Soft correlations in layered niche networks

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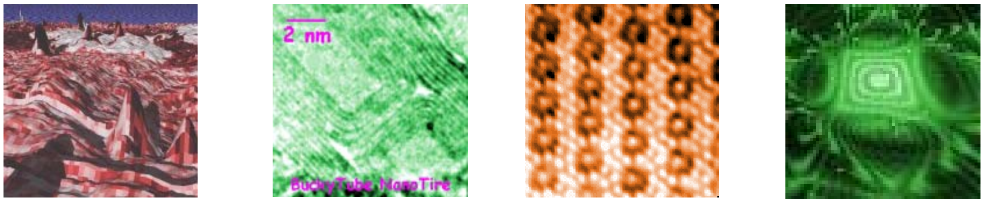
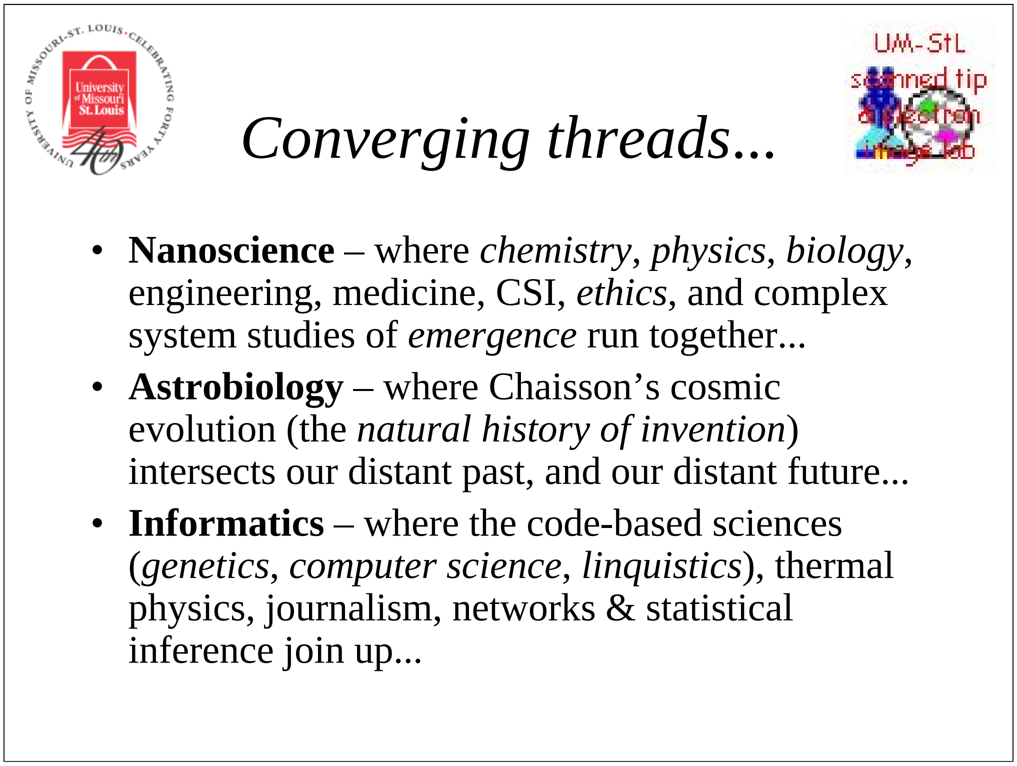


Outline

- Correlations, nanoscience, & stardust
  - *convergent disciplines & multiscale thought*
  - *mutual information & reversible thermalization*
- Pulling together (self-referentially)
  - *complex excitations correlated with simple codes*
  - *physical boundary-directed niche networks*
  - *symbiosis with multi-scale codes, and their dynamics*

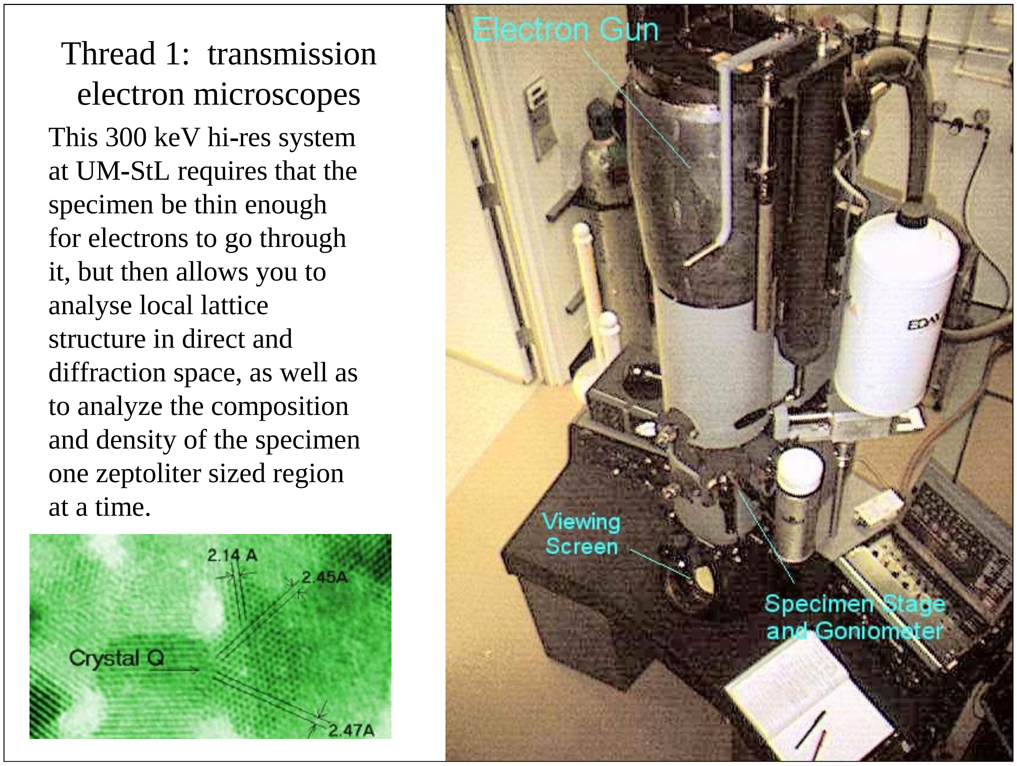
The first part of this talk uses several convergent disciplines to introduce an integrative perspective on correlation-based complexity over a range of scales in time and space. The basic idea is that a small number of physical boundary types (namely gradients, membranes, and code-pool edges) serve as pivot points in the organization of complex system correlations. The second part raises the question of layered networks in this context, but poses more problems than solutions. That's where you come in.



Converging threads...

- **Nanoscience** – where *chemistry*, *physics*, *biology*, engineering, medicine, CSI, *ethics*, and complex system studies of *emergence* run together...
- **Astrobiology** – where Chaisson's cosmic evolution (the *natural history of invention*) intersects our distant past, and our distant future...
- **Informatics** – where the code-based sciences (*genetics*, *computer science*, *linquistics*), thermal physics, journalism, networks & statistical inference join up...

Like complex systems, these threads have been referred to as "disruptive science" because of the cognitive dissonance that occurs when disciplines merge.



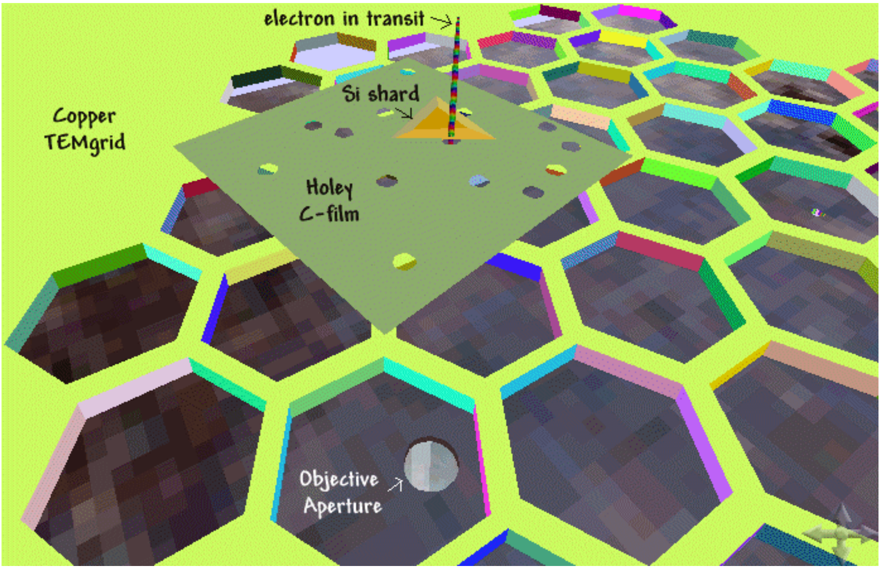
Thread 1: transmission electron microscopes

This 300 keV hi-res system at UM-StL requires that the specimen be thin enough for electrons to go through it, but then allows you to analyse local lattice structure in direct and diffraction space, as well as to analyze the composition and density of the specimen one zeptoliter sized region at a time.

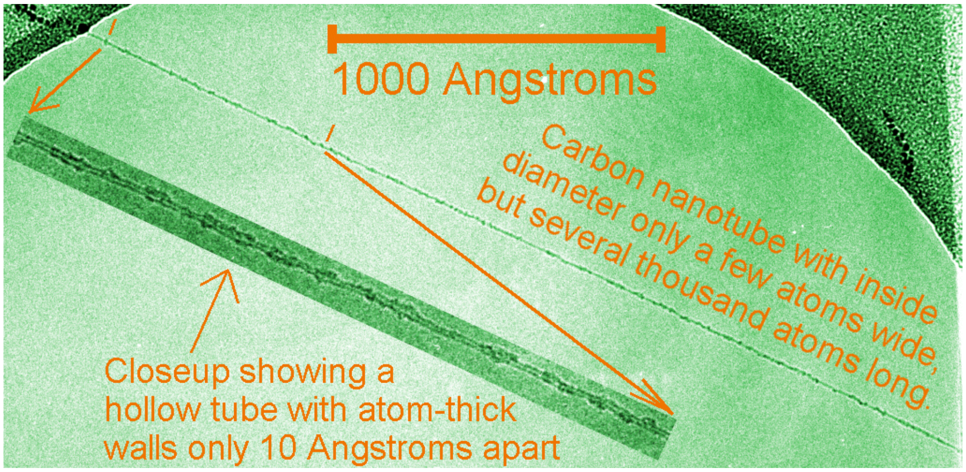
One perspective on nanoscience starts with electron scatterers like that shown above. The images from these instruments are relatively “two dimensional”, but high resolution is possible as shown in the photo of tungsten atom columns (with one missing) in nanocrstals of tungsten carbide by Wentao Qin (UM-StL, now Motorola/FreeScale). Transmission electron microscopes with point resolution much below the spacing between atoms now typically cost between $2M and $5M. These instruments are more like “clothes for visiting small places” than xerox machines, for example, in that they do little by themselves and do a wide range of different things in the hands of different operators.

To read more about these things and their applications cf. 2005 J. Appl. Phys 98 114308, and http://newton.umsl.edu/~run/nanoed.html .

What happens inside that microscope,
from the vantage point of a sub-millimeter sized observer...



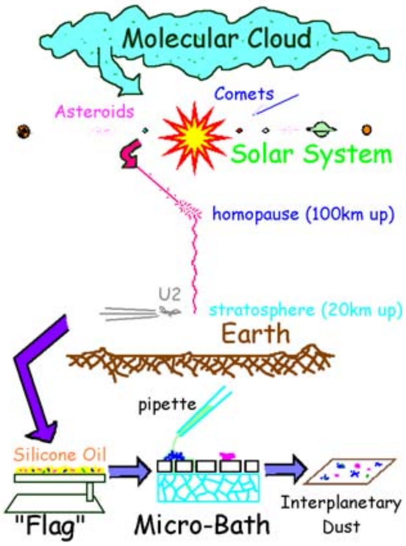
This shows what the "active region" of a transmission electron microscope might look like if you were only a tenth of a millimeter in height. Here electrons having significant longitudinal and transverse coherence width pass through a delicately suspended thin specimen ,and then through an objective aperture a few tens of microns across, located a couple of millimeters below the specimen.

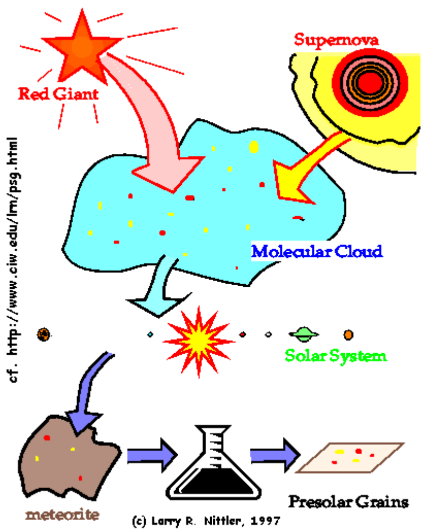


Single walled nanotube only 5 atoms across, prepared in a turbulent flame by Washington University grad student Chad Unrau. Given their vanishing size and predictable shape, such tubes also show potential as substrates for studying molecules dwarfed by a 500A wide virus. These exploration tools introduced me to...

This 5-atom wide nanotube suggested to us the possibility of using such tiny cylindrical structures as “support stages” for the study of many types of individual small molecule, given that the support structure is both tiny and predictable in shape. On this scale a typical virus might cover up half of the scale bar, while the whole field width is less than a tenth of the diameter of a red blood platelet.

Thread 2: Interplanetary & Interstellar Dust *in the Lab*, including `Stardust@home`

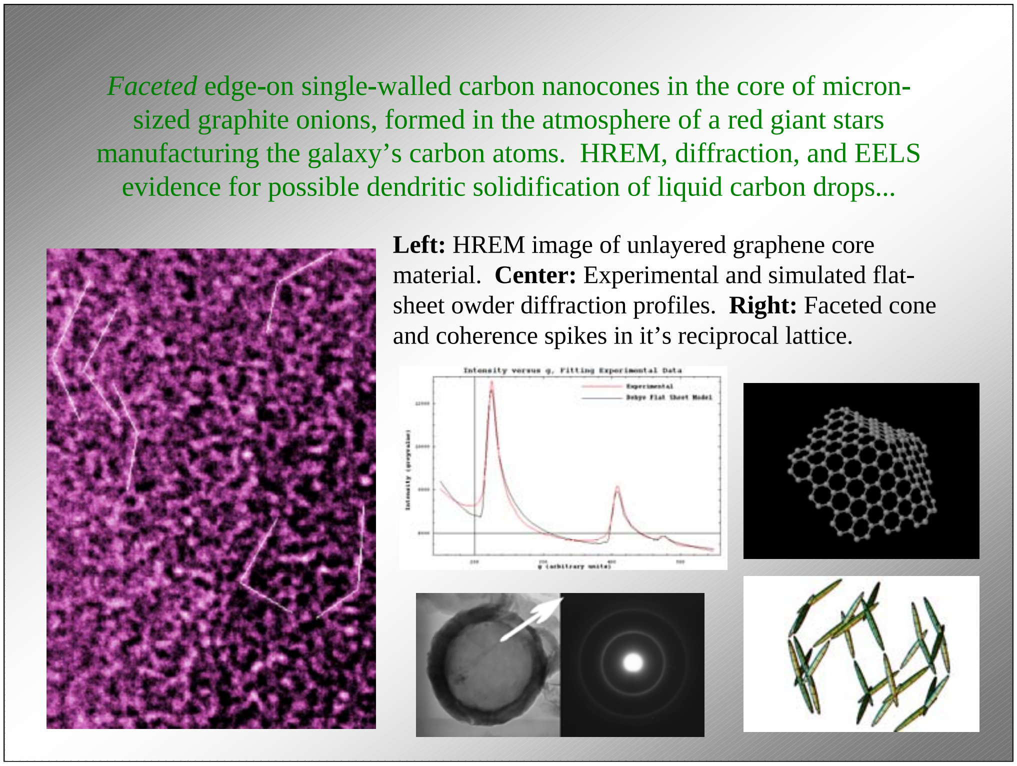




cf. http://www.ciw.edu/lm/psg.html

(c) Larry R. Nittler, 1997

My perspective on astrobiology has been shaped by electron microscopy, as well as by Don Brownlee at U. Washington. Don pioneered the first stratospheric collections of interplanetary dust (schematic left above). Thanks particularly to Anders\Lewis at U. Chicago and Bernatowicz\Zinner at Washington U., studies of presolar grains from meteorites (schematic right above) are now a routine source of astrophysical information e.g. on things like nucleosynthesis cross-sections in stars. The Stardust comet sample return mission on which Don Brownlee is PI may have also brought back some contemporary specimens of interstellar dust this past February. If you'd like to help to find those interstellar dust grains, check out http://stardustathome.ssl.berkeley.edu/ .



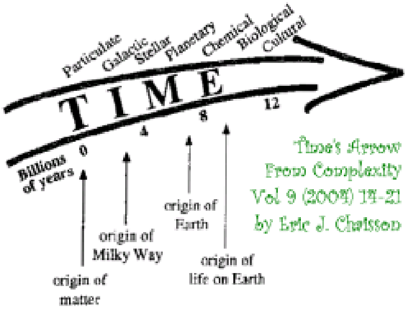
Faceted edge-on single-walled carbon nanocones in the core of micron-sized graphite onions, formed in the atmosphere of a red giant stars manufacturing the galaxy’s carbon atoms. HREM, diffraction, and EELS evidence for possible dendritic solidification of liquid carbon drops...

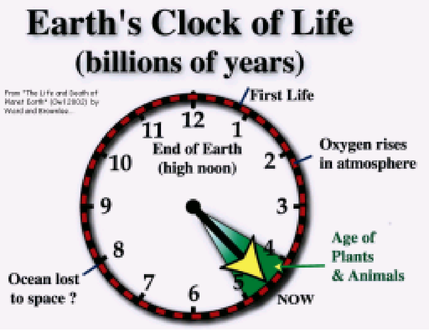
Left: HREM image of unlayered graphene core material. **Center:** Experimental and simulated flat-sheet owder diffraction profiles. **Right:** Faceted cone and coherence spikes in it’s reciprocal lattice.

Aside: “Materials astronomy” includes the laboratory examination of dust particles whose atoms have been bonded together for more than half the age of the universe. Recent work in our lab on presolar stardust for example revealed these single walled nanocones, in the core of micron-sized spheres whose Ne and C isotopes (among other things) show that they were condensed in the atmosphere of a late AGB star from the early Milky Way, like those that nucleo-synthesized most of the carbon atoms in you.

To read more about this, cf. 2002 Ap. J. Lett. 578 L153 and http://www.umsl.edu/~fraundor/isocore.html.

Multiscale Awareness in Time



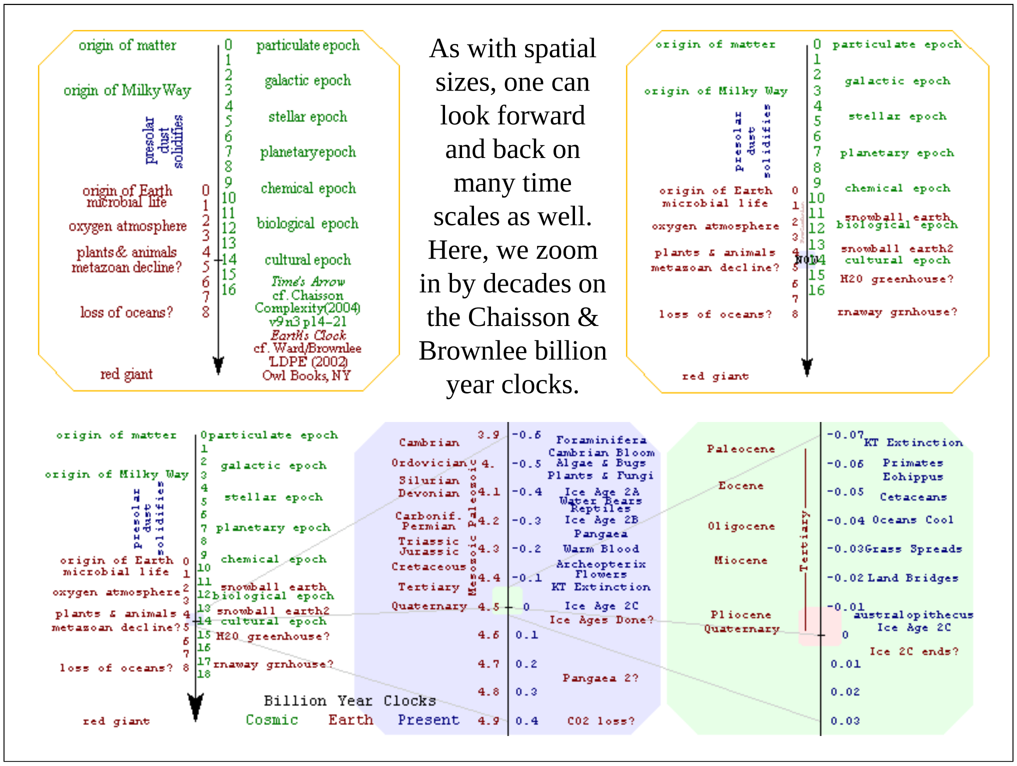


- Chaisson’s cosmic evolution: emergence (starting with neutral atoms, galaxies, stars, planets, geocycles, biocycles, motorcycles, etc.) as a natural history of invention.
- Ward and Brownlee: astrophysical observations suggest that planets suitable for multi-cell life are rare, and that earth will support such life only for about a billion years (now half gone).

In this and other ways, astrophysical observations are contributing to our understanding how planets and stars (including our own) evolve. The remaining slides on this thread begin with a synthesis between two interesting books, one by Brownlee and geologist Peter Ward (also UW Seattle) on earth’s clock, and the other on time’s arrow by astronomy book author Eric Chaisson at Tufts University.

Eric optimistically discusses the cosmic evolution of steady-state systems that trade free energy for increasingly complex subsystem correlations. This integral view of evolution lets students see how real-time observations of stellar and planetary evolution are a seamless part of the living fabric on earth.

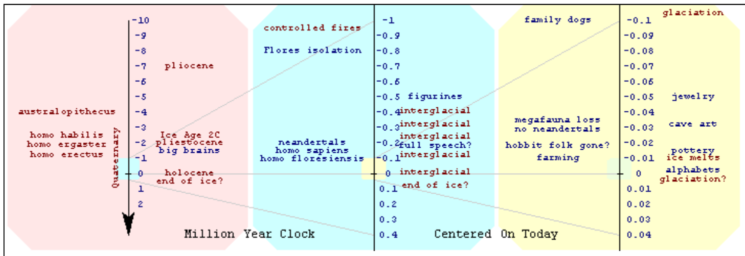
Ward and Brownlee, who elaborated on the rarity of planetary chances for metazoan evolution in their book “Rare Earth”, in “The Life and Death of Planet Earth” discuss on the billion year time scale how earth is only a temporary home for such complex systems. If one zooms in on the present in a calendar made by combining these billion year clocks, you’ll find that we’re in the middle of what is likely the third multi-glaciation ice age since metazoan lifeforms on our planet came into their own a half-billion years ago. Moreover, solar evolution and carbon loss processes suggest that this age of plants and animals will have run its course on a comparable time scale in the days ahead.



As with spatial sizes, one can look forward and back on many time scales as well. Here, we zoom in by decades on the Chaisson & Brownlee billion year clocks.

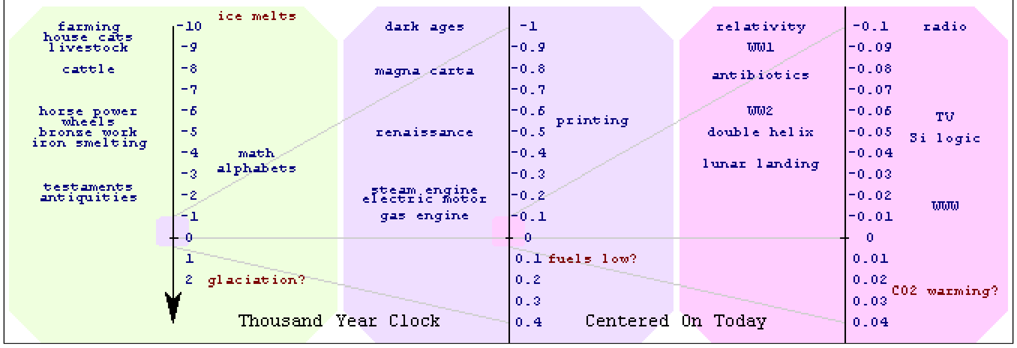
Starting from those billion year clocks, we begin to zoom in (by orders of magnitude) to smaller time scales. Note from the position of the Cambrian bloom at top of the central panel that metazoan life has been very active for at least 1/30th of the present age of the universe.

The process of interstellar grain transport with help of stellar radiation pressure and galactic arm mixing, mentioned earlier, takes over 100,000 years. That means that just before Pangaea 2 near the bottom of that panel (when the continents once again cluster), our descendants might start to detect the fruits of work in upcoming centuries at exploiting that transport process in reverse, by sending earth-designed nannites to seed new star systems across the Milky Way. At the very bottom of the central panel, one effect begins to be felt (namely CO2 depletion) of the carbon subduction that, according to studies discussed by Brownlee and Ward, will eventually put our planet back into the hands of one-celled organisms.



Three decades of the million year clock centered on today (above) telescope further down to three decades on the thousand year clock (below) whose last panel brackets the last and current centuries.

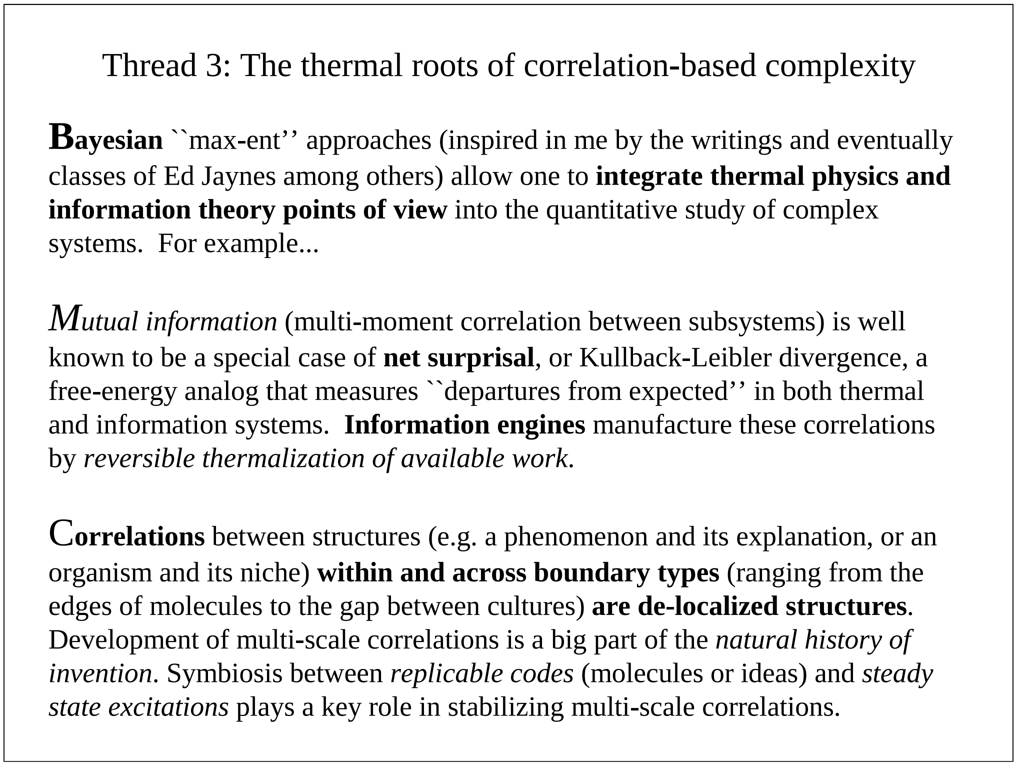
Correlated subsystem states (e.g. atoms, galaxies, stars, planets, biogeochemical cycles, cells, communities) develop as free energy is spent. Thus the fossil fuel legacy of multi-celled life's 1st half may be useful for its 2nd half. This brings us to...



Another 6 magnitudes of "zoom-in" bring us to a calendar for the past and current century, and evidence that on a local scale subsystem correlations continue generate new surprises. Highlights include australopithecus (upper left panel), the domestication of fire (top center), the start of a long symbiotic relationship with canines at the outset of the last glaciation (upper right), the current interglacial which brought with it discovery of food production and writing (lower left panel), the magna carta and moveable type (bottom center), and the discovery of relativity and electronic communications in the century panel (lower right).

From the earliest to the most recent times, Chaisson joins many in discussing the role of free energy (and what he calls cosmic evolution) in the emergence of correlations. It is this connection between the natural history of correlations and thermal physics that we take up next.

Aside about forward/backward looking powers of ten in time: For more on what one sees as one "zooms in toward the present" on these calendars, cf. http://www.umsl.edu/~fraundor/ifzx/earthtimes.html.



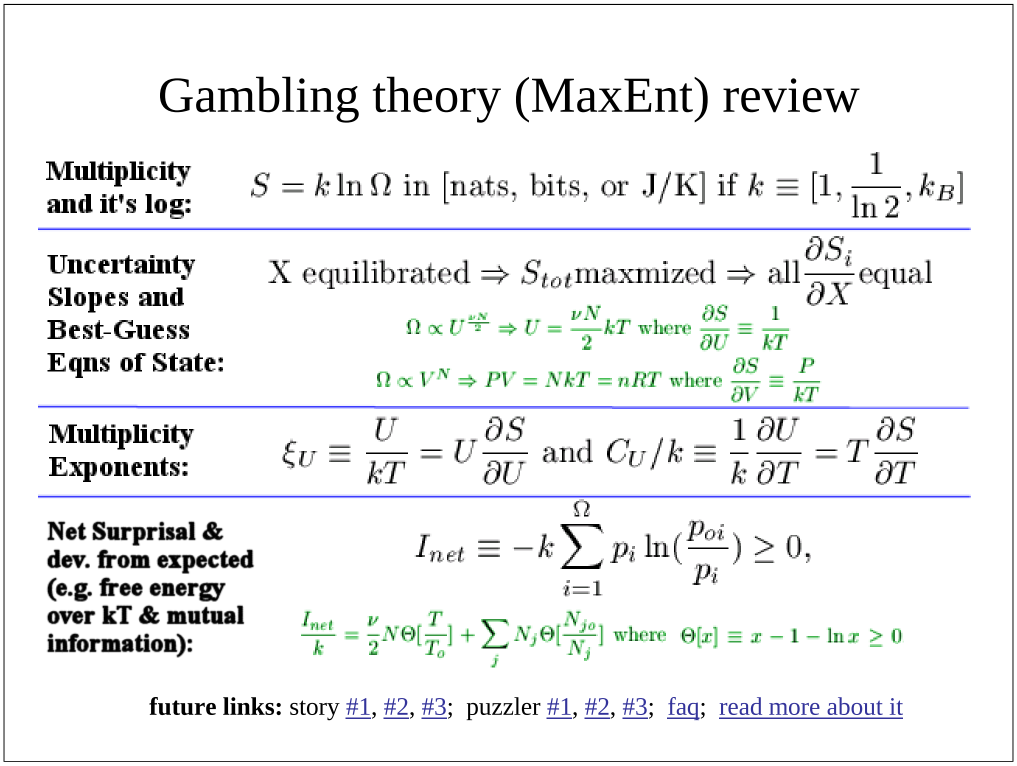
Thread 3: The thermal roots of correlation-based complexity

Bayesian ``max-ent’’ approaches (inspired in me by the writings and eventually classes of Ed Jaynes among others) allow one to **integrate thermal physics and information theory points of view** into the quantitative study of complex systems. For example...

Mutual information (multi-moment correlation between subsystems) is well known to be a special case of **net surprisal**, or Kullback-Leibler divergence, a free-energy analog that measures ``departures from expected’’ in both thermal and information systems. **Information engines** manufacture these correlations by *reversible thermalization of available work*.

Correlations between structures (e.g. a phenomenon and its explanation, or an organism and its niche) **within and across boundary types** (ranging from the edges of molecules to the gap between cultures) **are de-localized structures**. Development of multi-scale correlations is a big part of the *natural history of invention*. Symbiosis between *replicable codes* (molecules or ideas) and *steady state excitations* plays a key role in stabilizing multi-scale correlations.

What does thermal physics have to say about evolved correlations? We start with a text-only outline here.



Gambling theory (MaxEnt) review

Multiplicity and it's log:

$$S = k \ln \Omega \text{ in [nats, bits, or J/K] if } k \equiv [1, \frac{1}{\ln 2}, k_B]$$

Uncertainty Slopes and Best-Guess Eqns of State:

$$\text{X equilibrated} \Rightarrow S_{tot}\text{maxmized} \Rightarrow \text{all}\frac{\partial S_i}{\partial X}\text{equal}$$

$$\Omega \propto U^{\frac{\nu N}{2}} \Rightarrow U = \frac{\nu N}{2}kT \text{ where } \frac{\partial S}{\partial U} \equiv \frac{1}{kT}$$

$$\Omega \propto V^N \Rightarrow PV = NkT = nRT \text{ where } \frac{\partial S}{\partial V} \equiv \frac{P}{kT}$$

Multiplicity Exponents:

$$\xi_U \equiv \frac{U}{kT} = U\frac{\partial S}{\partial U} \text{ and } C_U/k \equiv \frac{1}{k}\frac{\partial U}{\partial T} = T\frac{\partial S}{\partial T}$$

Net Surprisal & dev. from expected (e.g. free energy over kT & mutual information):

$$I_{net} \equiv -k\sum_{i=1}^{\Omega} p_i \ln(\frac{p_{oi}}{p_i}) \geq 0,$$

$$\frac{I_{net}}{k} = \frac{\nu}{2}N\Theta[\frac{T}{T_o}] + \sum_j N_j\Theta[\frac{N_{jo}}{N_j}] \text{ where } \Theta[x] \equiv x - 1 - \ln x \geq 0$$

future links: story #1, #2, #3; puzzler #1, #2, #3; faq; read more about it

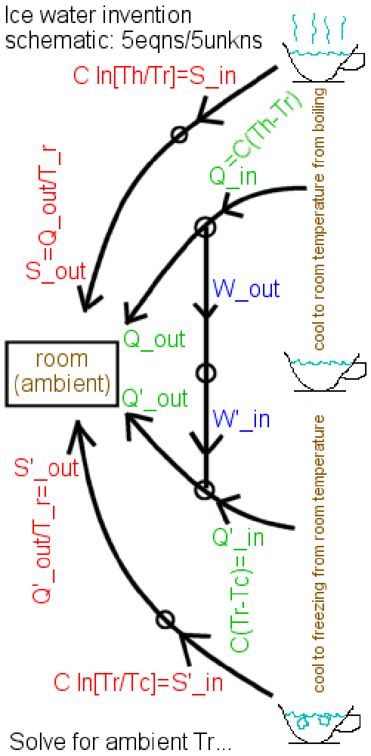
Now a few well known equations. For each row, note the relationship discussed, and it's units.

(i) If we define surprisal as the log of probability's reciprocal for each accessible state, average surprisal (entropy, uncertainty) has information units (how many are familiar with this?);

(ii) Max-ent best guesses (e.g. in micro-canonical, canonical, pressure and Gibbs ensembles) yield intensive Lagrange multipliers. These are typically derivatives that involve entropy and an extensive conserved quantity X, which "equilibrates" as initial conditions fade. For example, 1/kT = dS/dE makes temperature an energy derivative that's not always proportional to total energy, much as acceleration is not always proportional to velocity, in spite of occasional textbook allusions to the contrary (how many have seen this?);

(iii) Dimensionless integral and differential capacities (elaborate here) then have units of what? (Answer: bits per 2-fold increase in X or one of it's multipliers cf. "Heat Capacity in Bits" 2003 AmJPhys 71 1142-1151); and

(iv) Net-surprisals (AKA relative or cross-entropy) in information units measure finite deviations from expected, and reduce near equilibrium to availabilities (free energy over kT) and in the case of correlated subsystems to mutual information (now fashionable in the study of evolving codes, nonlinear dynamics, and quantum computing).



A UIUC intro-physics homework problem...

...solvable with three approaches:

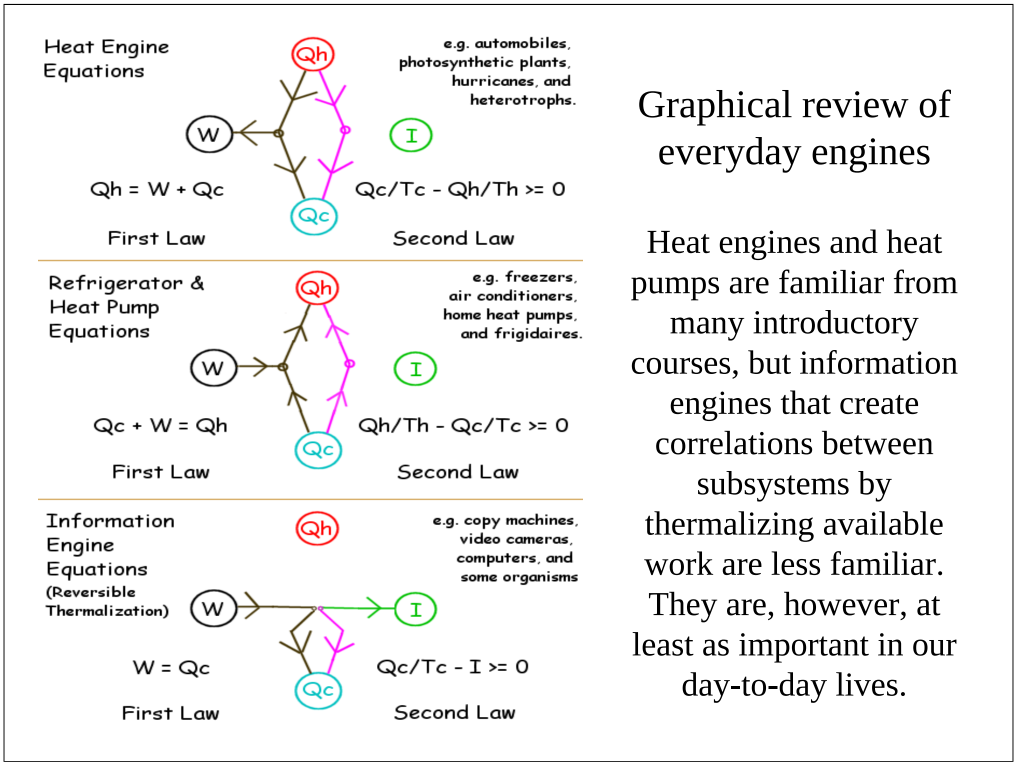
- p-chem: Carnot engine and heat pump
- thermal physics: heat & entropy flows
- information physics: equal net-suprisals

$$C^*\Xi[T_h/T_r]=C^*\Xi[T_c/T_r]$$

where...

$$\Xi[x]\equiv x-1-\ln[x]$$

A practical application of net surprisals involves a problem that my daughter was assigned in a physics course when she was a student here at U of I. Imagine a device which takes in a cup of boiling water, and outputs a cup of ice water. What is the maximum temperature at which such a device can operate without requiring an external source of available work? I’m told that chemists would tackle with problem using Carnot engine and heat pump efficiencies, we might use heat and entropy flows in introductory physics, but by far the simplest approach involves assuming that an unpowered device can’t increase the net surprisal of the water cup relative to ambient. As shown above, equating net surprisals yields a simple equation that shows that such a device is possible even if the ambient temperature is well above 100F.



Heat Engine Equations

e.g. automobiles, photosynthetic plants, hurricanes, and heterotrophs.

$Qh = W + Qc$

First Law

$Qc/Tc - Qh/Th >= 0$

Second Law

Refrigerator & Heat Pump Equations

e.g. freezers, air conditioners, home heat pumps, and frigidaires.

$Qc + W = Qh$

First Law

$Qh/Th - Qc/Tc >= 0$

Second Law

Information Engine Equations
(Reversible Thermalization)

e.g. copy machines, video cameras, computers, and some organisms

$W = Qc$

First Law

$Qc/Tc - I >= 0$

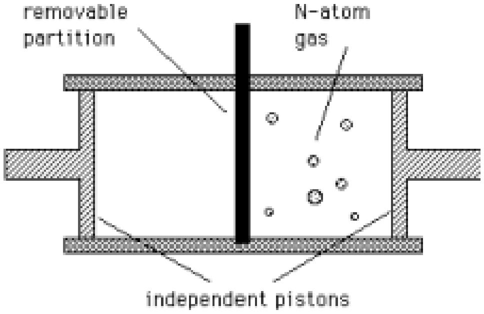
Second Law

Graphical review of everyday engines

Heat engines and heat pumps are familiar from many introductory courses, but information engines that create correlations between subsystems by thermalizing available work are less familiar. They are, however, at least as important in our day-to-day lives.

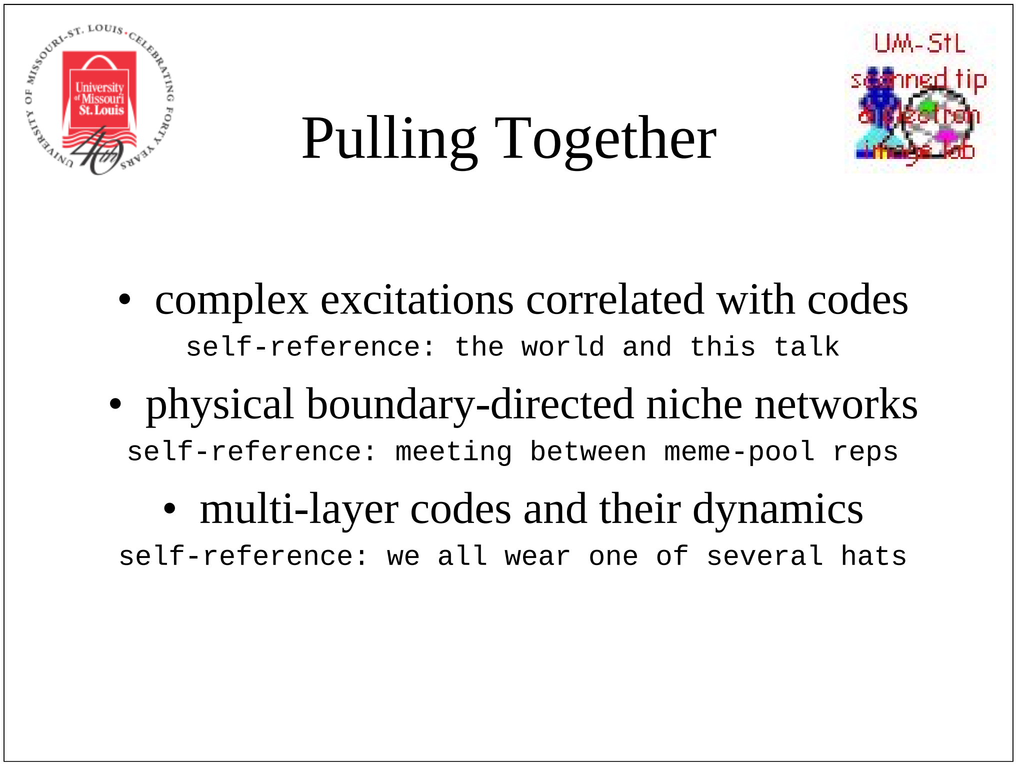
This approach to visualizing heat and entropy equations also works for heat engines, heat pumps. Information engines are less well known (primarily because thermodynamics traditionally avoids subsystem correlations). However, they are at least as ubiquitous.

Natural units for temperature & entropy facilitate the application of thermal physics to information engines…



The price of correlating two subsystems (e.g. a code and
and excitation) is for Szilard’s vacuum-pump memory
and in general: Work/I = $kT_{ambient}$ ln(2) [e.g. in joules/bit].

For example, information engines that reversibly thermalize work to create correlated subsystems are quite topical in modern day studies of code replication (cf. Tom Schneider at NIH), of code origins (cf. the recent Scientific American article by Bennett and others on chain letters), and of quantum computing (cf. articles in the past decade on mutual information and it’s applications by Seth Lloyd). A pre-print on essentially this same device, written by Bradley Chase and Alfred Hübler (http://www.santafe.edu/education/reu/2005/files/bchaseREU2005.pdf), was made available at the meeting.



Pulling Together

- complex excitations correlated with codes

`self-reference: the world and this talk`

- physical boundary-directed niche networks

`self-reference: meeting between meme-pool reps`

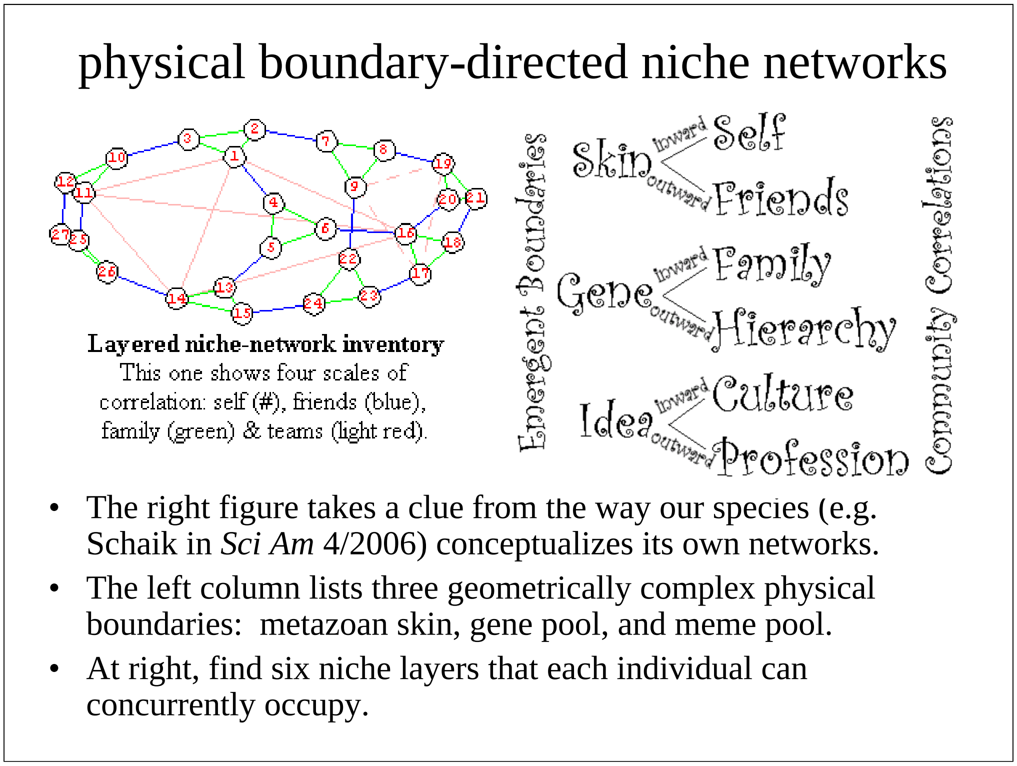
- multi-layer codes and their dynamics

`self-reference: we all wear one of several hats`

Work in the foregoing “convergent disciplines” suggests possibly useful connections for those involved in various types of complex systems research, as well as to correlations in economic and social systems being explored by experts in other fields represented at this meeting.

the excitation-code correlation is an old story

- If you “know” the state of a binary system (e.g. the x-component of a half-integral spin), then you and that binary system share one bit of mutual information.
- The isolated subsystem second law concerns the time dependence of uncertainty about its contents, and hence the mutual information shared by observer & subsystem.
- A statement is “true” if and only if it correlates with the excitation to which it refers.
- The recent example by Lapilli et al (PRL 2006) confirms that different Hamiltonians (i.e. underlying excitations) can yield the same thermodynamics (macroscopic description), even over a range of temperatures.



physical boundary-directed niche networks

Layered niche-network inventory
This one shows four scales of correlation: self (#), friends (blue), family (green) & teams (light red).

Emergent Boundaries

Skin inward Self
Skin outward Friends
Gene inward Family
Gene outward Hierarchy
Idea inward Culture
Idea outward Profession

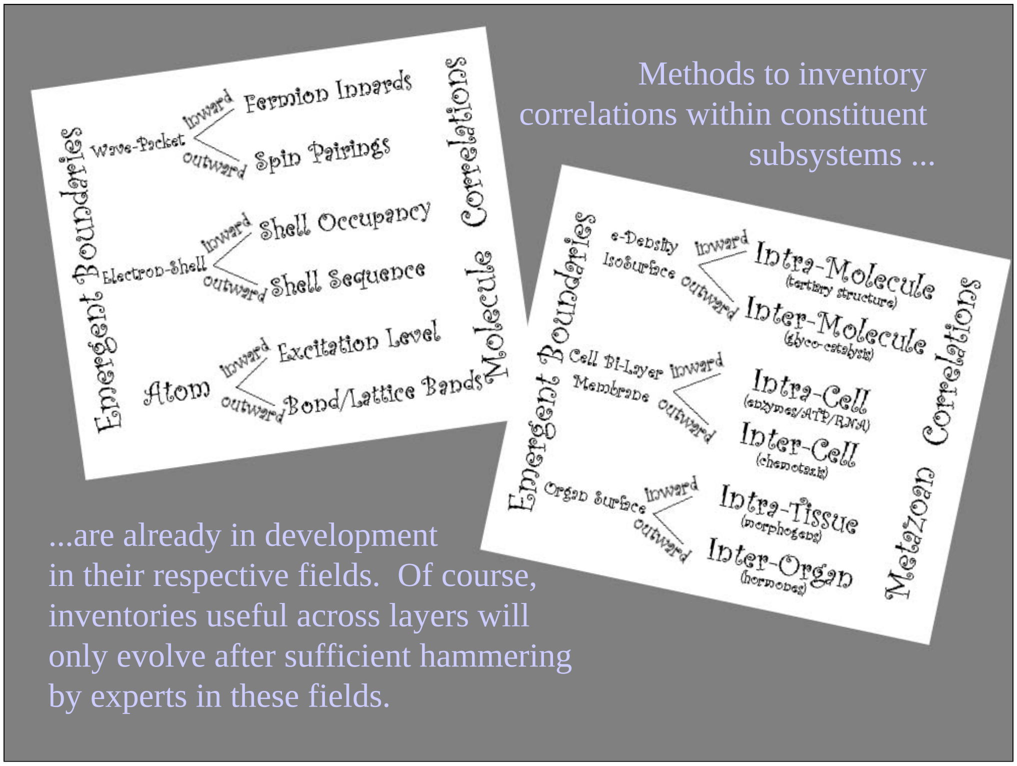
Community Correlations

- The right figure takes a clue from the way our species (e.g. Schaik in *Sci Am* 4/2006) conceptualizes its own networks.
- The left column lists three geometrically complex physical boundaries: metazoan skin, gene pool, and meme pool.
- At right, find six niche layers that each individual can concurrently occupy.

Note: We refer to the correlations between individuals discussed here as “soft” because they are both (i) easily perturbed, and (ii) difficult to assess objectively even by the individuals directly involved. The recent Scientific American article mentioned above illustrates how these kinds of connections have recently been assessed as objectively as possible in comparing some orangutan communities. This work also provides excellent evidence that soft correlations are fundamental to the natural history of invention in human society as well.

Question from Wayne Davis of UIUC: Why only 6-levels?

Answer: There are essentially only three physical boundaries involved: Metazoan skins, molecular code-pool boundaries (already nightmarishly complicated in a geometric sense), and idea code-pool boundaries (e.g. as physically encoded in recordable speech, writing, and a wide range of replicable digital formats including video) are the physical boundaries which underpin those inward and outward looking niche structures (and associated idea sets) that we spend most of our time talking about. In order of increasing layer-scale these six subjects of discussion are health care, pair bonds, family matters, political hierarchy, culture/religion, and scientific/extra-cultural processes and lore.

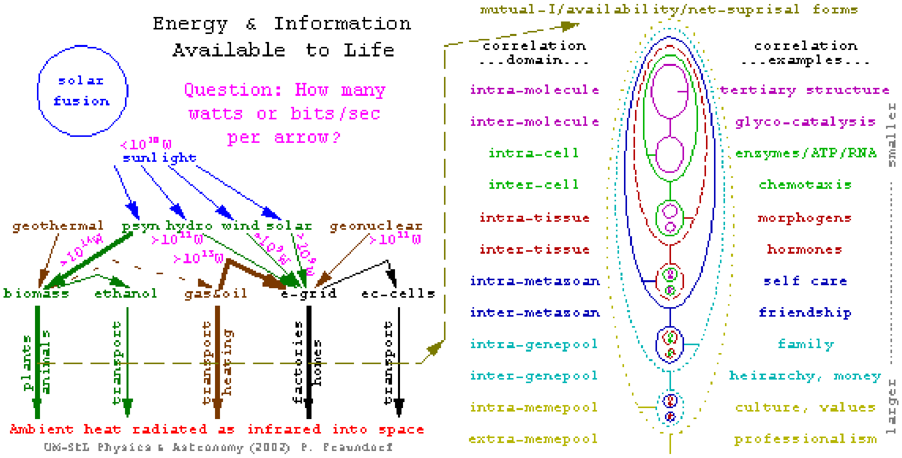


Methods to inventory correlations within constituent subsystems ...

...are already in development in their respective fields. Of course, inventories useful across layers will only evolve after sufficient hammering by experts in these fields.

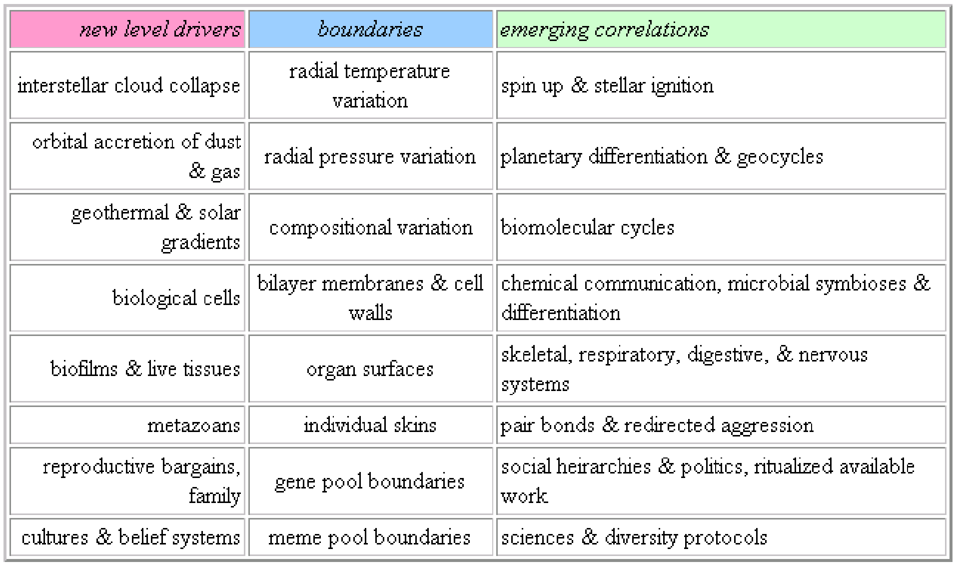
This slide illustrates schematically how many of the other types of correlation discussed at this conference might be integrated into the larger picture as well. In turn, the larger picture of correlations associated with emergent physical (typically gradient, membrane, and eventually code-pool) boundaries allows for some striking, and potentially quantitative, visualizations...

Given a way to inventory correlations in such a layered niche network, informatics then says that reversible thermalization fits beatifully into the energy/information flow picture...



The left hand side of this plot tracks the flow of available work through e.g. from incoming sunlight to its exit from our planet as thermal radiation. The right hand side illustrates correlations within and across half a dozen sub-system boundary types, ranging from molecule surfaces to the boundary between cultures. Thus thermal physics in natural units provides clues to the role of reversible thermalization in the natural history of invention. This will continue to impact our day to day life, particularly as social distance across the planet continues to shrink. The physics of information can in this way help tie together disparate studies of evolving complexity.

These layers of correlation-based complexity also stack temporally, putting the natural history of invention into the same integrative context



new level drivers	*boundaries*	*emerging correlations*
interstellar cloud collapse	radial temperature variation	spin up & stellar ignition
orbital accretion of dust & gas	radial pressure variation	planetary differentiation & geocycles
geothermal & solar gradients	compositional variation	biomolecular cycles
biological cells	bilayer membranes & cell walls	chemical communication, microbial symbioses & differentiation
biofilms & live tissues	organ surfaces	skeletal, respiratory, digestive, & nervous systems
metazoans	individual skins	pair bonds & redirected aggression
reproductive bargains, family	gene pool boundaries	social heirarchies & politics, ritualized available work
cultures & belief systems	meme pool boundaries	sciences & diversity protocols

The table above sketches the sequential development of these boundaries, and physical systems to which associated concepts apply, through the natural history of invention. For the remainder of this talk, we'll concentrate on the last three rows in this table, i.e. on correlations involving metazoan individuals.

The foregoing discussion of layered niche networks raises some questions

- How long have all six layers been evident with humans? For example, just as **metazoans** and the Cambrian bloom were prefaced by certain technological developments in our ***symbiosis with molecular codes***, so **intra-cultural behaviors** have leveled-up with the development of ***spoken language***, and **inter-cultural behaviors** with the development of ***written and electronic communcation***.
- If shared human development predates the availability of six distinct layers, does that mean that as individuals we cannot be expected to do all six well at the same time?
- Can objective measures of standing crop be developed which complement census and GNP, for example?
- Chaisson has observed that complexity correlates phenomenologically with free energy rate density. Will a lower per capita free energy rate mean we can’t maintain all six layers?

(1) Elements of culture (e.g. song, dance, fashion, bauer) are of course familiar in communities of many other species. However, with the development of written symbols and language the distinction between culture and extra-cultural knowledge has taken a leap in human communities not evident before say 40,000 years ago.

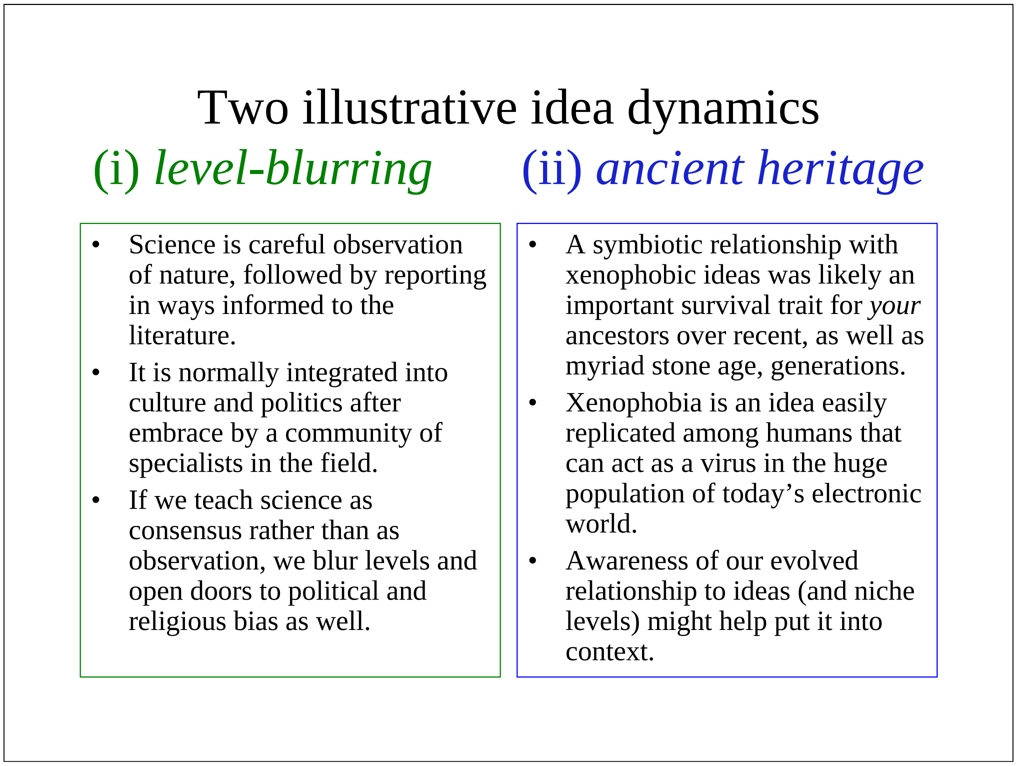
(2) Perhaps you can do equally well with all six niche layers, but I certainly can’t.

codes (we-memes) have been developed to maintain each niche layer

- We have separate bits of *lore* for taking care of: ourselves, our friends, our family, our community, our culture, and our profession.
- Just as biologists have discovered that molecular codes have a life and perspective of their own, so do increasingly mobile idea codes. Taking their perspective into account is crucial. For example:

science as observation versus consensus

niche-level humility versus evolved xenophobia



Two illustrative idea dynamics

(i) *level-blurring* (ii) *ancient heritage*

- Science is careful observation of nature, followed by reporting in ways informed to the literature.
- It is normally integrated into culture and politics after embrace by a community of specialists in the field.
- If we teach science as consensus rather than as observation, we blur levels and open doors to political and religious bias as well.

- A symbiotic relationship with xenophobic ideas was likely an important survival trait for *your* ancestors over recent, as well as myriad stone age, generations.
- Xenophobia is an idea easily replicated among humans that can act as a virus in the huge population of today's electronic world.
- Awareness of our evolved relationship to ideas (and niche levels) might help put it into context.

On the confusions introduced by bundling scientific observation with scientific consensus, both Martin Gardiner and non-scientist Michael Crichton have things to say which carry some truth.

On the interaction between media and xenophobia, when I was in college the media inspired unjustified xenophobia e.g. that made students afraid to participate in a productive "big brother" program at an infamous housing project in the region. Today, by comparison, mediated xenophobia now not only generates real hazard, but has become a business opportunity for folks from all walks of life.

Recap: Convergent disciplines, like nanoscience, astrobiology & informatics, support that...

- Correlations (created by reversible thermalization of free energy) between subsystems are oft used to monitor evolving complexity's standing crop.
- Symbiosis between steady state excitations and replicable codes is a recurrent theme on earth, where correlations are sometimes represented by a layered network defined with respect to physical boundaries of wide-ranging size & complexity.
- Five of the six niche layers for individuals (looking inward and outward from the physical boundaries of metazoan skin, gene pool, and meme pool) have been distinct for much of human evolution.
- Blurring of these levels may be expected to result from declining free energy per capita.
- The dynamic of ideas supporting these levels deserves study.

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