Note: underlined text links to the Web

Life, Knowledge and Natural Selection

How life (scientifically) designs its future

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Philosophy of Science – Future by Design
August 23-24, 2014

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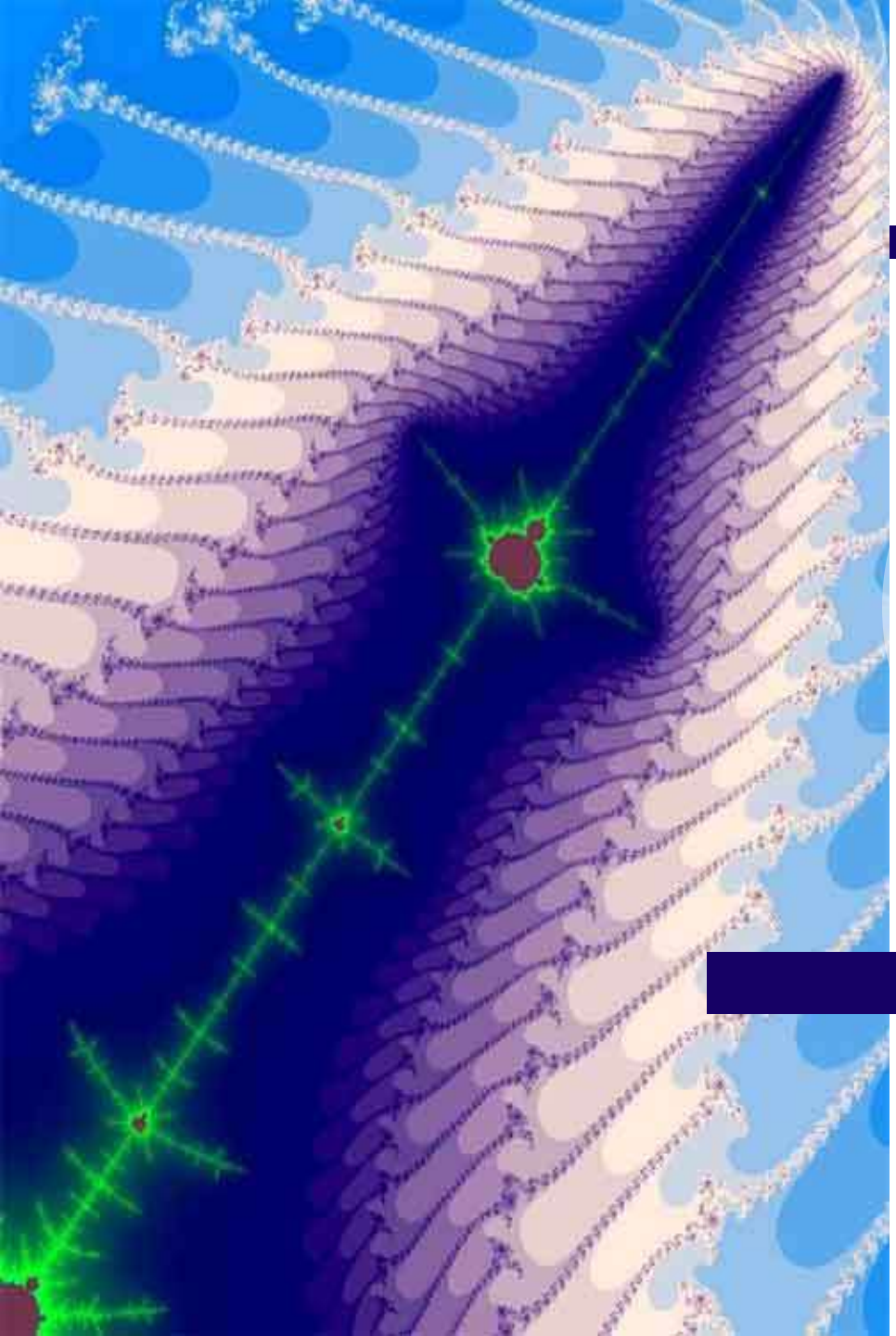
Google Citations

Three main topics for today

- **Unified theory of knowledge and life** (life does science to live)
  - **Karl Popper (1972)** evolutionary epistemology – **what makes K reliable?**
    - **"General theory of evolution"** – error elimination and the inevitable growth of K
    - **Three ontological domains (worlds)** – physical, mental, encoded knowledge
  - **Epistemic cut** – Howard Pattee (1995 →) concept from biophysics
  - **Autopoiesis** - Maturana and Varela (1980) - **reliable K makes systems living**
- **Evolution and revolutions in cognition & knowledge** Thomas Kuhn (1970)
  - Major cognitive revolutions (= step changes) from the beginning of memory and life
    - Origin of memory and cognition in dynamic structure
    - Genetic memory
    - Cultural memory
  - **Add technology**
    - Explicit/Tangible memory & communication (i.e., writing & printing)
    - Virtual memory, cognition & communication at light speed
- **Moore's Law** – compresses time and space through exponential growth
  - 5 million years of human history concatenates many technological/cognitive revolutions
  - Will we reach a post-human singularity in our life times?
- Extract from "Application Holy Wars or a New Reformation – A fugue on the theory of knowledge"

My background for this presentation

- Microscopy, protozoology & marine biology as a curious child
- Physics (1957-59)
- Hands on work with digital computers (1958→)
- Zoology (BS San Diego State Univ, 1964)
- Evolutionary biology (1960→) PhD Harvard (1973) studying lizard genetics, cytogenetics, systematics, and speciation
- History and philosophy of science while at U Melb. (1977-79→)
- Computer literacy education and tech communication (1982→)
- Banking systems analysis & documentation (1988-89)
- Documentation and knowledge management systems analysis and design for Tenix Defence on $7 BN ANZAC Ship Project (1990-2007)
- Exploring the co-evolution of knowledge and life at all levels of organization (2001 →)



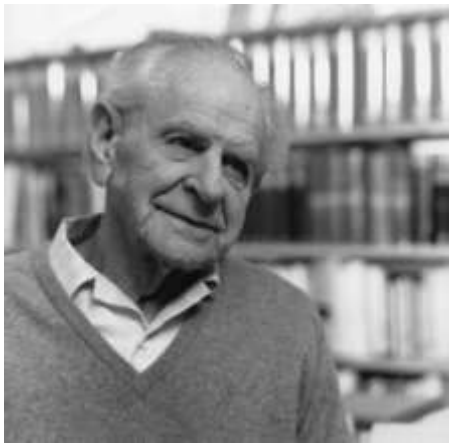
PART ONE

Biologically-based theory of knowledge and life

Scientific knowledge is tested solutions to problems (Popper)

All living things "do" science to stay alive

What makes knowledge reliable?
Karl Popper's biologically-based epistemology



- Popper 1959 – "The Logic of Scientific Discovery"; 1963 – Conjectures and Refutions:
  - There is no such thing as induction
  - We can't prove if we know the truth
  - Deductive falsification is deterministic
  - **Make bold hypotheses and try to falsify them – what is left is better than what has been falsified**
  - Demarcation between science and pseudoscience based on falsifiability (stringent testing to eliminate errors)
  - **More clued in to physical and biological sciences than most philosophers**
- **Popper (1972 – "Objective Knowledge – An Evolutionary Approach")**
  - Knowledge as solutions to problems
  - All knowledge is constructed
  - Falsification also not reliable: claims can be protected against falsification by infinite regress of auxiliary hypotheses
  - "**Tetradic schema**" to eliminate errors and build knowledge
  - "**Three worlds**" **ontology**
- Many contemporary philosophers misunderstand Objective Knowledge – especially radical constructivists (e.g., Constructivist Foundations)
  - "**Objective knowledge**" = knowledge inertly codified into/onto a physical object (DNA, print on paper, pits on a CD, domains on a magnetic surface)

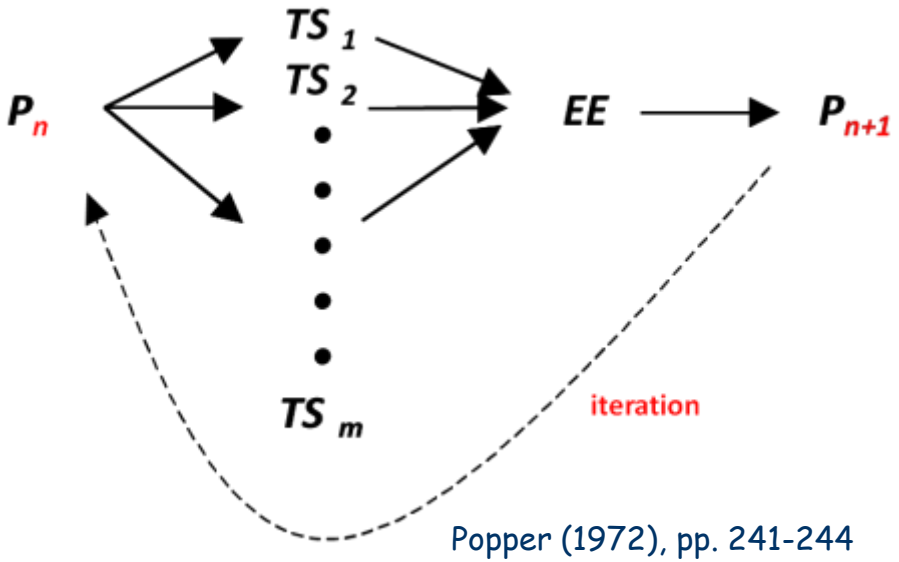
Karl Popper's first big idea: "tetradic schema" / "evolutionary theory of knowledge" / "general theory of evolution"

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

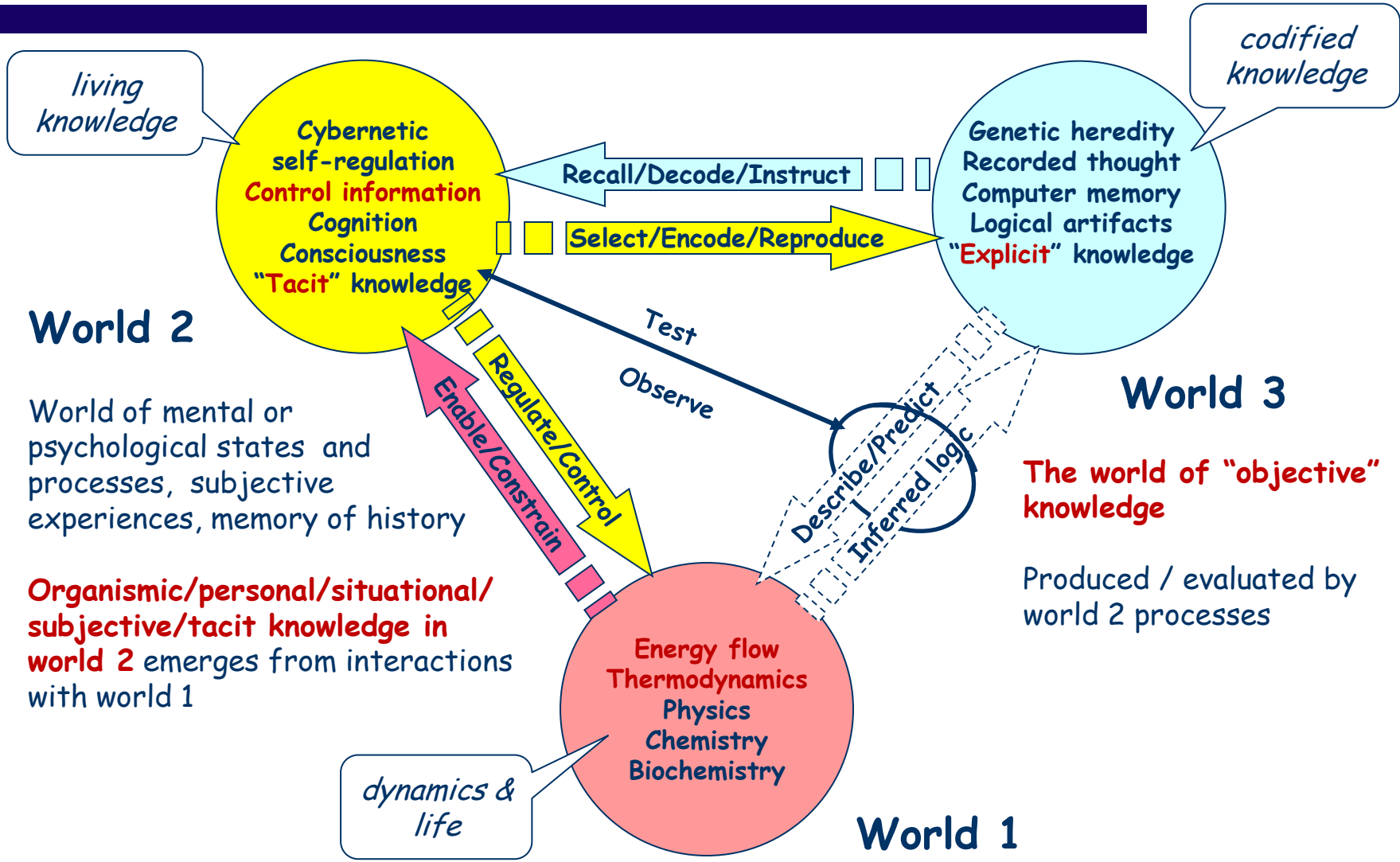


Popper (1972), pp. 241-244

The whole process is iterated

- **TS**s may be embodied as dynamic "structure" in the individual 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
- **Explicit expression and *criticism* of theories lets them die in our stead**
- **Through cyclic iteration of creation and criticism, sources of errors are found and eliminated**
- Surviving solutions become more reliable, i.e., approach reality
- Surviving TSs are the source of all knowledge!

Popper's second big idea from Objective Knowledge: "three worlds" ontology



World 2

World of mental or psychological states and processes, subjective experiences, memory of history

Organismic/personal/situational/ subjective/tacit knowledge in world 2 emerges from interactions with world 1

World 3

The world of "objective" knowledge

Produced / evaluated by world 2 processes

World 1

Existence/Reality

Howard Pattee's "Epistemic cut" concept clarifies relationships between biophysical reality and Popper's three worlds

- Popper did not physically justify his ontological proposal
- **Howard Pattee** (1995) "Artificial life needs a real epistemology"
  - An "**epistemic cut**" (a.k.a. "Heisenberg cut") in both physical and philosophical senses refers to strict ontological separation between:

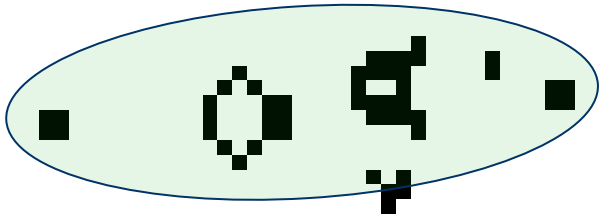
    Knowledge of reality from ***reality itself***, e.g., description from construction, simulation from realization, mind from brain. Selective evolution began with a description-construction cut.... *The highly evolved cognitive epistemology of physics requires an epistemic cut between reversible dynamic laws and the irreversible process of measuring [or describing]....*
  - No evidence Pattee or Popper ever cited the other
  - See Pattee (2012) Laws, Language and Life. Biosemiotics vol. 7 (key chapter)
- One epistemic cut separates blind physics of world 1 from cybernetic **"control information"** (Corning 2001) for self-regulation, cognition, and living memory in world 2
- A second epistemic cut separates the self-regulating dynamics of living entities from the knowledge objectively encoded in books, computer memories and DNAs and RNAs

Varela et al. (1974) define life as autopoiesis
Reliable knowledge makes systems living

- Six criteria are necessary and sufficient for autopoiesis
  - **Bounded**
    - System components self-identifiably demarcated from environment
  - **Complex**
    - Separate and functionally different subsystems exist within boundary
  - **Mechanistic**
    - System dynamics driven by self-sustainably regulated flows of energy from high to low potential driving dissipative "metabolic" processes
  - **Self-defining**
    - System structure and demarcation intrinsically produced
    - Control information/survival knowledge embodied in instantaneous structure
  - **Self-producing** (= "*auto*" + "*poiesis*")
    - System intrinsically produces own components
  - **Autonomous**
    - self-produced components are necessary and sufficient to produce the system.
- Autopoiesis is a good definition for life

Doing "science" makes a system living

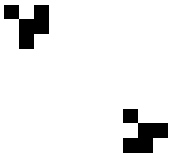
- Autopoiesis (Maturana & Varela 1980; see also Wikipedia)
  - Reflexively self-regulating, self-sustaining, self-(re)producing dynamic entity
  - Continuation of autopoiesis depends on the **dynamic structure of the state in the previous instant producing an autopoietic structure in the next instant through iterated cycles** ()
  - **Selective survival builds knowledge into the system one problem solution at a time** (Popper 1972, 1994)
- **By surviving a perturbation, the living entity has solved a problem of life**
- **Structural knowledge** demonstrated by self-producing cellular automata

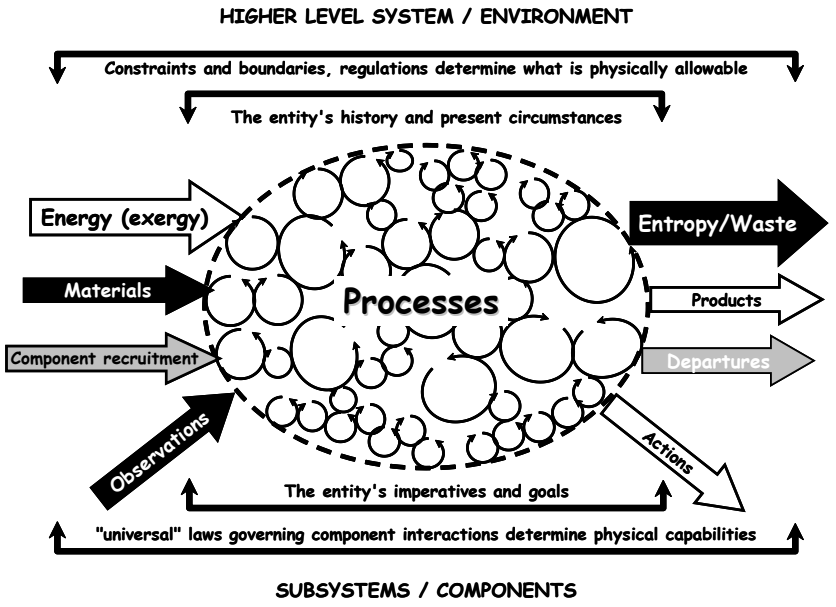


Gosper's Glider Gun cycles in 14 steps

Gliders – cycle in 4 steps

Rule:
Live cell with 2 or 3 live neighbours lives
Dead cell with 3 live neighbours lives
All other live cells die





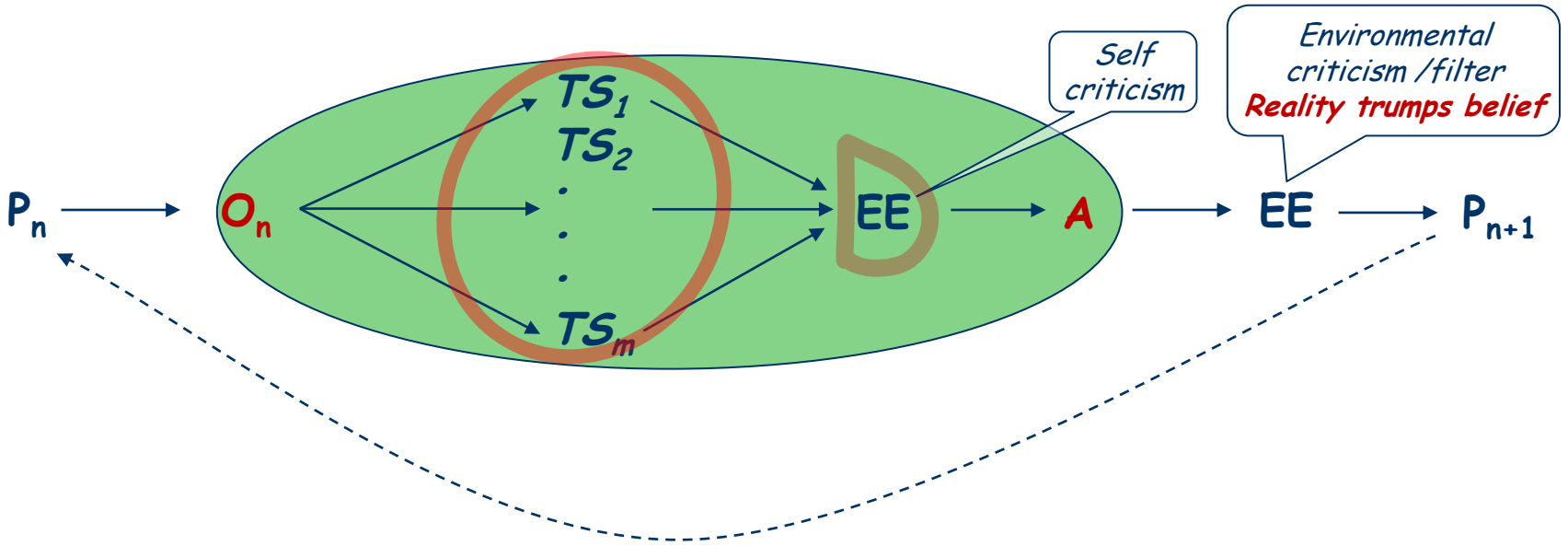
Some OODA definitions after Col. John Boyd's OODA Loop process

- Generic process for any complex adaptive entity
  - **Observation** assembles **data** about the world (including the entity's own prior effects and those of its competitors on that world). *Data* is given context relating to interactions with the world.

    Orientation processes **information** from those observations into semantically linked **knowledge** to form a world view comprised of
    - recent observations
    - memories of prior experience (which may be explicit, implicit or even tacit)
    - genetic heritage (i.e., "natural talent")
    - cultural traditions (i.e., paradigms)
    - sense making (i.e., inferring meaning)
    - analysis (destruction) of the existing world view
    - synthesis (creation) of a revised world view including possibilities for action.

    This generates **intelligence** (in a military sense).
  - **Decision** selects amongst possible actions generated by the orientation, action(s) to try. Choice is governed and informed by
    - **wisdom** based on experience gained from previous OODA cycles
  - **Action** puts tests decisions against the world. The loop begins to repeat as the entity observes the results of its action.

Popper's General Theory of Evolution + John Boyd's (1996) OODA Loop process



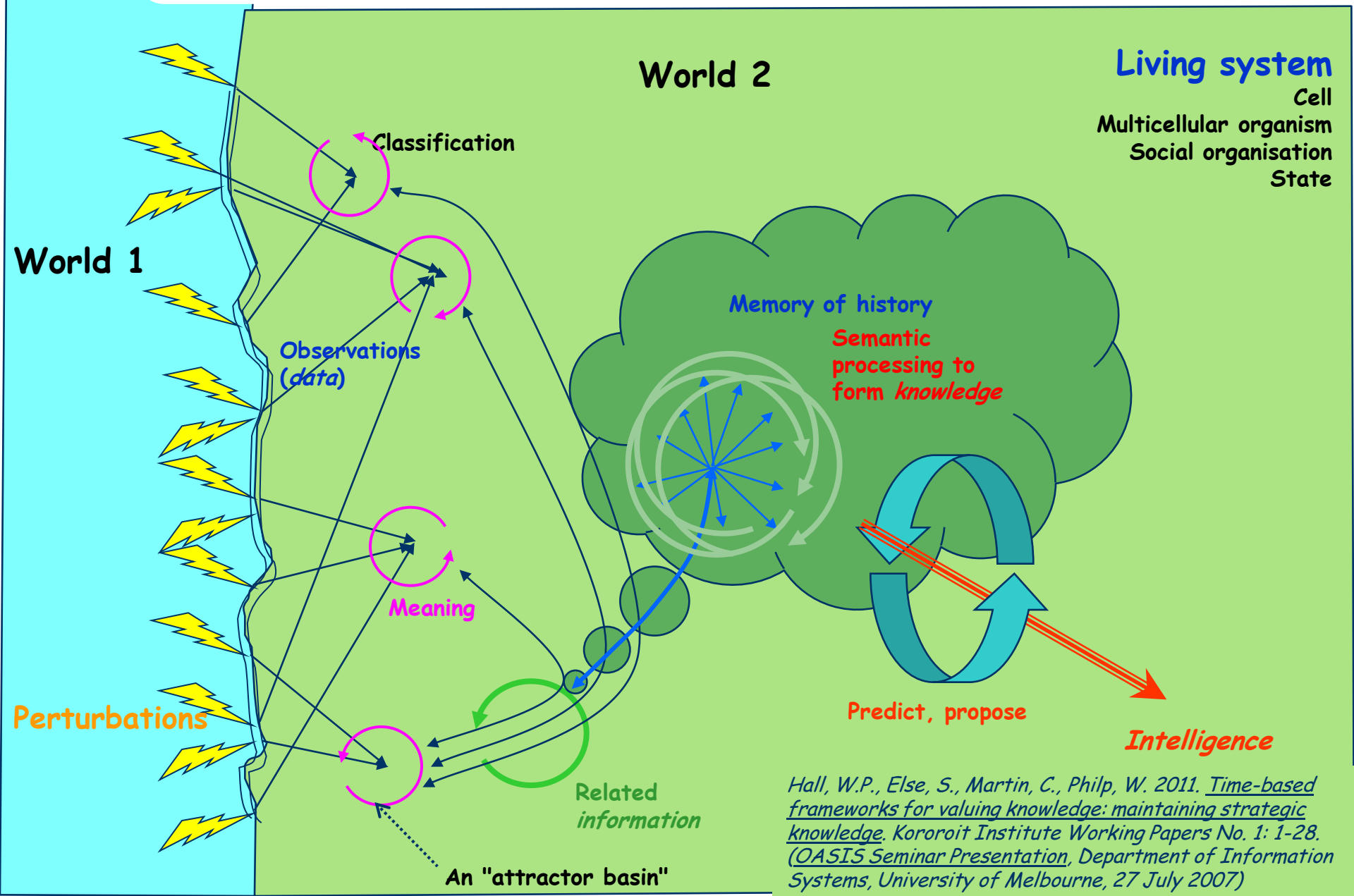
O = **Observation** of reality; ***O*** = Making sense and **orienting** to observations with solutions to be tested; ***D*** = Selection of a solution or making a "**decision**"

A = Application of decision or "**Action**" on reality

The real world is a filter that penalizes/eliminates entities that act on mistaken decisions or errors (i.e., Darwinian selection operates)

- Conscious self-criticism eliminates bad ideas
- If errors remain, the environment penalizes or eliminates entities acting on the errors – ***Reality trumps belief***

Information transformations in the living entity through time



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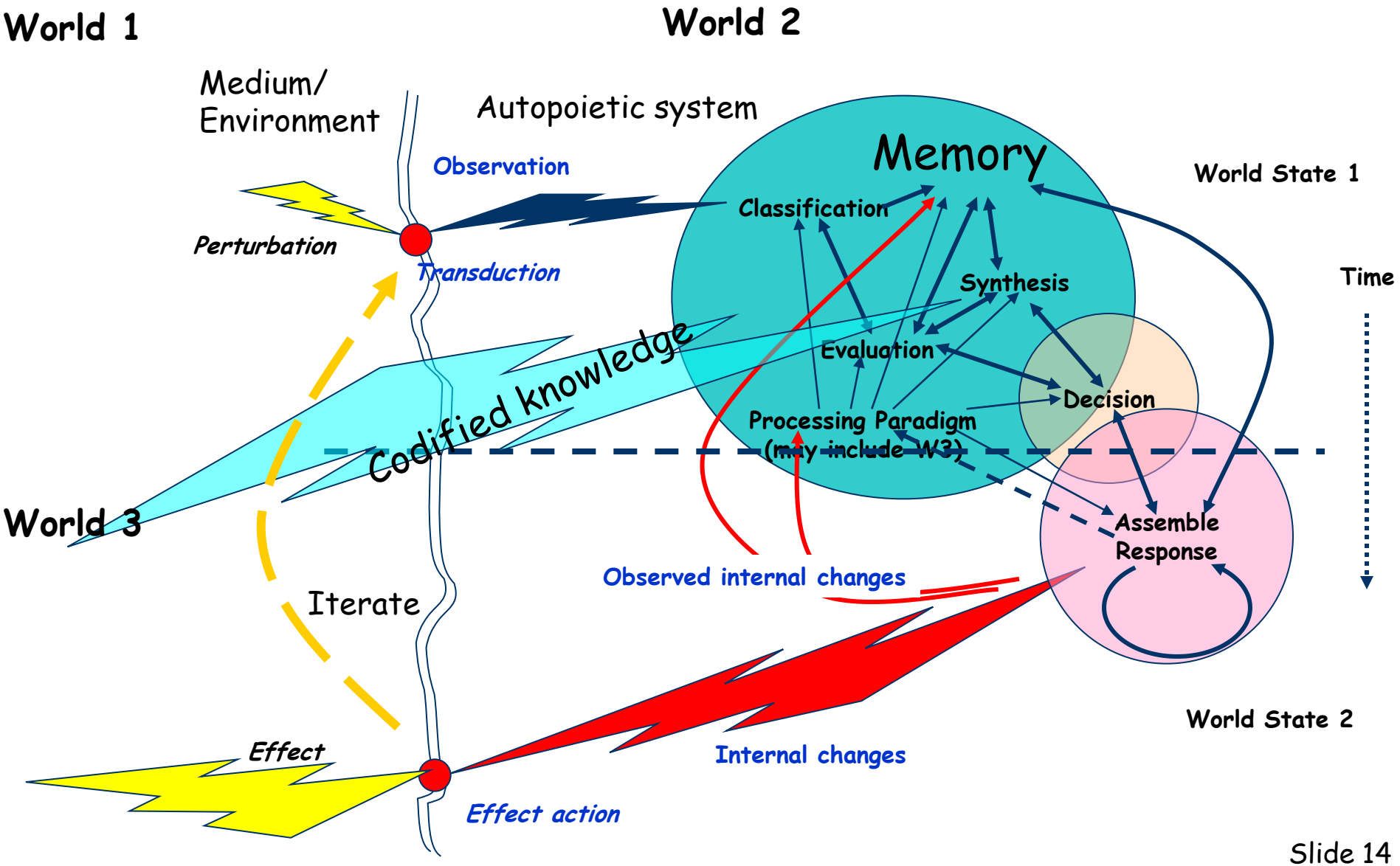
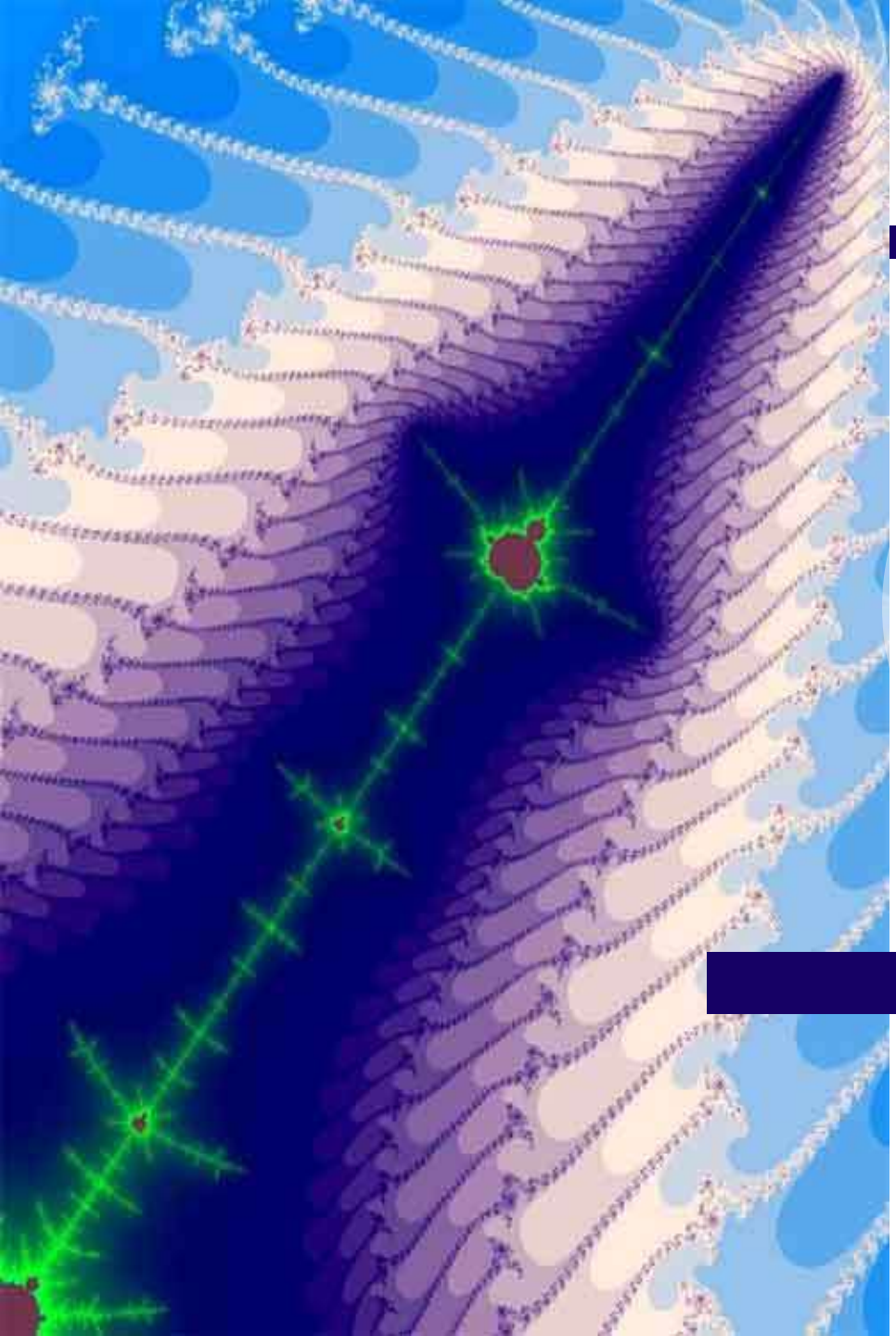
Another view





Evolution and revolutions in living systems

Evolutionary vs revolutionary capabilities for growing knowledge

Evolution vs revolutions

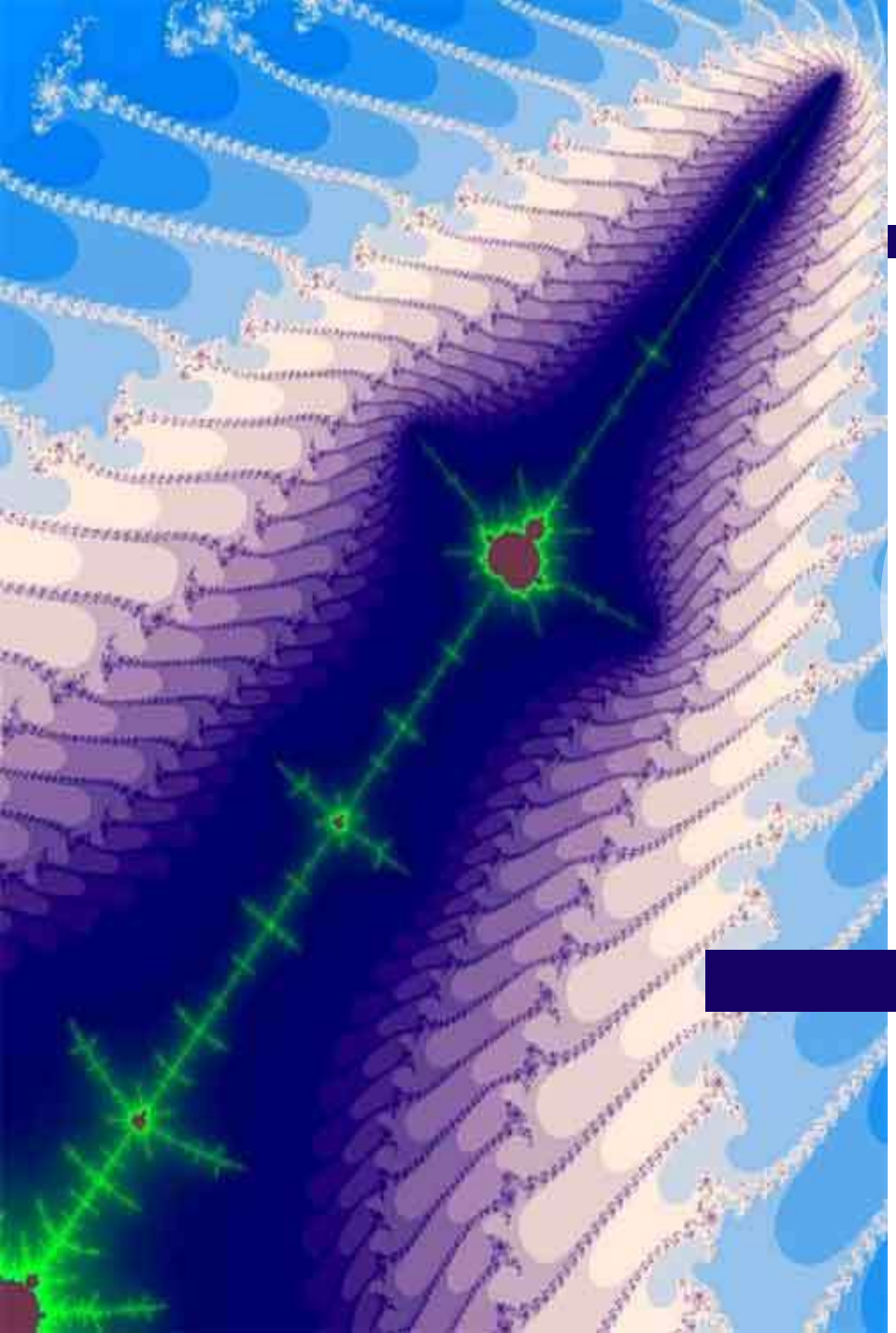
- Thomas Kuhn (1970) – Structure of Scientific Revolutions (= chaotic & discontinuous changes in non-linear systems)
  - **Normal Science** = **incremental evolutionary change** within an established world view/cognitive structure
  - **Scientific Revolution** = **discontinuous change** resulting from emergence of a new/disruptive cognitive structure
- Concepts apply more broadly than scientific theory
  - Technology – normal technological development disrupted by new technologies doing same things in new ways
  - Biology – **slow incremental change producing better adaptations to local peaks in the adaptive landscape, may be punctuated by "grade shifts" creating new landscapes opening new realms for adaptive radiations**

Time-line for the most fundmental revolutions in knowledge storage, processing power and bandwidth

- Memory and cognition in dynamic structure of the autopoietic system (W2 only) – **4.5 billion years ago – physics begets life**
  - Virtuous cyclical dynamics at the molecular level able to maintain homeostatic control in some circumstances
- Genetic memory at the molecular level (W2 + W3) - **4 bn years ago**
  - Add RNA & DNA
- Multicellular memory (molecular W2 + W3 + cellular W2) – **2-1.5 bn years ago**
  - Add dynamic structure in cellular neurons ➔ neural nets ➔ brains
- Group cultural memory (molecular W2 + W3 + cellular W2 + organizational W2) – **5 million years ago**
  - Add tacit then linguistic creation, communication & sharing of knowledge
- Codification, storage & transfer of knowledge in and via tangible artefacts, e.g., writing & communication (molecular W2 + W3 + cellular W2 + organizational W2 + W3) – **5 thousand years ago**
- Virtual memory, communication, cognition at light speed – **50 years ago**
- *Global brain* – **now!**

Knowledge-based revolutions in material technology cause grade shifts in the ecological nature of the human species

- Accelerating change in our material technologies:
  - > 5 *million years ago* - **Tool Making**: sticks and stone tools plus fire (~ 1 mya) extend human reach, diet and digestion
  - ~ 11 *thousand years ago* - **Agricultural Revolution**: Ropes and digging implements control and manage non-human organic metabolism
  - ~ 560 years ago **Printing** enables Reformation & Scientific Revolution
  - ~ 2.5 *ca* - **Industrial Revolution**: extends/replaces human and animal muscle power with inorganic mechanical power
  - ~ 50 years ago - **Microelectronics Revolution**: extends human cognitive capabilities with computers
  - ~ 5 *years ago* - **Cyborg Revolution**: convergence of human and machine cognition with smartphones (today) and neural prosthetics (tomorrow)



PART TWO

Evolution and revolutions in living systems

Evolutionary vs revolutionary capabilities for growing knowledge

Evolution vs revolutions

- **Science = processes for growing reliable knowledge**
- Thomas Kuhn (1970) – Structure of Scientific Revolutions (= discontinuous & chaotic changes in non-linear systems)
  - **Normal Science** = **incremental evolutionary change** within an established world view/cognitive structure
  - **Scientific Revolution** = **discontinuous change** resulting from emergence of a new/disruptive cognitive structure
- Concepts apply more broadly than scientific theory
  - Biology
    - **Incremental change providing better adaptations to local peaks in the adaptive landscape**
    - **May be punctuated by "grade shifts" providing access to new landscapes opening new realms for adaptive radiations**
  - Technology – normal technological development disrupted by new technologies doing old + new things in new ways

Timeline for the most fundmental revolutions in biological knowledge storage, processing power and bandwidth

- Memory and cognition emerged in dynamic structure of the autopoietic system (W2 only) – 4.5 billion years ago – **physics begets life**
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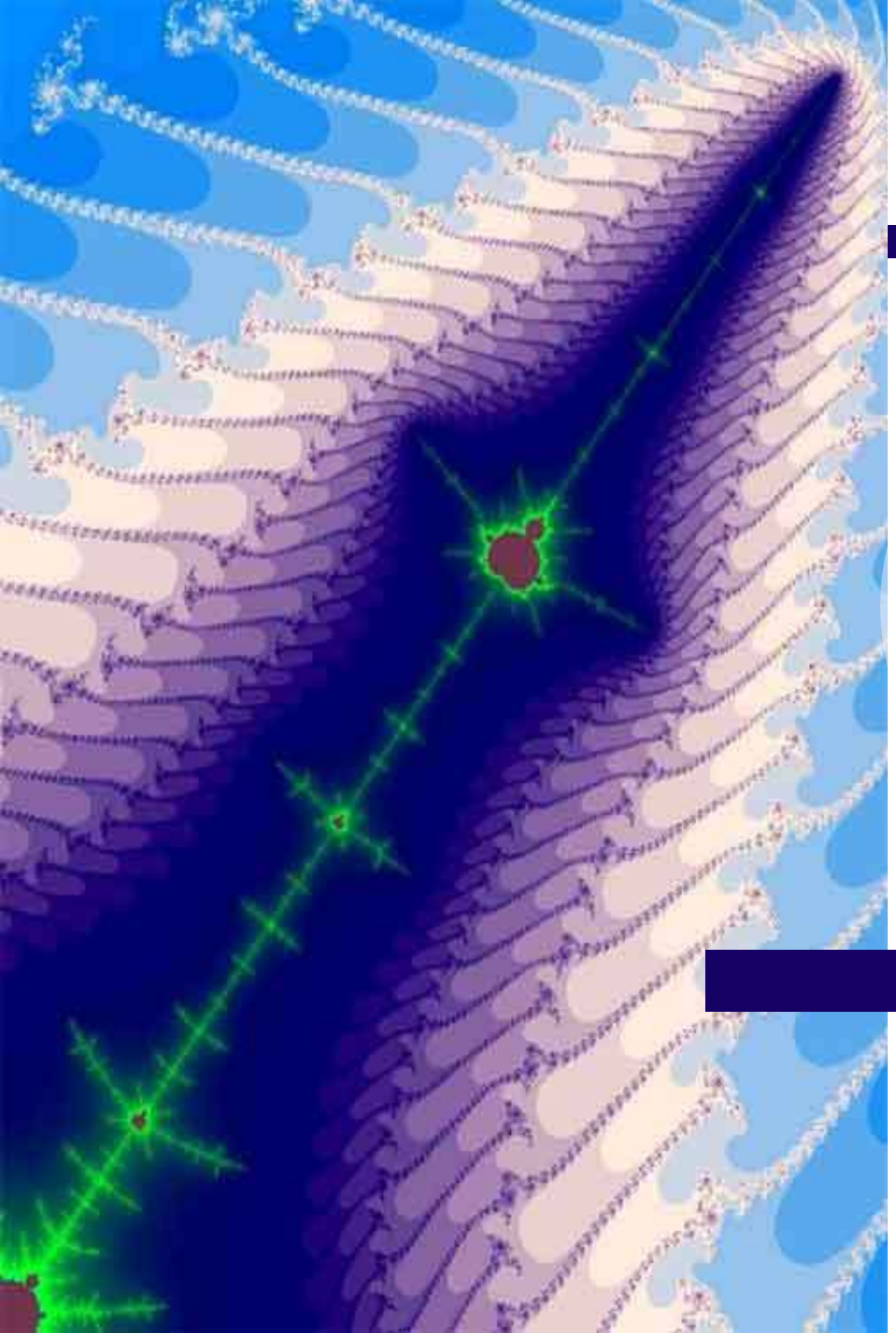
- *Global brain* – **now!**

Grade shifting revolutions in human technologies repeatedly reinvent the nature of & bandwidths for individual cognition

- Accelerating change in extending human cognition
  - (> 5 *mya* – Tacit transfer of tool-using/making knowledge adds **cultural inheritance** to genetic inheritance)
  - (~ 2 *mya* - Emergence of **speech** speeds direct transfer/ criticism of cultural knowledge among individuals)
  - ~ 11 *kya* – 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)
  - ~ 5.6 *ca* - **printing and universal literacy** transmit knowledge to the masses (cultural use of technology)
  - ~ 32 *ya* - **computing** tools actively manage corporate data/ knowledge externally to the human brain (*32 Y*) and personal knowledge (World Wide Web - *18 Y*)
  - ~ *10 ya*- **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)



5 million years of human history concatenates many cognitive revolutions

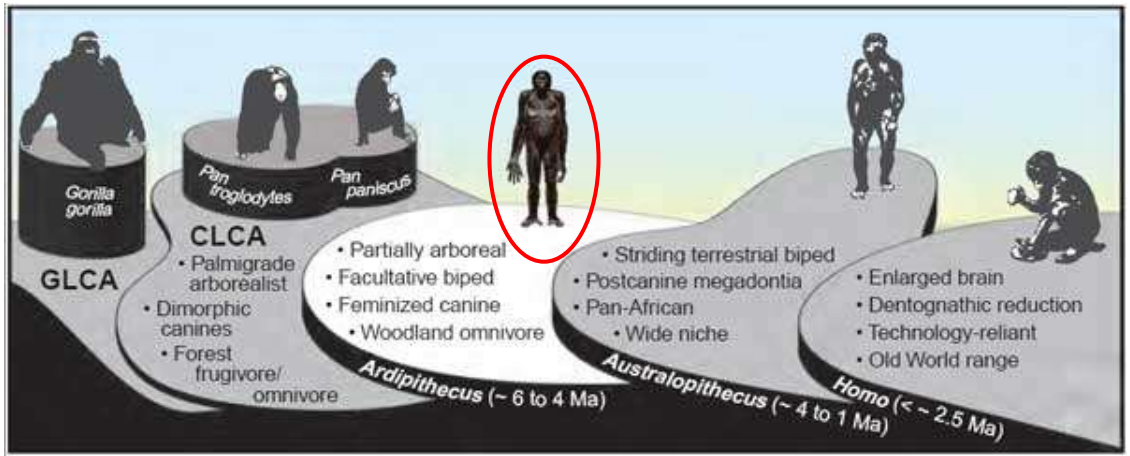
Where we started: socially foraging, tool-using forest apes in East African Garden of Eden > 5 mya

(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.

Adaptive plateaus achieved in the Pliocene as our ancestors became more bipedal and better adapted to open and arid environments (White et al. 2009)



Knowledge-based autopoietic groups as higher-order evolutionary entities

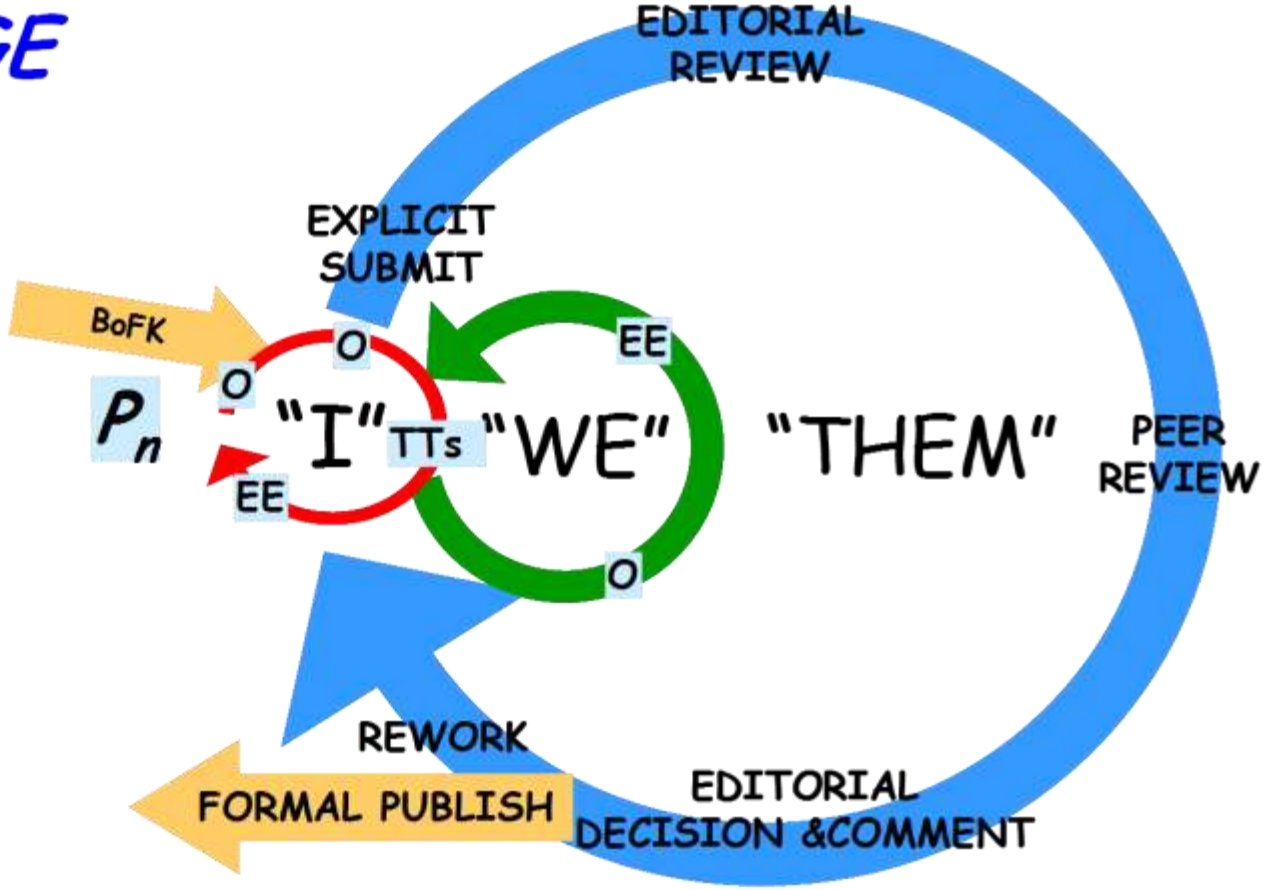
- **Accumulated knowledge determines system's structural adaptations to ensure survival and (re)production**
- **Hierarchically nested systems are possible**
  - **Cells → Organisms → Social organizations → Communities**
- ***A group* is defined to be autopoietic if it exhibits all the criteria**
  - *Bounded* (groups geographically and socially separated with culturally regulated and limited mixing)
  - *Complex* (groups formed of several to many individuals playing various different roles in group)
  - *Mechanistic* (energetically/economically driven interactions of group individuals determine group functions)
  - *Self-referential* (group identity and boundaries determined by culturally transmitted knowledge)
  - *Self-producing* (group retains its continuity beyond the lifetimes of single individuals through individual reproduction and recruitment combined with indoctrination in and transmission of accumulated cultural knowledge from one generation to the next)
  - *Autonomous* (the group manages its own survival and continuity through knowledge-based interactions of its individual members)

Advances in group/organization cognition combined with technology enable other grade shifting revolutions

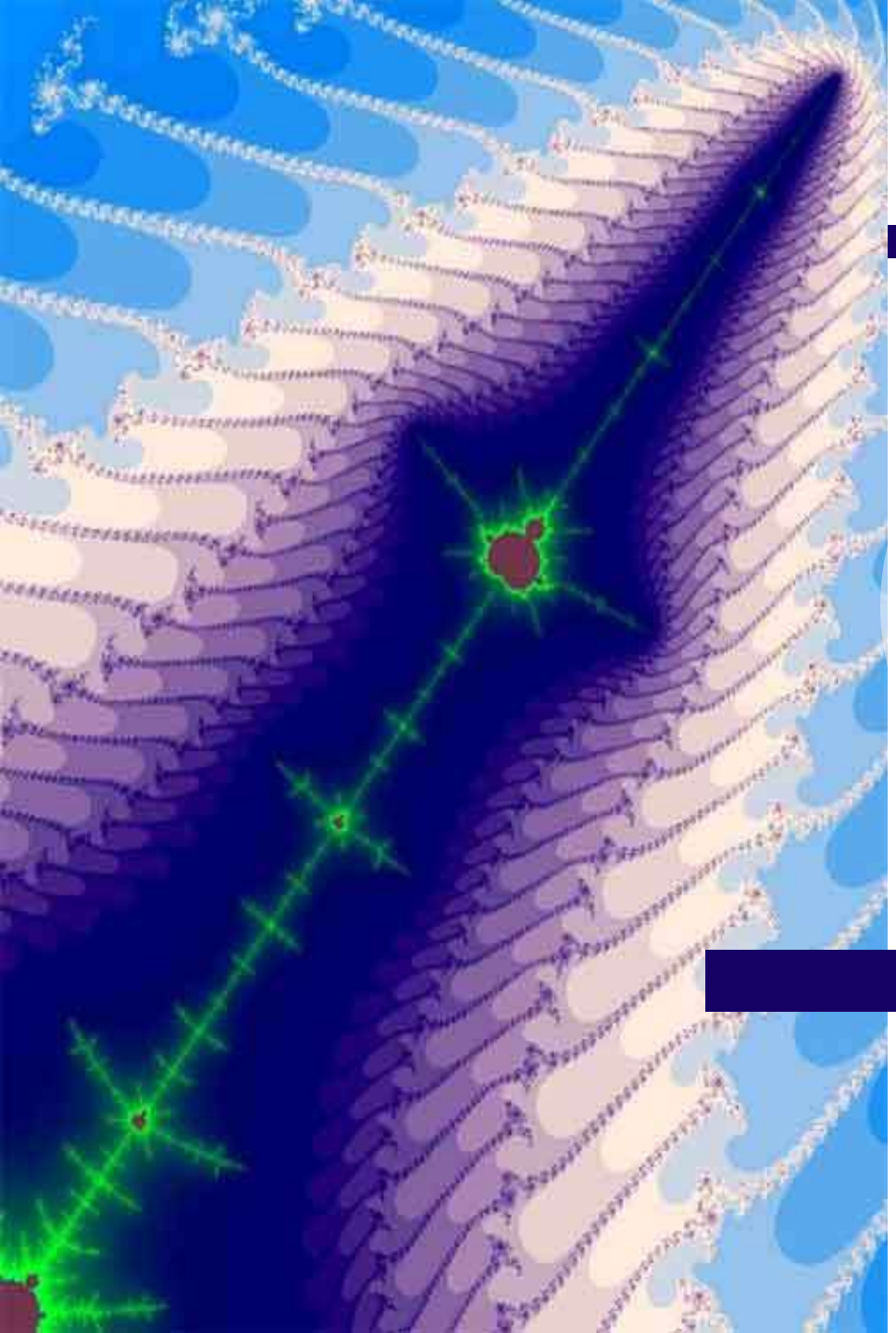
- Genetic memory is adaptive
- ***Cultural memory is additive as well as adaptive !***
- Accelerating change in extending group cognition
  - > 5 *million years ago* – **social hunting/defence** → **cooperative foraging & hunting** → **autopoietic groups**
  - ~ 2.0 *mya* - **linguistically coordinated activities** to share group knowledge (mime, dancing, singing, story-telling, myth, ritual)
  - ~ 200 *thousand years ago* – **mnemonics/songlines** apply ritual & method of loci to landscapes to build & retain cultural memories
  - ~ 12 *kya* – **mnemonic guilds & monumental architectures** enable husbandry, settlement, farming & economic specialization
  - ~ 7 *kya* – **tokens & writing** enable bureaucratic cities & states
  - ~ 600 years ago – **communications, coordination** & rise of chartered companies
  - ~ 100 ya – **instant communication** & rise of transnationals
  - ~ *Now* – emergence of **global brain** & global cognition

Scientifically constructing formal knowledge to control the world (Hall & Nousala 2010; Vines & Hall 2011)

KNOWLEDGE SOCIETY



- Formal knowledge is considered "safe to use"



PART THREE

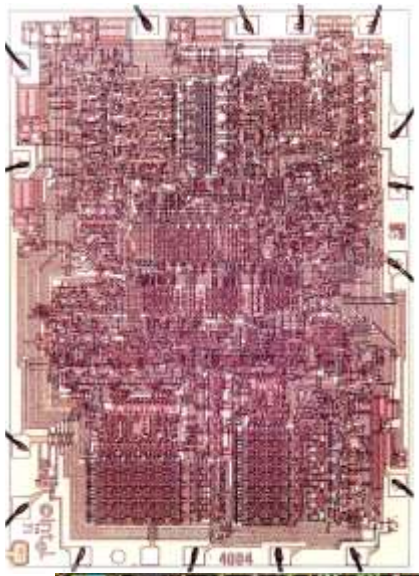
Exponential growth and Moore's Law

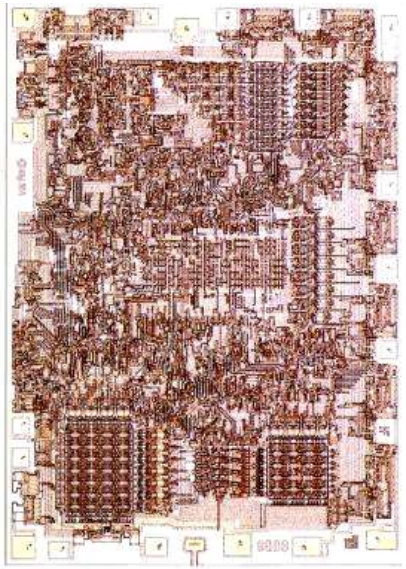
The incredible shrinking of time and space

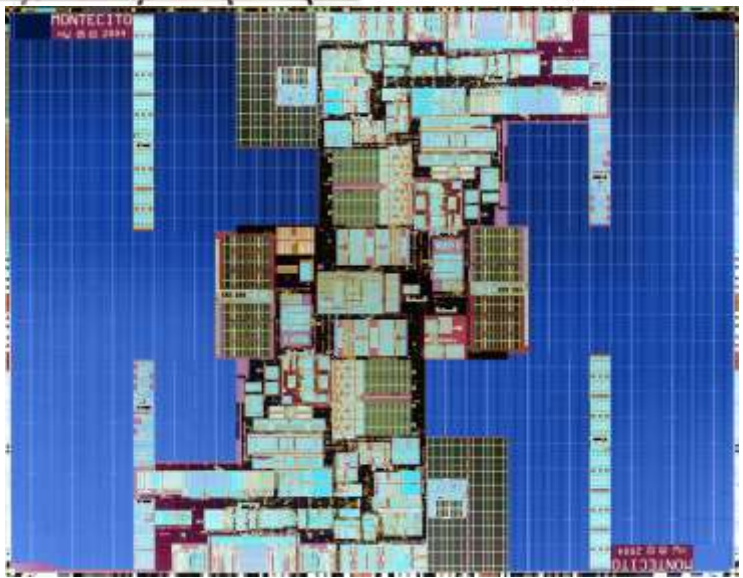
Knowledge-based revolutions in material technology cause grade shifts in the ecological nature of the human species

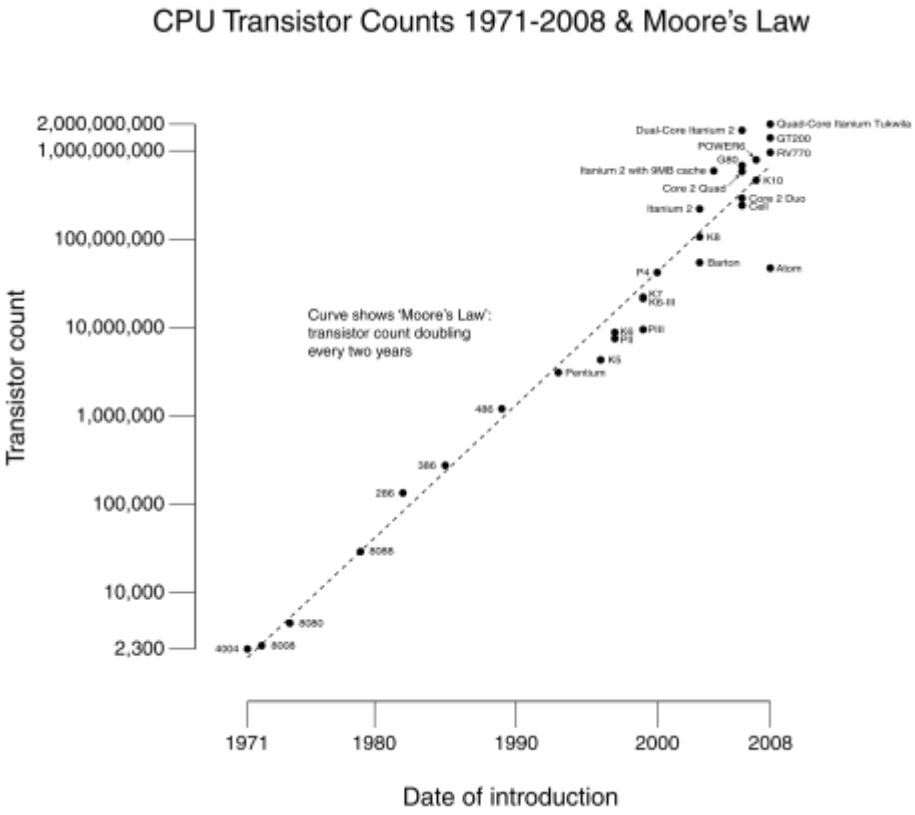
- Accelerating change in human material technologies:
  - > 5 *million years ago* - **Tool Making**: stick and stone tools plus fire (~ 1 mya) extend human reach, diet and digestion
  - ~ 11 *thousand years ago* - **Agricultural Revolution**: Ropes and digging implements control and manage non-human organic metabolism
  - ~ 560 years ago **Printing** enables Reformation & Scientific Revolution
  - ~ 250 years ago - **Industrial Revolution**: extends/replaces human /animal muscle power with inorganic mechanical power
  - ~ 50 years ago - **Microelectronics Revolution**: extends human cognitive capabilities with computers
  - ~ 5 *years ago* - **Cyborg Revolution**: convergence of human and machine cognition with smartphones (today) and neural prosthetics (tomorrow)

Microelectronics Revolution
Large scale integration and Moore's Law



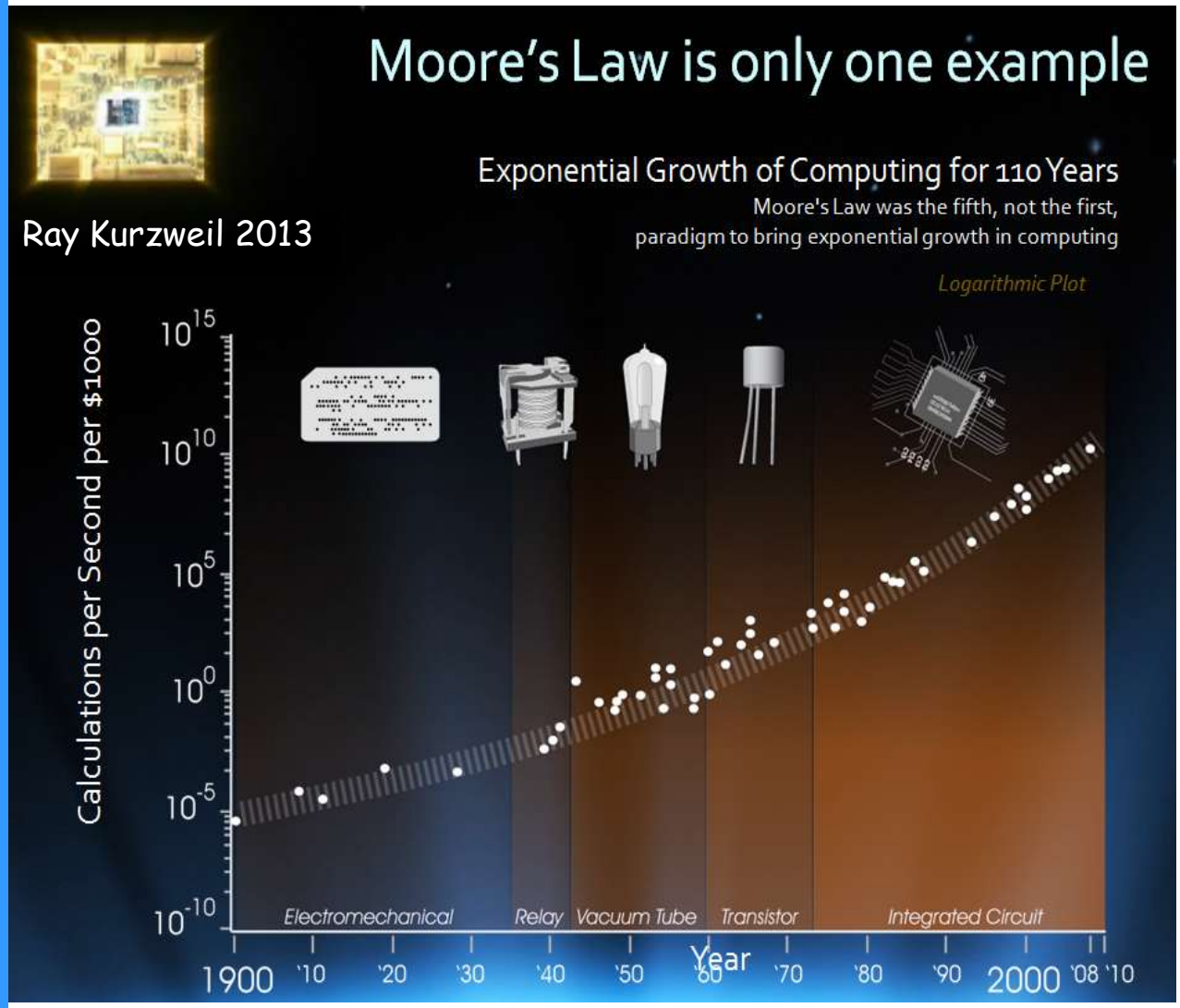






Moore's Law as applied to the evolution of microprocessors. Recent studies show the rate of increase is actually hyper-exponential. Magnetic storage density doubles even faster, as does total processing power. Chips are 4004 (2300 transistors, 1971), 8008 (3500 transistors - 1972), and Dual-Core Intel® Itanium® Processor (1.3 BN transistors - 2006)

Hyperexponential growth in computing technology



- Beyond flat IC's
  - 3D IC's
    - Heat management
  - Biomolecular (e.g., DNA)
    - Speed
    - Transduction
    - Interface
  - Quantum
    - Heat management

The Microelectronics Revolution and the increasing externalization and convergence of individual and social cognition

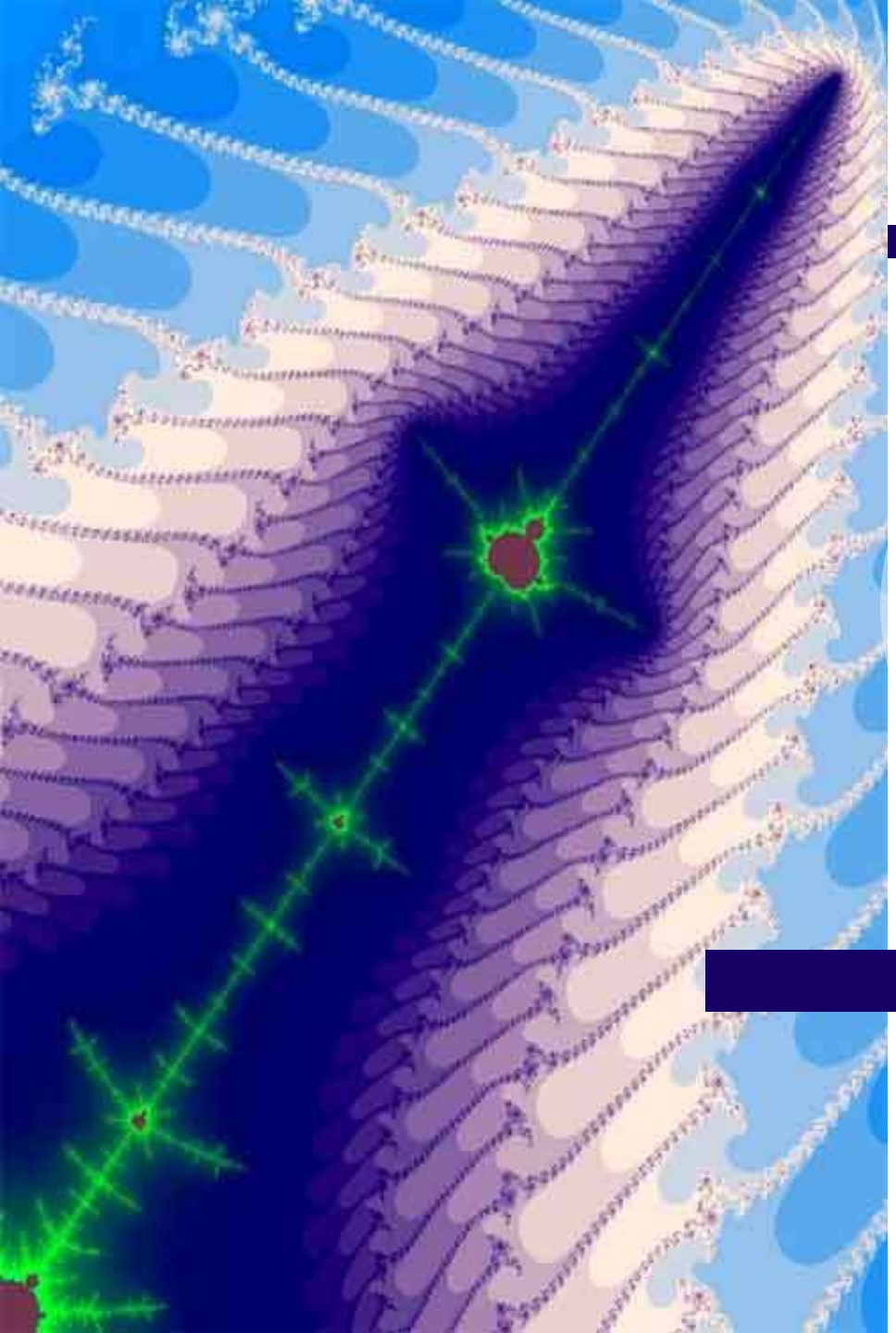
——— Externalizing cognition ———

- ~ 150 Y mechanical and electro/mechanical technologies for corporate/scientific number crunching & data processing
- ~ 60 Y birth of electronic digital processing
- ~ 43 Y invention of integrated circuit microprocessors and automatic fabrication
  - **Moore's Law & the still continuing hyperexponential growth of processing power**
  - Extending and replacing more and more human cognition
- ~ 35 Y automated processing, storage, distribution and retrieval of personal and corporate knowledge. (Wordstar 1979)
- ~ 22 Y networking knowledge with the World Wide Web (Tim Berners-Lee 1992)

——— Universal access to the world knowledge base ———

- ~ 20 Y Mosaic Netscape Navigator 1994
- ~ 16 Y free open-source browsers Mozilla Firefox 1998
- ~ 14 Y one billion web pages indexed, more than two billion by end of 2000
  - Last decade provides instant web search, access & retrieval of virtually the entire scientific & technical literature via Google Scholar/research library subscriptions
  - Majority of all English language book titles scanned, indexed, and available (if out of copyright), with smaller fractions non-English books processed.

——— Networking brains directly – towards a global brain/mind? ———



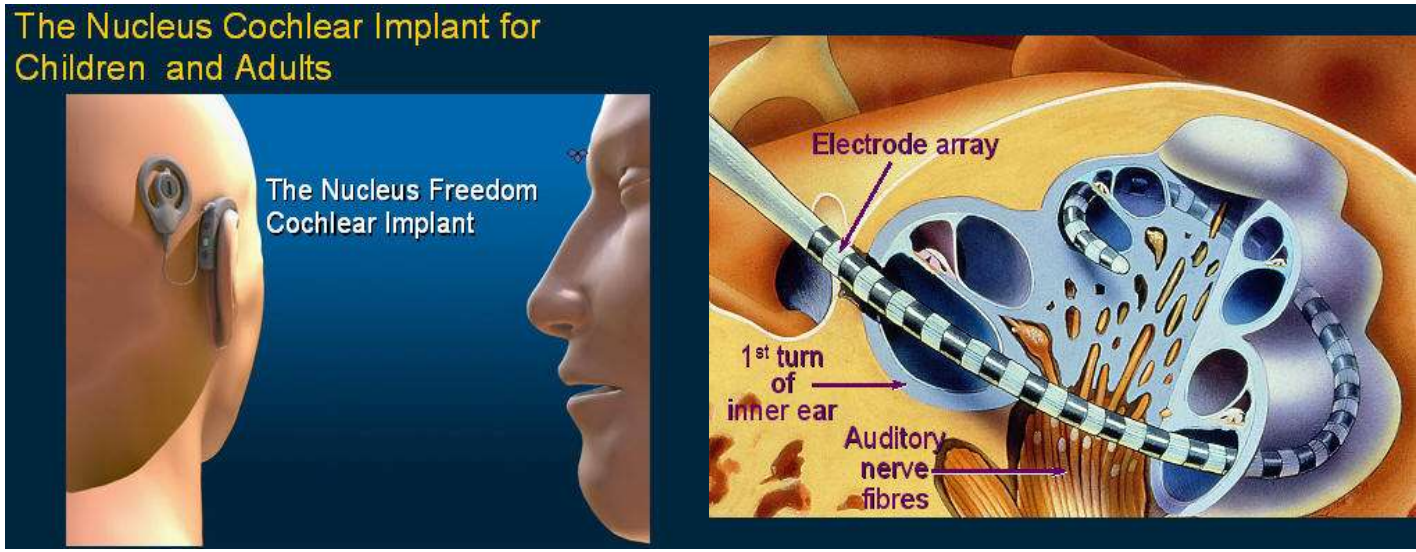
Emergence of the networked post-human cyborg still driven by natural selection

Interconnecting minds and cognitive processes via the cloud, "social computing" and convergent technology

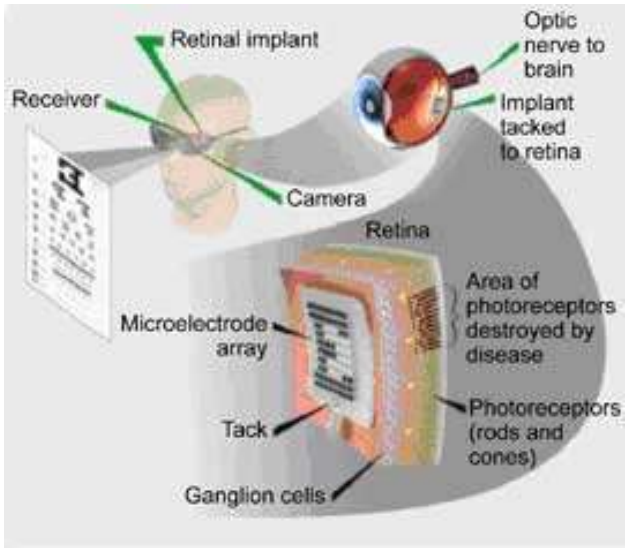
- **Technological convergence – mobile phone becomes a cognitive prosthesis**
  - **Email**: ARPANET (1971), TCP/IP (1982), SMS text (2002),Gmail (2005)
  - **Internet browsing & Search**: MOSAIC/Netscape (1994),Google (!997)
  - **Internet telephony**: Voice over IP (1994), Skype (2003)
  - **Media**: iTunes (2000), Amazon Kindle (2007), Google Play (2008)
  - **Still and video imaging**: Picassa/iPhoto (2002); YouTube (2005);
  - **Cloud storage**: Napster (1999), BitTorrent (2001), Amazon S3 (2006), DropBox (2008)
  - **Business/Office tools**: Google Docs/Drive (2007)
  - **Geospatial**: Google Earth/Maps 2005; Panoramio (**geolocated photos converging with Google Earth/Google Maps** – 2005)
  - **Social**: chat rooms (1980); Groups/Listservers (1992), LinkedIn (2003), Facebook (2004), Twitter (2006)
  - **Knowledge construction/sharing/broadcasting**: Wikis (1994), Wikipedia (2002), Blogs/Wordpress (2003)
- **Human-computer interfacing**
  - Head-mounted displays (1960's)
  - Google Project Glass (2013)
  - Networked SmartWatches (2014)
- **Implanted/embodied human-machine interfaces**
  - **Cochlear implants/Bionic Ears**
  - **Retinal implants/Bionic Eyes**
  - **Direct brain reading and stimulation**

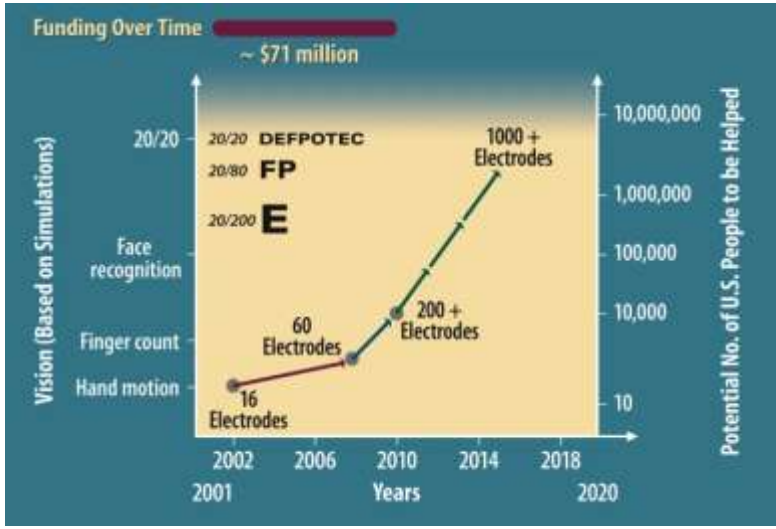
Sensory integration: Count on Moore's Law to drive the price down

Direct stimulation of the cochlea (Graeme Clark Foundation, How the cochlear implant (bionic ear) functions.)

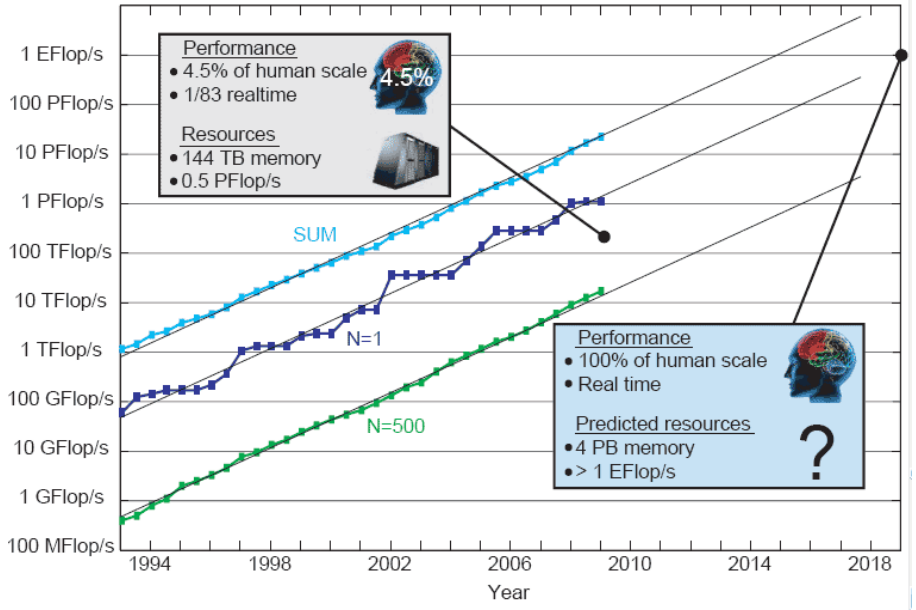


Direct stimulation of the retina (Bionic Eye. DOE Artificial Retina Project)





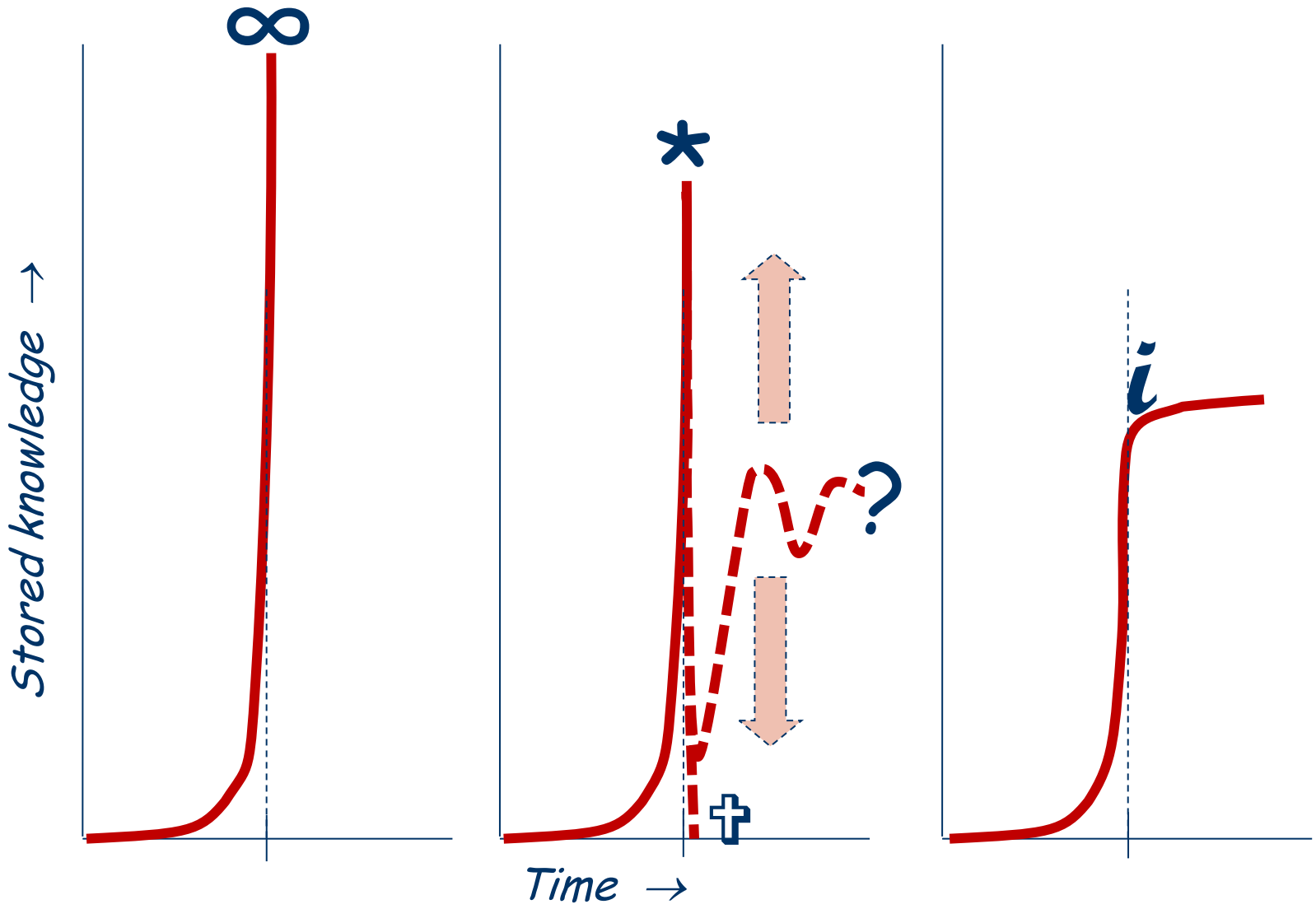
Brain simulation and emulation
Blue Brain Project / Human Brain Project

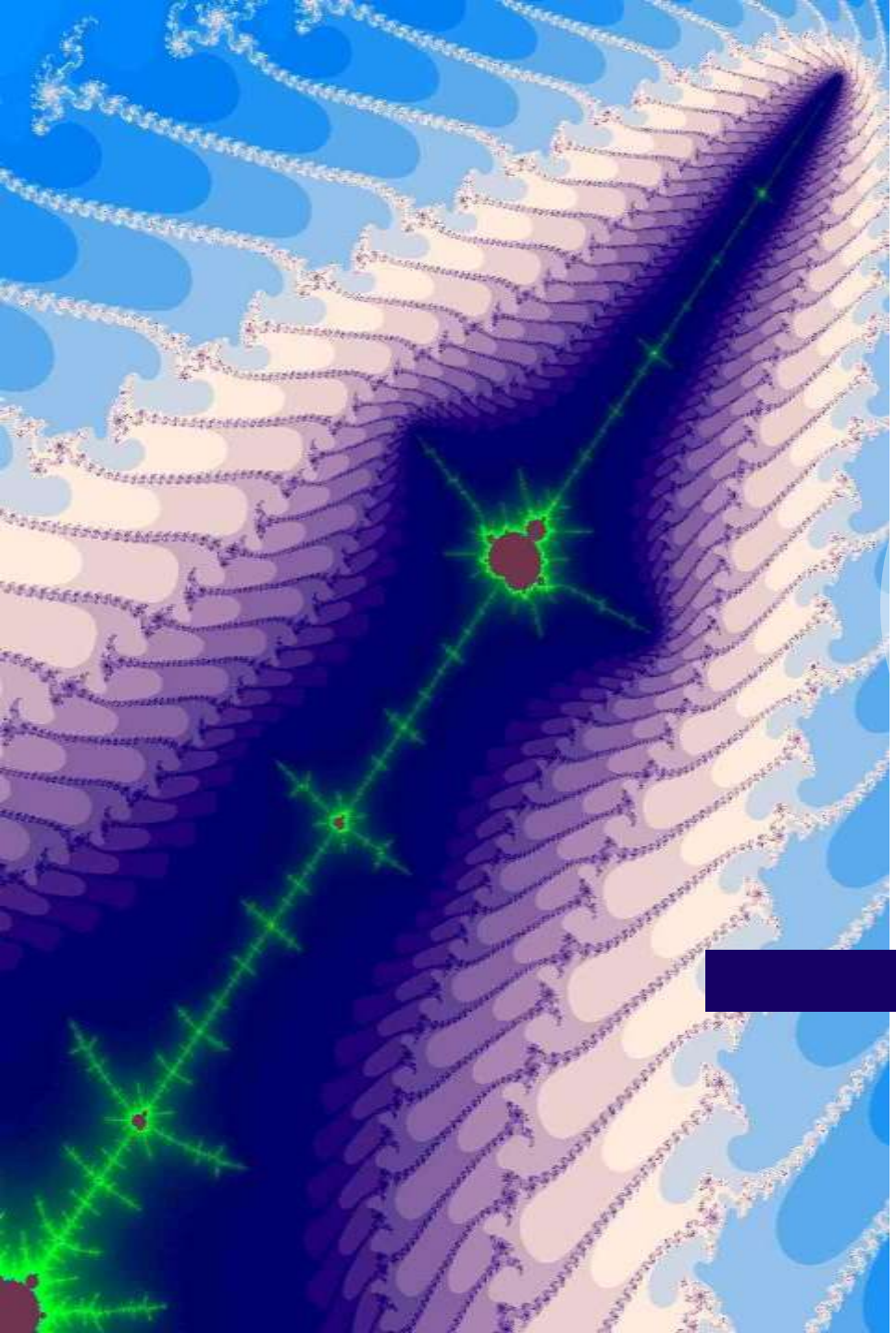


- Human Connectome Project
  - US NIH funded 2010-2015
  - Map of neural connections in the brain
  - Broadly, a connectome includes mapping of all neural connections in an organism's nervous system

- Simulation & emulation
  - Modelling of synapses & neurons
  - Neurons on chips (Moore's Law)
  - EU Blue Brain/Human Brain Projects
    - Single cell: 2005
    - Neocortical column: 2008 – 10,000 cells
    - Mesocircuit: 2011 – 100 columns
    - Rodent brain: ~2014 – 100 mesocircuits
    - Human brain: ~2023 – 1000 x rodent brains

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





THE END

Papers elaborating the ideas can be found on http://www.orgs-evolution-knowledge.net.

For working drafts and extracts see https://www.dropbox.com/sh/odx80z06k1bsbb4/AADrCRlSdqv8ivBPKPov8oHwa