Consciousness as we know it: the role of learning

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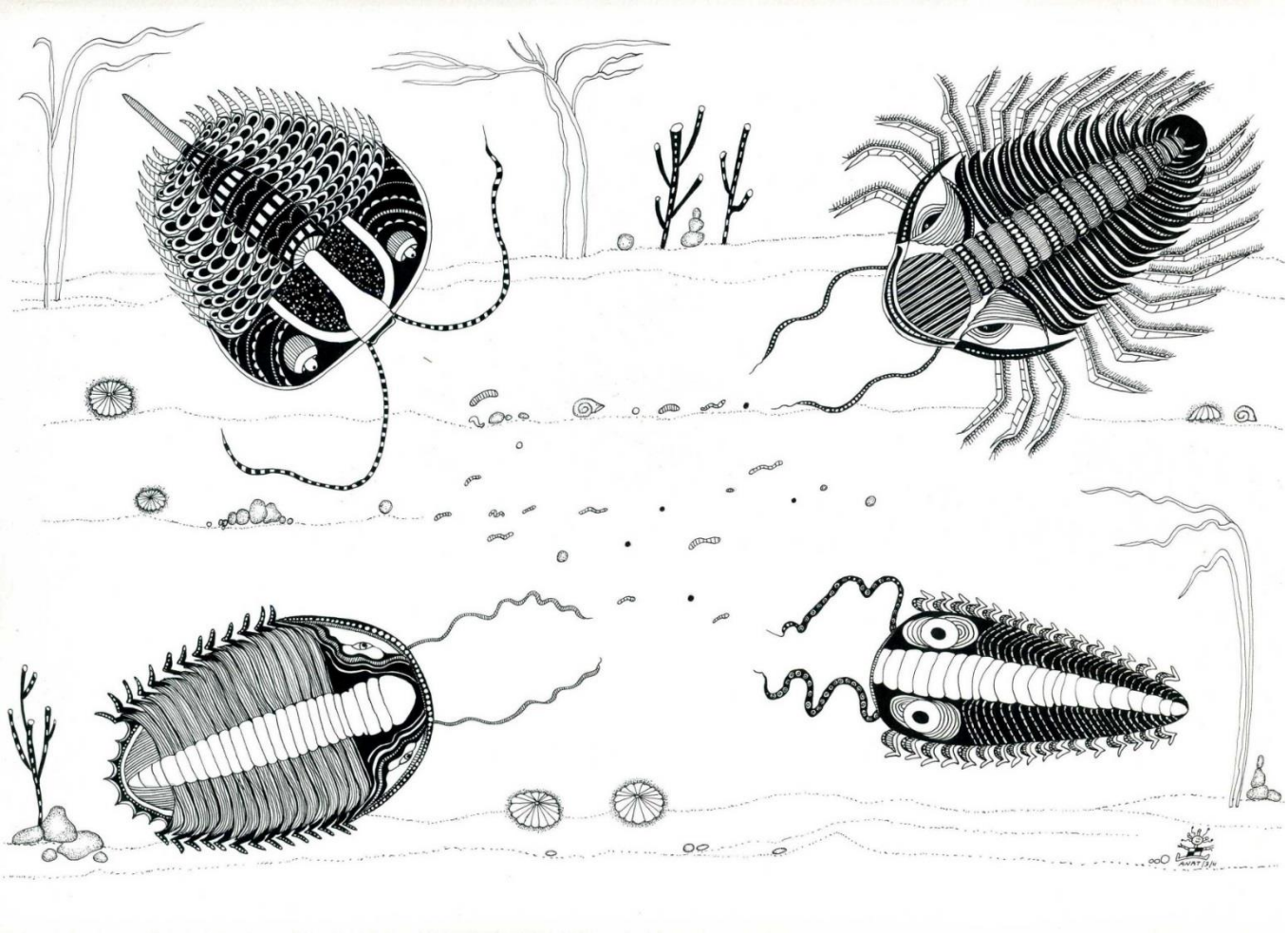


Mind can be understood only by showing how mind has evolved (Herbert Spencer 1890)

What is minimal consciousness?

Minimal consciousness = sentience = subjective experiencing

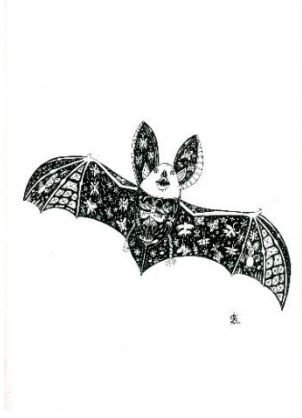
The most basic (non-reflective) subjective feeling that includes exteroceptive (e.g. visual, olfactory), interoceptive (e.g. pain, hunger, thirst) and proprioceptive (bodily position) experiences

What approach do we use? What do we suggest?

Consciousness should be treated as a dynamical, intrinsically-teleological system (Aristotle's "sensitive soul").

We use an evolutionary-transition approach.
There were three major teleological transitions: to life, to consciousness, to rationality. We use the transition to living entities as a guiding heuristic

We suggest that the evolution of learning drove the evolution of minimal consciousness



Based on the origin of life research program

I. List necessary and sufficient characteristics/criteria

II. Suggest a transition marker: a capacity or property that requires an enabling system that satisfy the criteria. It may allow the "reverse engineering" of the enabling system

III. Construct a toy model spelling out the dynamic organization that can instantiate the system

IV. Point to evolutionary scenarios: when, where, and how did the process happen?

V. Reframes philosophical questions in the light of the evolutionary characterization of the system

The transition marker for life: unlimited heredity

In *The Major Transitions in Evolution* (1995), John Maynard Smith and Eörs Szathmáry discussed the transition from chemistry to biology. Following Gánti, they suggested a distinction between **limited** and **unlimited heredity**.

Limited heredity: the number of possible hereditary variants in the system is small, and therefore evolutionary change is extremely limited.

Unlimited heredity: the number of hereditary variations is practically unlimited and evolution is therefore open-ended.

Unlimited heredity presupposes an autopoietic system enabling system (enabling system: a system that enables the developmental construction and the sustainability of the evolutionary-marker-trait)

Unlimited heredity is a marker for a transition to sustainable life.

A list of jointly sufficient consciousness characteristics

(based on common features suggested by many philosophers and neurobiologists)

- Flexible value (valence) systems and goals
- Unity and diversity through sensory binding
- Global availability of information involving multidirectional feedback and reentrant interactions (implies causal efficacy of mental states)
- Temporal thickness (sensory-temporal persistence)
- Selection– involvement of processes of exploration and selective stabilization at different levels (neural, action), leading, through inhibitions, to serial information processing; includes processes of selective attention
- Intentionality (aboutness): mapping/representation
- Embodiment, agency, self (mechanisms leading to coherence and flexible stability of world and body images from a point of view)

A transition marked for minimal consciousness: Unlimited Associative learning (UAL)

UAL is a specific form of classical and operant associative learning where:

i) The conditional stimulus (CS) or the behavior is Compound – i.e., consists of several “fused” features (e.g., color, shape, texture) and/or pattern of actions that are learned as a conjunction rather than separately.

ii) It is Novel – i.e., neither reflex-eliciting nor pre-associated with the unconditional stimulus (US) or with reinforcement through previous learning.

iii) The learned CS or the learned sequence of actions can subsequently support second-order conditioning acting as a US or reinforcement in itself.

With UAL the number of associations that can be learned and recalled within and between modalities during the ontogeny of an individual far exceeds those that actually form during its lifetime. Just as unlimited heredity enables open-ended evolution, so unlimited associative learning allows open-ended ontogenetic adjustments, and through cumulative learning can lead to complex behavior.

The functional architecture of UAL

- There must be mechanisms that integrate the various underlying features to form a compound; the encoding must be multi-stage, hierarchical and predictive (based on discrepancy signals or PEs).

- There must be a dedicated memory system that enables subsequent retrieval, based on the learned compound patterns.

- The evaluation system must be able to assign valence to any compound input.

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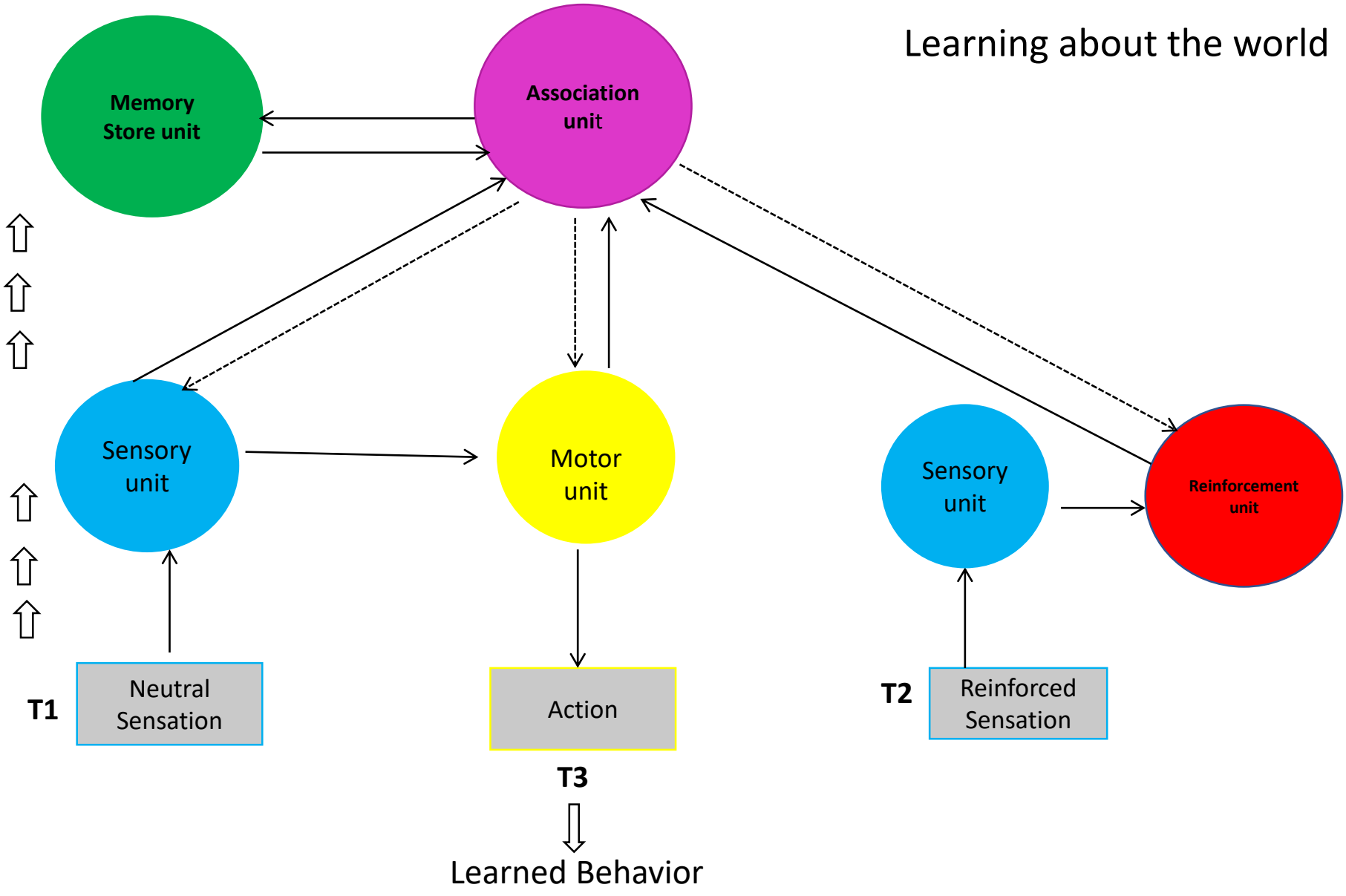
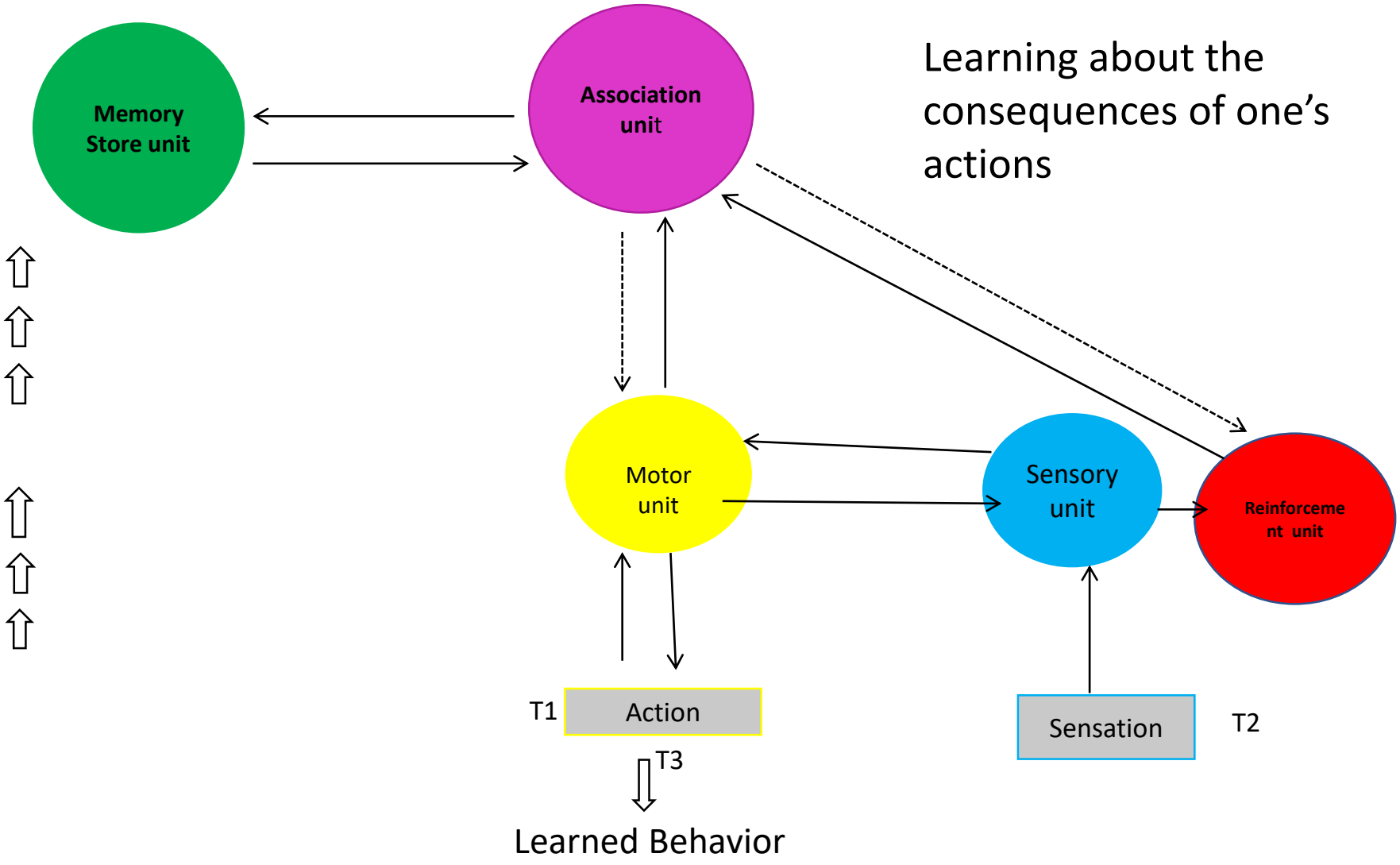
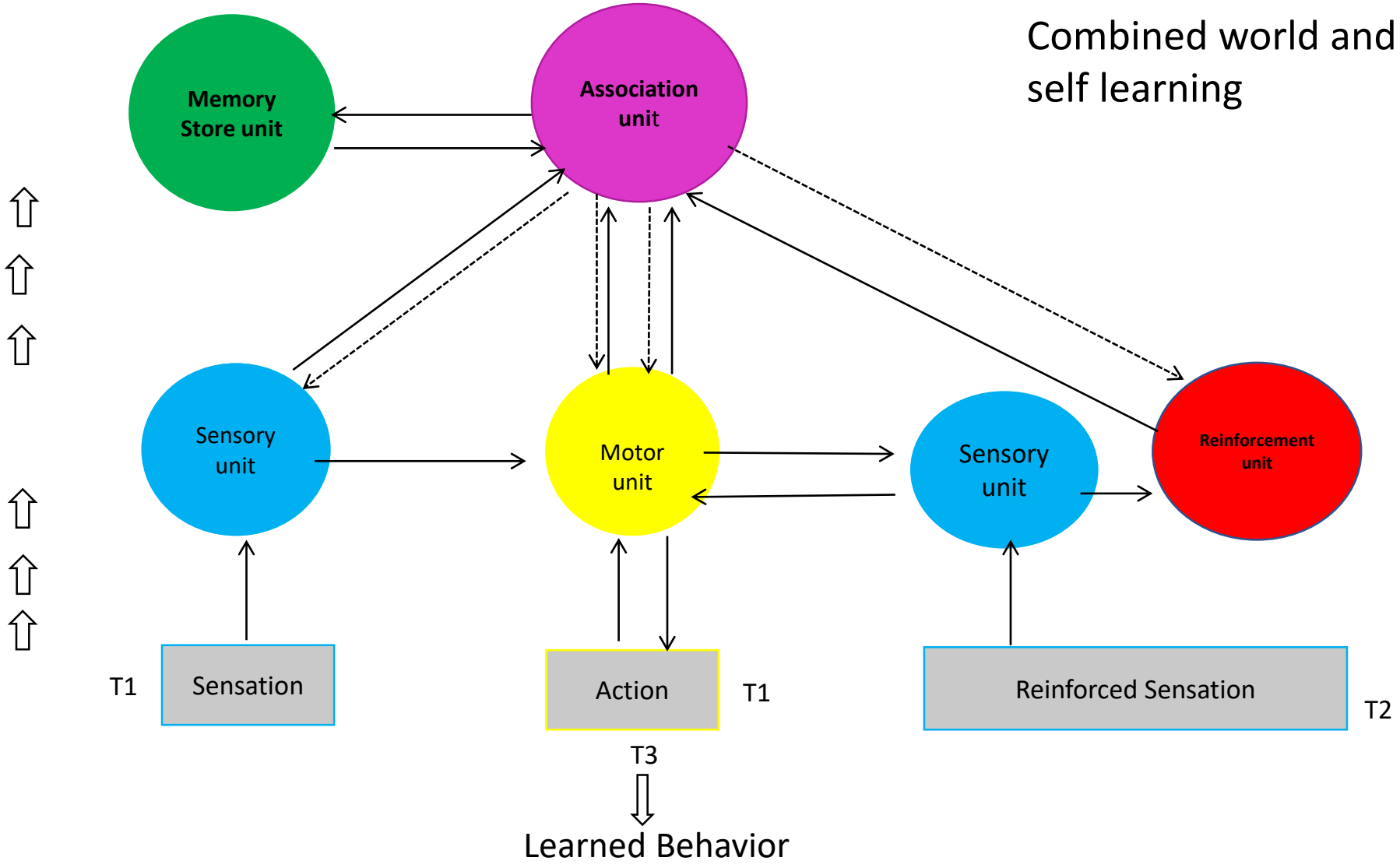

Learning about the world
Memory Store unit
Association unit
Sensory unit
Motor unit
Sensory unit
Reinforcement unit
T1
Neutral Sensation
Action
T2
Reinforced Sensation
T3
Learned Behavior


Memory Store unit
Association unit
Learning about the consequences of one's actions
Motor unit
Sensory unit
Reinforcement unit
T1
Action
T3
Learned Behavior
Sensation
T2


Combined world and self learning
Memory Store unit
Association unit
Sensory unit
Motor unit
Sensory unit
Reinforcement unit
T1
Sensation
Action
T1
Reinforced Sensation
T2
T3
Learned Behavior

The attributes of UAL are compatible with the characteristics of minimal consciousness

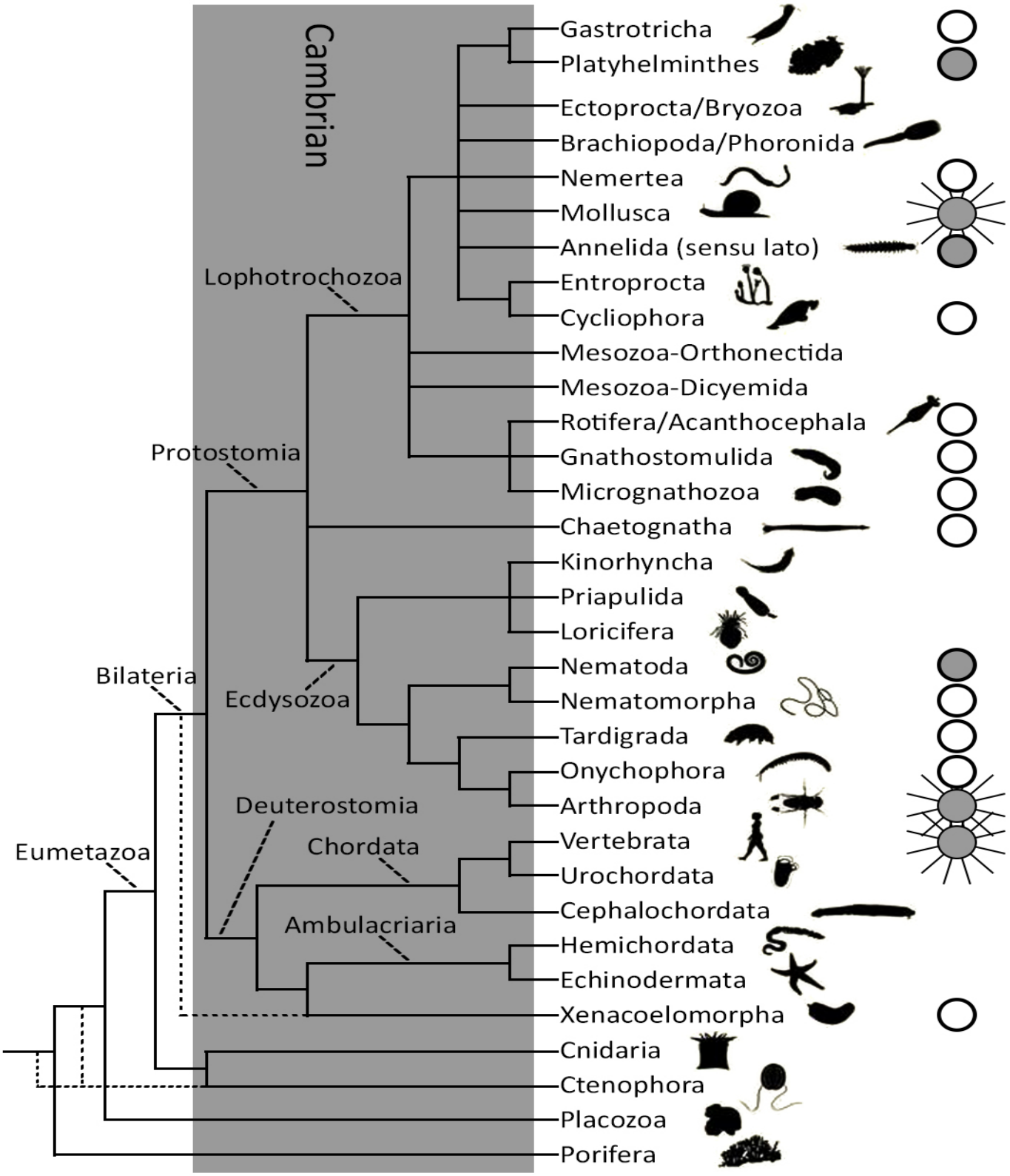
- **Flexible value systems and goals**: UAL requires that the animal can flexibly attribute valence to guide its behavior.
- **Unity and diversity through sensory binding**: binding refers to the formation of a compound stimulus
- **Global accessibility of information**: Through interactions among memory, perception, action, and valuing, information from all modalities is accessed.
- **Temporal thickness**: UAL, which implies reentrant interactions, requires time.
- **Selection**: Processes of exploration and selective stabilization at different levels of biological organization are central to UAL; selectivity through inhibitions entails serial processing and often involves selective attention.
- **Intentionality:** Predictive-coding, which is entailed by UAL, is intentional – it is “about” the world and the body since it requires models of the world, of the body, and of action, and is based on mapping/modeling-relations between sensory signals and their latent external causes.
- **Embodiment and self**: a coherent and stable distinction between the interior (self) and the exterior (environment) is generated through processes of reafference and blocking.

These characteristics cluster and form a natural grouping in most vertebrates, many arthropods and some cephalopods

UAL suggests how consciousness is distributed in the animal world

The distribution of UAL or its proxies suggests that UAL may have evolved independently in at least three taxa – the molluscs, the arthropods and the vertebrates – and was probably lost in certain groups (e.g., in some parasitic arthropods). Its distribution and the distribution of the brain anatomies supporting it suggests that it evolved in arthropods and vertebrates during the Cambrian era (540-485 MYA), and in some cephalopods about 300 millions years ago.

Phylum	**Learning type**
Mollusks (Cephalopods: Octopuses, squids, cuttlefish)	Pavlovian conditioning (involving perceptual fusion); Operant conditioning (involving novel action patterns) Spatial learning
Arthropods (many)	Pavlovian conditioning with compound CSs (involving non-elemental learning) Operant conditioning (involving novel action patterns and spatial learning) Conceptual learning Number-based learning Navigation learning
Vertebrates (most)	Pavlovian conditioning with compound CSs (including non-elemental learning) Operant conditioning (involving novel action patterns and spatial learning) Conceptual learning Number-based learning Navigation learning


Cambrian
Gastrotricha
Platyhelminthes
Ectoprocta/Bryozoa
Brachiopoda/Phoronida
Nemertea
Mollusca
Annelida (sensu lato)
Lophotrochozoa
Entroprocta
Cycliophora
Mesozoa-Orthonectida
Mesozoa-Dicyemida
Rotifera/Acanthocephala
Protostomia
Gnathostomulida
Micrognathozoa
Chaetognatha
Kinorhyncha
Priapulida
Loricifera
Bilateria
Nematoda
Ecdysozoa
Nematomorpha
Tardigrada
Onychophora
Deuterostomia
Arthropoda
Eumetazoa
Chordata
Vertebrata
Urochordata
Cephalochordata
Ambulacriaria
Hemichordata
Echinodermata
Xenacoelomorpha
Cnidaria
Ctenophora
Placozoa
Porifera

We suggest that UAL was the adaptability driver of the Cambrian explosion

UAL is **a positive** marker of animal consciousness – its presence can tell us that an animal is endowed with minimal consciousness, but its absence cannot determine whether or not an animal is non-conscious.

A human who does not manifest UAL, such as a neonate or an anencephalic human, can nonetheless be minimally conscious, because she is endowed with a preexisting, actively exercised, evolved, UAL-supporting organization that is in place even when UAL itself cannot be manifest for developmental or pathological reasons **(ontogeny does not recapitulate phylogeny in this case**).

Just as we consider a cell as alive even after its nucleus has been removed and it therefore lacks an unlimited heredity system, as do human erythrocytes which can live ~120 days without a nucleus, so can an animal devoid of UAL be considered minimally conscious as long as it possesses a preexisting, evolved and functional enabling system potentially supporting UAL. **The *evolutionary origins* of UAL and its enabling system were, however, coupled.**

“Consciousness is a “**fighter for ends**, of which many, but for its presence, would not be ends at all.” (James 1890).

Consciousness, like life, is a teleological system, its teloi being the desires that the animal strives to fulfil. The processes constituting consciousness, such as UAL, have functions**.**

The emergence of consciousness led to the generation of a *new functional realm*.

Concluding comments

We suggested that minimal consciousness is a facet of complex associative learning in animals.

The evolution of UAL entailed minimal consciousness.

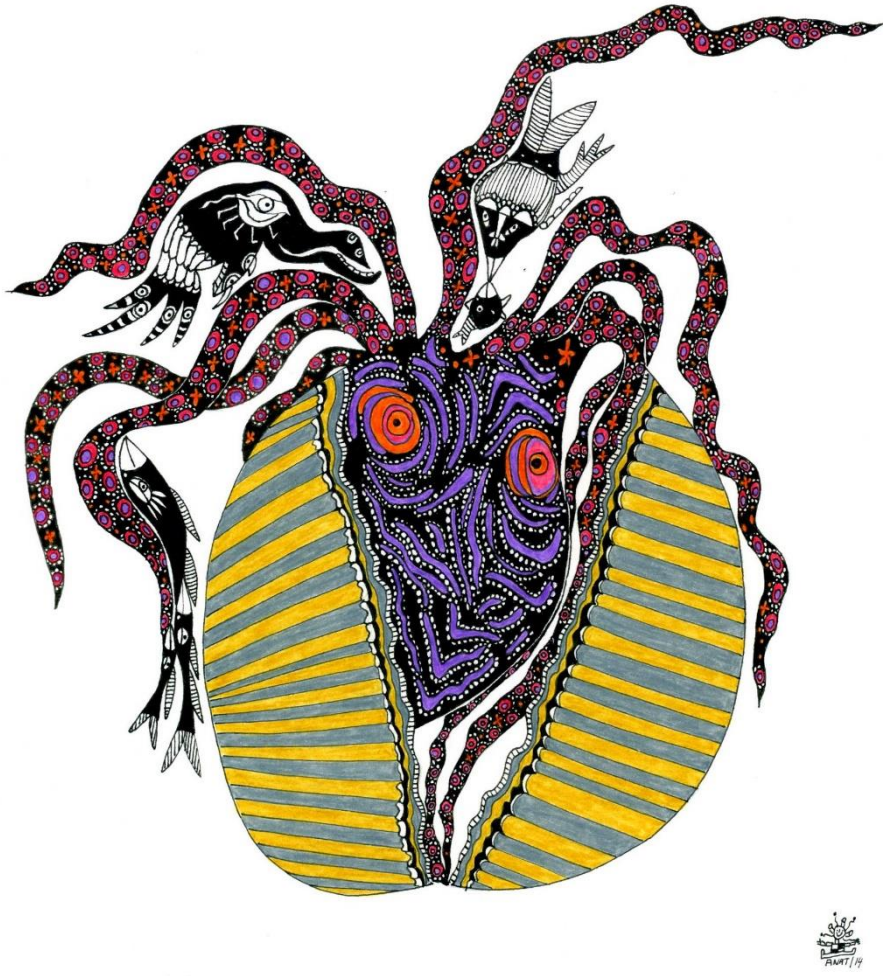
UAL was necessary and sufficient for minimal consciousness when it first evolved; it is a sufficient, not a necessary condition during the development of animals with a UAL capacity.

UAL evolved in arthropods and vertebrates during the Cambrian, and in the cephalopods about 250 millions years later. It was one of the drivers of the Cambrian explosion.

Consciousness is best regarded as a teleological system, not a function.

Although robots able to implement UAL will be built one day, this will not sufficient to render them conscious (just as a genetic algorithm implemented in a computer chip does render the chip alive).

Thank you!



		Integrating into compound patterns (correspond to SIU, MNU, AU)		Globally acting value mechanisms and factors (correspond to REIU)	Memory for compound patterns (correspond to MEMU)
		Exteroceptive (perception of external world and of body parts)	**Proprioceptive** (movement of body in space)		
Vertebrates		cortex, superior and inferior colliculi, cerebellum	superior colliculus, Cerebellum	cortex, basal ganglia (nucleus accumbens and ventral striatum), cingulate cortex, amygdala, reticular formation, subtantia nigra, thalamus, periaqueductal gray, cerebellum, hypothalamus, mammillary bodies, pituitary; dopamine	cortex, hippocampus, basal ganglia, cingulate cortex, fornix, mammillary bodies, cerebellum
Arthropods	**Insects**	mushroom body, central complex	central complex	lateral accessory lobe, and perhaps also the MB and the central complex (FB and EB), in which there are dopamine receptors, specific neurons; dopamine and octopamine	mushroom body, central complex
	Crustaceans	hemiellipsoid body	central complex	central complex; octopamine and serotonin	hemiellipsoid body, central complex
Mollusks	**Cephalopods (e.g. octopus)**	superior frontal lobe, vertical lobe and peduncle	Brain and peripheral nervous system	Vertical lobes octopamine and serotonin	superior frontal lobe, vertical lobe

Predictions:

1. Masked unconsciously learned stimuli will not be conditioned and serve as US for second-order conditioning.

As predicted by our hypothesis, masked, unconsciously-perceived, novel CSs, such as complex pictures of flowers or mushrooms, do not give rise to conditioning (Öhman & Soares, 1993), while masked angry faces do.

We predict that once consciously learned, previously novel compounds will be responded-to when masked.

2. Only when conscious of percept will animals be able to recognize new goals by assigning priority to different motivating states (X is positive in context A, negative in context B; X has priority in context D, and is of secondary importance in context E).

3. Only when conscious, will animals be able to engage in causal reasoning

4. The structural, neural and molecular systems underlying UAL are expected to be strongly correlated with those underlying consciousness.

5. Several predictions regarding the co-evolution of UAL and the stress response.