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Theory of complexity: interconnectedness, emergence and hierarchical structure

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The world consists of inter-connected processes. It is an illusion to think that "*things"* exist. As argued by Alfred North Whitehead processes are ontologically fundamental. Since the building blocks do not consist of "*things"* with specific intrinsic properties, we can hope that a general science of the processes underlying and controlling the behaviour of apparently very different situations such as the evolution of an ecosystem or the performance of a piece of music by a band, may very well exist.

A saxophone and a tree doesn't have much in common. But a jazz band and a forest might very well have. Say for instance in the way information is moving around amongst the components and in how structures evolve. The similarity may extend further. For instance, a saxophone is of course not really a "*thing"*. It is collection of processes that move objects around and generates the process of variation in air pressure; which in our mind becomes the wonderful phenomena we call music. Similar for ecosystems. What we see as "*things*", building blocks, or components at one level, are at another level themselves collections of components participating in processes.

Why is this, rather self-evident observation, important to us here. Because, as soon as one realises that the world is made of inter-connected processes and not of "*things"*; one also immediately realises why Complexity Science is the most fundamental of the sciences and why a place like the Complexity Science Hub Vienna, is likely to create more fundamental insights about the world we are surround by than, say, the Large Hadron Collider ever will do.

How should complexity science go about uncovering the generalities behind the super complex systems such as the brain, the economy or ecologies? By finding ways to extend the tremendously successes of statistical mechanics. The science of multi-component systems developed around 1900 not least here in Vienna by Boltzmann. At present, statistical mechanics has its greatest successes when applied to equilibrium systems. Complexity Science needs to discover ways to systematically extend statistical descriptions to far from equilibrium. In doing so we must not be naïve, we must not be too attached to our old formalisms. But there are indications that ordinary statistical mechanics of systems at or near equilibrium may point us in the right direction. We need to expand our understanding of intermittency, tipping points, stability – in short: we need to understand the emergence of hierarchies. We need to identify which aspects of complex systems are typical across many types of systems and we need to learn what kind of mathematical formalism is able to capture and describe the emergent hierarchical structures.

Big Data will undoubtedly be a big help. But only if we use the access to big data to identify simple unifying concepts. We won't gain much insight by making our models as complicated and involved as the phenomena we try to understand or as data rich as our Big Data banks.

What is a viable theory of complex systems behaviour going to involve? My guess is that we need to understand co-evolution, we'll need to use simple networks (not networks that are as multileveled and as complicated as the real systems) and we'll need statistical mechanics in conjunction with information theory – most likely involving a greatly generalised version of the entropy Boltzmann studied here in Vienna. Perhaps we'll be able to identify multi-parametric families of entropies with information theoretic interpretations. And perhaps we'll be able to derive the probability measures needed to analyse a specific complex system by a kind of generalised maximum entropy procedure, which is able to fix the free parameters of our entropy and there by pick out the relevant entropy and, importantly, its time dependence. Should we find such a formalism we would indeed have a theory of Complexity.