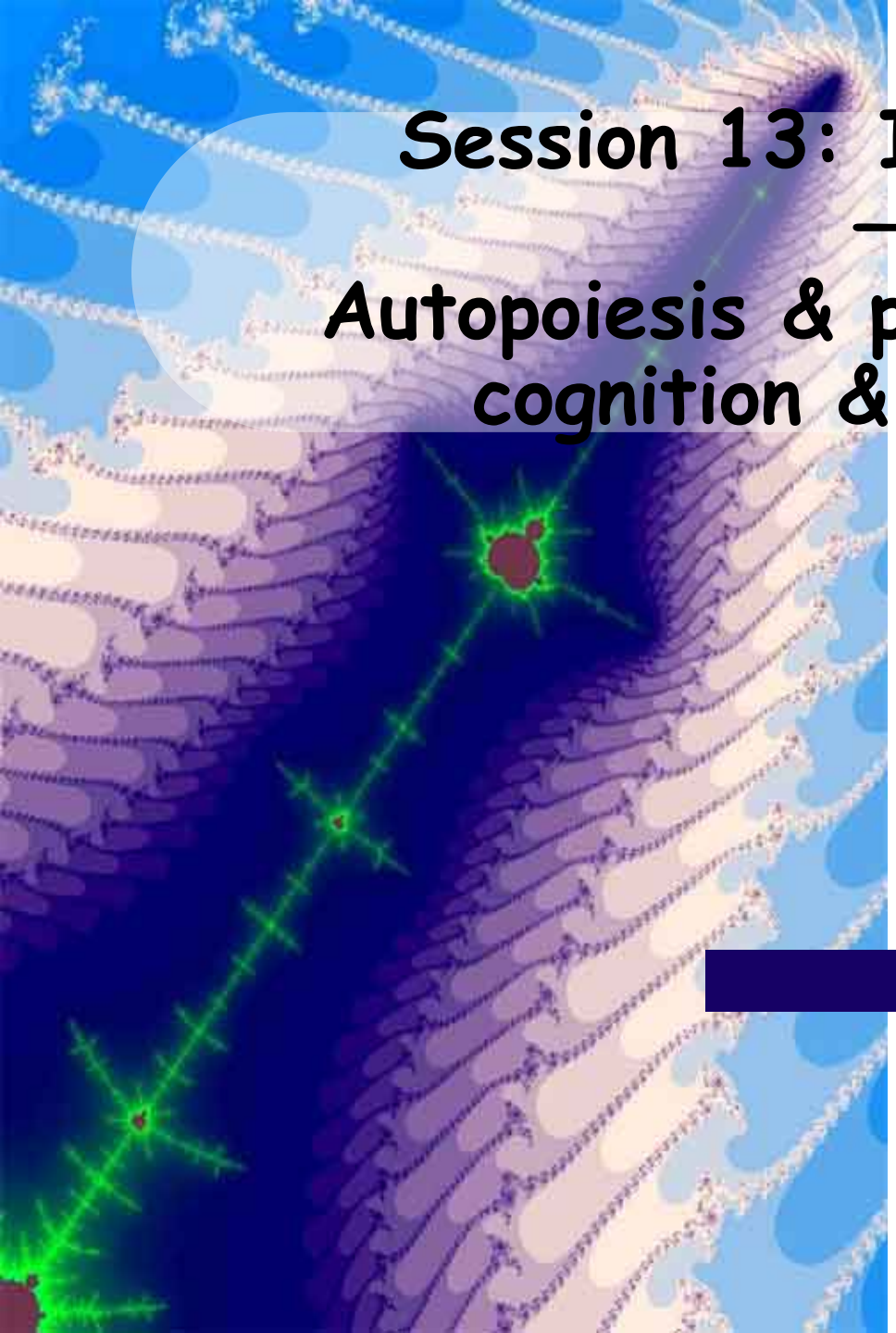

Session 13: Interlude (1)

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Autopoiesis & physics of life, cognition & knowledge

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Access my research papers from Google Citations

Tonight

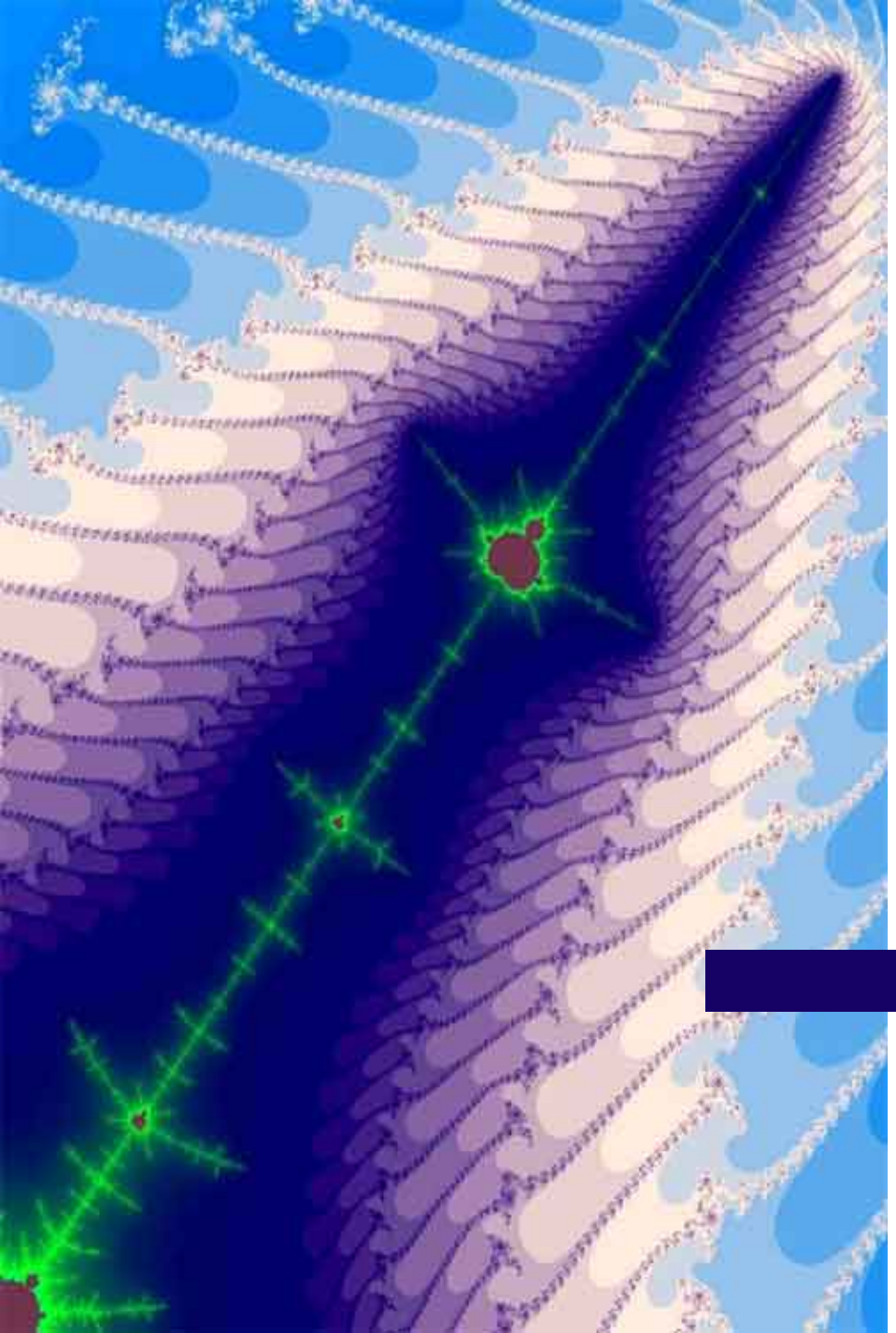
- The last session was the midpoint in the content of my book
  - The material on the history and impacts of technology on individuals was comparatively simple and non-problematic to write up
  - Largely complete by the end of 2003.
- Writing about technology in organizations was *not* simple
  - Needed to reformulate theories of living systems, knowledge & organizations from first principles before writing could resume

INTERLUDE

Recap and a Look Ahead [done in the last Meetup session]
Physics of Systems
- System concepts and dynamics
- Chaos
- Attractors
- Dynamic system concepts in the real world

Two views of how time, change and causation lead to evolution
- Causation, change and time at the quantum level
- Thermodynamics is the driving force of evolution at the macroscopic level

What is Life?
- Autopoiesis
- The spontaneous emergence of autopoiesis and knowledge



Understanding the physical basis of systems, change and dynamics

My background in physics, chemistry & biology

- Academic studies
  - $2\frac{1}{2}$ years of university physics despite dyslexia with maths
    - Thermodynamics, analytical mechanics, atomic physics
      - Motion, inertia, electro-magnetics, gravity, strong & weak forces
    - 2+ years assisting in a neurophysiology research lab
  - Biology, ecology (ecosystems theory), physiology, genetics
  - Chemistry, organic chemistry, biochemistry, biochemical genetics
- Research
  - Genetics and cytology (cytogenetics and genetic systems)
  - Comparative biology (anatomy and ethology)
  - Evolutionary biology (systematics, biogeography & speciation)
- Teaching (~ 7 years full time, ~3 part time)
  - Gamut of organismic zoology and genetics
  - Presented an understanding of life deriving from first principles
    - Thermodynamics, physical constraints, natural selection and evolution
    - Adaptation
    - Levels of organization

Physics of systems

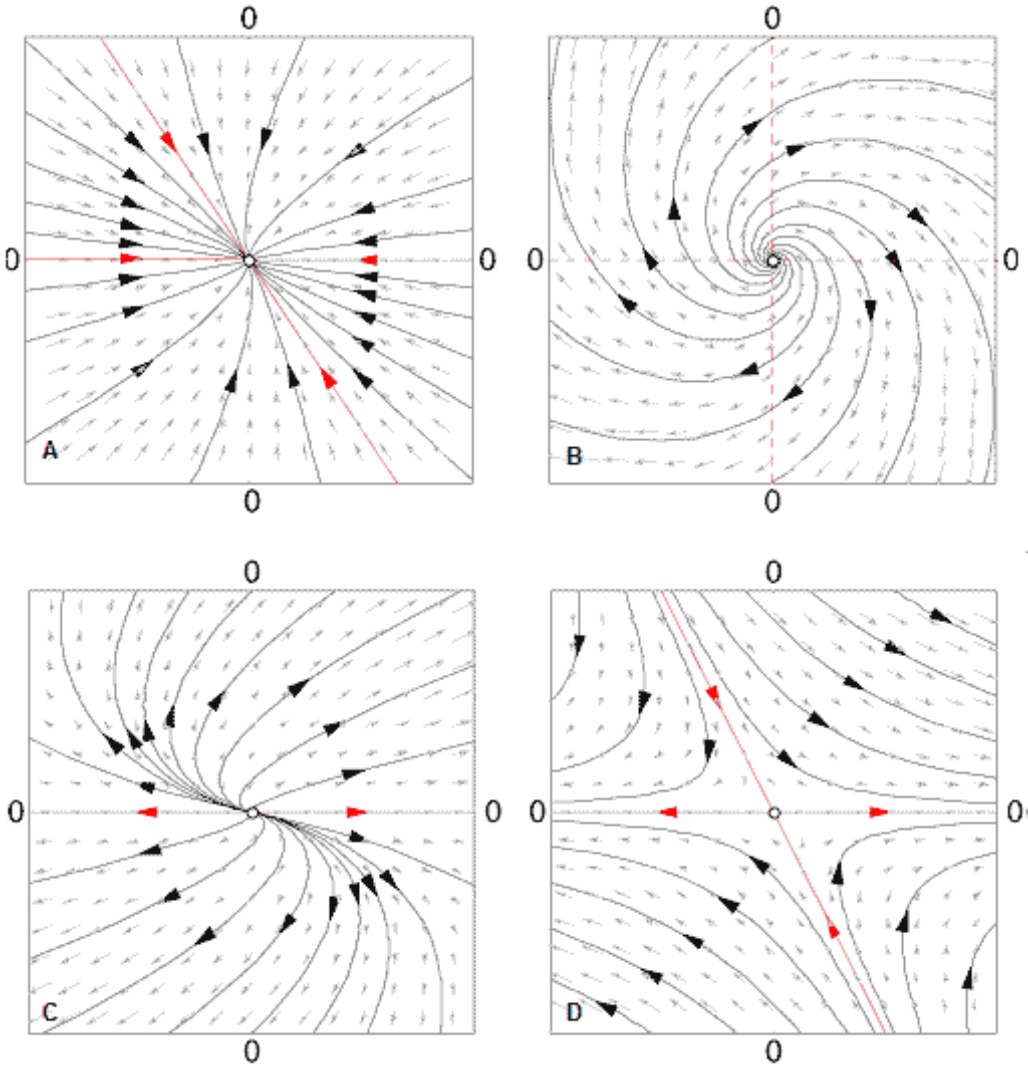
- Some definitions
  - **System**: a defined or demarcated collection or assembly of elements or components that actually or potentially interact physically
  - **Dynamics**: explains how particles and systems move through time under the influence of causal effects and forces
  - **Dynamic system**: causally interconnected set of particles or components that changes through time as the result of causal forces that propagate through the components as one particle influences others, and so on
  - **Causation structure**: The network of oriented relations represented by the graph associated with the interaction configuration; i.e., the path of propagation for all the possible causal effects triggered by a transition occurring in any dynamical object or system whose equivalent node is "connected" to a particular location in the graph
- See Urrestarazu (2012)
  - Urrestarazu was a student of Maturana who went on to study solid-state physics
  - Provides a meticulously developed understanding of the structural dynamics of complex systems of particles/components

Dynamic systems

- Formal definition: Systems that change through time where changes in the causation structure can be represented by a mathematical formalization that describes the time dependence of each component's position in an n-dimensional state space where each dimension corresponds to a degree of freedom (i.e., a model describing the temporal evolution of a defined system)
  - *Deterministic*: there is a unique state or set of states at each point in time.
  - *Stochastic*: there is a probability distribution of possible states at each point in time.
  - *State space* (= *phase space*): collection of coordinates (dimensions) that gives a complete description of the system (may be continuous or discrete). Given the current state of the system, the evolution rule predicts the next state or states.
  - *Time*: may also be continuous or discrete.

Vector fields and trajectories

- When parameters of a dynamic system are set to a point in the system's state space, the vector associated with that place in space points in the direction of the place in phase space that will be occupied by the system in the next instant.
- A set of differential equations describing the dynamics of the system allows a vector to be calculated for each point in state space.
- Its changes follow the vector field



Vector fields and trajectories in a planar state space from Wikipedia. Location 0,0 is point of stable or unstable equilibrium

Chaos, Attractors and dissipation

- Chaos:
  - long term system behavior is unpredictable, tiny changes in the accuracy of the starting value diverge to anywhere in its possible state space
  - Deterministic, stochastic, & dissipative
- Attractor:
  - a set of numerical values which a system tends to evolve towards or away from, for a wide variety of starting conditions of the system. System values that get close enough to the attractor values remain close even if slightly disturbed
    - Fixed point or points
    - Limit cycles or torus
    - Strange or fractal
  - Attractor basin
    - **a** region of state space, such that any point (any initial condition) in that region will eventually be iterated into the attractor.
    - May be several to many such basins in a phase space
- Dissipation
  - result of an irreversible process in complex thermodynamic systems

Dynamic systems in the real world – some more concepts

- Dissipation - gradual conversion of available energy in the dynamic system to entropy (i.e., unusable heat) through friction, turbulence or other processes according to the second law of thermodynamics.
  - Unless energy is added from outside, natural systems towards the state of lowest energy available within the local attractor basin.
- Perturbation - change imposed from outside the defined structure of a physical system that will arbitrarily change the location of the system in its state space
  - system parameters may be moved to another attractor basin, or even to a trajectory that that directs the system's evolution towards zero or infinity (i.e., stasis or disintegration)
- Equilibrium - point of minimum energy in the state space of a dynamic system where the system will remain at rest unless it is perturbed through the addition of energy in some form (global or local)
- Thermodynamic equilibrium - system in a state where there are no unbalanced potentials (or driving forces) within the system. A system that is in equilibrium experiences no changes when it is isolated from its surroundings and can do no work on its surroundings.

Causation, change and evolution

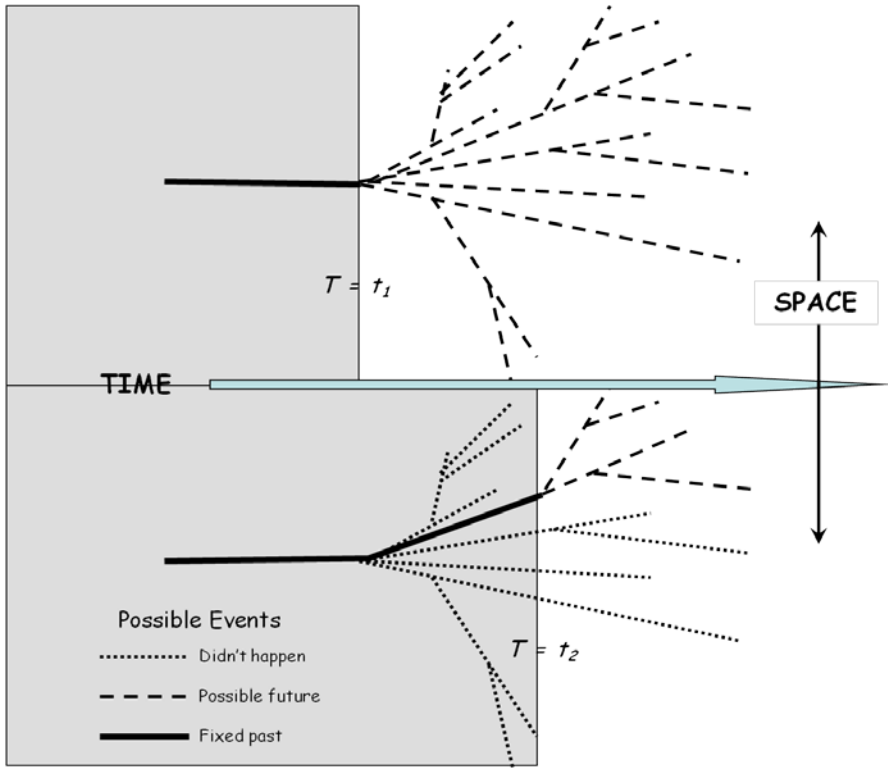
- Aristotle:
  - Material cause - the material from whence a thing has come or that which persists while it changes, as for example, one's mother or the bronze of a statue (see also substance theory).
  - Formal cause - whereby a thing's dynamic *form* or static *shape* determines the thing's properties and function, as a human differs from a statue of a human or as a statue differs from a lump of bronze (i.e., the state space of a dynamical system).
  - Efficient cause - which imparts the first relevant *movement*, as a human lifts a rock or raises a statue.
  - Final cause - the criterion of completion, or the end or aim, of an action or instrument of action, as Socrates takes a walk after dinner for the sake of his health (i.e., telos - deprecated by evolutionists & physical scientists)
- Change: what happens in progression from one state to another
  - meaningless without time
- Evolution: progressive change through time

Time: a grossly neglected aspect of physics

- Einsteinian space-time: the block universe
  - Time is the 4th dimension in a 4D hyperspace
  - Everything exists – what you see depends on your current location
  - Implies nothing changes except your location
    - No capacity for free will or decisions
- Quantum world: stochastic nature of quantum mechanics
  - Future is undetermined, present state of the world progresses through a sequence of instants of becoming
    - Penrose's quantum mechanical entanglement and collapsing wave functions spread over microseconds to milliseconds
    - Deutsch's concept of multiverses
    - Smolin's loop quantum gravity
  - Ellis etc's emerging or evolving/crystallizing block universe
    - "past" is unchangeably fixed spacetime block (if it exists at all)
    - "future" exists only as possibilities until a particular possibility emerges and is realized in the present instant.
    - "*present*" or "*now*" is an instant of quantum mechanical interaction when one of many possible future worlds becomes real and establishes the possibilities for the next instant.

A universe open to top-down causation

- Kauffman's "adjacent possible"
  - Possible configurations of state space that may exist in the next instant from "now"
  - Except in the multiverse, only one of these crystallizes in the next instant – which then provides the cause for forming the next future state.
  - Each step in the advance of time prunes all but one configuration and establishes the basis for a manifold of possibilities in the next step.
- How does this allow us to make choices?
  - Planck time ~ 5 x 10^{-44} sec.
  - physiology of human perceptions and decisions are measured in milliseconds

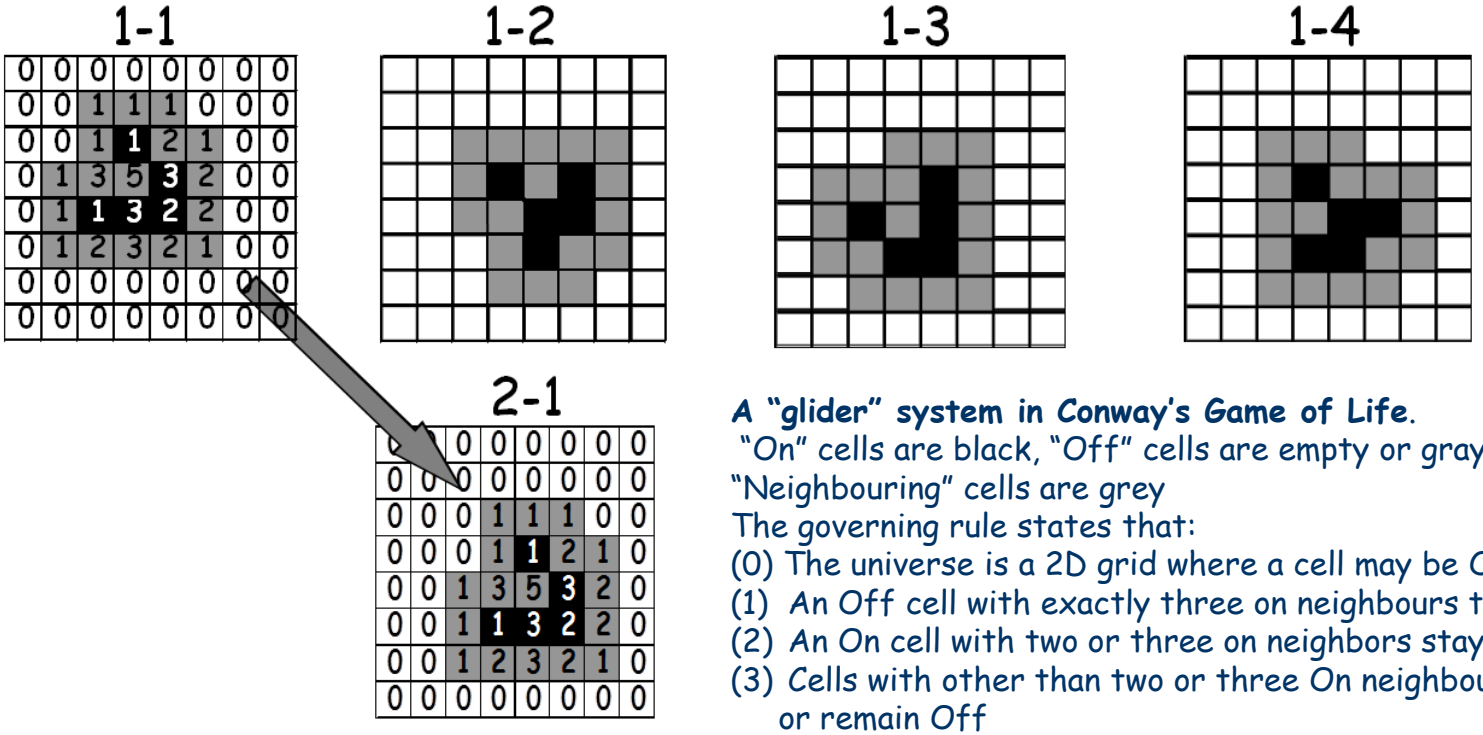


Trajectory of a particle through space and time where the motion is randomly perturbed. (After Ellis 2006b; Ellis & Rothman 2010). t_1 and t_2 represent different instances of becoming or "nows". The trajectory in the past either no longer exists or cannot be changed, and the possible future trajectories don't exist until they are realized or crystallized in the continually iterating now.

Upward and downward causation at the system level

- The instantaneous state of state space constrains its state in the next instant to the adjacent possible.
  - This present state also reflects the historical sequence of prior instances
- *Upward causation* involves the operation of governing rules on lower-level entities causing changes in the system comprised of those entities
- *Downward causation* refers to the effect that the existence of the system in a higher level environment has on the system's properties and interactions
- Selective processes based on instantaneous structure of phase space may affect the probabilities that particular adjacent possible states have to be realized
- As will be seen, these biased probabilities may act as a form of downward causation, where organization of the larger structure biases the sequences of realizations

Demonstrating upward and downward causation in a toy universe

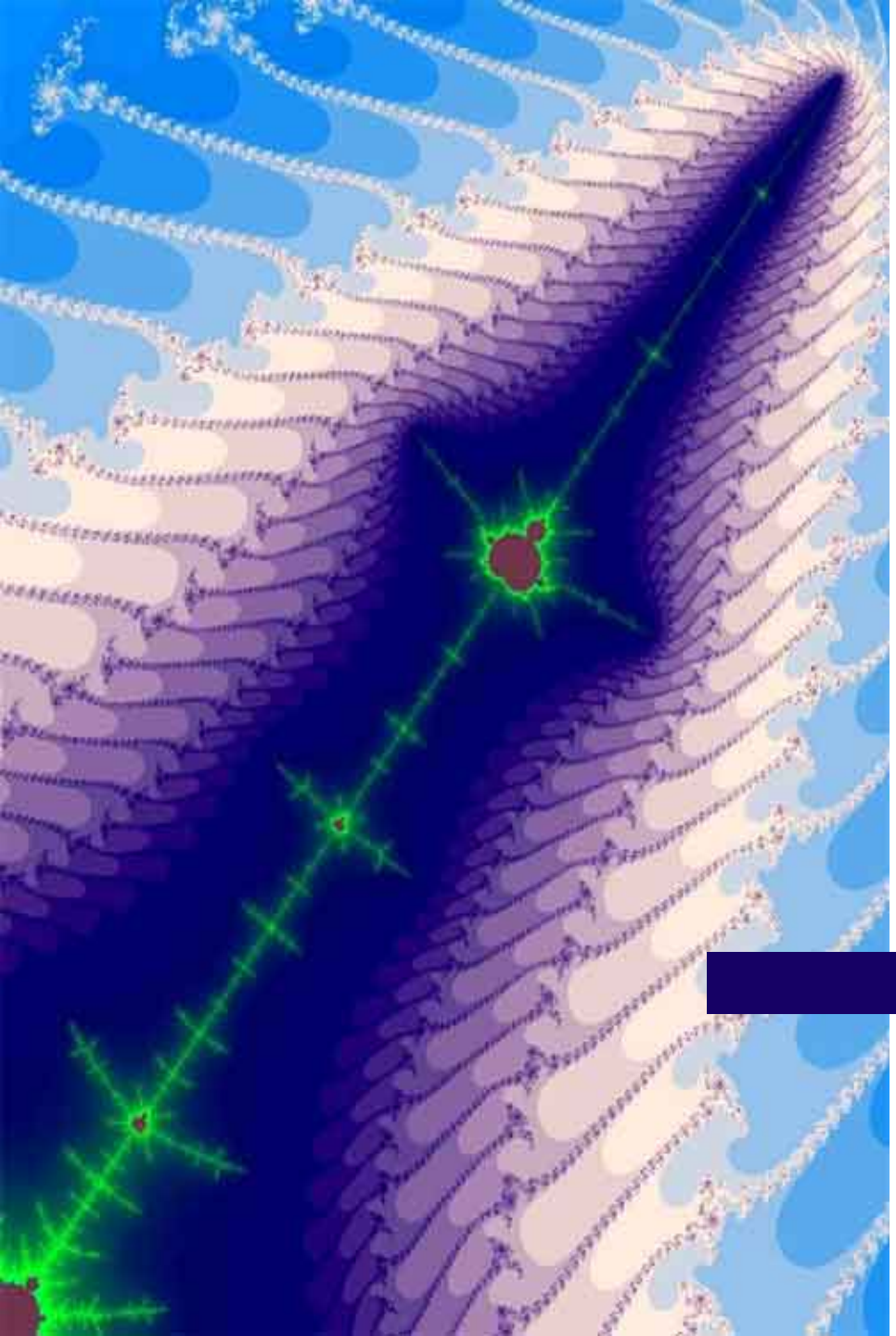


A "glider" system in Conway's Game of Life.
"On" cells are black, "Off" cells are empty or gray. Empty "Neighbouring" cells are grey
The governing rule states that:
(0) The universe is a 2D grid where a cell may be Off or On;
(1) An Off cell with exactly three on neighbours turns On;
(2) An On cell with two or three on neighbors stays On;
(3) Cells with other than two or three On neighbours turn Off or remain Off

- System has only one adjacent possible in each next instant
- Upward causation = application of the governing rules to individual cells
- Downward causation = location on On cells at time instant "Now" determines location of On cells at time instant Now + 1

Thermodynamics

- **First law of thermodynamics**: quantity of energy (matter is a form of energy) is conserved, but may change its forms
- **Second law of thermodynamics**: energy (and energy-rich matter) will *spontaneously* flow (or be converted) only from high potential forms to lower potential forms.
  - Change in potential resulting from a particular conversion process is measured in terms of **entropy** (representing degraded energy in the form of heat that cannot be used in thermally isolated systems to drive reactions, i.e., to do work)
  - The entropy/disorder of the universe as a whole or in a closed/ isolated macroscopic system system (i.e., not able to exchange any form of energy with its surroundings) will spontaneously only increase with time.
- **Dissipation**: as the entropy of a system increases, its ability to do work decreases
- **Exergy**: quantity of energy in a system available to do work in a given thermodynamic environment
- A major quandary for many is to explain the evolution of increasingly complex and exergy rich living organisms.



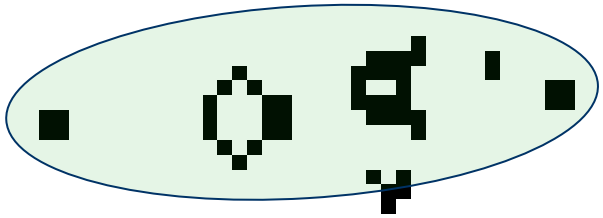
Emergence of life and knowledge

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

Solving problems of survival makes a system living

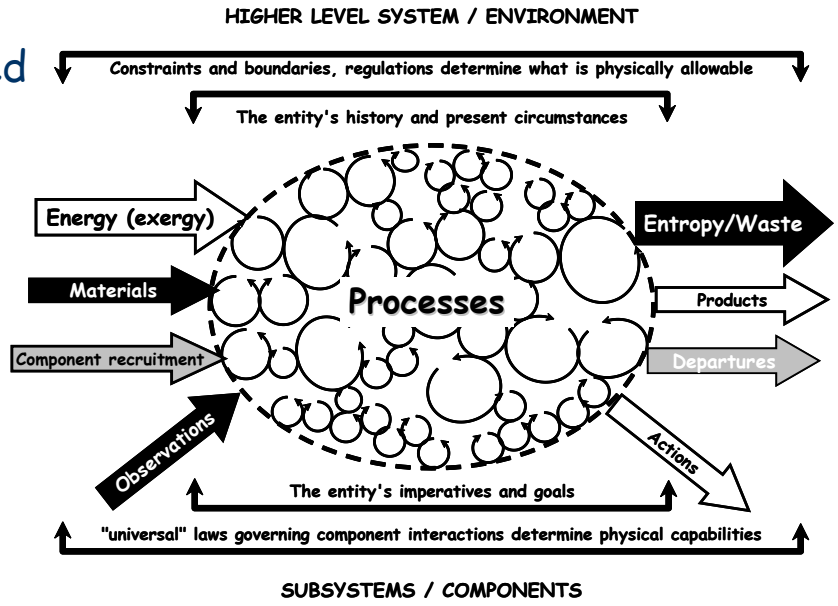
- Autopoiesis (Maturana & Varela 1980; see also Wikipedia)
  - Reflexively self-regulating, self-sustaining, self-(re)producing dynamic entity
  - Continuation of autopoiesis depends on the **dynamic structure of the state in the previous instant producing an autopoietic structure in the next instant through iterated cycles**
  - **Selective survival builds knowledge as corrective feedback 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** embodied in dynamic structure, e.g. as demonstrated by self-producing cellular automata



Gosper's Glider Gun cycles in 14 steps

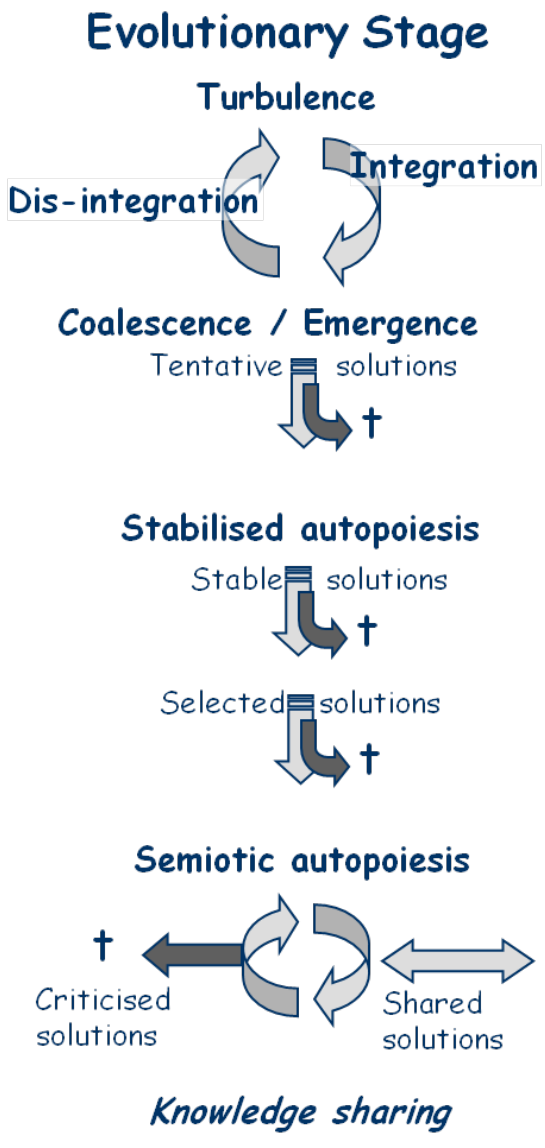
Gliders – cycle in 4 steps

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



Coupled subsystems in an autopoietic entity

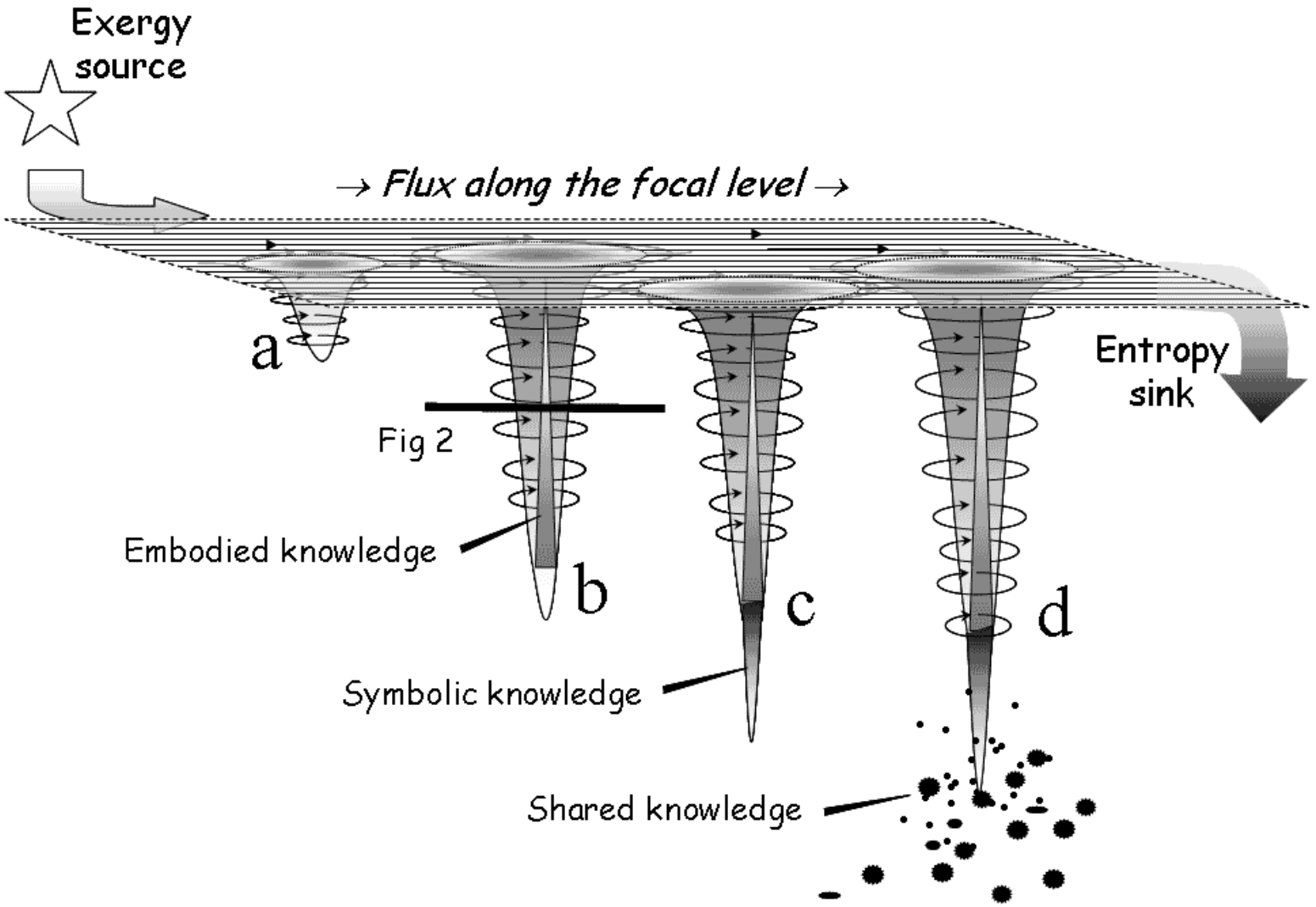
Co-emergence of autopoiesis and knowledge



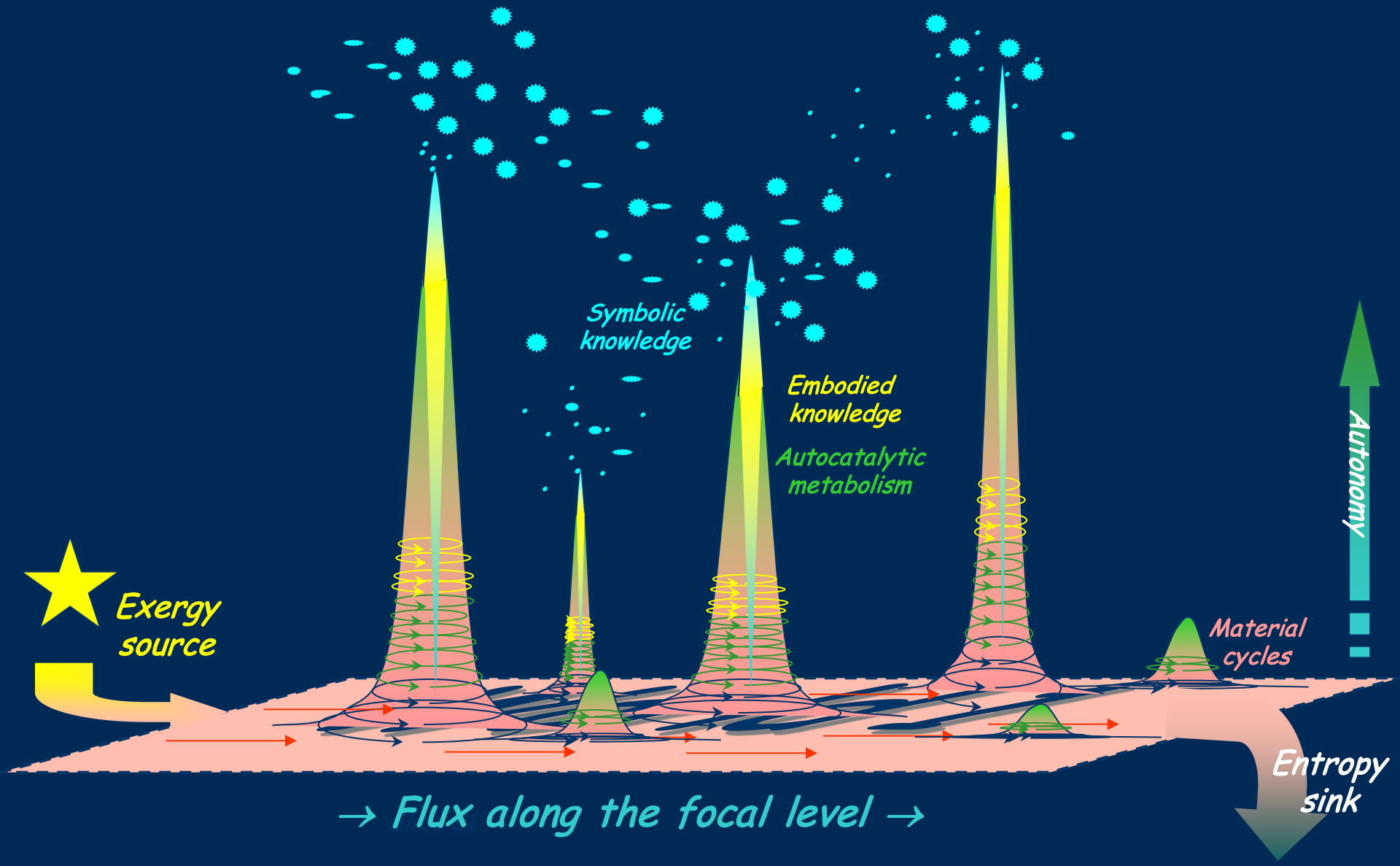
Nature and growth of autopoietic knowledge

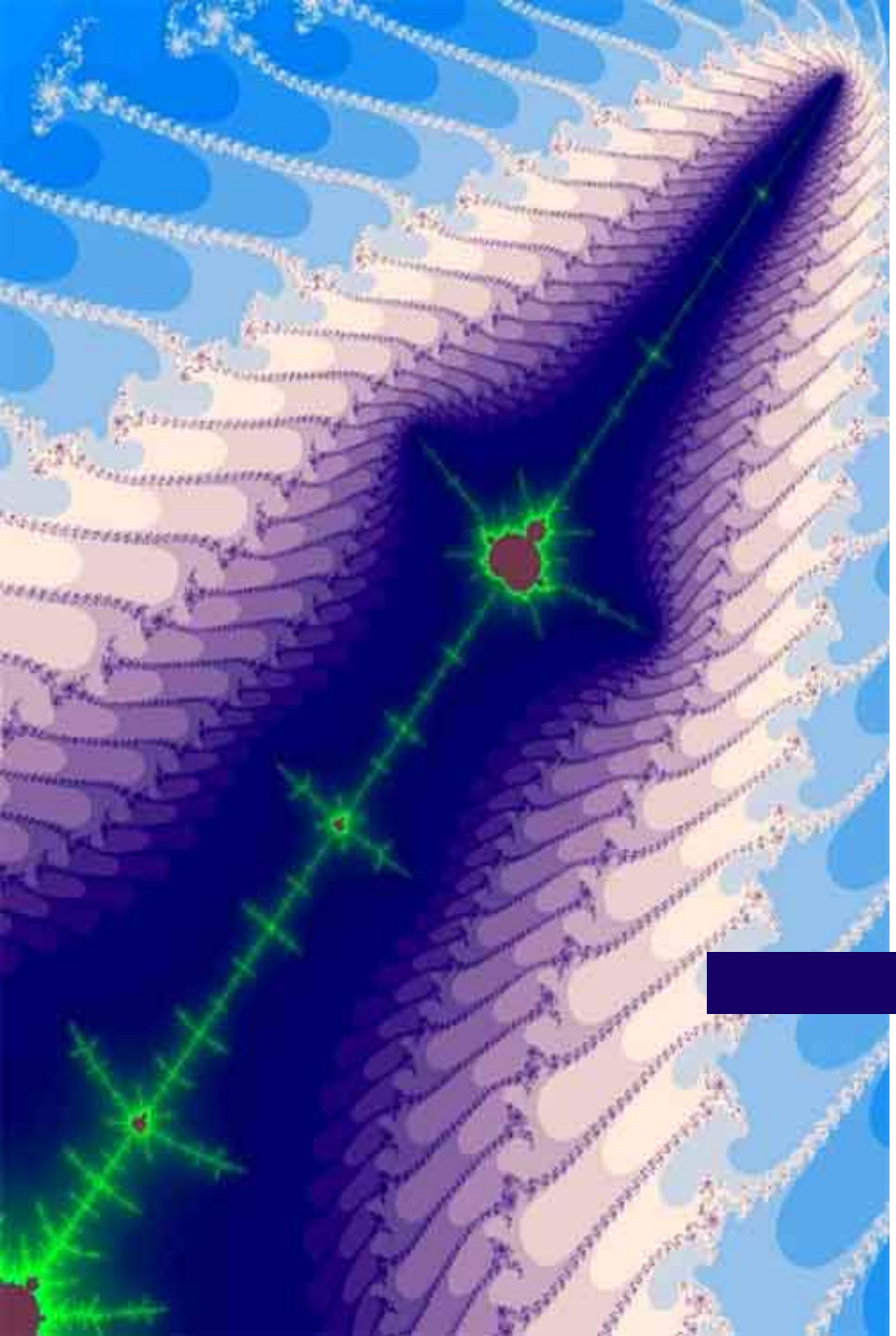
- **Turbulence:** Turbulent flow from available energy (exergy) sources to entropy sinks forces conducting systems to become more organised (state of decreased entropy) – (Prigogine, Morowitz, Kay and Schneider, Kauffman)
- **Coalescence:** Coalescent systems have no past. Self-regulatory/self-productive (autocatalytic) activities that persist for a time before disintegrating leave uncoordinated components whose individual histories may "precondition" them to form autopoietic systems. Each emerged autopoietic system represents a tentative solution to problems of life. Those that dis-integrate lose their histories (heredity/knowledge).
- **Stable Solutions:** Stable systems are those whose knowledge enables them to persist indefinitely. Competition among such systems for resources is inevitable. Survivors thus perpetuate historically successful solutions into their self-produced structure to form structural, dispositional or tacit knowledge (W2). Those failing to solve new problems dis-integrate and lose their histories, i.e., their accumulated knowledge dies with them.
- **Semiotic autopoiesis:** Replication, transcription and translation. With semantic coding and decoding, knowledge can be preserved and replicated in physiologically inert forms for recall only when relevant to a particular problem of life. Such objective knowledge may be shared across space and through time.

Emergent eddies in the dissipation of exergy



Emergent autopoietic vortexes forming world 2 and world 3 in a flux of exergy to entropy





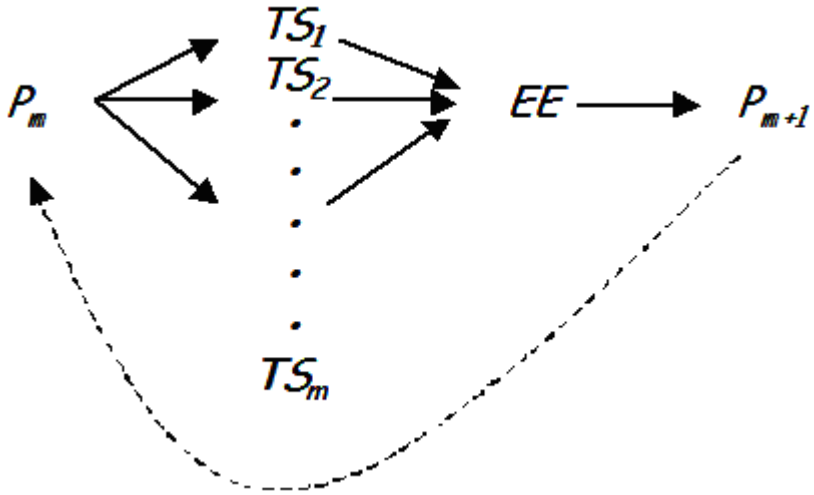
Cognition

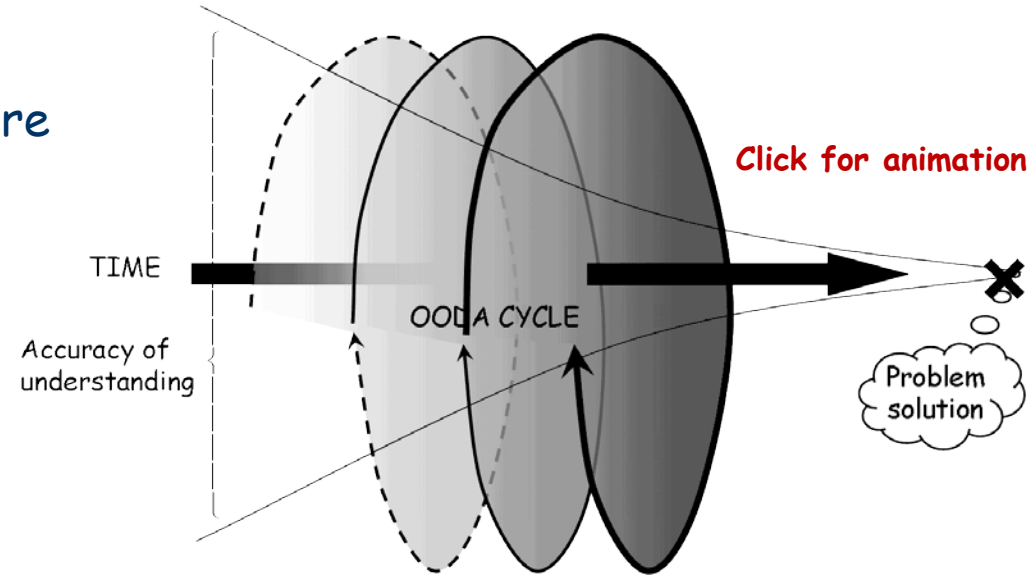
The spurious problem of reflexivity and circular closure in Luhmann's social systems theory

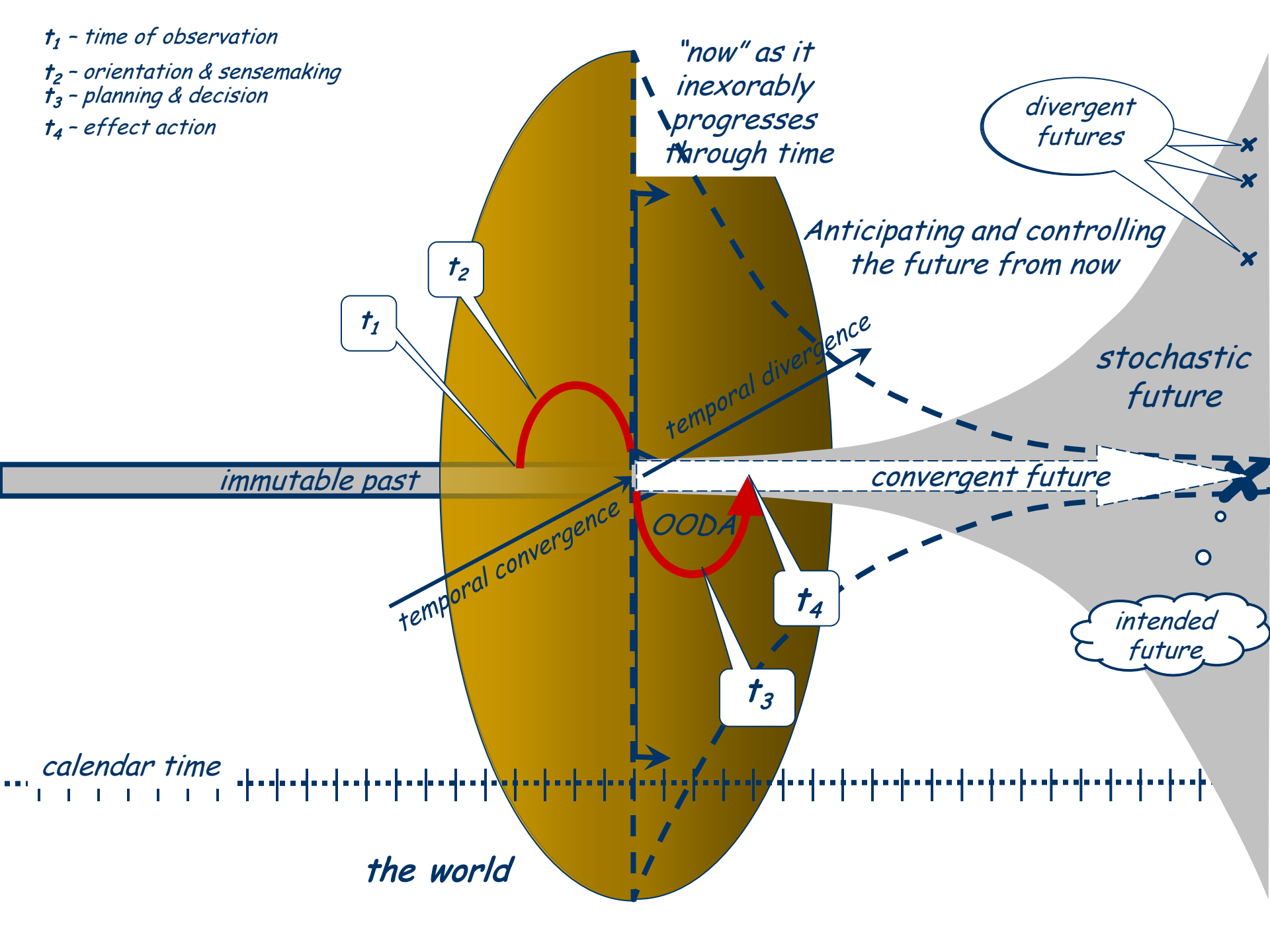
- Maturana and Varela worked in the school of second order cybernetics, concerned that observers & environment also formed part of the system
  - Developed a convoluted and abstruse language to reflect this concern
  - Created great difficulties for others attempting to understand some comparatively simple ideas
- Niklas Luhmann concept of the vicious circle:
  - Corrective feedback from self-observation forms a paradoxical and viciously closed causal chain, where A causes B and B causes A
  - Went to esoteric extremes in an attempt to work with the apparent paradoxes.
- There is no vicious circle:
  - Cycles of causation are not instantaneous – they propagate through time
  - Learning cycles are not closed, they are open-ended spirals

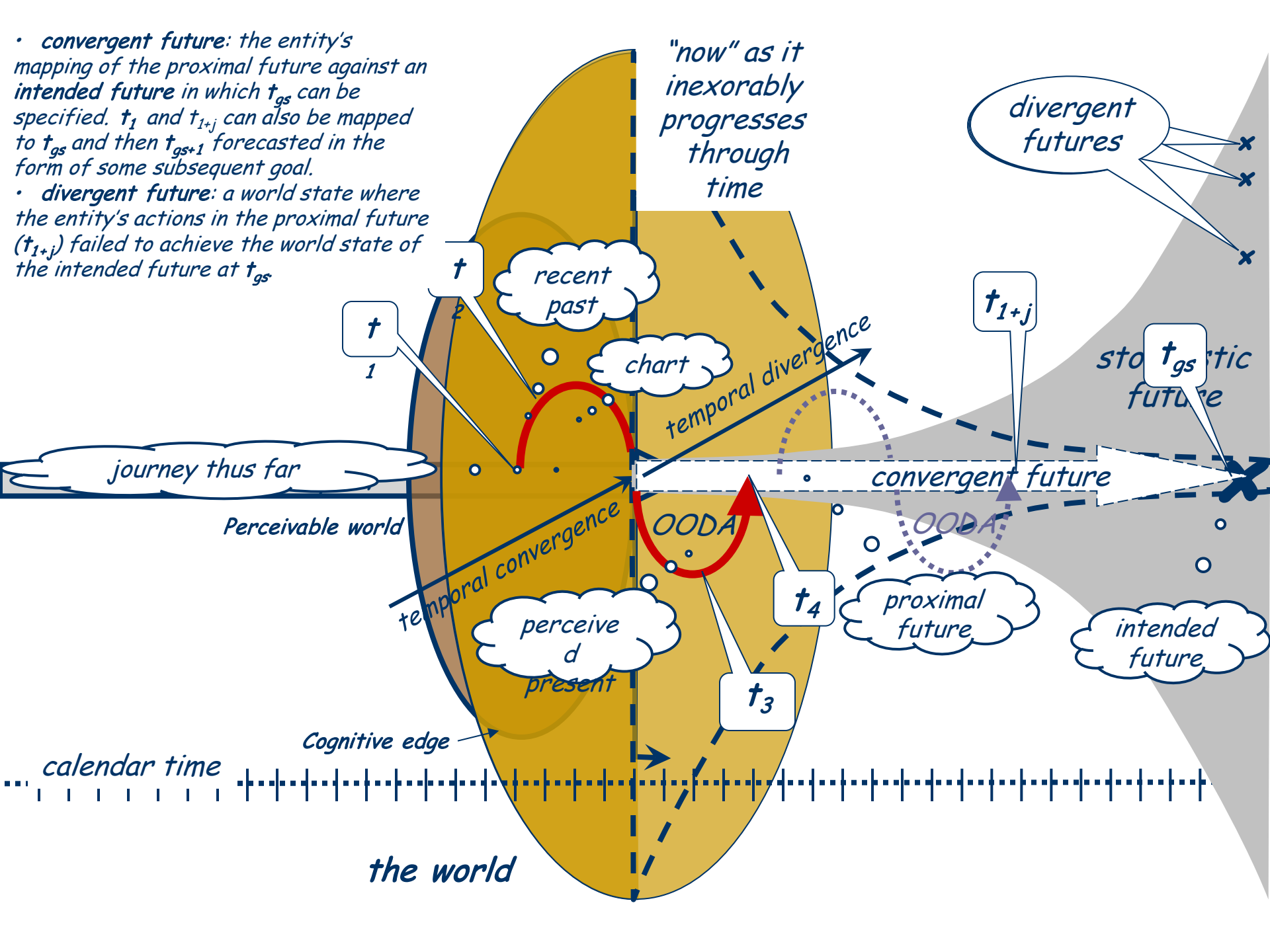
Learning cycle

- Popper's evolutionary theory of knowledge
  - Adjacent possible states leading to divergent dynamics cause structural dis-integration & loss of autopoiesis
  - Remainder stay in attractor basin of a solution
  - Problem solution incorporated in structure goes on to a revised problem
- Stabilizing/corrective feedback is basis for cognition






t_1 – time of observation
t_2 – orientation & sensemaking
t_3 – planning & decision
t_4 – effect action
"now" as it inexorably progresses through time
divergent futures
Anticipating and controlling the future from now
t_2
t_1
temporal divergence
stochastic future
immutable past
convergent future
temporal convergence
OODA
t_4
intended future
t_3
calendar time
the world


• convergent future: the entity's mapping of the proximal future against an intended future in which t_{gs} can be specified. t_1 and t_{1+j} can also be mapped to t_{gs} and then t_{gs+1} forecasted in the form of some subsequent goal.
• divergent future: a world state where the entity's actions in the proximal future (t_{1+j}) failed to achieve the world state of the intended future at t_{gs}.
"now" as it inexorably progresses through time
divergent futures
t_2
t_1
recent past
chart
temporal divergence
t_{1+j}
t_{gs}
journey thus far
convergent future
Perceivable world
temporal convergence
OODA
OODA
t_4
proximal future
intended future
perceived present
t_3
Cognitive edge
calendar time
the world

Probably inevitable that autopoietic organization will emerge in any sufficiently complex dynamic world

- Causation, thermodynamics, time, and the impact of the adjacent possible on the unfolding now
  - Turbulence
  - Eddies
  - Selection for stabilizing feedback leads to structural memory
- Next week will consider emergent processes in Popper's three worlds
  - Cognition & heredity
  - Autopoiesis at multiple level of organization

INTERLUDE

Cognition, structural/dispositional knowledge, codified knowledge and systems of heredity

Theory of Hierarchically Complex Dynamic Systems and Higher Orders of Autopoiesis

Hierarchy theory

Levels of organization

Two views of the hierarchical structure of living systems

Emergence of new levels of living organization in the complex hierarchy of living things

Second Order Autopoiesis: Multicellular Organisms

Third Order Autopoiesis: Colonies and Societies

Human economic and social organizations