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A Framework of Adaptation

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***Abstract*— This short report gives an overview of my research in progress about adaptation — developing a conceptual framework of adaptation that gathers, analyzes, and develops further the knowledge and understanding of what adaptation and adaptivity are, and what properties and processes constitute, manifest, foster or hinder adaptation and adaptivity.**

I. Motivation

My main scientific interests are Artificial Life and Artificial General Intelligence. And one of the key characteristics of both life and intelligence seems to be adaptivity — the ability to adapt — which means that the fields of Artificial Life and Artificial Intelligence would benefit a lot from having a good scientific understanding of adaptation.

Also, adaptation processes can be found everywhere — in biological systems, social systems, artificial systems, and possibly more — therefore a better understanding of adaptation provides a deeper insight into our complex world, and helps to manage existing and to create new highly adaptive systems in very different fields of science and areas of life. Evolution theory is all about long-term adaptation, psychology is (among other things) interested in how people cope mentally with various changes in their life, business research tries to find ways to make companies survive and flourish in the ever more turbulent markets, computer and software engineering moves towards making systems better at reconfiguring and repairing themselves without costly and time-consuming human intervention, and so forth. When trying to understand, manage or create large complex systems, the issue of adaptivity almost always arises to the set of top concerns, even so much so that it has become quite common to use the term Complex *Adaptive* Systems when referring to the subject of research, management and design efforts in various fields that deal with systems consisting of large numbers of interacting components. In fact, it is difficult to imagine anybody who would not benefit, at least in principle, both in their professional and personal undertakings, from advanced knowledge of what adaptation is and how it works.

II. Framework of Adaptation

A. Did not exist

My reasons for wanting to understand adaptation are quite practical — it would provide me with very useful tools for understanding, managing and creating highly adaptive systems. Therefore I would have been glad to quickly get this knowledge from some existing source and then to move on to my main interests — developing and implementing actual ALife and A(G)I systems. But although adaptation is an extensively used concept and there are a lot of adaptation-related scientific works available, I am not aware of any well-systematized overview of adaptation that I would consider sufficient for my purposes — an overview that would be interdisciplinary, yet detailed enough; that would analyze and explain the concepts of adaptation and adaptivity to their core, not just based on some specific field of science (e.g., there exist approaches based on evolution theory, some are inspired by cybernetics, etc., but in my opinion they all have a somewhat limited, and in some cases even potentially misleading, views on what adaptation and adaptivity are); that would gather and describe the various properties that make systems more or less adaptive; and that would describe the various processes of adaptation, in specific cases and in general.

B. Is feasible

If such an extensive overview and analysis that I would consider suitable for my purposes does *not* exist, then one might suspect that maybe creating one is just not feasible due to adaptation being such an extensive and kind of a vague topic. However, based on what I have learned and come up so far, I am convinced that it is possible to create a theoretically important and practically useful scientific overview and analysis of adaptation and adaptivity that is considerably wider and, in some aspects, deeper than the existing ones. Very important steps towards it have certainly been already made by other researchers: various useful generalizations exist based on evolution theory, cybernetics, information theory, and more, so generalizations of adaptation are definitely possible and considered feasible and useful by some other researchers, too. What I am currently doing is taking it a few (qualitative) steps further by providing an integration of various existing works and building-developing a more comprehensive understanding on top of that foundation.

C. Is a framework

It may be tempting to call the desired result a General Theory of Adaptation and Adaptivity, but at least in current stage it seems to be better not to. Calling it a theory tends to put one into the mindset of incrementally assembling a consistent well-integrated description of adaptation and adaptivity, which can easily lead to gathering mainly the pieces of information that fit well into the theory-under-construction, with the danger of either not noticing or not

making explicit the existence of those aspects of these concepts that do not seem sufficiently suitable or relevant when viewed through the lens of that particular theory. In principle, the goal most probably still is to create a good sound and deep theory, and at least with regard to defining the concepts I am clearly heading that way, but by and large at the current stage the goal is to gather very different aspects of and views on what adaptation is and what might be relevant to understanding it. Therefore the name *framework* looks more suitable — a basic supportive structure that helps to organize the thought, but allows for the smooth inclusion of loosely related or even directly conflicting views.

D. Structure of the framework

At the most general level, the framework is divided into the following parts:

- *Definitions* — how adaptation and adaptivity have been defined so far, how to define them more generally yet more rigorously, and whether or how to quantify and measure them.
- *Properties and processes* that constitute, manifest, foster or hinder adaptation and adaptivity.

Both of these parts have, obviously, many subsections and branches. My PhD thesis is basically the first half of the first version of the framework — it deals mainly with definitions and touches upon a few of the properties and processes.

III. Definitions

In order to have in-depth discussions about and understanding of adaptation, it would be a good idea to define it in a scientifically sufficiently rigorous way. Some people say that when someone is dealing with actual adaptive systems, then they already know very well what adaptation means in their context, and the abstract theoretical treatises about definitions would not help the practitioner much and might only be of interest to people who enjoy philosophizing. I, however, disagree — developing and exploring the conceptual understanding and formalizations of adaptation can be considered basic (fundamental) research, and even if it is not always obvious how to directly apply the theory, over time it can and highly likely will lead to important advances also in practice (and, importantly, the very reason why I started working on the definitions was practical considerations — to properly understand the concept of adaptation so as not to just think in terms of concrete specialized ways of adaptation when dealing with actual adaptive systems, but to have a broader view that might give such insights and new ideas that the very application-specific approaches are less likely to provide).

A. A review of existing definitions

I have compiled a rather large review of existing definitions from various disciplines, including biology, human research (psychology, organizational research, etc.), computer systems, etc. The definitions are quite diverse and illustrate different views on the concept of adaptation. In general it seems to be possible to identify four main sources of ideas that have generated or inspired a large part of the definitions: evolution theory, cybernetics and control theory, and studies of human behavior both on the level of everyday experience and in scientific disciplines. But each of them has some assumptions and biases which, while possibly adequate within their own domains, should be explicitly taken into account when trying to create an interdisciplinary generalization of the concept of adaptation.

B. Defining adaptation

Based on the understanding gathered from the aforementioned review, and on the general intuition, adaptation as a process is apparently about *changing something (itself, others, the environment) so that it would be more suitable or fit for some purpose than it would have otherwise been* (or, alternatively, to avoid the teleological term *purpose*, would just *be rated higher by some fitness function*). This includes reacting to disturbances by lessening their negative impact and, if possible, by restoring the pre-perturbation fitness levels, as well as improving the system and / or situation in an otherwise stable environment.

In biological systems, the most common (but typically implicit) goal is survival, and the mechanisms of adaptation are evolution on the longer timescale and developmental, physiological, behavioral and learning processes on the level of individual organisms. In general, however, the fitness function relevant to a particular system and situation can be anything, not only survival. Which leads to the relativity of adaptation — for a statement "this system is adaptive" to have any rigor it should be complemented with further specifications: what is the goal (or fitness function) of the system with regard to which it is considered to behave adaptively, in which environments the system can be said to behave adaptively (because no real system can do universally well in all possible conditions, at least with regard to any practically feasible goal), what is the time interval in which the system performs well with regards to its aims (as, for example, shortsighted fitness-improving actions can lead to later significant losses), and, also, not all of the processes in the system under study are necessarily beneficial for the specified goal, thus instead of only speaking about the adaptivity of the system in general, a more detailed description may be appropriate (where some of the system's processes are considered adaptive and others not).

We might even say (in the spirit of Lotfi A. Zadeh [1]) that due to the relativity of adaptation it does not really matter so much *whether* a system is in principle adaptive or not (most of them are, in some way or another, except the fully static ones). What matters is, depending on the circumstances, whether the system is adaptive *with regard to some specifications*, or *with respect to what* it is adaptive.

As of what it means to *adapt* (as differing from "being adaptive", which is, roughly speaking, the *capability* to adapt in different situations-environments), my current working definition is:

> Given a time period and a fitness function or a goal, we can say that (the process of) adaptation

occurred in a system over this time period and with regard to that fitness function or goal, if within this time period there was a (set of) change(s) in this system (possibly, but not necessarily, also propagating outside the system) that made the system more fit with regard to the given fitness function or goal over this time period than it would have been without that (set of) change(s) (all else being equal, except those additional changes inside and outside the system that were triggered by this (set of) change(s)), and that (set of) change(s) was triggered by some factor(s) that were at least partly correlated with this increase in fitness.

This requires, admittedly, further development (clarifying or improving the terms "(set of)", "triggered", "some factor(s)", and "at least partly correlated", pondering if in some situations the definition should also require the fitness function to have some significance for the system itself, etc.) and certainly does *not* contend to be the one and only definition of adaptation ever. But it already *does* seem to be considerably more rigorous than most existing general definitions, and considerably more general than most existing rigorous definitions (yet not overly general, such as some definitions that, for example, do not differentiate between adaptivity and robustness).

IV. Properties and Processes

The second part of the framework of adaptation is planned to explore the various properties and processes that constitute, manifest, foster or hinder adaptation and adaptivity, including, but not limited to:

- *Modifiables* — what could be changed during the process of adaptation.
- *Variability* — adaptation is about changing something, and change is pretty much synonymous with "variation in time".
- *Modularity* — can foster changeability via replaceability, gradual change, parallelism, redundancy, encapsulation, etc.
- *Ways of testing alternatives* — in those systems that adapt using the variation-selection loop, the variations should be tested and rated in some ways.
- *Feedback usage* — problems and possibilities related to fitness-relevant feedback.
- *Adaptive landscape perspective* — analyzing the processes of adaptation by using the mental tool of adaptive landscapes.
- *Storing experience. Representations* — in systems that adapt using learning, some information about the experiences has to be stored somehow, and there are many possibilities to do that, as well as many potential problems.
- *Teaching and training* — especially for more advanced adaptive systems, getting taught / trained is one of the useful ways to get better fast, or at all.
- *Information transfer between systems* — related to both learning and groupwork, and includes transfer between concurrently existing systems as well as one-way transfer in time to systems that will start existing / working later.
- *Ways of sensing* — an inflow of information about the situation is crucial for the majority of adaptive systems.
- *Ways of processing information* — information as such is usually not that much of a help by itself until it is processed in some way, explicitly or implicitly, for the task at hand, in given case for adapting.
- *Malfunctioning and cost of adaptive mechanisms* — the more complex the mechanisms of adaptation get, the more ways they can fail, plus having them in the system usually costs some resources.

For all of these I have already gathered a sizable amount of relevant information (a huge amount of relevant knowledge already exists in various fields of science — the point here is to gather, integrate and analyze it specifically from the viewpoint of adaptation) that is either waiting to be processed or already processed.

V. Life and Intelligence

As already mentioned, my main motivation for exploring the concept of adaptation is that adaptation has a crucial role in aliveness and intelligence — the ability to adapt seems to be inseparable from the property of being alive, and of behaving intelligently. Some researchers have even considered the possibility of using adaptation as the very defining element of life and intelligence (see, e.g., [2] and [3]).

So, an interesting idea worth further thinking is to, indeed, define both life and intelligence directly and simply through adaptation, and my current working versions of these definitions are:

> **Aliveness** is the amount of adaptation processes occurring in a system. A system is **alive** when processes of adaptation occur in it. The more processes of adaptation occur in a system, the **more alive** it is.

and

> **Intelligence** is a system's capability to adapt. A system is **intelligent** if it has a capability to adapt. The more capability to adapt the system has, the **more intelligent** it is.

where *adaptation* is understood as in my definition given in section III-B

These are, admittedly, rather bold definitions that would consider living and / or intelligent a much larger set of systems than the usual scientific understanding of life and intelligence supports, but, then again, being alive and being intelligent do not necessarily need to be some extremely special properties, and it seems that defining them this way provides us with a very interesting and elegant model of viewing the world and of thinking about life and intelligence, a model that is free of the many typical problems with various questionable exceptions and edge cases and anthropocentrisms. Therefore this line of thought is well

worth further development and analysis, and might yield quite interesting insights.

But even if it so happens that adaptation turns out to be an overgeneralization of life and intelligence (i.e., that life and intelligence should be defined in a more detailed way than just through adaptation), then almost all of the research resulting from constructing the framework of adaptation is still very important and useful, because if not the defining characteristic, then at least a key characteristic of life and intelligence is adaptation nevertheless, and we really are interested in the ability to build, manage, and analyze highly adaptive systems. Or, in other words, we may argue about whether defining life and intelligence via adaptation is reasonable or not, but what we almost always are most interested in in the fields of ALife and AI (as well as in many others) is achieving high / suitable adaptation and adaptivity.

VI. Next Steps

The main next steps in developing the framework are improving the proposed definitions of adaptation and adaptivity, and developing the second part of the framework — the overview of various properties and processes that constitute, manifest, foster or hinder adaptation and adaptivity.

VII. Acknowledgements

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