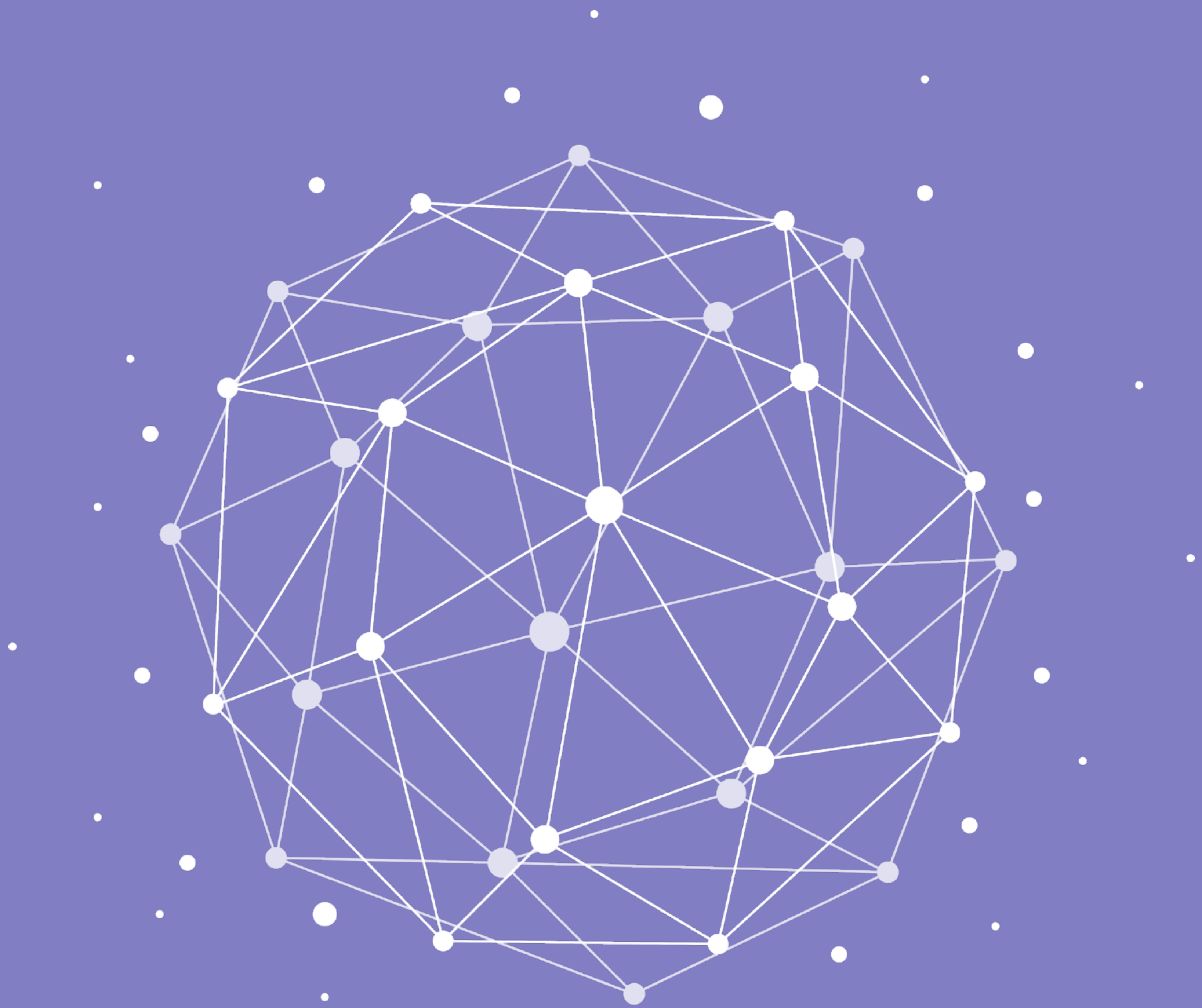
Complexity Theory

A Field Guide to Complex Systems

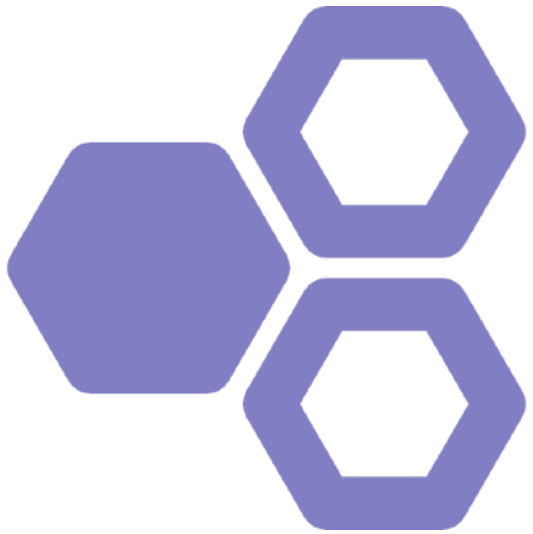


What we Cover in This Guide

Probably the number one reason we fail to be successful in our endeavors to tackle complex issues is due to our failing to understand and work with complexity. Successful interventions in to complex systems requires a basic understanding of complexity. This is given to us by complexity theory, which helps us to understand the basic features and dynamics of complex systems such as self-organization, nonlinearity, networks, adaptation and evolution.

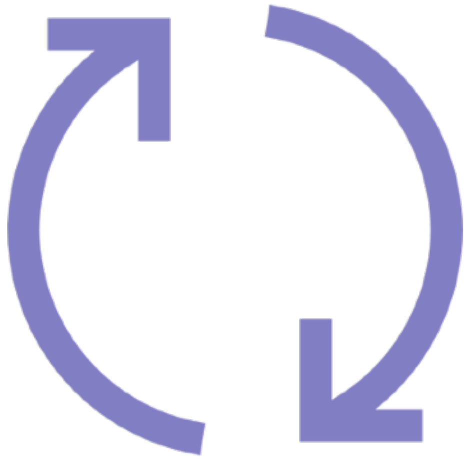
This guide is designed as a synthesis of the many different perspectives and approaches to complexity theory. The most important thing is a conceptual and intuitive understanding for complex systems. The aim here is primarily to communicate the central concepts in an intuitive fashion. This should enable readers to be able to understand and communicate in a few words what complexity is and the key features to complex systems.

After much time spent reviewing the literature on the subject, we identify four basic interpretations to the theory of complexity that forms the structure to this guide seen on the following page.



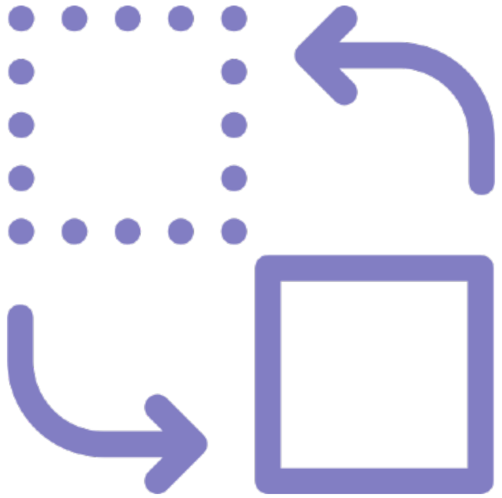
1. Self-Organization

Self-organization deals with how many small distributed parts interact and self- organize to create global patterns of organization.



2. Nonlinearity

We talk about the difference between linear and nonlinear systems and chaos theory



3. Phase Transitions

We see how interdependence between elements creates feedback loops that can lead to exponential change and phase transitions

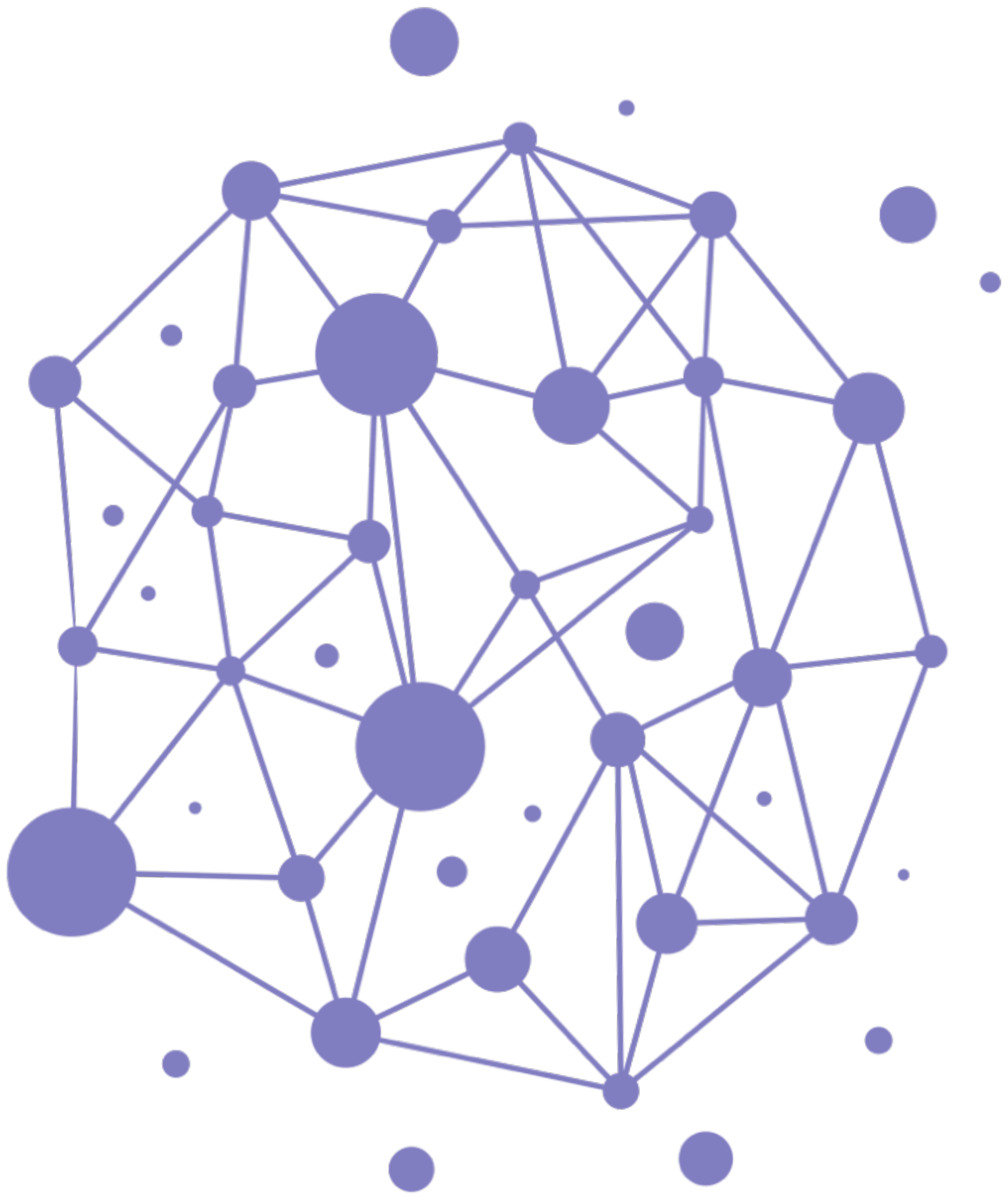
4. Networks

We explore network theory which helps us to capture and describe the structure and architecture of complex systems of all kind

What is Complexity Theory?

Complexity theory is a set of theoretical frameworks used for modeling and analyzing complex systems within a variety of domains. Complexity theory draws upon models developed in many different areas such as computer science, ecology, physics, mathematics, and engineering. Out of these different models has emerged a core set of commonalities that over the past few decades has come to be recognized as a generic framework for studying complex systems in the abstract.

Complexity theory is used to model and interpret the dynamics and behavior of systems that exhibit complexity. To do this it encompasses a very broad and diverse set of models and methods, such as network theory, self-organization theory, systems theory, nonlinear systems dynamics, evolutionary theory, game theory.



What is Complexity Science?

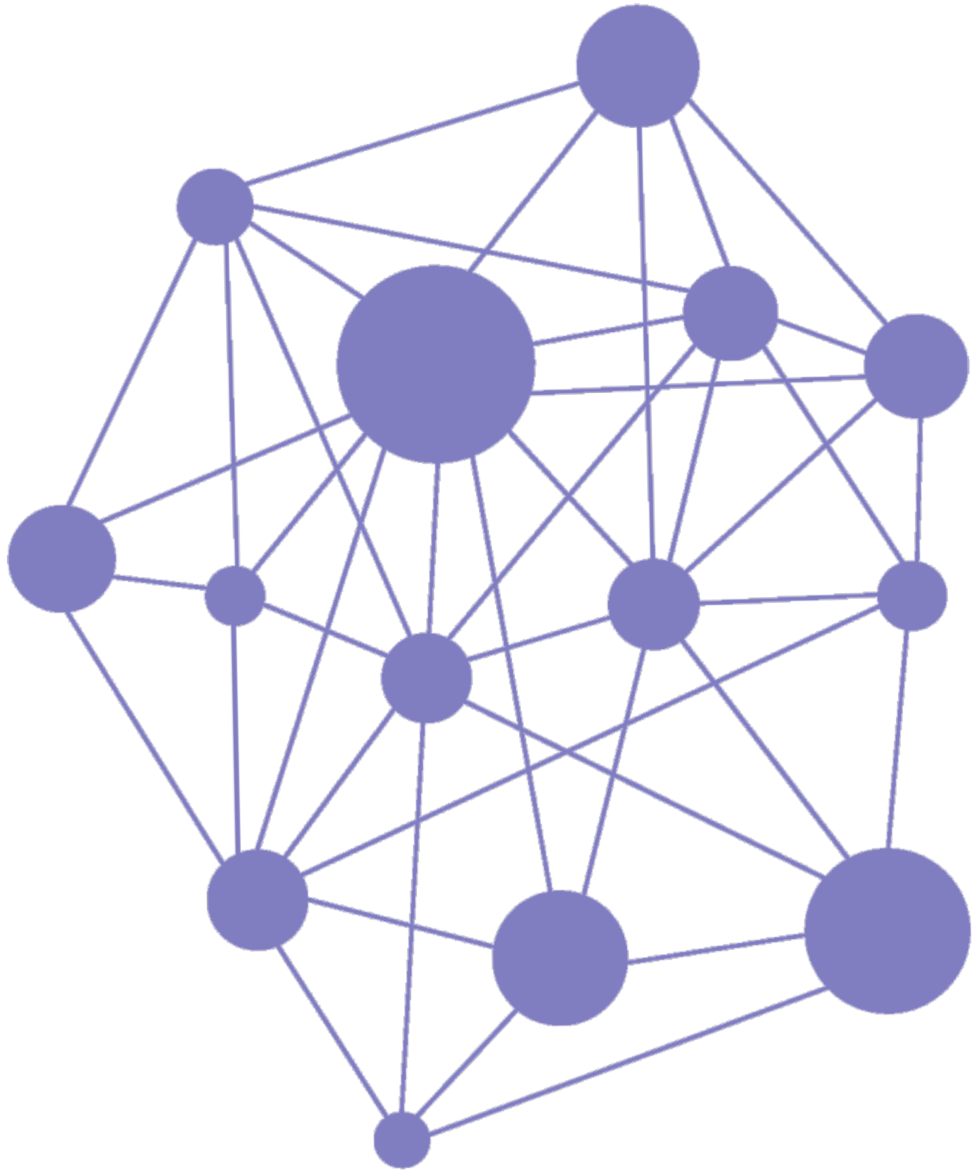
Complexity science is a new approach or method to science that has arisen over the past few decades based on the new theoretical framework of complexity theory and computational methods in order to make an empirical investigation of the complex systems that make up our world; such as weather patterns, ecosystems, the internet or cities.

On a methodological level complexity science uses various forms of computational methods such as agent-based modeling, cellular automaton, network analysis among other computational and data-driven methods. Complexity science is a science fundamentally based on computation. Because complex systems typically involve a great many parts, a vast array of connections, emergence and highly dynamic behavior it is typically not possible to model them without computer models and simulation.

Why Complexity Theory?

Although the world has always been complex with recent advances in economics, information technology, globalization and urbanization, among other developments, we find ourselves living in an increasingly complex world. If we look at where our money, food, clothes, car or media comes from we will note that they were the product a vast networks that span around the planet; what we call complex systems.

Although we are now starting to recognize these complex systems we are far from understanding them. Our more traditional reductionist approach to science leaves us ill-prepared to understand complexity. This lack of understanding means a lack of capacity to manage or design them. The result of this is a lack of agency when it comes to shaping the outcomes of the systems that affect our lives collectively. Thus gaining a better, theoretical and empirical, understanding of complex systems is central to responding to the most complex challenges of our time.



What is A Complex System?

A complex system is a special class of system that has evolved to exhibit complexity, meaning that it is characterized as having many different parts that are highly interconnected and interdependent.

Systems start simple and go through a process of evolution to become more complex. The evolution of complexity involves the process of differentiation - meaning the system comes to have more parts, with those parts being more specialized - and integration - meaning the parts become more interconnected and interdependent.

Through this process of integration and differentiation during the system's development, it comes to have a large number of diverse elements that are highly interconnected and interdependent, what we call complexity.

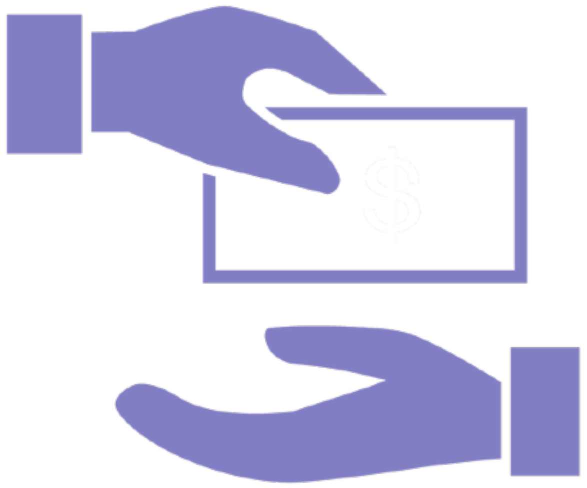
Examples of Complex Systems

Global Biosphere

Many different subsystems, from ocean currents to weather patterns, from microorganisms to the geosphere.

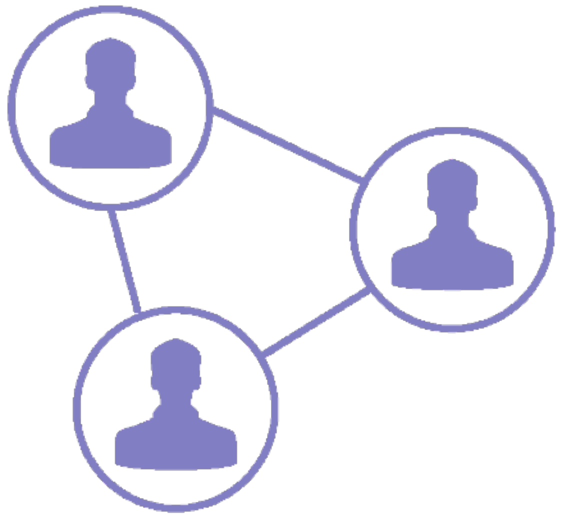
Cities

Millions of people, social and economic institutions, technology and environment all interdependent



Financial Markets

Many different agents interacting and reacting to each others behavior to create the emergent state of a market



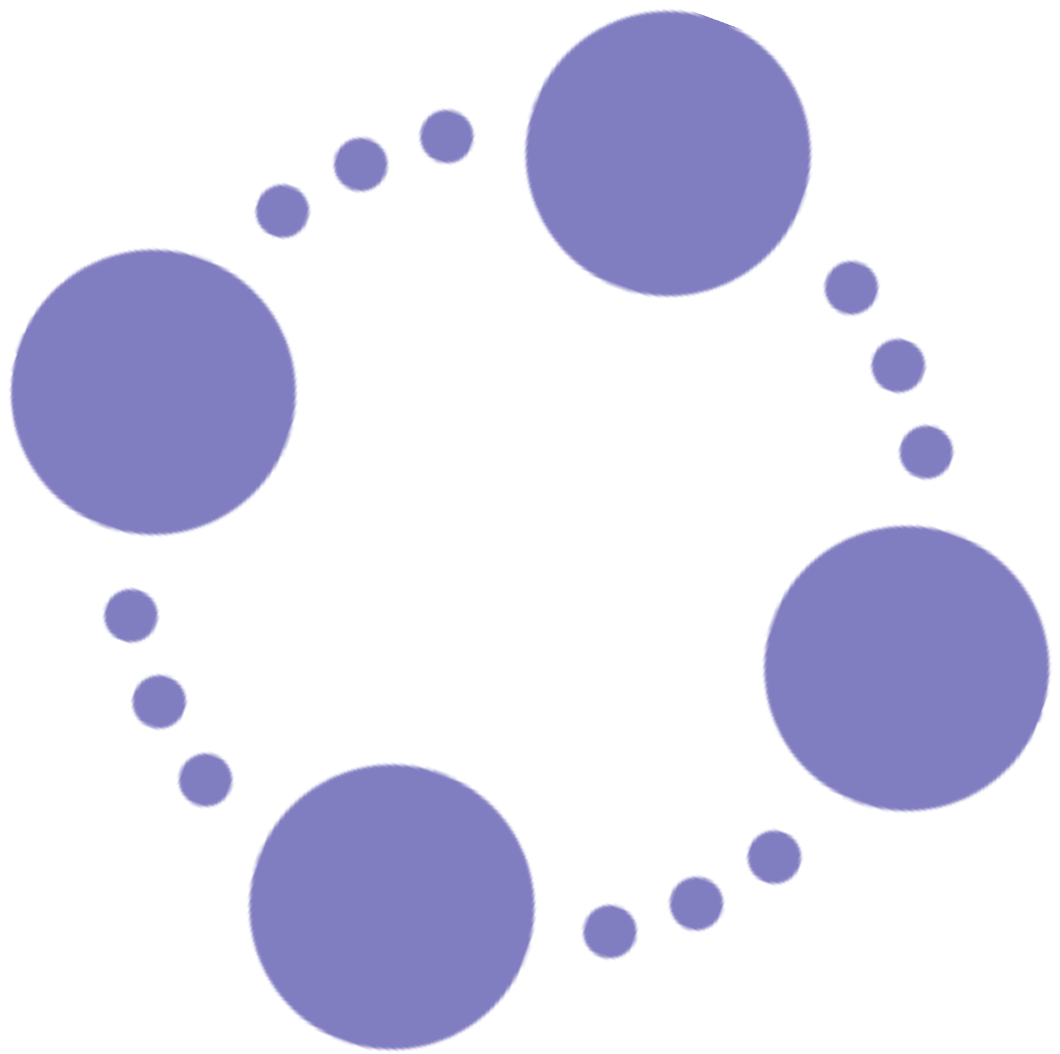
Social Networks

Individuals forming large networks with complex structures that determine information flows

What is a System?

A complex system is a special kind of system. A system is simply a set of parts called elements and a set of connections between these parts called relations. These parts can be ordered or unordered, an unordered system is simply a set of things. Because there is no specific structure or order we can describe a set by simply listing all of its elements and their properties.

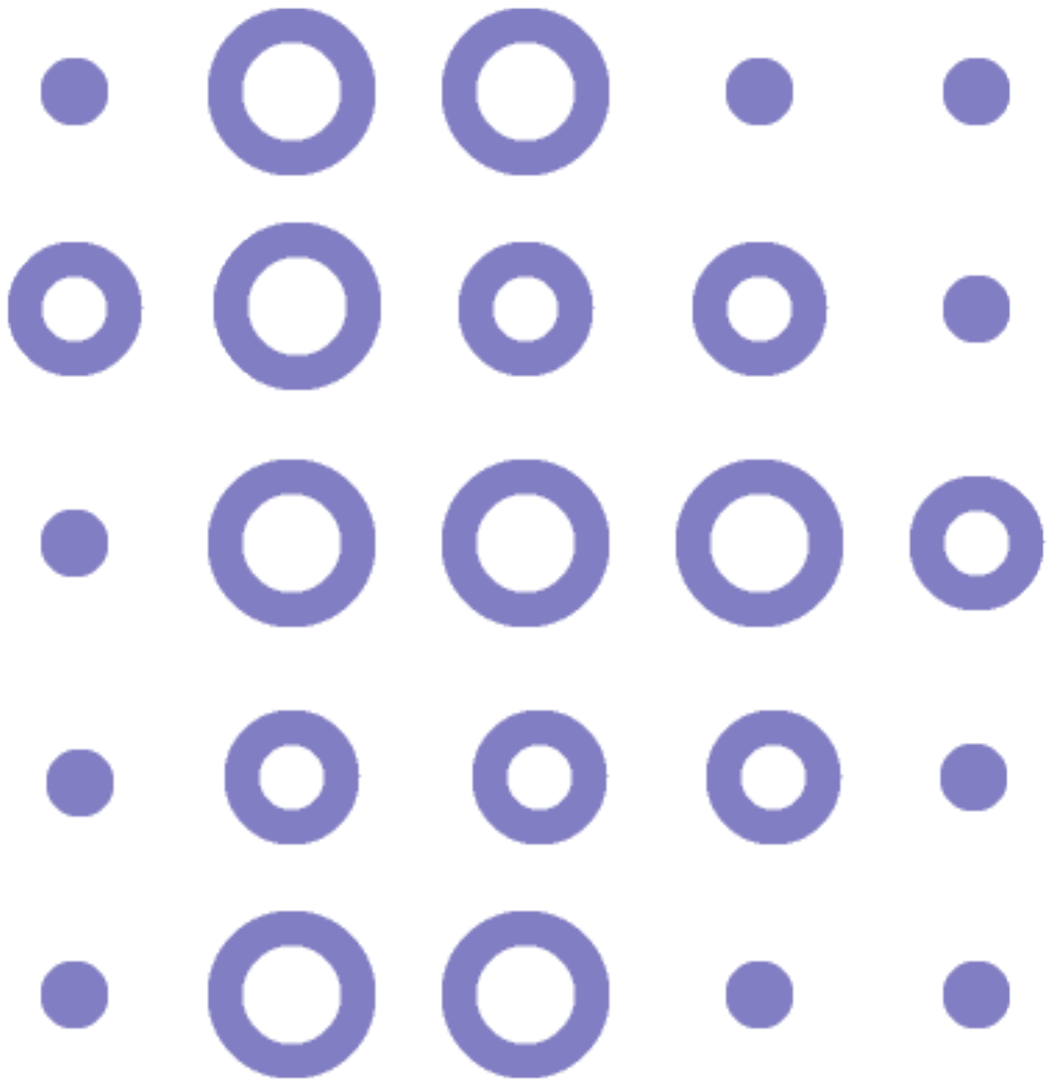
If in contrast, through the relations these parts are ordered in a specific way then they can function together as an entirety and out of these parts working together we get the emergence of a global pattern of organization that is capable of functioning as a coherent whole; this whole we call the system. The basic model of a system consists of elements and relations, that are interconnected and interdependent in forming a whole system that operates in some environment.



What is Complexity?

Complexity is a property of a system, systems that are complex have many parts that are interconnected and interdependent. Complex systems consist of many parts; many elements interacting on many different levels. Complexity arises when these parts come to have many interconnections between them. Likewise interdependence between the parts is also a central characteristic of complexity. Parts cannot be fully separated or isolated but form synergies with feedback dynamics.

While the parts to a complex system may be interdependent they typically also have high degrees of autonomy and/or adaptive capacity. Elements have a degree of autonomy often through their capacity to adapt to their local environment according to their own set of instructions. This means the system may organize itself in different ways and is not determined by some top-down global pattern, but instead may exhibits self-organizing behavior and evolutionary dynamics.

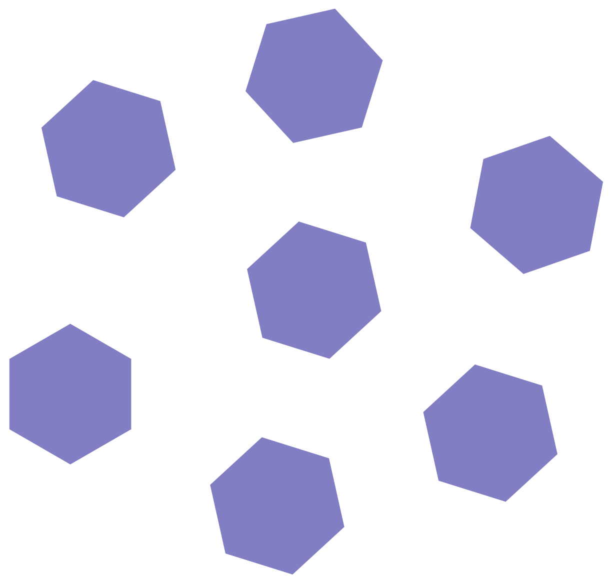


Self-Organization

Self-Organization Overview

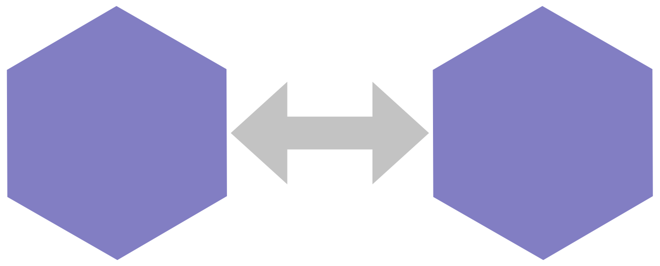
Self-organization is one of the major themes within complex systems and a pervasive phenomenon in our world, complex organizations like schools of fish, ant colonies, or car traffic manage to organize themselves into emergent patterns without any form of global coordination. This is somewhat counter-intuitive to our traditional assumptions where we tend to assume that organization and order need to be imposed by some external entity. Self-organization fascinates many people precisely because it is generated internally; hurricanes, consciousness, and swarms of bees are other examples of organization emerging out of the internal interaction between the component parts.

Self-Organization - How it Works



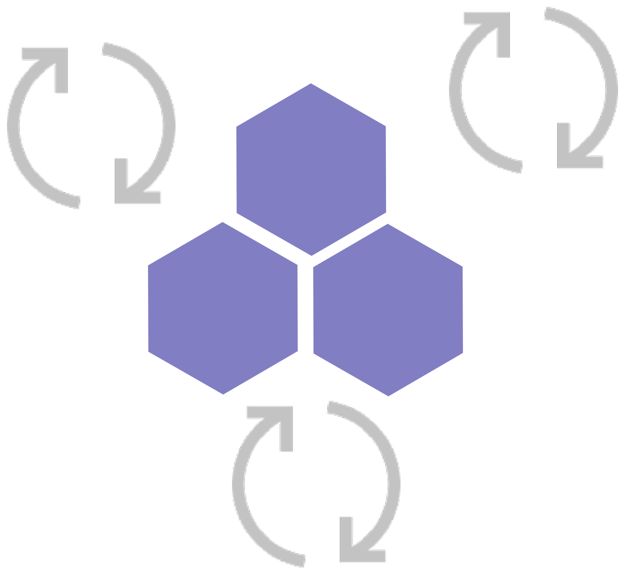
Initial Disorder

Self-organization can only take place in the absence of a fixed global pattern



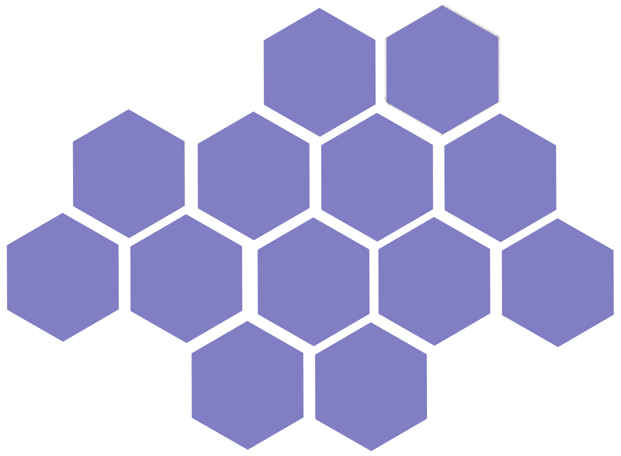
Peer Interaction

Component parts interact & some elements come to synchronize their states



Feedback

As coordination results in more efficient outcomes it creates a positive feedback dynamic



Attractors

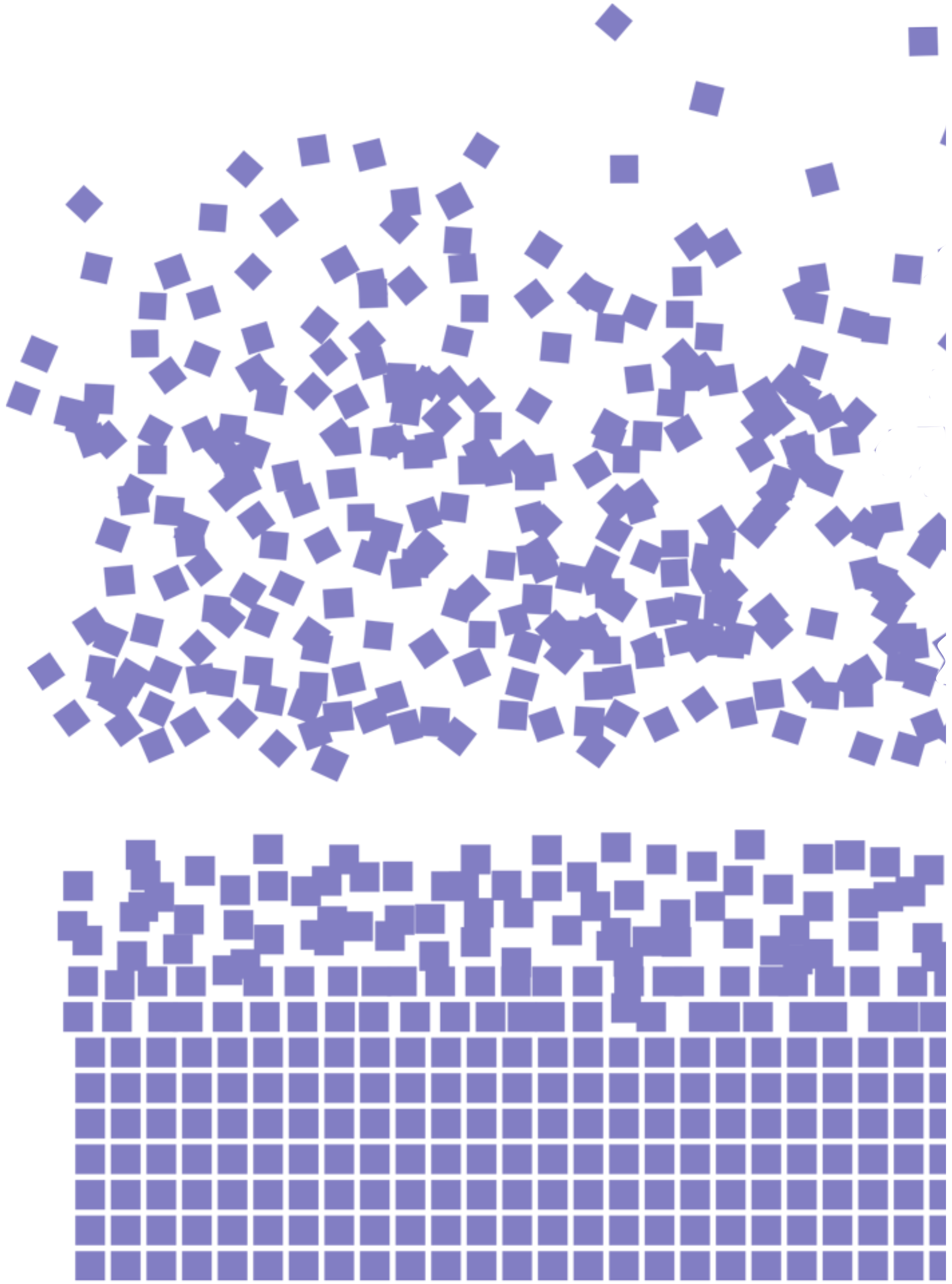
Positive feedback creates explosive growth bringing parts into an emergent pattern

Organization

Complex systems are composed of many small parts without centralized control. Without centralized control global organization is an emergent feature of the local interactions between the parts. self-organization presents a concrete model for understanding how this process takes place.

The theory of self-organization has come to explore a new approach to the age-old question about the emergence of order in the universe. We tend to assume when we see an ordered system that the order was somehow externally imposed on the system.

Self-organization describes a process whereby a system transitions from an initially disordered state to an ordered system through local internal interactions only, without the need for a global design pattern to be imposed. A key aspect of this is the need for an initial state of disorder that creates the space for emergence to happen.



Peer Interaction

The second essential element is dense peer-to-peer interactions between elements of the organization. Interactions and information need to be flowing horizontally not vertically. Dense interactions are important because all the members may start out with divergent opinions, activities or agendas, but the more they interact the greater the requirement to coordinate their states.

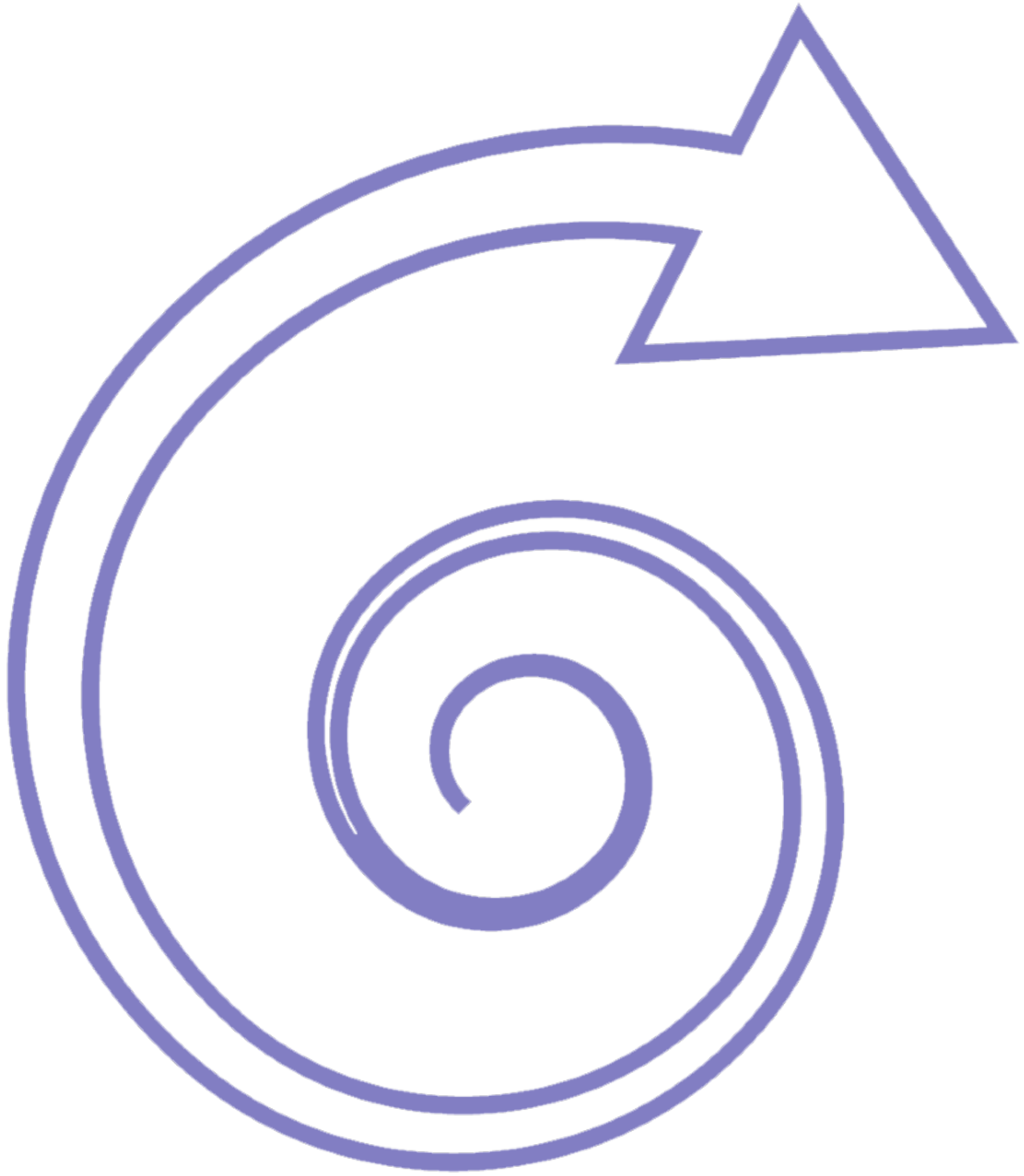
For example, as long as we build a big wall separating societies we can all go on doing our different things without much need for coordination or emergent organization. However, when we take down that wall, we may well all come into initial conflict but it will be more difficult for us in the long run to maintain our divergent activities and there will be a much higher reward for coordinating activities because of the increase in peer interaction.

Autonomous Elements

Whereas traditional centralized forms of organization are relatively static, self-organization is a dynamic process, that requires certain conditions, most importantly it requires autonomous or adaptive elements densely interacting locally.

If we look at the process of self-organization within a flock of birds or school of fish, we see emergent self-organizing patterns form through each fish or bird operating under their own set of simple instructions to follow their local neighbors while also maintaining a certain distance from them.

Because all the elements are responding locally and can act immediately to what they experience self-organizing systems are often highly robust being able to adapt rapidly and reform after an external alteration.



Feedback Dynamics

Feedback loops are the mechanisms through which some local small event, which may have been random at the start, can get amplified into a new macro level pattern of organization. A positive feedback loop is one that is self-reinforcing, more begets more. The more products a business sells the more it can invest in its business, meaning it can produce better, cheaper products, meaning it will sell more, etc. This is a nonlinear process of change.

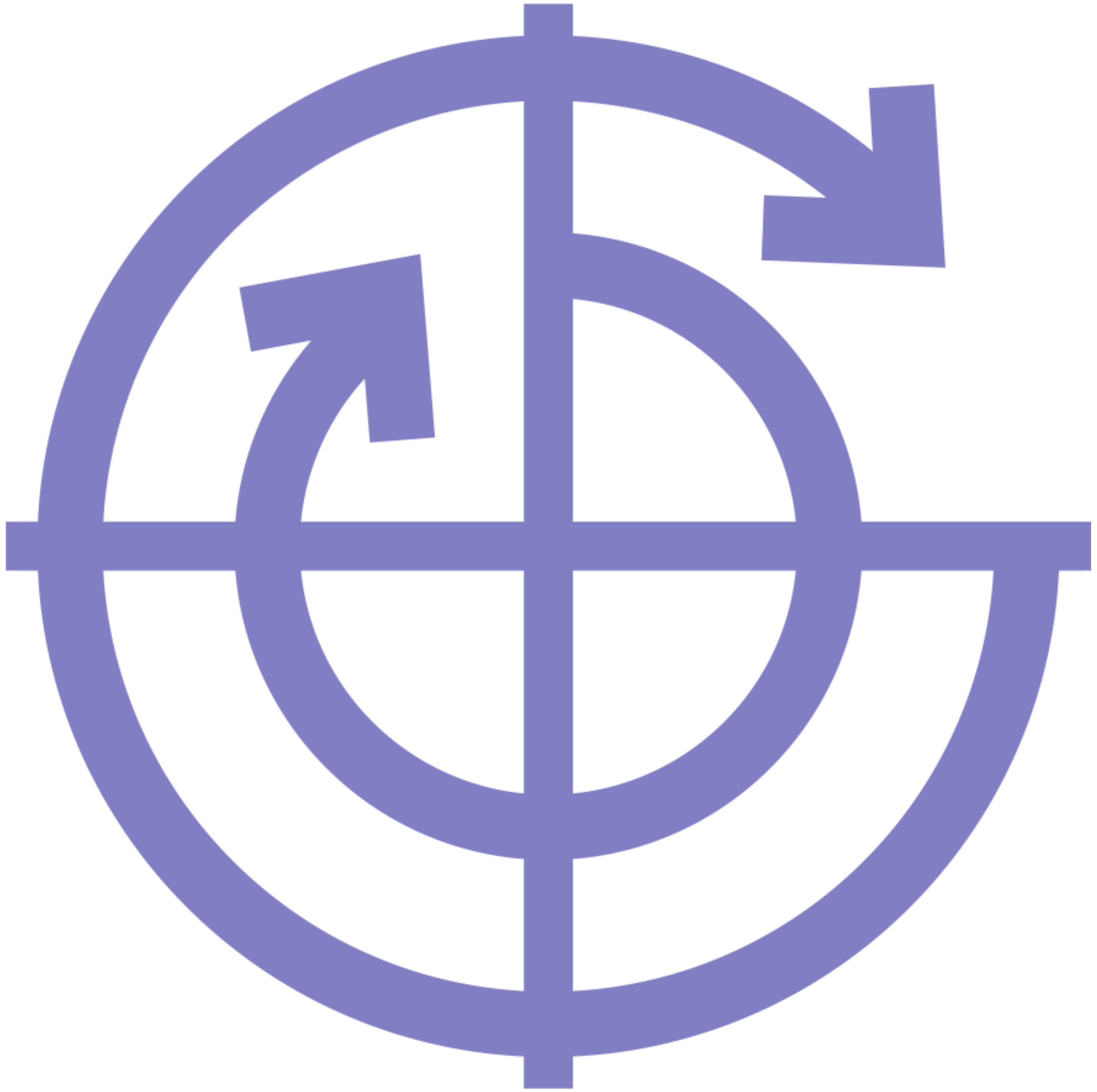
An example of this might be a wave at a football match, this is an emergent self-organizing phenomenon as no one is coordinating it. Some small - one or two people raising their arms - initial event takes hold and gets amplified into a large macro phenomenon; it emerges out of the synchronized states of the members. The more people that join in the wave the stronger the signal for others to do like wise, thus more begets more through positive feedback which amplifies the change process.

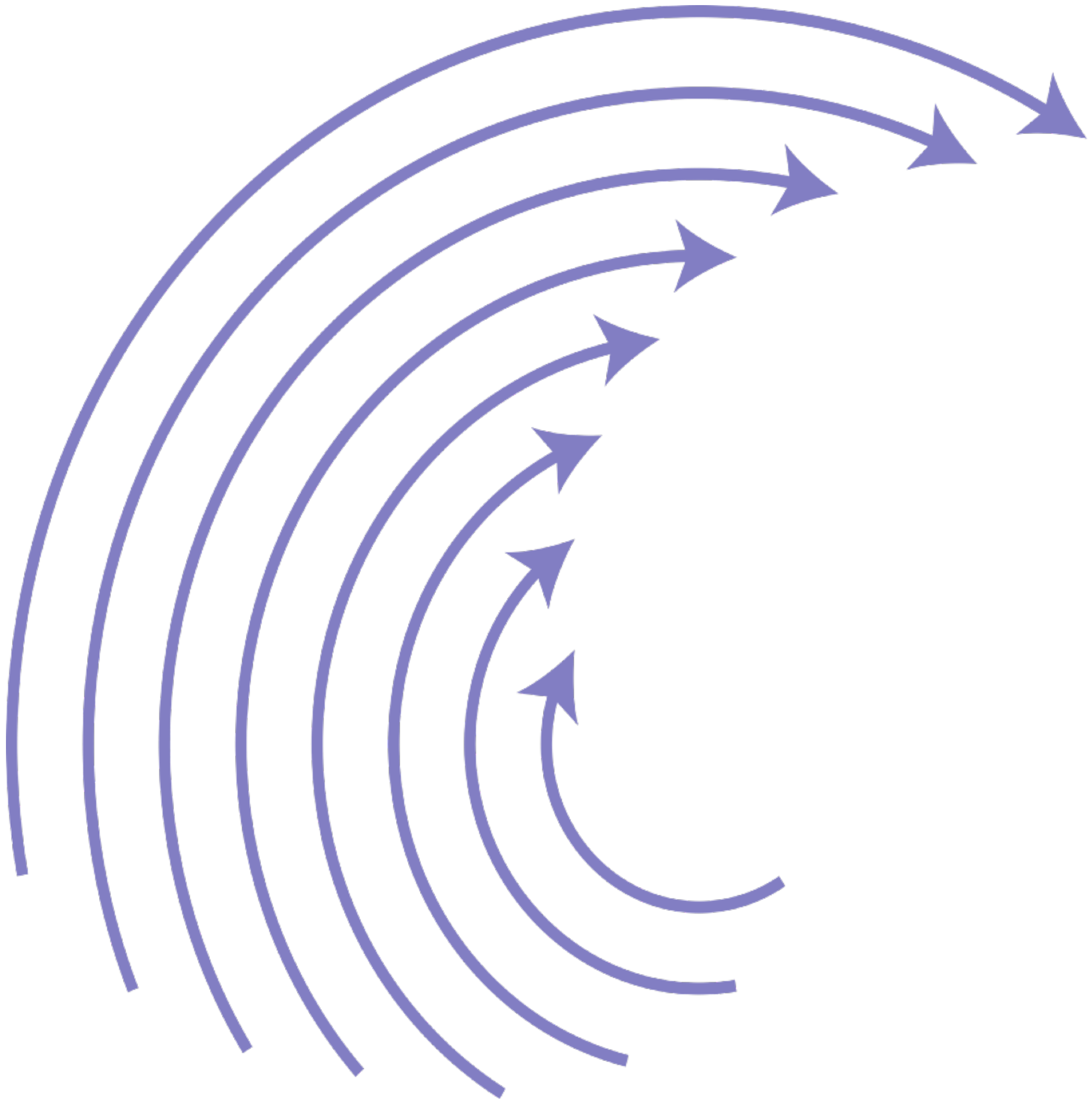
Attractors

As this positive feedback process of change continues we reach a point where there are more elements in this new configuration than not. At this point the new pattern becomes the default - that is to say, the easiest option to take - and we can call this an attractor. An attractor is a set of values or states toward which a system tends to evolve for a wide variety of starting conditions to the system.

Those elements in the system that interact more often and come to some form of consensus or coordination then form an attractor. Because they are now working together they are more effective than the other members in the organization, thus generating better results which makes it more attractive for others to join that organization because they will get a greater reward from it. We now get a positive feedback loop as the more people that join the organization the more valuable it becomes for future prospective members to do likewise.

Nonlinear Systems





Overview

Although it is often said that nonlinear systems describe the vast majority of phenomena in our world. They have unfortunately been designated as alternatives, being defined by what they are not. For centuries science and mathematics have been focused upon simpler linear interactions and orderly geometric forms that can be described in beautifully compact equations. It is only in the past few decades with the rise of chaos theory that scientists have begun to approach the world of systems that are not linear.

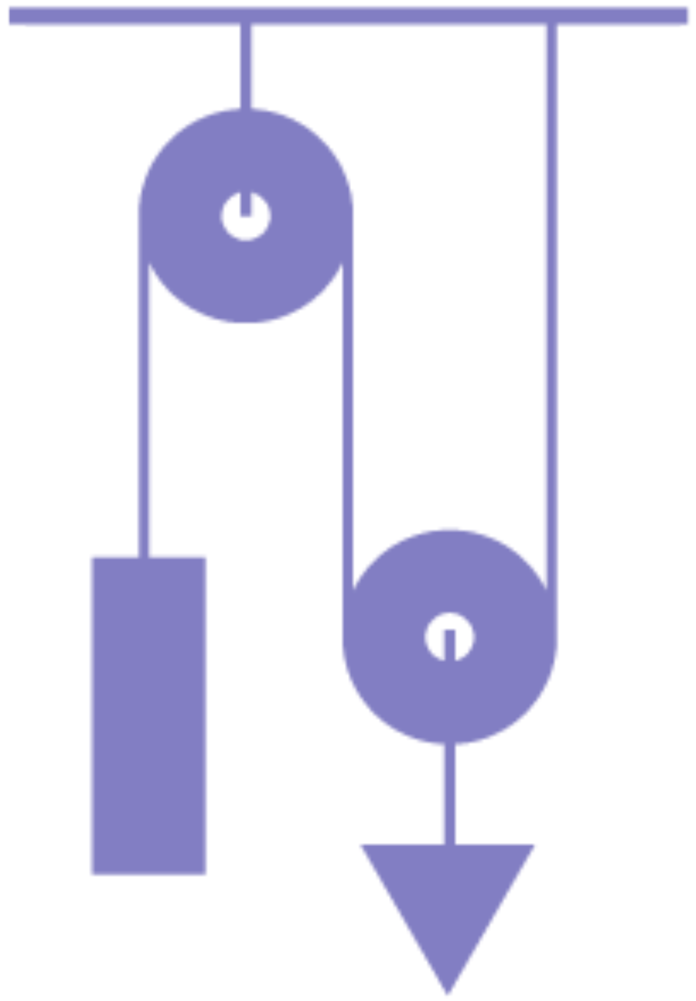
Nonlinearity describes how when two things interact the output is more or less than the sum of their parts in isolation, thus it is non-additive and nonlinear. This nonlinearity arises out of the interdependency between elements within a system and interdependence over time through feedback loops.

What is a Linear System?

Linear systems are characterized by what is called the superposition principles. There are just two principles; the additivity principles and the homogeneity principle.

Additivity states that when we put two or more components together, the resulting combined system will be nothing more than a simple addition of each component's properties in isolation. If we take two apples and weigh them each will have a given weight, now if we combine them the combined weight will be nothing more than the sum of each taken separately

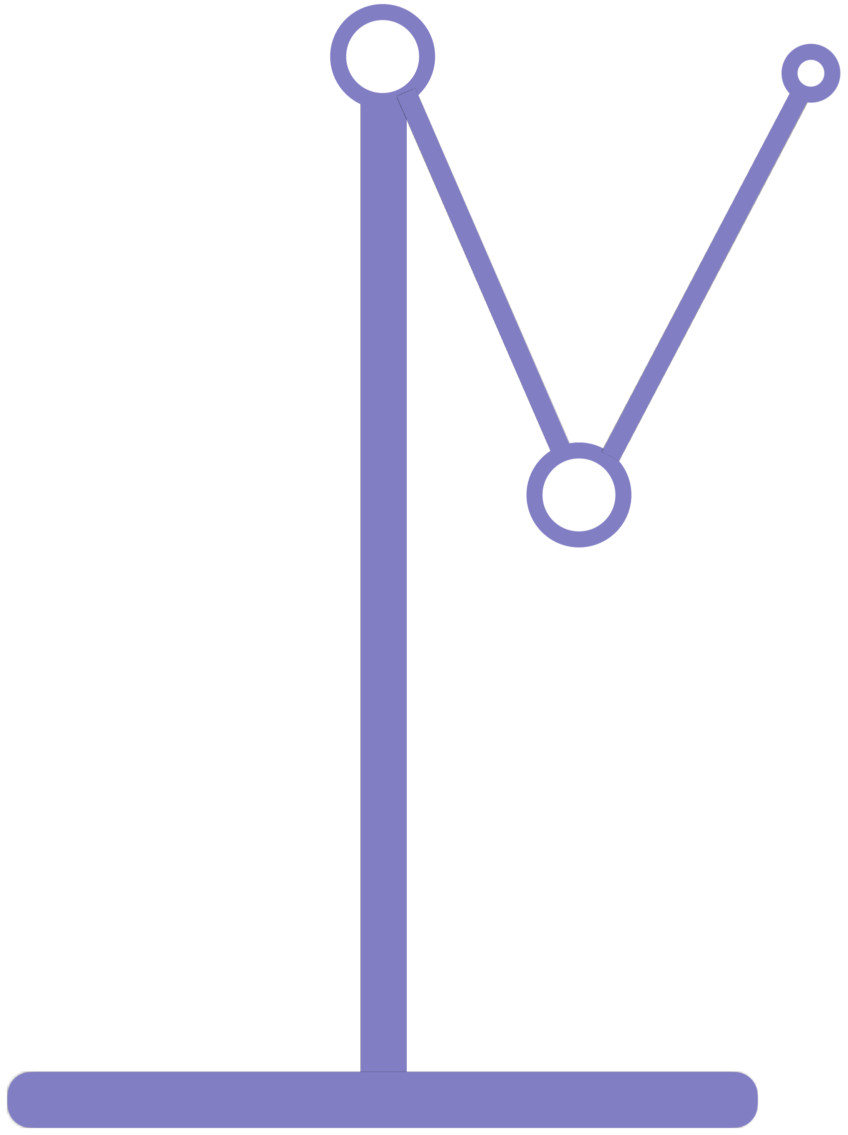
The principle of homogeneity states that the output to the system is always directly proportional to the input. Twice as much into the system, twice as much out, four times as much in, four times as much out, and so on. The direct implication of this homogeneity principle is that things scale in a linear fashion, which clearly fails to account for the effect that the output of the previous state of the system will have on its current or future states.



What is Nonlinearity?

Nonlinear systems can be defined as those that defy the superposition principles. The additivity principle breaks down in nonlinear systems because the way we put things together and the type of things we put together affects the interactions that make the overall product of the components combination more or less than a simple additive function; thus defying the additivity principle. There are many examples of this such as bees and flowers creating a synergistic interaction.

The homogeneity principle implies that there is no feedback loop over time, that things exist in something of a vacuum. However as soon as we put a system into its environment where it operates within both space and time, there will inevitably be feedback loops, as the actions it takes affect its environment and other systems with those effects feeding back to affect the future state to the system. If our economic activity pollutes our environment now this will over time feedback to affect future economic activity.



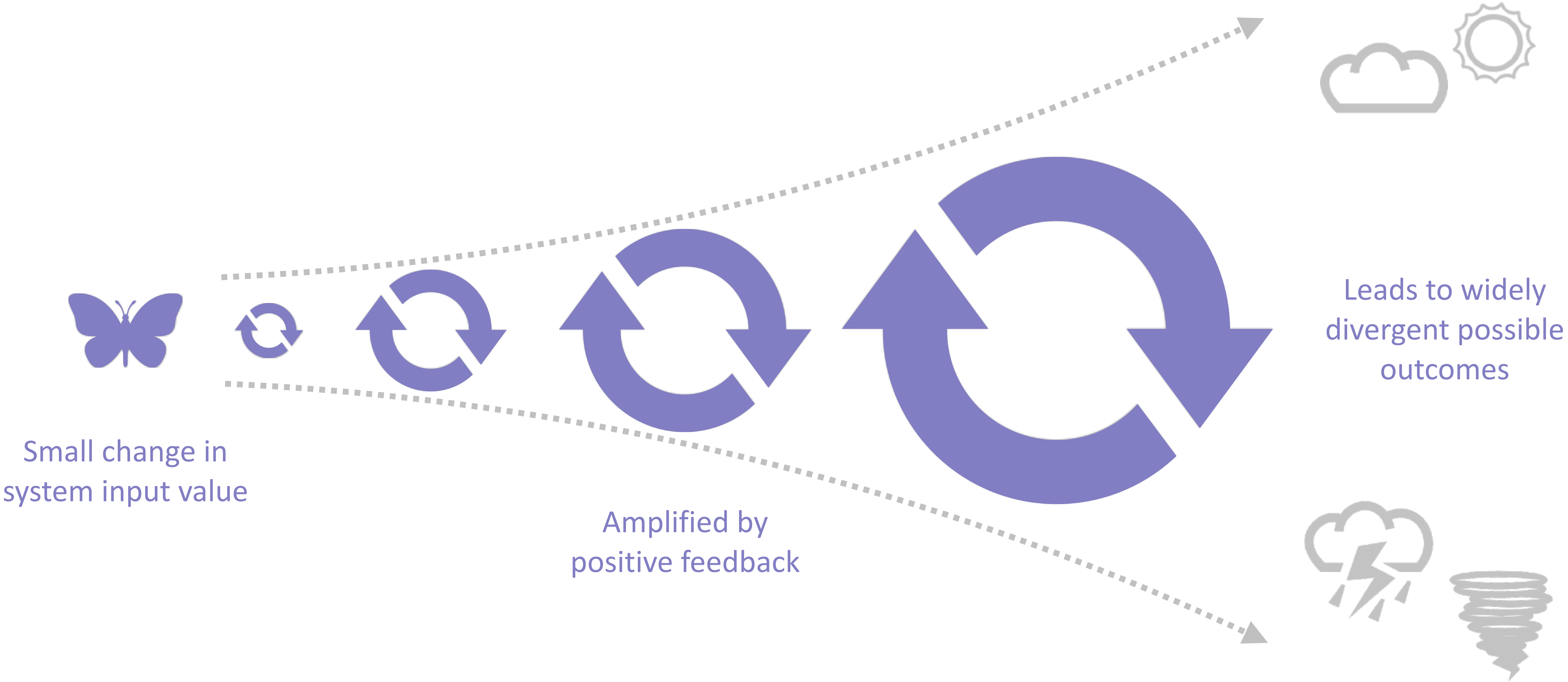
Chaos Theory

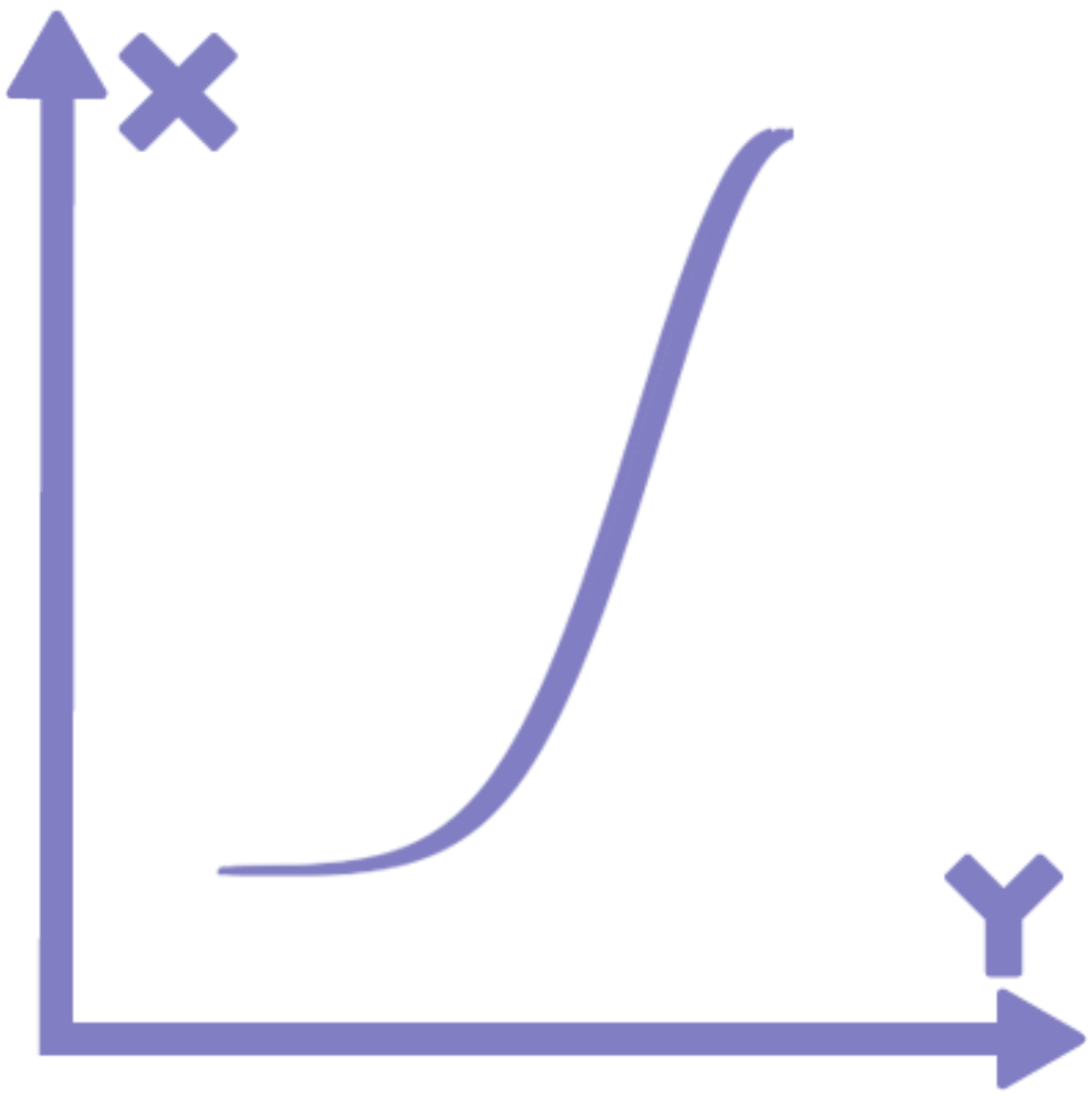
Chaos describes how a system's dynamics over time may be sensitive to initial conditions, resulting in the potential for widely divergent outcomes given only very small differences in the system's input values, thus making the future state of the system very difficult to predict. This chaotic and unpredictable behavior happens even though these systems are deterministic, meaning that their future behavior is fully determined by their initial conditions, with no random elements involved.

A double pendulum is a classic example of a chaotic system, consisting of only two interacting components, each limb, with these limbs being both strictly deterministic when taken in isolation, but when we join them this very simple system can, and does, exhibit unpredictable chaotic behavior. Starting the pendulum from a slightly different initial condition would result in a completely different trajectory.

What is Chaos?

Chaos theory is the study of nonlinear dynamical systems that are highly sensitive to initial conditions - eg weather patterns - popularly referred to as the butterfly effect. Small differences in initial conditions yield widely diverging outcomes for such systems, rendering long-term prediction generally impossible.



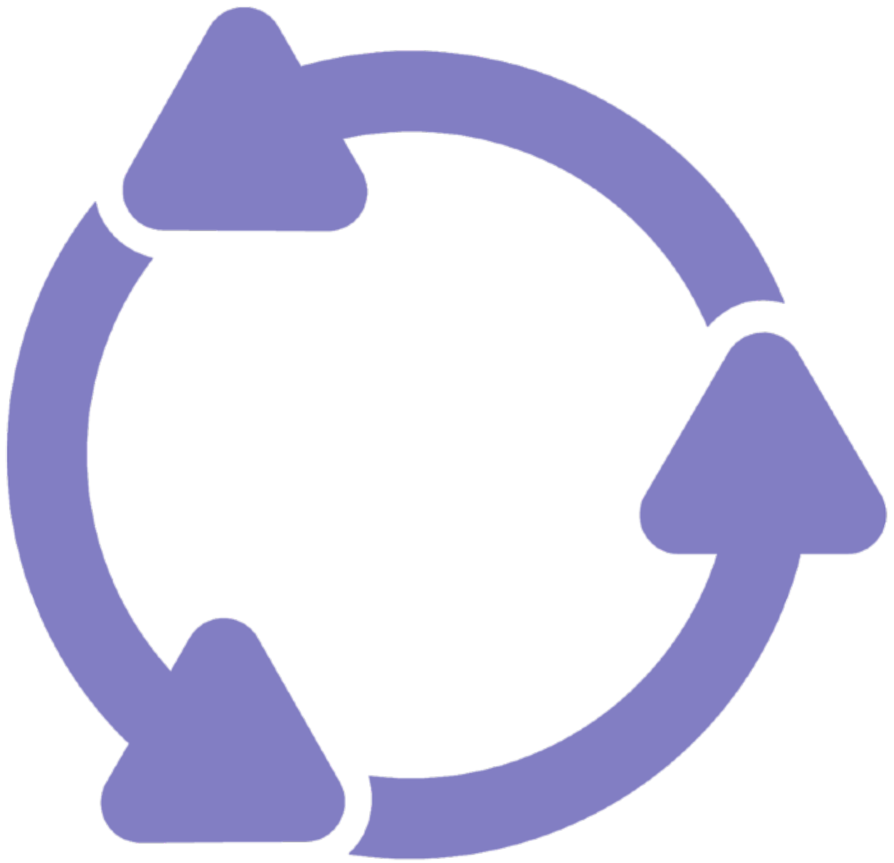


Phase Transitions

Feedback Loops

Feedback is at the heart of nonlinear phenomena of almost all kinds, feedback in space or over time is what generates nonlinear behavior. A feedback loop can be defined as a channel or pathway formed by an 'effect' returning to its 'cause,' and generating either more or less of the same effect. An example of this might be a dialogue between two people, what one person says now will affect what the other person will say and that will in turn feed back as the input to what the first person will say in the future.

Feedback loops are divided into two qualitatively different types, what are called positive and negative feedback. A negative feedback loop represents a relationship of constraint and balance between two or more variables when one variable in the system changes in a positive direction the other changes in the opposite. A positive feedback loop in contrast, is a self-reinforcing process, where more begets more, the increase in the values associated with one element in the relation effect the other to also increase in value, with this then, feeding back to increase the value of the first. The result is a compounding effect and exponential change.



Equilibrium

The concepts of equilibrium and non-equilibrium are an extension of the idea of linearity and nonlinearity. Equilibrium is a point of stasis where a system has equal forces acting on it; thus equilibriums systems states are created by negative feedback. Equilibrium systems states and the negative feedback that creates them can be seen to be “normal” as they equate to a stable and sustainable process of development. For example, we could identify this equilibrium state in someone who is working to pay their living. The person creates an income which is then spent again on supporting themselves, creating a financially sustainable situation as the inflows and outflows balance each other.

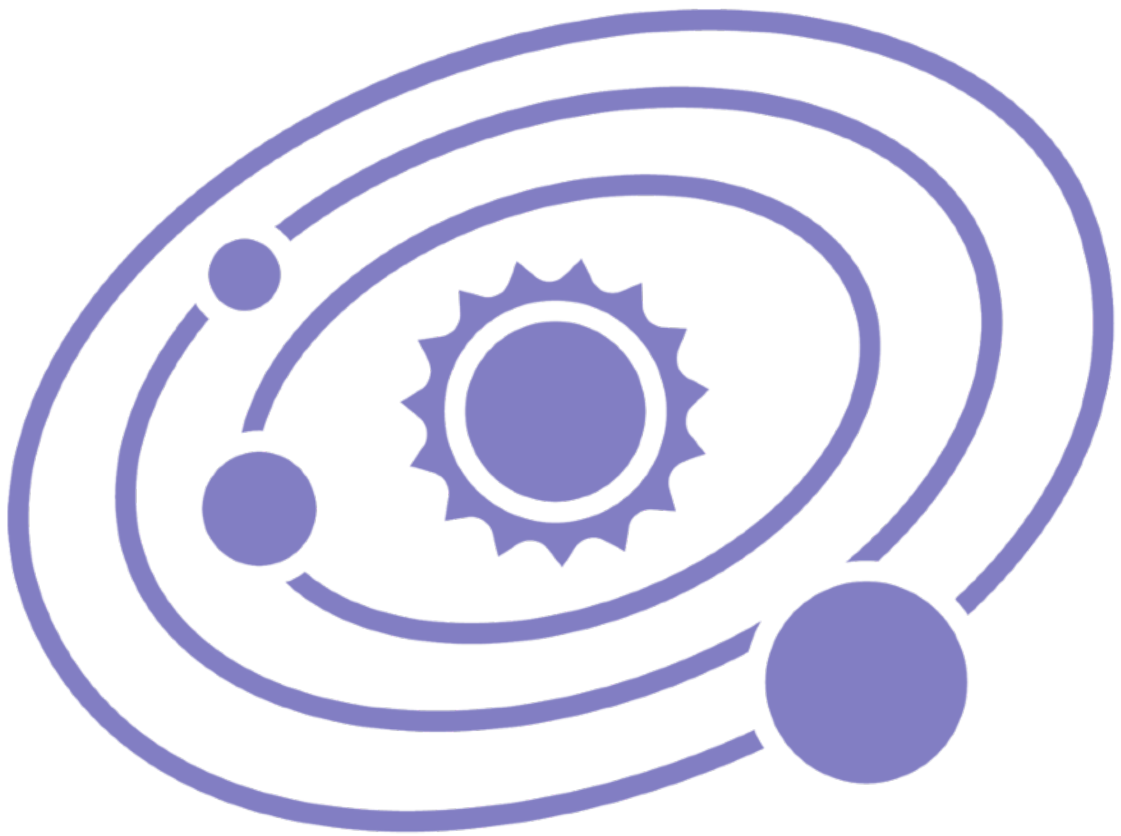
A system moves towards non-equilibrium when an action is taken without there being a counteraction to balance this. When each action induces the system to go off in the same direction - positive feedback - the system can rapidly become destabilized and move towards a non-equilibrium state of change, which is unsustainable. For example, a financial bubble is a non-equilibrium state of development because there is no counterbalancing force on the price of the assets, so it just stays increasing.

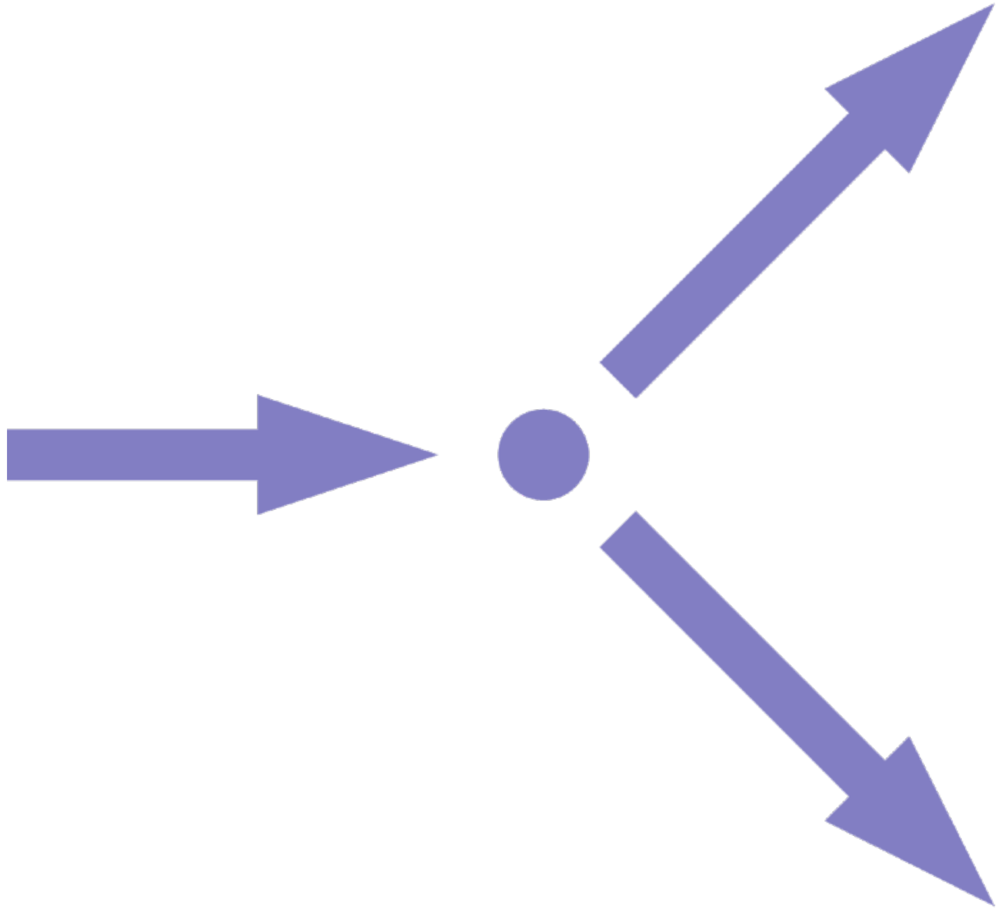
Attractor

For any given system we can create a state space representing all the possible states that the system might take. For example, during a week a person may have a number of different activities, e.g. working, resting, entertainment, exercising, etc. each of these is a state that would be represented in the space of different states to the person's activities.

Over time what we see is that systems typically settle in to routine set of states that represent the different counter balancing forces in the system. The attractor is then this subset of states that corresponds to the system's typical behavior.

An attractor is a set of states towards which a system will naturally gravitate and remain cycling through until altered. When a system is in a stable single attractor it has a single equilibrium representing the primary counterbalancing forces acting on it.



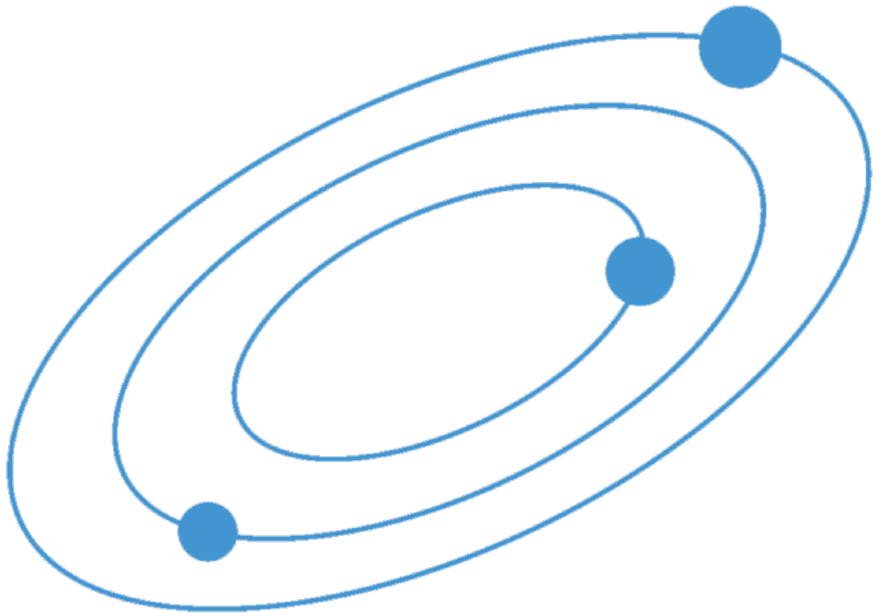


Bifurcation

A bifurcation means a branching out. In the case of nonlinear systems theory, the term refers to a point where the future trajectory of an element in a system divides or branches out, as new attractor states emerge. From this critical point it can go in two different trajectories which are the product of these attractors. Each branch represents a trajectory into a new basin of attraction with a new regime and equilibrium.

A bifurcation is a qualitative topological transformation in the state space resulting in a spitting of this attractor into two distinct stable attractors. For example, this could be a political system, where during a revolution what was previously a dictatorship with a single basin of attraction now becomes a system with two basins of attraction; the old regime and the counter movement.

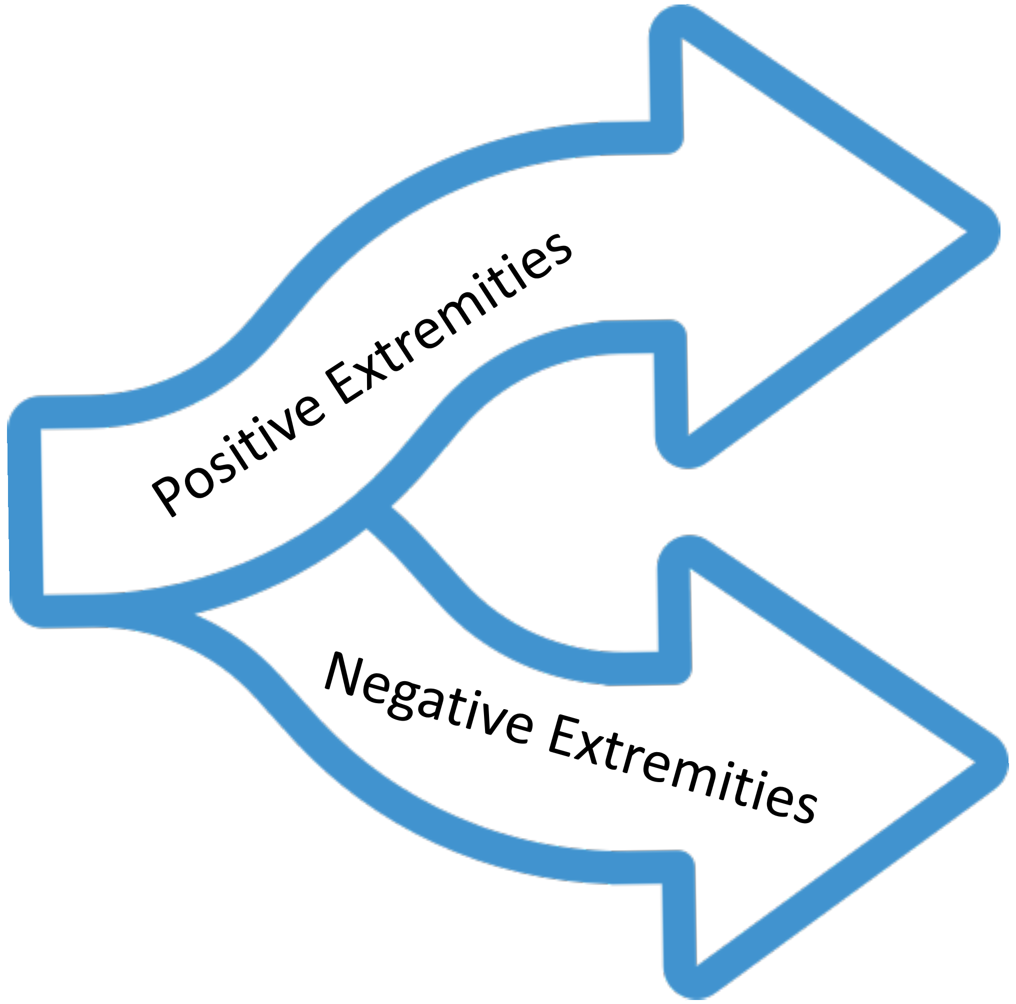
Linear Regime



Single Attractor

Strong negative feedback stabilizing system around centralized pattern of organization.

Phase transition

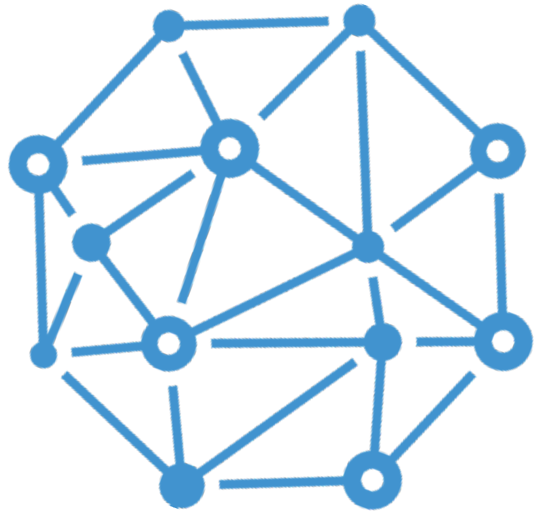


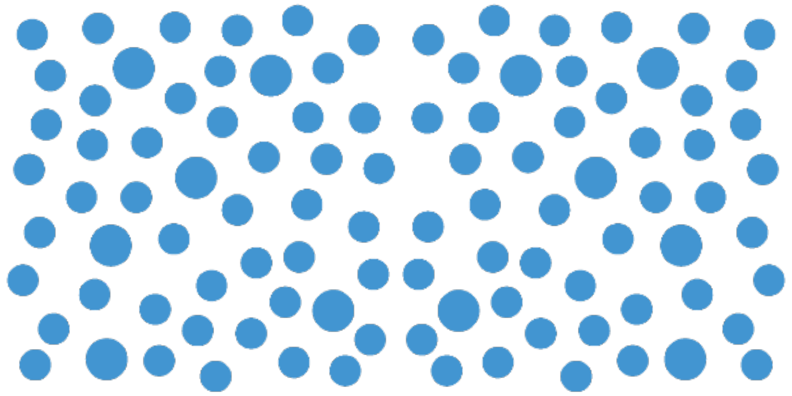
Bifurcation

Emergence of two basins of attraction, bistability, oscillation, non-linear regime with chaotic behavior

Emergence

Emergence of a new level of complexity with new macro functions and capacities





Self-organized Criticality

Collapse to lower level of organization, loss of complexity required to support macro-level functions.

Regime Shift

A regime defines a macro-level pattern of organization within a system and an ordered way of operating. When a system experiences high levels of positive feedback it can be pushed out of its stable basin of attraction, far-from-equilibrium and enters into a phase transition period characterized by rapid change and instability. During a phase transition, a bifurcation forms and the system moves into a new regime, under a new set of feedback loops that create a new basin of attraction with a new equilibrium, or regime.

Every time a negative feedback loop is broken the system moves farther away from its stable equilibrium attractor. As it moves away it moves towards a critical phase transition area far from its equilibrium; an unstable regime governed by positive feedback where some small event can get amplified rapidly driving the system through the phase transition into another basin of attraction. During a regime shift the system comes to have two or more basins of attraction and can flip between them, this is called "bistability."

Phase Transition

A phase transition may be defined as some smooth, small change in a quantitative input variable that results in an abrupt qualitative change in the system’s overall state.

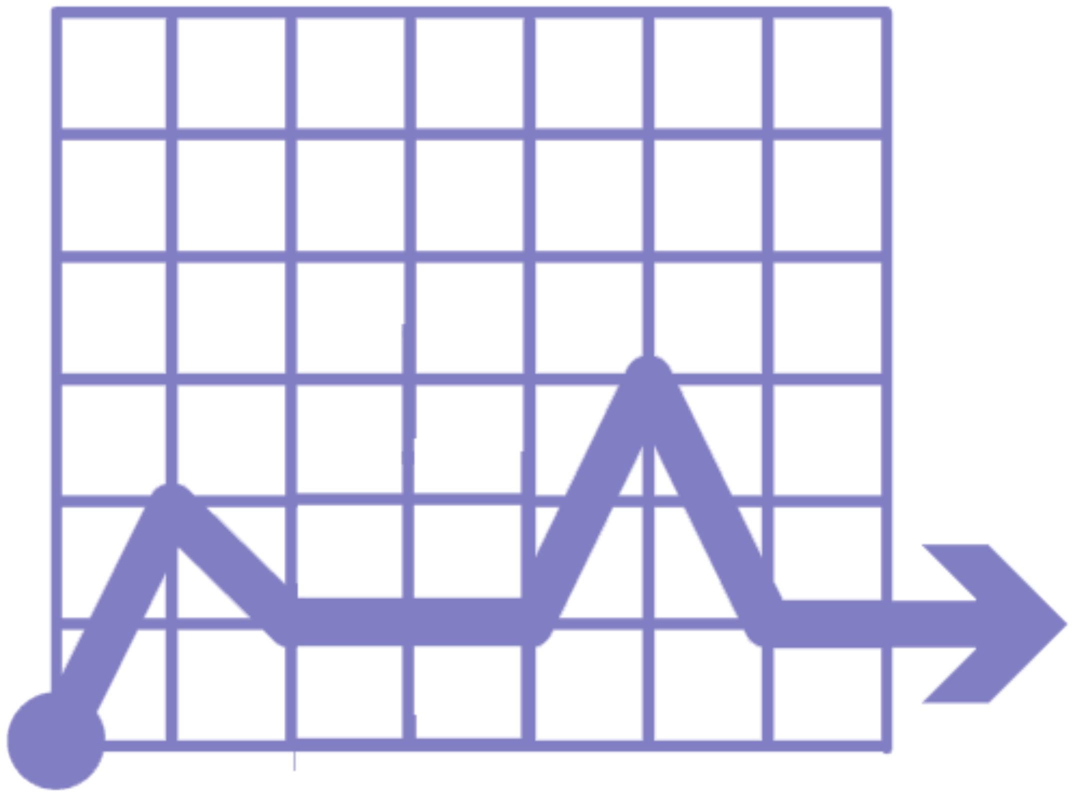
The transition of ice to steam is one example of a phase transition. At some critical temperature, a small change in the system's input temperature value results in a systemic change in the substance after which it is governed by a new set of parameters and properties. For example, we can talk about cracking ice but not water, or we can talk about the viscosity of a liquid but not a gas as these are in different phases under different physical regimes and thus we describe them with respect to different parameters.

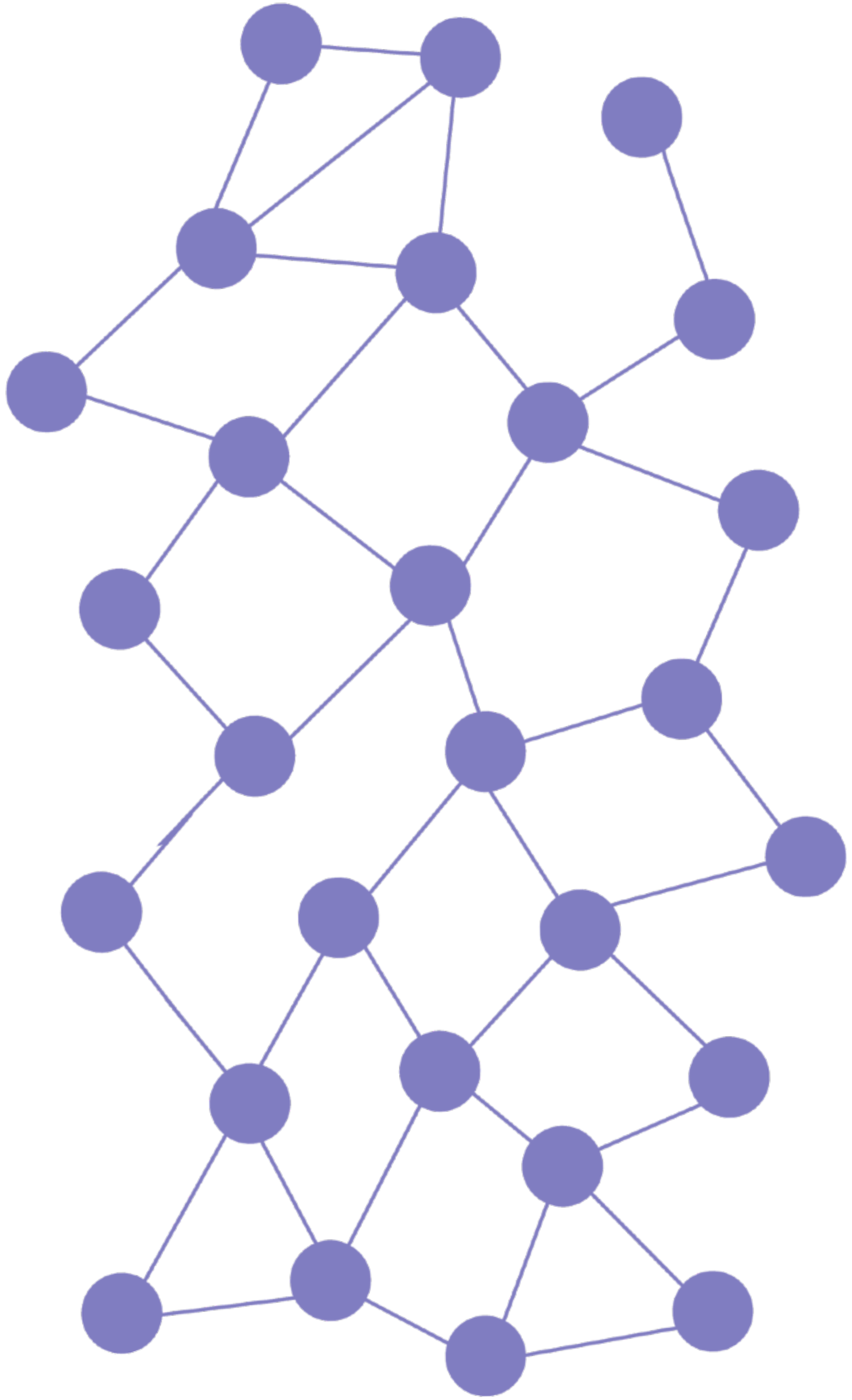
Punctuated Equilibrium

As opposed to linear systems that may develop in an overall incremental fashion, the exponential growth that nonlinear systems are capable of leads to a different overall pattern to their development, what we might call punctuated equilibrium.

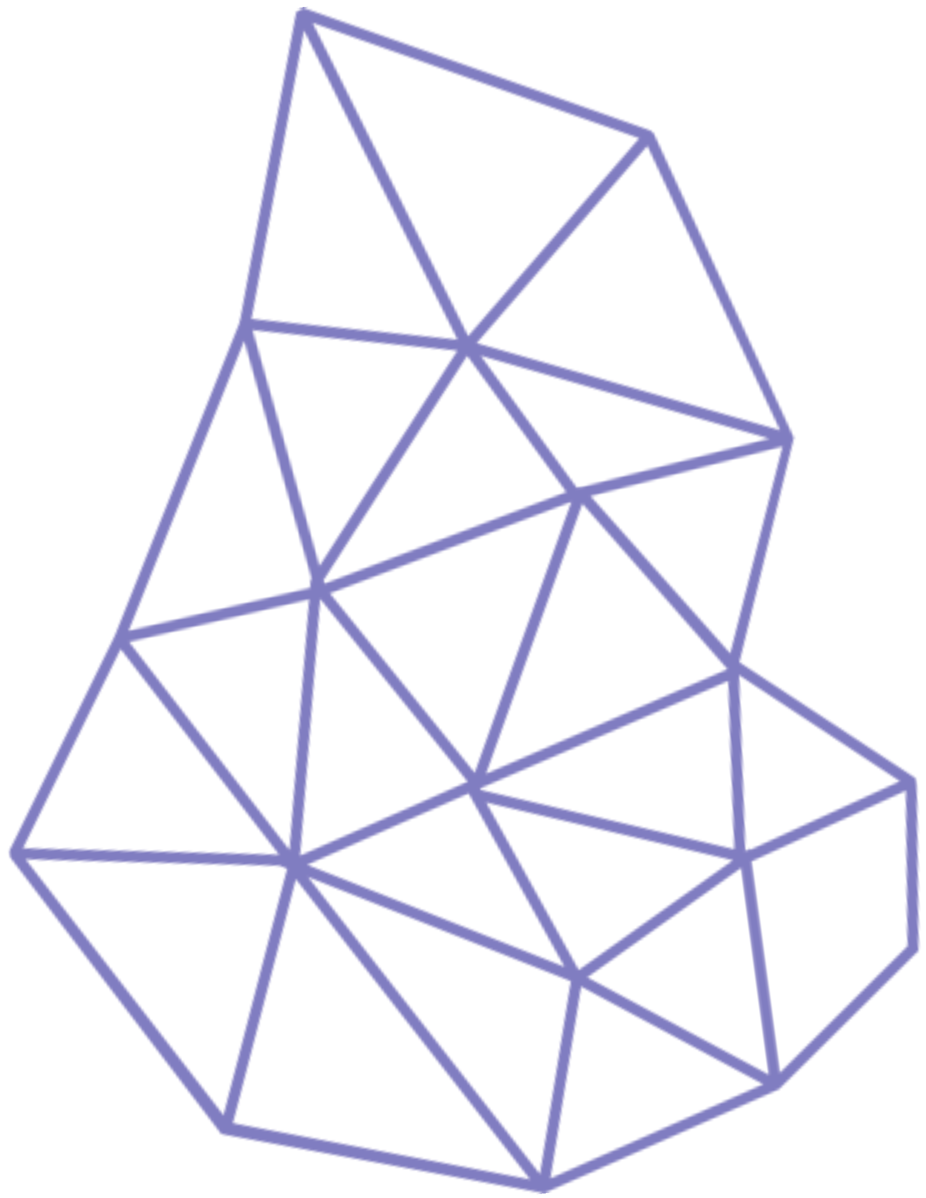
Within this model of punctuated equilibrium, the development of a nonlinear system is marked by a dynamic between positive and negative feedback, with negative feedback holding the system within a basin of attraction that represents periods of stable development. These stable periods are then punctuated by periods of positive feedback which take the system far from its equilibrium and into a phase transition as the fundamental topology of its attractor states change and bifurcate.

Examples of this punctuated equilibrium might be the development of economies that go through periods of stable growth then rapid change through an economic crisis and recovery.





Network Theory

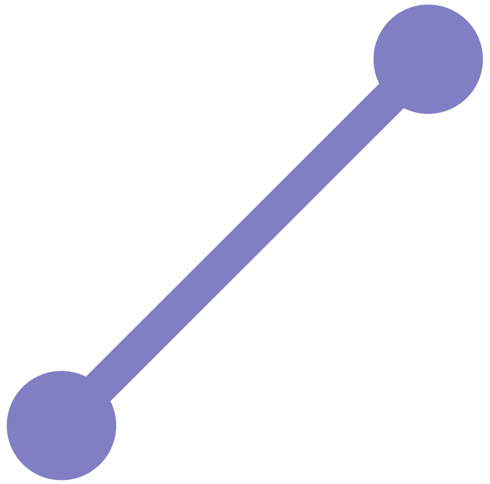


Overview

Network theory can be understood as the study of connectivity. Network theory is before anything a way of looking at systems that focuses our attention on connectivity. What network theory can contribute to our understanding of complexity is an analysis of the structure to complex systems; it tells us about their overall makeup and the topology of how they are interconnected. Network theory explicitly focuses our attention on the connections between parts and how that shapes the part and the overall system.

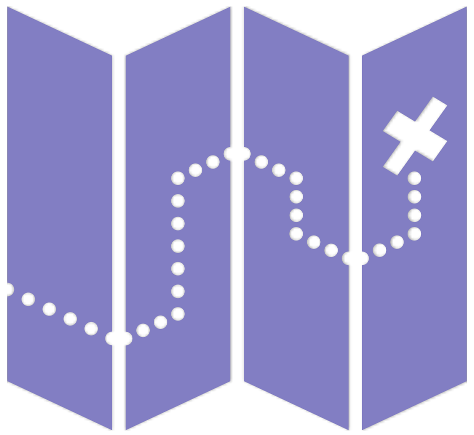
This perspective will become relevant when the system reaches a certain degree of connectivity, at which point it becomes more defined by the network of connections rather than the specific behavior of the parts. It now becomes relevant to switch our focus to looking at the nature of connectivity within the system and we use network theory to do this.

The Nature of Networks



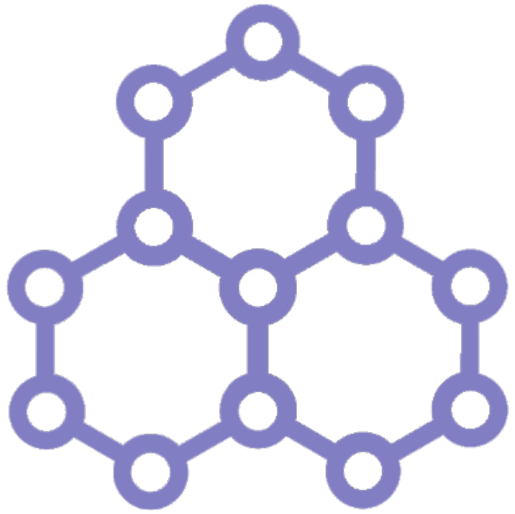
Relational

Networks are based on a relational paradigm, they focus our attention on connectivity and structure



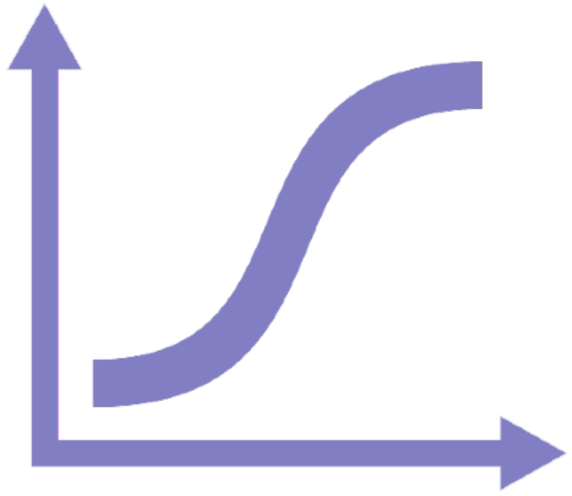
Topology

Networks create a very different kind of space to the one we are used to, we call this their topology



Emergence

Networks are not formal, they typically emerge in an organic fashion, from the bottom-up



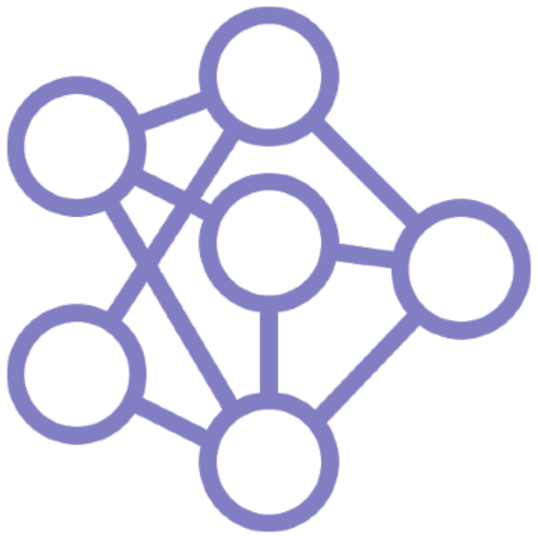
Nonlinear

Networks are inherently complex and nonlinear as linkages can grow exponentially relative to nodes

What’s Covered Here

Graph Theory

Graph theory is the basic formal mathematical language for describing networks

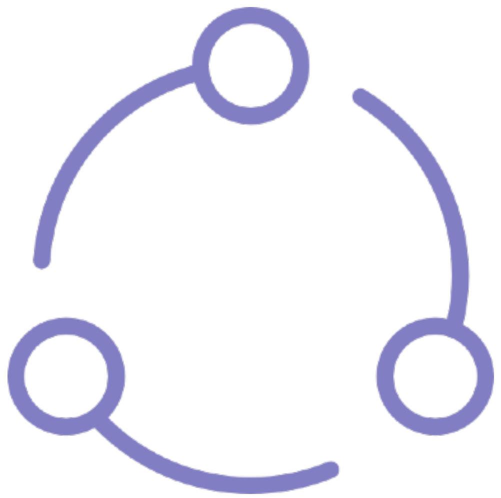


Network Structure

Networks are defined by their structure as this shapes how things flow across them

Types of Networks

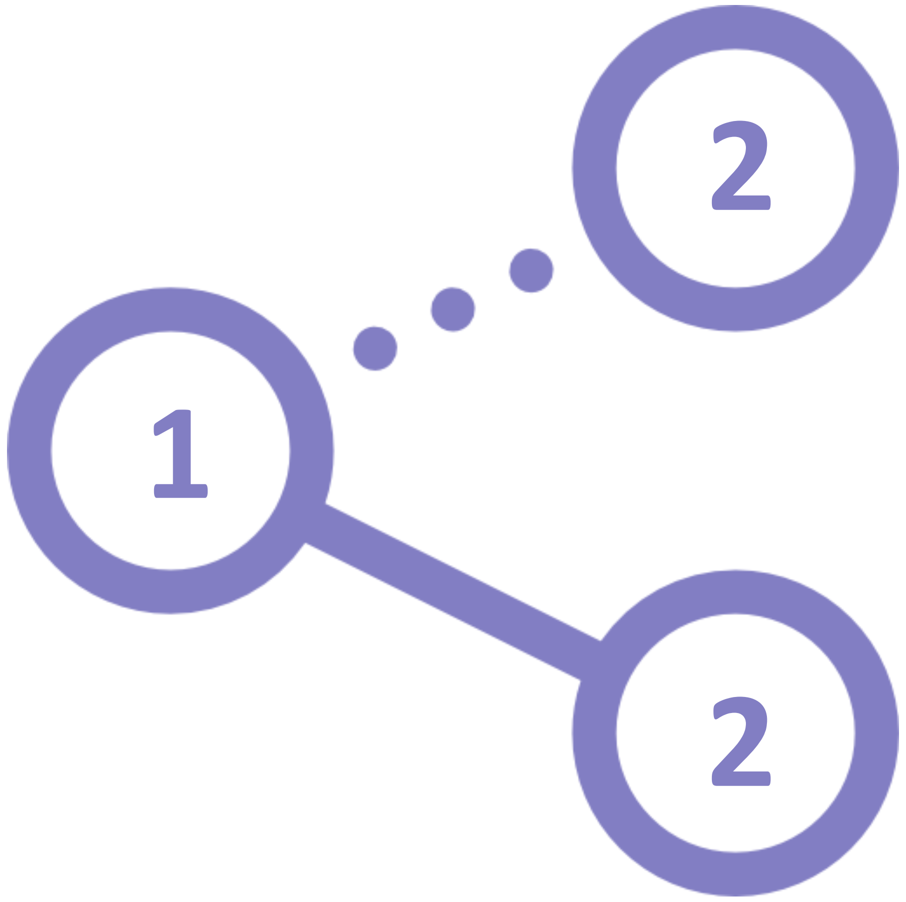
Different network types have been identified as reoccurring across a wide variety of systems



Network Dynamics

Network dynamics looks at the conditions under which networks form, grow or disintegrate

Graph Theory



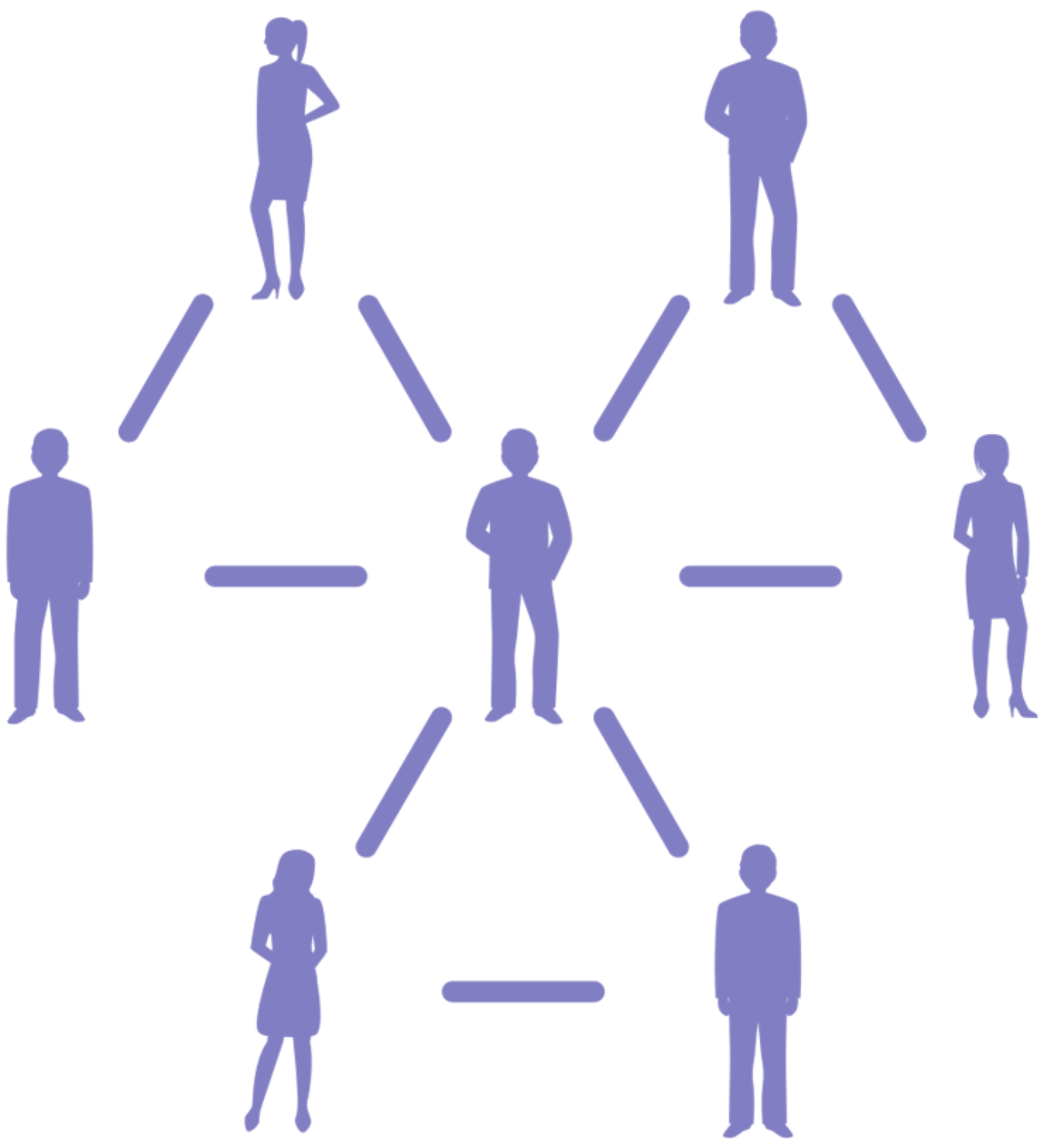
Network theory comes from graph theory, the area of mathematics that studies networks. Graph theory is a formal language that provides us with the basic vocabulary to start to talk about networks. Graph theory helps us in starting to understand the basic elements of graphs, the basic parameters to defining nodes and connections. The theory of graphs helps us to define important and basic features to a network such as degree of connectivity, node centrality, weighted graphs etc.

Graphs can be relatively simple having only one kind of relation between the parts or more complex multi-level graphs. Graphs that have multiple types of edges and nodes are called multiplex networks which allow us to capture how different networks interrelate, overlap and affect each other. For example, a city may be modeled as a multiplex network consisting of many intersecting networks, e.g. water systems, transport networks, social networks etc. It is important to be aware that real world complex systems are the product of many overlapping networks interacting dynamically.

Node Centrality

A primary question people wish to answer when analyzing a network is that of how influential or significant a given node is within the overall network, this is called the node centrality. For example, we might want to know, who is the most influential person in a social network, or most important business within an industry.

Centrality indices are answers to the question "What characterizes an important node?" However this question is not simple to answer as there are many factors that can give a node an influential position within a network and it often depends on the question being asked.



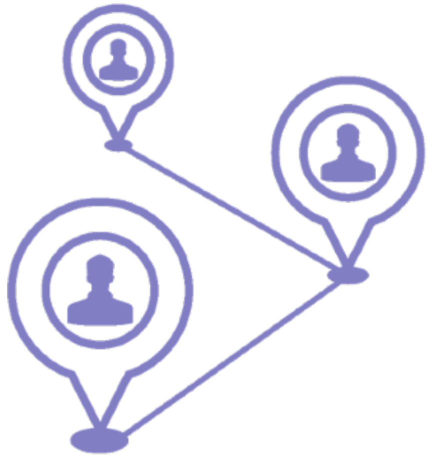
Metrics for Quantifying Node Centrality

Degree of Connectivity

A measure of the direct number of connections the node has

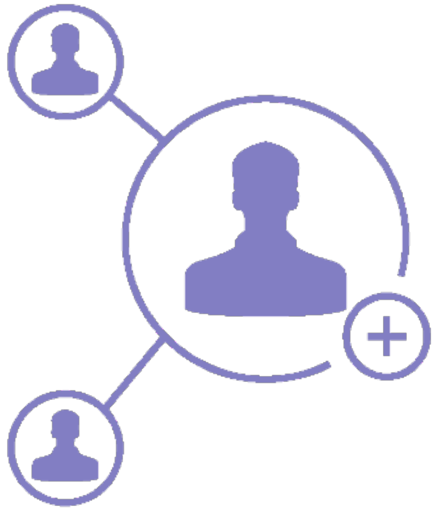
Closeness Centrality

How close a node is to any other node, i.e. how easily the node can reach other nodes



Betweenness Centrality

Captures the node's role as a connector or bridge between other groups of nodes



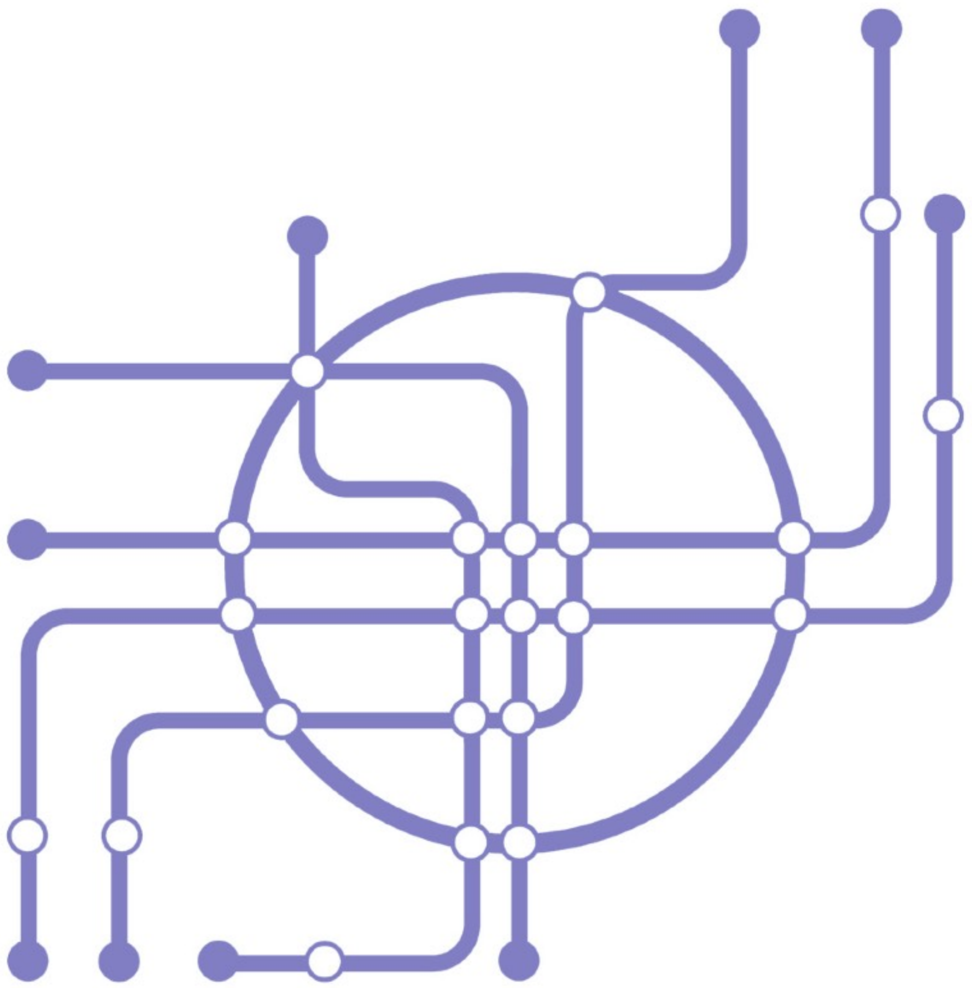
Prestige Metrics

How significant a node is based upon how significant the nodes it is connected to are

Network Structure

The structure of a network may be called its topology. Topology is the overall pattern or structure to a network; the way in which the constituent parts are interrelated or arranged. Within the context of network theory, it defines the way different nodes are placed and interconnected with each other and has a significant effect on how something will spread through the system. Examples of different network topologies include star, tree or ring structures.

Many parameters can be identified as affecting this structure such as the overall degree of connectivity, the number of nodes, the average path length, the systems diameter etc. Primary among these parameters is network density, how connected is the overall system. Key Concepts here include network topology, connectivity, diameter, clustering and more.



Types of Networks

The degree to which a network is centralized or decentralized is a key determinant of its overall workings. This feature to a network is captured by the network's degree distribution. Degree distribution tries to capture the difference in the degree of connectivity between nodes in a graph. It is really asking the question, do all the nodes have roughly the same amount of connections or do some have very many while others have very few connections?

By answering this, we will get an idea of how centralized or distributed it is, which is a defining factor to networks telling us how something will flow through it, which nodes have influence, or how quickly can we affect the entire network. Key concepts here include degree distribution, Small World networks, Scale Free networks, distributed graphs and centralize vs decentralized networks.

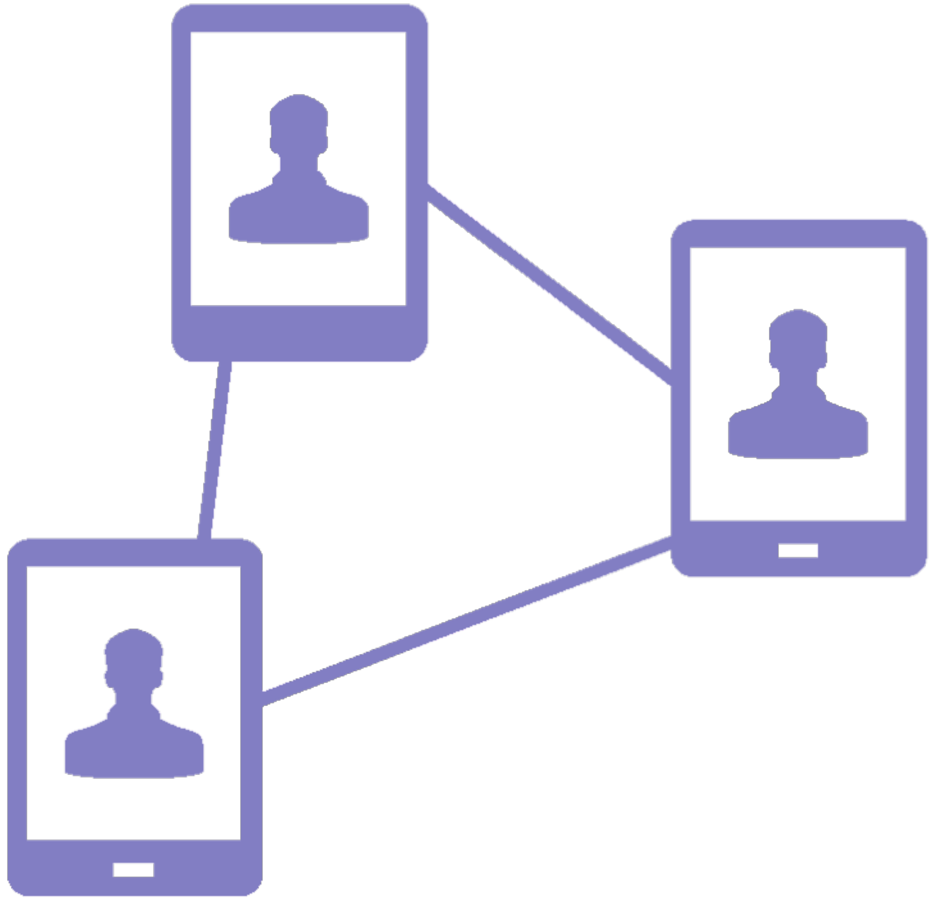
Centralized Networks

Centralized networks represent networks with a very high degree distribution, meaning they are very unequal in terms of how connected and influential the different nodes in the network are. In this type of network structure there will be very many nodes with a very low level of connectivity and a very few with an exceptionally high degree of connectivity.

A good example of a centralized network might be global banking activity, as a very few core nodes dominate the global financial system. This type of centralized structure to a network is surprisingly prevalent in our world seen in social networks where a very few people may have millions of followers while the vast majority have few.

These kinds of networks are often the product of preferential attachment which describes how a resource is distributed among a number of nodes according to how much they already have, so that those who already have a lot receive more than those who have little. In more familiar terms this is called "the rich get richer."

Decentralized Networks



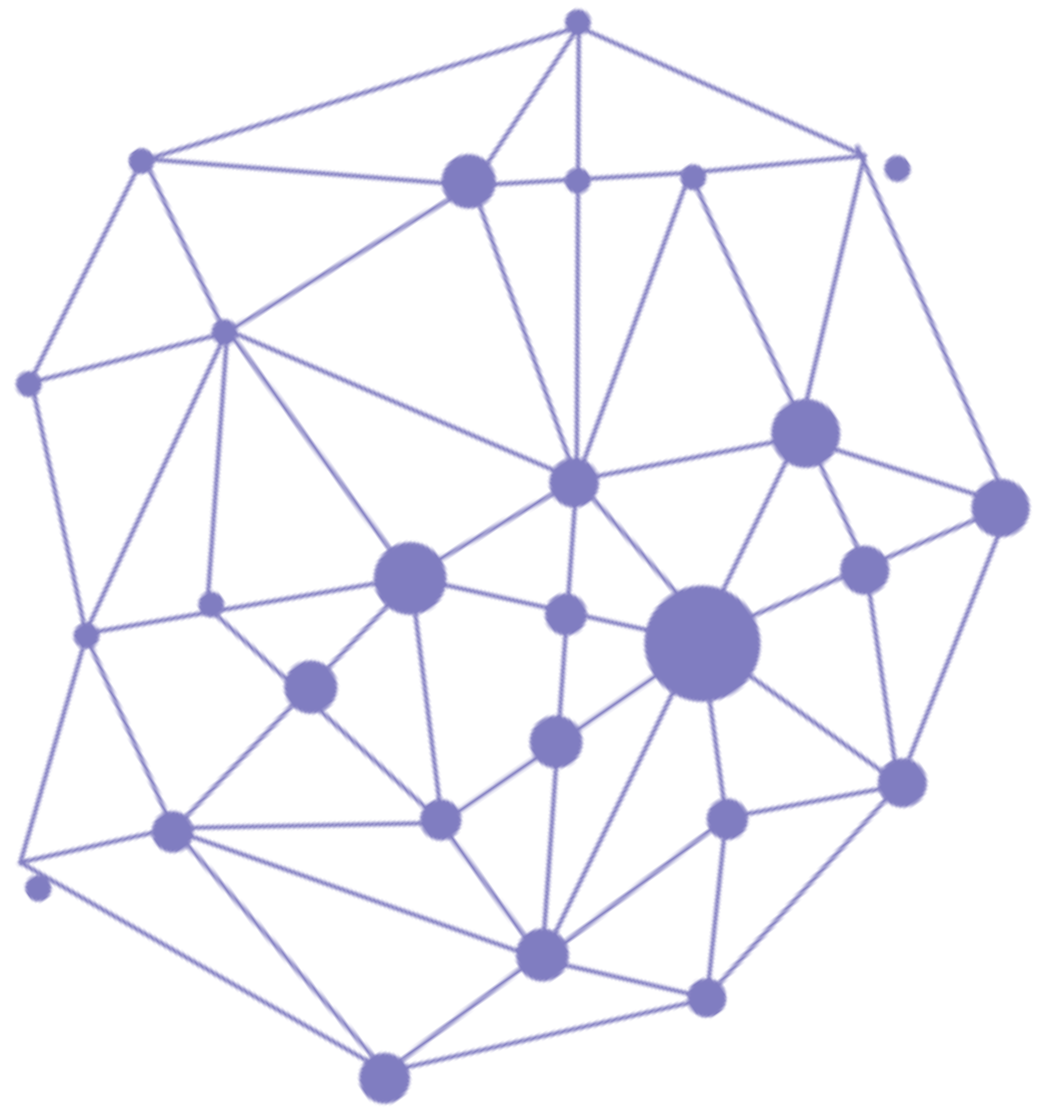
Distributed networks are defined by a low level of degree distribution. This means that most of the nodes have a similar degree of connectivity. As there are no dominant nodes to provide global functions for the entire network, each node must contribute to the network's maintenance. In a distributed network there is limited centralized global coordination, nodes are largely self-sufficient and are not dependent upon nodes outside of their neighborhood.

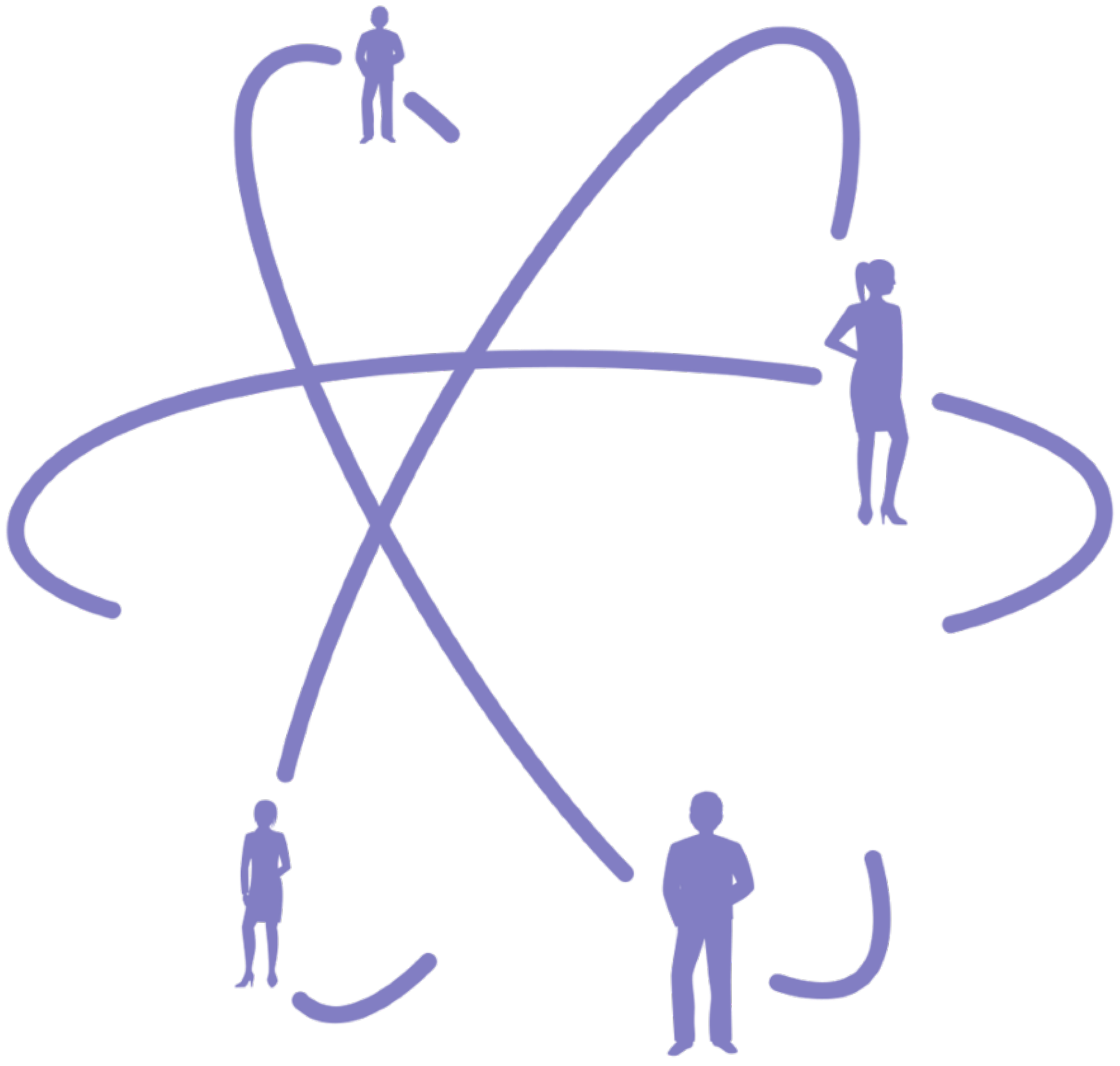
An example of a distributed network might be a community alert group, where each member of the community has equal responsibility and authority to act when there is an event that others should know about. There is no hierarchy, and in this example, the network is only actualized when needed, thus placing very limited constraints on its members. Within the world of computing distributed networks are also called mesh networks.

Characteristics of Decentralized Networks

Distributed networks have a number of advantages and disadvantages. On the positive side, they may be very robust to failure. As there is no critical or strategic nodes in the network, any node can theoretically be replaced by any other. As noted elements may have a high degree of autonomy, with limited network maintenance taxes placed upon them. But also this type of network can be less efficient in many circumstances.

Without centralized nodes, there is typically limited capacity for centralized batch processing to leverage economies of scale, and diffusion across the network can be slow as there are no central hubs with which to reach many nodes in a single hop. This can also create problems in terms of coordinating the network as a whole. In many ways, a distributed network represents a system in a fine balance and relatively stable state and this is often not what we see when we look at real-world networks - which are typically centralized in some way to take advantage of the efficiencies created.





Network Dynamics

The study of how networks form, grow and change over time is a relatively new area of research, but it is critical to understanding how to foster the development of some types of networks and reduce the development of others. Likewise, the rules under which a network was created and developed will play a large role in how something will spread across it and ultimately how robust it is to failure. For example, researchers have studied innovation as a process of diffusion across a network.

Because networks are inherently nonlinear their growth is typically nonlinear also, meaning there will likely be sub-linear growth up to a certain tipping point, and then positive feedback will kick-in to give us super-linear exponential growth. If enough nodes join the network, then we may reach the critical mass and get a tipping point. The tipping point is the critical point in the system's development as it defines where positive feedback will gain traction leading to rapid and irreversible state change.

Network Diffusion

Network diffusion describes how something spreads out or diffuses along the connections of a network as a function of the properties of its nodes and the structure of connectivity within the system. A classic example of this would be the diffusion of a disease through some population; equally we might be dealing with how the loss of one species in an ecosystem has an effect on others; the spread of financial contagion from one institution to another; or the spread of some information within a group of people. This spreading on a network is called network propagation or diffusion.

The network's topology is a key consideration in understanding how something is likely to spread across it, the primary factor here being simply the overall degree of connectivity of the network. We also need to ask whether this dissemination is random or strategic. That is, whether there is some logic behind the promotion and dissemination aimed at strategically affecting nodes that have a high degree of connectivity, and thus enabling a more rapid diffusion.

Network Robustness

Network robustness is the capacity for a network to maintain functionality given some perturbation. Network robustness may be modeled in terms of some external perturbation that propagates through the system, destroying links and nodes on its way. In such a case we want to ask how easily does it spread and what is the resistance to its spreading within the network.

When talking about network robustness & resilience, we are often asking what will happen to the network's overall connectivity and integration if we remove some components or connections, equally how will this failure then spread within the network system. A network's robustness is a function of a number of different parameters such as its degree of overall connectivity, the nature of the connections in the system and the overall structure of the network - e.g. is it centralized or distributed - among other factors.

Conclusion

Takeaways

Complexity theory is a powerful set of models to help us better understand complex systems. By understanding complexity theory we can truly start to work with complexity rather than against it - which is a huge advantage given the world of complex systems we find ourselves inhabiting in the 21st C.

Many of the findings from complexity science run counter to our intuition and traditional linear ways of thinking. For this reason it is important that we are aware of these features to complex systems before making interventions; otherwise our best made plans may well fail by simply operating under the wrong assumptions. The number one reason we fail in tackling complex issues is because we operate based on simple linear assumptions and fail to recognize the nature of complexity.

Complexity theory includes a vast and sophisticated set of models. Going in-depth on these is far beyond the scope of this short guide, thus this guide should certainly not be thought of as exhaustive. Here we have simply touched upon some of the key aspects to complex systems that you will need in order to get a basic understanding for their dynamics and characteristics. We encourage you to continue your reading in this area so as to broadened your understanding of complexity and your capacity to work with it.

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Meaning it is composed of many diverse and autonomous components that interact in a nonlinear, networked fashion with the whole system evolving over time.

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