CAN ECONOMIC ENTROPY BE INTEGRATED INTO BOTH IT AND HUMAN SYSTEMS?

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1. INTRODUCTION
The interfaces of engineering and behavioral sciences¹ need to be studied through the economic dimension to provide a value measure to entropy analysis in an age of rapid socio-technological change. From electronics to human engineering, the concept of Entropy and the fact that entropy continuously increases in the universe is used to explain many related phenomena.

Economics is the science traditionally dealing with questions of scarcity. The allocation of scarce resources (natural and human) involves broad questions of values, preferences, efficiency, and equity. Advances in the physical and ecological sciences in recent years have led to the notion of sustainability. This called for a need to include the Second Law of thermodynamics, also known as the entropy law. Entropy exists in all systems, nonliving and living, that possess free energy for doing work. As system energy declines, entropy increases. Entropy has precise mathematical and statistical definitions, but can be approximately defined as the degree of disorder or uncertainty in a system. If a system is isolated, or cut off from all inputs of matter and energy, it will tend toward a maximum, according to the Second Law of Thermodynamics. Neoclassical theory of Economics presently incorporates First Law principles, i.e. conservation of energy and materials, demonstrating conditions under which prices, indicating the preferences of rational economic agents, accurately reflect resource scarcity, and conditions in which markets efficiently allocate scarcity. Nonetheless, the entropy law imposes an additional constraint of directionality on all physical processes not reflected by conservation alone.

The concept of entropy is explained differently for each engineering system. Electronic² systems involve Design Entropy whereas Conditional Entropy is used in various Artificial Intelligence³ systems. It is also used to study maximum entropy correlated equilibria (Maxent CE) in multi-player games⁴.

2. OBJECTIVES
1. To study the reusability of various electronic components used in electronic circuit designs.
2. To study the economics of the dissipative structures and entropy involved.
3. To study and analyse various types of Entropies in different systems.

In Menhorn Benjamin & Slomka Frank’s “Design Entropy Concept-A Measurement for Complexity” aim was to design and derive a method for calculating complexity in Digital Electronic circuits. Initially this complexity in integrated circuits was measured by Moore’s Law¹ by counting number of components per integrated function. Also Shannon’s Information Entropy⁵ was used to calculate the behavioral entropy of a given component. The formula derived from Shannon’s Information Entropy is then used to write the Behavior Entropy formula for a component having N(c) inputs, M(c) outputs and Z(c) possible states for each input and output (the value of Z(c) is usually taken to be 2 as it is True or False in case of digital circuits). The Structure Entropy is then calculated recursively for all the sub-components involved in the project. Verification Entropy is calculated for the project by summing up the verification entropy of one instance of each sub-components and adding to it the verification entropy of the project itself. This approach helps to calculate the Complexity and hence the Design Entropy of any digital circuit. This concept allows circuits to be split into components and takes reusability into consideration.

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⁴ Menhorn Benjamin & Slomka Frank’s “Design Entropy Concept”
⁶ Luis E. Ortiz, ECE Department, Robert E. Schapire, Dept. of Computer Science Sham M. Kakade, Toyota Technological Institute (2004) “Maximum Entropy Correlated Equilibria”

Concepts of Menhorn Benjamin & Slomka Frank’s “Design Entropy Concept-A Measurement for Complexity” explained in appendix-A.
into account. Complexity of an embedded circuit was calculated using the concept of Shannon’s Information Theory which takes into account the entropy of a system.

Design entropy is calculated by taking analogy from Shannon’s Information Entropy. The information (=value) from component (=variable) b is transmitted (=assigned) to component (=variable) a. The cost analysis related to the design entropy specifications is done.

The design entropy analysis done using the concepts and formulae for Behaviour Complexity (Entropy), Structural Complexity (Entropy), Verification Complexity on three different designs of a Full-Adder.

**Design-A:**
This design uses 3 AND, 1 OR and 2 NOT gates.
- Behaviour Complexity(Entropy): \(4 \log(2)\)
- Structural Complexity (Entropy): \(16 \log(2)\)
- Verification Complexity: \(12 \log(2)\)
- Cost of NOT gate IC7404: Rs. 20
- Cost of AND gate IC7408: Rs. 20
- Cost of OR gate IC7432: Rs. 20
- Total Cost: Rs. 60

**Design-B:**
This design uses 6 NAND gates.
- Behaviour Complexity(Entropy): \(4 \log(2)\)
- Structural Complexity (Entropy): \(18 \log(2)\)
- Verification Complexity: \(7 \log(2)\)
- Cost of Quad 2-Input NAND IC7400: Rs. 20
- Total Cost: Rs. 40

**Design-C:**
This design uses 1 AND and 1 XOR gate.
- Behaviour Complexity(Entropy): \(4 \log(2)\)
- Structural Complexity (Entropy): \(6 \log(2)\)
- Verification Complexity: \(10 \log(2)\)
- Cost of AND gate IC7408: Rs. 20
- Total Cost: Rs. 40

Design-C, proves to be the most efficient both with reference to Design Entropy and Cost.
In Culham Richard J & et.al. (2001) “Optimization of Plate Fin Heat Sinks Using Entropy Generation Minimization” In IEEE Transactions on Components And Packaging Technologies, Vol. 24, No. 2 aim was to optimize the heat sink design parameters based on a minimization of the entropy generation.

The model development is subject to the following underlying assumptions:
1) no spreading or constriction resistance; 2) no contact resistance at fin to base plate connection; 3) no bypassing of flow; 4) uniform approach velocity; 5) constant thermal properties; 6) uniform heat transfer coefficient; 7) adiabatic fin tips.
For long term performance and durability of electronic components it is important to minimize heat losses and high temperature generation. Hence, thermal resistance of the components needs to be reduced. This can be done efficiently by increasing the surface area of the device by introducing heat sinks and extended surfaces. Parametric studies can be undertaken to obtain a relationship between thermal performance and design parameters. The entropy generation associated with heat transfer and frictional effects serve as a measure of the ability of the sink to transfer heat to the surrounding cooling medium. The simplest approach to entropy generation minimization is obtained by fixing all parameters in the heat sink design and then monitoring the change in entropy generation[as that particular design variable is changed over a typical range]. The solving of the differential equations leads to formation of six cases where varying the number of changing parameters gives different results.

5 Calculations and formulae are stated in the appendix-B.
6 Cost analysis is done in appendix-C.

7 Culham Richard J., Member, IEEE, and Muzychka Yuri S. (june 2001) ”Optimization of Plate Fin Heat Sinks Using Entropy Generation Minimization” in IEEE TRANSACTIONS ON COMPONENTS AND PACKAGING TECHNOLOGIES, VOL. 24, NO. 2
Entropy generated in the heat sink is given in terms of heat dissipation rate; temperature excess of the heat sink base plate; total drag force; free stream or approach velocity; absolute environment temperature and total number of fins. The optimal value of the variable being calculated is N (number of fins) by calculating the value of entropy generation in the heat sink. The optimized value of the number of fins and other design parameters of a heat sink are calculated using the concept of minimum entropy generation.

In GanapathiVarun & et. al. (2001) “Constrained Approximate Maximum Entropy Learning of Markov Random Fields” aim is to estimate parameters in Markov Random Fields (MRFs) using maximum entropy with moment matching constraints. The main concept applied for formulating a new method for optimization in MRFs is based on the fact that dual of maximum likelihood is maximum entropy subject to moment matching constraints. The whole problem and constraints are transferred from maximum likelihood method to maximum entropy form and then use the loopy belief propagation method to solve it further. The problem is then optimized using double loop method. In the maximum entropy problem, sharing parameters corresponds to reducing the number of rows of the moment-matching constraint matrix, thereby reducing its rank. The lower the rank, the less constrained the optimization problem.

A random probability distribution is taken and then Markov Random Fields concept is applied to it. Variables used are basically any real life optimization problem which involves MRFs.

The difficulty of solving Markov Random Field algorithm is reduced by using maximum entropy concept and applying mathematical concepts such as Lagrange multipliers.

In Ortiz Luis E. & et. al. (2004) “Maximum Entropy Correlated Equilibria” aim is to study maximum entropy correlated equilibria (Maxent CE) in multi-player games. The Maximum Entropy Principle (Maxent) can serve as a principle for selecting among the many possible Correlated Equilibria of a game. This is because Maxent CE gives individual players additional guarantees over arbitrary CE. Equilibrium is generally considered the solution of a game. Equilibrium can be viewed as a point where every player is “happy,” i.e., no player has any incentive to deviate from the way they play. The concept of conditional entropy in information theory provides a measure of the predictability of a random process from another. Conceptually, we can think of the conditional entropy as a measure on how hard this is: the larger the conditional entropy, the harder the prediction. Computing the Maxent CE is a convex optimization problem, and algorithms already developed can be used for it. In particular a logarithmic-gradient and a gradient-ascent algorithm show that they are guaranteed to converge to the Maxent CE for any game. A multi-player game (situation) is being optimized using the Maximum Entropy parameter. Conditional Entropy is used as a parameter to calculate relative entropy of one process with reference to another. It is shown that maximum entropy is a useful guiding principle to the selection of equilibrium in game theory.

In Gu Yu, McCallum Andrew, Towsley Don “Detecting Anomalies in Network Traffic Using Maximum Entropy Estimation” aim is to develop a method that detects network anomalies by comparing the current network traffic against a baseline distribution. Packets are divided into classes along multiple dimensions on the basis of packets’ protocol information and destination port numbers. A maximum entropy baseline distribution of the packet classes is determined by using a density model from a set of pre-labelled data using the concept of Maximum Entropy. The Maximum Entropy estimation procedure consists of two parts: feature selection and parameter estimation. The feature selection part selects the most important features of the log-linear model, and the parameter estimation part assigns a proper weight to each of the feature functions. The final model is then built using these two steps simultaneously. The empirical distribution of the packet classes under observation is then compared to this baseline distribution using relative entropy. The packet classes that contribute significantly to the relative entropy are then recorded. If certain packet classes continue to contribute significantly to the relative entropy, anomaly warnings are generated. Maximum Entropy is the parameter which determines the baseline distribution and it is estimated using Gibbs distribution having log-linear form. Anomalies detection in the network traffic using Maximum Entropy estimation and relative entropy is calculated mathematically using Gibbs distribution and Kullback-Leibler (KL) divergence. The experimental results show that it effectively detects anomalies in the network traffic including different kinds of attacks and port scans. This anomaly detection method identifies the type of the anomaly detected using entropy concepts. This method requires a constant memory and a computation time proportional to the traffic rate.

In Model Garret’s (2004) “Entropy and Subtle Interactions” in Entropy, Vol. 18, No. 2, pp. 293–306 aim is to use entropy considerations to determine the types of subtle interactions (SI), that are consistent with the second law of thermodynamics. In the initial application of the second law of thermodynamics to Subtle Interactions or psi phenomenon, a decrease in the entropy of the receiver could not be compensated for by a rise in that of the agent because the agent acted later. Because of

9 Luis E. Ortiz, ECE Department, Robert E. Schapire, Dept. of Computer Science Sham M. Kakade, Toyota Technological Institute (2004) “Maximum Entropy Correlated Equilibria”
10 Term explained further in appendix
11 Expression given in appendix-C
this delay in compensation, the entropy of the receiver could not decrease. The close overlap of precognition and psychokinesis and the related difficulty of determining which entity is agent and receiver mean both should follow the second law of thermodynamics independently. After relaying entropy and Subtle Interactions their types are discussed. Type 1 is human-human interaction (Precognation of world events and telepathy and prayers and healing). Type 2 is Human-Electronic Random Event Generator, Type 3 is Human-Non-Electronic Inanimate System and Type 4 is Inanimate System-Inanimate System. SI that are consistent with the second law of thermodynamics typically involve a quantum trigger with amplification. The complete experiments are based on interactions between various inanimate and animate objects. The variables will be the subtle interactions that occur due to these interactions and these are proved by relating it to the concept of entropy. With the experimental evidences provided it is clearly shown that SI are consistent with the second law of thermodynamics. Unless evidence to the contrary arises, SI experiments that have a chance to yield positive results are those in which the agent and the receiver each exhibit non decreasing entropy.

In Durrett Greg & et.al. “A Genetic Algorithm to Minimize Chromatic Entropy” aim is to design a Genetic Algorithm for optimization of chromatic entropy. If reducing the number of colors also reduces chromatic entropy, it is not necessarily true that the coloring yielding the minimum chromatic entropy is a minimum coloring. For any given color sequence or pattern, its chromatic entropy is calculated using the general information entropy formula. As it is difficult to theoretically optimize the chromatic entropy, Genetic Algorithm is used for the same. The connections between graph coloring and chromatic entropy indicate that a GA for one might be effectively adapted to the other. An analogy can be established with the genomes used to solve graph coloring problems. Thus mutation and crossover concepts are used to develop this algorithm. In mutation swapping takes place between two adjacent nodes and in crossover a new child node is created by the already existing one. Parameters used here are Chromatic Entropy and concepts of mutation and crossover to build a Genetic Algorithm. GA to minimize conditional chromatic entropy for a given graph with a joint probability distribution over its vertices is implemented and proved experimentally.

In Valero Antonio, Torres Cesar and Valero Alicia “Application of Thermo-economics to Industrial Ecology” aims to apply the concepts of thermodynamics to an industrial system and hence study its economics. Individually three sample systems namely a power plant, a cement kiln and a gas-fired boiler are examined and their characteristics such as Fuel and Product, Waste and By-Products, Productive Structure and External Resources are then assessed. Initially these systems are taken as isolated ones and their costs are calculated in terms of monetary units per unit of time (€/h) and is called Exergoeconomic cost. These costs are then calculated by making these isolated systems a single unit by supplying the output product of one as the input to the other. This reduces the exergoeconomic costs considerably and thus increases the efficiency of the system when used as an open system rather than isolated one. The main parameters being measured here are exergy and exergoeconomic costs. Formal mathematical computations are provided for calculating them. The main concepts and tools of Thermoeconomics have been studied and new ideas related to Industrial Ecology was introduced and applied to a case study comprising a coal-fired power plant, a cement kiln and a gas-fired boiler producing steam.

In Salthe S.N.(2010) “Maximum Power And Maximum Entropy Production: Finalities In Nature” in Cosmos and History: The Journal of Natural and Social Philosophy, vol. 6, no. 1 aim is to formulate a relation between maximum power and maximum entropy for a better understanding of human engineering. Maximum power is obtained during work at the most effective combination of work load (resistance) and work rate. The power produced in any system is related to entropy by Power = work rate + entropy produced. This means that an increase in work rate will lead to an increase in free energy (Entropy) and thus they are directly related. The Maximum Entropy Production Principle and this concept together lead to the fact that every system in nature tends to maximize its entropy thus maximizing its power and hence efficiency. With biotic dissipative structures, the energy flow is preservative in nature. It is supposed that living dissipative structures would, while active, tend to use their free energy stores near the range of maximum power. Aging in organisms shows that when the effectiveness of striving declines, an organism is setup for recycling. It is also proved that the per unit mass energy throughput of organisms steadily declines onto an asymptote as they spin out their lives. This is an expression of the “minimum entropy production principle as it works out in dissipative structures. Thus, when an organism fails to contribute as much as they had been doing to the maximum entropy production, they begin to fail. Power and entropy are the parameters that are being understood in the context of human engineering. Maximum power concept supports the existence of human dissipative systems. The maximum entropy production principle in the more general sense gives human engineering a broader sense.

In Chang Ling-Zhang (2003) "Dissipative Structures Of Electromagnetic Field In Living Systems” in HBI Deutchenlad, Version 4/12/2003 aim is to explain the science of acupuncture and other energetic medicine on the basis of dissipative structures in living systems. Acupuncture and other energetic medicines were initially considered to have placebo effect. But with the concept of dissipative structure theory given by Belgian Scientist Ilya Prigogine these practices were understood better. His theory changed the study from being of isolated system to open system. The dissipative structures of

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12 Terms explained further in appendix-A

14 Durrett Greg, Muriel Medard, and Una-May O’Reilly” A Genetic Algorithm to Minimize Chromatic Entropy"
electromagnetic field composed of chaotic standing waves were found to exist in the cavity of living systems. These structures were self-organizing. They were viewed as non-equilibrium systems and so entropy maximization and energy minimization in these structures lead to the understanding of relation between acupuncture points and the organs which they affected. It sheds light on transmission of signals and hence proves the relationship between organs and acu-points and the effect of needling. Parameter studied is dissipative structures in living systems. The dissipative structures in living systems provided a scientific explanation for acupuncture and other energetic medicines based on the principle of entropy maximization.

On IT, Engineering and Human systems:
Entropy is a parameter which defines and describes a number of processes happening around us. From Management to Psychology and Engineering Systems, entropy explains a lot of phenomenon happening around us. Taking help from the research already done on this topic, two models that describe the function and presence of entropy in Information Technology and electronic engineering branches are developed. These models have entropy as a parameter which brings about a change in the system by itself changing its value or form. The model on Reusability makes use of experimental data collected for calculating the exact costs and internal entropy structures. Experiments to determine the reasons for failure and non-functioning of the integrated circuits were calculated. The Information Technology model talks about the advancements in this field and the contributions of entropy to it. The third model describes entropy in humans and takes up the concept of human engineering.

3. REUSABILITY MODEL:
Any circuit component is a combination of basic Gates and Integrated Circuits (ICs). These components can as well be used in various combinations to form bigger combinational logics which perform practical applications. These integrated circuits have a lifetime and they stop functioning due to certain reasons. These reasons can be high temperature or voltage fluctuations. Application of very high temperatures (or sudden overshoot of voltages) results in the change of structural entropy of the semiconductor that is internally present in the IC. This reduces the reliability and lifetime of a given IC. Then any of these circuits can be reused with high percent of reliability. The basic parameter which can be used to measure reusability is the number of runs in which the circuit design can be used. It is seen experimentally that the ICs can be reused till the time their internal entropy structures remain intact. Any change in the entropy due to heat generation will lead to change in the structure of the semiconductor vapor and hence the IC is regarded non-functional. From an economic point of view ICs are very inexpensive components. A general IC costs around Rs.20. Constructing a circuit design using multiple such IC would depend upon the design construction. A simple adder circuit which adds two bits and gives the output would cost around Rs.40 at most. So a component that can add two 4 bit numbers would cost around Rs.160. So a simple and practically usable component such as an adder would cost around Rs.160 and function accurately for a large number of runs. This adder is thus a reusable component and can be placed anywhere, where addition of 2 binary numbers is supposed to be carried out.

In conclusion, reusability of electronic circuits depends on the entropy structures of the components used.

4. INFORMATION TECHNOLOGY MODEL:
Information Technology is one such area which has seen a complete makeover in the past few years. Development and advancement is the key to it. The IT industry is another engineering area where concept of entropy can be used to determine the growth in this sector. IT industry started at a point and then as new technologies came up, dissipative structures started forming and new technology took over. This can be explained using entropy. Changes can be seen as randomness or chaos as it disturbs the stability of an already running technology. As this entropy increases it leads to the entry of a new technology and the earlier one fades out.

This can be explained using a tree diagram
This describes each generation of Computers Technology that existed and developed in the past years. Right now it is Artificial Intelligence where progress is taking place. On full development and testing of artificial intelligence technology it will add another generation to this chart and thus lead to an increase in entropy.

This graph clearly depicts the variation of entropy of Programming languages with time. A decrease in the entropy of C++ is accompanied by the increase in entropy of Java, thus showing that C++ paved the way for development of Java.

IT has seen a lot of technological advancement and thus there has been a continuous increase in entropy in this sector.

5. THE HUMAN MODEL:
Entropy is not just limited to inanimate and non-living systems but is very much present in the living systems as well. In simple terms, entropy is a measure of order and disorder in our human bodies. If left alone, these aging systems go spontaneously from low entropy and order, to high entropy and disorder i.e. from life to death, where death is maximum disorder or maximum entropy. This means one can show the direction of time (time’s arrow) since natural things proceed in the direction of increasing entropy.

Several research efforts had presented both methodologies and results for the estimation of entropy generation during human lifespan. The main idea proposed by most of these investigations is that entropy can be related to aging through irreversible cell damage, entropic aging or thermal de-naturation, which indicates structural changes with heat thereby affecting the performance of cells. The studies also suggest that there is a limit of entropy generation that can be correlated to lifespan.

Entropy in humans is affected by parameters such as metabolism, diet, exercises etc.
The percent distribution of fats and carbohydrates in the diet does not seem to have a significant impact on the predicted lifespan to reach limit entropy. When these nutrient % distributions are interchanged inside the recommended ranges, the average lifespan change is on the order of one trimester or less.

For proteins the results are completely different. Proteins yield a very low efficiency in forming ATP by metabolism; therefore the change in the diet % of protein causes significant entropy differences from the base case.

To sum up, effective ways to increase lifespan are to reduce the diet protein intake to the minimum recommended for a healthy diet and to reduce the lifetime average caloric intake by 5–10%. However, no health or disease consideration had been taken into account.

6. REFERENCES
[18] Menhorn Benjamin And Frank Slomka Design Entropy Concept