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The Archaeology of Innovation: Inventing our way out of trouble

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Contents

- The challenge
- The innovation perspective
- Biology is only part of the story
- Cognitive bootstrapping
- Four ‘revolutions’:
  - Settling down
  - Urbanization
  - Empires
  - Energy
- The drivers
- Some implications

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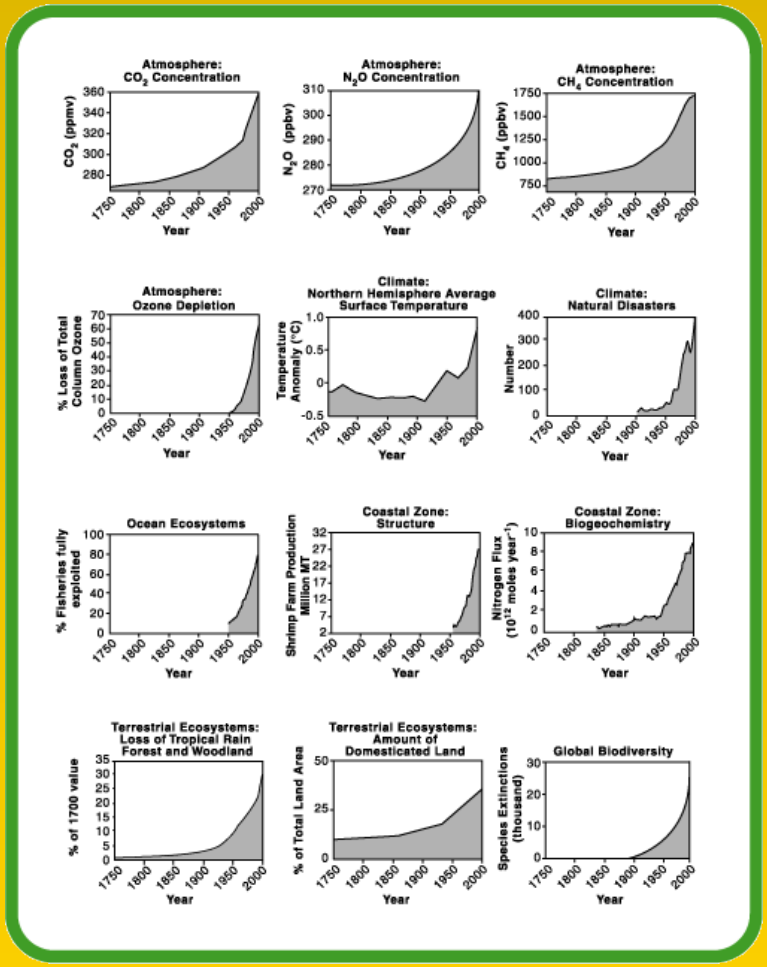
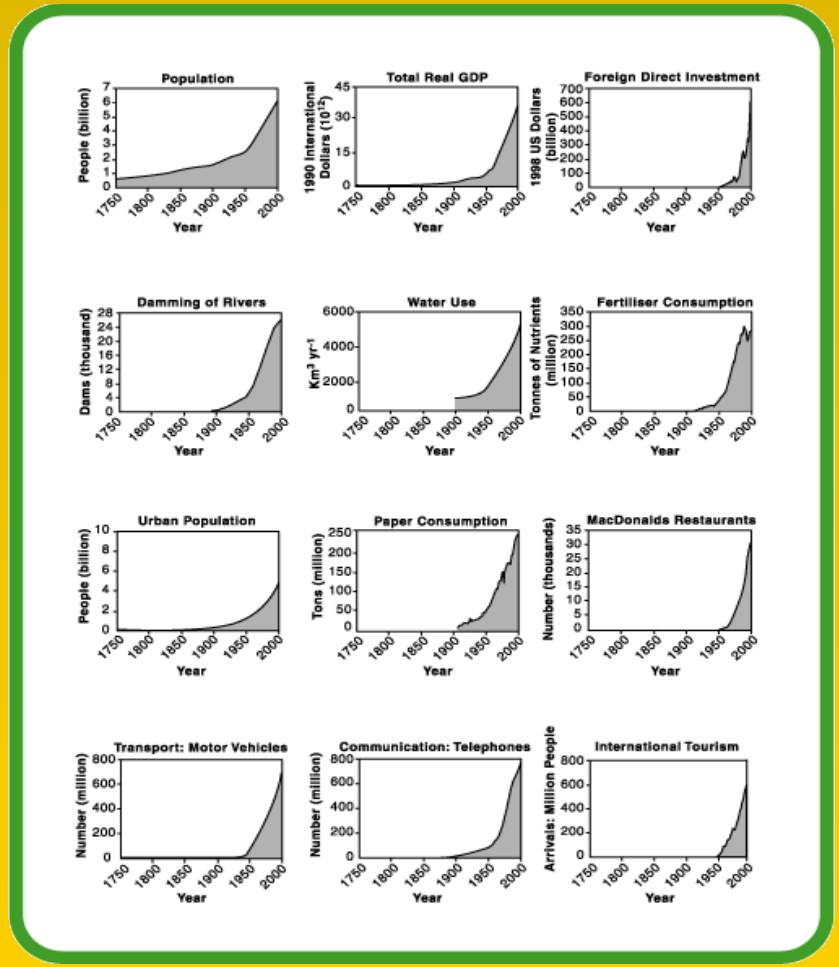
The environmental crisis…





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Looking at the long term

- Including the long-term dynamics
  - Tectonics over 10^5 years
  - Cultures over 10^3 years
- Observing complete cycles
  - Not only the last 100 or so years
  - Observing wider range of behaviors
  - Correcting for bias
- Observing the change of change
  - From long-term investment to short-term 'dealing'

The innovation perspective

- Which questions do the 'hockey-stick' curves pose?
  - Why did 'it' take so long?
  - Why did 'it' go so fast, once 'it' got going?
  - What is 'it'?
- **'It' is not the climate or the environment, but the innovative capacity of society**
  - *What is different about humans that they can develop complex technologies?*
  - Are the enabling factors biological or socio-cultural?

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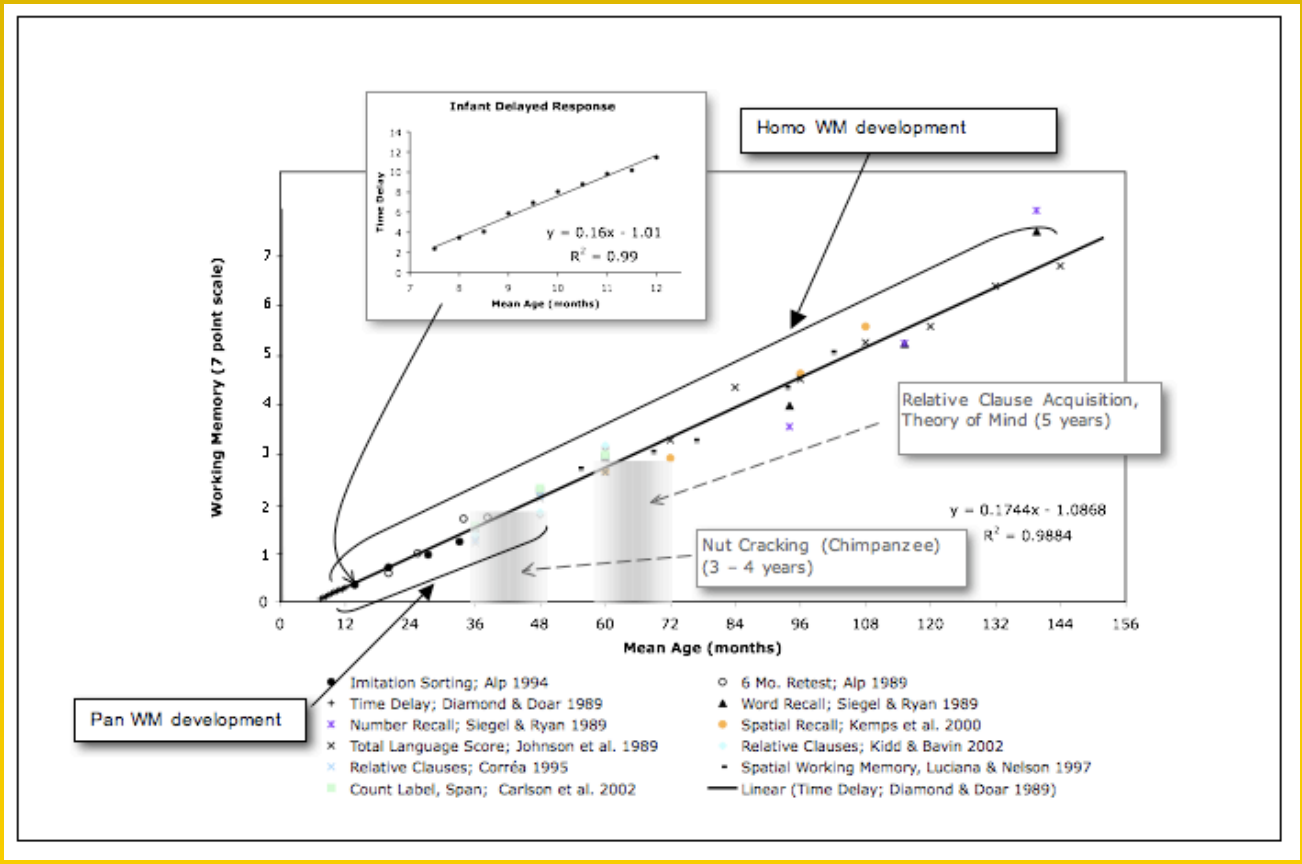
Short Term Working Memory seems the clue

- STWM differs between humans and primates & other animals
- Can we document this?
- Direct evidence: size of adult STWM impacts on operations
  - Chimpanzee nut cracking involves 3 objects (anvil, nut, hammer)
  - 25% of chimpanzees never learn to do this: STWM is 2 +/- 1
  - Other tests point to same: token combinations, object manipulation, gesture combinations
  - Modern human STWM is 7 +/- 2
- Indirect evidence:
  - STWM development
  - Encephalization

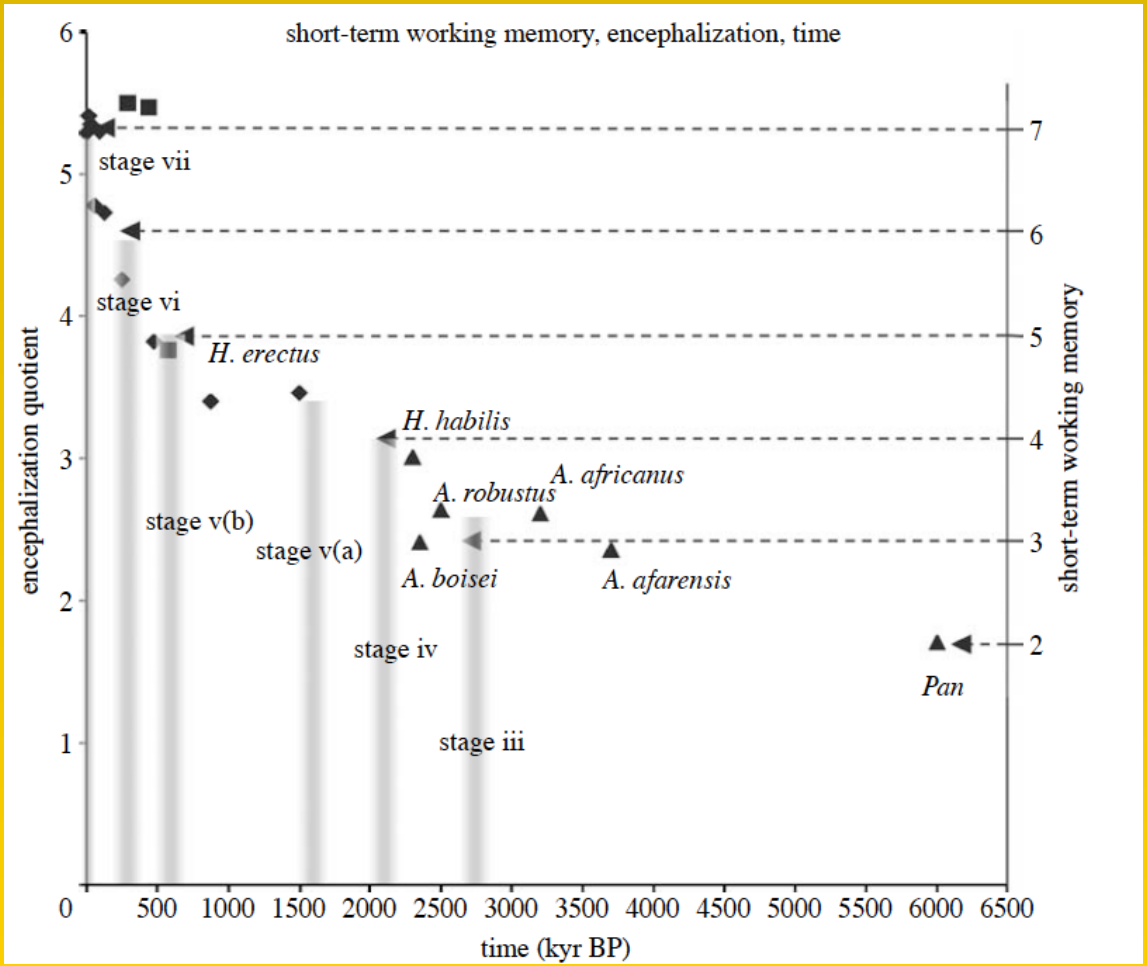
STWM develops with age



Trend line projected from Time Delay Response regressed on Infant Age (see inset). Data rescaled for each data set to make trend line pass through mean of that data set. Working memory scaled to STWM = 7 at 144 months.

Fuzzy vertical bars compare age of nut cracking among chimpanzees with age for relative clause acquisition and Theory of Mind conceptualization in humans.

Encephalization takes time



Graph of encephalization quotient (EQ) estimates based on hominid fossils and Pan.

Early hominid fossils have been identified by taxon. Each data point is the mean for hominid fossils at that time period. Height of the 'fuzzy' vertical bars is the hominid EQ corresponding to the date for the appearance of the stage represented by the fuzzy bar. Right vertical axis represents STWM. Data are adapted from as follows: triangles, Epstein (2002); squares, Rightmire (2004); diamonds, Ruff et al. (2004).
EQ = brain mass / (11.22 * body mass$^{0.76}$) (Martin 1981).

Artifacts and STWM development

- Size of STWM is constraint on cognitive complexity of early artifacts
  - Derive from conceptual complexity of artifacts indication of size of STWM
  - The simplest conception of an artifact is a combination of geometric and topological properties
    - Example: Oldowan chopper conceived as cutting line made by repeating ‘point’ flaking
- Cognitive complexity of stone tool conception is indicator for STWM development
- Similar arguments made for language development and abstraction in kinship systems
- Next slide shows evolution

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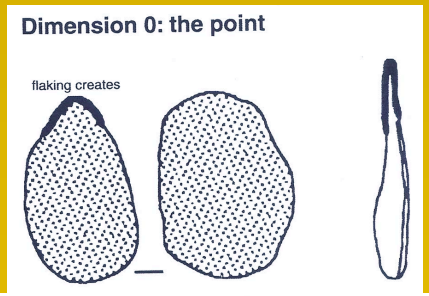
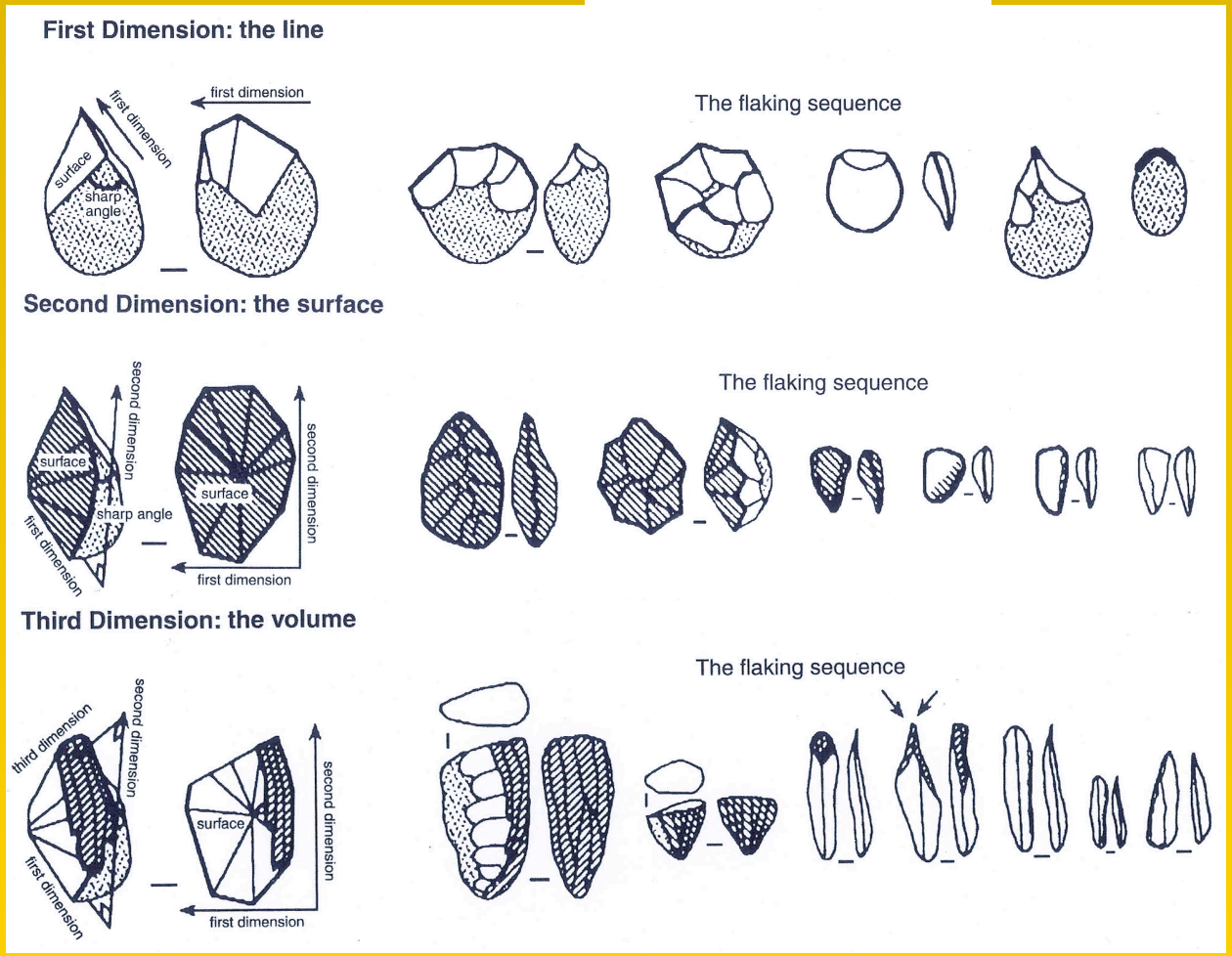
The road to 3-D





Gaining control over all three spatial dimensions took some 2 million years

After: N. Pigeot, 1990

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Evolution of stone tool technology

Stage	Concept	Action	Novelty	Dimensionality	Goal	Mode	STWM	Age BP	Example
1	Object attribute	Repetition possible	Functional attributes already present; can be enhanced	0	Use object		1		
1A	Relationship between objects		Using more than one object to fulfill task	0	Combine objects		2		
2	Imposed attribute	Repetition possible	Object modified to fulfill task	0	Improve object		2	> 2.6 My	Lokalalei 1
3	Flaking	Repetition	Deliberate flaking, but without overall design	0: Incident angle < 90°	Shape flakes		3	2.6 My	Lokalalei 2C
4	Edge	Iteration: each flake controls the next	*Débitage:* flaking to create an edge on a core	1: Line of flakes creates partial boundary	Shape core	1	4	2.0 My	Oldowan chopper
5	Closed Curve	Iteration: each flake controls the next	*Débitage:* flaking to create an edge and a surface	2: Edges as generative elements of surfaces	Shape biface from edge	2	4.5		
5A	Surface	Iteration: each flake controls the next	*Façonnage:* flaking used to make a shape	2: Surfaces intended elements, organized in relation to one another	Shape biface from surfaces	2	5	500 Ky	Biface hand–axes
6	Surface	Algorithm: removal of flake prepares next	Control over location and angle of flaking to form surface	2: Surface of the flake brought under control but shape constraint	Serial production of tools	3	6	300 Ky	Levallois
7	Intersection of planes	Recursive application of algorithm	Prismatic blade technology; monotonous process	3: flake removal retains core shape – no more shape constraint	Serial production of tools	4	7	> 50 Ky	Blade technologies

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Palaeolithic stone tool evolution

Oldowan chopper

Acheulean handaxe

Mousterian handaxe

Levallois tool

Solutrean blade

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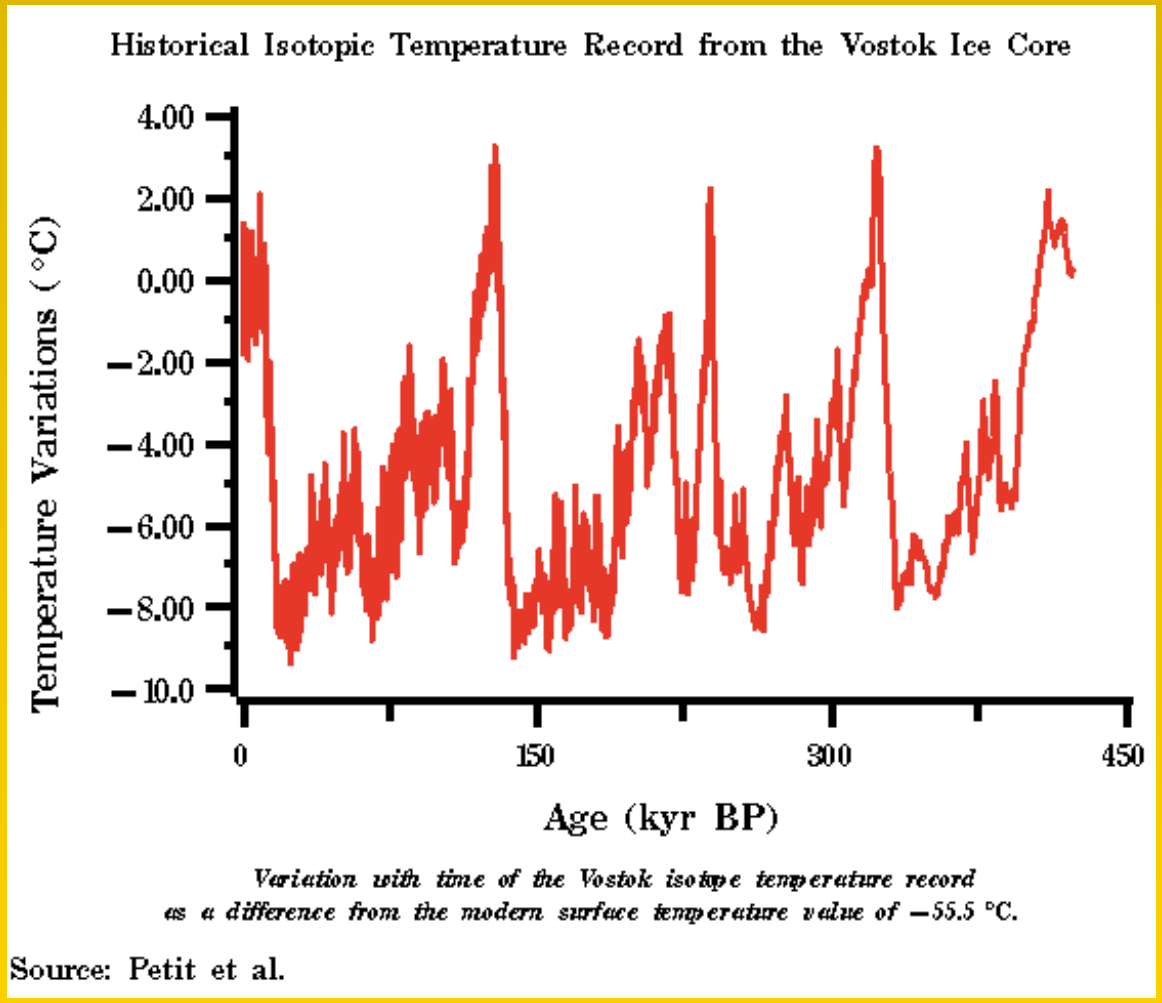
Pleistocene Climate is unstable



Climate change was dramatic, but cultural change was minimal

Why is that so?

How did Pleistocene hunter-gatherers survive?

- Throughout the Pleistocene, humans survived through the (Ice) ages, by
  - Harvesting the environment's offerings
  - A multi-resource strategy
  - Adapting to change by moving
  - Staying below the environment's carrying capacity
    - Australian famines only in river valleys
- And that, without much change in behavior:
  - People lacked the know-how to inter-act with their environment; they could only re-act to it
  - Change and risk were the order of the day
  - Yet people minimized change
    - Epirus caves inhabited where tectonics keep change limited

Operations available c. 50,000 years BP

- Distinguish between reality and conception
- Categorization based on similarities and differences
- Feedback, feed–forward and reversibility
  - Memory and control loops
  - Mental generation of events potentially to be inserted in operations
- Basic hierarchies
  - Point-line-surface-volume
  - Size (hierarchy of scales)
  - Control loops
- Partonomy
  - Reversal between core and flakes as tools
- Sequentiation and anticipation
  - Separation between stages of production

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Modern Humans

- STWM of 7 +/- 2 is sufficient for all cognitive needs of Modern Humans (*Homo sapiens sapiens*) to date (but how about the future?)
  - Biology no longer a constraint!
  - That constraint explains slow evolution up to this point, acceleration from now on!
- Explosion of new operations
  - Are there other constraints?
  - What are the consequences of acceleration?

Bootstrapping process now the limit

- In the simplest terms:
  - More people --> more needs --> more problems --> more brainpower --> more people …
- In not so simple terms:
  - Problem solving structures knowledge --> increases information processing capacity —> allows the cognition of new problems —> creates new knowledge --> more and more people involved in processing information —> population and its aggregation increase
- In the process, major social transformations

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Mesolithic/Neolithic tools

Magdalenian tools

Later Mesolithic tools

Mesolithic composite tools (reconstructed)

Neolithic axes

Neolithic fish trap

Neolithic basketry (reconstructed

‘Inventions’ c. 10 Ky BP

- Control over shape complete
  - Flake removal from large to small, polishing
- New topology
  - Solid around void: pots, baskets, houses
    - Separation of concepts of surface and volume
    - Tangled hierarchy of concepts: surface defining volume is defined by other volume
- Inversion of sequence of manufacturing
  - From small to large
    - Assembling instead of removing
- Stretching temporal sequences
  - Separate stages of manufacturing

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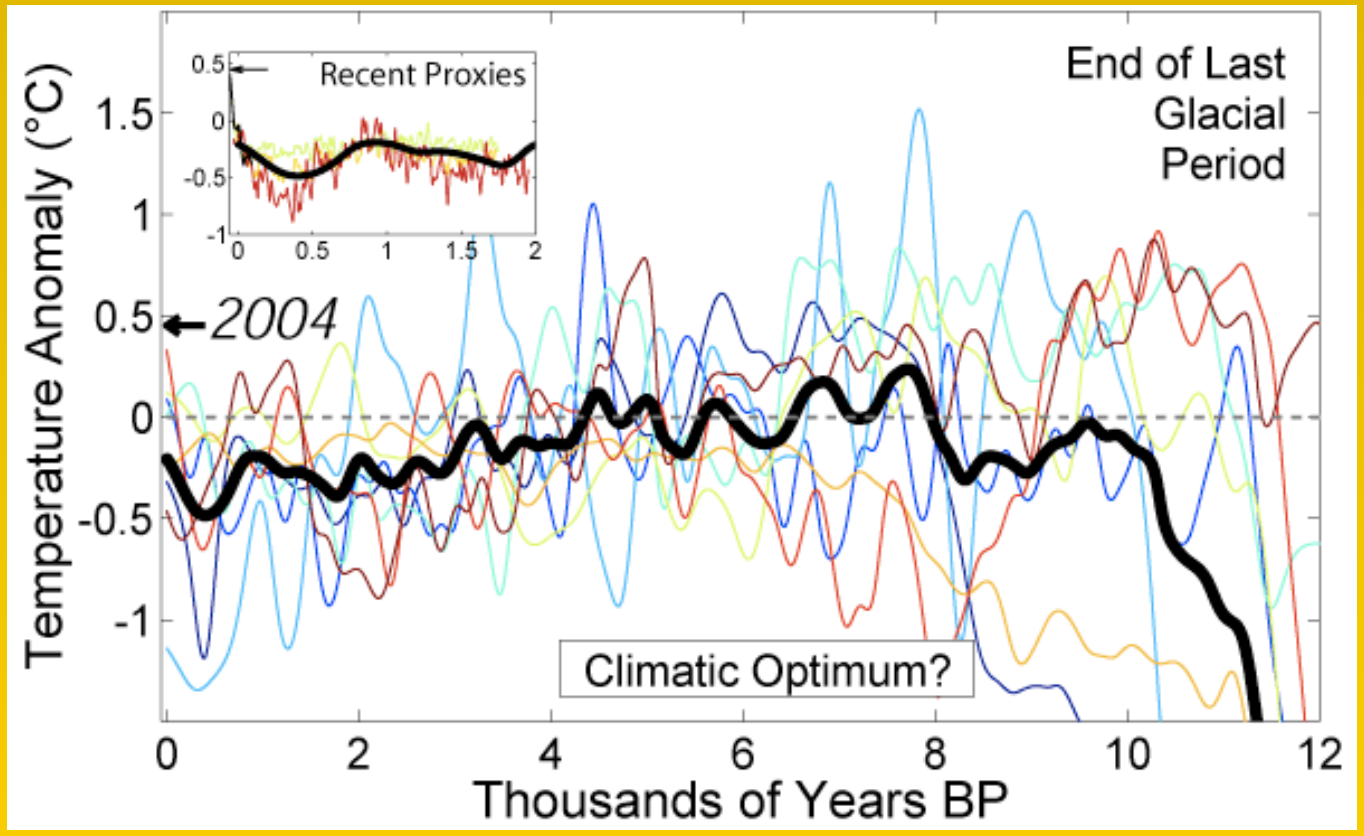
Holocene climate stabilization



After Robert A. Rohde, Global Warming Art

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What happened in the Neolithic?

- A fundamentally different way of life…
  - Change in subsistence base: cultivation, herding
  - New technologies: ceramics, basketry, huts
  - Different mode of life: villages
  - Different social life: larger groups
  - Different perception of space & time
- From harvesting the environment to investing in it. Why?
  - Mobility no longer the way to meet challenges
  - Old system was adapted, could have continued
  - Change in conceptual toolkit evolved during Pleistocene
- Is climate driver or enabler?

Neolithic technologies

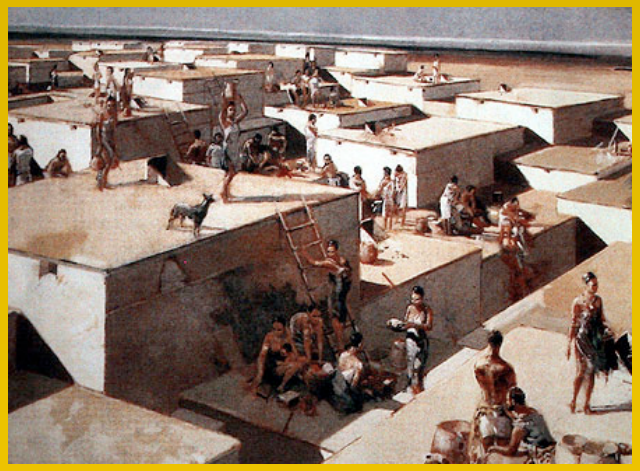
Mergarh neolithic village, Iran

Neolithic ard (reconstructed)

Stonehenge

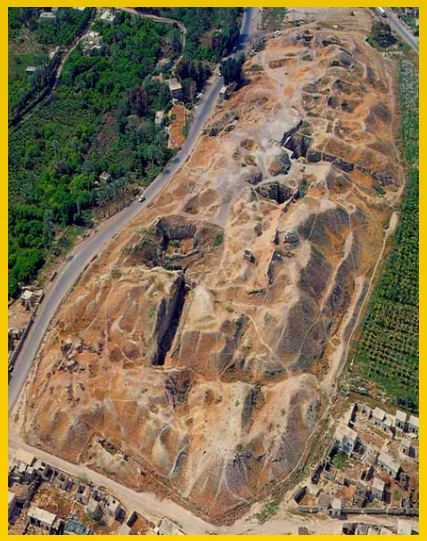
Neolithic statue, Romania

The first villages



Catal Hüyük, Turkey

Jericho, Israel



Skara Brae, Orkneys

How did that change the dynamics?

- Reciprocal relationship to environment and climate
  - Climate can change society *and vice versa!*
- Growing interventionism in nature
- Sedentary societies try to control environmental risk:
  - Simplify the environment
  - Spatial and technical diversification
- As the system integrates, it is more vulnerable to disturbances
- The emphasis shifts to problem-solving
  - Diversification and specialization
  - Ever larger interactive groups
- The cost is growing social complexity
  - Increasing investment in maintaining society
  - As groups grow, cohesion becomes a problem

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The first 'cities'

Uruk (reconstruction)

Hamukar

Caral, Peru

The bootstrapping process reaches a different stage

- Urbanization is costly in energy terms
- Need for better problem solving is the driver, bringing more and more people in more direct contact
- Dynamical structure organizes the environment in order to draw energy from it:
  - Outbound flow: organization;
  - Inbound flow: energy
- To keep the flows going, innovation in center is essential
  - Innovation needs/attracts people
  - Innovation requires many cognitive dimensions, thrives in towns, comes to drive urbanization

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Cities emerge in clusters

Etruria

Aegean

Mesopotamia

Crete

Maya and Aztec

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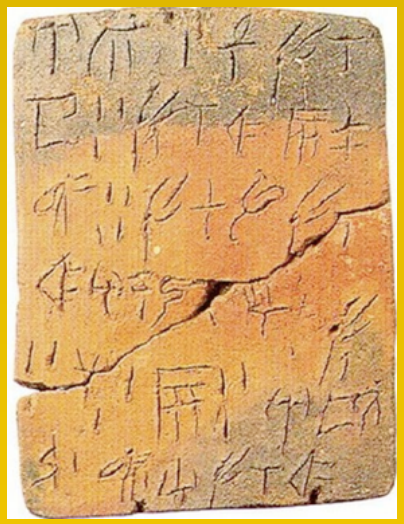
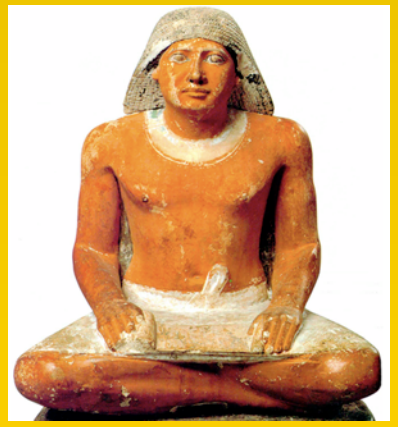
Accounting and writing



Laws, administration, archives

Administration and law (Hammurabi) enforcement created the first bureaucracy (Egyptian scribe), the first archive (Ebla)



The Imperial revolution

- Energy ever more of a constraint
  - Dynamical structures to cross societies, languages, cultures …
  - Not possible unless they can use pre-collected energy (treasure)
- Roman Empire as an example
  - Grew on the back of centuries of ‘leaked’ organization to Mediterranean periphery
- From ‘power to’ to ‘power over’:
  - Formal institutions and their roles
    - From conflict resolution to resource and people management
  - Roads and communication

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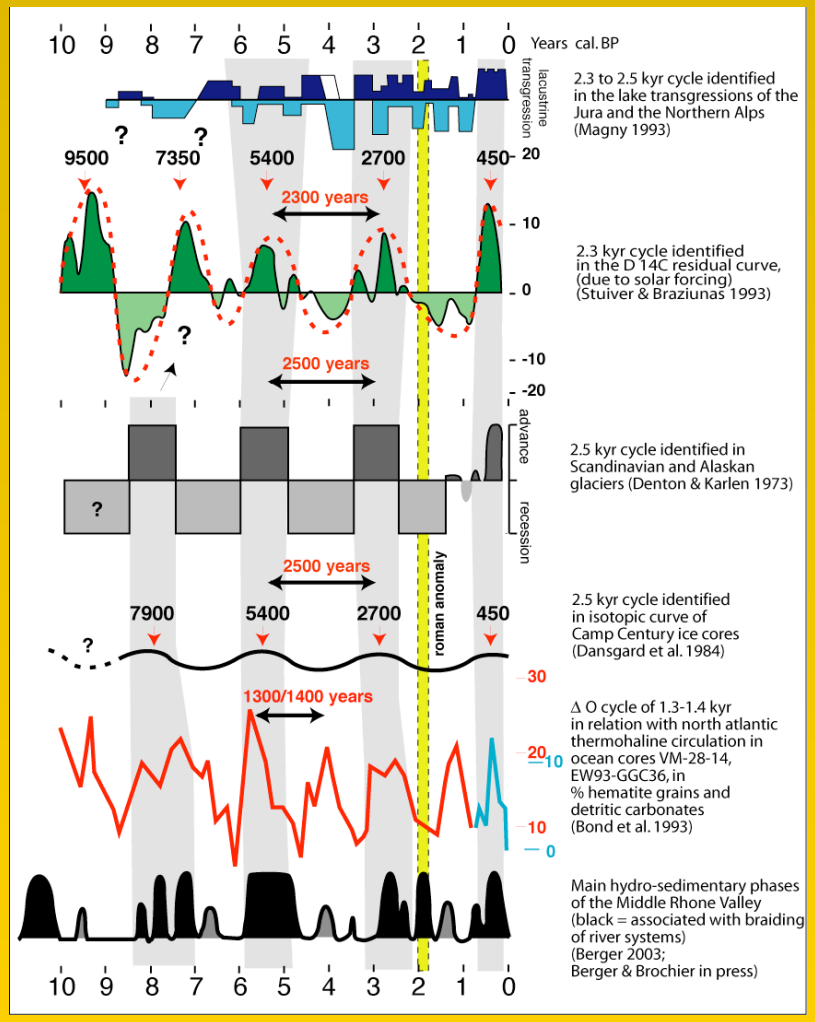
Growth of the Roman Empire 44 BC-AD 117

As it grows …

…roads keep it together

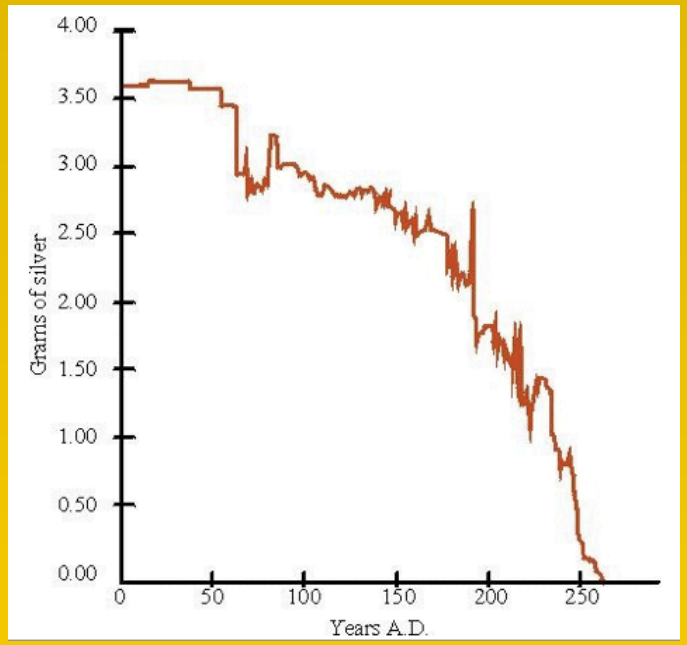
Anthropogenic climate change



- Agro-industry around the Mediterranean causes regional anthropogenic climate change
- From 1st Cty AD need to feed Rome
- Olives, vines, wheat
- Serious degradation

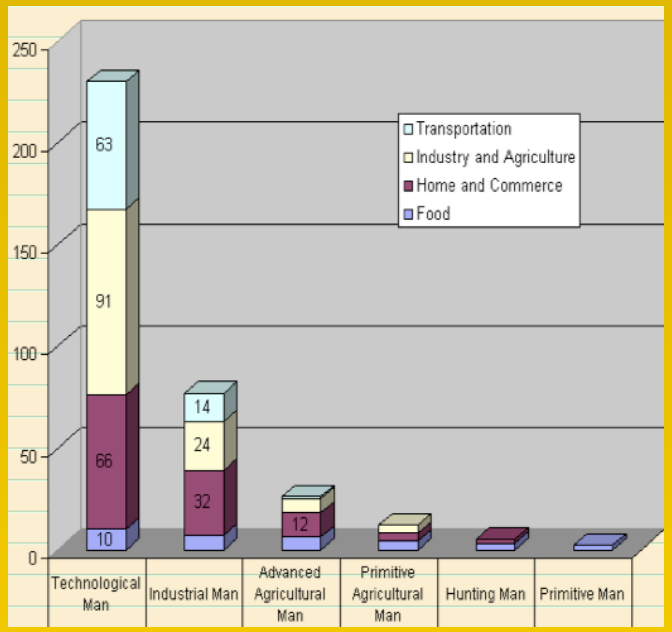
Imperial collapse

- Not really a collapse in population terms, only in organization terms
  - Splitting the Empire into four parts
  - Armies lose control at edges: incursions
- Net annual productivity too low to carry overheads
  - Increases in taxation
  - Inflation
- Loss of attractivity - people fall back on local solutions
  - Latifundia become local powers
  - Nimes loses control over water
  - Centers at the edges of the Empire (e.g. Trier)



Debasement of Roman Coinage (after J. Tainter 1988)

The Energy revolution c. 1800



Way free to harness 10,000 watts/person, invested in society and material culture

- All earlier societies limited by energy needs
  - Colonial Empires
- Energy problem solved (temporarily) with fossil energy around 1800:
- Innovation becomes endemic, supply-driven
- Western society dependent on it to continue creating value and attracting people into its system

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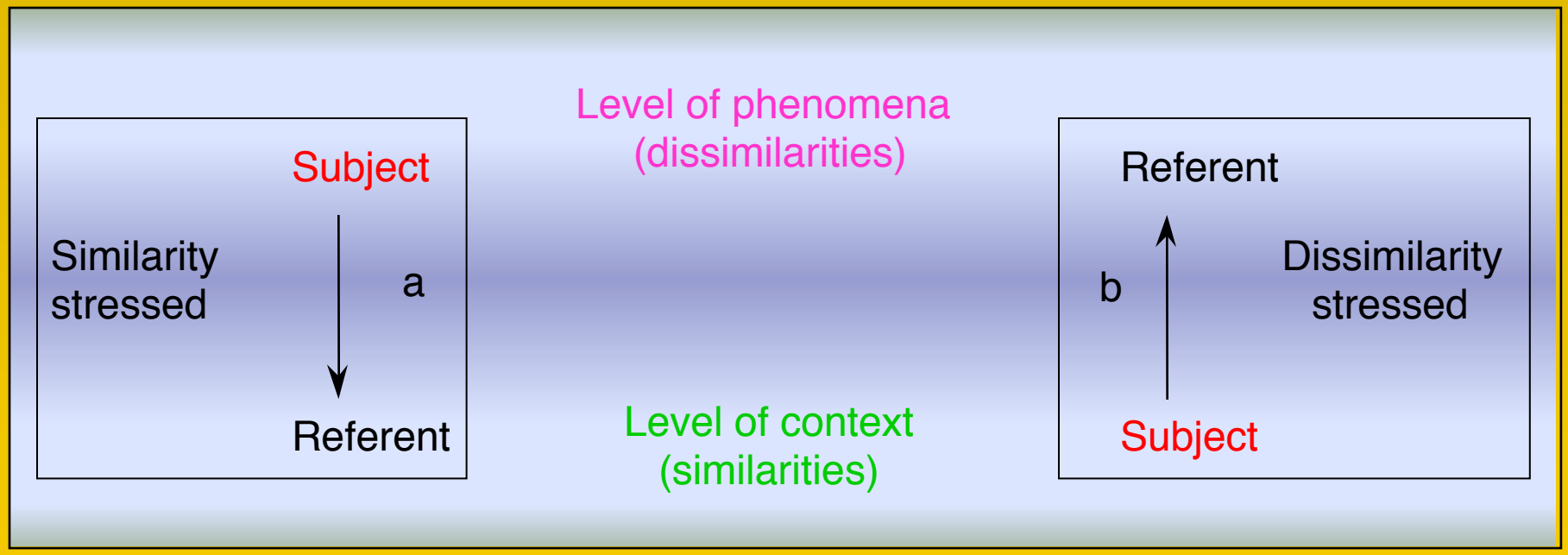
The underlying pattern

- Once the biological constraints to innovation have been overcome we see repeatedly:
  - Innovations leading to challenges, to innovations
  - Humans overcoming major hurdles
- What drives that dynamic?
  - A tangled hierarchy between two perceptions of the relationship between old and new, society and environment,
  - Leading to more and more human innovation and intervention in the environment unless constrained externally

The perception cycle



Opening a category ...

… and closing it

Two ways to perceive a relationship...

Milieu ...

- Humanity is compared to nature
- The cohesion of nature, its unknown aspects, its strangeness and force are amplified,
- The confusion and the handicaps of humanity are accentuated;
- Humanity is *passive* in a natural environment which is *active* and aggressive
- Change is attributed to nature, and people have no other choice but to adapt to nature;
- Natural changes tend to be viewed as dangerous, because they are beyond the control of humanity.

Environnement

- Nature is compared to humanity
- The cohesion and strength of nature is diminished, its known aspects emphasized
- Cohesion and strength are accentuated in humanity
- Humanity is *active* and aggressive in a natural environment that is *passive*
- Humanity tends to be viewed as the source of all change, people as creating their environment
- Natural changes seem more controllable and lose their dangerous appearance

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… and their interaction

- The "*milieu*" and "*environnement*" perspectives are complementary
- By their interaction, natural dangers are exaggerated and those of human intervention systematically undervalued.
  - This encourages society to intervene in its natural environment
  - It gives the impression that society's actions reduce risks
- In reality, society reduces by its actions the predictability of natural phenomena.
  - Society loses control: the more it transforms its surroundings, the less it understands them.
- ***This seems to be an irreversible tendency!***

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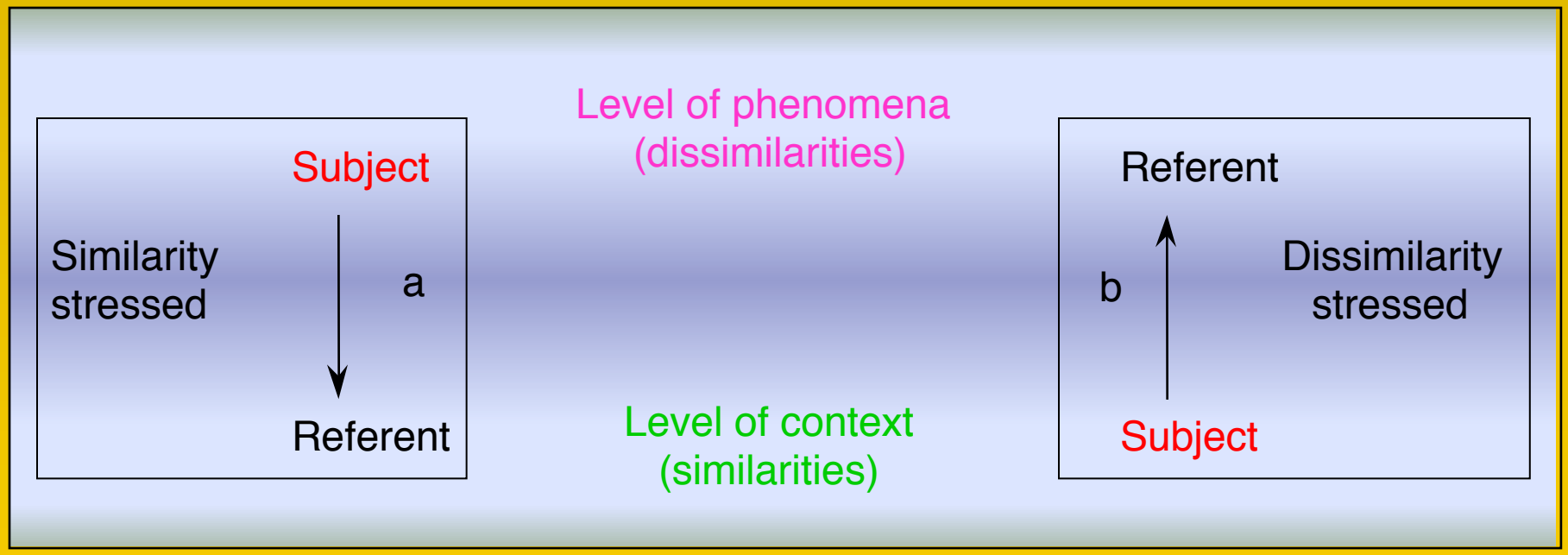
As a result

- At some point, a socio-environmental system goes out of control, because the above dynamics are irreversible
  - The appropriation of nature points in this direction
  - So does the human perception of the relationship between people and their environment
  - So does human risk perception
  - So does the relation between cognition and action
- What are the effects?
  - System pushes itself into a trap
  - Short-term solutions create long-term problems
  - Increasing cost of problem-solving
  - Reduction of flexibility
  - Risks and ‘time-bombs’
  - Initial structuring also structures the form of the demise?

The Information revolution as opportunity

- We're only at the beginning: NBIC
- We have the means to control matter, energy and information
- To shape our future, we must
  - Understand the innovation process
  - Decide the (sustainable) future we want
  - Battle (with) ourselves to achieve change
- Sustainability firmly within the social sciences
  - The innovation debate as an essential component
  - Complex systems approach because of increased in dimensionality
  - Computer science and modeling essential tools
- Redefine our social structures and institutions

The perception cycle



Summarizing the past...

… Anticipating the future

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Past, present and future

- Looking back
- Reducing dimensions
- Increasing appearance of control
- Focus on results
- Causal dynamics
- Merging space-time
- Inductive statistics
- Lawlike generalizations

- Looking forward
- Increasing dimensions
- Increasing appearance of uncertainty and risk
- Focus on preconditions
- Dynamics of emergence
- Branching space-time mathematics
- Scenarios

Reconsidering invention

- Is invention indeed completely unpredictable?
- Our ideas are under-determined by our observations – and over-determined by existing insights
- By taking a generative approach to invention and innovation can we make a probabilistic assessment of future inventions?
  - Two beginnings: ceramic research
  - USPTO categories assessment

Invention is locally happening in a network

- The network connects:
  - People
  - Ideas
  - Materials
  - Functions
  - Objects
- If we can map the network, can we identify the constraints and potentialities of innovation?

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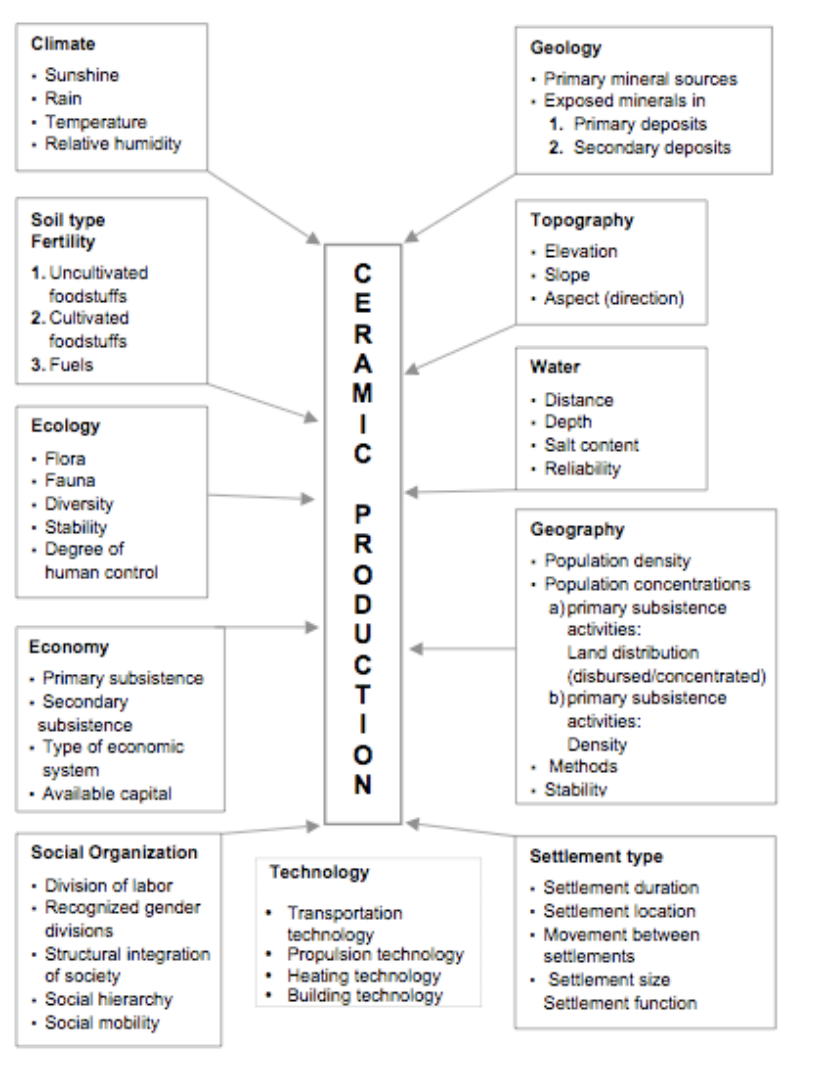
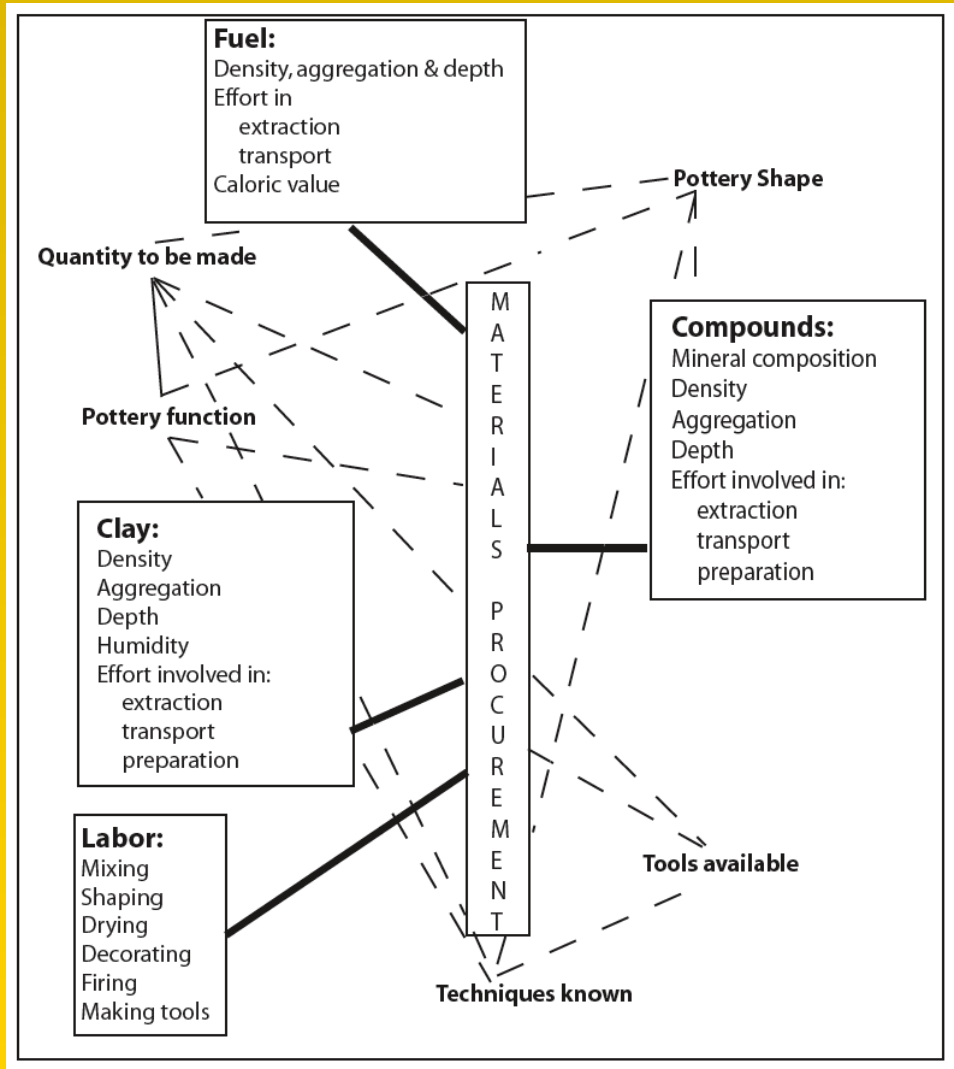
The ceramic system





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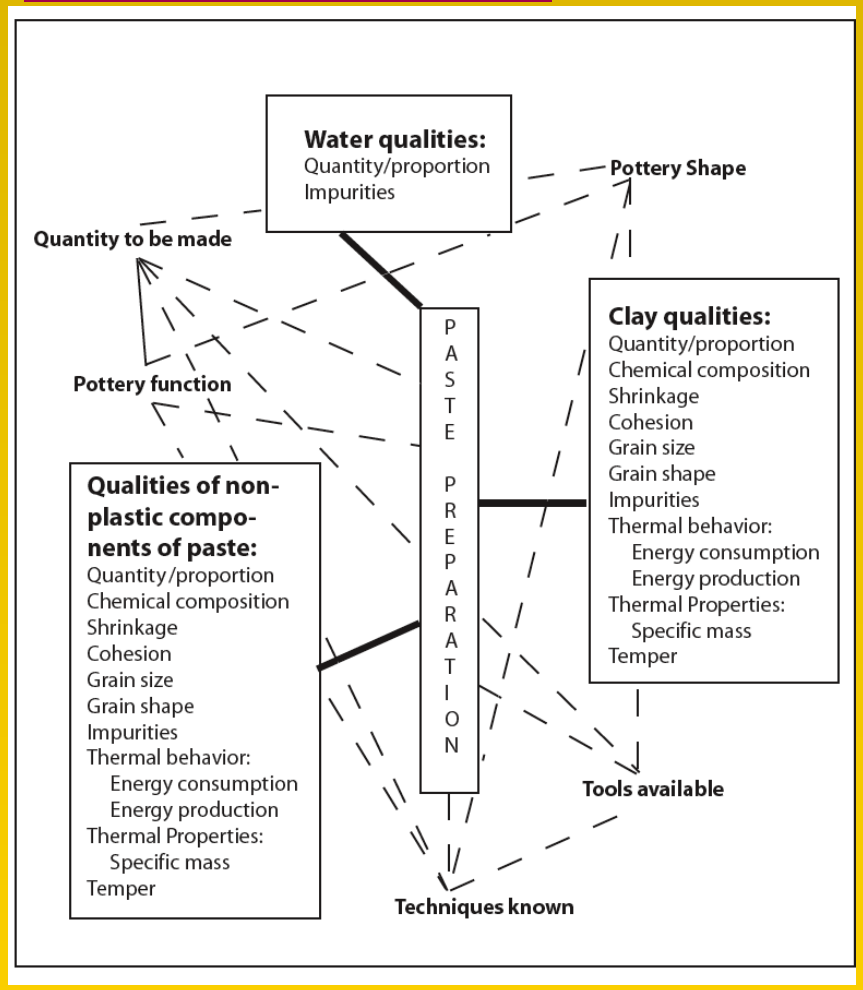
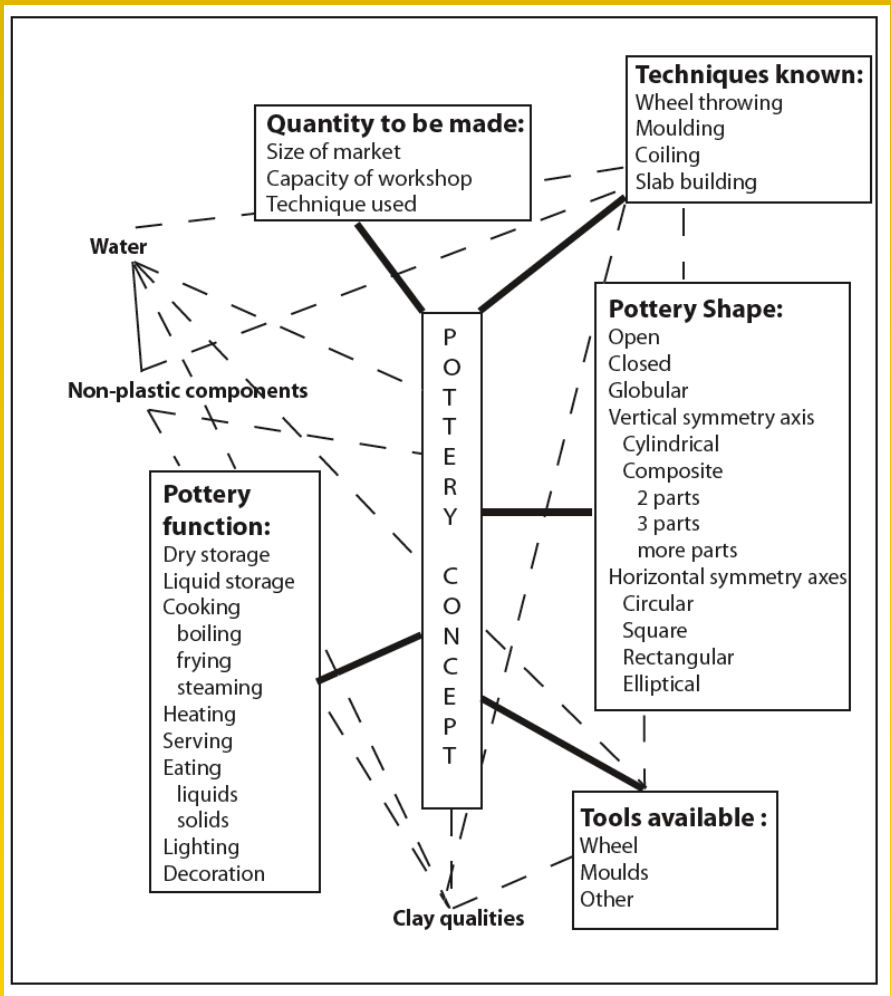
Paste preparation and conceptualization…





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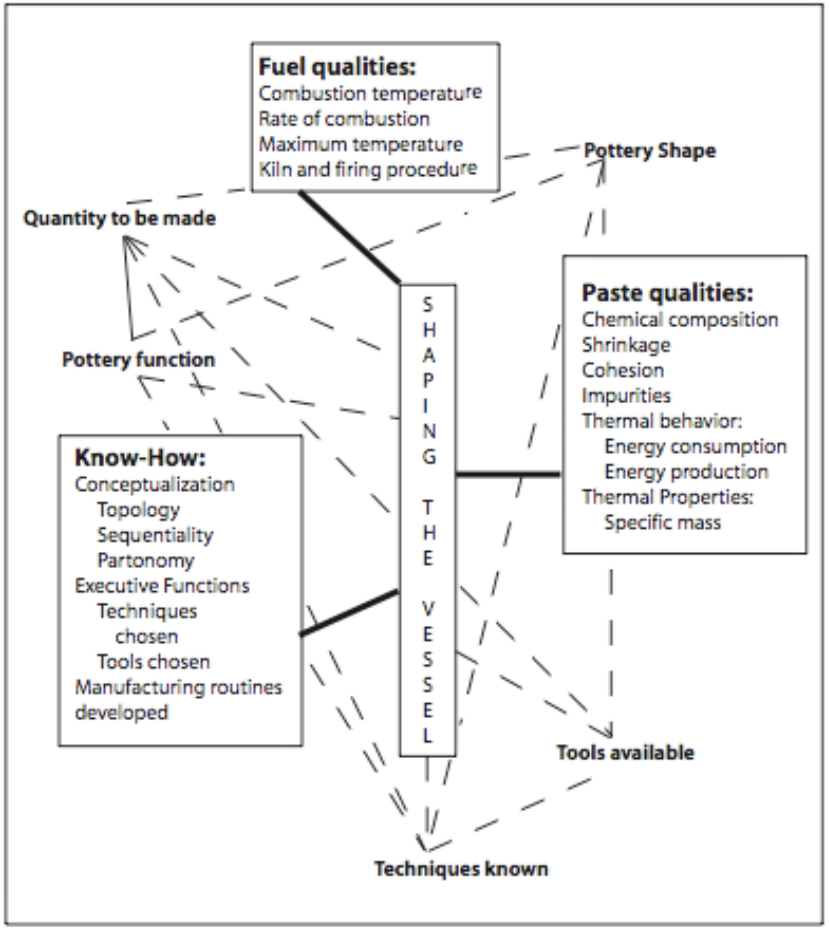
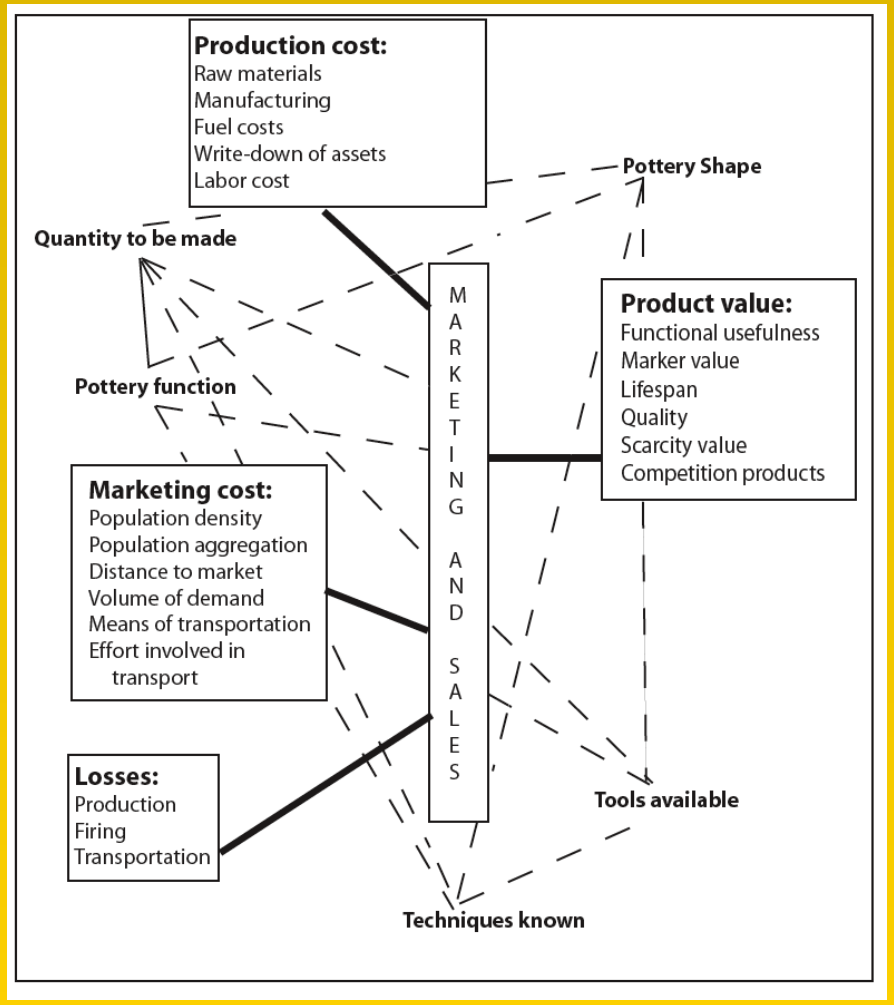
Shaping and marketing …





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The pottery system states …

Table 1. Some states of a pottery making system.

	variables	household production	household industry	individual industry	workshop industry	village industry	large-scale industry
Economy	Time involved	Occasional	Part-time	Full-time	Full-time	Part-time/Full-time	full-time
	Number involved	One	Several	One	Several	several	Many
	Organization	None	None	None	(Guild)	Certain	Certain
	Locality	Sedentary or itinerant	Sedentary or itinerant	Itinerant	Sedentary	Sedentary	Sedentary
	Hired hands	None	None	None	Some	Some	Labour force
	Market	Own use	Group use	Regional	Village/town	Region (wide)	Regional and export
	Raw materials						
	Clay	Local	Local	Local	Neighbourbood	Neighbourhood	Neighbourhood/distant
	Temper	Local	Local	Local	Neighbourhood	Neighbourhood	Neighbourhood/distant
	Water	Local	Local	Local	Local	Local	Local
	Fuel	Local	Local	Local	Neighbourhood	Neighbourhood	Neighbourhood/distant
	Investments	None	None	Few	Some	Some	Capital
	Seasonality	Production as needed	Season w/o other work	All year except winter	All year/good weather	All year/good weather	All year
	Labour division	None	None	None	Some-considerable	Some-considerable	Detailed
	Time involved per Pot	High	High	Medium	Medium-low	Medium-low	Low
	Status	Amateur	semispecailist	Specialist	specialist	Specialist	Specialist(few techniques)
Technology	Manuf. techniques tools	Hand/small tools	Hand/small tools	Hand/small tools	Mould/wheel	Mould/wheel	Wheel/cast/press
	Sed. Basin	None	None	None	When needed	When needed	Needed
	Wheel	None	None; rotary support	Turntable	Various kinds	Various kinds	Kickwheel or similar
	Drying shed	None	None	None	Needed	Needed	Needed
	Kiln	Open firing	Open firing/impermanent	Impermanent	(semi-) permanent	(semi-) permanent	Permanent
	Raw materials						
	Clay	Wide range	Wide range	Wide range	Narrower range	Narrower range	Narrow range
	Temper	Wide range	Wide range	Wide range	Narrower range	Narrower range	Narrow range
	Water	Any	Any	Any	Any	Any	Any
	Fuel	Wide range	Wide range	Wide range	Narrower range	Narrower range	Narrow range
	Range of pottery	Narrow	Narrow	Wide	Narrow or wide	Narrow or wide	Narrow or wide
	Range of functions per pot	wide	wide	wide	narrower	narrower	Narrower
Examples		Kabyles, N Africa	Cameroon, Tanzania	Tibet	Bergen-op-Zoom Farnham Haarlem	Tzintzuntzan Temascalcingo Djerba	Wedgwood Delft

ASU Complex Adaptive Systems Initiative
Arizona State University

There is a coherent logic

- Though that logic is not predictive, it co-determines the probability of certain innovations occurring
- We can therefore hope to narrow down the possibilities
- Other constraints are social, functional, cultural – we need to take those into account as well
- Modeling the whole as a complex network, I think, may allow us to understand innovation better
- It could thereforte help to focus innovation in the directions that we'd like to see