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The edge between chaos and order, and what it can teach us (complexity series)

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This post is a first on a series on Complexity Theories, specifically thought for facilitators and people who have a deep curiosity in the science and its practical applications for leading our lives and work

We begin by order and chaos as different states in which a system behaves, and the interesting phase that happens in between.

What is this edge of chaos? It is a zone of transition between the ordered and the chaotic state. Our scientific understanding from a variety of disciplines under the umbrella of complexity theories are pointing towards this edge, and are speculating that some of the most interesting, rich, and adaptive behaviors happen at this edge. Some even have gone so far as to say that this in between realm holds the key to understand nature, that it can perform universal forms of computation (see Wolfram), or that this spontaneously arising complexity is the key driver of evolution (as Kaufmann does). But first off, let's start small, from the discovery of chaos, and a very humble life form; we will later zoom out onto some bigger picture considerations.

What is chaos?

If we trace it back at the Copernican revolution, the history of our scientific outlook on the world can be told as a love story with certainty, and a disdain for its absence. The scientific worldview, so much at the center of our current understanding of reality, had a dream: Isaac Newton gave us basic, universal laws by which the universe operates. With knowledge of cause and effect via these laws, and given perfect knowledge of the initial conditions of the universe at a given time t, we could predict in detail the future. Some dreamed of doing it, some others tried to do it, and the failure was remarkable. In the 1800's, Poincare tried to prove that the motion of planets is entirely predictable once you know their initial positions; he failed quite publicly, but that failure seeded the most interesting conclusions: we started peeking into chaos. The mathematical discovery was consequential: given some initial conditions, and a set of simple, deterministic rules, a system would show a certain behavior over time. One definition of chaos that comes from the hard sciences such as mathematics is that of deterministic chaos: Given a set of initial rules, and some input conditions to a system, change one parameter just by an infinitesimal bit, and the outputs the system produces are completely different, unpredictable.

Another definition of chaos is that of a lack of any organization: all actions that parts of a system perform are independent, without any coordination or distinguishable pattern, and hence very little capacity to predict what will happen next. Many would say “no capacity at all” to predict what happens next. (For a fuller explanation see my pedantic language note at the bottom).

If there is stillness in the eye of the storm, what’s sitting at the edge of it, in that transition phase where the wind stops blowing so violently? Can we make order out of chaos? Does it arise naturally? And if so, how?

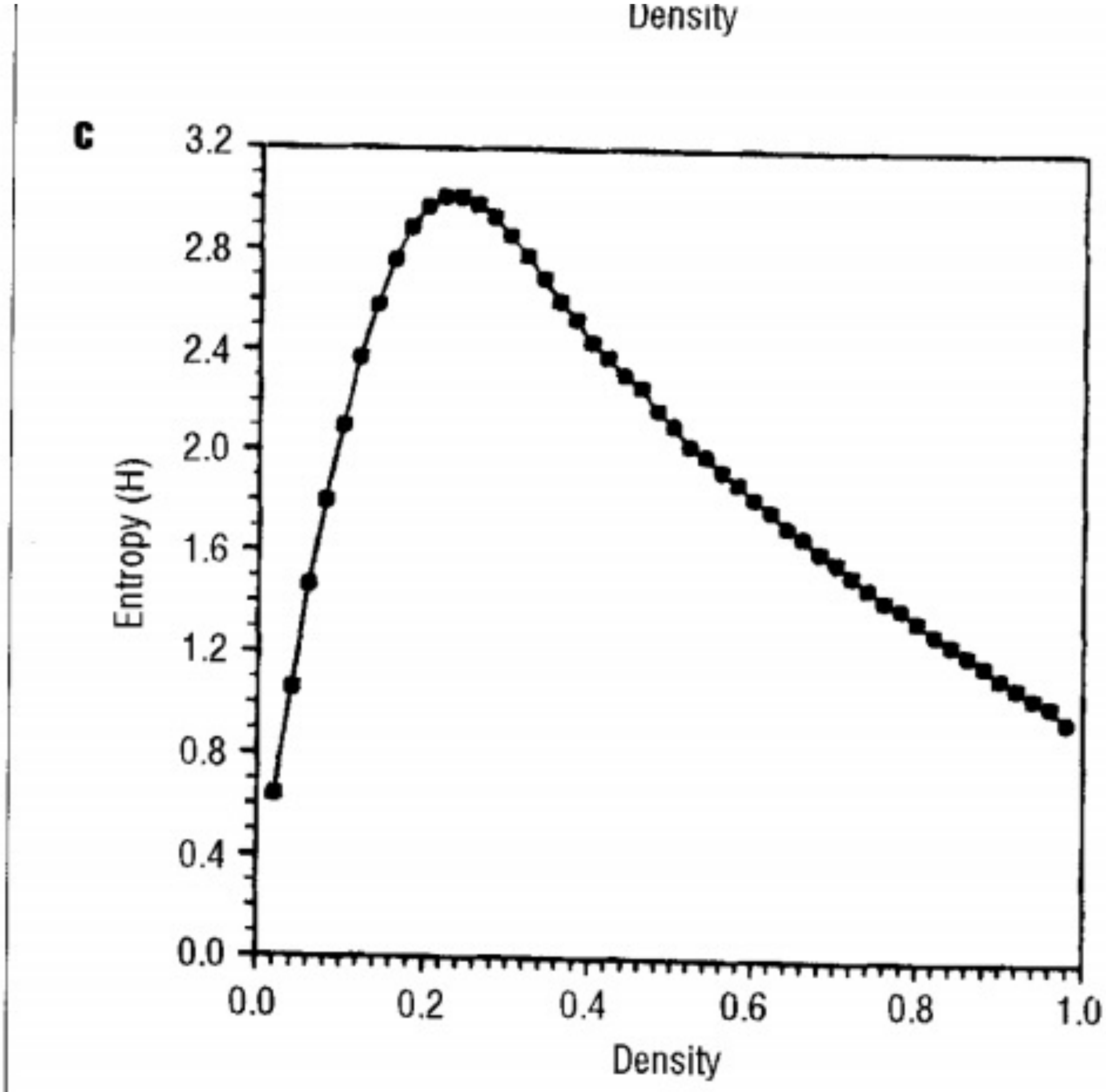
To answer this question, we turn to colonies of ants.

The humble soldier ant is unremarkable under many regards. Nearly blind, with a very limited cognitive capacity - and yet when you put a few thousands of them together, they start performing some impressive tasks, from foraging food, to building nests and bridges with their bodies. How could an insect so simple taken alone perform complex behavior when in a large colony? Colonies of ants exhibit phases of order-chaos transition. The study of different types of ants have used both observations and computer simulations to make sense of their behavior, and scientific models have given us important insights that reflect well their actual behaviors. A colony computer model usually contains an environment in which the ants move (a “universe”), and very simple rules about how they behave: an ant often walks around randomly, it can start moving by itself or by being activated by contact from another ant, it would follow a neighbor’s path when it detects a chemical trail, etc. The models plotted the activity of the individual rules for interaction, assuming they were all the same, plus the density of the ants in the colony (how many, how close together they are, hence how more likely to get in touch with one another and influence each other’s behavior). Then you start with an initial scenario given at random, and you run the model to map out the collective behavior over time.

Over these basic rules you can observe a few qualities: that there is variety at the individual level; there is enough density because of proximity; there are rules (often very simple ones) by which all agents affect each other’s behavior. Then the question is: when you plot this into a model and let the ants go, what is the colony going to do?

What they found is that there is some really interesting and complex behavior that happens where both order and chaos co-existed.

They came up with a classification of three scenarios of a global pattern exhibited by the colony as a whole: a lot of aimless uncoordinated movements by the ants; a group of ants that is working like a clockwork and doing all the same thing; and a most interesting state where there was both high coordination of behavior and a high variety of individual variability. The model predicts that at an increasing density of interactions between the ants, the behavior moves from completely chaotic into one that starts showing a coherent pattern -as if the entire colony is acting as one intelligent whole.



At first (far left) the ants are running around -say,searching for food, as in many models was actually the case- with no coordination at all. While the individual actions are all different and unpredictable, what happens for the colony as a whole does not give us much useful information or a very intelligible pattern yet -and that's why the informational entropy is still low. What this means is that the colony seen a whole does not manifest the most informationally rich behavior it could express.

When the density increases, for instance because there are more ants bumping into one another, the state of the colony as a whole expresses its greatest possible diversity: there is a mix of stability and randomness. How is that visible? You spot stability when you are able to discern an intelligible pattern (for instance, they seem coordinated in carrying out tasks) and the ants manifest a type of unique conduct of the system taken as a whole. At the same time there is a high diversity of what each ant does, which makes it so information-rich. In fact, if you were able to predict every single ant's next move, its information richness would be minimal, but instead at the edge between chaos and order you have the maximum of both predictability and unpredictability.

As the density increases, their collective acting becomes more and more stable and therefore predictable. The level of coordination of the collective veers towards its theoretical maximum, but this comes at a price. If so much of what an individual is doing is determined by the group, individual variation diminishes, and so does its possibility to show a diversity of tasks. Back to the original question: “What is the colony going to do, given these simple initial rules?” It depends and is more nuanced than what I’ll write, but overall the colony could behave in one of three possible states: in a random one that resembles complete chaos, in a highly ordered state, or there is potential for emergent complex behavior at the level of the whole.

If ants are not your thing, let’s use a music band instead to illustrate the point. The random state resembles a jazz quartet tuning their instruments and not even listening to one other, hence playing a seemingly uncoordinated flurry of noise; the far end on the right can be imagined as a band of drummers playing a single beat in unison with no variation. I bet none of the two tracks would make it into your playlist, for the most complex music comes from the edge between individual diversification and freedom on one hand, and synchronization and alignment on the other. It is also the most informationally rich as it produced enough order to be a song from start to finish, and unpredictable enough because of the various instruments weaving together a sound that is complex and appealing to our taste.

What does this all mean, or imply?

If we go back to our ants, there are a few interesting implications with all this.

In the ordered state, there is more stability, more predictability, and the behaviors exhibit a lot of coordination but not much newness. It is great for storing information, but very rigid for transmitting new information fast enough to let it propagate. When foraging ants find an ample food source, their colony moves into a state of highly ordered behavior, which is great for exploitation of a known source at efficient rate.

In the chaotic state there is little or no stability to show any coherent pattern of collective behavior. There is very little predictability because very few behaviors -if at all- are coordinated, but this brings its advantages, too. For foraging ants, this can work very well to explore new areas in all possible directions, and it helps with the fast spreading of information: the signals have the potential to travel fast, but there is not always guarantee they will propagate or create enough ripples to produce new behaviors other than in a niche.

The complex state sits at the edge in between chaos and order: there is enough individual diversity to generate newness (for instance in explorations) and at the same time enough coordinated, consistent behavior to create internal stability, exploit a food source, and create predictable patterns.

What implications does this bring?

What, if anything, can be learned from this as we live in many systems that can exhibit these possible states as well? Before we draw analogies, two important caveats:

- the models are just models, not the reality. And yet they have been able to give cogent explanations to some behaviors
- Humans are not ants, neither they are information processing machines, and for good reasons: they are governed by far more complicated rules (are we governed by rules at all?)

Still, some of the insights from the chaos / order edge can prove helpful as heuristics, as tentative maps as they help us make sense of many systems behavior: why in a busy and seemingly chaotic road crossing in Kampala so many drivers could each find their way out of a scramble with relatively no trouble?

An ordered state is predictable and robust: small wonder many love it (especially when they happen to be the ones who control it); and yet there is less and less ability to adapt and evolve, such as passing on information, exploring new pathways, etc. Chaos is unrivalled at generating newness of behavior, and yet the spreading of information does not necessarily lead to a system-wide change, nor guarantees the storing of that information, unless the system has a) enough interconnections to adopt a new behavior as a coordinated whole and b) enough order to store its information. The desire for order (too much order) often can make us tilt all the way to the opposite extreme of chaos.

Some musings that you might find useful:

- how much individual freedom to explore new pathways are available in a system you are currently embedded in?
- how much does the system need an exploration of an existing source (seen in a broad sense) that promises stability and predictability?
- how much does the system need new explorations that may be completely at the edge of the current areas you are looking into?

In my next post, I will discuss implications for how we lead, live, and react to various states. (Thanks Chris Corrigan and Bronagh Gallager for edits and comments on a draft of this post)

Note on terms used:

I am aware of the Cynefin framework and have intentionally used the word 'chaos' for a state that is yet uncoordinated. To be fair, the literature on complexity theories uses the word 'chaos' in a more strict sense to define 'deterministic chaos', which is the first example at the beginning of the post whereby you change initial condition in an equations and you get completely unpredictable and apparently random results (which is also called "extreme sensitivity to initial conditions" and is still a deterministic form of chaos in mathematics). What can be found on the left hand side of the diagram of the colony behavior in terms on the density / entropy chart belongs to unordered domains of the Cynefin framework, whereas the tail on the right slopes down to the ordered domains (as far as I understand them). More on this in later posts that specifically address Cynefin

But if you dig into old articles like the ones I use as references, you may find they use the word 'disorder' for the initial stages of random, uncoordinated acts that show no sensible pattern at all. Since in Cynefin terms 'disorder' has a different meaning more akin to not knowing yet in which state the system is, I avoided to call 'disorder' the state on the left-hand side of the chart.

Some sources for this piece:

Octavio Miramontes: Order-disorder transitions in the behavior of ant societies (1996) DOI 10.1002/cplx.6130010313

Lixiang Li et al.: Chaos–order transition in foraging behavior of ants (2014) DOI 10.1073/pnas.1407083111

Mel Mitchell: Complexity. A guided tour (2009)

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2 comments

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To add an ancient, faith-related element to Marco's article on chaos theory and formation...

The Hebrew word translated into English, Tovu wa-bohu, may be generally translated as chaos or formlessness. This word is found in the book of Genesis (Genesis 1:2) and the formelessness (primordial stuff) from which God (YHWH) forms. (תֹהוּ וָבֹהוּ).

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Victor Branagan
Director, Clearly Sustainable I Sustainability… ··· 3mo

Thanks for this article Marco. Really insightful. I always feel that chaos carries so many loaded prejudices that it is hard to get to the real importance of the word. Also, there is so much fear for so many of us around the uncertainty of chaos that I think it really holds back the exploration of the edges. This hinders innovation which I believe requires 'staying with the uncomfortable' long enough to see if there are real opportunities there. Too often we mask this fear with our 'busy-ness' by demanding quick solutions or 'give me the short version' and this allows us to dismiss explorations into the unknown as un-workable without really exploring them.
Keep up the good work.

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Thanks for the comment dear Victor; I am following the recent developments of the Cynefin and find it a really fascinating way to understand and make sense of complex adaptive systems. More on this to come!

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