

Gabora, L. (April 2013). Convergent evolution. In (Maloy, S. & Hughes, K., Eds.) *Brenner's Online Encyclopedia of Genetics, 2nd edition* (pp. 178-180). Amsterdam: Elsevier.

CONVERGENT EVOLUTION

LIANE GABORA

Contact information:

Liane Gabora

Department of Psychology, University of British Columbia Okanagan campus, 3333

University Way Kelowna BC, V1V 1V7, CANADA Ph: (250) 807-9849

Fax: (250) 807-8439

email: liane.gabora@ubc.ca

<http://people.ok.ubc.ca/lgabora/>

Keywords:

Analogous structures, biodiversity, coexistence, common ancestry, competition, cultural evolution, divergent evolution, ecological niche, evolutionary relay, homologous structures, homology, homoplasy, parallel evolution, re-evolution

Glossary:

1. Analogous structures – Traits arising through convergent evolution.
2. Divergent evolution – The opposite of convergent evolution; species with a common ancestor evolve different traits, perhaps increasingly occupying different ecological niches.
3. Evolutionary relay – How independent species acquire similar characteristics through their evolution in similar ecosystems at different times.
4. Homologous – Having a common ancestor.
5. Homoplasy – Similarity in species of different ancestry that is the result of convergent evolution.
6. Parallel evolution – Two independent species evolving together at the same time in the same ecospace acquire similar traits.
7. Re-evolution – The re-appearance of a trait following the loss of the genes for the trait.

Synopsis:

Convergent evolution occurs when organisms that are not closely related evolve traits that are similar, or analogous, as an adaptive response to similar environmental pressures. The genes responsible for the two versions of the trait may be quite different. Examples include the evolution of wings in the bat, the bird, and the pterodactyl, and the evolution of glycoproteins with antifreeze properties by fish in the Arctic and Antarctic.

Chapter text:

Convergent evolution refers to the evolution in different lineages of structures that are similar or *analogous*, but that cannot be attributed to the existence of a common ancestor; in other words, the fact that the structures are analogous does not reflect homology. The similarity may reside at the phenotypic level, in which case the lineages share the overt trait but the underlying DNA sequences are different. Convergent evolution occurs when species occupy similar ecological

niches and adapting in similar ways in response to similar selective pressures. Traits that arise through convergent evolution are referred to as *analogous structures*. They are contrasted with *homologous structures*, which have a common origin. The opposite of convergent evolution is *divergent evolution*, whereby related species evolve different traits.

Well-documented cases of convergent evolution of similar DNA sequences are not plentiful; such cases are usually restricted to a few amino acids. Convergent evolution can mislead phylogenetic inference because it mimics shared ancestry. Standard phylogenetic methods are not equipped to differentiate between the two. When convergent evolution is mistaken for homology, this produces a phylogenetic tree that is falsely reticulate or bushy in appearance, i.e. species appear to originate from a common ancestor when in fact that is not the case.

Examples

Camera Eye of Cephalopods and Vertebrates

A famous example of convergent evolution is the camera eye of cephalopods (e.g., squid and octopus), vertebrates (e.g., mammals). Their last common ancestor had just a simple photoreceptive spot. The final structure is remarkably similar but it was achieved through different evolutionary paths, as evidenced by one significant difference: whereas in vertebrates, the blood and nerve vessels enter from the front of the retina, in the cephalopod eye, the blood and nerve vessels enter from the back. In other words, they are wired in the opposite direction.

Wings of the Bat, Bird, and Pterodactyl

Another oft-cited example of convergent evolution is the wings of the bat, the bird, and the pterodactyl. The forelimbs of each of these vertebrates independently morphed over time into wings that became used for flight. As with the camera eye, similar evolutionary pressures and similar aerodynamic constraints on the shape, size, and movement of wings led to the evolution of wings in birds and bats that are remarkably similar in construction. The bat wing is homologous to human and other mammal forearms because they share an ancestral state despite serving different functions. Insects also independently evolved wings for flight.

Body Plans

Very similar body plans evolved independently in two clades, the marsupial fauna of Australia and the placental mammals of the Old World. These include the body plans of sabre-toothed cats and flying squirrels. Another example of analogous body plans is the torpedo shaped body of sharks, dolphins, and ichthyosaurs (swimming dinosaurs).

Antifreeze Glycoprotein in Fish

Fish in both the Arctic and Antarctic have evolved glycoproteins that act like antifreeze. The glycoproteins circulate in the blood and surround tiny ice crystals, stopping them from growing. This slightly lowers the temperature at which their body fluids would freeze. These two populations of fish split long before they evolved the antifreeze genes, and in fact the genes that produce the antifreeze proteins are quite different. This indicates that independent episodes of molecular evolution occurred, with the same functional outcome.

Other Examples

Other noteworthy examples of convergent evolution include the smelling organs of the terrestrial coconut crab and those of insects, and the shells of brachiopods and bivalve mollusks. There are also many examples of convergent evolution in plants. These include a number of hormones in plants and fungi such as gibberellin and abscisic acid, and the independent evolution in different species of plants of prickles, thorns and spines, which prevent or limit herbivory. Many different plants have evolved flowers and nectar to attract pollinating species. Another example is the rare Tasmanian Beech tree is the only true deciduous (leaf shedding) tree in Australia. Although it was long thought to be a relative of the northern hemisphere species, DNA analysis revealed that it arose independently and that its origins date back to the Gondwana-southern supercontinent.

Distinction from Related Phenomena

Re-evolution

In re-evolution, a trait is lost because the genes responsible for it are lost, and then they evolve again later in the same lineage. As a result, members of a lineage at time A share a trait with members of that lineage at time C that is not shared with members of the lineage at an intermediate time B. Unlike convergent evolution, organisms from time A and time C that share the trait are closely related. It is sometimes difficult to determine whether a gene was genuinely lost, or whether it been ‘switched off’ and then re-enabled later.

Evolutionary Relay

Evolutionary relay refers to the evolution of similar traits in independent species that live in similar ecosystems at different times. An example of evolutionary relay is the dorsal fins of extinct ichthyosaurs and sharks.

Parallel Evolution

Parallel evolution occurs when independent species acquire similar characteristics while evolving together at the same time in the same ecospace. An example of parallel evolution is extinct browsing-horses and paleotheres. The difference between parallel and convergent evolution is the following. Consider members of two lineages that are similar with respect to some trait. In parallel evolution, the ancestors of their respective lineages were similar with respect to that trait. In convergent evolution, the ancestors of their respective lineages were not similar with respect to that trait. Thus in convergent evolution they became increasingly similar over time.

Sometimes, the ancestral forms are unspecified or unknown, or the range of traits considered is not clearly specified. In such cases, distinguishing between parallel and convergent evolution is not straightforward. For example, the striking similarity between placental and marsupial forms have been considered a case of convergent evolution, because they each had a long evolutionary history prior to the extinction of the dinosaurs under which to differentiate. However they have also been viewed as an example of parallel evolution starting from the common ancestor of all marsupials and placentals. In the end, whether a particular case is considered parallel or convergent may depend on how far back one looks in their ancestral lines.

Convergence in Cultural Evolution

Convergent evolution also takes place in culture. All humans have similar needs, our bodies move in similar ways, and we have a shared sense of pleasure and displeasure, comfort and

discomfort. Our environments provide us with similar materials from which to construct artifacts, and certain materials are best suited to particular purposes. These factors constrain how elements of culture change over time. Thus, much as species that are not closely related but occupy similar ecological niches may evolve similar traits, cultures that are not derived from the same ancestral culture may evolve similar artifacts, sports, cooking techniques, and so forth.

Because culture evolves differently from living organisms, convergent evolution presents more of a challenge for the classification of elements of culture than it does for the classification of organisms. The degree of relatedness of different species can be determined not just through examination of their phenotypic traits, but through examination of their DNA. Thus even if organisms share a trait, if the genes underlying that trait are different, the trait will not be considered evidence that they are closely related. Moreover, horizontally transmitted traits are by and large not inherited, and therefore lost from the lineage, e.g. if an organism loses its tail, its offspring are not born without a tail. Therefore, convergent evolution of biological lineages happens slowly, and is relatively easy to track. Finally, because organisms must solve many problems (reproduction, locomotion, digestion, etc.) the probability that a species is mis-categorized on the basis of any one trait (i.e. how it solves any one problem) is low. Artifacts, on the other hand, are often constructed with a single use in mind. (Though artifacts developed for use in one context may be used to solve other problems, e.g., a screwdriver may be used to open a can of paint). Therefore, there is greater danger of mis-categorization arising through the assumption that similarity reflects homology. Moreover, there is no cultural DNA to help us distinguish trait similarity due to true convergence from trait similarity due to shared ancestry, and since horizontally transmitted traits are retained, culture is harder to track. Finally, there are no restrictions on 'what can mate with what'; i.e. For these reasons, the application of phylogenetic methods to culture can lead to a classification that assumes homology when it is not present, and that is therefore misleadingly reticulate or bushy in appearance.

Theoretical Issues

The degree to which the diversity of life forms reflects convergence is the subject of a popular controversy. In the book 'Wonderful Life', Stephen Jay Gould claims that if the tape of life were re-wound and played back, completely different forms of life would have evolved. However, Simon Conway Morris argued that because all life forms are acted upon by the same environmental and physical constraints, and there are a finite number of effective solutions to some challenges, they gravitate toward certain body plans that effectively solve the problems of survival. Conway claims that, given enough time, even the evolution of intelligence is inevitable, citing its evolution in primates, crows, and dolphins. Thus, he claims, convergence plays a central role in shaping the products of evolution.

Scheffer and van Nes showed that self-organized clusters of look-a-likes may emerge spontaneously from the coevolution of competitors. This makes intuitive sense because there are two alternative ways to survive together: being sufficiently different or being sufficiently similar. Their theoretical model suggests that there is a tendency for evolutionary emergence of regularly spaced lumps of similar species along a niche axis. Their model also suggests that convergent evolution is more likely in species-saturated communities with high levels of competition.

Further reading:

Doolittle RF (1994). Convergent evolution: the need to be explicit. *Trends in Biochemical Sciences*, 19, 15–18.

- Chen, L., DeVries, A. L. & Cheng, C. H. (1997). Convergent evolution of antifreeze glycoproteins in Antarctic notothenioid fish and Arctic cod. *Proceedings of the National Academy of Sciences USA*, 94, 3817–3822.
- Collin, R. & Cipriani, R. (2003). Dollo's law and the re-evolution of shell coiling. *Proceedings of the Royal Society B: Biological Sciences*, 270(1533), 2551–2555.
- Gould, S. J. (1989). *Wonderful Life: The Burgess Shale and the Nature of History*. W.W. Norton & Company.
- Kozmik, Z.; Ruzickova, J.; Jonasova, K.; Matsumoto, Y.; Vopalensky, P.; Kozmikova, I.; Strnad, H. Kawamura, S. et al. (Jul 2008). Assembly of the cnidarian camera-type eye from vertebrate-like components. *Proceedings of the National Academy of Sciences USA*, 105(26), 8989–8993.
- Morris, S. C. (2005). *Life's solution: inevitable humans in a lonely universe*. Cambridge, UK: Cambridge University Press.
- Zhang J, Kumar S (1997). Detection of convergent and parallel evolution at the amino acid sequence level. *Mol Biol Evol*, 14, 527–536.

[List of relevant websites of interest to the reader]

http://www.sciencedaily.com/articles/c/convergent_evolution.htm

http://www.pbs.org/wgbh/evolution/library/01/4/1_014_01.html

[Biographical details – up to 200 words and a photo]

Liane Gabora is a professor of psychology at the University of British Columbia, Canada. Her work capitalizes on her training in both theoretical biology and cognitive science. She researches the mechanisms underlying biological and cultural evolution, with a focus on the novelty generating, creative processes that drive evolutionary change, using both computer models and experiments involving human participants. Her goals are (1) to develop a comprehensive



theoretical framework for cultural evolution, and (2) by undertaking a comparative study of biological and cultural change, to arrive at a more comprehensive understanding of how something could evolve. She has over 100 published papers in academic journals, book chapters, and conference proceedings. She has given lectures worldwide and has over a million dollars in research grants. She was recently awarded the 2011 Berlyne Award from Division 10 of the American Psychological Association for outstanding research.

Figures and/or tables: please note that for any non-original figures or tables permission must be obtained from the publisher. Further information is available on the Resources tab, or on this webpage: <http://www.elsevier.com/wps/find/authorsview.authors/permissions>