Systems Theory Modeling Language (STML)

A lightweight framework for modeling systems in the abstract

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Introduction

Being able to model complex systems is a core challenge facing the development of contemporary science. Due to their high degree of connectivity, emergent structures and dynamic nature, studying complex systems requires both a reassessment of the traditional mechanistic paradigm within science and a recalibration to many of our theoretical and scientific methods analysis.

As opposed to much of traditional science, where knowledge and theories are mainly domain specific, the generality of complex systems (the fact that complex systems may be social, biological, engineered or physical systems) requires a significantly high enough level of abstraction to bridge the fundamental divides between the different domains of science. In many cases, complex systems are approached from either the social or natural scientist's perspective and statements are made about complex systems (in the abstract) that have only relevance within one domain. A classical example of this is the direct association between complex systems and complex adaptive systems made by many social scientists and biologist/ecologies allowing for the use of some implicit notion of agency and teleology which does not hold for many physical complex systems. Inversely those approaching complex systems from a natural science (particularly physics) are more used to understanding complex systems in terms of statistical mechanics, probability/information theory, nonlinear dynamics and apply the standard tools of mathematics, all of which are largely limited in their relevance to physical systems.

An increased level of abstraction is required in developing theoretical frameworks for complex systems that have the breadth to be of relevance within all domains of interest. Not only does a theoretical framework for complex systems need this large breadth to be of relevance, it also needs depth. That is to say, the development of generic models for complex systems requires both significant high-level qualitative reasoning (in order to appropriately contextualized the given subject matter) and significant quantitative/analytic capability required to gain a rigorous computable model of a given system. Systems theory is a well-developed theoretical framework that can provide us with sufficient capacity for qualitative reasoning and abstraction (to be of generic relevance) whilst also interfacing with our existing quantitative methods (standard mathematics and is particularly suited to translation into the algorithmic logic of computation) and thus is uniquely positioned to function as the foundation to an integrated language for modeling complex systems in the abstract.

This paper then presents a lightweight modeling language that builds upon standard concepts within systems theory, such as efficiency, energy, and entropy, integration, emergence, environments etc. Starting by building up a group of elementary soft axioms the paper goes on to create a set of parameters for defining sets, complexity, systems and complex systems. This paper is primarily qualitative in nature designed to provide a generic mechanism for structuring our reasoning about systems and complexity, whilst also working to provide a basic standardizable vocabulary and notation to support this.

Axioms & definitions

Energy (e^+) is the capacity to do work or to perform a function within a given environment.

Entropy (e^-) is the incapacity to do work or the state of minimum potential energy.

A Resource(r) is a stored form of energy or entropy. Thus a resource can be either an energy resource (r^+) or an entropy resource (r^-).

A Process (P) Is the generic transformation of some input to some output.

A Function (f) is the process or transformation of resources from a lower potential energy to a higher potential energy, the conversion of entropy into energy.

Example: The functioning of a factory processes raw materials into finished goods that are of greater value within its environment.

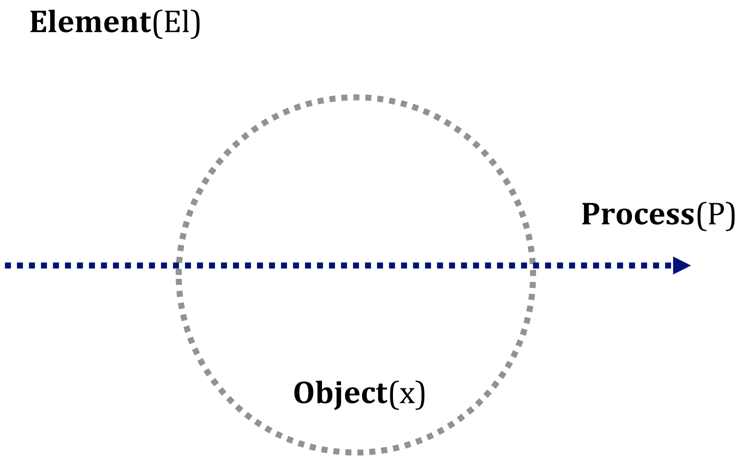
Dissipation(d) is the processing of resources inputted from a high potential energy state to an output of resources at a lower potential energy states, from energy into entropy.

Examples: the rolling of a ball down a hill dissipates kinetic energy as it transforms the system from a high potential of gravitational energy to a lower level.

Inertia(In) is defined as the resistance to change or the incapacity to perform a function, manifest as a boundary condition that resists change.

Elements

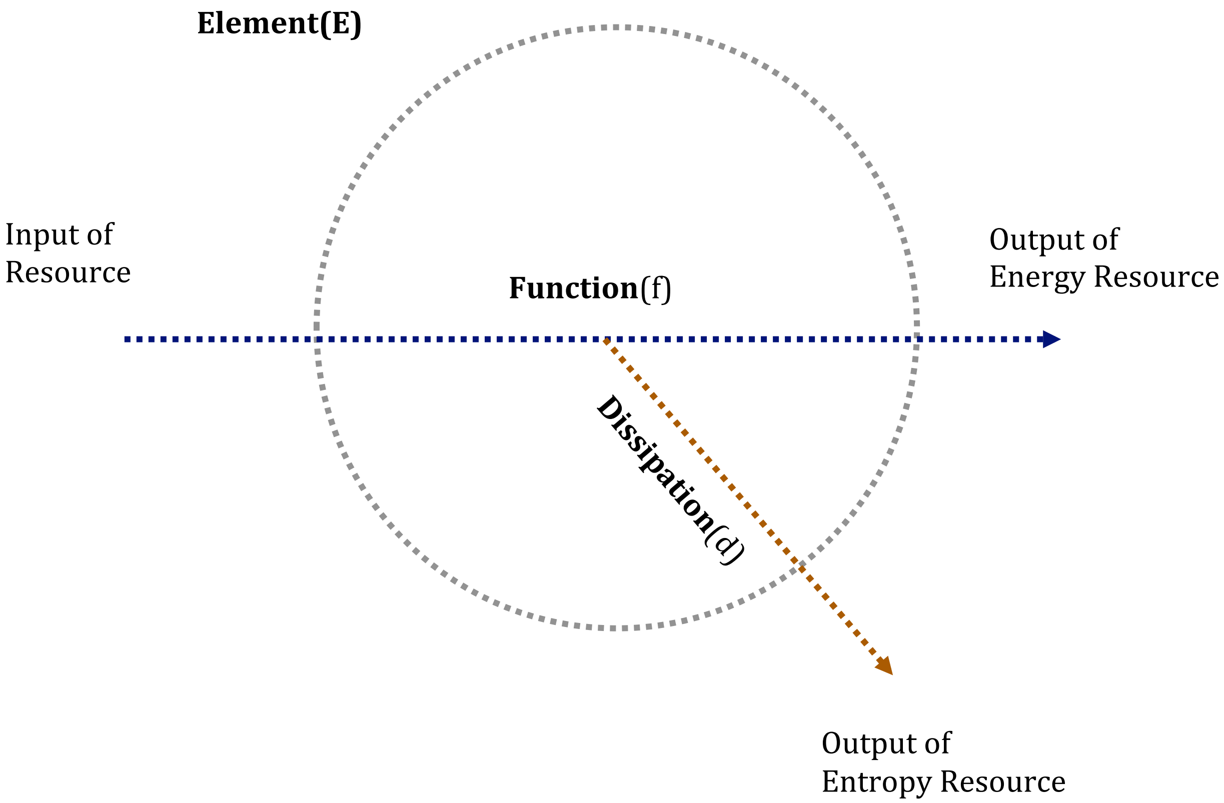
An **Element** (El) is the most basic unit of analysis within our model it is elemental in that it is not constituted of sub-components. An element is defined as a composite of a process(P) that enables change and an object(x) representing its boundary and resistance to change.



Examples: A plant cell is an example of an element (with respect to the study of a plant), it performs some set of processes (metabolism) whist also maintaining a stable and constant structure that is bounded. A car may also be an example of an element, consisting of a static structure (such as the chase) and a set of mechanical and chemical processes that enable it to operate.

Elements operation

An **element operates** through the input of some resource from its environment; this input may be processed in one of two ways. The element may perform a function on the input thus outputting a resource of a greater or high potential energy back to its environment, or the element may perform a dissipative operation, conserving the energy resource within the elements boundary and outputting the resources at a lower state of potential energy.

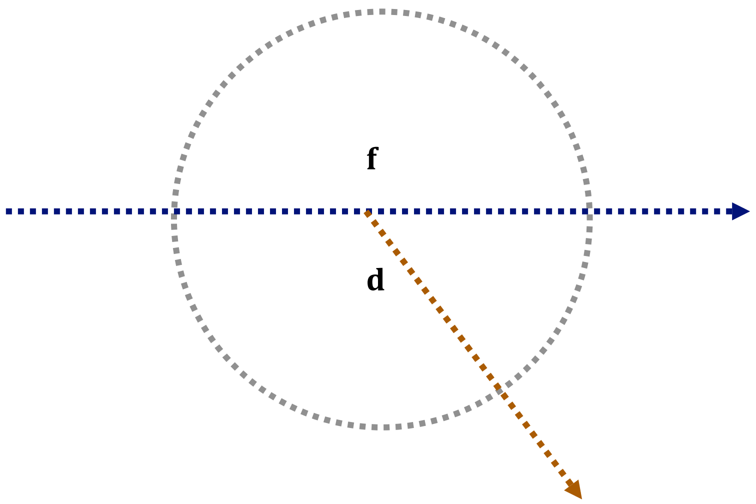


Examples: A person may use the resources they consume during a day to go to work and perform some function within their society or they may stay at home playing computer games. Thus with respect to the individuals environment (society) they have dissipated the resources they consumed whiles returning waste back to their environment.
Another example might be a bicycle, if the bicycle is functional, then the energy inputted from the rider may be processed through the mechanical system to generate the desired output, which is transportation. If the bicycle is dysfunctional then the energy inputted will be dissipated within the mechanics of the system, with limited functional output but instead some form of energy that is incapable of performing work, such as heat from friction that can not be harnessed by the cyclist for the desired activity.

Element Efficiency

An element is defined by its degree of efficiency (Ef). Efficiency is a ratio between the resources that an element functionally processed versus the resources it dissipates.

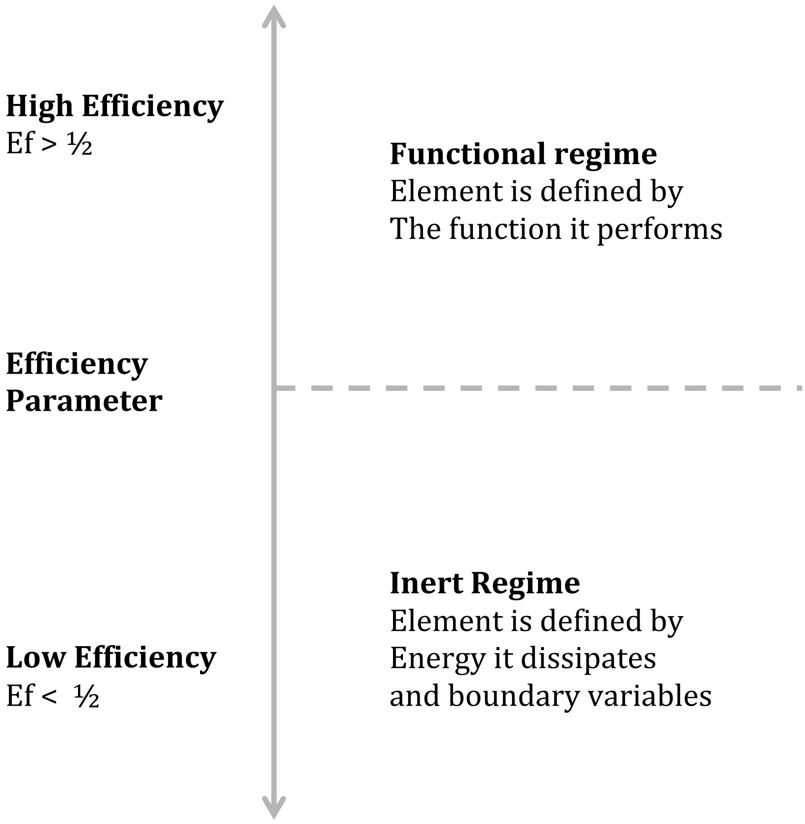
Efficiency = f : d



Examples: Many of our engineered systems are measured in terms of this type of efficiency, such as the energy efficiency of a light bulb or fuel efficiency of a car. Outside of engineering another example might be an economy that takes in some amount of resources (natural, human, financial etc.) and generates both a functional output in terms of developing the economy (better infrastructure, more human capital, greater financial capital etc.) and dissipates some of the resources inputted, with the efficiency of the overall system a simple ratio between the two that can be expressed as an rational number.

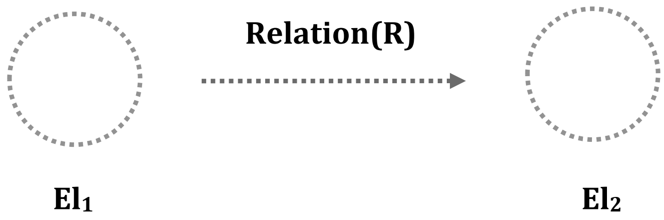
Element's efficiency parameter

Thus we have our first parameter that is a measure of an element's efficiency as it goes from low efficiency (with high dissipation, entropy and strong boundary condition) to high efficiency (where elements are defined by the function they perform).



Relations

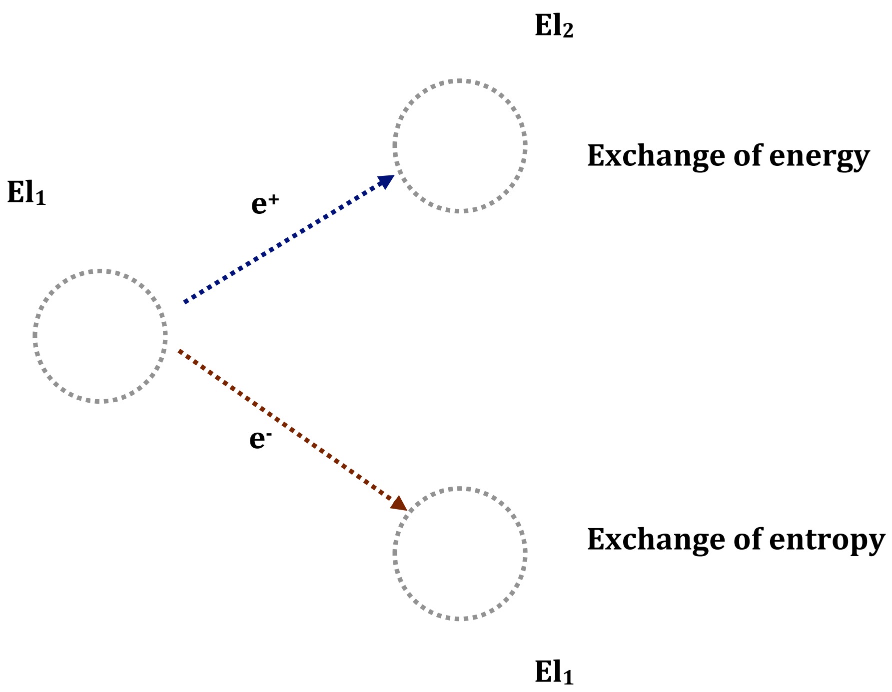
A **Relation(R)** between two or more elements is defined as an interaction or connection between constituent elements wherein the variables associate with one become correlated with those of others within the relation. These variable colorations maybe positive or negative, meaning they can move in the same direction or in opposite directions depending upon the type of relation. If there is no coloration between to variables then they are not connected and do not share a relation.



Examples: a relation is a very basic and omnipresent concept; for example if a trader invests in a market then a variable associated with the market becomes associated with the trader, a change in the market whether is goes up or down is correlated with that of the wealth of the trader. As another example we could site a relation between a romantic couple, when the emotional/psychological state of one changes then this will effect that of the other, the associated variables are interdependent.

Relation type

The type of relation between elements is defined by the type of resource exchanged, if they exchange a positive resource then it is deemed a synergistic or integrative relation, if on the other hand the relation represents an exchange of entropy between elements this is termed an interference or disintegrative relation.

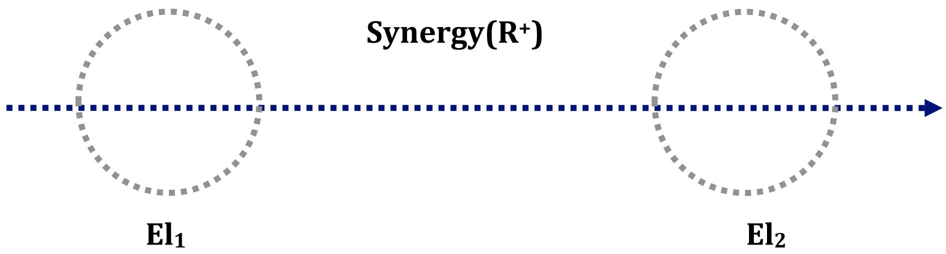


Examples: The relation between to drugs can be a negative one, where when proscribed together they interfere with each other resulting in an overall destructive effect. Or the drugs can be synergistic, complimenting and enhancing each other's effect. Another example might be two businesses within a given market sector, they may engage in a competitive relationship thus creating a dynamic of interference between them, or they may chose to cooperate and through this synergistic relation enhance the overall state of the market.

Synergistic relations

A **synergistic relation**(R^+) or integrative relation is the exchange of an energy resource between elements, where elements concatenate and exchange resources to perform a common function. The term *synergy* comes from the Greek word *synergos* meaning "working together". A synergy is a positive interaction between two or more elements result in the integration between elements.

Within integrative relations the variables associated between the constituent elements are associated through a positive correlation, meaning if the value of one changes then the values of the other elements also change *in the same direction.* With the gains of one being amplified in the gains of others, through synergistic relations the entire system may become more than the simple sum of its parts in isolation.



Examples: Multicellular organisms maybe an example of this; through the exchange of resources cells integrate to function as an entire organism, each is then dependent upon the whole system functioning, which in turn brings them into a relation of positive coloration with all other cells in the system. Within a corporation the various departments are expected to freely exchange resources thus enabling them to perform a collective function and integrating them into a common entity.
The division of labor within many animal and human communities could be sited as another example; ant colonies and advance market economies are examples of synergistic relations where the net result is greater than the product of the individual elements acting in isolation.

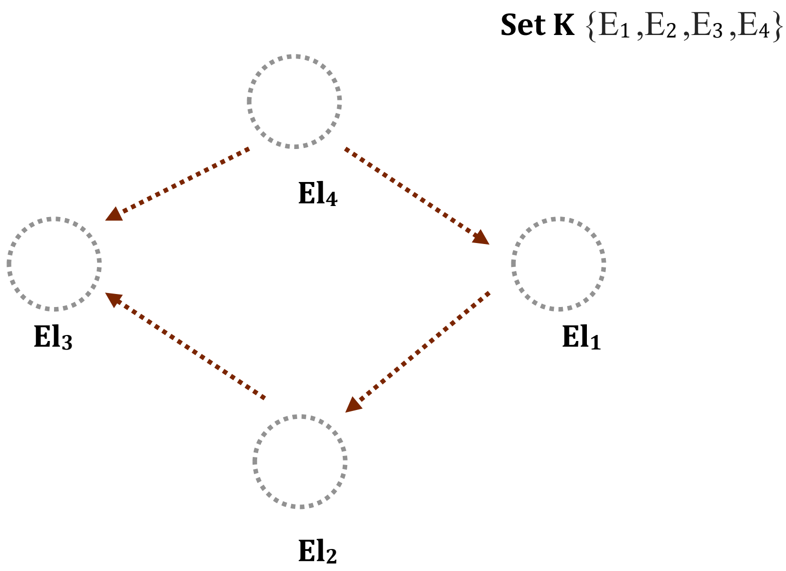
Interference

A relation of **Interference** (R^-), also called a disintegrative relation, is the exchange of entropy between elements, where the exchange of entropy between elements results in relations of exclusion and disintegration. Within disintegrative relations element variables are associated through a negative correlation, meaning if the value of one changes then the value of the other elements changes *in the opposite direction*.

Examples: When two sound wave formations are out of sync with the trough of one wavelength meeting the crest of another they are said to be destructively interfering, resulting in the sum of the wavelengths combined being less than the sum of the wavelengths individually. Listening to two pieces of music at the same time is another example; they interfere with each other to result in a system (experience) that is less than the sum of its individual components in isolation.

Sets

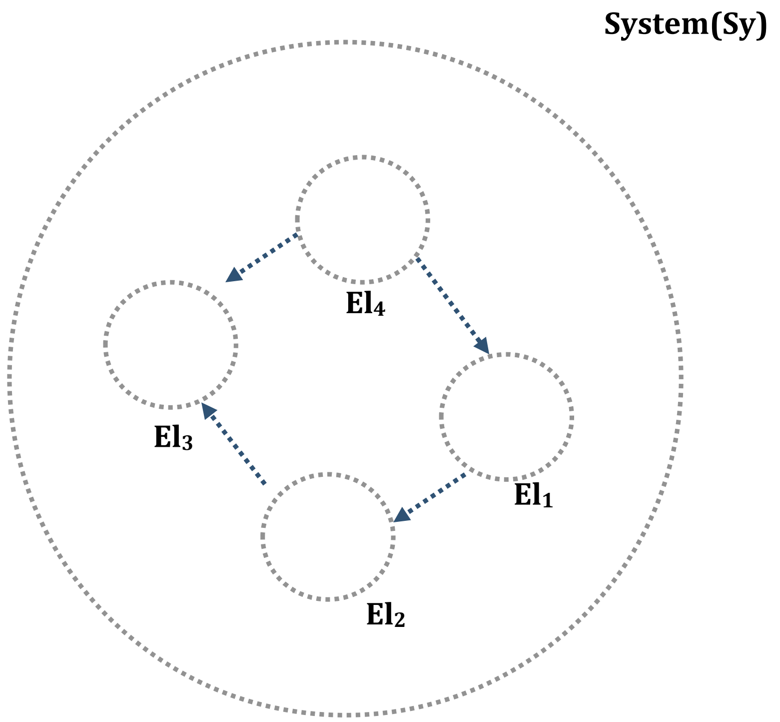
A **set**(S) is a composite entity composed of elements with low efficiency and thus disintegrative relations. Being composed of elements that operates within a component based inert regime, sets are defined by the static boundary properties of their constituent elements, high entropy means low statistical correlation between their properties.
Without relations between elements sets are governed by a component based regime. The whole set is an additive function of the properties of its individual components. Sets can then be modeled using standard set theory notation.



Example: If we have a group of people waiting at a bus stop, we call them a group or set of people because they share no relation that integrates them in to a system. We can only describe them by itemizing each individual, the whole set of people is nothing more than the properties of each individual added up. A set of cup on a table is another example of this they do not share any relations that integrate them as an entirety, thus they are defined by the static properties of each cup in isolation.

Systems

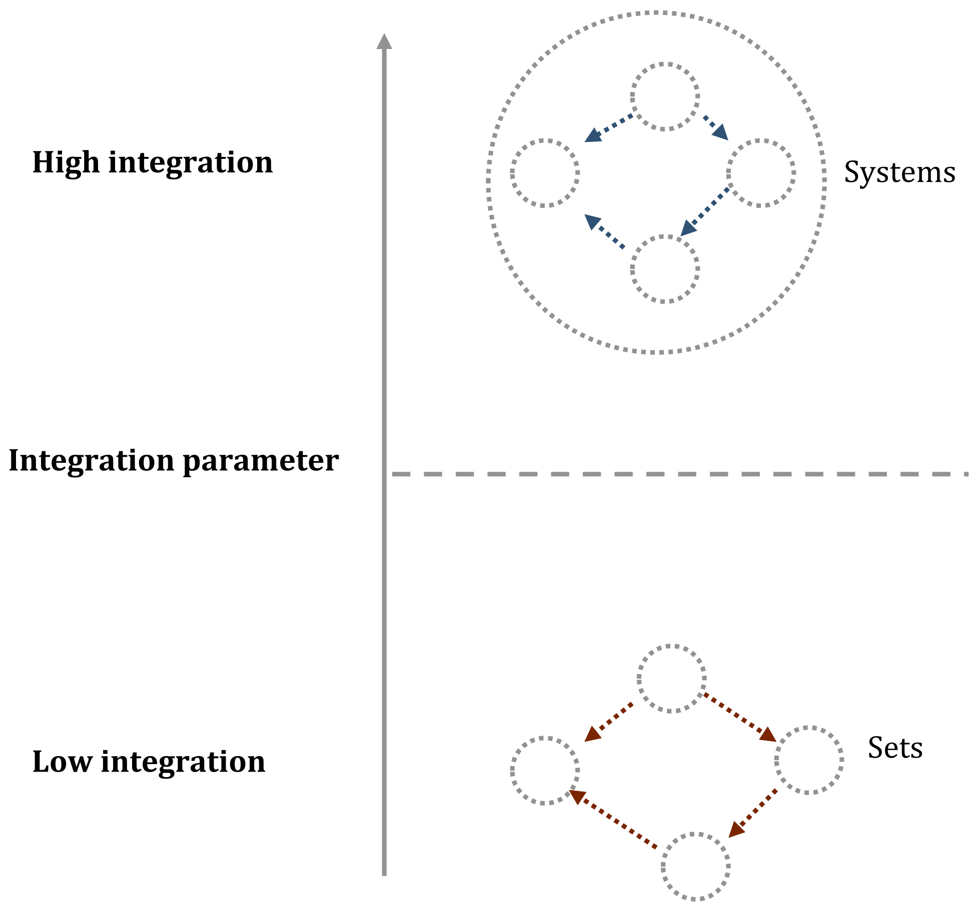
A **system**(Sy) is defined as a composition of elements with synergistic relations between them. These integrative relations mean that the system shares some common function giving it a macro scale structure that is an emergent property of the organization of elements in performing the collective function of the system as an entirety.
Because the elements within a system share a common function (and are shaped by their operating within a specific organization with other element) means that systems are defined by the organization of their relations instead of the properties of the individual components.



Example: For example the human body is a system because its organs (elements) are interconnect and interdependent in serving the overall function of body. In order for the whole body to function as an entirety each organ has to be specifically designed in relation to its functioning within the whole system.

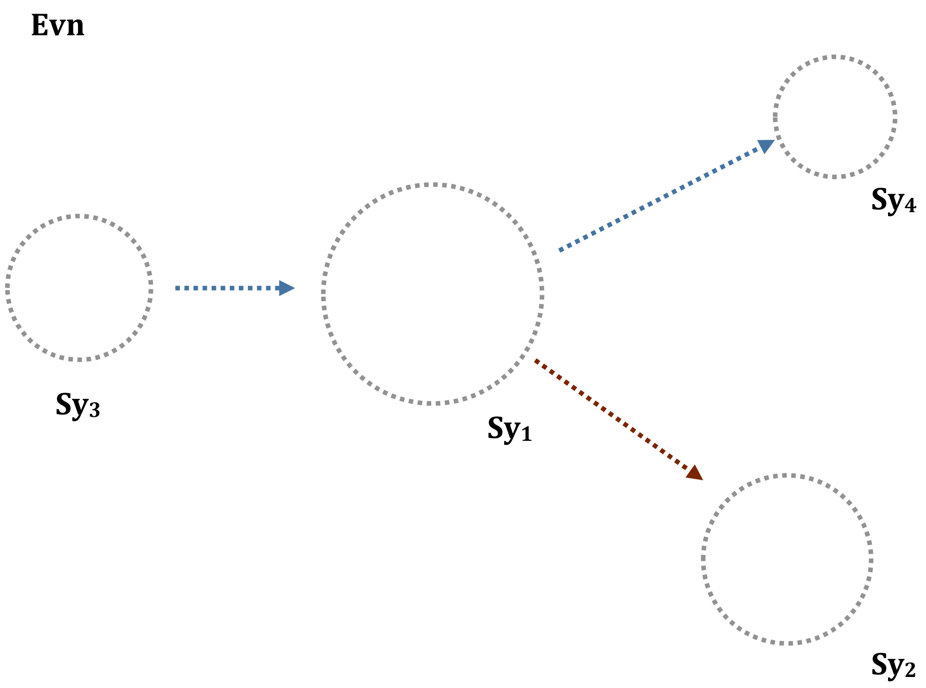
Integrative parameter

At this stage we have defined two types of composite entities, sets and systems depending upon the type of relations within the composite. We can then define a parameter between the two, defining the degree of integrative relations, what we will call the integrative parameter.



Systems environment

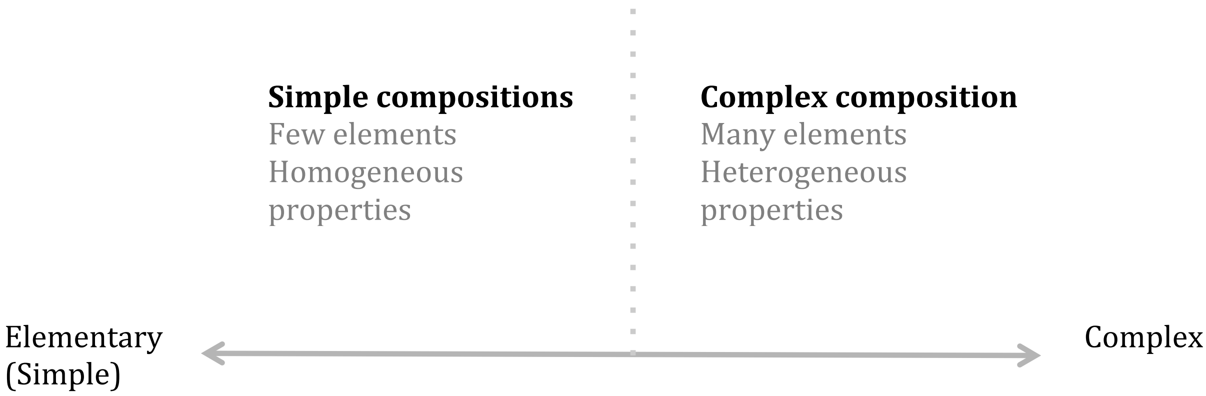
The **environment** (Evn) represents the sum total of the system's interactions with other entities during its operation. An environment then is the context to a system, that is to say where it is in relation to other systems that it interacts with. An environment is the broadest unit of analysis representing the sum total of systems and interactions that we are considering within any given model.



Example: with respect to a nation state international politics represents its environment, it consists of all the other elements that the nation state will interact with during the course of its political operations.

Differentiation

Differentiation (df) is a process of making or becoming different during the course of growth or development. Thus it can be equated to the process of diversification. Diversity is a function of the number of elements within a system or environment and their number of different states. We can then define a parameter of differentiation ranging from systems with a low level of diversity to those with a high level. Differentiation takes place thought the operations of division and duplication, thus producing more elements than previously existed allowing them to become more specialized and increasing their degree of technical efficiency.



Differentiation parameter

Examples: cellular differentiation within advanced biological systems is the process by which less specialized cells become more specialized cell types. Differentiation occurs numerous times during the development of a multicellular organism as the organism changes from simple zygote to a complex system of tissues and cell types.

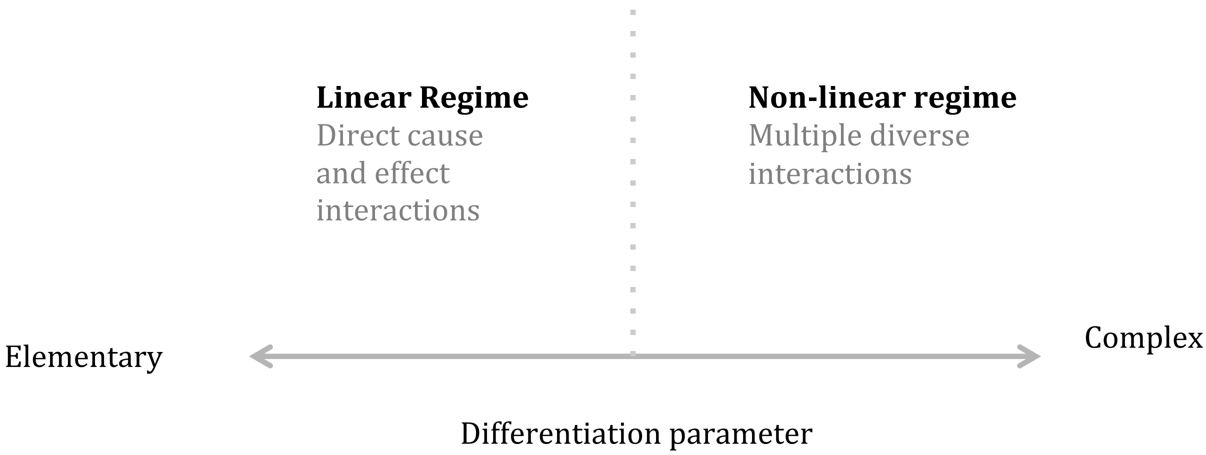
An example within social systems might be the process of social modernization which is the transition societies make from their traditional origins as an integrated society united under a common cultural canopy of faith and religious values, all of which bond the individuals into an organic whole (with limited space for individual agency and autonomous identity groups). To becoming a modern society that is largely a composite of multiple different social groups with high degrees of autonomy and individual agency.

Simple (elementary) compositions

Elementary composites are made-up of few elements with low diversity. Limited diversity means they can be treated as homogeneous elements and with few elements their interactions can be modeled in a linear fashion.

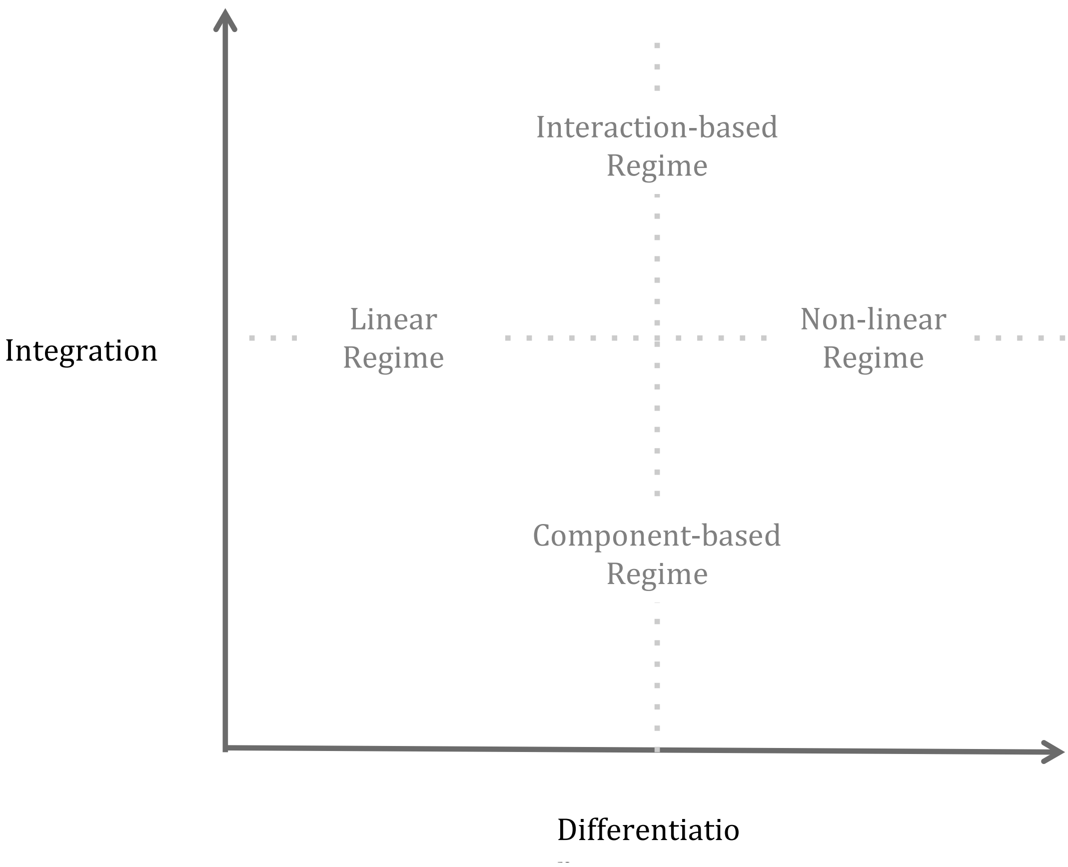
Complex composition

Complex composites are made-up of many diverse elements. Multiple interactions between heterogeneous elements result in a non-linear regime (Involving measurements in more than one dimension).



Systems state space

By combining these two parameters (integration and differentiation) we create a state space model for composite entities.



Regimes

This state space model can then be used to map-out four distinct regime spaces:

Linear component based: In the bottom left of the model we have a regime governed by linear interactions between inert objects as described by the framework of classical physics.

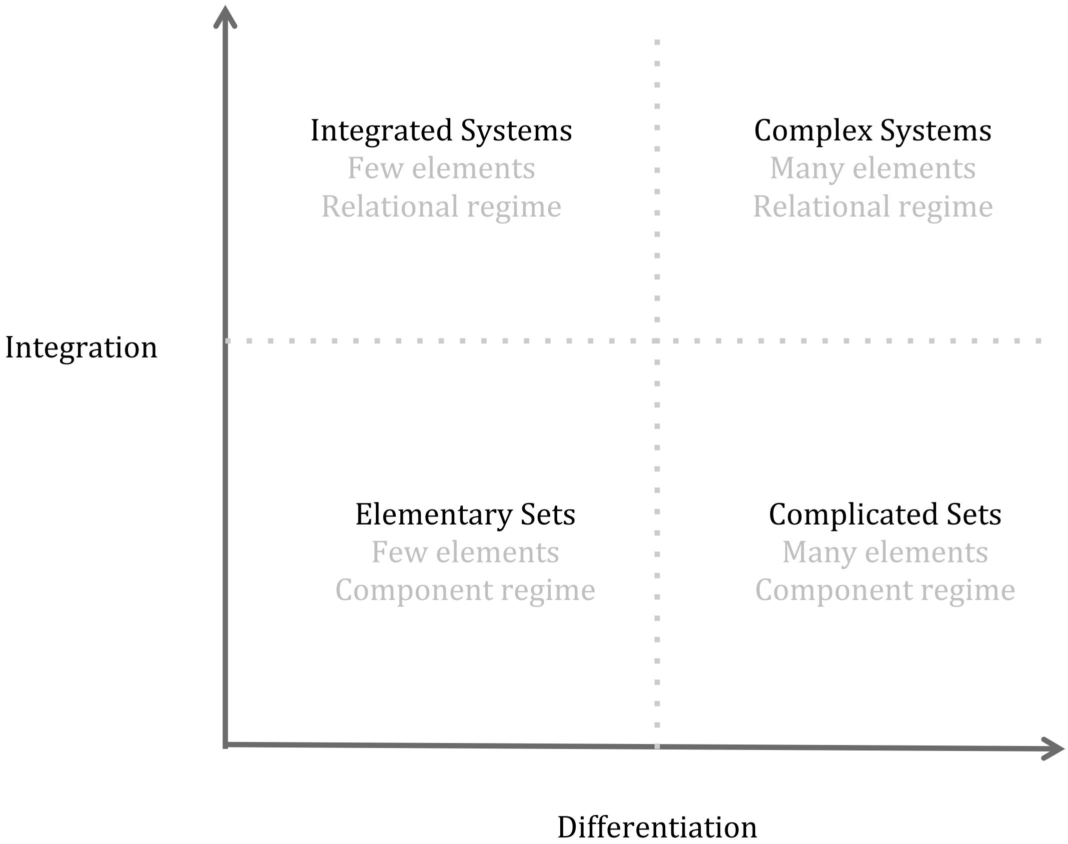
Nonlinear component based: In the bottom right of the model we have a regime governed by the framework of statistical mechanics, with the use of probability theory and stochastic.

Linear interaction based: In the top left of the model we have a regime governed by the framework of systems theory.

Nonlinear interaction based: In the top right of the model we have a regime governed by complex systems theory.

Types of Composite entities

Each regime space them generates a given type of composite entity



Elementary Sets

Elementary sets are composites governed by the properties of their components without integrative relations there are no macro scale structure. A pile of bricks on the ground are an example of this they are not designed to serve some common function thus we can describe them by simply describing the properties of each component in the set with the superposition principal holding.

Complicated Sets

Complicated sets are composed of multiple elements with limited integrating relations. Gas in a chamber is an example without integration there is no emergent macro scale structure, the composition is the sum of its parts and is best describe using statistics and probability. The extreme version of a free market economy may also be an example, with millions of products many of which compete for the same market position (lack of integrative relations) resulting in limited macro scale coordination (emergence) and the system being governed simply by local level interactions.

Integrated systems

Integrated systems are highly interconnected and are governed by macro scale structures that control and constrain behavior on the micro level thus limiting the diversity of elements within the system, resulting in a lack of the diversity. A socialist economy is an example of an integrated system, macro scale social institutions govern micro level economic activity, traditional communities are another example where the individual is subordinated to the social group resulting in a high degree of integration within the social system but a low level of subsystem differentiation.

Complex systems

Complex systems are both integrated and differentiated. Systems with either a low degree of integration or differentiation don't behave like complex systems. Thus complex systems are primarily defined by this dynamic between macro scale integration and micro level diversity, with the system governed by different parameter on different levels. There are emergent structures on the macro level that shape and influence the behavior of elements on the micro level but also elements on the micro level have autonomy to shape and create the macro scale patterns. Thus there is a phase transition as we go from the micro level to the macro level and this constant interplay between micro and macro makes complex systems highly dynamic.

Conclusion

This paper has been designed as a lightweight framework or language for modeling various types of systems and composite entities, helping to structure our reasoning about systems in the abstract and to provide a conceptual model for understanding the basic parameters that generate the various state regimes we typically encounter in the systems sciences. Being only the second version of this framework it is admittedly still underdeveloped, course grained and requiring significantly more work to develop a language with enough granularity to make it computable, but this will be the aim of future versions.