Positive Feedback, Exponential Growth and the Evolution of Human Culture

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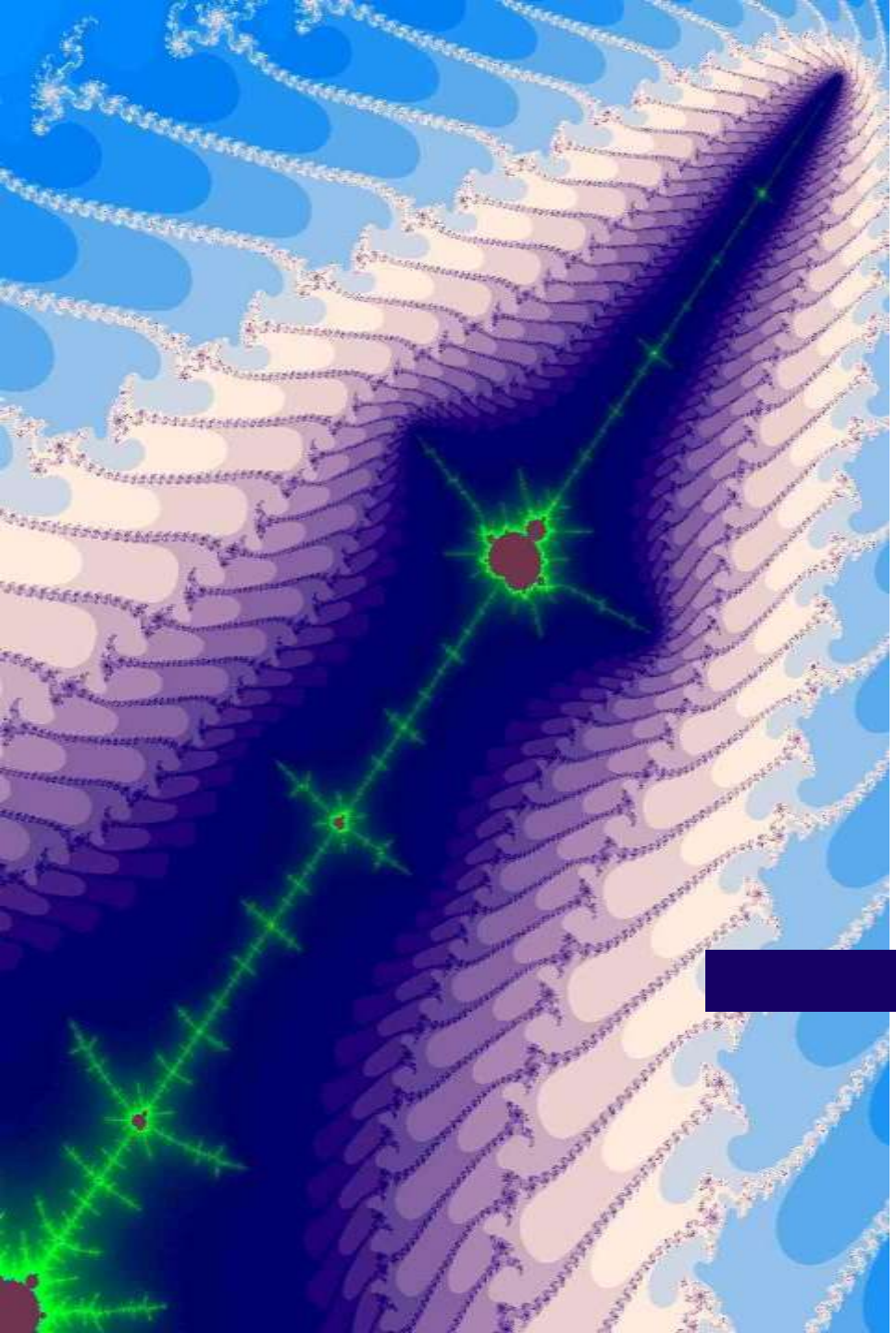


Context

Introduction

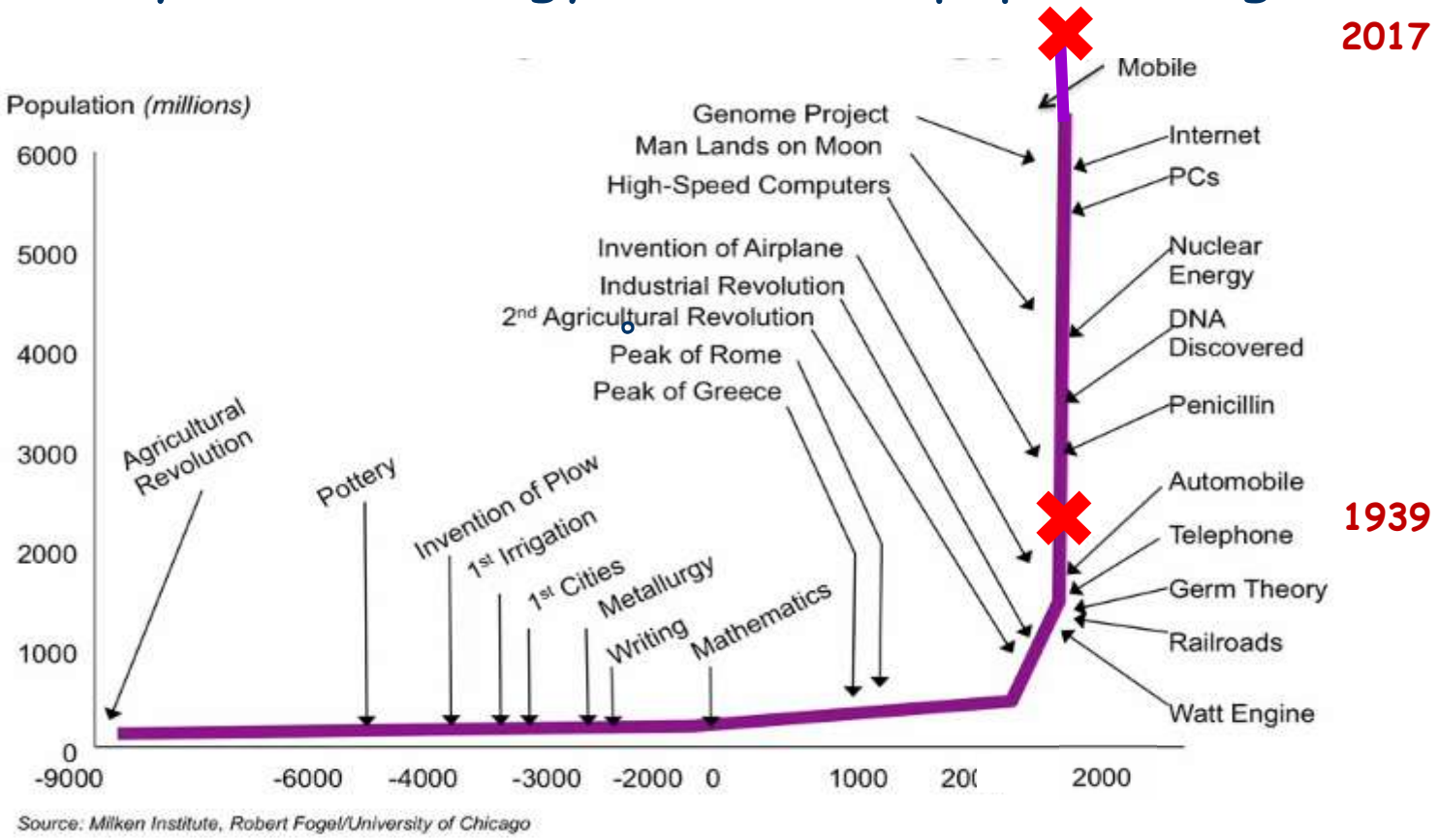
- I began my intellectual life as an evolutionary biologist
- (Hands on experience with all generations of computer technology)
- Word processing led to a second career analyzing and designing engineering knowledge management systems
- Pulling the threads together to develop an understanding of the co-evolution of technology and human cognition
- A question I often ask myself:
  - **What makes humans so unique that our species has been able to dominate the physical and living resources of our entire planet to such an extent that we seriously threaten the future existence of all species – including ourselves?**

Humanity's global footprint

- Humanity's growing population and affluence has already exceeded the "*carrying capacity*" of our planet.
- In 2013 the Global Footprint Network estimated that "humanity uses the equivalent of 1.7 planets to provide the resources we consume and absorb our waste", or around $1\frac{1}{2}$ years to replace one year's biological biological impact on the planet
- **Global footprint does not include**:
  - Depletion of critical non-renewable resources for our technologies such as oil, rare elements, etc.
  - Unsustainable use of fertile soil and fresh water
  - Collapse of world fisheries
  - Human induced global warming and climate change leading to ocean acidification, rising sea levels and inundation of prime agricultural lowlands.
  - the impacts our footprint has on possible keystone species, critical for maintaining ecosystem health
- **Rising extinction rates suggests much of the world is teetering on the edge of ecological collapse**

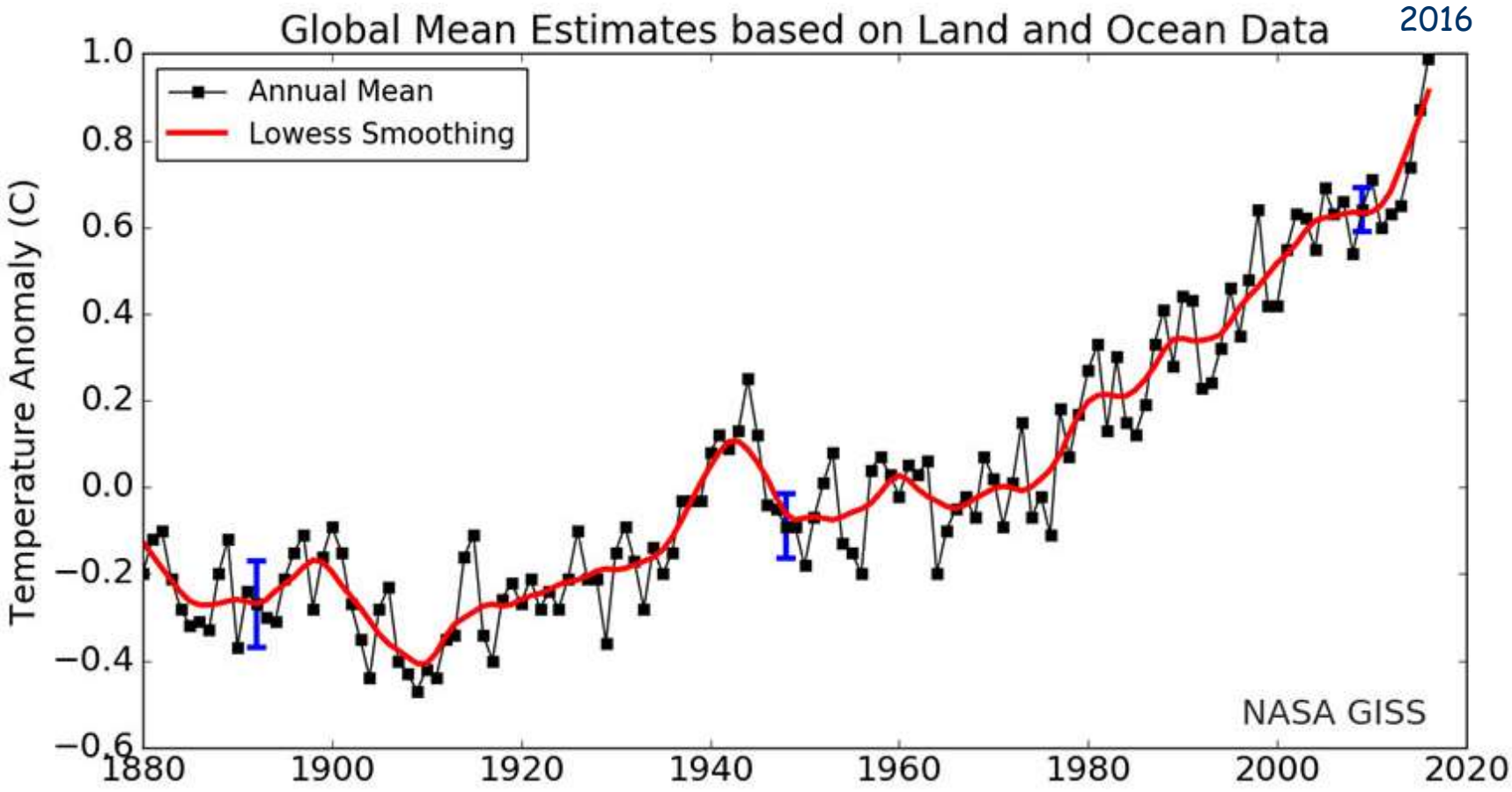
Human populations, knowledge, and technology have been growing exponentially

History of technology and human population growth



- World population when I was born in August 1939 ~2.3 bn
- **World population now ~7.5 bn; increased × 3.26 in my life**

Rapidly increasing global average temperature indicates human impacts on the planet as a whole



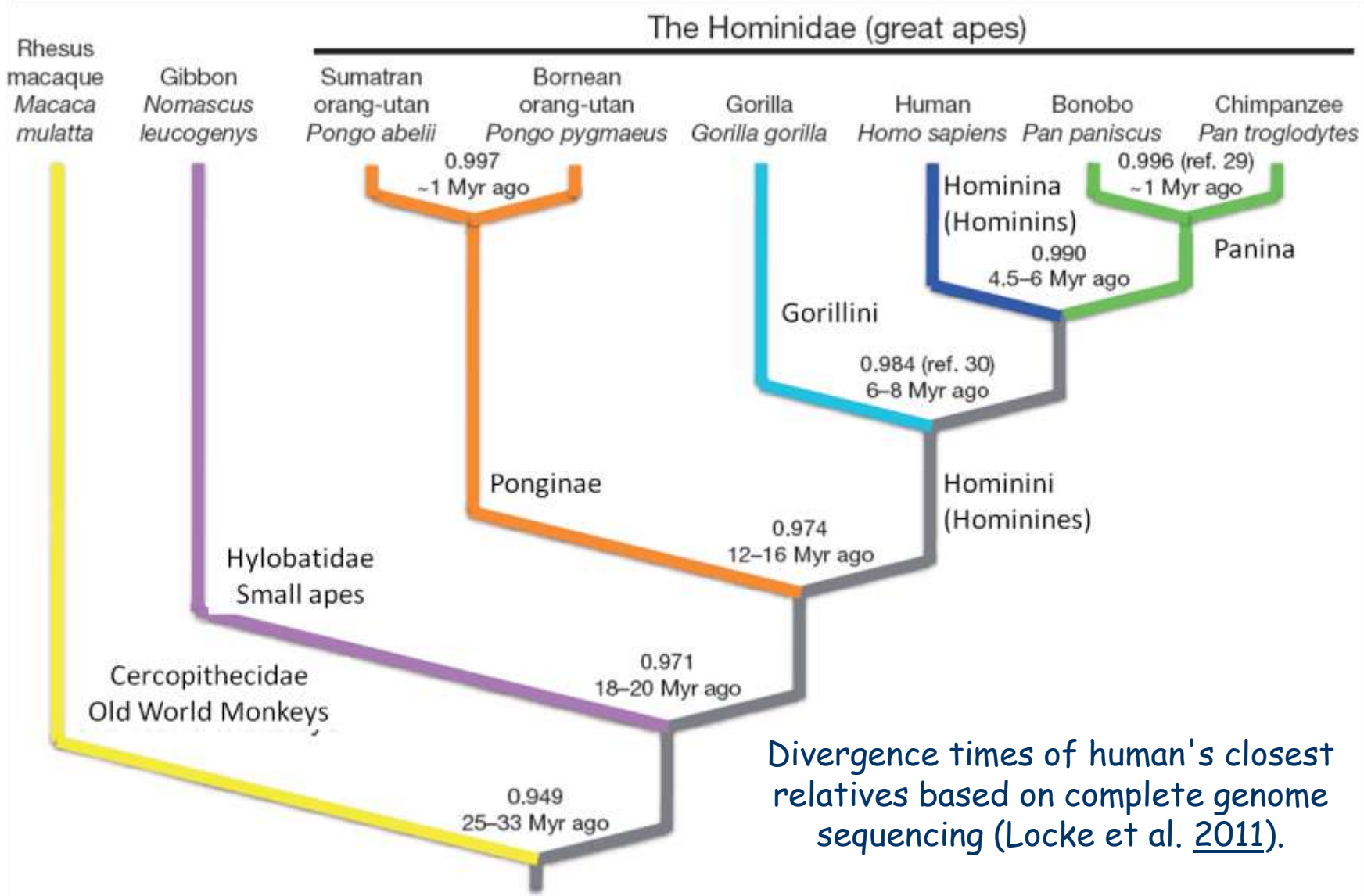
A conundrum

If humans evolved on Earth, how did we suddenly become so uniquely different as to imperil all other life on the planet?

- Humans are apes: 98-99% of human and chimpanzee DNA is identical
- ~6-7 million years ago we had a common ancestor
- Where do we come from?
- Why are we so different?
- Stephen Jay Gould: Is this contingent or predictable?
- What does this tell us about our possible futures?
- Humans now dominate the planet to the extent that we threaten all other life on the planet
- All other apes are marginalized or facing extinction

How did it happen?

Comparative genomics – genetic differences are comparatively trivial



Divergence times of human's closest relatives based on complete genome sequencing (Locke et al. 2011).

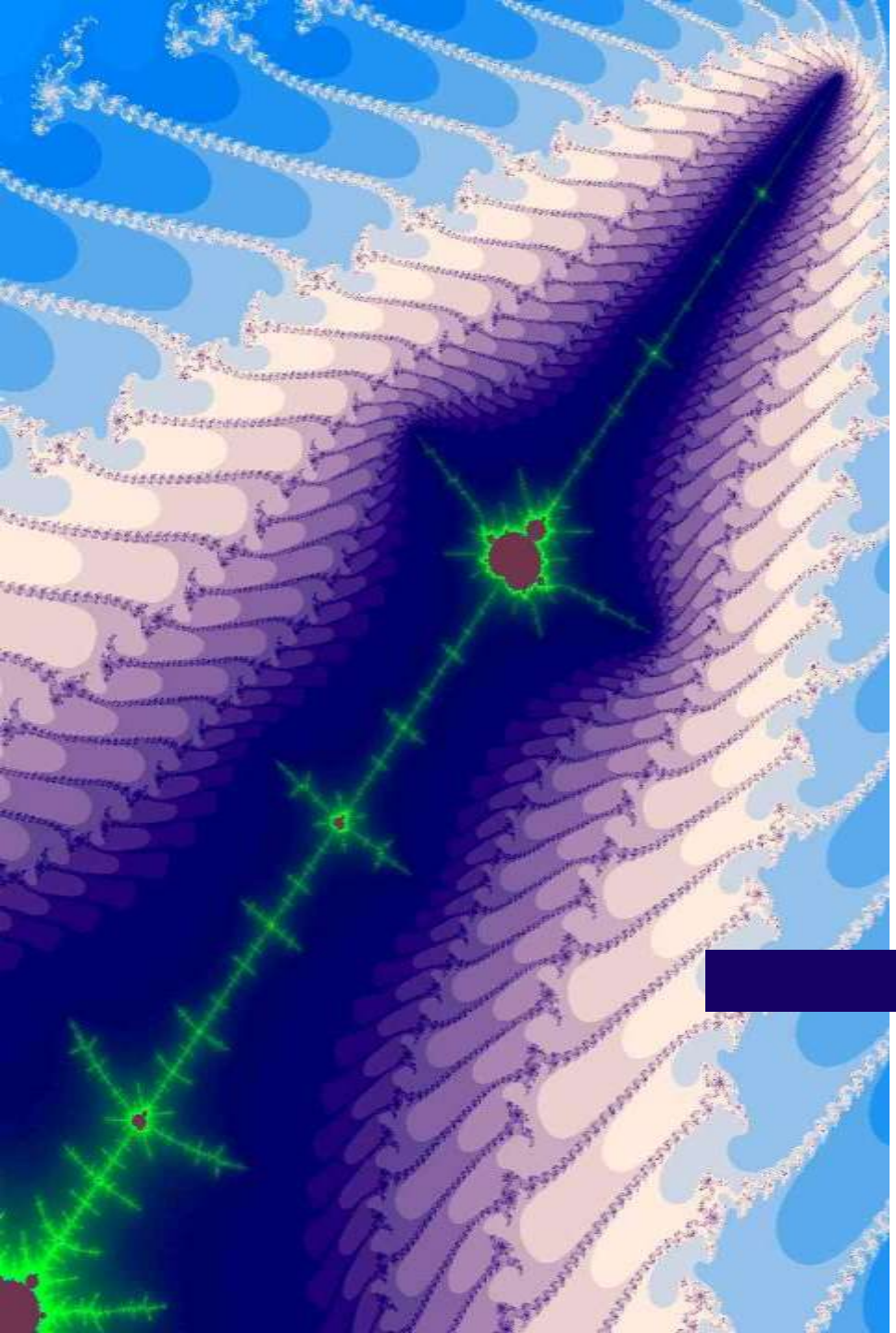
Socially foraging, tool-using forest apes in East African Garden of Eden > 5 mya

(click pictures below to view videos)

Chimps use probes to collect ants. Probe is inserted almost to full length into earth.

Child watching mother crack otherwise inedible palm nuts using stone hammer & anvil.

- Bipedal gait enables grasping hands to evolve manipulative capacity
- Progressive evolution of brain-eye-hand coordination
- Social organization (long childhood within a social troop) provides opportunity for learning and knowledge transfer



Evolutionary hypothesis

—

How tool-using forest apes came to dominate Planet Earth

An evolutionary hypothesis

- How and why did our ancestors 5 mya – not greatly different from today's chimpanzees and bonobos become us?
  - Evolution cannot anticipate the future (or can it?)
  - The success of a lineage or species depends on it occupying and maintain an ecological niche where it can out-compete other contenders for the resources available in that ecological space.
    - Evolution of populations is driven by constant arms-races with other pops contending for those resources.
    - Individuals must access enough resources to survive and reproduce subsequent generations also able to access adequate resources.
    - Genetically determined anatomical, physiological, and behavioral adaptations are all involved in maintaining access to the necessary ecological space for population survival.
- Two aspects of hominid biology are particularly important to maintaining the successful continuity of an evolutionary lineage
  - **life history**
  - **system of heredity**
- **Hypothesis: blind evolution put us in a place where groups and individals began to consciously anticipate the future**

Popper's evolutionary theory of knowledge

Natural selection builds knowledge (= solutions to problems)

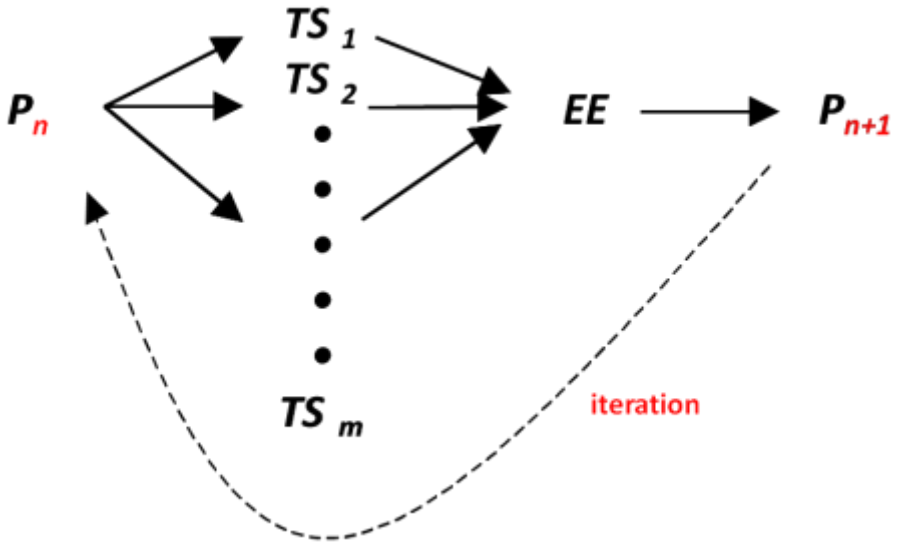
P_n a real-world problem faced by a living entity

TS a tentative solution/theory. Tentative solutions are varied through serial/parallel iteration

EE a test or process of error elimination

P_{n+1} changed problem as faced by an entity incorporating a surviving solution

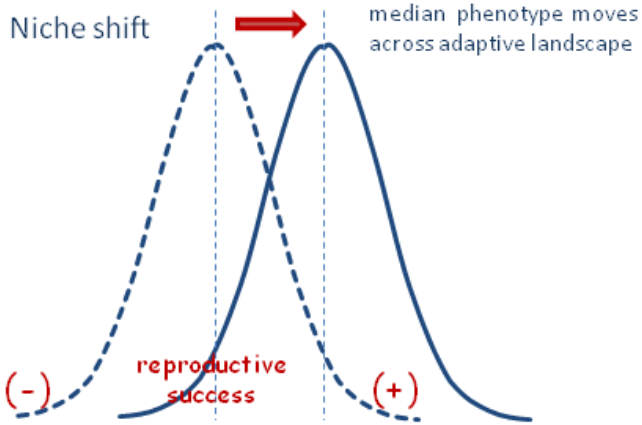
The whole process is iterated

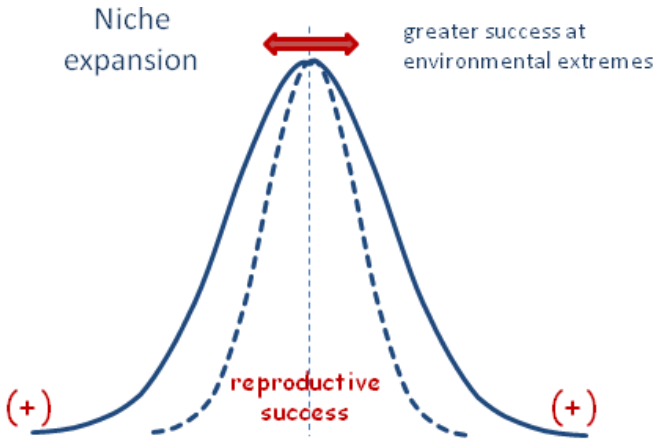


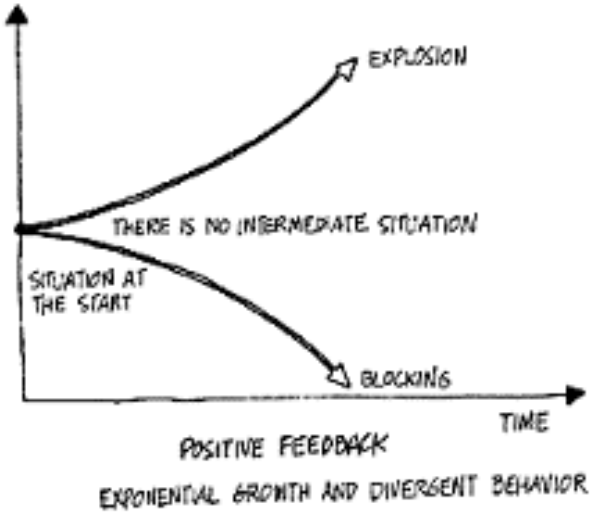
Karl Popper, Objective Knowledge – An Evolutionary Approach (1972), pp. 241-244

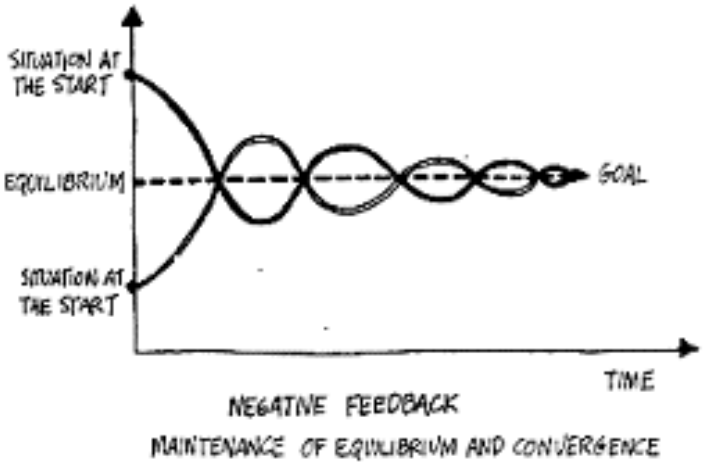
- All knowledge claims are constructed, cannot be proven to be true
- **TS**s may be embodied as "living structure" in the "knowing" entity, or
- **TS**s may be expressed in words as hypotheses, subject to objective criticism; or as genetic codes in DNA, subject to natural selection
- **Objective expression and *criticism* lets our theories die in our stead**
- Through cyclic iteration, sources of errors are found and eliminated
- Solutions/theories become more reliable as they survive repetitive testing
- Surviving TSs are the source of all knowledge!

Natural selection and feedback









"System of heredity"

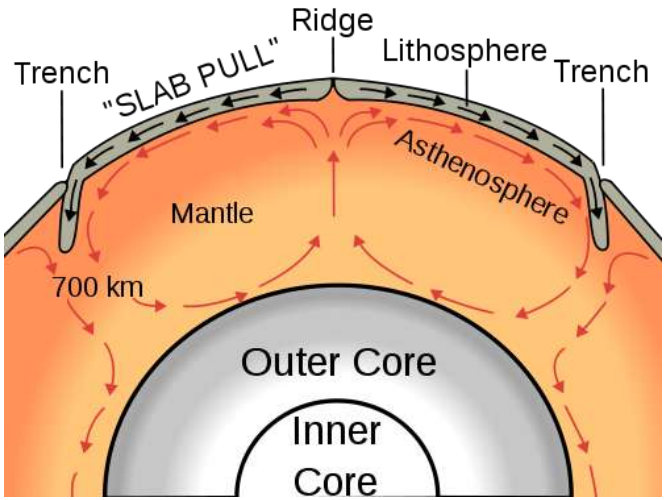
- The heredity of a species/population is ***knowledge*** transmitted from one generation to the next that determines its capacity to occupy and survive in an ecological niche
- **Genetic inheritance**: my PhD thesis focused on the role of "genetic systems" in managing and transmitting hereditary knowledge
  - "genetic system" = aspects molecular genetics, cytogenetics, and population biology that determine evolutionary plasticity, etc.
  - These aspects are themselves subject to evolution via natural selection
- **Cultural inheritance**: survival knowledge helping to determine the capacity for occupying and surviving an in ecological niche may also be culturally transmitted
  - "cultural system" = aspects of neurobiology, behavior, and population biology affecting adaptability are also subject to selection
- Thus, **System of heredity** = genetic system + cultural system
- Hypothesis is that natural selection led humans to evolve increasingly powerful cultural systems that now gives us conscious control over our evolution including ability to anticipate

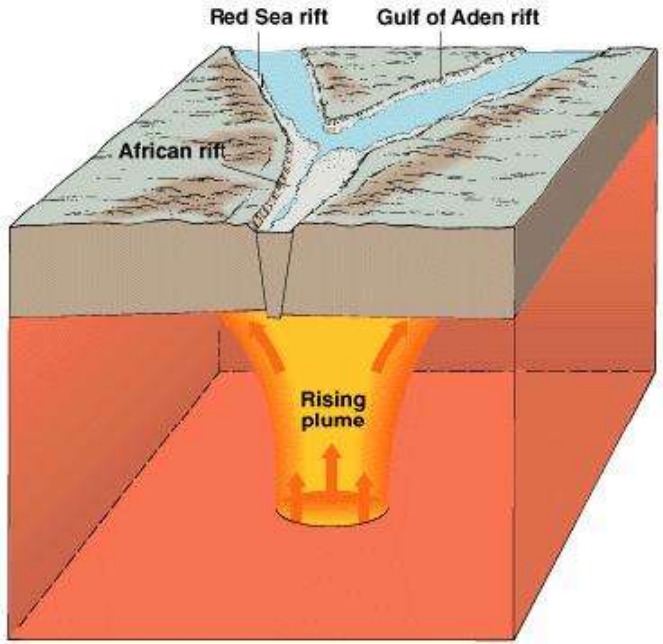
Origin of humanity: Primate life in the primeval tropical forests

- Ancestral great ape was a clambering tree dweller probably able to walk along the tops of branches
  - Grasping hands & feet
  - Binocular vision
  - Lived social in persistent groups
  - Primarily frugivorus
  - Used hands to access hidden/ protected food items
  - May have used resources from ground
  - Large size minimized predation risk
- In most seasons our ancestors could forage in trees and the ground with little effort for readily available fruits, herbs, nuts, and insects and the occasional small mammal prey

- They probably slept in trees, and while on the ground during the day, if they encountered one of the few large carnivores hunting in the forest, e.g., leopards (Boesch 1991), they could easily escape up a tree
- Biology was probably similar to today's chimpanzees and bonobos, our closest living relatives who continue to live in the Primeval Eden

Our ancestors' expulsion from Eden: Plate tectonics – the splitting of crustal domes lifted by plumes

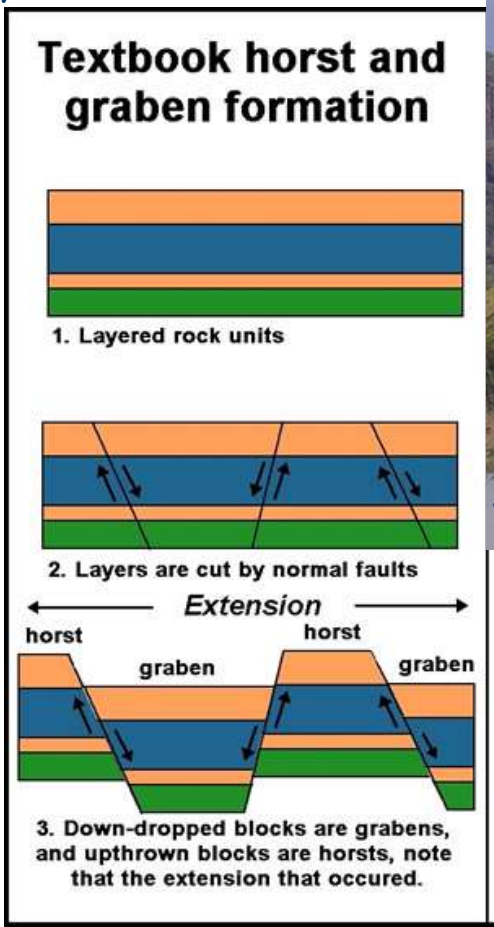




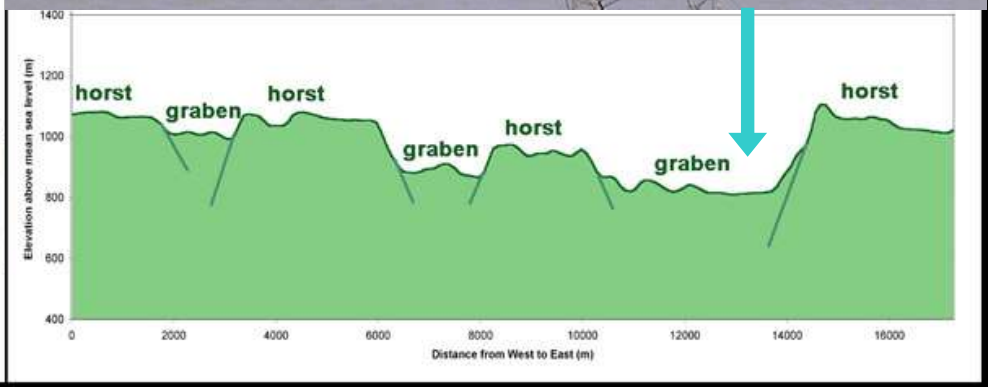
Wood & Guth (2013)

Plate tectonics 2 –Eden destroyed

- Rising mountains on either side of rift block rain
- Cause increasing aridity & seasonality



Wood & Guth (2013)

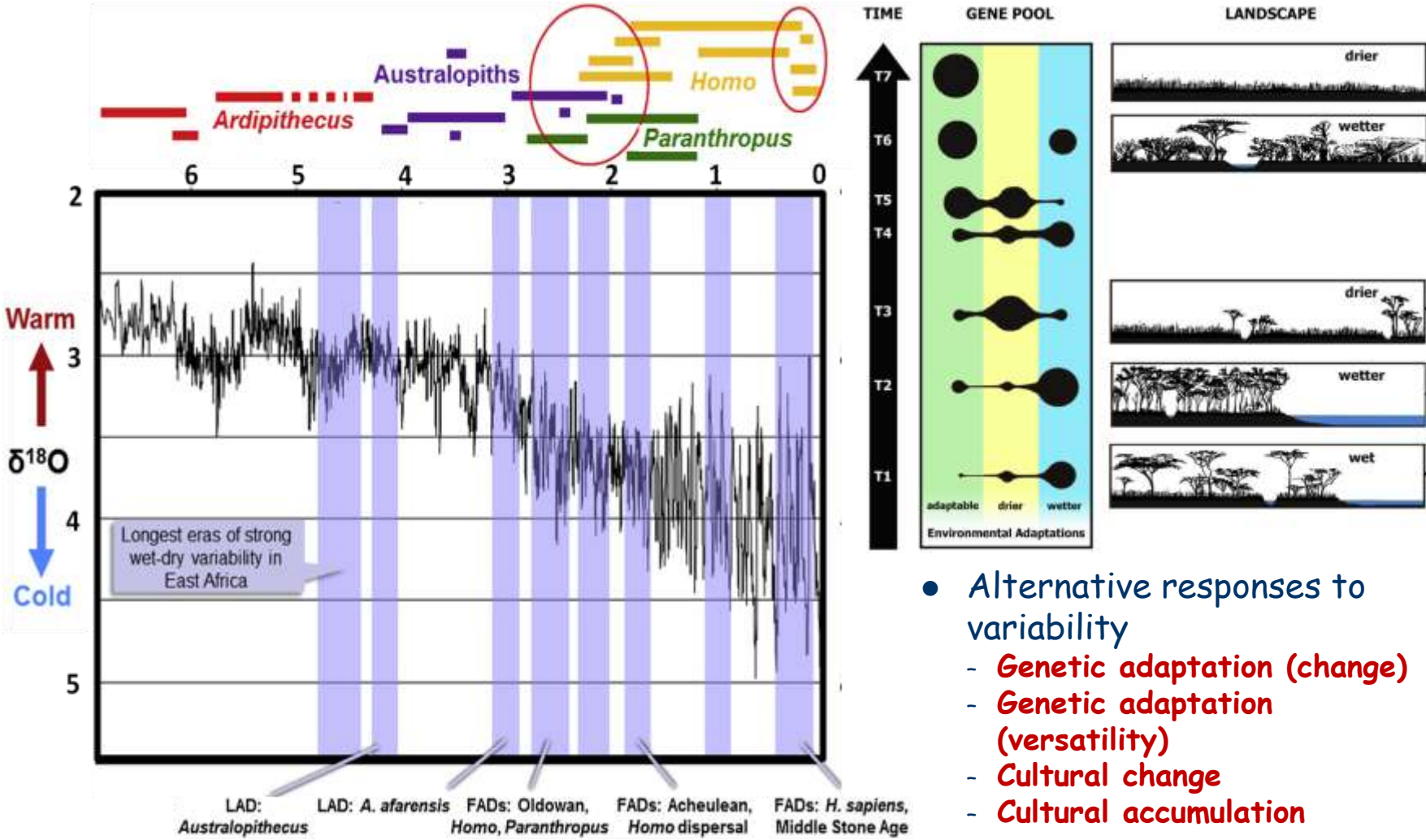


Da Vinci: Taking fruit from the tree of knowledge and the expulsion from Eden (Sistine Chapel)

The Bible and Leonardo got it wrong – actually, it was the other way around

Expulsion from Eden selected for more knowledge

Hominin evolution and environmental variability over the past 7 million years



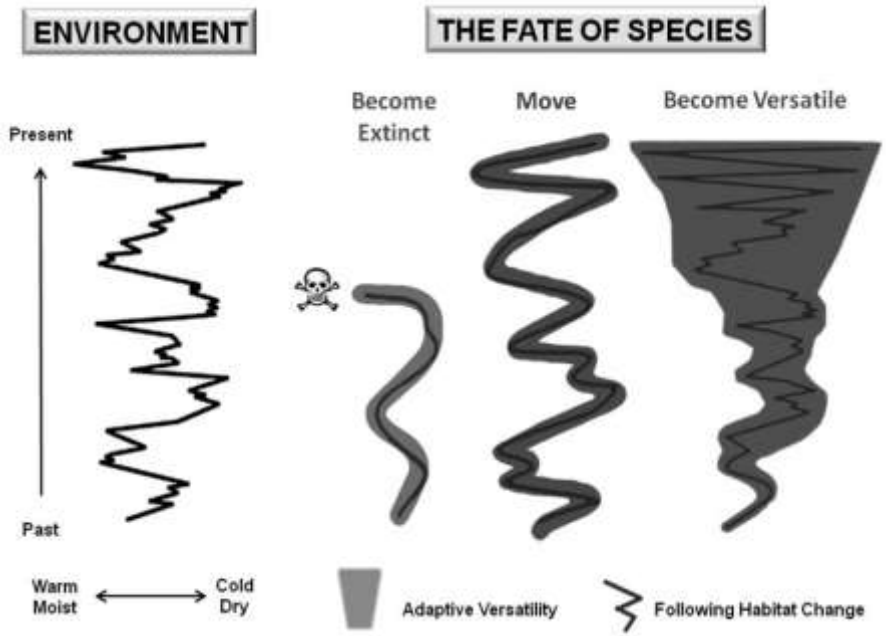
- Alternative responses to variability
  - **Genetic adaptation (change)**
  - **Genetic adaptation (versatility)**
  - **Cultural change**
  - **Cultural accumulation**

Potts 2013. Hominin evolution in settings of strong environmental variability. Quaternary Science Reviews 73, 1-13

Potts & Faith 2015. Alternating high and low climate variability: The context of natural selection and speciation in Plio-Pleistocene hominin evolution. Journal of Human Evolution - DOI: 10.1016/j.jhevol.2015.06.014

Impacts of environmental change and variability in E African Rift (Olduvai, etc.) between 3.0 and 1.5 mya

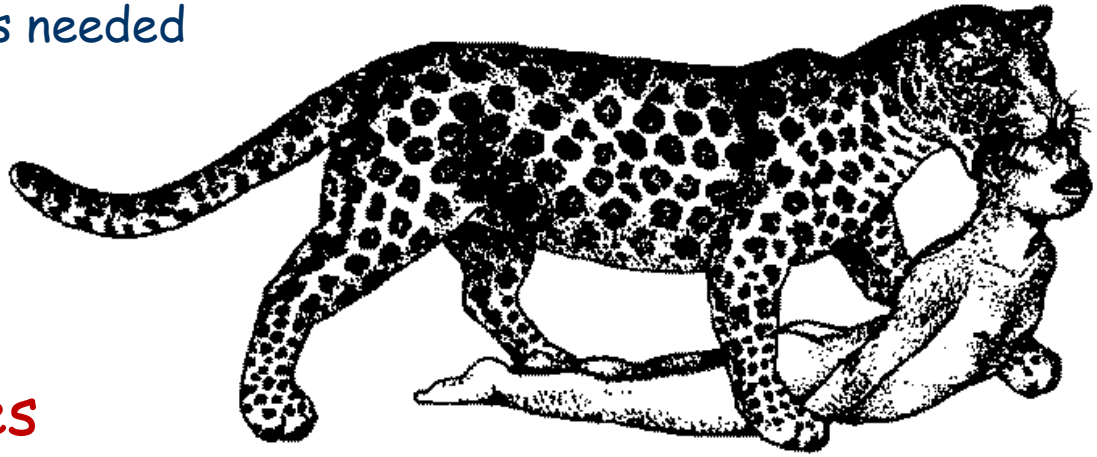
- Long periods (lasting ~130–330 ky each) of magnified moist-arid variability occurred between 3.0 and 1.5 mya.
- Possible modes of adaptation
  - Fail to track (= extinction)
  - Track with adaptive change (shift niche)
  - Become more versatile (expand niche)
- Limits to genetic adaptation
  - Slow & ponderous (intergenerational)
  - Do one thing or the other not both
- Cultural adaptation
  - Fast (intragenerational)
  - **Group-based phenomenon** – cultural knowledge pertains to group not particular individuals
  - Group knowledge easily lost (dependent on intergenerational knowledge transfer, in turn dependent on genetically determined capacities, group size, structure, and dynamics)
  - **Culturally transmitted knowledge relating to tool-making and use was grade-shifting**
- Savanna ape inherited limited capacity to transmit cultural knowledge and existing **culture of simple tool-making and use** from CLCA



Potts, R. 2013. Environmental and behavioral evidence pertaining to the evolution of early *Homo*. Current Anthropology 53(S6), S229-S317.

Surviving on the savannah to reproduce

- Forest-dwelling chimpanzee-human last common ancestor (CLCA)
  - Primarily frugivorous with some tool-based extractive foraging
  - Fission-fusion social structure, some transfer of cultural knowledge
  - High selfishness, limited cooperation in defense and hunting
- Savanna apes as extractive foragers & scavengers
  - Edible plant resources more widely scattered and harder to find
  - New kinds of resources needed
    - Roots, tubers and nuts
    - Meats
  - New dangers
    - Big cats
    - Hyenas
    - Wild dogs
- Selection pressures
  - Imagine where food might be hidden
  - **Increase memory & cognitive capacity**
  - **Build, retain & transfer cultural knowledge**



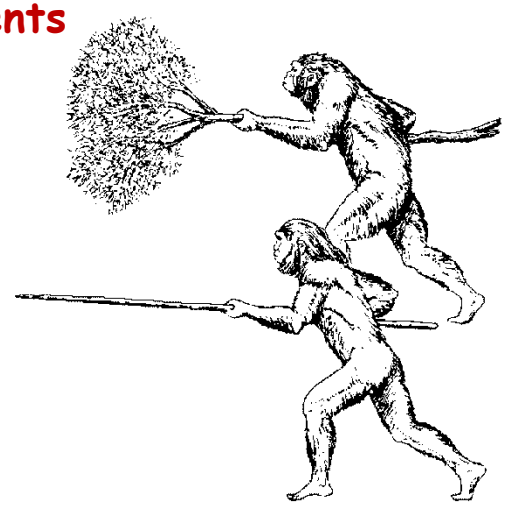
(Tattersall 2012)

Finding enough food to make a living

- Optimizing dietary quantity and quality
- Modes of acquisition/foraging in a deteriorating Eden require increasing knowledge
  - Random picking (if it looks, smells, & tastes good, eat it)
    - Genetics determines informs "goodness" (looks, smells, & taste)
  - Targeted picking (know what is in season and where to find it)
    - Long life, good memory of time and landscape, cognitive mapping of world
    - Too much for trial-error learning – major benefit from cultural knowledge
  - Extractive foraging (know where edibles hide & how to extract them)
    - Innovation and ability to imagine the invisible
  - Tool assisted extraction & processing (find & make inedible edible)
    - Using levers and hammers to extend and empower the physical body
  - **Putting things together to make complex tools and processes**
    - Understanding causation
- Extending cognition
  - Mapping the territory
  - Imagining where food might be hidden & how to access it
  - **Retaining & sharing know how**
  - **Increase cognitive capacity to manage more/more complex knowledge**

Cooperative defense and scavenging of carnivore kills cached in trees gave early hominins increased access to meat on the savanna

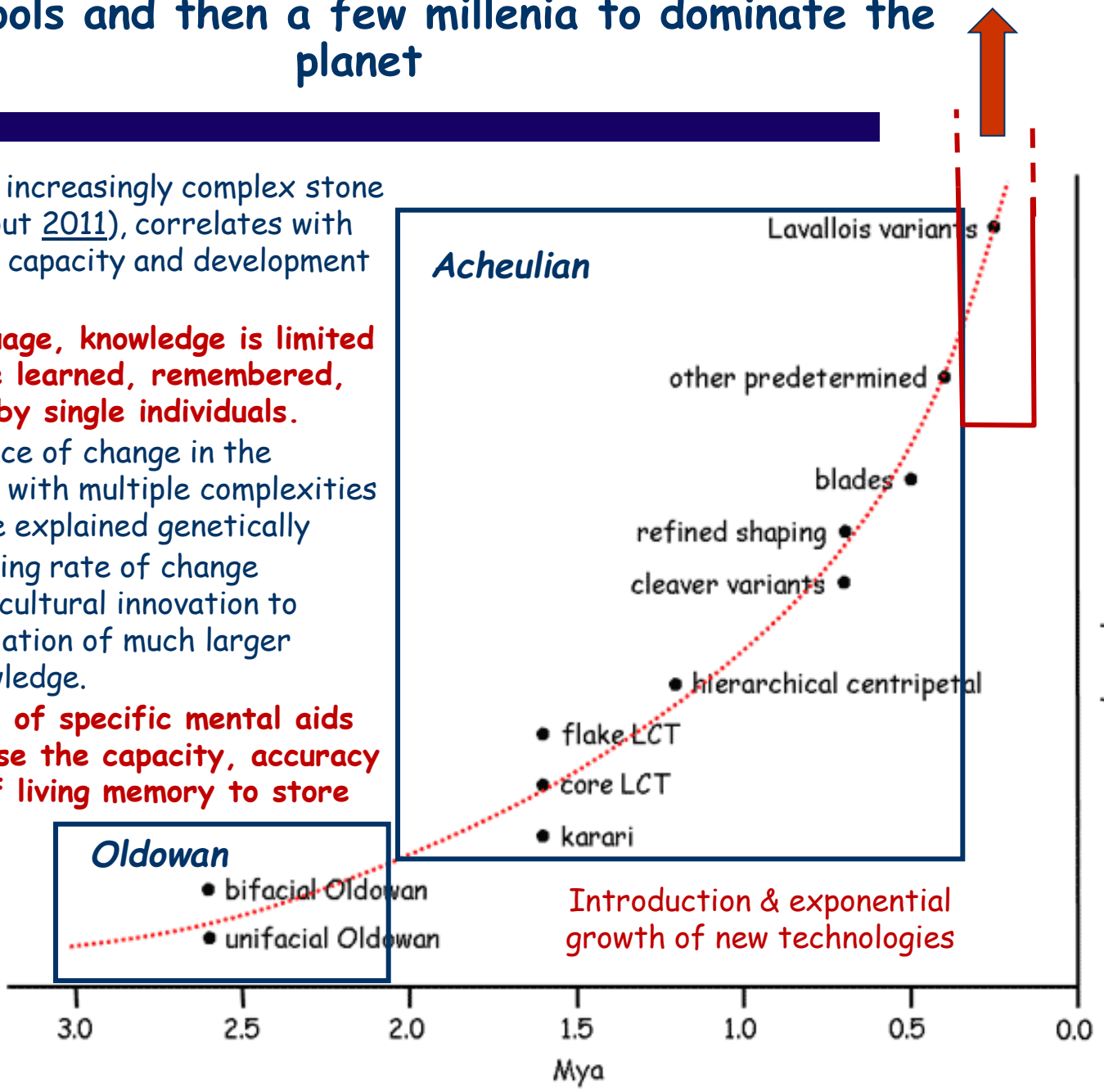
- Savanna offers limited resource of edible plant foods but a rich supply of grass-eating herbivore meat (*most food found on the ground*)
- Chimpanzee social defence against leopards is uncoordinated mobbing with clubs
  - Might be enough to deter leopard from returning to tree cache
  - Wouldn't stop a pride of lions or mob of hyenas on ground
- Simple requisites for grade shift to **aggressive scavenging** on the ground
  - **Coordinated & cooperative defense and offense using effective deterrence**
  - **Oldowan butchering tools for cutting skin & ligaments**



Hominins using haak en steek branches as tools (Guthrie 2007): **a**. for driving big cats away from their prey. **b**. The simple conversion of a thorn branch into a "megathorn" lance for active hunting.

It took millions of years for our ancestors learn to make complex tools and then a few millenia to dominate the planet

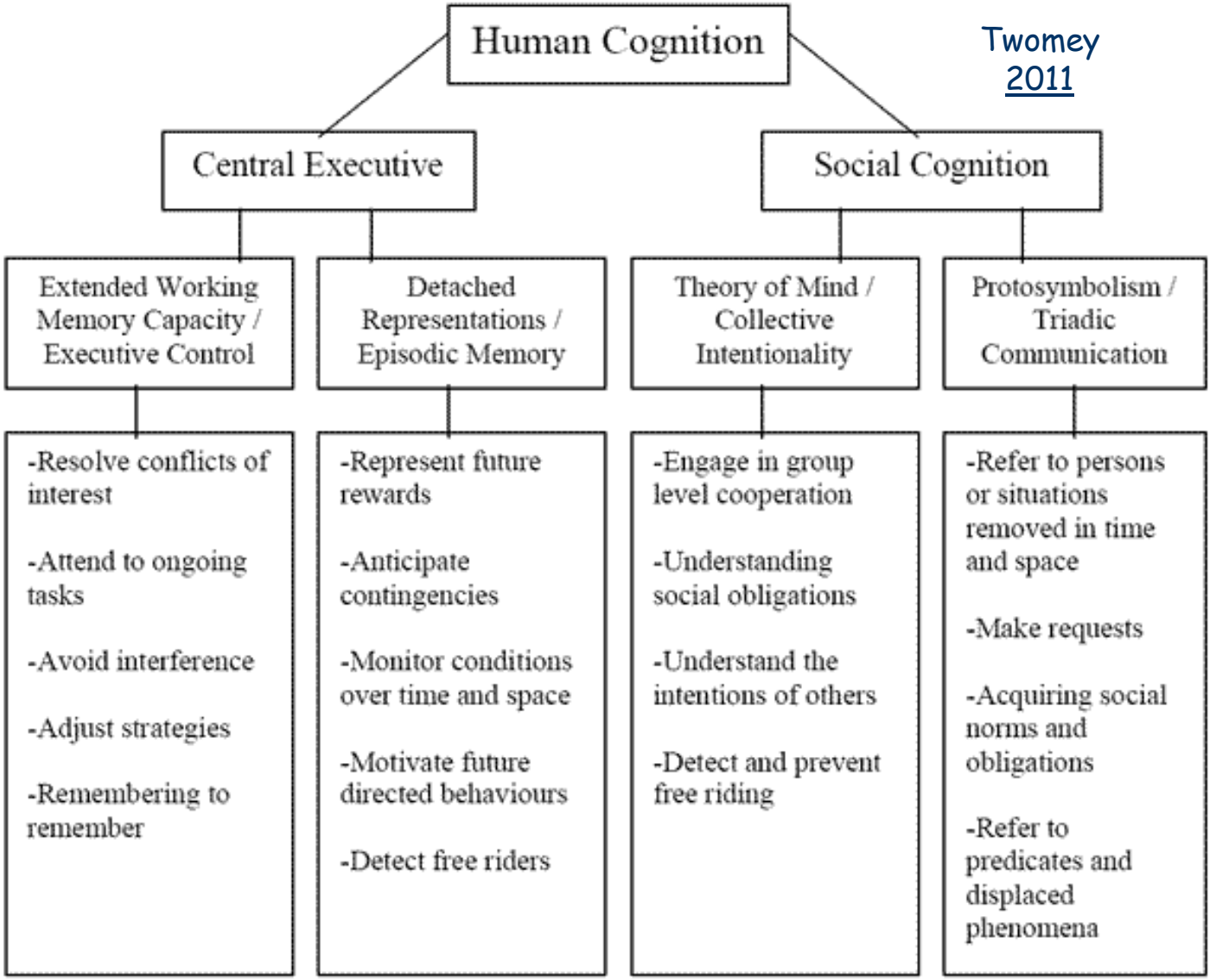
- Development of increasingly complex stone tools (after Stout 2011), correlates with increasing brain capacity and development of language.
- **Even with language, knowledge is limited by what can be learned, remembered, and passed on by single individuals.**
- By < 500 kya, pace of change in the capacity to deal with multiple complexities is too fast to be explained genetically
- < 50 kya increasing rate of change suggests major cultural innovation to support accumulation of much larger volumes of knowledge.
- **mnemonics: use of specific mental aids to again increase the capacity, accuracy and duration of living memory to store knowledge**
  - **Storage**
  - **Indexing**
  - **Recall**
  - **Transmission**



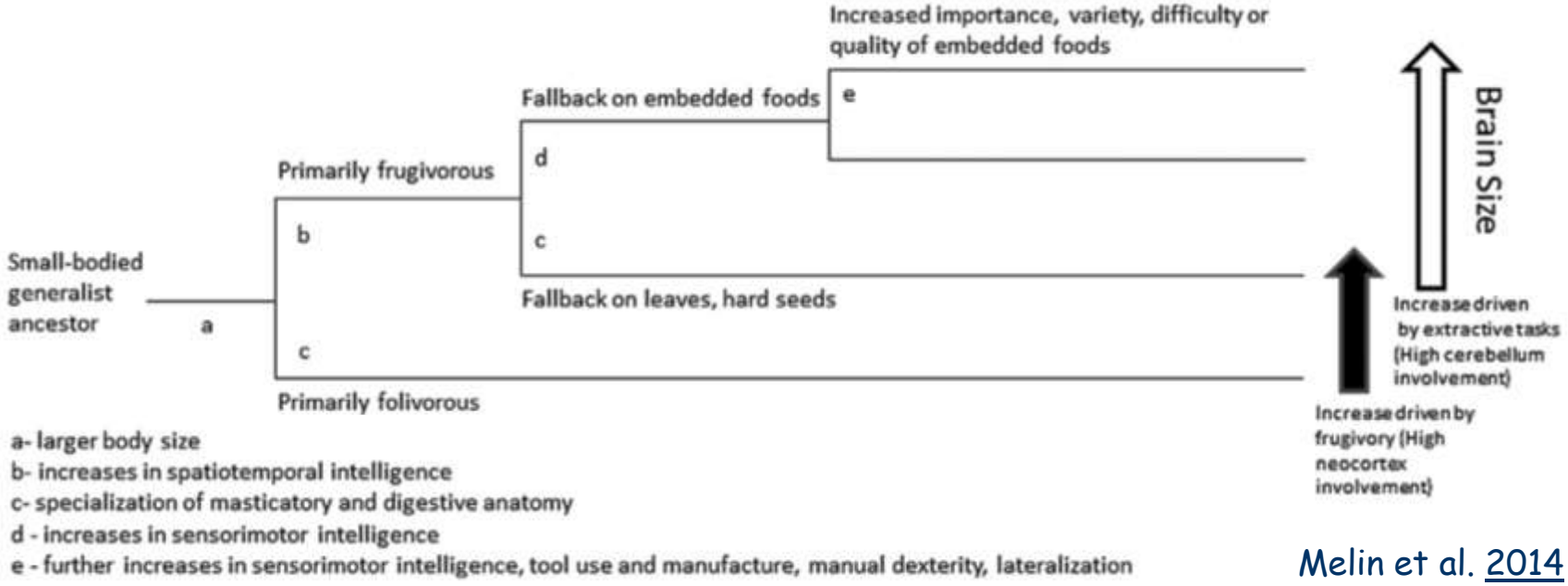
Cognitive improvements for the cultural accumulation of knowledge begins to dominate adaptive evolution

- Acheulean tool-kit gives early *Homo* the fangs and claws it needed to become top carnivore on the savanna
  - Limited changes in the *erectus* toolkit over one million years
  - Suggests it was not easy to refine & modify tool use due to cognitive limitations
  - Also, without effective means to preserve & transmit knowledge culturally, technological innovations may be lost & reinvented several times & may take hundreds of thousands of years to be consolidated
- Carnivorous hominins expand into spread through Eurasia as *H. erectus* (and other species?)
- Selection for cognitive improvements
  - Social capacity to work cooperatively & share proceeds & knowledge
  - Foresight for planning
  - Capabilities for memory, learning and teaching
  - Neuromuscular coordination for tool-making
- **As cognitive capacity improves via genetic selection, the capacity for the cultural storage and sharing on knowledge also grows**

What comprises cognitive capacity?

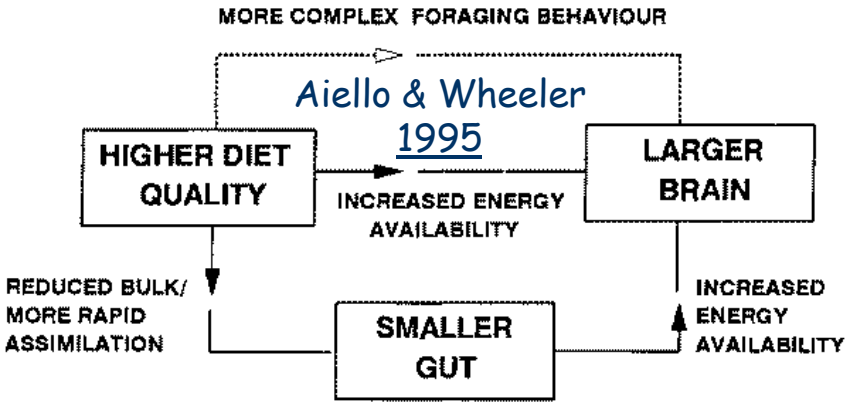


Selective tradeoffs involving diet & cognition



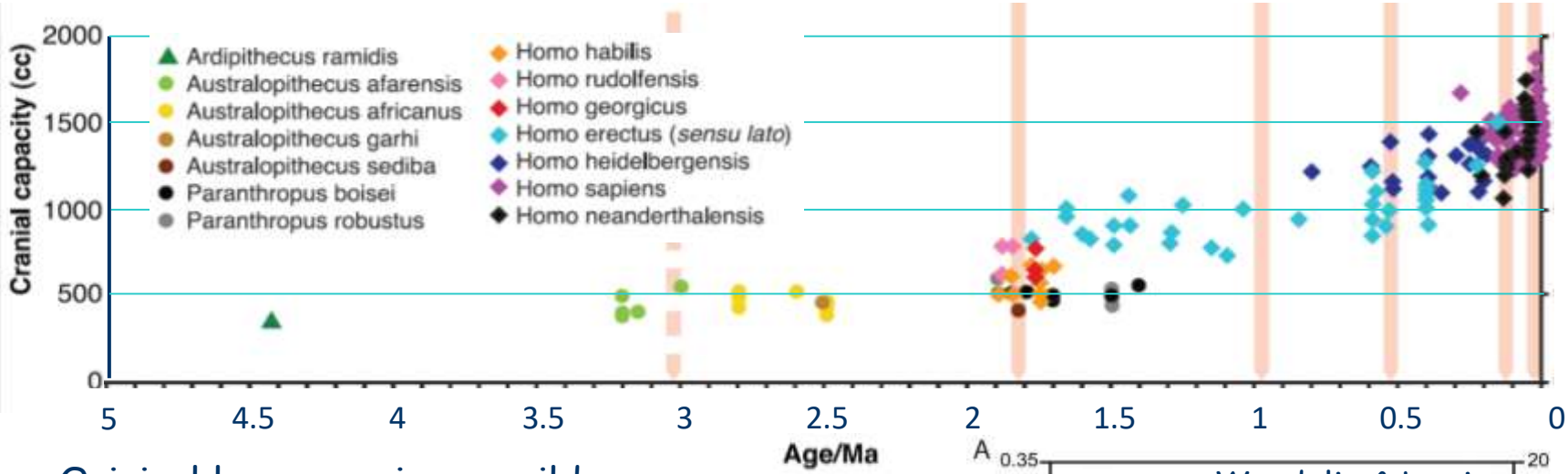
Melin et al. 2014

- Environmental deterioration forced early hominins to work harder to find and extract hidden/imbedded foods.
- Larger brains are energetically costly
  - Selective feedback on tradeoffs between cognitive capacity and masticatory/digestive capabilities
  - **Work smarter to find better quality foods releases energy to becoming smarter yet**

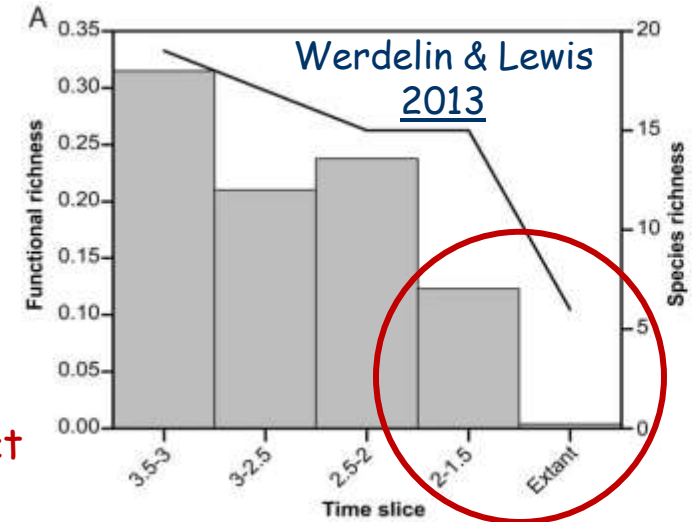


Hominins become top savanna carnivores

- Speciation & increasing brain size over time associated with pulses of climatic variability (Shultz et al. 2012; Shultz & Maslin 2013)

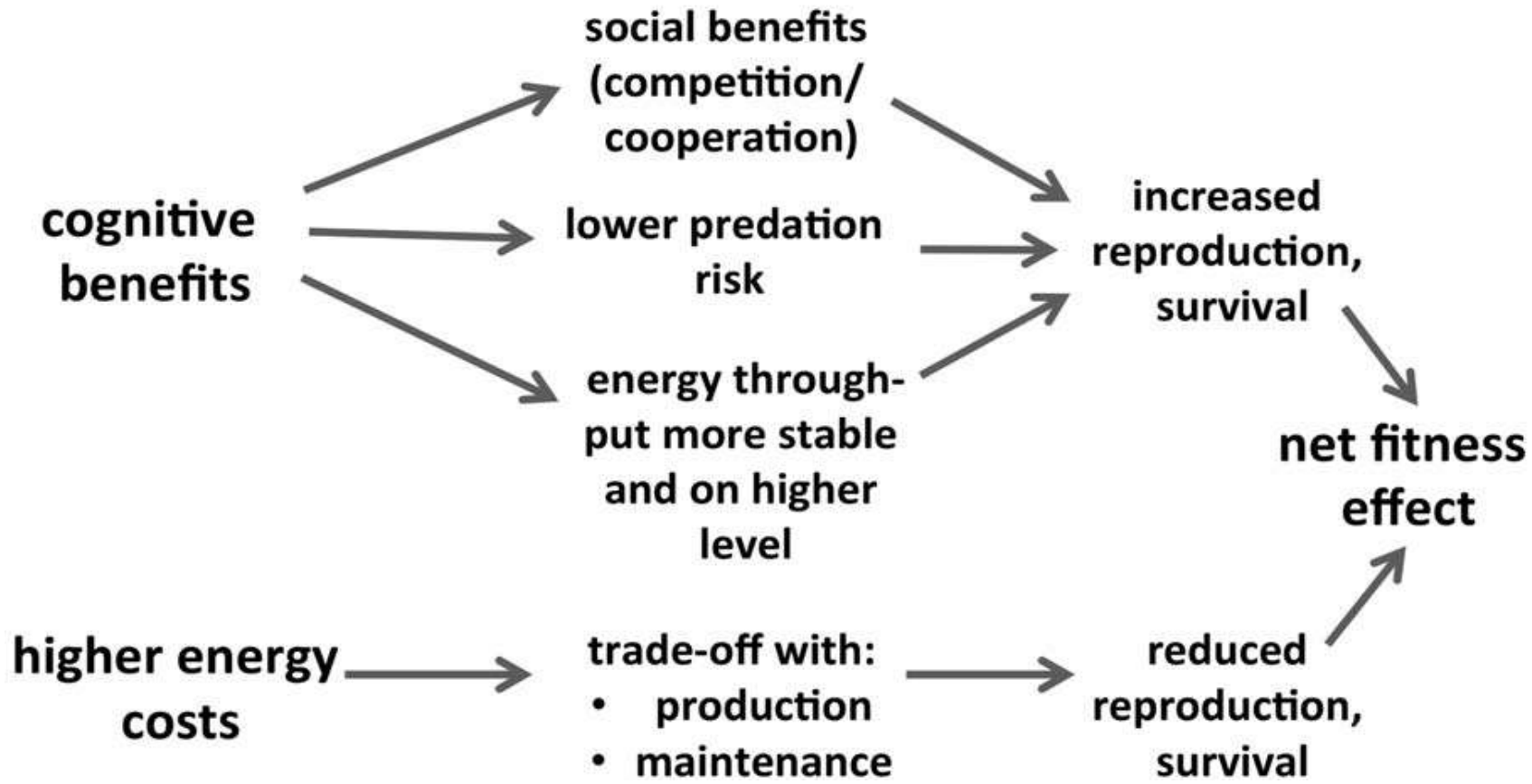


- Original large carnivore guild
  - lions, leopards, three sabertooth cats, large bear, bear-sized wolverine, several large hyenids, wild dogs, etc.
- 3 mya aggressive scavanging
- 2 mya active hunting with spears & cutters
- By 1.8 mya Olduvai hunters were top carnivores taking prime bovid prey (Bunn & Gurtov 2013) and most large carnivores were essentially extinct



Another set of tradeoffs

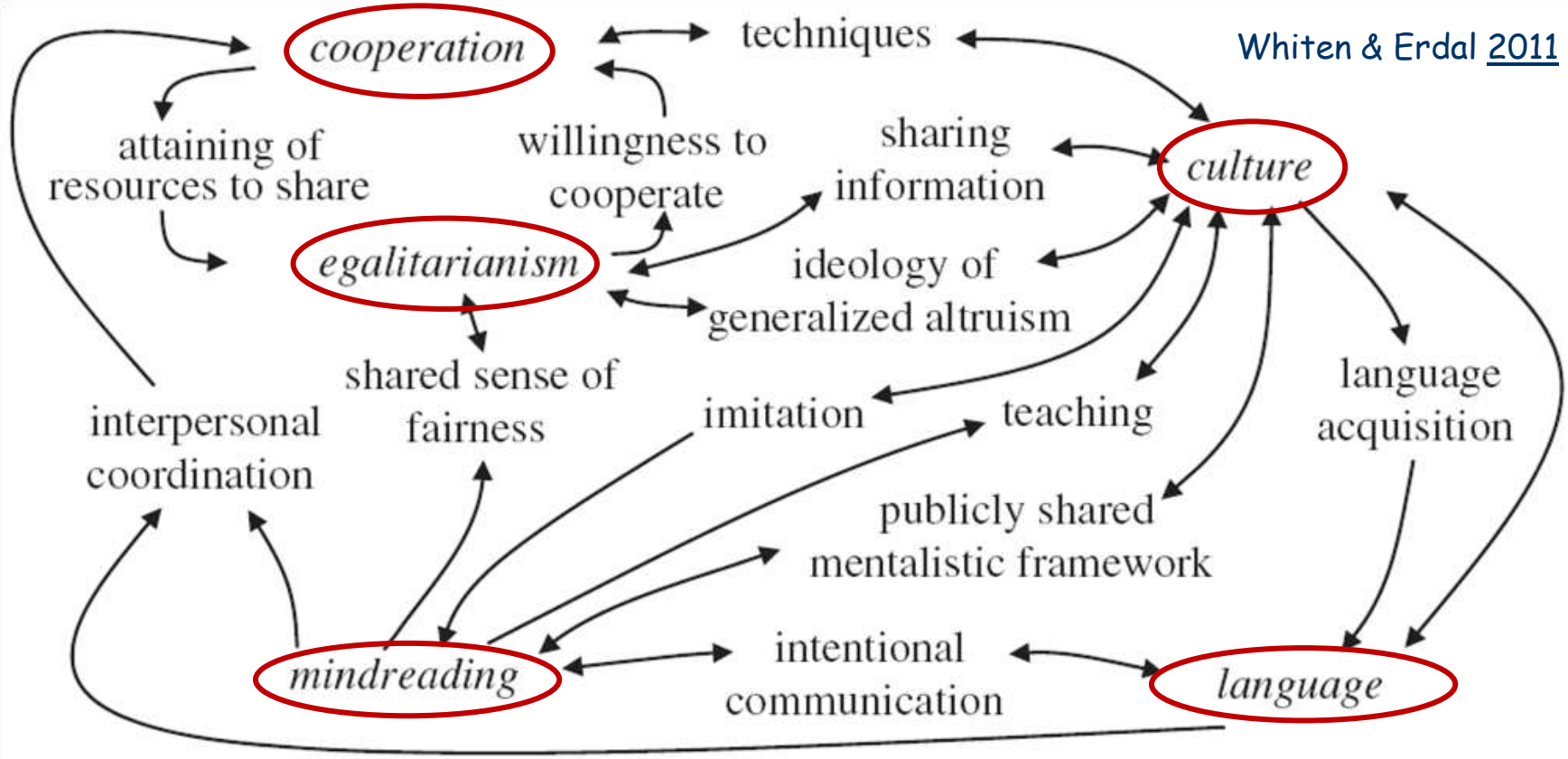
Correlates of larger brain size



Isler & van Schaik 2014

Early human groups pioneered a particular socio-cognitive niche based on 5 principal capacities

- Socio-cognitive niche: cooperation, egalitarianism, mind-reading (theory of mind), language, cultural accumulation
- Principal classes of social cognition in hunter-gatherer bands and inferred reinforcing relationships between them



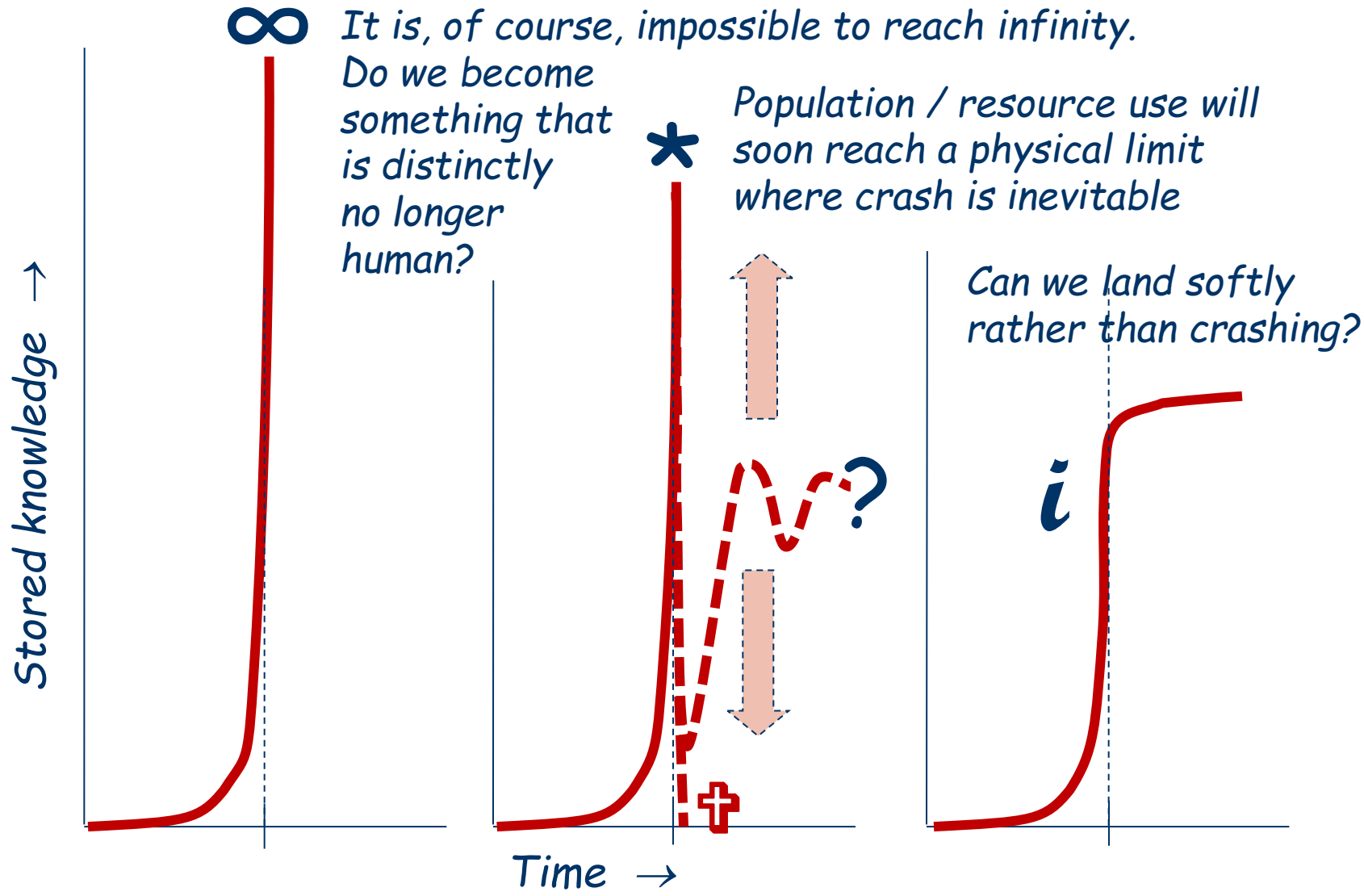
Positive feedback ➔ cultural imperative

- Beyond immediate survival, competition and natural selection drives entities to evolve strategic power over resources
  - *epistemic power* - the wisdom ("know that") and know how to apply power effectively,
  - *will power* - the decision or will to apply power,
  - *logistic power* - available resources enabling the application of power
- Cultural inheritance ➔ transmission of adaptive knowledge
- **Knowledge sharing in group ➔ selection at group level for strategic power over environment**
  - The competitor with the more complete and accurate picture of the world is more likely to achieve the predicted results from an action than will be the case for a competitor with a less complete and accurate picture.
  - An entity that can decide and act in less time than a competitor alters reality so it no longer conforms to the competitors' observations of the world.
- The entity holding strategic power makes the world appear to be chaotic to less powerful entities.

Revolutions in human technologies repeatedly reinvent the nature of & bandwidths for individual & social cognition

- Accelerating changes extend human cognition
  - >> 5,000,000 *yrs* – Tacit transfer of tool-using/making knowledge adds **cultural inheritance** to genetic inheritance)
  - ~ 2,000,000 *yrs* - Emergence of **speech** speeds direct transfer of cultural knowledge between individuals)
  - ~ 100,000 yrs – Invention of **mnemonic strategies** (100 K) and architectures (12 K) for indexing and managing of survival knowledge
  - ~ 11,000 *yrs* – Invention of **physical counters** (*11 K*), **writing and reading** (*5 K*) to record and transmit knowledge external to human memory (technology to store transfer culture)
  - ~ 575 yrs - **printing and universal literacy** transmit knowledge to the masses (cultural use of technology)
  - ~ 65 *yrs* - **computing** tools actively manage corporate data/ knowledge externally to the human brain (*65 Y*) and personal knowledge (World Wide Web - *25 Y*)
  - ~ *15 yrs* - **smartphones** merge human and technological cognition (human & technological convergence)
  - ~ *Now*: Emergence of **human-machine cyborgs** (wearable and implanted technology becoming part of the human body)

Will exponential knowledge growth end in a singularity, spike or inflected S curve?



Natural selection got us to where we are now.

Is our current situation contingent or is it written in our heredity?

Yet, this isn't the last word.

We have the cognitive capacity and technology to inflect our population and technology growth curves to manage a soft landing.

Will we/can we choose to do so?