Complexity and its Relevance in Science and Society

Manan Khattar

December 7, 2017

Throughout this course, we've tried to normatively characterize, or more accurately understand the rationale behind the normative characterization of, different aspects of existence. Whether it's one culture over another, morality over immorality, one automaton vs another kind of automaton, there has been some defining characteristic whose presence has allowed us to argue the value of one of these values over the other. In 1968, Charles H. Bennett argued that metric to be "logical depth," or computational content. In this sense, the more complex/self-referential/uncomputable/time-intensive a schema/algorithm is, the more normative it is from both a social and evolutionary perspective, and thus survives to be built on and improved by future generations. We've related the difference in complexity between a set and its power set, and solving P-complete vs NP-complete problems, to reducing the complexity of a person or treating them as uncomputable. As such we've thoroughly explored the relationship between logical complexity, computer science, and social ethics, but in doing so we've neglected to mention the other kinds of complexity prevalent in the Universe; specifically, the Kolmogorov complexity that relates so excellently with entropy in both the informational and physical sense. We now look at some interesting conclusions that can be drawn by studying the latter; in particular, Leonard Susskind's argument in his book *The Black Hole War* that the Universe ultimately prefers less complexity and more entropy, and all the 3-dimensional information in black holes and possibly the Universe can be ultimately reduced to a 2-dimensional hologram of that information. We then develop a discussion of complexity theory linking the two fundamentally distinct concepts of quantum mechanics and general relativity. We conclude with a somewhat whimsical discussion of the treatment of complexity in today's society, both Western and Eastern, and how in that could lie a tie between algorithmic complexity and logical complexity.

In their essay entitled "Organized Complexity: Is Big History a Big Computation?," Jean-Paul Delahaye and Clément Vidal downplay the importance of complexity in a physical and informational sense, "random complexity" as they call it. They deem it unable to account for the distinctive information found in an organized entity; they argue, for example, that the Kolmogorov complexity of a random string can be mimicked with a completely different string with the same randomness, so it doesn't enclose organized information. I disagree with this premise—first of all, it assumes that something that is truly random still encloses some sort of information. By definition, informational complexity is the lack of entropy, so if something is truly random, lacking any kind of complexity or pattern, there is no useful information that logical depth could encapsulate that algorithmic entropy could not. This in fact raises the question: why do humans, no less Drs. Delahaye and Vidal, or more generally organized life, value a different kind of complexity than seemingly the rest of the Universe? Why is this idea of organizational complexity so important to life as we know it, how does this relate to the theoretical computer science principles we've covered? I would argue that just as there are differing levels of complexity within one subfield, such as the number of objects and the number of relations between objects, there are differing levels of complexity itself. This self-referential nature of complexity, this strange loop found in the very subject itself, seems to suggest that complexity as a study is not computable in some sense, and is thus very characteristic of what it means to be human.

Disorganized complexity seems to study particles or entities as a whole and study them with statistical/mathematical/computer science methods; indeed, this principle is the basis for Boltzmann's H-theorem, and much of statistical thermodynamics. An ideal example for this would be a collection of gas molecules in a chamber; the millions of molecules themselves have interactions between themselves, ranging from gravity to electromagnetism to even strong weak and strong nuclear forces on scales infinitesimally small. However, in studying them we ignore the impact of these forces and instead use statistical mechanics methods to argue that the entropy of the system never decreases over time; alternatively, the physical complexity of the system never increases with time. As a physical formulation this law, the second law of thermodynamics, is unique—not only is it not a hard and fast law, subject to being violated with some non-zero probability like most statistical events, it is also the only major law that is not reversible with time on a macroscopic scale. This fundamentally limits the complexity of the system in a sense, and perhaps give rise to the existence of organizational complexity as a sort of pushback against the seemingly inevitable march towards the heat death of the Universe. If this time inevitability were reversible, perhaps there would be no need for organizational complexity at all, as the Universe would naturally tend towards organization, at least part of the time.

Interestingly enough, quantum mechanics and the informational theory of black holes can be used to study the issue of complexity, and reveal conclusions that while not directly applicable to human experience can nevertheless provoke some reflection about the development of the Universe and our role in it. In the quantum world the second law of thermodynamics does not necessarily apply—researchers at the Department of Energy's Argonne National Laboratory investigated the behavior of quantum particles with respect to the H-theorem and found instances of local negative entropy, meaning the complexity of the system spontaneously increased. Perhaps even more interestingly, researchers at the Beijing National Laboratory for Condensed Matter Physics studied the second law of thermodynamics as it relates to "quantum memory," and while I do not completely understand the phenomenon, it is hard to miss the seeming connection between the quantum world and many of the traits that characterize organizational complexity. General relativity, and its crowning achievement the black hole, are stubbornly difficult to describe in a quantum mechanical framework; indeed, the theory of quantum gravity is one of the biggest unsolved problems in modern physics. I hypothesize, without scientific proof, that a possible reason for this difficulty is the inherently different mechanisms these two systems have with respect to complexity theory. While we have argued that quantum states tend to introduce the complexity of a system, Leonard Susskind argues in *The Black Hole War* that black holes are much the opposite; to resolve Hawking's information paradox, it is necessary that black holes store their information on their 2-dimensional event horizon, much like a hologram. (For a more detailed treatment of the subject, read Susskind's book, it's excellent.) In doing so, they reduce the amount of information in the system from three degrees of freedom to two, also reducing complexity. Perhaps if these two contradicting complexity theories can be resolved, than an approach to quantum gravity can be found? It's an interesting problem to chew on assuming one has much more theoretical background than I.

In conclusion, I want to address the final variety of complexity—the kind that we humans use in our everyday conversations, the kind that has a negative connotation and that we generally try to avoid. This course has argued that greater complexity is good—assuming that humans are intractable and uncomputable has been shown to be the normative course of action. Why, then, do we like to take shortcuts, compute people to a few fundamental characteristics, prefer lesser complexity? The answer perhaps lies in the less energy expenditure, from a neurobiological perspective, required to do so. Here we can find a relation, however tenuous, between organizational and informational complexity—depending on schemas, being in a state of logical disequilibrium, expends less energy, thus keeping the amount of physical complexity higher. I suppose this could suggest that the "normative" aspects of life are equivalent in a sense to reducing the amount of physical complexity in the world by increasing the amount of organizational complexity, and vice versa. Whatever the case may be, the topic of complexity is an immensely interesting and far-reaching one, and learning more about its implications through this course has been a great time.