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Evolutionstheorie und Schöpfungsglaube

Neue Perspektiven der Debatte

Mit 4 Abbildungen

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Inhalt

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Einleitung

Das Darwin-Jubiläumsjahr bot eine willkommene Gelegenheit, um mit Darwins Theorie und ihren Weiterbildungen in der modernen Evolutionsbiologie erneut in ein produktives Gespräch einzutreten, das dabei vorrangig das Ziel verfolgt, im interdisziplinären Austausch die wirklich klärungsbedürftigen bzw. strittigen Sachfragen zu sondieren und die damit verbundenen besonderen Herausforderungen anzunehmen. Für eine diesbezügliche Bestandsaufnahme schien es – nicht zuletzt im Blick auf künftige gemeinsame Bemühungen – ratsam, eine interdisziplinäre Tagung an das Ende einer ganzen Reihe von wissenschaftlichen Veranstaltungen zu setzen, die zum Darwin-Jubiläums-Jahr auch in Wien stattgefunden haben. Dies sollte es auch erlauben, besondere interdisziplinäre Themenfelder und Akzente in den Vordergrund zu rücken, die bislang vergleichsweise vernachlässigt wurden bzw. diejenigen Probleme betreffen, die vor allem für ein produktives Gespräch zwischen Evolutionsbiologie, Philosophie (somit auch der Naturphilosophie und der Wissenschaftstheorie) und auch der Theologie – und zwar jenseits weltanschaulichen Gezänks – von vorrangigem Interesse sein müssen.

Interdisziplinäre Veranstaltungen, die mehr sein wollen als lediglich der Routine folgende Pflichtübungen, setzen bei den Teilnehmern die Einstellung voraus, dass man sich in der Sache auch wirklich etwas zu sagen hat, d. h. sie verlangen somit auch auf die Bereitschaft der Gesprächspartner, voneinander zu lernen. Gerade die sehr kontroversiell und weltanschaulich besetzten und mit erhöhter Öffentlichkeitswirksamkeit ausgetragenen Debatten in den letzten Jahren haben freilich die unverminderte Aktualität und die Notwendigkeit einer interdisziplinären wissenschaftlichen Verständigung eindringlich vor Augen geführt, ebenso die offensichtlichen und hartnäckigen (und teilweise auch gezielt geförderten) Missverständnisse und Hindernisse. In solcher Hinsicht spricht einiges dafür, dass sich in den vor einigen Jahren neu aufgeflammten Debatten rund um das Thema „Evolutionstheorie und Schöpfungsglaube“ auch ein diesbezügliches Versäumnis der letzten Jahrzehnte widerspiegelt: Hat man sich da möglicherweise allzu unbedacht mit einem bloß ko-existierenden, buchstäblich „nichts-sagenden" und teilnahmslosen – sei es auch von wechselseitigen freundlichen Gesten und Versicherungen begleiteten – „Nebeneinander" bzw. mit einer eingespielten kulturellen und akademischen Arbeitsteilung begnügt – mit einem (von faulen Kompromissen nicht immer unterscheidbaren) Harmonie-Bedürfnis, das allerdings, ein wenig näher besehen, dort und da doch auf das stillschweigende Eingeständnis hinauszulaufen schien, dass – gleichsam im Sinne einer doppelten Buchführung – eine Auseinandersetzung in den substanziellen Sachfragen selbst in Wahrheit jedoch als wenig aussichtsreich erscheinen müsse? Hat also ein vermeintlich schiedlich-friedliches Nebeneinander dabei möglicherweise auch über eine gewissermaßen von freundlicher Teilnahmslosigkeit überdeckte Sprachlosigkeit hinweggetäuscht und interdisziplinären Klärungsbedarf derart womöglich eher verdeckt? Oder hat man sich mitunter vielleicht allzu hastig mit der zwar nicht falschen, aber doch ein wenig zu einfachen und bequemen wechselseitigen Versicherung begnügt, dass schöpfungstheologische Aussagen nicht als naturwissenschaftliche Thesen misszuverstehen sind und naturwissenschaftliche Theorien wiederum nicht als Antworten auf bzw. als Ersatz für die mit der menschlichen Existenz verbundenen Sinnfragen gelten können?

So richtig dies auch sein mag, so erübrigt dies doch keineswegs die notwendige Verständigung über die klärungsbedürftigen bzw. über vielleicht wirklich strittigen Sachfragen. Jedenfalls muss die kurzsichtige Strategie, sachorientierte Kontroversen im „Streit der Fakultäten" dem Bestreben nach faktischer Koexistenz zu opfern, erst recht stets darauf gefasst sein, dass durch besondere Umstände erneut tiefe Gräben aufbrechen und sich die thematisch einschlägigen Auseinandersetzungen unversehens auf ein pseudowissenschaftliches Terrain verlagern, hier rasche (auch mediale) Verbreitung finden und somit wissenschaftlich seriöse Argumentation durch das Wechseln von „weltanschaulichem Kleingeld" ersetzt bzw. verdrängt wird.

Demgegenüber wollte die anlass-bezogene interdisziplinäre Tagung, die im Februar 2010 an der Universität Wien stattgefunden hat, auch eine Art „Bestandsaufnahme" sowie eine unumgängliche interdisziplinäre Verständigung darüber leisten, wo ein konstruktives diesbezügliches Gespräch zwischen den Disziplinen gegenwärtig einsetzen muss, das sowohl dem evolutionstheoretischen Forschungsstand bzw. dem Erklärungspotential entspricht, gleichermaßen dem theologischen Selbstverständnis und nicht zuletzt auch den unumgänglichen Perspektiven einer theologischen Hermeneutik genügt.

Der vorliegende Band dokumentiert die für die Publikation überarbeiteten Beiträge zu der genannten Wiener Tagung. Interdisziplinäre Veröffentlichungen stellen für Autoren und Leser immer auch besondere Herausforderungen dar: Es gilt, den Gesprächspartnern bzw. Lesern auf verständliche Weise Einblick in die Grundlagen der eigenen Disziplin zu geben und die spezifischen Zugangsweisen gemäß dem jeweiligen Forschungsstand zu erörtern. Die Reihenfolge der Beiträge wurde so geordnet, dass sie zu vier Themenbereichen jeweils einen Dialog verschiedener Disziplinen darstellen.

Die erste Gruppe der Beiträge ist den Grundlagen und Methoden der Evolutionstheorie gewidmet. Mit Rücksicht auf die genannten Problemlagen war es naheliegend, zunächst die neueren Entwicklungen und Wandlungen der Struktur der Evolutionstheorie und den derzeit erreichten evolutionsbiologischen Forschungsstand zu sondieren. Mit dem beanspruchten Erklärungspotential der zeitgenössischen biologischen Evolutionstheorie ist auch ein neues Selbstverständnis verbunden.

Gerd Müller zeichnet in seinem Beitrag die wichtigsten Paradigmen biologischer Evolutionstheorien von Darwin über die „neodarwinistischen" Ansätze bis zur Synthetischen Theorie nach und deckt dabei eine Reihe von Missverständnissen auf, die aus einer jeweils verkürzten Sichtweise von Anliegen und Methode dieser Ansätze resultieren. Anhand neuer Strömungen und Erkenntnisse der modernen Evolutionsbiologie werden anschließend weitere maßgebliche zukünftige Forschungsaspekte skizziert.

Christian Kummer SJ unterscheidet in seinem Beitrag drei verschiedene Aspekte des Begriffs „Evolution": „Evolution" als reales „Phänomen", als „Theorie" bzw. als „Paradigma". Damit möchte er auch unverzichtbare epistemologische Grundlagen bereitstellen, die in den einschlägigen Debatten nach wie vor oftmals ignoriert werden. Eine solche Erkundung sieht Kummer nicht zuletzt für die angemessene Beurteilung der Möglichkeiten und Grenzen evolutiver Ansätze als unverzichtbar an.

Hans-Dieter Klein wendet in seinem naturphilosophischen Beitrag das Hauptaugenmerk auf die Klärung der Begriffe „Species" und „Deszendenz", die für evolutionstheorische Konzeptionen natürlich von grundlegender Bedeutung sind. Ein naturphilosophischer Beitrag muss sich diesbezüglich insbesonders an der Klärung der damit verbundenen philosophischen Voraussetzungen orientieren, wobei sich die damit verknüpfte naturphilosophische Unterscheidung zwischen „Deszendenz" und „Evolution" als besonders bedeutsam erweist.

Hans Poser zeigt in seinem Beitrag, weshalb und in welchem Ausmaß evolutionäre Denkmodelle nicht nur die Biologie, sondern die moderne Weltsicht insgesamt bestimmen. Dabei erweist sich, dass das „evolutionäre" Deutungsschema freilich eine Reihe philosophischer Voraussetzungen in sich birgt, deren Freilegung und Analyse eine unverzichtbare Aufgabe für die „Wissenschaftstheorie" darstellt und auch nur so Problemnivellierungen und mangelnder Differenzierung entgegen zu wirken vermag.

Erhard Oeser erörtert sodann in einer ebenfalls wissenschaftstheoretischen Perspektive „Evolution" als „universales Paradigma der Wissenschaft". Von T. Dobzhansky stammt der bekannte Satz: „Nothing in biology makes sense except in the light of evolution". In seiner universalen Anwendung hat dieser Satz zweifellos Konsequenzen für viele Problemstellungen, nicht zuletzt bezüglich der Weltstellung des Menschen, der Kultur und Gesellschaft und natürlich auch hinsichtlich der engeren Thematik des „Schöpfungsglaubens".

Ein zweites Themenfeld ist sodann der „Evolutionstheorie im Dialog" der verschiedenen Disziplinen gewidmet.

Philip Clayton will in seinem Beitrag vornehmlich aufweisen, wie sich die Paradigmen der Biologie selbst gewandelt haben. Der Ansatz der modernen Systembiologie (system biology) betrachtet demgemäß nicht alles ausschließlich von der „Genetik" aus, sondern nimmt durchaus größere „Systeme" in den Blick. Damit verbundene Konsequenzen für das Verständnis von „Leben" und „Kultur" werden in diesem Beitrag ebenfalls benannt.

Ulrich Körtner untersucht sodann das Verhältnis von Naturwissenschaft und Theologie nicht über den Weg der Naturphilosophie, sondern orientiert an einer hermeneutischen Zugangswiese. Einen Schwerpunkt bildet dabei auch die Auseinandersetzung mit Konzepten von „Teleologie" und „Teleonomie", deren kritische Unterscheidung freilich auch in zeitgenössischen naturphilosophischen und wissenschaftstheoretischen eine wichtige Rolle spielt.

Horst Seidl erkundet im Ausgang von der klassischen Metaphysik aristotelisch-„scholastischer" Prägung die Möglichkeiten und Grenzen einer Naturphilosophie und versucht dabei näherhin den Nachweis dafür zu erbringen, dass und inwiefern diese traditionellen philosophischen Konzeptionen noch immer als ein bleibender Beitrag für das gegenwärtige Gespräch mit den Naturwissenschaften angesehen werden dürfen.

Hans-Dieter Mutschler fragt in einer wiederum ganz anders orientierten Zugangsweise bzw. Zielsetzung nach den Möglichkeiten eines fruchtbaren Dialogs zwischen Theologie und Naturwissenschaft und ist dabei vorrangig darum bemüht, in Auseinandersetzung mit verschiedenen Denkmodellen, die diesbezüglich heute verwendet werden, Minimalbedingungen für das Gelingen dieses Diskurses zu benennen.

Celia Deane-Drummond findet in ihrem Beitrag einen bisher kaum bedachten theologischen Zugang, indem sie „Evolution" radikal mit „christologischen" Themen ins Gespräch bringt und sich dabei näherhin an der Konzeption des „Theodramas" orientiert, das mit dem Namen des katholischen Theologen Hans Urs von Balthasar verknüpft ist: Diese theologische Anknüpfung soll es ermöglichen, das Wirken Gottes in der Welt verstehbar und in der Folge auch das christliche Glaubensbekenntnis „buchstabierbar" zu machen.

Ulrich Kattmann beleuchtet eine meistens zu wenig bedachte Perspektive des Gesamtthemas: Als „Fachdidaktiker" der Biologie sondiert er Möglichkeiten, Schülern das Thema „Evolution" im Unterricht in verständlicher und in auch für andere Fächer „anschluss-fähiger" Weise näher zu bringen. Damit verbindet er den Hinweis darauf, dass bzw. weshalb auch im säkularen Umfeld der Begriff „Evolution“ häufig auf verschiedenste Weise sehr rasch zum Thema „Schöpfung“ in Beziehung gesetzt wird.

Eine dritte Gruppe von Beiträgen blickt in die Zukunft mit dem Versuch, „Evolution“ weiterzudenken.

William Carroll entwickelt ausgehend von Thomas von Aquin einen starken Begriff von „Schöpfung“, der eine solche Autonomie „natürlicher Prozesse“ aufweisen soll, dass derart schon bei ihm ein theologisch-philosophischer und ein naturwissenschaftlicher Zugang nicht als schiefes Konkurrenzverhältnis gedacht werden muss.

Vittorio Hösle versucht mit einer Besinnung auf die philosophische Bedeutung teleologischer Prinzipien in vielen Verweisen auf die philosophische Tradtion Wege für eine natürliche Theologie nach Charles Darwin aufzuzeigen. Besonders aufschlussreich ist dabei Hösles Bezugnahme auf die damaligen einschlägigen Kontroversen zwischen Darwin und dem Botaniker Asa Gray, die in vielerlei Hinsicht offensichtlich keinesfalls bloß von wissenschaftshistorischem Interesse ist.

Ronald Cole-Turner geht innerhalb des Themenfeldes „Evolution weiterdenken“ in einer zukunftsorientierten theologischen Perspektive der Frage nach, was das „Deutungsschema Evolution“ insbesonders im Blick auf die wissenschaftlich-technologische Evolution der Menschheit bedeutet und welche Chancen und Risiken hier zu bedenken sind.

Der letzte Teil ist dem Thema „Evolutionstheorie und Anthropologie“ gewidmet.

Ludwig Huber verweist in seinem kognitionsbiologischen Beitrag auf „Intelligenz“-Leistungen von höherentwickelten Tieren, die oftmals wesentlich größer und umfangreicher sind als allgemein angenommen wird. Besondere Aufmerksamkeit wird dabei der evolutionären Entwicklung von Verhaltensweisen gewidmet, die nach Hubers Urteil durchaus auch „moralisch“ genannt werden dürfen.

Ulrich Barth skizziert in seinem anthropologischen Beitrag zunächst die christliche Schöpfungstheologie aus ihren Quellen und entwickelt anschließend – unter dem Leitbegriff „Gottebenbildlichkeit“ – ein christliches Menschenbild und dessen Bedeutung für die Ausbildung der philosophischen Konzeption der „Menschenwürde“.

Christian Illies stellt sodann in fünf anthropologisch begründeten Thesen die unverzichtbare Bedeutung der Evolutionswissenschaften für eine philosophisch fundierte Ethik dar; gleichwohl verlangt dies auch eine kritische Besinnung auf die Grenzen einschlägiger Ansprüche seitens der Evolutionswissenschaften, zumal nur dadurch auch naturalistische bzw. „biologistische“ Reduktionismen zu vermeiden sind.

Erwin Dirscherl fragt im Ausgang von den biblischen Schöpfungserzählungen nach dem Zusammenhang zwischen Sprache und Zeit; vor diesem Hintergrund rückt sodann die konstitutive „Dialogizität“ ins Blickfeld, ohne deren vorrangige Berücksichtigung auch eine philosophische und theologische Thematisierung der Weltstellung des Menschen unzulänglich bliebe.

Kurt Appel macht schließlich ebenfalls „Zeit“ zum besonderen Thema seines Beitrages. Ein vertieftes Zeit-Verständnis wird darin als die Bedingung dafür geltend gemacht, um sowohl Aporien kreationistischer Ansätze als auch hartnäckige Schwierigkeiten im Dialog von Theologie, Philosophie und Naturwissenschaften überwinden zu können.

Die Herausgeber dieses Bandes danken den Herausgebern der Reihe „Wiener Forum für Theologie und Religionswissenschaft“ für die Aufnahme in diese Reihe der „Vienna University Press“.

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Die Herausgeber Wien, im Frühjahr 2013

Grundlagen der modernen Evolutionstheorie

Gerd Müller

Evolutionary Theory Today: Three Myths Rejected

Die theistische Kritik an der wissenschaftlichen Evolutionstheorie richtet sich häufig gegen den so genannten Neo-Darwinismus, sowie gegen die angeblich grundlegende Rolle des Zufalls in der biologischen Erklärung und die vermeintliche Unmöglichkeit des natürlichen Entstehens komplexer biologischer Strukturen. Im vorliegenden Kapitel werden diese Darstellungen berichtigt. Ausgehend von einem Überblick über die aktuellen Komponenten der Evolutionstheorie wird gezeigt, dass der Neo-Darwinismus nicht das heutige Evolutionsparadigma repräsentiert, dass Zufall kein konstitutives Element der evolutionären Theorie darstellt und dass organismische Komplexität in der modernen Evolutionstheorie eine hinreichende Erklärung findet. Die gegenwärtigen Formen einer "Erweiterte Synthese" erhöhen nicht nur den Erklärungsgehalt der Theorie sondern beinhalten auch ein verbessertes Verständnis von den kausalen Mechanismen der biologischen Evolution. Abschließend wird gezeigt, dass bestimmte Formen theistischer Argumentation sich Fehldarstellungen der wissenschaftlichen Evolutionstheorie zu Nutze machen, um einen Rückgriff auf teleologische Prinzipien in der Erklärung der belebten Natur zu argumentieren. Es wird gefordert, dass sich teleologische Erklärungsmodelle dem Kriterium der empirischen Überprüfbarkeit stellen.

The depiction of animal diversity as emerging from an egg, shown on the frontispiece of William Harvey's mid-17th century "Exercitationes", was a revolutionary statement. It argued against both preformationism and spontaneous creation: *Ex ovo omnia* – but, through Zeus's opening of the egg, by divine guidance. Today, many of my colleagues in the biosciences would claim that in the light of evolutionary theory and our knowledge of genetics this picture simply needs to be replaced by one in which all life forms spring from DNA variation – without supernatural guidance, of course. The internet provides ample evidence of this widespread notion, with a sheer avalanche of images showing human and animal shapes in combination with ingeniously coiled double strands. It is understandable that such simplistic caricatures of evolution generate widespread opposition. I am going to argue that Harvey's notion of relating epigenetic development to organismal diversity was in fact the more correct: The contemporary theory of evolution is significantly characterized, among other modifications since the so-called Modern Synthesis of the 1930s and 40s, by the inclusion of development.

I will discuss evolutionary theory, not evolution. This is a crucial distinction, often forgotten in discussions like ours. Evolution is the phenomenon we observe, the continued generation, variation, diversification, and extinction of organismal forms on earth over geological time. It is what scientists describe, measure, and analyze with an arsenal of advanced methodology: We calculate the rates of change, the dynamics of populational variation, the time periods of speciation, the distance of genetic variants, the frequencies of mutations, the geometries of morphological modification, and so forth. This kind of data represents the factual evidence of organismal change over time that we term evolution. It is scientifically established beyond doubt. Several hundred biomedical papers appear every day, and no scientific study has ever produced any kind of evidence that contradicted the occurrence of organismal evolution on this planet. Hence we can regard biological evolution as a scientific fact.

The *theory* of evolution is the conceptual framework that aspires to explain the facts of evolution in a scientific way. This is a different matter. A theory is prone to modification and growth. New results of research appear, and the new data need to be theoretically accommodated. This might require an alteration or expansion of the theoretical framework, and sometimes even its radical innovation or rejection. Critical debate and even harsh academic dispute may arise among scientists over certain components of a theory. Thus a theory is never complete and will itself evolve, as is the case with evolutionary theory. However, it cannot be repeated often enough, the theory of evolution is not a statement about *whether* evolution has taken place but about *how* it took place. All scientific controversies concern this latter aspect, not the prior. My task will be to introduce the current status of that theory.

I will approach this issue via three "myths" about evolutionary theory that are commonly raised in controversial debates like the one that prompted the present volume. One is the label "neo-Darwinism" frequently attached to the current theory. The second is the characterization of the scientific position as a "mere chance" argument, in particular with regard to human evolution. The third is the proposal that evolutionary theory cannot explain organismal complexity. I will show that "neo-Darwinism" does not represent the current status of the theory (and, hence, its criticism is misguided), that chance is not its central explanatory element (and, hence, is not the devilish factor that biologists are accused of introducing into the explanation of life), and that the occurrence of complex structures of life finds sufficient explanation within the current theory (and, hence, does not require the postulate of supernatural intervention). I will address these three themes in sequence and conclude that renewed calls for a teleological narrative of biological evolution depend on false representations of the scientific explanation.

The evolution of evolutionary theory

Let us begin with the current status of evolutionary theory and so-called "neo-Darwinism". Public attacks of proponents of Catholicism on science in general, and on evolutionary theory in particular, are full of criticism of "neo-Darwinism"[1]. But besides such attacks being unfounded in principle, due to the absence of evidence, neo-Darwinism is not where the theory stands today. Of course, there is a historical core. Darwin (1859) coined an amazingly simple principle. He related three variables to each other, namely the variation, heredity, and multiplication of the individuals of a species. He argued that favorable variations result in a larger number of offspring bearing the variant, and via inheritance this successful variant will be distributed in the population. Since the numbers of offspring always exceed the numbers of survivors that can propagate the hereditary determinants of different variants, an assortment process implicitly occurs, a principle he termed "natural selection". Its result is an increased capacity of the members of a species to cope with given environmental conditions through continued optimizations of organismal form and function, i. e. adaptation.

This is only one aspect of Darwin's theory, but it is sufficient for the present purpose. Darwin did not know about the causal origins of variation, neither did he know about the material basis of heredity. For this he had to make certain assumptions, and he took into account the possibility of the propagation of experiences made by the individual to subsequent generations. These "Lamarckian" components were later removed by Weismann and others, Mendelian genetics was introduced, and this "cleansed" kind of Darwinism became known as "neo-Darwinism". Neo-Darwinism was the theoretical nucleus around which more concepts from other research domains subsequently became integrated into what has been called the Modern Synthesis. This conceptual fusion happened in the 1930s and 1940s and included primarily mathematical population genetics and experimental genetics, but also systematics, a better understanding of speciation, and more[2].

The Modern Synthesis is a theoretical framework focused on variation. Its key

1 e.g., Schönborn 2005.
2 Huxley 2010.

symbol is the Gaussian curve representing the distribution of character variation in a population, whether they are molecular, morphological, physiological, or behavioral characters. Variation is arranged around the populational mean, and any factor that is able to shift that mean in one direction, or affects the width of the distribution, is regarded as an evolutionary factor. Natural selection can be responsible for such shifts, but so can be drift or accidental effects, such as a meteor impact that cuts off a part of the population. In essence, this was how the Modern Synthesis viewed evolution, from the perspective of statistical correlations of phenotypic variation with supposed or abstract genetic variation. At the time when the Synthesis was established, genes were conceived units of inheritance, their material composition was not known. There existed no molecular genes, let alone the methods to analyze their sequences or visualize their activity. Thus, although highly successful in explaining a fundamental evolutionary mechanism and its general effects on variation in populations, the classical theory neglected certain features of organismal evolution and invited criticism, both scientific and unscientific. But the Modern Synthesis theory is roughly 70 years old, much has happened since.

Most notably, the 1950s witnessed the discovery of the DNA, followed in subsequent decades by the establishment of methods to extract molecular genes – now we speak of physical genes. Methods that visualize gene activity in cells and embryos were developed from 1984 onwards, followed by a proliferation of quantitative methodologies and the analysis of whole genomes, culminating in the human genome project. In the wake of genomics, we are now in a flurry of "omics"-approaches, generating massive amounts of molecular data that require advanced bioinformatic tools for their organization and analysis. This represents a significant shift in the empirical basis of evolutionary biology. In the face of these and further developments in other areas of biology, it would be very surprising, indeed, if the theory of evolution had remained unaffected and static. Actually it remained not unaffected, and I will briefly survey some of the conceptual consequences these modern approaches had for evolutionary theory.

Let's start out with *Genome Evolution.* Today it is possible to obtain full genetic sequences from representatives of all major clades, and sometimes even from extinct organisms, in reasonably short amounts of time. Genomic technologies made clear that it is not just single genes that mutate or evolve, but there exist a number of mechanisms by which significant portions of the genome can be changed at once, for instance through duplications, lateral transfer, mobile elements, etc., and can subsequently become coopted into entirely new function, i.e., existing genes can serve different roles in new generative contexts. This represents a quite different picture from the one that required independent mutations of single genes that needed to fit together – a major issue in traditional accounts, which were faced with the problem of how to obtain all these fitting variations for a complex structure to arise. We now see that no such requirement is necessary, batteries of the same ancient genes operate in different settings in different organisms, permitting much more rapid instances of evolution than previously assumed by the Modern Synthesis. Genomic change introduces a new dynamics to evolution[3].

Besides genomics several other theoretical advances became decisive. One important aspect is the level-of-selection or unit-of-selection problem in the classical theory. At the time of the Synthesis, the sole accepted unit of natural selection was the individual, even though hints existed already then of supra-individual forms of selection. But these were not recognized by the canonical theory. Today it has become commonplace to assume a number of supra-individual and also infra-individual levels of selection, most of which have been well demonstrated and are combined under the heading of *Multilevel Selection*[4]. The question remains how important some forms of selection really are in actual cases of organismal evolution. Species selection, for example, is still much under debate. But it is clear that natural selection is effective beyond the level of the individual and, hence, also allows for different scenarios of evolutionary change.

Furthermore, under the assumption of the Modern Synthesis there was only one form of inheritance – genetic inheritance – that had been accepted as the vehicle for transmitting information from one generation to the next. Today we know in addition about *Epigenetic Inheritance*, *Behavioral Inheritance*, and *Cultural Inheritance.* Again a more pluralistic array of concepts is taken into account, and these are not merely abstract notions. Scientists operate with these concepts. They analyze, for instance, behavioral inheritance and transgenerational epigenetic inheritance. The latter has recently gained widespread attention through the works of Eva Jablonka and Marion Lamb (2005). These authors demonstrate multiple cases in which non-DNA-based modulations of gene activation are transmitted not only from one cell to the next, but apparently also from generation to generation. At least there are well documented instances of that behavior, which differs substantially from the assumptions of the Modern Synthesis. Again the question remains: How important are such phenomena in the big picture of evolutionary change? But it is established beyond doubt that these phenomena exist[5] and must be taken into account.

One of the most influential innovations in evolutionary theory comes from a relatively young field of research that relates evolutionary change to embryonic development. Although it had been clear for a long time that the forms of organisms can only change if their development is altered, there were no

3 Bernardi 2005.
4 Wilson 2010.
5 Jablonka / Raz 2009.

methods available to address this issue. New tools in experimental and molecular biology changed that situation in the early 1980s. By now the field has become known through the shorthand of EvoDevo, standing for Evolutionary Developmental Biology. Besides a host of empirical results this new research program has afforded a number of concepts that take evolutionary theory beyond the Synthesis paradigm. One example is *Facilitated Variation*, proposed by Marc Kirschner and John Gerhart (2005). It argues that because of the extensive interconnectedness of all developmental processes, the change in one component is easily integrated by all other components of the developing embryo. Hence evolution does not need to "wait around" until there is fitting genetic variation available in the participating components of the embryo. Instead there is immediate accommodation at the epigenetic level and therefore ontogenetic development greatly facilitates the origin and integration of new phenotypic variation. According to this concept, new variation is not merely a consequence of genetic change but also of the rules operating at the developmental level. Importantly, the kind of variation that can be generated in evolution will be both constrained and facilitated by the historically acquired and entrenched processes of ontogeny in each organismal lineage. Not every change to a developmental system is possible with the same kind of likelihood. Thus, developmental systems pose constraints on what kind of variation becomes available in a given lineage, providing limitations and opportunities on where selection can be effective and where it cannot.

Another theoretical advancement resulting from EvoDevo research relates to the origin of multicellularity and the first organization of body architectures. "Single cell" organisms had more than a billion years to develop their genetic repertoire. When multicellularity arose, these organisms had a gamut of molecular properties already in place, such as those defining the adhesivity of cell surfaces. But in the new multicellular context the same molecular properties of single cells became the mediators of physical behaviors of cell masses, and the resulting configurations must have provided the earliest forms of multicellular bodies that would become exposed to natural selection once they became heritable as a joint unit. These emergent behaviors, which are characteristic of multiscale systems such as biological organisms, are fundamental to causal accounts of organismal evolution. Stuart Newman's *Generic Form* concept explains how a limited number of primordial multicellular assemblies will arise automatically from a basic repertoire of molecular patterning modules[6]. This demonstrates that evolution does not generate "endless forms", as suggested by a well known book title[7]. Rather, only a limited array of macroscopic shapes and

6 Newman 1994; Newman / Bhat 2009.
7 Carroll 2005.

structures can have resulted from early multicellular interactions, such as cell sorting and clustering. Natural selection would have acted to stabilize such generic forms against external perturbations and would have generated further variations of the basic themes that resulted from early self-organized cell patterning.

EvoDevo also introduces an important distinction that was not present in the Modern Synthesis, namely a distinction between the processes of variation and those of innovation, as well as between their respective outcomes, adaptation and novelty[8]. Innovation did not occur in the Synthesis theory, because, as pointed out above, it was predominantly a variational theory in which only continuous and incremental forms of change were addressed. It concentrated on the mechanisms of population change and on the adaptative variation resulting from natural selection. But how those characters that are subject to variation arose in the first place was not part of the Synthesis. The fossil record hints that origination rates of new orders and new species are not uniform and not equally distributed across the biosphere[9].

In our own work on *Epigenetic Innovation*[10] we have shown that new characters in organismal bodyplans can arise as by-products of developmental systems that are exposed to perturbation, whether experimentally or environmentally induced. These novel elements result from the emergent properties of cellular organization, such as in the skeletogenic system that produces cartilages and bones. The continued addition, for instance, of new skeletal elements is well documented in vertebrate evolution. There is no possibility for natural selection being directly responsible for the appearance of such novel characters, simply because selection can only act on features that exist already. But the gradual selectional modification of developmental parameters, such as the relative proportions of body parts or of other quantitative cell and tissue properties, can take a system to developmental threshold points at which it will react according to its own propensities and generate incipient structures as a side effect. Subsequent evolution and natural selection may genetically stabilize such rudiments, but, in stark contrast with the received theory, the mode of their origination is explained by innovation events, in which byproducts of developmental change generate the kernels of novelty.

Finally, to mention a last field of advancement in contemporary evolutionary theory, the modern behavioral and ecological sciences also provide new conceptual contributions. An example is the concept of *Niche Construction*[11]. In

8 Müller / Newman 2003, 2005.
9 Jablonski 2005.
10 Newman / Müller 2000; Müller 2010.
11 Odling-Smee et al. 2003.

departure from the Synthesis theory, in which natural selection is seen as a unidirectional factor affecting variation in organismal populations through exterior environmental conditions, niche construction theory argues that organisms, in turn, actively modify their environment – think of termite mounds, ant hills, beaver dams, or human ecological influences. This kind of altered environment, however, becomes the selective environment for subsequent generations of that same species, which continues to modify the environment, and thus, to some extent, its own selectional conditions. Niche construction theory introduces a feedback dynamic between evolving populations and evolving environments. In addition, the environmental features generated by organismal activity represent an extra-corporal inheritance mechanism, which can become even more effective in advanced kinds of cultural systems, such as with humans.

The present structure of evolutionary theory that arises from the inclusion of the factors and concepts mentioned above, and of others not here addressed, has been labeled "Postmodern Synthesis" or "Extended Synthesis"[12]. Compared with the classical model, these modern versions represent a more complex and pluralistic picture, in which several kinds of feedback relations occur in evolving populations, in which the statistical notion of gene pools is replaced by pools of developmental systems, in which several forms of inheritance and of selection may operate, and in which the evolution of organismal forms is not explained merely by external factors of natural selection but also by the internal and inherent propensities of the generative processes that build these forms.

The current expanded theory framework has a number of consequences regarding the relative importance of the factors that made up the traditional account. Maybe the most significant difference is the changed role of natural selection. Under the Modern Synthesis assumption natural selection was the predominant directional agent in evolution. In the extended theory natural selection becomes a boundary condition, permanently operating hand-in-hand with genetic variation at the population level, but the specificity of the phenotypic outcome is taken to be determined by what has been called "developmental dynamics." At the same time the extended version of evolutionary theory has become less gene centric and overcomes the restriction to incremental forms of change.

In conclusion of this section I reemphasize that "neo-Darwinism" is not the prevailing evolutionary paradigm. Nearly a century has passed since the period of neo-Darwinism, and the current version of evolutionary theory, whether depicted in the way chosen here, or from any other perspective, is very different from the versions reported in theistic and creationistic texts, of which "in-

12 Pigliucci / Müller 2010.

telligent design" is but a puffed up variant. It is obvious that much of the rhetoric in such texts is directed against inadequate characterizations of evolutionary theory.

The role of chance in evolutionary explanation

"Blind fate", "pure chance", "complete randomness", "mere accident" are terms frequently heard in theistically motivated criticisms of the scientific theory of evolution. They are meant to expose a constitutive reliance on chance inherent to the scientific explanation of life, human evolution in particular. But is it true that biologists argue that the organismal manifestations of the evolutionary process are a product of chance? The numerous writings to the contrary, explaining the actual role of chance events in biology[13], haven't had the least effect on the tenacious perpetuation of misrepresentations of the chance element in evolution. Hence my hopes to succeed this time are not high, but I will give it another try.

Much ink has been spilled over the distinction between randomness in the sense that the chain of causes leading up to an observable event is incomplete – in principle, as some would say – and, on the other hand, randomness in the sense of stochasticity, in which the causal chain is complete, but the exact timing or location of one or several of its events are unpredictable. Whereas evolutionary theory doesn't make use of the former, it is correct that stochasticity is important in the mathematical framework of population dynamics – capturing probabilistic events, sampling error, etc. But this is not what is meant by "chance" in evolution. The evolutionary meaning of chance pertains to the relationship between variation (and innovation) and natural selection. "Evolutionary chance" denotes independence of certain kinds of genetic variation relative to the directionality imposed by natural selection. It does not mean that all mutations are equally likely or that unknown causes direct mutational change.

Evolutionary chance, as defined above, is neither simply stochastic or probabilistic, nor coincidental or a-causal. Instead, it refers to the relation between variation and adaptive change. But how variation is generated, whether there is stochasticity in genetic recombination, whether mutation is randomly affected by chemical substances or by cosmic radiation, whether mutations are predictable or unpredictable, is of no importance in the explanation of the outcomes of the evolutionary process. The occurrence of chance in variation does not mean that these outcomes are accidental. Rather to the contrary: The

13 e.g., Eble 1999; Millstein 2000; Gould 2002.

fundamental characteristic of biological evolution is the establishment of robust organizations of matter that withstand accidental perturbation. Evolution is the increasing removal of chance interference with biological organization. Take the different kinds of body architectures that evolved in animals. Once they are established and fixated, they remain constant – with variation – over hundreds of millions of years. Once an insect – always an insect!

Leaving molecular evolution aside, for the sake of the present discussion, the factors that account for organismal evolution are contained in the principle of natural selection and its interplay with individual development. Whereas natural selection is a means for maintaining favorable variants in a population, primarily governed by conditions external to the individual organism, the physical properties of cell and tissue interaction in development, and their genetic regulation, constrain and facilitate variation. These factors provide the explanation for how new structures arise and become integrated with existing body architectures. Natural selection and the generative laws of developmental processes together account for the evolutionary ordering of organismal structures and complexity (see below). Chance, by contrast, is not a constituent element of explanation for why and how specific structures arise in biological evolution.

Interestingly enough, the insistence on "mere chance" in the criticism of evolutionary theory seems to serve a different purpose. It is meant to designate a component in evolution that scientists recognize, but fail to explain. This would leave space for supernatural intervention, a potential inroads for divine manipulation. But, as pointed out above, the argument is fundamentally flawed, because chance in biological evolution has a very particular meaning. A similar misunderstanding is sometimes voiced from a physics perspective, when it is argued that Heisenberg's principle introduces a fundamental causal uncertainty into biological evolution. Besides the fact that quantum mechanics is quite unlikely to have any direct effect at the scale of macromolecules and gene mutation, even if it did, this would not influence in any way the workings of natural selection or of generative tissue propensities and, hence, the evolutionary outcome. In any case, so far no quantum effects were shown to be effective in biological evolution, even though, in an unlikely alliance, renowned physists are assisted in their uncertainty argument by lay scholars who otherwise muse about the beneficiary effects of mare's milk[14].

In summary, whereas different kinds of chance events may interfere with the evolutionary process and may affect the particular course of a given lineage's phylogeny, the theory of evolution contains no claim that the generation of life's forms is a consequence of accident or haphazard. Rather to the contrary, evolution is characterized by increasing fixation, entrenchment, and robustness

14 Huber / Thirring 2011.

which stabilize organismal forms and, thus, buffer organized life from the effects of random variation. Biological evolution is anti-chance.

The origin of complexity

"You can observe a lot just by watching", American League idol Yogi Berra famously pronounced. In a similar vein proponents of design creationism argue that complex biological features have not originated from an unguided evolutionary process, because "the human intellect can readily and clearly discern purpose and design in the natural world, including the world of living things"[15]. In less arcane formulations, various examples have been proposed to demonstrate that highly complex organismal structures, such as bacterial flagellae or vertebrate eyes, have not arisen by natural evolution. On the one hand such assertions are again based on the "not possible by mere chanc" argument we have already treated above, but on the other hand, and more importantly, these arguments are directed against a form of evolutionary theory that did not seek to explain the origin of biological complexity. Here the design defenders actually would have had a point in the past: The classical theory of the Modern Synthesis explained the behaviors of genetic variation in evolving populations in a statistical-mathematical sense, but it did not aspire to explain the origin of specific complex features of the phenotype. However, as indicated in the first section, the current theory of evolution has overcome this restriction and now explicitly addresses the issue of complexity.

For several decades biologists have studied the development of complex organismal systems and their evolutionary changes. The central questions of this research is how cellular structures arose and how single cells came to establish the complicated and diverse body patterns found in nature. The science that is occupied with the investigation of these topics has been introduced in the first section under the name of evolutionary developmental biology or EvoDevo. Since its inception the field has diversified into multiple strands of research, including the analysis of gene regulatory networks that underlie the development of different body architectures. The most revealing and astonishing result in this area was the discovery that organisms of very different body organization share a large number of their key regulatory genes. The evolutionary origin of new structures and organismal architectures is not based so much on the introduction of many new genes, rather it is the repeated activation and modification of the dynamical interactions among existing genes and their products that was instrumental.

15 Schönborn 2005.

Complicated morphological structures, which have been peddled as examples of irreducible complexity, such as the human eye, in reality are well understood in both their molecular regulation and cellular interactions that generated the different anatomical versions of eyes in evolution. As indicated above, basic regulatory genes implicated in laying down the very first fields of eye formation are shared by all taxa that have evolved eyes. The differentiation pathways of many of the subsequently forming eye structures are equally well understood. Furthermore, the comprehensive comparison of different taxa shows how complex eyes, such as in vertebrates, have evolved from more simple structures in phylogenetic ancestors, tracing back the origin of eyes to single photoreceptor cells and their light sensitive capacities. No significant step in the evolution of eyes is miraculous or unexplainable, and the same holds true for other examples of so-called "irreducible complexity".

It should be noted that gene regulation is not the only and not even the primary source of complexity in organismal evolution. As with all multiscale systems, complexity arises from the interactions among many different levels organization. These include not only the molecular and structural levels, but also organismal behavior and cognition, as well as ecological and cultural feedback interactions. Hence the increase of complexity is a general feature of evolving, living systems. But order and complexity also arise autonomously in non-living systems, ranging from the micro-scale of chemical and physical organization, such as protein folding patterns or snow flakes, to the macro-scale of planetary systems and the universe. Living systems are only different in the sense that they have coopted these self-organizational properties of matter by an information processing apparatus, ensuring the reliable inheritance and repetition of organization in every new generation.

Systems theory and EvoDevo respectively provide general and specific explanations for the origin of complex structures in evolution, even if not every single organismal feature has been studied in detail. The argument that certain structures of living beings are somehow irreducibly complex, i. e. too complex to have evolved from simpler structures and thus indicating preordained design, has been scientifically and legally refuted[16]. As with the two other topics discussed above, the continued reiteration of this view amounts to the perpetuation of an unsubstantiated myth.

16 Jones 2005.

Teleology from a biological perspective

Nearly 3000 years of teleological argument have pervaded Western thought, and it is not to be expected that a mere 150 years of evolutionary insight will easily erase these entrenched patterns of reasoning. The more so, since teleology comes in many different guises, and the masters of their trade artfully switch between them. In his systematic and comprehensive refutation, Hartman (1951) likened teleology to a mirage, a subjective sensation that nevertheless conjures a false image. He concluded that it will not be eradicated as a belief system and will likely stay with us forever. How right he was. But there is one thing that can be done, and this is to expose some of the wrong assumptions about evolutionary theory that are associated with current teleological narratives.

The chance argument and the complexity argument have both been used in support of recent defenses of crude teleology. Since "a whirlwind blowing through a junk yard cannot put together a jet plane", one notorious argument runs, evolution cannot have generated organismal diversity by chance. These kinds of far fetched analogy are then taken as the starting point for characterizing biological evolution as a planned process. Besides the fact that such stories profoundly misrepresent the biological approach, they are directed against a false understanding of the role of chance in evolutionary theory, as pointed out above. The same holds true for the complexity myth: "Because a watch must have a designer, equally complicated natural systems must also have a designer". The fact that this argument can be traced back as far as Cicero doesn't make it any better. To draw teleological conclusions from a simple comparison of man made objects with natural objects is not a scientifically adequate method. This is common knowledge since the period of enlightenment, whereas modern science shows through repeatable experiment how complex features arise in natural systems[17].

Biological systems are not without teleological components. This has been correctly argued in philosophical discourses[18]. There is goal directed behavior in individual organisms, there is goal directed development in individual ontogenies, there is goal directed function in physiological processes, etc. But all these goal directed processes are effective within the individual life span of an organism, and they are a consequence of evolutionary processes having established functional relationships among organismal components in previous generations. This kind of teleology has always been recognized in biology, even if it was rarely called by that term. But it is a version of teleology that does not

17 e.g., Kauffman 1993.
18 Nagel 1965; Ayala 1970.

imply a preordained relationship of means to a given end. Hence it seems useless for the theistic argument.

Beyond crude biologistic teleology there are certainly more subtle strands of teleological reasoning, some of which are represented in this volume. But, at least with regard to their biological applications, they usually harken back to chance and complexity in evolution. In this regard it is necessary to request that the propositions of evolutionary theory be represented correctly, and that the misrepresentations I have pointed out in this chapter be abandoned. Furthermore the defenders of teleological reasoning in evolution are requested to present testable proof for their arguments. Plan and purpose in nature cannot be observed "just by watching".

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