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Term Project Summary

For my term project I have been researching convergence and the theory of optimal design through different comparisons of organisms. Reading these studies I have learned of the many forms convergence can take beyond the physical, such as convergence in gene circuits within microorganisms and convergence in glycoproteins within fish.[1] After researching this topic in multiple studies the question of optimal design still remains. I have come up with my own questions based on optimal design but instead of focusing on physics I have based it on the genetic potential every organism possesses to evolve. The theory of optimal design comes from Simon Conway Morris of Cambridge University, who theorised that the laws of physics limit the ways a species can evolve and therefore different species can develop similar traits. The specific traits that Morris is talking about are the construction of wings across species such as many insects, mammals, and birds.[3] Morris theorizes that wings evolved similarly across these species thanks to the laws of physics and since the number of possible solutions for flight is limited by physics, other traits must be limited by other laws of physics. While I agree with Morris in that physics would come into play with the success of a bird's ability to fly I think that convergence traits arise due to similar environmental shifts or because organisms share the same genetic material needed to fulfill a basic function and therefore that function is consistent across species. The genetic potential within organisms pertains to mutations in their genes leading two different organisms to a similar result. The problem with using physics as a basis for convergence is that there is a lot of grey area or instances where physics does not play a major role. For example, the construction of limbs across species is functionally similar but physically differently[4]. The species were evolving to keep up with their changing environment and the ability to move across changing terrain would lead to getting more food from further areas and getting away from predators. Other organisms have adapted to survive in their changing environment by altering their internal mechanisms and the proteins that they produce.

Fish in the northern and southern poles have both evolved to produce antifreeze glycoproteins or AFGPs, but they evolved these independently over the 2.5 million years it took the northern and southern hemispheres to freeze.[1] Both fish had mutations that helped them evolve to create these AFGPs and since they were faced with the same environmental problem of how to survive in freezing temperatures and they both developed antifreeze.

Another example of using building blocks present within organisms is within E. coli and S. cerevisiae and their shared network motifs in regulatory networks. Both microorganisms developed the same regulatory chains to relay information within their respective circuits. The biologists found that these gene circuits did not share a common ancestry and that the interactions between the regulators occur rapidly creating new gene circuits altogether.[2] But these new circuits did not always perform the given task and therefore the preferred circuits were kept while others were discarded. Even though these circuits appear randomly the simplicity of their structure means that there are a set number of ways that a defined gene circuit will form a bifan or a feed-forward circuit. This gives more evidence for optimal design in that there is a set way or right way for these circuits to form and because of these set rules it is no surprise that two organisms that produce regulatory chains would form similar motifs.

The scientific information incorporated into the project were the physical similarities of convergent traits and an organism's ability to adapt to its environment before the environment became uninhabitable. In another study I read, scientists and engineers looked at convergent traits in movement across uneven terrain in order to build better walking robots.[4] They highlighted problems that faced each of the highlighted species and studied how the species overcame obstacles. These scientists and engineers researched the limb structure of insects and mammals and concluded that they had a set number of good solutions, or building blocks, in order to create their robot.[4] I began making my creative project using this idea of building blocks and a set number of blocks in order to make a larger image. I also used the idea of simple structures as seen in the study of gene circuits to make my project, which took the form of a game, more understandable as a visual object. The simplicity of the regulatory motifs is what made them so easily definable.[5] By performing only a few tasks the data recorded on each regulatory chain is easier to understand and I realized after trying to explain my concept to some of my peers that a simpler execution would better convey the ideas of convergence to someone who had minimal understanding of evolution.

The creative direction I took my project in was through a game called Tangrams,a puzzle game that uses a library of shapes to create a larger image, with multiple possibilities for an answer. The library consists of seven geometric shapes: two larger right triangles, two smaller triangles, one middle sized triangle, a square, and one parallelogram. Since its invention during the Song dynasty[6], there have been over 6500 different combinations created using tangrams and out of those combinations I chose to focus on some of the paradox shapes.[7] Paradox shapes are tangram puzzles that have the same silhouette but but are composed of a different arrangement of pieces. Although these pieces are different they both are used to fulfill the puzzle much like convergent traits are can appear the same but originate from different places in order to solve an environmental puzzle. The original paradox shapes were too specific so I have simplified them by removing extra pieces that would have represented a head or a tail. These shapes are a symbol for a trait that the organism would have once it evolved to it's new environment. The individual shapes are the organisms building blocks that are rearranged to form something new. The game will be played with two teams of people in order to minimize the problem solving time and each team would get a set of tangrams. The sets are different colors representing two different organisms and each team will get one of the shapes from a paradox set representing the similar problems each organism is facing. Since the desired shapes are near identical I have given clues as to where single pieces go so that the teams do not come up with the same arrangement. Also this eliminates the possibility of one team having a harder puzzle than the other. Each card was hand printed with colors that I see as representative of life: blue and red. Blue for the ocean where most organisms if not all of them began, and red for blood and the life force that courses through many species. The shapes were hand painted onto the cards with black ink but I left a few clues in the puzzles as to where certain shapes should be placed. The tangrams for each team are colors that compliment the cards. The red team gets light blue tangrams while the blue team gets orange. The colors are also easily read on their surfaces.

For the sake of competition there is a time limit for each round with three rounds in total. The idea for a time limit came to me after reading the study of AFGPs in fish because the biologists found that the trait would have had to evolve in the 2.5 million years it took for Earth's poles to freeze.[1] The time limit on each round is the amount of time the organism (each team) had time to evolve to survive in the changing environment (the desired final shape of arranged Tangrams). For the first round the time limit is three minutes. This is a considerable amount of time for a simpler puzzle but I do not expect all who play to be familiar with Tangrams so it is time to get acquainted with the game. The second round is a minute and a half; by now the players should be able to figure out how the pieces fit together, and there is another clue to help them complete the desired shape. The final round is only one minute and is the most difficult. Teams are not expected to complete the shape and therefore become extinct, reminding them that time is not on the organism's side and does not wait for it to catch up to it's changing environment.

The intended audience for this project are people who have a basic understanding of evolution and an interest in problem solving games. While the game is based in science the ability to visually work through a problem can increase an interest in the subject matter. Besides having an interest in science many people also love puzzles as they are a low risk problem that leaves one with a feeling of accomplishment. When that accomplishment means that an organism continues to exist the satisfaction is multiplied. After players had completed the game many of them began to grasp the concept of convergence as two answers to the same problem and they also wanted to know about how else convergence manifests in organisms. The spark of interest after completing the game was unexpected. I wanted to convey ideas of convergence through physical appearance and also the concept of time catching up to an organism but I was then able to list other instances of convergence and reasons why it may have occurred.

Bibliography

1. 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 but they evolved it separately rather than from a common ancestor. I used the concept of a time limit for evolution to bring a time component into my creative work.

2. 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 the microorganic level. The two organisms use similar regulatory structures to relay information, and I used this concept of similar parts or building blocks as a base to explore the simple and similar shapes of Tangrams and how those shape can also come together with thousands of possible outcomes.

3. Bale R, Neveln ID, Bhalla APS, MacIver MA, Patankar NA (2015) Convergent Evolution of Mechanically Optimal Locomotion in Aquatic Invertebrates and Vertebrates. PLoS Biol 13(4): e1002123. https://doi.org/10.1371/journal.pbio.1002123

This source provided me with Conway Morris's theory on convergence as it pertains to the laws of physics, a theory that I built upon to come up with my own question and gave evidence for physics playing a smaller part in other cases of convergence.

4. 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=YnsYRgvbpu0EBGWskxIGqHe5cGo%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. I also used this to apply a building block concept to my creative work.

5. Mangan, S., and U. Alon. "Structure and Function of the Feed-Forward Loop Network Motif." *Proceedings of the National Academy of Sciences of the United States of America* 100.21 (2003): 11980–11985. *PMC*. Web. 18 Apr. 2017.

I used this source to understand the structure of feed-forward loops and to define network motifs.

6. Jiannong Shi. Robert J. Sternberg, ed. *International Handbook of Intelligence*. Cambridge University Press. pp. 330–331. ISBN 978-0-521-00402-2.

This book was used to understand and explain the origins of Tangrams in the Song dynasty and how much the game has evolved since then.

7. Loyd, Sam (1968). *The eighth book of Tan – 700 Tangrams by Sam Loyd with an introduction and solutions by Peter Van Note*. New York: Dover Publications. p. 25.

This book provided me with the tangram paradoxes with which I drew direct comparisons to convergent traits across species.

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CONVERGENCE THE GAME: RULES

1. Form two teams of two to three players each and give each team a set of Tangrams. Place a round one card face down in front of each team. The time limit is 3 minutes. There is no penalty for finishing early but if the puzzle can not be completed the team will lose.

2. Much like two organisms adapting to a similar change in their environment there are two possible answers to the problem. Scientists have found that the bacteria E. coli and S. cerevisiae share the same configurations for sending information called Network Motifs. It was discovered that these bacteria did not have such motifs in their common ancestor and therefore have evolved these motifs on their own. Each team's card has been given a clue as to where a piece will go in order to complete the puzzle. Using the pieces in front of you create the shape of the network motifs used by both microorganisms.

3. Round two is has similar rules but half the time limit (1:30). In 2004 a group of engineers teamed up with scientists to design better robots by looking at convergence. The engineers were able to pick and choose the structure of their robots limbs from an array of species that had evolved ways to get across rough terrain. Using the pieces of in front of you create the shape of a completed leg structure.

4. The third round is the most difficult and has the shortest amount of time. On one card there is another isolated shape but instead of a clue is a negative space where the team must NOT put a shape down. In 1997 researchers discovered that fish living near the northern and southern poles produced their own antifreeze using glycoproteins that was not present in their common ancestor. The common ancestor of both fish did not need antifreeze because the poles were not frozen yet, but during the 2.5 million years that these two fish were around the poles began to freeze and they had to adapt to their changing environment by producing antifreeze. Using the pieces in front of you complete the design of the different glycoprotein responsible for producing antifreeze in each fish.

5. If you have completed each round congratulations! Your species have evolved traits that look the same in order to keep up with their changing environments and continue to exist. Although the overall images *look* the same they are made with a *different* combination of building blocks. If you have failed along the way your organism has gone extinct, unable to adapt to its changing environment.