Thor Kimmell
Evolution
Chris Jensen

Term Project Proposal

My Project will focus on the development of convergent evolution and homoplastic traits in organisms. Many of the articles I chose for my research suggest that convergence is in fact "Optimal Design" and the independent evolution of similar traits makes sense because organisms evolve to best suit their environment. We know that organisms evolving to best suit their environment is the basis for evolution, but the idea of Optimal Design suggests that there is a best fit for a given environment. Simon Conway Morris, the chair of Evolutionary Palaeobiology at the University of Cambridge, states that "convergence occurs because principles of physics limit the number of good solutions available."[1] This means that convergence occurs when multiple organisms evolve to solve the same physical problem. Not only does each organism evolve to keep up with a changing environment, but they evolve similar traits and abilities due to their similar situations. This hypothesis has not been completely proven across all examples of convergence, but optimal design is a hypothesis that is favored among many biologists researching convergence. Spawning from the hypothesis of optimal design I will explore the development of convergence in different pairs of organisms and how or why these traits formed. In reading articles based on convergence and homoplastic traits I have learned that convergent evolution is not only limited to physical traits as I had previously thought, it extends to social behaviors and even the gene circuits in microorganisms.

In a 2003 study biologists Gavin C Conant and Andreas Wagner published a paper about convergent evolution in genetic networks specifically the bacteria E. coli and the yeast S. cerevisiae. They cited studies on gene circuit motifs in regulatory networks done in 2002[2] as a basis for their theory that the shared network motifs in the bacteria E.coli and the yeast S. cerevisiae arose independently of one another by recruiting unrelated genes. Conant and Wagner took this information and went further with it, stating that if this convergent evolution is provable, then it also proves the existence of natural selection in the gene circuits of the two microorganisms. The other foreseeable answer to their inquiry was that these network motifs came about due to the gene circuits of the microorganisms' ancestors and the fact that genes and genomes duplicate themselves at a high rate and over time they would become more diverse leading to two different microorganisms that share specific gene networks. The biologists chose to test the convergent possibility. These networks motifs found in both microorganisms are regulatory chains: feed-forward circuits, and a bifan; regulatory chains (gene regulatory network or GRN) are used to define or outline molecular interactions for recording data.[3] A bifan motif is made up of two nodes cross-regulating two target nodes. This means that the two source nodes each regulate the two targets, but do not regulate each other. A feedforward loop or FFL is three regulations that happen across three genes. The first gene, or gene A, regulates to both gene B and gene C. In addition to this gene B also regulates to gene C.[4] In order to find out how these

---

[1] Ritzmann, Roy E. et al. "Convergent evolution and locomotion through complex terrain by insects, vertebrates and robots" pp. 362

[2] Lee, T.I. et al. Science 298, 799–804 (2002); Milo, R. et al. Science 298, 824–827 (2002); Shen-Orr, S.S., Milo, R., Mangan, S. & Alon, U. Nat. Genet. 31, 64–68 (2002)

[3] GRNs and Their Applications: Understanding biological and medical problems in terms of networks.

[4] Mangan S, Alon U. "Structure and function of the feed-forward loop network motif"

gene circuits evolved the biologists defined two ways that a gene circuit could prove a common ancestor. Using a graph system where points were plotted based on two pairs of genes in a circuit parring being duplicates and plotting points where two nodes are connected by circuits that shared a common ancestor. The other method of testing for a common circuit ancestor was the size of the largest family of circuits sharing a common ancestor in a given microorganism. They then located the duplicate genes using BLASTP, a protein specific version of the software BLAST which locates similarities in biological sequences.[5] Using this method on the two types of circuits found in E. coli Conant and Wagner found that they were not from a common ancestor. They then tested 18 different types of yeast circuits and only three of them showed a common ancestor which they wrote could have been due to chance because the yeast genome is rich with duplicate genes, and finding a few duplicates was well within reason. Not only did their findings show that gene circuits do not share common ancestors, they also found that new interactions between regulators can occur rapidly creating new gene circuits altogether. And through natural selection, the circuits are created based on what interactions work best for their given task.

Conant and Wagner end their paper by stating that finding that gene circuits evolve repeatedly is evidence for the theory for optimal design thanks to the design of a feed-forward chains and that the convergence in protein sequences can play an important part in highly organized gene circuits. This also relates to Morris's definition of convergence because the of the limited ways that gene circuits can form. The existence of these circuits in two different microorganisms, which are unrelated, is indeed an example of "the number of good solutions available". Through my research so far the theory of Optimal Design has come up multiple times and it has often used to explain how two organisms can evolve mechanisms that were not present in their common ancestor. Another example of this and an example optimal design is Arctic fishes ability to produce their own antifreeze completely separate from each other and using different genes.

In a 1997 study biologists from the University of Illinois looked at antifreeze producing glycoproteins in fish from both Antarctica (notothenioids) and northern regions (cod). They found that even though the fish were far apart on the phylogenetic tree they produced almost identical forms of antifreeze.[6] These antifreeze glycoproteins or AFGPs in both types of fish are made up of polyprotein, a larger protein that is cleaved into smaller proteins that have different functions in the body. Upon further analysis of the AFGPs in both kinds of fish is is clear that they evolved their antifreeze differently from one another instead of directly evolving it from a common ancestor. The first proof of this is that the AFGPs in Antarctic fish originate from a digestive enzyme in the pancreas called trypsinogen while the Arctic fish did not share the same gene sequence. On top of this both fish also process the polyproteins that make up AFGPs differently. If the polyproteins had come from a distant ancestor they would have processed them in the same way and the biologists explain that it is not logical for the fish to have reinvented the way they process the AFGP polyproteins once they evolved further. The biologists then looked at fossils of the fish and concluded that they most likely diverged 40 million years ago but the

---

[5]"BLAST: Basic Local Alignment Search Tool." National Center for Biotechnology Information. U.S. National Library of Medicine, n.d. Web. 25 Mar. 2017

[6] Chen, Liangbiao, et al. "Convergent Evolution of Antifreeze Glycoproteins in Antarctic Notothenioid Fish and Arctic Cod." pp 3817–3822

freezing of the northern hemisphere occurred only 2.5 million years ago meaning that when the fish diverged they had no need for AFGPs. Also the northern hemisphere froze after the south so the development of antifreeze in the northern fish was even further removed from the southern fish. The fact that there was no need for antifreeze when the fish diverged and that the AFGPs originated within different places inside the fish is enough to prove convergence in the two species. What did lead to the development of AFGPs in both species was that they both had to survive in a freezing environment and in the period of time that both oceans were freezing the fish were able to adapt. Before I had thought that a common ancestor was the only way organisms could evolve certain traits; that a common ancestor provided the building blocks for later evolutions to expand on but with these fish I learned that the blocks can be more abstract and traits can arise from completely different places in different genes. The fact that both fish could evolve to produce a similar antifreeze is another demonstration of optimal design at work and possibly the closest example of nature having one right answer.

I have also learned that convergence is not only studied to understand the past to present of organisms and it can be studied for future projects in other scientific fields. In 2004 scientists at Case Western Reserve University looked at convergence in insects and vertebrates and their motion across rough terrain to create the most successful rough terrain robot.[7] They defined success as the ability to move quickly in an environment regardless of obstacles and therefore a successful robot could do the same. Early on in the paper the scientists note that while biomimicry (imitating systems that occur in nature in order to solve problems in the modern world)[8] is an ideal approach, the connections in the nervous system of insects are more complex than computer systems in robots and they have censors all over their body to better aid in quick decisions and their small size gives them more opportunities for traversing an area than a larger robot would have. As they look at other animals the scientists mention Conway Morris's theory on the limited number of good solutions there are in nature, and keeping this theory in mind they look at convergent traits in species. The scientists looked at the gait of insects and mammals and then the skeletal structure of each species. What they came up with was a six legged robot where each pairing of legs on each side was unique meaning that the robot had three distinct pairs of legs with their own type of articulation. As they looked further at the structure of the species limbs they noticed that the insects were using much more movement to understand and traverse their surroundings. Multiple limbs as well as their antennae let them take in their surroundings quicker and react to them, but still that would mean a large amount of sensors covering the robot and possibly limiting its ability to move through a variety of terrain (a successful robot would be able to walk on sand or avoid water, but if there are too many sensors the robot becomes too delicate and therefore useless for the objective of the project). The scientists concluded that there were "only a few good solutions"[9] given the number of pieces they had to work with. This directly relates to Conway Morris and even though it is using optimal design to come up with solutions for the future instead of reasoning for answers in the past, the concept of an answer is still present and it is a concept that I want to focus on in my creative project.

---

[7] Ritzmann, Roy E. et al. "Convergent evolution and locomotion through complex terrain by insects, vertebrates and robots" pp. 361

[8] Vincent, Julian F. V.; et al. "Biomimetics: its practice and theory"

[9] Ibid. pp 377

For my creative piece I want to turn this theory of optimal design into a visual piece. So far in class the diagrams and examples of convergence have been side by side examples of animals or a focus on one particular trait. I want to create a more abstract diagram to convey that there is more than one way to solve a problem. For organisms this problem is most commonly successful survival which can mean how they moving around, reproduction, and getting food in their respective environments. I have been looking at more basic form based symbols and structures that when combined are able to build into intricate shapes. These shapes would be representations of environmental obstacles and the desired shapes would be evolutionary responses to overcome or in the case of optimal design, perfectly fit the problem. Through my research on the kind of shapes and devices I could use to bring this idea to life I first settled on a table top version of the Japanese game show Hole in the Wall where contestants would play a kind of human tetris to fit through a moving wall before they were pushed into a pool of water. The environmental problem would be the wall, the solution would be the hole, and not being able to create a solution (evolve) would result in landing in the water (extinction). I decided this was too complex and messy and searched more before finding Tangrams, a puzzle game that uses a library of shapes to create a larger image, with multiple possibilities for an answer. Using a library of shapes I want to create images that display a problem with multiple ways to successfully solve the problem as a metaphor for different organisms evolving to solve similar problems of their own. I want to use simple geometric shapes like triangles and parallelograms because these are shapes most people know and therefore they can easily think with them through more and more complex situations. For my game I will laser cut shapes in different colored plexiglass as well as make screenprints on paper of different silhouettes of the desired design. The plexi shapes will be able to be arranged on the paper so that they correctly fill out the design, successfully evolving the organism with the environment. The way I want the game to be played is a competitive game where two teams are given the same number of assorted shapes in two colors, one team with orange plexi pieces and the other with blue plexi pieces. Then they would each be given the paper with the print of the environmental problem and be given a set time to complete the puzzle. If the teams complete the design in the required time they evolve, if not they become extinct.

Bibliography

"What Is Biomimicry? – Biomimicry Institute." *Biomimicry Institute*. N.p., n.d. Web. 26 Mar. 2017.
http://biomimicry.org/what-is-biomimicry/

Biomimicry definition.

"BLAST: Basic Local Alignment Search Tool." National Center for Biotechnology Information. U.S. National Library of Medicine, n.d. Web. 25 Mar. 2017.
https://blast.ncbi.nlm.nih.gov/Blast.cgi?CMD=Web&PAGE_TYPE=BlastHome

A software that locates similarities in biological sequences used by

Chen, Liangbiao, Arthur L. DeVries, Chi-Hing C. Cheng. "Convergent evolution of antifreeze glycoproteins in Antarctic notothenioid fish and Arctic cod". PNAS. vol. 94, no. 8, 1997
http://www.jstor.org/stable/41912

Scientists observed that fish that live in the north and south poles both produce their own antifreeze to survive in the extremely cold climate. It is possible that these fish had a common ancestor that possessed this antifreeze but these scientists believe that these fish evolved their antifreeze abilities independently once they migrated to their respective poles. They were able to locate the gene that produces antifreeze in one of the fish, but it completely unrelated to the other fish's production of antifreeze

Conant, Gavin C; Wagner, Andreas. "Convergent evolution in gene circuits" *Nature Genetics*; New York 34.3 (Jul 2003): 264-6.
http://search.proquest.com/openview/2499768c6fa97f87ffb3a63128c92bde/1?pq-origsite=gscholar&cbl=33429

The scientists in this article observe convergent evolution on yet another level. Instead of plants or animals they focused on genes. In the article Convergence is referred to as "optimal design" and they compare the evolution of E.coli and the yeast Saccharomyces and also trace back to a common ancestor between the two. This shows that convergence can happen anywhere regardless of the size or nature of something and can even happen in things that are not considered "living" like plants and animals are.

Emery, Nathan J., and Nicola S. Clayton. "The Mentality of Crows: Convergent Evolution of Intelligence in Corvids and Apes." *Science*, vol. 306, no. 5703, 2004, pp. 1903–1907., www.jstor.org/stable/3839824.

This article is a discussion on the evolution of intelligence and behaviors in crows and apes. Like apes, crows can use tools and they also are both social species. Emery and Clayton believe that these animals are able to reason in similar ways despite having different brain structures. This article is useful for my understanding of homoplasy because it discusses the evolution of mental capability across species and not just similar physical traits.

Heather L. Norton, Rick A. Kittles, Esteban Parra, Paul McKeigue, Xianyun Mao, Keith Cheng, Victor A. Canfield, Daniel G. Bradley, Brian McEvoy, Mark D. Shriver; Genetic Evidence for the Convergent Evolution of Light Skin in Europeans and East Asians. *Mol Biol Evol* 2007; 24 (3): 710-722.
https://academic.oup.com/mbe/article/24/3/710/1240790/Genetic-Evidence-for-the-Convergent-Evolution-of

The scientists in this Journal give another example of convergence in the skin pigmentation between people in Europe and East Asia. Scientists built their research on the relationship between ultraviolet radiation and skin tone. They isolated a few genes that are responsible for skin pigmentation throughout the world and then found a few that affect Europeans but not East Asians. This selection of genes has led them to believe that the phenotype for lighter skin is different for people native to the two regions.

Julian F.V Vincent, Olga A Bogatyreva, Nikolaj R Bogatyrev, Adrian Bowyer, Anja-Karina Pahl. "Biomimetics: its practice and theory". J. R. Soc. Interface 2006 3 471-482; DOI: 10.1098/rsif.2006.0127. Published 22 August 2006
http://rsif.royalsocietypublishing.org/content/3/9/471

More definitions and explanations of biomimicry.

Lee, T.I. et al. Science 298, 799–804 (2002); Milo, R. et al. Science 298, 824–827 (2002); Shen-Orr, S.S., Milo, R., Mangan, S. & Alon, U. Nat. Genet. 31, 64–68 (2002)

2002 studies on gene circuit motifs cited by Conant and Wagner as a basis for their theory of shared network motifs in microorganisms.

Mooney, Harold A., and E. Lloyd Dunn. "Convergent Evolution of Mediterranean-Climate Evergreen Sclerophyll Shrubs." *Evolution*, vol. 24, no. 2, 1970, pp. 292–303., www.jstor.org/stable/2406805.

The discussion in this article is about characteristics in plants that grow in similar climates around the world. Even though this article is from the 70s, as far as I can tell the information around this study has not gone through a major change since then. The article has good diagrams of growth patterns in different plants as well as graphs that relate to soil moisture and temperature of the environment. I was not surprised to find homologous traits in plants that share similar environment, but it is interesting that these are considered "native plants" in their respective areas. This could mean that these shrubs share a common ancestor.

Polyprotein definition

https://www.merriam-webster.com/medical/polyprotein

Ritzmann. Roy E, Roger D. Quinn. "Convergent evolution and locomotion through complex terrain by insects, vertebrates and robots". *Elsevier*, vol. 33, no. 3, 2004, pp. 361-379.
http://s3.amazonaws.com/academia.edu.documents/45271707/Ritzmann_204.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1487561689&Signature=YnsYRgvbpu0EBGW

skxIGqHe5cGo%3D&response-content-disposition=inline%3B%20filename%3DConvergent_evolution_and_locomotion_thro.pdf

In order to build better robots for off road these scientists look at how vertebrates and arthropods independently evolved to traverse difficult terrain. By looking at the two species the scientists get two answers on how to go about engineering this movement and therefore multiple approaches to take. Not only do these scientists look at the evolution of leg movement across species, they then take this and apply it to a current project.

Trypsinogen definition
https://en.wikipedia.org/wiki/Trypsinogen

Zimmer, Carl. *Evolution: The Triumph of an Idea*. Harper Collins Publishers. 2001.

This book by Carl Zimmer is a companion to the PBS series *evolution* and features many examples of genetic discovery while being written in a easily understood way. Zimmer mentions Darwin's first attempt to try and relate species homogeny as well as giving examples of universal attributes across species, like how almost every animal has eyes. This goes beyond just similar bone structures and gives an explanation as to why so many animals have similar characteristics despite being so distant.