Designing Knowledge Based Systems as Complex Adaptive Systems

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Abstract. The paper proposes that knowledge based systems must be designed as complex adaptive systems and any other approach is not fundamental, even if sometimes it yields good results. Complex systems are characterized as having global behavior not always explainable from local behavior. Here we propose that the way we perceive knowledge in AI needs to change to Complex Adaptive, hence the need for a paradigm shift is stressed. Almost all historical KBS were not complex systems in an authentic sense. But it is not a good idea to criticize them because with available resources and theories, they did their best. Sooner or later, we will have to design our KBS as complex adaptive systems, so why not sooner. There are three mechanisms that must be part of any knowledge based system, viz., Interdependency and fluidity, mechanisms for attribution of emergent properties and self-organization.

Keywords. Knowledge Based Systems, Complex Adaptive Systems, Cognitive Fluidity, Self-organization.

1. Introduction

Although the time has come that our perception of the whole field of AI should be of complex systems and more rule-based, well-defined and logic style approaches need rethinking, we confine ourselves to the discussion of KBS in this paper. Richard Loosemore [1] argues

> "One the most basic assumptions made by Artificial Intelligence researchers is that the overall behavior of an AI system is related in a lawful, comprehensible way to the low level mechanisms that drive the system……..this apparently innocent assumption is broken, because all intelligent systems, regardless of how they are designed, must be complex systems"[1]

Evidence in anthropology and psychology suggests that mental fluidity is central to human cognition. It is this fluidity that lends us our higher level abilities that only our species Homo sapiens sapiens possess. If our goal is to build human-like intelligence, the only valid path is complex adaptive systems – since by their very nature these systems can efficiently produce an analog of mental fluidity. Human cognition is a complex adaptive system [2], hence KBS have to be complex adaptive, it cannot be otherwise. For the purpose of this paper when we talk of KBS, it encompasses all areas of Artificial Intelligence that handle knowledge including case-based reasoning, expert systems, etc.

Complex systems are the systems that involve interactions among various components and as a result of these interactions global emergent behavior emerges in a system. [3] suggests "interdependence" among various components is a more generic term since it is the interdependent parts that create emergent properties rather than interconnected parts. Complex systems are known for various characteristics; among them widely discussed are emergence, self-organization and non-linearity. Here it is important to mention that KBS must be complex adaptive rather than just complex because it must be sensitive to any new knowledge that enters the system. For the detailed study of complex systems reader is referred to [3, 4] and for complex adaptive systems to [5].

There are three mechanisms that must be part of any knowledge based system, viz., Interdependency and fluidity, a mechanism for attribution of emergent properties and self-organization. These mechanisms will not only make knowledge more complex, but also make it adaptive to new information that comes in.

2. Interdependency in Knowledge Bases

Referring to the brains of early humans, Mithen [6] asserts:-

> "we can safely state that in spite of linguistic differences, all Early Humans shared the same basic type of mind:a swiss-army-knife mentality. They had multiple intelligences, each dedicated to a specific domain of behavior, with very little interaction between them……..Early Humans seem to have been so much like us in some respects, because they had these specialized cognitive domains; but they seem so different because they lacked a vital ingredient of the modern mind: cognitive fluidity" [6]

Grounding his arguments with evidence from archaeology and anthropology he further suggests that "cognitive fluidity" is responsible for our intelligence and the rise of human civilization (including art, science and religion). Even our closest cousins Neanderthals did not had this ability. But it is very unfortunate that AI researchers and builders of the KBS have totally disregarded this ability and created systems that stored information like Early Humans. Cyc [7] did better by at least creating Neanderthal-like common sense, that is, there are not very flexible across-the-domain connections. The time has come that our perspective changes and we start treating knowledge as complex for AI purposes. Unfortunately what should have been done first will be done last. All the KBS in the past, without exception, were fundamentally flawed because they represented knowledge "as is" without giving any consideration to the fact how a thing can be represented in terms of other entities.

Besides anthropology, there are theories by psychologists and computer scientists to account for our mental fluidity. Arthur Koestler [8] proposed the Bisociation, the mechanism in human mind, through which different planes of thought come together to produce a novel thought. Karmiloff-smith [9] came up with a Representational Redescripton model explaining how children's representations become more flexible with age. Fauconnier and Turner [10] proposed theory of conceptual blending, in which multiple concepts can blend to form a new concept with emergent properties. Boden [11] also suggested that transformation of conceptual spaces is central to our thought processes. [12, 13] came up with a program Copycat to model analogical thought but

they asserted it can be extended to all fluid mental concepts. The major achievement [13, 14] of the Copycat program was to show that human cognition is a "complex adaptive system." The above works unanimously offer a unique insight into the workings of the human mind - In human mind, elements from different areas are interdependent and often come together to form a coherent whole whose properties may be emergent.

Creating highly fluid systems that are complex and adaptive is what is required. KBS should be capable of "Seeing one thing in the frame of other" and free merger of concepts should be the rule. High-Interdependency among representations must be the rule in any Knowledge Base. Each concept must be represented from the perspective of other concepts in the knowledge base. And a concept should have representation from the perspective of multiple other concepts. This is done to ensure high interconnectivity, which obviously will not only make KBS highly fluid but also adaptive, just like human cognition. R.M. French [15, 16] has argued that representation for any AI system, if it is not malleable, then it is necessarily flawed. According to him, the representations that are fixed can never produce an analog of human cognition and fluidity. Each representation should not be "as is", that is, there must not be fixed representation of any concept.

3. Emergence

The reason emergence becomes a central issue in the design of knowledge bases is that there are global properties possessed by entities which are not reducible to the components and subparts of the entities. For example – Psychological characteristics of the human brain cannot be explained in terms of just one neuron or many neurons taken independently. Rather interconnections and interdependence of the neurons display emergent behavior. Emergence is discussed in detail in [3, 17].

Let us consider a hypothetical knowledge base. Assume the representation to be either predicate calculus, logic, semantic network, frame based or any symbol manipulation representation. Also, we assume our knowledge base to be all-inclusive, that is, containing all the information in the world. Suppose we examine the concept of "Automobile" in our knowledge base. If we start with any possible initial state of the concept "Automobile" in any representation, and from there try to derive this property "Means of transportation", we see that no matter what change we make to that state it is simply impossible to derive the property "Means of transportation" bottom-up since derivation is the process of sequential state transition in which a part or subpart of the information is changed to reach an end state. However, the emergent property can never be an end state because

1.) The concept "Automobile" is represented in the form of its parts (engine, tires, windows, mirror, doors and their relationships). Information "Means of transportation" is not contained in any one part, or combination of few parts, rather it is the interactions of all the parts that emerge this property, hence, trying to extract information "Means of transportation" from the parts is impossible. This property "Means of transportation" is the property of specific configuration created by all of the components and their interactions making up the concept "Automobile". Derivations, as in any representation lead to an end state in a deterministic fashion, however starting from any initial state in this problem we can never be sure that the next state will lead us to correct end state (our

property). Hence the property is not derivable from the inner components and is globally emergent.

2.) To derive the property from all the other information in the knowledge base besides the "Automobile" concept, it is that the property if it is the property of another entity in the knowledge base, then it is going to be an emergent property of that entity, that is, not derivable from its own components. For example - the property "Means of transportation" can be attributed to the concept of "Horse" and it is non-derivable for this concept. Since we have already seen that the property cannot be obtained from its own components, the only way is for the property to transfer from one point in the knowledge base to another point by transferring from one whole to another whole. The property of the concept "Horse" can be transferred to the concept "Automobile" in whole.

We need to have such mechanisms in our systems that help us in attribution of emergent properties because trying to derive any higher order property from lower level components is almost impossible. Analogical reasoning is one such mechanism but there are many more similar strategies that must be incorporated in the systems. The idea is to transfer stuff from one whole to another based on some criteria, and not try to derive things bottom up.

4. Self-Organization

Karmiloff-smith [9] while proposing his RR model wrote

> "My claim is that a specifically human way to gain knowledge is for the mind to exploit internally the information that it has already stored……..by redescribing its representations or, more precisely, by iteratively re-representing in different representational formats what its internal representations represent."[9]

The above lines clearly hint to the process of self-organization in the human mind. A process analogous to re-representation mechanism is a necessity in a complex adaptive KBS. [18] suggested self-organization is a requirement for any system if it is to be creative. The idea of incorporating self-organization is simple – any new information is connected to lots of other information and this interdependency can lead to potential effects on all the interdependent information. The goal of self-organization is to adapt the whole KBS to any incoming information so that all the information is represented in the most accurate state in the KBS. Accurate state in the KBS is variable since induction of any new information can change the accuracy. For example – in the nineteenth century, the most accurate explanation for universe was in terms of Newtonian physics, however, in the twentieth century after new information came in (Theory of relativity), the most accurate explanation for universe was in terms of relativity.

The more inter-dependent various fragments of knowledge inside the knowledge base are, the more they are prone to the effects of the induction of new knowledge. This new knowledge, if it modifies any knowledge in the KBS, can subsequently lead to chain of modifications because this modified knowledge is highly interdependent with various other fragments of knowledge. The system must be capable of self-organizing at this stage, that is, just by using all the information that is internal to the KBS, the system should be able to reach most accurate representation or perception or frame for each fragment of knowledge that is effected by newly induced knowledge in some way.

5. Conclusion

No doubt, the road to making knowledge complex and adaptive for AI is filled with some serious bottlenecks, nevertheless, it is reachable. Designing complex adaptive KBS is the most ideal approach that will make them adaptive by incurring several advantages over conventional systems. The most significant advantage being increase in information resulting from high interdependency in the knowledge base. Since each entity or situation can be perceived in multiple frames, our systems will have an option to choose best frame that is most accurate representation relative to other representations, thus increasing system's information, reliability and adaptiveness.

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