DELEGATING CONTROL: FROM INFORMATION FLOWS TOWARDS INTELLIGENT LIFE. O. Witkowski[12], [1]Cross Labs, Tokyo, Japan [2]Earth-Life Science Institute, Tokyo Institute of Technology, Tokyo, Japan (okw@elsi.jp).

Transitions in Information Flows: After life originated on Earth, the next important transition was the emergence of intelligent life, in which simple organisms self-organized into dynamical networks to compress and express complex information in the environment about their own preservation. Intelligence can thus be understood as information flows between single organisms, enabling them to make predictions about the environment on much shorter timescales than Darwinian evolution. As information is substrate-independent, it constitutes an ideal tool to bridge between artificial models and real life. Here, we combine artificial life models, which simulate emergent dynamics of living systems based on arbitrary substrates, with information-theoretic measures to determine the dynamics of transfer of control and autonomy. Beyond providing us tools to study the emergence of life on Earth, this approach also helps us understand the nature of systems delegating control to other systems, during life's major evolutionary transitions.

Autonomy and Control: From computational theory to statistical mechanics, information seems to be found all across the domain of physics, and seems to retain all its properties regardless of the media in which it is instantiated [1]. This substrate-independence and interoperability property are what made possible symbolic representations such as the genetic code, which allowed for life to develop upon it, eventually leading to human cognitive capabilities such as language and science.

Perhaps the most obvious example of the importance of information transfers can be found in the complex models of evolutionary biology. Biological information is not only stored in genomes, and passed on through generations to generate living organisms. At a much shorter timescale, relevant information about the environment is also transferred through the interactions between these organisms, allowing them to survive in complex environments. These information transfers allowed assemblies of single organisms to evolve sensorimotor couplings at the group level, thus giving rise to the first cognitive systems: systems capable of finding intelligent ways to process and exchange information, in order to solve their own viability, i.e. their ability to maintain themselves and persist in variable environments.

Cognition is the informational software to life's physical hardware. If life can be formulated computationally to be the search for sources of free energy in an environment in order to maintain its own existence, then cognition is better understood as finding efficient encodings and algorithms to make this search probable to succeed. We can therefore consider cognition as the abstract computation of life, with the purpose to make the unlikely likely for the sake of survival.

Unfortunately, intelligence has traditionally only been studied by breaking down cognitive functions to gain insight into their compositional subsystems, by introducing black boxes that fail to explain underlying mechanisms and are not detailed enough to realistically validate the model.

This work addresses this issue, making a step towards understanding the origins of cognitive processes from a bottom-up approach, by creating an information-based theory explaining the viability value [2] of information in a concrete instantiation of a dynamical system. This constructive computational approach, by giving access to all the information in the dynamical system, formalizes the pathways leading the information networks between individuals to develop cognitive capabilities.

In practice, we extend the approach by [3] and [4], and compute approximate measures based on Granger causality.

From Artificial Life to Life Detection: "What I cannot create, I do not understand" is a well-known quote attributed to Richard Feynman. In order to elucidate the origins of intelligence, we need to be able to reconstruct the conditions of its emergence, and fully understand how the information mechanisms relate to the nature of intelligent processes. This is the reason why we based this study on a computer simulation, within which we can tracked information transfers, and quantified the way they relate to their survival value.

We apply the measure is then applied in a multiagent model, to capture how agents expand their cognitive control. In the following, we present the application of such measure on a model of collective dynamics [5] [6].

Our hope is that this approach will ultimately lead to a generalized technique to compute the probability of finding life elsewhere in the universe, by arming us with new computational tools to search for it.

AI and Control:

One unexpected area of application for our model is its value in addressing the current fears of AI. The recent revolution in deep learning has revived numerous old fears of artificial intelligence, and much ink has been spilled on wild claims of the technology taking over the world. Will AI take over? If we consider human intelligence to be distinct from the technology it created, are the dangers of technology increasingly absorbing human jobs real? More than mere jobs, AIs may absorb the part of computation on Earth of which humans are in charge. For example, one could fear that in the future humans may offload so much thinking to their smartphones, that they will eventually become considerably less capable of performing the kind of computation they used to before. Can we turn this all into a scientific question? This type of question is not new, and connects back to a large chunk of literature in information theory, control theory, and artificial life [3] [7], which provided a framework for capturing autonomy and related notions, in dynamical systems. We propose that with the help of modeling tools from artificial life, combined with information-theoretic measures to frame computational offload, we can capture the dynamics of a system delegating relevant computation to another. This, in turn, allows to investigate under which conditions technology, instead of replacing the systems that created them, comes to synergies that allow each subsystem to expand its computational processes over larger `computational spaces'.

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