The Second Law and Rivalrous Digital Information (Or Maxwell's Demon in an Information Age)

Conference or Workshop Item

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Introduction

About 35 years ago a Romanian exile in the US, Nicholas Georgescu-Roegen wrote about the impact of the economic process on the environment. He used a fundamental though not widely known law of nature called the second law of thermodynamics to explain that consuming endlessly, without thinking about how natural resources were going to be replenished, would be likely to have consequences. That law and Georgescu-Roegen's thoughts then have implications for the knowledge society.

There is a widespread belief that once information is digitised it can be copied and distributed at zero marginal cost but digital information fundamentally depends on access to a source of energy. And it turns out that large data centres and servers use up a lot of energy. The big technology companies' energy bills can run into hundreds of millions of dollars. In a world facing an energy crisis that means digital information is a little more rivalrous than we originally thought...

A billion years ago…

To begin I would like to take you back a few years. Evolution has been plugging away on this little planet for about a billion years now, during which process information[2] has been acquired. Whether knowledge has been acquired, however, I sometimes wonder.

Some cells now carry within them all the information – the organism's DNA required to be outstanding micro-organisms, spiders, octopuses, dogs, cats or human beings. The entire blueprint of all life on the planet has emerged in a teaching process in which Richard Dawkins[3] ascribes the role of teacher to natural selection: fitter individuals survive if only because their genes give them the legs to out run a lion or attract a mate. The whole thing is all pretty mindless – in the sense of having no consciousness – and brutal – the naturally lame antelope just won't outrun the lion often enough to survive too many generations. If the DNA code includes the instruction "dodgy leg" then tough.

Oil and coal

By 450 million years ago evolution had left the land surface of the planet with quite a few trees. Well actually there were more than a few and when these died and laid down layer upon layer of sediment through thousands of generations and millions of years, the earth eventually turned them into carbon rocks or coal deposits.

Later in two main episodes starting about 150 million years ago and 90 million years ago respectively the sediment from billions of oceanic micro-organisms got turned into the earth's main oil deposits, again over a period of millions of years. Once cooked the oil flowed through the cracks in the undersea architecture of rocks and found homes under land and sea in natural large caverns and oil fields from which we pump it today.

Evolutionary Triumph and limited rationality

By 65 million years ago evolution had led the dinosaurs to rule the earth until there was a celestial road traffic accident, when the earth had a collision with rather a large rock from space and that spelled the end for the dinosaurs.

Natural selection was by no means finished though and arguably then produced its greatest triumph – 2 legged, upright, rational thinkers, a bit like those of us gathered at the GIKII workshop preceding the VI Computer Law World Conference at Edinburgh in the autumn of 2006. Except perhaps we were not as rational as we sometimes like to think. We have tended to be aggressive towards other members of our species as well as other species – more so than any other animal before or since – and engaged in wars for territorial or personal or political or other gains.

We also discovered those carbon rocks buried hundreds of millions of years ago were good for burning and generating energy and facilitated an industrial revolution[4] with much greater levels of trade and its associated processes. The coal extraction and burning was a dirty business but there were plenty of *poor* two legged rational thinkers to do that.

Then we discovered the oil cooked 150 and 90 million years ago respectively and discovered that was also good for burning and generating energy – more efficiently and slightly cleaner than the coal. Then there was the horseless carriage and highways and there was no stopping us.

The trouble was there was one great flaw in our ability to reason – we tended to focus only on part of the picture and more specifically that part that affected us. So the institutions big and small, just like the individual, focuses on self promotion and self preservation just as the trading system we had evolved encouraged us to do.[5] We began to poison the earth and overheat it with excessive greenhouse gases.[6] In addition we neglected to deal with the looming depletion of those energy sources so conveniently cooked up by our planet many millions of years ago.

Entropy and the Second Law of Thermodynamics

Which brings us to entropy and the second law of thermodynamics,[7] which I'm assuming will not be all that familiar to a group of lawyers, even a highly technically literate group of lawyers such as those who congregate at computer law conferences. So forgive me if I am over-simplifying.

The second law of thermodynamics comes in a number of indigestible formal statements[8] which I will spare you the detail of given that my presentation is scheduled just prior to lunchtime but basically the law is nature's version of the old adage "there's no such thing as a free lunch." The Second Law which says that when energy gets used some of it always gets wasted. It is sometimes described as "Time's Arrow" because it determines that processes proceed in a certain direction – hot coffee cools through heat transfer to the surroundings, petrol is used up when a car is driven up the hill but not re-created in the petrol tank when the car comes down the other side. These familiar everyday observations are evidence of the validity of the second law.

Nicholas Georgescu-Roegen, who with his wife fled communist controlled Romania by stowing themselves away in barrels on a freighter heading for Turkey and finally settling in the US, published *The Entropy Law and the Economic Process* in 1971. This was the first serious exposition in modern economics pointing out that there were limits to growth based on the combined finite nature of the earth's resources and the limits of the second law. Georgescu-Roegen described the second law as the "basis of the economy of life at all levels." He believed that we would come to pay for those finite coal and oil and other natural resources which we have been rapidly burning through over the course of the past couple of centuries in more ways than one.

The Second Law and digital information

A – so far – minor though neglected effect of the second law is the impact it will have on digital information in the knowledge economy… through the energy costs of current ICT architectures.

There is a widespread belief that once information is digitised it can be copied and distributed at zero marginal cost – i.e. "for free" – but digital information fundamentally depends on access to a source of energy. And just a few questions about this assumption before moving on –

How many people have broadband internet connections at home?
Anyone got that for free?
Anyone got their PC for free?
How about your printer?
Scanner? Digital Camera?
Mobile phone?
Free electricity?
What nobody?

So we need a whole pile of moderately costly hardware and software, which rapidly becomes slow, obsolete and in need of replacing, as well as access to energy utilities *before* we can get access to all this "free" information. With the "Waste Electrical and Electronic Equipment Directive" (WEEE) due to be implemented in the UK in 2007, by the way, the cost of this rapid obsolescence is likely to have an impact on hardware prices locally, and likewise across Europe as it is getting gradually implemented in the national laws of EU member states.

Right then, getting back to the energy link to digital information – the latter cannot exist without the former. So every single item of digital information has an associated energy cost. And it turns out that the technology industry's large data centres and servers use up a lot of energy. The big technology companies' energy bills can run into hundreds of millions of dollars. In a world possibly facing an energy crisis that means digital information is a little more rivalrous than we originally thought.

I did a little experiment with my home computer, one day when my wife brought the children to visit their grandparents. I shut off all the other electrical devices in the house and checked the electricity meter to see how much energy my home PC and associated peripherals used. It turned out that they use about a unit of electricity

every nine hours, when not doing any heavy processing, or 1/9th of a unit an hour. That's just my one low spec. home PC. Multiply by 20 million, assuming there is that number of household PCs in the UK. That's about 2.2 million units of electricity per hour if the PCs are just switched on running on idle. UK domestic PCs just ticking over are using over 2 megawatts. Now look at companies like Microsoft, Google, Yahoo!, Sun Microsystems, Amazon and other big high technology companies with their need for massive computer based data centres, which when that much hardware is running together in relatively small physical space needs vast amounts of power devoted to cooling alone and you're suddenly faced with high energy costs, simply to keep this high tech network that is the Internet with its energy guzzling PCs at the ends merely ticking over. Sun CTO, Greg Papadopoulos estimates the cost of the data centres alone at about 25 gigawatts, which would require dozens of power plants to supply; before even thinking about the hundreds of millions of networked user PCs.

The current architectures are energy intensive and could be greatly improved e.g. the Ndyio project in Cambridge[9] but the 2nd law ultimately tells us that improvements in efficiency of the technology will not make the problem of limited and diminishing energy resources go away. It will merely delay the day.

In an energy rich economy these costs might not get a lot of attention but a global economy in which we may see rationing of dwindling energy resources like oil, has implications for digital information and who gets access to it. That concerns me as an educator, at a time when we are increasing our level of dependence on digital information, especially since I am already concerned about how developments in intellectual property and other information laws are moving in the direction of restricting access to information anyway.

I've been convinced by the arguments of eminent scholars like Larry Lessig,[10] James Boyle[11] and Yochai Benkler[12] that the entertainment industries, in particular,[13] have driven through changes in intellectual property laws which have thrown the system out of balance. Using intuitively attractive and selectively defensive rhetoric complaining about teenagers "stealing" music online and not being able to compete with infringing copies of works available for "free" online, they have managed to convinced legislators of the need for changes like the Digital Millenium Copyright Act (DMCA) of 1998, European Union Copyrights (and related rights) directive (EUCD) of 2001 and the IPR Enforcement directive (IPRED) of 2004. A couple of questions again relating to the 'can't complete with free' line:

Anyone buy bottled water?
Why not drink the tap water?

Bottled water companies can't possibly compete with free.

Boyle argues that changes in law and technology could be leading to a kind of "second enclosure movement"[14] which threatens not only our ability to make informed decisions about those complex information systems, but even something as fundamental as our access to the basic raw materials of education. This is something which has been a problem in the developing world for generations. Relative to average incomes,[15] a student paying $80 for a book in Indonesia would be the equivalent of a US student paying nearly $3200 for the same book in the US. Now

that such access issues might come to attention of the middle classes in the West, ironically in an age where so much information is allegedly free, I wonder if the restrictions will stimulate some kind of response. There is a very recent and still raw example stemming from the educational technology sector relating to Blackboard's patent on the platforms used to deliver online courses, which I suspect will be the subject of intense discussions at another big conference in Edinburgh this week at Heriot-Watt University – the Association for Learning Technology's 13th International Conference, *ALT-C 2006: the next generation.*

Summary

To sum up then on the 'The Second Law and Rivalrous Digital Information', when it comes to digital resources, which by their very nature require an energy source to exist, there is no such thing as a free lunch. Given that energy resources are finite and we may be about to hit Hubbert's peak[16] on global oil production, that has consequences for shape of the global knowledge economy, as well as more locally on issues as fundamental as access to the raw materials of education. Maxwell's demon has not yet succeeded in breaching the second law in the classical universe.

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[1] Maxwell's demon was a thought experiment by the physicist James Clerk Maxwell, about the possibility of breaking the second law. He described it as follows "... if we conceive of a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are as essentially finite as our own, would be able to do what is impossible to us. For we have seen that molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower molecules to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics." *Maxwell's Demon: Entropy, Information, Computing* edited by Harvey S. Leff, Andrew F. Rex, (Institute of Physics Publishing, 1990) p4..

[2] *Information, Systems and Information Systems: Making Sense of the Field* by Sue Holwell and Peter Checkland, Wiley, 1998, pp 86-92. Holwell and Checkland use four categories to make sense of information –
Data – all the facts that exist about the world
Capta – the facts selected or created that we choose to pay attention to
Information – having paid attention to some facts we relate them to other things, put them in a context and derive some meaning from them. The process can be individual and/or collective
Knowledge – the process of turning data into information can lead to the recognition of wider patterns and connections of structures of related information. These larger, longer living structures of meaningful information constitute knowledge]

[3] See *The Blind Watchmker* or *The Selfish Gene*

[4] See *Making Sense of the Industrial Revolution: English Economy and Society 1700-1850* by Steven King amd Geoffrey Timmins, Manchester University Press, 2001 and
The Day the World Took Off - the Roots of the Industrial Revolution by Sally Dugan and David Dugan, Channel 4 Books, 2000 for excellent accounts of this world changing era.
[5] See *An Inquiry into the Nature And Causes of the Wealth of Nations* by Adam Smith (1776), available online at the Adam Smith Institute http://www.adamsmith.org/smith/won-index.htm
[6] See *Heat: How to Stop the Planet Burning* by George Monbiot, Allen Lane, 2006 and *Silent Spring* by Rachel Carson, Houghton Mifflen, 1962
[7] To which subject are devoted hundreds of miles of engineering library shelf space all over the world but I will refer you, for a full account, to the classic text I used as an undergraduate, *Fundamentasl of Classical Thermodynamics*, (2nd Edition, SI Version) by Gordon J. Van Wylen and Richard E. Sonntag, John Wiley and Sons, 1976
[8] Example Kelvin-Planck statement: "It is impossible to construct a device that will operate in a cycle and produce no effect other than the raising of a weight and the exchanging of heat with a single reservoir. Clausius statement: "It is impossible to construct a device that will operate in a cycle and produce no effect other than the transfer of heat from a cooler body to a hotter body
Both amount to saying you can't turn heat into work without losing some of it, or you can't turn heat into an equivalent amount of work
[9] http://www.ndiyo.org Ndiyo, pronounced 'nn-dee-yo', is the Swahili word for "yes". Ndiyo! is a project based in Cambridge and set up by John Naughton and Quentin Stafford-Fraser to foster an approach to networked computing that is simple, affordable, open, less environmentally damaging and less dependent on intensive technical support than current networking technology.
[10] *The Future of Ideas,* Lawrence Lessig, (Random House, 2001)
[11] *Shamans, Software and Spleens: Law and the Construction of the Information* Society by James Boyle (Harvard University Press, 1997); James Boyle, *The Second Enclosure Movement and the Construction of the Public Domain*, 66 Law & Contemp. Probls. 33 (2003), *available at:* http://www.law.duke.edu/shell/cite.pl?66+Law+&+Contemp.+Probs.+33+(WinterSpring+2003)
[12] *The Wealth of Networks* by Yochai Benkler (Yale University Press, 2006)
[13] I think that the publishing industry is by and large smarter than the entertainment companies though they have been understandably concerned about the advent of this vast copying machine called the Internet; and also acted imho unnecessarily defensively to developments like the Google Book project
[14]James Boyle, The Second Enclosure Movement and the Construction of the Public Domain, (2003) http://www.law.duke.edu/pd/papers/boyle.pdf
[15] The Consumers International, Asia Pacific Office, Kuala Lumpur, Report, Copyright and Access to Knowledge, February, 2006.
http://www.consumersinternational.org/Shared_ASP_Files/UploadedFiles/23775AAE-3EE7-4AE2-A730-281DCE859AD4_COPYRIGHTFinal16.02.06.pdf
[16] Hubbert's Peak: The Impending World Oil Shortage by Kenneth S. Deffeyes (Princeton University Press, 2001)