

## ON THE QUESTION OF CONVERGENT EVOLUTION IN BIOCHEMISTRY

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**Abstract.** Convergent evolution is an ubiquitous phenomenon, since it occurs at the levels of morphology, physiology, behavior (Eisthen and Nishikawa, 2002), and at the molecular level (Pace, 2001). Evolutionary convergence is significant for the central problem of astrobiology. Since all forms of life known to us are terrestrial, it is relevant to question whether the science of biology is of universal validity (Dawkins, 1983), and whether the molecular events that were precursors of the origin of life are bound to occur elsewhere in the universe wherever conditions are similar to the terrestrial ones. We discuss evolutionary convergence and its classification into functional, mechanistic, structural and sequence convergence (Doolittle, 1994), which should help us in the context of astrobiology defining bioindicators in the exploration of the solar system.

### 1. Introduction

The question "What would be conserved if the tape of evolution were played twice?", which is relevant to astrobiology has been raised repeatedly in the past (Fontana and Buss, 1994); it underlies one of the basic questions in astrobiology. Since all forms of life known to us are terrestrial organisms, it is relevant to the question of whether the science of biology is of universal validity (Dawkins, 1983; Chela-Flores, 2003).

The sharp distinction between chance (contingency) and necessity (natural selection as the main driving force in evolution) is relevant for astrobiology. Independent of historical contingency, natural selection is powerful enough for organisms living in similar environments to be shaped to similar ends. Our examples will favor the assumption that, to a certain extent and in certain conditions, natural selection may be stronger than chance (Conway-Morris, 1998; 2002). We raise the question of the possible universality of biochemistry, one of the sciences supporting chemical evolution.

### 2. Evolutionary divergence and convergence

The universal nature of biochemistry has been discussed from the point of view of the basic building blocks (Pace, 2001). One of the main points made in that paper is that it seems likely that the building blocks of life anywhere will be similar to our own. Amino

acids are formed readily from simple organic compounds and occur in extraterrestrial bodies such as meteorites. Themes that are suggested to be common to life elsewhere in the cosmos are the capture of adequate energy from physical and chemical processes to conduct the chemical transformations that are necessary for life: lithotrophy, photosynthesis and chemosynthesis. Other factors in favor of the universality of biochemistry are physical constraints (temperature, pressure and volume), as well as genetic constraints.

Divergence and convergence are two evolutionary processes by which organisms become adapted to their environments. Evolutionary convergence has been defined as the acquisition of morphologically similar traits between distinctly unrelated organisms (Austin, 1998). While there are many examples of molecular divergence, the same is not true of molecular convergence.

Convergent evolution is said to occur when a particular trait evolves independently in two or more lineages from different ancestors. This is distinct from parallelism, which refers to independent evolution of a trait from the same ancestor. Although many of the best-known examples of convergence are morphological, convergence occurs at every level of biological organization. However, this paper focuses on molecular convergent evolution. We would like to proceed with examples of molecular convergence along the classification by Doolittle (1994) into Functional, Mechanistic, Structural and Sequence convergence.

### 2.1. FUNCTIONAL CONVERGENCE

This refers to molecules that serve the same function but have no sequence or structural similarity and carry out their function by entirely different mechanisms. Despite the fact that alcohol dehydrogenases in vertebrates and *Drosophila* bear no sequence similarity, and their tertiary structures are entirely different, they catalyze alcohol into acetaldehyde by different chemical reactions; they both remove hydrogen from alcohol (Doolittle, 1994).

### 2.2. MECHANISTIC CONVERGENCE

Mechanistic convergence occurs when the sequence and structure of molecules are very different but the mechanisms by which they act are similar. Serine proteases have evolved independently in bacteria (e.g. subtilisin) and vertebrates (e.g. trypsin). Despite their very different sequences and three-dimensional structures, they are such that the same set of three amino acids forms the active site.

The catalytic triads are His 57, Asp 102, and Ser 195 (trypsin) and Asp 32, His 64 and Ser 221 (subtilisin), thus giving a consensus catalytic triads of the sort [Asp/Glu] His [Ser/Thr] (Doolittle, 1994, Tramontano, 2002).

### 2.3. STRUCTURAL CONVERGENCE

This refers to molecules with very different amino acid sequences that can assume similar structural motifs, which may carry out similar functions. For example,  $\alpha$  helices and  $\beta$  sheets can be formed from a number of different amino acid sequences and are found in many proteins.

## ON THE QUESTION OF CONVERGENT EVOLUTION IN BIOCHEMISTRY

One example given by Doolittle (1994) is of the remarkable similarity in fibronectin type III and immunoglobulin domains (cf., Fig 1). They are composed of series of three and four stranded  $\beta$  sheets that are virtually identical in structure despite a lack of sequence similarity between these two molecules.

### 2.4. SEQUENCE CONVERGENCE

In protein evolution, sequence divergence, rather than sequence convergence is the rule. In sequence convergence, one or more critical amino acids or an amino acid sequence of two proteins come to resemble each other due to natural selection. If the putative ancestral amino acids at a particular site were different in the ancestors of two proteins that now share an identical residue at that location, then convergent evolution may have occurred. The most frequently cited case of convergence and parallelism at the sequence level is the digestive enzyme lysozyme in a number of unrelated animals – the langur (a primate), the cow (an artiodactyls), and the hoatzin (a bird) – that have independently evolved the ability to utilize bacteria to digest cellulose (Kornegay, 1996; Zhang and Kumar, 1997). Here, a few specific residues have convergently evolved to allow digestion of cellulose-eating bacteria.



Fig. 1a. Variable Light Chain Dimer of Ferritin Antibody (Nymalm *et al.*, 2002)



Fig. 1b. Solution structure of the fibronectin type III domain from *Bacillus circulans* WL-12 chitinase A1 (Jee *et al.*, 2002)

### 3. Discussion and conclusions

We have assumed that natural selection seems to be powerful enough to shape terrestrial organisms to similar ends, independent of historical contingency. In an extraterrestrial environment, it could be argued that the evolutionary steps that led to human beings would probably never repeat themselves; but that is hardly the relevant point: the role of contingency in evolution has little bearing on the emergence of a particular biological property (Conway-Morris, 1998). Besides, it can be said in stronger terms that essentially, evolutionary convergence can be viewed as a 're-run of the tape of evolution', with end results that are broadly predictable. The inevitability of the emergence of particular biological properties is a phenomenon that has been recognized by students of evolution for a long time. It is being referred in the present paper as 'evolutionary convergence'. This phenomenon has been illustrated with examples taken exclusively from biochemistry, although its occurrence extends over other branches of the life sciences. The assumed universality of biochemistry suggests that in solar system missions, biomarkers should be selected from standard biochemistry.

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### 5. References

- Austin, D. F. (1998) Parallel and convergent evolution in the Convolvulaceae, in *Diversity and Taxonomy of Tropical Flowering Plants*, eds., P. Mathews and M. Sivadasan, Mentor Books, Calicut, India, pp. 201-234.
- Chela-Flores, J. (2003) Testing Evolutionary Convergence on Europa. *International Journal of Astrobiology* (Cambridge University Press), in press.
- Conway Morris, S. (1998) *The Crucible of Creation. The Burgess Shale and the Rise of Animals*, London, Oxford University Press, p. 202.
- Conway Morris, S. (2002) First Steps towards defining galactic niches. Paper presented at the IAU Symposium 213 Bioastronomy 2002 *Life Among the Stars*. Summary of Proceedings, Hamilton Island, Great Barrier Reef, Australia July 8-12, Australian Centre for Astrobiology, Sydney, p. 12.
- Dawkins, R. 1983, Universal Darwinism, in *Evolution from molecules to men*, Bendall, D.S. ed., London, Cambridge University Press, pp. 403-425.
- Doolittle, R. F. (1994) Convergent evolution: the need to be explicit. *Trends Biochem. Sci.*, **19**, 15-18.
- Eisthen, H.L. and Nishikawa K.C. (2002) Convergence: Obstacle or Opportunity? *Brain Behav. Evol.* **59** (5-6), 235-239.
- Fontana, W. and Buss, L.W. (1994) What would be conserved if "the tape were played twice"? *Proc. Natl. Acad. Sci. USA.*, **91**, 757-761.
- Jee, J., Ikegami, T., Hashimoto, M., Kawabata, T., Ikeguchi, M., Watanabe, T and Shirakawa, M. (2002). Solution Structure of the Fibronectin Type III Domain from *Bacillus circulans* WL-12 Chitinase A1. *J. Biol. Chem.*, **277**, 1388-1397
- Kornegay, J. (1996) Molecular genetics and evolution of stomach and nonstomachlysozymes in the hoatzin. *J. Mol. Evol.*, **42**, 676-684
- Nymalm, Y., Kravchuk, Z., Salminen, T., Chumanevich, A.A., Dubnovitsky, A.P., Kankare, J., Pentikainen, O., Lehtonen, J., Arosio, P., Martsev, S. and Johnson, M.S (2002). Antiferritin VL homodimer binds

## ON THE QUESTION OF CONVERGENT EVOLUTION IN BIOCHEMISTRY

- human spleen ferritin with high specificity. *J. Struct. Biol.* **138**(3), 171-186
- Pace, N. R. (2001) The universal nature of biochemistry. *Proc. Natl. Acad. Sci. USA* **98**, 805-808.
- Tramontano, A. (2002) Private communication.
- Zhang, J. and S. Kumar (1997) Detection of convergent and parallel evolution at the amino acid sequence level. *Mol. Biol. Evol.*, **14**, 527-536.