

Emergence

What is your definition of emergence? Are there any examples you can provide? Is there any relevant data available? Please include your name with your response.

Beautiful book: [Strogatz S. *Sync: The emerging science of spontaneous order*](#)

Indika Rajapakse: Emergence is defined as the convergence of the global dynamics of a system of agents to a low-dimensional attractor, such as a fixed point or a limit cycle.

Krishna Saxena - Emergence is a phenomenon where a system of subunits/agents develops new properties due to the increase in some monotonic axis (e.g., number of training iterations, [grokking](#); number of parameters, [double descent](#); etc.). Interestingly, for these two emergence phenomena, anyone can observe them by training neural networks on an arbitrary dataset.

Ira Velasco

Definition: The word 'emergence' can be used to describe complex systems that have properties that only exist/be understood relative to the system as a whole. The systems cannot be understood through their own individual components/parts.

Example: Human Language

Relevant Data:

- [The emergence of hierarchical structure in human language](#)
- [An evolutionary context for the emergence of language](#)

Zuchen Li

My Definition: An unexpected surprise that only reveals itself after you've done it.

Example: The biggest surprise of diffusion models was discovering that a simple denoising process could outperform GANs in generation quality while offering unprecedented training stability and controllability. What started as incremental noise removal unexpectedly revealed remarkable scaling properties and universal applicability across domains—from images and videos to protein structure prediction. This paradigm shift transformed diffusion from a theoretical curiosity into the foundation of modern generative AI, powering everything from DALL-E to AlphaFold 3.

Foundational Papers: [Denoising Diffusion Probabilistic Models](#) ; Image generation: [High-Resolution Image Synthesis with Latent Diffusion Models](#) ; Biology application: [Accurate](#)

[structure prediction of biomolecular interactions with AlphaFold 3](#) ; right now even [AnoDDPM: Anomaly Detection with Denoising Diffusion Probabilistic Models](#) and [Effective Data Augmentation with Diffusion Models](#)

Deepan Islam

Definition: Emergence is when individual interaction laws produce a complex behavior or pattern that is not encoded by these individual laws. The typical examples are bird flocking and schools of fish. The classic paper is by Cucker and Smale: <https://people.mpi-inf.mpg.de/~mehlhorn/SeminarEvolvability/CuckerSmale.pdf>

But I find <https://juliadynamics.github.io/Agents.jl/stable/examples/flock/> this to be a nice visualization.

Shreyan Purwar

Definition: Emergence is the process by which complex patterns or behaviors arise from simple interactions between individual components in a system, which creates something new and greater than what was before.

Example: Financial Markets

- <https://pdodds.w3.uvm.edu/files/papers/others/1999/arthur1999a.pdf>
- <https://jasss.soc.surrey.ac.uk/12/2/reviews/lebaron.html>

Ci-Yu Wang

Definition: Emergence refers to the widespread and diverse ways in which interactions among simple components in natural, virtual, or conceptual systems give rise to increased complexity and novel system-level properties, making the collective behavior qualitatively different from that of the individual parts. (Source: <https://astrobiology.nasa.gov/news/all-about-emergence/>)

Example: Formation of stars

Xiyuan Mei

Definition: Emergence is the appearance of collective properties or some behaviors that generate from interactions among many individual components, even though these properties may not be present at the level of any single component. For example, in finance, phenomena such as price bubble or excess volatility can emerge even when each trader follows simple and rationale rules.

Source: <https://www.nature.com/articles/17290>

Yayu Zhang

Def: Emergence means a phenomenon that many simple individuals come together and interact by following some simple rules. Through these interactions, the group suddenly shows new and complex capabilities at a collective level. These capabilities are which individuals themselves do not have.

Ex: tornado

Source: <https://plato.stanford.edu/entries/properties-emergent/>

Chengqi Lu

Definition: Seedling emergence is the process where actively growing embryos during germination break through the seed. It involves the sequential appearance of the primary root (radicle) for soil anchorage and water absorption, followed by the embryonic shoot (plumule) which eventually reaches the soil surface to develop leaves.

Source: <https://byjus.com/biology/difference-between-germination-and-emergence/#2>

<https://www.sciencedirect.com/topics/earth-and-planetary-sciences/seedling-emergence#:~:text=Seedling%20Emergence%20%2D%20an%20overview%20%7C%20ScienceDirect.How%20useful%20is%20this%20definition?>

Example: Plant tomato seeds in a flower pot, and a week later see tender leaves emerging from the soil.

Julian Whittaker

Definition: Emergence occurs when many simple and individual entities or components interact with each other to form or expose patterns or behaviors that would otherwise not be possible on their own.

Source: <https://astrobiology.nasa.gov/news/all-about-emergence/>

Example: One could consider nearly all human achievements a result of emergence but a standout might be setting foot on the moon or taking flight for the first time.

Nick Reynolds

Definition: Emergence is the superpattern that emerges when one sufficiently understands constituent elements in a system, but either through human or natural ignorance cannot characterize the behavior of an ensemble of elements.

Example: superradiance in atomic ensembles

Mark A. Farag

Definition: It's a self organised process, which leads a system from a lower to a higher state of order. The order can be measured by entropy. Entropy decreases with increasing the order, while the emergence increases with the order.

Source:

https://www.google.com/books/edition/Organic_Computing_Technical_Systems_for/9bxEDwAAQBAJ?hl=en&gbpv=1

Example: Applying heat to a materials

Christopher McCullough

Definition: Emergence is a phenomenon in which increasingly complex properties result from the organization of simple parts that are typically unable to possess or exhibit these properties themselves. As a result, the whole is greater than the sum of its parts.

Source: [Kurzgesagt - In a Nutshell](#) gives a good, high-level overview of Emergence and several examples, including the one below.

Example: Atoms → Molecules → Proteins → Cells → Organs → Individuals → Societies

Name: Jianyu Hua

Definition:

Emergence describes how collective interactions among simple components give rise to system-level behaviors or functions that do not exist at the level of individual parts.

Example:

In acoustics, structured wave fields such as acoustic vortex beams carrying orbital angular momentum (OAM) emerge from the coherent superposition of many simple wave sources. While each emitter produces a basic harmonic signal, their coordinated phase relationships generate global properties—such as helical phase structure and angular momentum—that no single source possesses.

Source / Relevant Data:

Experimental amplitude and phase measurements of acoustic arrays reveal stable vortex cores and mode-dependent field patterns only at the collective level, demonstrating emergent behavior in wave systems.

<https://plato.stanford.edu/entries/properties-emergent/>

Name: Xiaopu

Definition:

Emergence refers to a phenomenon in which system-level behaviors or capabilities arise from interactions among many simple components, and these behaviors cannot be observed in any individual component alone.

Example:

Traffic congestion. Individual drivers typically follow simple and reasonable rules, such as maintaining a safe distance and adjusting speed smoothly. However, when many drivers interact

on a highway, small fluctuations in speed can be amplified through feedback effects, leading to sudden traffic jams that occur without accidents, lane closures, or visible bottlenecks.

Source:

<https://iopscience.iop.org/article/10.1088/1367-2630/10/3/033001>

Karl Li

Definition: Emergence refers to a phenomenon in which interactions among many simple parts produce complex outcomes, structures, or behaviors that do not exist at the level of the individual components and cannot be explained by those components in isolation.

Example: The human brain. Individual neurons only transmit electrical and chemical signals, but when billions of them interact in organized networks, they give rise to consciousness, memory, and emotions

Source: <https://astrobiology.nasa.gov/news/all-about-emergence/>

Simon Wu

Definition: Emergence refers to global patterns or behaviors that arise from many simple local interactions, even though those patterns are not explicitly programmed or predictable from any single component alone.

Example: Urban traffic congestion

Ruoxi Wang

Definition: Emergence is that multiple simple components come together and form a large complex system, and have properties that any simple component does not have.

Example: The hive, or multicellular organisms.

Vincent Li

Definition: Emergence is the process by which interactions among many simple components/organisms give rise to collective behaviors or properties that are not present, or directly inferable, at the level of individual components.

Example: Ant colony foraging behavior - individual ants follow simple, self-determined paths-randomly roaming for food. Yet, at the colony level, ants collectively discover and move using the shortest paths to food sources and adapt to obstacles without any central control.

Source: <https://necsi.edu/emergence>

Jiahao Han

Definition: Emergence is the phenomenon where the system-level properties appears from the interactions among multiple fields, instead of any single material or specific part.

Example: In the battery field, emergence is the overall behavior of a battery due to the interactions among electrochemical, thermal, mechanical and control processes, not directly

inferred from any single material and cell. Thermal runaway propagation is caused by heat transfer, mechanical confinement and gas generation. Altogether causing the thermal runaway.

Data Source: [Thermal runaway mechanism of lithium ion battery for electric vehicles: A review](#)

Hadi Nassar

Emergence is when a simple system, made of many simple parts, shows new behavior that you cannot understand just by looking at one part alone.

Example: Traffic jams

Julian Lopez

Definition: Emergence is when a system shows behavior or properties that arise from interactions between parts and do not exist in the individual sense alone.

Example: In mechanical engineering, an example could be when complex system-level behavior (strength, flow, stability) arises from simple components interacting under physical laws, even though no single component “contains” that behavior by itself.

Penelope Lialios

Definition: Emergence is when a complex system has properties that its parts do not have on its own due to their interactions.

Example: The human immune response - single immune cells do not produce a whole immune response to a pathogen, it requires a coordinated effort and interactions to fight off sickness with other immune cells and tissues

Shiloh Dunaway

Definition: Emergence is how patterns and behaviors arise out of complex systems.

Examples: Flocks of birds, ice forming, traffic, suburbs

Annika Backer

Definition: Emergence refers to the phenomenon where complex patterns, behaviors, or properties arise from the interactions of simpler components. These higher-level properties cannot be easily anticipated by looking at the individual components alone. Essentially, the “whole is more than the sum of its parts.” Emergent properties often appear at higher levels of organization and are context dependent.

Examples: biological (coordinated flocking in birds and complex nest-building in ant colonies, physical (snowflakes and phase transitions (freezing/boiling), and social or economic (traffic patterns and market fluctuations).

Relevant data: 10.1186/s13742-016-0152-3 (Clusterflock: a flocking algorithm)

Yiqi Wu

Definition: In machine learning, I define emergence as a regime change where a model exhibits a qualitatively new capability (or behavior) that is absent or near-chance below a scale/training threshold but becomes reliably measurable above it, as a monotonic control variable increases (e.g., parameters, data, compute, or training time)

Examples: Emergent abilities with scaling in LLMs: Wei et al. describe abilities that appear in larger models but not smaller ones under certain evaluation setups.

Source: <https://doi.org/10.48550/arXiv.2206.07682>

Jiabao Li

Definition: Emergence occurs when a complex entity has properties or behaviors that its parts do not have on their own, and emerge only when they interact in a wider whole.

Example:

1. The human body is a good example of emergence, as individual parts on their own cannot perform complex functions or support life. Only through coordinated interactions among organs and systems does life emerge.
2. Group is a good example, too. For instance, a team developing an application consists of specialized roles such as frontend, backend, and data engineering. While each role contributes specific skills, the final product emerges from their collective collaboration.

Data:

Data from the human body provide good examples. Data such as brain MRI and cardiac CMR can help analyze how complex functions emerge from interactions among biological components.

Source: Wiki of emergence (<https://en.wikipedia.org/wiki/Emergence>)

Joseph Duhamel

Definition: Emergence is a phenomenon where a complex system takes on properties or patterns that are not readily apparent or realized in the simpler components of the system.

Example: Emergence occurs when a hive or colony of bees swarms. Millions of bees can move in an organized fashion entirely off of single bee-to-bee interaction. This is sometimes called the creation of a “superorganism” and occurs either when the bees are attacking something or when they are moving the queen to find a new hive.

Source: [Of biofilms and beehives: An analogy-based instructional tool to introduce biofilms in school and undergraduate curriculum.](#)

[What is Emergence?](#)

Matthew Wong

Definition: Emergence seems to be features of a model or system that arises after reaching a certain amount of complexity, something that can't be contained in any other system of lower level. In other words it is like leveling up something that transforms properties into something that can only be replicated at a high level.

Example: Reading an article "Emergence," by Vintiadis, they underline how neural networks comprises of layers of neurons that at a low level do simple linear algebra but overall highlights pattern analysis.

Source: <https://iep.utm.edu/emergence/>

Minh-Chau Bach

Definition:

Emergence is when new system-level properties arise from interactions among simpler parts, even though those properties are not present in the parts themselves. The key idea is that the combination of interaction and feedback over time produces qualitatively new behavior or structure

Examples:

In domestication, traits like docility or diverse coat colors arise from long-term interactions between humans and environments, not from a single deliberate design step.

Relevant Data and Sources:

Genomic studies show that domestic animals accumulated new functional mutations and greater trait variation after entering human-managed environments. Archaeological data also show gradual changes in animal body size and herd management over thousands of years, indicating traits emerged progressively rather than appearing all at once.

https://www.rpgroup.caltech.edu/aph150_human_impacts/assets/pdfs/Larson_2014.pdf

Uly Borek

Definition: Emergence occurs when a system demonstrates distinct properties or behaviors as a function of component-level interactions that are poorly defined at the component-level.

Examples: The human capacity to read, emergent forgiveness as opposed to moralized or forced forgiveness, generalization in machine learning, how rain makes you wet.

Relevant Data & Sources:

- [The unique role of the visual word form area in reading](#)
- [Generalization \(Machine Learning\)](#)
- [Forgiveness](#)

William Vogel

Definition: Emergence is the phenomenon where complex, system-level patterns or behaviors arise from the interaction of many simple components, even though those patterns are not explicitly present in the individual components themselves.

Example: In satellite constellations, global communication or Earth-observation capability emerges from the coordinated operation of many individual satellites. A single satellite cannot provide continuous global coverage, but through orbital phasing, handoffs, and network coordination, the constellation exhibits a new system-level capability absent in any one spacecraft.

Source: <https://www.nasa.gov/centers-and-facilities/ames/what-is-nasas-distributed-spacecraft-autonomy/>

Jake Gwinn

Definition: Emergence is the quality or phenomenon where new higher level patterns or features can be recognized at a group level from the interactions of smaller or lower level components or features. These patterns or features are not explicitly seen in the lower level components. In short, the interactions or sum of the parts does something that the parts themselves cannot.

Example: This is ubiquitous in music. Basic sound waves, when patterned by simple rules (like scales or rhythm), create complex, recognizable structures like melodies, harmonies, and rhythms that listeners perceive as meaningful themes or stories. Specifics include: Timbre as an emergent spectrum; Polyrhythm to composite rhythm, ensemble intonation and beating. Even improvisation of groups can show emergent collective dynamics.

[*The Science of Music*](#), Mark Newman, Amazon KDP (2023). See also [Mark Newman](#)

Yinan Dong

Emergence is when system-level patterns arise from many local interactions among simpler parts, and that often become clear only when you look at the system at the right scale. For example, some social events among human.

Junyu Lu

Definition: Emergence is defined through "Biological Relativity," asserting that there is no privileged level of causality. Instead, each level of organization possesses its own causal power, allowing higher-level systems to influence lower-level components through downward causation.

Example: Human organizations, such as corporations or universities, demonstrate this. The organizational structure persists and retains the power to direct actions (like strategy or hiring) independent of specific individuals, effectively constraining the behavior of the "parts" (employees) within the system.

Source: *The Music of Life: Biology Beyond the Genome* (2006).

Allison Park

Definition: Emergence occurs when a system collectively comes to a certain decision or state of being, particularly driven by interactions within the system.

Example: Some examples of emergence are the development of fads/trends, social movements, and music genres. Each of these begins with one person doing something. Other people then see/hear this thing and do something similar. This happens over and over again until the original thing has developed into something bigger. This process shows the emergence of a new fad/trend/social movement/music genre that starts with one person, spreads to other people, and then becomes popular enough within society to have a "life" of its own.

Spencer Rosenblum

Definition: The recognition or discovery of a pattern, or new system, from pre existing data or a pre existing state

Example: To me, the classic example of emergence is the butterfly. Butterflies begin their lives as caterpillars, existing and operating in the same way as many instincts, such as millipedes. Then, after a stage of metamorphosis, the caterpillar **emerges** as a butterfly. Similar trends can

sometimes be observed in fish, birds and ants (which seemingly act random, but when placed in the larger context of a group a pattern may emerge). Similarly, insights and take aways may be observed from numerical data when placed in different context

Name: Yahir Ruiz-Meneses

Definition: Emergence is the process by which new behaviors or functions come into being from the interactions of simpler components, even though those behaviors are not present in the individual parts themselves.

Example: In aerospace engineering, flutter is a phenomenon that arises from the interaction between structural elasticity, aerodynamic forces, and inertial effects. Moreover, the wing structure alone does not “flutter.” The airflow alone does not cause instability. But when airflow interacts with a flexible wing at certain speeds, a self-sustaining oscillation suddenly emerges. This oscillatory motion is not designed into any single component, but emerges from their coupling. The system transitions from stable behavior to a new dynamic state once a critical condition (airspeed) is reached.

<https://onlinelibrary.wiley.com/doi/10.1002/msd2.12015>

Syed Wafi Abdullah Noor:

Definition: We can think of emergence as the ultimate teamwork effect, where a group creates something far smarter or more complex than any single member could manage on their own. It's what happens when simple parts interact without a leader telling them what to do. The group essentially develops a life of its own that is totally different from the individuals inside it.

Example: A starling murmuration is a massive flock of birds that moves like a fluid, shapeshifting cloud. There is no leader. Instead, the complex pattern emerges because every individual bird follows three simple local rules: Separation (don't crowd neighbors), Alignment (steer where neighbors steer), and Cohesion (stay close to neighbors).

Source: Craig Reynolds (1987), "Flocks, Herds, and Schools."

Zihe Ban:

Definition: Emergence occurs when wholes (e.g. the economy) produce outcomes that differ categorically from those that the parts (e.g. human agents) can produce individually. “Emergence is about the properties of wholes compared to those of their parts, about systems having properties that their objects [i.e. elements] in isolation do not have.

Example: Prices are emergent because no single buyer or seller “contains” the market price by themselves; the price arises from the *connective structure* of many agents interacting through exchange.

Source: <https://www.sciencedirect.com/science/article/abs/pii/S0167268112000200?>

Hongyi Liu:

Definition: Emergence is a phenomenon that a collective system exhibits new properties or behaviours but individual components do not have on their own. It emphasizes the new function created by the interaction between each as a whole.

Example: Embryonic patterning is driven by precise spatial and temporal regulation of gene expression across many cells, resulting in the emergence of highly organized tissue structures.

Source: Garcia-Guillen J, El-Sherif E. From genes to patterns: a framework for modeling the emergence of embryonic development from transcriptional regulation. *Front Cell Dev Biol.* 2025;13:1522725. Published 2025 Mar 20. doi:10.3389/fcell.2025.1522725

Jiayue Tang:

Definition: Emergence refers to the phenomenon in which complex, organized behavior or new functions arise from interactions among simpler components, even though these properties are not present in the individual parts themselves.

Example: In ecology, stable ecosystems arise from interactions among species. In physics, synchronization phenomena such as those described in Strogatz's *Sync* show how spontaneous order emerges in systems ranging from fireflies flashing together to coupled oscillators. In social systems, collective behaviors like consensus formation or crowd dynamics emerge from repeated local interactions between individuals.

Source: Tasos Papastylanou, Rodrigo Ramele, Luca Citi, Caterina Cinel, et al. (2023). PES - Pandemic Emergency Scenario. OpenNeuro. [Dataset] doi:10.18112/openneuro.ds004477.v1.0.2

Zhiyu Shuai:

Definition:

Emergence is the phenomenon where a system composed of active, energy-consuming agents breaks thermodynamic equilibrium at the micro-scale, leading to macroscopic phases or collective motion (like "living crystals") that are impossible in passive equilibrium systems.

Example:

Motility-Induced Phase Separation (MIPS). In populations of self-propelled bacteria or synthetic active colloids, clustering emerges purely because particles slow down when they collide. Unlike oil and water separating due to chemical repulsion, this separation emerges solely from the dynamics of motion and crowding, creating dense "liquid" phases amidst dilute "gas" phases without any attractive forces.

Source/Data:

Li-Heng Cai, et al. "Active matter in complex environments." *Nature Reviews Physics*, 7, 120–135 (2022).
<https://www.frontiersin.org/research-topics/23310/active-matter-in-complex-environments/magazine>

Alessandra Serrano Marroquin:

Definition: Emergence describes situations where interactions among many simple units give rise to system-level interactions and behaviors that cannot be attributed to any one of those

individual units alone. These behaviors are a result of local interactions and feedback that become visible when the system is viewed as a whole.

Example: The slime mold (*Physarum polycephalum*) is a collection of several simple cellular units that act as one functional unit when aggregated together. As a whole, they exhibit several complex behaviors to best adapt to their environment, including maze solving, food selection, and network optimization. A classic example of this behavior was observed in a paper by [Tero et al. \(2010\)](#) where the mold “developed a transport grid by connecting food sources representing the stations of the Tokyo railway system” (Ghanbari et al., 2023). This is all done without the slime mold having a centralized nervous system or brain.

Source: Farshad Ghanbari, Joe Sgarrella, Christian Peco, Emergent dynamics in slime mold networks, Journal of the Mechanics and Physics of Solids, Volume 179, 2023, 105387, ISSN 0022-5096, <https://doi.org/10.1016/j.jmps.2023.105387>. (<https://www.sciencedirect.com/science/article/pii/S0022509623001916>)

Ran (Wendy) Hu

Emergence refers to the phenomenon in which complex behaviours arise from interactions among simple components, even though such behaviour is not encoded at individual levels. Collective systems exhibit behaviour that can not be understood by examining isolated parts of the system.

An example is how individual neurons in neural networks perform basic transformations and activations. When organized in a large-scale system and applied to massive datasets, the system is able to perform image recognition, language understanding, and other functions.

Reference: Wei, J., Tay, Y., Bommasani, R., Raffel, C., Zoph, B., Borgeaud, S., et al. (2022). *Emergent abilities of large language models*. arXiv:2206.07682. <https://arxiv.org/abs/2206.07682>

Micah Thorpe

Emergence describes the varied mechanisms that components in any realm achieve more complexity and become greater than the sum of their origins. An example in nature is ants forming a colony which behaves differently than the individual ants when working together.

Source: ["All About Emergence", Marc Kaufman](#)

Advaith Balaji The property where models or systems exhibit new, unexpected, and often sophisticated capabilities only after reaching a certain scale in parameters, training data, or computing power. Some of these capabilities could include complex thought, reasoning, rationale, problem solving, and more. An ability is emergent if it is not present in smaller models or systems but is present in larger ones.

Source: <https://arxiv.org/pdf/2206.07682>

Alexander Arnold - Emergence refers to complex patterns, behaviors, or properties that arise from the interactions of simpler components, where the collective behavior cannot be easily predicted by analyzing the individual parts alone. An example can include traffic flow patterns, individual drivers follow simple rules, yet traffic jams and wave-like congestion patterns can emerge without any single cause.

Shreya Shanbhog - Emergence is when a group of simple things come together and form something new that none of the single things could do on their own. The new thing isn't obvious just by looking at the individual parts. It "emerges" when they interact.

Example: PCA (Principal Component Analysis) takes many related data variables and mathematically combines them to find a few new directions that explain most of the variation in the data. These directions are not given in the data. They emerge from correlations between variables.

Source: <https://en.wikipedia.org/wiki/Emergence>

Michael Hintzen - Emergence is the development of a novel property or trend not seen or predicted in the original set of parameters. This property or trend comes about from the interaction of initial items and is not planned for nor initially predicted before interactions take place. Examples include The flow of traffic, where city planners create roads in a way with the intention of drivers going somewhere. They might also attempt to predict the choices of drivers. But only after the roads are built, the behaviour of drivers is seen and an unexpected behaviour can emerge.

Source: ["The Emergent Behaviour of Traffic", Joseph B. Altepeter](#)

Logan Wilder

Definition: Emergence is when a group of entities have behavior that is lacking in the individuals of the group.

Nick Feinauer

Definition: Emergence is the phenomenon where interactions among many simple components give rise to new, collective behaviors or functions that do not exist at the level of any individual component and cannot be fully understood by studying the parts in isolation.

Example - Birds flocking. Each bird follows simple rules like maintaining distance, yet the flock as a whole is coordinated and exhibits a fluid motion.

Chen Li

Definition: Emergence is the idea that complex, organized behavior can arise from the interaction of many simple parts, even though each part follows only basic rules and has no awareness of the overall pattern.

Example - ants: one ant just follows simple rules, like following a smell, but many ants together can find food and build nests. Each is simple, but the group is organized.

Ruitao Shen

Emergence describes how simple units following local rules generate complex behaviors that no single unit could produce alone. Biological intelligence offers a clear example. A single neuron fires or stays silent based on its inputs. Yet billions of neurons, connected through synapses and communicating via electrochemical signals, give rise to perception, memory, and decision making. The computational power of the brain does not reside in any individual cell but emerges from network interactions across spatial and temporal scales. We see similar principles in other systems: ant colonies solve optimization problems through pheromone trails, flocks of birds coordinate turns without a leader, and immune cells mount targeted responses through distributed signaling. Recent work using calcium imaging and high density electrophysiology now allows us to observe these collective dynamics directly, revealing how population activity patterns encode information that single neuron recordings cannot capture.

Hanyun Cui

Emergence refers to situations where interactions among simple components produce new, system-level properties that do not exist in the individual parts.

Examples:

In biology, thinking emerges from interactions among neurons, and a heartbeat emerges from synchronized heart cells. In social systems, group consensus can emerge from repeated individual interactions. In physics, superconductivity emerges when electrons move in a coordinated way. These ideas are discussed in *Sync*.

Source: NASA Astrobiology, “All About Emergence”:
<https://astrobiology.nasa.gov/news/all-about-emergence/>

Trevor Perl

Emergence is when a property of systems that is made up of components is observed in only the complex system alone, and not in the individual components that make up the system. An example of this is quantum entanglement, which is an example of strong emergence. This occurs when two particles' spin states become entangled, meaning that their spin states are now entangled / dependent on the other, even if they are many light years away. If the spin is changed on one, the other will be changed, so the system of two particles has a phenomenon that is not present in the individual particles.

Source: <https://www.youtube.com/watch?v=66p9qlpnzzY>

Amanda Xu

The concept of emergence can be interpreted as the manifestation of a novel function/phenomenon from synergistic interactions of smaller components/parts, a novel phenomenon previously unobserved just by examining any of the singular components alone. Emergence is highly prevalent in biology; a notable example is the emergence of physiological function on the whole-organismal level, including behavior and consciousness, from cellular/neural networks. In a sense, the vitality of a living organism “emerges” from the biological interactions of its parts across hierarchical organization. From cells (neurons) to

tissues, organs, and then systems. In order for a behavioral output or movement to emerge, every single component of the biological system must cooperate in synchrony.

Reference, “Commanding Emergent Behavior with Neural Networks:
[10.1016/j.xcrp.2025.102857](https://doi.org/10.1016/j.xcrp.2025.102857)

Donghyun Kim

Emergence refers to the phenomenon in which interactions among simple components give rise to new behaviors, patterns, or functions that are not present in the individual parts themselves.

Yaoyu Chen

Emergence refers to the phenomenon where interactions among many simple components give rise to new behaviors or functions at the system level that do not exist in any single component. It emphasizes how connections and interactions matter more than the properties of individuals alone.

For example, a single neuron cannot think, but many neurons working together can produce thought; similarly, individual heart cells cannot create a heartbeat, but their synchronized contractions do.

Emergence also appears in social systems, where repeated interactions among people can lead to shared opinions or group consensus.

These phenomena are often studied using system-level data, such as network structure, synchronization measures, or patterns in collective behavior.

<https://www.goodreads.com/book/show/5597902-complexity>

Kristian Popov

Definition: I think of emergence as the idea of how, out of the combination of many small, simple base components, complex or interesting structure, behavior, and properties arise.

Examples: In the physical sense, I think of things like magnetism and viscosity — which arise from “collective” behavior as opposed to the behavior of the individual particles. I also think of the brain or of deep neural networks which are made of many seemingly simple neurons. In a more esoteric sense I also think of nations, made of individual people — “E Pluribus Unum” which means “out of many, one” is written on the dollar bill.

Data: This book [“Growing Artificial Societies”](#) details an agent-based simulation wherein tribe conflict / inequality / other behaviors naturally arise from the agents. Look up sugarscape.

Luohaoran Wang

Emergence means when a system is composed of many simple parts, these parts interact to produce properties or patterns at a “system-level” that cannot be directly predicted by examining any single part in isolation.

For example, in an Impressionist or Pointillist painting, each individual stroke of paint is merely a small patch of color or a single brushstroke. Yet when countless such strokes are layered across the canvas in a deliberate composition, the viewer perceives complete objects, layers of light and shadow, and an overall sense of atmosphere.

Reference: Pointillism (2020) Wikipedia. Available at: <https://en.wikipedia.org/wiki/Pointillism>.

Justin Ogata

Definition: Emergence is defined as the phenomenon where a complex system exhibits properties, behaviors, or functions that its individual constituents do not possess on their own.

Example: Hive minds are an excellent example of emergence because individuals themselves are simple organisms with limited intelligence, but as a collective are very complex and highly capable.

Data: <https://www.emergentmind.com/topics/artificial-hivemind-effect>

Ezilsurendar Udayasuriyan

Definition: Emergence describes the ubiquitous and hugely varied mechanisms by which simple components in nature (or in the virtual or philosophical world) achieve more complexity, and in the process become greater than the sum of all those original parts.

Example: A great example of emergence is a colony of ants or bees. Each insect follows simple local rules (like following pheromone trails or responding to nearby neighbors), but when thousands act together without any leader, they create an organized system, like a beehive or ant colony that can build structures, find food efficiently, and defend itself in ways no single ant or bee could do alone.

Source: <https://astrobiology.nasa.gov/news/all-about-emergence/>

Aryan Singh

Emergence is when simple parts interacting under basic rules produce behaviors or capabilities that you couldn't predict by looking at any one part in isolation. The structure of their interactions and the scale at which they operate are the key aspects of this phenomenon. This is evident everywhere from neurons firing to give rise to thought to individual drivers creating traffic jams.

The crucial conclusion here is that true explanation lives at the system level, not the component level, and data collected at the right scale is what makes emergent behavior visible.

Haohua Zhang

Definition: When multiple relatively simple components interact with each other, the system exhibits new behaviors or properties at the overall level that cannot be directly deduced linearly from the properties of individual parts.

Example: Vehicle steering behavior (oversteer/understeer) cannot be predicted from any single component of the vehicle, such as the tires, steering system, suspension elements, or body structure; rather, it is an example of emergence arising from the interactions among these subsystems.

Jang Hyun Lim

I think a single definition becomes too broad to be useful, so it is better to treat “emergence” as an umbrella label and then classify it into domains with different triggers, metrics, and response protocols. There can be numerous categories, below is my example of two categories.

1) Human emergence (medical / safety)

Definition: Time-critical threats to human life, health, or public safety requiring immediate assessment, triage, and intervention.

Examples: cardiac arrest, stroke symptoms, severe bleeding, overdose, fire-related injury, violent assault, suicidal crisis (requires professional support).

2) Mechanical emergence (equipment / infrastructure failure)

Definition: Unexpected equipment or system malfunction that creates immediate risk of harm or mission failure, requiring rapid shutdown, isolation, repair, or redundancy switching.

Examples: battery thermal runaway warnings, coolant leak in a critical system, infusion pump malfunction in a hospital, aircraft mechanical fault, grid substation failure.

Elvin Tseng

Emergence refers to a complex thing (system/pattern/object) that arises from a collection or interaction of small things. An example is fractal.

Caleb Albright:

Emergence is when the interaction of many small parts becomes a lot more complex system, where patterns begin to arise. I think of water molecules that are individual, but because of more complex interactions and properties, particularly surface tension and viscosity, they interact to become larger systems that cling together where their behavior can be predicted as a pattern.

Sihan Chen

I think an emergency is when many simple parts interacting locally produce a new, stable and system-level pattern that people cannot fully explain by looking at any single part alone.

Example:

- 1) Market price shift. Every person makes individual decisions to buy or sell with limited information, but together their actions can create trends, bubbles or sudden changes. Price rising attracts more buyers, price dropping causes more selling, and this loop produces system-level behavior that isn't controlled by any single trader.
- 2) Flocking: Each animal follows simple local rules like “don’t crash” or “match direction with nearby neighbors. Even with no leader, the group can move and turn as one coordinated unit, so group-level coordination in flocking is the emergent behavior.

Mike Reynolds

Emergence is characterized by the creation of temporary or permanent coherent structures in multi-scale systems. They exist as a result of causal links between agents/actors and generally show patterns that are not possible at the micro-level (birds:micro::flocks:macro).

Tingwei Zheng

Definition:

A large number of simple individuals spontaneously generate new capabilities or characteristics at the overall level through local interaction, which are not possessed by a single individual, and such characteristics cannot be predicted in advance by disassembling individuals.

Example:

The most surprising emergence of large language models is that when the parameter scale hits the hundreds of billions, the models suddenly have tools they were never trained to use. A single model parameter is only numerical, and the local attention mechanism only encodes semantic associations. But when the parameter scale and the amount of training data reach the threshold, the model spontaneously learns to call external tools such as calculators and search engines to solve complex problems, such as automatically calling calculators to verify results in mathematical calculations. This ability does not arise from targeted training, but emerges from the collaborative interaction of large-scale parameters, directly driving the leap of AI from generating content to solving complex tasks.

Papers:

Attention Is All You Need <https://arxiv.org/abs/1706.03762>

Toolformer: Language Models Can Teach Themselves to Use Tools

<https://arxiv.org/abs/2302.04761>

Flamingo: a Visual Language Model for Few-Shot Learning <https://arxiv.org/pdf/2204.14198.pdf>

Yixiang Fei

Definition:

Emergence is when a coherent, system-level structure of function arises from many interacting parts, even though no single part “contains” that structure by itself. In dynamical-systems terms, it often appears as the collective state collapsing onto a low dimensional pattern/attractor

Examples:

Synchronization: fireflies flashing in unison
Collective motion: bird flocking / fish schooling

Marcin Sobotka

I read an article a while back about Marie Curie. She was studying radioactive elements and noticed that an isolated item with radioactive properties is actually shinier and thus more radioactive when in its original ore, and so it is more prone to its chemical makeup and surrounding materials and will experience collective behavior such as nuclear decay. Essentially my idea is that there is collective behavior such as decay that may be more/less affected when in ore form as opposed to being isolated with radioactive properties. Hope I understand this right.

Yifeng Huang

Emergence refers to the phenomenon in which coherent, structured, or meaningful macroscopic behavior arises from the interactions of many simple components, without being explicitly programmed or directly inferable from the rules governing individual components. In emergent systems, the whole exhibits properties that are qualitatively different from those of its parts.

A classic example is flocking behavior in birds: each bird follows simple local rules (alignment, separation, cohesion), yet large-scale coordinated motion emerges at the group level. Another example is synchronization in coupled oscillators, such as fireflies flashing in unison or neurons exhibiting rhythmic activity, as described in the Kuramoto model.

Lucy Zhao

Def. Emergence refers to the appearance of coherent, system-level behavior or structure arising from interactions among many simple components, where such behavior is not present or meaningful at the level of any individual component. Importantly, emergent phenomena are often best described at a reduced or low-dimensional level, even though they originate from high-dimensional interactions.

Eg. A canonical example is synchronization in coupled dynamical systems. In models such as the Kuramoto model, each oscillator follows a simple local phase dynamics, yet when coupling strength exceeds a threshold, the population abruptly transitions from incoherent motion to global phase synchronization. No single oscillator “contains” synchronization; it emerges from collective interaction.

Source. Strogatz, S. H. Sync: The Emerging Science of Spontaneous Order. Hyperion, 2003.

Rajdeep Mukherjee

I think Emergence can be defined as a situation where a higher level regularity becomes a workable explanation of a dynamical system, even though regularity depends on the system's lower-level makeup, i.e., the macro pattern is grounded in the parts but has a kind of autonomy in description and explanation that we don't get by only considering the individual components.

Examples: From a machine learning perspective, we can think of Mixture of Experts Large Language Models (MoE LLMs) showing emergence. An MoE architecture is one where certain weights of a LLM (certain networks) are activated when some input is given. This can thus be thought of as a combination of many "experts" who form a dynamical system.

Sources: <https://iep.utm.edu/emergence/>, <https://pmc.ncbi.nlm.nih.gov/articles/PMC10887681/>, <https://www.britannica.com/science/emergent-property>, <https://www.frontiersin.org/journals/complex-systems/articles/10.3389/fcpxs.2025.1667670/>

Romeo Ruan

I think emergence can be understood as a situation where aggregate-level structure or regularity provides a meaningful and practically useful explanation of a system, even though that structure is generated by interactions at a lower level. In other words, macro-level behavior is grounded in micro-level components, but cannot be fully understood or efficiently described by analyzing those components in isolation. The higher-level description has a degree of explanatory autonomy, despite being dependent on the underlying parts.

Example: In insurance, portfolio-level loss behavior exhibits emergence. Individual policyholders' claims are driven by heterogeneous risks. At the micro level, each policy follows its own stochastic process. However, when these policies are considered together, we may have heavy-tailed loss distributions.

Source: <https://www.investprogram.org/students/insurance-in-real-life/law-of-large-numbers.aspx>

Rachel(Rui) Shi

I think emergence can be defined as complex patterns or behaviors that arise from simple interactions among individual components without centralized control. These system-level behaviors cannot be fully understood by analyzing each part in isolation. For example, flocking behavior in birds emerges from simple alignment rules, and epidemic waves arise from individual infection and recovery processes. Relevant data include time-series data (e.g., infection curves), agent-level trajectory data, and outputs from simulations such as agent-based or SIR models, which help us study how local interactions generate global structure.

Le Zhang

Emergence is when many simple parts interact with each other and produce a new pattern or behavior at the system level. This new behavior is not something we can easily see by only

looking at one individual part. In other words, the whole system can show properties that the separate parts do not have.

One example is traffic congestion. Each driver only makes simple decisions, such as slowing down, speeding up, or keeping distance from the car in front. However, when many drivers interact on the road, small changes can build up and create a traffic jam, even when there is no accident or clear cause. Relevant data could include vehicle speed, traffic flow, road density, and time-series data from highway sensors. This kind of data can help show how individual driving behavior leads to larger traffic patterns.

Victoria De La Rue

Filippo Michelis

I think of emergence as a property of a system that cannot be predicted from the properties of the single components of the system.