INTRO

The octopus is a fascinating creature – we tend to group it with other animals we would consider to have a form of 'higher intelligence' like dolphins, monkeys, birds, and ourselves, despite the fact that the octopus champions a radically different nervous system organization from the rest of this group. They are curious and like to tinker with novel objects and use tools to engage with their environment. Despite being colorblind they can effortlessly change their skin color to camouflage or mimic other animals. They are attentive, especially in captivity, and can recognize individuals, shoot jets of water at specific targets that particularly annoy them, and escape as soon as nobody is watching. Their behaviors are opportunistic and context-sensitive, and from many accounts it seems that these creatures may get some kind of feeling of boredom that leads to their mischievous activities.

Studying how these complex behaviors can emerge from such a divergent evolutionary path can help us to come to a more generalized idea of what it means to be intelligent, and hopefully gain some insight into the difficult problem of understanding conscious development. This paper will attempt to summarize and extract some of the things I learned from Peter Godfrey-Smith's book, *Other Minds*, in addition to other sources I have been able to explore to build a more cohesive story. To break down an ambitious goal of understanding consciousness – there are three emergent questions of interest that I specifically want to focus on:

1. **How did living systems develop?**
2. **How did nervous systems develop?**
3. **How did conscious systems develop?**

This won't be comprehensive by any means but more of a fun summary of the story of life where I will try my best to include the pieces I found most interesting and important to the story. So let's go ahead and begin by jumping right into the development of life itself.

LIVING SYSTEMS

How should we define a living system anyway? For simplicity I will generalize it to mean any system of chemical arrangements that can take energy from its surroundings and use it to replicate itself (a replication machine!). The first replication systems probably came from an extremely lucky combination of spontaneous chemical arrangements in the primordial soup of early Earth – we at least know floating around in liquid water was critical for this to even be possible.

A replication machine has only one 'goal' and really it isn't a goal at all but rather an ability: to replicate itself. It also has only one true enemy: entropy, also known as the increasing random disorder of the universe. Entropy sometimes prevents replication systems from completing their goal by causing them to prematurely fall apart. Entropy is thought to be always increasing in the universe and eventually all organized 'systems' of the universe will break down into a perfectly uniform random chaos. The first successful replication machines overcame entropy and replicated themselves – but those replications weren't perfect and would have had some small copy-errors. Random variations in copy-errors produced random variations in the successfulness of the next generation of replication machines – some got worse at replicating and others got better. Replication machines with some copy-error that made them better were more likely to continue replicating – and this established a positive feedback loop describing the process of natural selection leading to evolution. Over time, tiny incremental copy-errors that accumulated in the successful generations appeared to be getting better at solving problems about resisting entropy longer to acquire more energy and replicate more. This is a common theme that permeates all 3 of the questions posed in the beginning – constantly selecting for incremental random variations has the appearance of generations learning to solve problems about successfully replicating. By chance this led to life diverging into a variety of successful strategies. Examples of replication strategies may include putting more energy into a few replications to improve their chances of success (like humans) or investing less energy to produce many replications (like cuttlefish), as well as varying the timing, frequency, social exchange of replication tools, and any other variations you could think of – ultimately leading to the great diversity in life we experience in the world today.

The strategy of replication determines a lot about the life of the species, including how long it lives. Godfrey-Smith mentions some of the evolutionary theory of species' varying lifespans – he is particularly shocked when learning that the octopus and cuttlefish naturally fall apart after just a year or two despite putting so much investment into metabolically expensive and adaptable nervous systems. The likely conclusion is that different reproduction strategies imply different biological investment strategies – and investing in early reproduction will select for genes that help the organisms to live to at least the optimal age for reproduction, but those same genes may actually cause maladaptive problems later in life. Since accumulating these kinds of genes would help achieve more successful reproduction, the possible negative side-effects later in life would also accumulate over generations in a species, leading to a duration in the species' lifespan when most of the organisms that seem to be thriving may suddenly experience a sudden wall of maladaptive mutations – causing a dramatic deterioration in their health. This theory supports the idea that successful replication is the primary 'goal' of life – and survival beyond that optimal time is just a secondary afterthought.

The early stages of single-cell microbial life were the first step in discovering the importance of sensory-motor causal arcs (a sensation of the environment causing a useful reaction). The best replicators of the time likely had already developed capacities to move using flagella and sense chemicals in their external environment using receptors – but the improving connection and coordination of these mechanisms would greatly improve the effectiveness in their ability to obtain energy for replication. Not only does it allow them to reactively avoid harmful chemicals and move towards beneficial ones, but they can also sense and react to chemicals produced by each other – paving the way for early social behaviors like cooperation and competition. Even these early forms of microbial life had the capacities for complex social interactions like quorum sensing, sharing genetic material, and engulfing each other to develop strange symbiotic relationships which ultimately led to the first animal cells. Since light serves as both a source of information and a source of energy, it's also not a huge surprise that eyespots and photosynthetic abilities developed in these early stages too. All of these accumulated developments appear to characterize a 'drive' for survival, gathering energy, and reproduction, but it's important to keep in mind that they are only random products of this natural selection process – and still far from any idea of 'thinking' or 'consciousness' that we may entertain.

With a ton of oxygen in the atmosphere from photosynthetic microbes – creating the protein collagen becomes a new possibility allowing for colonies to literally stick together and gradually make the big transition to multicellularity. In colony behavior (which has its own selective benefits), useful chemical reception is increasingly 'social' because most of an individual's environment consists of neighboring individuals, and these messaging systems can get repurposed and internalized in a multicellular system.

NERVOUS SYSTEMS (a new ability!)

Now we have the start of some kinds of multicellular ancient sponges with little ability to actively move as a unit creating new challenges to overcome and opportunities to develop which naturally evolves into their ability to coordinate their movements better. The development of neuronal type cells becomes the solution to this problem with their ability to send faster, targeted electrical signals to other cells across a much greater distance. An organized network of these neurons makes it possible for the coordination of many micromovements to produce impressive macromovements. Some life was now beginning to look like slow-moving organized conglomerates. Examples found in the fossil record were Kimberella & Dickinsonia – slug-like animals that scavenged microbial life on the seafloor. There was also the Cnidarians like sea anemones, coral, and likely some primitive jellyfish floating around at this time with larger basic nerve nets that helped movement coordination. Godfrey-Smith mentions that nobody seems to know why jellyfish would have developed stings at this relatively peaceful point in time, but it seems at least plausible to me that a floating bug-zapper-like sting probably served an effective niche.

As multicellular animals got better and better at movement coordination, another benefit of nervous systems became clearly important – the development of connections between external sensing and coordinating those macromovements. Better sensory systems developed, which lead to more information that could be known about the environment - but more information also makes it more difficult and complex to produce actions – so the need for some kind of quick internal processing also became important. This was compounded by the fact that other organisms were also developing these capacities and began waging energy wars on each other via predation and stronger competition. The Cambrian explosion is a time of rapid evolutionary development as organisms had much more selective pressure to survive in an arms race style chaos – with animals getting faster, stronger, and developing better weapons and defenses which helped them survive longer and acquire more energy to reproduce successfully. A critical development that can act both as a weapon and defense is the sensory ability to use light to ‘see’ the other organisms moving around (advancing vision). This was the beginnings of complex active bodies which produced the arthropods (with exoskeletons), chordates (with internal skeletons), and cephalopods (with protective external shells). Somewhere along the way we’ve already breezed past humans’ modest common ancestor with the octopus, which may have just been a simple flat worm-like creature with a simple nervous system and simple eyespots. Everything since then has developed completely independently in cephalopods and vertebrates like us. The octopus and cuttlefish among the cephalopod branch may be the closest thing to meeting intelligent aliens we will ever get.

Weaknesses and vulnerabilities that cause a failure to reproduce tend to get weeded out by natural selection – and many species that don’t make the cut go extinct entirely. Those that are adaptive enough to survive appear to serve as ‘solutions’ to these problems. When a significantly stronger selective pressure like predation or natural disasters acts on a species, the survivors would be those that were in some way much better at withstanding the harsh conditions, having some kind of resistance. Maybe they were specifically better equipped in some way, but with a large variety of pressures it is more likely that they were simply more flexible and responded adaptively to their environment. Some early cephalopods ditched their protective shells which put a much more significant selective pressure on them because they now were easy snacks for a variety of other animals. This short period of highly selective pressure may have been a significant part of the reason the octopus developed such large nervous systems – their complex situational awareness, context-sensitive behavior, and curious interest in novel tools may have proved to be just the kind of flexibility that was needed in order to survive long enough to reproduce. A very similar kind of story may also have occurred in humans – where ancient primate ancestors that were stronger stayed in trees and pushed out the weaker ones. The weaker ones had to adapt to the new niche where they were exposed to predators on the ground. Luckily, like a superbug, they rose to the occasion, and the intense selective pressure led them to develop more advanced social capacities in addition to a flexible and creative manipulation of their environment. If humans and octopus didn't possess the advanced capacities their nervous systems offered, they would probably not be around today.

CONSCIOUS SYSTEMS (a treasure chest of new abilities!)

Understanding consciousness is probably as big of a challenge as understanding the natural universe that surrounds it. It is a type of subjective experience so complicated that it can't reasonably be tackled head on. Human consciousness is likely not a single thing at all, but rather a collection of interconnected abilities our nervous system provides us to make flexible, intelligent, and context-sensitive behaviors. These abilities are entirely rooted in what we can physically perceive and process through interacting with the world around us.

The first major step of subjective experience probably came with the simple 'drives' to survive, get food, and reproduce. These 'drives' were then aided by sensory mechanism advancements like chemoreception, vision, and nociception to perceive the world in better detail, and distinguish between 'self' and 'not-self.' The complicated sensory information was then put to better use in some basic internal representation that actively updated to generalize, discriminate, and recognize patterns of subjective experiences over longer periods of time. This is related to concepts of perceptual constancies (like object permanence) which a variety of animals have been shown to exhibit. This also suggests at least some basic ability to perceive time and sequences of events. To make a system like this even more adaptive it could be used to actively plan for the future and develop expectations where investing more energy now may lead to a better supply of food later. Advancements in social perceptions are also incredibly important in some intelligent animals like us because being able to accurately predict the behaviors of other animals is highly adaptive. Many mammals, birds, and the octopus seem to have at least some extent of intelligent social cognition – but humans take this ability the furthest with the development of language.

Animals today have wildly different sensory mechanisms and internal representations which lay the foundation for their diverse subjective experiences. I think it may be true that the only subjective experience you can fully understand is your own at this exact moment in time. You are not the same person you were 5 years ago and thus you can only generalize most of the subjective experience of yourself at that point in time. The same goes with empathizing with or understanding other people, especially those with similar genetics or shaped by similar experiences as you. I think this may even be rigorously statistic, where we could infer, to some degree, the commonly shared subjective experience within a species, or even between species based on the physical variation of their nervous system. While the octopus has a very similar eye to our own, which solves a similar problem, the visual processing behind it could be completely different. Marr's level of analysis (separating the physical implementation from the algorithm and the problem it attempts to solve) is the only way I see us being able to reasonably tackle understanding of any of these complex mechanisms that collectively contribute to the consciousness we enjoy today.