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The Mosaic Theory of Natural Complexity A scientific and philosophical approach

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Chapter 1. Mosaic Architecture in Living Beings

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Chapter 1

Mosaic Architecture in Living Beings

The evolutionary path towards complexity

Why has evolution given rise to a certain number of living beings of great complexity? This is obviously not the case for all species and organisms, as some have evolved *down* the “complexity hierarchy¹⁰”. Evolutionary processes can lead to an *increase* as well as a *decrease* in the anatomical complexity of organisms. Extreme cases of such a decrease can be seen with certain parasites, *e.g.* the tape worm (*taenia*) with an anatomical structure inferior to the structure of what was probably the free-moving evolutionary predecessor. In general, however, observations show that more complex beings exist now than in earlier times. The general trend of evolutionary processes seems to be towards *increased* complexity. The arguments developed in the present text will be that this trend cannot have been caused solely by random processes, that some powerful organizing mechanisms have been involved in the development towards complexity.

In relation to Darwinian processes, the hypothesis presented here is compatible with Darwin’s theory of evolution and evolutionary reasoning, and specifically with processes of natural selection as argued by Darwin. While I am clearly a Darwinian, I do not believe that Darwin’s natural selection theory can explain everything in evolutionary processes. I believe that in the field a complexity there is space for general integrating mechanisms as a complement to natural selection. The mosaic theory I am advocating here clearly concerns such general integrating mechanisms.

Juxtaposition, integration and mosaic structures

I shall first present the integrating mechanisms which, I believe, are involved in biological evolution towards complexity and shall then provide several concrete examples of their appearance in biological systems.

The principles underlying my argument are two basic operations, which I have named Juxtaposition and Integration¹¹. Juxtaposition, as the term suggests, is the accumulative positioning of identical or similar units, one next to the other, a process similar to forming a necklace with identical or similar beads. Cells grouped

¹⁰ Gould 2002.

¹¹ Chapouthier 2001.

to form an organ, or birds gathering together at night to sleep can be cited as examples of the juxtaposition process. In a juxtaposed arrangement, all juxtaposed units have more or less the same function; there is no hierarchy; none is under the command of another.

Integration involves a process which differentiates and combines the original units, thus generating entities one step up the hierarchy, comprised of the same original units which then become component parts, *e.g.* a necklace with beads of different colours or shapes forming a snake-like image. Organs developing for the harmonious functioning of an organism, or bees together in the complex structure of a hive, can also be cited as simple examples of the integration process.

By further juxtaposition and subsequent integration, new higher level structures (*e.g.* necklaces of necklaces, or necklaces of necklaces of necklaces) can then be produced. Figure 1 is a diagram illustrating the processes.

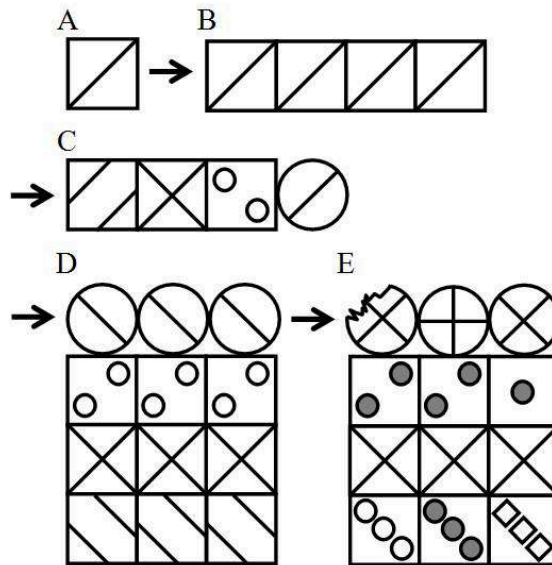


Figure 1 - Juxtaposition and integration.

Single identical units (A) can be added (juxtaposition, B). Changes can then occur in B juxtaposed structures to produce C (integration). By further juxtaposition (D) and subsequent integration (E), new higher level structures can be produced. In theory these processes can be repeated ad infinitum to produce ever higher levels of complexity. In practice, at least in biology, there are limits, *e.g.* combinations of colonies of organisms. Adapted from G. Chapouthier, *L'Homme, ce singe en mosaïque*, Odile Jacob Publisher, Paris, 2001.

A convenient model for these juxtaposition and integration processes is the art of the mosaic: small ceramic tiles – *tesserae* – are juxtaposed and integrated in a mosaic to depict a figure, yet each individual tile retains its own distinctive features (shape, size, texture and colour). In philosophical terms, the properties of the complete mosaic subsume the component parts but do not cancel out the autonomous existence of the properties of these component parts. In this metaphor of mosaics, as in the art of mosaics, the whole, *i.e.* a set level of a living being, still leaves its component parts with autonomous properties. The mosaic is thus used as a general model expressing the different levels of complexity of living beings. Venturing beyond the realm of living organisms, as will be seen later, the mosaic metaphor can be used to describe a number of structures with organization similar to that of living organisms with integration occurring at one level yet leaving lower level units in a state of relative autonomy.

Let us first look at examples of living organisms with many cases of mosaic architecture arising from repeated juxtaposition and integration.

Genetics

In the field of genetics, the genome can be subdivided into exons which are the gene segments responsible for (*i.e.* coding for) chemical actions in the cell and ultimately the way it lives (it metabolism), and introns which are silent genes with no direct active function. With time, introns can duplicate, and the silent duplication of introns may be seen as a form of *juxtaposition* of identical elements. It has been argued that juxtaposed introns may then silently undergo multiple mutations over time, developing patterns (*i.e.* *integration* of component parts) that can ultimately be expressed as functional exons and code for new organs and/or functions. This has been reported by authors such as Ohno¹², arguing that it is one of the basic processes of genetic evolution. This genetic hypothesis may offer an explanation of the development of new complex organs, for when the complex set of integrated introns emerges as exons, their action (on a new function or organ) could then be selected through natural selection. When a new set of exons is useful to the animal, it will be selected and survive; in the opposite case, it will disappear. This selective process thus fits traditional Darwinian theory. The processes of duplication of introns and mutations to create new genetic structures which can later emerge as exons may be considered, before natural selection, as mosaics processes as defined in the present text.

¹² Ohno 1970.

Molecular level

At the molecular level, several biologically active macromolecules (hormones, enzymes, receptors, toxins etc.) can be given as examples of juxtaposed and integrated structures. I have chosen two of the many possible examples: the botulinum toxin and the GABA A receptor complex.

The botulinum toxin is a powerful neurotoxic substance secreted by the bacterium *Clostridium botulinum* and related bacteria. Its main action is to block the release of acetylcholine, one of the most useful brain neurotransmitters. Botulinum toxin is a macromolecular complex of several (juxtaposed) units with a neuroactive (toxic) component and several associated non-toxic proteins. Thus the botulinum toxin can be seen as a molecular juxtaposition of units where the functional action emerges from efficient integration of the different parts¹³.

In contrast, GABA (gamma-Aminobutyric acid) is the most important inhibitory neurotransmitter in the central nervous system, being present in nearly one-third of the brain synapses. The GABA A receptor complex is a group of five juxtaposed subunits located on the membrane of the nerve cell. When activated by GABA, the receptor complex acts on the chloride channel making it possible for chloride to enter the nerve cells, causing hyperpolarization of the membrane and blocking nerve impulses. GABA can have antiepileptic effects, can counter anxiety (anxiolytic actions) and can have a negative impact on memory (amnesic actions¹⁴). Independently of the reception and actions of the GABA molecule (the main ligand on the receptor complex), GABA subunits are also specific for the reception and correlated actions of other ligands, as can be seen with pharmaceutically active compounds such as antiepileptic drugs, barbiturates, anaesthetics, benzodiazepines and alcohol. Here too, the functional action of the receptor complex is the result of the integration of the five juxtaposed subunits activated by their different ligands¹⁵.

Anatomy

Looking at the anatomy of organisms, in unicellular organisms, two principles can be seen at work when isolated cells evolve to become either a juxtaposed organism, *e.g.* *Gonium* (with all juxtaposed cells playing exactly the same role), or an integrated organism, *e.g.* *Volvox*, (with different types of cells living together, suggesting that an integrating process is beginning and will develop into multicellular organisms, see figure 2). In multicellular animals, two types of anatomical organization operate, either as two layers of cells, one external and one internal (*i.e.* “didermal” animals such as polyps), or three layers of cells with bone and/or muscle forming an intermediate layer (“tridermal” animals, ranging from worms to insects vertebrates).

¹³ Poulain 2010.

¹⁴ Chapouthier 2003; Venault & Chapouthier 2007.

¹⁵ Chapouthier 2003; Venault & Chapouthier 2007.

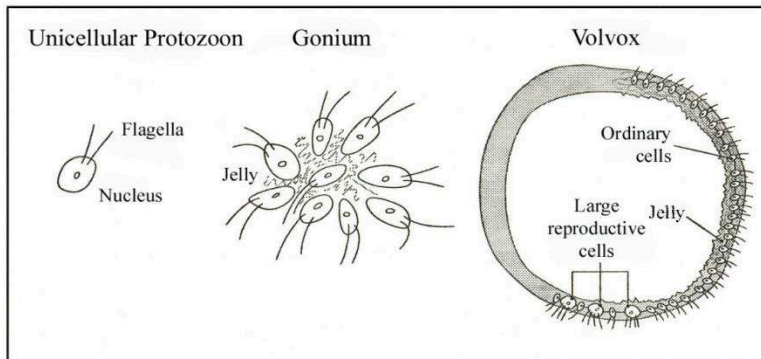
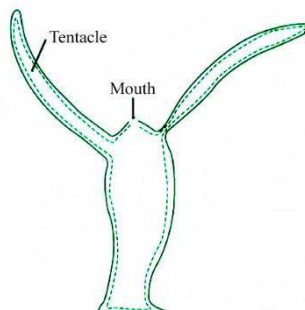


Figure 2 – Emergence of complexity in unicellular organisms.
In unicellular organisms, juxtaposition can produce structures such as Gonium, and integration can produce structures such as Volvox, these being on a higher level in evolutionary processes. Reproduced, with permission from the publisher, from G. Chapouthier, L’Homme, ce singe en mosaïque, Odile Jacob Publisher, Paris, 2001.

In addition to individual isolated polyps such as sea anemones or jellyfish, two-layer species can produce huge collections of identical polyps juxtaposed over kilometres, as in vast coral reefs (see figure 3). But there are also colonies of non-identical elements such as siphonophorae floating on the sea, comprised of different types of polyps (defensive, floating, digestive and reproductive) forming a group as a mosaic colony. In a siphonophora, each polyp is one part of the extensively integrated colony.



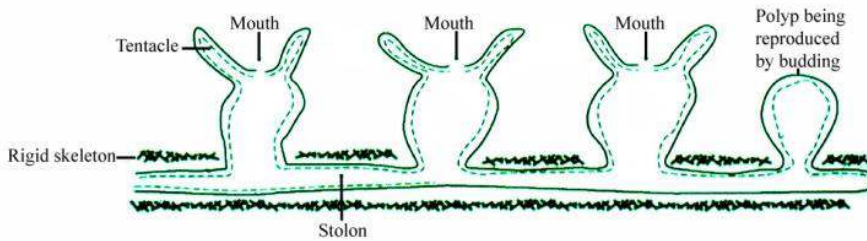


Figure 3 – Emergence of complexity in two-layer organisms.
In two-layer species, single polyps (top) are juxtaposed to produce colonies of identical polyps (bottom). Integration (not shown) produces colonies of siphonophorae, with different types of polyps (defensive, floating, digestive and reproductive).
With permission from the publisher, from G. Chapouthier, L'Homme, ce singe en mosaïque, published by Odile Jacob, Paris, 2001.

In three-layer organisms, animals such as the earthworm are formed of largely juxtaposed segments called metameres. Equivalents of individual (single) metameres can also be found free, *e.g.* in certain worms such as planarians. While earthworms can be seen as a mainly juxtaposed structure, metameres are also observed, to varying degrees, in more integrated animals. Most animals, whether insects, molluscs or vertebrates, are integrated structures with an earthworm-like arrangement but with different locations for the nervous system (dorsal in vertebrates and ventral in molluscs and insects), but this cannot be analyzed here. It not easy to identify the original metameres in these developed animals, although there are some exceptions: the segmented insect abdomen or the segmented ribs and vertebrae of vertebrates, clearly revealing the original juxtaposition in these mainly integrated organisms. Expressed differently, the segments of the bee abdomen and the segmentation of chimpanzee ribs and vertebrae are remnants of prior construction by juxtaposition still visible in the integrated organism.

Can the principle of juxtaposition apply to complete organisms such as the bee, chimpanzee or human being? The human being can provide the case of anatomical juxtaposition of two individuals with Siamese twins. However, as humans are constantly moving, any bid to extend this juxtaposed situation into something which could be considered proper integration is greatly limited. Partially integrated Siamese twins as observed and reported (with striking cases of sisters with two heads but only one abdomen, or only two legs for two twins) are exceptional cases and therefore not likely to be included in Darwinian selection.

At the level of organisms, juxtaposition is more likely to be social that anatomical.

Social structures in animals

Social contact provides a context for complex three-layer organisms, such (*e.g.* bees or primates) to be governed by the principles of juxtaposition and integration, ultimately producing social mosaics. Some animals adopt juxtaposed settings, *e.g.* birds gathering together to sleep or forming flocks when all have the same role or are part of the same purpose. In sophisticated cases such as the bee hive or troops of primates, the situation is clearly integration with different subjects having different roles and serving different purposes: the queen bee, worker or male in the hive (and similar examples could be given with termites and other ants), the mothers, young females, dominant males and peripheral males in primate troops. And it is obvious that in societies of human primates all individuals have different social roles. With individuals as parts, animal societies can be seen as integrated mosaics.

In human societies, integration can be developed to varying degrees. The degree of autonomy of individual subjects (the parts) in relation to society (the whole) is the measure of what can be called freedom. In democratic societies, there is obviously greater – freedom – for individuals than there is in totalitarian societies. The case of human societies will be developed later when analyzing the mosaic architecture of the human mind and its capabilities.

All integrated levels of living beings, whether cells, polyps, metamerous or individuals, still have basic units at a lower level retaining a certain degree of autonomy, even though they are now part of a whole at a higher level. This is the mosaic model, similar to the combination of individual tiles (*tesserae*) in an artistic mosaic. In biology, the properties at a given level form a whole, while still leaving a relative degree of autonomy to the component parts. Examples can be found with the organization of physical organs, but I shall focus on the brain, the essential organ for the mind, devoting the next chapter to the human brain.

The Human Brain

The human brain is the most complex structure known to science, and mosaic-like features and processes can be identified in it.

The brain initially forms as five encephalic vesicles, juxtaposed at the embryonic stage and later integrated until reaching the complex stage of the adult brain (see figure 4). The brain is clearly the result of a succession of juxtaposition processes and integration processes.

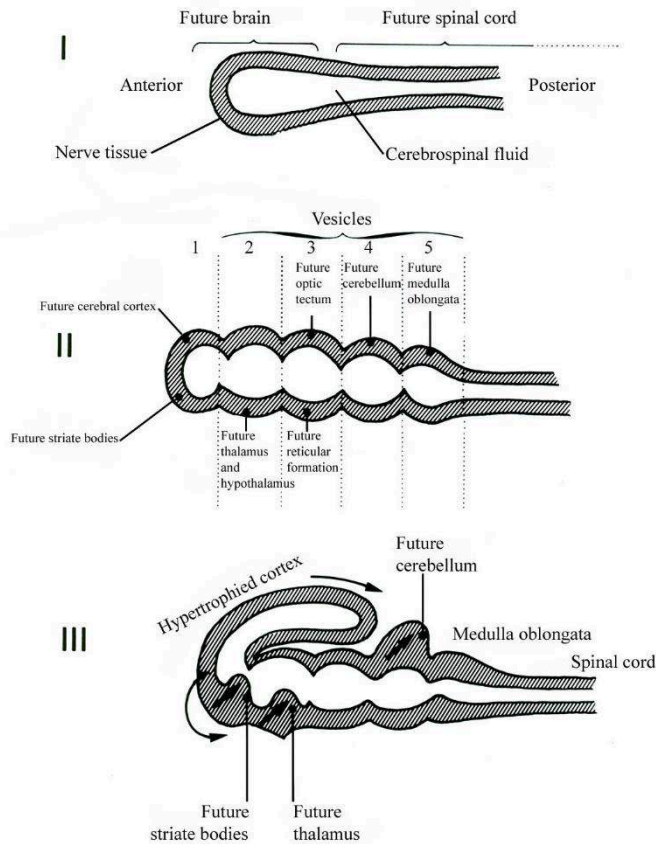


Figure 4 – Emergence of complexity in the brain.

The brain in the embryonic stage starts as a single vesicle (top), then becomes a juxtaposition of five encephalic vesicles (middle) which are subsequently integrated in the course of a preliminary stage before ultimately becoming the structure of the adult brain (bottom). Reproduced with permission from the publisher, G. Chapouthier, L'Homme, ce singe en mosaïque, published by Odile Jacob, Paris, 2001.

We shall examine the higher part of the brain, the roof of the first vesicle and known as the cerebral cortex; in the human brain it is mainly what is comprised of the neocortex. The neocortex of the human brain is so extensive that it covers much of the other structures and divides itself into two hemispheres, left and right. The cerebral neocortex can be seen as a mosaic of a number of functional areas (for the senses and motor skills) which control the expression and understanding of spoken and written language, sight and hearing, and areas for “higher” functions such as attention. Each area has specific functions, but they still contribute

harmoniously to the workings of the cerebral cortex (the whole). The cerebral cortex offers a fine example of an organ operating as a mosaic of different stage, initially juxtaposed during the embryonic and throughout development until full integration as an adult.

The two hemispheres of the brain deserve attention. In primitive vertebrates they are simply juxtaposed, each one controlling the contralateral side of the body. Observations of certain birds and mammals show that the two hemispheres have achieved a level of integration, each acquiring specific functions not performed by the other hemisphere; *e.g.* bird song is often controlled by the left hemisphere. In adult humans, the two hemispheres have very different functions. In right-handed human subjects, the left hemisphere manages analytical processes such as language, and the right hemisphere covers more general processes such as the perception of images. In normal subjects, the two hemispheres operate in harmony as a two-part mosaic. In pathological cases, however, “split-brain” subjects have suffered an accident breaking the connecting fibres needed for the two hemispheres to communicate (via the brain structure known as the *corpus callosum*); the two hemispheres then are no longer integrated but simply juxtaposed, and the person’s brain operates in two parallel and independent ways (the effects on their ability to think will be reported below).

Other biological arguments

A number of biological arguments can be presented as evidence to back my mosaic thesis. Some have been developed by other thinkers independently of my own research and can fit my model perfectly, and other authors have made explicit reference to my thesis.

Richard E. Michod, a biologist and professor at the Department of Ecology and Evolutionary Biology at the University of Arizona (USA), has developed theses on the complexity of living beings, independently of my philosophical work on mosaic structures, and has reached similar conclusions. Michod has noted how much biological evolution is linked to integration (a term he uses) of (simple) individuals into individuals at a higher level of complexity. He argues that the main reasons that have led to the diversification of living beings and their hierarchical organization are “mutations of individuality”, moving from genes to animal societies, going through all the levels of complexity observed in biology, including cells, groups of cells, organs, organisms and societies. Michod’s main interest is anatomical complexity; he has not focused, as I have (see below), on thought and language. One of his great achievements is to have experimentally analyzed some of the processes involved. While my position remains speculative, Michod has conducted experiments to uncover the underlying molecular processes behind the switches to different levels of complexity¹⁶ and in particular for the aggregation of cells in the algae *Volvox* mentioned above in figure 2. The work of Richard E.

¹⁶ Michod 1999, 2009.

Michod offers an extremely interesting approach in modern biology investigating what is one of the most puzzling questions of biological evolution – complexity.

The important question remaining is how does the switch between juxtaposition and integration occur. On the cellular level, interesting ideas have been developed by Paul B. Rainey and his colleagues on the evolutionary origins of multicellularity¹⁷. The authors define three possible routes for the transition from multicellular systems comprised of similar cells (MLS1) providing a juxtaposed state to an integrated state (MLS2) where a new multicellular Darwinian being exists independently and is able to have an independent reproductive process. On the first route, single cells can form aggregates which, once established, live their own lives and are able to multiply without requiring the single cell state. In this first case, single cells continue to reproduce as single cells on one level and aggregates reproduce as aggregates on another level. The second route has constant and repeated formation of aggregates from single cells, *i.e.* the aggregates cannot reproduce independently but emerge regularly from single cells. One example is metazoan reproduction with the germ/soma distinction. In the third route, aggregates can be produced repeatedly and regularly by single cells, as is the case for the second route, but these aggregates can also generate single cells, meaning that a living being can exist in two different states or phases, as single cells or as aggregates that can merge into the other.

This view of three possible routes for multicellularity to evolve from unicellular precursors can lead to further analyses of possible underlying genetic mechanisms or further Darwinian or non-Darwinian evolution of these different routes. While an abrupt switch from a unicellular to a multicellular life form may be possible, as in route 1 with aggregates immediately separating from their single cell precursors, the authors argue for a more gradual form of evolution. Routes 2 and 3 would make it possible to have greater “fluidity between individual and group states” and therefore “repeated opportunities to transition¹⁸”. They also note that different pathways followed by the different organisms are “likely to be dependent on specific ecological conditions¹⁹”. And transitions between the three different routes may even be possible before the organism settles into a stable configuration.

Further research by the same team²⁰ included an experimental investigation of the first stages of multicellularity, studying the bacterium *Pseudomonas fluorescens* which occasionally develops simple multicellular structures. A mutation causes single cells to overproduce cell-cell glue, leading to juxtaposed cell-mats that spread “because the group of mat-forming cells reaps an advantage (access to oxygen) that is denied to individual cells²¹”. But the life of these multicellular mats is very brief as “cheating cells” soon appear, these being cells that “do not contribute towards

¹⁷ Libby & Rainey 2013; Hammerschmidt *et al.* 2014.

¹⁸ Libby & Rainey 2013.

¹⁹ Libby & Rainey 2013.

²⁰ Hammerschmidt *et al.* 2014.

²¹ Hammerschmidt *et al.* 2014.

group integrity, but nonetheless take advantage of the benefit that accrues from being part of a collective²². “Cheater suppression” may be an important mechanism at the cellular level in the transition towards permanent multicellularity. The experiment subjected a bacterium a “cheat-purging regime” which extended the duration of the multicellular mats. This is the first experimental evidence of the persistence of simple (juxtaposed) multicellular structures.

The American scientist Stephen M. Modell²³ began by investigating healthcare, suggesting that general Biocosmological principles could be applied to healthcare which was seen as a general and complex structure; he then extended the scope of his study to the entire living kingdom. Not only is there classical Darwinian selection at the genetic level, but Modell²⁴ also sees space for “additional laws” to explain the complexity of biological forms, arguing that in evolution “surely there must be more than simple randomness at work.” On energy, Modell talks of the involvement of “islands of energetic stability, which, supplemented by selective adaptation, could account for new levels of evolutionary complexity”, a position very similar to modern biophysical theories developed by Prigogine²⁵ and Tonnelat²⁶. All of this could ultimately lead to morphological changes in organisms. Modell quotes my hypothesis of duplication (juxtaposition) followed by integration leading to mosaic structures, recognizing that such “combined processes may be responsible for the emergence of complexity” in the human brain, and also seeing it as a possibility at the different morphological levels of living beings. Modell suggests that as a paradigm, these juxtaposition–integration processes demonstrate the thesis–antithesis–synthesis triune common to philosophy and Biocosmology, again focusing on the potential for common ground between modern Biocosmological stances and classical dialectics.

The engineer and physiotherapist Moshe Feldenkrais (1904–1984) developed his well known therapeutic method²⁷ based on a technique involving kinaesthetic feelings: a person practicing the method must learn to feel distinct parts of the body (*e.g.* bones) separately; analysis of the juxtaposed feelings then leads to better integration, *i.e.* functional integration of movements.

In different ways, the thinkers cited above offer arguments for the mosaic model of living beings. It may be done directly, as with the experimental work of Michod, or indirectly, as with Modell’s reflections, or even through a clinical and practical approach, as for Feldenkrais, but all can be seen as juxtaposition/integration of simple structures to form more complex ones.

²² Hammerschmidt *et al.* 2014.

²³ Modell 2006.

²⁴ Modell 2011.

²⁵ Prigogine & Kondepudi 1998.

²⁶ Tonnelat 1995.

²⁷ Beringer 2010; Feldenkrais 1994.

An epistemological rehabilitation of sexual reproduction

Living beings have one of two modes of reproduction, sexual and asexual.

Sexual reproduction, the most recent in evolutionary terms, “blends” genes during the stage when the two gametes (paternal and maternal) form the egg-cell, although there are variations at this the earliest stage of reproduction. Darwinian selection follows with the ability to select the variations which are useful for the survival of the organism. As sexual reproduction produces such variations at an early stage, it is very well suited to selection. In fact, sexual reproduction is the basis for most Darwinian models.

Asexual reproduction produces identical copies of one structure, by first doubling to form two similar structures which eventually separate. Examples of the process can be seen with the growth of biological tissue in organs, plant cuttings, animal polyps and even human twins. If an event prevents the two similar structures from splitting, they remain attached and juxtaposed, but may at a later stage experience variations, thus producing differences, the variations occurring at a later stage.

Asexual reproduction is ubiquitous in the living world and can produce complexity through the integration of both juxtaposed and non-separated structures as stated above. My thesis of complexity in mosaic formation thus stands as a clear epistemological rehabilitation of the role of asexual reproduction which is only too often overlooked. The argument is that complexity of living beings mainly arises from the non-separation of structures produced through asexual reproduction and from subsequent integration.

The model is compatible with Darwinian theory which I recognize as important for the understanding of the biological diversity produced through sexual reproduction, but the mosaic model is not directly based on Darwinian principles. My arguments could be compared to the approach of the Brazilian philosopher Paulo C. Abrantes²⁸ in dealing with Darwinian and non-Darwinian multi-level selection in evolutionary dynamics. Abrantes analyzes what he calls “transitions in individuality”, *i.e.* transitions from a simple individual level to a broader level, integrating single entities as part of a greater entity; *e.g.* switching from an organism to a population. He shows that to reach a higher level, it is necessary to go through lower-level processes of “de-Darwinization,” therefore once the lower level has been subsumed as a part, it is no longer governed by the rules of Darwinian selection.

In general, when the mosaic model is compared to Darwinian theory, it can provide an explanation for the emergence of more complex biological systems starting from simple original cells. The in-depth analysis of the mosaic model by the Australian philosopher Arthur Saniotis²⁹ included the following comments. “The Mosaic model created by Georges Chapouthier [...] not only challenges biological reductionism but also provides an integral approach towards understanding

²⁸ Abrantes 2011.

²⁹ Saniotis 2013.

biological processes³⁰.” In the present text, I have chosen to focus on complexity rather than emergence, while also recognizing that complexity arising with new properties and from originally simpler structures is indeed a phenomenon of emergence. In other words, the mosaic model is an original way to interpret emergence within biological systems.

Partial conclusion

My thesis presented here is an endeavour to interpret the architecture of biological systems. The argument, in line with Darwin’s theory of evolution, explores the development of living beings and their shift towards greater complexity. Basic phenomena, whether in genetics, anatomy or social structures of animal populations, provide the key principles in evolution towards complexity: juxtaposition and integration. These processes produce structures that fit the mosaic principles, *i.e.* juxtaposition, accumulating similar units, and integration, developing into a more sophisticated version with the original units then becoming component parts. Observations of structural and functional complexity in living organisms, in both genetic and anatomical structures, tally with the organizational features of mosaic structures. At the biological level, observations can lead to an important epistemological rehabilitation of asexual reproduction, thus providing a possible explanation for the emergence of more complex organisms during the geological periods.

³⁰ Saniotis 2013: 334.