DYNAMIC EMERGENCE OF FEATURES
.
IN COMPLEX SYSTEMS

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Abstract

An epidemic involves numerous persons and institutions in handling and mitigating the situation due to medical urgency time pressure, political pressure and aggravated by the need to act in partially unknown territory. Many fields of knowledge have to be brought together to fight the challenges. The individual organizations, their actors and the general public have to interact with one another and this often results in unexpected situations, behavior and results, we speak of emergent effects.

Emergent effects sometimes are a welcomed support for actions taken, enhancing the desirable effects, but often they turn out the be counter-productive, reducing or even destroying the intended results. Emergent behavior of systems are a theoretically and practically challenging area of research. There is a rich knowledge about emergence in technical, medical and philosophical domains, for emergence in human behavior and societal issues there seems to be little knowledge available.

Our contribution is to distinguish between general properties on one side and and features on the other side (the relevant and characterizing properties of a complex the system) and associate phenomenon of emergence with the feature set of a system.

1 Motivation: The elusive concept of Emergence

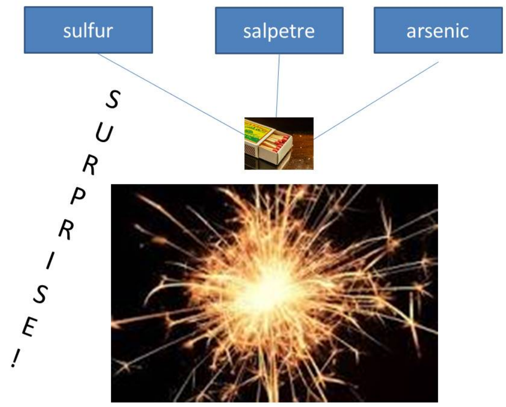

Fig. 1:

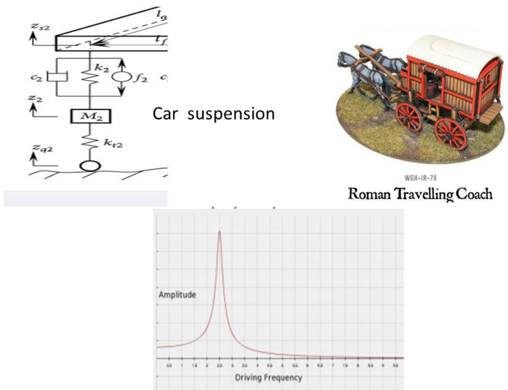

Fig. 2:

Definition (**emergence**):
Emergence occurs when an entity is observed to have properties its parts do not have on their own, properties or behaviors that emerge only when the parts interact in a wider whole

- since 19th century a topic of philosophical discussion.
- Emergence is the interaction of two (or more) component systems.
- an INTERESTING property becomes a FEATURE!
- Property becomes suddenly 'important, critical, useful, ... '

> Definition (**emergency**):
> An emergency is an urgent, unexpected, and usually dangerous situation that poses an immediate risk to health, life, property, or environment and requires immediate action (Wikipedia-english, 2013, keyword: 'Emergence')

Both have to do with "SURPRISE"
involve the concept of "system"!
My experience: there is "Emergence in Emergency"

A pandemic is a situation during which many people, as well as technical and social systems have to interact. Decisions considering limited resources, based on often unreliable data must be made usually with short notice and under psychological stress. A pandemic challenges the interplay between of human, governmental, and administrative systems etc. taking the health systems to their limits. A critical factor is the time pressure, preventing long-term deliberations concerning about measures to be taken. The involved systems usually consists of numerous interacting subsystems ('components'), often in large numbers(!). Each subsystem contributes one or more needed functionality to the total system. Novel components and creative combinations are often in order to succeed.

In the technical/physical world emergence has been identified and analyzed for a long time. Around 1890 Henri Poincaré introduced the 3-body conjecture into the thinking of the scientific world as an example of emergence (Francois, 2004, entry 0070). Even simple composite systems exhibit - under certain situations- unexpected and even undesirable behavior. A well-know example is the resonance of a car's suspension system at certain speeds.

This behavior has been labelled 'emergent'. It has undergone intensive investigations and discussions in System Theory (Klir, 2001; Jackson, 2003; Gibb et al., 2021). It turns out (as will be shown in the sequel) that the concept of a 'feature of a system' is one of the keys in understanding emergence.

Despite the large difference between nature, technical systems and society, emergence can be recognized - mutandis mutatis - in all those domains.

Lessons learnt from the theoretical investigation of technical systems can be of use to understand the situation arising in societal systems, and the positive and negative effects of various measures, including emergent situations.

This paper discusses the basic concepts of interaction of components in systems and will give an explanation of emergence by considering "features" as relevant and characterizing properties of a system.

The discussion of **figure vs. ground** will lead us to human psychology which allows us to filter the incoming information so as to reduce the computational load to be taken care of (Maier, 2015). It is also linked to cultural differences between different nations (Chroust, 2020). Some examples will support our opinion.

2 Approach and Method

2.1 The notion of System

Following (Thome, 1993) and (Open Systems Group, 1981) a *system* is defined as an assembly of components and their relationships such that

1. Components **connected** in an **organized** way. This organization -> behavior of a system.
2. Components are **affected** by being in the system but not outside the system.
3. Properties are **different**t from the sum of properties of components.
4. The assembly is active, it has a **purpose**.
5. identified as being of special interest (a **'human concept'**!)

A **purpose** is 'realized' ('implemented') by one or more **'features**' of a system

Definition (**Feature (set)**): is a relevant set of specific properties intended to perform the purpose of a system.

Different Purposes have intended and UNINTENDED effects

A key to the concept of 'system' is the phrase 'in an organized way'. This is sometimes called 'synergetics' (Minati and Pessa, 2002, p4-5)

Components and/or the system will show different properties and behavior, depending on the internal structure of the systems (Chroust, 2002), i.e. depending on the way the components are connected. *(Example: Connecting 3 lamps in series or in parallel makes a drastic difference in the light they produce and the energy they consume.)*

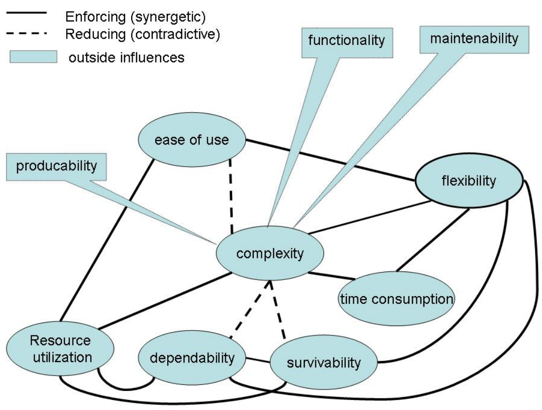

Fig. 3: Mutual influences on Basic Properties

2.2 Purpose of a System

Definition (**System Property**):
... is any distinguishable attribute characterizing it. We may notice or ignore different properties (depending on the situation)

.

Definition (**Purpose of a System**):
A systems is created for a 'job to do' : its PURPOSE or function ("Functionalistic view")

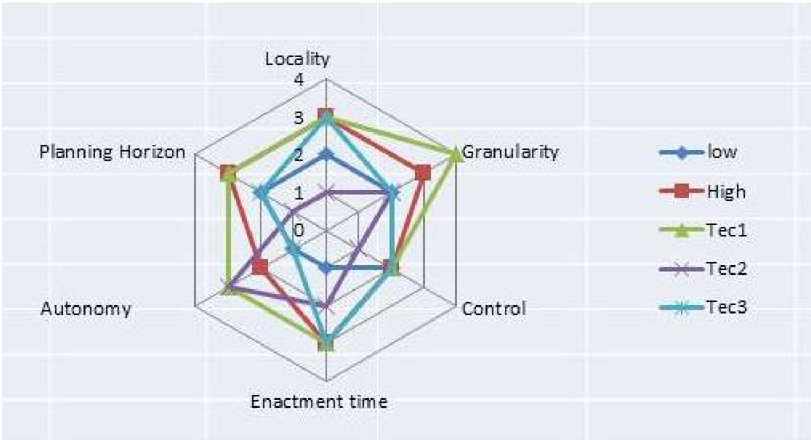

Fig. 4: Different purpose - impact of features

- relevant (essential) versus irrelevant properties
- some noticed by the observer, others not -
- our mind is a necessary filter
- distinguish between *'figure'* and *'ground'*.
- Component Replacement : same feature set ... different components!
- besides 'features' each component has further properties!

"The optimist sees the cheese, the pessimist sees the holes in it"
"A feature is in the eye of the beholder"

What do you see?

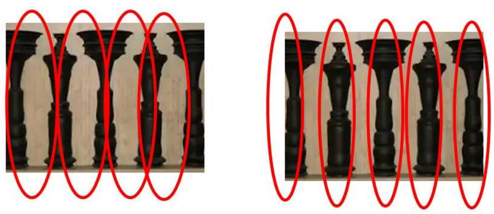

Fig. 5: recognize a feature

When talking about systems we have to distinguish, amongst other concepts, between properties, functions and features of a system.

A property of a system is any distinguishable attribute characterizing it. The human mind can find (and notice) or ignore numerous different properties.

Functionalism is the main characteristic of any theory aiming at explaining a system's behavior in terms of usefulness, purpose or practicality. R.M. Snow states: "Functionalists view any system in terms of the 'job' it was created to do: its purpose or function " (Francois, 2004, entry 1362). Thus systems are built with a "purpose" in mind.

We define the **Purpose** of a System as an abstract notion explaining in some (often general) terms what the system is supposed to do. A purpose is 'realized' ('implemented') by one or more 'features' of a system (Francois, 2004, entry 693)

J. van GIGCH offers a context view of purpose: "Inanimate systems are devoid of visible purpose. They acquire a specific purpose or function when they enter into relationship with other subsystems in the context of a larger system" (van Gigch, 1993). In contrast "the *purpose* or objective of a living system (or artefact) is defined by its internal programs and controls, including those programs acquired by learning" We expect systems to provide some useful service (i.e. one of more 'functions' or 'features', their purpose). The interconnection between the components of a system (the internal 'structure') is an important property of a system.

A **feature** is a relevant set of specific properties intended to perform an identified purpose of a system. As a consequence the **Feature Set** of a system describes the totality of all the features of a system at a specific point in time. The view of the features of a system will change dynamically. A system's features depend on the structure of the system and on the properties of some (all?) of its components.

Their choice depends on the purpose or use we attribute to a system. The feature set change with the purpose we attach to the system.

Fig. 6:

2.3 What is a feature?

The concept of a 'feature' needs to be specified (Fiadeiro, 1996; Philippow et al., 2003).

- Features are system properties but not all properties are features.
- In Wikipedia around 25 different meanings of 'feature' are listed
- In software a **feature** is a logical unit of **behavior** specified by a set of functional and non-functional requirements (e.g. automatic brakes)
- Different persons may appreciate different features!

- Systems are usually constructed with a certain purpose in mind, implemented via "features", namely to fulfil one or more purposes. To implement the various required features one or several components are combined in order to satisfy the various required features either alone or in cooperation with other components.
- Note that a system will have many properties - some of them are usually not even taken notice of by the observer. The identification of a feature of a system is attributed to the system by an external observer who considers a combination of properties to be of use in some way. Many features of a system can be identified and named without any change in the structure or behavior of the system..
- For our purpose we can define: *"a feature of a product* can be described as a prominent or distinctive user-visible aspect, quality, or characteristic of the software.".

2.4 Properties, Purpose, Figures and Features

Basically we are interested in the *features* of a systems - the actual composition of a system is not of central importance. Replacing a component by a different one providing the same feature is often a welcome technical option with respect to cost, performance, etc. In this vein F. Bonsack emphasizes the necessity to clearly distinguish "property" from "function". A property is associated with a given system, but many systems can have the same properties AND a system (or part thereof) can be replaced by another system providing the same function (see 'property and function' in (Francois, 2004), item 2680).

What is sometimes forgotten, is that each component may - or rather will - have additional properties beyond the "interesting features".

"A feature is in the eye of the beholder"

Some of the features are *relevant and essential* with respect to the system's intention and/or purposes, some of them are noticed by the observer but not relevant, others are not even noticed. In psychological terms we can interpret this as a need to filter the information around us. *(Example: As a saying goes: "The optimist sees the cheese, the pessimist sees the holes in it")*

In more scientific terms the psychological interpretation is that we always distinguish between *'figure'* and *'ground'*. The Figure-Ground perception describes one of the most fundamental ways in which we simplify a visual image. how we simplifying a visual scene. Figure-ground perception refers to the tendency of the visual system to simplify a scene into the main objects that we are looking at ("the figure") and everything else that forms the background ("ground").

For different persons, the distinction of figure and ground is often completely different. This is the result of upbringing, education, current interest, intentions or needs. (Wikipedia-english, 2013, keyword: 'Figure-ground (perception)')

2.5 Possible Interaction of Features

When combining the components of a system the features of the individual components may interact with one another in different ways. The Feature Interaction can be of following types:

neutrality The features of each component contribute to the total feature set without interference.

cooperation The features of each component 'reinforce' one another. The resulting feature is based on some aggregation of properties (Chroust, 2002) like summation, weighted summation, sums of squares and even more complex aggregation function.

reduction The individual features of each component weaken the effect of one another to some extent, a situation well known in medicine where adding further medicine may reduce the effectiveness of the present ones. *(Example: A classical example is a medicines blocking the intended effect of another one)*

contradiction The features of two (or more) components contradict one another. *(Example: feature collision: a classical example is an automatic safety door lock permitting only the owner to open the door, but an emergency door-opening procedure exists in case of a fire. Faking a fire alarm would open the door to a hacker...)*

emergence

2.6 What is Emergence?

- A new, surprising and relevant property when two systems interact
- such changes of properties might be overlooked.
- the whole is greater than the sum of the parts
- examples: swarms of birds, state of matter (e.g. melting, exploding), human consciousness

Intuitively speaking 'emergence' of a system is linked to 'surprise' (Pessa, 1998). Emergence describes the experience that the whole is greater than the sum of the parts: interactions among the components of a system lead to distinctive novel properties. Emergence has been used to describe the flocking of birds, the phases of matter and human consciousness, along with many other phenomena. Since the seventeenth century, the notion of emergence has been widely applied in philosophy, particularly in contemporary philosophy of mind, philosophy of science and metaphysics. It has more recently become central to scientists' understanding of phenomena throughout physics, chemistry, complexity and systems theory, biology and the social sciences (Gibb et al., 2021; Artime and De Domenico, 2022; Saager, 201).

We have to note that essentially these 'emergent' properties were often latent in the system, but irrelevant or even unnoticed, they belonged to the 'ground', see section 2.4. Using the system under changed conditions causes some properties to became significant or even essential: they become a useful, desirable or destructive and undesirable feature. This features require our attention and analysis. A typical feature is the oscillation of an electronic circuit for tuning into a given radio station.

2.7 Types of Emergence

Maier distinguishes four different hierarchical levels (Maier, 2015):

Simple Emergence : A 'simple emergent' property can readily be predicted (not just explained) by modeling the individual system's components and their interconnection. If overlooked, the system designer justifies it by: *"the emergent property was simply overlooked" (→ the possibility of overweight of a complex system.*

Weak Emergence : A 'weak emergent' property can be readily and consistently reproduced by simulating the complete complex system, but not by simulating the individual components in isolation. It cannot be consistently predicted in advance. If overlooked, the system designer justifies it by: *"we forgot to consider the feedback from on component to another. (Example: Feedback of microphone and loudspeaker in a room.)*

Strong Emergence : A 'strong emergent' property cannot be described and modelled within the set of the considered features of a system. This property becomes a new feature of the system, welcomed, not welcomed or even disastrous. But it lends itself to being modelled. If overlooked, the system designer justifies it by: *"we never realized that this property would show this behavior" (Example: In order to understand and control it, the in-car vertical movement must be introduced as a feature)*
.

Spooky Emergence : An 'spooky emergent' is not only a strong emergent property, but its behavior cannot be modelled in its totality by our means, mostly (always?) due to the multitude of often subtle outside influences and/or a huge dimensionality of the model. If overlooked, the system designer justifies it by: *"We could not foresee this behavior, and it is not even repeatable"! (Example: The 3-body conjecture introduced by Henri Poincaré (see (Francois, 2004, entry 0070)) is of this type)*

Simple Emergence : developer:*"the emergent property was simply overlooked"* (→ 'the overweight was too much')

Weak Emergence : developer: *"we forgot to consider the feedback from on component to another".* → microphone and loudspeaker were too close

Strong Emergence : developer: that's new! In the past the vertical movement was not noticeable. textit"we never thought that this system would show this behavior" (→ the vertical movement suddenly was too big to ignore)

Spooky Emergence developer: Wow! We have no idea where it comes from and what to do about it!! (→ Nobody modelled that!

- Quantum Mechanics
- social system interaction
- Human consciensness
- 'supernatural events' ??

We should note that the classical examples for emergence, even if they have sometime unexpected and even dangerous effects like the resonance of the car or the oscillation of an electronic circuit can readily (and have been for a long time) easily be modelled and - if desirable - avoided in a design. Obviously this effect is not 'spooky' at all. When we model a system (mentally or mathematically), in order to simplify modelling we usually ignore certain 'irrelevant influences', e.g. in software systems the influence of temperature, the curvature of the earth when travelling short distances, the influence of the observer, etc. Sometimes, however, these ignored influences may cause 'emergent properties'. The literature is full of such examples. The only remedy is to enlarge and often modify the model,

- a mixed blessing in engineering
- e.g. Resonance:
  useful radio reception
  disastrous and destructive: break-down of a bridge
- in technical disciplines mostly an undesirable side effect.

3 Consequences: Feature Interaction and Emergence

3.1 Emergent Features

The interaction of features is a mixed blessing in engineering. It enables useful function, e.g. radio reception by utilizing resonance. On the other hand it can also have disastrous and destructive effects like the break-down of a bridge due to undesirable resonance.

In technical disciplines emergence is one of the key issues (Chroust, 2002; Gibb et al., 2021), and in most cases an undesirable side effect.

A key to understanding emergence is the 3rd statement in the definition: *"The system has properties different from the sum of the properties of the components"*. This implies the appearance of *new* properties which *emerge* in the course of composition. These properties cannot be detected or modelled based on the components alone (Pessa, 1998). This situation gave rise to a complex theory of *emergence*, which is still highly controversial (Baas and Emmeche, 1997; Brunner, 2002; Huemer, 2001).

We define : An **emergent feature** of a system is a consequence of the interaction of the totality of features of a system. It cannot be determined by considering the features of the individual components in isolation. At least at its first recognition it comes as a surprise. Thus it is necessary to investigate the interaction of components which is largely determined by the system's structure (i.e. by the way the parts are connected to form the system) (Thome, 1993).

It is obvious that emergent properties complicate the prediction of system properties since their value can only be determined by considering (beyond the participating components) the system structure (Chroust, 2002). As long as we allow *any thinkable* composition of the system there is little chance of making any reasonable statements about emergent system properties. A restrictive set of admissible composition will allow some statements to be made about the behavior of emergent properties under composition.

The above discussion leads to a new view of the phenomenon 'emergence'. It also removes some of the almost mystical notions of emergences. The notion of 'emergence' is based on the notion of features of a system (and not of all properties of that system). Features are considered to be the user-recognized and 'relevant' necessary properties of a complex.

3.2 Emergence in Social Systems

- numerous emergent features.
- due to variability and volatility of human behavior more difficult to investigate
- more often emergent!
- important in management and business

Spontaneous leadership, e.g. in disasters Spontaneous leadership is a result of need, environment and personality (ILD (ed., 2000), in contrast to organizational leadership, (as in the GLOBE-study (House et al., 2004)).

Team Excellence Teams work coherently and surprisingly good.

Creative Teams Team performance is a complex emergent property of excellent teams (Katzenbach and Smith, 1993)

Personal Feeling of Flow This is the elating feeling of a well-running activity (Chen, 2007). Everything runs smoothly

More thoughts on this fascinating aspect can be fond in (Artime and De Domenico, 2022).

Fig. 7:

4 Discussion

The paper has discussed a new idea: The differentiation between 'properties' and 'features' of a systems: in contrast the the potentially unlimited number of properties of a system there is only a limited number of 'features' which are the focus for modeling and use of a system.

The concept of 'figure' versus 'ground' allows a natural way of introducing new features, in the case of emergence when the original set of features is not sufficient. This also introduces a logical and natural way when speaking about emergence, including the hitherto somewhat mystical notion of certain forms of emergence. We realize that for social systems the concepts presented in this paper are also useful.

The consideration of feature interaction provides a sound basis for the influence on the behavior of systems based on the features of the individual components. It also allows a quite clear description of feature collision and emergence.

This paper shows the strong mutual influence of features and emergence. This discussion can be a basis for consolidation of terminology in this domain. I hope that it will be a source for fruitful discussion and additional clarification.

5 additional Figures

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