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Atwood's Machine Revisited

1 References

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B. 121117 NTF - Economics, MEP and MEPP R2.doc
C. 130609 5th BPE 7th USSEE Conference in Vermont
D. 150101 NTF Atwood's Machine R4.docx
E. 141222 XLS Atwood's Machine R4.xls
F. 141223 NTF Email exchange with Dr Hall
G. 150105 AM Shape Study R1.docx
H. 150105 AM Shape Study R1.xlsx
I. "Robert Costanza, "Maximum Power Principle", http://www.eoearth.org/view/article/154526/
J. Cockshott, Cottrell, Michaelson, Wright and Yakovenko, Classical Econophysics, Routledge Advances in Experimental and Computable Economics, Routledge, Taylor and Francis Group, London and New York, 2009.
K. 140124 PPR - Definition of EI with equations R12.docx
L. 130919 PPR - The Enveloping Curve R4.docx
M. 140930 PPT Atwood's Machine Revisited.pptx (contains my graphics)
N. 141230 NTF Entropy in an ABM R6.docx
O. 150109 NTF A Rethink of E and E R3.docx

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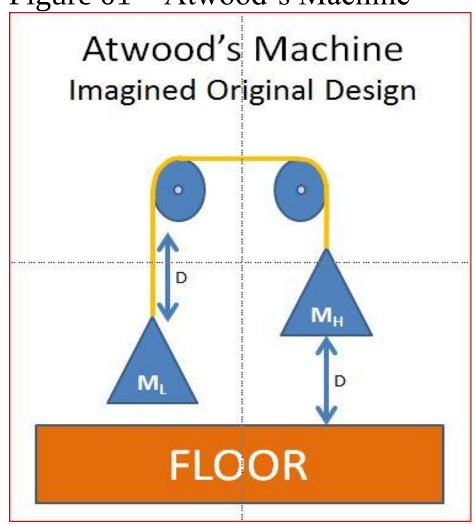
2 Background

First, I will clarify the timeline for the development of this line of inquiry:

- At Ref A I first noted the similarity between the distribution of wealth in the PMM of ModEco and the Maxwell distribution of speeds, and speculated about the existence and role of 'economic entropy' of a fashion.
- When I wrote Ref B I was beginning to speculate about the role of the MEPP in economic systems.
- When I attended Ref C I learned from Dr Hall's presentations more about Odum, and his work on the MPP, and began to speculate on a connection between the MEPP and the MPP.
- The next few notes have gone through several iterations as I try to understand the MPP, with the view that this will help me eventually to also understand the MEPP, the least-well-argued of the two proposed versions of the 4^{th} law. The first version of Ref D was written about 140907.

This is the third significant revision of this note trying to understand the gizmo called Atwood's Machine. (See Figure 01 to the right.) For short, in this NTF, I will call it the AM. In an email exchange with Dr C.A.S. Hall (Ref F) I sent him a previous version of this note asking for comment, and he responded with some very detailed comments. This NTF is being extensively rewritten to include and address his comments, and only includes the first half of that rewrite. The second half is yet to come.

Figure 01 – Atwood's Machine



3 Purpose

To understand Atwood's Machine (the AM) and its implications for the linkage between the MPP and the MEPP. To use Atwood's Machine as a means to better understand the phenomenon of self-organization of economic systems.

4 Background

It seems to me that there are two very similar "laws" proposed as the fourth law of thermodynamics: the Maximum Entropy Production Principle (MEPP) and the Maximum Power Principle (MPP). Neither of these has received wide acceptance. Both have explanatory use in understanding self-organization. Here are both laws *in my words*:

- MEPP – An open system (with respect to energy) can/will self-organize to achieve the maximum rate of entropy production possible.
- MPP – An open system (with respect to energy) can/will self-organize to achieve the maximum rate of energy expenditure possible.

In the above wording I have removed some nuanced wording to exaggerate the similarity between the two proposed laws. For example, I gloss over the following:

- The MPP is concerned with 'useful' energy expenditures, which occur when the AM is operating at 50% efficiency.
- The MEPP does not make it clear what entropy production is, or whether it is referring to instantaneous rate of production, average rate, or whether it is during approach to equilibrium or after arrival at some sort of stationary state.
- Neither does the MEPP refer to efficiency.
- In neither case is it clear to me when these laws can or will kick in. What is the trigger phenomenon?
- In neither case is it clear to me why these laws would do what they are purported to do.

The more nuanced wording does not help me much with these difficulties. So, rather than reading a lot of words I expect I will not understand, my goal here is to think it through for myself, translating what I read and hear into my own words.

So, there are some difficulties I must think through, more of which will become clear as I try to understand Dr Hall's comments on the first version of this file. On the positive side, I strongly believe that both proposed laws (1) are true in some fashion, (2) that they can be reconciled, and (3) together they can provide deeper insight into the phenomenon of self-organization of economic systems. I believe this all the more strongly now that I understand that those that Dr Hall refers to as Odumites believe that the MPP does exactly what I want to believe it does.

In the Ref D NTF (with its associated Ref E spreadsheet) I have explored the obvious physics of the AM, explored the hump-backed curve discovered by Odum and Pinkerton and mentioned by Costanza in Ref I which is the source of the 50% rule, and looked for a connection with my entropy-related E-curve (developed in Refs K and L). The two curves are similar, but not the same. E.g. Odum's curve is asymmetric, but my curve is symmetric.

In the Ref G NTF (with its associated Ref H spreadsheet) I have explored the asymmetry of Odum's hump-backed curve that was noted in Ref D. It's linear at the extreme left, and a power curve at the extreme right!

Ref M is the power point set of graphics used in this NTF.
Ref N is a note about entropy in the context of ABMs, my overall application for this stuff.
Ref O is a note written as an attempt to grapple with some of the issues raised by Dr Hall, returning to first principles as I know them. I felt I needed to rethink my understanding of the questions "What, exactly, is energy?" and "What, exactly, is entropy?"

Refs D and G are needed background reading to this NTF. In this NTF I want to explore the less-than-obvious physics of the AM, and the prepare for digging into the nature of the MPP.

5 Discussion

In an email from Dr Hall, at Ref F, in response to my request for comments, Dr Hall said:

> *"If I understand your question I do not think they (MPP and MEPPP) would be the same because Maximum power is about maximum rate of useful work (note useful) which is at an intermediate rate. Maximum generation of entropy would be I think* **at the maximum**

> **rate the process can occur** *but at that rate no useful work would occur - all the energy would go into heating the ground under the basket when it hits." (My bolding.)*

The phrase 'at the maximum rate the process can occur' is, it seems to me, the nub of the issue. But, one must ask, what constrains a process to half speed, or allows it to proceed at full speed? Is the constraint an important part of the issue? I am reminded of a sailboat tacking upwind. The phenomenon of 'tacking' seems to me to have similarities with the phenomenon of 'self-organization'. It is not intuitively obvious that an object can use the forces in the wind to move in a direction opposite to the direction of the wind. Neither is it intuitively obvious that a system can use the destructive processes of energy consumption and entropy production to self-organize.

To be precise, if the AM were to be allowed to produce entropy at a 'maximum rate' then M_L would be negligible in size, compared to M_H, efficiency would be zero, and no useful work would be done. **So, clearly, in the instance of the AM, a straight-forward interpretation of the MEPP is fundamentally and totally at odds with the MPP.**

So, I suppose I must look for a less-than-straight-forward interpretation of the MEPP, and possibly of both proposed laws, if I am to find a reconciled version.

As I study the AM I am impressed with how it puts a different perspective on several things, raising some very tricky questions as it does so. There are four inter-related concepts that I am trying to understand. It think the best order to address them is as below, so that start at a simple atomic level and work towards a more comprehensive understanding of how the AM might function in a larger open system:

A. Closed systems:
    a. Energy consumption in a closed AM;
    b. Entropy production in a closed AM;
B. Open systems:
    a. Entropy production in an open AM.
    b. Energy consumption in an open AM.

5.1 Re-thinking energy and entropy

I need, first, to clarify my understanding of the words energy and entropy. I have been changing my views on this slowly over the past two years or so. A number of other notes are relevant. Before tackling the rewrite of this note I had to pull them together in a summary note (at Ref O).

In summary of Ref O, we use metaphors for energy and entropy that are based on the similarity to physical substances. These metaphors include concepts of localization, flow from locality to locality, of quality or grade, and of transformation from type to type. Such metaphors capture many aspects of energy and entropy, but misrepresent others (such as the intensive nature of entropy, or the localization of potential energy). These metaphors are:

- eminently attractive because they translate very abstract ideas (set of accounting identities with partitioning rules, averaging formulae and conversion factors) into concrete terms that we understand from everyday experience (flows of liquids);
- extremely powerful because they have advanced our understanding of dynamic systems a very long way in the past 200 years; and

- somewhat misleading in the details, because they are masking things that I do not currently understand.

I strongly suspect that energy and entropy do not exist physically, but only as accounting principles. We see effects. We posit a flow of something, or a production of something. But nothing (no physical thing) exists other than the effects we observe. To be as blunt as possible, neither energy nor entropy exists, except as practical accounting tools in the minds of scientists and engineers. Neither is ever produced, nor does it flow or move about. For this reason, if I really want to understand the connection between the MPP and the MEPP I think I must always keep that in mind. [Having completed this note, and doubled back to revise and finalize it, I note that I have marked several instances of this where I am concerned as LOLM or LOAM. What I really need is a derivative concept of entropy that is extensive in character (vice intensive) and conserved. ???]

So, in the following discussion I will try to address the four concepts outlined above in respect of the AM, and implicitly addressing some of Dr Hall's comments on the previous draft. I have deferred the big questions about the MPP and MEPP to a next note, as this one is already pretty long.

5.2 Energy Consumption in a Closed AM

5.2.1 What is a 'Closed' AM?

I have some difficulty deciding what the AM would look like as a closed system.

When M_H hits the floor, energy is transformed into waste heat, or similar forms of unusable energy, in some kind of heat sink. A closed system would have to include that heat sink. And, there is no energy source except within the configuration of the AM itself before it starts to function.

Also, no real-world system is ever entirely closed, except for a finite universe-as-a-whole. Scientists speculate that the universe is finite in size, though the arguments are cloaked in mathematics that would cross your eyes, so I suppose there is at least one closed system. So, the issue is this: What can I exclude, and still consider what remains of the AM "closed enough"?

At Ref D I examine two versions of the AM as a closed system. In the first pass, I essentially view the floor as the heat sink, I use the expression 'mg' for force due to gravity, and run the AM as a two-mass machine. In the second pass, I add the Earth as a third body, assuming that the forces due to gravity are three-way forces according to the expression $G(m_1m_2)/r^2$. In that analysis I convinced myself of two things:

- The gravitational interaction of $M_L \Leftrightarrow M_H$ is not just small, but it cancels to exactly zero, whether large or small. So, only the $M_L \Leftrightarrow E$ and $M_H \Leftrightarrow E$ interactions are relevant.
- The variance of the gravitational forces due to the Earth on the two masses of the AM is very small as long as the distance fallen is small compared to the radius of the Earth. So, 'mg' is a reasonable approximation. I suppose this means that the potential energy differences are valid, as long as they are relatively small differences compared to the potentials associated with a fall all of the way to the centre. [Having completed the note, and doubled back for revisions as needed, I don't see this as an issue in anything I have done.]

5.2.2 How Does the Closed AM Work?

In short, I am reasonably convinced that it is safe to go with the first more simple analysis, based on the version of the AM in Figure 01, but keeping in mind that the Earth plays a massive role, and it does not appear in Figure 01.

This system has an endowment of energy at start, and as it is allowed to autonomously 'run' to a conclusion, some of that energy 'is consumed' and some entropy is 'produced'. This statement is using the language of the liquid metaphor (to which I will hereafter refer as the LOLM). Using the language of the accounting metaphor (to which I will hereafter refer as the LOAM) it looks a bit different. (I discuss metaphors in Ref O.) The initial endowment of energy in some of the sub-systems of the AM falls, and in some of the sub-systems it rises by an equivalent amount, but as degraded energy. At the same time, the entropy of the entire system rises.

So, where is the initial endowment of energy localized (i.e. what are the sub-systems) and what are the transformations?

First, where is it localized? Some of this may prove to be not relevant, but for the sake of completeness, I am trying to be meticulous:

- Some is in the $M_L \Leftrightarrow E$ gravitational sub-system, but it is initially inaccessible due to the upwards normal force of the floor counterbalancing the downwards force of gravity.
- Some is in the $M_H \Leftrightarrow E$ gravitational sub-system, and it is accessible due to the difference in height of the floor and M_H from the centre of the Earth.
- Some is in the heat sink(s) in the form of inaccessible heat – inaccessible in the sense that it cannot be used to run the AM backwards or forwards, and plays no role in the speed or functioning of the AM. I guess I have to posit two heat sinks: one that receives the kinetic energy of M_L at end, to wit, the air; and one that receives the kinetic energy of MH at end, to wit, the floor.
- Some is in the chemical potential energy (and associated kinetic energy) of the atoms in the string that couples the masses together. This is inaccessible and presumed to play no role in the operation of the AM.
- Some is in the two masses as heat that is consistent with the 'room temperature' T, which temperature the entire machine exhibits at start.

The only accessible endowment of energy, at start, is in the $M_H \Leftrightarrow E$ subsystem, and is equal to $M_{H\times}g_{\times}D$.

What are the transformations?

A digression: I say some of the energy is inaccessible because there are constraints on when and how energy can transform, and those constraints prevent those many possible sources of energy from participating. Now, that is a curious thought. The AM has only one degree of freedom, in the physical sense. In particular, the string connecting the two masses places a very peculiar constraint on the system that is a fundamental aspect of interest in the AM.

At end, the endowment of accessible energy in the $M_H \Leftrightarrow E$ subsystem has flowed (LOLM) to the $M_L \Leftrightarrow E$ subsystem and to the two sinks (air and floor). When M_H hit the floor all of its kinetic energy flowed into the floor as heat, and all of the kinetic energy of M_L transformed into vibrational energy in the string and the bobbing mass until it dissipated into the air as heat. For now, I prefer to consider the masses and string and pulleys to be unable to absorb heat. The air and the floor are the locations where the heat naturally went.

5.2.3 Three Closed Scenarios

5.2.3.1 Scenario 1 – $M_H <= M_L$

When M_H is released, and allowed to fall, the system does not move. The Newtonian forces on M_H, M_L and the mass assembly as a whole are all opposed by forces of equal magnitude and opposite direction, putting the machine is a state of dynamic equilibrium. M_L exerts no pressure on the floor. M_L and M_H are held in place by forces of tension in the string, which are exactly matched by the gravitational forces.

Such a state of 'dynamic equilibrium', or any kind of equilibrium, is worth thinking about, a bit. Energy is 'transforming', is flowing, is active in many ways, but it is not degrading, and no entropy is being produced. There is energy in the system by reason of rotational, vibrational and translational motions. Collisions and vibrations are indications that the energy is transforming from kinetic form to potential form and back at high rates, and possibly at irregular times. I believe that the law of equipartition of energy says that, for as many ways that the energy can be divided up, there will be equal amounts of energy allocated to each. This tells me that entropy will be maximized, within the constraints of the circumstances.

Until that equipartition of energy is reached, in those instances in which it applies, energy can still redistribute itself (LOLM), and entropy can still rise. But once equipartition is achieved, all energy fluxes must add to zero, and entropy cannot rise.

This kind of dynamic equilibrium exists in all parts of the AM in this scenario. In the next two scenarios, only one constraint is changed. An unopposed force comes into play, and the system is no longer in such dynamic equilibrium with respect to that one aspect of the system. A 'run' of the AM is the process whereby nature re-establishes that state of dynamic equilibrium.

5.2.3.2 Scenario 2 – $M_L < M_H <= 2 M_L$

When M_H is just ever-so-slightly greater than M_L, there is a small net gravitational force acting on the mass assembly. But I know from Equ 7 of Ref D that efficiency E = M_L / M_H. When M_H is slightly greater than M_L, efficiency is close to 1. As M_H climbs in size, efficiency drops as the reciprocal. When $M_H = 2M_L$ then E = ½ and the MPP is in full effect. But, as M_H rises, the 'power' of the AM, as defined by Odum, is rising.

When $M_H = 2M_L$ then exactly half of the original endowment of energy has flowed into the $M_L \Leftrightarrow E$ subsystem, and the other half has flowed into the two sinks.

When $M_H < 2M_L$ the amount of energy that has flowed into the $M_L \Leftrightarrow E$ subsystem is more than half of the original endowment in the system. The efficiency of this system, as defined by Odum, is then greater than ½.

5.2.3.3 Scenario 3 – 2 $M_L < M_H < \infty$

This is the part of the domain of M_H for which power, as defined by Odum, decreases, and not just efficiency, as M_H rises.

When the AM runs 'at the maximum rate' (to use Dr. Hall's phrase) the higher heavier mass (M_H) can be so large that the smaller mass (M_L) is negligible and effectively zero in size. M_H is, basically, just falling unconstrained under the force of gravity, as if there are no strings attached. All of the initial potential energy of M_H due to the $M_L \Leftrightarrow E$ interaction is transformed to kinetic energy of the mass assembly of (M_H+M_L). Just a fractional second before the end (when it strikes the floor), neglecting the effects of air friction, friction on the pulley, or elasticity of the string, all of the energy is now kinetic energy in/of the mass M_H due to its downward velocity, a velocity computed as the average velocity of all atoms and molecules within it. Just a fractional second after it strikes the floor, all of that kinetic energy is now transformed into a variety of types of energy including: sonic compression waves in the air, the floor, and within the mass; vibrational, rotational and translational energies of atoms and molecules. To keep it simple, I will presume, without loss of generality, that this waste energy all goes into the floor and the air, and not the masses, the pulleys or string.

This is what I have dubbed, in Ref O, incoherent kinetic energy. These are all forms of energy that are quickly converting between kinetic and potential energy, but at a dramatically faster rate than previously, and with no common direction for associated kinetic movement, and an average momentum of zero. It is 'waste' because I do not know how this heat can be captured and used to do 'useful work'. There is also some small amount of energy, possibly infinitesimally small, that is converted to chemical potential energy of a more stable and permanent nature in the form of chemical changes in molecules, broken bonds, new bonds. All of this energy is lost, or wasted, or degraded, or consumed, never to be useful again, ever, in the history of the universe. Wow!

It seems like:

- highly non-localized gravitational potential energy stored in the distances between atoms within M_H and atoms within the Earth;
- is transformed (as M_H falls) slowly and methodically into very coherent kinetic energy;
- which is then transformed (as M_H smacks down) quickly and randomly into very incoherent but highly localized kinetic energy; which
- then quickly reverberates or cycles between kinetic and potential forms of various kinds as ions re-arrange, as atoms vibrate or erratically bounce off of each other, and as compression waves expand or heat diffuses.

Where, exactly, does the energy come from, and where does it go to? The gravitational potential energy comes from the distance between the Earth and M_H. $F=G(M_H+M_E)/r^2$ where M_E = mass of the Earth. There are scales of negligibility, since $M_E >> M_H >> M_L$ in this instance. As M_H falls towards the Earth and gains kinetic energy, we know, due to Newton's second law, that the Earth also falls towards M_H and gains kinetic energy. When M_H smacks down both the gained coherent kinetic energy of M_H and of the Earth are converted to incoherent kinetic energy, in the sense defined above. But, that incoherent kinetic energy is highly localized, now, at the precise spot where M_H smacked down. It is "lost" from the perspective of the AM, but not entirely "lost", yet, to the biosphere, as represented by the heat sink, the floor.

Suppose I allow the floor and the air to be in open contact with the biosphere. We now have a hot spot, a little puddle or clump of heated or abnormally energized matter, and that energy has the ability to and necessity of dispersing, driven by the (as I imagine them) motive forces that make all puddles of heat disperse. The heat conducts, convects and radiates outwards. The sound waves carry energy at high speed to great distances and deposit it as smaller puddles of heat elsewhere, and the process takes up again. Eventually, along the road to heat death of the universe, all of this incoherent random energy may be emitted as infra-red photons and radiate into space to become part of the microwave background radiation that has no ability to change anything, and is truly "lost".

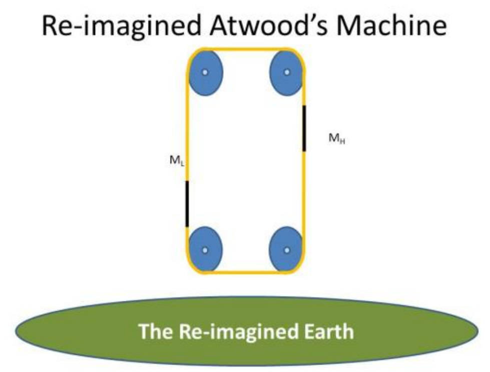
But, that's jumping ahead to an open system consideration.

To be precise, back to the real world, the AM is part of a closed system only if we consider the universe as the enclosing closed super-system. Hmmm! I don't see the difference between this and an open system. But, perhaps I can re-imagine the AM in such a way that it is truly a closed system.

5.2.4 The Reimagined AM as a Closed System

I can imagine a re-imagined version of the AM in which M_H and M_L are on a closed loop of string on a set of 4 pulleys. (See Figure 02.) I'll call this machine the Re-imagined AM, or RAM, for short. In the RAM the string is infinitely flexible, inelastic, and weightless except for the blue sections which have a mass of M_H and M_L as shown. The pulleys are, again weightless and frictionless. M_H is, again, heavier than M_L, and, at start, higher than M_L.

Figure 02 – The RAM



To make it truly closed I also have to imagine a universe in which the machine sits on the Earth and there are no other heavenly bodies. The Earth is subject to no tectonic or tidal forces, has no atmosphere, and radiates away no energy of any kind. This imaginary super-system is truly closed.

In the RAM, there is no need of consideration of the floor or the air as heat sinks. M_H never smacks down to the floor. M_L never bobs about causing reverberations in the string. Before a run begins, the RAM has the same net endowment of accessible energy as the AM considered above.

When this version of the AM is started, M_H no longer crashes into the floor converting its kinetic energy into waste heat, but, rather, it coasts along the bottom for a while, and then climbs up the other side, and its kinetic energy is re-transformed back to gravitational potential energy again. At the same time, the re-imagined earth bobs briefly and ever so infinitesimally towards the AM like a gigantic yoyo, then bobs away again. Situational potential energy transforms to localized coherent kinetic energy (of the mass assembly within the AM as well as a wee smidgen associated with the bobbing Earth) and back to situational potential energy. The change in kinetic energy of the Earth is extremely small and usually ignored in such discussions, but I want to not discard it here.

The RAM is clearly totally fictional, and could not be demonstrated in a lab, as can the AM, but it serves to clarify what is happening in the AM. The highly idealized RAM, being subject to no friction at all, is a perpetual motion machine in which gravitational potential energy and kinetic energy are transformed one to the other and back again in a slow never-ending cycle. This is exactly the kind of transformation of energy you might imagine in an idealized two-body solar system. All energy transformation here is reversible. No energy is ‘consumed’ or degraded or wasted or lost in any way. All energy remains as ‘useful’ at any stage in the cycle as it is at any other stage of the cycle. I would speculate that no entropy is ‘produced’ at any time. The entropy (S) of the RAM is constant. The grade of the energy (G) in the RAM is constant. There is a connection between G and S. I speculate that $G \propto S$, and in other circumstances I define $G \equiv (1 - S / S_{max})$ which implies $\Delta G = -\Delta S/S_{max}$.

But, if I allow for heating due to deformation of the string, vibrations in the string, or friction of the pulleys, or if I allow the Earth to be subject to internal fluctuations of any kind, then the imaginary RAM would run down as energy is degraded and flows to a sink, and as entropy is produced.

About the RAM, Dr Hall says:

> *“Yes, the machine would run forever, just like a frictionless Ferris wheel. But the problem is, I think, IF you want to do any work with it you have to slow the machine down, starting a whole train of events that uses up that energy. So the energy is lost ...”*

Got it!

5.2.5 Dynamic Equilibrium?

Here’s a question about the RAM. Is it in dynamic equilibrium?

According to that fount of all wisdom, Wikipedia, dynamic equilibrium is defined as:

> A dynamic equilibrium exists once a reversible reaction ceases to change its ratio of reactants/products, but substances move between the chemicals at an equal rate, meaning there is no net change. It is a particular example of a system in a steady state.
>
> http://en.wikipedia.org/wiki/Dynamic_equilibrium

A reversible reaction is not the same as a reversible physical change. Is it? It’s talking about rates of atoms changing from state to state, which is part of what I am looking for. But, it is similar to the RAM. I would like to say that the RAM, once in motion, is in a state of dynamic equilibrium of some kind. Perhaps the notion of ‘dynamic equilibrium’ I am looking for is a little too ideal and Platonic. It will cycle through all of its possible states, forever, as the mass assembly cycles through its trajectory, and all other vibrating atoms and molecules each cycle through their trajectories?!? Hmmm? I think it is in dynamic equilibrium.

5.2.6 The Path of Degradation

Here's a thought: Is the path to degraded energy always:

- from a state of highly non-localized potential energy transforming slowly and methodically to highly coherent kinetic energy, and back again;
- to a state of more localized sub-systems of potential and kinetic energy cycling at middling speeds;
- ultimately to a state of tiny highly localized sub-systems of potential/kinetic energy cycling at relatively high speeds.

I don't think that idea is totally correct, but it is an interesting thought.

5.2.7 The Constrained AM

So – let me get back to the AM. I need to go back and re-think these two heat sinks. I discuss these two heat sinks with some care and some worry. I don't want to make carelessly reductionist assumptions, but, rather, careful assumptions. Since the second law of thermodynamics implies that universal entropy always rises, the heat sinks for a closed AM cannot be the classic heat sink, at equilibrium with all parts of itself at all times. The usual trick is to assume that changes in the system happen so slowly that the heat sink is always at equilibrium with itself. The entropy in such a sink would never rise, so including such a heat sink in a closed AM requires that the entropy in the AM would never rise either. Besides, a smack-down of M_H is fast, so that assumption of slow change is not acceptable. Instead, the heat sink must be one for which:

- When perturbed, it goes into a slowly changing state of equilibration;
- The thermodynamic equilibrium of the heat sink can be perturbed (dis-equilibrated) in the locality of the associated mass, (the air for M_L, the floor for M_H), causing a temporary increase in the rate of evolution towards equilibrium;
- It takes a finite time for thermodynamic equilibrium to be re-established in the heat sink;
- The entropy of the sink rises as its equilibrium is being re-established.

I need to return to the idea of the AM running at maximal rate. M_L is so small as to be essentially non-existent. I could say that the AM is now 'unconstrained' as the link, the constraint, with M_L is of no effect. But, it is still constrained by the laws of kinematics. So, it is really only unconstrained in the sense that it is not coupled to another sub-system. Newton's laws of motion are a set of inescapable constraints.

What is it, exactly, that is happening as I make the size of M_H a bit smaller and the size of M_L a bit larger so that M_L is no longer negligible in size, by comparison. I can call this a more constrained AM. When the AM is constrained to run at less than maximal rate, it is different from running at the maximal rate. How is it constrained? It's internal sub-systems are coupled in such a way that part of the original endowment of high-grade energy is not degraded, and is reserved for later. The lower lighter mass (M_L), which has increased to a non-negligible size, is raised, and the reserved high-grade energy stored therein.

5.3 Entropy Production in a Closed AM

As per Ref O, entropy is never ‘produced’, but, rather, it rises.

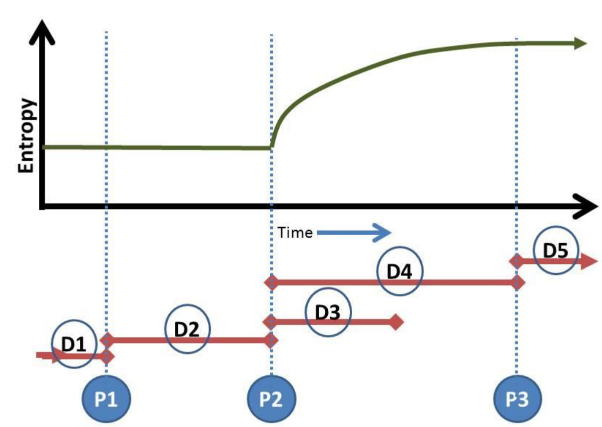
In general, the second law of thermodynamics says (my words) that a closed system will reconfigure itself until it reaches a steady state, after which time it will remain in that steady state forever, or, until such time as it is opened to interactions with another (probably containing) system. It also says that the entropy of this closed system will rise asymptotically towards an upper limiting value as the system approaches a steady state, and then the entropy will remain at or near that limiting value as the system remains at steady state.

Although I have studied a wide variety of formulae, including that of Clausius, for entropy, I am unsure how, exactly, to calculate the entropy of the AM. It involves $\Delta S=-\Delta Q/T$, and I have found many examples that address one part of a system, but how you combine it for different sub-systems of different temperatures beats me. I haven’t been able to find a single worked example of a calculation of entropy for a closed system not at equilibrium. They must be out there!

So, let me surmise what happens in this closed system. For scenario 1, no entropy is produced. For scenarios 2 and 3, I think there are eight kinds of change in the system from before a run to after a run. I can separate these into durations (D) and points in time (P), as follows (See Figure 03.):

- D1 – Prior to the run the AM is in a steady state. Mass MH is held in place and not allowed to fall. This state exists for a duration of time;
- P1 – The perturbation happens, the mass M_H is released, in some fashion, and when that constraint is removed from the system, the mass assembly starts to move. This is a point-in-time event;
- D2 – The mass assembly accelerates as M_H falls ever more quickly towards the floor and M_L rises accordingly. This is a process that takes a finite duration of time;
- P2 – M_H smacks into the floor, and a hot spot is created in the floor at the point of contact. M_L stops accelerating upwards at the same time. This is a point-in-time event;
- D3 – M_L follows a kinematic trajectory upwards briefly, then falls, then bounces as the string catches it, causing, M_H, perhaps, to jostle as well, and causing the string to vibrate. For simplicity, I will assume that M_H is not jostled, and all of the kinetic energy of M_L is spent in the vicinity of its final resting place. This is a process which takes a finite amount of time;

Figure 03 – Change time line



- D4 – Starting at the same time that change #4 starts, hot spots appear in both of the heat sinks, and that heat dissipates until equilibrium is reached again within in each sink. The hot spot in the floor appears immediately, and the hot spot in the air appears over time, as the energy of change D3 is transmitted to the sink. These processes take a finite amount of time;
- D5 – Eventually, the sinks each reach their own equilibrium, and the AM is completely in a steady state once more.

What I have learned from consideration of the RAM is that entropy does not change during D1 and D2. But a constraint of some kind is removed at P1 that sets the entire process in motion. I can posit a hold/release mechanism. Then, something really dramatic happens at P2 which removes a significant constraint on the system, but it is a qualitatively different constraint than was removed at P1. The 'something' dramatic is the creation of hot spots in the sinks. These perturb the equilibrium in the sinks, and then the system is free to reconfigure itself so as to maximize entropy within the new constraints.

D2 is a reversible process, as the RAM shows. D3 and D4 are non-reversible processes.

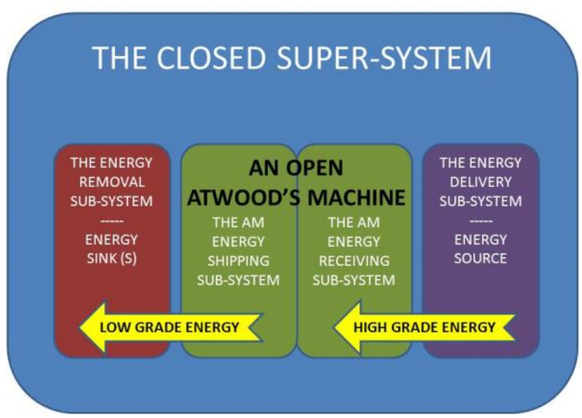
The system as a whole is closed, so no energy enters or leaves the system. But, some energy does do work, and does degrade, starting immediately after P2. Prior to P2 I cannot really say that any work is done. There is the appearance of work as M_L is raised, but it is counter-balanced by negative work as M_H falls. This counterbalancing happens because of the peculiar coupling between M_L and M_H. [I seriously struggle with the idea that things can accelerate when I must consider that no work is done. I think this is a matter of the failure of the LOLM. I must return to this issue in the next follow-on note.]

5.4 Entropy Production in an Open AM

For ease of reference, I am going to refer to an AM that is open with respect to energy as an OAM.

Perhaps surprisingly, I find it easier to imagine how entropy production would work in an OAM that has a constant flow of energy through it, than imagining how energy consumption would work. I do understand that this is a bit of a flight of fancy, but I think it is a reasonable way to view the system, and characteristic the system. So, in this section I take what I worked out in the previous two sections for closed AMs, and try to imagine how an OAM would function. I do this for two reasons:

Figure 04 – Open AM in its super-system



1. My analyses at Refs D and G are both about a closed version of the AM. The MPP is about the behaviour of open systems, so, if the AM is going to give me insight into the MPP, I need to think about one of the following:

a. an OAM that is primed (loaded with high-grade energy) and discharged (emptied of waste energy) in a serial loop; or
b. a large array of OAMs which can be primed and discharged, perhaps in synchrony, perhaps asynchronously, but for which the priming and discharge events are separated in time. Such an array would act like an energy storage tank, like a capacitor, safeguarding energy until it is needed.

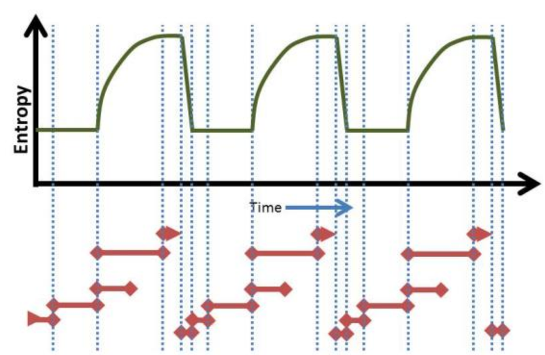
2. There are no closed systems in reality, so, to be applicable, the AM needs to be understood in terms of an open system.

5.4.1 Sub-systems of an Open AM

What would an open Atwood's Machine look like? It must have a flow of energy through it. On average, the energy flowing in must equal the energy flowing out, for some 'long enough' duration of time. The law of conservation of energy requires this. (LOLM).

I need to restate that in LOAM (accounting metaphors) instead of LOLM (liquid metaphors). That's tricky. Maybe I need to divide the closed super-system, of which the OAM is an open sub-system, maybe I need to divide it into the delivery sub-system (the energy source) and the removal sub-system (the energy sink). Then I need to divide the AM into two subsystems: the receiving sub-system and the shipping sub-system. This would look like Figure 04.

Figure 05 – Imagined entropy production cycles within an open AM.



On average, over time, the drop in energy in the energy source must equal the rise in energy in the energy sink. But there is an even tighter constraint – the net changes in energy across all four sub-systems must always be zero, both on average, and on a moment-by-moment basis.

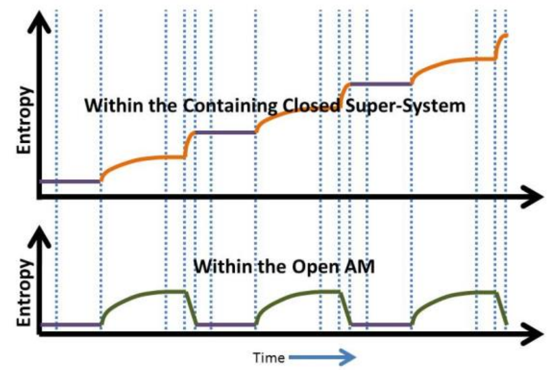
5.4.2 Serial Cycles of Entropy Production

The role of the energy source would be to change the OAM from its D5 state (in Figure 03) to its D1 state, and then release it. This would just require the addition of two extra types of duration change that we might call the D6 and D0 processes that removes the waste heat, and that primes the OAM with energy. As part of the priming action, there is also a point-in-time event P0, at which time the primed mass is held in place, for later release. Imagine Figure 03 redrawn with D0 and P0 on the left, and D6 on the right.

Then, the OAM would go through a cycle of priming steps and discharge steps one after another as the energy flows through it. This is getting fanciful, but the entropy level within the AM as cycle follows cycle might look like Figure 05. Assuming that the energy input (D0) happens during at the same time as the energy removal (D6) the contained energy in the AM would not change, being constant. If these are serial, then there would be an energy dip, a long or short pause, and an energy rise again. So, then, we have an entropy production engine in which the relative sizes of the masses determines the efficiency and power, as defined by Odum, and the total energy is constant or wobbles between two values.

But, what happens in the super system when the 'priming' is happening? No doubt, it requires high-grade energy to prime an OAM, not just for the energy to be placed therein, but also to do the work of placing that energy there. So, I would guess that, during the D6/D0 steps (the discharge and priming steps) of the operation of the OAM, while the entropy of the OAM is falling back to some ground level, (denoted by the flat purple intervals in Figure 06, bottom graph), the entropy in the containing closed super-system is rising. Why? Because it takes work to prime an OAM, and when work is done, waste heat is generated. I need to be careful here. Figure 06 assumes that entropy inside the AM and external to the AM are additive, which assumes entropy is extensive, and it is not. So I cannot be certain that Figure 06 is entirely correct. But, I think the general concept is correct. Entropy of the enclosing super-system rises both when the AM is primed, and when it discharges.

Figure 06 – Imagined entropy production cycles inside and outside of the open AM.



5.5 Energy Consumption in an Open AM

So, now, I get to the tricky part. What would energy consumption look like in an OAM functioning in the milieu of a larger enclosing super-system. This is the sort of milieu in which the MPP would be operative. So, before I think too hard about the MPP I should, it seems, think about OAMs in such a milieu – in such an environment.

5.5.1 Arrays of OAMs as Temporal Storage

I don't see the regular serial reuse of open OAMs (i.e. a constant duration of time from priming to discharge) to be the real answer to the issues around the MPP. The diagrams in Figures 05 and 06 might represent, I suppose, the serial actions of a single OAM such as a molecule of chlorophyll. But that view does not link it sufficiently into the larger milieu to be explicative of anything.

So, until now I imagined the D6/D0 actions to be coincident in time. That doesn't work. I see that now. These need to be separate steps, but I don't want to revise my Figures 05 and 06 for now. (TODO: Xxx) What I do see coming out of the above thoughts is the OAM as a storage device that is charged with high-grade energy at some point, and then, from which a fraction of that high-grade energy can be released for later 'useful' consumption. So, instead of regular clockwork-like priming and discharging, I would see priming occurring when high-grade energy is available, and discharging occurring when the stored high-grade energy is needed. Then an OAM can be viewed as a high-grade energy storage and transport device.

As such, a containing super-system might organize to have a number of OAMs (e.g. chlorophyll molecules) hanging around, just in case a high-grade energy source becomes available (say, a Sunny day). It would use them to charge a bunch of other OAMs and store them, and then bring them out of storage later, as needs determine. In Figure 06, the flat purple bars represent step D1, in which the OAM is primed, but not yet released. The duration of that purple bar can be short (milliseconds) or long (years).

Now, of course, this is all just my imagination running **WILD**, but, if this is the way OAMs actually work, it offers a lot of explanatory power, I think. How would you 'prime' an OAM with high-grade energy? I would use another OAM with even more high-grade energy. And, where would I find an OAM with loads of high-grade energy. I would look to sugars, starches, alcohols, fats, and oils. And, how would I prime those OAMs? With photosynthesis.

I imagine a suite of little OAMs priming a chlorophyll molecule by attracting and putting in place some CO_2 and some H_2O. Then, during a purple pause (a la Figure 06 purple bars), I would wait for an appropriate photon of light with sufficient high-grade energy to smack the package and produce a sugar molecule. That can be stored, as an OAM having a purple pause, and later 'used' to prime a smaller OAM that has a 'use' – possibly, say, an ATP molecule. And that OAM can be used to prime a smaller OAM, say, a cellular organ of some kind. Etc. Now, I know I'm way out of my depth here, but the idea seems workable to me, even if I have the biology and organic chemistry wrong. It's like a dose of energy cascades (LOLM) through a series of OAMs. How would that work?

5.5.2 How Do I Link Them?

Now I get to the really tricky part. If I were to draw a diagram similar to Figure 03 for the OAM, it would look the same but with the addition of a falling line for the D0 step when the OAM is being primed. But, it bothers me that, if I look at the diagram in Figure 03, I cannot tell by looking at it whether it is a high-efficiency AM, or an extremely low-efficiency AM. The diagrams for both would be the same. Just simply hooking a bunch of them together into a linked chain of AMs would not give me any additional insight, which is what I need.

All of the energy coming out of an OAM and going into an energy sink will be low-grade energy in the form of waste heat. The difference between an efficient, or an inefficient, OAM is all inside. Let me think through three examples:

- The broken uncoupled OAM example.
- The zero efficiency example.
- The 50% efficiency example.

Suppose that I view the OAM as two coupled subsystems: a left-hand subsystem and right-hand subsystem that are coupled by the string. Let me call them the LH-OAM and the RH-OAM. I am unsure that I can do this, that it has meaning, because the linkage between the two masses makes these systems closely coupled, and they can hardly be considered separate sub-systems. But, understanding that its not a perfect representation, it still helps me to keep the parts well-ordered in my mind. So, the LH-OAM consists of the mass M_L, the heat sink that receives the kinetic energy of M_L internally to the OAM, the string (the coupling with the RH-OAM), and the priming mechanism that acts on M_L, and the release mechanism that allows M_L to rise at the end of a purple pause. The RH-OAM consists of the mass M_H, the heat sink that receives the kinetic energy of M_H internally to the OAM, and the string (the coupling with the LH-OAM). I think its arbitrary where I put the priming mechanism and the release mechanism since the masses are coupled, and they can be primed and released from either side. For now I have placed them in the LH-OAM, without intending any loss of generality.

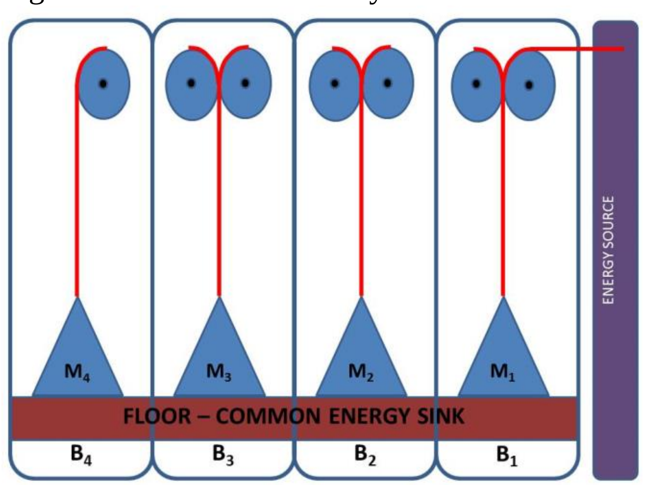
The broken uncoupled OAM example – Suppose that the string is cut, and, for the nonce, each side has a priming and release mechanism. Then, on priming the OAM, both masses would be raised. On release, both would crash to the ground. On release, all of the internal gravitational potential energy would be converted to coherent kinetic energy, then all would be converted to a mix of incoherent kinetic energy, and chemical potential energy, all reverberating at various but fast frequencies. Unlike a normal OAM, no high-grade energy could continue to be stored in the broken OAM. Such a device could still be used for storage and release of high-grade energy. It has a priming mechanism. It has a release mechanism. Such a device could be primed, stored for a long purple pause, then brought out and released as needed. The question in my mind, then, is why does nature seem to prefer unbroken OAMs? Assuming that it does. Are all energy storage devices merely synonymous with such broken OAMs?

The zero efficiency example –Suppose that $M_H >> M_L$. $E = M_L / M_H \cong 0$. Then, within each cycle, at the D0 step, the AM is primed with an endowment of $M_H gD$ Joules of high-grade gravitational potential energy. And, within each cycle, at the point of the M_H smack down, all of that energy is converted to waste heat. At the next D6/D0 step it is expelled into the heat sink, all $M_H gD$ Joules of it, even as the OAM is being re-primed. In this case, all of the action is in the RH-OAM, and the OAM is not functioning as an OAM in any respect. It is just consuming and degrading energy at 100% of flow through. This is not fundamentally different from the broken uncoupled OAM in the previous example.

The 50% efficiency example – Now, $M_H = 2M_L$. In step D0 the LH-OAM is primed with an endowment of high-grade energy as M_L is pulled down to the floor. At the same time, due to the coupling of the string, the RH-OAM is also primed (moved to start position). The total energy input into the OAM is $M_D gD$ where M_D is (M_H-M_L).

So, this is the example that I really want to understand. Actually, any example where ¼ < E < ¾ is of interest, as this is the region of the hump-backed curve where the MPP operates, but E = ½ will do as the test case. I need to understand how an energy cascade, such as is implied in my discussion of OAM priming another OAM, etc. It's time to think about how such a cascade might work.

Figure 07 – A Linkable Array of OAMs.



5.5.3 A Linkable OAM Array and Energy Cascade

Suppose I have four half OAMs (labelled B_i; 1 <= i <= 4) lined up in a row, numbered from B_1 to B_4, from right to left. Each contains one mass (labelled M_i), a hold/release mechanism, one or two pulleys, and one or two strings, as shown in Figure 06. If I connect one of the middle half OAMs to its neighbor on the left, it becomes an RH-OAM, but if I connect it to the half OAM on the right, it becomes a LH-OAM. [This is certainly not realistic, as it would be really difficult to build this, and operate it. But, as a thought experiment, it's going in the right direction.] Suppose I want to imagine a linkable array of OAMs with common efficiency E = M_L/M_H. Rearranging that equation I get $M_L = EM_H$. If E = ½ and M_1 = 8, then M_2 = 4, M_3 = 2 and M_4 = 1; WLOG. I could have varying E along the chain, but, for simplicity I'll assume constant E along the chain. I guess my real point is, there are combinations of mass that would not work, or that would be less efficient or less effective. The half OAMs are all uncoupled except for the one at the far right, which is semi-coupled to the energy source. I had to move the energy source to be positioned on the right, or I would have had to use a mirror image of the OAM here, and I didn't want to do that. I have also merged the two sinks per OAM into a single common energy sink for the whole array. I probably could have done that before, but I am not 100% sure it made sense before. Is there any reason why this would be a bad idea now? I don't think so.

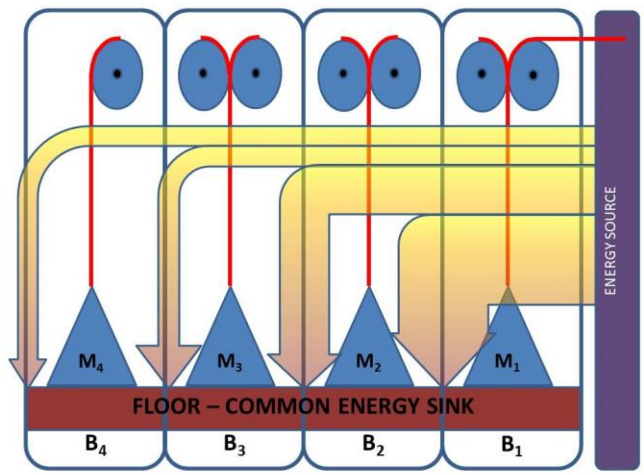
In the following I try to refer each action to the 'D' durations and 'P' events identified in Figure 03 and following text. This four-sub-system linkable OAM array would function like this:

1. D0 – High-grade energy is pumped into B_1 as M_1 is raised a distance D off the floor.
2. P0 – M_1 is fixed in place using the hold/release mechanism of B_1. A purple pause ensues.
3. New – The coupling is removed from the B_1-Source sub-system pair.
4. New – The coupling is placed on the B_1-B_2 sub-system pair, and they become an OAM. B_1 is the RH-OAM, and B_2 is the LH-OAM.
5. P1 – M_1 is released using the hold/release mechanism. The purple pause comes to an end.
6. D1 – M_1 falls as M_2 is raised.
7. P2 – M_1 smacks down, and M_2 stops accelerating upwards.
8. D3 – M_2 bobs about until its kinetic energy is dissipated entirely into the heat sink.
9. D4 – The hot spots in the heat sink dissipate over time until a new equilibrium is achieved in the heat sink.
10. P0 – M_2 is fixed in place using the hold/release mechanism of B_2. A purple pause ensues. This is the same as step 2, but shifted over one sub-system to the left.
11. Repeat steps 3 through 10, but making these five replacements:
    a. Source becomes B_1
    b. B_1 becomes B_2
    c. B_2 becomes B_3
    d. M_1 becomes M_2
    e. M_2 becomes M_3
12. Repeat steps 3 through 10 again, but this time the B_3-B_4 sub-system pair form the OAM.
13. I now sit with M_4 fixed in a raised position. Uncouple B_4 from B_3. B_4 cannot be coupled with the environment, in this diagram, and so is a simple energy consumption engine with no ability to store 'useful' energy in a following sub-system. All of its energy flow goes directly into the common sink as it is released and falls unconstrained to the floor.

At each major operation of one of the temporarily coupled OAMs, there is a preservation of the grade of a portion of the energy flow, and there is a degradation of a portion that is transformed into waste heat and dumped in the common energy sink. The amount that is degraded at each step is determined by the efficiency E of the particular OAM operating at the time, where $E = M_i / M_{i+1}$.

In Figure 08, when B1 and B2 are coupled, supposing E = ½, then ½ of the energy is degraded and dissipated as that OAM runs, transferring energy from B1 to B2. When B2 and B3 are coupled, another half of the energy is degraded and dissipated. When the uncoupled B4 operates, all of its energy is degraded and dissipated. I note that this does not show the energy degraded when B1 is primed in the first place. I don't know how much that is, and it is probably a random amount that depends on the priming mechanism. One could posit yet-another-half-OAM, but, where would the chain stop? I would speculate that it stops when you get to the boundary of the self-organizing-system in which this linkable array of half OAMs exists.

Figure 08 – Energy Flows.



So, I think, when E = ½ for all steps and stages in the transfer of energy through this linkable array, that is the ideal energy consumption profile for all of those self-organizing systems that are under the control of the MPP. Any variation from a common value of E = ½ would be selected out as other linkable arrays with more ideal efficiencies would be available. As energy cascades through the system, the rate of energy degradation decreases as per the various values of E of the temporary OAMs coupled along the way, and the rate of entropy production decreases. So, any selective process that chooses one link over another, due to efficiency considerations, would also select for entropy production.

6 OKAY!!!??! That was really painful.

So, after all of that, I am finally ready to tackle the real question:
How does the MPP work, and why, and what is its connection, if any, to the MEPP?

I will defer that to another note, as this one is getting too long.