative behavior of evolutionary systems

13.1. 2 Basic questions

In studying the qualitative behavior of evolutionary systems, 2 basic questions arise:

(1) How does the system behave in the long run (depending on the initial conditions)?

- Convergent behavior to a fixed point
- Cyclic behavior
- Growth against ∞
- Chaotic behavior
- Bifurcation

(2) Is a species evolutionarily stable (ESS) or evolutionarily unstable?
A species A is said to be evolutionarily stable with respect to another species B (or a mutant of A) if any very small amount of B within a pure species A immediately dies out again.

13.2. qualitative behavior of simple systems

For simplicity, we consider only 2 types A and B. Basically, we have to distinguish the following cases in qualitative behavior:

(1) Of which growth type are the 2 types A and B: linear (0.th order), exponential (1. order), or with interaction (2. order)
(2) How does the interaction occur?
- No interaction
- by indirect interaction due to constraints (e.g. limited resources)
- through direct interaction

- within the species ($c_{AA} > 0, c_{BB} > 0$)
- with other species ($c_{AB} > 0, c_{BA} > 0$)

Some **examples are** given for illustration:

a. for 2 species with linear growth (i.e. growth rate $a_A > 0, a_B > 0$) holds both for unlimited resources, i.e. for the system of equations

$$\dot{n}_A = a_A$$
$$\dot{n}_B = a_B$$

as well as with limited resources, i.e. for the system of equations

$$\dot{n}_A = a_A - \phi n_A$$
$$\dot{n}_B = a_B - \phi n_B$$
$$n_A + n_B = n = konstant$$
$$\dot{n}_A + \dot{n}_B = 0$$

that

$$\lim_{t\to\infty} x_A = \frac{a_A}{a_A + a_B}$$

b. for 2 species with (pure) exponential growth (i.e., growth rate $b_{AA} > 0, b_{BB} > 0, b_{AB} = b_{BA} = 0$) holds for both unlimited resources and limited resources, that $\lim_{t\to\infty} x_A = 0$ if $b_{AA} < b_{BB}$

c. for 2 species with interaction growth (i.e., growth rate $c_{AA} > 0, c_{BB} > 0$), a singular point occurs for unbounded resources (the absolute frequency approaches infinity at a point in time $t_{singulär}$). For the relative frequencies holds:

(1) for **un**limited resources

$$\frac{c_{AA}}{c_{BB}} < \frac{n_B(0)}{n_A(0)} \quad \Rightarrow \quad \lim_{t\to t_{singulär}} x_A(t) = 0$$
$$\frac{c_{AA}}{c_{BB}} > \frac{n_B(0)}{n_A(0)} \quad \Rightarrow \quad \lim_{t\to t_{singulär}} x_A(t) = 1$$

(2) for limited resources, the same applies with $\lim_{t\to\infty}$ instead of $\lim_{t\to t_{singulär}}$

d. at unlimited resources exponential growth of B always prevails over linear growth of A: $\lim_{t\to\infty} x_A = 0$

e. with limited resources, on the other hand, a system with (pure) linear growth of A and (pure) exponential growth of B leads to a stable equilibrium with $n_A^* = \frac{a_A}{b_{BB}}$

f. with unlimited resources in a system with (pure) exponential growth ($b_{AA} > 0, c_{AA} = 0$) of A and with interaction growth ($c_{BB} > 0$) of B, the interaction growth of B ($c_{BB} > 0$) always prevails over (pure) exponential growth of A ($b_{AA} > 0, c_{AA} = 0$): $\lim\limits_{t \to t_{singulär}} x_A = 0$

Interaction growth of B ($c_{BB} > 0$) corresponds to cooperation of B. In summary, this means that cooperation prevails over exponential growth.

g. with <u>limited</u> resources, a system with (pure) exponential growth ($b_{AA} > 0, c_{AA} = 0$) of A and with interaction growth ($c_{BB} > 0$) of B is bistable depending on the initial value $n_B(0)$ and on b_{AA}, c_{BB} :

for $n_B(0) < \frac{b_{AA}}{c_{BB}}$ A prevails and for $n_B(0) > \frac{b_{AA}}{c_{BB}}$ B prevails.

Formally, these statements can be easily shown with Mathematica.[32]

Why can cooperative interaction prevail over exponential growth? Qualitative statements are often of great importance for understanding evolution. As an application, one can e.g. explain from the two statements **f**. and **g**. why interaction growth (cooperation) can prevail over exponential growth. According to statement **f**., in a system with unlimited resources, interaction growth (cooperation) always prevails over exponential growth. However, in a system with limited resources, invasion of cooperation into an exponentially growing system is never possible because of statement **g**. That cooperation nevertheless exists in a system with limited resources can be explained in the following way. At low population densities, resource constraints do not yet matter, so a cooperating mutation can increase over time (statement **f**.). Restricted resources do not play a role until high population densities are reached. If A has then already exceeded the threshold $n_B > \frac{b_{AA}}{c_{BB}}$, cooperation then prevails according to statement g. even despite the effect of limited resources.

13.3. Derivation and meaning of the replicator equation

In the literature, the replicator equation is used to describe evolutionary games and their qualitative behavior. It is defined as a differential equation system for the relative frequencies:

$$\begin{aligned} \dot{x}_A &= \left(c_{AA}x_A + c_{AB}x_B - \phi\right)x_A \\ \dot{x}_B &= \left(c_{BA}x_A + c_{BB}x_B - \phi\right)x_B \\ &\textit{with} \\ \phi &:= (c_{AA}x_A + c_{AB}x_B)x_A + (c_{BA}x_A + c_{BB}x_B)x_B \end{aligned}$$ <13.1>

32 https://www.dropbox.com/s/61qdo6k5b1ugxhr/WW%20dominiert%20exp%20dominiert%20linear%20Version%202.nb?dl=0

ϕ describes the average fitness of A and B. If one substitutes in the replicator equation in the form <13.1> ϕ and simplifying, we get the replicator equation in the form

$$\begin{aligned} \dot{x}_A &= x_A x_B\left((c_{AA}-c_{BA})x_A+(c_{AB}-c_{BB})x_B\right) \\ \dot{x}_B &= -x_A x_B\left((c_{AA}-c_{BA})x_A+(c_{AB}-c_{BB})x_B\right) \end{aligned} \quad \text{<13.2>}$$

The use of <13.1> as a starting point is usually not justified in more detail and therefore "falls from the sky", as it were. The only thing listed is that ϕ guarantees with this definition that the sum of the relative frequencies $x_A + x_B = 1$, which must always hold. The usual derivation of the replicator equation is therefore not very convincing. This is especially so because the starting point for the behavior must always be the equations for the absolute frequencies and not for the relative frequencies. This is because the behavior of the relative frequencies is a consequence of the behavior of the absolute frequencies and not the other way around. In the following, therefore, a derivation is given which starts from the equations for the absolute frequencies and from which it can be seen why the replicator equation has such a great importance for evolutionary games.

The starting point is the differential equation system for the absolute frequencies in evolutionary games without limited resources

$$\begin{aligned} \dot{n}_A &= c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= c_{BA} n_B n_A + c_{BB} n_B n_B \end{aligned} \quad \text{<13.3>}$$

and the differential-algebraic equation system in evolutionary games with limited resources.

$$\begin{aligned} \dot{n}_A &= c_{AA} n_A n_A + c_{AB} n_A n_B - \phi n_A \\ \dot{n}_B &= c_{BA} n_B n_A + c_{BB} n_B n_B - \phi n_B \\ n_A + n_B &= n = konstant \\ \dot{n}_A + \dot{n}_B &= 0 \end{aligned} \quad \text{<13.4>}$$

The 3rd equation is an algebraic equation resulting from the limitedness of the resources. It corresponds to a constraint. The 4th equation results directly from the 3rd equation by differentiation. This equation is usually needed to solve the differential-algebraic system of equations.

Both differential equation systems lead to the same differential equation for their relative frequencies:[33]

$$\begin{aligned} \dot{x}_A &= (n_A+n_B)x_A x_B\left((c_{AA}-c_{BA})x_A+(c_{AB}-c_{BB})x_B\right) \\ \dot{x}_B &= -(n_A+n_B)x_A x_B\left((c_{AA}-c_{BA})x_A+(c_{AB}-c_{BB})x_B\right) \end{aligned} \quad \text{<13.5>}$$

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[33] Proof see: https://www.dropbox.com/s/j4prx01naexenqj/Herleitung%20der%20Replikatorgleichung%20%28konstante%20Rep.rate%29%20Version%2010.nb?dl=0

https://www.dropbox.com/s/q30qkqsy71xd4al/Herleitung%20der%20Replikatorgleichung%20%28h%C3%A4ufigkeitsabh.%20Rep.rate%29%20Version%206.nb?dl=0

This differential equation system <13.5> for the relative frequencies differs from the replicator equation in the form <13.2> only by the factor $(n_A + n_B)$. In the case of limited resources, it holds $(n_A + n_B) = n = konstant$. In this case, the two equations differ only by a constant velocity factor n and therefore exhibit the same behavior qualitatively (i.e., for $t \to \infty$). Anyway, in the case of unconstrained resources, the two equations behave the same qualitatively (i.e., for $t \to \infty$) for the important case when $\lim_{t\to\infty} n_A(t) \lim_{t\to\infty} n_B(t) \neq 0$, which is the case, for example, when all coefficients $c_{ij} > 0$.

In summary, then, the importance of the replicator equation lies in the fact that it can generally be used to describe the qualitative behavior of evolutionary games with and without limited resources.

13.4. Qualitative behavior of evolutionary games

Given the replicator equation for evolutionary games in the form <13.2>

$$\begin{aligned} \dot{x}_A &= x_A x_B \left((c_{AA} - c_{BA})x_A + (c_{AB} - c_{BB})x_B\right) \\ \dot{x}_B &= -x_A x_B \left((c_{AA} - c_{BA})x_A + (c_{AB} - c_{BB})x_B\right) \end{aligned}$$

we can see that the qualitative behavior is only determined by the sign of $(c_{AA} - c_{BA})$ and $(c_{AB} - c_{BB})$.

Accordingly, one distinguishes **4 types of evolutionary games:** <13.6>

Of particular importance is also the question of whether a species A is "**evolutionarily stable"** (ESS "evolutionarily stable strategy"), i.e. that an invasion of a new species B is not possible, or that an arbitrarily small amount of B cannot prevail, but dies out immediately.

I.e. A is evolutionarily stable with respect to B:

$$\begin{aligned} &\textit{It exists } \delta > 0, \textit{ such that for all } \varepsilon < \delta \textit{ and } x_A(0) = 1 - \varepsilon \\ &\textit{and } x_B(0) = \varepsilon \textit{ holds } \lim_{t\to\infty} x_A(t) = 1 \end{aligned}$$

This is the case when

$$\begin{aligned} &c_{AA} > c_{BA} \textit{ or} \\ &c_{AA} = c_{BA} \textit{ and } c_{AB} > c_{BB} \end{aligned} \qquad \text{<13.7>}$$

Proof:

$$\begin{aligned} &c_{AA} > c_{BA} \textit{ or if } c_{AA} = c_{BA}, \textit{ then } c_{AB} > c_{BB} \qquad \Rightarrow \\ &\textit{It exists a } \delta > 0, \textit{ such that for all } \varepsilon < \delta \textit{ and} \\ &\textit{for } x_A(0) = 1 - \varepsilon \textit{ and } x_B(0) = \varepsilon \textit{ holds}: \\ &\textit{fitness of } A = c_{AA}(1-\varepsilon) + c_{AB}\varepsilon > (1-\varepsilon)c_{BA} + \varepsilon c_{BB} = \textit{fitness von } B \quad \Rightarrow \\ &\textit{for all } \varepsilon < \delta \\ &x_A(t) > x_A(0) = 1 - \varepsilon \Rightarrow \\ &\lim_{t\to\infty} x_A(t) = 1 \end{aligned}$$

14. Representation of evolutionary systems and economic systems as GCD models

14.1. Basics

In the general case, GCD models describe, in simplified terms, systems whose dynamics are determined by "individual utility optimization". That is, all agents try to influence the system in such a way that their own individual) utility grows as much as possible. The actual dynamics is then determined by the resultant of all the forces that the agents exert on the system. In a paper (Glötzl, Glötzl, und Richters 2019) we describe GCD models as the basic mathematical models for describing economic systems. In this chapter, we show that not only can one describe economics with GCD models (see Chap. 14.2), but that ultimately all evolutionary games can be understood and described as GCD models (see chap. 14.3). GCD models are thus an important theoretical basis for a unified understanding of evolution.

A major significance of GCD models is the following: The main mathematical models describing economics today are based on general equilibrium theory (maximization under constraints). A fundamental requirement for the general equilibrium theory to be applicable is that the individual utility functions are aggregable to an aggregate utility function. This means that the system (instead of many individual utility functions) can be described equivalently by a single utility function. In the simplest case, this is possible if the utility functions are self-referential, i.e., if the utility of A depends only on the variables that relate to A and the utility of B depends only on the variables that relate to B. This means that the system can be described equivalently by a single utility function. For example, this means that A's utility depends only on how much A has of a good itself and does not depend on how much others have of that good.

Game-theoretic models are used in economics precisely because they are not subject to these restrictions on the aggregability of utility functions. Especially in the Prisoner's Dilemma (see Section 16.4.2), the most important model of game theory, A's utility depends not only on his own behavior, but also on the behavior of his opponent. However, game-theoretic formalisms are not suitable for modeling the standard situations in economics, as they are usually described today with the help of models of general equilibrium theory.

GCD models overcome these two drawbacks. On the one hand, all essential models based on general equilibrium theory are nothing but special GCD models. On the other hand, GCD models are not restricted to aggregable utility functions and all evolutionary games can always be interpreted as GCD models as well. In this sense, GCD models represent a meta-theory or a meta-methodology to conventional economic models and game-theoretic models of evolution. Thus, only GCD models provide a unified basis for describing all evolutionary systems and variation mechanisms from the earliest beginnings of evolution to the systems and mechanisms of economics. In this sense, they are a fundamental method for understanding evolution.

With the help of the representation as GCD models, in particular also the especially important terms "individual optimization", "overall maximization" and "aggregability" can be formally cleanly defined and understood. The basis for this is provided by the theory of Helmholtz decomposition for arbitrary dimensional vector functions. This is an extension of the well-known Helmholtz decomposition in physics for 3-dimensional vector functions. We describe this in detail in chap. 15.6.2.

14.2. Definition of GCD models

For any number of agents (whether individual economic agents or representative agents for individual groups of economic agents), the general basic concept of GCD models can be verbally described as follows:

- Starting from an economic state at time t, which is defined by n stocks x_i and n flows y_i $(i = 1,\ldots,n)$ each of the m agents ($j = 1,\ldots,m$) has an interest in changing this state and an economic power μ_i^j to enforce its interest.
- He therefore exerts an economic force f_i^j on the change of the flows in the direction in which his interest increases most. His actual effective force is proportional to his expended economic force f_i^j and his economic power μ_i^j . The interaction of all forces and power factors leads to an "ex ante" dynamic.
- l constraints Z_k $(k = 1,..,l)$ such as accounting identities, lead to additional constraint forces. The "ex post" dynamics result from the interplay of the n interest-driven forces (times the power factors μ_i^j) plus the l constraint forces. The l constraint forces result either in analogy to classical mechanics from the l Lagrange multipliers λ_k times the corresponding gradient of Z_k or from the l Lagrange multipliers ϕ_k times the direction to the origin in analogy to biology or another way (for details see below).

The basic concept of GCD models can thus be represented (in the case of constraints analogous to classical physics, d'Alembert's principle) by the following system of equations: ($i = 1,...,n$ designates the different variables, $j = 1,...,m$ the different agents, $k = 1,...,l$ the different constraints)

$$\begin{aligned} x_i' &= y_i \\ y_i' &= \sum_{j=1}^{m} \mu_i^j f_i^j(x,y) + \sum_{k=1}^{l} \lambda_k \frac{\partial Z_k(x,y)}{\partial y_i} \\ Z_k(x,y) &= 0 \end{aligned}$$

<14.1>

Of particular importance is the case where the forces can be defined in terms of individual utility functions $U^j(y)$ of the agents j :

$$f_i^j(x,y) = \frac{\partial U^j(y)}{\partial y_i}$$

For the basic system of equations <14.1> the following is thus obtained

$$\begin{aligned} x_i' &= y_i \\ y_i' &= \sum_{j=1}^{m} \mu_i^j \frac{\partial U^j(y)}{\partial y_i} + \sum_{k=1}^{l} \lambda_k \frac{\partial Z_k(x,y)}{\partial y_i} \\ Z_k(x,y) &= 0 \end{aligned}$$

<14.2>

This system of equations can be interpreted as follows: The "rational" preference or economic interest, and hence the economic force, that an agent will exert to change a variable is greater the more its individual utility increases in the process. The actual change results from the interaction of all these forces and the constraint forces. It is the resultant of the individual optimization strategies of the agents and the constraint forces.

In neoclassical models, rather than assuming that each agent seeks to maximize its individual utility, the economic system is assumed to be governed by the maximization of a single utility function, which we refer to as the "master utility function" MU . If such a master utility function exists, the basic system of equations can be written as follows:

$$\begin{aligned} x_i' &= y_i \\ y_i' &= \frac{\partial MU(y)}{\partial y_i} + \sum_{k=1}^{l} \lambda_k \frac{\partial Z_k(x,y)}{\partial y_i} \\ Z_k(x,y) &= 0 \end{aligned} \qquad \text{<14.3>}$$

If $MU = U^A + U^B$, we denote the master utility function as the overall utility function $\hat{U}$. This gives

$$\begin{aligned} x_i' &= y_i \\ y_i' &= \frac{\partial \hat{U}(y)}{\partial y_i} + \sum_{k=1}^{l} \lambda_k \frac{\partial Z_k(x,y)}{\partial y_i} \\ Z_k(x,y) &= 0 \end{aligned} \qquad \text{<14.4>}$$

14.3. Evolutionary games as GCD models

Evolutionary games are usually described via the so-called replicator equations (see Chap. 13.3). The replicator equations are behavioral equations for the relative frequencies of species. At this level, however, the equivalence to GCD models is not directly visible.

However, the behavior of the relative frequencies is always derived from the behavior of the absolute frequencies. The equivalence of evolutionary games to GCD models is more easily seen at the level of the behavioral equations for the absolute frequencies than at the level of the behavioral equations for the relative frequencies.

Since GCD models generally describe a mechanism of individual utility optimization, evolutionary games can also be interpreted as individual utility optimization models. This interpretation is usually not unique. Using the standard interaction system as an example, we show 2 possible interpretations below.

14.3.1. First GCD interpretation of the standard interaction system.

The power μ_{AB} of species B to affect the change in the number of individuals of species A, i.e. $\dot{n}_A$, is obviously proportional to the frequency of encounter of an individual of species B with an individual of species A. If all individuals meet with equal probability, the frequency of encounter is proportional to the product of the absolute frequencies of the two species $n_A n_B$ (or also proportional to the product of the relative frequencies of the two species $x_A x_B$), i.e.

$$\mu_{AB} \ proportional \ n_A n_B$$

Each time A and B meet, there is then a change in the frequencies of A in the magnitude of the partial derivatives of the utility functions with respect to n_A.

E.g. the standard interaction system <12.7>

$$\begin{aligned} \dot{n}_A &= c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= c_{BA} n_B n_A + c_{BB} n_B n_B \end{aligned} \qquad \text{<14.5>}$$

can be described as a GCD representation in the following interpretation:

$$\begin{aligned} &U_A = c_{AA} n_A + c_{BA} n_B && utility \ function \ of \ A, \\ & && i.e. \ utility \ of \ all \ individuals \ of \ A \\ &U_B = c_{AB} n_A + c_{BB} n_B && utility \ function \ of \ B, \\ & && i.e. \ utility \ of \ all \ individuals \ of \ B \\ &\mu_{AA} = n_A n_A \quad \mu_{AB} = \mu_{BA} = n_A n_B && \mu_{BB} = n_B n_B \\ & && frequency \ of \ an \ encounter \\ & && in \ which \ an \ interaction \ occurs \end{aligned}$$

This in turn results in <14.5>

$$\begin{aligned} \dot{n}_A &= \mu_{AA} \frac{\partial U_A}{\partial n_A} + \mu_{AB} \frac{\partial U_B}{\partial n_A} = n_A n_A c_{AA} + n_A n_B c_{AB} \\ \dot{n}_B &= \mu_{BA} \frac{\partial U_A}{\partial n_B} + \mu_{BB} \frac{\partial U_B}{\partial n_B} = n_B n_A c_{BA} + n_B n_B c_{BB} \end{aligned}$$

So, in summary, the frequency of A, B changes along the resultant of the gradients of the utility functions of the species A, B corrected with the power factors μ. The power factors μ can also be considered as velocity factors because they are proportional to the frequency of encounter of the individuals. Note that very often the frequencies of encounter are not proportional to $n_A n_A$, $n_A n_B$, $n_B n_B$ but are quite different in the case of cooperative mechanisms, e.g., grouping or spatial arrangements. (see chap. 16.4.3).

14.3.2. Second GCD interpretation of the standard interaction system.

The standard interaction system <12.7> respectively <14.5>

$$\begin{aligned} \dot{n}_A &= c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= c_{BA} n_B n_A + c_{BB} n_B n_B \end{aligned}$$

but can also be described in the following interpretation as a GCD representation of this game:

$U_A = \frac{1}{2} c_{AA} n_A^2 + c_{AB} n_B n_A$	*utility funktion of A,* *i.e. the utility of all individuals of A*
$U_B = c_{BA} n_B n_A + \frac{1}{2} c_{BB} n_B^2$	*utility funktion of B,* *i.e. the utility of all individuals of B*
$u_A = \frac{\partial U_A}{\partial n_A} = c_{AA} n_A + c_{AB} n_B = b_{AA}$	*additional utility for A due to an* *additional individual of A* *equals the growth rate of A*
$u_B = \frac{\partial U_B}{\partial n_B} = c_{BA} n_A + c_{BB} n_B = b_{BB}$	*additional utility for B due to an* *additional individual of B* *equals the growth rate of B*
$\mu_{AA} = n_A$	*the possibility ("power") of A to* *enforce its own utility by changing* n_A
$\mu_{BB} = n_B$	*the possibility ("power") of A to* *enforce its own utility by changing* n_B
$\mu_{AB} = \mu_{BA} = 0$	*the possibility ("power") to enforce* *its own utility by changing the* *frequency of the other species is* 0 *respectively vice versa*

This in turn results in

$$\dot{n}_A = \mu_{AA} \frac{\partial U_A}{\partial n_A} + \mu_{AB} \frac{\partial U_B}{\partial n_A} = n_A (c_{AA} n_A + c_{AB} n_B) + 0 = c_{AA} n_A n_A + c_{AB} n_A n_B$$
$$\dot{n}_B = \mu_{BA} \frac{\partial U_A}{\partial n_B} + \mu_{BB} \frac{\partial U_B}{\partial n_B} = 0 + n_B (n_A c_{BA} + n_B c_{BB}) = c_{BA} n_B n_A + c_{BB} n_B n_B$$

14.3.3. Examples GCD/Individual utility optimization

We use the second interpretation of the standard interaction system <14.5>.

If $c_{AA}, c_{AB}, c_{BA}, c_{BB}$ are time-independent constants, the evolutionary system of the standard interaction system results as above.

(Individual) utility function for species A, B:

$$U_A = \frac{1}{2} c_{AA} n_A^2 + c_{AB} n_B n_A$$
$$U_B = c_{BA} n_B n_A + \frac{1}{2} c_{BB} n_B^2$$

Additional utility for an individual of species A, B:

$$u_A = c_{AA}n_A + c_{AB}n_B = \frac{\partial U_A}{\partial n_A} = b_{AA}$$
$$u_B = c_{BA}n_A + c_{BB}n_B = \frac{\partial U_B}{\partial n_B} = b_{BB}$$

results in the evolutionary system for evolutionary games

$$\dot{n}_A = \mu_{AA}\frac{\partial U_A}{\partial n_A} + \mu_{AB}\frac{\partial U_B}{\partial n_A} = n_A(c_{AA}n_A + c_{AB}n_B) + 0.\frac{\partial U_B}{\partial n_A} = u_A n_A = b_{AA}n_A$$
$$\dot{n}_B = \mu_{BA}\frac{\partial U_A}{\partial n_B} + \mu_{BB}\frac{\partial U_B}{\partial n_B} = 0.\frac{\partial U_A}{\partial n_B} + n_B(c_{BA}n_A + c_{BB}n_B) = u_B n_B = b_{BB}n_B$$
$$Note: \mu_{AA} = n_A,\ \mu_{BB} = n_B,\ \mu_{AB} = \mu_{BA} = 0$$
$$u_A = b_{AA}, \qquad u_B = b_{BB}$$

If $c_{AA}, c_{AB}, c_{BA}, c_{BB}$ are time-dependent, the following results from the general GCD model of individual utility optimization

$$\dot{n}_A = \mu_{AA}\frac{\partial U_A}{\partial n_A} + \mu_{AB}\frac{\partial U_B}{\partial n_A}$$
$$\dot{n}_B = \mu_{BA}\frac{\partial U_A}{\partial n_B} + \mu_{BB}\frac{\partial U_B}{\partial n_B}$$
$$\dot{c}_{AA} = \mu^A_{AA}\frac{\partial U_A}{\partial c_{AA}} + \mu^B_{AA}\frac{\partial U_B}{\partial c_{AA}}$$
$$\dot{c}_{AB} = \mu^A_{AB}\frac{\partial U_A}{\partial c_{AB}} + \mu^B_{AB}\frac{\partial U_B}{\partial c_{AB}}$$
$$\dot{c}_{BA} = \mu^A_{BA}\frac{\partial U_A}{\partial c_{BA}} + \mu^B_{BA}\frac{\partial U_B}{\partial c_{BA}}$$
$$\dot{c}_{BB} = \mu^A_{BB}\frac{\partial U_A}{\partial c_{BB}} + \mu^B_{BB}\frac{\partial U_B}{\partial c_{BB}}$$

with the above utility functions

$$U_A = \frac{1}{2}c_{AA}n_A^2 + c_{AB}n_B n_A$$
$$U_B = c_{BA}n_B n_A + \frac{1}{2}c_{BB}n_B^2$$

in particular the following evolutionary system

$$\dot{n}_A = \mu_{AA}\frac{\partial U_A}{\partial n_A} + \mu_{AB}\frac{\partial U_B}{\partial n_A} = (c_{AA}n_A + c_{AB}n_B)n_A$$

$$\dot{n}_B = \mu_{BA}\frac{\partial U_A}{\partial n_B} + \mu_{BB}\frac{\partial U_B}{\partial n_B} = (c_{BA}n_A + c_{BB}n_B)n_B$$

$$\dot{c}_{AA} = \mu_{AA}^{A}\frac{\partial U_A}{\partial c_{AA}} + \mu_{AA}^{B}\frac{\partial U_B}{\partial c_{AA}} = \mu_{AA}^{A}\frac{1}{2}n_A^2$$

$$\dot{c}_{AB} = \mu_{AB}^{A}\frac{\partial U_A}{\partial c_{AB}} + \mu_{AB}^{B}\frac{\partial U_B}{\partial c_{AB}} = \mu_{AB}^{A}\frac{1}{2}n_B n_A$$

$$\dot{c}_{BA} = \mu_{BA}^{A}\frac{\partial U_A}{\partial c_{BA}} + \mu_{BA}^{B}\frac{\partial U_B}{\partial c_{BA}} = \mu_{BA}^{B}\frac{1}{2}n_A n_B$$

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$$\dot{c}_{BB} = \mu_{BB}^{A}\frac{\partial U_A}{\partial c_{BB}} + \mu_{BB}^{B}\frac{\partial U_B}{\partial c_{BB}} = \mu_{BB}^{B}\frac{1}{2}n_B^2$$

15. Variation mechanisms structured according to biological or economic causes

Variational mechanisms are, as said, mechanisms that change an evolutionary system. Very often this happens by changing single constants of the evolutionary system.

15.1. Random variation

$$a \rightarrow \tilde{a}(\omega)$$
$$b \rightarrow \tilde{b}(\omega)$$
$$c \rightarrow \tilde{c}(\omega)$$

or for example

$$\begin{aligned} \dot{n}_A &= c_{AA} n_A n_A + c_{AB}(\omega) n_A n_B \\ \dot{n}_B &= c_{BA}(\omega) n_B n_A + c_{BB}(\omega) n_B n_B \end{aligned} \quad \rightarrow \quad \begin{aligned} \dot{n}_A &= c_{AA} n_A n_A + c_{AB}(\omega) n_A n_B \\ \dot{n}_B &= c_{BA}(\omega) n_B n_A + c_{BB}(\omega) n_B n_B \end{aligned}$$

Both the mutation of a single base of a DNA and the complex change of genes during sexual reproduction are examples of random variation.

15.2. Long-term variation through adaptive dynamics

Viewed over time, mutations and selection mechanisms alternate. If the mutations each lead to a small change in a biological trait p and the selection mechanisms occur much more rapidly than the mutations, the temporal evolution of a property p can be described using the methods of "adaptive dynamics" (Dieckmann 2019; Metz, 2012). A central equation in this context is the so-called "canonical equation" for describing the time-varying property p:

$$\dot{p} = \frac{1}{2} \mu \sigma^2 n(p) \left. \frac{\partial f(p', p)}{\partial p'} \right|_{p'=p}$$

μ	*Mutation rate*	
s^2	*Variance of mutation effects*	
n(p)	*Number of individuals with trait p*	<15.1>
f(p', p)	*Invasion fitness (growth rate of initially rare individuals with trait p' in a population with trait p)*	

In the sense of chap. 11.1 the properties

$$p = a_A, b_{AA}, b_{AB}, c_{AA}, c_{AB}, a_B, b_{BA}, b_{BB}, c_{BA} \text{ or } c_{BB}$$

describe biological traits of species A and B whose temporal evolution under the given conditions can be described according to the canonical equation <15.1>.

Variational mechanisms are biological (or economic) mechanisms that lead to a change (variation) of these parameters. Adaptive dynamics thus describes a (long-term) variation mechanism, e.g.

$$\dot{n}_A = b_{AA} n_A \quad \rightarrow \quad \begin{aligned} \dot{n}_A &= \tilde{b}_{AA} n_A \\ \dot{\tilde{b}}_{AA} &= \frac{1}{2}\mu\sigma^2 n_A \left.\frac{\partial f(\tilde{b}_{AA}, b_{AA})}{\partial \tilde{b}_{AA}}\right|_{\tilde{b}_{AA}=b_{AA}} \end{aligned}$$

15.3. Variation due to change in the environmental situation

If the environmental situation $u = u(t)$ changes with time and a biological trait (a, b, c) depends on the environment u (e.g. if the growth rate $b_{AA} = b_{AA}(u)$ depends on the environment u) there results a variation of the biological trait

$$b_{AA}(t_0) = b_{AA}(u(t_0)) \quad \rightarrow \quad b_{AA}(u(t)) = \tilde{b}_{AA}(t)$$

In this sense, evolutionary games can also be understood as evolutionary systems in which the growth rate depends on the number of individuals of one's own species A and the number of individuals of the foreign species B, i.e. the "environment", and this environment is constantly changing:

$$\begin{aligned} &u(t) = (n_A(t), n_B(t)) \\ &b_{AA}(t) = b_{AA}(u(t)) = b_{AA}(n_A(t), n_B(t)) = c_{AA} n_A(t) + c_{AB} n_B(t) \\ &\dot{n}_A(t) = b_{AA}(t) n_A(t) = \left(c_{AA} n_A(t) + c_{AB} n_B(t)\right) n_A(t) \end{aligned}$$

Epigenetic changes (environmentally induced switching on and off of genes) can also be seen as a special case of variation due to environmental change, e.g.:

$$c_{AA} = c_{AA}(u_0) \rightarrow c_{AA}(u_1) = \tilde{c}_{AA}$$

15.4. Variation through constraints

The occurrence of a constraint due to limited resources e.g.: $n_A + n_B = n$

leads indirectly to a change in the evolutionary system

$$\begin{aligned} \dot{n}_A &= a_A + b_{AA} n_A + b_{AB} n_B + c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= a_B + b_{BA} n_A + b_{BB} n_B + c_{BA} n_B n_A + c_{BB} n_B n_B \end{aligned} \rightarrow \qquad \text{<15.2>}$$

$$\rightarrow \begin{aligned} \dot{n}_A &= a_A + b_{AA} n_A + b_{AB} n_B + c_{AA} n_A n_A + c_{AB} n_A n_B - \phi n_A \\ \dot{n}_B &= a_B + b_{BA} n_A + b_{BB} n_B + c_{BA} n_B n_A + c_{BB} n_B n_B - \phi n_B \\ n &= n_A + n_B \\ 0 &= \dot{n}_A + \dot{n}_B \end{aligned} \qquad \text{<15.3>}$$

Elimination of ϕ yields

$$\dot{n}_A = \frac{1}{n}(a_B n_A + b_{BA} n_A n_A - a_A n_B - b_{AA} n_A n_B + b_{BB} n_A n_B -$$
$$-c_{AA} n_A n_A n_B + c_{BA} n_A n_A n_B - b_{AB} n_B n_B - c_{AB} n_A n_B n_B + c_{BB} n_A n_B n_B) \text{<15.4>}$$
$$\dot{n}_B = -\dot{n}_A$$

A fictitious example of a constraint by a state or religious norm would be that the ratio of the number of priests A to the number of other people B must be constant. This would result in the constraint

$$n_A / n_B - const = 0$$

Constraints can lead to

- that an individual utility optimization is transformed into an overall utility maximization, i.e. that the individual utility functions become aggregable (cf. chap. 15.6)
- that a Prisoner's Dilemma situation is overcome by the fact that the constraint makes cooperation evolutionarily stable and therefore cooperators prevail over defectors. Constraint conditions can therefore also represent a cooperation mechanism (see Chap. 16.4.6)

15.5. Targeted variation through mind performance

15.5.1. The difference between random variation and targeted variation

At the beginning of evolution there are random variations (mutations). In the course of evolution, however, targeted variation mechanisms become more and more important. Epigenetic variations can be regarded as the first precursor of targeted variation. Horizontal gene transfer and sexual reproduction do not lead to the transmission of random mutations, but to the random transmission of mutations that have already successfully prevailed evolutionarily (see chap. 4.7.2) and can therefore be seen as simplified targeted variation mechanisms. Important true targeted variation mechanisms are (see chap 4.7.3):

- imitating, learning, teaching
- logical thinking
- individual utility optimization
- overall utility maximization
- animal and plant breeding
- genetic manipulation

These lead to an enormous increase of the evolutionary speed, because presumably evolutionary unsuccessful "misdevelopments" are avoided and thereby, as it were, detours of the evolution are shortened.

15.5.2. Targeted variation through imitation, learning, teaching

If B adapts his behavior to A's behavior when he meets A, the result is e.g. $c_{BA} \to \tilde{c}_{BA} = c_{AB}$ i.e.

$$\begin{aligned} \dot{n}_A &= a_A + b_A n_A + c_{AA} n_A n_A + c_{AB} n_A n_B \\ \dot{n}_B &= a_B + b_B n_A + c_{BA} n_B n_A + c_{BB} n_B n_B \end{aligned} \quad \rightarrow$$

$$\rightarrow \begin{aligned} \dot{n}_A &= a_A + b_A n_A + c_{AA} n_A n_A + c_{BA} n_A n_B \\ \dot{n}_B &= a_B + b_B n_A + c_{BA} n_B n_A + c_{BB} n_B n_B \end{aligned}$$

The change of the evolutionary system is basically the same for imitating, learning, teaching. The difference, however, consists first of all in the efficiency. Adaptation is more rapid and better by teaching than by learning, and by learning better and more rapid than by imitating. But the even more essential difference between imitating, learning and teaching is that the respective cognitive preconditions for it are very different. This is the reason that the variation mechanisms imitating, learning and teaching have developed chronologically one after the other in the course of evolution (see chap. 5.8, 5.11, 5.12)

15.5.3. Breeding

If A has a desired trait, breeding can increase the growth rate of A by α and if B has an undesired trait, breeding can decrease the growth rate of B by. This leads to the targeted variation

$$\begin{aligned} \dot{n}_A &= b_{AA} n_A \\ \dot{n}_B &= b_{BB} n_A \end{aligned} \quad \rightarrow \quad \begin{aligned} \dot{n}_A &= (b_{AA} + \alpha) n_A \\ \dot{n}_B &= (b_{BB} - \beta) n_A \end{aligned}$$

The ability to breed animals or plants, however, obviously requires a mental capacity, which in the course of evolution was given for the first time only in Homo sapiens.

15.5.4. Genetic manipulation and modification of information

In genetic manipulation, desirable or undesirable traits are altered not by changing the growth rate of the species, but by targeted intervention in the genome. In a broader sense, for example, the modification of the laws of a state can also be seen as a targeted variation of the general information underlying a state. In this context, a state is seen as a species in the broader sense.

15.5.5. Overall utility maximization

Overall utility maximization is always possible with or without constraints. For simplicity, we formulate variation by overall utility maximization only for the case where there are no constraints. (In principle, the presence of constraints does not change anything). We illustrate the principle using the generalized interaction system as an example <12.10>:

$$\begin{aligned} \dot{n}_A &= c_{AA} \mu_{AA} n_A n_A + c_{AB} \mu_{AB} n_A n_B \\ \dot{n}_B &= c_{BA} \mu_{BA} n_B n_A + c_{BB} \mu_{BB} n_B n_B \end{aligned}$$

For an understanding of the difference between overall utility maximization and individual utility optimization, see Chap. 15.6.

15.5.5.1. Discrete overall utility maximization

$$\begin{matrix} \dot n_A = c_{AA}\mu_{AA}n_A n_A + c_{AB}\mu_{AB}n_A n_B \\ \dot n_B = c_{BA}\mu_{BA}n_B n_A + c_{BB}\mu_{BB}n_B n_B \end{matrix} \rightarrow \begin{matrix} \dot n_A = \tilde c_{AA}\mu_{AA}n_A n_A + \tilde c_{AB}\mu_{AB}n_A n_B \\ \dot n_B = +\tilde c_{BA}\mu_{BA}n_B n_A + \tilde c_{BB}\mu_{BB}n_B n_B \end{matrix}$$

where $\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB}$ are the solutions of a maximization problem for a overall utility function $\hat U$ (with or without constraints):

$$0 = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{AA}}$$
$$0 = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{AB}}$$
$$0 = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{BA}}$$
$$0 = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{BB}}$$

15.5.5.2. Continuous overall utility maximization (gradient dynamics)

$$\begin{matrix} \dot n_A = c_{AA}\mu_{AA}n_A n_A + c_{AB}\mu_{AB}n_A n_B \\ \dot n_B = c_{BA}\mu_{BA}n_B n_A + c_{BB}\mu_{BB}n_B n_B \end{matrix} \rightarrow \begin{matrix} \dot n_A = \tilde c_{AA}\mu_{AA}n_A n_A + \tilde c_{AB}\mu_{AB}n_A n_B \\ \dot n_B = +\tilde c_{BA}\mu_{BA}n_B n_A + \tilde c_{BB}\mu_{BB}n_B n_B \end{matrix}$$

Where $\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB}$ are the solutions of a differential equation system with a overall utility function $\hat U$ (with or without constraints):

$$\dot{\tilde c}_{AA} = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{AA}}$$
$$\dot{\tilde c}_{AB} = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{AB}}$$
$$\dot{\tilde c}_{BA} = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{BA}}$$
$$\dot{\tilde c}_{BB} = \frac{\partial \hat U(\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB})}{\partial \tilde c_{BB}}$$

15.5.6. Individual utility optimization

$$\begin{matrix} \dot n_A = c_{AA}\mu_{AA}n_A n_A + c_{AB}\mu_{AB}n_A n_B \\ \dot n_B = c_{BA}\mu_{BA}n_B n_A + c_{BB}\mu_{BB}n_B n_B \end{matrix} \rightarrow \begin{matrix} \dot n_A = \tilde c_{AA}\mu_{AA}n_A n_A + \tilde c_{AB}\mu_{AB}n_A n_B \\ \dot n_B = +\tilde c_{BA}\mu_{BA}n_B n_A + \tilde c_{BB}\mu_{BB}n_B n_B \end{matrix}$$

Where $\tilde c_{AA},\tilde c_{AB},\tilde c_{BA},\tilde c_{BB}$ are the solutions of the differential equation system with the individual utility functions U_A,U_B (with or without constraints):

$$
\begin{aligned}
\dot{\tilde{c}}_{AA} &= \frac{\partial U_A}{\partial \tilde{c}_{AA}} \mu_{AA}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{AA}} \mu_{AA}^{B} \\
\dot{\tilde{c}}_{AB} &= \frac{\partial U_A}{\partial \tilde{c}_{AB}} \mu_{AB}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{AB}} \mu_{AB}^{B} \\
\dot{\tilde{c}}_{BA} &= \frac{\partial U_A}{\partial \tilde{c}_{BA}} \mu_{BA}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{BA}} \mu_{BA}^{B} \\
\dot{\tilde{c}}_{BB} &= \frac{\partial U_A}{\partial \tilde{c}_{BB}} \mu_{BB}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{BB}} \mu_{BB}^{B}
\end{aligned}
$$

To understand the difference between overall utility maximization and individual utility optimization, see the following chap. 15.6.

15.6. The difference between overall utility maximization and individual utility optimization: theory and meaning

15.6.1. For understanding

To better understand the difference between overall utility maximization and individual utility optimization, and to justify why we speak of "maximization" one time and "optimization" the other, consider the following:

We avoid the term "maximization" in individual utility optimization, in contrast to overall utility maximization, because the dynamics of individual utility optimization usually do not lead to a maximum. Both agents try to influence the variables in the direction of the gradient of their utility function, i.e., they both try to optimize their own utility function. In fact, the dynamics evolves in the direction of the resultants (possibly weighted by power factors) of the two gradients of the individual utility functions. In Prisoner's Dilemma situations, this can even lead to a decrease in the respective individual utility for both agents.

In contrast, the dynamics of overall utility maximization always leads to a maximum under the usual assumptions of convexity of the overall utility function. It runs in the direction of the gradient of the overall utility function (gradient dynamics).

15.6.2. Theoretical foundations

For simplicity, we first describe the case for dimension 2. Let $y = (y_1, y_2) \in \mathbb{R}^2$ be any variable and $f = (f_1, f_2) = (f_1(y_1, y_2), f_2(y_1, y_2)) \in \mathbb{R}^2$ be a vector function of this variable. With this we can define the following dynamic system:

$$
\begin{aligned}
\dot{y}_1 &= f_1(y_1, y_2) \\
\dot{y}_2 &= f_2(y_1, y_2)
\end{aligned}
$$

The **Helmholtz decomposition** (Glötzl und Richters 2021) states that there is a (up to a constant) uniquely determined "gradient potential" $G(y_1, y_2)$ and a (up to a constant) uniquely determined "rotation potential" $R(y_1, y_2)$, such that

$$f_1(y_1,y_2)=\frac{\partial G}{\partial y_1}+\frac{\partial R}{\partial y_2}$$
$$f_2(y_1,y_2)=\frac{\partial G}{\partial y_2}-\frac{\partial R}{\partial y_1}$$

Definition: $f=(f_1,f_2)$ is called "**rotation-free**": $\Leftrightarrow\ R\equiv 0$.

It holds the following essential **theorem**:

$$f=(f_1,f_2)\ rotation-free \Leftrightarrow \frac{\partial f_1}{\partial y_2}-\frac{\partial f_2}{\partial y_1}=0 \Leftrightarrow \begin{pmatrix} f_1(y_1,y_2) \\ f_2(y_1,y_2) \end{pmatrix}=\begin{pmatrix} \frac{\partial G}{\partial y_1} \\ \frac{\partial G}{\partial y_2} \end{pmatrix}$$

We call a dynamic system determined by **individual utility optimization if** there are utility functions $U_1(y_1,y_2), U_2(y_1,y_2)$ and power factors $\mu_{11}, \mu_{12}, \mu_{21}, \mu_{22}$ (where power factors may also depend on time and on y) such that

$$\dot{y}_1=f_1(y_1,y_2)=\mu_{11}\frac{\partial U_1}{\partial y_1}+\mu_{12}\frac{\partial U_2}{\partial y_1}$$
$$\dot{y}_2=f_2(y_1,y_2)=\mu_{21}\frac{\partial U_1}{\partial y_2}+\mu_{22}\frac{\partial U_2}{\partial y_2}$$

The term individual utility optimization is based on the following interpretation: The change of y_1 is determined by:

- the interest $\frac{\partial U_1}{\partial y_1}$, that agent 1 has to increase its utility function U_1 times the power μ_{11}, that agent 1 has to enforce this interest,
- plus the interest $\frac{\partial U_2}{\partial y_1}$ that agent 2 has to increase its utility function U_2 times the power μ_{12}, that agent 2 has to enforce this interest.

The change of y_2 results analogously.

Note: Dynamics determined by individual optimization need by no means lead to an optimum or to a fixed point.

We call a dynamical system determined by **master utility maximization** if there is a "master utility function" $\hat{U}(y_1,y_2)$ such that

$$\dot{y}_1=f_1(y_1,y_2)=\frac{\partial \hat{U}}{\partial y_1}$$
$$\dot{y}_2=f_2(y_1,y_2)=\frac{\partial \hat{U}}{\partial y_2}$$

Note: When $\hat{U}$ is convex, master utility maximization does indeed lead to a maximum. ("The gradient method leads to the maximum").

Therefore, from the above theorem, the following **corollary** follows for the relationship between individual utility optimization and master utility maximization:

Individual utility optimization is equivalent to master utility maximization if and only if individual utility optimization is rotation-free, i.e..

$$\begin{aligned}
&\frac{\partial f_1}{\partial y_2} - \frac{\partial f_2}{\partial y_1} = \\
&\quad = \frac{\partial}{\partial y_2}\left(\mu_{11}\frac{\partial U_1}{\partial y_1} + \mu_{12}\frac{\partial U_2}{\partial y_1}\right) - \frac{\partial}{\partial y_1}\left(\mu_{21}\frac{\partial U_1}{\partial y_2} + \mu_{22}\frac{\partial U_2}{\partial y_2}\right) = \\
&\quad = \left(\mu_{11}\frac{\partial U_1}{\partial y_2 \partial y_1} + \mu_{12}\frac{\partial U_2}{\partial y_2 \partial y_1}\right) - \left(\mu_{21}\frac{\partial U_1}{\partial y_1 \partial y_2} + \mu_{22}\frac{\partial U_2}{\partial y_1 \partial y_2}\right) = 0
\end{aligned}$$

because then there exists a gradient potential G, which can be considered as a master utility function $\hat{U}$. Exactly in this case the individual utility functions are called **aggregable**. It follows directly that a dynamic determined by individual utility optimization leads to a maximum if there is a convex gradient potential G and the rotation potential $R \equiv 0$.

Important sufficient conditions for the aggregability of individual utility functions to a master utility function are:

(1) individual utility functions are "quasilinear:

$$\begin{aligned}
&U_1 = d_{11}y_1 + d_{12}y_2 + d_1,\ und\ U_2 = d_{21}y_1 + d_{22}y_2 + d_2 \Rightarrow \\
&\qquad \Rightarrow \hat{U} = (\mu_{11}d_{11} + \mu_{12}d_{12})y_1 + (\mu_{12}d_{12} + \mu_{22}d_{22})y_2
\end{aligned}$$

(2) individual utility functions are self-referential:

$$\begin{aligned}
&U_1(y_1, y_2) = U_1(y_1)\ und\ U_2(y_1, y_2) = U_2(y_2) \quad \Rightarrow \\
&\qquad \Rightarrow \hat{U}(y_1, y_2) = \mu_{11}U_1(y_1) + \mu_{22}U_2(y_2)
\end{aligned}$$

(3) Power factors depend only on agents and not on variables:

$$\begin{aligned}
&\mu^1 := \mu_{11} = \mu_{21}\ und\ \mu^2 := \mu_{12} = \mu_{22} \qquad \Rightarrow \\
&\qquad \Rightarrow \hat{U} = \mu^1 U_1(y_1, y_2) + \mu^2 U_2(y_1, y_2)
\end{aligned}$$

We call a dynamic system determined by **overall optimization** if the following holds for the master utility function $\hat{U}(y_1, y_2)$

$$\begin{aligned}
&\hat{U} = U_1 + U_2 \\
&i.e. \\
&\dot{y}_1 = f_1(y_1, y_2) = \frac{\partial \hat{U}}{\partial y_1} = \frac{\partial U_1}{\partial y_1} + \frac{\partial U_2}{\partial y_1} \\
&\dot{y}_2 = f_2(y_1, y_2) = \frac{\partial \hat{U}}{\partial y_2} = \frac{\partial U_1}{\partial y_2} + \frac{\partial U_2}{\partial y_2}
\end{aligned}$$

An important sufficient condition for the equivalence of individual utility optimization and overall utility maximization is when there is a master utility function $\hat{U}$ and all power factors are 1:

$$\mu_{11} = \mu_{21} = \mu_{12} = \mu_{22} = 1 \qquad \Rightarrow \qquad \hat{U} = U_1(y_1, y_2) + U_2(y_1, y_2)$$

For the extension of the Helmholtz decomposition (Glötzl und Richters 2021) to arbitrary dimensions holds (ROT is a special defined operator):

(1) $\dot{y} = f(y) = grad\, G(y) + ROT\, R(y)$

(2) $f \ rotation - free \Leftrightarrow$

$$\Leftrightarrow \text{ for all } i < j \text{ holds } \frac{\partial f_i}{\partial y_j} - \frac{\partial f_j}{\partial y_i} = 0 \Leftrightarrow$$

$$\Leftrightarrow f(y) = grad\, G(y)$$

The extension of the concepts of individual utility optimization, master utility maximization, aggregability of individual utility functions, overall utility maximization to a higher dimension than 2 is evident.

15.6.3. About the importance in the economy

In a paper (Glötzl, Glötzl, und Richters 2019) we describe GCD models as the basic mathematical models for describing economic systems.

The economic assumption of the "**invisible hand"** for economic processes corresponds more or less to the assumption that economic processes can be described by overall utility maximization.

Individual utility optimization can lead to the maximization of a master utility function under the conditions mentioned above. However, this is by no means always the case. Such situations are called "**fallacy of aggregation**" in economics. (See also Arrow's impossibility theorem („Arrow-Theorem“)[34] and social choice theory („Sozialwahltheorie“)[35])

[34] https://www.wikiwand.com/de/Arrow-Theorem
[35] https://www.wikiwand.com/de/Sozialwahltheorie

15.7. About the relationship between random variation, long-term variation by adaptive dynamics, individual optimization and overall utility maximization.

For simplicity, we describe the relationships using the standard interaction system

$$\begin{aligned}\dot{n}_A &= c_{AA}n_A n_A + c_{AB}n_A n_B \\ \dot{n}_B &= c_{BA}n_B n_A + c_{BB}n_B n_B\end{aligned} \qquad \text{<15.5>}$$

15.7.1. Random variation

Random variation results in a new species B that interacts with A and is characterized by the traits $c_{BA}(\omega), c_{BB}(\omega)$. At the same time, the trait c_{AB} of A comes into play. The dynamic development is determined by the evolutionary system

$$\begin{aligned}\dot{n}_A &= c_{AA}n_A n_A + c_{AB}n_A n_B \\ \dot{n}_B &= c_{BA}n_B n_A + c_{BB}n_B n_B\end{aligned} \quad \rightarrow \quad \begin{aligned}\dot{n}_A &= c_{AA}n_A n_A + c_{AB}n_A n_B \\ \dot{n}_B &= c_{BA}(\omega)n_B n_A + c_{BB}(\omega)n_B n_B\end{aligned}$$

described. Suppose B dominates A, then B prevails and A dies out.

15.7.2. Long-term variation through adaptive dynamics

Adaptive dynamics is a simplified description of the multiple succession of random variation and subsequent selection of the most successful mutant. Although the individual mutations are random, the traits evolve deterministically (under appropriate assumptions) to the ultimately most successful mutant. The dynamics of the change of the traits is described by the corresponding canonical equations. Altogether, this results in a simplified differential equation system of the type

$$\begin{aligned}\dot{n}_A &= c_{AA}n_A n_A + c_{AB}n_A n_B \\ \dot{n}_B &= c_{BA}n_B n_A + c_{BB}n_B n_B\end{aligned} \rightarrow \begin{aligned}\dot{n}_A &= c_{AA}n_A n_A + c_{AB}n_A n_B \\ \dot{n}_B &= \tilde{c}_{BA}n_B n_A + \tilde{c}_{BB}n_B n_B\end{aligned}$$

$$\begin{aligned}\dot{\tilde{c}}_{BA} &= \frac{1}{2}\mu\sigma^2 n(B)\left.\frac{\partial f(\tilde{c}_{BB},\tilde{c}_{BA},c_{AA}c_{AB})}{\partial \tilde{c}_{BA}}\right|_{(\tilde{c}_{BB},\tilde{c}_{BA})=(c_{AA},c_{AB})} \\ \dot{\tilde{c}}_{BB} &= \frac{1}{2}\mu\sigma^2 n(B)\left.\frac{\partial f(\tilde{c}_{BB},\tilde{c}_{BA},c_{AA}c_{AB})}{\partial \tilde{c}_{BB}}\right|_{(\tilde{c}_{BB},\tilde{c}_{BA})=(c_{AA},c_{AB})}\end{aligned}$$

15.7.3. Individual utility optimization, overall utility maximization

The formation of the variation mechanism of utility optimization or utility maximization obviously requires that individuals are able to form the concept of a utility at all. The concept of utility is an immaterial concept. The formation of immaterial concepts was only possible with the complex cerebrum of Homo sapiens capable of logical thinking (see chap. 5.13).

The variational mechanism of overall utility maximization is described by the differential equation system

$$\begin{aligned}\dot{n}_A &= c_{AA}n_A n_A + c_{AB}n_A n_B \\ \dot{n}_B &= c_{BA}n_B n_A + c_{BB}n_B n_B\end{aligned} \rightarrow \begin{aligned}\dot{n}_A &= \tilde{c}_{AA}n_A n_A + \tilde{c}_{AB}n_A n_B \\ \dot{n}_B &= \tilde{c}_{BA}n_B n_A + \tilde{c}_{BB}n_B n_B\end{aligned}$$

$$\begin{aligned}
\dot{\tilde{c}}_{AA} &= \frac{\partial \hat{U}(\tilde{c}_{AA},\tilde{c}_{AB},\tilde{c}_{BA},\tilde{c}_{BB})}{\partial \tilde{c}_{AA}} \\
\dot{\tilde{c}}_{AB} &= \frac{\partial \hat{U}(\tilde{c}_{AA},\tilde{c}_{AB},\tilde{c}_{BA},\tilde{c}_{BB})}{\partial \tilde{c}_{AB}} \\
\dot{\tilde{c}}_{BA} &= \frac{\partial \hat{U}(\tilde{c}_{AA},\tilde{c}_{AB},\tilde{c}_{BA},\tilde{c}_{BB})}{\partial \tilde{c}_{BA}} \\
\dot{\tilde{c}}_{BB} &= \frac{\partial \hat{U}(\tilde{c}_{AA},\tilde{c}_{AB},\tilde{c}_{BA},\tilde{c}_{BB})}{\partial \tilde{c}_{BB}}
\end{aligned}$$

where $\hat{U}$ is the overall utility function.

The variation mechanism of individual utility optimization is described by the differential equation system

$$\begin{aligned}\dot{n}_A &= c_{AA}\mu_{AA}n_A n_A + c_{AB}\mu_{AB}n_A n_B \\ \dot{n}_B &= c_{BA}\mu_{BA}n_B n_A + c_{BB}\mu_{BB}n_B n_B\end{aligned} \rightarrow \begin{aligned}\dot{n}_A &= \tilde{c}_{AA}\mu_{AA}n_A n_A + \tilde{c}_{AB}\mu_{AB}n_A n_B \\ \dot{n}_B &= +\tilde{c}_{BA}\mu_{BA}n_B n_A + \tilde{c}_{BB}\mu_{BB}n_B n_B\end{aligned}$$

$$\begin{aligned}
\dot{\tilde{c}}_{AA} &= \frac{\partial U_A}{\partial \tilde{c}_{AA}}\mu_{AA}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{AA}}\mu_{AA}^{B} \\
\dot{\tilde{c}}_{AB} &= \frac{\partial U_A}{\partial \tilde{c}_{AB}}\mu_{AB}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{AB}}\mu_{AB}^{B} \\
\dot{\tilde{c}}_{BA} &= \frac{\partial U_A}{\partial \tilde{c}_{BA}}\mu_{BA}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{BA}}\mu_{BA}^{B} \\
\dot{\tilde{c}}_{BB} &= \frac{\partial U_A}{\partial \tilde{c}_{BB}}\mu_{BB}^{A} + \frac{\partial U_B}{\partial \tilde{c}_{BB}}\mu_{BB}^{B}
\end{aligned}$$

Where U_A, U_B are the individual utility functions.

The basic structure of the differential equation system of adaptive dynamics is obviously similar to the two differential equation systems. The main difference is that in the differential equation system of adaptive dynamics, the invasive fitness $f(\tilde{c}_{BB},\tilde{c}_{BA},c_{AA}c_{AB})$ results from material biological traits and the traits ultimately (by definition) "actually" lead to the maximum fitness or reproduction rate possible for a given invasive fitness function.

In utility optimization or maximization, the concept of utility is in each case a fictitious immaterial concept that is formed according to a certain algorithm from experience and logical conclusions in the cerebrum. However, this utility "calculated" in advance by the brain and the optimization or maximization dynamics do **not** guarantee in every case that the dynamics "actually" lead to the maximum fitness or reproduction rate. This is because obviously either the experiences may not be representative or may be stored incorrectly, or the algorithm may be flawed from the beginning. In particular, however, even if the algorithm of individual utility optimization is not flawed, it may still lead to the dynamics not reaching the individual utility maximum, as can be seen from the Prisoner's Dilemma.

Nevertheless, the existence of such algorithms for utility optimization in the cerebrum of Homo sapiens has obviously increased the fitness or reproduction rate on average, despite all shortcomings, to such an extent that they have represented a huge evolutionary advantage. Since the algorithm of individual utility optimization has to calculate only the own utility but not the utility of others, it is much easier for the cerebrum than the algorithm of overall utility maximization. Temporally, therefore, the individual utility optimization has developed first in the evolution. Whether also the algorithm of the overall utility maximization, e.g. an algorithm for the maximization of the survival probability of mankind, will develop, only the future will show.

15.7.4. The interplay between overall utility maximization (cooperation) and individual utility optimization (competition)

Ignoring the evolutionary development of new variations, cooperation in the sense of overall utility maximization in Prisoner's Dilemma situations leads to an increase in the weighted total fitness of the system relative to individual utility optimization (see Theorem <16.3> in chap. 16.4.2).

However, taking into account the evolutionary development of new variations, it is quite possible that competition in individual utility optimization will cause "stronger" species to prevail, so that overall fitness, taking into account the newly evolved species, will increase over time.

Thus, it may well be that, taking into account the new emerging species, an equilibrium over time between overall utility maximization and individual utility optimization leads to the fastest increase in the overall fitness of the system.

Thus, it does not seem surprising that in economic systems, too, a balance between cooperation and competition leads to the "best" outcome.

16. Variation mechanisms structured according to effects

16.1. Changes of the growth type

Starting from a standard evolutionary system

$$\begin{aligned}\dot{n}_A &= a_A + b_{AA}n_A + b_{AB}n_B + c_{AA}n_An_A + c_{AB}n_An_B \\ \dot{n}_B &= a_B + b_{BA}n_A + b_{BB}n_B + c_{BA}n_Bn_A + c_{BB}n_Bn_B\end{aligned}$$

<16.1>

and depending on which of the coefficients finally become greater than 0, arises

- a pure constant growth $\tilde{a} > 0, \tilde{b} = 0, \tilde{c} = 0$
- a purely linear growth $\tilde{a} = 0, \tilde{b} > 0, \tilde{c} = 0$
- a pure interaction growth $\tilde{a} = 0, \tilde{b} = 0, \tilde{c} > 0$

- a mixed growth $\tilde{a} > 0, \tilde{b} > 0, \tilde{c} > 0$

16.2. Death

The variation mechanism death corresponds to the occurrence of negative growth rates.

$$b_{AA} \to \tilde{b}_{AA} < 0$$

From an evolutionary point of view different types of death exist:

Death due to change in **environmental conditions** $b_{AA}(u) \to b_{AA}(\tilde{u}) < 0$

Death due to limited **resources**: see Chap. 11.3

Death as **prey**: see Predator-prey system chap.12.7.2

Death by **old age** and disease:

> With limited resources, death from old age or disease leads to the possibility of more offspring. This leads to a more rapid formation of new mutations or variations, and thus to the possibility of new better mutations becoming established more rapidly. Overall, therefore, death by age or disease is of evolutionary advantage. Therefore, it has emerged as an essential element of all life.

16.3. Win-win mechanisms

The majority of the biomass consists of win-win systems. This is understandable because individuals in win-win systems have a relatively higher utility and thus a relatively higher survival advantage. Examples are:

- Systems with the same or similar genetic material e.g.
  - Cells from multicellular organisms
  - Individuals of an ant colony
  - Swarm behavior
- Systems with different genetic material ("symbiosis") e.g.
  - Lichens as symbiosis of fungi with algae
  - Animals and their gut bacteria
  - Flowering plants with their pollinators
  - Ants and aphids, etc.

In biology, the formation of win-win systems is usually determined purely genetically ("hardware based"). In economics, the formation of win-win systems is determined by the optimization of individual utility functions. Examples are:

- Exchange
- Division of labor
- Trade
- Investment

16.3.1. Symbiosis

Case 1: 1st order growth (A increases growth of B and vice versa)

$$\begin{aligned}\dot{n}_A &= 0 \\ \dot{n}_B &= 0\end{aligned} \quad \rightarrow \quad \begin{aligned}\dot{n}_A &= b_{AB} n_B \\ \dot{n}_B &= b_{BA} n_A\end{aligned}$$

Case 2: 2nd order growth (A increases growth **rate** of B and vice versa)

$$\begin{aligned}\dot{n}_A &= 0 \\ \dot{n}_B &= 0\end{aligned} \quad \rightarrow \quad \begin{aligned}\dot{n}_A &= c_{AB} n_A n_B \\ \dot{n}_B &= c_{BA} n_B n_A\end{aligned}$$

16.3.2. Economic utility functions

If A's individual utility U_A depends only on the quantity m_A^1 of the single good 1 that A possesses, then in economics utility is typically modeled as follows:

$$U_A(m_A^1) := (m_A^1)^\alpha \qquad \textit{with } 0 < \alpha < 1$$

If the utility U_A of A depends on the quantities m_A^1, m_A^2 of the two goods 1,2 that A possesses, and if the two goods depend on each other in the sense that the utility is 0 provided that only one of the two quantities is 0, then in economics utility is typically modeled as follows:

$$U_A(m_A^1, m_A^2) := (m_A^1)^\alpha (m_A^2)^{(1-\alpha)} \qquad \textit{with } 0 < \alpha < 1$$

If B's utility U_B also depends only on the goods that B owns, e.g.

$$U_B(m_B^1, m_B^2) := (m_B^1)^\beta (m_B^2)^{(1-\beta)} \qquad \textit{with } 0 < \beta < 1$$

then U_A, U_B can be aggregated to an overall utility function (see Chap. 15.6.2)

$$\hat{U}(m_A^1, m_A^2, m_B^1, m_B^2) = U_A(m_A^1, m_A^2) + U_B(m_B^1, m_B^2)$$

i.e. that the dynamics or the equilibrium are determined by the gradient of $\hat{U}$. Thus, the individual utility functions are not aggregable exactly in the case when the dynamics cannot be described by overall utility maximization, but only by individual utility optimization.

Money represents a special good. Denote m_A^0 the amount of money (good 0) that A owns. Money is characterized by 2 special properties:

$$(1) \qquad \alpha = 1, \quad d.h. \quad U_A(m^0) = m^0$$

$$(2) \qquad U_A(m^0, m_A^1) = U_A(m^0) + U_A(m_A^1) = m^0 + U_A(m_A^1)$$

i.e. the utility of money and a good are independent from each other, that means the utilities add up.

16.3.3. The fundamental importance of documenting debt relationships as a variation mechanism for the emergence of win-win systems.

We have already explained the following in chap. 5.10.2 section. For the sake of systematics, it will be repeated here.

16.3.3.1. The documentation of debt relationships as a catalyst for the formation of win-win systems

We first show why mechanisms for documenting debt relationships are of such fundamental importance for the emergence of win-win systems.

Assume that a specific variation (change in the evolutionary system) leads to an additional utility for both species and thus to a win-win situation. This is described by

$$\begin{aligned} \frac{dn_A}{dt} = f_A(t) \quad &\rightarrow \quad \frac{dn_A}{dt} = f_A(t) + z_A(t) \\ &\quad\;\; \textit{with added utility } z_A(t) > 0 \textit{ for } A \\ \frac{dn_B}{dt} = f_B(t) \quad &\rightarrow \quad \frac{dn_B}{dt} = f_B(t) + z_B(t) \\ &\quad\;\; \textit{with added utility } z_A(t) > 0 \textit{ for } B \end{aligned}$$

$f_A(t)$ and $f_B(t)$ are arbitrary growth functions describing the growth before variation.

We call a variation in which the additional utility arises for both species at the same time or place Case 1 variation. As an example of a Case 1 variation, consider, for example, a variation that allows for the exchange of goods. A variation where the additional utility arises at a different time or place, we call Case 2 variation. As an example of a case 2 variation, consider, for example, a variation that enables the purchase and later sale of goods.

Because there are many more opportunities for a variation to produce an additional utility at some other time or place than there are opportunities for a variation to produce an immediate additional utility at the same place, Case 2 variations arise more easily and thus more frequently than Case 1 variations. On the other hand, a Case 1 variation leads more quickly and without detours to an additional utility for both individuals. Therefore, once the variation has occurred, Case 1 variations prevail more easily than Case 2 variations.

Therefore, a mechanism which transforms a case 2 win-win situation into a case 1 win-win situation (or a sequence of case 1 win-win situations) is of particular importance. Indeed, this obviously leads to a beneficial variation not only occurring more frequently, but also to a more rapid implementation of this variation. The most important mechanism for this is the **documentation of debt relationships**. Documentation of debt relationships is, as it were, a catalyst for the formation of win-win situations.

This is illustrated by the following example. B gives A a good that represents a value of 3 for B and a value of 5 for A. At a later point in time, A gives a good to B that represents a value of 3 to A and a value of 5 to B. This corresponds to a case 2 cooperation. For the time evolution of the utility of A and B then holds:

Case 2 Cooperation (without documentation of the debt relationship with money):	Utility A	Utility B
Initial situation	**0**	**0**
Utility change at time 1 due to goods	**+5**	**-3**
Overall utility change at time 1	**+5**	**-3**
Utility change at time 2 due to goods	**-3**	**+5**
Overall utility change at time 2	**+2**	**+2**

A variation that allows the use of money or promissory bills to document debt relationships converts the case 2 cooperation into the sequence of two case 1 cooperations. Buying the good for 4 monetary units gives A a utility of 5 - 4 = 1 and B a utility of 4 - 3 = 1. The utility arises for both at the same time and place. It is therefore a case 1 cooperation. At a later point in time, there may be a sale of a good from A to B, i.e. a second case 1 cooperation. For the temporal development of the utility of A and B then applies:

Sequence of case 1 cooperations through documentation of the debt with money	Utility A	Utility B
Initial situation	**0**	**0**
Utility change at time 1 due to goods	**+5**	**-3**
Utility change at time 1 due to money	**-4**	**+4**
Overall utility at time 1	**+1**	**+1**
Utility change at time 2 due to goods	**-3**	**+5**
Utility change at time 2 due to money	**+4**	**-4**
Overall utility at time 2	**+2**	**+2**

By documenting debt relationships, there is obviously a continuous growth of utility over time for both parties, which makes the enforcement of this variation much easier and thus faster.

16.3.3.2. *The development over time of the various technologies for documenting debt relationships*

Social communities are created through interdependencies. Debt relationships of all forms are the most important mutual dependencies. Thus, debt relationships are the most important basis on which social communities are formed. When we teach children to say "please and thank you," the social community is strengthened. Because with the word “please”, someone indicates that he is willing to go into debt. With the word “thank you”, the social debt that has been incurred is acknowledged. Thus, saying the words please and thank you contributes to the fact that social debt occurs more easily and more often, and therefore social communities are strengthened by this behavior. Therefore, saying please and thank you has become an evolutionary practice.

More formally, the precondition for the possibility of documenting debt relationships is the existence of a storage technology. Since the documentation of debt relationships requires a storage technology for information, the evolution of win-win mechanisms is therefore closely related to the evolutionary theory of information.

For the formation of direct cooperation through the behavior of direct reciprocity (tit for tat, you me so me you) in the age [3.3], documentation of the debt relationships over a longer period of time was not yet necessary, since the reactions usually took place in immediate temporal proximity.

Over a longer period of time, debt relations were only possible by an efficient cerebrum in the age [4.1], which also had the ability to store complex information. As a rule, the first debt relations were characterized by 2-sided debt relations ("I helped you").

The emergence of cooperation through the mechanism of indirect reciprocity in age [4.2] (see chap. 16.4.5 and 5.12.2) is based on the formation of a high reputation for cooperators. The reputation of a cooperator can be seen as the documentation of the cooperator's achievements towards many other individuals without direct reciprocation. Reputation thus represents, as it were, the documentation of a social debt owed by the general public to a cooperator.

The emergence of a high reputation of an individual requires not only the ability to store complex information, but also the ability to communicate in the form of a simple language to spread knowledge about the reputation of the cooperator in the community. Therefore, indirect reciprocity was made possible in the course of evolution only in the genus Homo in the age [4.2], who were able to use a simple language for communication.

The next evolutionary step in the formation of debt relations was the possibility of forming commodity debts in the age [4.3] of Homo sapiens. As a special form of it can also be considered the tradition of providing gifts, which contributed to the stabilization of human societies by consciously producing debt relations through gifts.

The next major breakthrough in the age [5.1] was the ability and method to describe or value different debts with a single symbol. This one symbol is called money. Money has subsequently itself been subject to major technological change that has had far-reaching effects on the development of humanity. The technology of money and with it the documentation of debt relationships became more and more efficient: From coin money (Age [5.1]), to paper money [5.2], fiat money [5.3]), electronic money [6.1], to blockchain technology [6.2]. Money is the root cause of the huge extent of win-win mechanisms in humans, an extent found nowhere else in nature (Nowak und Highfield 2012). Money as an efficient documentation mechanism for debt relationships is thus also the actual cause for the dominance of humans on earth.

We are therefore particularly concerned to understand the emergence of the economic mechanisms of money, exchange, purchase, division of labor, and investment from the point of view of evolution (see the following chap. 16.3.4). That is, we want to understand the necessary biological, cognitive, and technical conditions that made these mechanisms possible in the first place.

Win-win mechanisms have a significant survival advantage for individuals. The development of ways to document debt relationships therefore has a dramatic impact on evolution.

16.3.4. The main economic win-win mechanisms

16.3.4.1. Exchange

Exchange is characterized by real performance and real counterperformance occurring at the same time and place. It thus arises from a case 1 variation (see chap. 16.3.3.1). This is a significant restriction compared to buying and selling goods, which do not have to take place at the same time and place.

16.3.4.2. Purchase

Buying is the exchange of a good for a particular good, namely a commonly accepted means of payment, also commonly referred to as money. Buying and selling can occur at any time and place. The possibility to buy therefore arises through a case 2 variation (see chap. 16.3.3.1). Buying is therefore much more efficient than the possibility of only exchanging. In buying, money is nothing more than a means of documenting the debt relations created by the transfer of the good in the purchase. And documenting debts with money becomes more efficient the more efficient a monetary system is. (Commodity Money→ Coin Money→ Paper Money→ Fiat Money→ Electronic Money→ Blockchain Money)

16.3.4.3. Division of labor

For division of labor to be efficient, it must be possible to produce the services and the counter-services at different times and to buy and sell them at different times. Division of labor therefore arises, like buying, through a case 2 variation and is therefore promoted quite substantially by the possibility of efficient documentation of debt relations.

16.3.4.4. Investment as a win-win mechanism

Capital can be considered as a separate species (in a broader sense). Humans and capital are basically related to each other in the same way as 2 different species. (see also chap.12.7.5)

Designate and apply

b_{AA}	*birth rate man*
b^*_{AA}	*death rate man*
β, γ, δ	*proportionality factors*
n_A	*number of man*
n_B	*number of machines, "capital"*
$Y = \beta n_B$	*GDP with Cobb – Douglas production function with* $\alpha = 0$
$I = \gamma Y$	*investitment*
$C = Y - I$	*consumption*

then the evolutionary system for man without investment is:

$$\dot{n}_A = (b_{AA} - b^*_{AA}) n_A$$
$$\dot{n}_B = 0$$

In order to bring out the essentials, we greatly simplify. We assume that the growth rate is proportional to consumption per capita. This results in:

$$\dot{n}_A = (\delta \frac{C}{n_A} - b^*_{AA}) n_A$$

In the case of a variation that leads to investments, the following results

$$\dot{n}_A = (\delta \frac{C}{n_A} - b^*_{AA}) n_A = (\delta \frac{Y - \gamma Y}{n_A} - b^*_{AA}) n_A =$$
$$= (\delta \frac{(1-\gamma)\beta n_B}{n_A} - b^*_{AA}) n_A = \delta (1-\gamma) \beta n_B - b^*_{AA} n_A$$
$$\dot{n}_B = I = \gamma Y = \gamma \beta n_B$$

i.e. with $b_{AB} = \delta(1-\gamma)\beta$ *and* $b_{BB} = \gamma\beta$ the evolutionary system "man-capital" results.

$$\dot{n}_A = -b^*_{AA} n_A + b_{AB} n_B$$
$$\dot{n}_B = b_{BB} n_B$$

This means that the variation mechanism "investment" leads to the fact that

$$\begin{matrix} \dot{n}_A = (b_{AA} - b^*_{AA}) n_A \\ \dot{n}_B = 0 \end{matrix} \quad \rightarrow \quad \begin{matrix} \dot{n}_A = -b^*_{AA} n_A + b_{AB} n_B \\ \dot{n}_B = b_{BB} n_B \end{matrix}$$

Because of the 2nd equation, the variation mechanism investment leads to a much higher growth of A, at least in the longer run.

The fundamental problem is primarily that capital is not subject to any constraints as long as there are resources in surplus. In this case, capital essentially grows exponentially. Moreover, a comparison with the predator-prey system

$$\dot{n}_A = -b_{AA} n_A + c_{AB} n_A n_B \qquad A \textit{ predator}$$
$$n_B = +b_{BB} n_B - c_{BA} n_B n_A \qquad B \textit{ prey}$$

shows, that the man-capital system differs from the predator-prey system (besides $b_{AB}n_B$ instead of $c_{AB}n_An_B$) in particular by the fact that for capital the negative feedback $-c_{BA}n_Bn_A$ is missing. Therefore, in contrast to the predator-prey system, the human-capital system does not lead to a cyclical but to an exponentially growing dynamic.

16.4. Cooperative mechanisms for overcoming Prisoner's Dilemma systems in evolutionary games

Win-win mechanisms transform neutral situations for 2 species into an advantage for both species. Cooperation mechanisms are special win-win mechanisms. They transform Prisoner's Dilemma systems in such a way that the cooperators rather than the defectors prevail.

16.4.1. What does cooperation mean in evolutionary games

Evolutionary games are characterized by the standard interaction system <12.7>

$$\begin{aligned}\dot{n}_A &= c_{AA}n_An_A + c_{AB}n_An_B \\ \dot{n}_B &= c_{BA}n_Bn_A + c_{BB}n_Bn_B\end{aligned}$$

and have a particularly great importance as evolutionary systems. Variational mechanisms in evolutionary games that lead to cooperative (altruistic) behavior prevailing are called cooperative mechanisms. They are of fundamental importance for evolution.

If "cooperators" K (altruistic individuals) and "defectors" D (selfish individuals) meet in the context of an evolutionary game, the dynamic evolution of the relative frequencies (apart from the velocity factor $(n_K + n_D)$, see Chap.13.3) is described by the replicator equation <13.2>:

$$\begin{aligned}\dot{x}_K &= x_Kx_D\left((c_{KK} - c_{DK})x_K + (c_{KD} - c_{DD})x_D\right) \\ \dot{x}_D &= -x_Kx_D\left((c_{KK} - c_{DK})x_K + (c_{KD} - c_{DD})x_D\right)\end{aligned}$$

In the simplest case, the following respective individual net utility ("payoff") results when 2 individuals meet:

When a cooperator encounters another cooperator, it receives an benefit $v > 0$ because of the other's cooperative behavior and has a cost $k > 0$. This results in

$$c_{KK} = v - k$$

When a cooperator encounters a defector, it only has a cost k but no benefit. This results in

$$c_{KD} = -k$$

Accordingly, a defector who encounters a cooperator has a benefit v without having to bear any cost

$$c_{DK} = v$$

and a defector who encounters another defector has neither an advantage nor a cost

$$c_{DD} = 0$$

This means that in any case

$$c_{DK} = v > v - k = c_{KK} \quad \text{and} \quad c_{DD} = 0 > -k = c_{KD}$$

Because of chap.13.3 <13.7> the cooperator K is not evolutionarily stable (not ESS) and because of <13.6> the defector D dominates the cooperator K, i.e.

$$\lim_{t\to\infty} x_K = 0, \lim_{t\to\infty} x_D = 1 \; if \; x_D(0) > 0$$

Substituting these concrete values into the replicator equation yields the dynamics

$$\begin{aligned} \dot{x}_K &= -kx_K x_D \\ \dot{x}_D &= +kx_K x_D \end{aligned}$$

It is particularly important to understand that in this evolutionary system the total weighted fitness $F(t)$ decreases with time. Let the weighted total fitness be defined by

$$F(t) := x_K f_K + x_D f_D = x_K(x_K c_{KK} + x_D c_{KD}) + x_D(x_K c_{DK} + x_D c_{DD})$$

then the following **theorem <16.2>** applies:

$$\begin{aligned} &Let\ v > k > 0.\ If \\ &c_{KK} = v - k \\ &c_{KD} = -k \\ &c_{DK} = v \\ &c_{DD} = 0 \\ &then\ it\ holds \\ &\dot{F}(t) < 0 \end{aligned} \qquad \text{<16.2>}$$

Proof of <16.2>:

$$\begin{aligned} &If\ x_K + x_D = 1\ then \\ &F(t) = x_K(x_K c_{KK} + x_D c_{KD}) + x_D(x_K c_{DK} + x_D c_{DD}) = \\ &\qquad = x_K(x_K(v-k) - x_D k) + x_D(x_K v + 0) = (v-k)x_K \Rightarrow \\ &\Rightarrow \dot{F}(t) = (v-k)\dot{x}_K \\ &because\ o\ the\ assumption\ (v-k) > 0. \\ &Because\ K\ is\ dominated\ by\ D\ it\ holds\ \dot{x}_K < 0 \Rightarrow \\ &\Rightarrow \dot{F}(t) < 0 \end{aligned}$$

16.4.2. The cooperation dilemma (Prisoner's Dilemma)

That K is not evolutionarily stable and is dominated by D is independent of the absolute size of the benefit v and the cost k . I.e., this is especially true for the case that $v - k > 0$. Because the fitness (growth rate) of the pure species K (i.e., $n_D = 0$) is stable because of

$$\dot{n}_K = c_{KK} n_K n_K + c_{KD} n_K n_D = (c_{KK} n_K) n_K = ((v-k)n_K) n_K = b_{KK} n_K$$

equals

$$(v-k)n_K$$

and the fitness of the pure species D is equal to 0, for the case $v-k>0$ the fitness of K is greater than the fitness of D and yet K is not evolutionarily stable with respect to D and is dominated by D. Moreover, the total fitness always decreases because of Theorem <16.2>. Therefore, this situation is called a dilemma, or more precisely a "**Prisoner's Dilemma".**

In the **language of evolution,** this dilemma means that cooperators (altruistic individuals) are displaced by defectors (selfish individuals), even though they alone have a higher fitness than defectors. That is, in these cases, the overall fitness of the population of K and D decreases over time.

This example can be extended to general evolutionary games:

$$\dot{n}_K = c_{KK} n_K n_K + c_{KD} n_K n_D$$
$$\dot{n}_D = c_{DK} n_D n_K + c_{DD} n_D n_D$$

An evolutionary game is called a Prisoner's Dilemma system if the fitness (reproductive rate) of the pure species K (cooperators) is greater than the fitness (reproductive rate) of the pure species D (defectors) and yet K is not evolutionarily stable with respect to D, i.e., an arbitrarily small set of defectors eventually displaces all cooperators. This is generally the case if

$$c_{DK} > c_{KK} > c_{DD} > c_{KD} \;\; und \quad 2c_{KK} > c_{DK} + c_{KD}$$

because then it holds:

$$\begin{array}{ll} (1) & overall\ \ fitness\ of\ \ pure\ K\, with\ n\ individuals = c_{KK}n \\ & overall\ \ fitness\ of\ \ pure\ D\, with\ n\ individuals = c_{DD}n \\ & It\ holds\ c_{KK}n > c_{DD}n \\ (2) & c_{DK} > c_{KK}\ and\ therefore\ because\ of\ <13.8>\ it\ \ follows \\ & that\ K\ is\ not\ evolutionary\ stabel \end{array}$$

Variational mechanisms that lead to overcoming this dilemma situation, i.e., that lead to the fact that cooperators can prevail over defectors or become evolutionarily stable, are called **cooperative mechanisms** (see the following chap.16.4.3). The importance of the cooperation mechanisms for the evolution results in particular from the fact that cooperation mechanisms lead to the fact that thereby the total fitness (total growth rate) of the system increases in relation to the total fitness of the Prisoner's Dilemma - system:

The following **theorem <16.3>** holds:

$$\begin{array}{l} Let\ n_K, n_D\ be\ the\ numbers\ in\ a\ Prisoner's\ Dilemma-Situation \\ (i.e.\ c_{DK} > c_{KK} > c_{DD} > c_{KD})\ with\ the\ constraint\, n_K + n_D = n\ and \\ designate\ \ F(t) = x_K f_K + x_D f_D = \\ \qquad = x_K(x_K c_{KK} + x_D c_{KD}) + x_D(x_K c_{DK} + x_D c_{DD}) \\ the\ weighted\ overall\ \ fitness, \\ then\ for\ all\ t\ it\ holds, that\ F(t)\ is\ increased \\ by\ both\ an\, increase\, of\ \ c_{KK}\ and\ a\ decrease\ of\ c_{DK}. \end{array} \qquad <16.3>$$

Proof: numerically graphically with Mathematica[36]

https://www.dropbox.com/s/iw6cgbkxwqob7vf/Satz%20Kooperationsmechanismus%20Version%204.nb?dl=0

Note <16.4>:

It follows from this theorem: If in a Prisoner's Dilemma system c_{KK} grows or decreases c_{DK} , then the overall weighted fitness of the system grows. Moreover, if c_{KK} grows or c_{DK} falls to the point that $c_{KK} > c_{DK}$, then K becomes evolutionarily stable with respect to D. Thus, precisely formulated, cooperation mechanisms are variation mechanisms that change c_{KK}, c_{DK} in such a way.

In the **language of economics,** this dilemma means that in such cases behavior determined by individual optimization (which is, for example, characteristic of a market economy in particular) does not lead to a maximum determined by overall maximization (cf. chap. 15.6)

16.4.3. Description of cooperation mechanisms

The simplest mechanism that leads to the enforcement of cooperation (altruistic behavior) over defection (selfish behavior) is the punishment of selfish behavior against altruistic individuals with a penalty s. This transfers the standard interaction system

$$\begin{aligned} \dot{n}_K &= c_{KK} n_K n_K + c_{KD} n_K n_D \\ \dot{n}_D &= c_{DK} n_D n_K + c_{DD} n_D n_D \end{aligned}$$

into the evolutionary system

$$\begin{aligned} \dot{n}_K &= c_{KK} n_K n_K + c_{KD} n_K n_D \\ \dot{n}_D &= (c_{DK} - s) n_D n_K + c_{DD} n_D n_D \end{aligned}$$

Obviously, K becomes evolutionarily stable with respect to D because of <13.7> when the penalty s becomes so large that $c_{KK} > (c_{DK} - s)$.

To understand possible cooperation mechanisms in general, one must analyze the substantive importance of each factor in the **general interaction system**, which is a generalization of the standard interaction system of evolutionary games (cf. chap. 12.4):

$$\begin{aligned} \dot{n}_A &= c_{AA} \mu_{AA} n_A n_A + c_{AB} \mu_{AB} n_A n_B \\ \dot{n}_B &= c_{BA} \mu_{BA} n_B n_A + c_{BB} \mu_{BB} n_B n_B \end{aligned}$$

Here the function μ_{AB} is a measure for the <u>frequency of</u> an interaction between A and B per time unit and the factor c_{AB} expresses the <u>effect</u> of the change on the absolute frequency of A. (Everything applies mutatis mutandis to all other μ, c). Typically, $\mu_{AB} = \mu_{BA}$.

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36 https://www.dropbox.com/s/iw6cgbkxwqob7vf/Satz%20Kooperationsmechanismus%20Version%204.nb?dl=0

The standard interaction system can then be considered as a special case with

$$\mu_{AB} = \mu_{AB} = \mu_{BA} = \mu_{BB} = 1$$

All cooperation mechanisms can be described by the fact that they lead to the fact that

$$c_{KK}\mu_{KK} \uparrow \text{ and / or } \quad c_{DK}\mu_{DK} \downarrow \qquad \text{<16.5>}$$

because then due to theorem <16.3> it holds (by substituting c_{KK} for $c_{KK}\mu_{KK}$ and c_{DK} for $c_{DK}\mu_{DK}$)

- that the overall weighted fitness of the system increases,
- that above a certain threshold $\lim_{t\to\infty} x_A(t) = 1 \text{ and } \lim_{t\to\infty} x_B(t) = 0$
- that cooperators are evolutionarily stable and thus cannot be displaced by defectors.

Thereby corresponds

$$\begin{array}{ll} c_{KK} \uparrow & \text{"Reward for K"} \\ c_{DK} \downarrow & \text{"penalty for D"} \\ \mu_{KK} \uparrow & \text{"more frequent interaction} \\ & \quad \text{between K among themselves"} \\ \mu_{DK} \downarrow & \text{"less frequent interaction} \\ & \quad \text{between K and D"} \end{array}$$

On this basis, all cooperation mechanisms can be easily understood (for more details, see the following two chaps.16.4.4 and 16.4.5)

16.4.4. Changing the effects of interaction by punishment, reward, constraint, insight, norms, contracts.

In a system of cooperators and defectors, the mechanism punishment can be seen as a mechanism that leads to a change in the effects of the interactions, in this case namely to a decrease of c_{DK}. Likewise, the mechanism reward, leads to an increase of c_{KK}. Both mechanisms lead, that above a certain threshold.

$$c_{KK} > c_{DK}$$

If this threshold is exceeded, cooperation becomes evolutionarily stable due to <13.7>..

In general, the factors $c_{KK}, c_{KD}; c_{DK}, c_{DD}$ that describe the effects of the interaction are changed so that

$$\begin{pmatrix} \dot{n}_K = c_{KK} n_K n_K + c_{KD} n_K n_D \\ \dot{n}_D = c_{DK} n_D n_K + c_{DD} n_D n_D \end{pmatrix} \quad with \quad c_{DK} > c_{KK} > c_{DD} > c_{KD} \quad \rightarrow$$
$$\rightarrow \begin{pmatrix} \dot{n}_K = \tilde{c}_{KK} n_K n_K + \tilde{c}_{KD} n_K n_D \\ \dot{n}_D = \tilde{c}_{DK} n_D n_K + \tilde{c}_{DD} n_D n_D \end{pmatrix} with \quad \tilde{c}_{KK} > \tilde{c}_{DK}$$

Similarly, constraints can lead to a decrease of c_{DK} and an increase of c_{KK} , making cooperation evolutionarily stable.

In addition to random variations, targeted variations play a particularly important role as variation mechanisms for enforcing cooperation. Only the mind has enabled people to recognize that certain situations correspond to a Prisoner’s Dilemma. Inddeed, a prisoner's dilemma can also be overcome by all the parties involved realizing that they are in a prisoner's dilemma. In order to overcome the prisoner's dilemma, they can then decide among themselves on an individual contract or general religious or state behavioral norms. The content of such contracts or norms then consists of corresponding constraint conditions, punishments or rewards.

This was a decisive step in the evolution of mankind. Ultimately, all state norms are based precisely on this insight. (see also 5.14.2)

16.4.5. Change in the frequency of interactions

In addition to altering the effects of interactions between individuals, mechanisms for enforcing cooperation are also possible, shifting the relative frequencies of interactions between cooperators μ_{KK}, between defectors μ_{DD}, or between cooperators and defectors μ_{DK}, μ_{KD} such that cooperators become evolutionarily stable.

$$\begin{pmatrix} \dot{n}_K = c_{KK} n_K n_K + c_{KD} n_K n_D \\ \dot{n}_D = c_{DK} n_D n_K + c_{DD} n_D n_D \end{pmatrix} \quad with \quad c_{DK} > c_{KK} > c_{DD} > c_{KD} \rightarrow$$
$$\rightarrow \begin{pmatrix} \dot{n}_K = c_{KK} \mu_{KK} n_K n_K + c_{KD} \mu_{KD} n_K n_D \\ \dot{n}_D = c_{DK} \mu_{DK} n_D n_K + c_{DD} \mu_{DD} n_D n_D \end{pmatrix} with \quad c_{KK} \mu_{KK} > c_{DK} \mu_{DK}$$

The simplest example is the complete separation of cooperators and defectors into 2 different groups, so that there is a random interaction between cooperators among themselves and defectors among themselves, but that there is no interaction between cooperators and defectors. In such a mechanism, the general interaction system between cooperators and defectors transitions to

$$\begin{aligned} \dot{n}_K &= c_{KK} \mu_{KK} n_K n_K + c_{KD} \mu_{KD} n_K n_D = c_{KK} n_K n_K + c_{KD}.0 = c_{KK} n_K n_K + 0.n_K n_D \\ \dot{n}_D &= c_{DK} \mu_{DK} n_D n_K + c_{DD} \mu_{DD} n_D n_D = c_{DK}.0 + c_{DD} n_D n_D = 0.n_D n_K + c_{DD} n_D n_D \end{aligned}$$

In this system, cooperators are obviously evolutionarily stable, provided $c_{KK} > 0$.

In general, $\mu_{KK} \uparrow$ and $\mu_{DK} \downarrow$ can be achieved mainly through

- **Network formation** (interaction mainly with neighbors, see chap. 5.7.7) leads to network cooperation
- **Group formation** (interaction mainly with members of one's own group, see also chap. 5.8.4) leads to group cooperation
- **Direct reciprocity**, in this case the cooperator plays the strategy TFT ("Tit for Tat") and the defector ALLD ("every time defection"), In this case there is an increase in the number of interactions in total due to repeated interactions. Therefore, $\mu_{KK} \uparrow$ increases and so does $c_{KK} \mu_{KK} \uparrow$ because of $c_{KK} > 0$. On the other hand, $c_{DK}.\mu_{DK}$ remains the same after the first round, because the defector defects and the cooperator also defects because of the game TFT (tit for tat), which leads to $c_{DK} = 0$ for all further rounds. Thus, it is also true for all further rounds that $c_{DK}.\mu_{DK} = 0$ and thus that $c_{DK}.\mu_{DK}$

remains the same (see also chap. 5.11.3). Direct reciprocity therefore leads to direct cooperation.

- **Indirect reciprocity** (interaction mainly with members with high reputation). Note: Reputation corresponds qualitatively to the **documentation of debt relationships!** (See also chap.16.3.3 and 5.12.2**).** Indirect reciprocity leads to indirect cooperation.

These mechanisms are described in more detail by Martin Nowak (Nowak 2006).

16.4.6. Cooperation through constraints

Constraints can, in principle, both change the effects of interactions and change the frequency of interactions.

All systems of norms, be they general value systems, moral systems, religious or state systems of norms, are ultimately nothing more than constraint conditions that lead to cooperation prevailing.

16.4.7. On the notion of kin selection and its relation to network and group cooperation.

16.4.7.1. The idea of kin selection (kin cooperation)

The idea of kin selection (kin cooperation) in animals goes back to J. B. S. Haldane (1955) and W. D. Hamilton (1964) and is most simply described briefly by the memorable quote from J. B. S. Haldane *"I will jump into the river to save two brothers or eight cousins."* The traditional explanation of kin selection is based on the principle of "inclusive fitness." [37]

"*When J. B. S. Haldane remarked, 'I will jump into the river to save two brothers or eight cousins', he anticipated what later became known as Hamilton's rule. This ingenious idea is that natural selection can favor cooperation if the donor and the recipient of an altruistic act are genetic relatives. More precisely, Hamilton's rule states that the coefficient of relatedness, r, must exceed the cost-to-utility ratio of the altruistic act: $r > c/b$. Relatedness is defined as the probability of sharing a gene. The probability that two brothers share the same gene by descent is 1/2; the same probability for cousins is 1/8. Hamilton's theory became widely known as "kin selection" or "inclusive fitness". When evaluating the fitness of the behavior induced by a certain gene, it is important to include the behavior's effect on kin who might carry the same gene. Therefore, the "extended phenotype" of cooperative behavior is the consequence of "selfish genes"* ".

This explanation is strongly challenged by M. Nowak et al. (Nowak, Tarnita, und Wilson 2010) in 2010, casting strong doubt on it, leading to a vigorous debate in Nature's "Brief Communications Arising" [38] [39] . We share M. Nowak's criticism. We assume that kin cooperation in animals is only possible if,

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[37] see footnote 37

[38] Nature 23 March 2011

[39] Brief Communications Arising | 23 March 2011,

Inclusive fitness theory and eusociality, Patrick Abbot et.al

Only full-sibling families evolved eusociality, Jacobus J. Boomsma et a

(1) When either the kinship relationship results in spatial proximity that leads to an increase in the frequency of interaction between relatives (e.g., pack formation, shared nesting in state-forming insects, etc.)
(2) or when relatives share a common identifying mark that they can perceive among themselves and that leads them to show a more frequent and, above all, different interaction with these relatives than with non-relatives.

16.4.7.2. Biological-cognitive preconditions

Sexual reproduction is, of course, the general precondition for defining kinship relationships between individuals at all.

In win-win interactions in networks (see chap. 5.5.2), there is generally no Prisoner's Dilemma to overcome and an interaction takes place only with network neighbors. In kin selection in case (1), on the other hand, a Prisoner's Dilemma situation is overcome and it is sufficient that offspring are frequently in the vicinity of their parents, so that more frequent interactions between related individuals occur as a result. In general, we speak of network selection when a mechanism leads to cooperation between neighboring individuals of a network.

In case (2), much stronger biological-cognitive preconditions are necessary:

- the phenotypes must be complex enough to be able to form appropriate recognition traits (e.g. smell, song, visual traits)
- the phenotypes must have sensors to perceive these recognition features
- the phenotypes must have (presumably at least) a polysynaptic reflex arc to respond differentially to relatives and nonrelatives in terms of interaction frequency and quality.

Kinship alone cannot cause relatives to cooperate with each other because kinship alone does not affect the quality or frequency of interaction. For this, additional properties are necessary such as spatial proximity between relatives or the existence of recognition features documenting kinship.

Kinship selection is therefore more likely to be a special case of network selection in case (1) or a special case of group selection in case (2).

16.4.7.3. First appearance

Kinship selection in the sense of case (1) can therefore have occurred in principle at the earliest since sexual reproduction, i.e. 1 billion years ago in the Neoproterozoic in age [2.3]. However, it can have acquired a special meaning only since the existence of predatory animals in the age [3.1] with the end of the Cryogenian 630 million years ago, because only by this real Prisoner's Dilemma situations have arisen.

Because kin selection in the sense of case (2) is essentially based on the fact that relatives form a special group, this can only have occurred at the earliest at the time of the occurrence of group selection in age [3.2]. (see Chap. 5.8.4 Group selection).

Kin selection and eusociality, Joan E. Strassmann et al
Inclusive fitness in evolution, Regis Ferriere et al.
In defence of inclusive fitness theory, Edward Allen Herre et al.
Nowak et al. reply

17. Summery and conclusions

A good theory puts the right terms in the right relationship. Newton's theory and Darwin's theory are good theories.

Newton puts the right terms, namely mass, acceleration and force, into the right relationship, namely Newton's law, which describes dynamics in the form of a differential equation. Darwin brings the right terms, namely biological species, genetic information, phenotype, mutation, into the right relationship, namely selection dynamics, which describes the dynamics of evolution in terms of differential equations.

Any good theory is also generalizable. Thus, general relativity and quantum field theory are generalizations of Newtonian theory. In this sense, the general theory of evolution sees itself as a comprehensive generalization of Darwin's theory. It extends the Darwinian concepts of biological species, genetic information, phenotype, mutation, and selection and replaces them with much more general concepts:

Darwinian theory of evolution	→	**general theory of evolution**
biological species	→	species (in a broader sense)
genetic information, genotype	→	general information
phenotype	→	form
mutation mechanism, mutation	→	variation mechanism, variation
selection dynamics	→	evolutionary dynamics

These conceptual extensions make it possible to describe evolutionary developments in very different areas from a unified point of view and in a unified time frame. Some examples:

Biology	hominins → homo → homo sapiens
Data types	RNA → DNA → electrochemical potential
Targeted variation mechanisms	Imitating → learning → teaching
Technologies	writing → letterpress → computing
Monetary systems	commodity money → coinage money → paper money → electronic money
Economic systems	exchange → division of labor → investment

Economic regimes	market economy → capitalist market economy →global capitalist market economy
Cooperation	group coop. → direct coop. → debt coop. →indirect coop. → norms coop
Driving forces	gradient of concentration →gradient of electrochemical potential →gradient of utility

The basic idea is to understand the "evolution of everything" as the emergence of new types of information and new information technologies in the following sense:

- A new type of information is associated with the emergence of a new storage technology.

- For each new type of information, 3 information technologies emerge in succession:

Storage technology, duplication technology, processing technology.

With this concept, the chronology of the whole evolution can be naturally divided into 7 or 8 ages:

Age	**Start Years ago**	**Storage medium**
[0]	4,6 10^9	Crystal
[1]	4,4 10^9	RNA
[2]	3,7 10^9	DNA
[3]	6,3 10^8	Nervous system
[4]	6,0 10^6	Cerebrum
[5]	5,0 10^3	External local memory
[6]	1,0 10^1	Cloud (Internet, networked memory)
[7]	*future*	Man-machine symbiosis

Each of the 7 ages can typically be divided into 3 sub-ages corresponding to the 7 information types with their corresponding 3 information technologies. Better and better information technologies are the basis for the fact that more and better targeted variation mechanisms could be formed. This explains the exponential increase in the speed of development and why development is probably heading for a singular point.

The course of evolution can be understood by the **following diagram**, which describes the evolution of evolutionary systems and variation mechanisms.

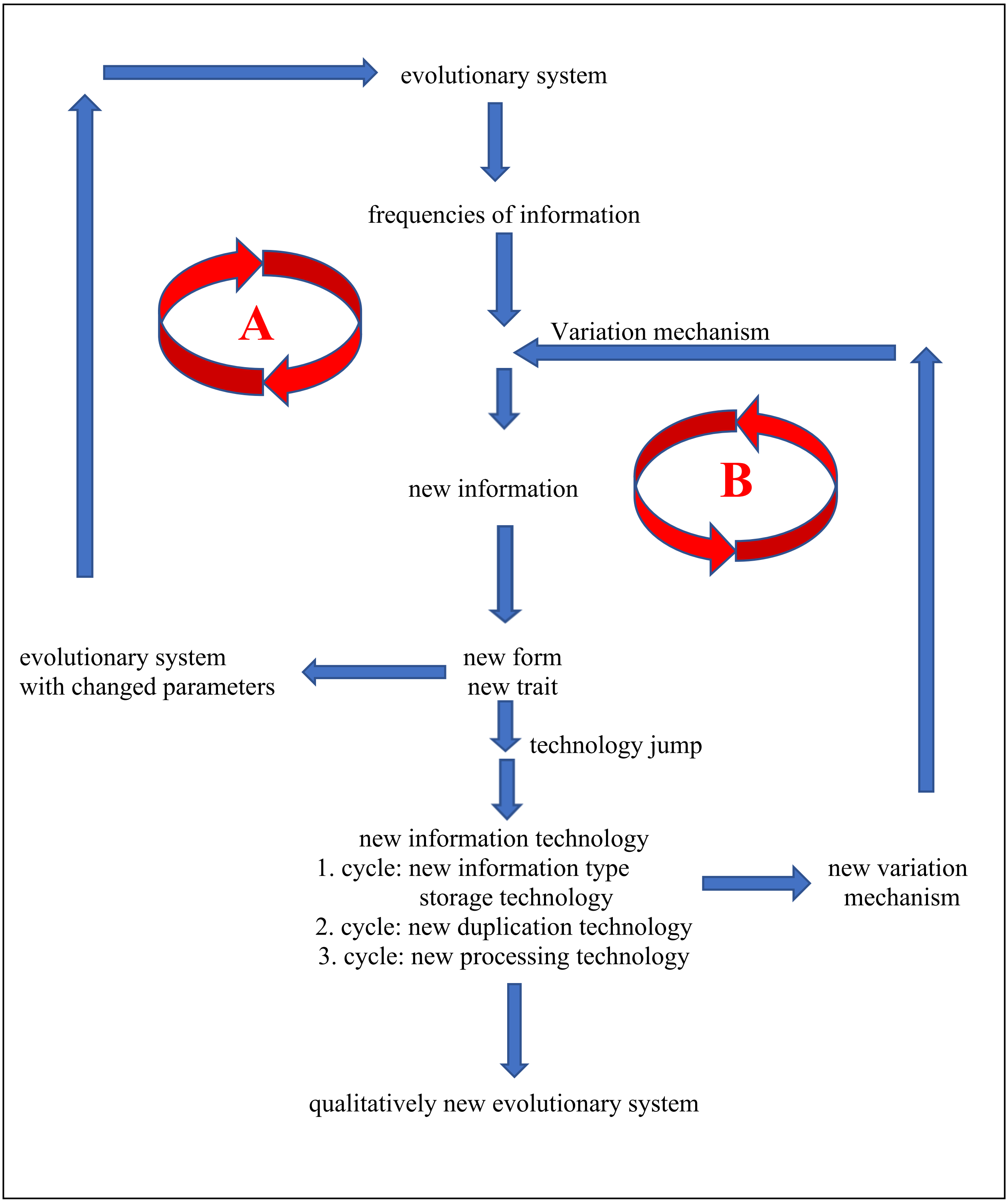

Diagramm:

Cycle A *represents essentially the Darwinian Theory for terms of the general theory*
Cycle B *represents an essential extension of the Darwinian theory to the general theory*

Cycle A essentially describes the **Darwinian theory**, which also applies to the new terms of the general theory of evolution. We write the respective Darwinian terms in brackets in the following. An evolutionary system (selection system) determines the dynamics of the frequencies of information (genetic information). A variation mechanism (mutation) leads to a new information (genetic information), from which a new form (phenotype) is formed. The new traits of the form (phenotype) lead to a new evolutionary system (selection system) with new parameters and the cycle A starts again from the beginning.

Cycle B describes one of the most important **extensions of Darwin's theory to the general theory of evolution**. Cycle A is run until a new trait appears in a new form that corresponds to a technological leap in an information technology. This technological leap may result from a new type of information with associated storage technology, a new duplication technology, or a new processing technology. It leads on the one hand to a qualitatively new evolution system and on the other hand to a new variation mechanism. This new variation mechanism influences in the consequence quite substantially the cycle A. In the sequence the cycle A is run through as long as until it comes to the next technology jump. Then again a qualitative new evolutionary system and a new variation mechanism emerges.

Examples of variations are all "random" mutations but also "targeted" variations that arise from **targeted variation mechanisms**. Such targeted variation mechanisms include: "imitating, learning, teaching", cooperation mechanisms, documentation of debt relationships by money, logical thinking, utility optimization, animal and plant breeding, genetic manipulation, etc.

Targeted variation mechanisms have a particularly high influence on the speed of evolution, because thereby detours of the evolution are shortened as it were and "wrong developments" are avoided.

The structure of the diagram and the emergence of targeted variations makes it possible to understand the exponential increase in the rate of evolution and why evolution is likely heading toward a singular point.

The following topics represent a selection of further new ideas presented in detail in the paper:

- Evolutionary theory of information

- Link between the evolutionary theory of information and the general theory of evolution.

- Megatrends of evolution

- Evolution of the driving forces

- Targeted variation mechanisms as essential elements of evolution

- Constraints as essential elements of evolution

- The illusion of free will as an evolutionary trait of success

- The documentation of debt relationships (especially in the form of money) as a catalyst for win-win and cooperation mechanisms

- The difference between individual utility optimization and total utility maximization

- From Artificial Intelligence 1.0 to Artificial Intelligence 2.0

The general evolution theory describes in the above sense in a systematic way all developments as they have proceeded on the earth under the given chemical-physical conditions since about 4 billion years. The essential considerations to it are, however, of such fundamental nature that the hypothesis is put forward that the evolution on other planets develops necessarily after the same 3 principles:

(1) that evolution inevitably produces new types of information, each with new storage technologies, new duplication technologies and new processing technologies,
(2) that the evolution is moving from simple systems to more and more complex systems, and
(3) that once evolution gets going, it proceeds at an exponentially increasing rate.

However, this does not at all lead to the conclusion that evolution always leads to the same result. The mechanisms of evolution are typically characterized by self-reinforcing mechanisms. Therefore, random changes in individual cases can lead to completely different processes of evolution. Even if evolution always proceeded according to the same principles, it would therefore lead to different results and traits in individual cases, even if the chemical-physical conditions were the same.

18. References

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