BIOLOGY AND THE POSSIBLE

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Philosophy and biology are vastly different worlds of thinking, which have common concepts. Among these, the idea of possibility is particularly significant presently. In many fields of contemporary biology and medicine, there is a sense of an expanding possibility of modifying living beings or structures. Things which were previously considered as impossible by many observers become feasible, although there are some doubts, for instance in the field of genetical therapy. Laboratory practice in biotechnologies is changing into large-scale industrial production in medicine and agriculture. This general sense of feasibility reminds us of analogous situations in the history of science, for instance in chemistry at the end of the nineteenth century, when organic chemists became able to create new molecules almost at will.

The fact, that biological structures are modifiable without loosing their overall stability raises a number of questions regarding the reasons why the biological kind of organisation makes it possible. We will have to discuss things at this level of biology itself, which corresponds roughly speaking to theoretical biology. But we will have to discuss things also at the level of philosophy in its most classical and even traditional sense. Indeed, there is a very striking and unexpected agreement between the ideas of classical philosophy regarding the possible's realisation, the idea that all possibilities are realised throughout time, and the fact that so many possibilities are envisaged and often realised by biologists today.

However, there is an additional reason why philosophy including some logic needs to be introduced in the discussion. Biologists make often use of the idea of possibility in their more popular writings. In his influential book *The Game of the Possible*, François Jacob stressed the contingent, matter-of-fact character of evolution, and developed the evolutionary tinkering idea. Other arguments are developed by Stephen Jay Gould in his book *Wonderful Life*, in which he deals with the idea of multiple possibilities and of counterfactual conditionals.

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Biologists are not always sufficiently aware of the subtleties and difficulties encountered by philosophers in their attempts to clarify the most obscure idea of the possible. Biologists are surely not the only scientists who should learn more of philosophy and logic. Logic should be taken here in its broader sense, since the most sophisticated developments of modal and temporal logics are of no use in contemporary biological research. In the broader philosophical meaning of the fundamental structures of thinking, logic permeates biological reflection and might be more firmly introduced in the thinking of biologists, in the same way as the more particular disciplines which are introduced as the research tools of contemporary biology, like complexity theory, probabilities etc.

Let us begin with some general remarks on the idea of the possible. One of the most puzzling things is its relationship with reality, which takes at least two forms: 1 – the idea that all possible states or events are realised throughout time, which is named since Arthur Lovejoy the Principle of Plenitude; 2 – the very strange philosophical relationship which has been discussed by Ludwig Wittgenstein in several places of his *Nachlass* as the conception of possibility as shadow of reality or as something similar to reality or very close to it. Wittgenstein's remarks were done in the context of his philosophy of mathematics. The idea of some kind of similarity between possible and real must be kept in mind in a biological context. Indeed, in biology the so called "possible states", which are described as possible for theoretical reasons, are endowed with their own probabilities, which means that they are more or less already realised. In still another sense, the often realised possibilities are just preexisting realities arranged in a different way. This is François Jacob's basic insight of evolutionary tinkering, which means that the same structure may be reused and serve different functions. It stresses the conservative side of biological evolution. The present enquiry aims at examining more closely the logical and semantical foundations of these biological ideas.

Surely, many disciplines should be mentioned in a systematic attempt to build bridges between philosophy and biology from the timely viewpoint of the possible and its realisations. These include the history of philosophy, also linguistics and semantics of natural languages, modal logic, temporal logic, probability theory, etc. on the one hand, and on the other hand virtually all biological and biomedical disciplines, especially evolutionary theory with its strong connection to developmental biology, biophysics and biochemistry with their strong thermodynamical background, as well as medicine and biotechnologies. To this list should be added some corresponding points of interest from both the logical and the ontological points of view: the indeterminacy of the causal agent in the use and meaning of the possible; the "could have been otherwise" argument in evolution (the counterfactual conditional); the realisation of the possible (its "spontaneous" nature in a Leibnizian world); the real plurality of the possible (with protein folding as an example); the possible as the feasible and its limits (with examples taken from medicine). The following table shows the connections between disciplines and problems, as well as the identity of problems across various disciplines:

SOME DISCIPLINES	SOME POINTS OF INTEREST
Logic and Semantics of Natural Languages:	Lack of Clarity in the Concept of Possible Compared with Impossible and Necessary Indeterminacy of the Agent Unreal Past, Counterfactual Conditionals
History of Philosophy:	Principle of Plenitude
Evolutionary Theory:	Unreal Past, Counterfactual Conditionals Indeterminacy of the Agent (Cf Logic and Semantics)
Biophysical Chemistry:	Plurality and Realisation of the Possible (Cf Plenitude)
Medicine:	Feasibility, Prediction

Some of these points will be discussed in the following way:

I Logic, Semantics of Natural Languages: definition of possibility as absence of impossibility; indeterminate character of the cause, incompleteness of the situation; time and modality, past possibles and unreal past, counterfactual conditionals.

II Contingency in Evolution: the "things could have been otherwise" argument (counterfactual conditional) as contingency argument in Stephen Jay Gould's *Wonderful Life*.

III The Possible and The Real: "evolutionary tinkering"; mutagenesis as internal source of change; Eigen's hypercycle as an explanation of stabilisation.

IV How Many Possibles and How They are Realised: the principle of plenitude; protein folding; prediction.

The first interesting point is in semantics and has consequences in logic. There are several meanings or broad categories of meanings which are associated with the idea of possibility. One can mention briefly five of these

ON GENETIC INFORMATION AND GENETIC CODING

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1. The proliferation of semantic descriptions of genes, and the reaction against it

One of the most striking developments in recent biology has been the proliferation of concepts such as *coding, information, representation and programming*, especially applied to genes. The idea that genes can be described as having semantic properties, as well as ordinary causal properties, has become so uncontroversial in many quarters that it now appears prominently in biology textbooks. Scott Gilbert's widely used developmental biology text, to pick just one example, tell us that "the inherited information needed for development and metabolism is encoded in the DNA sequences of the chromosomes" (Gilbert 1997, p. 5).

The concepts of *information* and *coding* are the most widely used semantic or quasi-semantic concepts in genetics. Throughout this paper I use the term "semantic" in a very general way, to capture a wide range of properties that involve meaning and representation. To *code for* something is an example of a semantic property. The concept of information is trickier, because of the role of mathematical information theory. Informational properties in the sense found in mathematical information theory are not fully semantic – for example, they do not involve a distinction between representation and misrepresentation. So occasionally I will also use the term "quasi-semantic" (as I did above) when I want to be so broad that I capture borderline cases – properties and relations that seem to have something important in common with clear cases of meaning and representation, but which are not clear cases themselves.

I said that the concepts of information and coding are the most widely used semantic or quasi-semantic concepts in genetics. As John Maynard Smith stresses in his own paper in this collection, there is now a large collection of related concepts used to describe genetic mechanisms – editing, proof-reading, synonymy, and so on – that derive from these central concepts. But in this pa-

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per I will focus just on coding and information. My aim is to work out what role these concepts play in our understanding of genetic mechanisms – what theoretical weight they bear and what help (if any) they really give us in understanding biological systems.

As well as examining general questions about the theoretical role of these concepts, I will focus closely on one particular way in which they are often used. The concept of genetic coding is used to express a distinction between traits of organisms: some traits are coded for in the genes and others are not. Frank Sulloway, for example, discussing work in evolutionary psychology, claims:

> [N]o one has identified any genes that code for altruistic behavior. Such genes are nevertheless believed to exist because certain aspects of personality that underlie cooperative behavior – for example, empathy, sociability, and even altruism itself – are moderately heritable. (Sulloway 1998, p. 34)

A trait is heritable, in a given population, if there is a certain statistical tendency for individuals with similar genotypes to resemble each other with respect to that trait. Heritability is a subtle concept, but the complications do not matter here. The important point is that Sulloway is saying that a *statistical* association between a psychological trait and genetic factors is evidence for the hypothesis that there are genes that *code for* that psychological trait.

Does Sulloway just mean that there are genes that *cause* the trait, or play some causal role in producing the trait? No, more than that must be meant. For suppose that research had found that cooperative tendencies have very low heritability, and are associated with certain environmental conditions. In the language Sulloway is speaking, that would *not* suggest that there are environmental conditions that "code for" cooperative tendencies. According to the standard framework, both genes and environmental conditions *cause* traits, but only genes *code for* them. The concept of genetic coding is apparently meant to pick out a *difference* between the causal paths leading from genes to traits, and the causal paths leading from non-genetic factors to traits. The concept of information is sometimes used in genetics in the same kind of way, although it is sometimes also used in quite different ways (section 2 below).

One possible view of the role of semantic concepts in genetics is that they are used to express a crude "genetic determinist" position. I think this interpretation is a mistake. It is true that in many popular discussions, the idea of genetic coding is associated with the idea that genetic causation is inflexible and inevitable; that "genes are destiny." But these views are not part of mainstream biological thinking. According to mainstream biology, the "expression" of the genetic message is a biochemical process with no special causal necessity attached to it, but a process with key differences from other processes involved in development and metabolism.

Given the philosophical questions raised by all semantic properties, given the methodological uncertainties illustrated by the Sulloway passage above, and given the lingering associations between genetic coding and genetic determinism, it is not surprising that some writers have objected to the very idea of genetic coding, and to other semantic descriptions found within genetics. Sahotra Sarkar opposes talk of coding because he thinks that as more details of biological mechanisms are discovered, the idea of genetic coding becomes less and less appropriate (1996). Advocates of "developmental systems theory" (Oyama 1985, Griffiths and Gray 1994) are suspicious of genetic coding because they are suspicious of all views of development which sharply distinguish the kinds of causal roles played by genetic and non-genetic factors. Philip Kitcher (forthcoming) has responded by claiming that the concept of genetic coding carries no explanatory weight, and is just a colorful mode of talk.

At the other end of the spectrum, some hope to give a precise analysis of the semantic properties found in genes, and to use this analysis to solve problems and clarify our knowledge in biology and philosophy. Within biology, John Maynard Smith (in this collection) and George Williams (1992) are examples of biologists who think that to understand evolution properly we need a good understanding of the special information-bearing role of genes (see also Szathmáry and Maynard Smith 1995). Within philosophy, the program of explaining how genes can have semantic properties has been undertaken by Kim Sterelny and his co-workers (Sterelny, Smith and Dickison 1996, Sterelny and Griffiths 1999), and by Wheeler and Clark (1999).

I will make three main claims in this paper. The first has to do with the concept of information. Like several other authors, I hold that we cannot analyze the special semantic properties of genes using the concept of information found in information theory. Information, in the standard sense, is not enough.

The second and third claims have to do with the concept of genetic coding. I argue that the concept of genetic coding does make a theoretical contribution to solving a specific, important problem in cell biology.

Although a specific and restricted concept of genetic coding can be defended, the idea of genetic coding has diffused out from its original theoretical context, and has insinuated itself into many other descriptions of biological processes. My third main claim is that when the concept of genetic coding is found outside its original home, it probably makes no positive contribution to our thinking about biological processes.

2. Information is not enough

Biology has to do with causal processes, but biologists insist on also using semantic concepts to describe genes and what they do. This is not a problem

ARCHITECTURE-BASED CONCEPTIONS OF MIND

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Abstract It is argued that our ordinary concepts of mind are both implicitly based on architectural presuppositions and also cluster concepts. By showing that different information processing architectures support different classes of possible concepts, and that cluster concepts have inherent indeterminacy that can be reduced in different ways for different purposes we point the way to a research programme that promises important conceptual clarification in disciplines concerned with what minds are, how they evolved, how they can go wrong, and how new types can be made, e.g. philosophy, neuroscience, psychology, biology and artificial intelligence.

1. Introduction

We seem to have direct access to mental phenomena, including thoughts, desires, emotions and, above all our own consciousness. This familiarity leads many people to believe they know exactly what they are talking about when they engage in debates about the nature of mind, and refer to consciousness, experience, awareness, the 'first-person viewpoint', and so on.

However, this conviction is at odds with the diversity of opinions expressed about the nature of the phenomena, and especially the widely differing definitions offered by various types of psychologists, cognitive scientists, brain scientists, AI theorists and philosophers, when they attempt to define concepts like 'emotion' and 'consciousness'.

The confusion has several roots, one of which is the *hidden* complexity of both the phenomena and the architectural presuppositions we unwittingly make when we use such concepts.

Another is the common error of believing that we have a clear understanding of concepts just because they refer to phenomena that we experience directly. This is as mistaken as thinking we fully understand what simultaneity is simply

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because we have direct experience of seeing a flash and hearing a bang simultaneously. Einstein taught us otherwise. That we can recognise some instances of a concept does not imply that we know what is meant *in general* by saying that something is or is not an instance. Endless debates about where to draw boundaries are a symptom that our concepts are confused, whether the debates are about which animals have consciousness, whether machines can be conscious, whether unborn infants have experiences, or whether certain seriously brain-damaged humans still have minds.

Such questions cannot be resolved by empirical research when there is so much disagreement about what sort of evidence is relevant. Does wincing behaviour in a foetus prove that it feels pain and is therefore conscious, or is it a mere physiological reaction? How can we decide? Does a particular type of neural structure prove that the foetus (or some other animal) is conscious, or is the link between physical mechanisms and consciousness too tenuous to prove anything?

This paper shows how the hidden complexity of our concepts and the phenomena they refer to explain why there is so much confusion and disagreement and indicates how we can begin to make progress beyond sterile debates.

Many of our concepts are implicitly architecture-based and different thinkers attend to different aspects of the architecture. They are also 'cluster concepts', referring to ill-defined clusters of capabilities supported by the architecture, and different views favouring different clusters. If we understand this we can see how to define different families of more precise concepts, on the basis of which answerable questions can be formulated. Which definitions are *correct* is a pointless question.

2. Architecture-based concepts

We can deepen our understanding of these concepts, and, where necessary, repair their deficiencies, by seeking an explanatory theory which accounts for as many phenomena as possible and then use it as a framework for systematically generating concepts. A common error is believing that we have to define our concepts before we seek explanatory theories. Typically it is only after we have a theory that we can understand the concepts describing the phenomena to be explained. So it is to be expected that we shall not be able to give good definitions of most of our mental concepts until we have good explanatory theories.

This does not imply that our pre-theoretical concepts are completely wrong. Our existing concepts of mind work well enough for ordinary conversational purposes (e.g. when we ask 'When did he regain consciousness?', 'Are you still angry with me?', etc.). So a good theory of the architecture underlying mental states and processes should generate concepts which *extend* and *refine* our previous concepts, rather than replacing or eliminating them.

New theories of the sub-atomic architecture of matter extended and revised our concepts of kinds of elements, kinds of chemical compounds, and kinds of physical and chemical processes. We still talk about iron, carbon, water, etc., though we also now know about isotopes and new sorts of elements and compounds, and many new kinds of processes involving previously known kinds of physical stuff. We still talk about solids, liquids and gases though we also know about other states of matter supported by the architecture.

2.1. Architecture-based cluster-concepts

Muddles in our pre-theoretical concepts of mind surface when we try to ask philosophical or scientific questions, e.g. 'How did consciousness evolve?' 'What are its neural correlates?' 'Which animals have it?' What we normally refer to as consciousness involves the exercise of a large, diverse, ill-defined cluster of capabilities (many of them unconscious!) supported by our information processing architectures. If there is no well-defined subset of capabilities which are necessary or sufficient for consciousness, then some of our apparently meaningful questions, like many questions involving cluster concepts, may be ill-defined. Many mental concepts share this semantic indeterminacy, e.g. 'emotion', 'intelligence', 'understanding', 'pleasure', etc.

The idea that there are cluster concepts, that various kinds of indeterminacy or, what has been called *open texture*, pervades ordinary language is very old, e.g. in the writings of Wittgenstein (1953), Waismann (1965) and many others. I shall attempt to explain how it comes about that ordinary mental concepts have that feature, and what to do about it.

2.2. Multiple architectures generate multiple families of concepts

The analogy suggested above between the way theories of the architecture of matter extend and refine ordinary concepts of kinds of stuff and the way a new theory of the architecture of mind could illuminate concepts of mentality, is only partial, because there is only one physical reality and one architecture for physical matter (although it may have many levels of abstraction), whereas there are many kinds of minds with different architectures.

Figures 1 (a) and (b) illustrate two typical architectural decompositions of an intelligent organism, software system, or robot. Figures 2 combines the two views and add further detail. Figures 3(a) and (b) elaborate further. Organisms with simpler architectures have fewer architectural layers, and simpler perceptual or motor subsystems. They would then support simpler collections of processes, and different concepts would be applicable to them. If insects