

Human-Centric Functional Modeling of Individual and Collective Biological Systems

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Abstract

Gaining the capacity to coordinate group research so that from observing the functionality of any system converging on a single best understanding of how that functionality is implemented is reliably achievable, requires a process that is able to analyze that system from a common perspective, such as might be achieved through decomposing that system into a common set of functional components. Human-Centric Functional Modeling provides the potential opportunity to decompose biological systems in this way in order to significantly increase collective ability to derive insight about the behavior of a wide range of biological systems, as well as in order to provide the capacity to derive insights from generalizing an understanding of any one biological systems to any other system or collections of such systems where that understanding might apply. This paper explores the methodology.

Keywords

General Collective Intelligence; convergence; biomedical engineering

Introduction

In Human-Centric Functional Modeling systems are modeled in terms of the functions they can be observed to have, as opposed to being modeled in terms of mechanisms by which those functions are theorized to be implemented. In this way, by defining the minimal set of functions required to represent all behavior of the system, and by defining boundary condition that must be met in order for that behavior to be stable, it is possible to describe all of the behavior of the system, without understanding the mechanisms by which those behaviors are implemented. This enables models to be constructed that represent the entire behavior of systems for which the mechanisms implementing those behaviors are currently too complex to be understood in complete detail. But since HCFM defines this behavior in terms of functional components with well-defined interfaces that remove the need to understand one component in order to understand another, this allows a more detailed understanding of how each component is implemented to be developed over time. With this approach, a universal functional model might potentially be developed for any individual biological system, or for any collection of such systems, and that functional model might be used to organize knowledge and research according to the functional components of that model so that it is possible to converge on a single “best” understanding of how each functional component is implemented, as well as how the system as a whole is implemented.

Modeling Processes in Individual Organisms

When the components of biological systems that are immediately adjacent interact, those first order interactions might produce some outcomes. As components of biological systems gain the capacity to interact indirectly with other components, leading to higher order interactions. Eventually all of those interactions might form a set of behaviors (functions) that can be repeated in order to adapt to the surrounding environment in a way that increases fitness. Assume that any system with repeatable behavior can be represented in terms of a set of functions through which the system can change its state. Assume also that those states exist within some functional domain in which all such states share some common property and therefore can be the outcome or the initial condition to the execution of any such function. Then after execution of any function within that set the system stays within the same functional domain. All the states accessible through those functions then form a “functional state space” through which the system moves. This functional state space can potentially be virtual and

abstract, such as in the case of the cognitive system which can be represented as moving through a space of concepts (a “conceptual space”). Or it can potentially be physical, such as in the case of the structures of the body, which can be represented as moving through a sensory-motor space in which each position of every body structure with regards to every other body structure defines its state. For example the forearm moves through a range of functional states (physical positions) with respect to the upper arm, which moves through a range of functional states with respect to the shoulder, so that the entire body is represented by a composite functional state space that is the product of the functional state space that defines the state of each component. In other words if the body is composed of two parts, each with their own functional state space, and part 1 has a functional state space with 2 dimensions, and part 2 has a functional state space with 3 dimensions, then the functional state of the body is a point in the product of those two spaces, that is, a point in two times three or six dimensions.

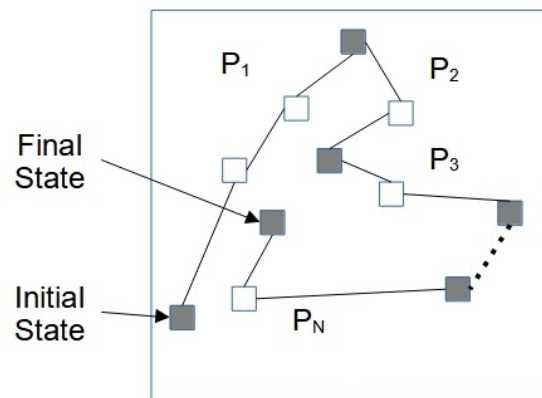


Fig. 1. Biological system trace a path through the functional state space of each functional domain.

Since the functions are stable and don't appear or disappear spontaneously, the “fitness” of the system to execute its functions must stay in a stable range. Defining a “fitness space” in terms of target value of fitness, actual value of fitness, and predicted value of fitness of the system that is achieved as a result of some action (some path) in functional state space, the path through this fitness space must stay within a bounded region in fitness space. In this sense the motion in fitness space must be stable globally throughout the fitness space, despite potentially being chaotic in functional state space due to random interactions with the environment.

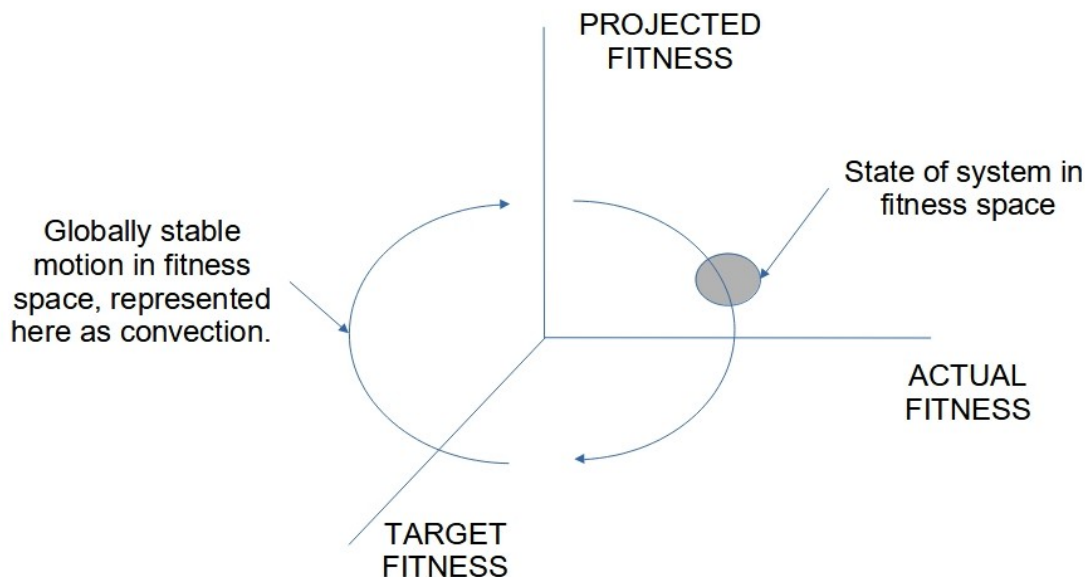


Fig. 2. Motion of biological system through the fitness space of a functional domain corresponding with the path traced through functional state space of that domain.

All the processes of life, beginning with homeostasis, can potentially be modeled in this same way. The definitions of these processes from a functional modeling point of view, and why life was modeled in terms of this particular choice of processes, are provided elsewhere [1], [2].

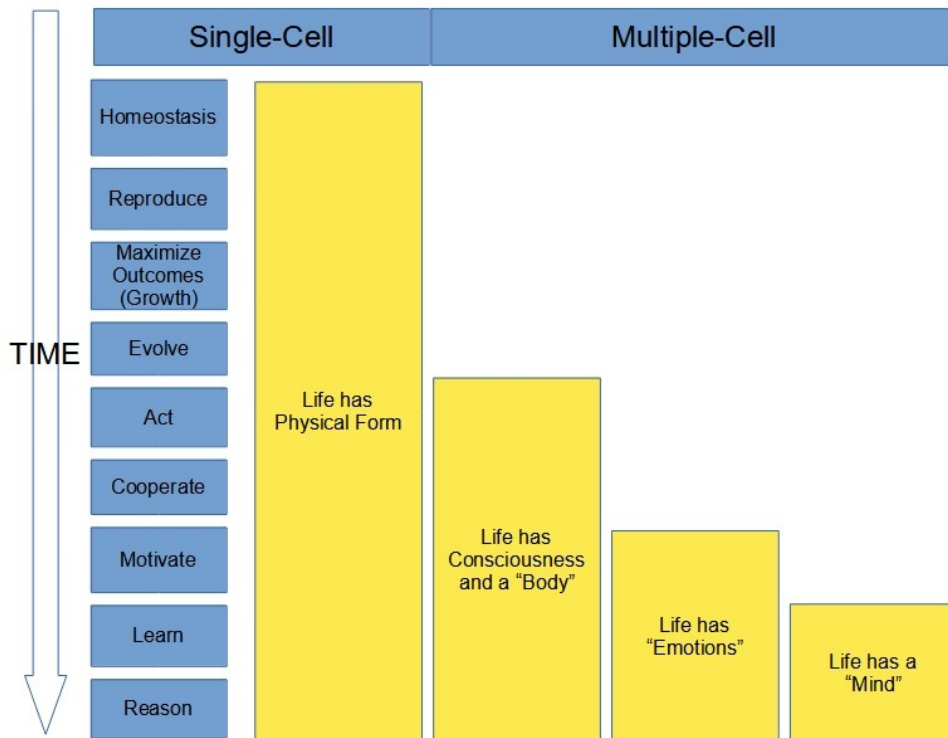


Fig. 3. The capacity for additional life processes accompanied by the functional components of biological systems.

Since this stability in fitness space can potentially be defined by the Lorenz equations for convection, which for a stable strange attractor for certain values of its parameters, then the same set of equations can potentially be used to model all living processes. Whether or not the Lorenz equations are the right choice is immaterial since they can be replaced by any other equations that display the same globally stable behavior if that other equation is more “fit”. The important thing is that at least one set of equations satisfying these conditions can be demonstrated to exist.

All these processes can be seen as adaptive processes that solve adaptive problems in different domains. Since these processes are nested within a hierarchy, as life executes these adaptive processes, these processes can be seen as adapting one another, causing life to wander through a composite “functional state space” as it evolves, reproduces, etc. Since any problem in any functional domain can be represented in terms of solving the problem of navigating from one functional state to another, general problem-solving ability in any functional domain can be represented as having the potential capacity to navigate the entire functional state space. This process of wandering through a number of

functional state spaces in a way that is governed by dynamics in each respective fitness space is represented as solving the general problem of giving life fitness to find the resources and other conditions required for stability of fitness (i.e. for continued “life”), in greater ranges of the state of the environment.

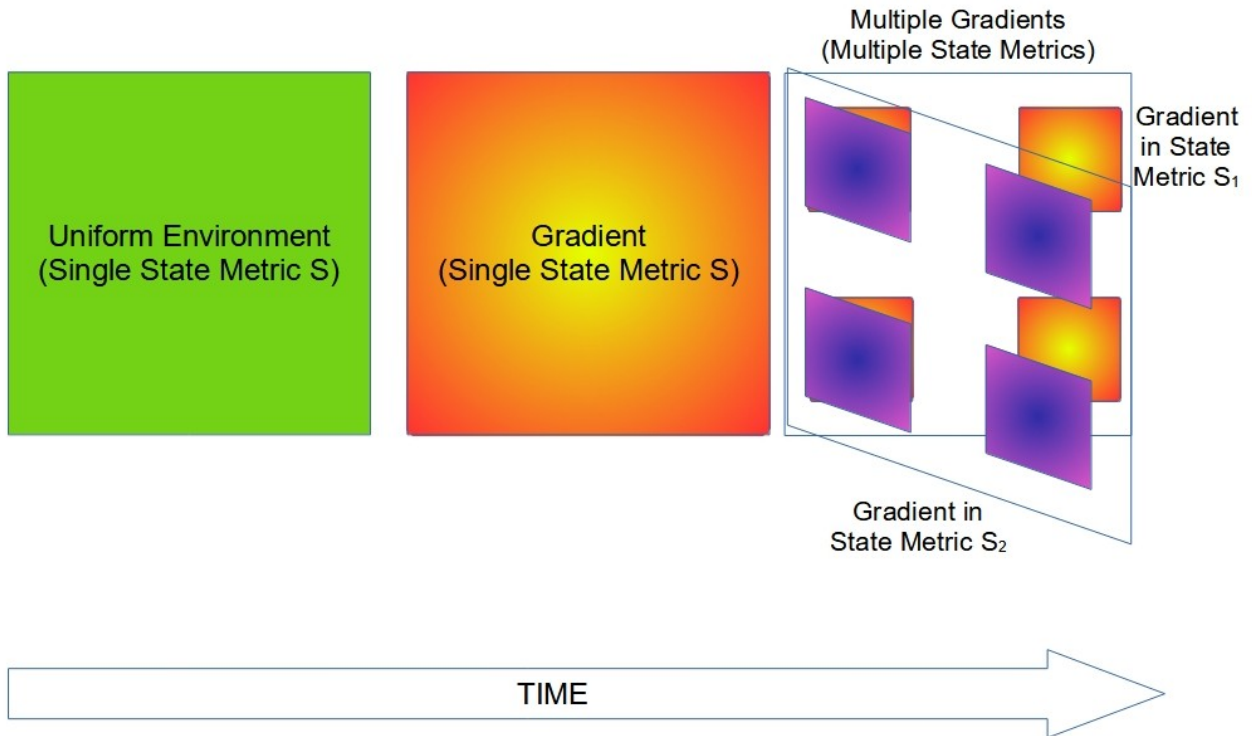


Fig. 4. Biological systems and their increasing ability to navigate complexity in their internal and external environments with time.

Assume that the maximum production of entropy occurs when systems display cyclic behavior. And assume that there are cycles in the environment, such as cycles of the earth’s daily rotation, cycles of the moon’s month orbit, cycles of the earth’s yearly orbit around the sun, or other cycles. Then any one of these cycles in fitness space can potentially become aligned with those cycles in the environment. From the functional modeling standpoint this is potentially the source of synchrony between individual organisms and cyclic patterns in the environment. In addition, functional models of group processes can also be defined in the same way, leading to synchrony in group processes as well.

Modeling Processes in Collections of Organisms

Any repeatable collective behavior might also be modeled with Human Centric Functional Modeling. Where the individual behavior of organisms acts to achieve some coherent collective functions, those functions might be modeled as forming a collective functional state space, where the motion within that functional state space is governed by dynamics of the collective system in it’s “collective fitness space”. Any collective behavior, whether swarms of insects, packs of wolves, pods of cetaceans, or the collective intelligence of humans might potentially be modeled this way where individual behavior is combined into collective behavior by some common targeted outcome that acts as an optimization function that optimizes fitness to achieve that collective outcome (i.e. that acts as a “collective

optimization” function). For example, for ants, survival of the colony might define the collective optimization function that governs group behavior.

In the case of humans, groups of humans have been characterized as having some innate general problem-solving ability, that has been described by a general collective intelligence factor (c), in analogy with the IQ or general intelligence factor (g) of individuals [3]. This factor has been described as being an emergent property of the group in that it optimizes collective outcomes, as opposed to individual outcomes [4]. While humans might have an innate general collective intelligence factor, which has been modeled [5], the requirements for a “General Collective Intelligence” or GCI platform [4], that combines individuals into a single group with the potential for significantly increased levels of that general collective intelligence factor has also recently been proposed. Through using Human-Centric Functional Modeling to define intelligence as the volume of a “conceptual space” that might be navigated by the cognitive system per unit time, this GCI has been shown to have the potential to exponentially increase intelligence [6] which according to this model has never been reliably achievable before, and cannot be again until the transition to a second order General Collective Intelligence or until the advent of Artificial General Intelligence, thereby potentially representing a fundamental phase shift in human civilization. Since an exponential increase in general problem-solving ability suggests an exponential increase in ability to solve any problem in general, this increase in problem-solving ability would be expected to be reflect in ability to model and understand individual and collective biological systems as well.

Implications

Human-Centric Functional Modeling of biological processes results in a hierarchy of functional models that potentially represent the way that any biological system solves any general problem in terms of navigation through the functional state space of each corresponding functional domain in the hierarchy of such domains. Viewing life as consisting of a hierarchy of adaptive problem-solving processes that might be represented using Human Centric Functional Modeling allows us to see that the solutions through which nature has already achieved general problem-solving ability, and the solutions through which nature has solved the problems of scaling general problem-solving ability through self-organization, and self-sustainability in any one domain, might be reused to solve problems in very different domains.

As an example, General Collective Intelligence is a hypothetical platform that replicates the patterns through which nature achieves general problem-solving ability in the cognitive domain, and also replicates the patterns through which nature gains the ability to exponentially increase impact on collectively targeted outcomes. General Collective Intelligence leverages Human-Centric Functional Modeling define a universal approach to modeling in order to maximize the capacity of humans to model and understand complex systems, so that groups might leverage the increased problem solving ability of GCI to more reliably converge on a single understanding of complex systems that is "most fit". Through doing so GCI is hypothesized to maximize collective capacity to solve "wicked problems" like understanding any complex biological system, so those problems might become reliably solvable.

Applying these patterns to understanding complex biological functionality and to solving complex problems in biomedical engineering, every prosthetic or other biomedical device can be represented as a functional component or set of functional components in a single universal model. Every material that component might be made out of can be represented as executing well-defined functions within that model, and doing so with different levels of “fitness” so that they can reliably be compared in every context. This enables all components of all biomedical devices to be decoupled into a single library so

that a system of collective optimization such as a General Collective Intelligence platform can enable groups to reliably converge on the implementation that is most fit for any application. The implications of the capacity to reliably converge on the best materials, designs, and every other property, for every prospective biomedical device, over the work of every biomedical researcher, are the potential to exponentially accelerate development of such devices as well as to exponentially increase impact on targeted collective outcomes.

One targeted outcome that might be exponentially impacted by GCI and other systems resulting from the Human-Centric Functional Modeling Approach is supporting such biomedical research in the first place. Nature doesn't have to budget to research how to build new living things, it grows the exploratory processes it needs so life can find the resources to feed its own growth in exploration from resources that are already there in the environment. Similarly, a General Collective Intelligence, as one implementation of Human-Centric Functional Modeling, defines processes that self-assemble to define networks of projects that cooperate to fund themselves, so that development might be sustainably self-funding at the scale required to achieve any targeted outcome. If nature was a research lab, it would be one that doesn't have to wait for funding to achieve any impact. Though changing the organization of research to reflect processes that nature spent billions of years perfecting, the methodology of every research process potentially becomes an experiment to validate our collective understanding of biological processes. Of course the challenge is that such self-assembling and self-sustaining networks of cooperation require GCI, which has not yet been implemented. However, if this challenge can be overcome, the principles underlying a living biology inspired solution such as GCI is represented through HCFM as the result of research that nature has been conducting for billions of years. This applicability allows this model to be disseminated more broadly to all biological research to make use of those insights.

Conclusions

In representing complex systems in terms of a minimal set of functions and a functional state space, Human-Centric Functional modeling reduces the problem of understanding those systems to the problem of navigating a path from one point in functional state space to another point in functional state space. Because these functions are human-centric, they are intuitively understandable without any technical language required. All problems then remain navigable within the capacity of human cognition. These functions are then in essence a representation with the potential to significantly increase human capacity to understand complex biological systems.

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