

The 'Right Brain' Architecture of a Holonic Manufacturing System

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Abstract

The goal of holonic manufacturing systems is to attain in manufacturing the benefits that holonic organization provides to living organisms and societies, i.e., stability in the face of disturbances, adaptability and flexibility in the face of change, and efficient use of available resources. A key attribute of this kind of system is the ability to define the reasoning model for independent holons (agents). This reasoning has commonly been accomplished through the development of a set of rules described in a textual programming language. These specific languages can be related to human language and specific algorithms processed by a human's left brain. Human expertise involves more than just processing analytical values, however. It also involves the integration of judgmental information processing. In this way, holons can consider issues like survivability, risk, safety, and performance against a dynamically changing set of goals. By integrating judgmental information processing into holonic manufacturing architectures, industry can come closer to achieving the original vision for the Intelligent Manufacturing Systems (IMS) program. In this presentation we propose a methodology for describing dynamic, judgmental rules that can be integrated into holonic manufacturing systems in a manner that maps to the human's right brain processing.

Introduction

Control systems for manufacturing operations have been defined as "large, complex artifacts which are designed to perform a clearly-defined task in a well structured, standardized environment".¹ This definition suggests little opportunity for adaptive behavior. In contrast, holonic manufacturing systems have been proposed as a collection of holons (agents) that negotiate amongst themselves to respond to the objectives of the "system". The word "holonic" is used to characterize the relationships between elements of a system. These relationships are characterized by autonomy and cooperativeness. Elements exhibiting these characteristics are referred to as "holons," as they behave simultaneously as autonomous (sub) wholes and as dependable parts.² Much of the research targeting the holonic manufacturing systems' domain has been directed at standardization of infrastructure concepts that support interaction and negotiation. Standardized methods of defining device properties and service offerings have been developed (device profiles and service profiles). Mechanisms for establishing

relationships and negotiating for work have been developed (standardized dialogs). Architectural issues relevant to the manufacturing domain have been developed to support event synchronization (messaging protocols). In addition to the work specifically focused on holonic manufacturing systems, the software industry has continued to develop the object oriented paradigm. This effort to model software functionality after its hardware counterpart has led to the development of object oriented languages that are now the standard for present systems. These object oriented models are intended to encapsulate problems such that one error is not propagated across an entire system. This model addresses the need to support reuse and allows objects to be treated like hardware assemblies.

This paper takes another view of the functionality of the holon or agent in the system. In addition to the infrastructure that allows the holon to work with other holons to accomplish its tasks, there is the core knowledge and understanding that defines how each holon “thinks”.

Much of the research and development activities associated with holonic manufacturing have been developed based on the concepts of the original von Neuman Architecture for computers, which includes the concept of an address pointer that increments through memory as it sequentially processes instructions. In object oriented terms, methods contain the functions performed by the objects. This concept of core cognizance and surrounding infrastructure has been termed the “cognitive iceberg” by Emmanuel Ransford.³ and has been further expressed by Carver Mead.⁴ It highlights the concept that there is a great deal of “engineering” below the surface which contributes to the cognitive process that defines the purpose of the holon, or agent.

PHYSICAL EMBODIMENT OF A HOLON

In a holonic manufacturing system one might consider every device and every human operator a potential agent, or holon. Only, however, when they actually make use of their independence while at the same time operate as part of the system with system objectives do they take on the role of a holon.

It is easy to realize two different kinds of cognitive processing performed by humans in a holonic manufacturing system: Fixed Rules and Judgmental Rules. Figure 1 identifies the basic characteristics of fixed and judgmental rules and relates them to the functions of the left and right brains of humans.

It is also important to identify memory and processing as two separate functions. This may be more physically apparent in microprocessor based devices than in humans, where memory chips house both processing instructions (rules) and data (variables). In humans there is recognition of short and long term memory. In humans there is also recognition of biases, expectations and intentions⁵ that are developed through experience. By incorporating these same services into a holon we provide the same abilities to adapt to new information and tune the reasoning process.

FIXED RULES

Some functions are based on hard and fast rules. When the time comes to perform a task and there is only one prescribed method of performing the task, the human performs that task according to well established rules. These rules might be described in a manual or cookbook. The rules might describe how to make use of other tools (turn ON, move left...). There is a “correct” way to respond. Formulas and absolute languages describe the rules. In humans, processing these types of rules, or this type of information, has been identified as “left brain functionality”. In industrial automation equipment, these rules are commonly developed with a common coding language. In some low-level hard-coded devices these rules may have been developed using a computer language like C or C++. When they are implemented in a Programmable Logic Controller, the language may be relay-ladder-logic diagrams, structured text, or a function block programming language. In any of the cases, the rules are commonly processed sequentially and provide a fixed answer or action.

JUDGMENTAL RULES

In order to achieve the advantages of a holonic manufacturing system, one needs to extend the cognitive capabilities of holonic devices. With humans, this is just part of the package. So in addition to performing tasks according to a set of fixed rules, a system benefits from the human’s ability to make judgmental decisions based on a set of judgmental rules. The human may observe an unsafe situation where damage or injury could be incurred if the rules were followed without thinking. In this scenario, the human may override the fixed rules and take an alternative path. These judgmental decisions have been identified as right-brain functions in humans where the brain is processing images rather than language. The human will balance or compare the impact of following the rules and potential hazards. The human may visualize the impacts of different optional actions. Some of these judgmental rules will be processed by the human by including information items in the decision-making process like work ethics, safety consciousness, or at times, opportunities for advancement or dissatisfaction with the supervisor. It has been suggested that to benefit from a holonic manufacturing system, the holons must “reason” about the behavior of the manufacturing system. It has also been suggested that manufacturing control units mostly require a routine-based behavior that is both timely and efficient and that this behavior should be either configurable or “self-adaptive”. The self-adaptive reasoning is not concerned with the agent’s reaction to a specific event, but supervises the behavior over time. This paper suggests a methodology that can provide the self-adaptive behavior of device-level agents in a holonic manufacturing system.

PROBLEM WITH CONVENTIONAL LOGIC

Conventional programming languages support constructs like IF, THEN, ELSE, WHILE, FOR I = 1 to n. These programming structures work well for well-defined problems and have served the computer industry well. They can be successfully used to transform data from one format to another according to a well-defined rule set. When problems are more complex, however, the time that it takes to develop solutions for complex problems, and the time it takes to test and debug them, may become prohibitive. The systems developed with conventional languages (including using the object oriented paradigm) may become hard to maintain because of their size and complexity. Complex cognitive

problems that are difficult or impossible to address with conventional coding solutions have been termed “wicked problems” by Dr. Horst Rittle as he addressed problems associated with city planning. These are problems where one is looking for the “best” answer, rather than a “correct” answer.

ALTERNATIVE COGNITIVE TECHNOLOGIES

Neural nets and fuzzy logic have evolved as technologies to address these more complex problems. Neural nets are trained to identify patterns. They are what might be termed a “mechanism” type of solution. Neural nets are modeled after the structure of the human brain. The assumption is that a human observes patterns throughout their life and then uses those patterns when new situations are observed in order to determine how to act. Humans benefit from having approximately 10^{11} nerve cells and 10^{14} synapses or connections to collect and map patterns.⁶ With an Artificial Neural Net (ANN) solution, there are many fewer neurons and connections to map patterns. There is also little opportunity to determine the reasoning behind an answer, since there is no real logic being applied.

Fuzzy logic is another approach to cognitive reasoning. It can be termed an expert system approach, since it requires an expert’s knowledge to define the rules. It uses features of linguistic uncertainty (human vocabulary terms to define values in rough terms) and assigns these values as membership functions to fuzzify, or blur, input data. This blurred data is then combined through geometric techniques to determine an approximate answer (defuzzification). The assumption is that “as complexity rises, precise statements lose meaning and meaningful statements lose precision” (Lotfi Zadeh). Fuzzy logic creates a repeatable answer using a formal rigorous process, but it suffers somewhat from a solution that is difficult to explain. Because fuzzy logic bases its value on defining membership functions based on human language terms it may sometimes be counter-productive to blur real data when accumulating information to make a judgmental decision.

Historically conventional Artificial Intelligence techniques of forward and reverse chaining have also been used to define reason based solutions. These expert system techniques use question and answer dialogs with humans who assign confidence factors to their responses to determine answers. These techniques are not normally used in manufacturing systems.

KNOWLEDGE ENHANCED ELECTRONIC LOGIC (KEEL) TECHNOLOGY

KEEL technology is suggested as an alternative to neural nets and fuzzy logic for holonic manufacturing systems when judgmental decisions or subjective actions are required. KEEL technology incorporates a graphical methodology for documenting the reasoning that maps closely to the process that the right brain uses to evaluate information. The size of the graphical elements defines the importance of information. Wires (lines) are used to indicate relationships between information items when one decision or action impacts another (or others). KEEL technology should be considered in the expert system domain, since it requires a human expert to define the rules. It is not a pattern matching system like neural net based systems. Figure 2 shows a simple set of three issues to be addressed, where consideration for the first issue contributes to the second, which in turn contributes to the third.

We suggest that complex problems are addressed by humans when considering different actions related to different issues, and considering how those actions might influence other actions. We also suggest that humans balance potential actions (for as long as they feel appropriate) until they determine the best collective courses of action to take when they have to make a decision. In cases where there is no time penalty they may stop thinking about the solution when they feel they have obtained the best solution, or when there is no apparent value to continue to think (worry) about the situation.

When KEEL designs are completed they are packaged as conventional source code in a variety of languages (C, C#, Java, VB, VB.NET, Flash, Flash Object Format, or PLC Structured Text). When executed, however, they are not processed as just a single series of sequential instructions. KEEL engines (conventional logic) process information iteratively until a stable answer is achieved. In this way they process complex situations in the same manner that we have described above regarding how humans solve complex multi-dimensional problems.

ADAPTABILITY

One of the key functional requirements of a holonic manufacturing system is its ability to exert reason when determining a course of action. KEEL technology supports this requirement by allowing external signals or commands from a higher authority to modify how the KEEL engine will interpret the data. Figure 3 shows how a device might respond to an input signal with a relative response. Figure 4 shows an external control signal that might be used to modify the interpretation of the input signal by the device. This external control signal might be just one of several factors that could modify the performance (rules) of the device. In this case, the external control signal is suggesting that there is another variable, not necessarily available to the holon, that needs to be considered as part of the holon's reasoning process. Figure 5 shows how the external control signal of Figure 4 can modify the rule of Figure 3 over its range. For example, a pump may adjust its speed based on the viscosity of the liquid it was pumping. An external vibration sensor may command the pump to adjust its rule-base because of vibration. In this way two independent functions could work together to perform the desired function in the best way. Figure 6 shows two screen shots where an external control signal from a "higher authority" is used to tune the decision-making process.

EXPLAINABLE AND AUDITABLE

Control systems are used to control devices in high risk environments. As such, the logic used to control those devices must be explainable and auditable. Should a problem arise, it must be possible to review the design and diagnose any perceived problem. If necessary, the design must be able to be fixed without undue time and effort. These systems can become even more difficult to resolve in holonic manufacturing systems when the devices are using their own judgmental rules to determine operation. It is mandatory that actions taken by the holons be audited. If production holonic manufacturing systems take snapshots of the raw data they use in operation, and capture this data as an XML file, the data can be used in the development environment to allow the humans to "see" why an action was taken. As shown in Figure 1, the designer can see the impact on Action 2 exerted by Action 1 (and also see the impact on Action 3 by Action 2) by tracing the wires between actions and reviewing the impacts (size of graphics).

STRATEGIC THINKING – GOAL SEEKING

One of the functional requirements of a holonic manufacturing system is to be able to address strategic goals. In a KEEL based system, these strategic goals are contributing factors to actions. It is these strategic values that are used to adjust the rules so when the system balances itself, the strategic goals participate in the decision-making process. Every human develops their own values and has their own personal objectives. Some of these objectives may be counter-productive to the goals of a holonic manufacturing system: wealth, junk food, the desire to play rather than work... When holonic manufacturing systems are constructed of devices with human-defined rules, it is possible to create systems with well understood rules. It is possible to build holons that consider their own safety or survivability as part of their reasoning model.

LEARNING VERSUS ADAPTING

In a holonic manufacturing system, each holon will have its own view of the world. It will be able to tune its own decision-making rules with self-diagnostics and fixed rules, similar to the rules that might be defined by continuous hours of operation or environmental variables. Interest in genetic algorithms has recently spawned significant research. In the broadest sense, there appears to be interest in systems that can “learn” completely on their own. These views are based on human models that recognize a human’s ability to increase knowledge as the human experiences new information throughout their life. For a holonic manufacturing system, this may not be a desirable trait. Uncontrolled learning and the ability to create an unacceptable rule base would not seem to be desirable. Bad things could happen. It appears much more desirable to allow humans to define a rule set and a model that allows the system to evolve only in certain ways. Because the cognitive functions discussed in this paper are completely defined by humans, the way it evolves is under control. It is more likely that system designers would allow the holon to “adapt” to certain influences in known ways. In this way, the holon could consider its own survivability only up to a point, and not to the detriment of the overall system. In other areas where the overall system performance could be improved, the designers may allow the holon more latitude in its adaptability.

In a completely open learning system, the cognitive portion of the system would be completely open to new ideas, new sensors, new data; and it would allow new information to contribute to the decision making process. Humans are somewhat able to accept new information, because of the vast number of neurons available to process information. While there is no physical limit to the number of inputs and outputs of KEEL based systems, the logic must be defined by human designers. For example, there is no way to incorporate temperature into an existing decision-making process if it was not included in the original design. This is the same case with most ANN based systems. If they had never been taught patterns that included temperature as an input, they would not know how to interpret temperature if it was later deemed to be important.

On the other hand, because KEEL engines process all information at once, if the new model of the problem space includes new data items and new relationships (rules and data); those new items would be evaluated. Figure 7 shows this mechanism. In most cases the rules will be defined external to the holon, in some kind of development environment where the designs can be tested before being

deployed. The holon will be actively performing its duties. Periodically it will schedule a re-evaluation of its subjective situation. In doing so, it will take its rule base from its Rule Memory and take a snapshot of its real-time inputs and “think”. The results will be presented as actions, or as new data, for other processing. Between these scheduled “think” activities, the Rule Memory can be reloaded. In this case, it can take into consideration any new sensor values that are available and any new relationships that have been identified by the system designer. While this cannot be considered true “learning”, it can provide a mechanism for “teaching” an active holon new cognitive functions while it is operating. This would only be done if the new cognitive rules had gone through extensive validation before deployment for safety reasons.

SUMMARY

Holonic manufacturing systems need to process conventional hard-coded logic to address the deterministic situations that exist in any control system. These same systems can benefit from judgmental reasoning when they are required to adapt to changing demands that are caused by component failures or by changing business drivers. KEEL technology is offered as an alternative to neural net and fuzzy logic based systems when *completely explainable actions* are required. The development environment which allows immediate feedback into the design process is an added benefit when the economics of managing any new technology need to be considered. The creation of holonic reasoning will seldom be addressed with a single technical approach (i.e., just conventional logic, just neural networks, or just fuzzy logic). KEEL technology might be considered one additional approach that could be applied when the situation demands explainable actions in a dynamic environment.

Left Brain

- **Logical Domain**
 - Language
 - Formulas
 - Signal Conditioning
 - Signal Transformation

Right Brain

- **Judgmental Domain**
 - Images
 - Analog Relationships
 - Identifying how each piece of information impacts other parts of the problem
 - Combination
 - Interpretation
 - Determining the Importance of Information
 - Balancing
 - Multiple solutions to determine the best overall set of actions

Formulas OF | THEN | ELSE

Neural, Fuzzy, KEEL

FIG. 1 – LEFT BRAIN – RIGHT BRAIN FUNCTIONALITY

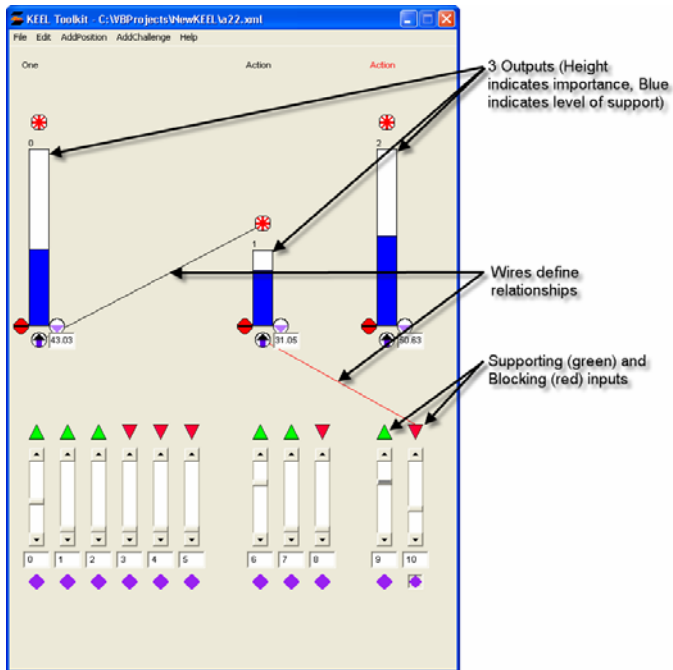


FIG. 2 – GRAPHICAL PROGRAMMING LANGUAGE

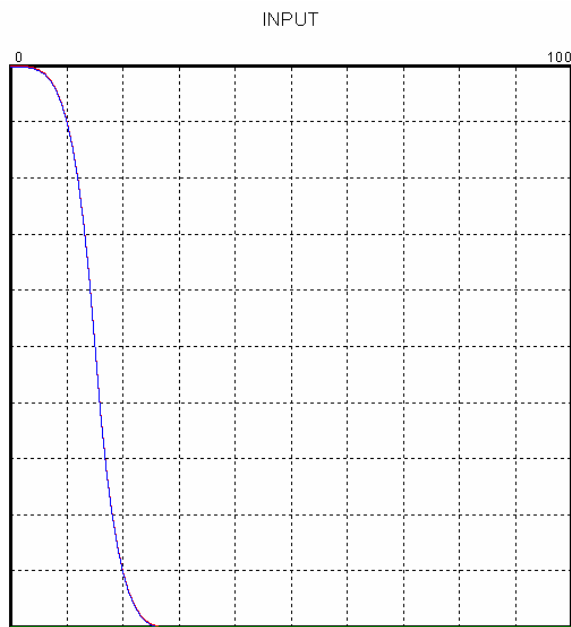


FIG. 3 – INTERNAL RULE FOR HOLON



FIG. 4 – EXTERNAL CONTROL SIGNAL FROM COMMAND AUTHORITY

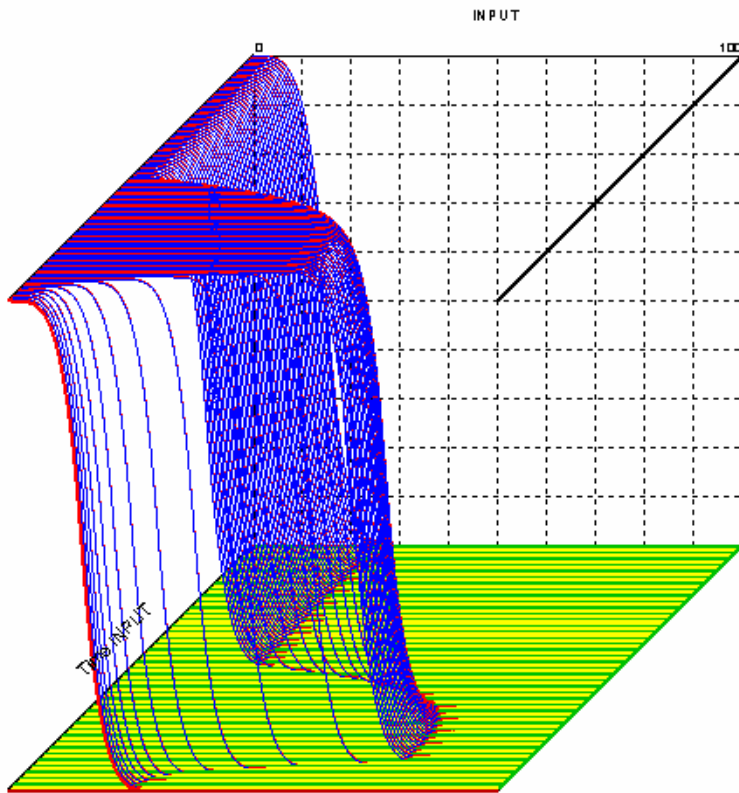


FIG. 5 – INTERNAL RULE MODIFIED BY EXTERNAL COMMAND

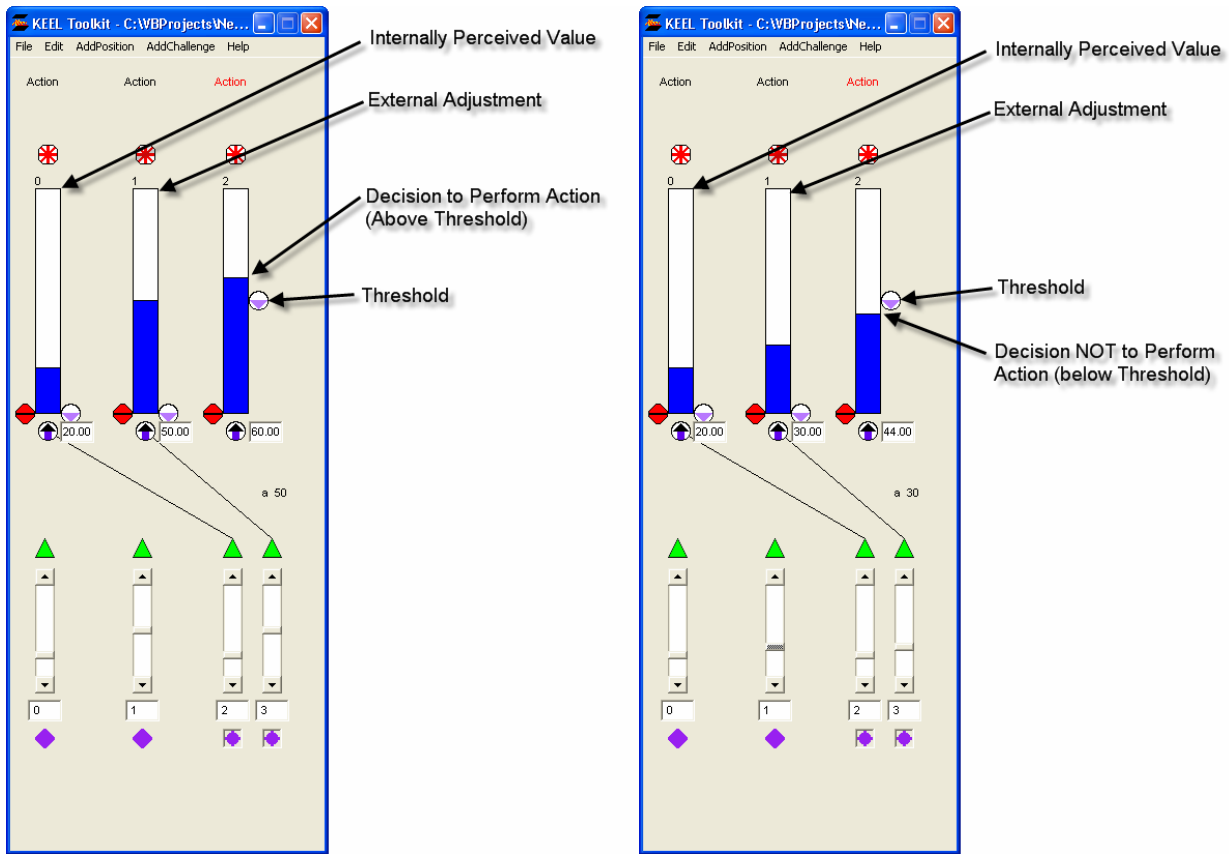


FIG. 6 – TRACEABLE ACTIONS

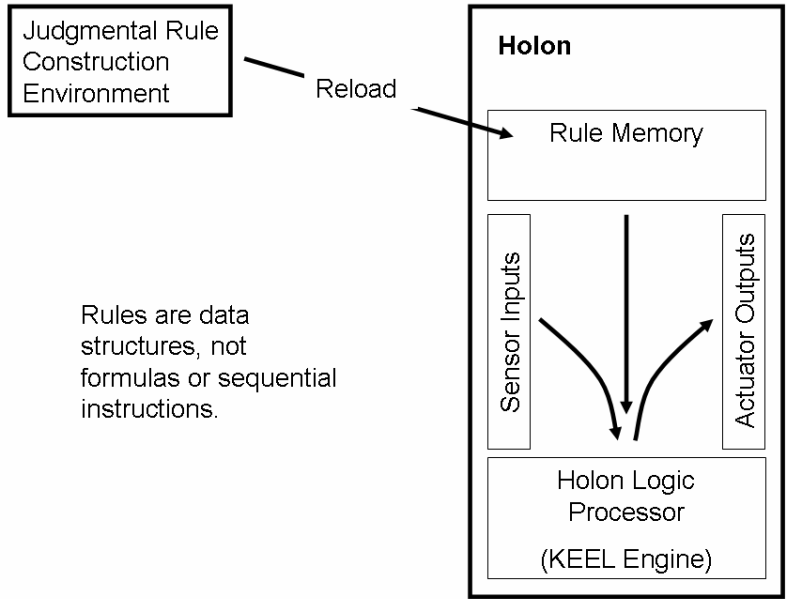


FIG. 7 – MECHANISM FOR CONSIDERING NEW IDEAS

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