My favorite insights

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In this essay I want to highlight my favorite insights as stand-alone stories (they can be read in any order) about genomic evolution. They are my favorite, as these are controversial and/or new, often from [1].

The evolution of evolvability

In a changing environment, it is vital for a prokaryote to be flexible. Itself and its offspring should preferable have a high variation in their genes. I was used to the idea that this variation was caused by rare, random mutations and insertions. This idea seems to be outdated.

Might the truth actually be the opposite? That nature not only allows mutations, but even stimulates mutations and insertions? A first hint is given by error-prone repair, facilitated by complex molecular systems [3] (instead of the higher mutation rate being an inherent property of stress). A second hint comes from horizontal gene transfer (HGT), which is a way to acquire DNA from outside of a cell, modifying the genome of the recipient. There are four types of HGT, each having multiple proteins involved as donor and/or recipient of the transferred DNA [2]. And even though the intake of DNA is energetically costly, these systems are highly evolved. The third and last hint are the Diversity Generating Retroelements (DGR), that generate hypermutagenesis within the genome (and thus the mutations are heritable).

Personally, I changed my view about the genome from something static to something fluid. I cannot yet see why nature stimulates mutations and insertions, as I am also used to think that these changes more often break a gene then improve a gene. It feels as if the term quasispecies, coined by Nowak, that was applied to viruses, may also enter the realm of the prokaryotes.

Evidence for group selection

On what level does selection act? Are extant organisms those that were fit as a species as a whole, or does selection act on the individual (which can even be detrimental to the species)? Some decades ago, infanticide in endangered animals was thought to be rare, as group selection was accepted. A decade later, the paradigm shifted to the individuals being the unit of selection, with an increase in infanticide being reported [9]. Still, group selection is controversial in current biology [4]. Yet, with our increased knowledge, can we still reject group selection in all cases?

In prokaryotes, genes can be acquired vertically (from the ancestor) and horizontally. In the latter, called horizontal gene transfer (HGT), a cell can obtain DNA (1) in free-floating form from the environment (transformation), (2) from another cell by direct contact (conjugation), (3) from infection by bacteriophages (transduction), and (4) from gene transfer agents (GTAs)

[2]. GTAs are, in contrast to transduction, friendly constructs that do not cause the cell to lyse, and appear to only serve the purpose of HGT. In other words: GTAs serve the sharing of DNA, with no evidence that the donor receives any direct benefit from this.

HGT by GTAs appears to be an example for group selection. But, in my humble opinion, group selection is not the only explanation possible: the first alternative explanation is that GTAs might yield a higher indirect fitness, as prokaryotes are often close to their relatives. This is supported by evidence that HGT (in general) is more common amongst closely related species [5]. The second alternative explanation for the seemingly altruistic nature of GTAs could be found by following the line of thought of the Selfish Gene, where a GTA is simply an additional way for a gene to spread. I find it interesting to find out unambiguously in which of the three (if not more) explanations GTAs fall into.

Evidence for Lamarckian genetics

Tout ce que la nature a fait acquérir ou perdre aux individus par l' influence des circonstances [...], elle le conserve par la génération aux nouveaux individus. Lamarcke [6] (English translation: all the acquisitions or losses wrought by nature on individuals, through the influence of the environment [...]; all these are preserved by reproduction to the new individuals which arise)

Lamarckianism (the Second Law of Lamarcke is quoted above) has had its share of critics. The well-known example of the giraffe's long neck, that the giraffe would have acquired by stretching it, passing the stretched neck to the next generation. Nowadays, this example is more often explained by natural and/or sexual selection. But there do have risen examples that are inherited as Lamarck imagined. One such example is the field of epigenetics, where the methylation of DNA appears to be commonly known. But, as the name implies, epigenetics does not change a genome sequence.

The CRISPR-Cas system, however, is both Lamarckian and genetic. It is a sort of immune system often present in prokaryotes [7], that stores fragments of viral DNA in the genome, acquiring a resistance that is directly caused by the environment and that is heritable.

Personally, I think this proves Lamarckianism to be possible in certain contexts. And these 'certain contexts' are as rare as there are prokaryotes.

Conclusion

In this essay I described three ideas of which I though were outdated and/or wrong. There were more: the idea that the genome is ordered randomly I had to abandon [8]. Also the idea of the 'virus empire' [1] would have fitted well in this essay.

The three ideas I did investigate, I chose to do so as stand-alone stories, so I can use them as a reference for myself. It will take some time to get used to these ideas and I hope discussion with my peers will make us again realize, that there is just one rule in nature without exceptions.

References

[1] Koonin EV & Wolf YI. 2012. Evolution of microbes and viruses: a paradigm shift in evolutionary biology? Front. Cell. Inf. Microbiol. 2:119

[2] Popa O & Dagan T. 2011. Trend and barriers to lateral gene transfer in prokaryotes. Curr. Opin. Microbiol. 14:1-9

[3] Galhardo RS, Hastings PJ, Rosenberg SM. 2007. Mutation as a stress response and the regulation of evolvability. Crit. Rev. Biochem. Mol. Biol. 42,399-435

[4] Maynard Smith J. 1998. The units of selection. Novartis Found. Symp. 213, 203-11. discussion 211-217

[5] Popa O, Hazkani-Covo E, Landan G, Martin W, Dagan T. 2011. Directed networks reveal genomic barriers and DNA repair bypasses to lateral gene transfer among prokaryotes. Genome Res, 21:599-609

[6] Lamarck J. 1914. Zoological Philosophy (trans. Hugh Elliot), p.113

[7] Koonin, EV & Makarova KS. 2009. CRISPR-Cas: an adaptive immunity system in prokaryotes. F1000 Biol. Rep. 1, 95

[8] Abby S. & Daubin V. 2007. Comparative genomics and the evolution of prokaryotes. Trends Microbiol. 15, 3

[9] Weissing FJ, personal communication