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THE CONSTRUCTAL THEORY OF INFORMATION

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Abstract. The Constructal Theory of Information creates a bridge between informaiton theory and thermodynamics. Definitions of the elemental thermodynamic information machine (the knowledge constructor) are proposed. It is shown that these definitions apply at all scales and to all methods of operation from DNA to social communication and technical intelligence. Further, it is shown that all real world organisms are composed of hierarchies of knowledge constructors and that the thermodynamic and information properties of the elemental knowledge constructor are transitive across all scales of hierarchical organisms regardless of their method of operation.

Key words: Heyer, constructal law, infonomics, infodynamics, information, knowledge, Turing.

1. DEFINITION OF THE CONSTRUCTAL THEORY OF INFORMATION (CTI)

The Constructal Law provides a method for understanding not only universal evolution, as Bejan describes, but also the rise of information based life forms. I will outline the Constructal Theory of Information (CTI), which unites information and thermodynamics. This theory also shows that three distinct information based life forms are evolving on the earth – DNA life, human cultural life and technical life, leading now to artificial intelligence - all defined by one theory of operation.

The significance of the CTI is the definition of the minimal information based life form as a thermodynamic engine, uniting the Constructal Law with the evolution of all life forms.

2. STATEMENT OF THE CTI

1) All life forms are macroscopic entities subject to the laws of thermodynamics. All must obtain and use energy to live. All must follow the Constructal Law to evolve, grow and/or reproduce.
2) All life forms are composed of information engines, regardless of their method of operation.
3) All information engines are based on the same elemental architecture – the Universal Turing Machine being one example.
4) The informational and thermodynamic (infodynamic) properties of information engines are transitive across all scales, hierarchies and methods of operation.
5) Knowledge is a property of all information based life forms, inseparable from their structure and required for their operation.
6) The expression of knowledge is the means by which all life forms control or harvest energy.

3. DEFINITION OF TERMS USED IN THE CTI

3.1. Definition of Life

According to the CTI, all life forms are physical entities based on the use of information to express knowledge and are subject to the laws of thermodynamics, regardless of their mechanism of operation.

With this postulate, we can make a universal definition of life that integrates both information and thermodynamics:

1. A life form is any macroscopic, finite machine (knowledge constructor, as defined below) that can receive information from the environment, integrate it logically with memory (stored information) to synthesize knowledge to perform an action (express knowledge), to control or harvest energy in the environment and use that energy to perpetuate its survival.
2. The question of how a life form originates, operates or replicates is secondary. Size, complexity and method of operation are arbitrary. A life form can be DNA based, an object fabricated by humans, or may be a hybrid of life forms as with humans and their tools, cars and computers.
3. To continue living, any organism must increase exergy collected to greater than the exergy needed for equilibrium operation. In order to grow, evolve or reproduce – to morph – it must obtain additional exergy, as shown by the Constructal Law.
4. The communication of information (knowledge) between and among organisms is a common feature of life forms. Communication can be intimate, as among the cells in a body, or extended, as in a flock of birds, or a human family or organization. With communication, the enclosing hierarchical organism becomes a knowledge constructor itself, inheriting the energetic drives of its members.

3.2. The three information families of life

All life forms are based on the same information and thermodynamic (infodynamic) principles. From this perspective, we can identify three great families of life. For brevity, these are provided without comment:

1. DNA Life
2. Human Social Life Forms (families, tribes, religions, companies, states, etc)
3. Machine Life (machines with embedded knowledge or intelligence).

3.3. Definition of information

Information is energy received by a sensor and passed to the processor of a sentient receiver (knowledge constructor).

Information is relevant only if the receiver already possesses stored information establishing a context for recognition of the received energy as information to be incorporated into knowledge.

Obviously, information can be stored in various ways, but it only becomes information if it can be received and understood by a sentient receiver. For example, a USB storage device may hold considerable information – if you have a computer to read it. A person without a computer could never prove that the device did or did not contain information.

The term information is often confused with the more accurate term “configuration” when used to describe processes in nature. Matter itself does not “contain” information.

3.4. Definition of knowledge

Knowledge is a physical and operational property of all life forms. Knowledge is an integral part of any knowledge constructor. Knowledge is created by the "processor" that receives information from an input (sensor), integrates it logically with memory, creates knowledge, and potentiates an action at the output (actuator). Knowledge can only be proven by observing its expression.

Knowledge is inseparable from the knowledge constructor that possesses it. This is a statement of the Completeness Theorem, described elsewhere.

4. ARCHITECTURE OF THE KNOWLEDGE CONSTRUCTOR

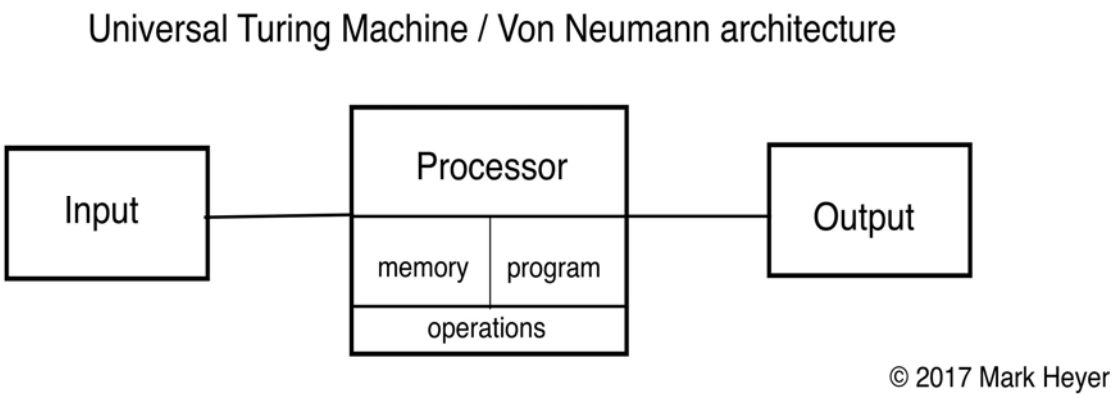

Fig. 1 – Universal Turing Machine (UTM) architecture [12–15].

The CTI applies this proven and universally accepted computing construct to a broader range of information-based mechanisms, including biology, humans and machines.

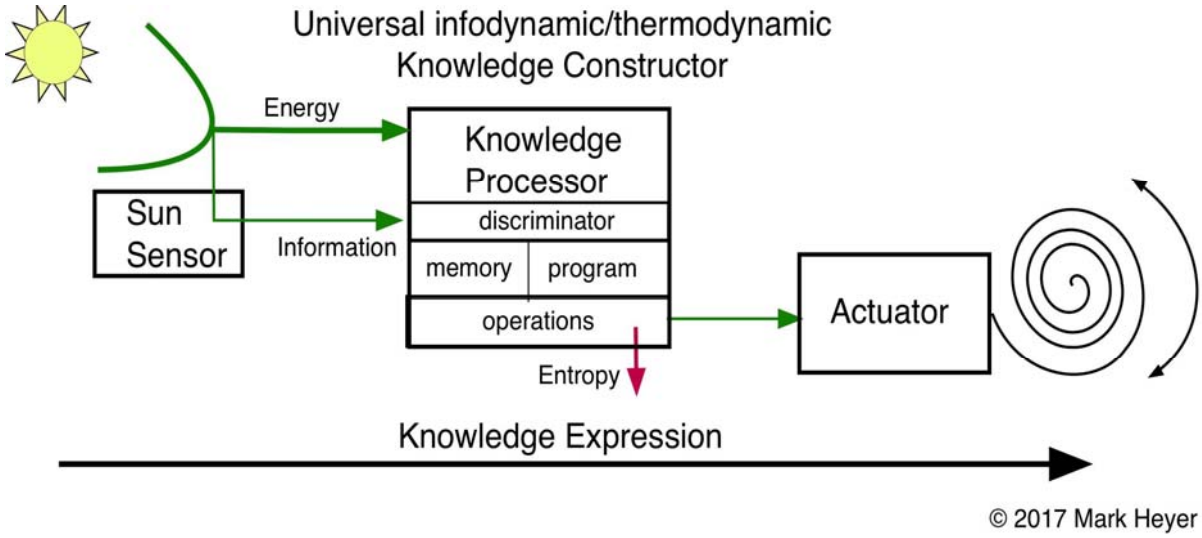

Fig. 2 – Infodynamic/thermodynamic knowledge constructor.

In Fig. 2, energy flows are indicated by the arrows. In this example, the knowledge constructor expresses its knowledge of changing solar intensity to rotate and maximize solar input.

4.1. Knowledge constructor principle of operation

The following description of the knowledge constructor depicts a theoretical entity without a specified physical embodiment or mechanism of operation:

1) No limit on its physical size or methods of operation, sources of energy or means of expression
2) No limit on the number of sensors, size and sophistication of the processing unit or memory, or power of the actuators.
3) No limit on the assembly of knowledge constructors into hierarchies.
4) The operation of the knowledge constructor is to receive information, in order to create knowledge, which enables physical actions (knowledge expression), to increase the flows of energy available to the system it inhabits – the arrow of constructal evolution.

- **Sensor** – Mechanism for receiving energy from the environment.
- **Discriminator** – Input to the knowledge processor. A method to "recognize" the sensor's energy input. This generally requires that the input be compared to a value in memory. ed.
- **Memory** – A means by which to recognize new (or unknown) inputs and to create knowledge about what action is to be taken in response to an input.
- **Processor** – At minimum, a logic unit to compare input with memory and decide on the action to be taken. The processor can have unlimited complexity, manage multiple sensors and actuators and subordinate knowledge constructors.
- **Actuator** – A physical mechanism used to control energy in the environment under the direction of the processor, e.g., a propeller, valve, switch, pump, etc.

4.2. Operation of the knowledge constructor

The operation of all knowledge constructors (as infodynamic/thermodynamic engines) is dissipative. Therefore they need a source of energy in excess of the exergy required for operation, to account for entropy production, per the second law.

In order to grow, evolve and reproduce, the knowledge constructor must achieve access to exergy above what is required for survival. It must use this extra exergy to morph and evolve its channels (sensors, processor and actuators), to increase the flow of energy through it, or the organism it is part of, in accordance with the Constructal Law.

There is no limit on the size or complexity of a single knowledge constructor. It may be microscopic, as in intracellular mechanisms, or the size of a house or the entire earth itself. It can have any number of sensors and/or actuators.

4.3. Knowledge constructor hierarchies

Hierarchies of knowledge constructors may form to maximize their shared capabilities to increase exergy access for the benefit of the group.

There is no limit to the size or function of knowledge constructor hierarchies. Communication allows the formation of virtual knowledge constructors even though the individuals may be distant, e.g., a flock of birds or a company.

The infodynamic and thermodynamic principles of the elemental knowledge constructor are transitive across all hierarchies, scales or methods of operation.

5. PROOF OF THE CTI

5.1. Proof of the knowledge constructor

1. The Turing proof of computability (Universal Turing machine) establishes the definition of the universal information machine.
2. All information-based life forms are composed of information machines, defined here as knowledge constructors.
3. All knowledge constructors are physical entities and thus governed by the laws of thermodynamics
   The complete proof is provided in the full text of this paper, available on request.

5.2. Proof of knowledge constructors in biology

A key part of the proof of the CTI is demonstrating that the Turing architecture operates in biological settings. This has been amply demonstrated in the literature. This proof is available in the full paper.

6. CONCLUSION

In this paper, I have shown that all forms of life share a common information and knowledge principle of operation, exemplified by the Turing proof of computability and the architecture of the Universal Turing Machine. Further, I have shown that all existential life forms are governed by the second law and the Constructal Law.

Therefore, I have defined the "knowledge constructor" as a physical entity that incorporates the Turing architecture and is governed by the laws of thermodynamics. This definition can be shown to be the fundamental basis of all life forms, regardless of their mechanism of operation.

Life forms can therefore be defined within the realms of DNA, human social life forms and machines. It provides a foundation for understanding and predicting the evolution of composite, or hybrid life forms.

The CTI also demonstrates that knowledge constructors can and do form hierarchies, and that their method of operation is transitive across all scales of hierarchy. Thus, a human being is a hierarchy of trillions of cells, bacteria, yeast and fungi, yet the human is driven by the same principle of operation as each of its parts.

This paper has not dealt explicitly with the issue of dependence, which is operational in all hierarchies. Dependence is the root of cooperation and specialization among the members of a hierarchical organization and gives rise to behaviors and advanced social behavior.

The author can be reached at: markh@heyertech.com. The complete paper is available on request.

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* Many of the references below are included in the original paper and do not appear in this abbreviated version. They are included here for completeness.