Mapping function and structure for an Anticipatory System: What impact will it have and is it computationally feasible, today?

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Abstract

Development of complex biological behaviors, such as anticipation, in a machine will require more than having a reduced instruction set and a fast computer, a thought contrary to that shared by many researchers today. What will be needed are new perspectives and insights into what a complex biological form is and what attributes are shared and/or differentiated by them. Only then will we really understand the cognitive processes that elicits 'intelligence and consciousness' and how it may be invoked, at some level, in machines. This will require moving away from the Newtonian concept of reductionism and time as an index to new concepts that invoke time as an arrow that breaks the symmetry evident in classical mechanics.

This paper attempts to provide an overview of the current thinking on Anticipatory Systems (AS) and what impacts they could have in and on our society. It identifies concerns that would be generated by the employment of such systems and formalizes a construct by which an anticipatory system model could be developed using today's technology.

Index Terms: Anticipatory systems, intelligence, behavior, human percepts, moral/ethical implications, political impacts, system constructs.

1 Introduction

Today, many researchers are trying to understand and mimic biological systems due to their decision-making efficiency. They are trying to understand the biological form and structure that permits such cognition and reasoning. Their intent is to blur the line between the mechanistic view of computational speed and the irreducible form of biology. The payoff will be a computationally efficient mechanism that could one day emulate human cognition and intelligence.

Why is this important? As researchers begin to develop a greater understanding of biological systems, they also begin to appreciate the biological implications of 'survivability in changing environments'. Emulating this behavioral trait in machines would revolutionize manufacturing. Machines would become self-aware, understanding the context within which they exist, their social responsibility to the whole (society), and the consequence of their actions and decisions. Then the question is can a machine develop survival skills similar to those possessed by biological systems. Or simply stated, *can a machine anticipate*? The answer to this question is found in the answers to a series of related questions.

- What is an anticipatory system and what is the current thinking on this subject?
- What human precepts and capabilities are needed to develop an anticipatory system?
- What technologies exist that could be applied to the development of an anticipatory system and what form would it entail?
- What effect will an anticipatory system have on society (manufacturing, commercial, private, scientific, and political)?
- Are there moral and ethical implications associated with an anticipatory system?

This paper hopefully provides a perspective on this set of questions that helps build a foundation of understanding on the importance and complexity of developing biological behavior, in this case anticipation, in machines.

2 Building A Conceptual Foundation For An Anticipatory System

"You are what you think" is a simple but elegant truth describing the perceptual differences that act as contrasting elements, separating one person's behavioral characteristics from those of another. In this context, "think" is defined as those elements that act as a descriptor of one's self – colored perception of the environment, conditioned response stimuli, and those particular elements of residual memory that make instances in time and space important to each of us as individuals. A major aspect of this is the rich store of neural information that is developed during our life times. This information provides much of our reasoning mechanisms that we use in dealing with systems, whether they are biological or physical. These traits are the result of environmental interaction and are descriptively presented as a process in which we learn important interactive correlates; commit them to memory; and on occasions where stimuli solicit, respond according to this store of information. Psychologists claim that this process can exist in several forms and that the implications are of great importance when the neural mechanisms of learning and its impact on "world" validation are considered.

Unique to this is the ability for humans to anticipate, i.e., reason in the future and make appropriate controlled responses based on some mediating factor that is associated with goal and purpose. This is accomplished through some formal cognitive pairing of information which accompanies our environmental interaction, providing the encoding mechanism that is present in an anticipatory reasoning system.

3 What is an Anticipatory System and what is the current thinking on the subject?

Anticipation is a complex behavior exhibited by all life forms. It's an ability of an organism to make controlled decisions based on 'known' future events and effect a redirection or change on the event by influencing the environment and/or system. This behavior is engendered by learning and adaptation and provides a formal reasoning mechanism that is diverse in nature and culturally rich. These decisions are, of course, volition acts requiring 'self awareness', an attribute decidedly a part of human reasoning and not that of animals. A point made by Walter Freeman [1] that animals can't volunteer. In this context, these volition acts are causally linked with a known goal or purpose. It should be noted that anticipatory systems are quite different from reactive systems in that reactive systems are responding to events that have already occurred while anticipatory systems are responding to events that will occur, with a certain confidence, in the future.

John Holland [2] defines an anticipatory system as an 'overt internal model used as a basis for explicit explorations of alternatives, a process called look-ahead. This overt capability is an aggregation of learning and long-term adaptation and is shared by agents (entities) which form a complex adaptive system. Some of these anticipations can be held in common by agents while others may not'.

Rosen [3] describes an anticipatory system as 'a system containing a predictive model of itself and its environment which allows it to change state at an instant in accord with the model's predictions pertaining to a latter instant'. Rosen speaks of the need to encode time into the model. Specifically, the need to clarify the relations between time, instantaneous state, and instantaneous rate of change. Rosen further differentiates between time as a parameter that acts as an index for the trajectory path (mechanics) and its role as an 'arrow of time', characteristically found in non-equilibrium thermodynamics. This *arrow of time* destroys the time symmetry that is evident in classical Newtonian mechanic and gives rise to probability and duality.

The author provides an alternative definition [4] for an anticipatory system. It is a self-consistent reasoning mechanism that allows a system (entity) to project and absorb behavior in advance of its occurrence (suspend time), extract motive and intent in context with the environment (situation), extend the species, and have an internalized cost function and scale of economy that maps to stated goals (missions). In this definition, a system (machine) is self-aware or understands the context within which it exists (social responsibility) and understands the implications of such, has a realization of its own influence on the environment and the influence of the environment on itself, perpetuates the species (as an entity and as a whole), and understands the consequence of its actions, and its obligations that are implied as a member of the environment (not a social outcast but a functioning member of a healthy environment).

The question is then:

Having described in detail a set of complex behavioral attributes associated with an Anticipatory System can such a system be developed, and if so, what are its implications?

Before attempting to answer this question, it is worth while spending a moment to address a major implication associated with the employment of anticipatory systems. And that is the need to understand and develop in machines foundational constructs similar to those human precepts that are held as invariant truths which provide the rich texture to linguistic constructs that provide consistent meaning in the exchange of ideas and information. They provide the common base for reasoning that humans rely on and expect when making decisions, judgments, or affecting causal responses. In developing anticipatory systems there will be a requirement that all such systems see and know certain precepts (metaphors) of behavior, environment, and causality. This will have a serious impact on algorithms that just 'see' events and do not provide the consistent mapping or feature descriptors necessary for the correct exchange of information and knowledge present in our own mental models. The issue – developing invariant descriptors for machines - will be a major challenge for deploying an anticipatory system.

4 What human precepts and capabilities are needed to develop an Anticipatory System?

Based on the above definitions, the author defines 16 basic characteristics or attributes of an AS that are entailed by a natural, living system. By living system, the author employs Robert Rosen's recognition of a living state (system) as one based on our perception of homologies between the behaviors exhibited by organisms and those absent in non-living systems. The reader is encouraged to read Rosen's book on Anticipatory Systems to gain a better read Rosen's book on Anticipatory Systems to gain a better understanding on the significance of this statement. The characteristics are as follows:

- Surviving in a dynamic environment
- Mimicking behaviors
- Learning and developing associative and non-associative behaviors
- Project behavior in advance of occurrence
- Internalized model of self, environment and their effects on each other
- Social responsibility and language
- Dynamic social organizational skills (gatherings)
- Internalized goals and associated cost functions
- Sliding scale of economy that is context dependent
- Suspend beliefs and extract motives and intent
- Understand competition and democracy
- Understand the concept of self sacrifice
- Possessing a consistent set of truths/models that are invariant
- Compress/suspend time for during event generations.
- A dissipative system that breaks infinite reasoning.
- Having an ability to establish 'meaningful' relationships with other objects.

This may not be an exhaustive list in the formal sense, but it is believed that any behavior attributed to an anticipatory system can be described by single or joint occurrences of any of the above descriptors.

What correlates exist in the current technology inventory that may be applied to the development of an anticipatory system and what would an AS structure look like?

The next section describes some of the complexities and needs that surround an AS. There, issues associated with a new structural (biological) math and new computer form (concepts) are described. This section details a form and structure that could be used to develop an AS model based on current technological capabilities.

Figure 1 is a hierarchical view of the AS model. As seen, there are five internal models (forms) needed to develop the AS paradigm. The following is a brief description of each.

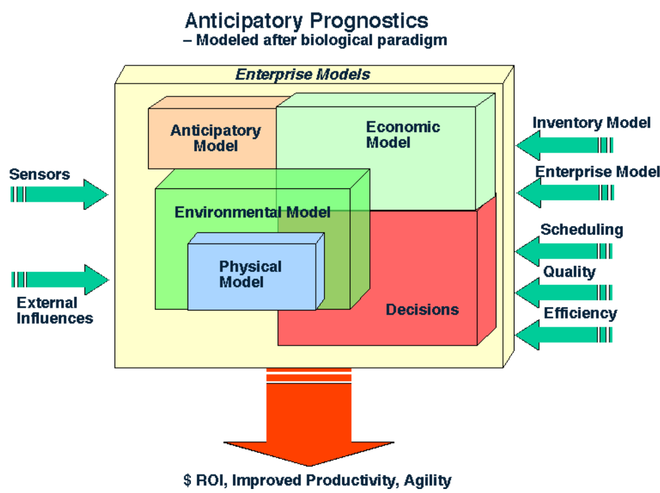

Figure 1. Diagram of the program structure.

Physical Model: The physical model includes a description of how the process (and the process equipment or system) operates on input materials to make a product. This description includes mechanical, thermodynamic, and other physical interactions.

The physical model takes inputs from sensors, from material data bases, from product specifications and requirements to generate the input for the other modules of the enterprise model.

Environmental Model: The environmental model includes not only the effects of environmental changes on the process and product (humidity, temperature) but the effects of the process on the environment as well (waste streams, heat).

Anticipatory Model: The anticipatory model takes the inputs from the other models as well as the historical data base, to anticipate changes and generate corrective recommendations before errors are manifested in the process or the product. It is based on an internalized model of the environment and the effect that the system has on it and vice versa.

Economic Model: The economic model integrates the business aspects of the enterprise along with the process to determine if the system is capable of performing its task at an acceptable cost, or if not, what actions must be taken to bring the process into line.

Decision Model: The decision model provides expert assistance to the system by considering resource availability, cost of conducting business, and priority of needs
The system in Figure 1 must be able to provide an ability to sense dynamic changes in sensors or system physical attributes that are systemic to

The system shown in Figure 1 must also provide a structure (architecture) capable of sensing dynamic changes in sensors or system physical attributes that are systemic to anomalous operation. From this the system can then deduce operational degradation and determine the impact of the sensors/elements on the system performance and, in some cases, the system's impact on the element (attrition). In addition, the system can anticipate current operational limitations and restrictions and then dynamically allocate resources, as needed, to continue operations under the current mission profile. In the event that continuation is impractical or too restricted, the monitoring system can recommend a safe operational degradation while prohibiting catastrophic failure. Under these conditions, a system would be 100% operational while having less than 100% functional capability.

A system such as the one described above would possess certain attributes characteristic of its functional requirements and unique to its real-time environment. The baseline functional requirements of the AS model would include sensor driven analysis and self-validation, sensor and component bases structural and material models, a distributed data base with inherent communication capabilities (internal to the net), intranode/internode communications, performance modeling, signal validation, and self-validation (self-referential).

Figure 2 shows an implementation scheme that was used to deploy an AS model in a manufacturing facility. As seen, a majority of the elements shown in Figure 1 were present. The AS model worked successfully in continuing machine/system operations under varying environmental and economic constraints.

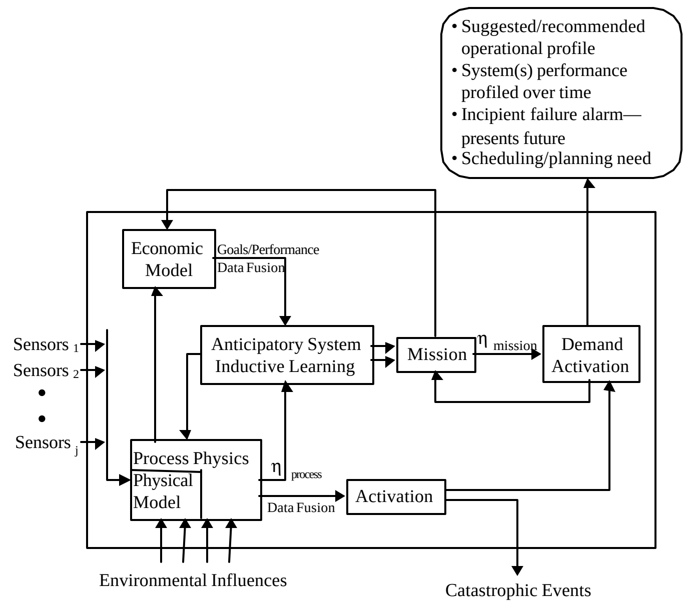

Figure 2. An Anticipatory System implementation scheme used to deploy an AS in a manufacturing environment.

What effect will an AS have on society (manufacturing, commercial, private, military, scientific, and political)?

When such a system is developed, it will have a profound effect on our society. From a manufacturing perspective, machines will possess a will to live and to succeed and yet understand self-sacrifice and competition. They will do whatever is necessary to be successful and will/could take any steps necessary to resolve problems that are impacting the goals and success of the manufacturing process including restricting or eliminating its own influence on the process. Groups of machines or equipment comprising the manufacturing process would then form collectives by establishing relationships with each other for the common good. These machines would have an understanding of the goals (secure the largest market share) and fully comprehend the fact that it is not just their ability to work and produce which secures profits but their ability to be the best in a competitive environment (other companies). These systems would then work together to survive in a dynamically changing environment that is constituted as outside influences, internal resources, and fluctuating market needs. A system such as this would be qualified as 'agile', having the ability to change in response to needs and would not suffer from isolation as current systems do. It would have the ability to secure valuable information for more effective resource planning and sense changes in pricing, customer requirements, and competitive influences allowing dynamic allocations of available resources. This would be achieved through smart agents and sentinels that act on behalf of the collective to collect and provide intelligence and information that is pertinent to its [plant] goals. With this capability the system would now become a market force, competing in the economy and possibly influencing the commercial sector through volition decisions of its own. Systems such as these could even form strategic alliances with similar or even diverse manufacturing groups to form work cooperatives that would go after new or emerging markets.

From the political perspective, politicians would be forced to consider new legislation stemming from AS impacts on employment. If such a capability existed for machines to exhibit the type of behavior assigned to anticipatory systems, could they possibly displace humans forcing a migration to more skill-centered activities and more advanced technical skills. Would our work force allow such a transition? Could these AS systems also move into these more advanced jobs? These questions would now become an issue for our local, state, and federal governments. How would they rectify this problem resulting from a technological advancement? Would they limit its employment for the sake of jobs? Would new legislation be introduced limit the ability of such diverse systems to cooperate in a commercial enterprise or venture? Would this constitute a monopoly? These questions may seem the fabric of science fiction, but they are real. The issue of limiting or eliminating the impact on job displacement by technology has already been broached.

The military implications are astounding. Equipment would now have an ability to make decisions on whether they can support missions based on their effectiveness to complete a task, the costs of doing so, and the importance or priority assigned to the mission. Here is where complex behavioral attributes such as self-sacrifice, having common precepts, teaming, and abilities to establish relationships become so important. They would make decisions based on their current health and ability and not what some call 'useful remaining life'. This term, 'useful remaining life', is not how humans make decisions so why should machines be forced to. Think of the past week. Did how long you are going to live influence your decision making process? Most likely it did not. There may be some instances, investment strategies or life threatening illness that do, but for the most part our decisions were based on the current context within which the decisions are made. What is called 'context dependent' decisions, a human behavior exhibited by all of us.

Having these machine capabilities would have a major impact on our lives. Our homes could now enter into symbionic relationships with us, as individuals, and any machines or systems that we encounter at work, play, or at home. Systems would understand context and anticipate our needs and wants on a daily basis. They could be linked to the internet, a wireless media, etc. to mine for information that is considered valuable to us and the systems, itself. One could imagine that the line that separates us from today's non-living entities such as our computers and our homes would blur to the extent that extracting causal relationships that describe our natural system would be inclusive of our working machines.

To have machines exhibit such complex behavior would be remarkable. To achieve this, though, the scientific community will have to clear significant technological, emotional, and philosophical differences that now permeate the community. In the scientific arena, a different view of science will have to be taken. Physicists, biologists, behavioral scientists, and the like will have to put their differences aside and meet on common grounds to make such a machine a reality. In doing so, researchers working together will develop a greater understanding of mathematical biology which will spawn an alternative mathematics of intelligence. In light of this, the reductionist view of science will have to give way to new and innovating thoughts on how systems such as these can be developed. Thoughts that blend non-equilibrium thermodynamics and 'arrows of time' [5] with quantum entanglement and new definitions of computers will have to be resolved. These new computers will be 'computable computers'. Similar in form and nature to the wet-ware we humans call brains. It will not have a separable architecture and software, it just is. What this will lead to is a major break through in the way we think about systems. A general language for machines will have to be developed that allows any machine to talk with others. This is critical in forming relationships. In addition to this, there will have to be common constructs (descriptors) that go beyond simple data transforms but to common, acceptable truths that each machine understands and reasons with. Only when these basic truths are developed can a machine hope to reason with other machines in a way that provides meaningful constructs and knowledge and information. When this is achieved, machines will move away from 'being' to 'becoming': A major departure in philosophical thought and scientific understanding.

5 Are there moral and ethical implications associated with an AS?

Employment of such systems into our world will come at a cost. It will require us to understand the social and legal implications of accepting them into our society and not just their impact on commerce. We will have to understand the influence that these machines have on us as individuals and groups and the consequences resulting from their volitional acts. We will also have to understand the moral obligations that we assume as benefactors of this new technology. We will have to question if machines understand choice and consequence associated with decisions. This is critical when ones considers that obligations instantiated when making decisions which is what separates us from other biological systems. When the true ramifications are realized, we will probably find ourselves institutionalizing safe guards on these systems and their use.

There will be ethical debates on what constitutes a sentient machine and what rights such systems have. Do machines that exhibit anticipatory behavior constitute biological beings? Are they conscious and are they capable of experiencing sensations? Do they have the right to make volitional decisions on their behalf? The essence of this question is posed by Jaegwon Kim and Robert Rosen. Kim [6], in his book Philosophy of MIND, asks the question: 'What is it for something to "have a mind", or "have mentality"?' Robert Rose asks a more detailed question: 'What is it about certain natural systems that makes us recognize them as organisms, and characterize them as alive'. Rosen continues by stating that the recognition of a living state rests on our perception of homologies between the behaviors exhibited by organisms and those absent in non-living systems. The answer to these questions will be at the core of our understanding and recognition of emerging intelligence and cognition in systems such as those that may exhibit anticipatory behavior.

Finally, debates will continue on the relationships between mental and physical properties and what exactly does it mean that a machine or system possesses anticipatory behavior. Will we define such systems in terms of objects, properties, relationships, and events, as suggested by Kim or will their be a mysticism associated with them?

6 Conclusion

The key question is can a man-made system develop behavioral skills similar to those possessed by biological systems, i.e., can they anticipate? Emulating genuine intelligence in machines would revolutionize such fields as manufacturing, commerce, and transportation, just to name a few. These systems would be self-aware, understanding the context within which they exist, their responsibility to the whole (society), and the consequences of their actions and decisions. Of course, along with these capabilities would come moral and philosophical obligations to understand the implications of employing such systems in our world.

It is envisioned that with a new math of intelligence, systems such as the ones described above could be built. This would necessitate the development of new concepts and ideas that embrace such mathematical constructs as non-equilibrium thermodynamics, arrows of time, quantum entanglement, category theory, and self-referential systems. Of course, there is nothing that precludes the development of a completely new science or mathematics that would render some or all of what we think we know of machine cognition obsolete. Only time will tell.

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