The Thermodynamics of Freedom

How Should Humanity Steer the Future? By allowing maximum individual freedom to pursue dreams and expand horizons. History has shown that humanity works best when freedom is maximized; in fact, the purpose of instituting governments is to maximize individual freedom. Treating a topic this general requires idealization and something resembling a statistical mechanics approach, leading to a thermodynamic model. We know that for thermodynamic work to be done a system must have *free energy*, else no work gets done. We link these different concepts of freedom in this essay.

This essay applies concepts of thermodynamics—specifically statistical mechanics—and of optimal control theory. Statistical physics assumes large numbers of elements, N , and total energy, *E.* The energy of labor, if not controlled by force, is controlled by money; so we measure energy in dollars. This applies generally to electrical energy one buys from a power company or to physical work one does on a day-to-day basis.

Humanity is seen as an *N*-body system, with $N \sim 10^{10}$, each assumed to have position, momentum, energy, and degrees of freedom. *Steer* implies a goal and means of reaching it, so we need both goals and control policies. We formulate two *idealized* goals and analyze them. To be relevant we address *real* goals, argued every day in the world.

While physicists developed statistical mechanical approaches to many-body problems, engineers developed control theory to deal with reaching goals. A control policy will regulate key system parameters in such way as to force the system toward the desired goal. Physics and control theories are extremely general; the type of *energy*, the type of *force*, and the specifics of the *goal* are typically subordinated to the formulation.

The complexity of our problem requires simplifying assumptions. We are concerned with the physical world of humans, so we deal with work and energy. In the extreme, work is forced: prison labor forced to break rocks. Few of us knowingly wish to steer humanity in the direction of complete physical slavery, so the control mechanisms will be informational and economic. Information control in society is too amorphous, thus we restrict our analysis to economic. Prigogine[1] notes that Gibbs, in 1903, introduced the idea of a representative ensemble:

> *"we may imagine a great number of systems of the same nature, but differing in configurations and velocities which they have any given instant, differing not merely infinitesimally, but so as to embrace every conceivable combination of configuration and velocities."*

Gibbs had in mind molecular systems, but had he hoped to derive a formal theory of human systems, he couldn't have done much better. To apply control theory to human affairs one needs simplifying assumptions. We choose *work is money* or its equivalent, *money is energy*. Everyone can understand this, as money is simply work abstracted and can be used in place of an individual's work to accomplish goals. I can

build a house or I can pay money to have a house built, the result is the same, and this is true enough to justify the basis of our key assumption:

> *Money and energy are interchangeable.*

Most statistical physics and most control theory can be formulated in terms of energy, E, so we can measure E in terms of money, $\$$. In fact, as this essay was written a *Physical Review Letters* paper[2] appeared dealing with distribution and fluctuations—*including wealth distributions*—in order to formulate non-equilibrium thermodynamics for driven (steered) systems. But first we discuss the relevant theory of control.

Control Theory

Newton, ~1650, defined controlling force as $F = ma$. Maxwell, ~1875, developed the basic idea of control—*feedback*—and applied it to his invention of a *governor* for steam engines and, thermodynamically, to *Maxwell's demon*. A century later, control theory had evolved to a theory of 'optimal' control, whereby one steers the system not only to reach a goal, but to extremize some cost function, such as fuel expenditure.

> *Our 'cost function' will be individual freedom — we wish to maximize individual freedom while reaching our goal.*

Schultz and Melsa[3] presented control theory in the state function formalism developed by physicists. Despite the focus on *linear control systems*, the treatment of *stability* (via the state function and second method of Liapunov) "*can be directly extended to the analysis of nonlinear… systems.*" As mankind is nonlinear, this is appropriate. But how does "stability" enter the picture? They note:

> *" if we are to know anything about a system, we must first know that it is stable."*

Summarizing, they state:

> *"… the basic idea of feedback control: look at the desired output and use that knowledge to affect the desired control."*

Thus the fundamental question: What is *the desired output*? *What is the goal?*

Possible Goals

While it is always interesting to fantasize about the future, the future begins right now, and right now we are generally offered two choices. We will simplify and idealize these choices and attempt to analyze them from a thermodynamic perspective.

> *Stability* is requisite so we make it a basic goal. As the idea is to *conserve* the actual existence of the system (humanity) we call '*stability*' the *conservative* goal.
>
> But mere existence is not humanity's *only* goal. To "steer humanity's future" implies *progression*, so we will call '*equality*' the *progressive* goal[4].

Defining properties of the many body system—the measurement units, the goal, and the cost function—enables our analysis by formulating the description in terms of distributions over the system. Statistical mechanics typically *distributes energy* over particles; here energy, work, and money will be used interchangeably.

Statistical Distribution of Energy

The macroscopic theory of measureable thermodynamics was augmented by development of the microscopic theory of statistical mechanics. This assumes a system of N particles partitioned into categories with n_j particles in the j^{th} category having energy ε_j so that, if energy E and number of particles are conserved then constraints apply:

$$\sum_j n_j = N \quad \text{and} \quad \sum_j n_j \varepsilon_j = E \,. \tag{1}$$

It is easy to show that this leads to a normal distribution. Key to this is the ability to 're-arrange' the particles in the partitions, and to count the possible ways in which the rearrangements can occur. Those arrangements (microstates) that result in the same total system energy are maximized in the sense that they lead to the 'most probable' state of the system. *It doesn't matter which individual particles are in which partition* (that is, how much energy they have), after equilibrium is reached, interactions that exchange energy tend to *stabilize* the equilibrium (shape) of the distribution. *Thus the fact of socio-economic mobility is accommodated naturally*. Although thermodynamic variables are based on macrostate measurements, the "partition function" derived through microstate analysis can be used to derive the macrostate variables of thermodynamics. The most relevant macrostate variables are 'free energy' dE available to accomplish work, temperature T, entropy S and work W:

$$dE = T\,dS - dW \,. \tag{2}$$

Temperature and pressure are considered constant ($dT = dp = 0$); temperature is a measure of average energy, and dS is a measure of change in system order. When work dW is accomplished, the *free energy* decreases. If there is no free energy, $dE = 0$, no work can be accomplished (through economic forces). [See *Endnotes.*]

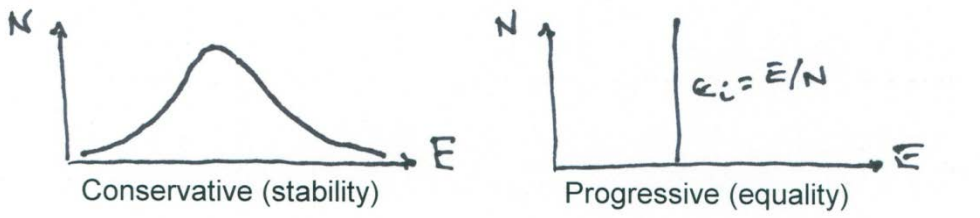
Sears[5], using a more general expression, $dE = dU - T\,dS - S\,dT + p\,dV + V\,dp$, notes that, in any infinitesimal process, the work done is equal to the decrease in the free energy of the system, while "the mechanical engineer is interested in reversibility and entropy … something has been "lost" when an irreversible process takes place in the steam engine or turbine." Sears states:

> *"What is lost, however is not energy but <u>opportunity</u> – the opportunity to convert internal energy to mechanical energy."*

With this very brief introduction to statistical mechanics and thermodynamics, we now return to the distribution policies that drive the system. We begin with the ideals:

The Ideals

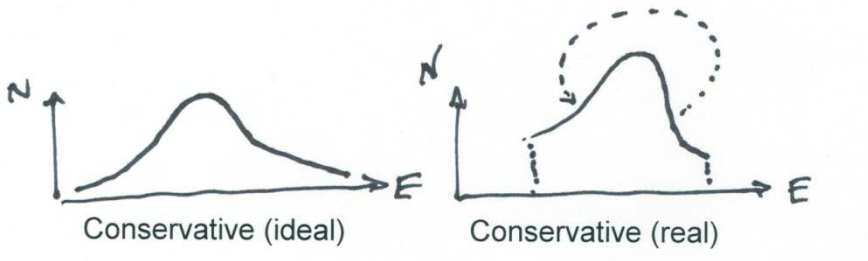
It's easy to state these ideals: The *stable* distribution is the *normal* or *Gaussian* distribution, in which deviations from equilibrium tend to restore the system to equilibrium. The *equal* distribution is even simpler: every human has the same energy/money. If we represent *energy per body* on the horizontal axis, and number of bodies with specific energy on the vertical axis, $n_i = n(\varepsilon_i)$, we find ideal distributions:



Physicists know that one distribution is natural, occurring almost everywhere in the natural world, while the other is almost impossible to find in nature. Such ideal distributions simplify the problem, but are not realistic, so we examine the problems with these ideal distributions, beginning with the conservative.

Concessions to Reality

The normal distribution ranges from zero to a maximum energy. At the low end, the available energy is insufficient to support life. This can be changed by establishing a *cut-off* in the normal curve via transfer payments. Taxation reshapes the distribution, truncating the high as well as the low end. An ideal conservative goal modified by humanitarian concerns complicates the analysis but does not inherently change the goal.

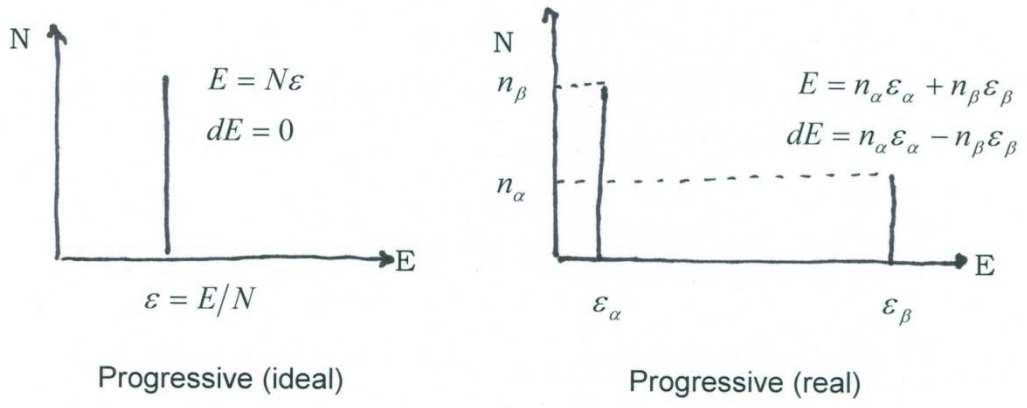


The establishment of a threshold changes bio-evolution to economic evolution. The human duty to care for one's family is natural; the decision to establish a poverty level or absolute threshold, below which no human should fall, marks the beginning of civilization. Call the artificial cutoff the *poverty level.* Once the marker is laid down, forces are brought into play whose goal is to move the marker, and, over time, as the bar keeps rising, most in poverty live better than did kings only a century or so ago[6]; many have flat screen TVs, *iPhones*, cars, housing, a fantastic range of entertainment[7].

So the simple goal of stability is modified from the natural Gaussian shape to a new more complex shape, reflecting the reality of humanitarian values. Next we find that the simple progressive ideal also comes up short against reality, and requires significant modification.

The progressive goal replaces *the normal distribution* with a *delta function* in the name of equality. But states where everyone is equal are not stable, or even possible, as most interactions are local, and many are 'nearest neighbor'. If no one controls more energy than anyone else, the free energy, used for accomplishing goals, vanishes. Since the goal of equality is to remove differences, this removes pressure, the thermodynamic force per area available to do work. As the difference between party i and party j equalizes, the energy difference $dE = |E_i - E_j| \to 0$. This is the free energy of the system, available to do work, providing the opportunity to accomplish goals. As it goes to zero, there is no 'difference of potential' that corresponds to force. [See *Endnotes*.]

So the *ideal* progressive goal is self-defeating. With no free energy the system becomes close to frozen. Even a fluctuation of local energy cannot move through the system in a preferred direction; it diffuses, hardly a control mechanism. How can this be made to work? The *realistic* goal recovers a non-zero free energy by the introduction of *two* classes—inherently *unequal*—an alpha class and a beta class.



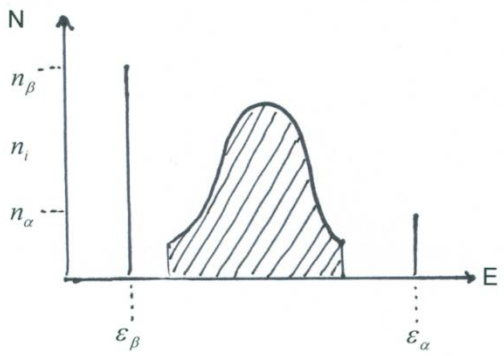
Now we have a *huge* free energy to do work with, which can be simply described as

$$dE = n_\alpha \varepsilon_\alpha - n_\beta \varepsilon_\beta \tag{3}$$

where n_j is the number of humans in class j and ε_j is the energy/wealth of each human in class j and where $n_\beta >> n_\alpha$ and $\varepsilon_\alpha >> \varepsilon_\beta$. In this workable scheme, *equality* is a smokescreen, since the progressive ideal, a state of "equality", is *impossible* according to this model. To allow free energy to work, the progressive reality must create an unequal two-class society, with vast numbers of serfs and a smaller number of elite lords: the governed and the governing.

If we overlay the truncated normal distribution on the two-state progressive system, the vast majority (all but the lords) appear better off in the natural system.

A conceptual overlay is shown:



Conservative overlaid on Progressive (not to scale)

What is not so clearly defined in the progressive goal is the mechanism for *enforcing equality*. If the system reaches its goal of $dE = 0$ at time $t = t_0$, are any intra-system exchanges of dollars allowed? Almost certainly yes. With no enforcement mechanism, after a few exchanges some will have more energy than others—so what was the point of *a moment of equality*, if citizens become once again unequal? Yet any enforcement mechanism capable of maintaining equality will be indistinguishable from slavery, requiring Berlin walls to keep slaves from escaping and internal passports to change position (from one city to another), thus reducing degrees of freedom. The *actual* goal, since the *ideal* is unattainable, becomes maximum control for alpha class, minimum freedom for beta class. Most discussion of competing goals gets lost in emotion, *ad hominism*, and irrelevant sidetracks—a reason to focus on *essential* aspects. For progressives, this is equality, for conservatives it is stability with maximum freedom.

> *The conservative goal is unequal in its essence*
>
> *The progressive goal is unstable in its essence*

It is impossible for 10^{10} humans to be 100% equal. Kurt Vonnegut (certainly no conservative) illustrated this in a short story *'Harrison Bergeron'* beginning[8].

> *"The year was 2081, and everybody was finally equal. They were not only equal before God and the law. They were equal in every way. Nobody was stronger or quicker than anybody else. All this equality was due… to the unceasing vigilance of agents of the United States Handicapper General."*
>
> *"… George and Hazel couldn't think about it very hard. Hazel had a perfectly average intelligence, which meant she couldn't think about anything except in short bursts. And George, while his intelligence was way above normal, had a little mental handicap radio in his ear he was required by law to wear at all times. It was tuned to a government transmitter. Every 20 seconds or so, the transmitter would send out some sharp noise to keep people like George from taking unfair advantage of their brains."*

Vonnegut illustrates well the absurdity of the idea that everyone can be made "equal".

A State of Fear

Vonnegut's vision of equality is scary. Recent polls [9,21] show that 72% feel the federal government is the greatest threat to the US future, while 37% actually fear the federal government. Communism is 'equality' based on fear and absolute force. Peter Gluck in his FQXi essay [10] observes from personal experience that "*the status of second class, oppressed citizen… in a communist dictatorship is an especially good school for learning about the non-ideality of the world and the sub-optimality of human existence.*"

The conservative ideal of stability *with maximum freedom* leads to normal distribution. The progressive ideal of equality leads to maximum freedom only for the state (law-makers who exclude themselves from the laws), with police required to enforce the unnatural state of "equality". For those who lack the history of the last century or can't imagine life in a master/slave state, I recommend *Child 44* by Tom Rob Smith[11].

Of course (in the US) we have neither ideal conservative nor progressive systems. But capitalism has skewed toward "crony capitalism", where tax monies are inordinately given to the organizations that most effectively buy off politicians, *both unions and corporations*. And government is structured such that one president and 100 senators accrue ever-expanding power—with citizens becoming relatively ever more powerless.

There is a big push for 'equality', but our thermodynamic analysis shows that equality of state is impossible. The question is whether the system is to be designed around a normal distribution of one class of citizens or a two-class system: master/slave. For most this is clear—for the alpha class, benefitting from their position, not so clear.

How should we steer the future of humanity? With local control.

Schultz and Melsa[3] early recognized that

> "*modern control theory dictates that these variables should <u>all</u> be fed back, after suitable weighting*."

They state: "*one of the basic aims of this book is to make the reader appreciate how and why all the system state variables should be fed back*." In economic terms, this implies that a centralized price-setting system, such as the Soviet's system to set fifty million prices, cannot compete with a system in which prices are set according to local supply and demand. The nature of centralized control is inefficiency: The huge dE shown in eq. (3) can get work done but the inefficiency is tremendous and the cost to the beta class almost unbearable—much of the Soviet citizen's day was spent waiting in line for goods, or even to pay. In the 80s, when travel restrictions loosened, Soviet visitors, seeing a Safeway food store for the first time, simply broke into tears. And a viral conservative email illustrates the inefficiency of our own overgrown government:

> During the three and a half years of World War II, starting with the Japanese bombing of Pearl Harbor in December 1941 and ending with the Surrender of Germany and Japan in 1945, the U.S. produced 22 aircraft carriers, 8 battle-ships, 48 cruisers, 349 destroyers, 420 destroyer escorts, 203 submarines, 34 million tons of merchant ships, 100,000 fighter aircraft, 98,000 bombers,

> 24,000 transport aircraft, 58,000 training aircraft, 93,000 tanks, 257,000 artillery pieces, 105,000 mortars, 3,000,000 machine guns, 2,500,000 trucks.
>
> We put 16.1 million men in uniform in the various armed services, invaded Africa, Sicily and Italy, won the battle for the Atlantic, planned and executed D-Day, marched across the Pacific and Europe, developed the atomic bomb and ultimately conquered Japan and Germany.
>
> It's worth noting, that during the almost exact same amount of time, the current US administration couldn't build a functioning web site.

Central planning creates scenarios like the recent 'Job Stimulus' where the average new job cost $400,000 (five to ten times the cost of real jobs.) Or where the majority of 'signups' under Obamacare were those who lost their existing plans. Is central control of one sixth of the economy the goal—with politicized IRS involved in a citizen's health, from cradle to grave? How do we decentralize inefficient government in favor of local control? Kirk notes[12] that *"classical control system design was/is generally a trial and error process in which various methods of analysis iteratively determine the design parameters of an 'acceptable system'".* John Hodge analyzes the problem beautifully in his 2014 FQXi essay [13]:

> *"Each social issue the federal government assumes is dealt with in the most expensive manner and in a trial-and-error manner… competition among the states to determine the best policy on any one issue is ignored [despite the fact that] trial-and-error is a problem-solving method for problems more complex than existing knowledge can predict. Increasing the number of trials decreases the time and expense needed to solve problems." [effectively parallel processing!]*

Based on *ubiquitous Internet connectivity*, many decentralizing options exist: *craigslist, Amazon, eBay,* … even privatized space efforts. Last week *Science* editorialized[14]:

> *"… private support is rising, a growing number of billionaires are investing in science ….[they] bring a refreshing new perspective to the projects they support, because they are typically not afraid to take risks, abhor bureaucracy, and nimbly cross disciplinary boundaries."*

almost the polar opposite of government supported science paid for by taxpayers. The problem is to design a system to replace the inefficient economic structure of government. We'll still need essential services (police, etc.), but there will be less reason to extract money in taxes to give to politicians to distribute to friends and supporters[15]. Or to create jobs at a cost up to 10 times the going rate, or pensions for public officials two to five times those of 'mere' citizens. So we should steer humanity's future away from a two-state centralized-control (control by the master class over the slave class) in favor of local distributed systems, attendant to local problems, with as efficient as possible a distribution scheme. It is good to recall that the Internet, as we know it, is only 20 years old, *iPad* less than a decade. Also significant are *PayPal, Bitcoin, E*TRADE, Amazon, eBay, MOOC*'s—key technology that *automates processing of money* allowing us to design a system to remove <u>much</u> of the control of money from the inefficient and corrupt processes of government. Sabine Hossenfelder [16] notes:

> *"The point here is not to manipulate people into changing their ways because I or you or some supercomputer thinks it would be better if we do more of this or that. The point is to help people make decisions. [But] the necessary information for individuals to learn… is too expensive. [And] we know how to solve these problems. We solve them by bringing close what is far away." [local feedback]*

Why not an educational fund to replace the welfare that pays people to do nothing? Base it on *paying people to learn*—replacing the current system, wherein one graduates with a degree and a debt equivalent to a mortgage on a modest home. Similarly, *unemployment benefits* should be replaced by the same educational fund. An effective program that rewarded learning would be an incredible improvement over a welfare system that often amounts to simply subsidizing a voting constituency. *Teach them to fish, don't feed them fish. Pay-to-learn courses* include any knowledge that improves society—classes on handling money, first aid, child care, or physics—with pay proportional to degree of difficulty. There will be cheaters, and scams, but how does this differ from the widespread fraud and abuse of welfare, disability, or other government largess today? Systems can be designed to minimize cheating.

An automated scheme for paying people to educate themselves has to be superior to paying people to secure their vote. Cost of government should fall as direct payments reach the people in need and pay for self-improvement. How do we design a complete system to replace an inefficient and impersonal government that has become the main problem. Obviously it won't be easy. It wasn't easy to design the money processing systems exhibited by *Amazon, eBay, E*trade* and others, or the game technology of "*The Room*" [17], or new educational schemes such as MOOCs[18]. But their existence proves that the technology and infrastructure needed are available, and they offer a possibility of better helping individuals than the transfer schemes based more on capturing a dependent voting bloc than on actually improving people's lives. I do not suggest government, conservative or progressive, can be made less corrupt in its nature. But new technology offers the possibility of automating some functions that involve government distribution of taxes, with the usual gains from disintermediation.

Summary:

When the natural order is characterized as "inequality", with the pretense that, when $dE = 0$ humanity will be equal, the focus is on achieving an impossible goal. Our statistical formulation makes clear that this 'feel good' term is misleading in the extreme. It is natural to argue over the optimal shape of distribution curves, but a thermodynamic framework should help us see the essential issues with clarity.

Further clouding the facts, there appears to be a psychological need in most people to believe in "something greater". For some this greater is *God*. For others, this greater is *The State*. This essentially religious aspect of the problem is not addressed in this essay, as it seems to be outside the bounds of rational solution. Any belief system may tend to subordinate rational facts to strongly held religious tenets. This essay is an attempt to lay out such facts clearly.

> Freedom requires choice, which is why equal opportunity represents freedom, and equal outcomes represent totalitarianism.

Endnotes:

Although our analysis is based in statistical mechanics, the concept of *free energy* derives from thermodynamics. The presentation follows Fermi's *Thermodynamics* [19].

Free Energy In purely mechanical conservative systems, energy is equal to the sum of the potential and kinetic energies, and hence is a function of the dynamical state of the system (i.e., the positions and velocities). If no external forces act, energy is constant, $U_A = U_B$, where A and B are successive states of an isolated system. With external forces, U_A need no longer be equal to U_B. If W is the work performed by the system during transformation from initial state A to final state B, then conservation of energy

$$\Delta U = U_B - U_A = -W\,, \tag{A1}$$

where $-W$ is the work performed by external forces during transformation, and W depends on end states and not on the path connecting them. In practice, only *differences* of energy are important in analyzing work. If no heat flows, $\Delta U + W = 0$, else we can define Q equal to the energy of heat that flows during the transformation

$$\Delta U + W = Q \qquad \textit{First Law of Thermodynamics} \tag{A2}$$

For cyclic systems, $W = Q$, i.e., the work performed during a cyclic transformation is equal to the heat absorbed by the system.

Entropy Next consider a system S that undergoes a cyclic transformation, such that during the cycle the system receives heat or surrenders heat to a set of sources having temperatures $T_1, T_2, ..., T_n$ and amounts of heat exchanged between the system and sources is $Q_1, Q_2, ..., Q_n$. It can be shown that

$$\sum_{i=1}^{n} \frac{Q_i}{T_i} \le 0 \tag{A3}$$

where equality holds for a reversible cycle. [*Energy/money can flow either way!*] If dQ is the infinitesimal amount of heat received by the system from a source of temperature T we have, over a complete cycle,

$$\oint \frac{dQ}{T} \le 0\,. \tag{A4}$$

This is the basis of *thermodynamic entropy*, S, a new function defined such that

$$S(B) - S(A) = \int_A^B \frac{dQ}{T} \qquad \text{where} \qquad dS = \frac{dQ}{T} \tag{A5}$$

such that entropy varies by amount dS when the system receives an amount of heat dQ at the temperature T ; the entropy of a multi-part system is very often the sum of the entropies. The *entropy is a measure of order in the system* and is related to information theory's entropy. If the temperature is constant, then

$$Q = \int_A^B dQ \quad \leq \quad T\{S(B) - S(A)\} \tag{A6}$$

which is an upper limit to the amount of heat which the system can receive from the environment. From (A2) we have $W = -\Delta U + Q$ and we define a function E, called the *free energy*,

$$E = U - TS \quad \text{such that} \quad dE = dU - TdS \tag{A7}$$

where

$$W \leq E(A) - E(B) = -\Delta E\,. \tag{A8}$$

For constant temperature systems, the work done by the system during the transformation is equal to the decrease in the free energy of the system. Consequences follow:

- "If the free energy is a minimum, the system is in a state of stable equilibrium; this is so because any transformation would produce an increase in the free energy [which contradicts the assumptions]."
- Thus the progressive state with huge free energy, $dE >> 0$, is unstable, while the ideal case of equality, in which $dE = 0$ cannot produce work.

Wealth Distribution The *natural distribution of energy* is Gaussian and self-restoring; exchanges of energy will maintain the shape of the distribution, hence it's *self-steering*. If a system ceases to be in equilibrium, we need non-equilibrium statistical mechanics, despite that there is no unified principle characterizing fluctuations. A *Phys Rev Lett* paper dealing with distributions[2], *including wealth distributions*, considering non-equilibrium thermodynamics for driven systems found gamma distributions which have been observed in the past in different contexts, states:

> *"– why the gammalike distributions arise in different contexts irrespective of different dynamical rules – still remains unanswered."*

I suggest the answer: The gamma function is the generalization of the factorial, the basis of the partition function—the fundamental entity from which the theory of statistical thermodynamics is derived. Robert Bruce Lindsey[20] presents the generalized Gaussian distribution formula, based on factorials, $n!$, and also introduces the gamma function:

$$\Gamma(n) = \int_0^\infty z^{n-1} e^{-z} dz \quad \text{where , for integers,} \quad \Gamma(n+1) = n! \quad \Rightarrow \quad n! = \int_0^\infty z^n e^{-z} dz \tag{A9}$$

We have argued that thermodynamic 'free energy' is the appropriate concept for analyzing wealth distribution policies for '*Steering the Future*' and therefore that statistical physics of distributions is relevant. A fact, that a generalized factorial applies "*in different contexts irrespective of different dynamical rules",* implies a range of application of such an approach and suggests that scientific analysis of distribution policies is valuable.

References *Note: All URL's verified on 18 April, 2014*

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