HIPPOCAMPUS COGNITIVE MAP: ENACTING COSMOLOGIC SCENE IMAGERY OF HUMAN ORIGINS FROM HAIDA GWAII WITHIN AN EXPERIMENTAL DIGRESSIVE ASSEMBLAGE

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ABSTRACT

The ability to be affected by the Northern Raven's vital materiality in the Yukon Boreal Forest of Canada prompted my creative desire to explore a novel digressive approach to the plot of human origins, specifically from the Cascadia Subduction Zone (CSZ). This tectonic plate boundary extends from Northern Vancouver Island to Cape Mendocino, California. As part of the Pacific Ring of Fire, the CSZ has experienced significant geological activity, which is evident in recent archeological records showing that villages along the coast were abandoned and submerged approximately 3,000 years ago during the late Holocene due to earthquakes and tsunamis. To challenge our perception of cosmological myths, I focus on two ancient stories from the oral tradition of Haida Gwaii (formerly known as the Queen Charlotte Islands), as recorded by John Reed Swanton: "Raven discovered many people inside a cockle" (Boas and Swanton 1905b, 320), and "Sing 7agang qiidaraagan—How Shining-Heavens caused himself to be born" (Swanton 1905b, 26). From a cognitive evolutionary perspective, two visual scenes highlight these stories : (1) the ocean-to-land transition of protohumans, as observed in the intertidal zone at Rose Point (Nai-koon) and Kaisun, and (2) the niche construction by organisms and the co-evolution of their ecological roles. Given the significance of oral tradition in a specific ecological niche on Earth, I hypothesize that sequentially ordered narrative events are interwoven within a hippocampal cognitive map, which supports long-term episodic memory. To explore this cognitive map, I will correlate visual scene imagery with recent studies on the emergence of cellular life (approximately 4.2 billion years ago), the development of cellular sentience and cognition, the niche construction by organisms, the neural substrates involved in encoding long-term episodic memory, and the crucial role of the hippocampus in imagination and cognition.

DEDICATION

I dedicate this thesis to my daughter, Isis Atenea

To Gwich'in Elder Elizabeth (Liz) Hansen from Inuvik

To the Haida Nation and the storytellers

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The narrative of protohumans emerging from the Pacific Northwest inspired me to correlate the scene imagery with recent studies on the cellular origins of life on Earth. In this quest, I sincerely thank my director, Joerg Esleben, for his incredible support and allowing me to pursue my interdisciplinary research. I am also thankful for my co-director, Karen Madsen, who allowed me to study the evolutionary life of microorganisms, such as archaea and bacteria, that preceded humans on Earth. I appreciate my thesis committee, Julie Laplante, for highlighting the importance of memory systems by considering cosmological stories and their connections to recent scientific research. I am grateful to Vincent Bergeron for his insightful comments regarding the hippocampus's role in memory and cognition, tracing back to the earliest vertebrates. I also thank Jorge Carlos Guerrero for his enlightening lectures on artistic and literary theories and Cristian Zaelzer-Pérez for his valuable critiques of my interdisciplinary research in mythology, art, and science. Also, I would like to acknowledge the authors quoted in this dissertation and specific images granting personal permission to support my research: Dr. Karin Öberg, Harvard-Smithsonian Center for Astrophysics; Dr. Kevin Lala, University of Saint Andrews, School of Biology; Dr. Peter Whiteley, Curator of North American Ethnology, American Museum of Natural History; Dr. Nathan Sowry, Smithsonian National Museum of the American Indian Cultural Resources Center. Finally, thanks to James Novoa for providing essential guidance throughout my journey. I am grateful to Celina Jeffery for her insights into my creative research process and to Gaston Lillo for his unconditional support and mentorship. Lastly, I thank Fernando De Diego for many years of friendship and for revealing the art of literary digression.

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CHAPTER 1. Introduction

Ga. o, Ga. o croaked the Northern Raven perched on top of a dwarf spruce in the pristine boreal forest of Canada. It was the morning of the portage from Duo Lake to the sandy banks of the Snake River on the Northern Yukon. As a presage of the journey in a Class III river, I embodied the Raven's call with reverence to the moment of exchanging glances. Ten days afterwards, our inflatable raft capsized at the second-to-last rapid. Battling the strong current, the team rescued me from where I was trapped inside the frame. Elizabeth (Liz) Hansen, a wise elder from Inuvik and my rowing companion blessed me with new life at the threshold of death on the foreshore.

1.1 Preface

Ga. o Ga. o [1] croaked the Northern Raven perched on a dwarf spruce. This dissertation was engendered by the inevitably transformative experience of being physically immersed in the Yukon's wild nature (2003).[2] Farther in time, I explored the literature on the (re)generative processes of autobiographical memory retrieval and reconstruction depending on cues specificity, which enabled me to structure this dissertation. Drawing from the Deleuzean-Guattarian concept of affect, the Northern Raven encounter in my research is understood as pre-personal intensity corresponding to the passage from one experiential state of the body to another and implying an augmentation in the capacity to think and act. The ability to affect and to be affected by human and nonhuman "vital materiality"[3] in the Yukon wild prompted the creative desire within myself to explore a novel experimental digressive approach to the plot of human origins from the coastal Cascadia subduction zone (CSZ)– the North American tectonic plate

boundary stretching from Northern Vancouver Island to Cape Mendocino California.[4] Since the CSZ is part of the Pacific Ring of Fire, recent archeological records demonstrate that the villages along the coast were abandoned and submerged in the late Holocene ~3,000 Mya as the result of earthquakes and tsunamis (Fedje 2003; Hutchinson and McMillan 1997). Nevertheless, to challenge perceptions of cosmologic myths, my primary source of evidence are two long-ago stories from Xaadaa Gwaay ("Islands of the People") recorded by John R. Swanton: "Raven discovered many people inside a cockle" (Swanton 1905b, 320), and "Sing 7agang qiidaraagan—How Shining-Heavens caused himself to be born" (Swanton 1905b, 26). The first story refers to the emergence of protohumans[5] from the ocean in a clamshell, followed by the construction of their distinctive niche by Raven at the Haida Gwaii archipelago. The second story brings us to the incarnation of Shining Heavens in a clam shell. He was found by an abandoned young maiden who became his mother while digging for clams on the seashore of the ancestral town of Kaisun, located on the west side of Moresby Island in the Haida Gwaii archipelago.

What is the thematic significance of these stories? (1) the ocean-to-land transition by protohumans as seen in the intertidal zone at Rose Point (Nai-koon) and Kaisun, (2) the niche construction by organisms and the co-direction of their evolutionary place, (3) the naturalistic visual scene imagery could yield information about the neural substrates of long-term episodic memory encoding and recall, (4) Haida is a language isolate with no proven genetic relationship to any family of language. (5) the incarnation of Shining Heavens and the interplanetary transfer of life. Considering the evolutionary basis of oral narratives, I hypothesize that in the visual scene, imagery of sequentially ordered events is embedded in a hippocampal cognitive map and its contribution to long-term episodic memory in a specific ecological niche. Two critical

questions guide my research: What makes cosmologic mythical narrative possible? How does the cosmologic visual scene imagery interact with the neural substrates of memory-based cognition? To unravel the cognitive map, I designed an experimental digressive assemblage (EDA), a virtual construction scaffold for networking with different vital materialities and interdisciplinary information. My goal through EDA is to enact the visual scene imagery of encoded events, forming coherent narrative memories. Following, I will correlate the retrieved information with recent studies on the evolution of cellular life on Earth~ 4.2 Gya, cellular sentience and cognition, the niche construction by organisms, the neural substrates of the hippocampus involved in episodic memory formation, and the generativity of language.

In recent years, to address the scarcity of fossilized human remains along the Pacific. Northwest of Canada, oral tradition has become a significant way for archaeologists to gain more insight into what human life was like during the late Pleistocene (McLaren et al. 2018; Lindo et al. 2017; Fedje and Mathewes 2014; Hutchinson and McMillan 1997; Boelscher 1988; Cruikshank 1981). For instance, Julie Cruikshank (1981) argues that mythic thought in the twentieth century has led to a fundamental re-evaluation of ourselves as human beings and our categories of knowledge:

> Since the Renaissance, it has been a feature of Western intellectual tradition to distinguish between non-Western and Western or "primitive" and "modern" thought, as though intrinsic differences separate the two. Anthropology developed within this tradition and has contributed to the dual classification system, particularly in distinguishing non-western beliefs from Western science. Within this framework, for example, western tradition is viewed as embodying "objective knowledge," and non-western traditions are interpreted as "magic" or "religion"

rather than technical thinking (71).

As Cruickshank indicates, the categories used by anthropologists to describe traditional societies may reflect their societies, and the formalist model applied to all societies reflects an arbitrary Western classification system "to make our worldview appear orderly" (71). In this vein of thoughts, re-evaluating our origins as found in oral tradition may lead us to the human organisms to the interrelated natural world.

Oral tradition is vital for Indigenous North American cultures and has continuously transmitted cognition to the next generation for thousands of years. Rick Budhwa (2002, 87),

He accounts for the possible relationships between various oral traditions and archaeological and geological data in his exploratory insights on the Pacific Northwest First Nations' history and perceptions of their place in the world. For millennia, the Indigenous people of the Pacific Northwest have maintained that proof of their long occupation in their niche is embedded in their oral traditions. For example, Budhwa shows evidence of Indigenous people's regional prehistory and their interaction with tsunami activity, such as that found in the Haida story "A: Strong Man Who Holds Up the World" recorded by Marius Barbeau (1953, 323). In recent years, the relationship between archaeologists and Northwest Pacific First Nations has improved by respecting and accepting each other's accounts. This epistemological engagement between science and oral traditional collective memory and knowledge enables me to explore novel cognitive insights on protohumans' emergence from the periphery of Canada's Pacific Northwest.

1.2 Haida Gwaii Archipelago

The peopling of the Pacific Northwest Coast predates the beginning of the Holocene. To understand the possible timing of early coastal migrations, it is necessary to first understand the

physical and biological environments along the Pacific Coast during the late glacial and early Holocene periods. In the geological time scale, the Pleistocene Epoch or the *Ice Age,* is defined as the period that began about 2.5 million years ago and lasted until about 11,700 years ago; the current stage is known as the Holocene. The most recent Ice Age occurred as glaciers covered a third of the Earth's surface. According to geological studies, at least five documented primary ice ages spanning about 100,000 during the 4.6 billion years since Earth was formed. The Pleistocene Epoch is the first in which *H. sapiens* evolved, and by the end of this epoch, humans could be found in nearly every place on Earth.

The morphology of Haida Gwaii and adjacent marine areas is a product of seismic uplift, the action of glaciers through the Pleistocene, and river and marine erosion and deposition. Ice from the mainland extended across the northern Hecate Strait and through Dixon Entrance to briefly coalesce with ice from Haida Gwaii, deflecting the ice sheet in Dixon Entrance westward. Glaciation reached its maximum extent sometime after 21,000 years ago. The deglacial retreat began sometime after 15,000 years ago. Ice had wholly left the region by 13,500 to 13,000 years ago, except for local remnant ice masses in the mountain valleys and cirques. Coastal evolution through the late Quaternary has shaped Haida Gwaii primarily by dramatic sea-level change, sediment supply, wave energy, and tidal currents. During deglacial regression, sediment supply was abundant. This resulted in extensive glacial outwash and glaciomarine deposition except where wave and current energies were high, such as Dixon Entrance and the western coast of Haida Gwaii. During the early Holocene transgression of the continental shelf, sediment supply was primarily restricted to the erosion of the previously deposited deglacial deposits, resulting in drowned wave-cut terraces and spit platforms as the sea level rose in steps. Sediment supply was reduced as sea levels increased, except for the northeastern coastline of Haida Gwaii. Here,

Holocene sea-level changes still impact the coastal zone and transfer sediment offshore (Fedje et al. 2005, 19–20). The Haida Gwaii archipelago has uncovered some of the most intriguing evidence of land migrations and shore-based cultures. More precisely, it came from about a mile offshore in Juan Perez Sound. The evidence was a small, triangular-shaped piece of basalt shaped into a blade. In 1998, researchers for the Geographical Survey of Canada, mapping the sea floor for four years, identified the basalt blade in a bucket of muck winched up from the sea floor. The blade dates about 10,000 years old, and its discovery is consistent with Haida oral tradition that the islands once were at least twice as large as they are today. People lived along the shore to be close to salmon, seals and other foods from the sea. According to Haida cosmology, "flood tide woman" forced them to move to higher ground. This is consistent with the geologic record that approximately 9,000–10,000 years ago, Ice Age glaciers melted, the islands shrank, and Beringia disappeared (Harrison 2023).

1.2.1 Haida Cosmology

The Council of the Haida Nation (2011) states:

> Over thousands of years, our histories have been carefully passed on through the generations through strict protocols in the delivery of knowledge. Through the recounting of our origins, the adventures of Raven, and the Supernatural among us, we maintain our sense of place and identity (1).

Haida mythical ideology holds that their origins occurred in the mythical past at Nee Kun, the northeastern seashore of Xaayda Gwaay ("Island of the People"). This cycle or age in Haida cosmology extends from the production of the two islands by Raven to the flood raised at Cape Ball, Graham Island. Then, it was occupied by the gods or supernatural beings alone. Before finally settling into the places, the supernatural beings held a contest to decide which should lie

under and support the islands. It occurred on the easternmost end of Maude Island in Skidegate Inlet, where New Gold Harbor stood. All the supernatural beings were gathered there, and, as most of them were Ravens, they feared that the son of *Djila Kun* (The greatest of all Creek Women), *Gudanxee Wat* (Stone-Ribs), would win the place. Whoever could lay three days under a fire continually dropping upon him was to have it, and only after four days had expired was Stone-Ribs obliged to give up. Haida knowledge is preserved and passed down for thousands of years in oral histories, called *k'aaygang. nga* or long, long ago ancient stories (Wilson and Harris 2014; Boelscher 1988). These cosmologic stories are treated as material property and cultural inheritance. Boelscher (1988) claims that "In mythical ideology, power obtained through contact with supernatural beings can be transformed into symbolic and material property, which in turn translates into social status" (167). This means that the standard dichotomies of Western epistemology, such as natural and supernatural, sacred and profane, animal and human, material and immaterial, do not apply to Haida's symbolic thought. For Boelscher, all beings and objects in nature had, and in some respects still have, multiple identities and multiple realities. In the same vein, Brian Thom (2003) suggests that the culture of the Pacific Northwest is a system of symbols and that underlying culture is a complex interplay of inseparable elements of language, thought, and reality.

My focus on Haida cosmologic stories is the visual scene imagery revealing the spatial layout of the environment and the relationship between the Supernatural, human and nonhuman. For example, the Butter Clam (*Saxidomus gigantea*), since it lives in the mid-intertidal and subtidal zones, in both stories plays the role of vessel for the transition of protohumans from the ocean to land, and the incarnation of Shining-Heavens. The relationship between clams and humans has been embedded in the Northwest Coast First Nations culture for the last 11,500 years

(Toniello et al. 2019). In this regard, archaeological studies of the Pacific Northwest offer new insights into the late Pleistocene peopling of postglacial environments and the purposeful transformation of the intertidal zone during the late Holocene to enhance and manage shellfish and fish populations. In addition, Haida is a language isolate with no known historical and genealogical relationships to any other known language in the North Pacific. It has two dialects: X̲aad Kil (Masset) on the northern island and areas of Southeast Alaska and X̲aayda Kil (Skidegate) in the south. Thus, looking at how Haida language and oral narrative evolved in its geophysical barriers scenario led me to explore the critical role of the hippocampus in spatial cognition and episodic memory encoding and retrieval.

1.2.2 The Jesup North Pacific Expedition (1897–1902)

The Jesup North Pacific Expedition was sponsored by the American Museum of Natural History in New York City to investigate the links between the people and the cultures of the Pacific Northwest Coast of North America and the Eastern Coast of Siberia. The expedition aimed to prove the Bering Strait Migration theory, which postulated that the North American continent was populated by the migration of Asian peoples across the Bering Strait (Lee 2017). However, Franz Boas, the expedition's leader, was more concerned with documenting the cultures on both sides of the Northern Pacific, which he and many other anthropologists feared would soon be lost to colonialism and acculturation. For example, team member John Reed Swanton spent ten months from the end of September 1900 to the beginning of August 1901 on the Haida Gwaii (the Queen Charlotte Islands). His primary task was to investigate the Haida's religious ideas, social organization, and language. From the stories recorded by Boas and Swanton, I found "The Raven discovered many people inside a cockleshell" and "Sing 7agang qiidaraagan—How Shining-Heavens caused himself to be born".

1.3 Human Origins: A Digressive Perception

The world as a structure of meaning and value has not appeared in the same manner to all human cultures, and cosmologic intelligibility belongs to this structured world. As an example, the famed historian of religion, Mircea Eliade, in his study "Cosmogonic Myth and 'Sacred History'" (1967) states that in most mythologies, the primordial stage of the world ends at a particular moment and that the supernatural beings, after having shaped the cosmos, abandoned the earth and disappeared (174). Eliade stresses the importance of the myth, the separation of the creator, and his progressive transformation into a *deus otiosus*:

> Man focuses his attention more and more upon those primordial creative events which are of consequence for human life. In other words, the coherent series of events which constitute the *sacred history* is incessantly remembered and extolled, while in the previous stage, everything which existed *before* that of the sacred history—first and foremost, the majestic and solitary presence of the creator God—fade away. If the High God is still remembered, he is known to have created the world and man, but this is all. Such a Supreme God seems to have ended his role by achieving the work of creation (178).

Eliade's insights into the sacred history of human-divine origins pertain to the creation schema of the *deus otiosus*, the idle god who retired from active life. In theory, there exist two controversial concepts of God – *Deus absconditus* (the hidden God) and *deus otiosus* (the idle God). The concept of *Deus absconditus* was embedded in the Reformist debates about the supremacy and incomprehensibility of God, with the leading thinkers being Luther and Calvin. The latter concept of the *deus otiosus* was enshrined in the mechanical turn of natural philosophy in the seventeenth century. It was endorsed by philosophers like Gassendi, Galileo, Descartes,

and Hobbes in an attempt to restore the insights of the Epicurean philosophy with its emphasis on atoms and a removed notion of God (Marwege 2022; Osler 1994; Wood 1967).

Looking beyond the sacred history and controversies over God, (I) immerse in EDA aiming to highlight an eco-evolutionary transition of protohuman from the ocean to a distinctive niche across the Pleistocene and Holocene geological time. That said, I first explore the discovery of deep ocean hydrothermal vents and their relevance to the concept surrounding the origin of life on Earth. Recent studies suggest that the Last Universal Common Ancestor (LUCA) of all cells emerged ~ 4.2 Gya from deep ocean alkaline vents and is the progenitor of two kinds of simple cells: archaea and bacteria (see Chapter 4). This suggests that, in the evolution of all multicellular eukaryotic species, such as humans, we live in close relationships with microbes of all kingdoms: archaea, bacteria, viruses, fungi and other small eukaryotes. These microbes not only passively colonize their host but have established a symbiotic relationship on all epithelial barrier sites during millions of years of co-evolution (Runge and Rosshart 2021). For example, Karl Möbius (1877) recognized the importance of these relationships in which organisms form a unit with surrounding species in the habitat, which he termed “biocenosis” or “living community.” Nowadays, the close interactions between a host and its associated microbial community are increasingly recognized as one functional unit defined as the holobiont,[6] a biocenosis on the individual level whereby each partner fulfils its crucial role (Esser et al. 2019; Bosch and Miller 2016). Thus, the origin of cellular life on Earth is crucial for correlating the emergence of protohumans from the ocean and their adaptability to their local triadic (ecological, neural, and cognitive) niche, as evidenced in the narrative.

1.3.1 Archaeogenetics and Brain Globularity

It is assumed that the genus *Homo* in Africa signals the beginning of the shift from increasingly

bipedal apes to primitive, large-brained, stone tool-making meat eaters that travelled far and wide. This early part of the human genus is represented by three species: *Homo habilis* 2.4 – 1.4 Mya, *Homo rudolfensis* 1.9 Mya, and *Homo* erectus 1.8 – 0.4 Mya. The study by Holly M. Dunsworth (2010) suggests that,

> For the first four million years or so of hominin evolution, the hominin fossil record is characterized by, among other trends, canine reduction and postcranial metamorphosis in the following genera: *Sahelanthropus*, *Orrorin*, *Ardipithecus*, *Australopithecus*, and *Paranthropus*. As the Pliocene epoch came to a close and global climate was shifting about 2.5 million years ago (deMenocal 2004) there is a concomitant change in the hominin fossil record (353).

As claimed by Dunsworth, *Homo erectus* signifies a significant shift in hominin evolution, notably through increased brain and body size and increasingly complex tools and behaviours. This is the origin of the genus *Homo*.

Likewise, the dominant archaeogenetic evidence of the skull/brain globular enlargement is ascribed to anatomically modern humans, the *H. Sapiens* from Africa and Eurasia. One of several contrasting interpretations of the archeological record sees a rapid emergence of behavioural modernity at the transition of the Upper Paleolithic in Europe and the Later Stone Age in Africa related to a mutation and consequently to neural changes called the "human revolution" model proposed by Klein (Neubauer et al. 2018, 1). Proponents of this model claim that modern human behaviours arose suddenly and simultaneously in the Old World, approximately 50 – 40 Mya. The search for revolutions in Western thought has been, in part, as Klein (2000) points out, a search for the soul, for the inventive spark that distinguishes humans from the rest of the animal kingdom, and therefore, separating our species from the biological

evolution. In addition, anthropological studies into the intellectual capacity of our ancestors have been restricted to examining the tools they created (DeFelipe 2011). It seems evident that only through globular encephalization are humans behaviorally modern, like *H. Sapiens*, capable of creating symbolic objects.

In cultural evolution, the information is stored in all aspects of cultural artifacts and practices. All these endeavours depend on the accretion of thousands of years of incremental progress and cognitive and cultural systems that allowed and motivated individuals to acquire and transmit accumulated knowledge and skills (MacLean 2016). Also, the behavioural shift is purported to signal a cognitive advance, a possible reorganization of the brain, and the origin of language. Roebroeks and Soressi (2016) acknowledge that "features used to mark behavioural modernity range from worked bone, ornaments, pigments, and complex multicomponent lithic technologies to material indicators of manipulations of symbols and abstract thought such as unequivocal art" (1). Some features are not exclusively known from modern human sites, and others have been documented systematically only since the Upper Paleolithic. Havarti and Reyes-Centeno (2022) also argue that the Middle to Late Pleistocene is highly relevant for studying human evolution. This is when the ancestral lineage of living humans developed, and thought might have first emerged as early as ~ 300 Mya in Africa from both fossil (Hublin et al. 2017) and genetic evidence (Lipson et al. 2020). Moreover, the study on the Neanderthals by Havarti and Reyes-Centeno corroborates,

> It is an iconic Pleistocene Eurasian species. Their trajectory is relatively well documented through a comparatively abundant record comprising partial fossil skeletons seemingly preserved through intentional burial, as well as a wealth of associated archaeological remains and, more recently, paleogenetic information

and even complete genomes (1).

The convergence of the Neanderthal and modern human lineages and its aftermath, starting at ~ 60 Mya, with the primary dispersal of modern humans out of Africa and concluding with the extinction of Neanderthals ~ 39 Mya, is also relatively well understood. However, the primary driving forces behind it – demographic, environmental, cultural, and cognitive are still intensely debated.

In evolution, a key derived feature in modern humans is the sizeable globular braincase underlying brain morphology and function that distinguish us from our Homo ancestors. Neubauer and colleagues (2018), based on computed tomographic scans and geometric morphometric analyses, examined endocranial casts of *H. sapiens* fossils from different periods. The data show that Hominin fossils from Jebel Irhoud (Morocco) that are associated with Middle Stone Age artifacts dated around 300,000 years ago display key features of modern human craniodental morphology but not globular braincases, thus forcing us to rethink the evolution of our species. Besides, Neubauer and colleagues suggest three key research analyses due to contrasting interpretations of archeological records: (1) when and how the endocranial globularity of modern humans emerged, (2) how this process relates to evolutionary brain size increase (Bruner et al. 2003), and (3) exploring the potential links between the brain evolution and genetics and behavioural changes. Neubauer and colleagues state that "the evolution of modern human brain shape is characterized by directional and gradual changes resulting in the typical globular modern human shape established at some point after about 100,000 years ago and probably before 35,000 years ago" (4). On this basis, ancient DNA[7] of archaic Homo representatives and *H. sapiens* fossils revealed derived genetic features that were fixed in *H. sapiens* after the population split from the clade, including Neandertals and Denisovans more

than 500,000 years ago (Castellano et al. 2014; Prüfer et al. 2014; Maricic et al. 2013; Meyer et al. 2012; Green et al. 2010). These genetic data suggest that positive selection within our lineage of genes is essential for brain function, behaviour, and, especially, nervous system development.

In addition, Meyer and colleagues (2012) developed a DNA library preparation method to reconstruct a high-coverage (30x) genome sequence of a Denisovan, an extinct sister group of Neandertals. According to this study, "a genetic contribution from Neandertal to the present-day human gene pool is present in all populations outside Africa, a contribution from Denisovans is found exclusively in islands of Southeast Asia and Oceania" (Reich et al. 2012) (2). Genome sequences of archaic human genomes allow the identification of derived genomic features that became fixed or nearly fixed in modern humans after the divergence from their archaic relatives. Neuro-oncological ventral antigen 1 (NOVA1) includes one of the few protein-coding differences between modern human and archaic hominin genomes that could affect human neurodevelopment. NOVA1 regulates alternative splicing in the developing nervous system. It is a master regulator of splicing genes responsible for synapse formation—the intercellular junctions specialized for fast, point-to-point information transfer from a presynaptic neuron to a postsynaptic cell (Südhof 2018). In addition, the analysis by Gregory and colleagues (2017) shows that Neanderthal genetic material introduced in the modern human lineage affects the skull and brain morphology of present-day humans.

Conversely, the study by Bruner (2019) argues that gene flow does not affect global human phylogeny:

> Firstly, possible remnants of Neanderthal genes are not found in all the living Populations, so, in any case, it is an issue dealing with local population genetics and not with global phylogeny. Secondly, as far as we can see, any potential gene

> flow has not changed the general biological model of the two lineages because modern human and Neanderthal fossils can always be discriminated in terms of phenotype. Thirdly, any gene flow did not alter the evolutionary fate of the two lineages. One went extinct, the other went to the Moon (1754).

Bruner points out that while the gene flow in living species supplies good samples, they cannot provide information on the process of evolution; they can only provide information on its product. Living species have evolved their own derived traits and, in some cases, can be inappropriate as models to investigate human evolution and ancestral features. As Bruner states, "After all, nobody would use humans as a model to understand chimpanzee evolution" (1754). Neither does the opposite choice sound straightforward. In paleoneurology, the main target is to understand the structural and functional relationships between the brain and the braincase to establish whether brain form changes are due to primary (intrinsic) brain changes or secondary (extrinsic) skull constraints.

Furthermore, Bruner argues: "Certainly, not every functional change is associated with morphological variations of the brain, and we must assume that many evolutionary cognitive differences are silent to the overall brain form. Absence of evidence, as usual, is not evidence of absence" (1756). In other words, defining the brain regarding morphological components is difficult. Its overall volume and form depend on distinct tissues and meningeal and blood mechanical forces, and the mechanisms of cortical folding are not well known (Tallinn et al., 2016; Bayly et al., 2014). For example, lobes are defined by conventional boundaries, and the localization of cortical areas may depend on the parcellation criteria (Glasser et al. 2016). According to Glasser, paleoneurology deals with comparative and evolutionary neuroanatomy and the evolutionary relationship between the brain and its braincase, and it is not a field

necessarily concerned with cognition.

In resume, a gradual evolutionary globular brain shape and size represent a synapomorphy of extant *H. sapiens* from Africa and Eurasia. Nevertheless, does the trait of the globular brain examines cognitive evolution from other ancestral societies without skull fossil records. For instance, those ancestors from the coastal Cascadia subduction zone. Therefore, to further insights for a digressive perception of protohumans' emergence from the Pacific Northwest, (I) immerse in EDA and navigate in time to the evolution of cellular life and cell sentience and cognition, then (we) set the course to the niche construction by organisms, and (we) expect to arrive to the earliest vertebrates neural innovation, specifically the hippocampus representational support of the scene imagery, memory and cognition.

1.4 Cellular Sentience and Cognition

A growing body of research suggests that the evolution of cell sentience and cognition long preceded the emergence of our species. In this framework, the single-cell organism and its living cognitive identity pose a question that digresses from the plot of H. sapiens-centered mentation: Can a single-cell organism be mindful? In the literature review Chapter 2, I advance novel ideas on the question, which also answers my research question: what makes cosmologic mythical narrative possible? Cellular sentience is essential for generating an evolutionary insight into the profoundness of the cosmologic narrative referring to ancestral events of human emergence from the ocean. Cellular sentience is the primary source of biological order and evolution that started approximately 4.2 billion years ago (Gya) with proto-cells emergence (Baluška et al. 2022). In this sense, the neuronal synapses have deep evolutionary origins and have evolved from proto-synapses (Baluška and Miller Jr. 2018; Grant 2009; Kosik 2009), which might underlie primordial sentience based on proto-feelings, proto-emotions, proto-qualia, and proto-

consciousness (Bronfman et al. 2016).

Regarding human cognitive evolution, the selected cosmologic stories include visual scene imagery of experience-dependent information and explicit learning in the context of the eco-evolutionary acquisition site. Explicit learning uses the synapsis to represent the subcellular substrate of learning and memory (Humeau and Choquet 2019) in episodic memory formation and the hippocampal cognitive map. This map represents relations and binding among memories within a multidimensional space, such as for organizing experiences and guiding behaviour across all domains of cognition (Dalton et al. 2022; Donato et al. 2021; Morton and Preston 2021; Moser et al. 2015; Schiller et al. 2015; Eichenbaum and Cohen 2014). In addition, scenes play a critical role in effectively retrieving relevant information from a cognitive map (Lee et al., 2023).

1.5 Niche Construction

Niche construction is a branch of evolutionary biology. It denotes processes whereby the activities of organisms modify their habitat, to which, in turn, the organisms evolve to adapt, thus creating their ecological niche in the environment. As the concept is extended to include the cognitive niche, Bretas and colleagues (2020) suggest that the brain capacity of our human ancestors underwent two phase transitions supported by preadaptation during the animal protolanguage period, resulting in the emergence of human language. “The transitions were (1) the emergence of the primate cerebral cortex, with its unique characteristic of additional cortical areas together with size expansion, and (2) the replacement of natural selection as the main evolutionary mechanism by *triadic niche construction*” (1) an interactive expansion of the ecological, neural, and cognitive niche. In addition, over the past two decades, studies suggest that episodic memory and scene imagination share fundamental neural dynamics and the process

for constructing vivid, spatially coherent, contextually appropriate scene imagery is strongly modulated by the neural dynamics of the hippocampal system and the ventromedial prefrontal cortex (vmPFC). In this regard, I will convey cognitive insight into cosmologic stories and the dynamic of cognitive traits and visual processing by enacting scene imagery.

1.6 Visual Mental Imagery

Joel Pearson (2019) demonstrates that almost any behaviour or cognitive process gained from sensory simulation tends to utilize mental imagery that covers all five senses. However, visual mental imagery tends to dominate. Humans are visual creatures, and the proportion of cortical tissue assigned to processing visual information is more significant than that of the other senses. In the brain, neurons devoted to visual processing comprise ~ 30% of the cortex**,** compared with 8% for touch and just 3% for hearing. Mental imagery involves activity across an extensive neural network spanning frontal areas right back to primary sensory areas. As Pearson states, "The neuroscience of imagery can be divided into work looking at the mechanisms involved in triggering the imagery process, mechanisms of generations or manipulation, as well as mechanisms underlying the strength and vividness of visual imagery content and its overlap with sensory perception" (Pearson 625). As stated, the mental generation of scene imagery is a crucial component of episodic memory processing. In addition, contemporary perspectives have converged to an inclusive account of hippocampal function that accommodates the flexible construction of predictive or fictive representations (Hassabis and Maguire 2007). As such, episodic memory depicts unique experiences and associated items and events with the spatial and temporal context in which they were experienced. For future retrieval, memories must first be encoded as a permanent trace or "engram" (Eichenbaum 2016)—the neural representation of memory that must be maintained and consolidated over time and, finally, can be recalled and

accessible to other cognitive processes.

1.7 The Hippocampus Cognitive Map

O'Keefe and Nadel (1978) argue that the hippocampus is the core of a neural memory system, providing an objective spatial framework within which the items and events of an organism's experience are located and interrelated. Specialized map-like representations emerged in the telencephalon of the first vertebrates as they adapted to a new way of life, especially during a major evolutionary transition in the Cambrian Period ~ 550 Mya, which marked a dramatic explosion of evolutionary changes in life on Earth. The study by Murray and colleagues (2017) corroborates that in the Cambrian Period, the earliest vertebrates adapted to a life of mobile, predatory foraging guided by distance receptors concentrated on their heads.

> Vision and olfaction served as the principal sensory systems for guiding their behaviour. Among their neural innovations, early vertebrates and anthropoids had a specialized map-like representation of the environment in the telencephalon that included a homologue of the hippocampus (47).

The conserved representations of the hippocampus also contribute to tasks that require recency, sequence, timing and order judgments, and evolving humans inherited all these traits. As a result, representations in the human hippocampus help to support the perception of scenes, perceptual learning about scenes, and both explicit and implicit memories about scenes. A visual scene is an inherited evolutionary trait that emerged during the anthropoid adaptations in the Oligocene Epoch, around 33.9 million to 23.03 million years ago. According to Lisman (2017), these operations deal with the context-dependent representation of complex memories, the role of mental exploration based on imagined rather than actual movements, and the use of recalled information for navigation and decision-making.

Edward C. Tolman (1948) conceived cognitive maps as extending generally to mapping life's experiences in any behaviorally relevant domain. He conceived the function of these maps as organizing specific events in a systematic fashion appropriate to the dimensions of the relevant context, and he argued strongly that the function of cognitive maps is to support expectancies and planning of behaviour to obtain sought goals. Humans and nonhumans have a mechanism for connecting map coordinates to fixed aspects of the environment that the perceptual systems, such as visual scenes of the landscape and scene-like and object-like landmarks, can identify. In this context, landmarks are entities that are useful for navigation because they are fixed in space (Epstein and Vass 2014). On this basis, to account for a new dimension of cosmologic stories from Haida Gwaii, the cardinal coordinates of the cognitive map, as perceived by the hippocampal neural basis, must reveal structured information of scenes of the ancestral Pacific Northwest environment.

A key function of the hippocampus is supporting the systematic organization of scene imagery and events in abstract space. For this study, a scene is defined as a naturalistic three-dimensional spatially coherent representation of the environment typically populated by objects and viewed from an egocentric perspective (Lee et al. 2021; Dalton et al. 2018). At the cellular level, the hippocampus cognitive map is the memory system in the brain that interacts with the external world. Humans and nonhumans have a mechanism for connecting map coordinates to fixed aspects of the environment that the perceptual systems, such as visual scenes of the landscape and scene-like and object-like landmarks, can identify. Landmarks are entities that are useful for navigation because they are fixed in space (Epstein and Vass, 2013). On this basis, to account for a new dimension of cosmologic stories from Haida Gwaii, the cardinal coordinates of the cognitive map, as perceived by the hippocampal neural basis, must reveal structured

information on scenes from the ancestral Pacific Northwest environment.

1.8 Methodology

To perform interdisciplinary research, I designed an *Experimental Digressive Assemblage* (EDA), a virtual construction scaffold structure embodying different planes of composition for networking with an agentic heterogenous assemblage of different materialities. The model of interdisciplinary research "links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any one field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process" (Aboelela et al. 2007, 341). By linking different fields, the interdisciplinary approach embraces freedom from disciplinary constraints to explore any theory, method, and phenomenon that the researcher(s) think is appropriate to resolve the question. Szostak (2016), drawing from Repko (2008), suggests that an interdisciplinary approach starts from the guiding question; the researcher first identifies relevant disciplines and then looks within those for relevant insights. Drawing from the evidential basis and purpose of interdisciplinarity, I delve deep into experimental art and its relationship with the degree of innovation and novel ways of thinking. In this dissertation, I associate my experimental art with the evolutionary transition from cell sentience and cognition to the hippocampus cognitive map, which is a topic based on a scientific experimentation process (see Chapters 4 and 5).

Elizabeth Grosz (2008) grounds art on the body:

> Art is the most direct intensification of the resonance and dissonance between bodies and the cosmos, between one milieu or rhythm and another. It is that which impacts the body most directly, that which intensifies and affects most viscerally. Through the plane of composition, it casts art as the way that the universe most

> directly intensifies life, enervates organs and mobilizes forces (29).

By working with the body, my project unleashes distinctive states of creative revelations that appear on a plane of composition for enacting the visual scene imagery of protohuman origins from Haida cosmology. Moreover, Grosz, drawing from Deleuze (1994a. 139), suggests that to rethink the body is an act of problematization:

> Thought is an active force, a positive desire, a thought which makes a difference, whether in the image form in the visual and cinematic arts … or the concept form in philosophy. Deleuze's project thus involves the re-energization of thought, the affirmation of life and change, and the attempt to work around those forces of anti-production that aim to restrict innovation and prevent change: to free lines, points, concepts, events from the structures and constraints which bind them to the same, to the one, to the self-identical (129).

Following Grosz's analysis of the Deleuzean project "to think as doing" (127), my endeavour for rethinking the body's emergence from the ocean is not confined to a mental or theoretical act. My experimental art process is inescapably interwoven with the dynamics of life and cellular evolution, a narrative of the/my body and its associated microorganisms, i.e., microbial eukaryotes, archaea, bacteria, and viruses, the so-called holobiont with ~ 4.2 billion years of evolution as my biological entity.

1.8.1 Experimental Digressive Assemblage (EDA)

EDA is a novel creative tool embodying three concepts: experimental art, literary digression, and assemblage (French: *agencement*). EDA is my time-navigating vessel steered by the creative agency of a heterogenous assemblage, a confederation of human and non-human elements, wherein the concrete elements and agencies are meaningful. For example, in its structure, I will

correlate cosmologic scene imagery of protohuman emergence from the ocean with the eukaryote cell, which is a cognitive and intentional supracellular consortium (Reber and Baluška 2021; Baluška and Reber 2019; Baluška and Lyons 2018, 2018b; Baluška et al. 2004, 2004b; Margulis 2004). Also, I can resource imagination, a biological function vital to human experience and advanced cognition. Broadly, imagination has a significant role in human creativity, agency, and everyday thoughts and actions (Comrie et al. 2022, 1). For my experimental practice, I immerse myself in EDA's structures to engage, conceptualize, connect, and compose within the creative forces of art and science to map cognition. According to Grosz (2008),

> Art, philosophy, and science each erect a plane, a sieve, over chaos, a historical temporal and mutually referential field of interacting artworks, concepts, and experiments (respectively), not to order or control chaos but to contain some of its fragments in some small space (a discourse, a work of art, an experiment), to reduce it to some form that the living can utilize without being completely overwhelmed (28).

Overall, for unravelling the hippocampal cognitive map, EDA planes of composition will enable me to enact and correlate the visual scene imagery in real-time semantic processing by relying on imaginative consciousness, which is vital to humans as an active process of creative experimentation and planning (Chapter 3).

1.9 Chapters Overview

Chapter 2, Literature Review, consists of four topic-oriented interdisciplinary stages signalling the progression of the creative process prompted by the Raven affect in the Yukon wild. (1) Affect and Desire, (2) Cognition-Based Evolution, Can a single organism be mindful?

(3) Niche construction, Enaction, (4) Digression, Assemblage.

Chapter 3: Cosmologic Scene Imagery Correlations. In this chapter, I use EDA to access information from chapters 2, 3, 4, and 5. By immersing myself in EDA, I enact and correlate the visual scene imagery with recent studies on Earth's function in the first part of its history, the emergence of cellular life, cellular sentience and cognition, organisms' niche construction, the role of the hippocampus in episodic and semantic memory, and the hippocampus as a cognitive map.

Chapter 4: Solar Nebula, Earth, Cellular Life. This is a support chapter inspired by Shinning-Heavens' incarnation in Kaisun. In this spatiotemporal frame, I navigate across the latest advances in astrochemistry, astrophysics, astrobiology, and evolutionary biology in search of materials, tools, and novel insights for charting life in the Cosmos. Back on Earth in deep-ocean alkaline hydrothermal vents. I envision a close encounter with the Last Universal Common Ancestor (LUCA) of archaea and bacteria as the first origins of cellular life on Earth.

Chapter 5: Hippocampus. This is a support chapter interconnected with Chapter 3. Here I explore the evolution of the mammalian central nervous system and, subsequently, the specialization of the hippocampus in humans to serve a critical function in episodic and semantic memory, navigation, cognition, and the cognitive map.

1.10 Conclusion

All life is cellular and started ~ 4.2 billion years ago with the emergence of the first cells, so I acknowledge that cell sentience and cognition long preceded the emergence of our species. Thus, in memory encoding and retrieval of cosmologic narrative transmitted by oral tradition, its correlation with neural evolutionary networks may reflect cellular inherent sentience and cognition leading to the hippocampal-entorhinal complex, which is critical for episodic memory

and language.

1.11 Chapter Notes

1. Ga. o, Ga. o expresses the Raven call as found in the story "Raven travelling" told to John Reed Swanton by Skaay or John Sky; *Haida Texts and Myths, Skidegate Dialect, Bureau of American Ethnology Bulletin, vol.* 29, no.1, 1905b, p. 121.
2. Yukon Wild Nature: Following the United Nations International Year of Fresh Water, The *Boreal Rendezvous* (2003) was organized by First Nations leaders and involved high-profile Canadians. This extensive conservation project is aimed at protecting the Canadian boreal forest ecosystem. One of Canada's ten canoe trips and related activities included the *Three Rivers journey project*, organized by the Yukon chapter of the Canadian Parks and Wilderness Society (CPAWS). I was selected as a visual artist to participate in the *Boreal Rendezvous–2003* at the Snake Rivers, Yukon.
3. Vital materiality is a theoretical framework to rethink the body's vital impetus and efficacy depends on the collaboration, cooperation, or interactive interference of many bodies and forces in pursuing their *vital materiality* enhancement. Vital materiality is intrinsic to matter that runs alongside and inside both human and non-human. Jane Bennett (2010) suggests that when humans are assessed as vital materialities, the distributive quality of creative agency resides in a *heterogeneous assemblage*, a confederation of human and non-human elements. The return to the vitality of matter is a critical discursive engagement to address realities on how human and nonhuman material bodies, spaces, and conditions contribute to the co-production of subjectivity and being in the world.
4. The limits of Cascadia were first defined to contain nearly the entire margin of the Pacific. Northwest, from Cape Mendocino through the Alaska Panhandle (Schuchert and Barrell

1914). Since then, the boundary of Cascadia has shrunk to become synonymous with the region where the Juan de Fuca plate subducts beneath the North American plate (Szeliga 2013).

Fig. 1. Credit: U.S. Geological Survey. Location of the Cascadia subduction zone. Image: Mustafa Lazkani/Federal Emergency Management Agency.

The Cascadia Subduction Zone (CSZ) extends approximately 1000 km from northern Vancouver Island to northern California (Fig. 1), where two tectonic plates collide. The Juan de Fuca, a small oceanic plate, is being driven under the North American plate. It is part of the Earth's famous "Ring of Fire," created by subduction zone processes as Earth's tectonic plates collide and move past each other. Volcanoes and earthquakes are characteristic features of subduction zones, and large-scale tectonic movements in subduction zones cause

Earth's largest earthquakes (Hyndman 2015). At the Queen Charlotte Fault, the North American Plate moves southeast, and the Pacific Plate moves northwest relative to one another. The Queen Charlotte plate boundary, near Haida Gwaii, B.C., includes the dextral, strike-slip, Queen Charlotte Fault (QCF) and the subduction interface between the down-going Pacific and overriding North American plates.

Alternatively, tectonic plate dynamics in the Pacific Ring of Fire subduction zones have presented discoveries of living organisms dating back 3.77–4.28 billion years ago. This data could be considered in the grand scheme of the prokaryotic and eukaryotic cell symbiotic evolution. Symbiogenesis, or endosymbiotic theory, is an evolutionary theory of the origin of eukaryotic cells from prokaryotic organisms, first articulated in 1905 and 1910 by the Russian botanist Konstantin Mereschkowski (O'Malley 2015) and advanced and substantiated with microbiological evidence by Lynn Margulis–Lynn Sagan in 1967 (Gray 2017).

5. Protohuman emergence: Swanton's original story is translated for children. Reid and Bringhurst (1984) use "little creatures" (34) in their translation of "The Raven and the First Man." However, I use protohumans from the Pacific Ocean because the story refers to symbiosis among species.
6. The holobiont concept has emerged as a theoretical and experimental framework to study the interactions between hosts and their microbial communities in all types of ecosystems (Simon et al., 2019). From protists (single-cell organisms) to humans, all animals and plants are inhabited by microbial organisms, ultimately forming a holobiont. Humans and all other organisms are metaorganisms composed of a host and a complex microbiome (Jaspers et al. 2017). Eukaryotes and prokaryotes interact dynamically to form the so-called metaorganism

or holobiont, a biocenosis on the individual level where each partner fulfils its versatile and crucial role. To Bosch and Miller (2016), "There are no germ-free animals in nature. Epithelia in contact with the environment are colonized by microbial communities, and all multicellular organisms must be considered an association of the macroscopic host in synergistic interdependence with bacteria, archaea, fungi, and numerous other microbial and eukaryotic species" (1). All multicellular organisms are characterized by synergism with interdependent bacteria, archaea, viruses, and other microbial and eukaryotic species, including fungi and algal symbionts. Already in 1877, the importance of these consortia was made evident by zoologist Karl August Möbius (1825 – 1908) by acknowledging that organisms form a unit with surrounding species in the habitat, which he termed "biocenosis" or "living community." Möbius was the first to recognize that an ecological system must be taken as a whole, and his biocenosis theory established itself as the basis of general ecology.

7. DNA (deoxyribonucleic acid) is arguably one of the most valuable tools scientists can use to understand living organisms. Our genetic code can tell us much about who we are, where we come from, and diseases we may be predisposed to contracting and acquiring. DNA is essential in identifying and separating organisms into species when studying evolution. However, DNA is a fragile molecule, and it degrades over time. For most fossil species, there is essentially no hope of ever acquiring DNA from their fossils, so answers to questions about their appearance, physiology, population structure, and more may only be partially answerable. For more recently extinct species, scientists have and continue to extract ancient DNA (aDNA), which they use to reconstruct the genome of long-gone ancestors and relatives.

CHAPTER 2. Literature Review

2.1 Introduction

This chapter accounts for my research development over time into four stages: (1) Affect and Desire, (2) Cognition-Based Evolution (CBE): Can a single-cell organism be mindful? (3), Niche construction, Enaction, (4) Digression, Assemblage.

2.2 Stage 1: Affect and Desire

In this stage, I proposed the need for proactive sensorial (re)identification in nature using encounters with different entities. I want to contextualize the affective change during my unavoidably transformative bodily experience immersed in the Yukon wild nature.

2.2.1 Affect

The concept of affect is an ontological and epistemological qualifier, "affect in philosophical thought signals physical, spiritual, cognitive, and intellectual processes and states" (Colman 2010, 11). The foundations of the concept proposed by Spinoza and Bergson became extended in the 1980s by Gilles Deleuze and Félix Guattari as the change or variation occurs when bodies collide or come into contact. Deleuze and Guattari in *A Thousand Plateaus* (1987) argue: "Affects are becomings" (256) between two states. It is the transition from one state to another. It expresses the modification of experiences through the additive forces, powers, and expressions of affective change, and its reaction produces modification or transformation in the affected body. Affect emerged as a pre-personal process of becoming an additive expression of change or variation caused by encounters between bodies. Deleuze and Guattari in *A Thousand Plateaus* (1987) describe Spinoza's studies involving the body transformation throughout space and time:

> To every relation of movement and rest, speed and slowness grouping and infinity

> of parts correspond to a degree of power. To the relations composing, decomposing, or modifying an individual, there are corresponding intensities that affect it, augmenting or diminishing its power to act; these intensities come from external parts or the individual's parts (256).

According to Deleuze and Guattari, "Affects are becoming Spinoza asks: What can a body do? We call the *latitude* of a body the affects of which it is capable at a given degree of power or rather within the limits of that degree" (256). The concept of affect complies with Spinozist dynamic ontology in which transformations in degrees of power are the defining characteristics of becoming. The Deleuzean–Guattarian affect points to the change or variation that occurs when heterogeneous bodies collide or come into contact, e.g., human and nonhuman encounters. Affect is a reactive and active force that can produce sensory or abstract results, is a physical and temporal product, and involves geography, biology, meteorology, astronomy, ecology, and culture. Within the Deleuzean-Guattarian framework, affect operates as a desired dynamic within any assemblage to manipulate meaning and relations where things and bodies are altered. In my research, the affective dimension sponsors a novel vision for the ruptured fleshed body to steer a dynamic process of (re)identification with the holobiont for reawakening alternative experientiality for learning and cognition.

2.2.2 Desire

Desire (French: *production désirante*) or "desiring production" is a key term found in *Anti-Oedipus* by Gilles Deleuze and Felix Guattari (1983) and refers to an active and positive reality, an affirmative vital force. Desire is creative and productive and maintains a causal relation with reality through assemblages and the body. All natural processes, even those beyond the human, are processes of desiring production as Deleuze and Guattari state: "Everything is a machine.

Celestial machines, the stars or rainbows in the sky, alpine machines … nature as the process of production" (9**).** Desiring production is thus not anthropocentric; it is the very heart of the world**.** Besides its universal scope, Deleuze and Guattari realized two things about desiring production:

> (1) there is no subject that lies behind the production which performs the production; and (2) the "desire" in desiring-production is not oriented to making up a lack but is purely positive. Desiring production is autonomous, self-constituting and creative: it is the natura naturans of Spinoza or the will-to-power of Nietzsche (26).

Deleuzean-Guattarian desire supports positive productively that supports the conception of life as material flows. On this basis, desire is an emancipatory concept that challenges the premises of "lack." Alison Ross, in her analysis of desire, posits:

> The psychoanalytic conception of desire as an insatiable lack regulated by Oedipal law is one of the main inaccuracies of desire that Deleuze tries to correct. Instead of desire being externally organized in relation to prohibitions that give it a constitutive relation to "lack," for Deleuze, desire is defined as a process of experimentation on a plane of immanence. Added to this conception of desire as productive is the conception of desire as positive. Whereas in psychoanalysis theory, desire is located within the individual as an impotent force, the positive and productive dimension Deleuze ascribes to desire makes it a social force (66).

Reinterpreted desire is viewed not just as an experimental, productive force; it is a force able to enhance the power of bodies in their connections within assemblages. Desire is the circulating energy enabling connections and relations between bodies, things, technologies, ideas, and social institutions. For example, the material flows from one experiential state of the body to another in

a specific environment, implies an augmentation of the body's power to act, and desire participates in this process as a sense of intense energetic resonance. In my research, desire is a creative, vital force, an impulse for enhancing the body's conatus and the power to act. This means exploring any theory, method, and phenomenon appropriate to enhance (my) cognition for specific tasks involving interactive cognitive processes from different fields through an experimental digressive assemblage.

2.3 Stage 2: Cognition-Based Evolution: Can a Single-Cell Organism be Mindful?

The living cognitive identity of a single-cell organism and its relation to the world poses a question which digresses from the plot of *Homo sapiens* centered mentation; can a single-cell organism be mindful?[1] Baluška and colleagues (2022) state, "all life is cellular, and the cell acts as the basic unit or 'atom' of life" (1). As life requires cognition at every scale to build on the heritage of billions of years of biological evolution, (I) push the boundaries for understanding the profoundness of the cosmologic narrative of protohuman emerging from the ocean in correlation with novel evolutionary tenets of cellular inherent sentience and cognition starting ~ 4.2 Gya.

2.3.1 Cognition-Based Evolution

Pamela Lyon and colleagues (2021) study on cognition as a biological evolutionary function proposes an alternative terminology based on a phyletically neutral definition of cognition as a biological function. The concept of "basal cognition refers to cognitive capacities in earlier branching phyla: prokaryotes, single-celled eukaryotes, and the constitutively multicellular eukaryotes, such as plants, fungi, and simple animals without and with the nervous system" (1). According to Lyon and colleagues, cognition is like respiration and is universally present from unicellular life to blue whales and every form of life in between, necessary for staying alive.

James A. Shapiro (2021) also argues that all living cells are cognitive because all living cells sense and respond to changes in external or internal conditions, and cognition is an essential feature of life because "all organisms have to adapt their physiology and behaviour to novel circumstances" (134). Shapiro's observations suggest that bacteria possess cognitive abilities such as discrimination between nutrients, chemotactic searching for nutrients, intercellular signaling, coordinated and directed multicellular activities, communication in establishing root nodule symbioses with multicellular eukaryotes, recognition and repair of genome damage and self/nonself discrimination in DNA incorporation. Even single bacteria and archaea are endowed with life-specific characteristics and features deemed as having a basal form of consciousness and intentional and cognitive capacities.

Baluška and colleagues (2021), getting down to the cell enclosement, propose that the plasma membrane acts as the primary nanobrain. "Nanobrains are behind the phenomenon of nano-intentionality (Fitch 2008), which is based on the fact that structural (phenotypic) plasticity is inherent not only to cells but is expressed in individual biomolecules" (6). For the authors, the senomic nano-mind generated via cellular nanobrains allows a scale-free cognition to generate the *self*. This cellular *self* can obtain meaningful content of the sensory information relevant to adaptation and survival. For instance, the eukaryotic cell is a cognitive and supracellular consortium, which is integrated through ancient proto-signaling networks based on electrostatic forces and reactive electrophilic redox species, dynamic cytoskeleton, and subcellular communication across organellar synapses (Baluška and Mancuso 2014).

Cellular sentience as the primary source of biological order and evolution started ~ 4.2 (Gya) with the emergence of protocells (Baluška et al. 2022). The neuronal synapses have deep evolutionary origins and have evolved from proto synapses (Baluška and Miller Jr.

2018; Grant 2009; Kosik 2009), which might underlie primordial sentience based on proto-feelings, proto-emotions, proto-qualia, and proto-consciousness (Bronfman et al. 2016; Hobson 2009). Thomas Henry Huxley (1853), in his 'epigenetic' philosophy of biology,[2] proposes that cells represent a trinity of three memory-storing media – Senome, Epigenome, and Genome-comprising a cell-wide informational architecture. Revisiting Huxley's ideas, Baluška and Reber (2019) advanced the cellular basis of consciousness (CBC) model, which proposes that all biological awareness, sentience and consciousness are grounded in general cell biology. Prokaryotic cells that merged to form chimeric eukaryotic cells had consciousness, and the two merged cells generated a supracellular consciousness (Margulis 2001). This consciousness is grounded in cell-to-cell communication for integrating diverse signaling inputs into coherent cellular behaviour (Baluška and Mancuso 2014).

In resume, Cognition-Based Evolution (CBE) offers an alternative to 20th-century conventional neo-Darwinism and, therefore, "energizes a reappraisal of natural selection, emerging from a singular base: cognition is coincident with life's origin, and what had been termed natural selection should instead be considered cognitive selection" (Miller Jr. et al. 2024, 1). This novel 21st-century evolutionary framework brings critical insights into how cells are intelligent and measure uncertain environmental information to sustain themselves. All biological and evolutionary development represents the perpetual autopoietic defence of self-referential basal cellular states of homeostatic preference (Miller et al. 2021; Miller et al. 2019). As Miller and colleagues (2021) state, "Evolutionary development is energized by intelligent cells upholding their fates through the measuring assessment of information and its deliberate communication. Consequently, cellular actions are based on measurement" (24). To enhance the validity of these measurements and improve their prediction, cells form collaborative

associations by building niches, “This enacts the multicellular ecologies that yield biofilms or holobionts” (25). As stated, collective and productive cellular information and natural cellular engineering mutualize niche construction and environmental sentience, which are essential for life's cognitive basis. Moreover, Baluška and Reber (2021) identified the subcellular sources for the emergence of sentience and consciousness at the cellular and subcellular levels: excitable membranes, oscillating cytoskeletal polymers, and structurally flexible proteins. These basic biophysical structures underlay the emergence of supracellular sentience from cellular sentience in multicellular organisms, such as the human holobiont.

2.3.2 Can a Single-Cell Organism be Mindful?

The study by Fred A. Keijzer (2017) advocates for the dissociation of cognition and intelligence from the paradigmatic status of the human mind in favour of biological embodied cognition. The human mind should not be considered the central feature of life evolution “while developing an independent parallel account of cognition that builds on the many biological intelligence cases. This parallel domain of cognition can accommodate forms of intelligence very different from human and animal examples” (2). This novel paradigm might open new ways of thinking about radically different forms of intelligence. To build on biological cognition, Humberto Maturana (1970) states:

> (1) Cognition is a biological phenomenon and can only be understood as such, any epistemological insight into the domain of knowledge requires this understanding.
>
> (2) If such an insight is to be attained, two questions must be considered: What is cognition as a function? What is cognition as a process? (7).

In general usage, the term “cognition” refers to the process of acquiring and using knowledge,

and, as such, it is assumed to be limited to organisms with an advanced nervous system that encodes knowledge about the environment for better survival. In addition, Humberto Maturana and Francisco Varela introduced a revolutionary perspective on what it means to be a living system: *autopoiesis* (Maturana and Varela 1987, 1980; Varela et al. 1979). For the authors, the essence of life is that it produces (poiesis) itself (auto). Living organisms are self-organized autonomous networks that produce and sustain themselves as a systemic whole–an *identity* within a particular domain (Maturana 1970; Varela 1997, 1979). As Varela argues:

> An autopoietic system is organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produce the components that: 1. through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them, and 2. constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network (Varela 1979, p. 13).

Any unity meeting these specifications is an autopoietic system, and any such autopoietic system realized in physical space is a living system. The key feature of a living system is the maintenance of its organization, i.e., preservation of the relational network, which defines it as a systemic unity. As Maturana and Varela (1987) suggest, all living beings have an autopoietic organization concerning the molecular origins of terrestrial living beings. It was necessary to have molecules capable of forming membranes sufficiently stable and plastic to be effective barriers and to have changing properties for the diffusion of molecules and ions over long periods concerning molecular speeds. For example, rigid molecules form silicon layers to participate in dynamic unities (cells) in an ongoing and fast molecular interchange with the

medium. Indeed, “It was only at that point in the Earth’s history when conditions were right for the forming of organic molecules such as proteins, which have enormous complexity and pliancy, that conditions were right also for the forming of autopoietic unities” (Maturana and Varela 1987, 49). This suggests that when all these sufficient conditions were present and ripe in the Earth’s history, autopoietic systems formed inevitably, and that was when life began. In addition, all the available evidence suggests that “many autopoietic unities with many structural variants emerged in many places on the Earth throughout perhaps many millions of years” (51). The emergence of autopoietic unities on Earth is a landmark in the history of our solar system. Maturana’s and Varela’s achievement is to present a theory that overcomes the division of mind, matter and life, and this understanding of life occurs by integrating life’s biological and cognitive dimensions.

2.3.2.1 Cell Sentience and Cognition

The evolutionary changes in the human brain's size and number of neurons have led to the reorganization of the underlying structure and function of neural circuits that have changed, especially the long-distance projection systems associated with language and digital dexterity. George Gaylord Simpson (1941) noted that “All the essential problems of living organisms are already solved in the one-celled protozoan, and these are only elaborated in man or the other multicellular animals” (17). Simpson recognized that there are different categories and degrees of individuality and that evolution among lineages has generated decreases and increases in individuality. Comparing a unicellular organism to a cell in a metazoan, he explained how, in the latter case, more individuality is now at the level of the metazoan, with its cells having lost nearly all the autonomy they had as independent organisms. Autonomy is the key feature of cell life, achieved by secreting and sensing devices that have shaped evolution.

At the genetic level, in her Nobel speech, geneticist Barbara McClintock (1983) refers to the homeostatic adjustments of the sensing device for recognizing when the amount of Ribosomal DNA (rDNA)[3] is above or below the standard amount and its proper adjustment: "A goal for the future would be to determine the extent of knowledge the cell has of itself, and how it utilizes this knowledge in a 'thoughtful' manner when challenged" (193). For McClintock, there are "shocks" by some mutagenic agents that the genome faces repeatedly and to which it is prepared to respond in a programmed manner. On this basis, some sensing mechanism must alert the cell to imminent danger and set an orderly sequence of events to mitigate the danger in motion.

Following this paradigm, evolutionary biologist Lynn Margulis, in a paper provocatively titled "The conscious cell" (2001), maintains that the origin of the eukaryotic cell via bacterial cell merger and the components that fused in symbiogenesis were already "conscious." Margulis states that by eubacterial-archaebacterial genetic integration, the chimera, an amitochondriate heterotroph,[4] evolved to have their prokaryotic-specific sentience.

> By study of what thrives now, we can reconstruct the past directly from living organisms, even "microbial mind"… Brains appear later, but consciousness, awareness of the surrounding environment starts at the beginning of life itself…The earliest cells generated the two great groups of bacteria: the one to which *Thermoplasma* belongs (archaebacteria) and the one to which the spirochetes belong (eubacteria). The process of symbiogenesis in the evolution of nucleated cells began at about 2,000 mya. The emergent property of the symbiont fusion was the origin of all larger forms of life (Margulis 57–58).

Lynn Margulis is recognized as one of the first scientists to discuss the evolutionary origin of

cellular consciousness, and she argued that prokaryotic cells that merged to form chimeric eukaryotic cells had a proto-consciousness. The two merged cells generated a supracellular consciousness (Fig. 2).

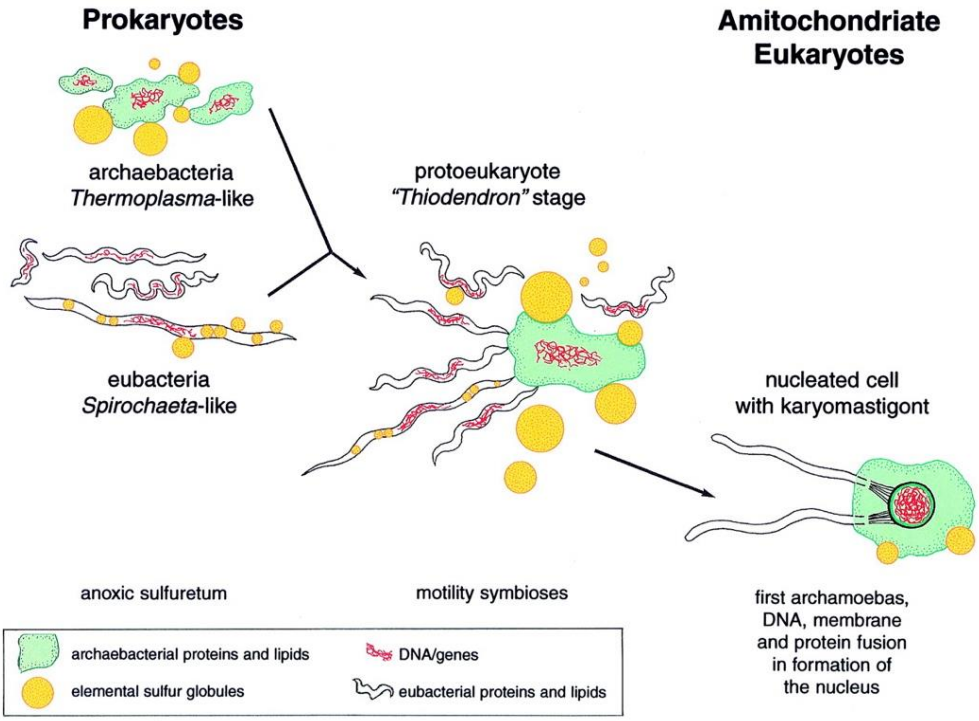

Fig. 2. Margulis et al. 2000, p. 6955. Origin of the chimeric eukaryote with karyomastigonts from a motile Sulphur-bacteria consortium.

Also, a recent study by Baluška and Reber (2019) discusses the cellular basis of consciousness (CBC) model. It proposes that all biological awareness, sentience and consciousness are grounded in general cell biology. For an insentient organism to carry out adaptive functions,

> The maximally adaptive process would be for the first unicellular organisms to have sentience encoded in its DNA and, in virtue of such a subjective capacity to monitor its metabolic and behavioural functions and be able to react adaptively to

> each of the valenced objects and events, it encountered. This, we maintain, is where the first minds appeared, and the mental states and functions of all subsequent species are derived from this urconsciousness (3).

According to the authors, the urconsciusness happened only once on this planet, and, like the underlying biomechanical processes that gave rise to life, every other species carries these essential pieces of genetic material that code for sentience. Moreover, this study identifies three subcellular sources for the emergence of sentience and consciousness. (1) The critical property of the cellular plasma membrane is its excitability, which is linked inherently to environmental cues and signals (Sacks et al. 2015; Gardiner 2012). An important feature of cellular membranes, particularly relevant for the cellular basis of sentience, is that their lipid bilayers have quasi-crystalline properties (Jewell 2011; Fergason and Brown 1968). Excitable membranes appeared early in the biological evolution of cells (Brunet and Arendt 2016; La Monaca and Fodale 2012) and are present not only in eukaryotes but also in prokaryotic species as well as in eukaryotic organelles of endosymbiotic origin (Baluška and Levin 2016). (2) A second possible source is the dynamic cytoskeleton. Microtubules are regarded as important in this respect (Sacks et al. 2015; Catterall and Zheng 2015; Gardiner 2015), and terahertz oscillations in tubulin have also been found to be affected by exposure to anesthetics (Gardiner 2015). Besides microtubules, the actin filaments behave as an excitable medium that, in addition to transporting vesicles and organelles, also transports ionic waves. (Craddock et al. 2017; van Haastert et al. 2017). (3) there are indications that unique proteins with fivefold symmetries and quasicrystal properties are relevant for the cellular and subcellular levels of sentience (Masi et al. 2009). To Baluška and Reber (2019) study,

> The three-dimensional structure of proteins is not dictated solely by the sequence

> of amino acids; proteins dynamically select one of several possible conformations according to physico-chemical conditions (Annila and Baverstock 2014). This flexible behaviour of proteins suggests that proteins also contribute to subjectivity within single cells (Annila and Baverstock 2014; Kovác 2008; Agnati et al. 2016; Koseska and Bastiaens 2017), (4.)

Kovác (2008) suggest that proteins are the elementary epistemological units of life; in his study on bioenergetics, he proposed that proteins demonstrate molecular sentience as "the capacity to incessantly sample conformational substates, one of which becomes stabilized upon recognizing the appropriate ligand" (1). A further study by Almén and colleagues (2009), by mapping the human membrane proteome, states that a "receptor is a protein that mediates a cellular response upon binding a ligand" (4). The authors identified 1,352 proteins as receptors and divided them into 63 groups. Moreover, Baluška and Reber (2019) suggest that trans-membrane proteins underlie the bio-electric excitability of membranes and control cell growth, development, movement, and morphogenesis in unicellular and multicellular organisms. For Baluška and Reber, these proteins are called Maxwell's demons–related to an experiment carried out by James Clerk Maxwell in 1867,[5] acting as thermodynamic ratchets, or imaginary gatekeepers, to support ordered life processes inside cells (Moore 2018; Loewenstein 2016). On this basis, Baluška and Reber state, "These metaphoric demons could, in principle, use survival-relevant information and knowledge accumulated over the whole of biological evolution (Annila and Baverstock 2014; Binder and Danchin 2011) to support living systems by resisting (though not violating) the second law of thermodynamics" (4), entropy. Following the above studies, the biological foundation of cellular consciousness is based on how an excitable plasma membrane, densely populated with biological Maxwell demons, such as sensors, receptors, ion channels,

transporters, and ATPases, can generate a senomic cellular field. The senome represents the sum of all the sensory experiences of the cognitive cell and its sensing apparatus (Baluška and Miller 2018). Moreover, based on the evolutionary origins of the eukaryotic cell, both the large, actin-based host cell and the smaller guest cell, which relied on the tubulin-based cytoskeleton, are proposed to be ancient archaea (Baluška and Lyons 2018). This may allow the merging of their fields to generate the new, more robust and senomic field of an emergent eukaryotic cell. In addition to the excitable plasma membrane and membranes of recycling vesicles, other cellular structures that are capable of contributing to the cellular fields are the large, bundled, vibrating elements of the cytoskeleton, such as F-actin[6] (Beta et al. 2020; Pal et al. 2019; Iglesias and Devreotes 2012) and microtubules (Kalra et al. 2020; Kucera and Havelka 2012). Both excitable plasma membrane and cytoskeletal elements have been proposed to generate proto-consciousness in individual eukaryotic cells. The eukaryote cell is a cognitive and intentional supracellular consortium (Reber and Baluška 2021; Reber 2019; Baluška and Reber 2019; Baluška and Lyons 2018, 2018b; Baluška et al. 2004, 2004b; Margulis 2004) integrated through ancient proto-signaling networks based on electrostatic forces and reactive electrophilic redox species, dynamic cytoskeleton, and subcellular communication across organellar synapses.

2.3.2.2 Cellular Communication and Language

The evolutionary origin of language remains unknown despite many efforts to determine the origin of this human trait. Following, I provide an overview of recent studies on language. Piai and colleagues (2016) point out that language is viewed as a cortical function [1] typically studied in isolation from memory. However, their study also demonstrates that the exact neuronal computations used by the hippocampus for memory function also subserve online language usage; “Our finding specify that the hippocampus complex contributes to language in an active

fashion, relating incoming words to stored semantic knowledge, a necessary process in the generation of sentence meaning" (11366). These findings integrate the studies of language and memory by expanding the role of the hippocampus theta oscillations and adding hippocampal structures to the neural network supporting language.

Duff and colleagues (2020) highlight the role of the hippocampus in episodic and semantic memory:

> New hippocampus-dependent representations are available rapidly enough to influence ongoing processing when new information is perceived; old information is retrieved; and representations are held on-line to be evaluated, manipulated, integrated, and used in service of behavioural performance. That is, the hippocampus is critical not only for the ability to form new enduring memories and to recover the past but also for the creation, maintenance, updating, and using of online representations in support of ongoing information processing (11).

According to this study, the hippocampus engages in real-time semantic processing through ongoing information. This advances our understanding of how words, concepts, and meaning, as well as episodes and events, are integrated, instantiated, and maintained in memory. It also offers novel insights into our most quintessentially human abilities: memory and language.

Based on epigenetic inheritance, John S. Torday (2021) hypothesizes that language evolved from cell-to-cell communication as the basis for generating structure and function embryologically and phylogenetically, as did all physiologic traits. The study of epigenetics is linked with evolution and development. Felsenfeld (2014) argues that "epigenetics reflect our understanding that although the complement of DNA is essentially the same in all of an organism's somatic cells, patterns of gene expression differ greatly among different cell types,

and these patterns can be clonally inherited" (2). Epigenetics is the study of mitotically and meiotically heritable changes in gene function that cannot be explained by changes in DNA sequence (Riggs et al. 1996; Riggs and Porter 1996). In addition, Lacal and Ventura (2018) suggest that epigenetics is the alterations in the gene expression profile of a cell that are not caused by changes in the DNA sequence. Epigenetic inheritance thus refers to transmitting certain epigenetic marks to offspring (Pang et al. 2017; van Otterdiij and Michels 2016). Behaviors and the environment can cause changes that affect the way genes work. Unlike genetic changes, epigenetic changes are reversible and do not change the DNA sequence, but they can change how a body reads a DNA sequence. Moreover, Torday (2021) states:

> Beginning with lipids forming the first micelle, a vertical integration of the evolved properties of the cell, from multicellular organisms to the introduction of cholesterol into the cell membrane, to the evolution of the peroxisome, the water-land transition and duplication of the bAdrenergic Receptor, the evolution of endothermy, leading to bipedalism, freeing the forelimbs for toolmaking and language, selection pressure for myelinization of the central nervous system to facilitate calcium flux, bespeaks human expression, culminating in the evolution of civilization (140).

As Torday states, this process is epitomized by the Area of Broca (a region in the frontal lobe) as the structural-functional site for motor control and language formation. The mechanistic interrelationship between motor control and language formation is underscored by the role of FoxP2 gene expression in both bipedalism and language.

Stephen C. Levinson (2023) suggests that early hominin communication was gestural, in line with all other Hominidae. The gestural phase of early language development left its traces

in how spatial concepts were implemented in the hippocampus and provided organizing principles at the heart of grammar. Levinson argues, “The ecological niche has likely left its multimodal signature deep in the heart of language structure, through the import by the gesture of spatial cognition into our human communication system” (7). Spatial memory encoding and cognition of vectorial information is the role of different neurons’ responses in and around the extended hippocampal system, far from the sensory periphery (Biscanski and Burges 2020). The responses of these neurons represent the fundamental neural basis for “the (bottom-up) representation of environmental layout and (top-down) memory-guided generation of visuospatial imagery and navigational planning” (1). Spatial relations are a subset of relational information (Eichenbaum 2018), and spatial selective cells found in the extended hippocampal system which may process abstract (Whittington et al. 2020; Constantinescu et al. 2016), auditory (Aronov et al. 2017) and visual (Biscanski and Burgess 2020) information of the role played by cells exhibiting receptive fields with vectorial characters in spatial paradigms.

2.4 Stage 3: Niche Construction, Enactive Cognition

Niche construction is a universal feature of living organisms. Niches are spaces for the biological units of selection, from cells to complex communities (Baquero et al., 2021). Species are biological units of individuation, and niches exist due to individual organisms in their space. Thus, cognition arises through the interaction between a living organism and its distinctive triadic niche (ecological, neural, and cognitive), which can be enacted by actively exercising the organism’s sensorimotor processes.

2.4.1 Niche Construction

The geneticist and evolutionary biologist Theodosius Dobzhansky (1967), in his paper “Changing man” describes it as follows:

> Evolution comprises all the stages of the development of the universe: the cosmic, biological and human or cultural developments. Attempts to restrict the concept of evolution to biology are gratuitous. Life is a product of the evolution of inorganic nature, and man is a product of the evolution of life (409).

Dobzhansky arguments went further, attesting that in the history of the Cosmos, man's evolutionary process has transcended itself into the realm of consciousness and culture. René Jules Dubos (1965), another well-known microbiologist, indicates in his article "Humanistic Biology": "Most enlightened persons now accept as a fact that everything in the cosmos—from heavenly bodies to human beings—has developed and continues to develop through evolutionary processes" (6). According to his argument, western society has accepted the historical scientific view of creation. Evolutionary concepts have also been applied in the arts and social institutions.

Darwin's natural selection theory argues that the environment poses problems for organisms which function as selection pressures, and these pressures lead to adaptive evolutionary responses. Placed in this context, the environment is an external initiator and prime cause of adaptive evolution, disregarding the active role of the organism. On the other hand, niche construction theory alludes to the process whereby organisms modify their own and each other's niches through their activities and choices. Richard C. Lewontin (1983), the founder of niche construction theory, raised concerns about conventional evolutionary approaches to adaptation because organisms actively shape the selection that acts on them. Niche construction theory describes how organisms modify their selective environment through activities and choices. In 1944, Nobel laureate physicist Erwin Schrödinger anticipated the concept:

> Thus, we have come to the conclusion that an organism and all the biologically relevant processes that it experiences must have an extremely "many-atomic"

> structure and must be safeguarded against haphazard, "single-atomic" events attaining too great importance. That, the "naive physicist" tells us, is essential, so that the organism may, so to speak, have sufficiently accurate physical laws on which to draw for setting up its marvelously regular and well-ordered working (4).

Schrödinger points out that a living organism should be capable of developing an ordered organization in its environment and that the physical interaction between an organism and the environment must obey a physical law of accuracy. For Lewontin (1983), an organism at every stage of its life is the result of a developmental process in which the internal genetic factors and the external environmental factors are in constant interplay. These organisms do not passively adapt to conditions in their environment, but actively construct and modify environmental conditions that may influence other environmental sources of selection. Odling-Smee (1988) was the first to coin the term "niche construction," which became recognized as an evolutionary process of "ecological inheritance." Since the appearance of *Niche Construction: The Neglected Process in Evolution* (2003) by Odling-Smee, Laland, and Feldman, it has become the primary source reference for the niche construction theory (NCT). An important reference worth quoting is that organisms play two roles in evolution:

> The first consists of carrying genes; organisms survive and reproduce according to chance and natural selection pressures in their environments. This role is the basis for most of evolutionary theory, it has been subject to intense qualitative and quantitative investigation, and it is reasonably understood. However, organisms also interact with environment, take energy and resources from the environment, make micro–and macrohabitat choices with respect to the environment, construct

> artifacts, emit detritus and die in the environment and by doing all these things, they modify at least some of the natural selection pressures present in their own each other's local environments. This second role for phenotypes in evolution is not well described or well understood by evolutionary biologists and has not been subject to a great deal of investigation. We call it "niche construction" (1).

All living creatures, through their metabolism, activities, and choices, partly create and partly destroy their niches on scales ranging from extremely local to global (Fig. 3).

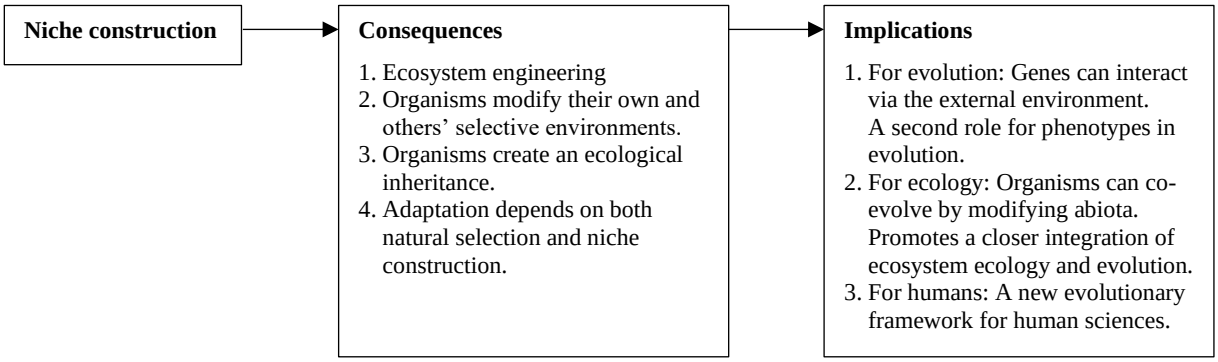

Fig. 3. Odling-Smee F. J., et al. 2003, p 3. The consequences of niche construction and their implications for evolutionary theory, ecology, and the human sciences.

Organisms choose habitats and resources to construct aspects of their environment, such as nests, holes, burrows, webs, pupal cases, and chemical milieu, and frequently choose, protect, and provision nursery environments for their offspring Odling-Smee and colleagues (2003) describe four significant niche ramifications construction: these processes (1) in part control the flow of energy and matter through ecosystems (ecosystem engineering); (2) transform selective environments to generate a form of feedback that may have important evolutionary consequences; (3) create an ecological inheritance of modified selection pressures for descendant populations; (4) provide a second process capable of contributing to the dynamic adaptive match

between organisms and the environment.

Niche construction is a universal feature of living organisms. It can alter ecological processes and modify natural selection, a widely accepted proposal (Laland et al. 2017). The modern synthesis[8] coined by Julian Huxley (1942) proposed that there is only one line of inheritance: genetic inheritance. Odling-Smee and colleagues (2003) propose that there is another line of inheritance, ecological inheritance. Niche construction involves modifications to the ancestral environment that are bequeathed to the next generation. This encompasses physical alteration of the physical environment and cultural artifacts, practices, and institutions in humans.

2.4.2 The Neural Niche

Since the Miocene origins of the hominin lineage ~ 6 Mya, behavioural and developmental plasticity have been an adaptive response to the local environment. According to Lafuente and Baldede (2019), "Developmental plasticity refers to the property by which the same genotype produces distinct phenotypes depending on the environmental conditions under which development takes place" (1). As said, the brain's neural circuitry is adaptive to structured sociocultural niches bequeathed to future generations. On this basis, I may suggest that human behaviour and neural plasticity are encoded in cosmologic narrative. Cosmologic stories are drawn from a society's history. A society's cosmology is its memory and cognitive system depicting unique experiences and associated items and events in the context of the specific environment and its interaction with the neural niche.

Joseph Altman (1962) first suggested that adult neurogenesis, or the generation of new neurons, occurs beyond development in the adult mammalian brain (Altman and Das, 1965). In

the neurogenic niches, adult neural stem and/or progenitor cells (NSCs) generate functional neurons and brain plasticity throughout life (Kempermann and Gage 1999), which have been implicated in learning, memory and affective behaviours. During adult neurogenesis, newborn neurons release feedback signals into the niches to regulate NSC proliferation and differentiation. NSCs reside in two major neurogenic niches in the adult mammalian brain where endogenous NSCs reside: the subgranular zone (SGZ) within the dentate gyrus of the hippocampus and the subventricular zone (SVZ) of the lateral ventricles (Bond et al., 2015; Ming and Song 2011). For example, extended brain functions sustained changes in the hominin ecological niche, which demanded further brain resources to adapt to it. These "interactions accelerated their evolution through a process of *triadic* niche construction" (Iriki and Taoka, 2012, 1). The triadic concept includes the "cognitive niche" as a newly acquired class of cognitive capacity (Pinker 2010) and the "neural niche" as a portion of neural tissue added through the expansion of the brain (Anderson 2010; Iriki and Sakura 2008). Further studies propose that at the neural niche level, experiences must first be encoded as a permanent trace or "engram," the neural representation of memory (Eichenbaum 2016). For learning to occur, an experience must result in enduring changes in anatomical connections and physiological processes within the brain. Rapid and efficient recall of this experience (e.g., an episodic memory) depends on these anatomic and physiologic changes. An engram is a sparse ensemble of neurons across multiple brain regions manifesting these learning-induced changes. A recent study by Miry and colleagues (2021) states:

> Neuronal allocation describes the phenomenon by which a specific population of neurons, but not others within the same network, are recruited to encode an experience as memory. Is this small subset of neurons chosen at random, or are

> they somehow predisposed to encode an experience? Studies with intracellular recordings in hippocampal CA1 neurons during novel environment exploration demonstrate that cells with relatively high excitability immediately before the novel environment exploration are more likely to become place cells (Cohen et al. 2017; Epsztein et al. 2011) or learning-activated engram cells (Li et al., 2020), suggesting a certain degree of predetermination (5).

Miry and colleagues advance our understanding of how engrams are formed and how they function in the hippocampal CA1 region, " where hippocampal cells encode place and experience" (8). Memory identity and fidelity through synaptic allocation are maintained and consolidated over time and, finally, can be recalled, becoming accessible to other cognitive processes. In humans, the hippocampal CA1 region, composed of pyramidal cells, is one of the most evolutionary conserved archicortical regions, critically involved in forming, consolidating, and retrieving memory (Benavides-Piccione et al. 2020).

In addition, a recent study on cognition from the body-brain–mind partnership by Buzsáki and Tingley (2023) suggests that sensory areas driven by environmental signals alone cannot ground their activity to anything meaningful. Grounding refers to the ability of the brain's circuits to assign meaning to changes in neuronal firing patterns that result from sensory inputs. As the authors state, "The brain interacts with the environmental niche through organs of the body. Due to the coevolution of the nervous system and periphery, there is extensive matching between their properties" (194). The brain's actuators—skeletal, autonomic, and endocrine systems together—are essential for attributing significance and meaning to inputs impinging on the organism and its ability to maintain stable homeostatic states. Buzsáki and Tingley's argument on cognition, including memory, can be explained by exaptation and expansion of the

circuits and algorithms serving bodily functions. “Exaptation of such circuits was likely exploited for exploration of the organism’s niche” (191). The hippocampal system's dual, endocrine-homeostatic and memory contributions illustrate these exaptation steps. Thus, transmitting memory is essential for learning and accumulating knowledge. These interactions among ecological, neural and cognitive domains of niches have contributed to our ancestors’ evolutionary process. In my research, this knowledge is found in the Haida oral tradition, specifically in the retrieval and reactivation of the background scene imagery (Zeidman and Maguire 2016) of the triadic niche, which leads to the contribution of the hippocampal system.

2.4.3 Enactive Cognition

A central proposal of the enactive approach to cognition is that there is a continuity of mind and life, which is to say that mental phenomena can be understood based on the principles that describe the organization and behaviour of all life, including the simplest life form such as the single-cell organism (Kyselo 2014; Varela 1997). An organism enacts the world it lives in; its embodied action in the world constitutes its perception and thereby grounds its cognition. Francisco Varela, Evan Thompson, and Eleanor Rosch first articulated the enactive approach in *The Embodied Mind* (1991). The authors claim: “In a nutshell, the enactive approach consists of two points: (1) perception consists in perceptually guided action and (2) cognitive structures emerge from the recurrent sensorimotor patterns that allow action to be perceptually guided” (173). The notion of perceptually guided action refers to the sensorimotor structure of the perceiver, which is how the nervous system links sensory and motor surfaces. In this way, in his local changing situation, the embodied perceiver can guide perceptually his actions and be modulated by environmental events. According to Varela and colleagues, the overall concern of the enactive approach is “to determine the common principles or lawful linkages between

sensory and motor systems that explain how action can be perceptually guided in a perceiver-dependent world" (2). Perception and action, in this sense, are embedded within and constrained by the environment as a cognitive domain. The perceiving organisms are not merely passive receivers of environmental stimuli. Organisms form a dynamic relationship with their environments, shaping how they interact with the world. Perception also contributes to mapping external features as a creative form of enacting significance based on the animal's embodied history.

> By using the term *embodied,* we mean to highlight two points: first, that cognition depends upon the kinds of experience that come from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological, and cultural context (173).

A living body enacts the world it lives in; its embodied action in the world constitutes its perception and thereby grounds its cognition. For Varela and colleagues, the action represents lived cognition, emphasizing that sensory and motor processes, perception and action are inseparable and have evolved together. Moreover, in a recent study, Thompson (2017) recapitulates cognition as enaction:

> In *The Embodied Mind*, we presented the idea of cognition as enaction as an alternative to the view of cognition as representation. By "representation" we meant a structure inside the cognitive system that has meaning by virtue of its corresponding to objects, properties, or states of affairs in the outside world, independent of the system. By "enaction" we meant the ongoing process of being structurally and dynamically coupled to the environment through sensorimotor

> activity. Enaction brings forth an agent-dependent world of relevance rather than representing an agent-independent world. We called the investigation of cognition as enaction the "enactive approach" (1).

Thompson indicates that the enactive approach draws on multiple sources—the theory of living organisms as autonomous systems that bring forth their cognitive domains, emerging works on embodied cognition and how sensorimotor interactions with the world shape cognition. *Enaction* is a framework emphasizing the experienced world determined by mutual interactions between the organism's physiology, sensorimotor circuit and the environment. Then, cognition arises through a dynamic interaction between an acting organism and its environment. In this sense, all living systems, from single-cell organisms to human beings, are ontologically endowed with teleological and sense-making agency. This conception of agency, which enactivism recasts in terms of "sense-making," has two mutually supporting ontological components: on the one hand, sense-making is argued to be an intrinsic characteristic of all living systems. On the other hand, organisms are discussed to bring forth their unique worlds by being sense-making agents.

In addition, Di Paolo and Thompson (2014) suggest that in humans, the embodiment thesis proposes that the body be crucial for cognition:

> (1) What is meant by the body? (2) What is meant by cognition? (3) What is meant by crucial?... (1) The body is adaptively autonomous and a sense-making system; (2) Cognition is sense-making and an adaptive process of active self-regulation; (3) Without the body, there cannot be sense-making, which is a bodily process of adaptive self-regulation" (76).

Following Di Paolo and Thompson, the link between body and cognition has been constitutive since ancestral times. In the environmental consequences of living activity, the organism

objectifies its sense-making for itself and other organisms. The self-differentiated subjective world of the sense maker and the objectified properties of the environment display the transforming relation among organisms in their mutual evolutionary structuring. In this sense, I draw from the human body's heritage as a sense-making multicellular living system formed by cellular continuity, in other words, by dividing previous cells. This "implicates that cellular ordered structures are physically and informationally continuous across the whole biological evolution since the beginning of life" (Baluška et al. 2022, 7). This biological order, together with the cognition and sentience of all cells, underlies the creative evolution and adaptations in a continuously running evolutionary narrative.

2.5 Stage 4: Digression, Assemblage

In this stage, in presupposing the unity and progression of a narrative, I use literary digression as an interruption to the anthropocentric plot of human-divine origins, precisely the one arising from creationism and the idea of the *Deus otiosus*. In addition, the concept of assemblage enables the production of a novel perception of reality using unexpected connections.

2.5.1 Literary Digression

The theory of literary digressions is shaped by a plot-centered notion of narrativity. It is used to diverge the reader's attention from the main plot. It is meant to be done intentionally to illustrate a point or add suspense to the story. Digression is a stylistic device authors employ to create a temporary departure from the main subject of the narrative, to focus on unrelated topics and to explain background details.

The first notion of digressions and the theoretical model appears in Quintilian's *Institutio Oratoria* (first century C.E.). Quintilianus asserts that a digression is "the part, added contrary to the natural order of the discourse, which discusses a point foreign to it, yet useful to the cause"

(247). In recent years, Peter Brooks (1992) constructed a theory of the plot that, beyond mere functionality – gives impetus and meaning to a succession of events. Brooks is interested in the plot and plotting, which he understands as "the design and intention of narrative, what shapes a story and gives it a certain direction or intent of meaning" (viii—xi). Brooks is specifically interested in questions of temporal sequence. By plotting, Brooks means "that which makes a plot move forward" and makes us read forward, seeking in the unfolding narrative a line of intention and portent of design that holds the promise of progress toward meaning. Ross Chambers (1999) claims that all narratives can only come into existence as narratives *per se* by not following the straight line, the shortest path, which leads from their beginning to their end; that is, they can only take shape as narratives by distancing their endings from their beginnings. Chambers states,

> Digressions, then, is a discursive "slide" or "slippage" along a line of continuity that links one context and its other, so that the new position one reaches is both linked with the first and discontinuous with it. One thing leads to another, as people say; and digression my transgress rules of cohesion, but not of cogency and coherence (12).

As stated above, digressions might transgress cohesion rules but not cogency and coherence. Frederick Samuel (2011), in his study, questions the plot-centred notion of narrativity, suggesting a rereading of the theoretical digression models advanced by Peter Brooks and Ross Chambers:

> The notion of a digression … is grounded in an understanding of narrative functionality that would later be codified by the Structuralist, from whose theoretical models the field of narratology would emerge. This structuralist-

> narratological notion of narrative functionality privileges the centrality and linearity of the story (though not necessarily the linearity of discourse), its progression, and, crucially, it is foundational teleology. In presupposing the unity and progression of a narrative, this model views digressions as an interruption, suspension, or aberration that impedes the purposeful trajectory of a narrative as a whole (Samuels 15).

For Samuels, digression is an *anti-narrative* device recuperated by the larger narrative whole, to which it is subservient. In presupposing the unity and progression of a narrative, Samuels's model views digressions as an interruption, suspension, or aberration that impedes the purposeful trajectory of a narrative. My research is directed at the emergence of the human body as holobiont, digression[9] for this purpose becomes an interruption into the anthropocentric plot of human-divine origins, specifically coming from the idea of the *Deus otiosus* (Latin: neutral god, hidden god, inactive deity). In the history of religions, this god withdrew after his creation from governing the subsequent course of earthly affairs, a model that has pervaded the Americas since colonial times. Thus, to engage critically in the emergence of humans, I seek learning and cognition from pre-contact cosmologic stories of the Americas. On this basis, my quest foresees the actualization and enhancement of the holobionic body conatus through enacting the visual scene imagery of human origins from the narrative of the periphery.

2.5.2 Assemblage

The concept of assemblage (French agencement) plays a crucial role in Deleuzean and Guattarian philosophy, and it is found in *A Thousand Plateaus* (1987) and *What is Philosophy?* 1994. For Deleuze and Guattari (1987), a horizontal and a vertical axis is associated with assemblages. The horizontal axis deals with "*machinic assemblages* of bodies, actions, and

passion" and "a *collective assemblage of enunciation*, of acts and statement, of incorporeal transformation of the bodies" (88). The vertical axis deals with "*territorial sides*, or reterritorialized sides, which stabilize it, and *cutting edges of deterritorialization* which carries it away." (88). Through its multiplicity, an assemblage is shaped by and acts on a wide range of flows. In practical terms, assemblages conceived by Deleuze and Guattari "are complex constellations of objects, bodies, expressions, qualities, and territories that come together for varying periods to create a new functioning way (Livesey 2010, 18).

Jane Bennett (2010), drawing from Deleuzean-Guattarian assemblage, focuses on five operational distinctions: efficacy, coherence, competence, power relations, and the nature of the actant:

> An assemblage is, first, an ad hoc grouping, a collectivity whose origins are historical and circumstantial, though its contingent status says nothing about its efficacy, which can be quite strong. An assemblage is, second, a living, throbbing grouping whose coherence coexists with energies and countercultures that exceed and confound it. An assemblage is, third, a web with an uneven topography: some of the points at which the trajectories of actants cross each other are more heavily trafficked than others, and thus power is not equally distributed across the assemblage. An assemblage is, fourth, not governed by a central power: no one member has sufficient competence to fully determine the consequences and the activities of the assemblage. An assemblage, finally, is made up of many types of actants: humans and non-human; animals, vegetables, and minerals; nature, culture, and technology (23–24).

For Bennett, the actant never acts alone in an assemblage. Its efficacy or agency depends

on many bodies and forces' collaboration, cooperation, or interactive interference. This idea challenges the traditional definition of matter as passive, inactive and inert since the active power of materials plays an essential role in the emergence of every event.

Drawing from the general logic of Deleuzean–Guattarian assemblage, Tomas Neil (2017) states that "all assemblages are political" (28). The consequence of this distinction is that it provides an alternative logic to unities in favour of multiplicity and the rejection of essence in favour of events. If the researcher wants to know an assemblage, I should know how it works: What is its structure? What is its political typology? According to Nail, the political typology reveals the political landscape of society and the processes of change that shape it. Once the researcher understands how the assemblage functions, (I) will be better positioned to diagnose, direct or shape the assemblage toward increasingly digressive aims and through discursive connections with different agential materialities. On this basis, an assemblage emerges when a function emerges, ideally innovative and productive. On this basis, my Experimental Digressive Assemblage (EDA) emerges to enact and correlate the visual scene imagery of two cosmologic stories for unravelling a hippocampal cognitive map of human cognitive evolution.

2.6 Chapter Notes

1. Can a single-cell organism be mindful? Dr. Karen Madsen, Director, CEGIIR (The Centre of Excellence for Gastrointestinal Inflammation and Immunity Research), Professor, Division of Gastroenterology University of Alberta, posed the question to me to be resolved according to the latest scientific research on the origin and nature of sentience.
2. The senomic field is the legacy of Thomas Henry Huxley (1825–1895). In his "epigenetic" philosophy of biology, cells are proposed to represent a trinity of three memory-storing media: Senome, Epigenome, and Genome, which comprise a cell-wide informational

architecture. The senome represents the sum of all sensory experiences of the cognitive cell and its sensing apparatus. Drawing from Baluška and Miller Jr. (2018), the senome translates physical signals from the outside world into the physicochemical language of cells. “It is a central feature for all cellular life, allowing DNA and RNA to support life processes. Without membranes generating the Senome, DNA and RNA are rather inert macromolecules unable to support the living processes” (5). For the authors, each biological organism is inevitably a subject, and its worldview is constructed internally from its particular self-referenced Senome evolved during its specific evolutionary trajectory and enfolded during its individual life; it is evident that the Senome of each organism is unique. Also, the dynamic environment—organismal interplay shapes the Senomes of individual organisms during their life so that even two genetic twin organisms will move apart concerning their Senomes according to their unique individual experiences, which necessarily accumulate during their individual life histories. Finally, Baluška and Miller Jr.(2018) propose that the Senome is the inherent partner of the Genome and the Epigenome. The Senome underlies sensory order (Hayek 1952), which gives all cellular organisms a sense of time and agency (Vuorre 2017).

3. According to Warmerdam and Wolthuis (2019), two aspects of the ribosomal DNA (rDNA) are remarkable: first, it contains hundreds of repeated genes, and second, it forms the most heavily transcribed region in the human genome. The ribosomal RNA (rRNA) transcribed from the approximately 600 rDNA repeats form the most abundant fraction of RNA found in eukaryotic cells (McStay 2016). Together with about~ 80 proteins, representing 10% of cellular protein levels, the rRNAs are built into ribosomes, the macromolecular machines through which messenger RNAs (mRNAs) are guided during protein synthesis (Boisvert et al. 2007). 16S rDNA gene sequencing is commonly used to identify, classify, and quantify

microbes within complex biological mixtures such as environmental samples (ex-marine water) and gut samples (ex-human gut microbiome). The 16S rRNA gene is highly suited as a target gene for sequencing DNA in samples containing up to thousands of diverse species.

4. Regarding an amitochondriate heterotroph, Lynn Margulis and colleagues (2000) posit that a chimeric cell evolved via symbiogenesis by syntrophic merger between an archaebacterium and an eubacterium. The archaebacterium, a thermoacidophil resembling extant thermoplasma, generated hydrogen sulphide to protect the eubacterium, a heterotrophic swimmer comparable to Spirochaeta or Hollandina that oxidized sulphide to sulphur. Hence, the common ancestor of all eukaryotes by genome fusion of two or more different prokaryotes became "chimeras" via symbiogenesis (Golding and Gupta 1995). According to Margulis and Colleagues:

   > Long-term physical association between metabolically dependent consortia bacteria led by genetic fusion to this chimera. The chimera originated when an archaebacterium (a thermoacidophil) and a motile eubacterium emerged under selective pressure: oxygen threat and scarcity of both carbon compounds and electron acceptors. The nucleus evolved in the chimera. The earliest descendant of this momentous merger, if alive today, would be recognized as an amitochondriate protist (6954).

   For references, (see Figure 4), showing the origin of the chimeric eukaryote. Also, the term syntropy involves fermenting bacteria and methanogen. Archaea is in a complex metabolic process during which hydrogen could be generated by acetate oxidation and/or acetate by homoacetogens from hydrogen.

5. Physicist James Clerk Maxwell argued that a hypothetical "being" with the faculty of seeing

individual molecules (Maxwell's Demon) could bring about such improbable distributions, thus violating the law of entropy. Maxwell's thought experiment would hypothetically contravene the second law of thermodynamics. This experiment is described at the end of his *Theory of Heath*, in the section called "Limitations of the Second Law" 1871:

> But if we conceive of a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are as essentially finite as our own, would be able to do what is impossible to us. For we have seen that molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower molecules to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics (308–309).

This text gave birth to Maxwell's demons, a fictitious being that has stimulated a remarkable and extensive series of scientific contributions to the present day. Moreover, the law of entropy is mentioned. It measures a system's thermal energy per unit temperature, which is unavailable for practical work. Because work is obtained from ordered molecular motion, entropy measures a system's molecular disorder or randomness.

6. F-actin is a crucial protein for cellular function and motility. In most eukaryotic cells, actin is the most abundant protein. Actin is an integral part of the cytoskeleton and is essential for

cell stability and morphogenesis. It participates in many crucial processes, such as cell division, endocytosis, and migration. The research by Rivero and Cvrcková (2007) on reconstructing the microfilament system of the ancestral eukaryote postulates that the presence of a complex cytoskeletal system is a hallmark feature of eukaryotic cells, distinguishing them from their prokaryotic (bacterial or archaeal) “cousins.” No extant prokaryote studied so far possesses obvious homologues of major cytoskeletal proteins shared universally among eukaryotes, such as actin or tubulin. However, several proteins exhibiting limited sequence similarity with specific cytoskeletal components and the ability to form filaments have been found (Doolite 2002; Egelman 2003; Margolin 2004). These include, among others, relatives of actin and actin-associated proteins, the FtsZ family of bacterial and archaeal tubulin-related proteins participating in cell division (Bramhill 1997) and an intermediate filament-like protein (crescentin) from *Caulobacter* (Ausmees et al. 2003).

7. The ventromedial prefrontal cortex (vmPFC). Guido Gainotti (2021) suggests the right ventromedial prefrontal cortex's leading role in integrating cognition and emotion and controlling impulsive reactions. The vmPFC plays a key role in integrating cognitive and emotional processes. This integration is important in the control of emotional reactions and responses. Shamay-Tsoory and colleagues (2005) showed that the right vmPFC regulates the interaction of emotion and cognition in producing empathic responses and that impaired “affective” theory of mind is associated with right vmPFC damage. It is important to note that the two brain regions associated with episodic memory and value-based decision-making are the hippocampus and the vmPFC. Howard and colleagues (2014) bring forth evidence of a cognitive map that comes from the spatially localized firing of hippocampal “place cells”

and entorhinal “grid cells,” which code for an animal’s current position in an environment (Hafting et al. 2005; O’Keefe and Nadel 1978).

8. Julian Huxley coined the term in his book *Evolution: The Modern Synthesis (*1942) on the need for a concerted synthesis. He claims that:

> Evolution may lay claim to be considered the most central and the most important of the problems of biology. For an attack upon it, we need facts and methods from every branch of the science – ecology, genetics, paleontology, geographical distribution, embryology, systematic, comparative anatomy – not to mention reinforcements from other disciplines such as geology, geography, and mathematics (Huxley 13).

The “modern synthesis” (MS) generally refers to the formulation of evolutionary theory that reconciles classical Darwinian selection theory with a newer population-oriented view of Mendelian genetics, attempting to explain biological diversity's origin. Biologists faced the problem of fitting genetics and natural selection together in a theory of evolution. Genetics gave scientists the mathematical framework for exploring natural selection and opened up questions about how reproduction affects which genes are passed to offspring.

Since modern synthesis (MS), or Synthetic Theory, still dominates evolutionary thoughts, an extended evolutionary synthesis (EES) is advocated due to significant advances in the biosciences:

> The material basis of inheritance has been unraveled and entire new fields of research have arisen, such as molecular genetics, evolutionary developmental biology and systems biology. In addition, new evolutionarily relevant factors have been described, including non-genetic inheritance,

> developmental bias, niche construction, genomic evolution and others (Müller 2017, 1).

According to Müller, while the standard theory (MS) concentrates on genetic and adaptive variation in population, in evolutionary developmental biology, the extended evolutionary synthesis (EES) framework emphasizes the role of constructive processes, ecological interactions and system dynamics in the evolution of organismal complexity and its social and cultural conditions.

9. I choose digressions as an essential component of creative freedom (Mansilla-Miranda 2016, Master of Arts Thesis). For instance, I draw from Spanish author Luis Martín-Santos (1924–1964). He was a surgeon, psychiatrist, and writer who got the reader's attention under Franco's dictatorship to give a diagnosis of the body utilizing metaphors. Martín-Santos's microscope became a dialectic tool for acutely analyzing society under oppression. Also, I draw from Virginia Woolf's (1882–1941) experiments with wandering, digressive narrative voices and her implementations of consciousness and subjectivity, including the possibility or impossibility of entry into minds other than one's own. For example, "The Mark in the Wall" traces a journey of the wandering mind, as it uses the eponymous "mark" as a starting point for its adventures in consciousness: "How ready our thoughts swarm upon a new object, lifting it a little way, as ants carry blades of straw so feverishly, and then leave it" (37). Woolf's stream of consciousness explores characters' thoughts, feelings, moods, and expectations. For instance, a conscious experience of the objective world around me could be regarded as a newly formed event memory. As an instance of mental imagery, it contains a retrieved event memory. As Ralf-Peter Behrend (2013) argues,

> The stream of conscious experience could be seen as evidence for the ongoing

> formation of event memories that are linked into episodic memory sequences, then unitary conscious experience could be defined as a symbolic representation of the pattern of hippocampal neuronal firing that encodes an event memory (1).

According to Behrend, the hippocampus rapidly forms event codes by integrating object information (derived from the ventral visual stream and orbitofrontal cortex) with contextual emotional information (from the anterior insula) and spatial environmental information (from the dorsal visual stream). These codes contain the informational content of objects embedded in an emotional and spatiotemporally extending context.

CHAPTER 3. Cosmologic Visual Scene Imagery Correlations

3.1 Introduction

This chapter is central to my dissertation because verbal or gestural storytelling is a fundamental characteristic of our species that represents the world. Following, I set the course and immerse myself into EDA: (1) to enact the visual scene imagery and its verbal pair associates (VPA) task with concrete imageable words for events and objects found in the Haida cosmologic stories, and (2) to correlate the retrieved information utilizing interdisciplinarity would elicit the hippocampus cognitive map.

3.2 Cosmologic Stories and Neuronal Cognitive Functions

Cosmologic stories of underlying events of human origins have been learned, relearned, and passed through Haida storytellers' memories for thousands of years, stabilizing long-lasting forms of these remote memories over time. Over the last few decades, providing insights into the neural circuitry that underpins memory updating, learning, and cognition suggest that a central feature of the brain is its ability to learn from experience and, based on memories, adapt future behaviour and synaptic plasticity is the cellular basis of learning and memory (Citri and Malenka 2008). Connectivity through life experiences provides the means of forming and storing memories. These cognitive functions result from evolutionary changes in the human nervous system's size and number of neurons and its neural circuits' cellular and molecular reorganization (Sousa et al. 2017).

Lynn Nadel (2021) argues that hippocampal formation plays a critical role in cognitive processes by stitching together spatiotemporally disparate entities and events.

It does this by 1) constructing cognitive maps that represent extended spatial

> contexts, incorporating and linking aspects of an environment that may never have been experienced together; 2) creating neural trajectories that link the parts of an event, whether they occur in close temporal proximity or not, thus enabling the construction of event representations even when elements of that event were experienced at different times; and 3) using these maps and trajectories to simulate possible futures (1).

A cognitive map creates a context representation associated with an item during encoding, "a process often referred to as *binding*, or *spatiotemporal binding"* (Ekstrom and Yonelinas 2021, 3). Successful binding of events and items to a unique spatiotemporal context allows an episodic memory to be differentiated from the myriad of other human experiences in a day. In practice, memory retrieval of episodic events encoded in cosmologic narrative may link the past and the present. For instance, Buzsáki and colleagues (2022) point out that verbally declarable memories can be obtained from the first-person (egocentric episodes) and third-person (allocentric semantic knowledge) perspectives:

> Since the separation of self from others and the environment is pervasive in the animal kingdom, this perspective allows for a forward strategy for studying memory in all animals, and it links episodic and semantic memories to egocentric (path-integration) and allocentric (map-based) forms of navigation, respectively (22).

For Buzsáki and colleagues, an episode is an unfolding storyline in time, which we recall as a trajectory or sequence of events as a structure in space. Based on this evolutionary perspective, memory is a mechanism that guides current and future behaviours by selecting appropriate actions based on past experiences. Some forms of memory are helpful only once

(single-utility or working memory), whereas others are useful for a lifetime (multiple-utility or long-term memory). Aspects of these operations are supported by interlinked physiological mechanisms and brain states, such as consolidation by which an initial memory trace stabilizes and becomes available for long-term retrieval. Indeed, over the years, according to Buzsáki and colleagues, the definition of memory has been simplified to indicate that knowing "what" corresponds to semantic facts, and knowing "what" happened, "where," and "when" corresponds to episodic events. Thus, by enacting scene imagery of "what," "where," and "when" components of the original episode in spacetime, it is possible to recreate what was encoded in the cognitive map. Moreover, adding a time axis to the "what" helps define first-person (egocentric episodic) versus third-person (allocentric semantic) memories since the ego-versus-allo separation is inherently present in the concept of spacetime.

3.3 Visual Scene Imagery Retrieval

The retrieval of scene imagery in real-time semantic processing highlights cognitive functions such as imaginative consciousness, vital to humans as an active creation and planning process. On this basis, EDA is an experimental platform for interdisciplinary material knowledge production. I use material and materiality to describe the relationship with the physical world and the substances constituting every object we encounter (Schlegel and Kneebone 2020; Bennett 2010). EDA enacts the visual scene imagery of the cosmologic narrative represented by the verbal paired associates (VPA), such as scene words and object words. The verbal paired associates (VPA) are typically regarded as a verbal memory task. Scene words and object words represent the verbal paired associates (VPA) task, which is emblematic of hippocampal function. To determine why VPA engages the hippocampus, Clark and colleagues (2018) used fMRI imagery with an encoding task involving closely matched pairs of scene words, pairs of object

words, and pairs of extremely low imagery abstract words (Fig. 4).

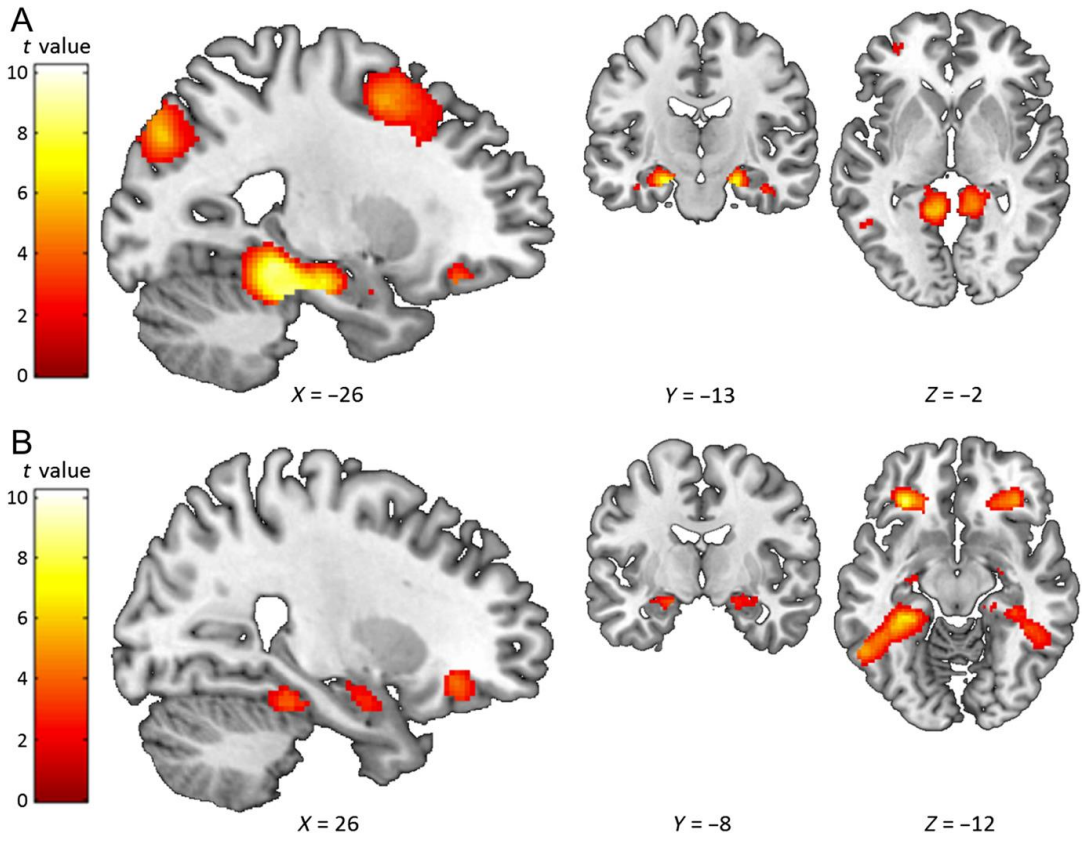

Fig. 4. Clark et al. 2018, p.1830. Comparison of high imagery Scene or Object word pairs with very low imagery Abstract word pairs. The sagittal slice is of the left hemisphere, which is from the ch2better template brain in MRicron (Rorden and Brett 2000; Holmes et al. 1998). The left of the image is the left side of the brain. The coloured bar indicates the t value associated with each voxel. (A) Scene word pairs > Abstract word pairs. (B) Object word pairs >Abstract word pairs. Images are thresholded at $p < .001$ uncorrected for display purposes.

As predicted, scene word pairs elicited greater bilateral anterior (but not posterior) hippocampal activity compared with Abstract word pairs (Fig. 4A). Object word pairs also showed greater bilateral anterior (but not posterior) hippocampal activity compared with the Abstract word pairs, along with engagement of bilateral parahippocampal cortex, fusiform cortex, and ventromedial prefrontal cortex (Fig. 4B). The research reveals a strong link between the anterior hippocampus and processing words in a VPA task mediated through scene imagery.

> This offers a way to reconcile hippocampal theories with visuospatial bias with the processing and subsequent memory of verbal material. Moreover, we speculate that this could hint at a verbal system in humans piggybacking on top of an evolutionarily older visual (scene) mechanism (Corballis 2017). We believe it is likely that other common verbal tests, such as story recall and list learning, which are typically highly imageable, may similarly engage scene imagery and the anterior hippocampus (Clark et al. 2018, 1839).

In resume, this study by Clark and colleagues corroborates that the anterior hippocampus is engaged while processing both scene and object word pairs compared to pairs, despite binding occurring in all conditions. Hence, my strategy is to retrieve from both stories, e.g., scene words such as Earth, beach, waves, wind, weather, cloud, creek, town, village; object and nonhuman words like cockleshell, raven, canoe, paddle, house, hook, bow, arrow, cormorant; goose, wren, blue jay, woodpecker, halibut, feather. Finally, the chronological order of phrases unfolding the narrative events is emphasized.

3.4 The story: *The Raven discovered many people inside a cockle*

At that time, the Raven travelled all over the earth, and one day, he found a cockle that was being thrown about by the waves. He heard a noise inside the shell. He went near to see what it was. He hid nearby and discovered many children in the cockleshell. Then he made towns. One of these he called Yaku lanas, another Kuna lanas, and he gave all the families of the Haidas their names. On the beach, he made a town, Tas lanas, and in the woods, he made one, which he called Sleng lanas ("the rear part of the house").[1]

Note by Swanton:

1. See "Story of the Food-giving-town people" and notes (321). They said to have been so named because they occupied the rear row of the five in this town. They are reputed to have

> occupied a similar position in the old town at Rose Spit and are more plausibly connected with that place. They settled later on Masset Inlet, although a branch moved to the west coast of Graham Island (84).

3.5 Visual Scene Imagery: Enaction, Retrieval, Correlation

Haida cosmogonic ideology holds that their origins occurred in the mythical past at Nee Kun, the northeastern seashore of Xaayda Gwaay. The Raven and a clam for the transition of proto-humans from the Pacific Ocean to the land are key visual imagery scenes of this story. According to John R. Swanton (1905b), Franz Boas, in 1897, at Port Essington, obtained this story from Charles Edenshaw, chief of the Sta'stas at Masset, British Columbia. The memory site at present is called Rose Spit, Coordinates: 54° 9′ 15″ N, 131° 39′ 37″ W.

Since ancestral times, the human experience of the world has been comprised of scenes that are perceived between the interruptions of eye blinks and saccades. Saccades are rapid eye movements that bring targets of interest into a person's field of view (Richmond et al., 2021).[1] It is shown that scene mental imagery dominates when people engage in critical cognitive functions such as recalling the past, imagining the future, and spatial navigation (Monk et al. 2020; Clark et al. 2020). The retrieval of long-episodic memories, e.g., cosmologic stories, could be characterized by a synchronized neural activity between the hippocampus and ventromedial prefrontal cortex (vmPFC). The mental generation of novel scene imagery is crucial to episodic memory processing (Barry et al. 2019). A scene is a naturalistic three-dimensional (3D) spatially coherent representation of the world typically populated by objects and viewed from an egocentric perspective (Dalton et al. 2018; Mullally and Maguire 2013). For instance, in sections of these two cosmologic stories, the scene imagery calls to attention specific space-defining object attributes, which have a privileged role in scene imagery construction by the hippocampus.

The Northern Raven (Corvus corax)

Modern birds such as ravens have filled a range of ecological niches with a great evolutionary success since the Jurassic period (Brusatte et al. 2015).

> Birds evolved from theropod dinosaurs during the Jurassic (around 165 – 150 million years ago) and their classic small, lightweight, feathered, and winged body plan was pieced together gradually over tens of millions of years of evolution rather than in one burst of innovation. Early birds diversified throughout the Jurassic and Cretaceous, becoming capable fliers with supercharged growth rates, but were decimated at the end-Cretaceous extinction alongside their close dinosaurian relatives (1).

For Brusatte and colleagues, the origin of birds is one of the best-understood major transitions in the history of life. It has emerged as a model case for using a combination of data from fossils, living species, genealogies, and numerical analyses to study how entirely new body plans and behaviours originate, and how prominent living groups achieved their diversity over hundreds of millions of years of evolution (Brusatte et al. 2014; Xu et al. 2014).

For the last 1.5 million years, the common raven (*Corvus corax)* has lived across the Northern Hemisphere is the most widely distributed of all corvids. Across its range in the Northern Hemisphere and throughout human history, the common raven has been a powerful symbol in culture and mythology. For example, the Haida, Tlingit, and Tsimishian of Canada's northwest coast have Raven moieties. In these cultures, Raven is both a trickster and a creator. Related beliefs are widespread among the peoples of Siberia and northeastern Asia. For instance, the Kamchatka Peninsula of the Russian Far East was created by the raven god Kutkh (Worth 1961; Jochelson 1908; Bogoras 1906). It is important to note that I selected the story "The Raven

Discovered Many People Inside a Cockle" by the Haidas because it relates to a natural process of evolution. In this sense, the scene imagery can be correlated with recent studies on the cellular evolution of life from the Earth's early ocean.

The Butter Clam (Saxidomus gigantea)

The Butter Clam (*Saxidomus gigantea*) is a recurrent image in Haida cosmology. The relationship between clams and humans has been embedded in the West Coast First Nations culture for 11,500 years (Toniello et al. 2019). Archaeological studies of the Northwest Coast offers new insights into the late Pleistocene peopling of postglacial environments and the purposeful transformation of the intertidal zone during the late Holocene to enhance and manage shellfish and fish populations. According to Fisheries and Ocean Canada (2018), this marine bivalve mollusk in the family Veneridae, the Venus clam, is found from the Aleutian Islands to northern California and is common throughout British Columbia wherever suitable conditions occur. They live in various soil types, from pure sand to pure gravel, but the typical substrate is a porous mixture of sand, broken shells, and small gravel. They occur in the lower third of the tidal zone but are also found to a depth of 30 ft below the zero tidal level. Clams are filter feeders, and some species might filter as much as 200 litres of salt water in a day; they filter out and consume substantial amounts of phytoplankton, bacteria, and other particles, thereby enormously contributing to maintaining water quality. This role has been present in bivalves since the Cambrian Period (541 (+/- 1) million years ago - 485.4 (+/- 1.9) million years ago) and provides important regulating services. Bivalve reefs can protect shorelines from storm surges or waves and can help stabilize land. Adding structure to what might otherwise be bare mudflats increases an area's habitat complexity, potentially making it more inviting to juvenile fish in search of refuge from predators or as a haven for other intertidal

invertebrates. A paleobiologist study by Fraiser and Bottjer (2007) suggests that before the worst mass extinction of life in Earth's history—252 million years ago—ocean life was
Diverse and clam-like organisms called brachiopods dominated. After the calamity, a clam-like organism called a bivalve took over when little else existed. Therefore, a clam is a niche for proto-human transition to the land, and being helped by Raven is crucial because species' biotic interactions are a fundamental driver of evolutionary change.

Children in a cockleshell emerging from the ocean

The plot involves protohumans emerging inside a clam or vessel from the aquatic to terrestrial transition. This reference prompted me to travel back in time to explore the correlations between this story, the formation of Earth in the first part of its history, and the emergence of cellular life in deep-sea alkaline hydrothermal vents.

A crucial evolutionary change in some vertebrates, such as fish, was in the Palaeozoic Era (Devonian period 419.2–358.9 million years ago) water-to-land transition, which allowed them key morphological and physiological modifications including limbs and the acquisition of lungs (Cupello et al. 2022). The discovery of these vents (1977) immediately impacted the hypotheses about life's origin because the vent system is a chemically reactive environment and is suitable conditions for sustaining prebiotic synthesis. In this regard, Michael Russell (2021) argued that life could have emerged in alkaline vents, with iron sulphide membranes being the earliest stage in the evolution toward reproducing cells.

Earth is ~ 4.6 Gya, and the first ocean condensed by ~ 4.4 Gya. By 4.3 to 4.2 Gya. Life required a source of energy for driving the emergence of metabolism, and water became essential to origins because it is both the solvent of all molecules of life (proteins, carbohydrates, lipids, and nucleic acids) and the most common reactant in microbial metabolic

networks (do Nascimento Viera, et al. 2020). Also, early life is identified and characterized by its metabolic interaction with Earth's chemical environment. The characterization of pre-3700 Mya life must thus be based on identifying and interpreting biogenic elements and isotope fractionations preserved in the rock record (Rosing and Frei 2004). As such, one of life's most important activities is the oxidation of the environment associated with sequestering organic material. The advent of this metabolic strategy marked the beginning of global atmospheric management by life and the determinant influence of life on Earth's climate. According to Rosing and Frei, this node on the tree of life is thus one of the most important geological events.

Metabolic origin may have started from the acetyl-CoA pathway of CO_2 fixation (Fuchs 2011) because it is a linear and exergonic process (Berg et al. 2010) that occurs in both archaea and bacteria (Fuchs 2011) and traces to the last universal common ancestor (LUCA) (Weiss et al. 2018, 2016). How metabolism arose is key to understanding how unicellular organisms such as the first microbes arose from the elements. In this sense, many studies concur that life arose at approximately 4.25 Gya in chemosynthetic ecosystems in deep-sea alkaline hydrothermal vents, and protocell membranes (Lane 2022; Jordan et al. 2019; Lane and Martin 2012) played a fundamental nexus between the cell and the Hadean Ocean ~ 4 Gya.[2] According to these studies life might originated by the continual growth of a self-referencing gelatinous iron sulphide membrane as a natural, evolving automaton.[3] By revisiting this idea, Martin and Russel (2003) suggest that all life is organized as cells. "Physical compartmentation from the environment and self-organization of self-contained redox reactions are the most conserved attributes of living things. Hence, inorganic matter with such attributes would be life's most likely forebear" (59). Life evolved in structured iron monosulphide precipitates in a seepage site hydrothermal mound at a redox, pH and temperature gradient between sulphide-rich hydrothermal fluid and iron (II)

contain waters on the Hadean ocean floor. In these environments, the individual biochemical reactions underpinning the synthesis of amino acids, nucleotides and cofactors in modern cells trace back to the Last Universal Common Ancestor LUCA because of their universality (Wimmer et al. 2021). The LUCA exergonic nature allows coupling of H_2-dependent CO_2 reduction to ion pumping and ATP synthesis, as in acetogens (Schuchmann and Müller 2014) and methanogens (Thauer et al. 2008), strict anaerobes that obtain both their carbon and energy from the reduction of CO_2 with H_2. In the continuity of this reaction, the first cells to emerge from the vent system have a carbon and energy metabolism that is based on the exergonic reaction of H_2 and CO_2, in which the cells synthesize acetate (acetogenic bacteria) or methane (methanogenic archaea) (Martin W. 2020; Branscomb and Russell 2018) as the main product of energy metabolism. As said, the first free-living cells were acetogens and methanogens, the starting point from which further physiological evolution took place.

Raven made towns and named them Yaku lanas and Kuna lanas

The house as a niche is one of the main contributions that the Raven made to the life of the Haida after he stole the concept from the Beaver. To Bill Reid (1978) Ttsaang - Haida Beaver, "In Haida Mythology, Beaver is one of Raven's adoptive uncles, from whom he stole the house itself and all its surroundings - the lake, the stream, all fish that swam in them, the fish trap, and so on, He is a symbol of prodigious renewable wealth" (Bill Reid Gallery). Niche construction describes how organisms can form their environments, increasing their capacity to adapt to their surroundings (Odling-Smee et al. 2003). Examples of niche construction include building nests, burrows, and mounds, alternating physical and chemical conditions by animals, creating shade, influencing wind speed, and alternating nutrient cycling by plants.

Since ancestral times, the Haida were divided into two social groups or moieties, Raven and Eagle**.** The Raven moiety was subdivided into twenty-two lineages, or families, and the Eagle moiety into twenty-three. Even supernatural beings belong to one or the other moiety.

Marriages had to take place between Eagles and Ravens rather than those who belonged to the same moiety, and children became members of the same moiety as their mother. Furthermore, Boelscher (1988) states,

> The Haida divide themselves into a number of matrilineal corporate groups sharing territory, resources, and symbolic property. Indigenous terms for local divisions, however, often transcend the lineage boundaries and designate people according to the geographic area of the islands their ancestors occupied, hence grouping together people of unrelated kin groups (17).

The Haida designate themselves locally according to their ancestral niches, constructed and named by Raven and consisting of a few to three dozen houses. The house was the centre of Haida's social, political, and economic life. It was constructed of western red cedar with a framework of stout corner posts that supported massive beams. The frame was clad with wide planks. Moreover, according to MacDonald (1983), the Kunghit Raven families in Ninstints occupied almost the same number of houses as the Eagles. Of the seventeen houses, "they included the Striped Town People; the Sand Town People; and the family which ruled Ninstints at the time of first contact with Europeans, those born at Born at Song of Victory Town" (8). It is important to note that these seventeen houses had their proper names, e.g. house number 17 was the Raven House. Here, the "niche" is construed as the set of natural selection pressures to which the population is exposed.

In recent years, Odling-Smee and colleagues (2013) have described some of the ecological and evolutionary impacts on ecosystems of niche construction and illustrated how it triggers environmental and evolutionary feedback, leaving detectable ecological signatures that can be investigated. For instance, mathematical models reveal that niche construction due to

human cultural processes can be as potent as niche construction that has evolved through biological evolution and establish that cultural niche construction can modify the selection of human genes and drive evolutionary events (Laland et al. 2016; Creanza and Feldman 2014). In human evolution, the most potent contributions to human ecological inheritance have probably occurred through cultural inheritance. If so, that requires the investigation of human evolution in the context of a theory of gene-culture coevolution that explicitly includes cultural niche construction. In terms of long-term gene-culture coevolution, a recent study by Waring and Wood (2021) suggests that the role of culture in human evolution constitutes a second system of adaptive inheritance. Composed of socially transmitted information, including language, beliefs, norms, institutions and technology, culture dramatically impacts how people survive and adapt to a given environment (Richerson and Boyd 2005). As Waring and Wood state, "Cultural inheritance may hold greater adaptive potential than genetic inheritance due to its mechanistic differences" (2). Thus, the primary explanation for the emergence of the human cultural inheritance system is that it provides a more flexible and rapid system of behavioural evolution than genetics alone allows.

Raven gave all the families of the Haidas their names

Among the Haida, names express the social and political order and link the social order to both the supernatural and the material world. The act of naming provides a link between symbols and material property. According to Boelscher, names also mediate on various levels:

(a) Temporally, they link the past generations with the present and future generations. They classify a person as an individual by having them carry the name synchronically but diachronically being one of a series of holders of this name.

(b) Spatially, they link a name to a lineage and thus to a place owned by that lineage. This link is expressed through the oral history of the name origin, which maps out the relations between the ancestor who first bore the name, his and other lineages, and the territory they occupied.

(c) Cosmologically, names mediate between the supernatural and the social world. Many names are thought to have originated in supernatural experience and then are conveyed for social purposes and the social-political context, reinforcing the constant flux between information from the supernatural world and social-political activity (152).

As stated by Boelscher, Haida names are carried by individuals of different statuses and are subject to renegotiation of meaning. A Haida does not simply bear a name but, during his lifetime, accumulates numerous names, some of which are more adequately described as titles. As names deal with symbols, property, and autobiographical referents, Pacific Northwest oral tradition is a system of symbols, and that underlying culture is a complex interplay of inseparable elements of language, thought, and reality (Thom 2003).

Symbols, such as concrete words (nouns or verbs referring to concrete objects and actions) and numbers, are represented in the brain as physical entities. Their crucial property is that "despite the simplicity of their surface forms, they have the power of evoking higher order multifaceted representations implemented in distributed neural networks spanning a large portion of the cortex" (Borghesani and Piazza 2017, 4). For Borghesani and Piazza, this internal state reflects our knowledge of the meaning of symbols and is called semantic representations. The question is, what are the neural substrates of semantic representations? Endel Tulving (1972) proposed a distinction between semantic and episodic memory. According to a recent study by Duff and colleagues (2020), Tulving stated that episodic memory referred to knowledge "about

temporally dated episodes or events, temporal-spatial relations among events" and noted that such memory is stored "in terms of autobiographical reference to the already existing contents of episodic memory store" (Tulving 1972, 385), Semantic memory was defined as the "memory necessary for the use of language. It is a mental thesaurus, a person's organized knowledge about words and other verbal symbols, meaning and referents, relations among them, and the rules, formulas, and algorithms for manipulating these symbols, concepts, and relations" (386). Tulving offered this distinction as something of a thought experiment, which he proposed might have utility in understanding and accounting for the broad range of memory phenomena and experimental findings of the time. Recent findings have been directed to understand their shared dependence on the hippocampus. Indeed, it is acknowledged that these two forms of memory interact during encoding and retrieval. The study by Duff and colleagues (2020) argues that "like episodic memory, semantic memory is a highly flexible, (re)constructive, relational, and multimodal knowledge system…and also depends critically on the hippocampus" (12). Overall, episodic and semantic interactions, interdependencies, and shared mechanisms advance our understanding of how words, concepts, and meaning, as well as episodes and events, are integrated, instantiated, and maintained in memory.

Raven made on the beach the town Tas lanas and in the woods Sleng lanas

The towns Yaku lanas, Yaku lanas, Tas lanas, and Sleng lanas belong to the lineage of the Gawa Xaadee and were recognized by the elders in 1980 (table 1).

Table 1: Lineage of the Gawa Xaadee, 1980.

Name	Meaning	No. According to Swanton
RAVENS		

Yaaku 7laanas	Middle town people	R 19
(a) Gawa Yaaku 7l	Masset-Inlet Middle town people	R 19a
(b) Yahl naas Yaaku 7l	Raven House Middle town people	R 19e
(c) Daadans Yaaku 7lanas	Dadens Middle town people	R 19
Kun 7lanas	Point-town-people	R 14
Stl'ang 7lanas	Rear-town-people	R 15
(a) Dou Stl'ang 7lanas	West Coast Rear-town-people	R 15d
Skidaakaaw	Eggs of Skidao	R 16
Kyanuusilee	[tom]-Cod people	R 17
Taas 7lanas	Sand-town-people	R 20
EAGLES		
Git7ans		E 13
Tsiits Git7ans	Git7ans of Tsiits	E 17
S7ajuugahl 7lanas	Crown people	E 14
Sdast'aas	Salmon eggs beginning to hatch	E 21
(a) Sdast'aas proper		E 21
(b) K'aawas	Herring eggs	E 21a
Ts'aa. ahl 7laanas	People of Ts'aa.ahl	E 23

Table 1. Boelscher, Marianne 1988, p. 34. Gawa Xaadee is commonly used to refer to all those amalgamated at Masset at the entrance of Masset Inlet from the entire northern portion of Graham Island, whereas Skidegate Xaadee designates those now living at Skidegate on the south of Graham Island.

In the early 1900s, Swanton (1905a) enumerated twenty-two Raven and twenty-three Eagle lineages, most of which had numerous localized branches. Of these lineages, six Raven and five Eagle lineages comprise those whose members now live in Masset. According to Boelscher, since the late-nineteenth-century population decline, many of the lineages, having become reduced in size, have re-amalgamated or nucleated, and others have become extinct. Also, in the early 1700s, some Haida migrated to Alaska, where they called themselves *Kaigini.*

The story "The Raven discovered many people inside a Cockle" and its correlation signals landmark-based allocentric spatial memory and cognition. The ability to encode and retrieve spatial relationships among elements of the environment signals the role of episodic memory and its support for adaptive behaviour. This idea is supported by neurophysiological data suggesting that spatial signals are prevalent within the hippocampal system concerning the external world. Place cell activity in area C1 of the hippocampus suggested that spatial representations are not centered on the self but are rather allocentric. Also, CA1 pyramidal neurons represent other information, such as objects, time, and events.

Moreover, recent research examining the circuit dynamics and synaptic plasticity suggests that the temporal relationships of inputs from entorhinal cortex layer III and CA3 could be critical for generating spatially tuned CA1 activity. On this basis, (I) highlight the hippocampus's representation of space and landmarks, essential for navigation and memory. In this story, the visual scene imagery of the embedded hippocampal cognitive map includes experience-dependent information on learning and cognitive activities within the ancestral triadic niche (ecological, neural, cognitive) construction. For example, the scene imagery calls to attention specific space-defining object attributes, which have a privileged role in the retrieval of long-term episodic memory and navigation characterized by synchronized neural activity of the

hippocampus/entorhinal cortex system. In practical terms, the scene imagery and its verbal paired associated material enabled me to correlate information across different fields of knowledge, such as Haida mytho-logic and socio-logic (Boelscher 1988), the cellular origin of life, the niche construction, and the neurophysiological basis of memory and consciousness.

3.6 Sing 7agang qiidaraagan—How Shining-Heavens caused himself to be born

In November 1900, this story was dictated at Skidegate by storyteller Ghandl or Walter McGregor, qay7ahl ‘laanaas Eagle lineage of qays7un (Kaisun), 49 years old at that time, and blinded by smallpox in his youth; to linguist John R. Swanton (1873-1958) assisted by Henry Moody, the principal interpreter. Swanton collected Haida texts and ethnographic and linguistic information in the Queen Charlotte Islands from September 1900 to August 1901 as part of the Jesup North Pacific Expedition (1897-1902) led by anthropologist Franz Boas (1858-1942). Swanton wrote in the end note of this story,

> This is one of the most important of all Haida stories, telling as it does of the incarnation of the sky god, the highest deity anciently recognized by them. Siñ, the name by which he is known, is the ordinary word for day as distinguished from night and from an entire period of twenty-four hours, which also is called “night,” but it seems to be more strictly applied to the sky above as it is illuminated by sunshine. Hence, I have chosen to translate the word “Shinning-heavens.” A similar conception is found among the Tsimshian of the neighbouring mainland, where the sky god is known as Laxha’. It would be interesting to learn whether it also obtains among the related Tlingit of Alaska (30).

On the above basis, three key ideas characterize this story: (1) its narrative digresses from

the miraculous conception of a child by the intervention of a deity; (2) the culture and myth reflect each other through the narrative plot; (3) the incarnation of the Spirit of Heavens in a clamshell is a call to explore the interplanetary transfer of life.

Spirit of Heavens was recovered from his clam vessel by an abandoned young maiden who became his mother. Curtis (1916) said her name was Tullájat (Orderly Woman). For the Haida, cosmologic stories are treated as material property and cultural inheritance. Boelscher (1988) suggests, "In mythical ideology, power obtained through contact with supernatural beings can be transformed into symbolic and material property, which in turn translates into social status" (167). Following Boelscher's logic on Haida mythology analysis, it must be perceived in "the context and meaning of a specific cultural idiom" (168). This idiom is conceptually and instrumentally connected to Haida's social relations with the supernatural and nature. The discourse about nature and its power in relationship to humans are stories called k'eiganaa, which are not restricted in time and express the supernatural interconnection with reality. This knowledge is preserved and passed down for thousands of years in oral histories, called k'aaygang. nga or long-ago ancient stories (Boelscher 1988). Hereon, *Haida Texts and Myths: Skidegate Dialect* by Swanton (1905b) takes on a novel plane of composition since it is recognized as the most important ethnographic and textual material. In addition, *Skidegate Haida Myth and Histories, collected by John R. Swanton* and edited and translated by Enrico (1995), add notes if necessary to clarify geographical features, phrase meanings, and paragraph indenting.

3.6.1 The Story

They say she was a chief's daughter at Dju.[1] Her father enslaved a person he owned to watch her. Then she said to the slave: "Tell a certain one that I say I am in love with him." And, when she

went out with him to defecate next day, she asked the slave if he had told him. And he said to the chief's daughter: "He said he is afraid of your father." He had not told him, and he lied.

She told the slave to tell another that she was in love with him, and again he did not tell him. He told her he feared her father. When she was unable to get any of her father's ten nephews she went with the slave. And her father discovered it.

Then they abandoned her. Only the wife of her youngest uncle left some food for her, they say.

She went down on the beach to dig for clams. After she had worked for some time, she dug out a cockle shell. In it a baby cried. Then she looked at it. A small child was in it. Then she took it to the house. She put something soft around it, and, although she did not nurse it,[2] it grew fast. Soon it began to creep.[3] Not a long time after that it walked about.

One time the child said: "Here, mother, like this." He moved his hand as if drawing a bowstring. Then she hammered out a copper bracelet she wore into a bow for him, and another she hammered into arrows. When she finished (the bow) she gave it to him along with the two arrows. He was pleased with them.

Then he went out to hunt birds. When he came back, he brought his mother a cormorant. His mother ate it. The day after he went hunting again. He brought in a goose to his mother. His mother ate it. And next day he again went hunting. He brought in a wren. Then he skinned it. He dried (the skin). He treasured it.[4] And next day also he brought in a K!u'tc!ix.u.[5] That, too, he skinned. That too, he dried. And the next day he brought a blue jay. He skinned and dried that also. The day after that he brought in a woodpecker. That he also skinned. That he also dried.

One time someone was talking to his mother (During the night). The house creaked moreover. And when day broke, he awoke in a fine house. The carvings on the house posts

winked with their eyes (they were so fine).[6] Master Carpenter let himself become his father. He got up and said to him: "Come, chief, my child, let me dress you up." Then he went to him and put fair-weather clouds[7] upon his face. "Now, chief, my son, come and sit idle seaward." As soon as he did so, the weather was good.

One time he asked to go fishing with his father. "We will pull out Devilfish-fished-for." And on their way to fish they pulled it out.[8] Then they stopped at House-fishing-ground.[9] He seated his father in the bow. After he had looked at the rising sun for a while he said: "Now, father, say 'The chief among them thinks he will take it.'" This his father said. "Say 'The one who comes around the island thinks he will take it,' father." And he said so. "Father, say 'The shadow increases upon Tc!i'nla-i;[10] hasten, chief.'" And so, he said. "Father, say 'The great one coming up against the current begins thinking of it.'" So, he said. "Father, say "The great one coming putting gravel in his mouth thinks of it.'" So, he said. And again, "Father, say 'Great eater begins thinking of it.'" So, he said.[11]

After he had finished saying these things it seized the hook. At once it pulled him round this island. He struck the edges of the canoe with his hands. He said to it: "Master Carpenter made you. Hold yourself up."[12] The thing that pulled him about in the fishing ground again pulled him round the island.

And when it stopped, he tried to pull in the lines. He pulled out something wonderful, headfirst. Broad seaweeds grew upon its lips.[13] It lay with halibut nests piled together (around it).[14] He began to put the halibut into the canoe. When the canoe was full, he pulled the canoe out to make it larger (the gunwales). After he had put them in for a while longer his canoe was full, and he released it.

Then they went away. He brought halibut to his wife. She dried them. Then he again

called for his son, and when he had finished painting him up, he said to him: “Now, chief, my son, go over there and see your uncles.” So, he started thither. He came and sat down at the end of the town. After he had sat there for a while, they discovered him. They came running to him. They found out who he was. And they again moved over to where his mother lived.

After they have lived there for a while, he went out wearing his wren skin. He said: “Mother, look at me!” Then his mother went out after him. He sat as broad, high, cumulus clouds over the ocean.[15] His mother looked. Then he came in and asked his mother: “Did I look well?” “Yes, chief, my son, you looked well.” Then he also took the blue-jay skin, and he said to his mother: “Look at me.” Then she went out after him. Her son sat blue, broad, and high over the sea.[16] Then he came in and said: “Mother, did I look well?” “Yes, chief, my son, you looked well.” And he also went out with the woodpecker and said: “Mother, look at me.” Then she went out after him. He sat over the sea, the upper part of him being red.[17] She smiled at her son, and when he came in, he said: “Mother, did I look well?” “Yes, chief, my son, the supernatural beings will not tire of looking at you.”[18]

Then he said: “Mother, I shall see you no more. I am going away from you. When I sit in front of Q!anA’ñ[19] in the morning, there will be no breeze. No one can touch me.[20] When the sky looks like my face as my father painted it there will be no wind. In me (i.e., in my days) people will get their food.”[21] “Now, chief, my son, when you sit there in the morning I will send out feathers for you.”[22]

Then he started off from his mother. His father also went off from her and said: “I also am going away from you. Settle yourself at the head of the creek.[23] I shall see you sometimes and I shall also see my son.” Then he, too, went off.

And in the evening, she called for her youngest uncle. She said to him: “When you go

fishing tomorrow wear a new hat and have a new paddle." And early next day they went fishing. Then she sat down at the end of the town with her knees together. And when she pulled up her dress the wind blew out of the inlet. Every time she raised it higher more wind came. When she had raised it to a level with her knees a very strong wind blew.[24] And she stretched her arm to the thread of life [25] of him only who wore the new hat, and she saved him, because his wife left something for her. That was Fine-weather woman,[26] they say.

Then she took her mat and property and started into the woods up the bed of the creek. And she fixed herself there. And a trail ran over her. She said that they tickled her by walking upon it, and she moved farther up. There she settled for good. When her son sits (over the ocean) in the morning, she lets small flakes of snow fall for (him). Those are the feathers.[27]

haw tlaan 'll riida - That is all.

Notes by Swanton and Enrico:

1. A stream flowing into the Pacific about $1^1/_2$ miles east of Kaisun.
2. According to Enrico's (1995) new translation, She did not suckle him, he grew fast (109).
3. Enrico, Very soon he began to crawl around. (109).
4. In Enrico's translation, this phrase means He thought highly of it (111).
5. I have not identified this bird with certainty, although the name is very much like that given me for the red-winged blackbird (Agelaius phoeniceus Linn). According to Enrico, the bird is a song sparrow.
6. A common expression to indicate the excellence of carvings.
7. Yen xagi't are long, narrow clouds, probably stratus, said to indicate that there will be fair weather the next day. According to Enrico's translation, Master Artisan put Kilsdlaay cirrus clouds on his face (which appear during fine weather).
8. Devilfish were usually employed to bait the hooks of halibut. To catch a halibut of supernatural character, they secure a devilfish of the same kind. Enrico's new translation states, "We will pull out Octopus-they-went-to-fish-for." (he said.) On the way he pulled him out. A supernatural octopus. Octopus is the usual bait for halibut.
9. The halibut fishing grounds were all named and were owned by specific families.
10. ts'inhlaay, The mountain just north of Louscoone Point (Enrico 1995, 111).
11. The incantations are uttered to induce the halibut to take the hook. In Enrico's translation, this paragraph is as follows: Kilsdlaay sat in the bow of his father's canoe. After the boy had watched the sun move for a while, he said, "Now, Father, "The chief amongst them is setting on the bait," say that." So, his father said it. "The one who has gone around the island is settling on it." say that, Father." And he said that. "The shadow is long now on ts'inhlaay,

chief! Hurry!" say that, Father." So, he said it. "Big shot coming out of the mouth of Juu is settling on it!" say that, Father." He said it. "Big shot going along swallowing pebbles is settling on it!" say that, Father." He said it. And "You are looking at it with the quartz pebbles you use for eyes!" say that, Father." "Big shot going around gobbling things is settling on it!" says Father." And he said it. As Enrico points out, At least formerly, Haida halibut fishermen used to exhort the halibut with similar incantation (111).

12. Enrico suggests, literally, 'Keep your head up by paddling with your hands (as if swimming)' (113).
13. In Enrico's translation, Its lips were covered with kelp fronds! (Macrocystis).
14. In another story, this creature is called Mother-of-halibut.
15. These various clouds are represented as Shinning-heavens with his different bird blankets on. Clouds are more
    often thought of as clothing of The-one-in-the-sea. Enrico's translation: She saw that he was a cumulus cloud rising out at the sea.
16. Enrico's translation, Her son rose blue and soft out at sea (113).
17. Enrico's translation, He sat on the sea red from the waist up (113).
18. According to Enrico, Swanton commented that clouds were more often thought of as the clothing of tanrwaan 'laana "The one out at sea," than that of sing 7ang qiidayaa (113).
19. An inlet or river. My interpreter suggested that it might be Qano'. It is an inlet north of Kaisun, but the name that occurs here is quite common. A river of this name flows into the sea near Frederick Island. According to Enrico, If I sit at the mouth of q'aanang in the morning, there will be no wind from any direction. q'aanang is Haines Creek on the west coast of Graham Island.
20. The word used here is also applied to the sons of chiefs who cannot be touched without bringing trouble upon the aggressor.
21. When Shinning-Heavens presides, or, in other words, when these clouds are seen, it will be calm at sea.
22. Enrico's translation: "Go ahead, dear Kilsdlaay, if you are sitting (there) in the morning, I will send you out bird down to fall upon you" (115).
23. According to Enrico, Make your place at the head of the river (juu randlaay).
24. Enrico suggests that the wind began to blow seaward when she pulled up her dress. As she raised it higher, the wind increased. When she pulled it up to her knees, the canoe capsized. The verb "capsize" here is singular, but above, it is said that more than one canoe went out.
25. Compare the story of "The one abandoned for eating the flipper of a hair seal," note 17., The word used here is wa'nwai, one of doubtful meaning. In note 17, Swanton states: Every animal and every human being is supposed to be provided with a "thread of life," an idea not found elsewhere in America so far, I am aware. Lïs, the word used here, is also applied to threads of mountain sheep wool. Another name, wa'nwai, is given in the story of How Shining-Heaven caused himself to be born (189). According to Enrico's translation, Then she seized only the thread of life of the person whose hat was new and saved him, they say, because his wife had left food for her (115).
26. Lla-djat, "Fine-weather-woman," is often referred to in the stories. One of the winds, the northeast wind, was named after her, and by the West Coast people, she seems to have been identified with the Creek woman at the head of Dju. According to Enrico's translation and notes, They say she (the mother of sing 7ang qiidayaa was tll 'laa jaad. "Northeast Wind Woman" tll 'laa being the northeast wind at qays7un) and Creek Woman of juu; see Swanton

(1905b: 24-25) for more. According to Curtis (1916), another name for this woman was sraana jaad gidaa qaatl'lwaraa 'Killerwhale Woman and Chief's Daughter Who Comes Down to the Water.'

27. Enrico's translation: When her son sits there in the morning, she always sends fine snowflakes to fall on him. That was the bird down.

3.6.2 The Visual Scene Imagery: Enactment and Correlations

Creativity requires the rapid combination and recombination of existing mental representations to create new ways of thinking and to generate novel ideas. According to Duff and Brown-Schmidt (2017),

> Hippocampal declarative memory, in its capacity for creating, updating, and in the juxtaposition of mental representations as well as their flexible and novel use, has been linked to creativity and creative thinking (Warren et al. 2016; Madore et al. 2015; Madore and Schacter 2014; Duff et al. 2013) (514).

The hippocampal declarative memory system directly supports discursive creativity and flexibility across communication partners and discourse contexts (Duff and Brown-Schmidt 2012). Declarative memory refers to memories that can be brought into conscious awareness and described and assessed verbally. It includes memories of past events (episodic) and facts (semantic memory) (Rutishauser 2019). Declarative memory, creative thinking, which is embedded in Haida oral memory calls to enact knowledge on the primacy of the performativity tradition between the storyteller(s), the listener(s) and the character(s), e.g., Raven, Tullájat (the chief's daughter), Master Artisan, sing 7ang qiidayaas (Spirit of the Atmosphere) of the cosmological past and present of Haida tradition. For instance, poet Gary Snyder (2007), in his comparative study of the Haida story "He Who Hunted Birds in His Father's Village" told by Ghandl in Haida and phonetically transcribed by Swanton (1900), describes the performativity setting:

> In the dark room, around the fire, children and old people, hearing and joying together in words, the acting and images. It is there that the shiver of awe and delight occurs, not in any dry analysis of archetypes or motifs–or the abstraction of the structuralist (xix).

Acting and images illuminated my desire to construct a virtual performative setting within EDA. Ute Berns (2009) suggests that narrative performance can actualize performativity.

> In its paradigmatic sense, this performance of a narrative denotes some concrete realization of the narrative in an actual, embodied and contingent process at a specific place and time. It prototypically demands the corporeal co-presence of actor(s)/presenter(s) and an audience/witnesses who co-construct the performance (McAuley, 2007). Though this concept of performance seems to derive from the meaning of 'to perform' in the performing arts, these minimal criteria also hold for conversational storytelling and cultural performances (98).

Performance may present the narrative directly or as mediated by a presenter or teller. In a nutshell, (my) body enacts a creativity-related cognitive process and its supporting neural substrates. (I) may suggest that Haida oral memory performance correlates to hippocampal functions for the (re)activation of episodic memory. Then, the retrieval of the visual scene images as neuroarchaeological material should extend the cognitive process in time and space due to memory structural plasticity. As Buzsáki (2010) states, cell assemblies are best understood in light of their output product, as detected by ''reader-actuator'' mechanisms.

They say the chief's daughter at Dju was abandoned because she slept with her slave. The wife of her youngest uncle left food for her.

The ecological niche is Dju, about $1^{1}/_{2}$ miles east of Kaisun. Kaisun is situated on the northwest

coast of Moresby Island. Moresby Island and the islands incorporated in the Moresby Archipelago have several ancient and uninhabited Haida Village sites: Kaisun (northwest coast), Cumshewa (Cumshewa Inlet), New Clew and Skedans (Louise Island), Tanu (Tanu Island), and Ninstints (Anthony Island). Cha'atl village is located on Cha'atl Island in Skidegate Channel, between Graham and Moresby Islands. In Swanton's (1905a) geographical map after Charles F. Newcombe (1851- 1924), the town is Qai'sun lnäga'-i (in old days). Family: Q! as lä'nas R 12 (Swanton 1905, 280). In Swanton's *Skidegate Haida Myths and Histories,* translated by John Enrico (1995), in his footnote, the location is Juu, "a creek near Kaisun, a few hundred feet west of Boomchain Bay, according to Solomon Wilson (in the placename information elicited by David Ellis)" (109). Kaisun historical village is located on Helgesen Island.
Coordinates: 53° 2′ 0″ N, 132° 27′ 0″ W.

They say

The storyteller starts performing an event. A recall to autonoetic consciousness (first person report), identified with episodic memory, gives rise to remembering in the sense of self-recollection in the mental re-enactment of previous events. In the brain, the hippocampus is required to represent spatial and coherent scenes or events. For an event to qualify as an episodic memory, details of the event and of the place in which it occurred must be present at retrieval, accompanied by autonoetic consciousness that enables one to travel back in time and subjectively relive an event or reexperience it (Zaman and Russell 2022; Gauthier et al. 2020). Moreover, in the neocortex, memories are stored across sparse and distributed neuronal ensembles of engram cells (Josselyn and Tonegawa 2020; Josselyn 2010). During memory recall, activity across these neuronal ensembles is selectively reinstated to recover enduring representations of the past. This reinstatement is thought to be mediated by the hippocampus, a

brain region important for learning and memory. A recent study by Koolschijn and colleagues (2021) about the hippocampus and neocortex activity coordination suggests that,

> In humans, a visual cue from a paired associate is accompanied by a transient increase in the ratio between glutamate and GABA in the visual cortex. Moreover, these excitatory-inhibitory fluctuations are predicted by activity in the hippocampus. These data suggest that the hippocampus gates memory recall by indexing information stored across neocortical circuits using a disinhibitory mechanism (1).

Glutamate is a major excitatory neurotransmitter in the brain and the central nervous system; this effect is due to glutamate receptors on the surface of brain cells. GABA is an amino acid that serves as the primary inhibitory neurotransmitter in the brain and a major inhibitory neurotransmitter in the spinal cord. It reduces the ability of neurons to send and receive chemical messages. According to Koolschijn and colleagues, memories are silent by balancing excitatory and inhibitory activity in the neocortex. “This is to prevent them from being disrupted by incoming information” (2). This study reveals that activity in the hippocampus and the visual neocortex increases when the visual cues are recalled. This said, the hippocampus reactivates memories stored in the neocortex by temporarily increasing excitatory activity to release memories from inhibitory control.

The chief

Traditionally, the elementary units of the Haida social organization are the two moieties, Ravens (yahl) and Eagles (goud), with membership being reckoned matrilineally and obtained at birth. As Curtis (1916) states, “the town chief was called laná-óka (People’s mother), a title which in a people who observed matrilineal descent, indicates that women may once have occupied this

position" (119). According to Curtis, since his sister's son succeeded a man, the position of town chief always remained in the same clan and phratry. Boelscher (1988), on the social categories and group confusion, suggest that the Haida people call the moieties "clans" or "sides" and the lineages "tribes" when speaking in English. In their language, moieties are k'waalaa, and lineages are gwaay gang. "Moiety and lineage organization provide the conceptual and inter-actional framework for reciprocal exchange and the validation of social status, for kinship categories and marital alliances, and for the ownership of property" (27). Traditionally, supernatural animals inhabiting the forest, oceans and shorelines are also classified as belonging to the Eagle or Raven side. Hence, the rank of village chief, according to Boelscher, is called 7laana 7leeygaa (7laana = town; 7leeygaa = "boss," "chief") (52). In historical times, in single-lineage villages, the village chief was also a lineage chief. In multilineage villages, he was the head of the lineage owning the town.

The daughter

The daughter, after reaching the age of puberty and before her marriage, slept with an enslaved person. Curtis (1916) argues that "in those days, the daughters of high chiefs were carefully watched so that they might be able to make a good marriage" (172). Also, Swanton (1905) provides an account that at puberty,

> the girl was kept indoors behind screens for about twenty days…After the twenty days were over, the girl took a bath, and none of the water was allowed to be spilled. It was taken back into the woods. If this were not done, she would not live long. Whatever she did at that time would remain with her always. Until four years had passed, she must eat no food except black cod. The-One-in-the-Sea, who owns the black cod, was said to feed her during this time. They thought that

the other fish would become scarce if they ate them (48).

Moreover, regarding the strategies involved in social reproduction, Swanton (1905a) suggests that in Skidegate, marriages were often arranged as soon as a child was born. If a woman wanted a certain boy to marry her daughter, she might give his mother several blankets while he was still young. “A young, unmarried woman was not allowed to do much work and lay in bed a great deal of time. This was so that she might marry a chief and always have little work to do” (50). Moreover, Boelscher (1988) adds, “The only marriage prescription of aboriginal Haida society was moiety exogamy: an Eagle must marry a Raven and vice versa” (113). While moiety exogamy imposed a structure on marital alliances, as stated by Swanton and Curtis, Boelscher corroborates that the marriages themselves were arranged for individuals as members of lineages, and within the framework of lineage and moiety exogamy, cross-cousins were traditionally regarded as the preferred spouse.

Tullájat (An orderly woman) knew the rules of cross-cousins as preferred spouses. However, when she was sending messages to her ten cousins, the enslaved person lied to her, saying that they were afraid of her father. Finally, she was abandoned because she slept with the enslaved person, someone from the lowest stratum in the Haida society. Nevertheless, as an act of compassion, the wife of her young uncle left some food for her. Moreover, enslaved people or xaldangee were captives taken during raids or sometimes traded through middlemen. Enslaved people were never numerous among the Haida. According to Boelscher, “In myths and oral histories, it is common to refer to a famous chief as having owned ten slaves, ten being the mythical number of extraordinary, unsurpassable wealth, in other words, social completeness” (60). Those of the highest prestige are said to have owned ten enslaved people.

She went for clams and found a baby inside one of them. The boy grew up quickly

Haida oral tradition and knowledge have an intimate relationship with the marine environment; as reported by the Haida elders,

> Over thousands of years our histories have been carefully passed on through the generations through strict protocols in the delivery of knowledge. Through the recounting of our origins, the adventures of Raven, and of the Supernatural among us, we maintain our sense of place and identity. (Council of the Haida Nation 2004, 1)

Due to this long and unbroken history, the Haida universe is inhabited by humans and supernatural beings, collectively called the sgä'na qeda's. The supernatural were those for whom the land was first created. They inhabit the atmosphere, the ocean, the woods, lakes, and streams. As Swanton (1905a) states,

> According to Haida spirit theory, every animal was, or might be, the embodiment of a being who, at his own pleasure, could appear in the human form. They seem to be looked at from two entirely different points of view. As animals, they were called Ginaa teeiga, birds, salmon, herring, devilfish, etc.; as supernatural beings in disguise, sgaana kedaas, Forest-People, Salmon-People, Herring-People, etc.
>
> As animals, they might be hunted or given as food to man by another animal who was a supernatural being; as supernatural beings themselves, they might entertain men in their towns, intermarry with them, help or harm them…(16).

The supernatural beings are divided into Ocean-People (tsaan xaadee), who comprise all fish, sea mammals and shell-fish, headed by killer whales; and Forest-People (hlkyaans xaadee), Land-Otters, Mouse-people, Deer-people, and Frog-people. "Every kind of quadruped and bird seems to have had a human form as well as an animal disguise, and each might help or harm men" (25).

Following Boelscher's (1988) studies on Haida symbolic thinking, the concepts of nature and beyond nature are merged as different forms of the same entity.

> The Haidas' relationship with the (super)natural world is shaped by the concept of power, sgaana, which is also the term for supernatural beings, and for those thought to be the highest among them, the Killer whales. Everything in nature is seen as a potential source for power, which can be harmful or beneficial to the person encountering it (167).

The entire natural world is seen as populated by sgaana "power." As stated by Boelscher, this power is intrinsic to supernatural beings, who can confer it upon humans voluntarily or involuntarily. It includes the ability to change shape, overcome spatial and temporal boundaries, extend sensory perception, and control the forces of nature. In addition, there is a sgaana that is not associated with animals. The ultimate source of all power is sins sgaana, Power-of-the-Shinning-Heavens, a being of the upper world who gives power to all things.

The incarnation of Power-of-the-Shinning-Heavens in a clamshell inspired me to explore the theory of interplanetary propagation of life.[4] Understanding the origin of life is one of the main challenges of modern science. It is believed that some basic pre-biotic chemistry could have developed in space, likely transferring prebiotic molecules to the solar nebula and later on to Earth. The study by Martín-Doménech and colleagues (2017) points to the detection of methyl isocyanate (CH_3NCO), which is a prebiotic molecule in the solar-type protostar, IRAS 16293–2422 B situated in the constellation Ophiuchus, Serpent-bearer. Likewise, Ginsburg and colleagues (2018) present an analytic model to estimate the total number of rocky or icy objects that could be captured by planetary systems within the Milky Way Galaxy and result in panspermia should they harbour life.

> Assuming planetary systems have asteroids and comets, dynamical interactions with the black holes can eject them at extreme velocities. Thus, they may traverse the entire radius of the Milky Way in $\sim 10^6$ yr. Such hypervelocity objects can become intergalactic. However, the capture probability for an intergalactic object is extremely low. If bacteria and other possible extremophiles have sufficiently long survival lifetimes, the GC can act as an engine for panspermia and seed the entire galaxy (5).

The presence of life could take the form of anything from chemical compounds such as nitriles and other precursor molecules for nucleotides, lipids, amino acids, microorganisms, hence, the entire galaxy could be exchanging biotic components across vast distances.

Like Earth, a planet at first glance needs to orbit in the so-called habitable zone, which is the "just right" distance from its star to host liquid water, a known requisite for life (The search for life, NASA 2021). The study by Öberg and Bergin (2021) points out that the chemistry of interstellar space influences the composition of planetary systems, whereby planets form and obtain their compositions in disks of gas and dust around young stars. "The chemical compositions of these planet-forming disks regulate all aspects of planetary compositions from bulk elemental inventories to access to water and reactive organics, i.e., a planet's hospitality to life and its chemical origins" (1). For Öberg and Bergin, in addition to the bulk compositions of the disk, the distribution of water and organics across disks may become incorporated into or delivered to terrestrial planets. The disk presents a rich organic chemistry and likely inherits much of the complex organic chemistry observed in protostellar envelopes.[5] The essential molecular precursors may have already been formed before the solar system's formation in its parental molecular cloud through the interstellar medium (ISM) chemistry. The study by Rivilla

and colleagues (2022) states:

> The molecular complexity of the ISM can provide us an illustrative view of the chemical reservoir that could have contributed to feed the prebiotic chemistry on the primitive Earth and could potentially develop similar processes in other places in the Galaxy under favorable Earth-like planetary environments (2).

Rivilla and colleagues (2022) report the detection of the molecular cloud G+0.693−0.027 (located close to the Milky Way galactic center) of several compounds of the nitrile family, including cyanic acid (HOCN) and three (C_4H_3N) isomers cyanoallene, (CH_2CCHCN); propargyl cyanide, ($HCCCH_2CN$); and cyanopropyne (CH_3CCCN), and the tentative detections of cyanoformaldehyde (HCOCN), and glycolonitrile ($HOCH_2CN$). For example, glycolonitrile ($HOCH_2CN$) is directly involved in the synthesis of ribonucleotides such as glycolaldehyde ($HCOCH_2OH$) (Jørgensen et al. 2012; Beltrán et al. 2009). For Rivilla and colleagues, the rich nitrile feedstock found towards G+0.693−0.027 confirms that interstellar chemistry can synthesize in space molecular species that could drive the prebiotic chemistry of the RNA world.[6] It is suggested that life on Earth was initially based on RNA only, and DNA and protein enzymes evolved later.

At the cosmic scale, stars are formed from a cloud of dust and gas called molecular clouds or stellar nurseries. Each stellar nursery can form thousands or even tens of thousands of new stars during its lifetime (Leroy et al. 2021). Thus, the chemical ingredients that gave rise to our planetary system were available in the nebula. The detected organic molecules are key building blocks for RNA—a DNA—like nucleic acid present in all living cells. Thus, Power-of-the-Shinning-Heaven's incarnation reminds (me) of our cosmic evolution.

Kilsdlaay asked his mother for a bow and arrow to hunt birds. She hammered the arrows from

her copper bracelets.

Kilsdlaay is the name of Shinning-Heavens. The chief's daughter did not breastfeed him since he grew up quickly. One time the child said: "Here, mother, like this." He moved his hand as if drawing a bowstring. Kilsdlaay's gesture and his mother's hammering skills created an innovative design of a bow and two arrows from her two copper bracelets. Copper is one of the first metals to be used by humans. Archaeological evidence suggests that the early Mesopotamians, around 5000 to 6000 years ago, were the first to fully harness the ability to extract and work with copper. The Northwest Coast of North America, stretching from Tlingit traditional territory in Alaska to the Coast Salish residing in Washington State, is characterized by a similar environmental biome. Various First Nations communities reside across it and share, to varying extents, cultural practices and ontological views. According to Thompson and Doonan (2019),

> These shared elements of culture are also intercut with regional diversity, particularly in relation to elements of language, architecture, and cultural practices such as marriage partner residence and kinship organization. Copper, as a material and artefact, played a part in the distinction and seems to have a long–established significance that was retained throughout colonial contact (Jopling 1989) (1).

The reference to copper metal and artifacts in oral narrative, alongside archaeological, anthropological and colonial records, demonstrate that copper was considered a robust and active material for many of the region's First Nations communities. Hence, linking copper in culture with the creative cognitive neural process demands reorganizing existing knowledge to generate novel and valuable concepts and features. The question is how these new concepts are formed, primarily through the processing of novelty and usefulness, which are usually regarded

as the key properties of creativity. Ren and colleagues (2020) study provides behavioural and neuronal evidence demonstrating the neural mechanisms of novelty and usefulness representation during the creative process mediated by the brain's hippocampus and adjacent medial temporal lobe (MTL).

> The hippocampus-MTG connection is involved in both novelty and usefulness concept processing and is associated with the interpretation of new conceptual knowledge. Moreover, the MTG is involved in integrating the creative concept and updating the memory system by forming different representational patterns of neural population codes. The creative integration of novelty and usefulness entails not only the formation of new associations, which could be critically mediated by the hippocampus and adjacent medial temporal lobe (MTL) areas, but also the formation of new concepts or categories, which is supported by the middle temporal gyrus (MTG) (14).

Ren and colleagues provide novel evidence for understanding the critical mechanism of new association formation and concept formation during novelty and usefulness processing in creative design. Creative thought relies on the reorganization of existing knowledge. This internal process is mediated by the hippocampus-middle temporal gyrus MTG and, in this story, is exemplified by the skillful use of copper and its transformation into three novel objects.

Kilsdlaay went out to hunt for birds. This continued for several days

When he came back the first day of hunting, he brought his mother a common resident (cR) Pelagic Cormorant (*Urile palagicus*). His mother ate it. The next day, he hunted a common abundant (ca) Emperor Goose (*Anser canagicus*) for his mother. Also, his mother ate it. And The next day, he again went hunting. He brought in a common resident (cR), Winter Wren

(*Troglodytes hiemalis*). Then he skinned it. He dried the skin. He thought highly of it. The next day, he brought in a common resident (cR) Song sparrow (*Melospiza melodia*). That, too, he skinned and dried it. The next day, he brought an uncommon resident (uR), Steller's Jay (*Cyanocitta stellerl*). He skinned and dried that also. The day after, he brought in an uncommon resident (you are) Woodpecker or Northern Flicker (*Colaptes auratus*). That he also skinned and dried it.[7]

The Haida were seafaring people, skilled anglers and hunters. Marine and land mammals and bird skins along the North Pacific were used for clothing. Haida Chiefs, especially in feasting times, wear richer skins and robes. Concerning the skin's power, for the Haidas, a conceptual continuum exists between humans, animals, and supernatural beings. Animals, as supernatural beings, can assume human form. They can appear in human shape by removing their animal skin (Boelscher 1988). As Boelscher states, "The means by which the change from human to animal state is affected is usually the skin (k'al), the outer wrapping. Mythically, the skin provides the wearer with the powers and features of the animal embodied" (175). As a supernatural will often wear the skins of animals, Chief Kilsdlaay–Power-of-the-Shinning-Heavens, before his departure, will perform to his mother wearing the bird skins.

Master artisan transformed the house for the powerful chief. He became his father. He dressed him and painted his face with cirrus clouds

One time during the night, Master Artisan, a supernatural being, came to talk to his mother. The title of Master Artisan in the Haida language refers to a being of great power who gives form to thought. That night, the Master Artisan transform the house for a chief. MacDonald (1983) points out,

> Lineage houses among the Haida symbolized the corporate image of the house

group, and entering into it marked a clear transition from the profane world to the spiritual world of the ancestors, bringing the Haida into intimate association with their cultural traditions" (18).

The alignment of houses in the village was based upon social rank, ideally with the houses of more prestigious house chiefs arrayed on either side of the house of the village chief, which occupied a central location in the house row. In houses of wealthy chiefs, the inside house-post and the screens at the rear also were carved (Fig. 5).

Fig. 5. Swanton, John R. 1905b, House Posts. *Contribution to the Ethnology of the Haida, Memoirs of the AMNH; [v. 8, pt. 1];* Publications of the Jesup North Pacific Expedition; v. 5, pt., Figures 9 and 10. Courtesy of the Division of Anthropology, American Museum of Natural History.

And when day broke, he awoke in a fine house. The carvings on the house posts winked with their eyes (they were so delicate, showing the excellence of carving).

The next day, Masters artisan became his father. He dressed Kilsdlaay and painted his face with cirrus clouds, a crest symbol belonging to the Raven moiety, which appears during fine weather, and when he was seated looking seaward, the weather was good. Face painting is considered an important tradition among Indigenous people of the Americas. Franz Boas, as a

participant and organizer of the Jesup North Pacific Expedition (1897), in his research of the North Pacific Coast wanted to obtain a series of representations on complex surfaces such as the face. According to Boas,

> The subjects that are used for this purpose are largely the crest of the various families. These are laid on in black, red, blue, and green; the colors being mixed with grease and put on with the fingers, with brushes, or by means of wooden stamps cut out for this purpose (14).

For example, fig. 6 shows a Haida facial painting with cirrus clouds. Boas (1898) suggests that the outline of the face represents the horizon, the red spots around it, and the cirrus clouds on the horizon. The same kind of cloud scattered over the morning or evening sky is shown in Plate VI, Fig. 2 & 3.

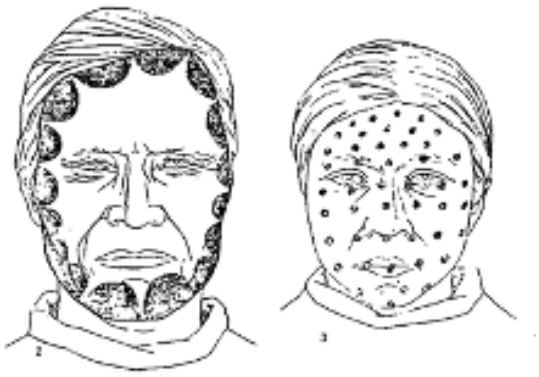

Fig. 6. Boas, Franz. 1898, Cirrus clouds on the horizon of the ocean; red. Used by the Taslä'nas of Dä' dens (Q'oa'la). (3) Cirrus clouds on the morning or evening sky; red. Used by LqënöLlä'nas of Q'u'na or Skidans. (Q'oa'la). From drawings by Mr. Rudolph Weber. Plate VI, Figures 2 & 3. Courtesy of the Division of Anthropology, American Museum of Natural History

Boas obtained these materials from Haida chief E'dansa (melting ice from a glacier) and baptized Albert Edward Edenshaw from Masset.

The House-Fishing-Ground. They recite an incantation to exhort the halibut to seize his hook.

The Mother-of-Halibut towed the canoe around the island.

Fishing has been fundamental to the social and economic lives of Indigenous peoples in the Northwest Coast of North America since the early Holocene, 10,700 years ago (McKechnie and Moss 2016; Moss and Cannon 2011a; Fedje et al. 2005). This story reflects Indigenous fishery practices' richness, dynamism, and complexity. For instance, halibut tends to be fished more in the spring and summer when they move into shallow waters. In shallow waters, halibut uses sound and sight to find food. In deeper waters, they use smell as the primary way of finding food. Creating a potent scent trail with live bait or artificial scents is key to attracting halibut.

On the way to the fishing grounds, they pulled a supernatural octopus, the usual bait for halibut. The Haida ancestral halibut fishing grounds were all named and owned by a family lineages. According to the scene imagery, the fishing ground is marked by landmarks such as mountain peaks. The house-fishing ground of this story is a cognitive map that could be located around Boomchain Bay and Englefield Bay. These bays surround seven islands: Saunders Island, Helgesen Island (Kaisun village and Dju), Carswell Island, Lihou Island, and Hibben Island. Hibben Island's high elevation point is 821 meters and can serve as a reference for the cognitive map.

He taught his father an incantation to exhort the halibut to seize his hook. As Enrico points out, at least formerly, Haida halibut fishermen used to exhort the halibut with similar incantation (111). The incantation in the story is phrased as a dialogue between father and son. An important landmark referred to in the incantation is a mountain named Tc!i'nla-i. "The shadow is long now on ts'inhlaay, chief! Hurry!" say that, Father." So, he said it. According to Enrico's translation, this mountain is located just north of Louscoone Point (Enrico 1995, 111). Following my vision quest, the name of this mountain should be elicited by the Haida Council since Louscoone Point is located in the south of Moresby Island. However, Mount Moresby is

the highest mountain in Haida Gwaii, with an elevation of 1164 meters and is close to Kaisun.

The Northwest Coast halibut V-shaped hook and line is both an Indigenous fishing technology, and an iconic object of rich cultural history (Malindine 2017). To Murdock (1963), "The hooks are made in a variety of ingenious forms out of yew or other wood, steamed and bent to the proper shape and equipped with barbs of bone or shell" (225). Also, hooks are covered with a complex effigy and animal carving to provide a spiritual lure to the halibut and form a connection with the fisherman. Delisle (2018), referring to (Fig.7), suggests that the 28-centimetre-long hook from Haida Gwaii, British Columbia, was purchased in 1937 by George Gustav Heye. The figural element depicts a human transforming into a river otter.

Fig. 7. Credit: National Museum of the American Indian, Smithsonian Institution (Catalog Number: 19/6270). Photo by NMAI Photo Services.

The Northwest Coast people believed the spirit carved on the hook would draw the fish to the hook and be successful. He pulled in the lines when the canoe stopped being pulled around the island twice. The monster halibut lips were covered with kelp fronds, and its nests piled around

it. Finally, his father filled the canoe, and he released it. Few people have equalled the Haidas regarding tool manufacturing in canoe building (Fig. 8).

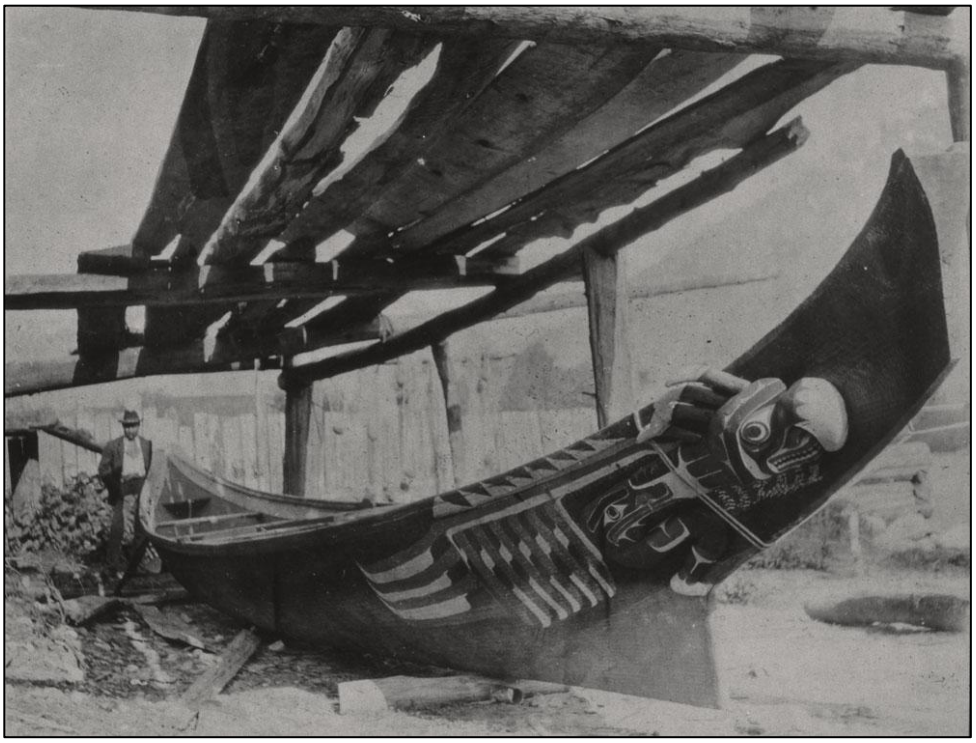

Fig. 8. *Haida-type canoe*, 1927. Courtesy of Library and Archives Canada. Public Domain.

According to Murdock, the largest canoes, seventy feet long and eight in beam, can carry thirty men and a load of three tons. It is important to note that these large canoes are hollowed from a single log (Fig. 12). When sufficiently shaped and excavated, the log is half-filled with water, and hot stones are added. In this way, the wood is softened so that the canoe can be widened in the beam by inserting stretchers or thwarts of gradually increasing size. These canoes were propelled and steered with paddles. Finally, an important note regarding the Haida canoe: Haida hereditary leader Gidansda Guujaaw of the Ravens Moiety states, “Tluu, the Haida canoe, was not a design that evolved, rather a gift from the supernatural” (Guujaaw 2023).

He painted his son's face so he could see his uncles in the nearby village.

The master artisan brought the halibut to his wife, and she dried it. Then, he dressed and painted his son as a chief to visit his uncles. As a Haida chief, Shinning-Heavens was dressed in his Chilkat robe featuring the clan crest and figures from oral tradition. Chilkat weaving is a traditional form practiced by Tlingit, Haida, Tsimshian, and other Northwest Coast of Alaska and British Columbia. Traditionally, the materials used were mountain goat wool and yellow cedar bark.

The boy dressed himself with his wren skin, then with his stellar jay skin, and he went out with his woodpecker skin

Mother, look at me!" he said. She saw that he was a cumulus cloud rising out at the sea. These various clouds are represented as Shinning-heavens with his different bird blankets on.

With his Stellar jay skin, he rose blue and soft out at sea, and with his Woodpecker skin, he sat on the sea red from his waist up. If we note in this story, Chief Kilsdlaay's dressing is a cognitive map of his power attributes left for his mother, the Haida people, and those of us who see him in the cumulus clouds and its colours.

Then he said, "Mother, I will not see you again. I am leaving you. If I sit at the mouth of q'aanang in the morning, there will be no wind from any direction.

According to Enrico's translation, if I sit at the mouth of q'aanang in the morning, there will be no wind from any direction. q'aanang is Haines Creek on the west coast of Graham Island. That said, when Shinning-Heavens presides, or these clouds are seen, it will be calm at sea, and people will get their food. His mother replied, go ahead, dear Kilsdlaay, if you are sitting (there) in the morning, I will send you out bird down to fall upon you. Then he departed, leaving a cognitive map for the Haidas and other people to read on the clouds for pleasant weather and to

honour his presence in time and space on Earth. His father was about to leave and advised her to take her place at the head of the river (juu randlaay).

In the evening, she advised her youngest uncle to wear a new hat and bring a new paddle when fishing the following day.

The next day, when they went fishing, she sat at the edge of the town with her knee drawn up. Enrico's translation suggests that the wind began to blow seaward when she pulled up her dress. As she raised it higher, the wind increased. When she pulled it up to her knees, the canoe capsized. The verb "capsize" here is singular, but above, it is said that more than one canoe went out. Then she seized only the thread of life of her young uncle and saved him because his wife had left food for her (Enrico 1985, 115). According to Swanton (1905b), "Every animal and every human being is supposed to be provided with a "thread of life," an idea not found elsewhere in America so far as I am aware. The thread of life is the lifespan of an individual. Lïs, the word used in this story, is also applied to threads of mountain sheep wool" (189). They say she was tll 'laa jaad. For Swanton, Lla-djat, "Fine-weather-woman," is often referred to in the stories. One of the winds, the northeast wind, was named after her, and by the West Coast people, she seems to have been identified with the Creek woman at the head of Dju. Then she settled inland. When her son sits there in the morning, she always sends delicate snowflakes to fall on him. That was the bird down.

3.7 Reflection

Nowadays, (I) ponder the potential of oral narrative for re-enacting the temporal processing of episodic memory by retrieving the visual scene imagery of a hypothetical hippocampal cognitive map. For future experimental studies on memory, unravelling the cognitive map may breach the evolutionary history of long-term episodic memory and its neural substrates supporting

cosmologic narrative performance from many generations of Haida storytellers.

Since the hippocampus is an essential hub for episodic memory processing, (I) provided insights on both stories based on the human ability to reinstate long-term episodic memory using what, where and when of past experiences. To account for long-term episodic memory, (I) enacted the visual scene imagery of experience-dependent information of learning and cognitive activities in the ancestral triadic (ecological, neural, cognitive) niche construction. Also, the scene imagery calls attention to specific space-defining object attributes, which have a privileged role in retrieving long-term episodic memory and language by the synchronized neural activity of the hippocampus/entorhinal cortex system.

3.8 Chapter Notes

1. Saccades bring targets of interest into the field of view. They are one of the four basic eye movements in humans, all of which are generated and modulated by components of a complex eye movement network involving cortical eye fields, thalami, basal ganglia, cerebellum, and brainstem structures (Richmond et al., 2021).
2. The Hadean Eon, named after the Greek god and ruler of the underworld Hades, is the oldest eon and dates from 4.5 to 4.0 billion years ago. The Archean Eon was preceded by the Hadean Eon, an informal division of geologic time from about 4.6 billion to 4 billion years ago and characterized by Earth's initial formation. Records of Earth's primitive atmosphere and oceans emerge in the earliest Archean (Eoarchean Era).
3. D. G. Green (1990) states that cellular automata provide global representations for context-sensitive processes that involve discrete state changes in interacting populations of discrete entities. The usual arrangement of cells is a rectangular grid, but different or flexible topologies are appropriate for some processes, such as growth. Many biological processes are

best modelled as interactions between separate cellular automata. Convolution processes are common. Russell and colleagues (1993) state that "The iron sulphide membranes formed vesicles which grew initially by hydrothermal inflation but evolved a capacity for growth and 'reproduction' by osmotically driven swelling and budding" (343). That said, life originated by the continual growth of a self-referencing gelatinous iron sulphide membrane as a natural, "evolving automaton." By revisiting the above idea, Martin and Russel (2003) suggest that all life is organized as cells. Physical compartmentation from the environment and self-organization of self-contained redox reactions are the most conserved attributes of living things. Hence, inorganic matter with such attributes would likely be life's forebear. Cosmic ancestry, which deals with the origin of life on Earth, is known as *panspermia* by the Greek philosopher Anaxagoras of Clazomenae (fifth century BCE), literally, "seeds everywhere" or the seed of life everywhere in the universe. Panspermia theory holds that microbial life is present in space or on bodies like comets or asteroids, and it can be safely delivered to Earth and start life there (Ginsburg et al. 2018; Lisgam and Loeb 2017; Lin and Loeb 2015; Parrilli et al. 2011). The fundamental astrobiological question is whether life can be transported between extrasolar systems. Lin and Loeb (2015) used a statistical model to argue that detecting a group of biologically active planets interspersed with areas where life is rare or nonexistent can be nearly irrefutable evidence for panspermia. If panspermia operates on galactic scales, there may be little or no habitable exoplanets without life. Consequently, if a survey of exoplanetary atmospheres across the Milky Way found that nearly all habitable planets had biosignatures, this would be robust evidence for galactic panspermia.

4. In a recent research, "PHANGS–ALMA: Arcsecond CO(2–1) Imaging of Nearby Star-

forming Galaxies" by Leroy and colleagues (2021), a team of astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) completed the first census of molecular clouds or stellar nurseries in the nearby Universe. The study reveals that contrary to previous scientific opinion, these stellar nurseries do not all look and act the same. Each stellar nursery in the Universe can form thousands or even tens of thousands of new stars during its lifetime. To better understand star formation in diverse types of galaxies, the team observed similarities and differences in the molecular gas properties and star formation processes of galaxy disks, stellar bars, spiral arms, and galaxy centers (Fig. 9).

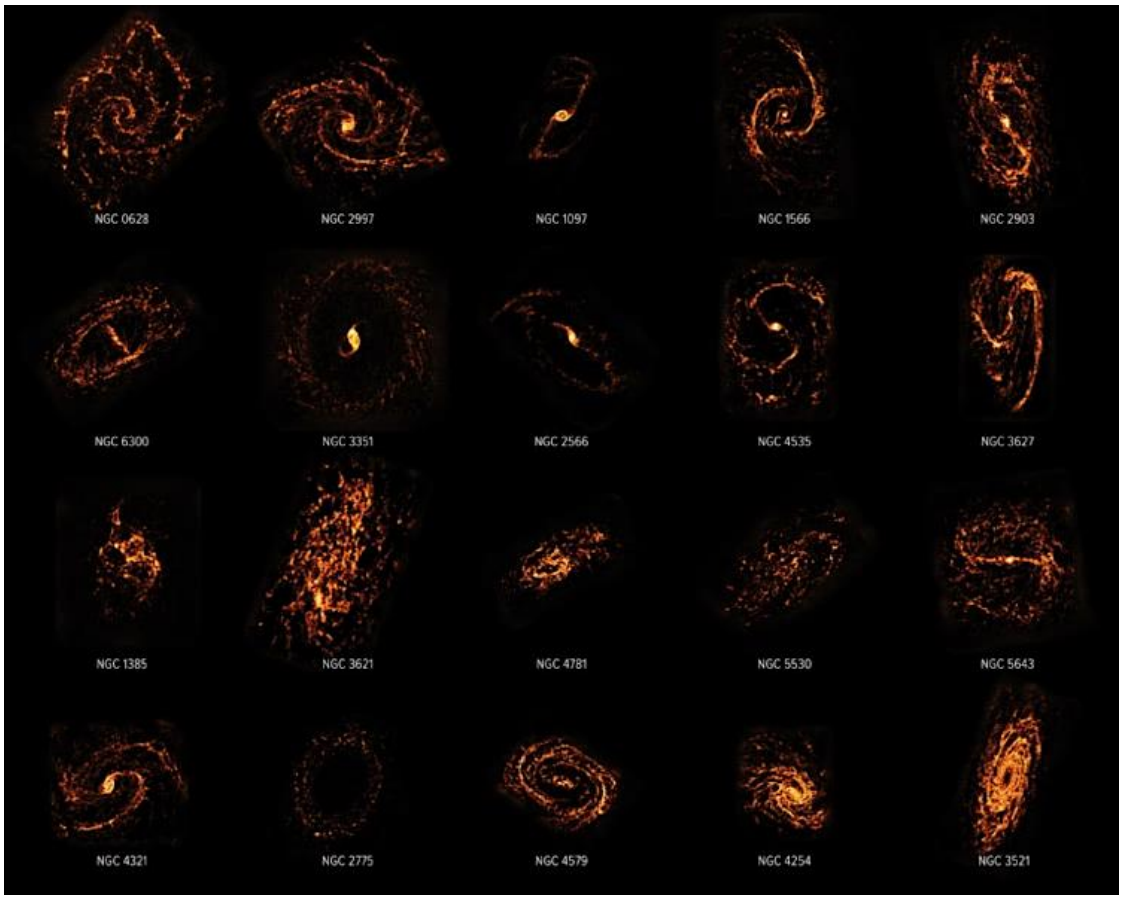

Fig. 9: Cosmic Cartographer Map Nearby Universe Revealing the Diversity of Star-Forming Galaxies 2021. ALMA detected radio waves emitted from molecular clouds in the galaxies, where stars are formed. Credit: ALMA (ESO/NAOJ/NRAO)/PHANGS, S. Dagnello (NRAO).

The authors confirmed that the location, or neighbourhood, plays a critical role in star formation. Regarding my thesis, this paper extended my knowledge of our Sun's formation and our planet's formation within a protoplanetary disk. Thus, the composition of planet-forming disks comes into greater focus in ways that may help us understand life's potential for development. I investigate this topic in Chapter 4, where I review current ideas about Earth's cosmologic formation and how it functioned in the first part of its history and, consequently, the emergence and evolution of life.

5. Öberg and Bergin's (2021) astrochemical study suggests that, during the protostellar stage, the central protostar continues to accrete mass from the surrounding cloud core or protostellar envelope. The temperature and density increase towards the center within the envelope due to stellar heating. Some of the accreting material spreads into a disk to preserve angular momentum, simultaneously funnelling matter onto the star. Angular momentum is also removed from the system through the launch of protostellar outflows and jets (Fig. 10c).

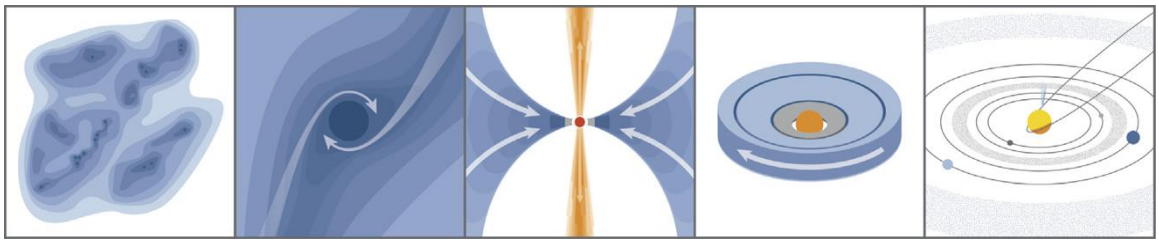

Fig. 10. Öberg and Bergin 2021, p. 3. Cartoon of the different stages characterizing low-mass (Solar-like) star and planet formation. a: Stars form in dense cores in interstellar molecular clouds. b: Star formation begins when such a dense core begins to collapse due to self-gravity. c: As the collapse proceeds, the center heats up forming a protostar. Accretion of remnant cloud material continues, funneled through a disk, which is formed as a consequence of cloud angular momentum. This stage is also characterized by outflows of material. d: Following the dispersal of the cloud remnant, the now pre-main sequence star is left with a circumstellar disk, which is the formation site of planets. The disk gas is dispersed through disk winds within ~2–5 Myrs, putting a halt to Gas Giant formation. e: Rocky and icy planets can continue to grow for another 100 Myrs, at which time a mature planetary system exists. Source: Image credit: K. Peek.

6. The RNA world hypothesis is a prevailing scientific idea about the early evolution of biological and pre-biological structures. Its main advantage is the assumption that RNAs, as the first living systems, were self-sufficient, i.e., capable of functioning as both catalysts and templates.
7. My reference for the hunted birds comes from the Laskeek Bay Conservation Society, Haida Gwaii (2010), and according to abundance codes and season of occurrence codes.

CHAPTER 4. Solar Nebula, Earth, Cellular Life

4.1 Introduction

In this chapter, I navigate across contemporary physical cosmology, looking for materials, tools, and novel insights into life in the Universe. The Haida cosmologic story inspired this chapter, *Sing 7agang qiidaraagan*—How Shining-Heavens caused himself to be born in a clamshell. On October 19, 2017, I was researching panspermia when 1I2017 ‘Oumuamua (a messenger from afar, arriving first) was discovered at the Pan–STARRS1 telescope system at Haleakala Observatory, Hawaii. ‘Oumuamua is the first known body of interstellar origin to enter our Solar System (Micheli et al. 2018; Meech et al. 2017). For Bialy and Loeb (2018) and Loeb (2021), it is a light sail floating in interstellar space as debris from advanced technological equipment. Thus, in my research, the incarnation of Shining-Heavens and the discovery of ‘Oumuamua, both in their forms, bring forth millions of years of cosmological evolution and the reminder that life might have developed in different forms in metal-rich cosmic environments in our galaxy and other galaxies.

To start this navigation, there are two insightful ideas for orienting my quest. Camprubí and colleagues (2019) provide a cosmologic overview that our Solar System contains numerous planetary bodies which likely contained (or still do) living beings. The icy moons of the Solar System (e.g., Enceladus, Europa, Titan) contain vast amounts of liquid water, which, at least in the case of Enceladus, arguably promotes hydrothermal processes (Waite et al. 2017).

> The detection of reduced inorganic molecules (Waite et al. 2017; Waite et al. 2009), as well as nitrogen—and oxygen-bearing organics (Khawaja et al. 2019) in the plumes of Enceladus, coupled with studies indicating Earth-based

> methanogens can grow under simulated Enceladus conditions (Taubner et al. 2018, 2015), suggests that organic molecules are currently being synthesized in its global ocean. It is even possible that these molecules derive, at least partially, from life (4).

According to Camprubí and colleagues, organic molecules synthesized from reducing Carbon Dioxide ($CO_{2)}$ through several carbon-fixation pathways in the global ocean offer a scene for the emergence of life in different environments of the Milky Way and on Earth. As liquid water is pervasive in the Universe, it is abundant on planetary bodies such as the icy moons of the Solar System, where it forms large or global sub-surficial oceans. As "the reason(s) behind life's emergence is(are) probably universal, it is possible this event occurs through several mechanisms and crystalizes around different core molecules across the Universe" (11). Thus, looking for oceanic worlds also means looking for hydrothermal sedimentary settings. Furthermore, in a recent discovery, Öberg and colleagues (2021), using the Atacama Large Millimeter /submillimeter Array (or ALMA) radio telescope in Northern Chile, have mapped 18 organic and inorganic molecules around five protoplanetary disks of young stars located 300 to 500 light years away from Earth.[1] For Öberg and colleagues, these planet-forming disks are teeming with organic molecules, some of which are implicated in the origins of life on Earth.

Since the beginning, microbial life has permeated Earth's critical zone (CZ), the outer layer where air, water, soil, rocks and living organisms interact. In this regard, comparative genomics, which involves analysis of the nucleotide sequences of genomes, shows that the known life forms comprise two major divisions: the cellular and the viral empires. The cellular empire and their evolutionary relationships can be traced back to the last universal common ancestor (LUCA), which gave rise to the three domains: Bacteria, Archaea, and Eukarya, which

is a new view of the bacterial and archaeal tree of life. Since all life is based on cells, any evolutionary perspective of the emergence of sentience and cognition, i.e., cosmologic stories, should be grounded in mechanisms that took place in prokaryotes' proto-consciousness, the simplest unicellular species that merged to form chimeric eukaryotic cells with supracellular consciousness (Margulis 2001).

In brief, I will navigate into cosmologic time/space ~ 4.2 Gya to bring forth insights on the formation of (1) The Solar Nebula, (2) Chondrite Meteorites and Chondrules, (3) Earth, Zircons, Water, Metabolism, (4) Hydrothermal vents, (5) LUCA or the Last Universal Common Ancestor), (6) The holobiont or meta organism, (7) Archaea.

4.2 Solar Nebula

In the beginning, the solar nebula was rotating in the Orion-Cygnus arm ~ 26,000 light years from the center of our spiral galaxy, the Milky Way. The solar system was formed ~ 4.567 Gya by the gravitational collapse of the molecular cloud, whose chemical and isotopic composition reflects about 9 Gya of galactic chemical evolution. According to Öberg and Bergin (2021), these clouds mostly contain gas. However, approximately one percent of the mass is sub-micron dust particles, initially composed of silicates and carbonaceous material. For Öberg and Bergin, star formation is mainly associated with dense molecular clouds (Heyer and Dame 2015), where densities are > 102 n_H cm^{-3} (hydrogen nuclei per cubic centimeter), which result in cloud interiors well shielded from external radiation, resulting in low temperature and most elements being bound up in molecules. As Öberg and Bergin point out, "competition between molecular formation and photodissociation during cloud assembly determines the initial chemical compositions of dense clouds" (Seifried et al. 2017; Clark et al. 2012; Glover and Mac Low 2007; Bergin et al. 2004a) (3). Photodissociation is the dominant process of removing molecules

in any region exposed to intense ultraviolet (UV) radiation. Amanda Doyle (2018) suggests that low-mass stars like our Sun are currently the most promising targets when searching for potentially habitable planets. However, new research has revealed that some stars produce significant amounts of ultraviolet (UV) radiation throughout their lifetimes. Such radiation could hinder the development of life on any orbiting planet (NASA, May 1, 2018. Consequently, as Öberg and Bergin point out, the chemistry evolves in the protostellar stage and with existing constraints on the chemical composition of the protostellar precursors to the mature, planet-forming disks. The chemical compositions of these planet-forming disks regulate all aspects of planetary compositions, from bulk elemental inventories to access to water and reactive organics. This is the kind of planet that will offer hospitality to life and its chemical origins.

In addition, between 2013 and 2019, astronomers on the PHANGS (Physics at High Angular Resolution in Nearby Galaxies) project conducted the first systematic survey of 100,000 stellar nurseries across 74 spiral galaxies in the nearby Universe to understand better how they connect to their parent galaxies (Fig. 11).

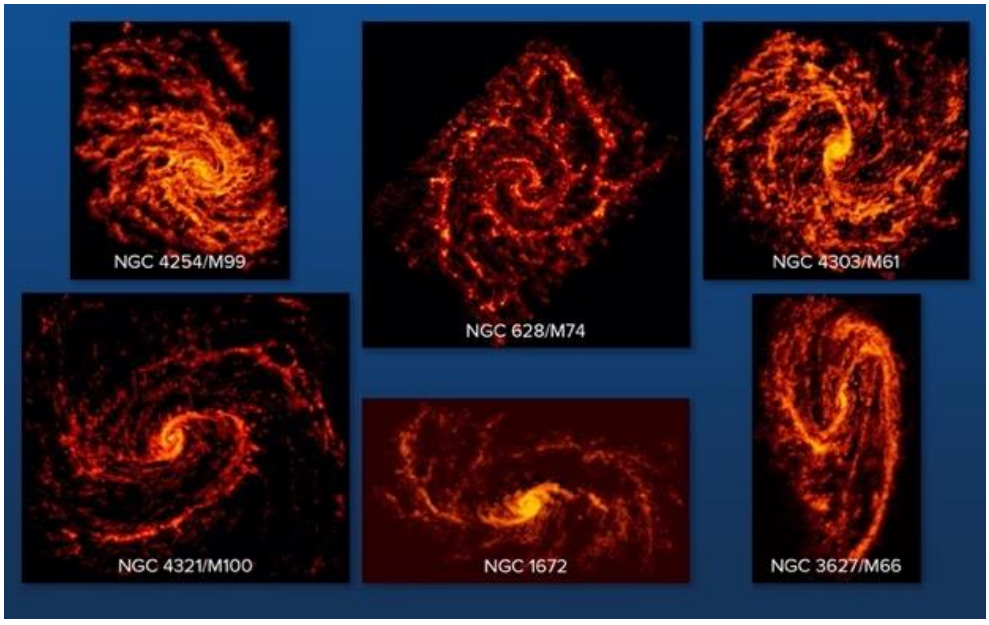

Fig. 11. National Radio Astronomy Observatory. Six ALMA-imaged galaxies out of a collection of the 74. The images were taken as part of the PHANGS-ALMA survey to study the properties of star-forming clouds in disk galaxies. Credit: ALMA (ESO/NAOJ/NRAO); NRAO/AUI/NSF, B. Saxton.

The project by Leroy and colleagues (2021), using the Atacama Large Millimeter/Submillimeter Array (ALMA) in Chile, unlocked clues on the role of molecules in planetary system formation and whether these young planetary systems in the making have what it takes to host life. The maps of the nearby Universe reveal the diversity of star-forming galaxies in molecular clouds or stellar nurseries. These stellar nurseries do not all look and act the same. Each stellar nursery in the Universe can form thousands or even tens of thousands of new stars during its lifetime. The team observed similarities and differences in the molecular gas properties and star formation processes of galaxy disks, stellar bars, spiral arms, and galaxy centers to understand star formation better. This study confirmed that the location, or neighbourhood, plays a critical role in star formation. Likewise, the molecular composition of protoplanetary disks comes into focus in ways that may help us to understand life and its potential for development in the Universe.

4.2.1 Protoplanetary Disk

Over the past decade, the disk population that orbits young stars-forming regions have been surveyed with the Atacama Large Millimeter/Submillimeter Array (ALMA). Understanding the disk properties and their correlation with the properties of the central star is critical to understanding planet formation. Interactions with their circumstellar material mediate stars' and planetary systems' formation and early evolution. This material is organized in a flattened disk of gas and solids that orbits the central host star (e.g., the Sun). A recent collaboration of scientists using the Atacama Large Millimeter/Submillimeter Array (ALMA) in Northern Chile mapped the chemical composition of the protoplanetary disks around five nearby young stars. According to Loomis and colleagues (2020), “The volatile contents of protoplanetary disks both

set the potential for planetary chemistry and provide valuable probes of defining disk system characteristics such as stellar mass, gas mass, ionization, and temperature structure" (1). The planetary chemical environment impacts the planet-forming disk; this means some planets have the organic composition to support life. Moreover, Öberg and colleagues (2021) at ALMA, as a part of the Molecules with ALMA at Planet forming Scales (MAPS) program, state that the distributions of molecules across disks regulate the elemental compositions of planets, including C/N/O/S ratios and metallicity (O/H and C/H) organic reservoirs across the disk, as well as access to water and prebiotically relevant organics that affect planet formation. Öberg and colleagues conceived MAPS according to the current understanding of protoplanetary disks' structure, dynamics, and chemistry (Fig. 12).

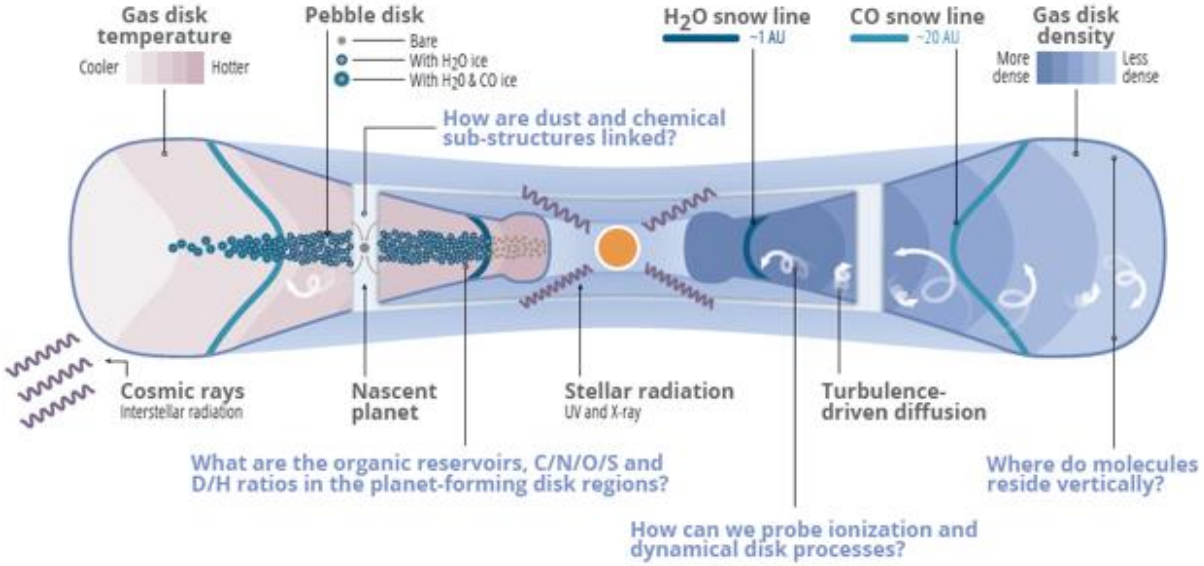

Fig. 12. Öberg et al. 2021, p. 2. Illustration of the protoplanetary disk structure on a logarithmic scale and its coupling to different gas and grain dynamical processes. Note the temperature gradient inward and upward (pink shading), which results in a series of midplane snowlines (shown at typical locations for a disk around a T Tauri star) and 2D snow surfaces reaching up into the disk atmosphere, as well as the inward and downward density gradient (blue shading). Disk surfaces are characterized by photon processes. Disk midplanes are, by contrast, cold and UV-poor, and the main volatile reservoirs (other than H_2 and He) are in icy grain and pebble mantles, especially exterior to the CO snowline. The four guiding questions used to design MAPS are written in blue. Image credit: K. Peek, adapted from Öberg and Bergin 2021.

Most importantly, Öberg and colleagues (2021) saw that the planet-forming disks around five young stars (IM Lup, GM Aur, AS 209, HD 163296, and MWC 480) are factories of a special class of organic molecules, so-called nitriles, which are implicated in the origins of life on Earth. Nitriles[2] are key contributors in reactions that lead to pre-biotic molecules such as RNA and amino acids for the origins of life.

4.2.2 Planetesimal Accretion

The planetesimal theory of the Russian astronomer Viktor Safronov (1941) elucidates that planets form out of dust grains that collide and stick together or accrete into larger bodies of about 1 km. Planetesimals are the building blocks of terrestrial planets, cores of giant planets, comets, and asteroids, and were formed from grains condensed in the interstellar medium or in the solar nebula. Further, the study by Zahnle and colleagues (2007) suggests that the accretion of terrestrial planets was in four stages:

(1) Settling of circumstellar dust to the mid-plane of the disk.

(2) Growth of planetesimals up to ~ 1 km in size.

(3) Runaway growth of planetary embryos up to ~ 10^3 km in size.

(4) Oligarchic growth of larger objects through late-stage collisions (42).

Stage 1 occurs over a time scale of thousands of years and provides a dense plane of material from which planets can grow; Stage 2 requires sufficient mass growth to build objects for gravity to play a role. Planetesimals on this stage needed to be about a kilometre in size for the gravitationally driven stage 3 to start. As volatiles would not condense in the inner solar system, an alternative suggests that, within the disk of dust and gas, collective effects can gather particles into pockets of locally high density that may promote collisional coagulation or gravitational collapse (Cuzzi et al. 2005; Weidenschilling and Cuzzi 1993). Local separation and clumping of

the material could also lead to large-scale gravitational instabilities, whereby an entire section of the disk has relatively high gravity and accumulates into a zone of concentrated mass (Ward 2000). On stage 3, runaway growth builds this 1 Km-sized object into 1,000 Km sized objects, "the bigger the object, the larger it becomes until all of the material available within a given feeding zone or heliocentric distance is incorporated into planetary embryos" (Zahnle et al. 2007, 42). Using models for the solar nebula's density, it is possible that Mars-sized objects originated in this fashion. Collisions, accretion, and mergers between the embryos have built up a smaller number of larger ones that can be called planets. However, Earth required a more extended history of collisions between such planetary embryos. The planetesimals and planetary embryos that built Earth came from a distance of over two astronomical units. In the Planet Distance Chart provided by NASA, 1 AU equals about 150 million kilometres (93 million miles).

The formation of planetesimals from the accumulation of dust and ice particles and planetary embryos is a crucial step toward assembling planetary systems (Johansen et al. 2014; Raymond et al. 2014). This formation occurred by streaming instabilities, followed by growth dominated by gas drag-assisted accretion of chondrules (millimeter-sized spherules) into asteroid bodies (Johansen et al. 2015) to form Mars-sized planetary embryos during the proto-planetary disk stage. These planetary embryos of the terrestrial planets formed rapidly, perhaps less than 1 million years after the solar system's origin. Fast formation implies that these embryos captured primary nebular atmospheres, and the evidence of primary atmospheres is preserved in the noble gases, consistent with the presence of solar noble gases on Earth and Mars.

In addition, a recent study by Lammer and colleagues (2020) provides a schematic timescale of the accretion of terrestrial planets, illustrating five main stages of formation (Fig. 13).

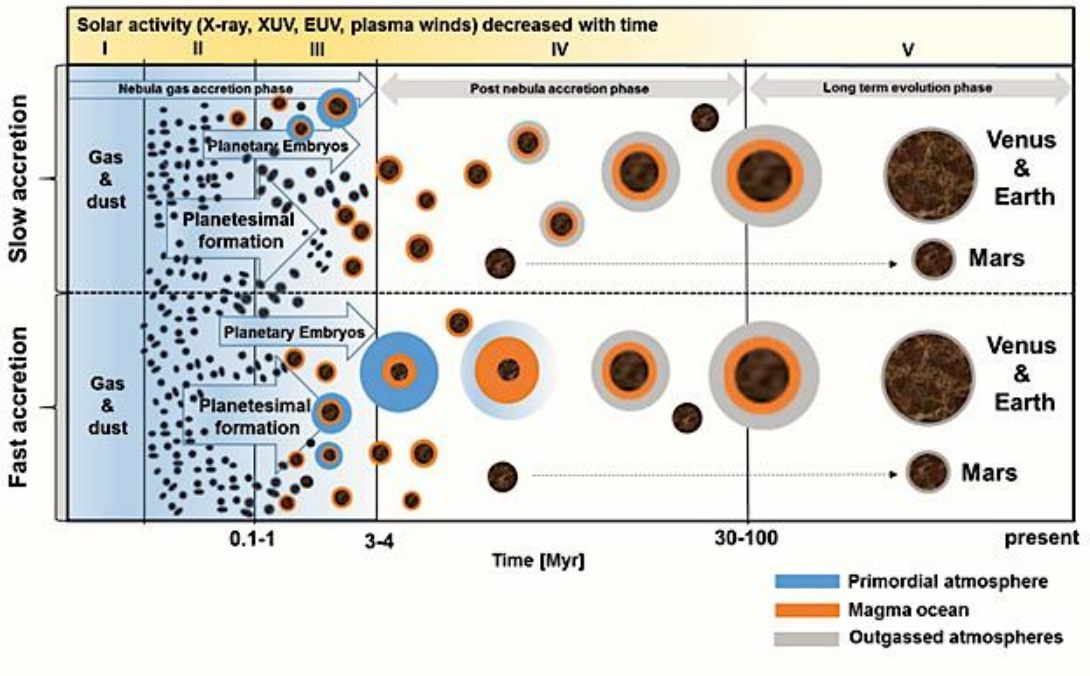

Fig. 13. Lammer et al. 2020, p. 3. Illustration of the five main formation stages of the terrestrial planet formation: dust settling (I), planetesimal formation (II), formation of planetary embryos (III), giant impacts including Earth's Moon-forming event (IV). The long-term evolution phase is where secondary atmospheres originate (V). The scenarios above the horizontal dashed line illustrate so-called slow accretion scenarios where terrestrial planets accrete most of their mass after the disk dissipated. The scenario below the dashed-horizontal line corresponds to a two-stage accretion scenario according to Jacobsen and Harper (1996), Harper and Jacobsen (1996), and Yu and Jacobsen (2011). Here, terrestrial planets accrete faster so that they can capture primordial atmospheres, which subsequently escape while the proto planets accrete their final masses. The shaded zone represents the presence of the protoplanetary nebula in the Solar System that dissipated after ≈3.3 – 4.5 Myr (Bollard et al. 2017; Wang et al. 2017). In both scenarios, the planets outgas steam atmospheres when their magma oceans solidify, and secondary atmospheres build up later-on due to volcanic outgassing and tectonic activities.

Lammer and colleagues' illustration shows that depending on their speed of growth before or after disk dissipation and their orbital locations of origin/destination, protoplanets will evolve into objects with different volatile and elemental abundances, which results in different elemental ratios compared to their initial ones due to subsequent atmospheric escape and impact erosion of atmospheres and crustal/mantle material (Lammer et al. 2020; O'Neill et al. 2020). The atmospheric escape processes can fractionate noble gas isotopes (Atoms with a different

number of neutrons) and moderately volatile rock-forming elements belonging to the primordial atmosphere, magma ocean-related environments, and catastrophically outgassed steam atmosphere at high temperatures (1000 – 2500K = 726.85°C – 2226.85°C). According to Lamer and colleagues (2020), when the disk dissipates after a short but efficient boil-off phase (Lammer et al. 2018; Owen and Wu 2016), the magma oceans of the former disk-embedded bodies solidify, and steam atmospheres are catastrophically outgassed (Fig. 14).

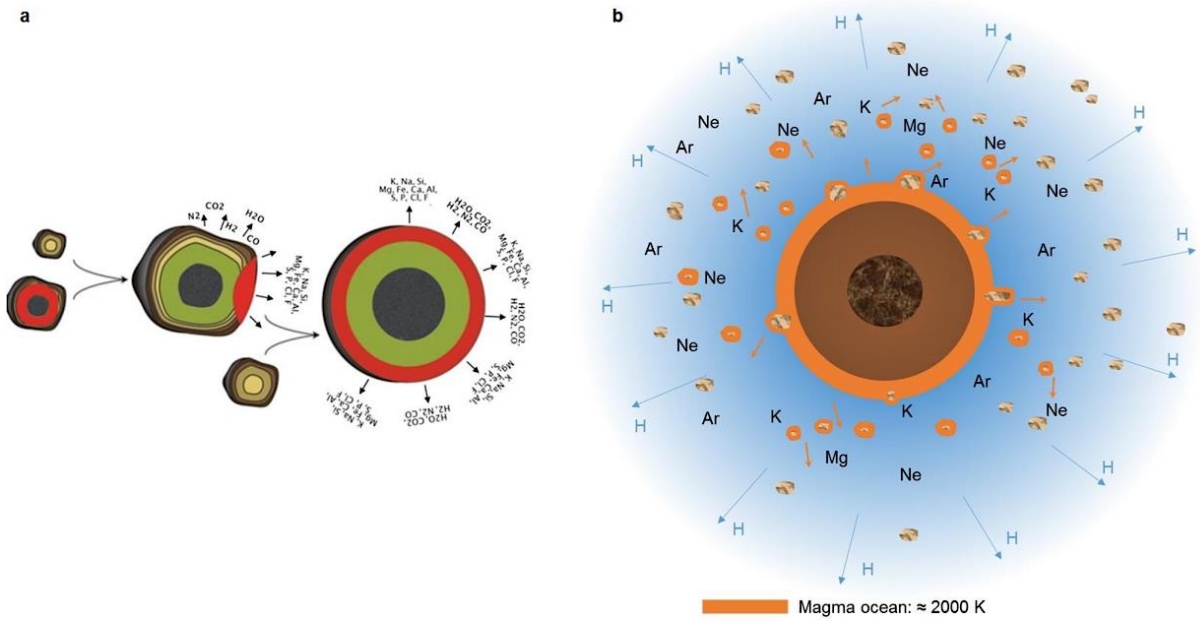

Fig. 14. Lammer et al. 2020a, p. 23. (a) Illustration of planetary embryo growth after Elkins-Tanton (2012) due to collisions between differentiated planetesimals/planetary embryos. The red areas correspond to magma from which various elements evaporate and can be lost directly at bodies with masses $\leq M_{\text{Moon}}$ (Benedikt et al. 2020; Young et al. 2019) and by dragging of hydrodynamically escaping H atoms dissociated either from H_2O molecules originated from catastrophically outgassed steam atmospheres during magma ocean solidification (Benedikt et al. 2020) or (b) from remnants of captured H_2-dominated nebula-based envelopes (Lammer et al. 2020b).

As Lammer and colleagues (2020a) suggest,

> Depending on the redox state, these catastrophically outgassed atmospheres contain H_2, CO (reduced interior) and/or H_2O and CO_2 (oxidized interior;

Nikolaou et al. 2019). The outgassed amount per element depends on the bulk composition of a particular planetary embryo and the solidification process of the mentioned magma ocean (e.g., Nikolaou et al. 2019; Salvador et al. 2017; Elkins-Tanton 2012, 2008) (19).

The variations of isotopes and volatile elements in different planetary reservoirs keep information about atmospheric scape, composition, and the source of accreting materials. For instance, the earliest atmospheric records of Venus, Earth and Mars are stored in the noble gases and their isotopes. The reason is that these elements do not react with other atmospheric species or the surface. Noble gas elements such as Ne (Neon), Ar (Argon), Kr (Krypton) and Xe (Xenon) and their isotopes contain historical records related to the early evolutionary processes starting during the accretion phase of planetesimals to planetary embryos before and after disk dispersal.

4.3 Chondrite Meteorites and Chondrules

The minerals that form carbonaceous chondrites can synthesize carboxylic acids, amino acids, and all the nitrogenous bases that form ribonucleic acid (RNA), the precursors of the first living organism. The excess of highly siderophile elements in the Earth's mantle is thought to reflect the addition of primitive meteoritic material after core formation ceased. The isotope composition of the siderophile element ruthenium (Ru) in solar system objects, including Earth and the parent bodies of chondrite meteorites, suggests that Earth’s volatile element budget may have been acquired much earlier (Fischer-Gödde and Kleine 2017), perhaps during its main accretion phase. New planet formation models based on the rapid accretion of pebbles onto asteroidal seeds suggest that Earth’s main accretion phase may have been completed within the ~5 Mya lifetime of the protoplanetary disk (Johansen et al. 2015). Elucidating the accretion history of Earth, including the timing of the addition of volatile elements, is critical for a

complete understanding of the timescales of terrestrial planet formation.

Schiller and colleagues (2020) propose that mass-independent isotope variability of nucleosynthetic origin among early solar system objects can be used to track the source and nature of the material precursor to the terrestrial planets. For example, the nucleosynthetic Iron (Fe) isotope composition ($\mu^{54}Fe$) of various meteorites shows that the only material matching the terrestrial composition is CI (Ivuna-type) carbonaceous chondrites that fell in Tanzania (1938), which represent the bulk solar system composition.

> Iron is a redox-sensitive siderophile major element whose partitioning between mantle and core is a proxy of the overall oxidation state of a planet. Iron readily oxidizes in the presence of water, substantially lowering its partitioning into the metal core (Clesi et al. 2016; Righter and Drake 1999). Therefore, if Earth became more oxidized during accretion and core formation, the mass-independent Fe isotope composition of Earth's mantle is predicted to be dominated by that of the late accreting material (Schiller et al. 2020, 1).

The existence of nucleosynthetic Fe isotope variability in solar system objects can provide an insight into the source of the material responsible for the delivery of water to Earth and the subsequent oxidation of Earth's mantle.

4.3.1 Chondrules

Most hypotheses postulate that chondrules originated from melting early formed dust by either localized or nebula-scale energetic events in the gas-rich stage of the protoplanetary disk. Simon and colleagues (2018) corroborate that the more refractory mineralogy of CAIs implies that they formed from precursor materials that condensed out of nebula gas at a high temperature (Grossman et al. 2002), perhaps closer to the protosun, or at an earlier, hotter nebula stage. Also,

there is evidence from radioisotopic age constraints that CAIs might be as much as ~2 Ma older than chondrules (Connelly et al. 2012).

Chondrules are the critical building blocks of planets. The main constituents of chondritic meteorites are primitive fragments of planetary bodies. A chondrite is a stony meteorite with chondrules, an example of a primitive meteorite that has not been altered since its formation in the solar nebula. Johansen and colleagues (2015) point out that their constituent particles allow us to study the first stage of planet formation, in which micrometer-sized dust grains grow to asteroid-scale planetesimals.

> Chondrules dominate the mass budget of most chondrite meteorites; they are millimeter-sized glassy spherules formed by transient heating events in the protoplanetary disc (Krot et al. 2003). The small matrix grains that fill the space between these chondrules likely entered the meteorite parent bodies as accretionary rims on the chondrules (Metzler et al. 1992) (1).

According to Johansen and colleagues, chondrules from individual chondrite groups are formed in different regions of the protoplanetary disk. They are subsequently transported to the accretion regions of their respective parent bodies. The region of asteroid formation dominated by chondrules over time is comparable to the observed lifetime of the protoplanetary disk around young stars in the Galaxy (Haisch and Lada 2001). In this context, observing young stars of different ages is used to determine circumstellar disk lifetimes and, thus, the amount of time available for planet building around these objects. Furthermore, Johansen and colleagues (2015) report the results of a model where asteroids and planetary embryos grow by accretion of chondrules onto planetesimal seeds formed by streaming instability. Particles of large enough size to be concentrated by streaming instabilities could have been present in the early stages of

the protoplanetary disk when planetesimals formed. These particles include macrochondrules (Weyrauch and Bischoff 2012), chondrule aggregates (Ormel et al. 2008), and ice-rich pebbles.

> All of this drift rapidly moves toward the Sun because of gas drag. Therefore, we assume that centimeter-sized particles were only present in the earliest stages of the protoplanetary disc, whereas smaller chondrules existed during most of the disk's lifetime (Johansen et al. 2015, 2).

Chondrule-sized particles may have been able to remain in the asteroid belt because of stellar outflows (Shu et al. 1996) or advection with the outward-moving gas in the mid-plane layer of sedimented particles (Bai and Stone 2010). Also, chondrule accretion can promote the growth of the largest embryos from the Moon, Mars, and Earth masses. Johansen and colleagues (2015) indicate that the dominance of planetesimal accretion in the initial growth toward Moon masses occurs because chondrules couple tightly to the gas at 1 AU. One astronomical unit is the average distance from the Sun to the Earth. 1 AU in KM = 149,598,000 kilometers. The gas density is more than a factor of 10 higher than at 2.5 AU. This prevents sedimentation, such that all chondrule sizes are well mixed with the gas, and it reduces the cross section for accreting chondrules because tightly coupled particles cannot be accreted from the full Bondi radius.[3]

The growth of embryos and terrestrial planets is more rapid than in a planet with the mass of the Earth already formed after 1.5 Myr. The importance of chondrule accretion increases if chondrules in the terrestrial planet formation region are more extensive, up to 1 cm (macrochondrules). In this context, the pattern of our Solar System was mainly attained in the turbulent first million years of its lifetime, from which planetary bodies formed through the accretion of dust and pebble-like objects such as chondrules (Johansen et al. 2015). A later study by Simon and colleagues (2018) suggests that essentially spherical Magnesium-rich silicate

chondrule and calcium-, aluminum-rich refractory inclusions (CAIs) are essential components of primitive chondritic meteorites. The concentration of these early-formed particles by nebular sorting processes may lead to planetesimals' accretion, and the particles' size distributions may constrain the accretion process (Fig. 15).

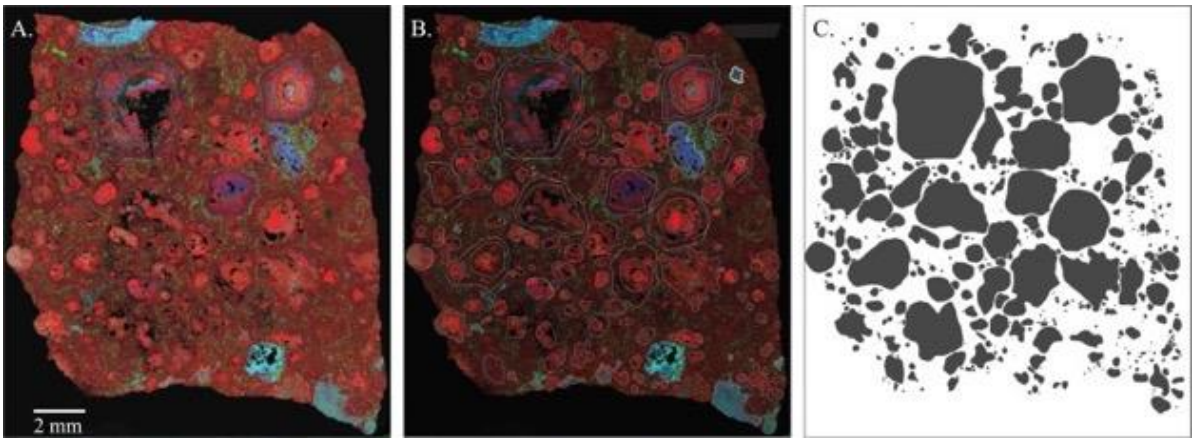

Fig. 15. Simon et al, 2018, p. 72. (A) Representative example of X-ray compositional images for one section of the Allende chondritic meteorite, with color coding. (B) Digitized particles, including rim(s) and (C) ChonMax particles, are shown in binary image.

Simon and colleagues present new particle size distribution data for Northwest Africa 5717, a primitive ordinary chondrite (ungrouped 3.05) and the well-known carbonaceous chondrite Allende (CV3). Largely spherical, magnesium-rich silicate chondrules constitute 30–80% of primitive meteorites and have been reported to be narrowly size-sorted (Ebel et al. 2016) as compared to more irregularly shaped, refractory CAIs that make up only 1–10% and thought to be less tightly sized-sorted (Hezel et al. 2008). The mineralogical, chemical, and isotopic composition of chondritic components provides important constraints on their initial formation conditions (Davis et al., 2018; Simon et al., 2018). However, for Simon and colleagues (2018),

> The characteristic distribution of particle sizes in primitive meteorites likely reflect a combination of how the various subgroups of particles initially

> formed (Charnoz et al. 2015), at different times and in different locations in the solar nebula, and how they were preserved and/or were concentrated (i.e., sorted) between formation and parent body assembly (70).

The compositional differences imply that they formed under different conditions and their likely age differences. An example of the broad size distribution of particle sizes measured across particle subtypes is shown in Allende (ChonMax and inclusions). ChonMax, AllchonCore, Rimmed, CoreWRim, and CoreNoRim are different ways to group chondrule subtypes, i.e., individual particles can belong to multiple groups. Allende is a well-studied CV3 oxidized carbonaceous chondrite that contains a range of nebular components, including a diversity of chondrule types and refractory inclusions like calcium, aluminum, and titanium. A more recent study by Oba and colleagues (2022) in three carbonaceous chondrites (Murchison, Murray, and Tagish Lake) has identified pyrimidine nucleobases of DNA and RNA nucleic acids, which contains the instructions to build and operate every living being on Earth.

> There are two types of nucleobases present in DNA and RNA: pyrimidine nucleobases that consist of a single six-membered nitrogen (N) heterocyclic ring whose N atoms are always in the one and three positions and include cytosine ($C_4H_5N_3O$), uracil ($C_4H_4N_2O_2$), and thymine ($C_5H_6N_2O_2$), and purine nucleobases that consist of six-membered and five-membered two ring N-heterocyclic structures whose N atoms are always in the 1, 3, 7, and 9 positions, including adenine ($C_5H_5N_5$) and guanine ($C_5H_5N_5O$) (Oba et al. 2022, 1).

According to Oba and colleagues, a diverse set of exogenous meteoritic organics, including Nucleobases may have been delivered to the early Earth during the late heavy bombardment period ~ 4.0 – 3.8 Gya (Ehrenfreund and Charnley 2000; Chyba and Sagan 1992) therefore, the

influx of such organics is considered to have played an important role in the chemical evolution of the Earth's primordial stage. Thus, an exogenous source (e.g. meteorites, comets, and interplanetary dust particles) that delivered organic molecules may have facilitated prebiotic reactions on the early Earth.

4.4 Earth

Earth is ~ 4.75 Gya old or more according to present estimates and began hot after the moon-forming impact and cooled to the point where liquid water was present for approximately 10 million years. Subsequently, the meteorite bombardment impacts may have briefly heated surface environments, leaving only hyperthermophile survivors like archaea and bacteria in rocks from Precambrian deep-sea vents (Sleep 2011; Stetter 2006; Brasier et al. 2002; van Zuilen et al. 2002; Schopf and Packer 1987). Expelled by impacts, microbes could have spread between the planets and moons of the early Solar System. Only superheat-loving microbes similar to the hyperthermophiles (Stetter 2006) would have striven and survived in the early times of life on Earth. By about 4.5 Gya, the moon-forming impact turned the Earth into a hot silicate atmosphere that cooled and condensed over ~ 1,000 years. As it cooled, the Earth degassed its volatiles into the atmosphere. It took another ~ 2 Mya for the magma ocean to freeze at the surface. The cooling rate was determined by atmospheric thermal blanketing. Tidal heating by the new Moon was a significant energy source for the magma ocean. After the mantle solidified, geothermal heat became climatologically insignificant, which allowed the steam atmosphere to condense and left behind a ~100 bar, ~500 K CO_2 atmosphere (Zahnle et al. 2007). Magma oceans with radiating temperatures ~ 2,500° K (2226.85 °C) forced all water from early accretion into the gas phase and converted all early accreted carbon to atmospheric carbon dioxide (CO_2) (Arndt and Nisbet 2012; Zahnle et al. 2007).

It is believed that life arose on Earth in a Hadean realm hidden from the rock record (Chyba 1993; Cloud 1988). For instance, Cloud used 3.8 Gya, while others have used 4.0 Gya. At present, all these definitions are equal. Chyba's (1993) study of the dating of terrestrial fossils and returned lunar samples reveals that the origin of life on Earth is violent and impact-ridden.

> Both microscopic fossil and fossil stromatolites (macroscopic structures formed by sediment-trapping algae) require life to have originated on Earth prior to 3.5 thousand million years ago (Gya) (Schopf and Walter 1983; Walter 1983). Controversial evidence for biologically mediated carbon isotope fractionation suggests that life may already have existed by 3.8 Gya (Schidlowski 1988). The terrestrial origin of life must have therefore coincided with the last stages of the heavy bombardment of the inner Solar System, during which those planetesimals remaining from planetary accretion were largely swept up or scattered (3351).

This bombardment is known primarily from samples returned from the Moon and determined by their radioactive dating and cumulative lunar crater density (for craters with diameters greater than 4 km) as a function of surface age–Basaltic Volcanism Study Project (BVSP I981). Chyba suggests that the early bombardment declined in intensity (roughly exponentially) through two to three orders of magnitude, dropping to its present comparatively low level by about 3.5 Gya. Similarities in plots of crater frequency as a function of crater diameter for the Moon, Mars, and Mercury have been interpreted to imply that all these worlds were bombarded by the same population of objects in early Solar System history (Strom et al. 2005; Strom 1987). According to Strom and colleagues (2005), the accretional remnants in the outer Solar System may have been in planetocentric orbits. They may represent remnants left over from the accretion of each satellite system. It is probable that before ~3.8 Gya, Earth was struck several times by objects

with impact energies sufficient to vaporize the entire terrestrial ocean, producing a greenhouse effect. Such impacts would effectively heat-sterilize the Earth to a depth of hundreds of meters. Whether this is equivalent to sterilizing the Earth depends on whether life originated and had time to evolve into protected niches at depths sufficient to be insensitive to surface heating and otherwise not fatally influenced by altered surface conditions. According to Chyba (1993), were the origins of life still ongoing at the time of such a giant impact, it seems likely that the result would be to reset the clock for life's origins; therefore, there may have been several "impact frustrations" (Oberbeck and Fogleman 1989; Maher and Stevenson 1988) of the origins of life (3352). It is possible that life arose on Earth many times, in many ways, and was wiped out by the impact of asteroids and comets. Perhaps the limiting factor for life's origins on Earth was not the chemical reactions but rather the time needed for Earth to settle down. As an example, the latter age is some 150 million years less than accretion at 4.56 Gya and merely 100 million years after the impact of the planetesimal Theia that led to the formation of the modern Earth-Moon system and the start of the Hadean (Goldblatt et al. 2010; Halliday 2005). The Great Impact Hypothesis suggests that ~ 4.5 Gya, a Mars-sized protoplanet labelled Theia, collided with Earth in the solar system's formative years.

4.5 Water

By 4.3 to 4.2 Gya, Earth had cooled sufficiently enough that there was liquid water (Mojzsis et al. 2001). Mojzsis and colleagues present insights into Earth's surface conditions based on a Hf (natural hafnium) isotope of detrital zircons of the crust-mantle evolution from the Narryer Gneiss Complex in Western Australia. The crystallization of Hadean zircons containing heavy oxygen isotopic compositions suggests the existence of a hydrosphere at or near the Earth's surface within about 200 million years of terrestrial core formation and the origin of the Moon at

4.5 Gya (Halliday 2000). Mojzsis and colleagues mention, "Liquid water, a source of energy, and organic raw materials are assumed to be necessary for the origin and propagation of life" (180). These results raise the possibility that a biosphere could have arisen on Earth at least 4.0 Gya, and the ocean volume in the Archaean was about twice as deep as today's (Arndt and Nisbet 2012; Sleep et al. 2011; Zahnle et al. 2007; Bounama et al. 2001; Lecuyer et al. 1998).

Water is cycled continuously through the modern mantle; the cycle starts with the degassing of magmas as they erupt at midocean ridges, oceanic islands, and island arcs via a process that feeds water and other gases into the atmosphere and hydrosphere. For Arndt and Nisbet (2012), this cycle continues with the hydration of basaltic rocks of the oceanic crust at mid-ocean ridges, and it terminates with the subduction of this hydrated crust back into the mantle. Some water cycles deep into the mantle, but most are liberated during dehydration of the altered oceanic crust. "The moderator of this cycle is the formation of hydrous minerals at low temperatures in the oceanic crust and the destabilization of these minerals as temperatures increase within the subducting slab" (527). These reactions occurred at shallower depths in the hotter Archean mantle and may have operated more efficiently. Hydrothermal convection currents started sequestering water to the primordial crust and mantle, which today bind one extra ocean volume (Fei et al. 2017; Hirschman 2006).

The first signs of life appear as carbon isotope signatures in Eoarchean rocks 3.95 Gya. (Tashiro et al. 2017). Thus, the first cells existed somewhere on the ocean-covered early Earth and in a narrow window of only about 200 million years. The genetic code (Kubyshkin and Budisa 2017) and amino acid chirality –a chiral molecule not superimposable with its mirror image (Haldane 1929)- are universal; all modern life forms trace back to that phase of evolution. That was when all cells' last universal common ancestor (LUCA) lived (Weiss et al. 2018).

Afterward, the emergence of life derives from taking the thermodynamic nature of living systems into account. This requires recognizing that living systems are inherently extremely far from equilibrium ("FFE") – that is, extraordinarily improbable and dynamic – organizations of matter (Branscomb and Russell 2019). In addition, Wimmer and colleagues (2021) argue that the role of water at origins differs widely in two perspectives. The view by Marshall (2020) suggests that "water is inhibitory at the origin of life because reactions that generate water, in particular polymerization reactions, proceed against the pushback of a 55 M product" (12).

Conversely, Do Nascimento Vieira and colleagues (2020) suggest that "water is essential to origins because it is both the solvent of all molecules of life and the most common reactant in microbial metabolic networks" (12). For Lamadrid and colleagues (2017), the hydrothermal alteration of mantle rocks (serpentinization) occurs in submarine hydrothermal systems and harbour abundant local microenvironments of low water activity. "Serpentinization affects the physical and chemical properties of oceanic lithosphere, represents one of the major mechanisms driving mass exchange between the mantle and the Earth's surface, and is central to the current origin of life hypotheses as well as the search for microbial life on the icy moons of Jupiter and Saturn (Lamadrid et al. 2017, 1). As we know, water is essential for life on Earth. However, "water molecules not only serve as a solvent and reactant but can also promote hydrolysis, which counteracts the formation of essential organic molecules" (Do Nascimento Vieira et al. 2020, 2717). Do Nascimento Vieira and colleagues asked, "How could hydrolysis have been regulated under prebiotic settings?" (2717). For Do Nascimento Viera and colleagues, the answer lies in geochemical sites with more bound water that supply the conditions for protometabolic reactions. Such conditions occur in serpentinizing systems, hydrothermal sites that synthesize hydrogen gas via rock–water interactions (Fig. 16).

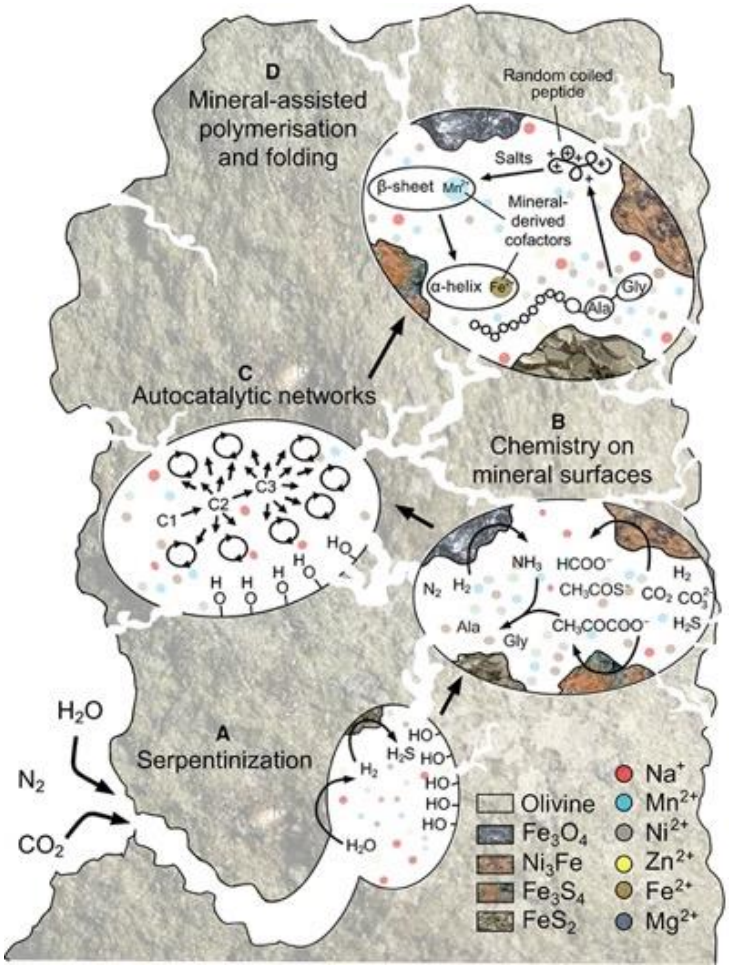

Fig. 16. Do Nascimento Vieira et al. 2020, p. 2726. Serpentinizing systems, water activities and origins. The figure schematically depicts hydrated pores (rock-bound water, hydroxyl groups) embedded in the olivine matrix of Serpentinising systems. (A) Serpentinization. H_2 is synthesized via interactions between water and olivine (for details, see). Catalytically active minerals, including magnetite (Fe_3O_4), iron sulphides (FeS_2, $Fe_3 S_4$) and Ni, Fe-alloys (Ni_3Fe) are constantly produced, whereas Fe_3O_4 arise from serpentinization, and sulphides and alloys as reaction products of H_2, H_2S and Fe^{2+} or Ni^{2+} ions. (B) Chemistry on mineral surfaces. With the help of such minerals as catalysts, N2 can be hydrogenated to ammonia (Kandemir et al. 2013; Schoonen and Xu 2001; Dörr et al. 2003), and CO_2 reduced to carbon compounds like a-ketocarboxylic acids (Preiner et al. 2020; Muchowska et al. 2019; Varna et al. 2018). The latter can react with activated ammonia to amino acids (Muchowska et al. 2019; Barge et al. 2019). Theoretically, also thioesters could be synthesized at this stage, although this is debatable (Reeves et al. 2014). (C) Autocatalytic networks. The reduction products could react to a variety of other N-containing carbon compounds like cofactors or nucleobases, especially in low water activity (high salt) conditions (Saladino et al. 2012 Heinz et al. 1979). Such complex monomers would fuel autocatalytic protometabolic networks (Xavier et al. 2020; Preiner et al. 2019; Steel et al. 2019). (D) Mineral-assisted polymerization and folding. Due to high salt concentrations and low water activity inside the pores, polymers such as polypeptides can form from amino acids

(Longo and Blabber 2014; Longo et al. 2013). Most folded proteins could achieve the necessary structure precision for their catalytic function without nucleic acids as templates, merely directed by water activity and salt concentration (Barbier and Brack 1992). They could concentrate substrates in their protected interior. Here, controlled hydrolysis (e.g., via trapped Mg^{2+} or Mn^{2+} ions and condensation reactions through mineral-derived cofactors could occur. Also, targeted CO_2 fixation would be possible in such protein pockets, using amino acids with nucleophilic side chains and incorporated transition metals such as Fe^{2+} or Ni^{2+} (Preiner et al. 2020; Varma et al. 2018; Fuchs 2011; Ragsdale and Pierce 2008). The micropores in ancient serpentinizing hydrothermal fields could be the earliest precursors of biological cells. All reactions described in this figure could subsequently happen in the same micropore, but pores at different physicochemical conditions may be needed for some of the stages to evolve. So, chromatographic effects (separation of products while migrating between two different pores) should be considered.

Serpentinization is a geochemical process that occurs when ultramafic rocks in the upper mantle interact with seawater drawn from cracks in the crust (Kasting and Holm 1992). The main gas-phase product of this process is molecular hydrogen (H_2), resulting from the reduction of water protons with iron minerals. Serpentinizing systems combine carbon, energy, and electrons in the form of CO_2 and H_2 in environments replete with low water activity (Martin and Russel 2007; Frost and Beard 2007; Nisbet and Sleep 2001; Holm 1992). According to Do Nascimento Viera and colleagues, serpentinization is widespread in today's oceanic crust (Holm et al. 2015; Früh-Green et al. 2004). Ultramafic, iron silicate-containing rocks react with seawater, release H_2, and are transformed into serpentine group minerals 'serpentinite,' $Mg_3Si_2O_5(OH)_4$ in the process—hence the name serpentinization.

Further, Wimmer and colleagues (2021) also indicate that the origin of life requires a source of energy to promote the primordial chemical reactions favourable to the thermodynamics of biosynthetic reactions in the Last Universal Common Ancestor (LUCA). The biosynthetic reactions of LUCA uncover a natural thermodynamic tendency of metabolism to unfold from energy released by reactions of H_2, CO_2, NH_3, H_2S, and phosphate.

The serpentinization process that underpins the formation of H_2 for CO_2

> reduction at metabolic origin entails rock-water interactions that consume about 20 molecules of H_2O per molecule of H_2 formed and about 100 molecules of H_2O per molecule of abiotic methane formed from CO_2 (Preiner et al. 2018). In the present calculations, water concentration is fixed at 55 M and cannot be changed in these calculations (Flamholz et al. 2012; Alberty 1998) (12).

Wimmer and colleagues suggest that water is the most common compound in the core reactions, appearing in 120 reactions, 97% of which are exergonic, regardless of whether water is consumed or produced against the 55 M gradient. From the thermodynamic perspective, H_2O exerts no inhibitory effect upon the reactions of core biosynthesis.

> The frequency of water as a reactant suggests that the reactions that gave rise to LUCA's metabolism arose in an aqueous environment, a premise preferable to the proposition that the chemistry of life began in non-aqueous environments and only later transformed *en masse* into the aqueous reactions of the cytosol (12).

The cytosol is the liquid component of the cytoplasm surrounding the organelles and other insoluble cytoplasmatic structures in an intact cell where various cell processes occur. In resume, Wimmer and colleagues (2021a) identified roughly 400 reactions used by archaea and bacteria to synthesize the amino acids, nucleotides and cofactors required for growth. Because these reactions are universal, they represent core biosynthetic metabolism in the last universal common ancestor (LUCA). As such, they can be seen as the endpoint of metabolic origin on the one hand and the starting point of physiological diversification on the other. Hence, since the beginning, water become essential to origins because it is both the solvent of all molecules of life and the most common reactant in microbial metabolic networks (Do Nascimento Viera et al. 2020).

4.6 Metabolism

Life on Earth involves chemical reactions by energy metabolism (Martin et al., 2021). Life requires a source of energy to drive the emergence of metabolism. Metabolic origin starts from the acetyl-CoA pathway of CO_2 fixation (Fuchs 2011; Fuchs and Stupperich 1986). Since it is linear and exergonic (Berg et al. 2010) and occurs in both archaea and bacteria (Fuchs 2011; Berg et al. 2010; Fuchs and Stupperich 1986; Rühlemann et al. 1985), it can be traced to the last universal common ancestor (LUCA) (Weiss et al. 2018, 2016). Hydrogen has been a source of electrons and energy since there was liquid water on the early Earth, and it fueled early anaerobic ecosystems in the Earth's crust (Arndt and Nisbet 2012; Sleep et al. 2011; Baross and Hoffman 1985). Preiner and colleagues' (2020) study suggests that Co_2 fixation by hydrothermal Hydrogen gas (H_2) within serpentinizing systems could have preceded and patterned biotic pathways.

> The acetyl-CoA pathway of CO_2 fixation uses the electrons and energy of H2 to simultaneously supply three key requirements for life: reduced carbon in the form of acetyl groups, electrons in the form of reduced ferredoxin and ion gradients for energy conservation in the form of ATP (Müller et al. 2018; Fuchs 2012)." (Preiner et al. 2020, 534).

For Preiner and colleagues, the acetyl-CoA pathway of CO_2 is linear, not cyclic; it releases energy rather than requiring energy input, and its enzymes are replete with primordial metal co-factors (Sousa and Martin 2014; Ragsdale and Pierce 2008). It traces to the last universal common ancestor (Weiss et al. 2016), and abiotic, geochemical organic syntheses resembling segments of the pathway occur in modern hydrothermal vents (McCollom 2016; McDermott et al. 2015) (Fig. 20).

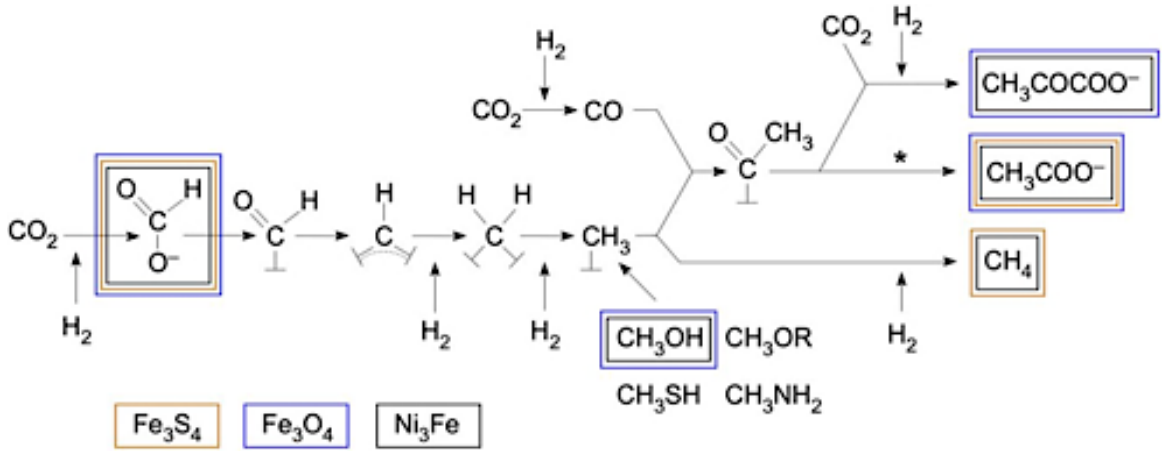

Fig. 17. Preiner et al. 2020, p. 539. Congruence between the acetyl-CoA pathway and reactions catalyzed by three iron minerals found in hydrothermal vents. The chemical reactions summarize the acetyl-CoA pathway as it occurs in hydrogenotrophic bacteria and archaea, as depicted in ref. (Fuchs 2011), with the exception of free formate, later discovered in the archaeal pathway (Wagner et al. 2016). The methenyl (=CH–), methylene (–CH_2–) and methyl (–CH_3) groups of the bacterial and archaeal pathways are bound to tetrahydrofolate and tetrahydromethanopterin, respectively, generically indicated here as catalysts (⊥). Colour-edged boxes indicate products observed in reactions using iron mineral catalysts. Asterisk indicates the reaction sequence in which energy is conserved as ATP via substrate-level phosphorylation in the biological pathway (acyl-nickel, thioester and acyl-phosphate intermediates employed by the enzymatic pathway for stepwise conservation of free energy in exergonic conversion of the nickel-bound acyl group to ATP (Fuchs 2011)…Methanol, methyl sulphide, methyl amines and methoxy groups from coal can serve as methyl donors for the pathway (Mayumi et al. 2016; Fuchs 2011).

4.7 Hydrothermal Vents

The discovery of deep-sea hydrothermal vent systems changed how scientists view the Earth's geological, geochemical, and ecological history. On February 17, 1977, the team led by Robert D. Ballard discovered the first chemosynthetic ecosystem at deep-sea hydrothermal vents in the East Pacific Rise mid-oceanic ridge. The Galápagos Rift Valley, along the boundary between the Cocos and Nazca tectonic plates, is where the sea floor is formed in a rift valley by continent-sized geologic plates slowly moving apart. Since this significant discovery, scientists have considered the idea, as one alternative to a prebiotic soup in shallow pools (Haldane 1929), that life might have originated at submarine hydrothermal vents (Baross and Hoffman 1985;

Corliss et al. 1981). Hydrothermal vents are one of Earth's earliest types of environments, having been a feature of our planet and the world's oceans since the Hadean, 4.6 – 4.0 Gya (Martin et al. 2008; Russell and Hall 1997).

It is hypothesized that life originated in the vent system because of its chemically reactive environment with suitable conditions and capable of sustaining prebiotic synthesis (Branscomb and Russell 2019; Martin and Russel 2007, 2003; Russel and Hall 1997; Russell et al. 1994). For Russel and Hall (1997), "The emergence of life is a geological issue. The question is how geochemical disequilibrium led to the first metastable metabolizing system" (378). Russel and Hall suggest that such a system was born of the attempts of hydrothermal fluid to reach equilibrium with the most ancient Hadean ocean, attempts that were continually frustrated by the spontaneous precipitation of an intervening iron monosulphide membrane (Russell et al. 1994). Many studies corroborate that life arose ~ 4.2 Gya in chemosynthetic ecosystems at deep-sea alkaline hydrothermal vents, and protocell membranes (Jordan et al. 2019; Branscomb and Russell 2019; Adam and Penner 2018; Deamer 2017; Lane and Martin 2012; Fuchs 2011; Nitschke and Russell 2009; Mulkidjanian et al. 2009; Deamer et al. 2002; Mitchel 1957) played a fundamental nexus role between cells and the Hadean Ocean. Also, it is hypothesized that the formation of the first cell as "internal" Niche Construction (Laland et al. 1999) through endosymbiosis (Margulis 1991) was the foundation for life and that subsequent niche constructions were iterative exaptations of that event (Gould and Vrba 1982).

Jordan and colleagues (2019), by creating protocells in hot, alkaline seawater (high on the pH scale), provided evidence that the origin of life could have been in deep-sea hydrothermal vents. Vesicles formed from single-chain amphiphiles (SCAs), such as fatty acids, probably played a key role in the origin of life. As stated, "we show that mixtures of these C_{10}– C_{15} SCAs

form vesicles in aqueous solutions between pH ~ 6.5 and >12 at modern seawater concentrations of NaC_l, M Mg^{2+} and Ca^{2+}. Adding C_{10} isoprenoids improves vesicle stability even further" (1705). Vesicles form most readily at temperatures of ~70 °C, requiring salinity and strongly alkaline conditions to self-assemble. Moreover, membranes, the nexus between cells and the environment, are fundamental to life. To Jordan and colleagues, "Beyond the requirement for compartmentalization, differences in ion concentration across the plasma membrane drive CO_2 fixation and energy metabolism in all modern autotrophic cells by vectorial chemistry" (1705). This deep conservation of membrane bioenergetics also points to the fundamental role of membranes at the origin of life (Lane and Martin 2012; Fuchs 2011; Nitschke and Russell 2009). In a minimal cell surrounded by an aqueous environment, it takes three main structures to build a primitive cell: RNA to store information, proteins to perform daily life tasks, and a cell membrane to keep everything in the same place (Cornell et al. 2019).

Furthermore, chemosynthesis uses chemical energy to fix inorganic carbon into organic carbon for microbial growth. Chemosynthetic bacteria and archaea form the foundation of vent ecosystems by exploiting the chemical disequilibrium between reducing hydrothermal fluids and oxidizing seawater, harnessing this energy to fix inorganic carbon into biomass (Dick 2019). Hydrothermal vents provide valuable insight into the environmental and ecological forces that shape microbial communities, and they help understand the limits, origins, and evolution of microbial life and metabolisms. For instance, Wimmer and colleagues (2021) state,

> In carbon metabolism, the acetyl-CoA pathway generates pyruvate as the main product (Fuchs, 2011) via reactions that require 10 enzymes and cofactors, yet those enzymes can be replaced by simple hydrothermal minerals such as awaruite (Ni_3Fe), which convert H_2 and CO_2 into formate, acetate, and pyruvate overnight

at 100 ^{o}C in water (Preiner et al., 2020), (2).

These findings connect the carbon and energy metabolism of acetogens and methanogens to spontaneous geochemical processes in H_2-producing hydrothermal vents via the chemical reactions of the acetyl-CoA pathway (Martin 2020). To Wimmer and colleagues, thermodynamic studies in geochemical systems also point to an origin of metabolism from H_2 and CO_2 in a hydrothermal setting, as the synthesis of amino acids (Amend and Shock, 1998) and even prokaryotic cell mass (Amend and McCollom 2009) from H_2, CO_2 and NH_3 is exergonic under the chemical conditions connected to H_2-producing hydrothermal vents.

4.8 LUCA

A single-cell, bacterium-like organism LUCA: the Last Universal Common Ancestor (Weiss et al. 2018, 2016; Martin et al. 2016), encapsulates life on Earth and emerges ~ 4 Gya in hydrothermal vents and is the progenitor of bacteria and archaea (Fig. 18).

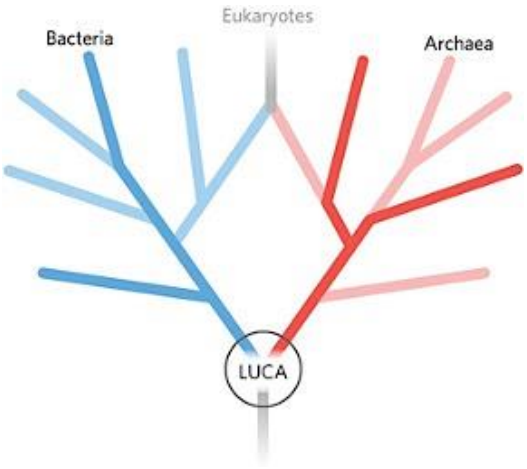

Fig. 18. Weiss et al. 2016, p. 2. Phylogeny for LUCA's genes. In the two-domain tree of life (Raymann et al. 2015; Williams et al. 2013), eukaryotes stem from prokaryotes, so the last universal common ancestor, LUCA, is the ancestor of archaea and bacteria. The tree shows a schematic phylogeny of phyla for a gene present in two archaeal and two bacterial phyla in which both prokaryotic domains are monophyletic. By applying the criteria—(1) the gene should be present in at least two members each of two bacterial phyla and two archaeal phyla (see Methods), and (2) the protein tree should recover the monophyly of bacteria and archaea—355 clusters were identified that trace to LUCA.

LUCA lived in iron-sulfur-rich hydrothermal vents and was anaerobic and autotrophic. It did not breathe oxygen and feed in a metal-rich environment around it. Its metabolism depended upon hydrogen, carbon dioxide and nitrogen, turning them into organic compounds such as ammonia. The study by Weiss and colleagues (2018) argues that one can ask questions about LUCA, and the most common way is to look for traits common to all cells, like ribosomes or the genetic code. In this context, comparative genomics and molecular phylogenetics are foundational for understanding biological evolution (Fig. 19).

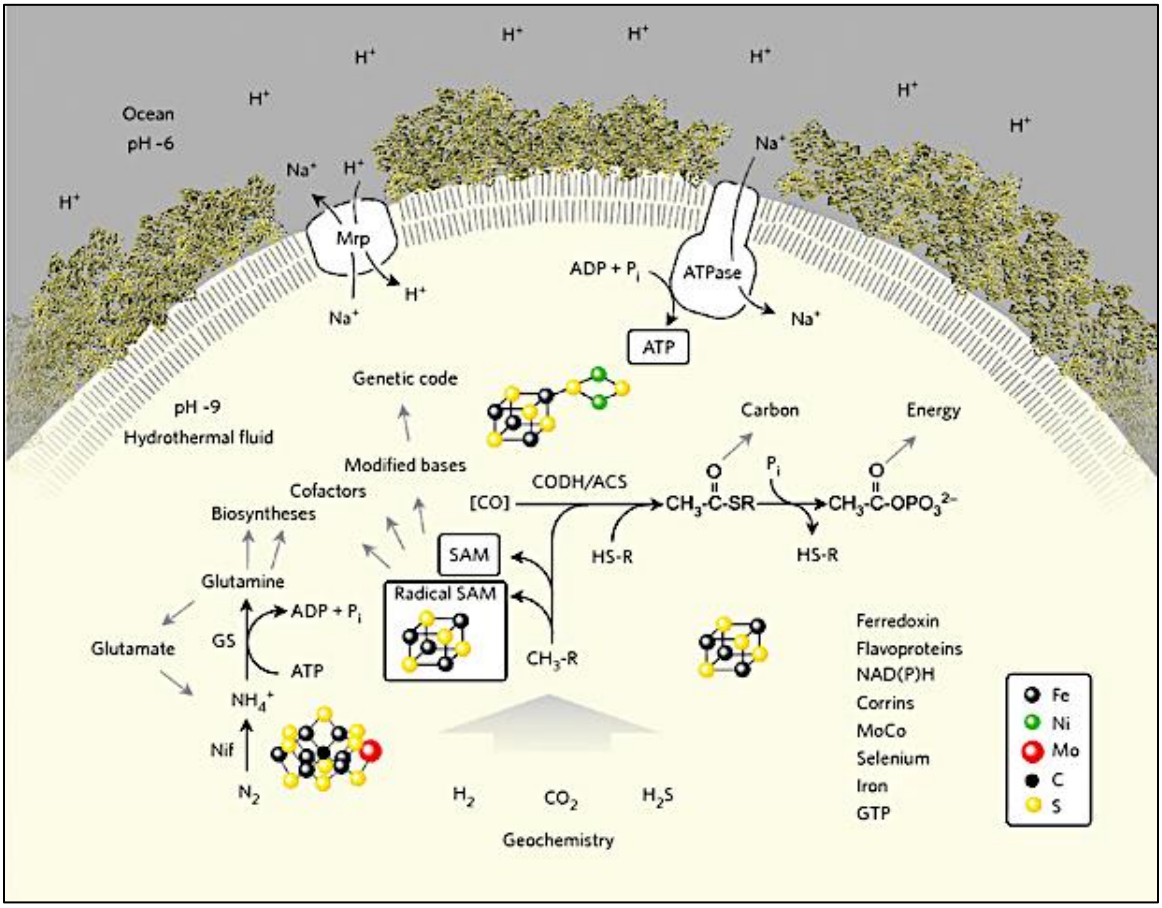

Fig. 19. Weiss et al. 2018, p. 8. “The physiology of LUCA.” Summary of the main interactions of LUCA with its environment, a vent-like geochemical setting (Lane and Martin 2012; Martin and Russell 2007; Russell and Hall 1997; Baross and Hoffman 1985). Abbreviations: CODH/ACS, carbon monoxide dehydrogenase/acetyl CoA-synthase; Nif, nitrogenase; GS, glutamine synthetase; Mrp, MrP type Na^+/H^+ antiporter; CH_3-R, methyl groups; HS-R, organic

thiols. The components listed on the lower right are present in LUCA, in addition to the cofactors. In modern CODH/ACS complexes, CO is generated from CO_2 and reduced ferredoxin (Ragsdale 2009). The figure does not make a statement regarding the source of CO in primordial metabolism (uncatalyzed via the gas water shift reaction or catalyzed via transition metals), symbolized by (CO). A Na^+/H^+ antiporter could transduce a geochemical pH gradient (indicated on the left) inherent in alkaline hydrothermal vents (Martin and Russel 2007; Russell and Hall 1997) into a more stable Na^+ gradient to feed a primordial Na-dependent ATP synthase (Lane and Martin 2012). LUCA undisputably possessed genes because it had a genetic code; the question of which genes it possessed has hitherto been more difficult to address. The transition metal catalysts at the nitrogenase active site and the CODH/ACS active site, as well as a 4Fe–4S cluster as in ferredoxin are indicated.

According to Weiss and colleagues (2016), genome data depict LUCA as an anaerobic, H_2-dependent thermophilic, diazotrophic autotroph with a WL pathway[4] that lived in a hydrothermal vent setting. Also, Martin and Sousa (2017) support that "early evolution occurred in the absence of molecular oxygen…In early evolution, O_2 can be neglected. Early microbial evolution was the age of anaerobes" (9). Archaea and bacteria were anaerobes and methanogens, and their gene distribution can be traced back to the LUCA.

The individual biochemical reactions underpinning the synthesis of amino acids, nucleotides and cofactors in modern cells trace back to LUCA because of their universality (Wimmer et al. 2021). From this standpoint, LUCA's exergonic nature allows the coupling of H_2-dependent CO_2 reduction to ion pumping and ATP synthesis, as in acetogens (Schuchmann and Müller 2014) and methanogens (Thauer et al. 2008), strict anaerobes that obtain both their carbon and energy from the reduction of CO_2 with H_2. Organisms that use the acetyl-CoA pathway still inhabit H_2-producing geochemical systems (Smith et al. 2019; Magnabosco et al. 2018), habitats that existed on the early Earth (Sleep et al. 2011). Wimmer and colleagues, by calculating values of 1G across the conserved and universal core of 402 individual reactions that synthesize amino acids, nucleotides, and cofactors from H_2, CO_2, NH_3, H_2S and phosphate in modern cells study, they found that "the 402 reactions of the biosynthetic core trace to the last

universal common ancestor (LUCA) and reveal that synthesis of LUCA's chemical constituents required no external energy inputs such as electric discharge, UV-light or phosphide minerals" (Wimmer et al. 2021, 1). As said, the biosynthetic reactions of LUCA uncover a natural thermodynamic tendency of metabolism to unfold from the energy released by the reaction of H_2, Co_2, H_2S, and phosphate. In addition, the study by Martin and colleagues (2021) on the setting of origins state,

> Concerning the transition from simple chemicals to systems of molecular self-organization, few hypotheses have clear concepts, help coming from network theories and concepts of autocatalysis (Xavier et al. 2020; Hordijk et al. 2012). The flux into and out of a steady state pool of reproducibly formed molecules (a metabolic "identity") has to be or become stable enough for them to form increasingly complex structures, ultimately seeding a process that we would describe as evolution today (9).

To Martin and colleagues, this leads to roughly seven phases in the origin of life hypotheses:

1. The initial setting and medium, including soluble materials and catalysts.
2. Generation of organic molecules—substrates and energy.
3. Concentration of organics.
4. Increased molecular system complexity.
5. Stable but far from equilibrium environment fostering the newly formed system.
6. Emergence of the first free-living cells.
7. The lifestyle of those first cells (10).

The setting of alkaline vents continuously synthesizes systems of inorganic microcompartments

that can concentrate the products of organic synthesis where they are made, offering a means to concentrate the products so that they can react further. According to Martin and colleagues, "the continuous supply of H_2 interfacing with inexhaustible reserves of CO_2 on the early Earth provides a continuous source of chemical energy to drive the system towards higher complexity" (12). In the continuity of this reaction, the first cells to emerge from the vent system have a carbon and energy metabolism that is based on the exergonic reaction of H_2 and CO_2, in which the cells synthesize acetate (acetogenic bacteria) or methane (methanogenic archaea) (Martin 2020; Martin 2008; Martin and Russel 2007) as the main product of energy metabolism. In this view, the first free-living cells were acetogens and methanogens, the starting point for further physiological evolution (Martin 2017). This narrative addresses the seven criteria outlined above in a level of explicit detail that others do not; it is compatible with the LUCA inferred from genomic reconstructions (Weiss et al. 2018, 2016) while, at the same time, connecting the origin of life narrative with actual microbial cells that still grow in such environments today.

4.9 Archaea

The proposed mechanisms for the origin of life on Earth include endosymbiosis and panspermia, and in both theories, archaea and bacteria are thought to have initiated an oxygenated atmosphere, creating new forms of life. The discovery of archaea by Woese and Fox (1977) demonstrates that life was divided into three primary lineages. The phylogenetic analysis of ribosomal RNA sequence characterization reveals that living systems represent one of three lines of descent: "(i) the eubacteria, comprising all typical bacteria; (ii) the archaebacteria, containing methanogenic bacteria; and (iii) the urkaryotes, now represented in the cytoplasmic component of eukaryotic cells" (1). For Woese and Fox, the third kingdom is represented by the methanogenic bacteria, a class of anaerobes with a unique metabolism that reduces carbon

dioxide to methane. The antiquity of the methanogenic phenotype plus the well-suited type of environment presumed to exist on Earth ~ 3 to 4 Gya led the authors to name this urkingdom the *archaebacteria*. Further studies by Bult and colleagues (1996) completed the first genome structure of an archaeon, *Methanococcus jannaschii*. Based on this experimental work, they found that archaea are related to humans and eukaryotes. Moreover, molecular evidence suggested that eukarya represented a sister group of archaea or that eukaryotes descended from archaea. Recent studies even hypothesize that eukaryotic hosts evolved from an archaeal ancestor in which numerous components with eukaryote-specific features are found (Adam et al. 2017; Spang et al. 2015).

Archaea are unique organisms for exploring the diversity of life and have the most extended evolutionary history on Earth (Medina-Chávez and Travisano 2022). They are foundational in the evolutionary origins of eukaryotes (Zaremba-Niedzwiedzka et al., 2017; Spang et al., 2015). Both geological evidence and molecular dating indicated that methanogenesis originated very early, and methanogens may represent one of the earliest life forms (Wang et al. 2021). Methanogens are obligate anaerobic archaea that produce energy from the biosynthesis of methane (Barlow et al., 2018). Archaea are genetically the most diverse taxa of life (Eme and Doolittle 2015); they live in exceedingly diverse habitats, including the most extreme environments, such as hydrothermal vents, terrestrial hot springs, and our guts.[5] They are also found in a diverse range of highly saline, acidic, and anaerobic environments that can be used as a proxy for studying life on other planets (Medina-Chávez and Travisano 2022; Baker et al. 2020). Furthermore, recent genomic findings in Asgard archaea show that they carry several genes formerly believed to be eukaryotic specific. This study of early events during eukaryogenesis and oxygen in Earth's history by Mills and colleagues (2022) indicate that

despite the influence of the serial endosymbiotic theory (SET) (Taylor 1974; Margulis 1967) on decades of eukaryogenesis research, "its metabolic and biogeochemical context requires considerable updating. Foremost, the discovery of hydrogenosomes (H_2 – generating organelles that synthesize ATP independently of O_2) and their common ancestry with aerobic mitochondria suggest a potential role for anaerobic energy metabolism during eukaryogenesis" (Mills et al. 2022, 520). The study by Mills and colleagues (2022) suggests that Eukarya arose from Archaea and are specifically related to newly discovered archaeal species with eukaryote-like features (Fig. 20).

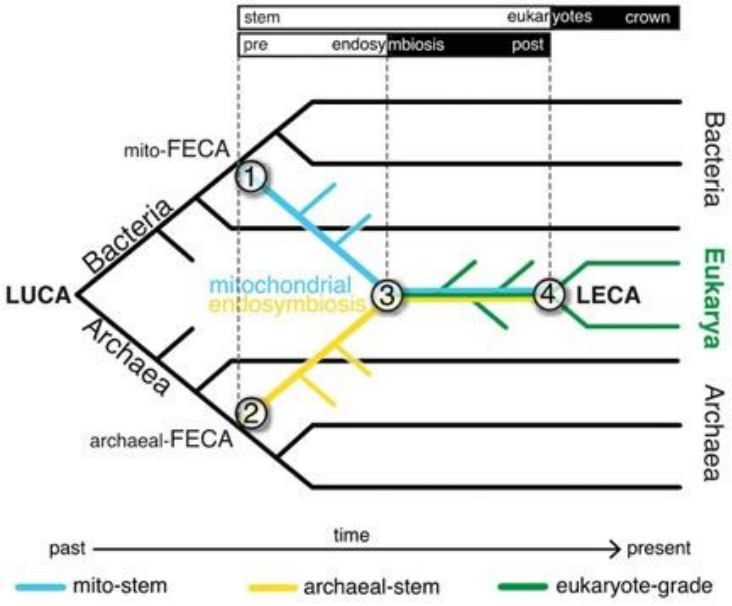

Fig. 20. Mills et al. 2022, p. 524. The many ancestors of eukaryotes. Eukaryotes can be determined to have possessed at least two FECAs, one reflecting divergence of the ancestral mitochondrion from its free-living α-proteobacterial relatives (mito-FECA; (1) and the other reflecting divergence of the eukaryotic host cell from its archaeal relatives (archaeal-FECA; (2). Eukaryotes, therefore, have at least two stem lineages: the lineage belonging to the archaeal host cell (yellow) and the lineage belonging to the ancestral mitochondrion (blue). The coalescence of these two stem lineages at mitochondrial endosymbiosis (3) may represent the achievement of a eukaryote-grade organization (green). Nevertheless, the eukaryote stem lineage continues through to the LECA (4), which is the last common ancestor of all living eukaryotes. LUCA is the last universal common ancestor.

Mills and colleagues claim that "the discovery and cultivation of the Asgard archaea has

reinforced metabolic evidence that eukaryogenesis was initially mediated by syntrophic H_2 exchange between an archaeal host and an α-proteobacterial symbiont living under anoxia" (520). The mid-Proterozoic Eon's primarily anoxic and low-energy ecosystems more reasonably served as the necessary cradle of eukaryotic life (Müller et al. 2012; Mentel and Martin 2008). As Mills and colleagues (2022) explain this process,

> While the permanent oxygenation of the atmosphere above trace concentrations is now thought to have occurred 2.2 billion years ago, large parts of the deep ocean remained anoxic until less than 0.5 billion years ago. Neither fossils nor molecular clocks correlate the origin of mitochondria, or eukaryogenesis more broadly, to either of these planetary redox transitions. Instead, mitochondria-bearing eukaryotes are consistently dated to between these two oxygenation events, during an interval of pervasive deep-sea anoxia and variable surface-water oxygenation (520).

For instance, the Asgard archaea live in anoxic ocean sediments. They can live symbiotically with bacteria -- possibly the same situation that led to the "metabolic coupling" that created the first eukaryote cells. The presence of eukaryotic signature proteins and the affiliation of Asgard archaea in phylogenetic analyses appears to support two-domain topologies of the Tree of Life, with eukaryotes emerging from within the domain of archaea, as opposed to the eukaryotes being a separate domain of life (MacLeod et al., 2019).

4.10 Reflection

Humans' emergence from the ocean and LUCA possibly share cognition of molecular immune memory and the instantiation of self-reference consciousness in a mutualistic evolutionary niche. In this context, Cognition-Based Evolution claims that all biological and evolutionary

development represents the perpetual autopoietic defence of self-referential basal cellular states of homeostatic preference over billions of years. These states are attained and maintained through self-referential measurement of information and its communication. Furthermore, the multicellular forms, either biofilms or holobionts, represent the cellular attempt to achieve maximum states of informational distinction and energy efficiency through individual and collective means. Recent evidence indicates that humans are a multi-species collective functioning as a holobiont in partnership between our eukaryotic cells and the microbiome. To gain those protections, all holobionic ecologies are products of natural cellular engineering as mutualistic niche constructions.

4.11 Chapter Notes

1. The distributions of molecules across disks regulate the elemental compositions of planets, including C/N/O/S ratios and metallicity (O/H and C/H), as well as access to water and prebiotically relevant organics. Emission from molecules also encodes information on disk ionization levels, temperature structures, kinematics, and gas surface densities, which are all key ingredients of disk evolution and planet formation models. The Molecules with ALMA at Planet-forming Scales (MAPS) ALMA Large Program was designed to expand our understanding of the chemistry of planet formation by exploring disk chemical structures down to 10 au scales. The MAPS program focuses on five disks—around IM Lup, GM Aur, AS 209, HD 163296, and MWC 480—in which dust substructures are detected, and planet formation appears to be ongoing (Öberg et al. 2021).
2. Nitriles play a key role as molecular precursors in prebiotic experiments based on the RNA-world scenario for the origin of life. These chemical compounds could have been partially delivered to the young Earth from extraterrestrial objects, stressing the importance of

establishing the reservoir of nitriles in the interstellar medium (Rivilla et al. 2022). We report here the detection of the molecular cloud G+0.693-0.027 of several nitriles, including cyanic acid (HOCN), and three C_4H_3N isomers (cyanoallene, CH_2CCHCN; propargyl cyanide, $HCCCH_2CN$; and cyanopropyne (CH_3CCCN), and the tentative detections of cyanoformaldehyde (HCOCN), and glycolonitrile ($HOCH_2CN$). The molecular cloud G+0.693-0.027, located in the Milky Way Galactic Centre, represents an excellent candidate to search for new isocyanates since it exhibits high abundances of the simplest ones, HNCO and CH_3NCO (Rodriguez-Almeida et al. 2021).

3. The Bondi radius is a calculated radius of the region surrounding an astronomical object from which surrounding medium (gas, dust) is likely to be drawn in and accreted. It includes the effects of the (relative) speed of the object through the medium and the medium's density and sound speed. Accretion due to such material falling from within the Bondi radius is termed Bondi accretion. The Bondi radius calculation was developed by modeling the accretion by a compact object (black hole or neutron star) of the medium it passes through. The concept has since been applied to planet formation, i.e., protoplanets passing through the material of a protoplanetary disk.
4. The study by Wood and colleagues (1986) states: “The distinctive feature of any autotrophic pathway* is the mechanism by which CO_2 is converted to the initial organic compound used for the subsequent anabolic reactions of growth” (14). The authors define “autotrophic growth as the ability to synthesize all cellular constituents from CO_2 or CO, except vitamins and cofactors which are recycled in the metabolism” (14). Also, a recent study by Alves de Sousa and Soares Rosado (2019) on primordial metabolism suggests that the “Wood–Ljungdahl pathway (WL), or the reductive pathway acetyl-CoA, is the largest carbon fixation

pathway in anaerobic conditions (Wood 1991)" (335). Anaerobic acetogenic bacteria and methanogen archaea use these biochemical reactions.

5. For most of the history of science, the human body has been regarded as a solitary entity. Nevertheless, recent research on the human microbiome pinpoints the importance of the gut microbiome in human evolution. In trans-kingdom symbiosis, gut bacteria cooperate with their animal hosts to regulate the development and function of the immune, metabolic and nervous systems through dynamic bidirectional communication along the 'gut-brain axis' (Moysidou et al. 2021; Rampelli et al. 2021; Morais et al. 2020; Galland 2014). Gut microbiota modulates the development and homeostasis of the Central Nervous System in the context of immune, circulatory, and neural pathways (Ma et al. 2019; Tremlett et al. 2017). Finally, the field research under Dr. Karen Madsen's supervision was conducted at The Centre of Excellence for Gastrointestinal Inflammation and Immunity Research—CEGIIR, University of Alberta.

CHAPTER 5. Synapsis, Nervous System, Hippocampus

5.1 Introduction

This chapter has two goals: (1) to provide an overview of synapsis and the nervous system evolution and (2) to bring insights into the critical role of the human hippocampus in episodic and semantic memory, navigation, and the cognitive map.

5.2 Origin of the Synapsis and the Nervous Systems

The evolutionary origin of synapses and neurons is a complex topic of research. It appears that the synapse between neurons evolved from cell-to-cell communication. On this subject, Burkhardt and Sprecher (2017) take an integrative approach to consider non-bilaterian Metazoans[1] with and without neurons for containing many components of the molecular set of tools for synapse function. These components' origin and assembly into ancient synaptic signaling machinery evolved before synapses. According to Burkhardt and Sprecher, in close relatives of metazoans, some proto-synaptic genes seem to be co-regulated at the transcriptional level, suggesting that parts of the synaptic signaling machinery might have been co-opted from ancestral roles that may still be observable today in their close relatives. Choanoflagellate cells, for example, have evolved ways to connect.

> The specific upregulation of voltage-gated Na–channels and secretory SNAREs in *S. rosetta* colonies makes it tempting to speculate that choanoflagellate cells can communicate with each other by electrical and/or chemical signaling using proto-synaptic proteins… A picture is emerging where an ancestral secretion apparatus consisting of secretory SNAREs, Munc18, Complexin, and a Munc13-like protein is already present in close relatives of metazoans and thus probably originated

before the first metazoans emerged (8).

A key synapse process is the rapid release of neurotransmitters from synaptic vesicles. The central machinery involved in this process comprises members of the SNARE (soluble N-ethylmaleimide-sensitive factor attachment receptor) protein family (Fig. 21).

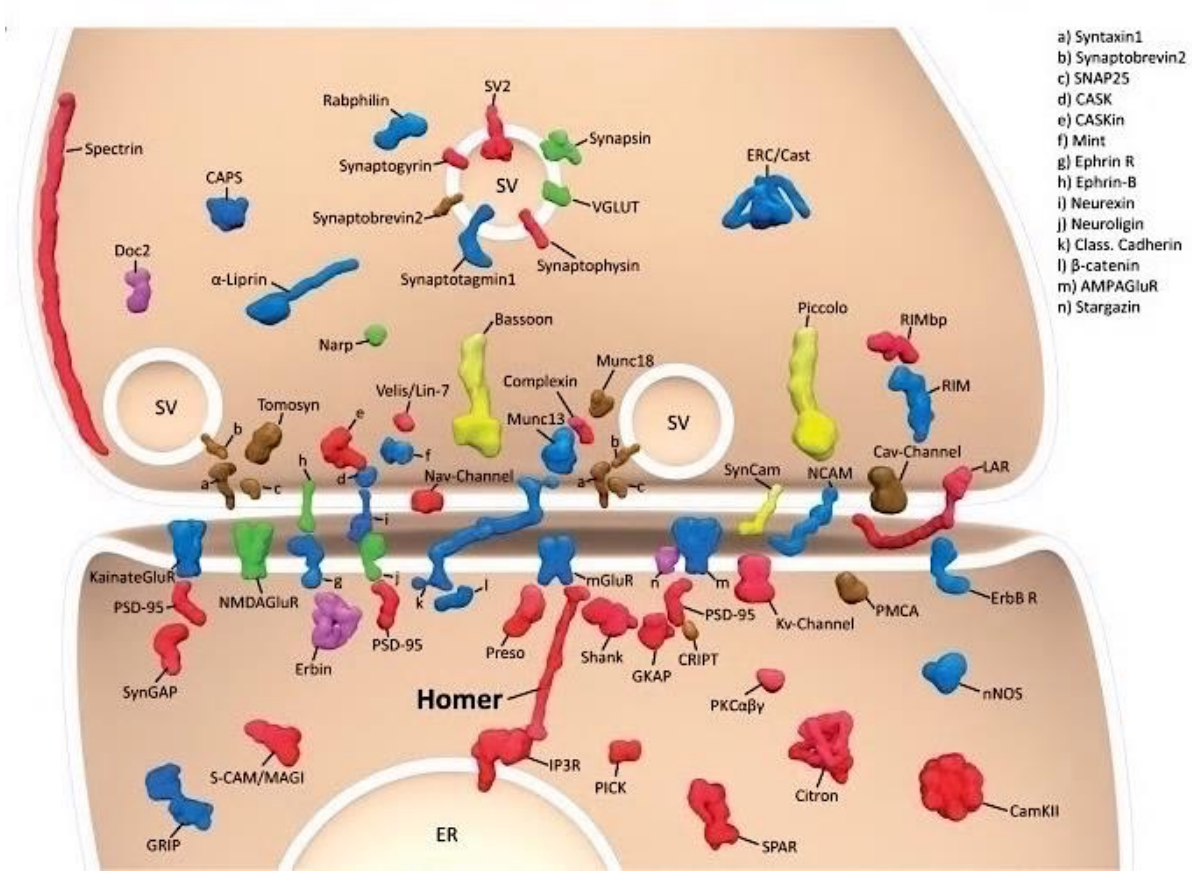

Fig. 21. Burkhardt et al. 2014, p. 2343. Graphic representation of an excitatory synapse indicating the subcellular contexts in which many pre- and postsynaptic proteins function. The phylogenetic distribution of each protein is indicated using the colour scheme in (A). SV, synaptic vesicle; ER, endoplasmic reticulum.

In vertebrates, the synaptic apparatus is mediated by the SNARE proteins synaptobrevin 2, syntaxin 1 and SNAP-25. Their assembly between the vesicle and target membrane is thought to drive membrane fusion (Burkhardt 2015). Conversely, Burkhardt and Sprecher (2017) state,

> A postsynaptic-like scaffold (a scaffold comprising of Dlg/PSD- 95, Homer, Shank and GKAP, which in metazoans with synapses clusters receptors at plasma membranes, likely evolved in metazoans only, despite the fact that these proteins are expressed in close relatives of metazoans and key residues for protein-protein interactions are present (8).

These findings show that close relatives of metazoans possess different precursors of synaptic activity, and to understand the origin of synapses and neurons, it is important to include them. The question is, how was the ancestral nervous system that gave rise to the human brain patterned? Michael Layden (2019) explains the similarities and dissimilarities of neuronal functions between species and clades and poses a fundamental question: did nervous systems evolve multiple times in animal evolution? For instance, Ctenophores (comb jellies) are the earliest diverging phylum whose species possess an apparent nervous system. The exact branching pattern of the early metazoans is contentious, but ctenophores represent either the oldest or second oldest branching metazoan phylum (Layden 2019; Simion et al. 2017). Also, most phylogenies place placozoans (simple animals that are marine and free-living), which do not have a nervous system, after the emergence of both ctenophores and poriferans (sponges). According to Layden (2019), "The placement of one or more animal phyla lacking nervous systems after ctenophore divergence challenges previous data that favoured a singular origin for all animal nervous systems" (152) (Fig. 22). Layden indicates that much of the evidence in support of the single origin stemmed from previous morphology-based phylogenies, which grouped ctenophores and cnidarians in the now non-existent group, the Radiata (Fig. 22A). However, "All three animal phyla possessing nervous systems shared a common ancestor suggesting that nervous systems arose once in the Radiata-Bilateria common ancestor" (153).

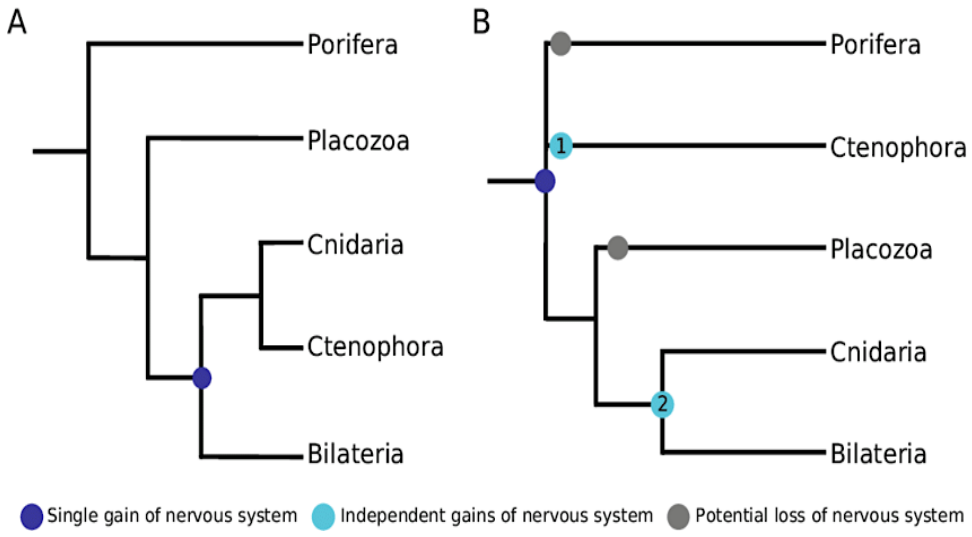

Fig. 22. Layden 2019, p. 153. Potential origins of animal nervous systems. (a) Traditional phylogenetic relationships of animals predicted a single origin for nervous systems in animals. (b) The inclusion of molecular data reorients the relationship of metazoan clades and suggests that nervous systems may have evolved multiple times.

This hypothesis was bolstered by identifying cross-reactive antibodies against neuropeptides that labeled neurons in all three groups, implying that bilaterian, cnidarian, and ctenophore neuronal subtypes partially overlap. However, it misses the genomic comparison of the molecular mechanism by which neurons function, the developmental patterning associated with proteins forming the nervous system tissue, and its functional conservation of ion channels.[2] "Nervous systems derived from a common ancestor should minimally have conserved ion channels that regulate electrical impulses using similar mechanisms, conserved pre- and postsynaptic proteins, and similar chemical neurotransmitters" (Layden 154). Remarkably, the study by Burkhardt and Sprecher (2017) argues that many critical postsynaptic proteins predate the emergence of animals. To better compare ion channels in animals, Liebeskind and colleagues (2015) found patterns of expansion and contraction indicative of extensive independent ion channel evolution within animal lineages. Ion channel proteins that drive impulse propagation are a convergent

feature of nervous systems regardless of whether they share a common ancestor. For Layden, "these findings equally support the possibility that a simplified nervous system existed in the ctenophore/cnidarian/ bilaterian ancestor or that nervous systems independently evolved at least twice" (156). Layden also proposes that the nervous system in the cnidarian/bilaterian ancestor most likely had a net-like architecture (Fig. 23).

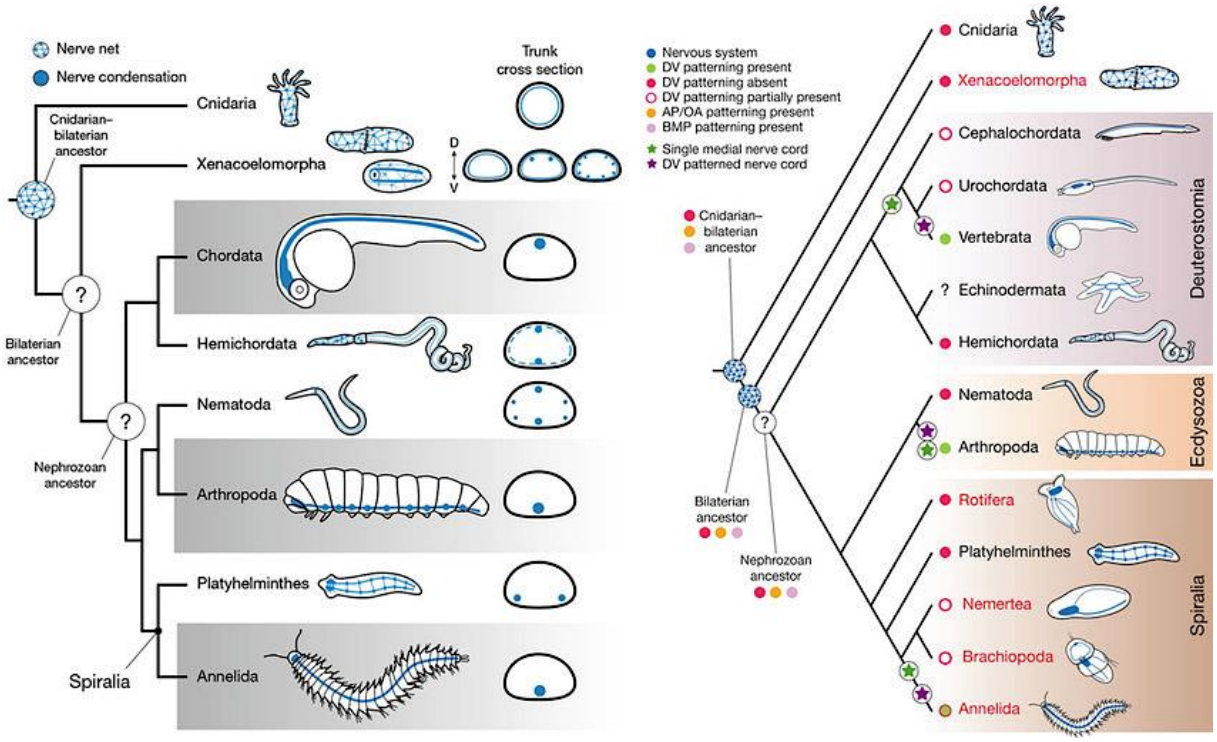

Figure 23. Layden 2019, p. 160. Origin and evolution of bilaterian central nervous systems. (a) Summary of neuroanatomy and potential origins of bilaterian central nervous systems. (b) Proposed scenario for neuroectodermal patterning during CNS development in bilaterians. The cnidarian/bilaterian ancestor possessed a nerve net and A-P patterning program. BMP activity patterned the axis perpendicular to the A-P axis (D-V in bilaterians). The ancestral bilaterian likely possessed a nerve net, but it is unclear whether the nephrozoan possessed a nerve net or CNS. D-V patterning is not tied to CNS patterning. Images adapted from Martín-Durán et al. (2018).

The nervous system has evolved many times and requires reorganizing the neuronal density to form a condensed brain and nerve cords. Layden states, "The notion that CNSs arose by

reorganization points to changes in developmental patterning being the most likely mechanism to explain its emergence" (159). In this framework, novel phylogenies incorporating molecular data have rearranged the bilaterian tree and described a new clade called the Xenacoelomorpha. The xenacoelomorphs are the most basally branching bilaterian group, and they represent the sister taxon to the nephrozoans (protostomes and deuterostomes). For Layden, "Xenacoelomorpha nervous systems are varied, and there are examples of nervous systems that fit the morphological definition of a centralized nervous system, and nervous systems organized as a nerve net (Martín-Durán et al. 2018; Perea-Atienza et al. 2015; Achatz and Martinez 2012)" (161). Either the CNSs evolved once in the urbilaterian, independently within the xenacoelomorphs and in the nephrozoan common ancestor, or independently within all three main bilaterian clades (xenacoelomorphs, protostomes, and deuterostomes). Further, Layden suggests that the initial evidence supporting a single origin of bilaterian CNSs comes from experiments conducted before xenacoelomorphs were recognized as a separate bilaterian clade, which said the CNSs evolved more than once. The issue for researchers trying to rationalize whether or not nephrozoan CNSs were homologous centered on the notion that, generally speaking, protostome nerve cords were positioned ventrally and deuterostome nerve cords were positioned dorsally.[3] The inversion model proposed by Saint-Hilaire (1882) suggested a homology of nervous systems even though they were formed in opposite regions of the embryo. In vertebrates, inhibition of BMP2/4 (Bone morphogenetic protein 2) signaling in the dorsal ectoderm was shown to be necessary for the specification of neural ectoderm[4] that gives rise to the CNS (Piccolo et al. 1996; Zimmerman et al. 1996). For instance, works in fruit fly (an arthropod like the lobster) determined that its CNS is derived from ventral lateral stripes of neural ectoderm specified where Dpp (the insect BMP2/4 homolog) activity is low (Francois et al. 1994). The evolution of an

extra-embryonic membrane in dipterans was accompanied by changes in the gene regulatory network controlled by the BMP/Dpp pathway, which is responsible for dorsal patterning in these insects. The highest source of Dpp activity in insects is dorsal, the opposite of vertebrates.

> In both insects and vertebrates, the central nervous system forms in a region with no or low Dpp/BMP2/4 activity, and the region of highest Dpp/BMP2/4 activity in arthropods and vertebrates is inverted relative to the other on the dorsal-ventral (D-V) axis BMP2/4 activity. The main conclusion that stemmed from this work was that the BMP2/4 is a conserved inhibitor of CNS specification in protostomes and deuterostomes and lent strong support to the notion that CNSs are derived from a common ancestral CNS that arises where BMP2/4 activity is inhibited. (Layden 162).

This discovery provides a resolution for two crucial issues: first, the data of the molecular program for including neural fates across multiple bilaterian lineages, and second, a mechanistic basis for the repositioning of a single molecule to explain the repositioning of the nerve cord on the bilaterian bauplan.[5]

5.2.1 The Chemical Synapses

A key factor driving the evolution of chemical synapses has been the selective pressure for developing multicellular living forms, with a pressing need for effective mechanisms enabling fast and temporally precise functional integration within growing biological organizations. Comparative genomic and proteomic studies suggest that the rise of metazoan dates back to ~1000 million years ago (Mya), followed by their extensive diversification during the Cambrian explosion ~ 540 Mya. The rise of specialized contacts for neurochemical integration has been

vital in advancing cell-to-cell signaling. It has also become a turning point in the evolution of the multicellular organization. Many molecular components of neurons, such as proto-synaptic proteins, evolved before neurons were present. According to Ovsepian and colleagues (2020), "Genomic and molecular analysis, has recently shown, that the majority of molecular scaffolds as well as the key ingredients of synapses, including proteins, are not neuron-specific, and most likely have emerged independently before the rise of neurons (Emes and Grant 2012; Ryan and Grant 2009)" (1). The systematic approaches to studying synapse evolution are based on proteomic, genomic, and coupled with molecular phylogenetics. This framework enables the identification of the specific adaptation that mediated the diversification and natural selection of synapses among species.

The study by Ryan and Grant (2009) demonstrates that knowing the proteomic composition of synaptic structures allows comparative genomics to deduce the composition of the last common ancestor of all synapses, the ursynapse. The question is how and why it originated by taking synaptic proteins identified in vertebrate model organisms and searching for orthologues in the genomes of two categories of organisms.

> The first category includes unicellular eukaryotes and multicellular metazoans that lack a nervous system and provide a means of identifying synaptic components that were present before the evolution of the nervous system. Such proteins, which make up the protosynapse, originated before the emergence of classical morphological synapses and have been coopted for synaptic roles. The second category is composed of nonbilaterian multicellular metazoans that have a nervous system, which allows the identification of synaptic components present in primitive synapses, giving us insight into the composition of the synapse at a

a relatively short time after it originated (Ryan and Grant 2009, 702).

For Ryan and Grant, the oldest synaptic protein families are still conserved in unicellular eukaryotes, such as the yeast *Saccharomyces cerevisiae* and the amoeba *Dictyostelium discoideum*. The calcium transporter PMCA (plasma membrane calcium ATPase) and protein kinase C (PKC) are found in both these unicellular species and also have fundamental synaptic roles in animals (Sakarya et al. 2007; Garcia and Strehler 1999; Muller et al. 1991). Ryan and Grant said the synapses would have evolved before axons and dendrites. An organism with a few strongly associated neurons would not need axonal projections for neuron-to-neuron communication. Therefore, synapse formation is a crucial step in the origin of the nervous system.

A further study by Grant (2016) on the molecular origins and evolution of the synapse indicates that via comparative genomics of synaptic proteins, all of the significant cell-biological processes of the pre-and postsynaptic terminal evolved in unicellular eukaryotes and that many of these proteins and pathways arose in prokaryotes (Emes and Grant 2012; Emes et al. 2008; Ryan and Grant 2009). Grant (2016) states that these include neurotransmitter release and response mechanisms—the vesicular release machinery and postsynaptic proteins mediating synaptic transmission and plasticity. “Hence, the synapse, which is the centrepiece of the metazoan brain, is built from molecular constituents that first evolved in unicellular organisms. These ‘protosynaptic mechanisms’ were coopted into the first nervous systems of metazoans” (2). In addition to revealing the molecular origins of synapses, comparative genomics and proteomics have discovered significant differences between invertebrate and vertebrate synapses. The molecular evolution of the synapse is summarized in (Fig 24). An important note is that despite synaptic proteins and scaffolds in all basal metazoan, the chemical synapse appears

earliest in Cnidaria and Ctenophora and is absent in their close relative Porifera (Kosik 2009; Westfall 1996). The sudden rise of the chemical synapse in Cnidaria and Ctenophora occurred in the absence of a large-scale reorganization of the synaptic genome (Kosik 2009), suggesting a significant unknown in the history of synaptic evolution and refutes the prospect of a gradual rise and incremental evolution of chemical synapses via small changes.

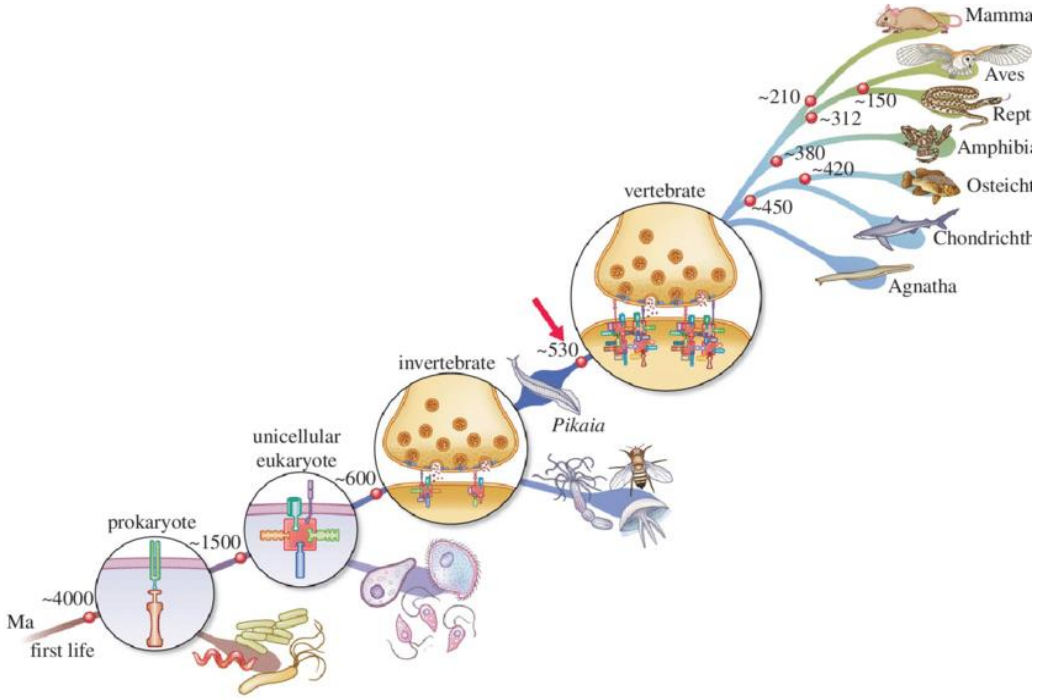

Fig. 24. Grant 2016, p. 3. Molecular evolution of the synapse. The postsynaptic proteins comprising the receptor and signaling machinery of vertebrate synapses arose in prokaryotes and eukaryotes and were coopted into the earliest metazoan synapses. The red arrow indicates the two genome duplications that expanded the numbers of proteins to produce the highly complex vertebrate synapse proteome around approximately 550 Ma. The subsequent radiation of vertebrate species is illustrated. Grant acknowledges the support of Debbie Maizels (Zoobotanica) for the illustration.

In addition, Ovsepian and colleagues (2020) extend the discussion of the evolutionary rise of the chemical synapse via co-option and reuse of the already existent essential morphological and molecular elements from non-neuronal ancestral forms for a new role in electro-chemical

integration. The merger of molecular scaffolds using diffuse paracrine signaling with junctional morphologies in early metazoan enabled close physical contact and exchange of molecules in unicellular eukaryotes and cellular colonies.

> The abundance of synaptic proteins with secretory and receptive elements in unicellular eukaryotes and primordial multicellular organizations devoid of neurons or synapses, and the existence of a variety of adhesion mechanisms relating independent cells in primitive cellular colonies (Ovsepian and Vesselkin 2014; Rokas 2008; King 2004) support such a possibility. In fact, the sudden rise of synaptic connections in basal metazoan without reorganization of the genome points toward the abrupt merger of release-receptive elements of paracrine transmission with morphologies enabling contacts for direct metabolic coupling in primitive cellular colonies (3).

Paracrine signaling acts locally between two close-together cells and moves them by diffusion through the extracellular matrix. Moreover, Ovsepian and colleagues suggest that in the nervous systems of invertebrates and developing vertebrates, the transitory metabolic coupling of neuronal precursors via junctional elements, as well as diffuse paracrine signaling, play a critical role in the landscaping and formation of definitive synaptic connections mediating chemical transmission. In synaptic evolution, direct contacts mediated via GJs (intercellular heterotypic gap junctions)[6] are regarded as the structural substrate for the electrical synapse.

> GJs along with electrical coupling can provide a passageway for the exchange of small molecules and metabolites, including $Ca^{2+,}$ cAMP, cGMP, IP3, and RNA in several cell types. These specialized connections not only enable fast and intimated exchange of signals between associated cells, but also play an essential

role in the formation of early contacts for the targeted exchange of chemical signals, which could lead to the rise of evolutionary precursors of chemical synapses (Ovsepian 2017; Ovsepian and Vesselkin 2014) (6).

The eclectic origin of the chemical synapse is supported via phylogenic and genetic evidence in Ctenophora and Cnidaria coincide with the occurrence of functional GJs in these species. In contrast, GJs are absent in Porifera, which also lacks chemical synapses (Abascal and Zardoya 2013; Shestopalov and Panchin 2008). The rise of two principal neuronal integration modes without a major genome reorganization implies their intimate evolutionary relationship in enabling complex mechanisms of cell-to-cell signaling (Fig. 25).

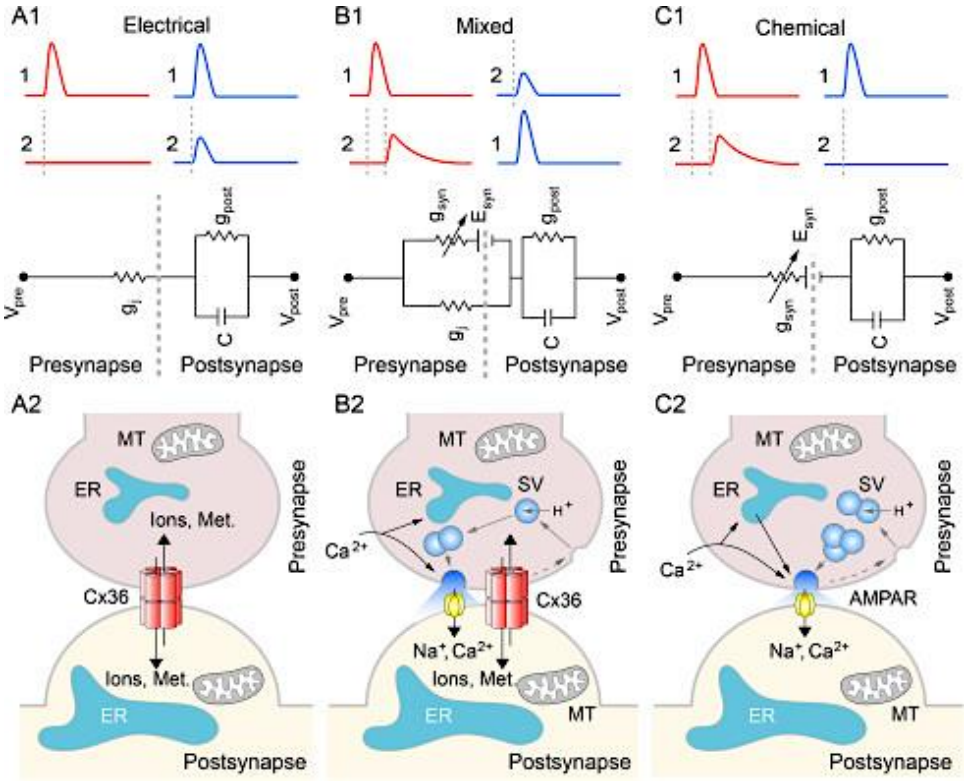

Fig. 25. Ovsepian et al. 2020, pp. 8–9. Principal modes of synaptic transmission. (A1— C1) Voltage dynamics in presynaptic and postsynaptic compartments related with synaptic transmission at electrical, mixed and chemical synapses (top) with equivalent circuits. Vpre, Vpost—membrane potential at pre- and postsynaptic compartments, respectively; gj, gsyn—

junctional and synaptic conductance, respectively; Esyn—synaptic reversal potential; C—membrane capacitance. Dashed line corresponds to the synaptic gap between the pre- and postsynaptic elements. At chemical synapses, upon arrival to the pre-synaptic terminal of the chemical synapse (right), the action potential triggers Ca^{2+} influx with transmitter release into the synaptic cleft with activation of postsynaptic response (1, 2 red; dashed line highlights the synaptic delay at the chemical synapse), which is abolished by synaptic transmission blockers (1, 2 blue) (C1). At mixed synapses (middle), in addition to chemical transmission (forward, red), depolarization can spread instantaneously across the synapse (1, 2 blue shows backward spread of depolarization; from post-to presynaptic elements; dashed line indicates the absence of synaptic delay due to direct coupling). Note that the voltage gradient is strongly attenuated at the GJ, due to the rectifying properties of GJ channels (B1). Finally, no forward chemical transmission can be detected at pure electrical synapses (1, 2 red), whereas a wave of excitation can instantaneously spread in both backward and forward directions (blue shows only backward spreading depolarization) (A1). (A2—C2) Schematic illustration of principal structural elements of electrical, mixed or chemical synapses. ER, SV, MT, and Cx36—endoplasmic reticulum, synaptic vesicles, mitochondria and hexameric connexin 36 channels, respectively.

The study by Ovsepian and colleagues indicates the emergence of the chemical synapse via co-optation with the tinkering of already-existent molecular scaffolds of paracrine transmission and cellular morphologies of GJs at dedicated synaptic sites. GJ coupling with an exchange of metabolites closely resonates with direct cell-to-cell connections in cellular colonies bound via cytoplasmic bridges. Currently, a large family of channel-forming GJ proteins (connexin (Cx) and their homologs) have been identified and cloned from various tissue types (Beyer and Berthoud 2018, 2017; Dermietzel 1998), with over 20 Cx genes identified in rodents and humans, of which five are highly expressed in the mammalian central nervous system (Elias and Kriegstein 2008). Such complementarity between the two principal modalities of neural integration and the prevalence of GJ in developing brains agrees with the binary homeostatic and integrative functions of mixed synapses. This is also in line with the well-established dynamic nature of GJ coupling, which also demonstrates the capacity to switch between metabolic and electrical integration modes. Upon merger with scaffolds and elements of chemical transmission, GJ contacts become capable of chemical transmission, forming mixed electrochemical synapses.

5.2.2 Synaptic Plasticity

Synaptic plasticity is the mechanism by which neural activity generated by an experience modifies brain function via modifications of the synaptic event or integration. It emphasizes the essential function of summation of excitatory and inhibitory postsynaptic potentials, thereby modifying subsequent thoughts, feelings, and behaviour. Nobel Prize recipient Santiago Ramon y Cajal (1906) revealed that the brain consisted of vast numbers of neurons communicating with each other through synapses.

Donald Hebb (1949) theorizes further that the neurophysiological changes underlying learning and memory occur in three stages: (1) synaptic changes, (2) formation of a cell assembly, and (3) formation of a phase sequence. Hebb states, "When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cats firing B, is increased" (62). A cell becomes more capable of firing another because the synaptic knobs develop and increase the area of contact between afferent axon and efferent soma (dendrites and body of the cell except its axon). The strength of a synapse might increase when the use of that synapse contributes to the generation of action potentials in a postsynaptic neuron.

Citri and Malenka (2008) argue that any experience modifies subsequent behaviour, at least in part through activity-dependent, long-lasting modifications of synaptic strength. The brain encodes external and internal events as complex, spatiotemporal patterns of activity in large ensembles of neurons that can be conceptualized as neural circuits. "A key feature defining the behaviour of any given neural circuit is the pattern of synaptic weights that connect the individual neurons that comprise the circuit." (3). According to Citri and Malenka, in the mammalian brain, the information is stored when activity in a circuit causes a long-lasting

change in the pattern of synaptic weights.

A further study by Langille and Brown (2018) suggests that Hebbian postulates contain two concepts: synaptic plasticity and "some growth process or metabolic change" in the neuron, which has been termed "intrinsic plasticity (Titley et al. 2017; Sehgal et al. 2013)" (2). According to Langille and Brown, synaptic activation is the first step in a chain of cellular and biochemical events. These events lead to memories formed in cell assemblies and neural networks that rely on synaptic modification for their formation. Neurophysiological theories of synaptic plasticity, based on the experimental phenomena of long-term potentiation (LTP) and long-term depression (LTD), are now used to explain the neural basis of learning and memory (Yang et al. 2016; Nabavi et al. 2014). Langille and Brown suggest two components of this theory: synaptic plasticity and intracellular biochemical changes; the issue is whether "memory" consists of the synaptic changes activated by intracellular biochemical changes or whether memory consists of the intracellular biochemical changes expressed via synaptic plasticity. Finally, Langille and Brown argue that memory, as conceived by Hebb, consists of both synaptic plasticity and "intrinsic plasticity" of the neurons (Lisman et al. 2018; Titley et al. 2017; Sehgal et al. 2013). You cannot separate one from the other (10). Besides the synapse change, memory is a series of processes involving molecular, biochemical, cellular and circuit-level changes in widespread constellations of neurons throughout the brain.

Finally, the study by Mansvelder and colleagues (2019) highlights findings on properties of human cortical microcircuits and synaptic plasticity; just like rodent synapses, human synapses can undergo plastic changes in response to various stimulation protocols, including high-frequency bursts, theta-burst stimulation and chemical induction (Chen et al. 1996). The challenge is to bridge the gap between various *in vivo* and *in vitro* approaches to studying

synaptic plasticity in the human brain and to find out in which forms of learning and memory they participate (Mansvelder et al. 2019, 191). A typical excitatory neuron receives information from 1–10,000 other neurons and transmits information to 50–100,000 neurons; “This complex morphology requires unique solutions to maintain and modify the proteins that are required for the nervous system’s correct wiring during development and for its function and plasticity during adulthood” (Holt et al. 2020, 557). Connectivity through life experiences changes provides the means of forming and storing memories. Long-lasting forms of synaptic plasticity, like long-term memory, require new RNA and protein synthesis[7] (Sutton and Schuman 2006; Davis and Squire 1984). Long-term plasticity can occur at some but not all synapses made by a given neuron, and a mechanism must also exist to classify the changes in gene expression to those synapses undergoing plasticity. Together, (1) the morphological complexity of neurons, (2) the volumetric dominance of the neuronal processes and (3) their capacity for plasticity indicate that there are unique challenges in setting up, maintaining and modifying the proteome, which is the complete set of protein expressed by the genome, in axonal and dendritic synaptic compartments (Fig. 26).

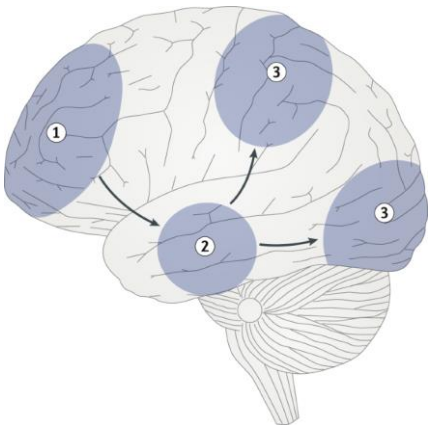

Fig. 26. Holt et al. 2020, p. 558. Neurons and numbers. a, Anatomy of a neuron. Neuron-specific cell parts, the sites of local protein translation and neuronal functions dependent on local translation are indicated. t, time. b, Localization, functions and per-synapse copy numbers of various synaptic proteins. Protein copy numbers are from Wilhelm et al. 2014, and Sheng and Hoogenraad 2007.

5.3 Visual Perception and Imagery

To humans, a large part of our sensory experience is visual. Pearson (2019) demonstrates that almost any behaviour or cognitive process gained from sensory simulation tends to utilize mental imagery that covers all five senses. However, visual mental imagery tends to dominate. For instance, in the brain itself, neurons devoted to visual processing number in the hundreds of millions and accept about 30 % of the cortex**,** compared with 8 % for touch and just 3 % for hearing. Mental imagery involves the activity of an extensive neural network covering frontal areas right back to primary sensory areas. According to Pearson, "The neuroscience of imagery can be divided into work looking at the mechanisms involved in triggering the imagery process, mechanisms of generations or manipulation, as well as mechanisms underlying the strength and vividness of visual imagery content and its overlap with sensory perception" 625).

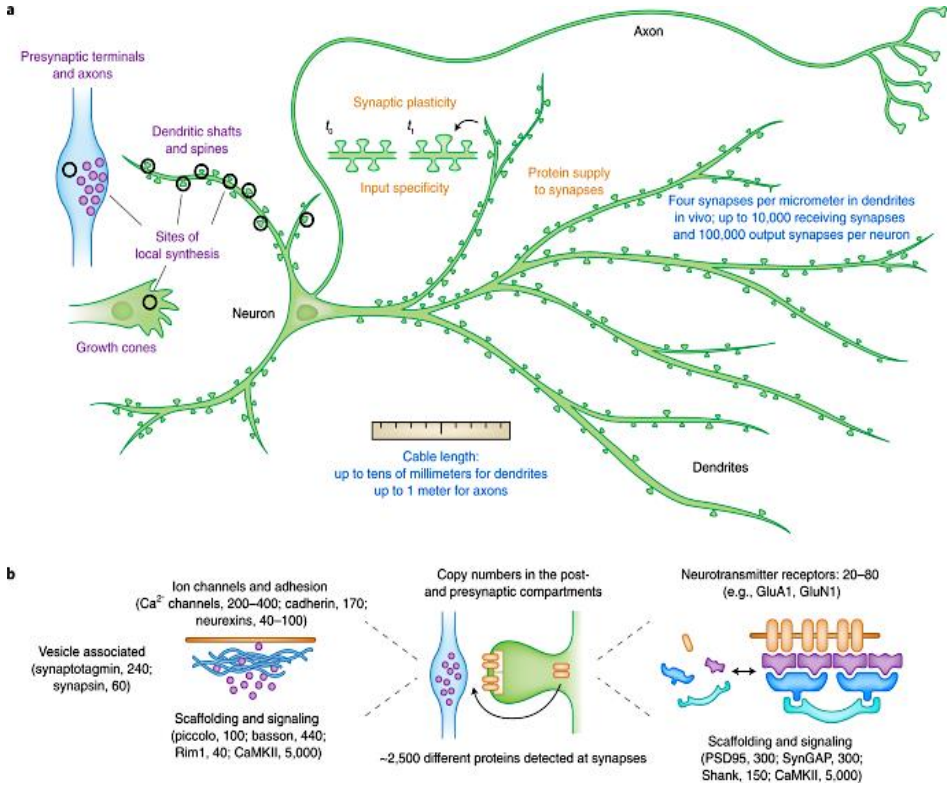

Fig. 27. Pearson, Joel. 2019, p. 626. A top-down general model of voluntary mental imagery: a reverse hierarchy. The initial mental action to create a mental image "begins" high in the cortical

processing hierarchy in the frontal cortex (step 1). This triggers a cascade of neural events, running "backwards," that next retrieves stored information or memories from more posterior regions such as medial temporal areas (step 2) (Kim et al. 2013) and sensory and spatial representations of the imagery content are then formed (step 3). If the "requested" representation involves movement and spatial locations, then other areas like the middle temporal area and parietal lobes would also be
involved.

Looking at a top-down general model of voluntary mental imagery, a reverse hierarchy: Step 2 points to the significant individual differences in imagery strength and vividness being harnessed for obtaining information about the neural mechanisms of spatial imagery (Fig. 27).

In addition, Dijkstra and colleagues (2019) suggest that visual experience can be triggered externally by events in the outside world, such as during perception, or internally by information from mental imagery. Mental imagery is a visual experience in which the content does not relate to any afferent stimulus but is derived from working memory (Fig. 28).

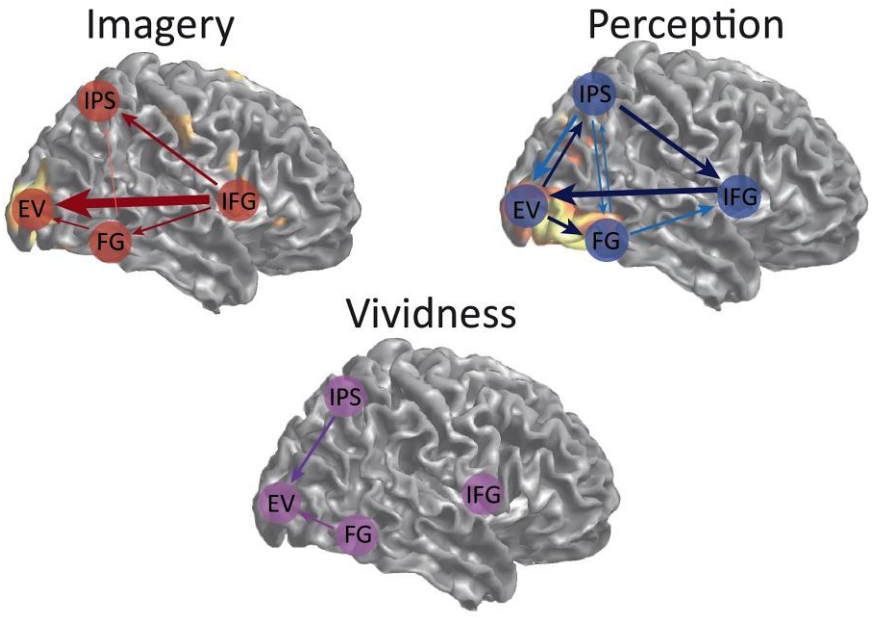

Fig. 28. Dijktra et al. 2019, p. 429. Effective Connectivity During Perception and Imagery. The results were obtained using dynamic causal modelling (DCM) of fMRI data during perception and imagery on four regions of interest (ROIs): early visual cortex (EV), high-level visual cortex/fusiform gyrus (FG), intraparietal sulcus (IPS), and inferior frontal gyrus (IFG). The arrows reflect connections that were significantly modulated on the group level by the different

factors. The widths of the arrows indicate the strength of the influence and light arrows reflect inhibitory connections while dark arrows reflect excitatory connections. Both imagery and perception rely on top-down recruitment of visual areas. The vividness of visual imagery correlates with the strength of top-down recruitment of early visual areas. Furthermore, whereas perception is accompanied by bottom-up connectivity, this is absent during imagery.

According to Dijkstra and colleagues, visual perception and visual imagery generate similar neural representations for the same content in occipital, parietal, and frontal brain areas. “During both perception and imagery, the parietal cortex engages in spatial and feature-based attention, while the frontal cortex represents task-relevant stimulus structure” (423). Finally, there is similar top-down connectivity between frontoparietal and visual areas during perception and imagery. “Imagery overlaps with specific time points during perception, corresponding with high-level processing. By contrast, the early bottom-up processing characterizing perception is absent during imagery” (423). “The neural representations of perceived and imagined stimuli are similar in the visual, parietal, and frontal cortex” (430). This study provides evidence that imagery and perception rely on similar neural mechanisms.

5.4 Hippocampus

A key feature of the evolutionary development of the mammalian central nervous system was its ability to store substantial amounts of information through the cellular mechanism of neuronal synaptic plasticity. In this context, accumulated evidence suggests that our species embodied experiences in evolution depend on the hippocampus, entorhinal cortex (the interface between the hippocampus and the neocortex) and neocortex cognitive functions.

Formal studies of the human hippocampus began in earnest after Scoville and Milner (1957) reported an experimental bilateral mesial temporal lobe surgery to control seizures in Henry Gustav Molaison (then known only as H.M.), who suffered a side effect of dense amnesia due to the hippocampus removal. Since then, two major independent lines of research

have been proposed for the hippocampal. The episodic memory view emphasizes the perception that memories are represented in a specific spatial and temporal context (Eichenbaun 2004; Cohen and Squire 1980; Scoville and Milner 1957). The spatial view was born after O'Keefe and Dostrovsky (1971) discovered hippocampal place cells, neurons that fire when an animal moves through specific locations in an environment. Since 1971, one of the important findings in neuroscience has been the discovery of place cells and grid cells in the hippocampal complex of mammals. For Hawkins and colleagues (2019), grid cells, in combination with place cells, learn a detailed model of the world. Grid cells represent the current location of an animal relative to those maps. In addition, recent advances have made it possible to study the cellular and network basis of defined operations. According to Lisman and colleagues (2017), "These operations deal with the context-dependent representation of complex memories, the role of mental exploration based on imagined rather than real movements, and the use of recalled information for navigation and decision-making" (1). Cognitive functions such as perception, imagination and recall of scenes and events — all engage the anterior hippocampus. In particular, functional differences between neural populations are located at different points along its anterior-posterior axis (Zeidman and Maguire 2016; Chase et al. 2015; Strange et al. 2014). For instance, Strange and colleagues (2014) show that, in addition to the gradients of gene expression and connectivity that vary along the length of the hippocampus, the anterior portion of the hippocampus (also known as the head, ventral or temporal region) can be distinguished from the intermediate and posterior sections (also known as the tail, dorsal or septal regions), with unique cellular morphology and functional characteristic.

Zeidman and Maguire (2016) point out that specific structures within the anterior hippocampus critically contribute to episodic memory, imagination and visual scene perception

(Fig. 29).

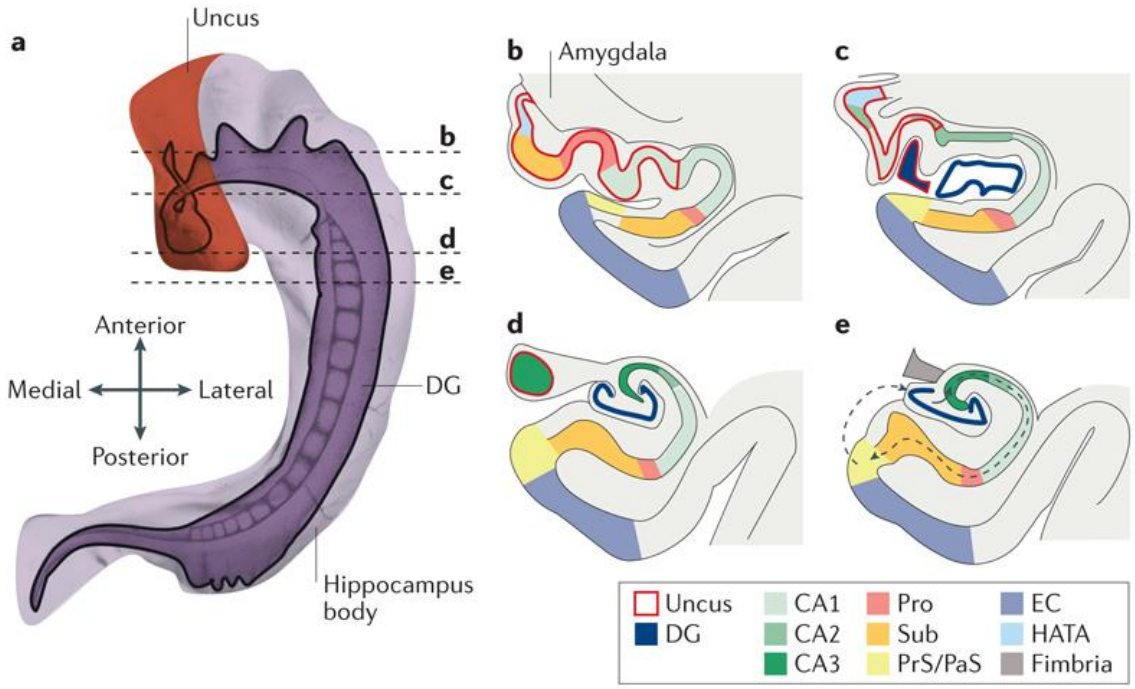

Fig. 29. Zeidman and Maguire 2016, p. 22. Anatomy of the anterior hippocampus. a) A schematic showing a dorsal view of the hippocampus with the dentate gyrus (DG) visible inside. The main hippocampus body, as well as the uncus are indicated. b–e**)** Coronal slices showing the hippocampal subfields in the anterior hippocampus. Red lines indicate subfields that are found within the uncus, and which have distinct cytoarchitectural properties relative to the main body of the hippocampus. The slices in panels b and c are at the level of the uncinate gyrus, whereas the slice in panel d is at the level of the intralimbic gyrus. The arrows in panel **e** indicate the flow of information in the canonical hippocampal circuit in the body of the hippocampus. EC, entorhinal cortex; HATA, hippocampal–amygdaloid transition area; Pro, prosubiculum; PrS/PaS, presubiculum and parasubiculum. Panel a is adapted with permission from REF. 94, Springer. Panels b – e, are adapted with permission from REF. 10, Wiley.

In humans, the hippocampus is positioned between the parahippocampal gyrus, the amygdala, and the posterior hippocampus. The anterior part of the parahippocampal gyrus bends over and rests upon itself, forming the uncus. “The various gyri… cover both the amygdala and the anterior portion of the hippocampus. Beneath this surface, the hippocampus is divided into cytoarchitectonically defined subfields. These are commonly thought of as being arranged in a

canonical circuit, which can be visualized in the cross-section of the main body of the hippocampus" (2). According to Zeidman and Maguire, in this circuit, neurons in the entorhinal cortex (EC), which is part of the neighbouring parahippocampal gyrus, project to the dentate gyrus (DG), which in turn drives subfield CA3, then CA2, CA1 and the subiculum. The subiculum and CA1 then project back to the EC". Also in this plane,

> The prosubiculum is situated between CA1 and the subiculum. The main body of the hippocampus bends medially in its anterior portion (Fig. 29a) to form the extraventricular part of the anterior hippocampus, which is positioned within the uncus. As a result, CA1 and the subiculum must bend around a wider radius than the other subfields (Rosene et al. 1977). Thus, the most anterior portion of the hippocampus is dominated by CA1 and the subiculum (Fig. 29b), whereas the more posterior part of the uncus contains only the DG, CA2 and CA3 (Fig. 29d). After the medial turn within the uncus, the subfields bend upwards, ascending vertically towards the amygdala (Fig. 29b,c), which changes their orientation from the coronal to the axial plane (2, 3).

Also, as McLardy (1963) suggested, there are subfields within the uncus with cellular 'peculiarities.' For example, CA1 in the uncus — referred to as CA1 — has smaller and more densely packed neurons than CA1 in the body of the hippocampus (note that CA1' is labelled uncal subiculum in an alternative nomenclature (Amaral and Insausti 1990). Moreover, Zeidman and Maguire (2016) state:

> The vertical part of the uncus has particularly differentiated cytoarchitecture — for instance, vertical CA1' contains more densely packed pyramidal cell bodies than horizontal CA1' or CA1 of the hippocampal body (Ding and Van Hoesen

2015). The functional implications of these cellular differences are unknown. Although the subfields are usually studied in slices perpendicular to the hippocampal long axis (the coronal plane in humans; see Figure 29b – e), connections also extend through the length of the hippocampus (Kondo et al. 2009, 2008). In the coronal plane and with a slight anterior inclination, mossy fibres project from the DG to CA3, and upon reaching distal CA3 they change direction to extend 3–5 mm in the anterior direction (Kondo et al. 2009). By contrast, associational and local connections within the DG — which may have excitatory and inhibitory roles, respectively (Kondo et al. 2008) — extend bidirectionally along much of the length of the hippocampus. The DG in the uncus is connected to the anterior DG in the main body of the hippocampus through these associational projections (Kondo et al., 2008). The connection from CA3 to CA1 (the Schaffer collaterals) and connections within CA3 also have longitudinal projections through most of the hippocampus (Kondo et al. 2009). Once again, the uncus is distinct, with the targets of projections of the uncal CA3 (CA3') being largely confined to CA3' and CA1' (3).

Zeidman and Maguire, after studying the anatomy of the anterior hippocampus, claim that, in the human hippocampus, visual perception, imagination and episodic memory recall depend on the creation of models of the world. These models serve to plan scenarios for replaying memories.

5.4.1 Hippocampus Phylogenetic

Murray and colleagues (2018) suggest that the hippocampus contributes to some of the most sophisticated aspects of human cognition. These aspects include episodic and autobiographical memory, scenario construction, constructive episodic simulation, future-thinking, prospection,

perspective-taking and situational modeling. In contrast to these highly derived cognitive capacities, the evolution of the hippocampus can be traced to the earliest vertebrates. These animals had a segmented musculature, a notochord, a dorsal nerve cord, paired eyes, olfactory organs on the head, and a brain that included the telencephalon, which consisted of a pallium and a subpallium (Fig. 30).

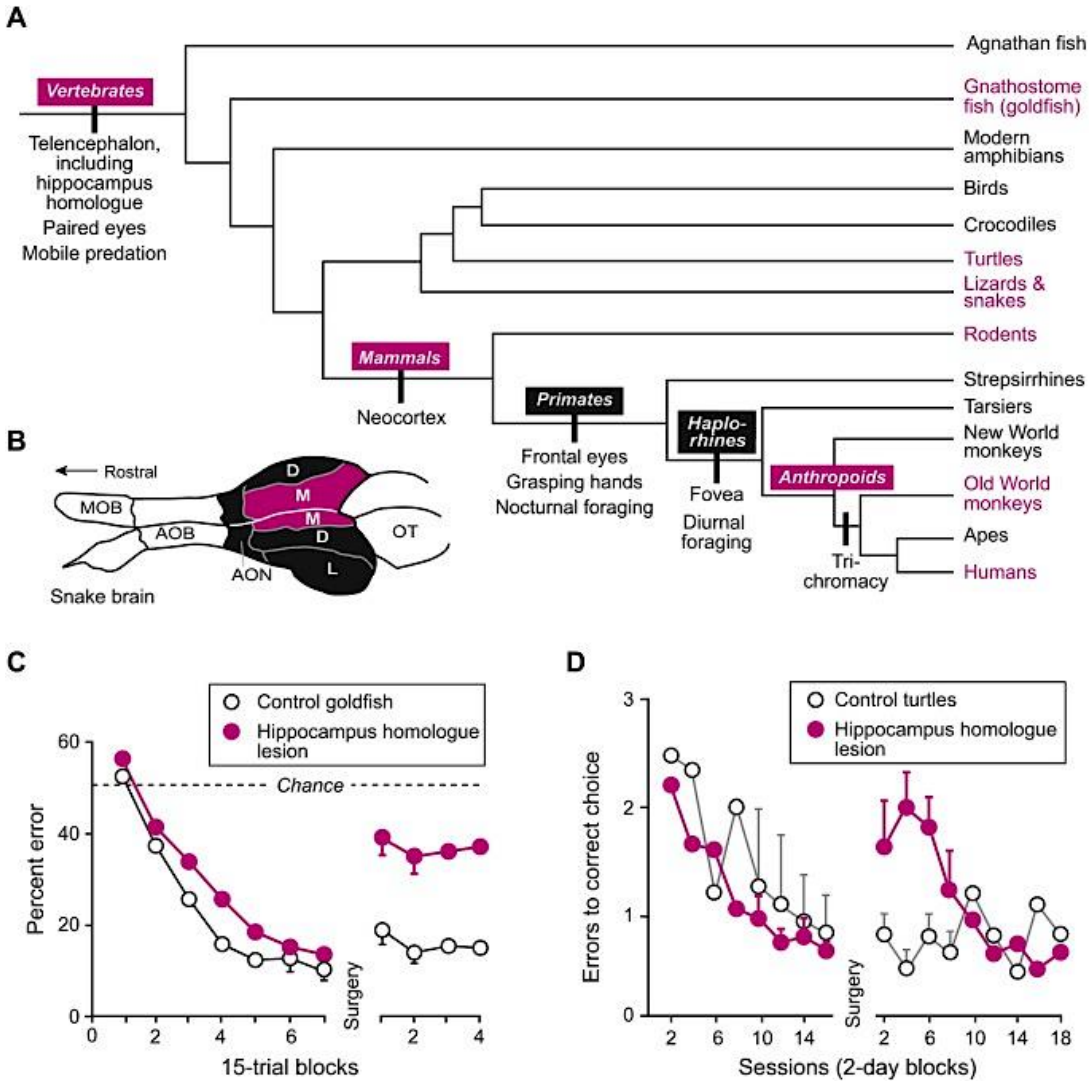

Fig. 30. Murray et al. 2018, p. 6. Vertebrate evolution and memory systems. (A) Cladogram designating selected lineages and some derived traits in those lineages. The magenta labels mark the animal groups highlighted in this article. (B) Drawing of a snake brain depicting three cortical fields: D, dorsal cortex; L, lateral cortex; M, medial cortex. The medial cortex is the reptilian homologue of the hippocampus. The snake brain represents the brains of lizards, turtles

and other non-avian, non-mammalian amniotes. Abbreviations: AOB, accessory olfactory bulb; AON, anterior olfactory nucleus; MOB, main olfactory bulb; OT, optic tectum. (C) Effect of removing the medial pallium, the everted homologue of the mammalian hippocampus, on maze learning and performance in goldfish (Rodríguez et al. 2002). Selected error bars show the standard error of the mean. (D) Effect of removing the medial cortex of turtles on their ability to navigate to a submerged platform containing food (López et al. 2003). Format as in (C).

According to Murray and colleagues, the homologue of this structure is called the medial cortex in modern reptiles (Fig. 30B) and the hippocampus in mammals. In anthropoids, as (Fig 30A) illustrates, the latter split into tarsiers and anthropoids after the divergence of strepsirrhine and haplorhine primates. Anthropoids inherited both traits (Heesy and Ross 2004). Over time, anthropoids increased in size from the few hundred grams typical of the earliest species to several kilograms. The change in body size mainly occurred after the divergence of Old World and New World anthropoids in the early Oligocene, ~34 Mya (Williams et al. 2010), requiring these animals to consume more nutrients than their smaller ancestors. As a result, anthropoid primates foraged over a more extensive home range than their ancestors had (Martin 1981). So, they made foraging choices at a distance, based predominantly on the foveal vision they inherited from their haplorhine ancestors. Moreover, the study by Murray and colleagues (2018) argues that,

> After Old World anthropoids developed the "routine" form of trichromatic vision, which requires a third opsin gene (Williams et al. 2010), colour discrimination became particularly important. Their larger bodies and extensive home ranges favoured a shift from leaping–grasping locomotion to the arboreal quadrupedal model of travelling that enabled them to cover more territory…these developments accompanied an upward grade-shift in brain size relative to body mass (Wise 2017; Allman 2000), (5).

The function of the hippocampus homologue of early vertebrates provided advantages in using vision and olfaction to guide behaviour. Collectively, the memory of sights and smells, their spatial layout, and the order and timing in which they should be encountered during a journey corresponds to a cognitive map (O'Keefe and Nadel 1978), which enabled early vertebrates to navigate toward places that afforded either resources or safety. Specialized map-like representations emerged in the telencephalon of the first vertebrates as they adapted to a new way of life, especially during a major evolutionary transition that occurred in the Cambrian Period (541- 485.4 Mya), which marked a dramatic explosion of evolutionary changes in life on Earth. According to Murray and colleagues, one important advantage of these map-like representations is that early vertebrates could use them to guide foraging and escape behaviours along novel routes. Another is that they could surmount unexpected obstacles. Their new capacities increased an ancestral ability to navigate by responding to stimuli that they had encountered in the past. Moreover, representations in the hippocampus homologue enabled advantageous behaviours that exceeded reflex-like responses reinforced by their past experience.

> The parts of the hippocampus homologue nearest the amygdala became specialized for the control of diverse behaviours related to homeostatic, procreative, affective and autonomic functions (Swanson 2000), and the parts nearest the septal pole became specialized for the fine-grain analysis necessary for navigating within foraging fields and towards places of safety (Murray et al. 2018, 3).

As mentioned by the authors, the conserved representations of the hippocampus also contribute to tasks that require recency, sequence, timing and order judgments, and evolving humans inherited all these traits. Moreover, in the scene processing network–explicit perception of

scenes, implicit scene perception (Lee et al. 2005), implicit scene memory (Chun and Phelps 1999), and perceptual learning about scenes (Graham et al. 2010; Lee et al. 2006). For example, the dentate gyrus plays a role in pattern separation for scenes (Berron et al. 2016), among other representations, and this probably applies to both explicit and implicit discrimination. In conclusion, Murray and colleagues suggest that in the scene processing network, the hippocampus works with other brain structures, which includes the subiculum (Hodgetts et al. 2017, 2016), posterior parahippocampal gyrus, retrosplenial cortex and traverse occipital sulcus. During the anthropoid evolution, the hippocampus homologue emerged to support the representation of visual background scenes. These scenes became crucial to our ancestors by using foveal vision for foraging choices at a distance. “The conserved representations of the hippocampus also contribute to tasks that require recency, sequence, timing and other judgments, and evolving humans inherited all of these traits” (Murray et al. 2018, 11). As a result, representations in the human hippocampus support the perception of scenes, perceptual learning about scenes, and both explicit and implicit memories about scenes. In conclusion, these representations serve as the basis for cognitive capacities, memories encoded in time within a specific spatial and temporal context.

5.5 Episodic and Semantic Memory

Tulving (1972) indicates that the hippocampus is essential for the spatial representation of environments and the ability to remember a specific event. It refers to both sensory and perceptual processes that participate in an organism’s awareness of its environment, and sensory processes may be influenced by perceptual processes and vice versa. “A perceptual event can be stored in the episodic system solely in terms of its perceptible properties or attributes and is always stored in terms of autobiographical reference to the existing contents of the episodic

memory store" (385). The argument is that the act or retrieval of information from the episodic memory store also serves as a type of input into episodic memory and thus changes the contents of the episodic memory store. The specific form in which perceptual input is encoded into the episodic memory can also be influenced by information in semantic memory. Tulving also states that semantic memory is the memory necessary for the use of language.

> It is a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them, about rules, formulas, and algorithms for the manipulation of these symbols, concepts, and relations. Semantic memory does not register perceptible properties of inputs, but rather cognitive referents of input signals " (386).

Tulving's semantic memory does not register perceptible properties of inputs but cognitive referents of input signals. The semantic system enables the retrieval of information that was not directly stored in it, and retrieval of information from the system leaves its content unchanged. In contrast, any act of retrieval constitutes an input into episodic memory. Hence, episodic memory refers to memory for subjective experiences and their temporal relations. In contrast, semantic memory is a system for receiving, retaining, and transmitting information about the meaning of words, concepts, and classification of concepts. Tulving final remarks:

> I argue that the two memory systems differ from each other (a) in the nature of stored information, (b) with respect to the denotative reference of input events, (c) in terms of conditions and consequences of retrieval, and possibly (d) in their susceptibility to interference and erasure of stored information. (402).

The two systems interact in handling mnemonic information for verbal materials; however, the extent of dependence on both systems may vary with the particular task.

Since Tulving proposed a distinction in memory between semantic and episodic memory, this difference has formed the foundation of theoretical and experimental work in the cognitive neuroscience of memory. The question is to what extent episodic and semantic memory share dependence on the hippocampus. Episodic memory depicts unique experiences and associated items and events with the spatial and temporal context in which they were experienced. In this mental scheme, the generation of scene imagery is a crucial component of episodic memory processing and was observed by Scoville and Milner (1957) following a bilateral medial temporal-lobe resection in patient HM (Henry Gustav Molaison 1926 – 2008). The patient had a persistent impairment of recent memory associated with the removal carried far enough posteriorly to damage portions of the anterior hippocampus and hippocampal gyrus.

A recent study by Piai and colleagues (2016) provides neurophysiological evidence that the hippocampal neural mechanisms that support declarative memory are also used for linguistic processing. Language is a perisylvian function studied in isolation from memory. This is the region around the left hemisphere's lateral sulcus (Sylvian fissure), including the Broca and Wernicke areas. Damage to the zone causes various forms of aphasia.

> This study reports neurophysiological evidence for the theory that the hippocampus plays an important role in language (Duff and Brown-Schmidt 2012). We demonstrate that the same neuronal computations used by the hippocampus for memory function, as measured through theta oscillations, also subserve online language use. Our findings specify that the hippocampal complex contributes to language in an active, ongoing fashion, relating incoming words to stored semantic knowledge, a necessary process in the generation of sentence meaning (11366).

To Piai and colleagues, context also plays a fundamental role in language, facilitating word retrieval (Piai et al. 2014; Griffin and Bock 1998) and enabling prediction during language comprehension (Smith and Levy 2013). The activation of a concept invariably results in the coactivation of other associated features or concepts (McRae et al. 1997; Collins and Loftus 1975). Given the critical role of the medial temporal lobe in retrieving learned associations (Eichenbaun 2004), Piai and colleagues examined activity recorded directly from the hippocampal complex of participants performing a linguistic-context task. Their study represents a significant step in language and memory integration. It expands the role of hippocampal theta oscillations for adding hippocampal structures to the neural network supporting language, relating incoming words to stored semantic knowledge, a necessary process in generating sentence meaning.

Barry and colleagues (2019) show that cognitive impairments beyond recalling experiences have been documented following hippocampal damage, including a deficit in imagination and future thinking (Kurczek et al. 2015; Kwan et al. 2010; Hassabis et al. 2007). For Barry and colleagues, one such interpretation is the scene construction theory, which facilitates mental representations, whether recollected or imagined.

> In this context, a scene is defined as a naturalistic 3D spatially coherent representation of the world typically populated by objects and viewed from an egocentric perspective (Dalton et al. 2018; Maguire and Mullally 2013). In support of this thesis, fMRI studies have revealed particularly anterior hippocampal recruitment while participants imagined novel scenes (Zeidman and Maguire 2016; Zeidman et al. 2015; Hassabis et al. 2007b). However, other regions, including the ventromedial prefrontal cortex (vmPFC), are recruited

during (Hassabis et al. 2007b) and seem necessary for (Bertossi et al. 2016a) scene construction. An outstanding question, therefore, is how vmPFC interacts with hippocampus during the generation of scene imagery (4375, 4376).

Barry and colleagues corroborate that a dialogue characterizes episodic memory retrieval between hippocampus and ventromedial prefrontal cortex (vmPFC). Also, the mental generation of scene imagery is a crucial component of episodic memory processing. To obtain their prediction on the interaction between the two brain regions during the construction of novel scene imagery, they leveraged the high temporal resolution of MEG. They combined it with a scene imagination task. The authors "conclude that episodic memory and imagination share fundamental neural dynamics and the process of constructing vivid, spatially coherent, contextually appropriate scene imagery is strongly modulated by vmPFC" (4384). According to the study, mental imagery of spatially coherent scenes or isolated objects resulted in comparable theta power[8] decreases in the left anterior hippocampus. In addition, dynamic causal modeling-DCM[9] of this interaction revealed that the vmPFC drove hippocampal activity during the scene construction process, and an analysis of event-related spectral perturbations showed that the activity of vmPFC preceded that of the hippocampus. In summary, the study by Barry and colleagues corroborates that the anterior hippocampus contributes to the mental construction of novel scene imagery (Dalton et al., 2018; Zeidman and Maguire, 2016; Zeidman et al., 2015; Hassabis et al., 2007b). Additionally, the study claims that theta power changes in the vmPFC preceded those observed in the hippocampus. These results characterize for the first time the core neural dynamics that underlie scene constructions, which are key cognitive functions of episodic memory retrieval, future thinking and scene imagination.

Additionally, the study by Duff and colleagues (2020) corroborates that key findings and

the broad consensus is that the hippocampus and surrounding medial temporal lobe (MTL) structures play a critical role in the encoding and subsequent retrieval of new long-term episodic memories (Rugg et al., 2015; Eichenbaum et al., 2007). The evidence for the link between episodic memory and the hippocampus came from studies of patients with hippocampal damage affected to recount episodes from the remote past (or relative to events experienced since the onset of amnesia) and the ability to acquire new skills and habits. (Rosenbaum et al. 2005; Corkin 2002; Scoville and Milner 1957). It is important to understand the role of the hippocampus in various stages of acquisition, maintenance, activation, and use of semantic memory in processing. Also, the parallel role of the hippocampus in the acquisition, maintenance, activation, and use of episodic memory. Further, Duff and colleagues claim that the hippocampus is critical for episodic and semantic memory.

> With the theoretical and empirical advances in the study of semantic memory and its neural bases, we can see that the depth and richness of semantic compare favorably to that of episodic memory and that they are both highly flexible (re) constructive, relational and multimodal systems reliant upon the properties of the hippocampus (3).

These methodological and theoretical approaches to studying the shared dependence of Episodic and Semantic memory on the hippocampus has provided an understanding of how words, concepts, and meaning are instantiated and maintained across memory systems and then activated and used on-demand in the same way episodes and events. This is consistent with proposals that the hippocampus plays a critical role in relational binding and the flexible (re)construction and (re)combination of rich multimodal features of events and experiences (Rubin et al., 2017). The hippocampal field of study has diverse methods for capturing and

quantifying episodic memory's relational features and contextual richness. For example, to study episodic memory, neuroscientists have coding schemes for rating and quantifying the spatial, temporal, and perceptual vividness and richness of event narratives (Levine et al. 2002). These experimental designs bring evidence of how episodes are (re)constructed, (re)combined, and integrated across time, space, and people (Eichenbaum, 2017; Schlichting and Preston, 2015).

Also, the hippocampus has long been associated with long-term memory. Converging evidence shows that the hippocampus also plays a critical role in memory for relations over noticeably short delays, and even when there are no delays at all, on the time scale of short-term or working memory (Hannula et al. 2017). Following Duff and colleagues (2020), "these findings suggest that new hippocampus-dependent representations are available rapidly enough to influence ongoing processing when: new information is perceived; old information is retrieved; and representations are held online to be evaluated, manipulated, integrated, and used in service of behavioural performance" (11). On this basis, the hippocampus is critical for forming new enduring memories, recovering the past, creating, maintaining, updating, and using online representations to support ongoing information processing. These findings raise the possibility of hippocampal involvement in real-time semantic processing and corroborate that the hippocampus may contribute to some aspects of unconscious or implicit semantic processing (Gaskell et al., 2019; Hannula and Greene, 2012). According to Duff and colleagues, the initial support for such a prediction comes from data pointing to hippocampal contributions to statistical learning, the process by which individuals uncover environmental patterns by tracking co-occurrence frequencies amongst stimuli. "In language, statistical learning is the proposed mechanism by which we learn to segment words from continuous speech (Saffran et al. 1996), uncover grammatical structure (Saffran and Wilson 2003; Gómez 2002), and learn to recognize

the phonotactic, orthographic, and morphological regularities" (Pacton et al. 2005; Chambers et al. 2003) (11). Evidence suggests that statistical learning mechanisms contribute to semantic knowledge by supporting the mapping of word meanings onto word forms (Lany 2014; Lany and Saffran 2011). To consider an implicit learning process, recent work on imaging and patient studies demonstrates the hippocampus' role in tracking statistical regularities in the environment across stimulus modalities (Covington et al., 2018; Schapiro et al., 2014, 2012). Duff and colleagues suggest that relational binding significantly affects the hippocampus's role in various stages of acquisition, maintenance, activation, and use of semantic information. For instance, an innovative approach to studying hippocampal contribution to online semantic memory processing comes from intracranial recording from depth electrodes in patients with intractable epilepsy. Hippocampal coding for real-time semantic processing depends on a mechanism similar to hippocampal coding for space/episodes: hippocampal theta power.

> Hippocampal theta power prior to the retrieval event was predictive of the semantic relationship in the two subsequently recalled words, suggesting that hippocampal theta power codes for semantic relatedness in multidimensional word space. These data are striking as they suggest a role for the hippocampus in tracking and representing the relations among words in semantic memory in a manner that is similar to how the hippocampus tracks and represents relations in physical space and events in episodic memory" (11).

These intracranial recording studies suggest that, in addition to the role of the hippocampus in the acquisition of new semantic memory and maintenance of remote semantic memory, it also encodes, tracks, and builds semantic relations of previously acquired words during online sentence processing to create meaning and facilitate communication (Gaskell et al., 2019;

Cross et al., 2018). The role of the hippocampus in semantic memory processing appears remarkably similar to the role the hippocampus plays in its support of episodic memory. In summary, Duff and colleagues integrate the study of episodic and semantic memory to advance an understanding of their interactions, interdependencies, and shared mechanisms. Finally, the study advances our understanding of how words, concepts, and meaning, as well as episodes and events, are integrated, instantiated and maintained in memory and provide novel insights into our two most quintessentially human abilities: memory and language.

5.6 Hippocampus Cognitive Map

In the original conception of the cognitive map, Tolman (1948), observing the impressive learning of rats in complex mazes, wrote:

> We believe that in the course of learning, something like a field map of the environment gets established in the rat's brain . . . The stimuli . . . are usually worked over . . . into a tentative, cognitive-like map of the environment. And it is this tentative map, indicating routes and paths and environmental relationships, which finally determines what responses, if any, the animal will finally release (193).

Tolman concluded that their brain must form an internal representation of the environment that transcends individual associations between maze junctions and actions needed for reward. He termed this system a "cognitive map" and argued that humans share this with rodents. He also postulated that humans map abstract entities. This cognitive map proposed by Tolman is a tool for organizing information across multiple domains of life and supporting flexible expression of acquired knowledge in purposeful behaviour.

There is evidence that the hippocampus supports the ability of episodic memory by

providing a spatial and temporal framework for relating experiences, thus creating a cognitive map of the organism's experienced world. The retrieval of long-term episodic memory of scene imagery and the representation of visual background scenes (Zeidman and Maguire 2016) calls into being the hippocampus cognitive map. At the cellular level, the cognitive map is the memory system in the brain that interacts with the external world. A cognitive map is an internal representation of the layout of an environment, capturing what entities exist in the environment, where these entities are located relative to each other, and how these entities interact throughout an event.

Consequently, the discovery of "place cells" in the rodent hippocampus, which encode location in the environment via their spatially localized firing patterns led O'Keefe and Nadel (1978) to propose that the hippocampus is the neural locus of the cognitive map and endows an animal with an environmental-centric spatial memory system, which maps space in the literal sense. For Spiers (2020), "the hallmark of this hippocampal map was the capacity to take efficient detours and exploit shortcuts through unexplored space" (168). O'Keefe, in the summary of his lecture for the Nobel Prize in Physiology or Medicine (2014) at Aula Medica, Karolinska Institutet, Stockholm, states:

> The Hippocampal Formation provides a cognitive map of a familiar environment which can be used to identify the animal's current location and to navigate from one place to another. The mapping system consists of a number of different spatial cells including ones which identify the animals place, direction, distance from landmarks such as the walls of an environment in a particular direction (boundary cells) and in some environments a metric for measuring distances between points in the map (grid cells). The grid cells cannot provide perfect

> metric in all environments since the grid pattern is distorted in asymmetrical environments such as trapezoids and the scale of the grids is increased in unfamiliar environment. There is evidence for two independent strategies for locating places, one based on environmental landmarks probably provided by the boundary cells and the other on a path integration system which uses information about distances travelled in particular directions provided by the grid cells.
>
> A similar spatial system exists in humans which additionally provides the basis for human episodic memory (305).

For the hippocampus, space and time have a privileged status because they are used to define and learn about the current context of an event. The hippocampus maps people and things to spatial and temporal positions within the boundaries of an event context. It has a strong bias to encode features within a 4-D spatiotemporal framework, but it also encodes variables that are behaviorally relevant, given the current context (i.e. sound frequencies and auditory selectivity).

> The critical point is that the hippocampus uses regularities in the environment across time and space in order to define a context (Ranganath and Hsieh 2016; Eichenbaum 2013; O'Keefe & Nadel, 1978), and this initial representation must be established in order to learn what is behaviorally relevant in that context. Once the behaviorally relevant variables are determined, then these dimensions are added to the cognitive map (684).

For example, in the story "Raven discovered many people inside a cockle." (Swanton 1905), the Pacific Northwest seashore configuration remains constant. Raven senses integrate information from a large number of cues of the environment; these factors become indicators of the context or landmarks. The hippocampal cells would likely map the ongoing experience relative to the

seashore boundaries. Suppose the seashore configuration changes one day because a strong wave throws out a clam, and the raven notices it. This new information will trigger the hippocampus to assign distinct context representations to the old vs. new seashore configuration. Because Raven has never heard strange noises inside the clam, it would be treated as an item to be mapped in the seashore context. The relevance of this story is that the clam becomes an event, not food for Raven; it was a space/time symbiotic vessel carrying embryonic forms of future humans. For Ekstrom and Ranganath (2018), "space and time serve as a primary scaffold to break up experiences into specific contexts and to organize multimodal input that is to be associated within a context. However, the hippocampus is capable of incorporating additional dimensions into the scaffold if they are determined to be relevant in the event-defined context" (2). Moreover, the hippocampus is situated between large networks of brain regions, and its role in cognition can be dynamically configured depending on the relevant extrahippocampal brain areas with which it interacts. Interactions with neocortical network "hubs" might be a mechanism for the hippocampus to preferentially emphasize any dimension of information coding. In this way, extra-hippocampal cortical brain hubs specify the dimensions beyond space and time that are relevant for representation by the hippocampus (Ekstrom and Ranganath 2018; Schedlbauer et al. 2014; Zhang and Ekstrom 2013)

5.7 Reflection

In this supporting chapter, (I) navigated across the evolutionary structures of cognition, starting from the synapsis to the nervous system, and the critical role of the hippocampus in episodic and semantic memory, navigation, and the cognitive map and its neural substrates. (I) might recall that comparative analyses of extant species have uncovered new evidence of evolutionary changes in the size and the number of neurons in the human nervous system, as well as the

cellular and molecular reorganization of its neural circuit. Since humans share most of their genetic, molecular, and cellular features with other non-human primates (NHPs), there are differences in cognitive and behavioural capacities between humans and NHPs. For example, syntactical-grammatical language, symbolic thought, self-reflection, long-term planning ability, autobiographical memory, the theory of mind, and the capacity to create art are the most distinctively human aspects of cognition and behaviour.

5.8 Chapter Notes

1. The evolution of multicellular animals (i.e., metazoans) from a unicellular ancestor is one of the most important yet least understood evolutionary transitions. "The Cambrian explosion was a unique animal radiation ~540 million years ago that produced the full range of body plans across bilaterians" (Heger et al. 2020, 1). According to Genikhovich and Technau (2017), "Bilaterality – the possession of two orthogonal body axes – is the name-giving trait of all bilaterian animals. These body axes are established during early embryogenesis and serve as a three-dimensional coordinate system that provides crucial spatial cues for developing cells, tissues, organs and appendages (3392). The emergence of bilaterality was a major evolutionary transition, allowing animals to evolve more complex body plans. Lanna (2015) states, "The non-bilaterian animals comprise organisms in the phyla Porifera, Cnidaria, Ctenophora and Placozoa" (284). These early-diverging phyla are crucial to understanding the evolution of bilaterian animals.
2. Neurons, muscle cells, and touch receptor cells use ion channel receptors to convert chemical or mechanical messages into electrical signals. For example, sodium channels are ion channels that transport sodium ions across cellular membranes. For Wang and colleagues (2017), "Voltage-gated sodium channels (VGSCs) are the basic ion channels for

neuronal excitability, which are crucial for the resting potential and the generation and propagation of action potentials in neurons" (534).

3. Metazoans "Metazoans (multicellular animals) that pass-through stages of development…and belong to one of three major branches: Diploblasts, protostomes (primitive invertebrates) and deuterostomes (chordates and echinoderms). This division helps understand the relationships between diverse groups of animals" (Gilbert 2000). The blastopore in protostomes developed into a mouth, while the blastopore in deuterostomes developed into an anal opening.
4. The CNS system involves three germinal layers: ectoderm, mesoderm, and endoderm, according to Elshazzly and colleagues (2023).

> The ectoderm is the key initiating player in the embryogenesis of the CNS. The ectoderm is further sub-specialized as the (1) surface ectoderm, which differentiates into the epidermis, nails, and hair. The ectoderm is also sub-specialized to form the (2) neural ectoderm, which gives rise to the neural tube and neural crest, which subsequently gives rise to the brain, spinal cord, and peripheral nerves. The endoderm gives rise to the lining of the gastrointestinal and respiratory systems. It also gives rise to abdominal organs such as the liver, pancreas, and bladder. The mesoderm is differentiated into 3 parts: *Paraxial mesoderm:* This part of the mesoderm contains mostly somites which give rise to the axial skeleton, dermis, and muscle. *Intermediate mesoderm:* This part of the mesoderm gives rise to the gonads, kidneys, and urogenital structures. *Lateral plate mesoderm* is further classified into parietal mesoderm and visceral mesoderm, which give rise to the limb skeleton and muscular wall of the gut tube,

respectively (PubMed. 2023).

5. The bilaterian bauplan: “The Cambrian explosion was a unique animal radiation ~540 million years ago that produced the full range of body plans across bilaterians. The taxon Bilateria consists of multicellular animals with bilateral body symmetry and constitutes a major and ancient radiation of animals” (Heger et al. 2020).
6. Proteins known as connexins form gap junction channels that provide a direct connection and enable the exchange of ions and small molecules between adjacent cells. According to Beyer and Berthoud (2018),

> Intercellular communication through gap junction channels is critical for coordinating the functions of cells in the tissues of all multicellular organisms by allowing direct exchange of ions and small molecules (including second messengers like Ca^{2+}, IP3 and cyclic nucleotides and oligonucleotides). Gap junction mediated coupling allows groups of cells to respond to a ligand synchronously, even when only a few cells express the ligand receptor. During development, gap junctions form communication compartments in which coupled cells differentiate together, while those that are not coupled acquire a different fate (1).

7. Ribonucleic acid (RNA) is a molecule that is present in the majority of organisms and viruses. Wang and Farhana (2023) state,

> It is made up of nucleotides, which are ribose sugars attached to nitrogenous bases and phosphate groups. Three general classes of RNA molecules are involved in expressing the genes encoded within a cell's DNA. Messenger RNA (mRNA) molecules carry the coding sequences for protein synthesis and are

called transcripts; ribosomal RNA (rRNA) molecules form the core of a cell's ribosomes (the structures in which protein synthesis takes place); and transfer RNA (tRNA) molecules carry amino acids to the ribosomes during protein synthesis. In eukaryotic cells, each class of RNA has its own polymerase, whereas in prokaryotic cells, a single RNA polymerase synthesizes the different class of RNA (PubMed 2023).

8. According to Buzsáki (2002), “Theta oscillations represent the "on-line" state of the hippocampus. The extracellular currents underlying theta waves are generated mainly by the entorhinal input, CA3 (Schafer) collateral, and voltage-dependent Ca^{2+} currents in pyramidal cell dendrites” (325). Moreover, Zhang and Jacobs (2015) show for the first time in humans that hippocampal theta oscillations are traveling waves moving along the length of the hippocampus in a posterior-anterior direction. “The existence of these traveling theta waves is important for understanding hippocampal neural coding because they cause neurons at separate positions in the hippocampus to experience different theta phases simultaneously. The theta phase that a neuron measures is a key factor in how that cell represents behavioural information” (12777). Moreover, the extracellular currents underlying theta waves are generated mainly by the entorhinal input, CA3 (Schaffer) collaterals, and voltage-dependent Ca(2+) currents in pyramidal cell dendrites. Schaffer collaterals are axon collaterals given off by CA3 pyramidal cells in the hippocampus. In addition, the study by Nuñez and Buño (2021) underscores that the theta rhythm results from complex interactions between circuital and intrinsic properties of MS-DbB and hippocampal neurons and that it plays a crucial role in cognitive processes such as learning and memory and the control of complex behaviours.
9. Dynamic causal modeling (DCM) is a framework for specifying models, fitting them to data

and comparing their evidence using a Bayesian framework for inferring hidden neuronal states from measurements of brain activity. According to Stephan and colleagues (2010), "DCMs are generative models of brain responses, which provide posterior estimates of neurobiologically interpretable quantities such as the effective strength of synaptic connections among neuronal populations and their context-dependent modulation" (3099).

10. The study by Josselyn and Tonegawa (2020) states,

> In 1904, Richard Semon introduced the term "engram" to describe the neural substrate for storing memories. An experience, Semon proposed, activates a subset of cells that undergo off-line, persistent chemical and/or physical changes to become an engram. Subsequent reactivation of this engram induces memory retrieval. Although Semon's contributions were largely ignored in his lifetime, new technologies that allow researchers to image and manipulate the brain at the level of individual neurons has reinvigorated engram research (3).

As argued by Josselyn and Tonegawa, during engram formation, eligible neurons in a given brain region compete against each other for allocation (or recruitment) to an engram. Neurons with relatively increased intrinsic excitability win this allocation competition to become engram cells.

CHAPTER 6. Conclusion

6.1 Protohuman Origin: A Quest Reflections

The complexity of human origins in different regions of Earth remains a debated topic, primarily due to the limited availability of fossil records. However, oral traditions have become a significant resource for archaeologists seeking insight into human life during the late Pleistocene to address the scarcity of fossilized human remains along the Pacific Northwest of Canada. Recent experimental studies on memory suggest that verbal and gestural storytelling are fundamental characteristics of our species and essential for representing the world. Memory, in all its forms, is critical for language development. Imagination is also recognized as an extension of episodic memory, providing the recursive and generative properties that underlie language in a spatiotemporal context. Moreover, current studies on extensive oral memorization and recital practices show a link between knowledge transfer, learning processes, and neural plasticity related to the hippocampus, particularly regarding its volume and density. Based on this, cosmological narratives and their related neural evolutionary networks may reflect cellular sentience and cognition, which leads to the hippocampal-entorhinal complex—an area crucial for episodic memory and language.

The evolutionary changes in the size and number of neurons have led to a reorganization of the underlying cortical functional structure. Neuroplasticity, or brain plasticity, refers to the nervous system's ability to adapt and change its activities in response to intrinsic or extrinsic stimuli by reorganizing its structure, functions, and connections. This neural circuitry is adaptive to the structured sociocultural environments passed down to future generations. For example, Haida cosmological stories illustrate memory and cognitive systems that depict unique

experiences, associating items and events within specific environmental and neurogenic niches. As our ancestors continuously developed new cognitive abilities, the brain's parietal cortex created new functional areas to support multi-sensory integration, advanced modes of representation, and enhancements to neural construction. According to current evidence, expanding brain functions led to changes in our ancestors' ecological niches, which required additional brain resources for adaptation. Specifically, the similarities between spatial and non-spatial behaviours have revived the idea of systematically organizing knowledge across multiple domains. Cognitive maps can thus be constructed from general patterns of abstract relationships independent of sensory representations, allowing them to generalize across different sensory environments.

These abstract representations can be viewed as foundational sets for describing relational knowledge. The brain's hippocampal-entorhinal system encodes various relational structures represented simultaneously but with distinct spatial organization, even when neither structure is relevant to the task. This enables the flexible selection of pertinent knowledge to guide goal-directed behaviour in novel situations. Ultimately, the hippocampal-entorhinal system constructs a model of the world, known as cognitive maps, to represent multiple types of knowledge. For instance:

1. Navigation within a clamshell represents a significant evolutionary milestone in both narratives. This element lays the groundwork for transitioning from aquatic to terrestrial locomotion in early tetrapods. High-resolution fossil evidence reveals that a substantial evolutionary shift occurred in certain vertebrates, such as fish, during the Palaeozoic Era—particularly in the Devonian period, which spanned from approximately 419.2 to 358.9 million years ago. This transformation resulted in essential morphological and physiological

adaptations, including the development of limbs, the acquisition of lungs, and the emergence of new ecological niches.

2. A crucial feature of human memory is our ability to recall real-life events through narratives linking distant experiences. This cognitive function evolved alongside modifications in the number and size of neurons within our nervous system and the reorganization of neural circuits at both cellular and molecular levels. Substantial evidence indicates that the hippocampus and entorhinal cortex play an essential role in constructing narratives that integrate distant events into a cohesive framework in the service of memory.
3. Cosmologic stories of human origins have been learnt, relearned, and passed through Haida storytellers' memory for thousands of years. In this framework, the hippocampus structural plasticity is in service for long-term memory consolidation and learning. As recent experimental studies suggest, the hippocampus engages in real-time semantic processing. This study gives us an understanding of how words, concepts, and meaning, as well as episodes and events, are integrated, instantiated, and maintained in memory and offer new insights into our most quintessentially human abilities: memory and language.
4. As I suggested, Haida cosmologic stories are embedded evolutionary processes linked to the multidimensional formation of the hippocampal cognitive map. Recent studies indicate that the Entorhinal-Hippocampal network represents relations among memories within a multidimensional space. These relational maps contribute to long-term episodic memory and support concept formation by representing relevant features for discriminating among related concepts. Thus, visual scene imagery navigation within hippocampal cognitive maps may contribute to creative imagination by recombining event elements or concept features (See Chapters 3, 4, 5).

5. For the Haidas, the ultimate source of all power is sins sgaana, Power-of-the-Shinning-Heavens, a being of the upper world who gives power to all things. His incarnation in a clamshell-like the first Haidas of the Raven moiety prompted (me) to navigate immersed in EDA to look for recent findings on prebiotic molecules of life. As a result:

   5.1 Martín-Doménech and colleagues (2017) point to the detection of methyl isocyanate

   5.2 (CH3NCO) is a prebiotic molecule in the solar-type protostar IRAS 16293–2422 B, situated in the constellation Ophiuchus, the Serpent-bearer.

   5.3 Öberg and Bergin (2021) saw that the planet-forming disks around five young stars (IM Lup, GM Aur, AS 209, HD 163296, and MWC 480) are factories of a particular class of organic molecules, so-called nitriles, implicated in the origins of life on Earth.

   5.4 Rivilla and colleagues (2022) report the detection of nitriles in the molecular cloud G+0.693−0.027, located close to the Milky Way galactic center. The detected organic molecules are essential building blocks for RNA—a DNA—like nucleic acid in all living cells. Thus, as an extension of the cognitive map, Power-of-the-Shinning-Heaven's incarnation reminds me of (my) cosmic life heritage.

6. Haida is a language isolate, and by enacting the scene imagery, I learnt about the cellular origin of language, long-term episodic memory, and the neural substrates of the hippocampus cognitive map (See Chapter 3). For example, this cognitive map includes toponyms such as Xaadaa Gwaay ("Islands of the People"), Gawa Yaaku 7l (Masset-Inlet Middle town people), Dju (A stream flowing into the Pacific); personal names: Tullájat (the chief's daughter), Lla-djat, (Fine-weather-woman); names of deities: Kilsdlaay.

In examining cognitive evolution within the context of oral narratives, it becomes clear that Haida oral storytelling may embody the neural evolutionary networks linked to cellular

sentience and cognition. Recent studies suggest that these networks lead to the hippocampal-entorhinal complex, which plays a crucial role in episodic memory and language. Verbal and gestural storytelling have thus become fundamental characteristics of our species, allowing us to represent and make sense of the world around us. Haida stories convey the essential attributes of a culture's identity, including thought and speech processes and cognitive capacities. These refer to the advanced functioning of the nervous system, mainly as it has developed in the human lineage.

During the evolution of the nervous system, the synapsis provided extant animals with the ability to integrate complex sensory information and translate the results of that integration into complex behaviour. Based on the synapsis and synaptic plasticity (my), research highlights memory encoding and retention, e.g. oral memory depends on the efficacy of synaptic connections among relevant neurons in the circuit where memories are stored. For instance, long-term potentiation (LTP) is studied as one of the basic neurophysiological mechanisms for learning and memory storage, strengthening synapses through repeated stimulation. In that sense, the selected cosmologic stories include visual scene imagery of experience-dependent information and explicit learning in the context of the eco-evolutionary acquisition site. According to recent studies, explicit learning uses the synapsis to represent the subcellular substrate of learning and memory in episodic memory formation and the hippocampal cognitive map. This map represents relations and binding among memories within a multidimensional space, such as organizing experiences and guiding behaviour across all domains of cognition.

Additionally, the visual scene imagery of different events refers to other times. Nevertheless, these long-ago stories become encoded in the context of integrated narratives. Using this information, (I) used the visual scene imagery associated with long-term episodic

memory functions on these grounds. As a result, the interaction with novel concepts through working memory and semantic correlation within current heterogeneous fields of knowledge enabled me to model my holobionic sense of self through neural plasticity for memory updating and enhancing imagination and cognition. Indeed, conscious memory of a new experience initially depends on information stored in the hippocampus and neocortex. Memory consolidation is when a temporary, labile memory transforms into a more stable, long-lasting form. Neuroplasticity is the mechanism by which the nervous system changes its activity in response to intrinsic or extrinsic stimuli by reorganizing its structure, functions, or connection. On this basis, an experience modifies brain function via modifications of the synaptic event or integration (which emphasizes the essential function of summation of excitatory and inhibitory postsynaptic potentials), thereby modifying subsequent thoughts, feelings, and behaviour.

Extending spatial navigation models that link episodic memory and imagination to work with visual scene imagery is essential. Recent evidence suggests that imagination is a biological experience, and it is vital to human experience. Broadly, imagination has a significant role in human creativity, agency and everyday thoughts and actions. In (my) dissertation, performing with imaginative consciousness and enacting the visual scene imagery associated with long-term episodic memory led me to an active process of creation, planning, and problem-solving. Within this framework, I designed an Experimental Digressive Assemblage (EDA), a virtual construction scaffold structure for visualizing my quest in real life.

Consequently, this structure was layout thinking of three dynamic levels: (1) scaffolding has been a critical component to aid infrastructure improvements and expansion, (2) scaffolding like a giant ladder was used by Bertolt Brecht (1898 – 1956) for staging his Epic Theatre and to heighten the spectator's participation (3) scaffolding as a metaphor of the limbic system (the

paleomammalian cortex, which is central for memory, sensations, emotions, and learning) to be my vessel for navigating across the cosmologic stories. During the navigation quest (Chapter 3), EDA played the role of an agentic heterogeneous assemblage, enabling a network with different vital materialities. It allowed my holobiont body (in biology, it is a novel paradigmatic shift rooted in symbiosis with the gut microbiota) to immerse (myself) in its structure and multiple planes of composition. In this realm, the virtual pages of the cosmologic narrative became performative material. Further in time, (I) saw a tridimensional screen of interactions for enacting and correlating the visual scene imagery of coherent narrative events, which included experience-dependent information and explicit learning in the context of the ancestral place of acquisition.

Inspired by Haida cosmologic stories for retracing (my) origins, (I) found in up-to-date studies that all life on Earth has evolved from single-celled organisms such as archaea and bacteria, and sentience and cognition are inherent features of the single cell life since its emergence as an autopoietic unity in the Archean era oceans. That said, the evolution of cell sentience and cognition preceded the emergence of humans; therefore, it is the primary source of biological order and evolution that started ~ 4 Gya. (I) my say, since the emergence of the first cells, this cellular self can obtain meaningful content of the sensory information for creative adaptation and survival. Furthermore, recent studies suggest that memory and cognition arose through the dynamic interaction between an organism and its environment since the beginning of phenomenal experientiality by cellular life on Earth.

Finally, the spatially coherent visual scene imagery embedded in Haida cosmological stories should account for (neuro)archaeological of human neurocognitive evolution in which the hippocampal cognitive map constantly interacts with the Pacific Northwest environment. In

conclusion, from an evolutionary perspective, cellular sentience and cognition since the beginning of life (chapter 4), as well as the hippocampus cognitive map and its neural niche (Chapter 5), are essential for generating an understanding of the profoundness of cosmologic narrative of human emergence from the ocean as found in Haida Gwaii oral tradition. Currently, I embody the vision quest inspired by Raven as a holobiont.

6.2 Afterthoughts

EDA's enactment and correlations of the visual scene imagery ignited a novel perception for (re)identification with our ancestral cognitive niche. Knowing our inherited biogenesis has helped (me) to embrace the body as a holobiont that has existed in complex forms for the last 4.2 Gya on Earth. Moreover, through their techno signatures, astronomy and astrophysics search for extraterrestrial intelligence (SETI) in exoplanetary systems. Using EDA, I will search for the Supernatural on two distant islands: Pacific North (Haida Gwaii) and Pacific South (Navarino). How did the incarnation of the supernatural in ancestral specific human evolutionary niches shape culture?

6.3 Chapter Note

1. To understand Earth's history, from the first cells emergence to humans, I traveled back through time using the Geological Time Scale to timing events appearing through the chapters of this dissertation: Hadean Eon, Archaean Eon, Proterozoic Eon, Mid-Proterozoic Eon, Late Paleo-Proterozoic Era, Meso-Proterozoic Era, Neo-Proterozoic Era, Palaeozoic Era, Cambrian Period, Devonian Period, Jurassic Period, Cretaceous Period, Oligocene Epoch, Quaternary Period, Pleistocene Epoch, Middle Pleistocene Epoch, Late Pleistocene Epoch, Holocene Epoch, Early Holocene Epoch, Late Holocene Epoch (Fig. 31).

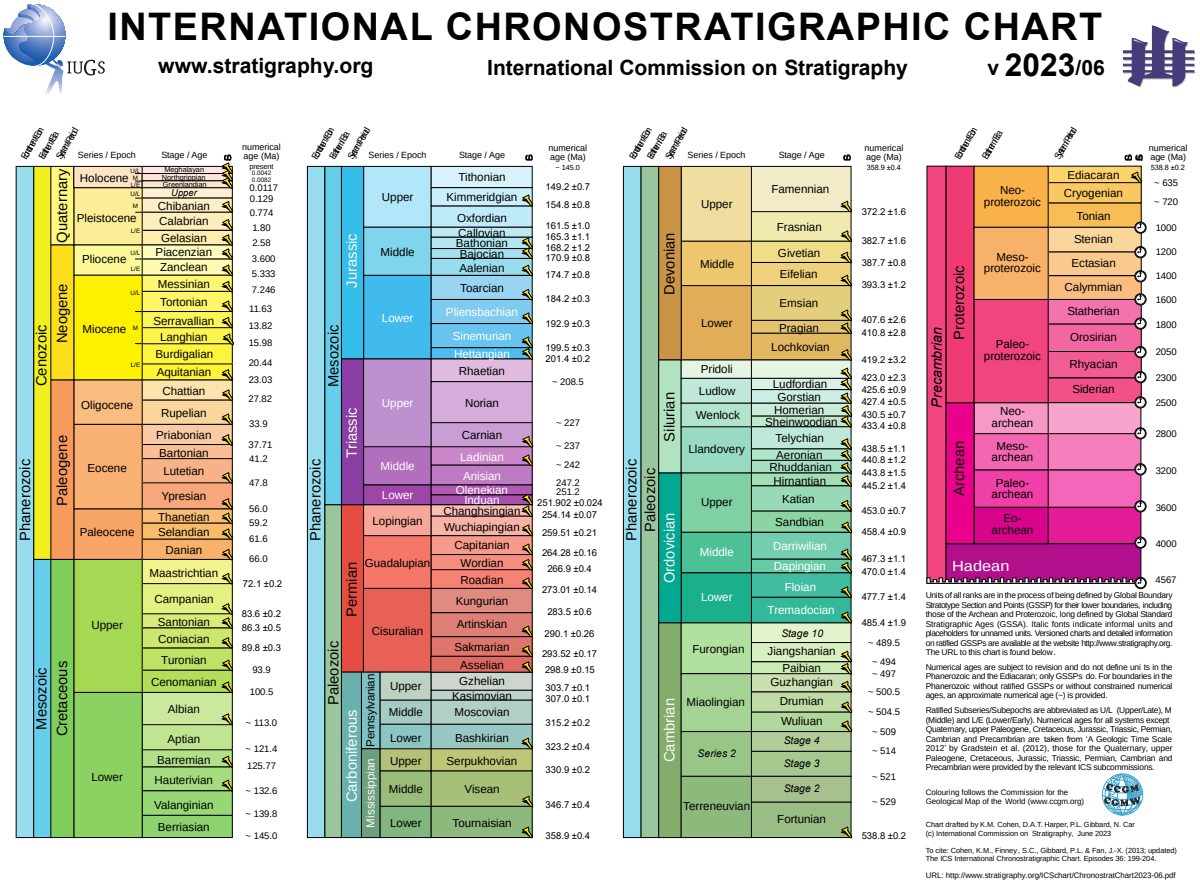

Fig. 31. https://stratigraphy.org/chart#latest-version.

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