Complexity and Uncertainty

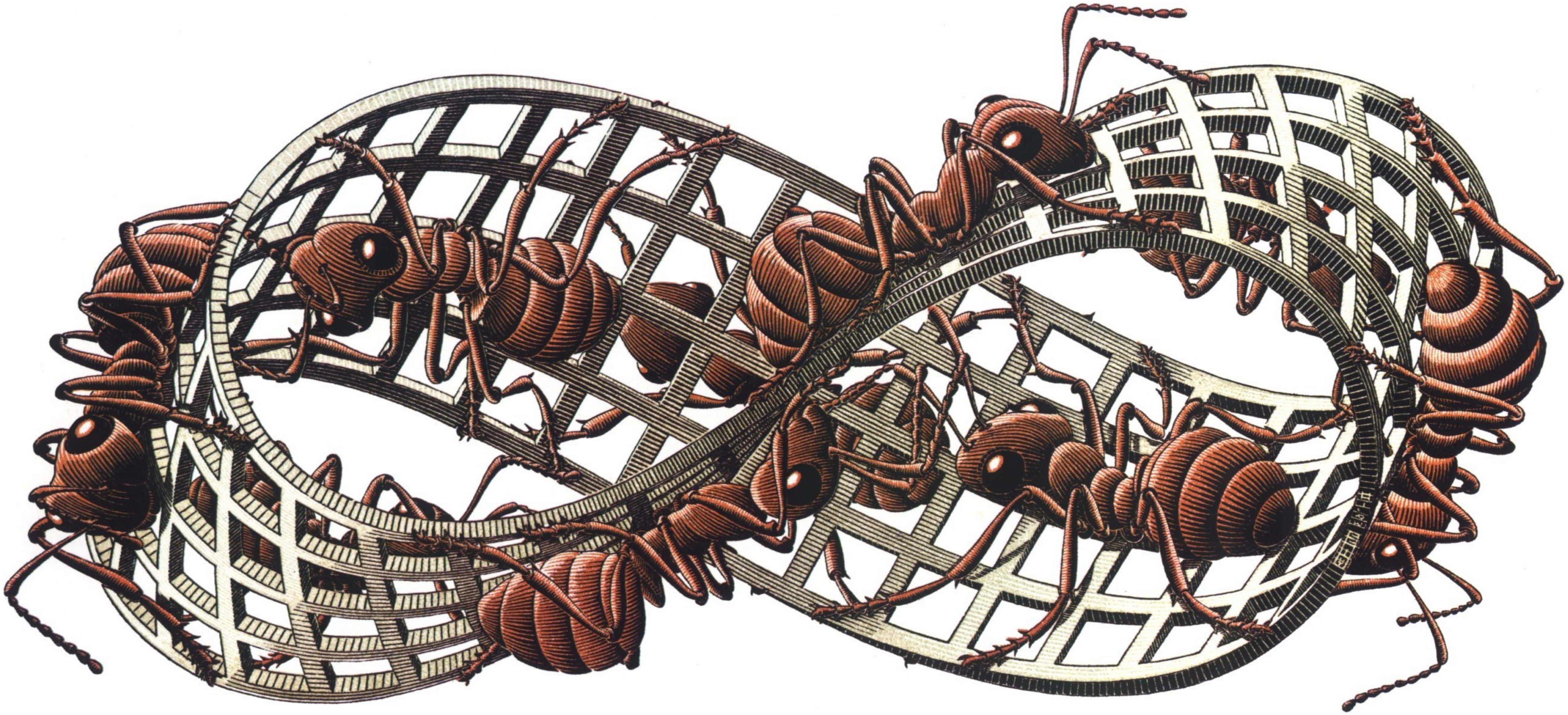
Dr. Gene Callahan’s Intro to Computer Science Class
February 19, 2021

Instructor: Joe Norman

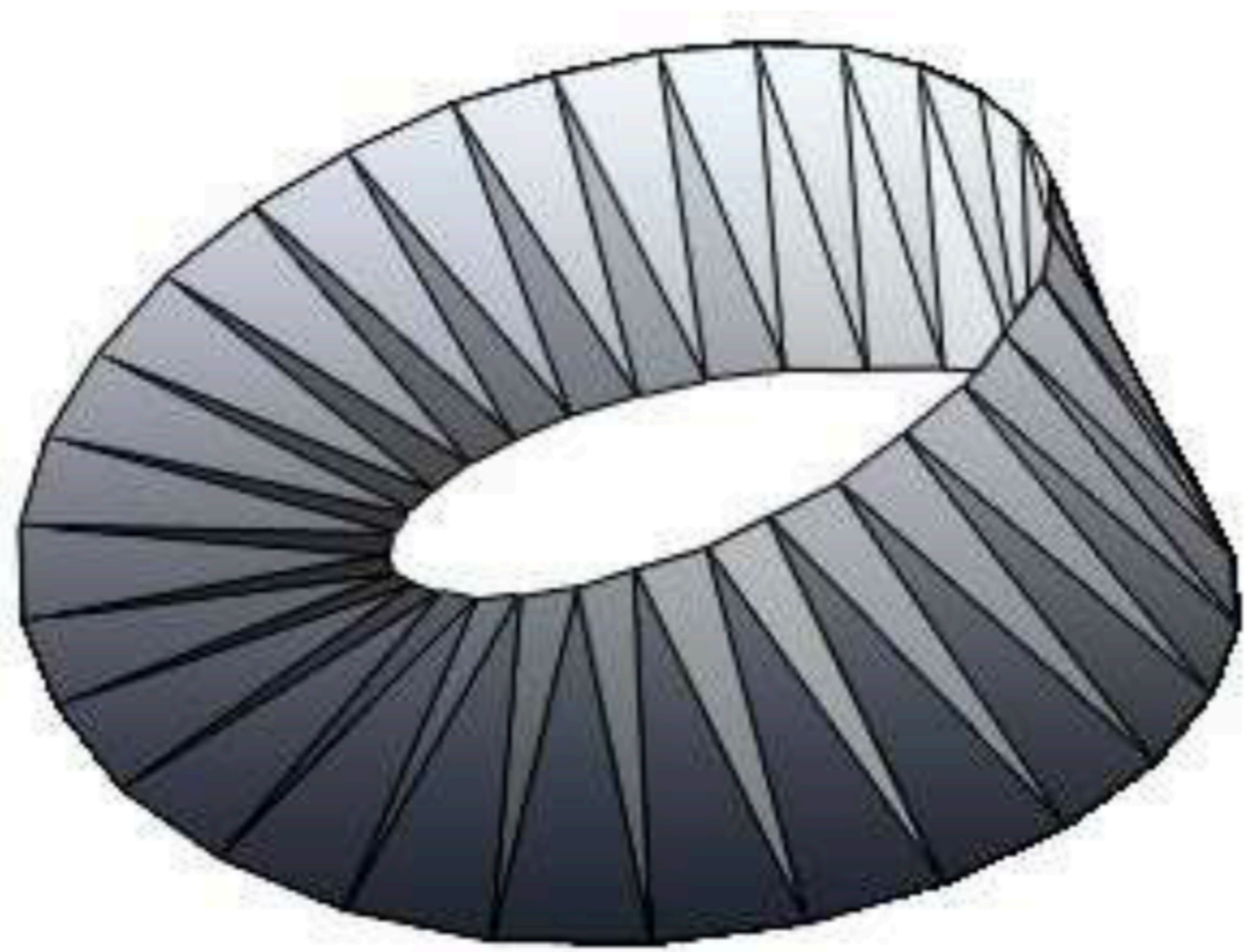
Complexity

Sources of Order / Innovation in Organic Systems / Sources of Uncertainty

Möbius Strip

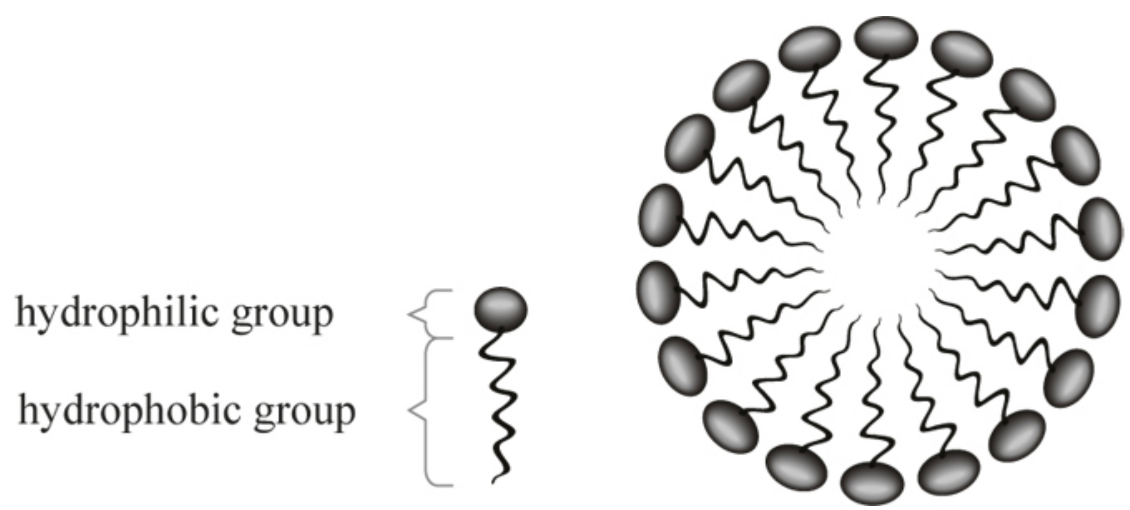


Möbius Strip



Self Organization

- No “plan”, “blueprint”, or “template”
- Distributed agents engage in “local” interactions and behaviors, order forms “globally”
- “Spontaneous” order



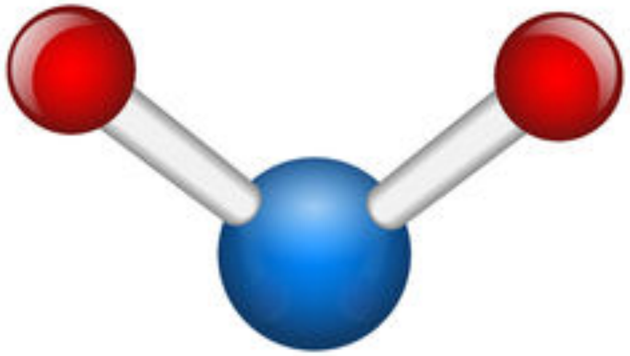
Complex Systems

Reductionism

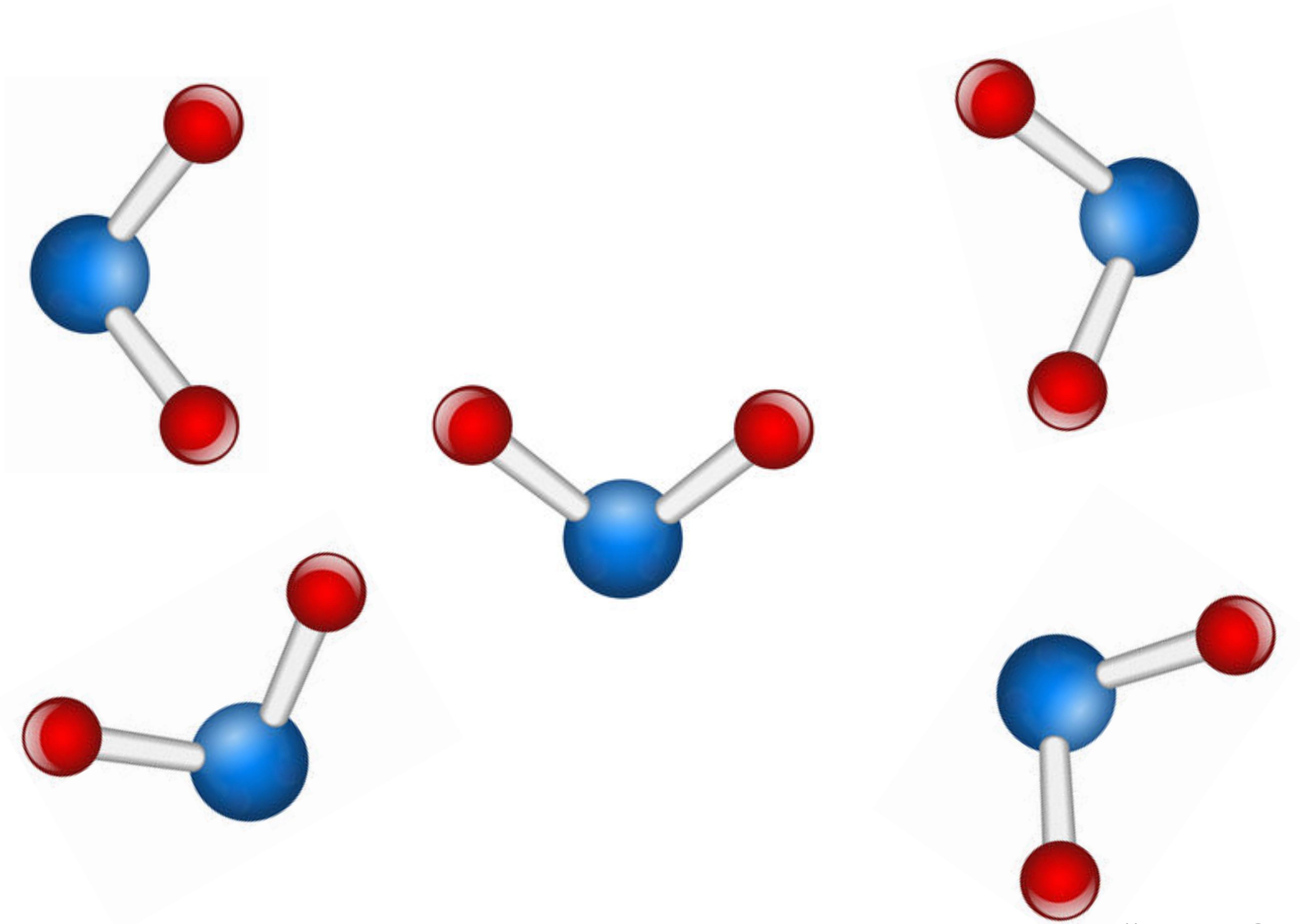
- Assumption about how the world works
- To understand the world (or any system):
  - Decompose it into parts
  - Study properties of parts
  - Putting the parts back together into big picture is trivial
- Through lens of reductionism: EVERYTHING can be understood this way (in principle)

Irreducibility and Emergent Properties

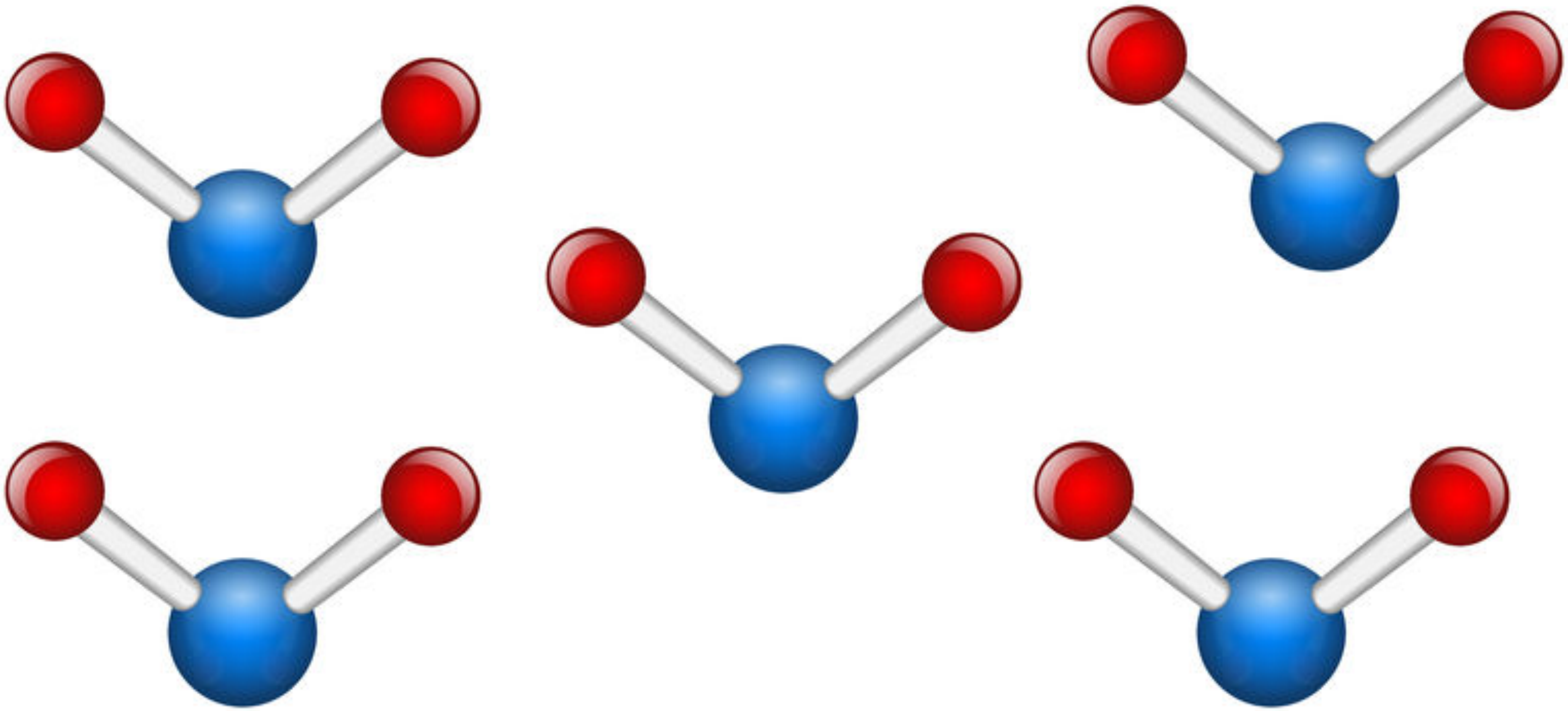
H20



H2Os



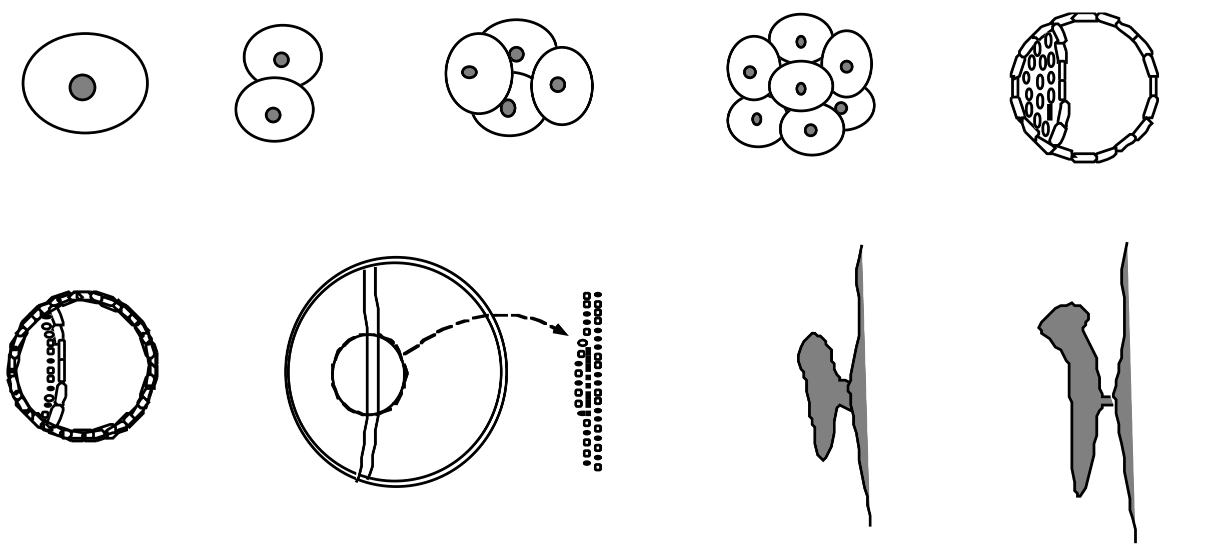
H2Os

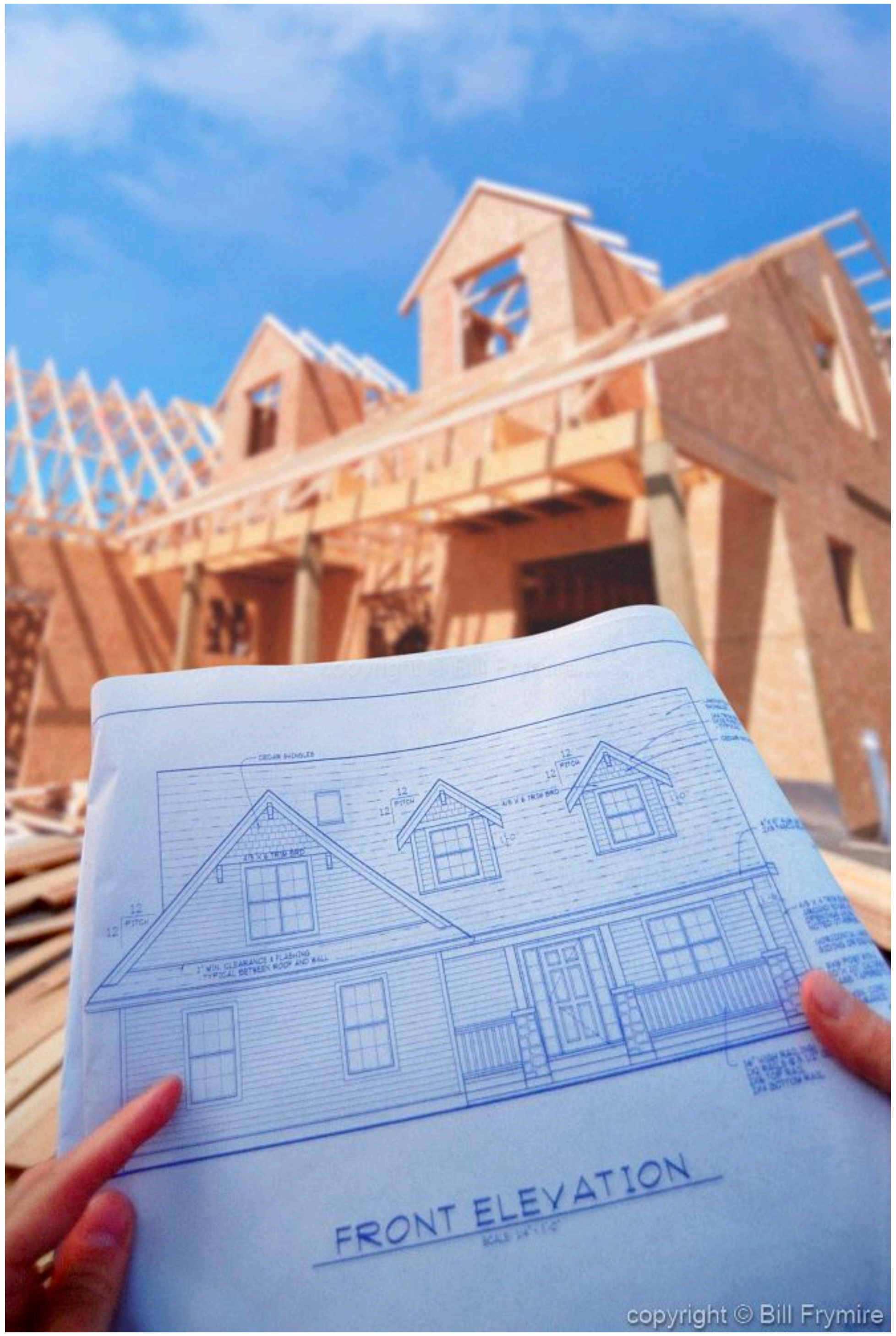


Musical Example

https://pianoapp.net/

Organization





Functions as Maps

- A “function” is a map, from every item in some set, to a single item in some set
- Like a little machine, you put something in at one end, and you get the something out at the other end
- A formula that defines a function is a way of compressing a description to define a map for all values in a set.
- A formula can DEFINE a function, but the notion of function is more general, and simply indicates a (single-valued) mapping

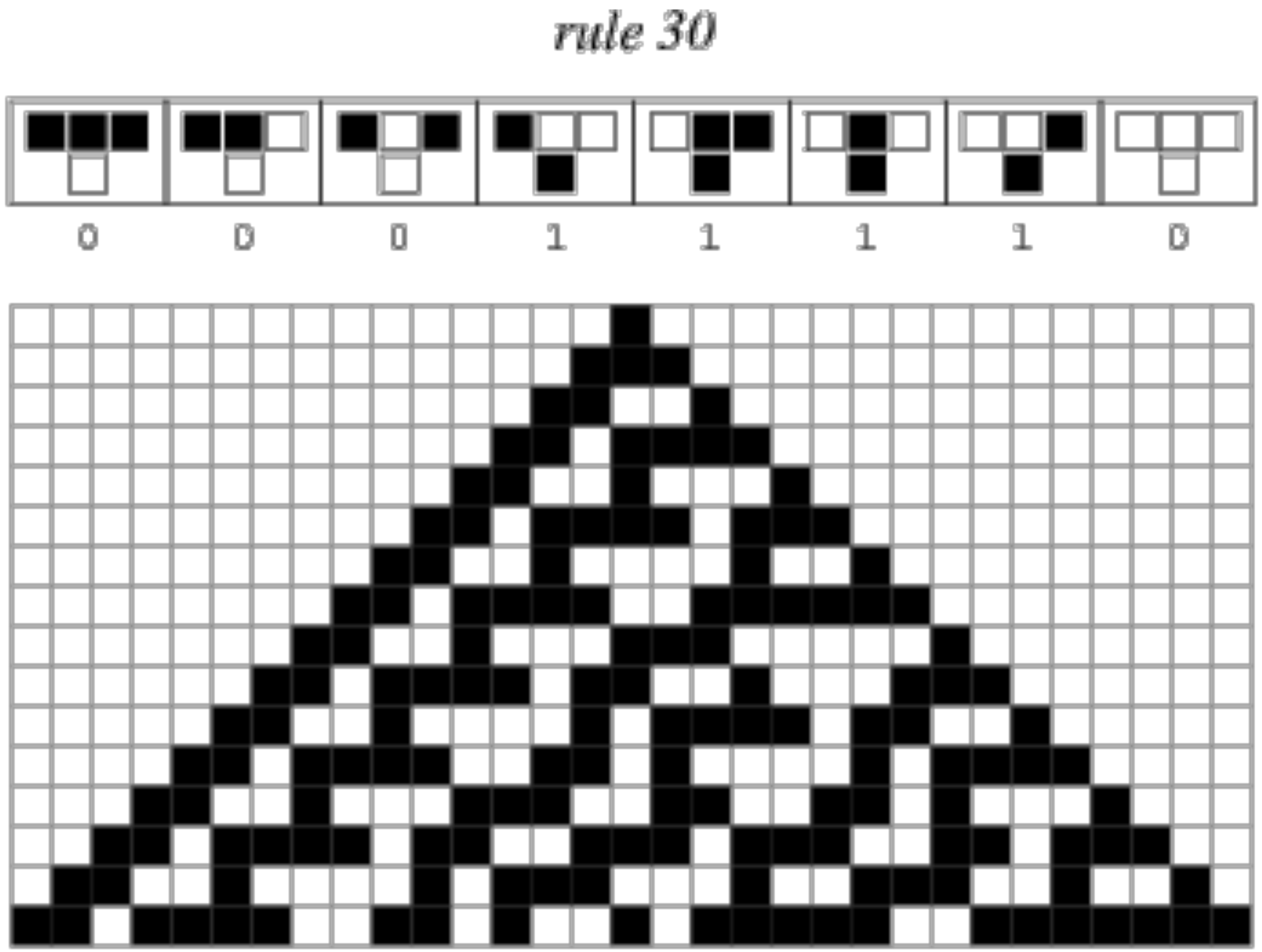
Recursive functions

- Put something in the function, get something out, put what you get out back in the function, keep doing that
- In discrete time, this is essentially a “difference equation”
  - s[t] = f(s[t-1])
  - f() here is the “dynamical law”
- Continuous generalization is a “differential equation”
  - dx/dt = f(x)

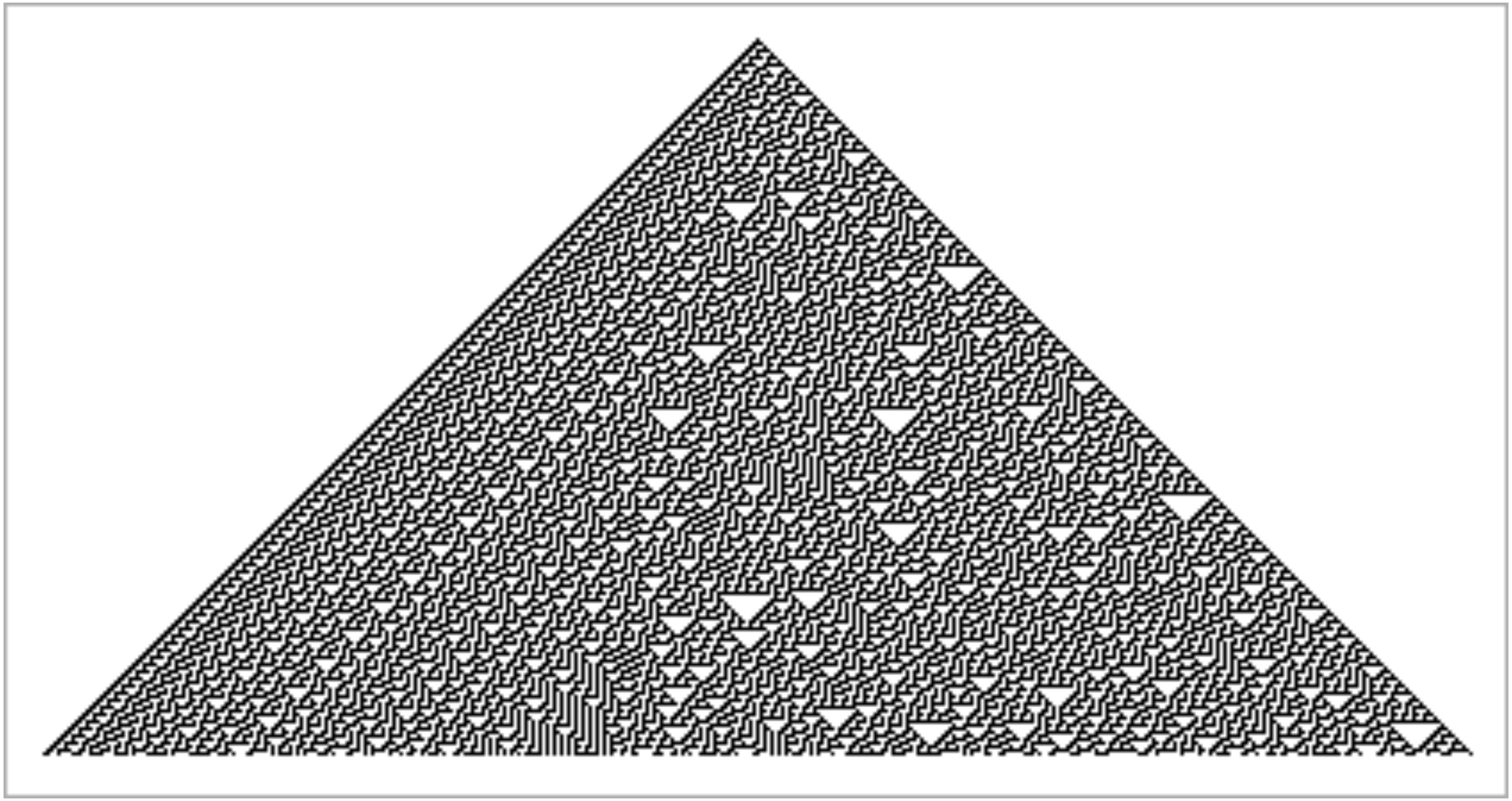
Dynamic patterns

- “Organization” of the dynamical law yields various behaviors
- e.g. fixed point (stable/unstable), cycle, reducible/irreducible

Cellular Automata



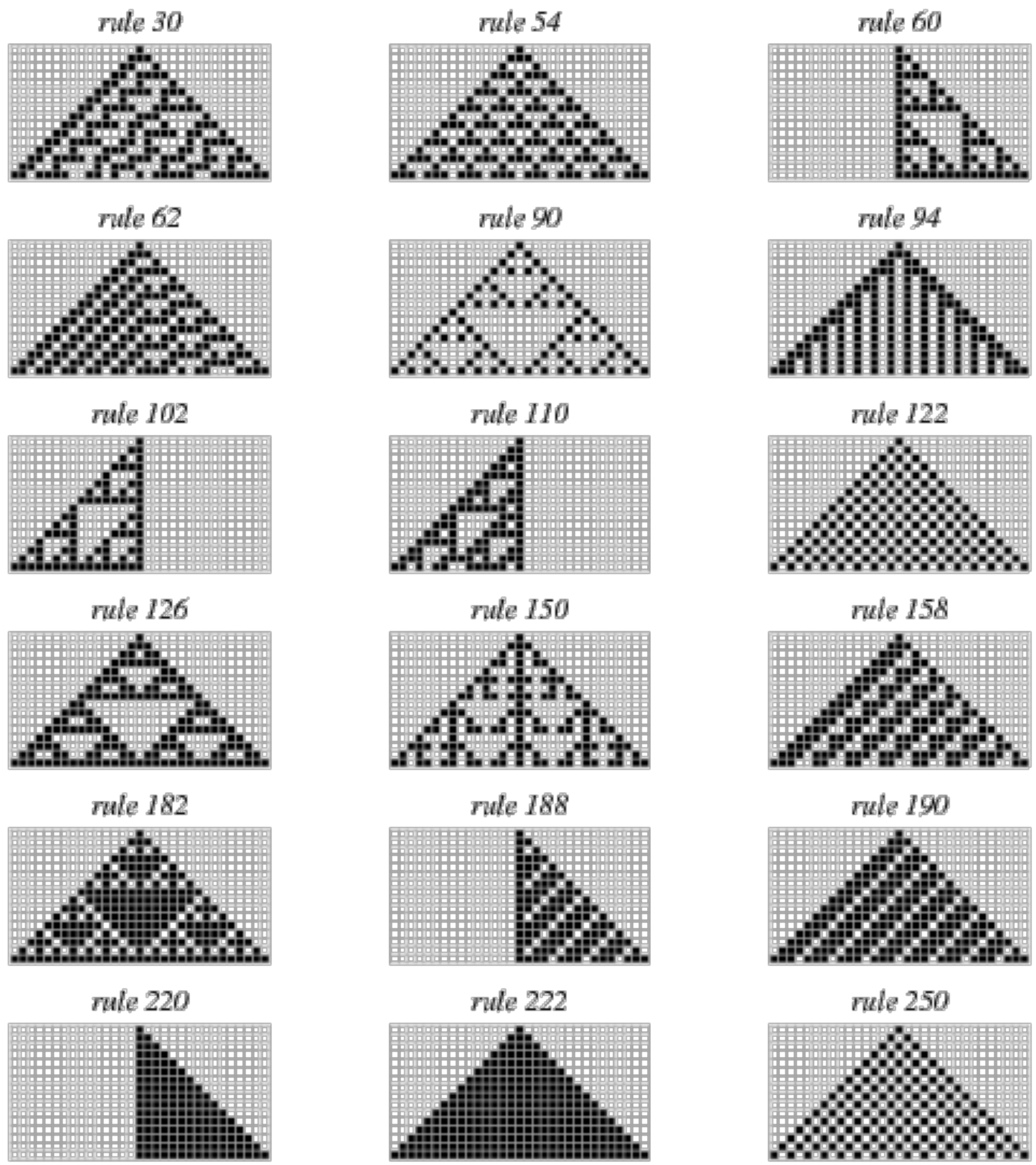
Cellular Automata



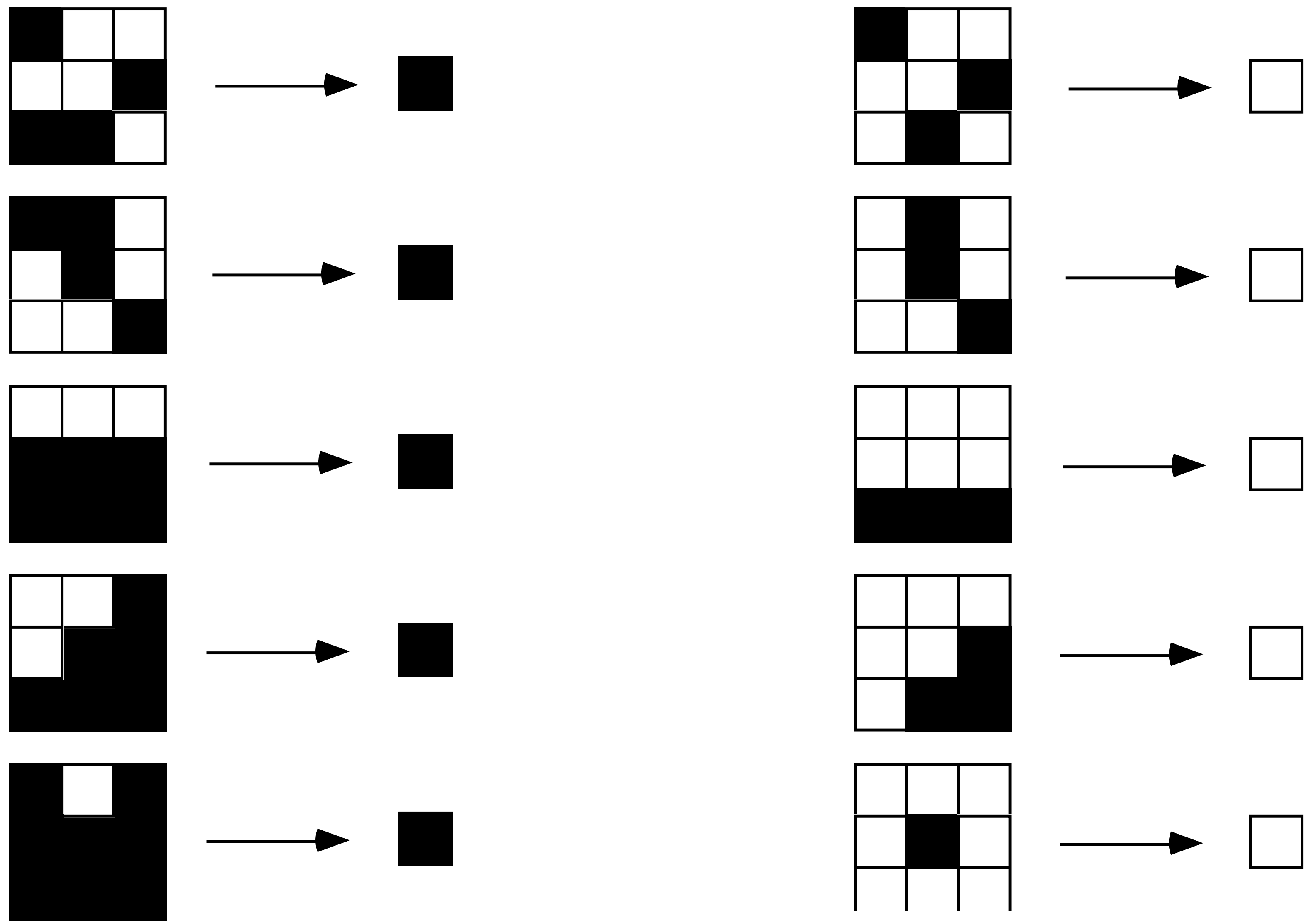
Cellular Automata

https://appliedcomplexity.io/eca/

Cellular Automata



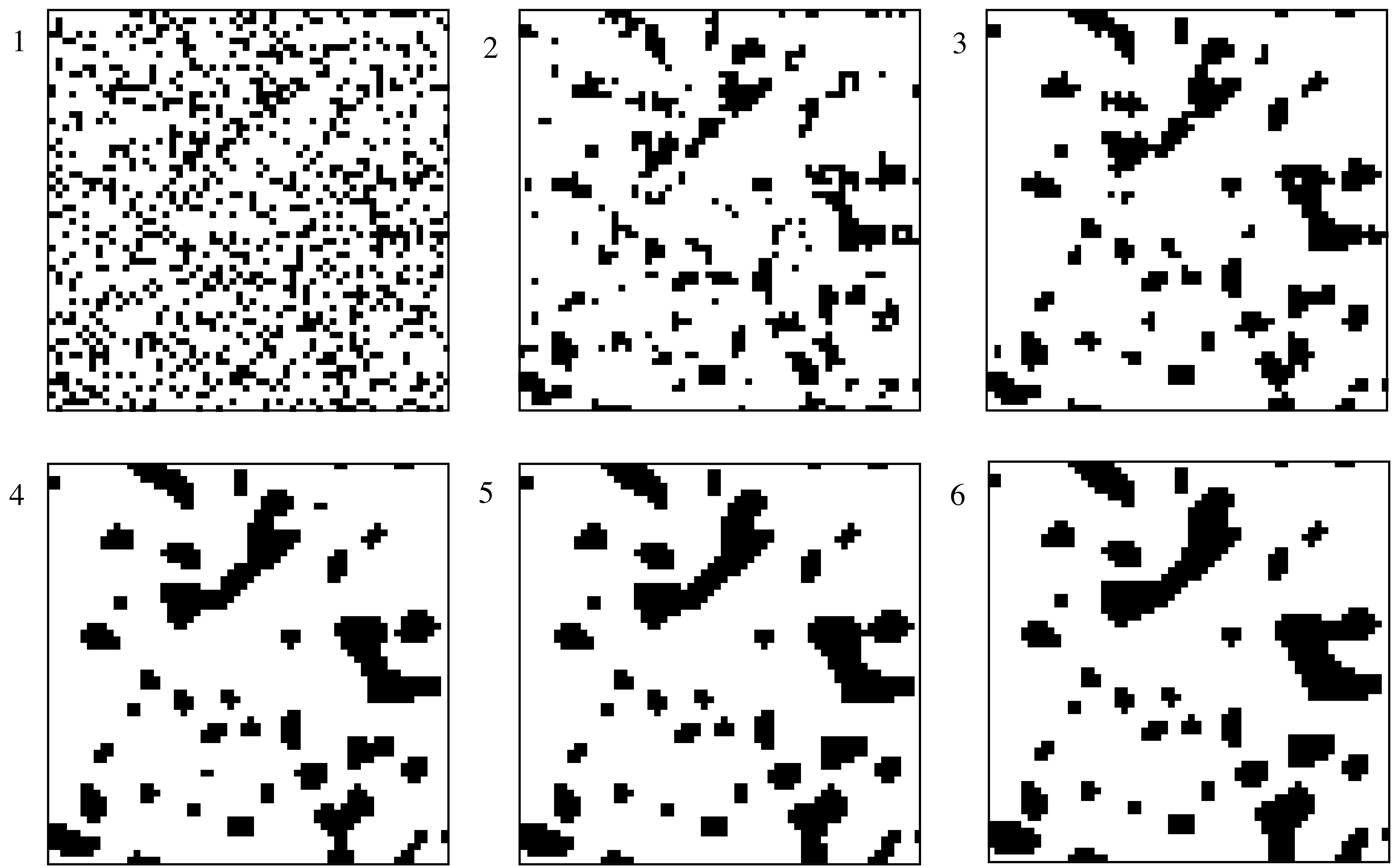
Panic



$$s_i = \mathrm{sign}(\textstyle\sum_{nn} s_j + 2)$$

https://appliedcomplexity.io/ca_panic/

Panic



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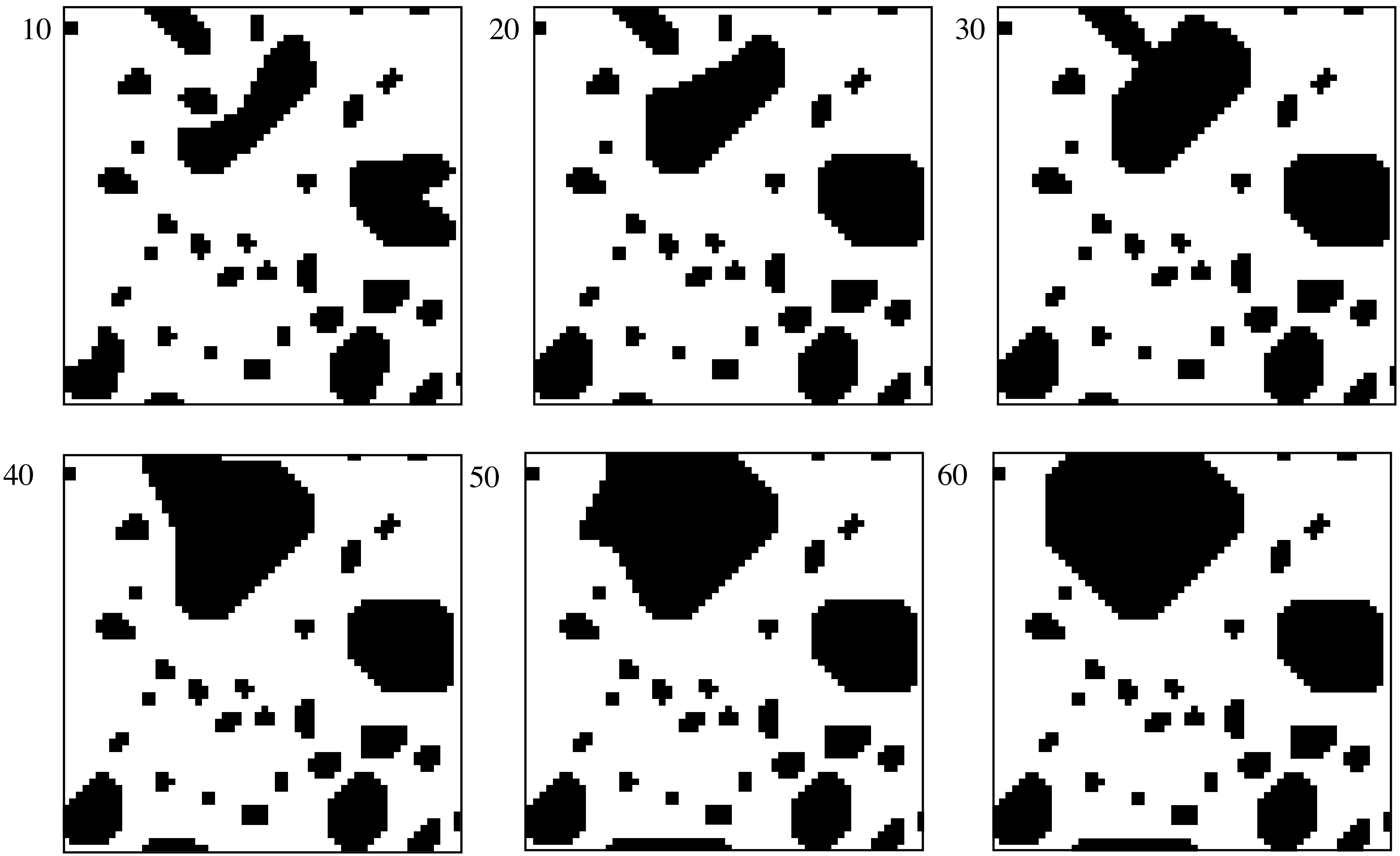

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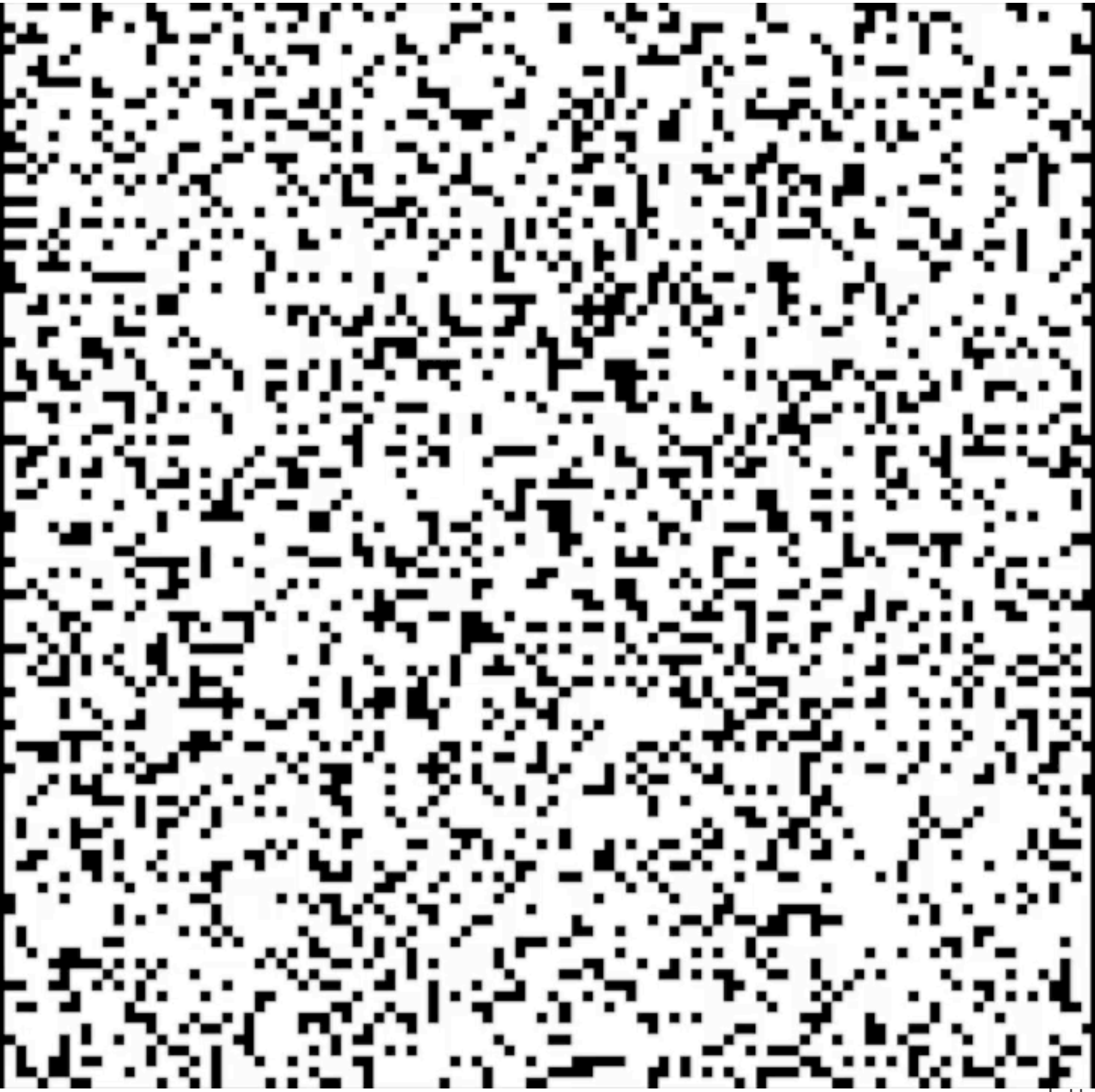

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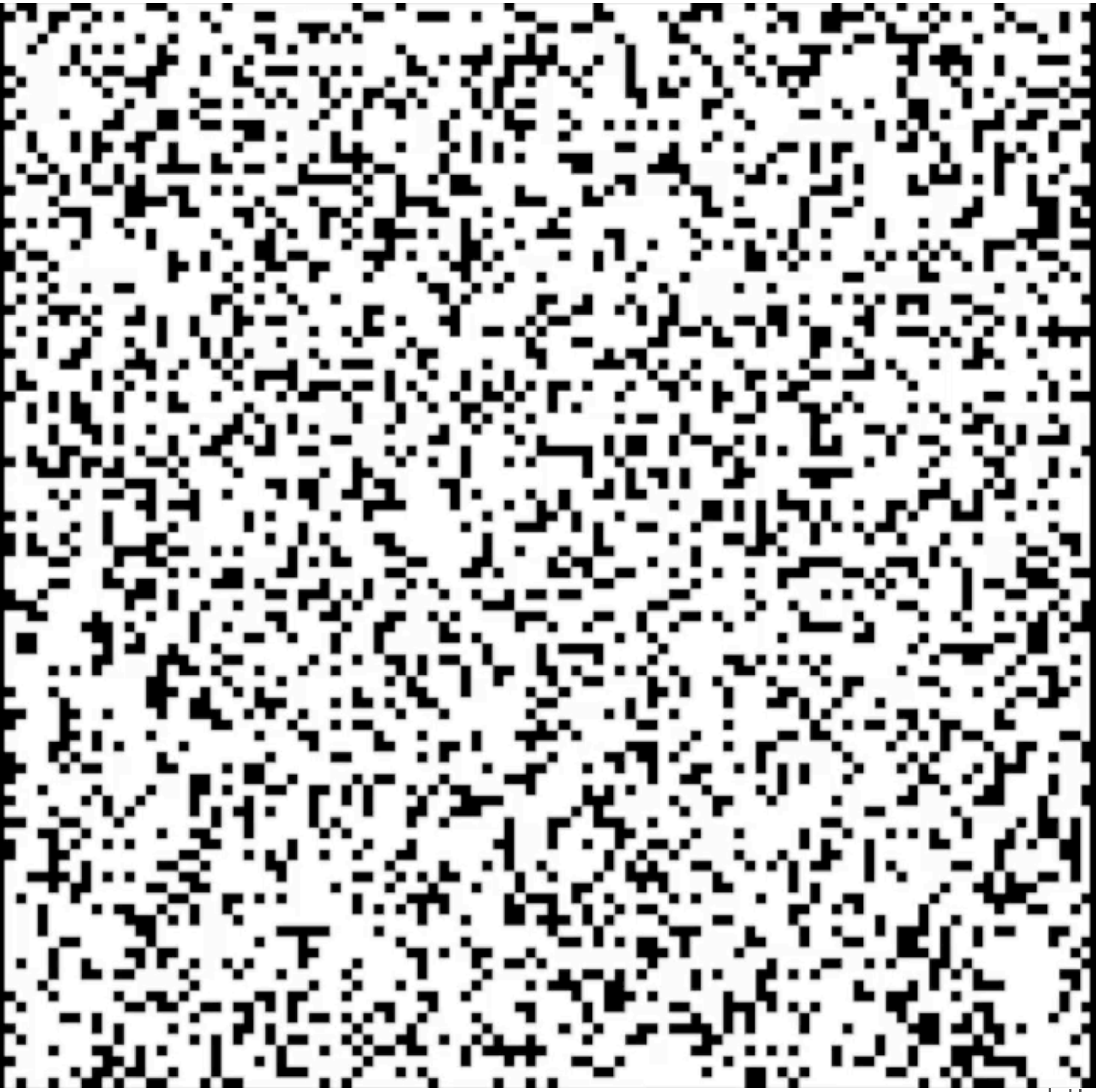
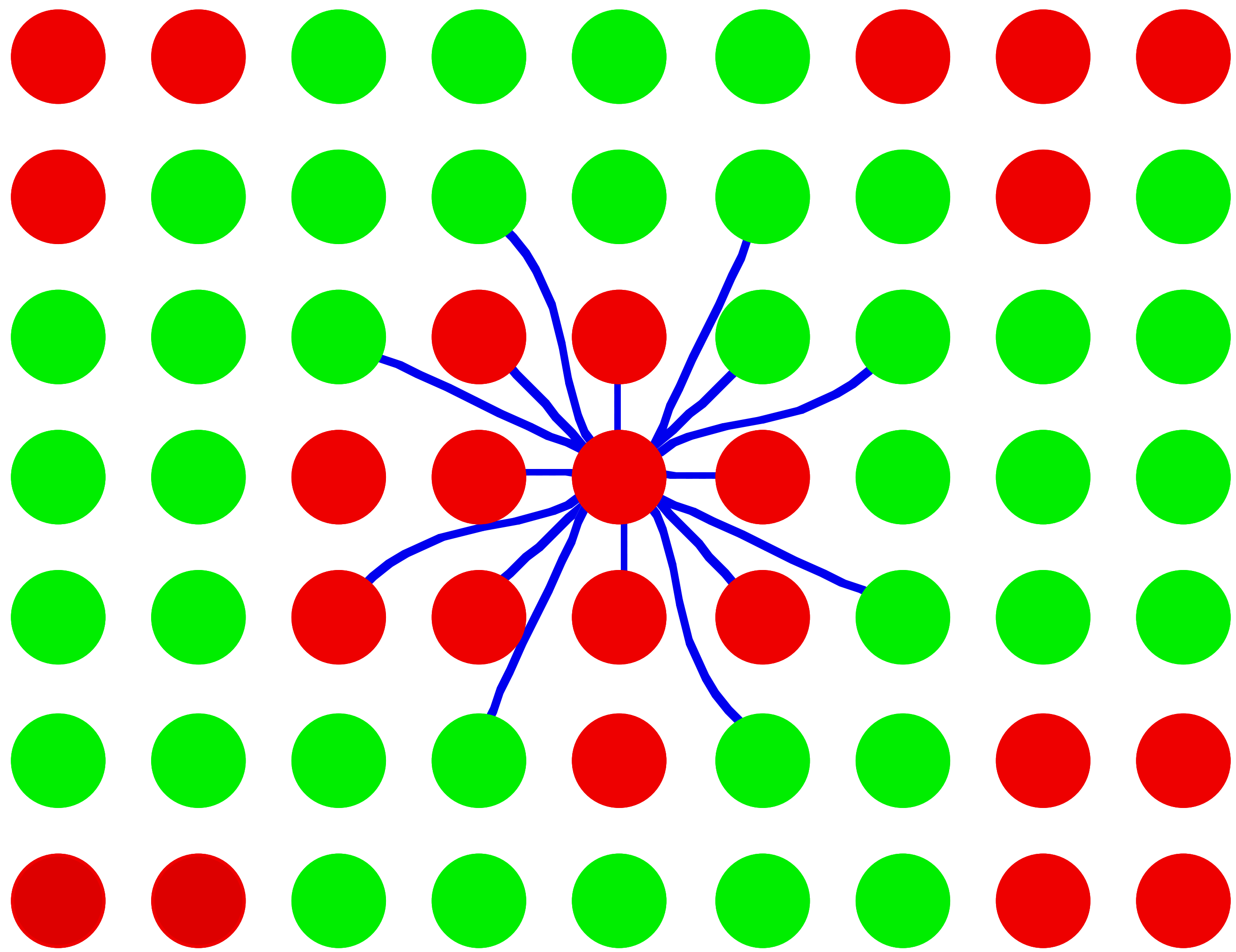


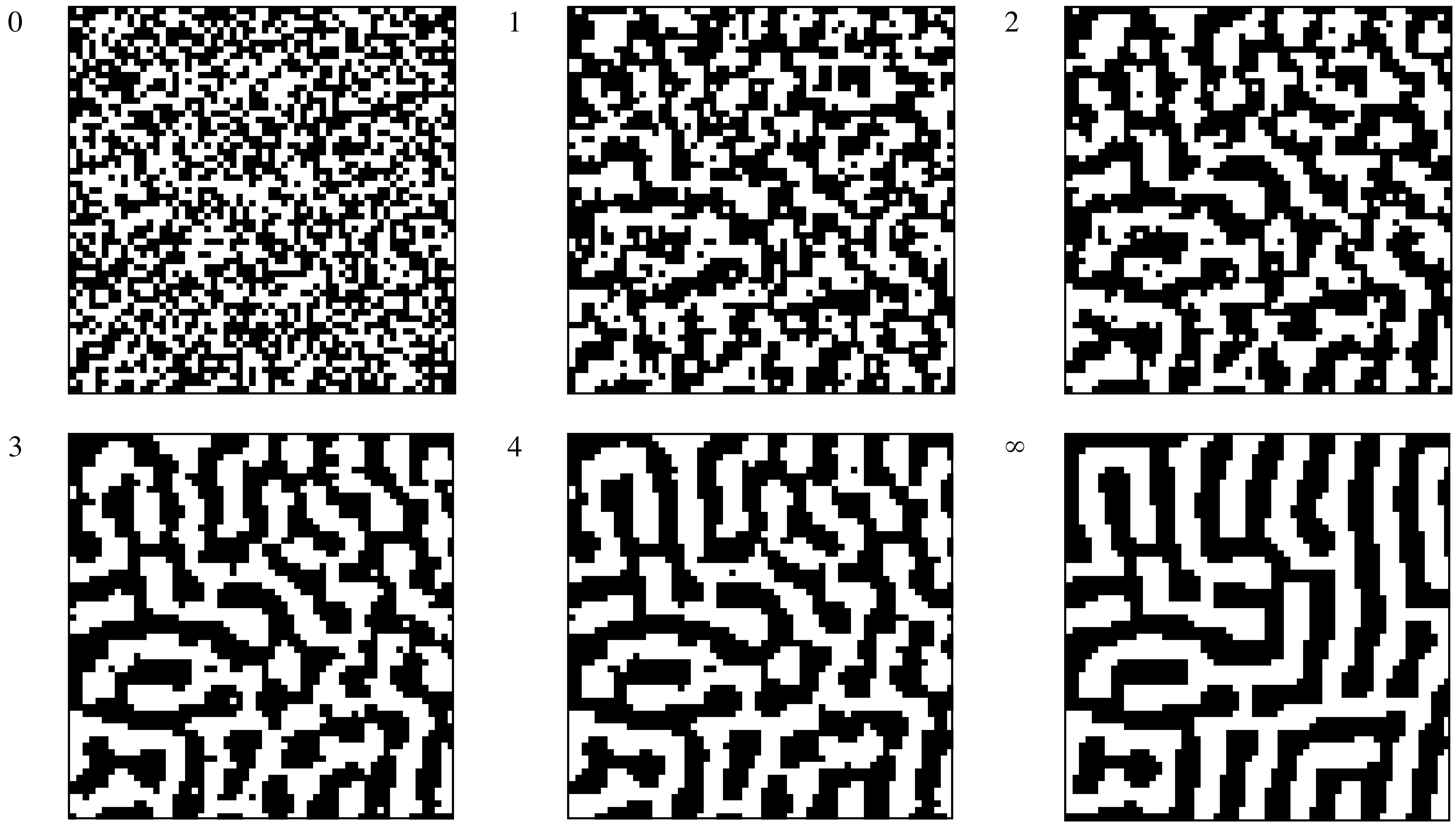
Local Activation
Long-Range Inhibition

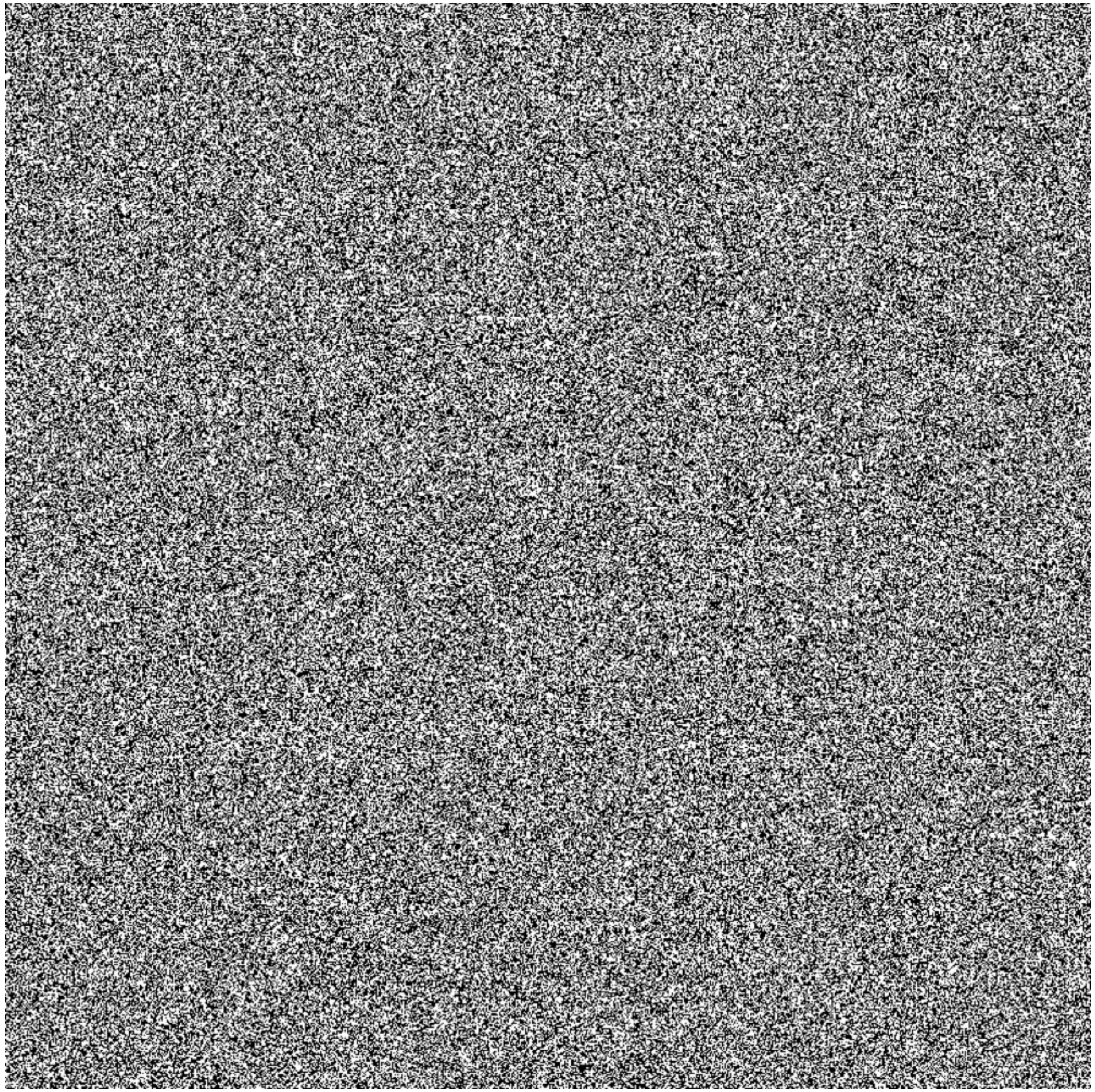


$$s_i = \text{sign}(h + J_1 \textstyle\sum_{|i-j|<R_1} s_j + J_2 \sum_{R_1<|i-j|<R_2} s_j)$$

do the same as close neighbors
do the opposite of further neighbors

Local Activation
Long-Range Inhibition





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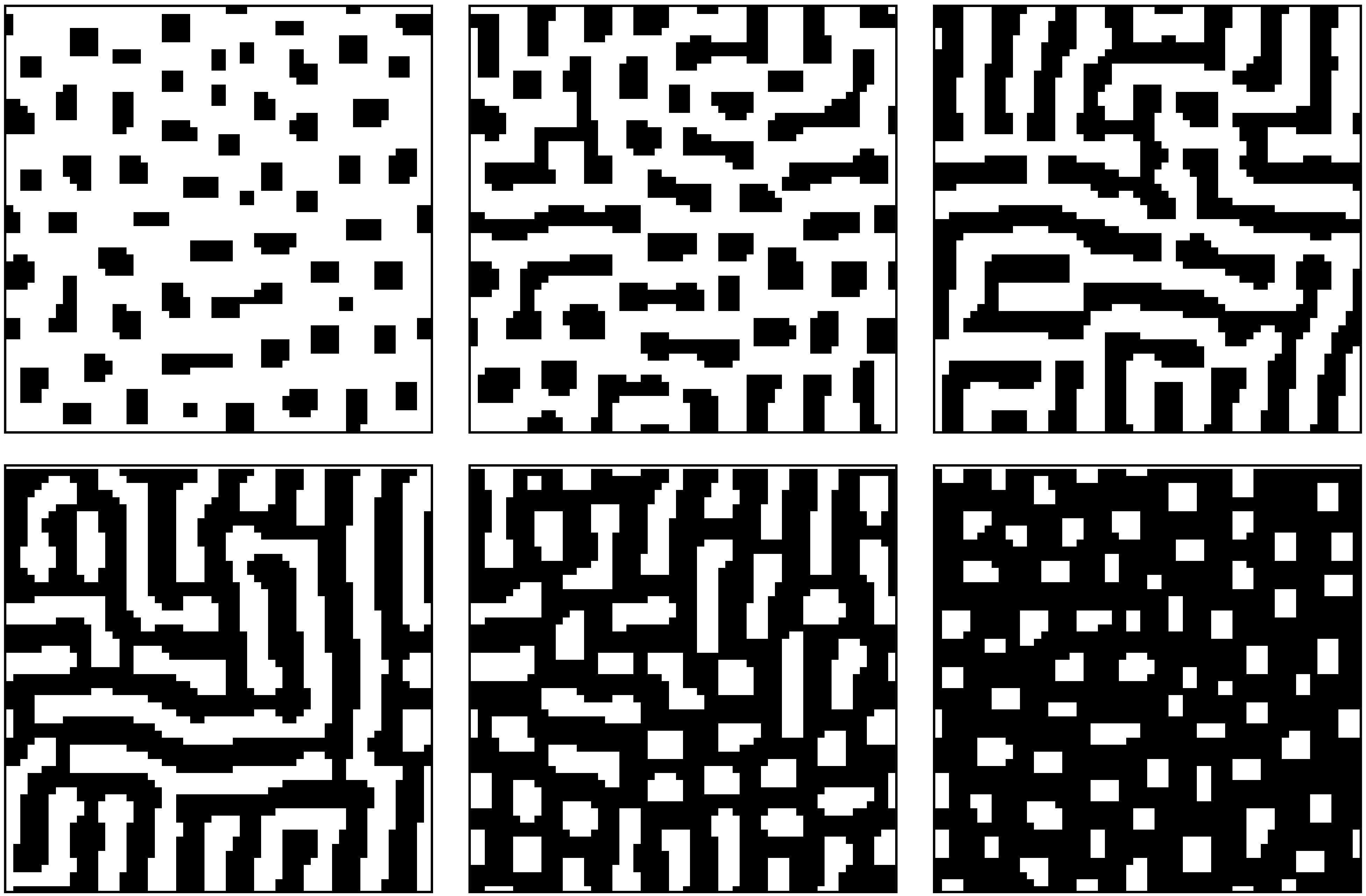
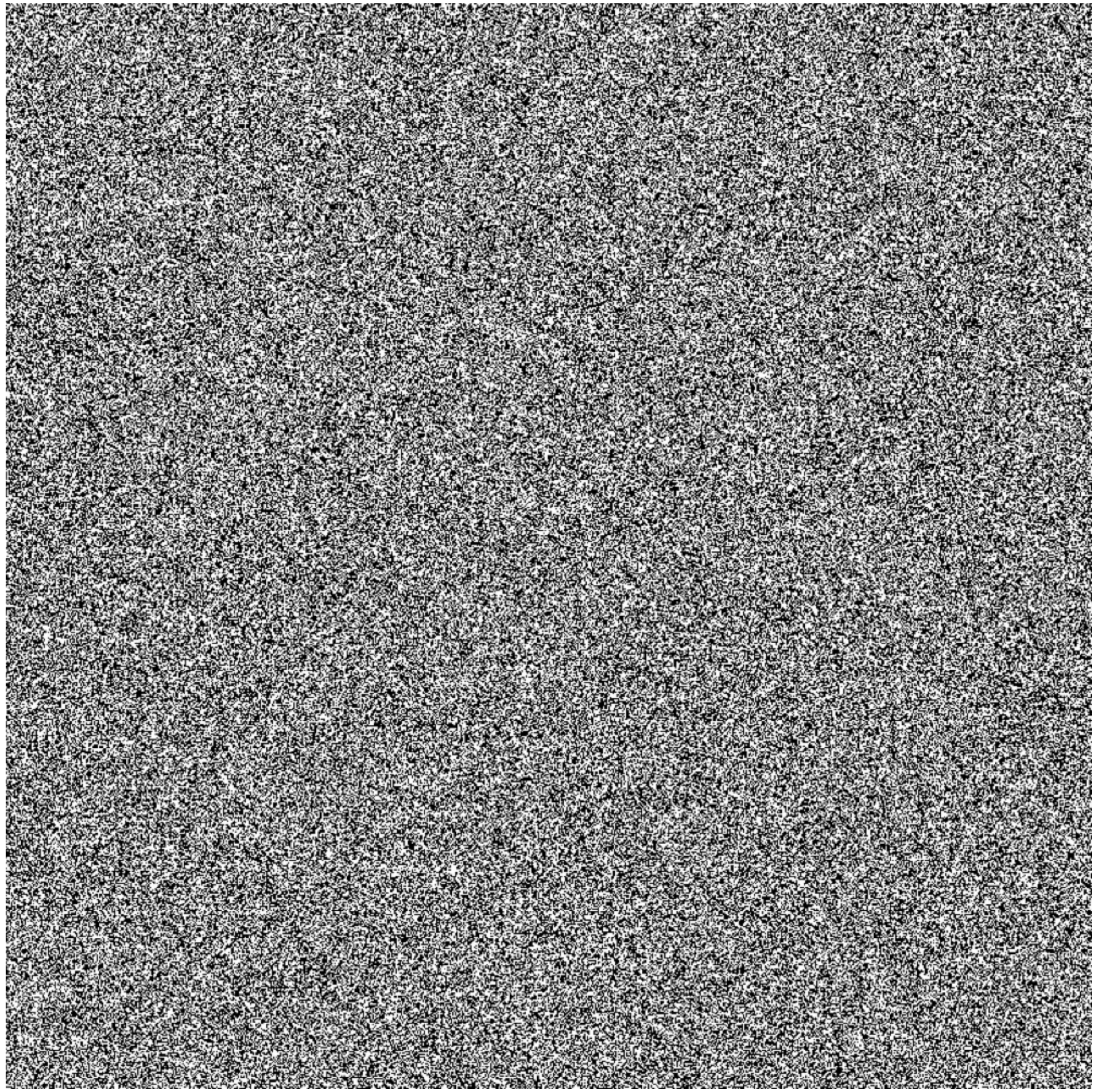
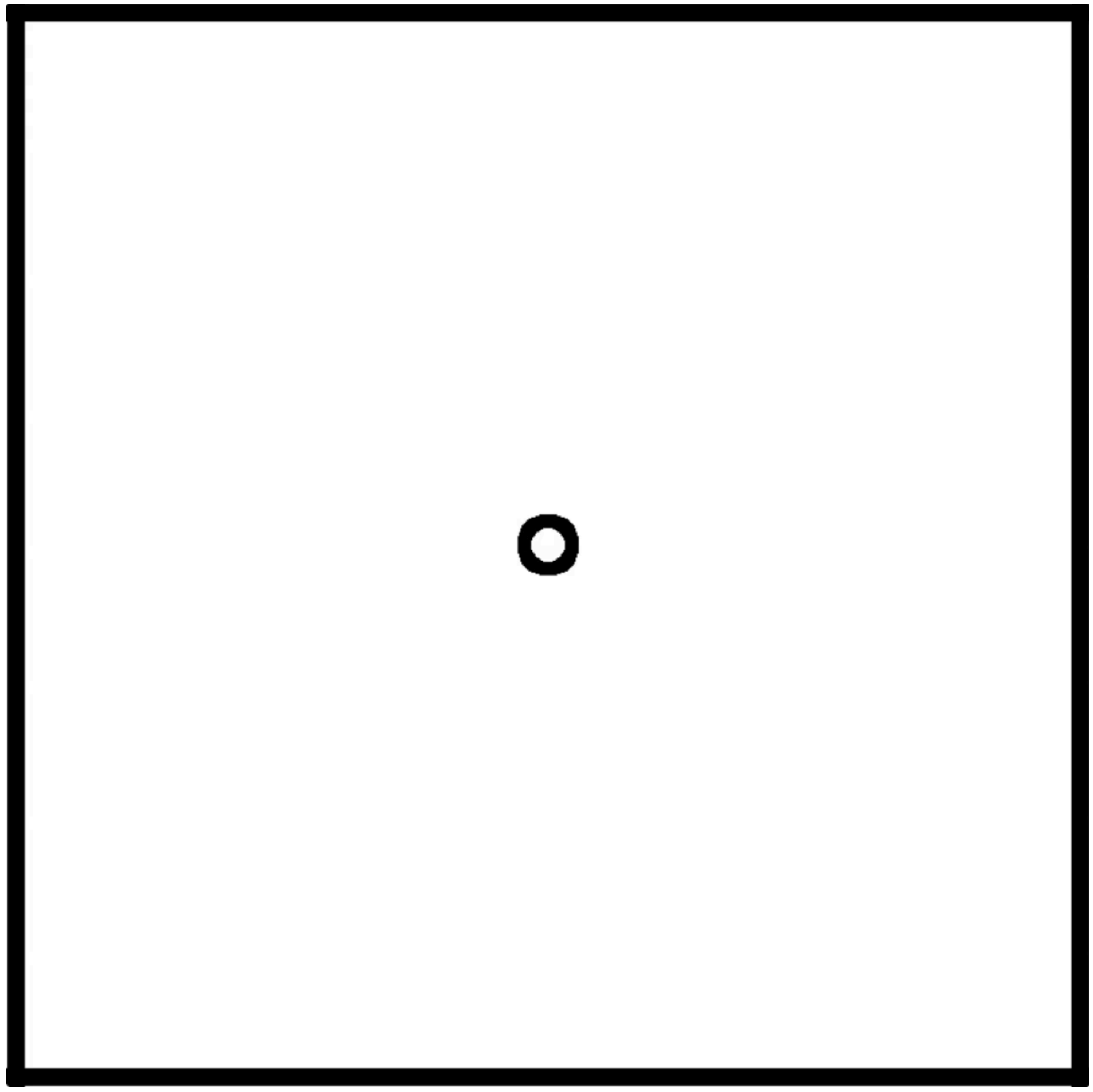
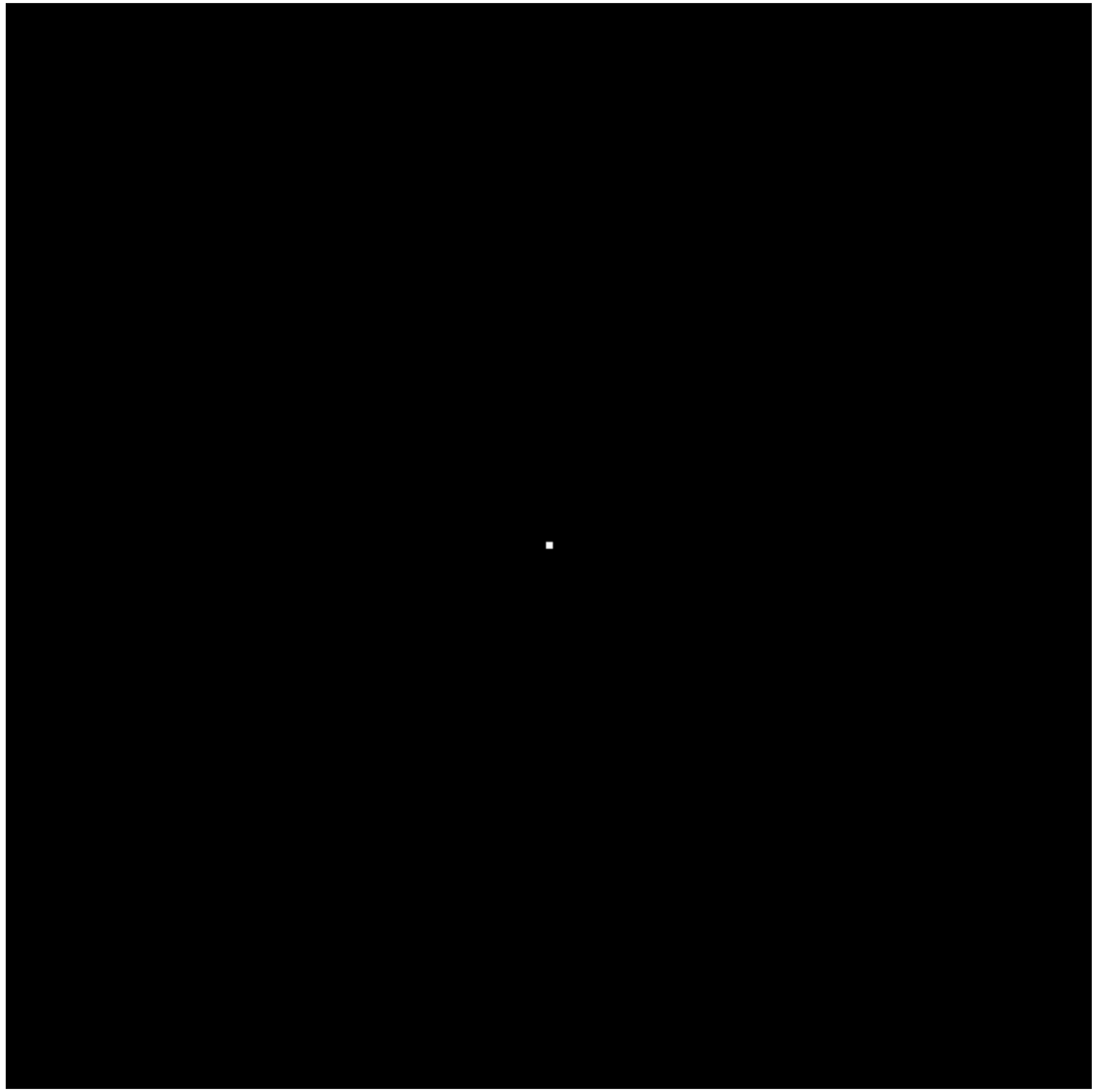


Same rule, different bias, different patterning







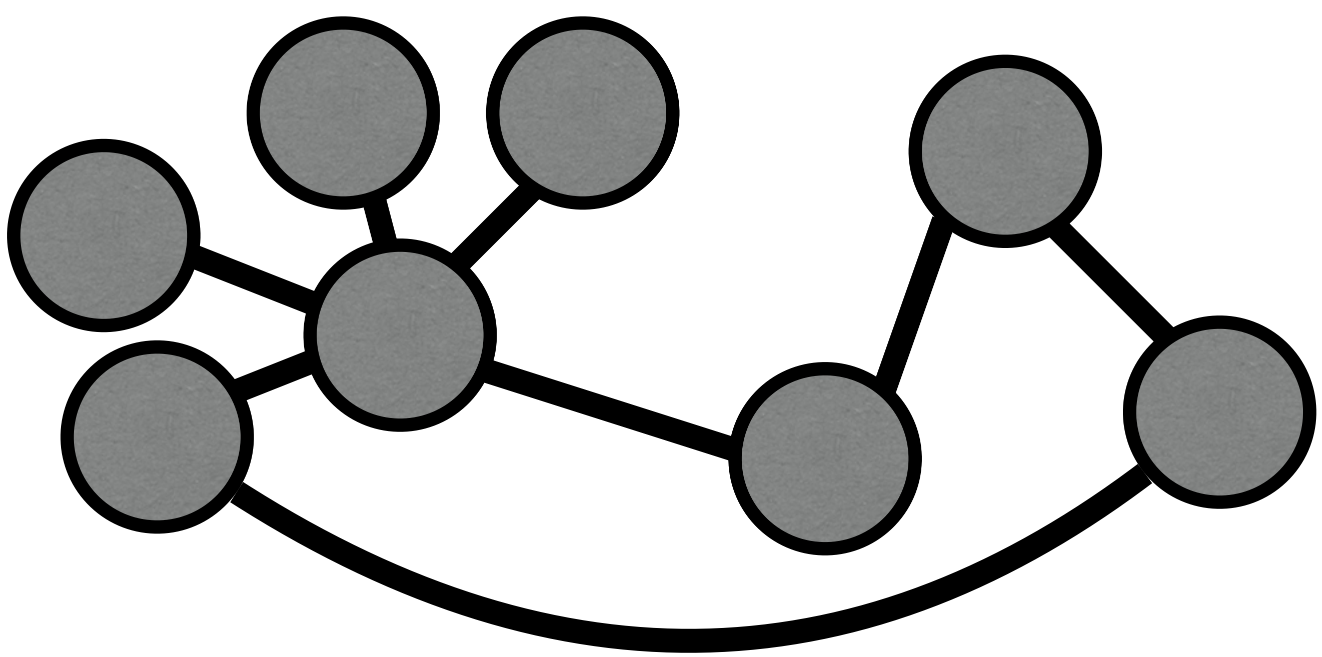
Game of Life

- https://bitstorm.org/gameoflife/

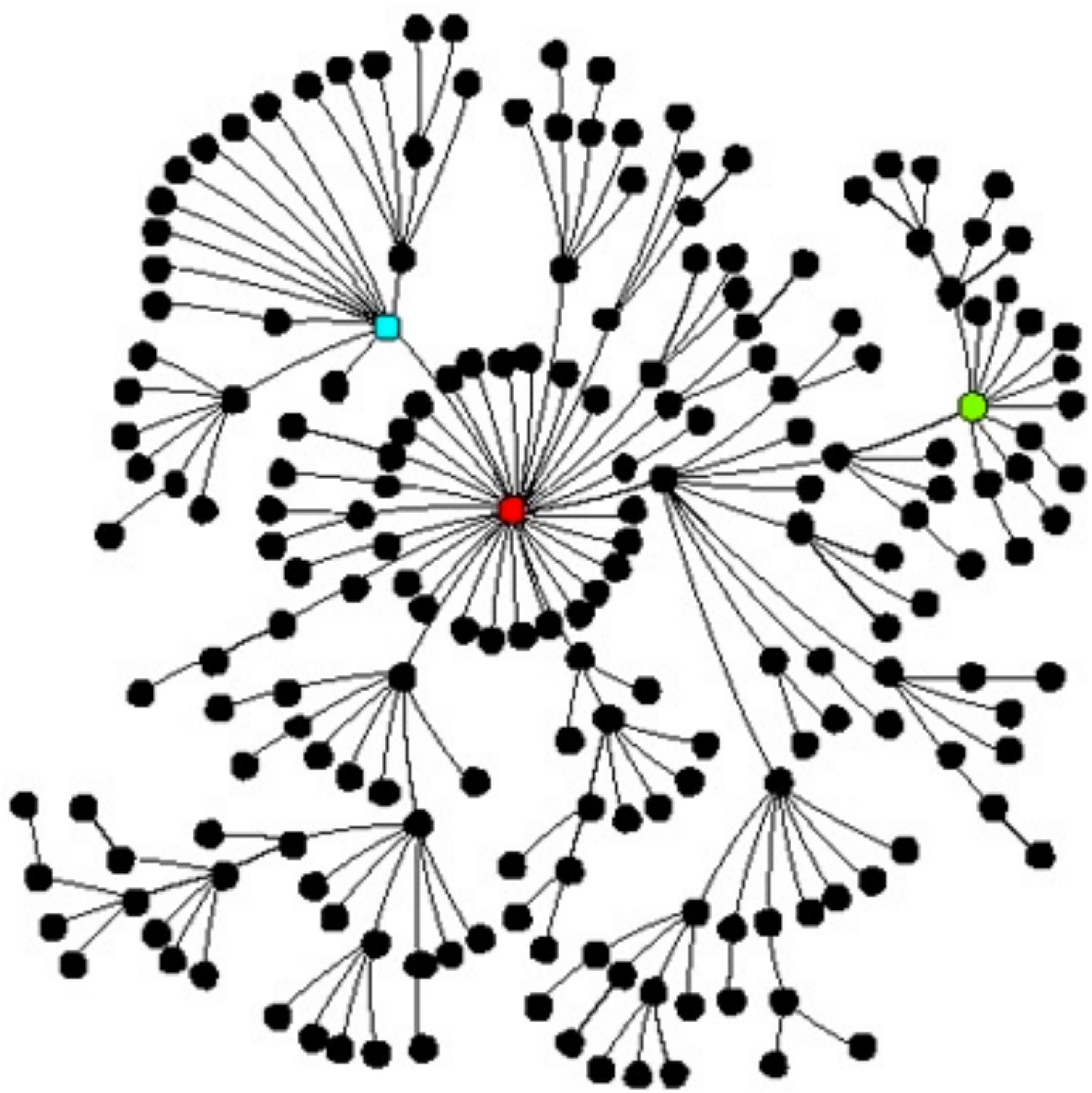
Networks

- Stripped down representation that preserves RELATIONSHIPS

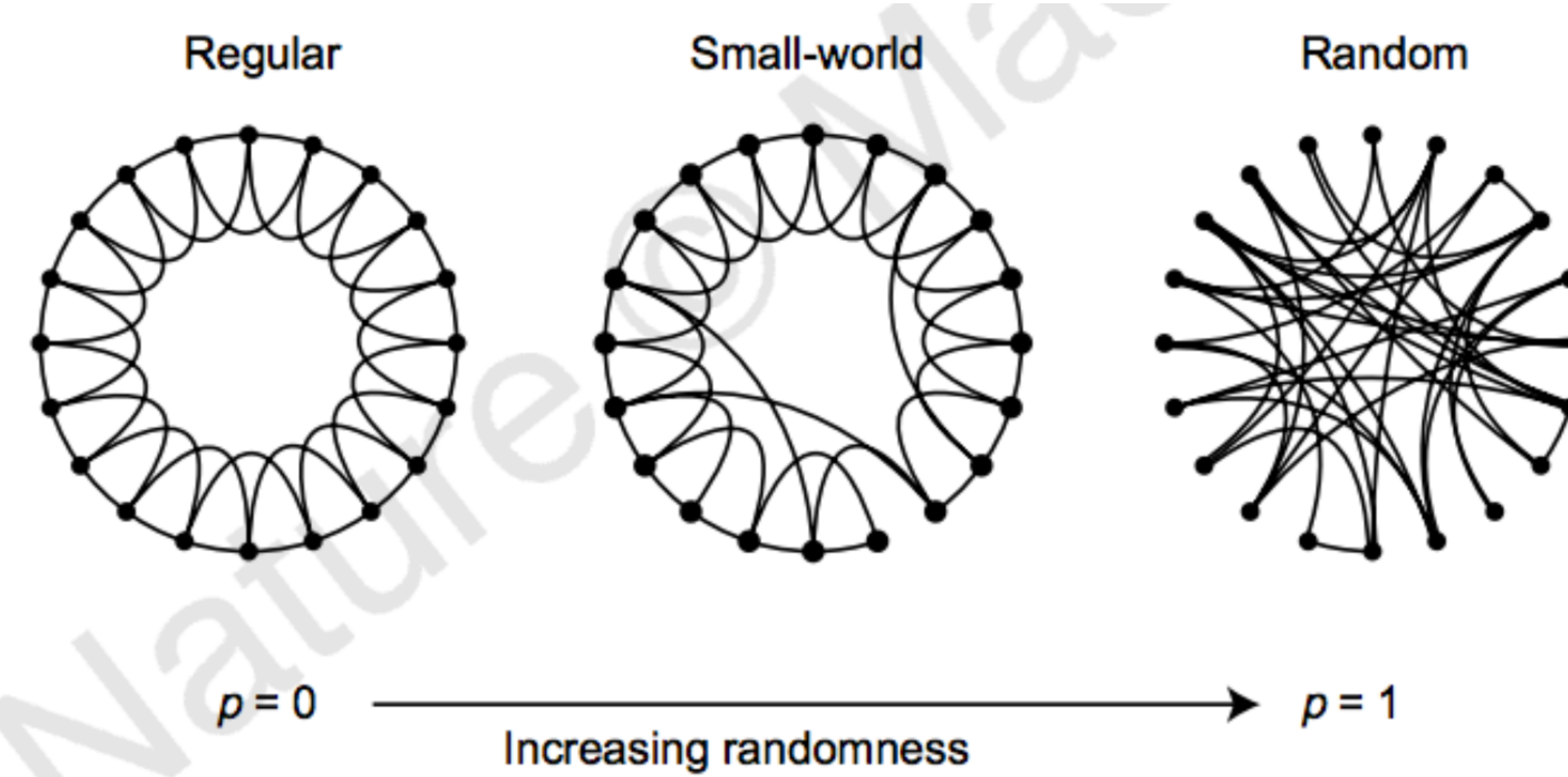
- Can be thought of as relaxation of spatial constraints of cellular automata



Network formation: Preferential Attachment



Small World



Agent Based Modeling

- Relaxation of constraints of network structure
- NetLogo Biology > Ants

Dynamics

- The Newtonian Paradigm: Recursive Maps
- Whats happening now is fully determined what was happening a moment ago
- s[t+1] = f(s[t])
    - difference equation
    - “discrete” time

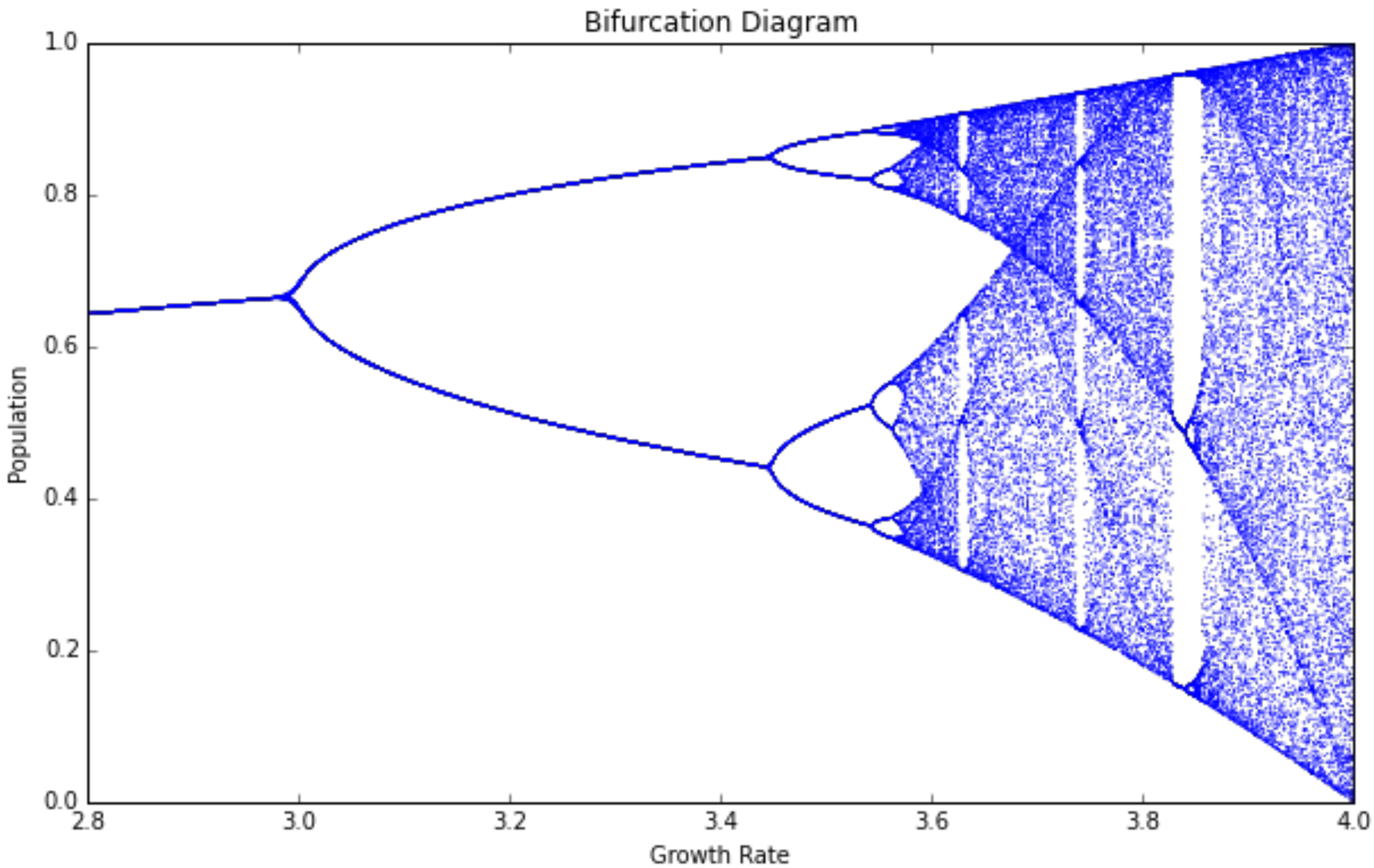
Examples / Exercises

- s[t+1] = s[t] + 1
- s[t+1] = 0.5 * s[t]
- s[t+1] = s[t] + 0.1*(s[t])
- s[t+1] = s[t] + 0.1*(-s[t])
    - Euler integration version of dx/dt = -x

Logistic map

- s[t+1] = A * s[t](1-s[t]), s in [0,1]
- notebook

Logistic map



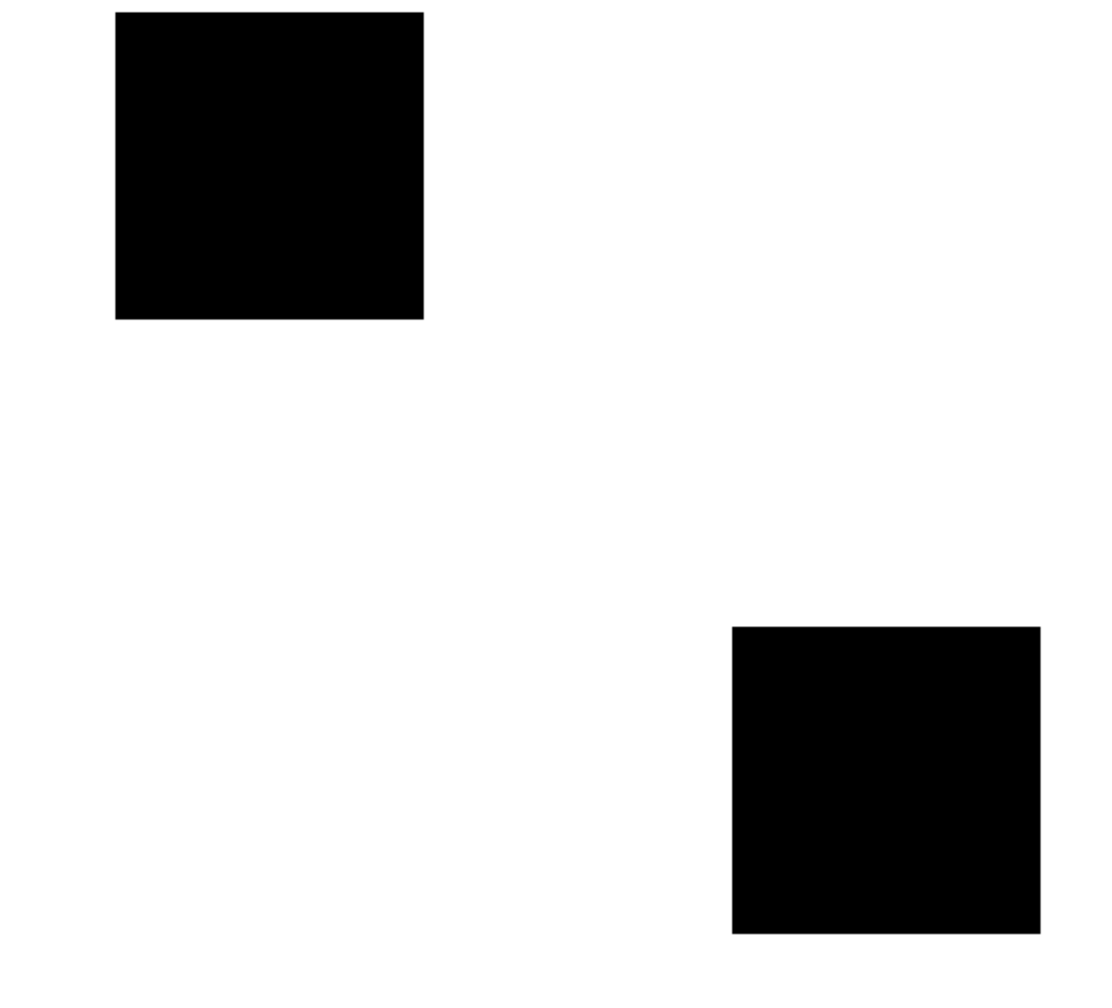
Chaotic Dynamics

- Entirely Deterministic
- Yet “random looking”
- Sensitivity to initial conditions
- Finite horizon of predictability
- Major monkey wrench in Newtonian expectations of predictability

Climate

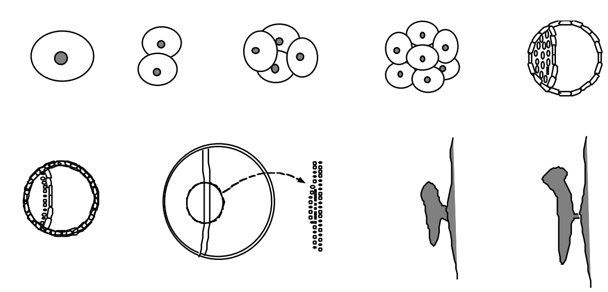
"The climate system is a coupled non-linear chaotic system, and therefore the long-term prediction of future exact climate states is not possible." IPCC, 2001

Multistability

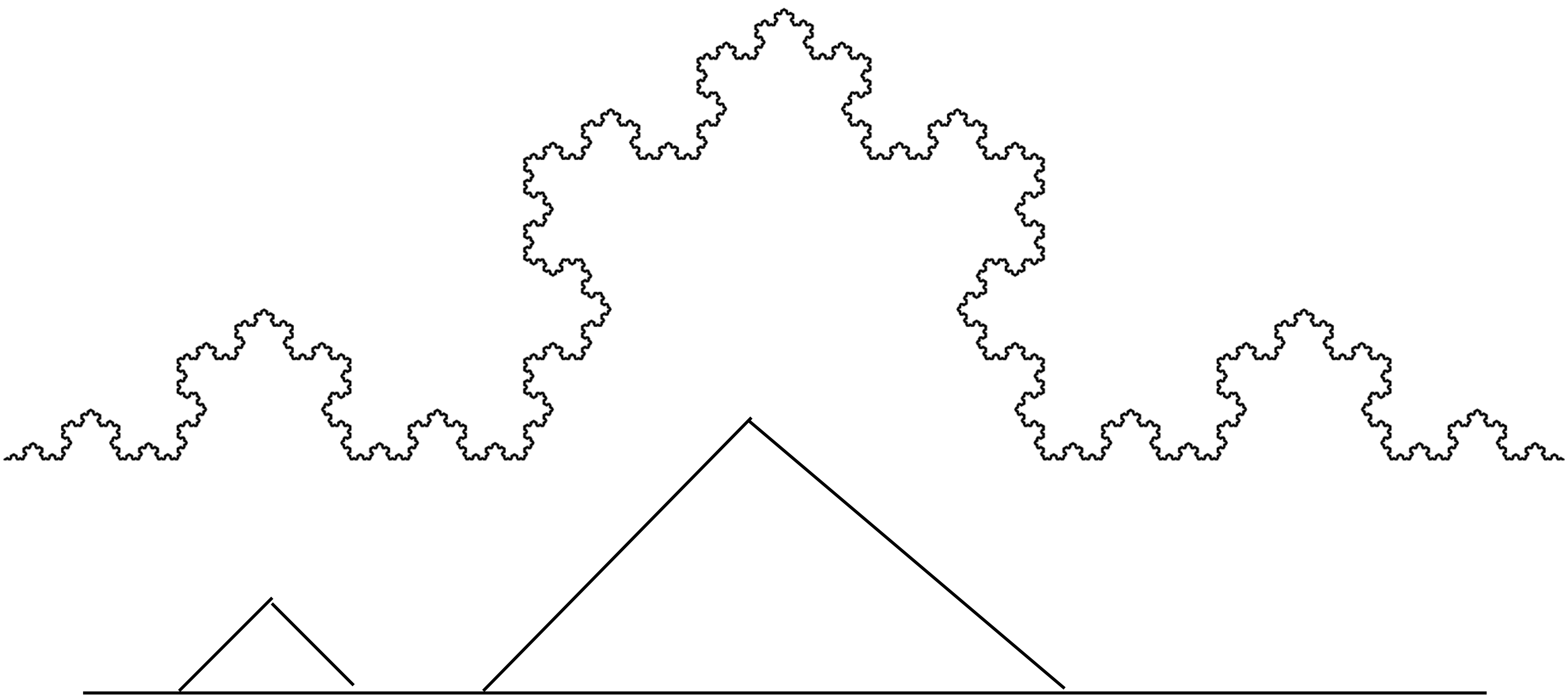


Self-organization Takeaways

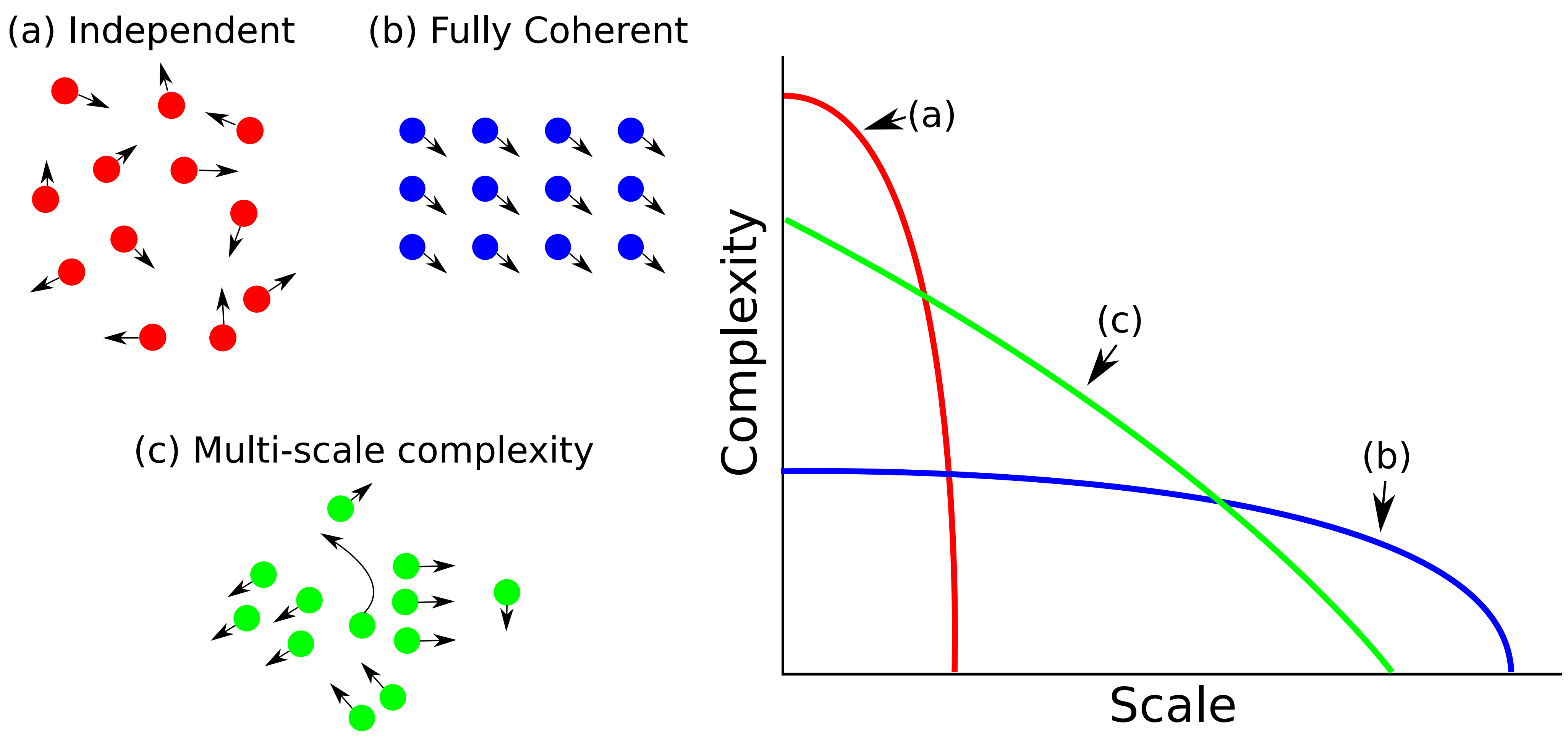
- Interactions dominate
- Simple rules produce a variety of patterns and potentially rich, complex structures and behaviors
- Computational irreducibility
- Universality
- —> Difficult to predict!



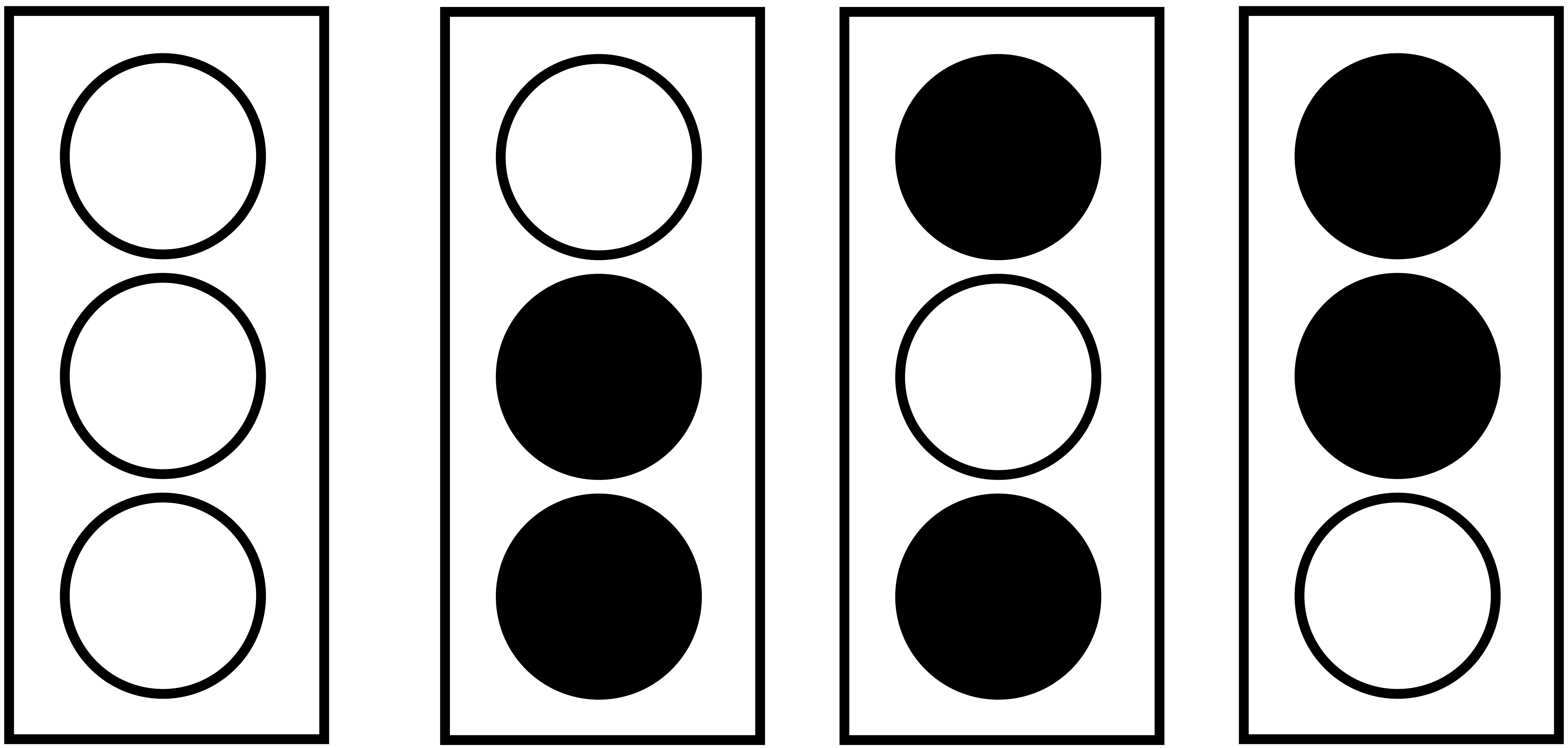
Multiscale Patterns



Multiscale Variety

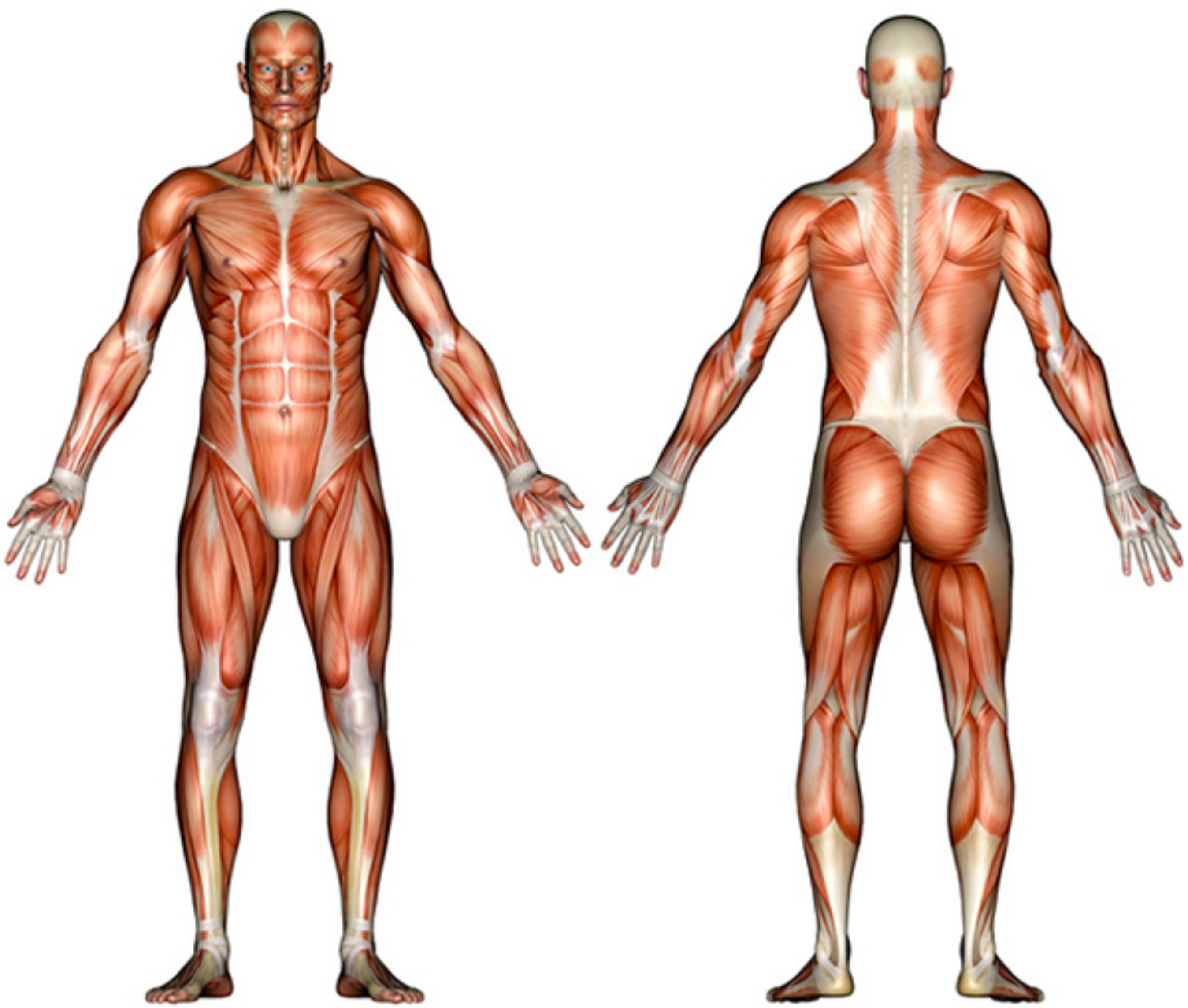


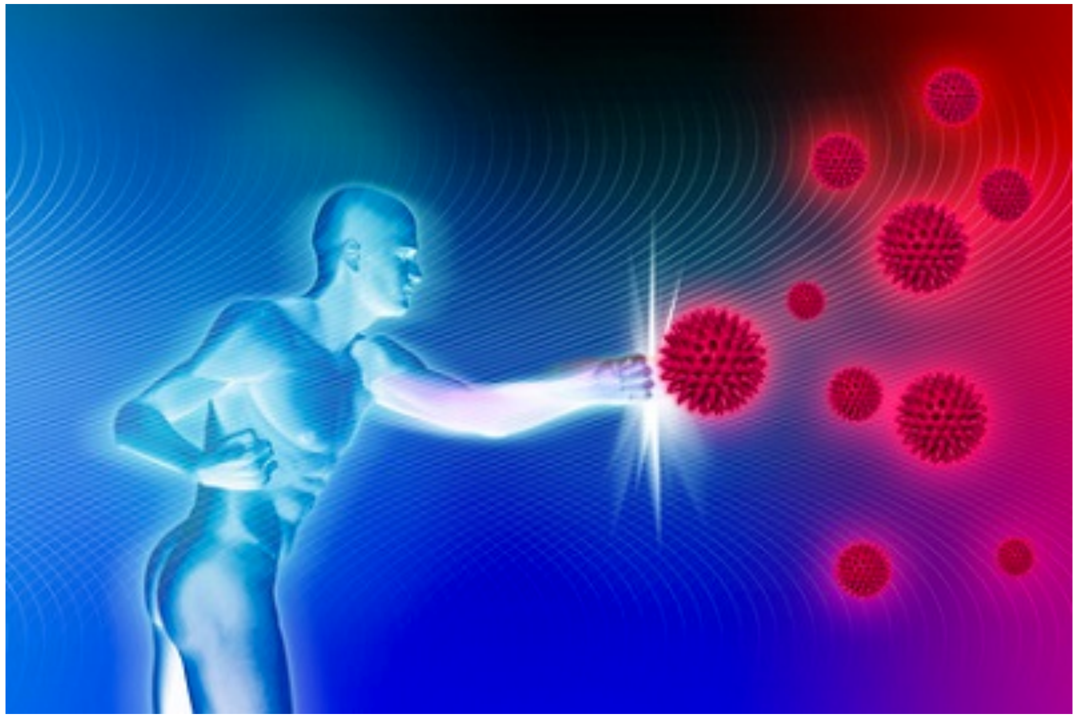
3-bit parity system

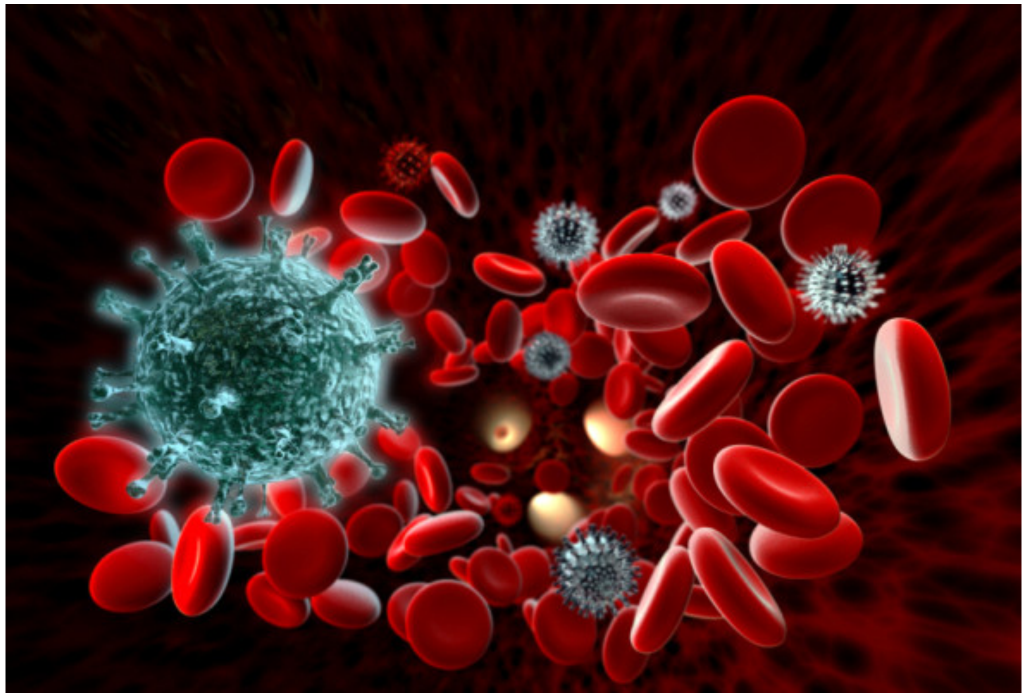


Architectural Variety

Multiscale Requisite Variety

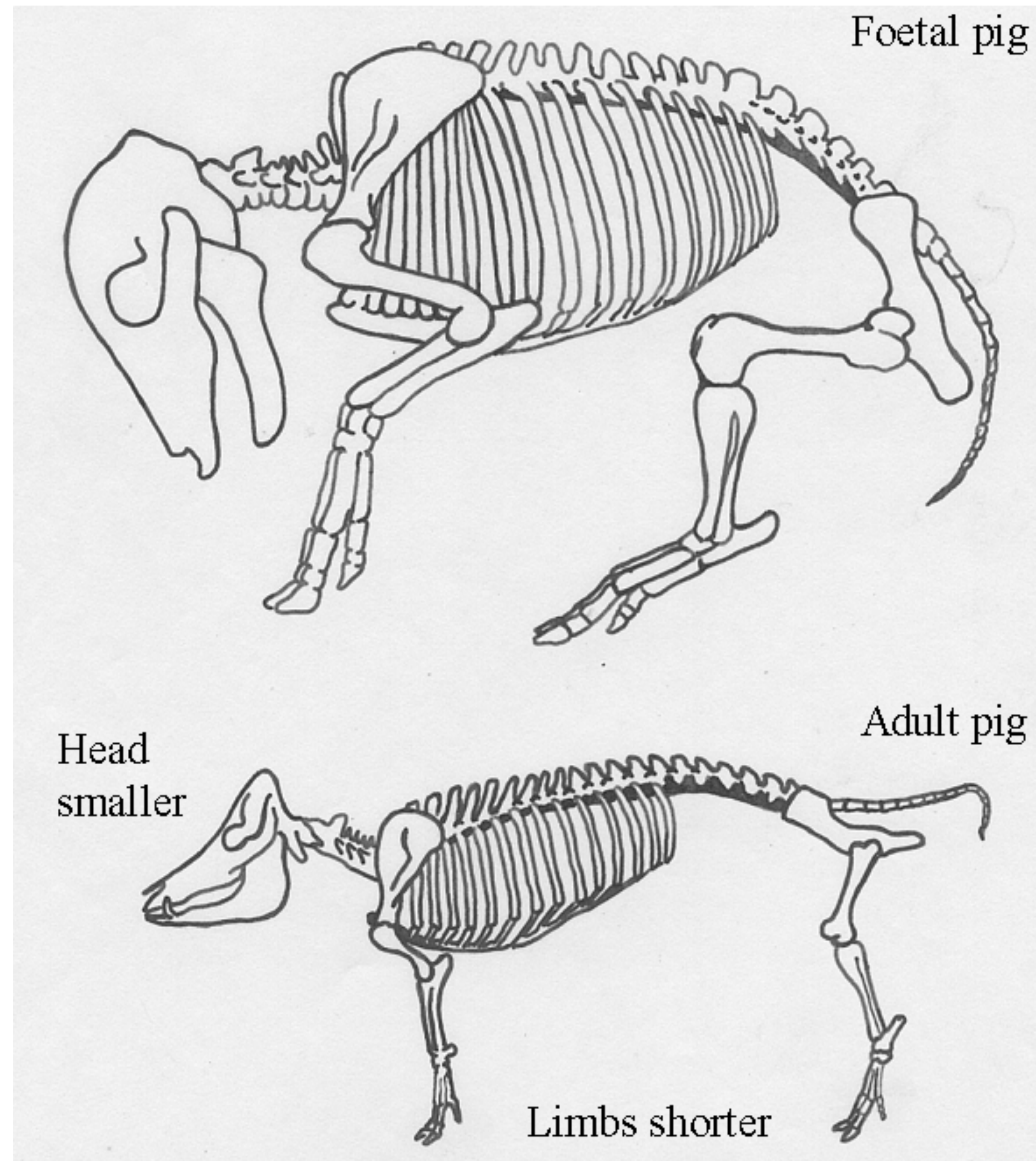




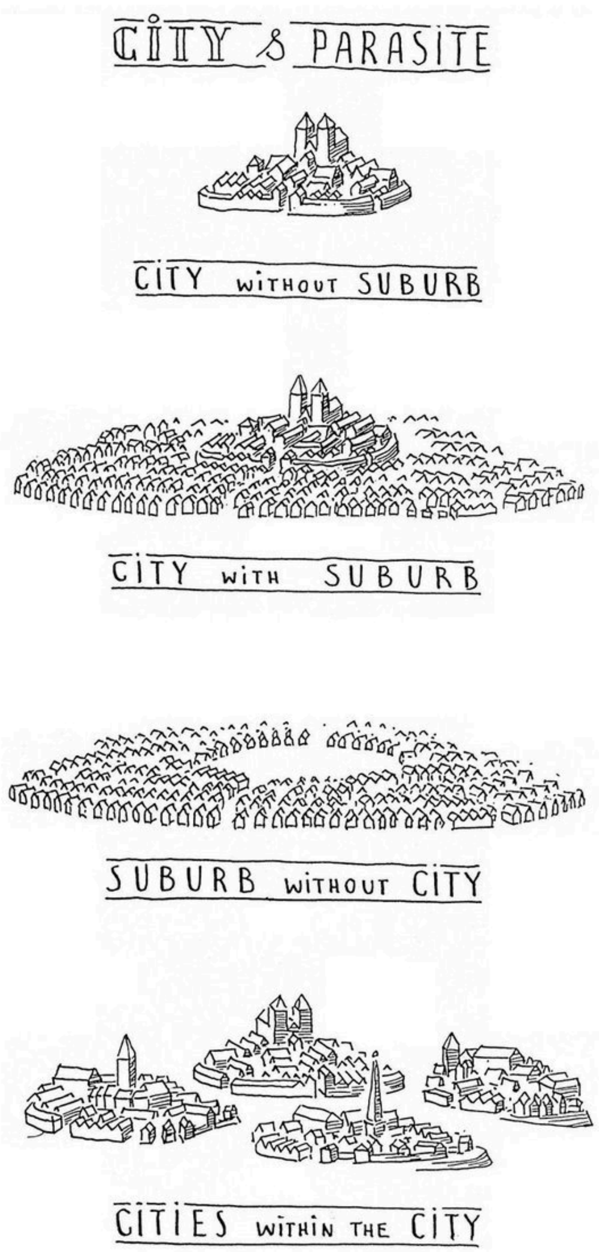


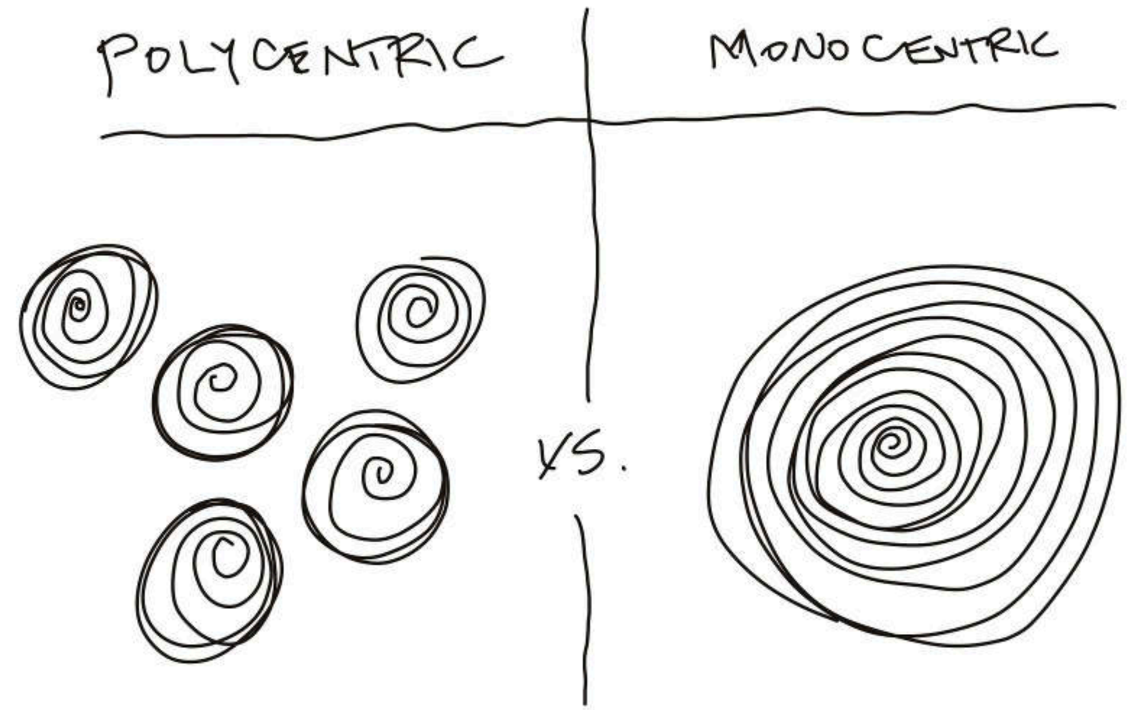
Multiscale Requisite Variety

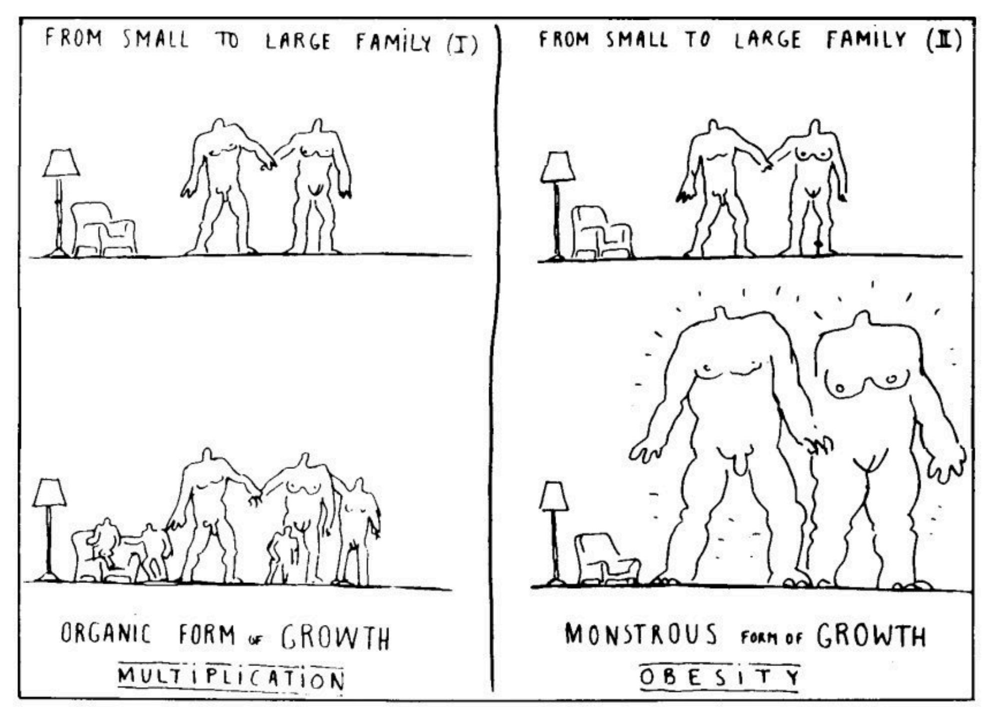
Scaling Relations



Scaling Relations



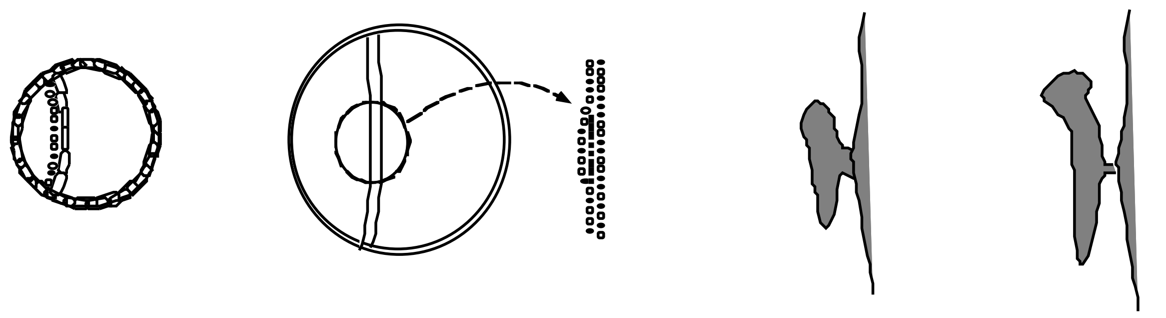




Innovation in Nature

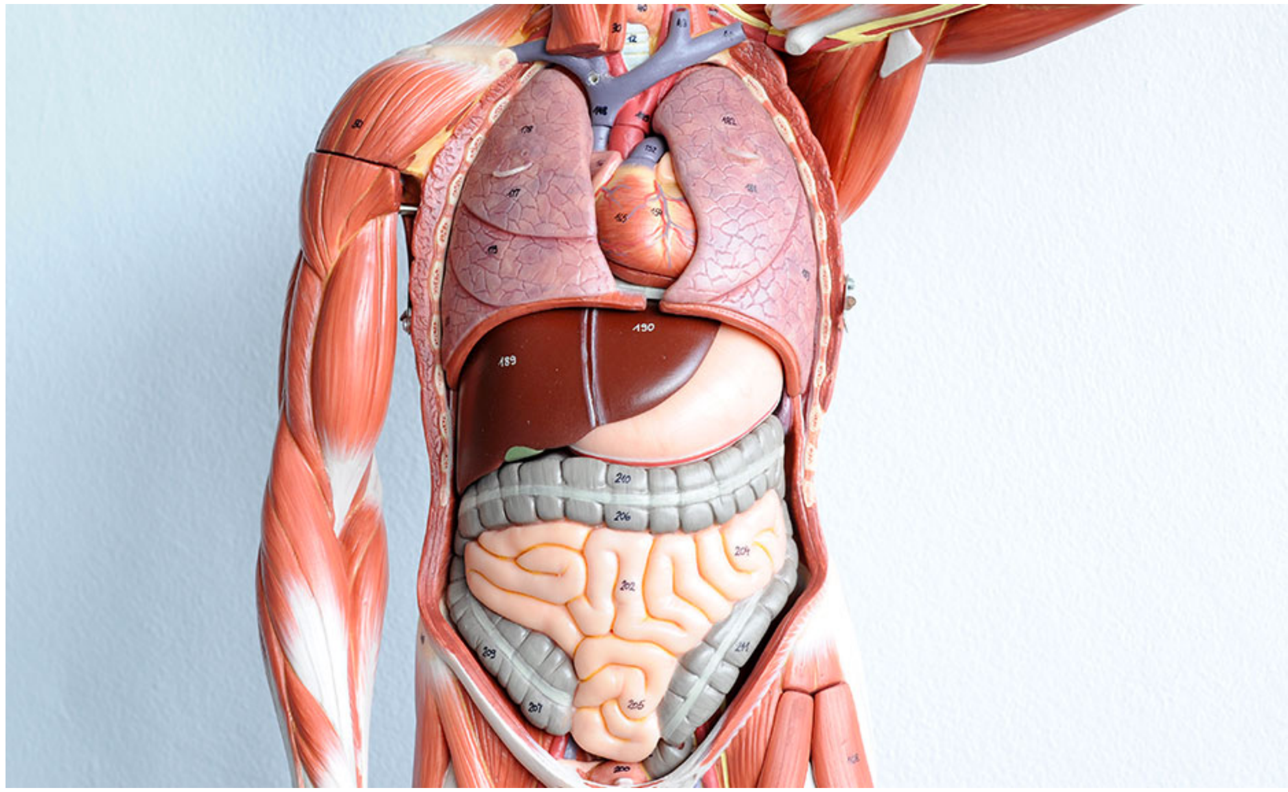
- Evolution
- Combination of **variety** (produced via self-organization) and **selection**
- Leads to complex *adaptive* systems

Parts from Wholes



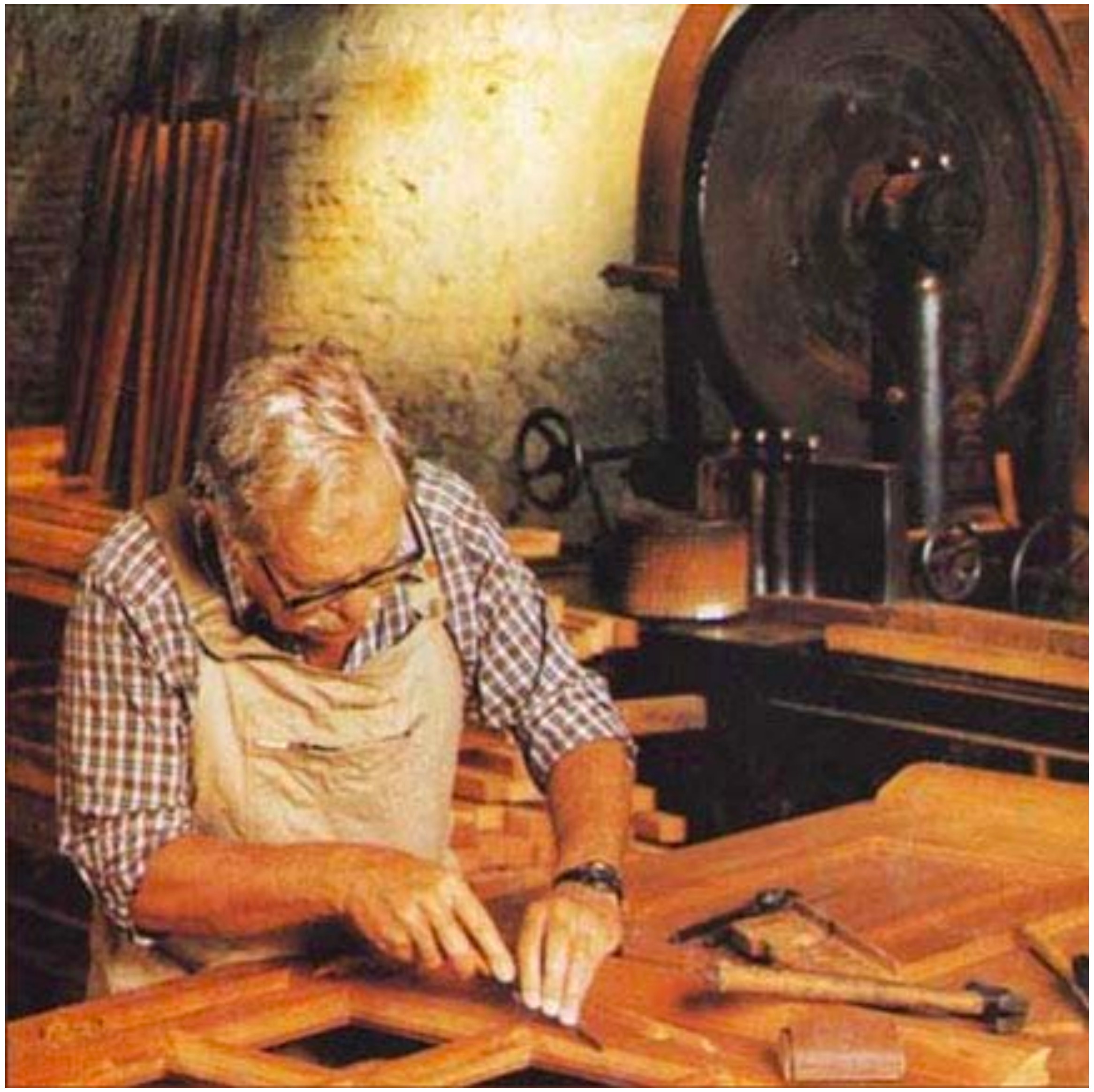
Emergence of Function

- Function of the heart: pump blood (at least)
- This functional property is by virtue of its relation to the rest of the system (system is autopoietic)

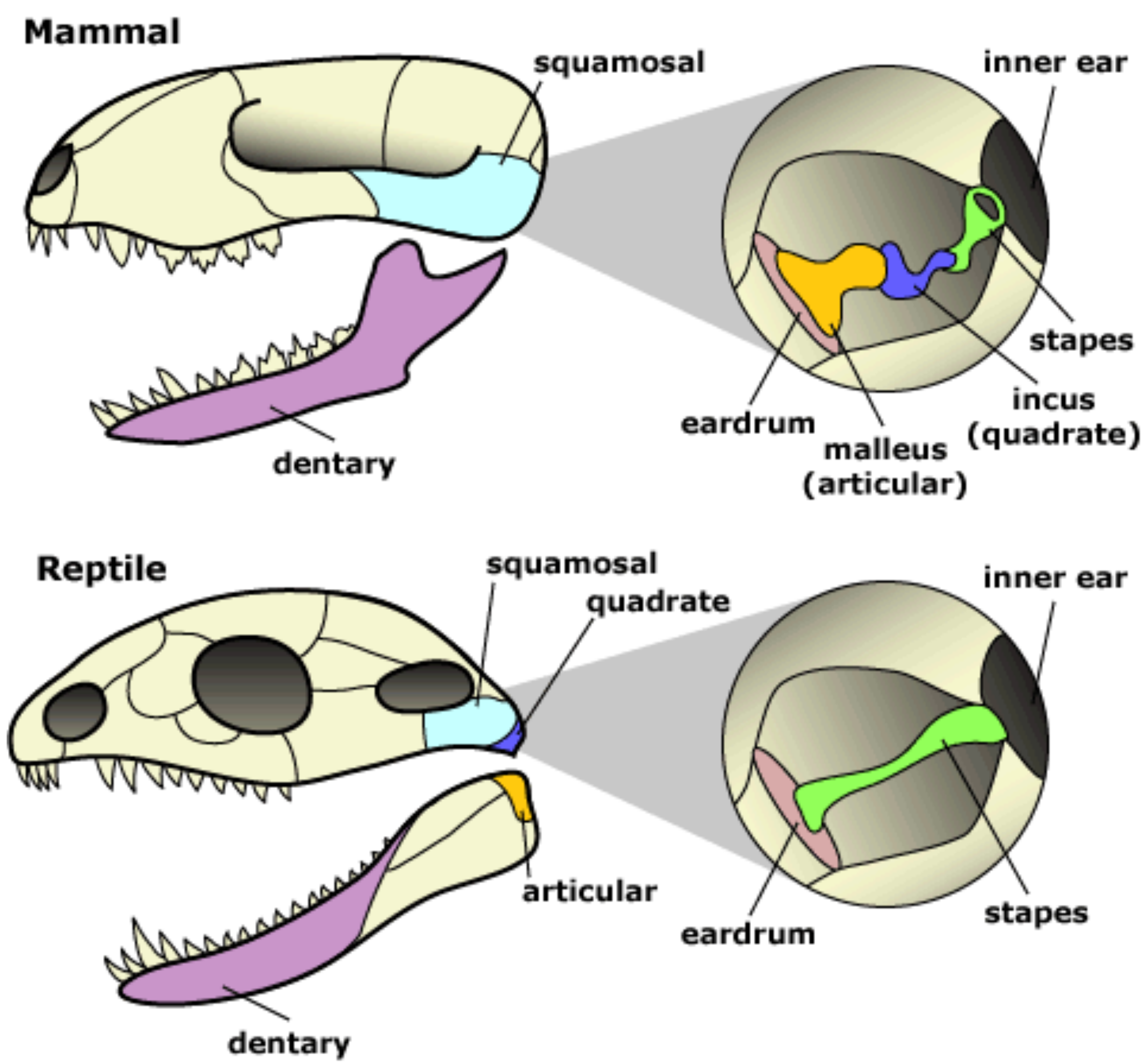


Which is faster?

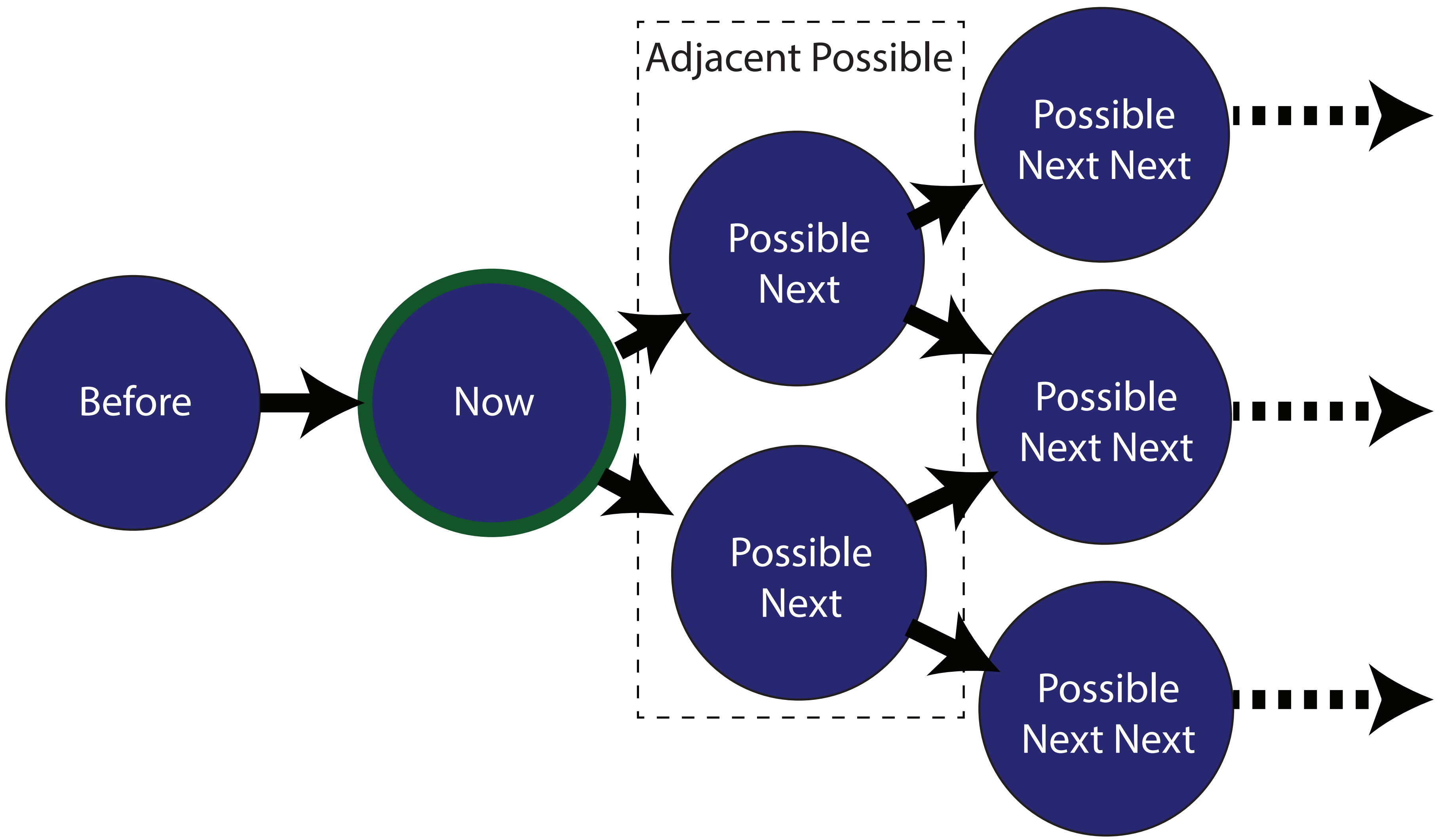
Who is smarter?



Pre-adaptation



Adjacent Possible



Co-evolution

Preadaptation in the economy

- Viagra was designed as a treatment for hypertension
- Play-doh was to clean wallpaper
- Bubble wrap was an attempt to make a “cool” wallpaper
- Frisbees were pie containers
- Pacemakers were originally for recording heart sounds
- LSD was a result of attempting to synthesize a respiratory and circulatory stimulant
- and and and…

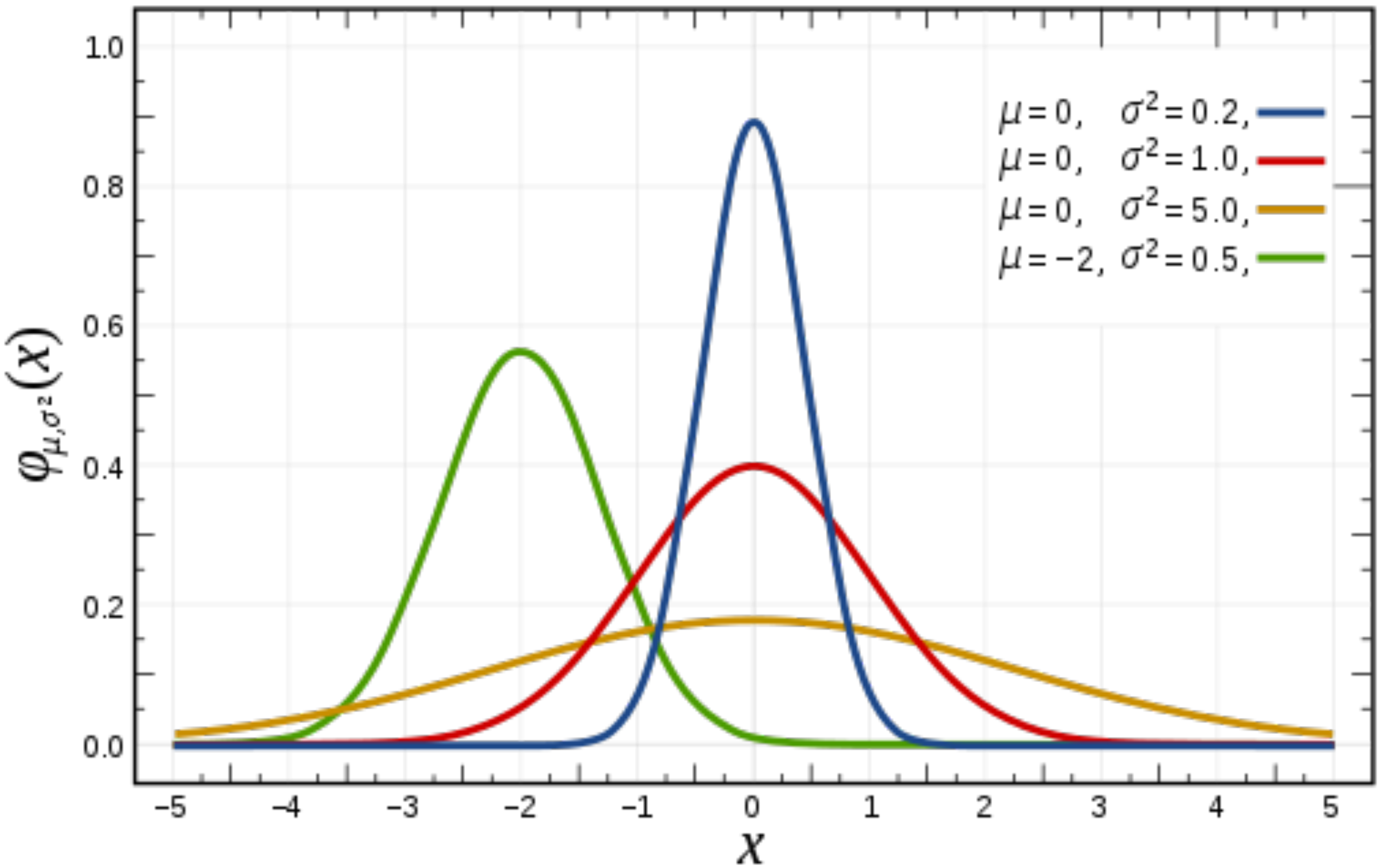
Sources of Uncertainty

- Opacity, much happens in complex systems, so much is hidden
- Emergent properties VERY DIFFICULT (some argue impossible) to predict a priori
- Computational irreducibility — no shortcuts!
- Indirect Effects
- Chaotic dynamics
- Multistability / non-functional relationships
- Observation-dependence
- Evolutionary weirdness e.g. functional ‘fluidity’

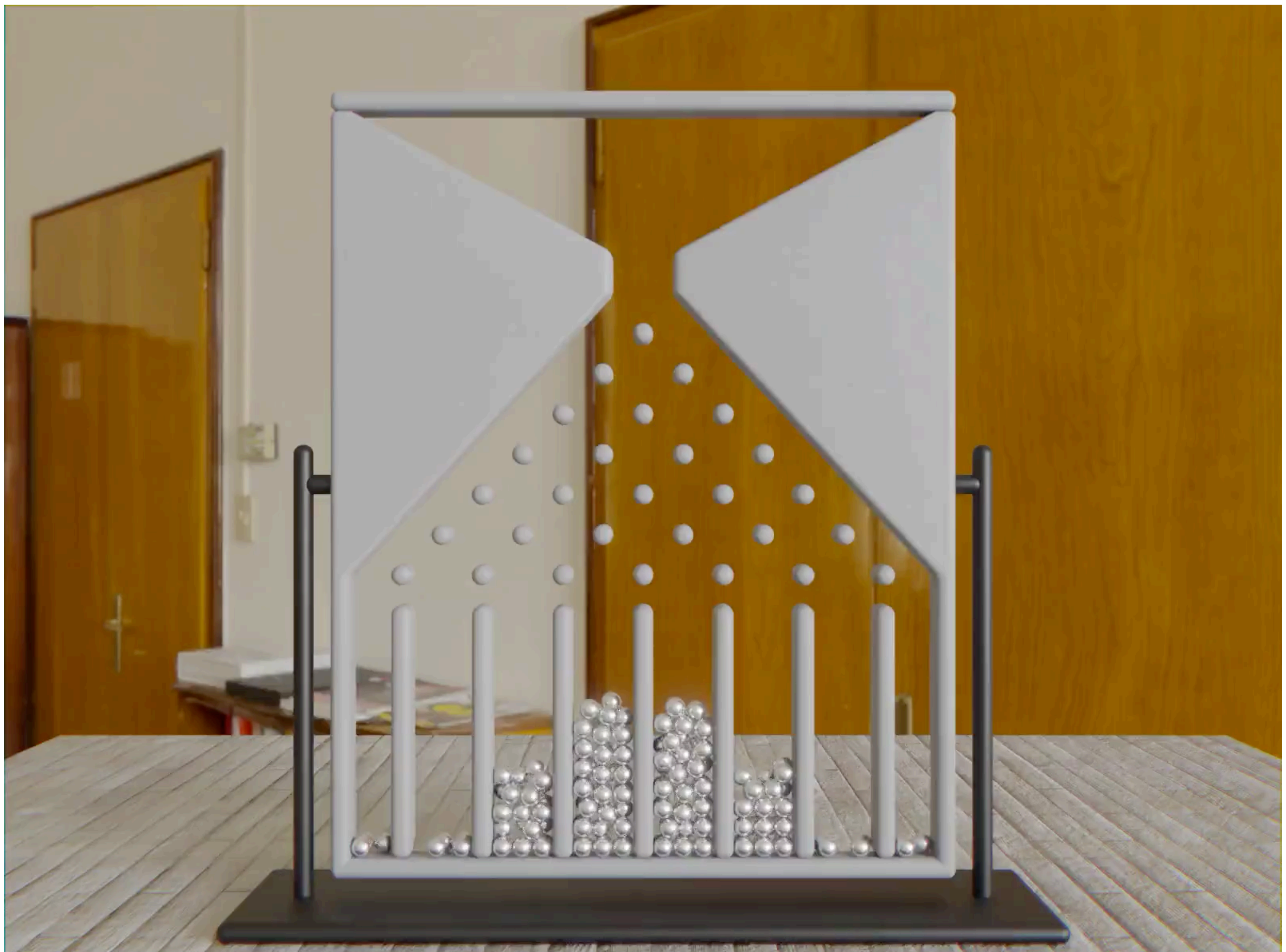
Uncertainty

Distributions / Tails: Thin and Fat / Random Processes

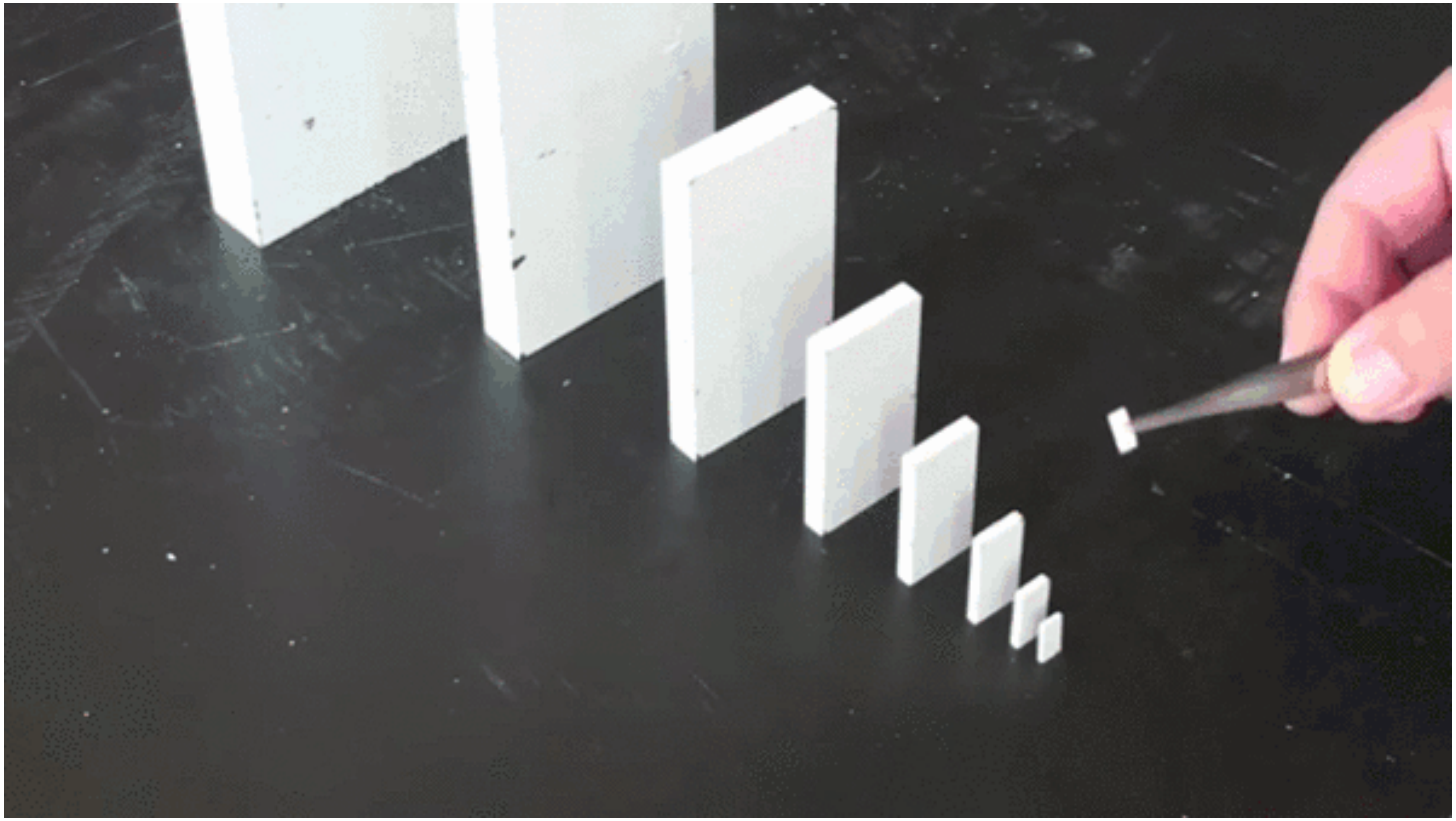
Normal Distribution



Galton Board



Dominoes



Avalanches

- NetLogo Chemistry and Physics > Sandpile

	Thin	Fat
Processes / Statistics dominated by	Body	Tail
Arise From	Independence / Logical boundedness / additive	Dependencies / unboundedness / multiplicative
Scales	Characteristic Scale	Scale-Free
Moments	Defined	Sometimes undefined
Rare events	not *that* extreme OR so rare will never happen	extreme events are rare BUT common enough that they HAPPEn

Stochastic Processes

- Process that depends on some random outcome
- “Random” complement to deterministic dynamical systems

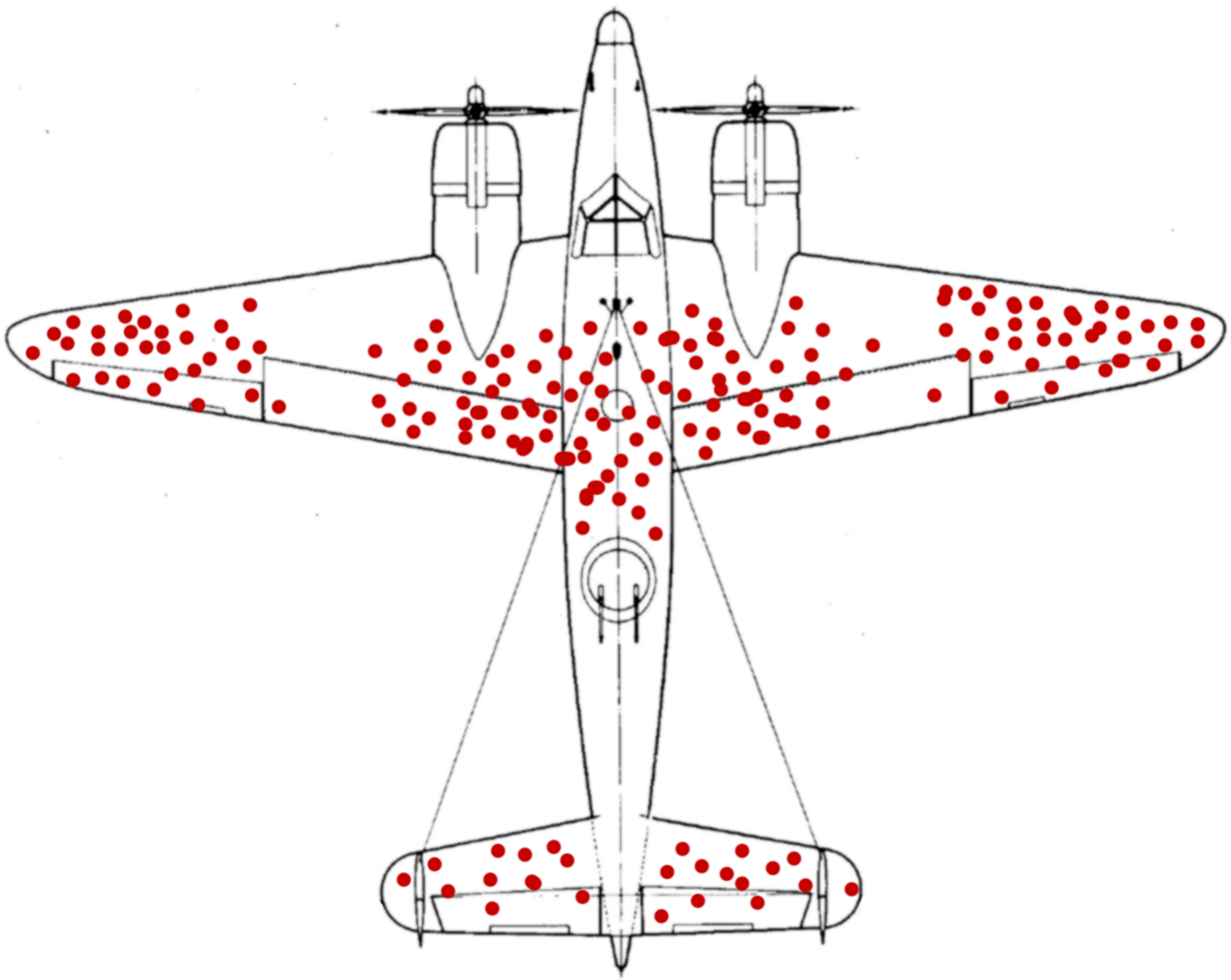
Random Walk

- Notebook

2D Random Walk with Fat Tails

- http://jwnorman.com/?p=82

Survivorship Bias



Curse of Dimensionality

- More data can mean more problems
- http://www.tylervigen.com/spurious-correlations

Precaution

Precaution

- Covering the irreversible downside AKA ‘ruin’

The Precautionary Principle (with Application to the Genetic Modification of Organisms)

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Abstract—The precautionary principle (PP) states that if an action or policy has a suspected risk of causing severe harm to the public domain (affecting general health or the environment globally), the action should not be taken in the absence of scientific near-certainty about its safety. Under these conditions, the burden of proof about absence of harm falls on those proposing an action, not those opposing it. PP is intended to deal with uncertainty and risk in cases where the absence of evidence and the incompleteness of scientific knowledge carries profound implications and in the presence of risks of "black swans", unforeseen and unforeseable events of extreme consequence.

This non-naive version of the PP allows us to avoid paranoia and paralysis by confining precaution to specific domains and problems. Here we formalize PP, placing it within the statistical and probabilistic structure of "ruin" problems, in which a system is at risk of total failure, and in place of risk we use a formal"fragility" based approach. In these problems, what appear to be small and reasonable risks accumulate inevitably to certain irreversible harm. Traditional cost-benefit analyses, which seek to quantitatively weigh outcomes to determine the best policy option, do not apply, as outcomes may have infinite costs. Even high-benefit, high-probability outcomes do not outweigh the existence of low probability, infinite cost options—i.e. ruin. Uncertainties result in sensitivity analyses that are not mathematically well behaved. The PP is increasingly relevant due to man-made dependencies that propagate impacts of policies across the globe. In contrast, absent humanity the biosphere engages in natural experiments due to random variations with only local impacts.

Our analysis makes clear that the PP is essential for a limited set of contexts and can be used to justify only a limited set of actions. We discuss the implications for nuclear energy and GMOs. GMOs represent a public risk of global harm, while harm from nuclear energy is comparatively limited and better characterized. PP should be used to prescribe severe limits on GMOs.

September 4, 2014

1 Introduction

THe aim of the precautionary principle (PP) is to prevent decision makers from putting society as a whole—or a significant segment of it—at risk from the unexpected side effects of a certain type of decision. The PP states that if an action or policy has a suspected risk of causing severe harm to the public domain (such as general health or the environment), and in the absence of scientific near-certainty about the safety of the action, the burden of proof about absence of harm falls on those proposing the action. It is meant to deal with effects of absence of evidence and the incompleteness of scientific knowledge in some risky domains.[1]

We believe that the PP should be evoked only in extreme situations: when the potential harm is systemic (rather than localized) and the consequences can involve total irreversible ruin, such as the extinction of human beings or all life on the planet.

The aim of this paper is to place the concept of precaution within a formal statistical and risk-analysis structure, grounding it in probability theory and the properties of complex systems. Our aim is to allow decision makers to discern which circumstances require the use of the PP and in which cases evoking the PP is inappropriate.

2 Decision making and types of Risk

Taking risks is necessary for individuals as well as for decision makers affecting the functioning and advancement of society. Decision and policy makers tend to assume all risks are created equal. This is not the case. Taking into account the structure of randomness in a given system can have a dramatic effect on which kinds of actions are, or are not, justified. Two kinds of potential harm must be considered when determining an appropriate approach to the role of risk in decision-making: 1) localized non-spreading impacts and 2) propagating impacts resulting in irreversible and widespread damage.

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1. The Rio Declaration on Environment and Development presents it as follows: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Climate models and precautionary measures

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Forthcoming in *Issues in Science and Technology*

THE POLICY DEBATE with respect to anthropogenic climate-change typically revolves around the accuracy of models. Those who contend that models make accurate predictions argue for specific policies to stem the foreseen damaging effects; those who doubt their accuracy cite a lack of reliable evidence of harm to warrant policy action.

These two alternatives are not exhaustive. One can sidestep the "skepticism" of those who question existing climate-models, by framing risk in the most straightforward possible terms, at the global scale. That is, we should ask "what would the correct policy be if we had no reliable models?"

We have *only one* planet. This fact radically constrains the kinds of risks that are appropriate to take at a large scale. Even a risk with a very low probability becomes unacceptable when it affects all of us – there is no reversing mistakes of that magnitude.

Without any precise models, we can still reason that polluting or altering our environment significantly could put us in uncharted territory, with no statistical track-record and potentially large consequences. It is at the core of both scientific decision making and ancestral wisdom to take seriously absence of evidence when the consequences of an action can be large. And it is standard textbook decision theory that a policy should depend at least as much on uncertainty concerning the adverse consequences as it does on the known effects.

Further, it has been shown that in any system fraught with opacity, harm is in the dose rather than in the nature of the offending substance: it increases nonlinearly to the quantities at stake. Everything fragile has such property. While some amount of pollution is inevitable, high quantities of any pollutant put us at a rapidly increasing risk of destabilizing the climate, a system that is integral to the biosphere. Ergo, we should build down CO_2 emissions, even regardless of what climate-models tell us.

This leads to the following asymmetry in climate policy. The scale of the effect must be demonstrated to be large enough to have impact. Once this is shown, and it has been, the burden of proof of absence of harm is on those who would deny it.

It is the degree of opacity and uncertainty in a system, as well as asymmetry in effect, rather than specific model predictions, that should drive the precautionary measures. Push a complex system too far and it will not come back. The popular belief that uncertainty undermines the case for taking seriously the 'climate crisis' that scientists tell us we face is the opposite of the truth. Properly understood, as driving the case for precaution, uncertainty radically *underscores* that case, and may even *constitute* it.

Systemic Risk of Pandemic via Novel Pathogens – Coronavirus: A Note

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THE NOVEL CORONAVIRUS emerging out of Wuhan, China has been identified as a deadly strain that is also highly contagious. The response by China to date has included travel restrictions on tens of millions across several major cities in an effort to slow its spread. Despite this, positively identified cases have already been detected in many countries spanning the globe and there are doubts such containment would be effective. This note outlines some principles to bear in relation to such a process.

Clearly, we are dealing with an extreme fat-tailed process owing to an increased connectivity, which increases the spreading in a nonlinear way [1], [2]. Fat tailed processes have special attributes, making conventional risk-management approaches inadequate.

General Precautionary Principle

The general (non-naive) precautionary principle [3] delineates conditions where actions must be taken to reduce risk of ruin, and traditional cost-benefit analyses must not be used. These are ruin problems where, over time, exposure to tail events leads to a certain eventual extinction. While there is a very high probability for humanity surviving a single such event, *over time*, there is eventually zero probability of surviving repeated exposures to such events. While repeated risks can be taken by individuals with a limited life expectancy, ruin exposures must never be taken at the systemic and collective level. In technical terms, the precautionary principle applies when traditional statistical averages are invalid because risks are not ergodic.

Naive Empiricism

Next we address the problem of naive empiricism in discussions related to this problem.

Spreading rate: Historically based estimates of spreading rates for pandemics in general, and for the current one in particular, underestimate the rate of spread because of the rapid increases in transportation connectivity over recent years. This means that expectations of the extent of harm are underestimates both because events are inherently fat tailed, and because the tail is becoming fatter as connectivity increases.

Global connectivity is at an all-time high, with China one of the most globally connected societies. Fundamentally, viral contagion events depend on the interaction of agents in physical space, and with the forward-looking uncertainty that novel outbreaks necessarily carry, reducing connectivity temporarily to slow flows of potentially contagious individuals is the only approach that is robust against misestimations in the properties of a virus or other pathogen.

Reproductive ratio: Estimates of the virus's reproductive ratio R_0—the number of cases one case generates on average over the course of its infectious period in an otherwise uninfected population—are biased downwards. This property comes from fat-tailedness [4] due to individual 'superspreader' events. Simply, R_0 is estimated from an average which takes longer to converge as it is itself a fat-tailed variable.

Mortality rate: Mortality and morbidity rates are also downward biased, due to the lag between identified cases, deaths and reporting of those deaths.

Increasingly Fatal Rapidly Spreading Emergent Pathogens: With increasing transportation we are close to a transition to conditions in which extinction becomes certain both because of rapid spread and because of the selective dominance of increasingly worse pathogens. [5]

Asymmetric Uncertainty: Properties of the virus that are uncertain will have substantial impact on whether policies implemented are effective. For instance, whether contagious asymptomatic carriers exist. These uncertainties make it unclear whether measures such as temperature screening at major ports will have the desired impact. Practically all the uncertainty tends to make the problem potentially worse, not better, as these processes are convex to uncertainty.

Fatalism and inaction: Perhaps due to these challenges, a common public health response is fatalistic, accepting what will happen because of a belief that nothing can be done. This response is incorrect as the leverage of correctly selected *extraordinary* interventions can be very high.

Conclusion: Standard individual-scale policy approaches such as isolation, contact tracing and monitoring are rapidly (computationally) overwhelmed in the face of mass infection, and thus also cannot be relied upon to stop a pandemic. Multiscale population approaches including drastically pruning contact networks using collective boundaries and social behavior change, and community self-monitoring, are essential.

Together, these observations lead to the necessity of a precautionary approach to current and potential pandemic outbreaks that must include constraining mobility patterns in the early stages of an outbreak, especially when little is known about the true parameters of the pathogen.

It will cost something to reduce mobility in the short term, but to fail do so will eventually cost everything—if not from this event, then one in the future. Outbreaks are inevitable, but an appropriately precautionary response can mitigate systemic risk to the globe at large. But policy- and decision-makers must act swiftly and avoid the fallacy that to have an appropriate respect for uncertainty in the face of possible irreversible catastrophe amounts to "paranoia," or the converse a belief that nothing can be done.

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Global Decentralization for Risk Mitigation and Security

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THE OUTBREAK of a novel Coronavirus we are facing is poised to become a global pandemic if current approaches to stemming its spread prove to be insufficient. While we can't yet say what the ultimate impact of this event will be, this crisis and governments' responses to it reveal vulnerabilities and fragilities in the structure of our global socioeconomic milieux that will continue to produce cascading crises regardless of whether or not we are successful in preventing devastation from this particular pathogen.

There are two interrelated issues of connectivity that produce global fragility:

1) Long-range physical connectivity that generates a contact-network topology with large hubs and short internode distances
2) Global centralization of essential functional roles (made possible by long-range physical and informational connectivity)

1 Long-range connectivity and the global neighborhood

Commercial air travel has effectively transitioned the interaction topology of the globe from a lattice to a network with small-world properties. It is a well-known result that adding long-range connections into a lattice network reduces the node-to-node path distances dramatically[1, 5]. The implications for contagion dynamics are significant: not only is humanity effectively one 'giant component', but the number of hops a vector must take to span the entire system is quite small – much smaller than on a large lattice in which all intervening locations must be traversed to span the system.

High-mortality pathogens that would otherwise cause local extinctions and prevent their own system-wide spread have no effective buffer in a small-world system[2].

2 Global centralization of function and its implications

Physical and informational connectivity on a global scale has created conditions in which large nation-states can serve particular socio-economic functions. This has been perceived as attractive way to organize global trade due to a focus on economies of scale and capturing efficiency via centralization and elimination of redundancy. As a consequence, other nations come to depend on flows of essential goods from these central global hubs such as food, pharmaceuticals and medical equipment, and infrastructural technology and components. Nowhere is this more true than China which has become the de facto global center of manufacturing of all types.

Dependence on such hubs generates systemic risk due to the necessity to maintain flows of these essential goods. This generates an unmanagable tradeoff: either adaptively disconnect in order to interrupt a contagion cascade and sacrifice the flow of necessary goods, or remain connected and invite a pathogen or other vector to grow without bound.

The vision of a global system in which central hubs uniquely serve particular functions is a direct analog of what we observe in complex multicellular organisms: particular and localized organ systems serve essential functions for the entire body[1]. A necessary consequence of this organizational scheme is the inevitable death cascade of the entire system. A single organ failure results in a the cessation of flows that are essential for the other components, and the organism perishes as a unit.

If we wish for the global human-system to avoid such a fate, we must encourage and insist on functional redundancy, and a vision of the globe as an ecosystem of organisms, rather than as an organism itself[3].

3 A Spatial trade strategy and Adaptive de-coupling

It is clear that if we choose to generate and maintain global flows of travelers and supply chains, we must also have a tolerance for temporary disconnection of long-range connections in the interest of preventing local contagion cascades that show the potential for severe harm from becoming global and systemic. This puts considerable constraints on

1. We refer here esentially to autopoietic systems. Autopoietic systems are self-generating, and organized as a network of component whose activites and interactions result in the continuous realization of the network components itself[4].

Ethics of Precaution: Individual and Systemic Risk

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PRECAUTIONARY decisions do not scale. Collective safety may require excessive individual risk avoidance, even if it conflicts with an individual's own interests and benefits. It may require an individual to worry about risks that are comparatively insignificant.

Assume a risk of a multiplicative viral epidemic, still in its early stages. The risk for an individual to catch the virus is very low, lower than other ailments. It is therefore "irrational" to panic (react immediately and as a priority). But if she or he does not panic and act in an ultra-conservative manner, they will contribute to the spread of the virus and it will become a severe source of systemic harm.

Hence one must "panic" individually (i.e., produce what seems to an exaggerated response) in order to avoid systemic problems, even where the immediate individual payoff does not appear to warrant it.

You are harming others by not "overreacting"

This happens when the systemic risk is small to the individual but common to all, while an individual's other idiosyncratic risks dominate her or his own life. The risk of car accident may be greater for an individual, but smaller for society.

In short you will end up harming yourself by ignoring these "irrational" risks

Under such conditions it becomes selfish, even psychopathic, to act according to what is called "rational" behavior – to make one's own immediate rankings of risk conflict with those of society, even generate risks for society. This is similar to other tragedies of the common, except that there is life and death.

In addition, there is a tradeoff short-term vs. long term for idiosyncratic risk. Over the long run, there is convergence between idiosyncratic and systemic: your risk rises if all others are infected and the risks of survival from other diseases drop.

For instance, during a pandemic that mostly spares young, healthy individuals, an independent emergency that would typically be routine may become untreatable because of lack of resources. Further, in conditions of severe societal breakdown, many additional risks will emerge for all agents that can't be reduced to the initial short term risk of infection to the individual.

In the current COVID-19 outbreak, such effects can be observed by a complete inundation of hospitals and their ICUs as local outbreaks take hold. This and other less visible thresholds change the dynamic of the pandemic as they are exceeded. Initially small risks become amplified and produce novel and unanticipated risks as the contagion makes impacts system-wide.

Precaution scales in a convex way for cross-dependent small idiosyncratic risks that end up dynamically extremely large at the systemic level.

For these reasons, the prudent and *ethical* course of action for all individuals is to enact systemic precaution at the individual and local scale. The breakdown of scale-separation that a multiplicative contagion induces connects the individual to the collective, making everyone both a potential bearer and source of risk.

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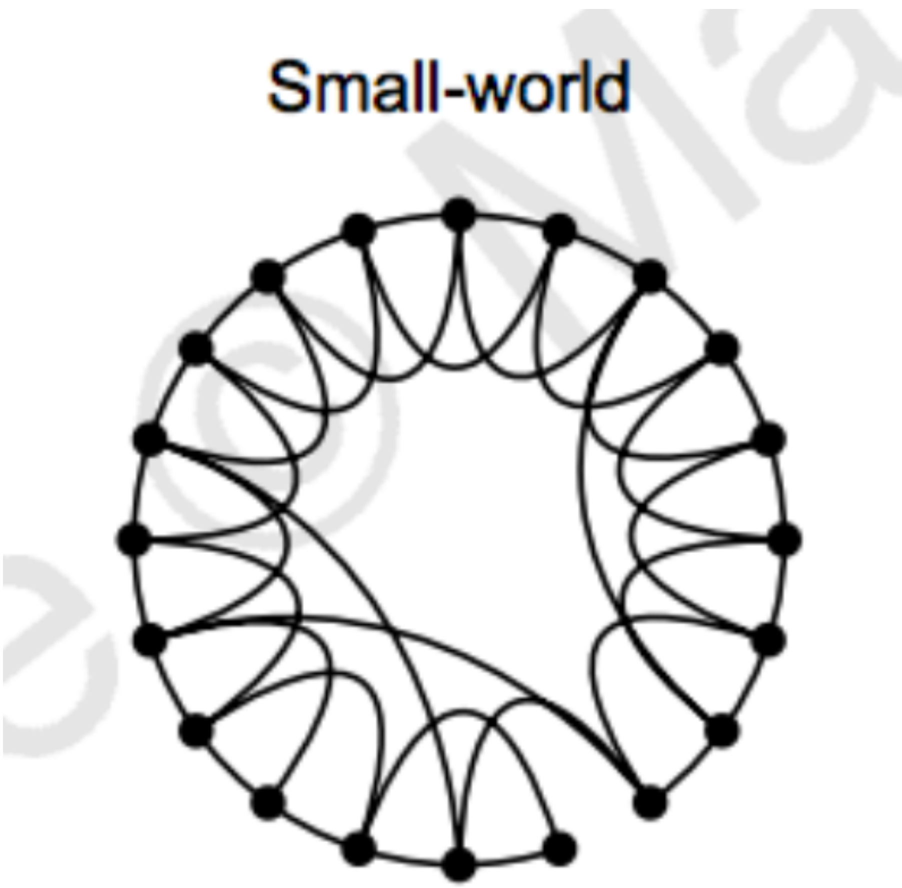
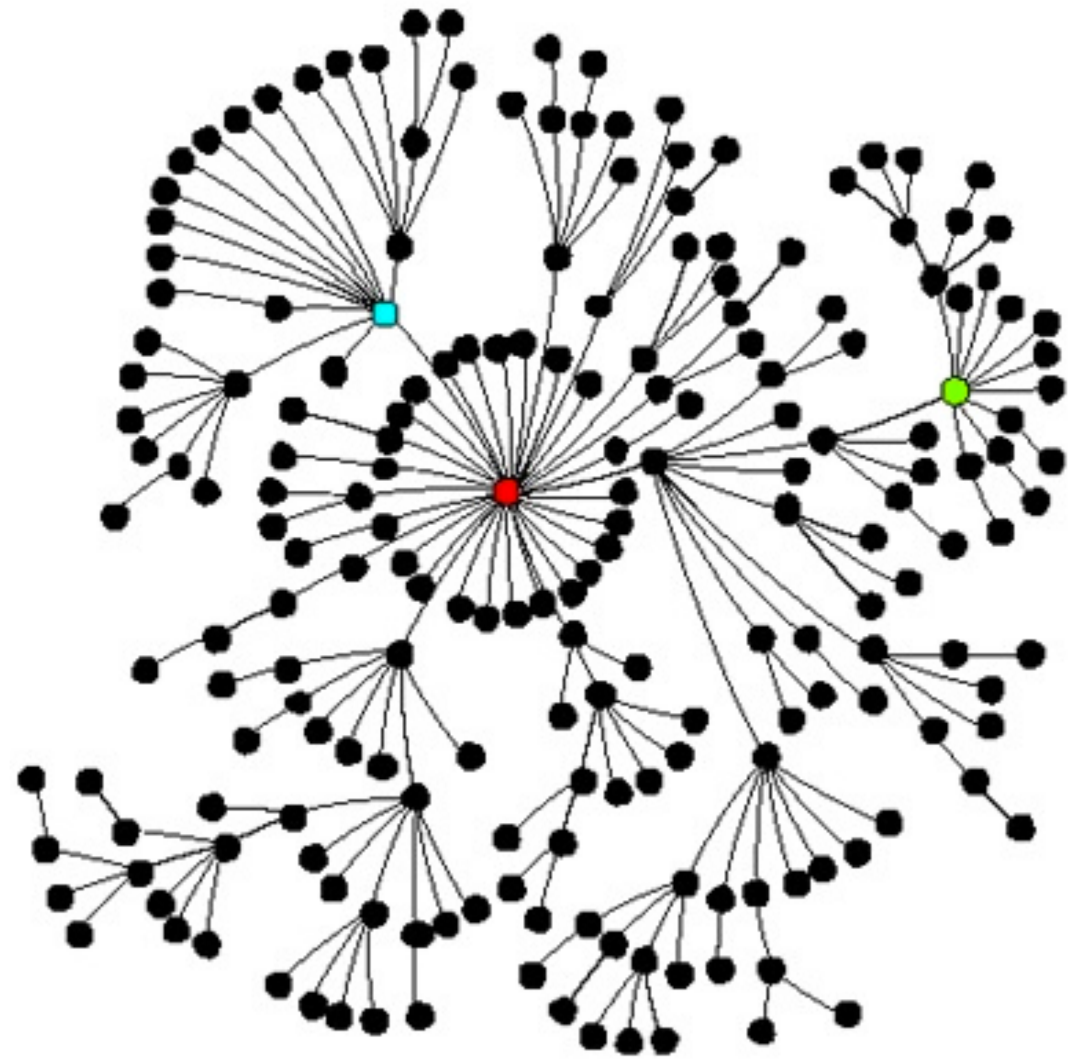
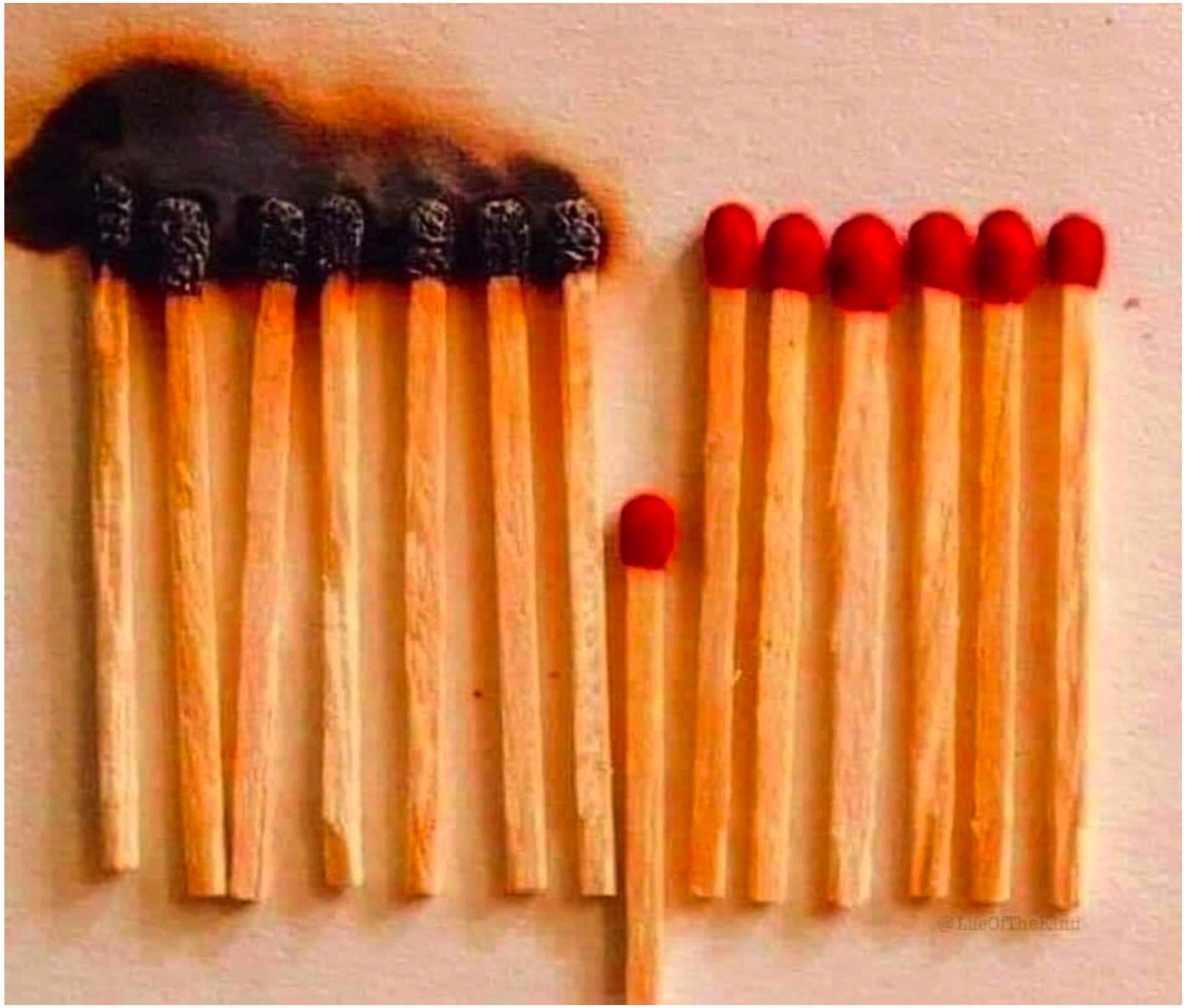
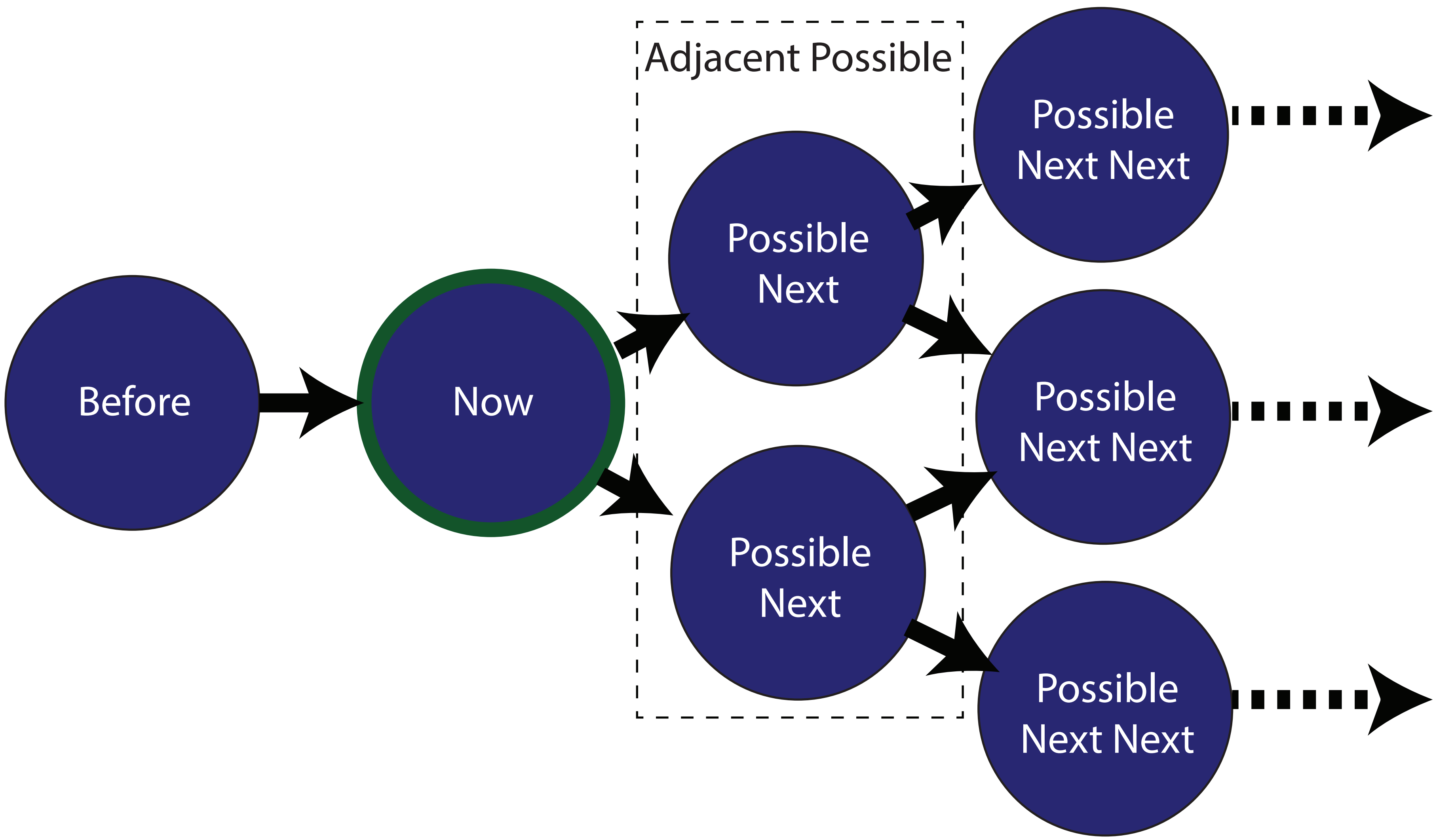
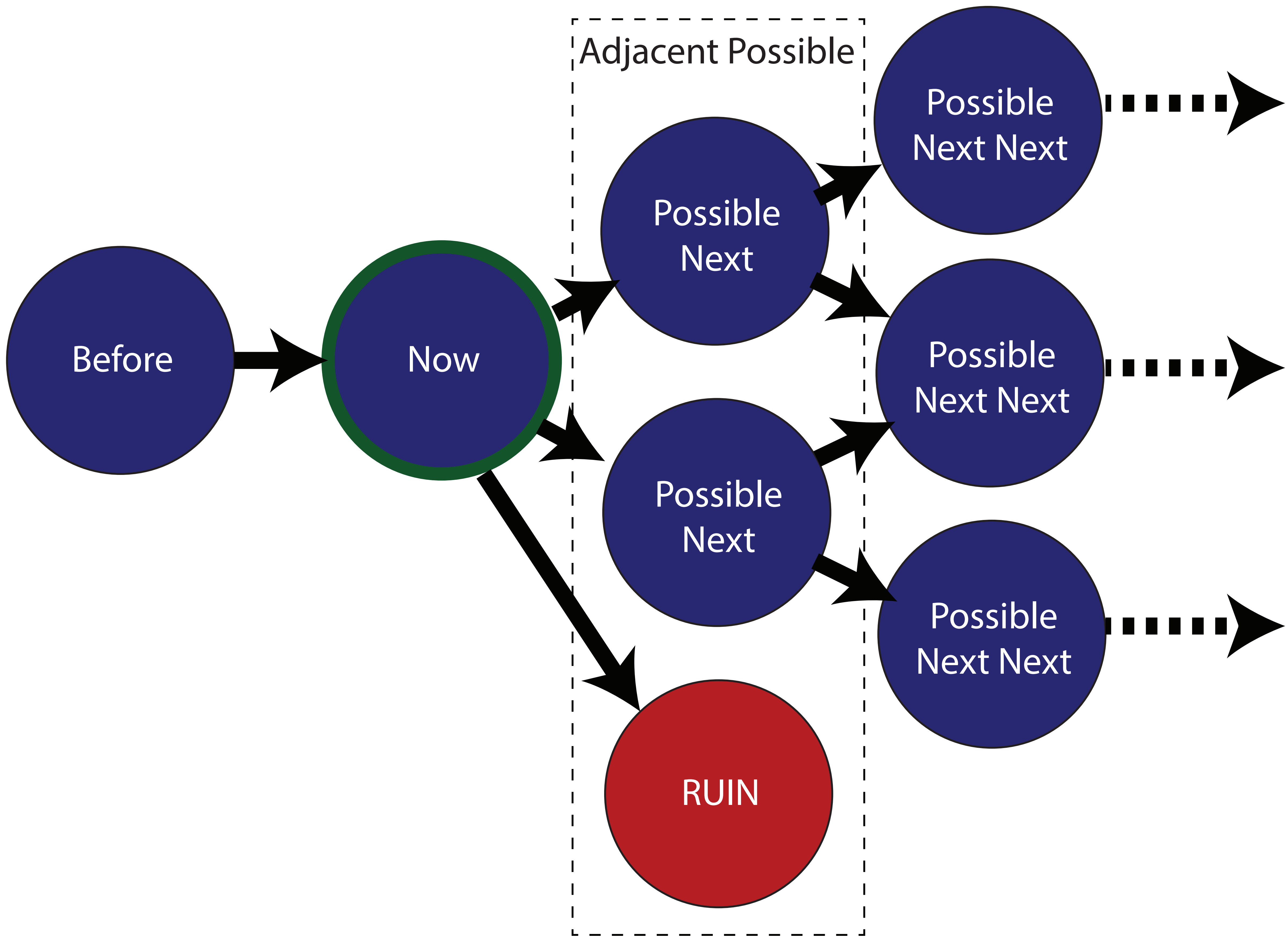

Small-world





Adjacent Possible




Adjacent Possible
Before
Now
Possible Next
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RUIN
Possible Next Next
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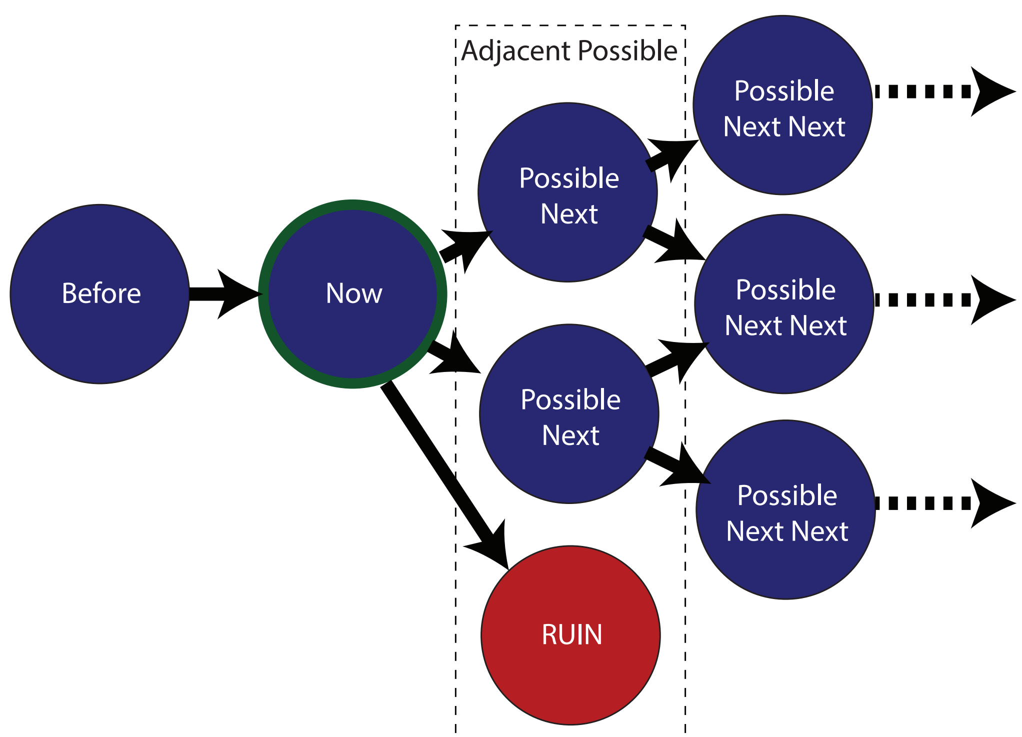
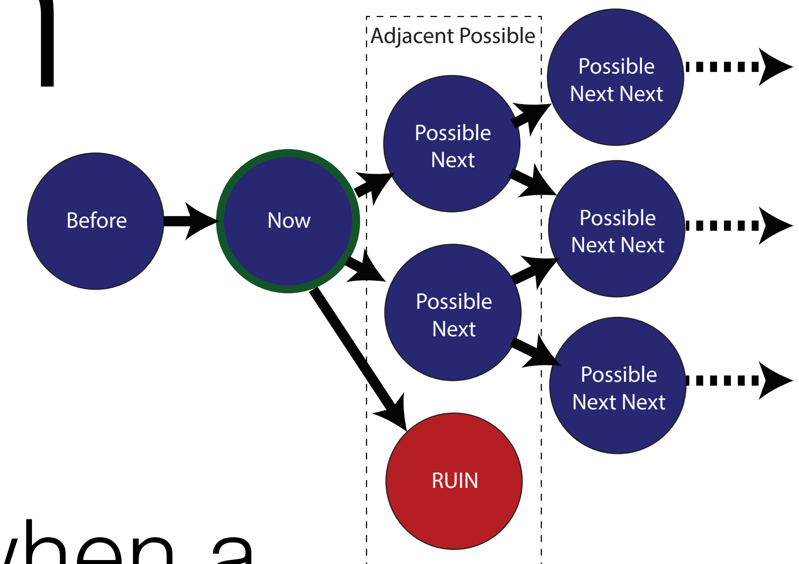
Precaution

- What kinds of risks are acceptable or desirable?
- What kinds of risks, given our current state of ignorance, are unacceptable?
- For some risks, we won't get a second chance

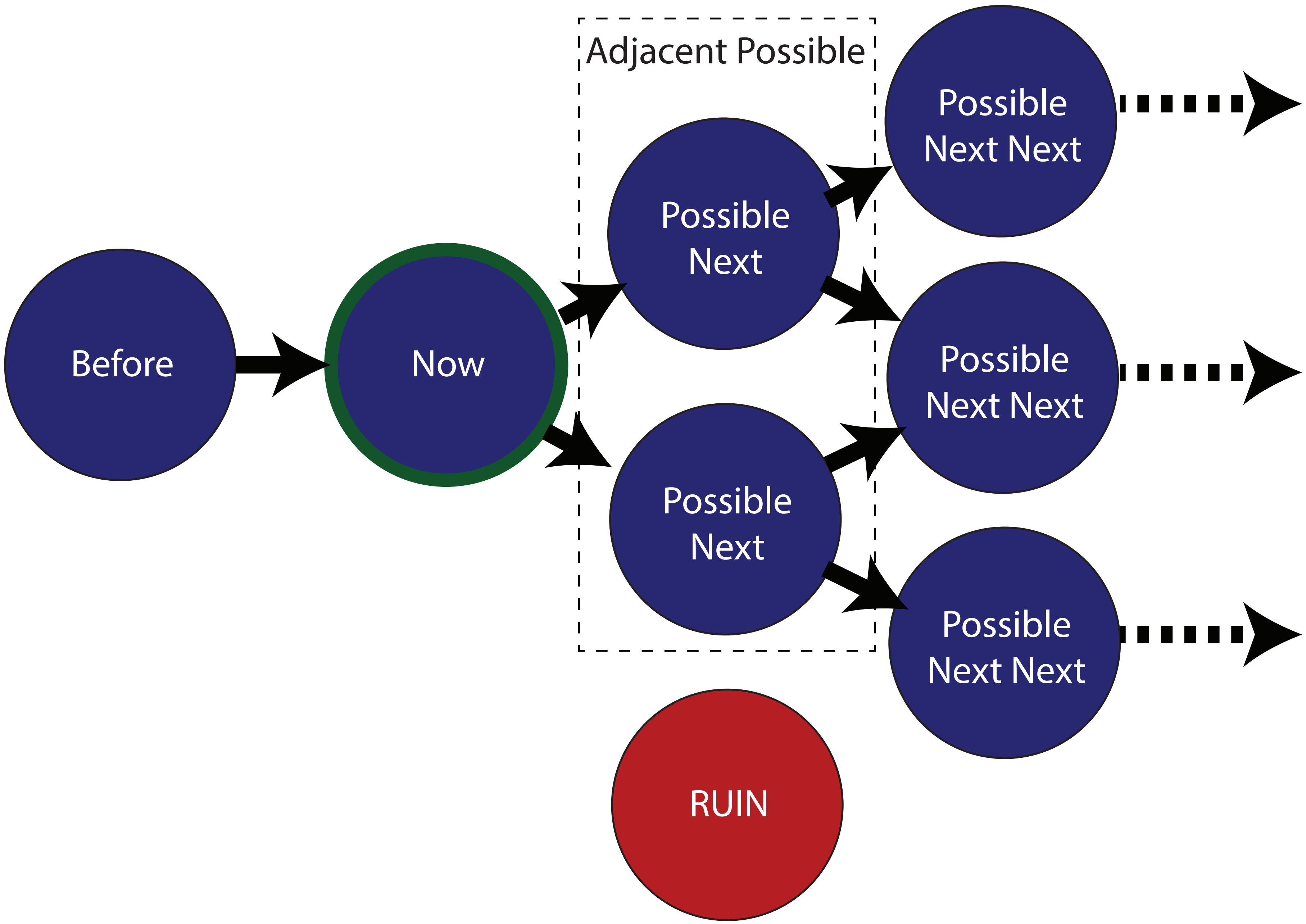


Precaution



- Cost-benefit analysis fails us here
- How to do a cost-benefit analysis when a distribution has an undefined mean? (for instance)
- When a system has potential for a ruinous absorbing state, the time and space statistics do not coincide (Peters and Gell-Mann)
  - a single trajectory does not obtain the ensemble (space) average!

Precaution



Keep ruin OUT of the adjacent possible!!!!!

Precautionary Principle

- If an intervention is:
  - systemic (propensity to spread)
  - non-reversible
  - ‘solves problems’ that can be solved more simply
- **PRECAUTION**

How to generate convex exposure?

- In general: Evolution!

  1. Try many small/local things (generate variety)

  2. Expose to environment/stress and weed out ‘losers’ (low-cost)

  3. Elaborate on (additional variety) and/or deploy winners (cash-in)

  4. Repeat

Agent-Level Navigation

Heuristics vs. Internal Modeling

- How does an outfielder catch a fly ball?
- Some challenges: visual ambiguity, air resistance, wind, time constraint
- Possible answer: leverage physical model of the situation in the brain based on sense data, make a prediction about where the ball will hit the ground, get there before it does (as in e.g. Dawkins 1976)

Heuristics vs. Modeling

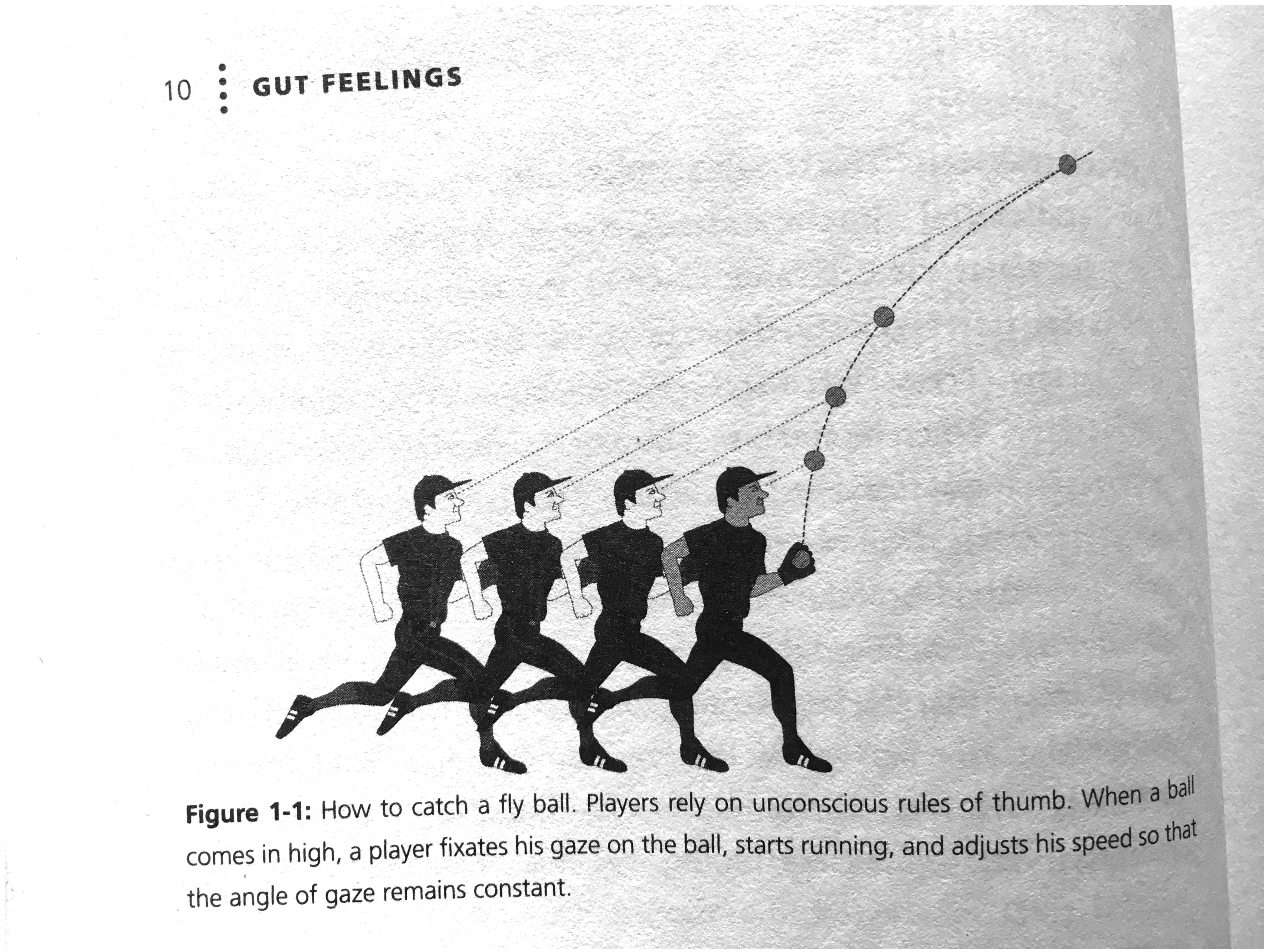
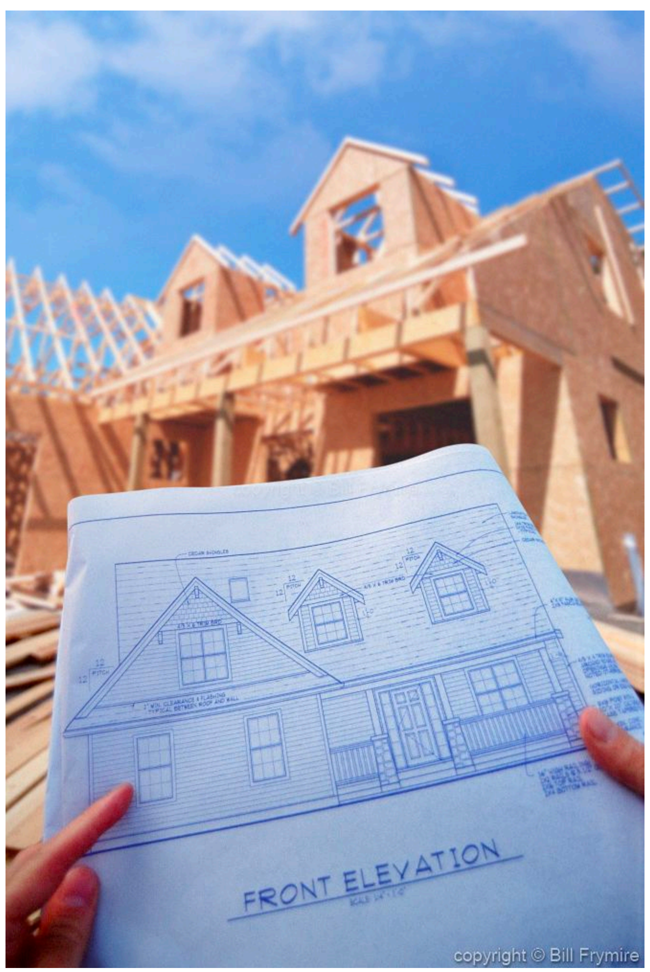

10 GUT FEELINGS

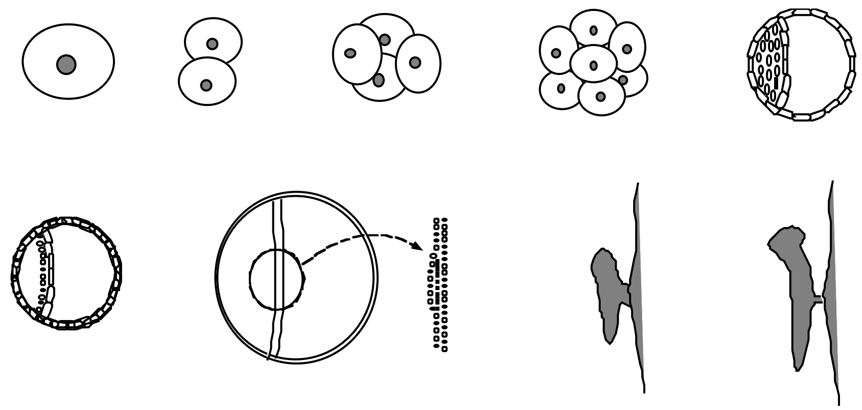
Figure 1-1: How to catch a fly ball. Players rely on unconscious rules of thumb. When a ball comes in high, a player fixates his gaze on the ball, starts running, and adjusts his speed so that the angle of gaze remains constant.

1/N Heuristic

Pattern Languages and Unfolding Wholes

Pattern Languages and Unfolding Wholes





Collective-Level Navigation

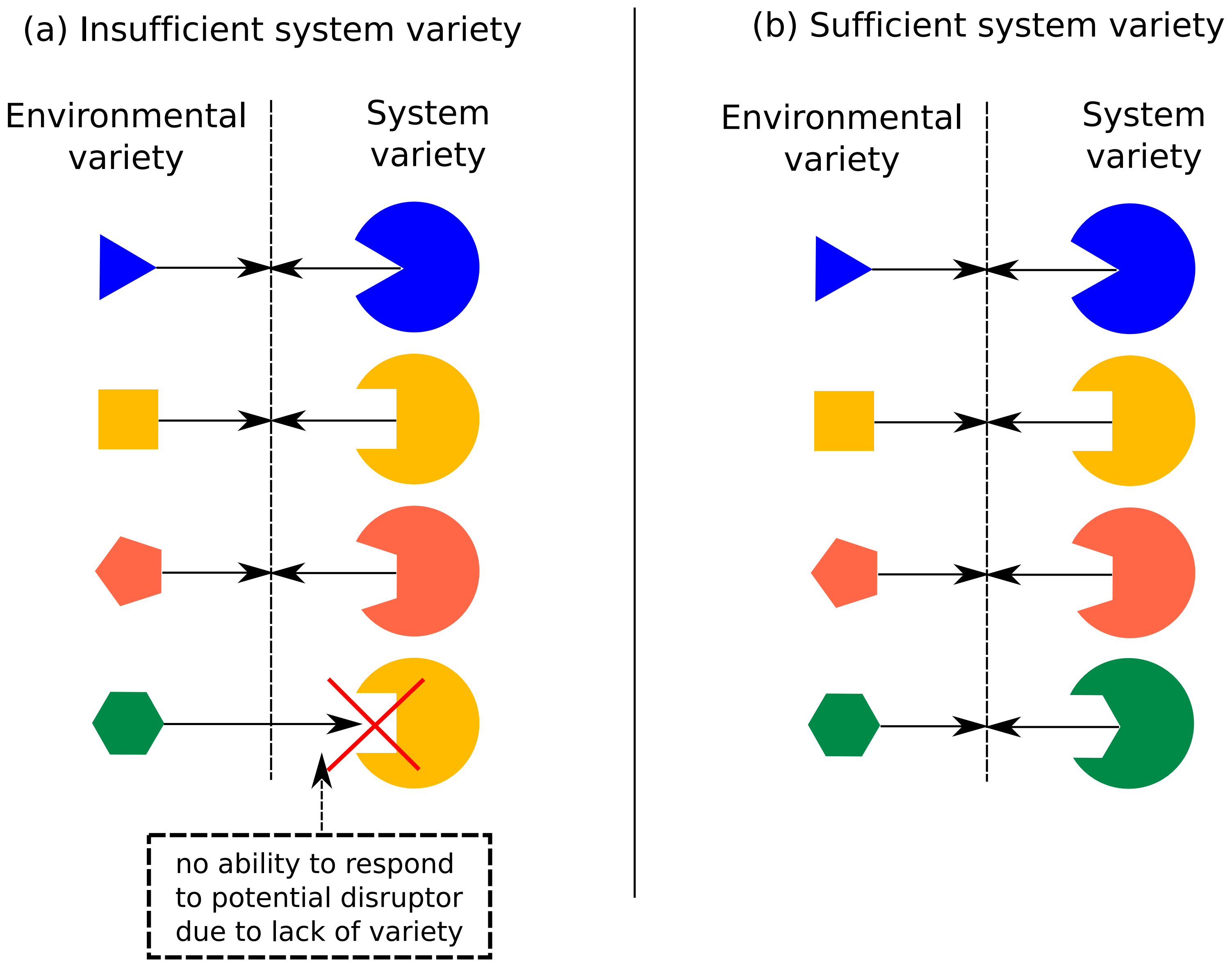
Evolutionary Engineering

- Complement to traditional engineering
- Focus on *selective pressures* instead of detailed requirements specification (articulate minimal requirements with maximal ambiguity)
- Focus on environment and ecosystem in which
  - teams develop tools / solutions autonomously based on current understanding
  - potential users gain exposure to tools and able to leverage tools to their own ends
  - feedback from end users to creators / engineers

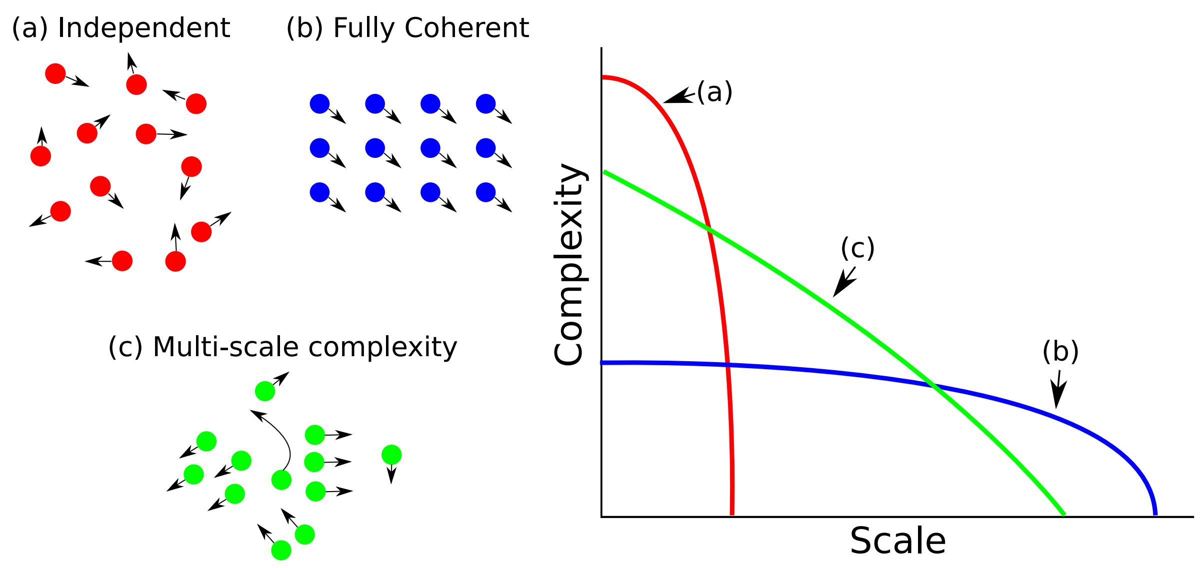
Case Study

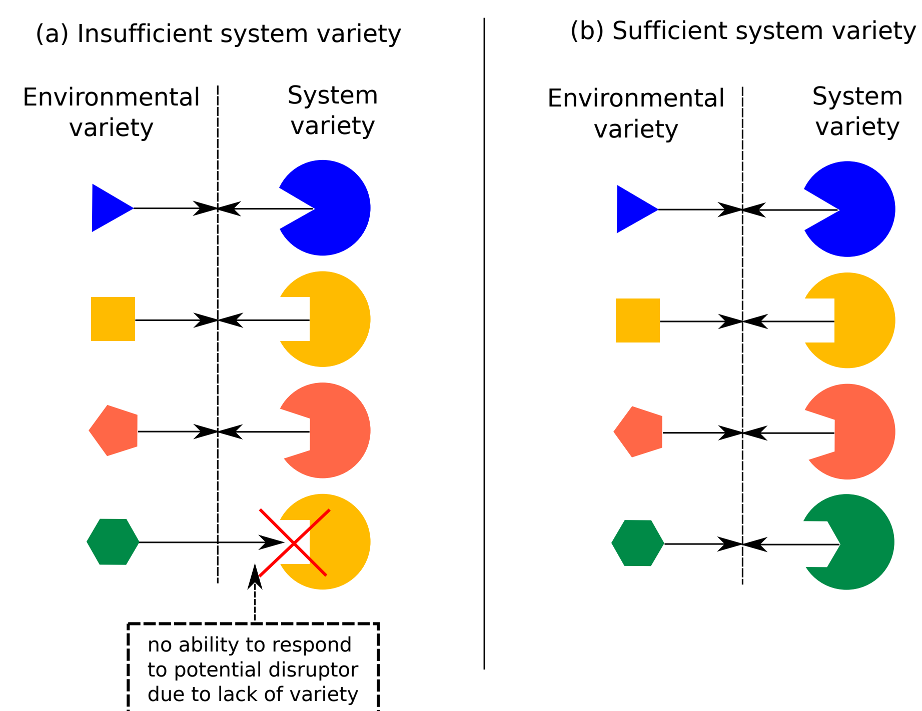
- In the early 2000's The US Military's Air and Space Operations Center was reimagined using evolutionary engineering approaches
- Old-AOC was procured in traditional way: requirements development, sourcing, final system integration.
- AOC had notorious integration issues, was not serving its intended purpose effectively.
- Environment was created
  - where developers interacted directly with end users
  - development teams were exposed to other teams' developments (co-opetition)
  - requirements started vague and became more precise through tinkering and experimentation
  - the best sources of relevant information were discovered through direct exposure to "effector nodes", rather than, "up the hierarchy"

Requisite Variety

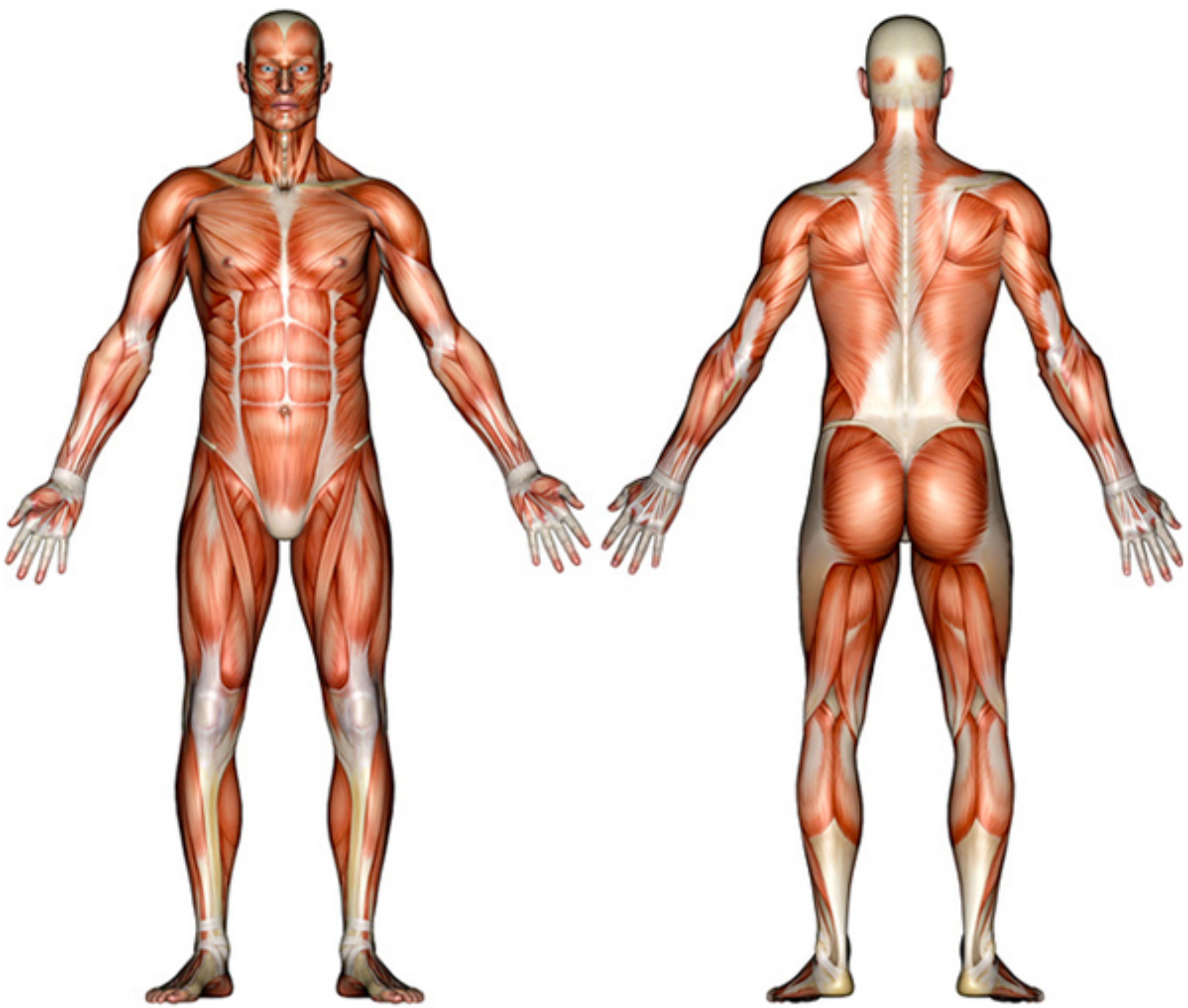


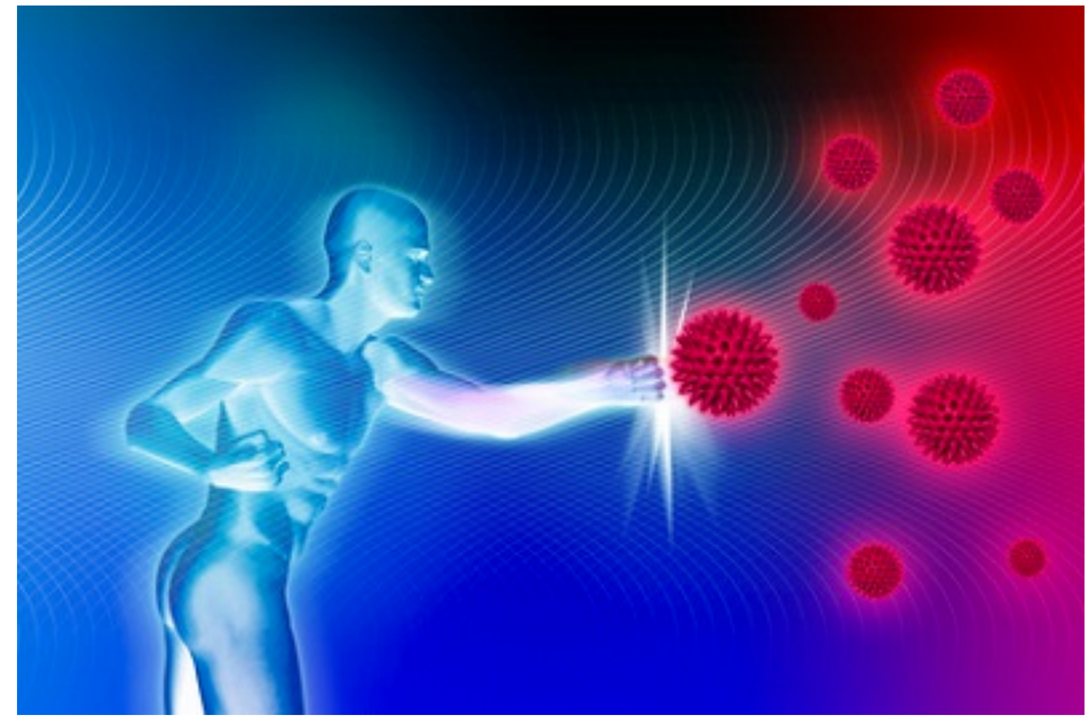
Multiscale Requisite Variety

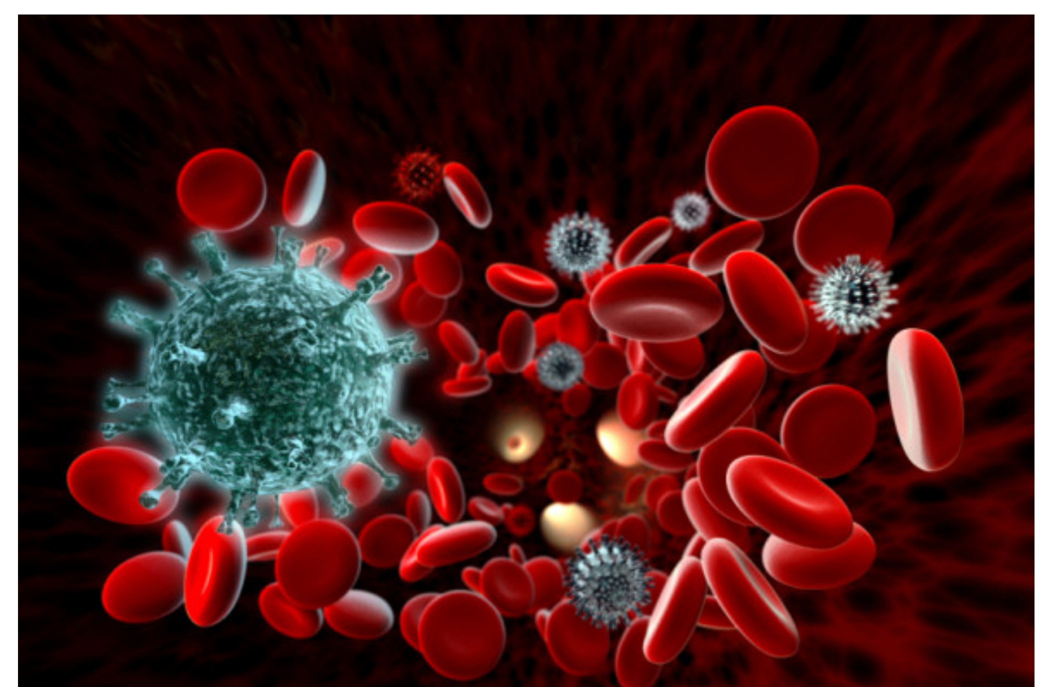




Multiscale Requisite Variety







Multiscale Requisite Variety

The IYI Mistake

- IYI sees order, assumes (top-down) design
- Doesn’t know the difference between construction and growth
- Makes a career by insisting their expertise is the only thing keeping things orderly
- IYI destroys emergent order with top-down fuckery

Unpredictability

- we are bad at anticipating emergent properties
- chaos, sensitivity to initial conditions, paths diverge (even if reductionism worked in principle, this would doom the prospect of long term predictability)
- evolution highly weird, functional significance hard to detect and understand
- overwhelming dimensionality
- massive interdependence and interconnectivity

Unpredictability

- Even in the BEST CASE SCENARIO: dynamical laws are fully known, current state of the system is known — the future evolution of the system is unpredictable beyond finite (small) time horizon

- We are FAR from the best case scenario

Approaches for the future

- Make room for self-organization and evolution
- Decentralize
- Limit IYI intervention to themselves (Don’t let Sunstein OR John Bolton near the White House ever again)