1983

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THE EVOLUTION OF SCIENCE:
A SYSTEMS APPROACH

by

Kai Hahlweg

Department of Philosophy

Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

Faculty of Graduate Studies
The University of Western Ontario
London, Ontario
August, 1983

ABSTRACT

This thesis is concerned with two interrelated sets of problems:

1.) How can we have knowledge in a universe of processes?
2.) How can knowledge be improved, and how is scientific progress possible?

To address the epistemological question in conjunction with the ontological is not a common approach in contemporary philosophy of science. I therefore begin the dissertation by arguing that these two areas of philosophy are intimately interrelated, and that the one-sided concentration on epistemological issues has led to an unsatisfactory account of the nature of knowledge. In particular it has led to a conflation of epistemology with methodology. I argue that methodologies carry with themselves certain presuppositions concerning the nature of the world and of human beings. Any proposed methodology assumes that the structure of the world is such that the alleged method can work, and that the nature of human beings is such that they are - at least in principle - capable of following the methodological prescription.

I suggest that we should attempt to construct a philosophical system within which epistemology and ontology mutually support one

another. Insights derived from modern science provide us with a basis for the construction of such a system.

I begin this task by arguing that scientific knowledge can be viewed as an extension of perception. Relying on insights derived from Gregory and Piaget I emphasize the constructive characteristics of our perceptual system and argue that they find their counterpart in the constructive nature of modern science.

Having outlined a constructivist view of knowledge I turn to the discussion of the ontological issues. At first I investigate the almost universally accepted metaphysics of reductionistic atomism and show, following Burtt, that many current epistemological problems can be viewed as being a direct result of the uncritical acceptance of this philosophy.

I propose as an alternative the adoption of a metaphysics of processes. I outline such an ontology, basing my model upon ideas derived from Prigogine's research on dissipative structures and Pattee's investigation of hierarchical organization. I explain how dissipative structures create stability in an instable world and link this insight to the constructive features of our perceptual and conceptual systems discussed earlier in the dissertation.

The resulting model shows how knowledge is possible in the strange world of processes which we probably inhabit. It further shows how knowledge can be improved and what progress through evolution means. This issue is pursued in greater detail in the last part of the dissertation. There I expound Waddington's cybernetic model of evolutionary change and show how it finds its counterpart in cognitive evolution.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor Professor Robert Butts for his patience and support during the gestation period of this dissertation.

I would like also to acknowledge Professors Ausonio Marras, Jeffrey Bub, and Robert Muehlmann, the members of my advisory committee, for their helpful comments and encouragement.

I am particularly indebted to my former teacher Professor Clifford Hooker whose emphasis on the interrelationship between philosophy and science shaped my philosophical views. His extensive commentaries on an earlier draft of this dissertation were much appreciated.

Last not least, I have to thank my friends Malcolm Forster, David Holdsworth, Richard Arthur, and Brian Donohue who read the thesis or parts of it and made constructive comments.

The philosophy department of The University of Western Ontario was most helpful in providing generous support during many years of study and research. Without it this thesis could not have been written.

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CHAPTER I

PROGRESS AND EVOLUTION

1.1. METHODOLOGY: A RETROSPECT ON BACON AND DESCARTES

Ever since the times of Bacon and Descartes the idea of scientific progress has been linked to the belief that there exists a perfect method, which, once discovered, would enable us to come to know the truth about nature. During the preceding centuries the capabilities of the arts and crafts had been considerably improved through an increasing number of important inventions such as the flywheel, the printing press, the compass.

Yet, what was the significance of these inventions compared with the possibility of finding a method which would enable man to gain new knowledge in a systematic fashion? Instead of having to wait for discoveries to occur randomly, subject to the whim of fate, a method would enable man to take the future in his own hands leading to new inventions based upon a better understanding of nature and culminating in an improvement of man's social and economical conditions. The belief in the possibility of finding such a method was voiced by Descartes in his Discourse on Method:

> (I perceived it to be) possible to attain knowledge which is very useful in life, and that, instead of that speculative philosophy which is taught in the Schools, we may find a practical philosophy by means of which, knowing the force and the action of fire, water, air, the stars, heavens and all other bodies that environ us, as distinctly as we know the different crafts of our artisans, we can in the same way employ them in all those uses to which they are adapted, and thus render ourselves the masters and possessors of nature (Descartes(1619),119).

Descartes and Bacon conceived of a new role for the "natural philosophers". Instead of engaging in the empty and barren talk of the schoolmen the modern philosophers would perform experiments in a systematic fashion. Theoretical knowledge thus gained was thought to be as certain and undisputable as the practical knowledge the craftsman exhibits in the perfomance of his art.

As different as Bacon's empiricist and Descartes' rationalist methods were, they both agreed that certain knowledge can be reached by their respective methods, that there could be only one right method of gaining genuine knowledge; they also agreed that the intellect has to be purged from irrational passions in order to make it a fit instrument for the reception and application of the scientific method. Knowledge thus gained was to better the conditions of the common people, the impoverished peasants as well as the city dwellers. God had expelled Adam and Eve from Paradise for eating from the tree of knowledge. Christianity had therefore tended to look back to the times before the Fall as a golden age, lost due to our tampering with knowledge not meant for us. Bacon's and Descartes' vision implied that man could be redeemed through knowledge. They believed that a great co-operative effort to marshal empirical and theoretical knowledge would lead to an intellectual regeneration, a return of man's dominion over nature which had been sacrificed at the Fall.

What were Bacon or Descartes to say if they could appear in our times and look at its achievements? In the fields of science and technology their boldest dreams have certainly been surpassed in ways they could not have even imagined. It is obvious that there has been progress in science and technology, yet,it is difficult to talk about progress with respect to the wellbeing of mankind. Indeed, we could point out the improvement in general erducation, the establishment of democratic institutions in many countries, the cooperation within international organisations,etc. We seem to have made progress in all of these and many other areas. However, if we think about the tremendous problems we are facing in the 20th century, the proliferation of wars, the increase in pollution, the problem of overpopulation, to name but a few, the statement 'we have made progress' seems to be rather empty. We seem to have no fewer problems than the people in the 17th century, although the nature of these problems has changed considerably.

How disappointed would be the great philosophers to realize that progress in science has not automatically resulted in a concomitant progress in the general welfare of human beings. Appalled by what they witness about the general state of mankind, they might turn to the universities and other great scientific institutions. There at least - so they might think - they will hear good news. The tremendous progress in science and technology is evidence enough that their dreams must have been fulfilled, and that a right method must have been found. A method that steered science through the centuries from one triumph to the next. Eager will they be to learn about this method from their modern philosophical collegues. But here, too, they would be disappointed in their expectations. The philosophers of the 20th century would have to concede that there is no unanimity among them about what the right scientific method is, nor whether we can expect ever to find such a method. That means, of course, that we can know one thing for sure. Even if it were to turn out that the majority of scientists were successful because they followed a particular method, they certainly were unaware of it. We can conclude that the actual practical role of methodological prescriptions is dubious, to say the least. If scientists have been so successful without paying allegiance to a particular method - or were at least unaware that they were following such a method - then the discovery of "the" right methodology would in all likelihood have few practical consequences. According to the original vision of Bacon and Descartes it was necessary to find the right method in order to guide scientists in their endeavors and lead them on the certain way to progress. The paradoxical situation has arisen that the sciences seem to fare quite well without following philosopher's advice and that methodology is in trouble.

1.2. AGAINST THE CONFLATION OF EPISTEMOLOGY WITH METHODOLOGY

So why are philosophers still engaged in methodological inquiry? Why do they not give up this apparently fruitless enterprise and direct their energies to more promising fields? I think that the main reason why methodology is still so much in the forefront of the philosophy of science is to be found in the conflation of epistemology with methodology. This identification has been central in much of 20th century theorizing on the theory of knowledge. Karl Popper says it bluntly: "Epistemology, or the logic of scientific discovery, should be identified with the theory of scientific method"(Popper(1959)49).

The identification of methodology with epistemology means that giving up methodology would mean giving up the theory of knowledge. That, of course, is too dear a price to pay. Epistemology is central to science and philosophy alike. Giving up the theory of knowledge would mean giving up hope of ever understanding how human beings can know and how they relate to their environing world.

But why should we accept the conflation of epistemology with methodology? Do not both areas deal with rather different, although related subjects? Should not a theory of knowledge deal with questions such as how do human beings, equipped with the kind of sense organs and the kind of brain they do possess, gain knowledge about the world, about themselves and about the relationship between both? In other words, does not epistemology presuppose scientific knowledge of our sensory organs, nervous system, brain structure, etc.? Should we not expect that epistemology will improve with the development of neurophysiology, psychology, biology? Should we not first develop a theory of how human beings can know before we tell them how they ought to proceed in the pursuit of knowledge? In other words should not epistemology be prior to methodology? If we adopt this stance then the apparent failure of methodology does not come as a surprise. It rather appears as a necessary consequence of a premature attempt to master a subject without doing one's homework first.

Why, then, are philosophers conflating epistemology with methodology? Why are they reluctant to take scientific findings into account when inquiring into the nature of knowledge? Why do they instead still rely on their intuitions of what does or does not constitute an acceptable theory of knowledge? I think that we can find the answer to this puzzle if we consider the apparent circularity which would obtain once we decide to use scientific criteria to evaluate our theory of knowledge. For, after all, it is the theory of knowledge itself which should provide science with such criteria. This circularity brings to the open a paradoxical feature in the relationship between science and epistemology. On the one hand we do need a powerful science in order to create a theory of knowledge sophisticated enough to deal with the complex issues of human nature. On the other hand it is the task of epistemology to criticize scientific procedures and evaluate whether or not they are sound. In other words, a successful science seems to presuppose a powerful epistemology which in turn presupposes a highly developed science.

The standard solution to this circularity is to deny that it exists in the first place. This is accomplished by giving a different status to both science and epistemology. Epistemology is thought to be prior to science. Once, we demarcate epistemology from science the question arises: how do we justify our epistemology?

In a more religious age it was thought that God, who created the world, had also endowed man with the necessary powers for understanding that world. If man relied entirely on those powers without permitting himself to be distracted, he was on the road to pure knowledge. In other words, God himself was the guarantor for man's claim to knowledge. In our own secular age the appeal to God's veracity is no longer accepted as a justification of man's claim to knowledge.

What kind of justification is left once we deny that either scientific knowledge or God's benevolence support our knowledge claims? Karl Popper provides us with a straightforward answer. Asked how he himself justifies his method of trial and error he replies: "The method of trial and error is a method of eliminating false theories by observation statements, and the justification for this is <u>the purely logical relationship</u> of deducibility which allows us to assert the falsity of universal statements if we accept the truth of singular ones."(Popper(1963)56,my italics).

Once we give up the belief that an external source (i.e. God) warrants the reliability of our knowledge, we are thrown back upon our human resources. These are further dramatically narrowed down if we also want to avoid the above mentioned circularity between science and epistemology. If we believe that this circle is vicious we will not allow science to help us in deciding whether or not our knowledge claims are justified. What remains is logic which is taken to be prior to and independent of science. Therefore, it is to logic that Popperians and modern empiricists alike turn as the ultimate authority which is to justify their epistemological claims. Logic, however, provides us only with rules of reasoning. Thus, epistemology becomes methodology which furnishes us with normative rules. Those rules, however, are applicable only to science, not to epistemology itself. For, if they were used to assess one's own methodology one would risk undermining the very foundation upon which their authority rests, i.e. the alleged absoluteness of logical rules. Thus, neither empiricists nor Popperians are willing to apply their own methodological prescriptions in order to assess the soundness of that very methodology. Therefore, we see that empiricists tend to be rather ahistorical and do not study the history of science in order to "induce" which kind of scientific strategy has been successful. Neither do Popperians attempt to falsify their own methodology or state under which circumstances they would be willing to give it up. On the contrary, they are eagerly looking for verifying historical instances, thus seemingly contradicting their own prescription. This noncritical attitude towards their own methodological prescription becomes intelligible once we see that it is based upon the view that epistemology equals methodology which equals logic which is immune to criticism.

Thus, neither examples taken from the history of science nor actual scientific practice can shake the belief of the methodologist in the appropriateness of his normative rules. The relationship between epistemology and science is strictly one way. Epistemology develops normative rules which tell the scientist how to proceed. Failure to accomplish anything by means of the proposed method does not reflect the inadequacy of that method but the inadequacy of the scientist. This one-way relationship is strikingly demonstrated by Popper's <u>principle of transference</u>: "What is true in logic is true in scientific method and in the history of science"(Popper(1972)6), and "what holds in logic must hold in genetics or in psychology"(Popper(1972)68).

The subjects Popper mentions have in common that they make epistemic claims. Epistemology, however, is identified with logic. Given those premises it follows that the logician has precedence over the psychologist, geneticist, and historian in so far as those scientists make cognitive claims. Any field of scientific investigation which attempts to understand processes of learning thus becomes merely an application of logic which is immune to empirical criticism. We are led to the sad conclusion that whereas any other area of human knowledge can be improved by empirical investigation and critical discussion, the epistemologist sits lonesome in his armchair, trying to find <u>the</u> correct logical system relying entirely on his own intuition without the benefit of interaction with other sciences.

1.3. THE METAPHYSICAL PRESUPPOSITIONS OF METHODOLOGY

Once we narrow down epistemology to logic we make it impossible for the philosopher to learn from his or other people's experience. Yet, do we really have to accept the idea that with logic we have reached the rock bottom of certainty and that there remain no further questions to be asked? Does not any alleged method assume that the structure of the world is such that the method can work, and that the nature of human beings is such that they are – at least in principle – capable of following that method? Even if we accept the argument that we cannot derive norms from facts, it nevertheless remains the case that the norms have to be compatible with the facts. A methodology, say, which would presuppose that we can read other people's thoughts would obviously be uninteresting given the actual capacities of human beings. Historians of science have been emphasizing the fact that neither empiricist nor Popperian methodologies describe what scientists actually do. This, of course, cannot falsify the alleged methodologies. Their defendants can always point out that they are dealing with normative issues whereas history is a purely descriptive enterprise. Nevertheless, a methodology which has no bearing on science as it actually has been practiced is hardly satisfactory. The history of science, therefore, plays an important role in the assessment of methodology by pointing out that a method which has never been applied by practicing scientists appears to be obsolete.

This criticism is doubtlessly very important. However, in the present context my argument is directed at a different target. Indeed, I am not interested in critizising any particular methodology at all. Rather, I intend to show that any method which conceives of logic as providing ultimate foundations for methodology is mistaken. Thus, my discussion of some feature's of Popper's thought is meant to exemplify this point rather than provide a comprehensive criticism of his philosophy.

Let me now return to my central point which is that any methodology carries with it certain presuppositions concerning the nature of the world and of human beings. In former times this was clearly acknowledged, and it was thought that the world was a rational construction of God. Man could come to know its rational blueprint in virtue of god's benevolence. Clearly this kind of justification will not do anymore. Thus, the question arises concerning the kind of non-acknowledged presuppositions in our present-day methodologies. I will again turn to Popper's epistemology and ask: how would the world have to be in order for his method of conjectures and refutations to work?

Central to the understanding of this issue is Popper's notion of truth which plays as important a role in his methodology as it does in the standard empiricist account. This is not to say that there are no important differences between these approaches. But those differences show up only with respect to the question whether or not we can actually ever come to express true facts about the world. Popper doubts that we can ever come to know true theories and points out that even if we did we would never know that we have attained our goal. Nevertheless this does not minimize for him the importance of truth as the ultimate goal for science to which all other goals have to be subjected: "We do not only look for biological or instrumental success. In science we search for truth"(Popper(1972)69,Popper's italics).

It is clear that the idea that we can come to know the truth about the world or that we at least are progressively approaching it - has a strong intuitive appeal. For - after all - what else can explain the remarkable success of modern science? Yet, it is by far not obvious whether or not the notion of truth is indeed useful for the conceptualization of scientific progress. What does it mean for Popper 'to get nearer to the truth? According to Popper "science aims at truth in the sense of correspondence to the facts or to reality"(Popper(1972)59). Thus,"we can explain the method of science and much of the history of science as the rational procedure for getting nearer to the truth"(Popper(1972)58). We can never know for certain if a statement or theory is true. It is, however, possible to establish the falsity of a statement or theory. This is the case because according to the laws of logic it is true that a false consequence of a statement proves that the statement is false (modus tollens). A true consequence of a statement, however, does not show that the premise in question is true, because true consequences can follow from false premises. Therefore, science should aim at finding contradictions which will make it possible to eliminate false premises.

All meaningful scientific statements will be either true or false. "Every statement has a content or consequence class. And every content contains a sub-content consisting of the class of all and only all its true consequences"(Popper(1972)47). By applying modus tollens we eliminate some of those false statements and thereby indirectly increase the percentage of true statements and their true consequences. We thereby increase the truth content of science. Thus,"we can identify the intuitive idea of approximation to the truth with that of high truth content, and low falsity content"(Popper(1972)52).

Every scientific (i.e. testable) theory will have deductive relations enabling inferences from observation statements. These inferences constitute the predictions of the theory. If we can demonstrate that a prediction turns out to be false we can conclude by applying modus tollens that the theory in question is false and ought therefore to be abandoned.

So much for a brief summary of Popper's concept of truth and its relationship to his epistemology. I shall now turn to a constructive criticism of his method.

Let us assume that we live in a universe where many levels of reality obtain, none of which is reducible to any other (nuclear, atomic, molecular, cellular, could be taken as examples for various levels). Let us further assume that those levels although generally distinct are only approximately independent. One may say that they overlap in certain frequencies and are only nearly decomposable, to use a term due to Simon (Simon(1973)25). Let us design an experiment to test a prediction P of theory T. This prediction is negative, i.e. it says that under certain conditions a particular kind of property does not obtain; for example, current flow should cease. (Nothing in the argument hinges on the prediction being negative. This is merely a means of avoiding to assign particular numerical values.) We perform the experiment and the outcome is non-negative, current does flow, i.e. we find not-P. Applying <u>modus tollens</u> according to Popper we conclude not-T and abandon the theory under consideration. What we would not have taken into account is the possibility that a different level of reality might have interfered with our experiment, i.e. we were inadvertantly addressing a different level of whose existence we were ignorant. To give a practical example, we might intend to measure electrical properties of chemical reactions but were dealing with a radioactive element which produces a flow of electrons not due to any chemical reaction.

If we take a reductionist stance we will hold that chemical reactions ought to be reducible to the interactions among the ultimate entities of matter (whatever they may turn out to be), and that therefore theory T ought to be abandoned anyway. (This would hardly be a practical or sensible procedure, but in the present context I follow Popper and concentrate entirely on the logic of the situation). If, however, the universe is of a different kind, and chemical reactions cannot be accounted for in terms of the properties of ultimate particles, then in abandoning T we could be abandoning a theory which is true. A different way of making the same point is by asserting that each level of reality constitutes a universe of discourse and alleged theories hold only for their respective universe. Reductionism would have to claim that the various universes stand in an inclusion relation; therefore <u>modus tollens</u> could be applied and would indeed point out false theories. If, however, the various universes of discourse are not deductively connected then <u>modus tollens</u> can only be applied within each individual universe of discourse. We do not know, however, how many levels of reality actually exist. Thus, we never know whether in testing an observation statement we are really addressing the theory we intend to test. If, for example, we live in a universe of processes which occasionally interfere, then we can never know for sure that we are actually tuning into the process we intend to investigate. There remains always the possibility that we are addressing inadvertantly a different process whose existence we are unaware of. It is like tuning a shortwave radio to Radio Free Europe and inadvertantly finding ourselves listening to Radio Moscow. To conclude from this that the Americans have turned communist seems to be premature, to say the least.

We see that whether or not Popper's methodology can work depends on the structure of the universe. This, however, we cannot know a priori. In fact, that is something science tries to find out. It is therefore not rational to follow Popper's methodology.

It may come as a surprise that Popper, the avowed pluralist seems to be committed to a reductionist metaphysics. Poppers pluralism, however, is of a different kind than the pluralism I envisaged. His ontology is basically an old fashioned triad of physical, mental, and ideal entities which are not reducible to each other. With respect to the physical, however, Popper like Descartes knows only of a one-level reality. It is interesting that in this respect Popper can also shake hands with the logical positivists who also - according to Bergmann - believed in one-level physical worlds (Bergmann(1954)IX).

I will give good reasons in the third chapter why we should believe in a many-levelled physical reality based upon a process metaphysics. For the purpose of the present discussion, however, it is, of course, irrelevant whether or not we find the conception of a non-reductionist metaphysics appealing or absurd, intuitive or far-fetched. What does count is that there are metaphysical presuppositions to be found in our methodological constructions and that therefore the view is untenable that with logic we have reached the bedrock of knowledge. It will simply not do to point to modus tollens or to some system of inductive logic and claim that any further epistemological problems are thereby eliminated.

The logical positivists and empiricists have tried to eliminate metaphysics from the realm of meaningful discourse, Popperians are more liberal in that they recognize that our theories are not directly "induced" from experience but are rather inventions of our own making. Being inventions they might come from any area of human interest, including myth and metaphysics. Yet the role of metaphysics is much more substantial than assumed by the Popperians. What I have tried to show is that empiricist and Popperian methodologies alike share metaphysical presuppositions whether they like it or not. This point is, of course, not new. It was also made by Bergmann who presents a careful analysis of the metaphysics of logical positivism (Bergmann(1954)). The claim that we cannot help but employ metaphysical presuppositions was made most forcefully by the late E.A.Burtt who writes:

> There is no escape from metaphysics, that is, from the final implications of any proposition or set of propositions. The only way to avoid becoming a metaphysician is to say nothing......If you cannot

> avoid metaphysics, what kind of metaphysics are you likely to cherish when you sturdily suppose yourself to be free from the abomination? Of course it goes without saying that in this case your metaphysics will be held uncritically because it is unconscious; moreover, it will be passed on to others far more readily than your other notions inasmuch as it will be propagated by insinuation rather than by direct argument (Burtt(1932)227,229).

1.4. HOW TO CONSTRUCT A NEW METAPHYSICS

Once we accept that we cannot do epistemology without employing metaphysical presuppositions, we can turn this seeming impediment into an advantage. We can construct a new metaphysics and build those features into it which we deem to be essential in order that knowledge becomes possible. I will argue in chapter three that the great epistemological issues we have been facing during the past three hundred years have arisen because of the reductionist metaphysics inherent in western science since Galileo. But why should we just want to stick to old metaphysical presuppositions if they turn out to lead to problematic consequences? We do not know the ultimate structure of the universe. Therefore, we can choose a different metaphysics, one which may enable us to pose new questions, and we can try to find the answers to these questions.

The proposal that we should construct our metaphysical presuppositions rather than fall prey to them does not mean, of course, that the selection of a metaphysics is arbitrary. Rather we should use all the possible care as if we were dealing with ultimate truth, for - after all - we could hit upon the correct structure of the universe. It is particularly important to choose a metaphysics which fits smoothly with the relevant sciences, i.e. relevant for the purpose of doing epistemology. The old reductionist metaphysics is based upon the primacy of classical physics. An alternative metaphysics should - I want to suggest - take the role of human beings qua biological and cultural organisms into account. It has to be possible for such beings to have knowledge about the world. In other words, I am suggesting that we should replace the old question of 'how can we know the world' by the new question 'how can the world be such that we can know it'.

There seems to be an obvious problem with the kind of metaphysical constructivism I am suggesting. The problem is the circularity about which I talked briefly above. Does not the approach I propose beg the epistemological question by presupposing what it means to prove ? In other words, if we construct our metaphysics in such a way that it presupposes a certain vision of human beings and their relationship to the environing world, then it will obviously be impossible to challenge those assumptions from within the resulting epistemology. But this, of course, is true for any metaphysics. This circularity cannot be avoided for the simple reason that the theory of knowledge itself professes to be knowledge.

Yet, there is no reason for assuming that we are dealing here with a vicious circle. For any epistemology can be assessed and evaluated according to criteria of performance. If a new philosophy provides us with new insights into the nature of knowledge and improves our understanding of the history of science then it has proven its value. If it also can serve as a guide to action, then, indeed, it fulfills the highest standards one can expect from any philosophy.

The founders of modern science and philosophy, men like Galileo, Descartes, and Newton also had avision of human beings and their intellectual capacities. When they constructed the framework for modern science, they built into it presuppositions which were perfecty reasonable for their times. During the 17th and 18th century, however, the science of classical physics reigned supreme, and the view of the clockwork universe became paradigmatic for future generations. It has been only during the past one-hundred years that the life sciences have made considerable progress. Yet, our view of the universe is still impregnated with the old metaphysical presuppositions.

In the third chapter I will look in some detail at those views of man and nature which are implicit in the mechanistic world view which was born during the scientific revolution of the 17th century. For the present purpose it is sufficient to note that in classical physics there is no place for the observer and his properties. Classical physics presents us with an objective picture of the world which is seen as a world without perceivers and actors. This results in deep epistemological puzzles. As scientific knowledge is always knowledge of objects entertained by subjects the question arises: what justifies the elimination of the properties of the observer? How can we bridge the gap between his perceptions which are subjective and the external world which is thought to be objective, but about which we can have knowledge only through our subjective faculties?

The epistemology I will be developing in this thesis rejects subject-independent "objective" knowledge. This, however, does not mean that knowledge becomes merely subjective, unreliable, and biased. It rather means that the categories "subjective" and "objective" cease to be applicable once we reject the metaphysical framework which arose with the birth of classical physics. Once the properties of the observer are built into our metaphysical framework, processes like perception, development, and evolution will become central for our epistemology as they have not been hitherto.

1.5. POPPERS'S PSEUDO EVOLUTIONARY EPISTEMOLOGY

One may hold that the increasing number of 'evolutionary epistemologies' shows that my claims are false and that biological concepts have already penetrated our contemporary philosophies. However, a closer look reveals that those epistemologies turn out to be not that evolutionary after all; that the alleged similarity holds only on a rather superficial level. In order to substantiate this claim let me take a closer look at Popper's evolutionary epistemology.

We have seen above that Popper makes it very clear that his method of trial and error is a logical method and that according to his 'principle of transference' it ought to be carried over into psychology, biology or even into the history of science. Thus, it can hardly be maintained that biological ideas were incorporated into Popper's epistemology. Are there other similarities between biological and scientific evolution? Let us hear what Popper has to say about this:

> The evolutionary tree grows up from a common stem into more and more branches. It is like a family tree: the common stem is formed by our common unicellular ancestors, the ancestors of all organisms. The branches represent later developments, many of which have, to use Spencer's terminology, 'differentiated' into highly specialized forms....
>
> The evolutionary tree of our tools and instruments looks very similar. It started presumably with a stone and a stick; yet under the influence of more and more specialized problems it has branched into a vast number of highly specialized forms.
>
> But if we now compare these growing evolutionary trees with the structure of our growing knowledge, then we find that the growing tree of human knowledge has an utterly different structure. Admittedly, the growth of applied knowledge is very similar to the growth of tools and other instruments: there are always more and more different and specialized applications. But pure knowledge (or 'fundamental research' as it is sometimes called) grows in a very different way. It grows almost in the opposite direction to this increasing specialization and differentiation.
>
> When we spoke of the tree of evolution we assumed, of course, that the direction of time points upwards-the way the tree grows. Assuming the same upward direction of time, we should have to represent the tree of knowledge as springing from countless roots which grow up into the air rather than down, and which ultimately, high up, tend to unite into one common stem. In other words, the evolutionary structure of the growth of pure knowledge is almost the opposite of that of the evolutionary tree of living organisms, or of human implements, or of applied knowledge.

> This integrative growth of the tree of pure knowledge....is the result of our peculiar aim in our pursuit of pure knowledge.....
>
> our aim of getting nearer to the truth explains the integrative growth of the tree of knowledge.
>
> In pointing out the difference between the evolutionary tree of instruments and that of pure knowledge I hope to offer, incidentally, something like a refutation of the now so fashionable view that human knowledge can only be understood as an instrument in our struggle for survival.....If our problem is a purely theoretical one - one of finding a purely theoretical explanation - then the criticism will be regulated by the idea of truth, rather than the idea of helping us to survive (Popper(1972)262-4,my italics).

There is a half-hearted, almost contradictory flavor to Popper's 'evolutionary epistemology'. On the one hand he emphasizes the universality of *the* evolutionary method which is the method of trial and error, of conjectures and refutations: "The fundamental procedure of the growth of knowledge remains that of conjectures and refutations, of the elimination of unfit explanations....Einstein may err, precisely as the amoeba may err"(Popper(1972)264-5). On the other hand Popper does stress that the evolution of *pure* knowledge differs fundamentally from the evolution of applied knowledge and of biological evolution. Pure knowledge is directed towards unification, other kinds of knowledge lead to diversification. Progress in science, however, means for Popper - as we have seen above - progress towards *the* truth,i.e. progress is identified with theoretical progress. In other words, precisely in that area of the growth of knowledge which Popper considers most fundamental for scientific progress evolution shows just the opposite pattern as - according to

Popper - we would have to expect if we were to take the evolutionary metaphor seriously.

Popper's so-called 'evolutionary epistemology' owes no debt to the findings of biology or any other life sciences. We have seen above that he conflates epistemology with methodology and methodology with logic. The method of trial and error is, in his own words, a logical method. Popper applied the evolutionary label much later, as is evident from Die Logik der Forschung which already contains all his later views without calling them evolutionary. (There are other important ideas which he developed in later works, for example the concept of verisimilitude and the three worlds ontology, but those ideas are of no interest for the present discussion.) Thus, Popper's emphasis on evolution appears to be a political move by which he may hope to make his methodology more attractive to all those philosophers and scientists who think that it is time for philosophers to take biological concepts more seriously.

1.6. HOW TO CONSTRUCT A NEW EVOLUTIONARY EPISTEMOLOGY

The evolutionary epistemology I will be developing in this thesis turns the standard approach on its head. I will have to say very little about 'the evolutionary method' - if there is such a thing - but will rather concentrate on the evolution of the perceptual and conceptual capacities of living organisms in biological evolution and the continuation of this process in human cultural evolution culminating in the evolution of modern science.

Let me begin by showing that - contrary to Popper - biological evolution is not only distinguished by increasing diversity but shows equally dramatical, <u>integrative</u> tendencies. Those tendencies are strikingly demonstrated by the development of the central nervous system:

> When we consider the lower animals particularly those in which there is little or no development of the CNS (animals such as flatworms, sea anemones, and star fishes) we often get the strong impression that the animal is only in a very loose and elementary sense an integrated organism. If we agree that in a great many of the lower animals 'mind' must be multiple, it appears that one of the most striking features of the progressiveness of the evolution is the way in which it has led to a very slow and gradual integration of all the centres of mental activity into a single one (Thorpe(1968)94).

Be it in phylogeny or ontogeny, in biological or in cultural evolution, integrative processes play a central role. There is no substantial difference between biological and scientific evolution in this respect. Diversification and integration appear as but two sides of the same coin. The increasing capacity of the central nervous system enables highly evolved organisms to adapt to heterogeneous environments. In this process the organisms shape and transform the world creating new niches for themselves which in turn enable other species to diversify and to evolve.

The increasing integration of modern science, too, has resulted in the construction of more powerful scientific theories which enable human beings to explore new ways of living. It has been said often enough and needs no special emphasis that science not only tells us something about the world but also transforms it. Be it in biology or in science, integration, diversification and ecological transformation are intimately interconnected processes, requiring a common and unified evolutionary explanation.

It may be said that the kind of integration Popper talks about and the kind I envisage are very different indeed. Popper talks about a reductionist integration of scientific theories (as an example he mentions the reduction of Kepler's to Newton's theory(Popper(1972)262)), whereas I talk about the integration of various intellectual capacities. But, of course, this difference in the meaning of 'integration' merely reflects the underlying difference in the metaphysical outlook. Popper lets the evolutionary tree grow upside down because he wants to insist that progress in science is to be identified with progress towards the truth. There seems to be no equivalent to this notion in biological evolution, and therefore Popper's evolutionary epistemology turns out not to be that evolutionary after all. For Popper, truth is the ultimate - though perhaps unattainable - goal. In evolution, however, there can be no ultimate and absolute goals for the simple reason that the evolution itself always changes the rules of the game with the consequence that what appears as a desirable goal today, may turn out to be a mere obstacle within a different future context.

I suggest that if we want to create a new, genuine evolutionary epistemology, where all trees grow in the same direction then we have to take the capacity of living things into account; the capacity to interact with their environment and through this interaction learn about and transform it.

It may be objected against my approach that the concepts of 'capacity' and 'improvement of our capacities' are rather vague, not suitable for careful philosophical analysis. At this stage of the discussion this is indeed the case. Yet, it is precisely the goal of this thesis to scrutinize and elaborate on these concepts. It is hoped that every chapter will contribute to the needed conceptual clarification, and that by the end of the dissertation I will have demonstrated that the notion of 'capacity' is not so vague after all. To present a full fledged definition at such an early stage would be premature and would raise more problems than it would solve.

1.7. THE PROGRAM:
A JOINT CONSTRUCTION OF EPISTEMOLOGY AND METAPHYSICS

Let me now recapitulate the main thrust of the arguments presented in this chapter and indicate the further direction into which they will lead us.

In the traditional approach progress in science is considered to be progress towards one desirable goal, i.e. the truth. Philosophers of science have been trying for the past three hundred years to understand this process and provide scientists with normative rules to guide them in their endeavors. In this task philosophers have been as unsuccessful as scientists have been successful in theirs. This strange dichotomy is in need of an explanation. It appears that scientists have been doing something right and that philosophers have perhaps been altogether wrong in their assessment of what scientists are doing right.

I suggest that what may be at fault are the underlying metaphysical presuppositions employed in methodology. In other words, what I am suggesting is that the nature of the world may be such that if scientists were to follow the standard methodological prescriptions, they would necessarily fail. The idea that metaphysics may be of crucial importance for methodology may appear strange, yet it is quite clear that any proposed method carries with itself presuppositions concerning the nature of the world and the nature of the observer. Any proposed methodology assumes that the structure of the world is such that the method can work and that the nature of human beings is such that they are - at least in principle - capable of following the methdological prescription.

Such presuppositions should not simply be taken for granted but should be brought to the open, scrutinized, and abandoned if found wanting. This I will do in chapter three. There I will discuss the almost universally accepted metaphysics of reductionistic atomism and will argue that our current epistemological problems can be seen as a direct result of the uncritical acceptance of that worldview.

Therefore it becomes a crucial task to develop a new metaphysical framework which does not lead to deep epistemological problems. In the construction of this framework I will be guided by the idea that we should replace the old epistemological question 'how can we know the world' by the new question 'how can the world be such that we can know it'. I will argue that such a universe must be a universe with observers, in particular it must be a universe where observers can change their own characteristics, i.e. where they can improve their knowledge. In such a universe evolution must be possible. This appears to be a reasonable demand if we consider that human beings, including their perceptual capabilities are a result of evolution. Further, the evolution of knowledge and of culture can be seen as a continuation of the evolutionary process, though on a linguistic instead of a genetic basis. Seeing evolution as a necessary prerequisite of human knowledge I will construct a process metaphysics within which evolution becomes possible. This construction will be based on non-equilibrium thermodynamics, in particular Prigogine's work on dissipative structures.

After having developed some understanding of what kind of systems can undergo evolutionary changes we can use that model for the conceptualization of scientific knowledge. This I will do in chapters four and five.

What is still missing in this dissertation is the development of a comprehensive case study in the history of science which could demonstrate that the proposed model is not only of theoretical interest but has also practical applicability. Because of time limitations this has not been undertaken in this thesis. For the same reasons I also do not discuss alternative models of scientific progress which have been proposed by other members of the philosophical community. A comparison between their ideas of scientific development and those put forward in this dissertation remains a *desideratum*.

In the model I will be developing, progress in science becomes progress in our intellectual capacities to apprehend the world. This view is just the opposite of the standard approach where the human sensory and conceptual capabilities are belittled because they do not show us the world as it *really* is.

The question arises whether or not it makes sense to speak of *one* reality out there, waiting to be comprehended, and whether we should view ourselves as separated from this reality, incapable of seeing it directly, whether we should visualize ourselves as being caught in a dimly lit cave, needing a guide (i.e. a proper method) to lead us out of our perceptual and conceptual limitations towards one immutable and timeless truth.

In a truly evolutionary view this ideal of knowledge becomes untenable. We do not know *in spite* of our imperfect organs of sensation and conceptualization but *because* of them. If it is true - and I think it is - that our sensory organs color what they transmit, that any perception involves interpretation, that we can view the world only through the lenses provided by our conceptual categories, then that means on the present view that the nature of the world is such that without the structures imposed on it by perception and conception no meaningful patterns or regularities could possibly emerge.

Is it possible to visualize such a world? In order to spark the reader's imagination let me present a metaphor; We all are familiar with the occasional interferences of various radio signals when we attempt to listen to one specific station. Imagine a particularly poor receiver which conflates not only neighbouring frequencies, but even those that are far apart. Clearly such a radio would be useless and we would prefer one which can receive merely one particular wavelength, but that one clearly, to one that receives many but conflates all of them. We can, however, improve our simple radio by developing the technology to tease the various signals apart. By improving the internal design of the radio receiver we can achieve an ever finer tuning into many frequencies.

Our perceptual organs can be compared to such a "simple" radio. They receive only a small spectrum of the frequencies which surround us. But if they could receive all of them and were to conflate them and see the world às it is', this world would be unknowable. By improving the design of the observer he can increase his access to the frequencies in an orderly manner. I will argue that this is what happens in science, and I will therefore discuss in the next chapter science as an extension of perception.

In other words I conceive the world as being a rather messy entity. Changes occur at the levels of the elementaryparticles, atoms, molecules, phenotypes, families, societies, planets, stars, and galaxies, and those changes occur <u>all at once</u>. If we are to have knowledge in such a universe, we have to learn how to tease the various frequencies apart. This is what the human species has been learning during its perceptual and conceptual evolution. By improving the internal design of the observer (i.e. developing increasingly sophisticated conceptual frameworks), more and more realms of reality have become accessible to him.

To envisage scientific progress as progress in our intellectual capabilities to apprehend the world, brings scientific knowledge rather close to practical knowledge. In the latter type of knowledge it is clearly the case that to progress means to increase one's capacity to act in a meaningful well coordinated manner.

I will therefore begin the next chapter with a discussion of practical knowledge and thereafter raise the question of what it is that distinguishes practical from theoretical knowledge.

CHAPTER II

SCIENTIFIC KNOWLEDGE AS AN EXTENSION OF PERCEPTION

2.1. THE DISTINCTION BETWEEN PRACTICAL AND THEORETICAL KNOWLEDGE

Every adult human being possesses practical knowledge, though to a greater or lesser degree. It is the knowledge we need in order to unlock a door, cook a meal, drive a car. This type of knowledge finds its best exemplifications in the various skills practiced by craftsmen and artists. It is important not only for our everyday life but provides also the foundation for other, more theoretical forms of knowledge. Without skilful instrument makers no measurement could be taken, no telescope could be built, and no modern chemical laboratory could function without the art of the glass blower.

In practical knowledge the artisan directly interacts with the object upon which she operates and which she transforms. She sets to her task with a certain idea in mind, a plan which she attempts to translate into the material at her disposal.

The knowledge required for the successful performance of a craft is knowledge of <u>how to do</u> something. This does not mean that theoretical knowledge will be of no use. On the contrary, knowledge of the physical properties of materials or of newly developed techniques is of great importance. But this theoretical knowledge only becomes relevant for the craftsman if it can be integrated into the actual procedures employed in the performance of a craft. For example, a glass blower may order a newly developed type of glass which he thinks suitable for special demands in the laboratory for which he works. Only if he is skilful enough to bend that new and unknown material to his plans, only if he succeeds in transforming it into a functional apparatus will his theoretical knowledge have any actual significance with respect to the practice of his craft.

In order to acquire a certain skill we have to learn how to coordinate our physical and mental capabilities in such a way that we can perform a task successfully. Practical knowledge is certain and indubitable in the sense that there are set public criteria which specify when a person can be said to have mastered a certain skill. Aside from this public aspect, it has also a highly personal aspect, because practical knowledge is not about the external world, in fact, it is not about anything at all. Rather it is embodied in our own activities.

The coordination of our various faculties into a smoothly running goal-directed activity is fundamentally a personal experience which, if well performed brings with itself a highly satisfying experience.

When we attempt to improve our practical knowledge we do it through exercising the respective skill, and, due to the personal aspect of practical knowledge, we usually can ascertain very well ourselves whether or not we have made progress. Thus, after having practiced a skill for a long time, say skiing down a steep mountain slope, we will know whether or not we have done well. We notice ourselves the better coordination of our movements resulting in a smooth and ideally effortless harnessing of gravity. Once our personal judgement is supplemented by a positive assessment of a qualified external observer, we can be sure that we have reached a certain level of proficiency in the skill or craft we are attempting to master. The existence of both -public and -personal criteria ensures that we will never be in actual doubt as to whether we have mastered a particular skill or craft.

There is thus no 'problem of knowledge' with respect to practical knowledge. The immediacy of the private experience combined with the comparative ease by which public criteria of progress can be established, make it appear enviably unproblematic compared to theoretical knowledge.

Nevertheless both kinds of knowledge are common to all normal adult human beings. In the performance of practical, as well as in the search for theoretical, knowledge we make use of our various organs of sensation and also of language.

We have seen that practical knowledge is acquired through the appropriate coordination of various human faculties. The question therefore arises whether we can account for theoretical knowledge as well by inquiring into the organization of our human resources. Before we can do so, however, it is important to pinpoint the central difference in both kinds of knowledge.

Theoretical knowledge is linguistically formulated and is knowledge of objects. The goal of theoretical knowledge is to find the various properties of and relationships between objects. In practical knowledge, the role of objects is, however, very different. Here objects are known in a very personal way. They pose resistance to our activities, thereby indicating the success or failure of our operations. The craftsman may create new objects or may use objects in the performance of his craft. Thus objects serve either as a means for achieving a certain end or they are the end themselves. If we assume that our mental and physical faculties are coordinated in such a way that they can best achieve their respective goals , then we have to conclude that in the case of a craft, our various human resources are coordinated in such a way as to enable us to create or improve objects. In theoretical knowledge, however, those very same faculties must be coordinated in a different way. There we want to find out the properties objects have qua being objects and we do want to eliminate those properties which are contingent on the observer, that is, we are searching for those facets of the external world which are invariant with respect to the operations we perform with and on them. Put another way, the created object carries inevitably with itself the imprint of its maker; the object which is of cognitive interest, however, must appear to be neutral with respect to the various manipulations it undergoes in the process of analysis. If we want to understand how our various human capabilities are organized in theoretical knowledge we have to begin by asking how it is possible that we conceive of invariant objects in the first place.

2.2. THE CONSTRUCTIVE NATURE OF PERCEPTION

The fact that we see objects located in space is, indeed, most astonishing. The great physicist Helmholtz had already pointed out in the 19th century that sensory activity starts at the surface of our body, yet we experience 'things out there'.(1) For the optical images in the eye are nothing but patterns of light. The retinal images consist of light and dark shapes and areas of color which the brain has to interpret in terms of the received retinal patterns. It is as a result of this interpretation that we see objects located in space. Gregory emphasizes the interrelationship between eyes and brain by calling our eyes "intelligent eyes", i.e. organs of sensation which are connected to the central nervous system in such a way that they can utilize the constructive power of the mammalian brain. Thus the retinal patterns are synthesized by <u>us</u> into objects (Gregory(1970)). That, of course, by itself, does not imply that there are no external objects. It only means that the received sensory information is not sufficient to give us direct and non-ambiguous experience of three dimensional entities. Our propensity to interpret received sensory information in terms of objects becomes particularly evident in cases where there really are no external objects, but we perceive them nevertheless. Indeed, it is very difficult for us not to construct objects out of sensory data. We "see" faces in the clouds and project our object hypotheses onto virtually everything, a fact used by psychologists in various tests. Thus people who are subjected to these tests (for example, the Rohrschacht test) will tend to see different objects when confronted with amorphous shapes. The object hypotheses selected by these persons will then indicate certain beliefs they hold. Thus it has been shown that our beliefs and perceptions are interrelated.

> Since perception is a matter of reading non-sensed characteristics of objects from available sensory data, it is difficult to hold that our perceptual beliefs - our basic knowledge of objects - is free of theoretical contamination. We not only believe what we see: To some extent we see what we believe (Gregory(1970)15).

What are the epistemological implications of the theory ladenness of perception? Do we have to forfeit the hope that genuine knowledge is possible because what we see is not simply the world 'as it is'?

I do not think that such a sceptical conclusion should be drawn from the existence of perceptual biases. For, after all, what could it mean to see the world as it 'really' is? There is no absolute stability in this universe. Things which appear stable to us, for example chairs and tables and rocks, are only stable within a particular time frame. If our lifespan were much longer, and our perceptions accordingly slower none of these objects would appear stable at all. On the other hand, if we could perceive the chaotic movements of molecules then again there would appear to be no stability in the world. If the sense of smell were as important to us as the sense of sight we would emphasize different features of this everchanging world, and again if we could "see" the world with the radar system of a bat, doubtlessly different stabilities would appear to be 'obvious'. The world is too rich to be captured in its entirety by any one creature. Everything is in constant flux, thus stability cannot be anything absolute but is always relative to the dimension of time and to the sensory equipment of the organism. It is clear that among all those changes some are of the utmost importance to us, whereas others are too fast (e.g. the movements of the atoms), or too slow (e.g. most geological changes) to have any immediate importance for the central evolutionary problem: how to survive in that ever changing world. The problem thus arises for our perceptual system of how to filter all this potentially available information and sort it with respect to the need of the organism.

The available information is most dramatically delimited by the physiological structure of the eye itself. Our visual sense allows us only to pick out a very small range of frequencies; we cannot 'see' microwaves or long waves, radar or x-rays. Our eyes are sensitive only to a narrow region of the total electromagnetic spectrum. Within that small region different wavelengths give different colors which together form what we call 'light'.

Because of these physiological limitations most of the changes occurring in the universe are forever inaccessible to naked-eye observation. Even those changes which are accessible to our visual sense and which produce changing patches of color on the retina are highly ambiguous. This raw material must be processed before it can yield useful information.

The most important problem our perceptual system has to solve is to distinguish between genuine changes which may or may not be causally connected to us and apparent changes which are internal to the observer and do not depict genuine change at all. For example, we close our eyes and the world disappears for us, but, of course, it does not really disappear. We turn our head and immediately the world appears to be different. Here again the occurred change tells us only something about ourselves but not about the world. What we need to learn is to distinguish the properties of the observer from those of the observed, or, to say it more precisely: as a first step on our road to knowledge we have to establish the identity of the observer and demarcate him from the rest of the world.

For the adult human there seems to be no problem. We simply know that the world does not change, just because we close our eyes or turn our head. Yet, this knowledge is not simply given, but learned in early childhood. Occasionally, like in cases of drunkenness or in certain diseases (for example, Meniere's disease) the constructive power of our perceptual system becomes manifest even in adults. In those cases these constructions break down and the world seems to spin when we turn our head; this results in a complete disorientation.

Piaget has shown in beautifully designed experiments how the young child learns to distinguish between changes dependent and those independent of her own perceptual activity. In order to arrive at the concept of an object independent to her she has to learn to coordinate her sensimotor experiences with the visual patterns in the eyes. Out of the chaos of fleeting, ever-changing impressions, she will learn to demarcate objects which are precisely those entities which remain invariant with respect to her own perceptual activities. The concept of a permanent object is not given a priori but a result of a learning process within which the child constructs parallel to the notion of her own self also the notion of 'things' outside herself.

Yet, to have acquired the concept of an object is by itself not enough to give us a trustworthy account of external changes. In order to account for these we have to assume a stable framework against which we can measure change. The most fundamental framework of this kind is the 'event space',i.e. our space-time framework. Within it we organize our experiences, order them in their spatial and temporal relationships. To know whether an object is right or left, in front or behind us, whether an event occurs before or after another event is of central importance if we are to survive in that ever-changing world of ours.

It was the profound insight of Kant to realize that if we want to account for any change at all, we have to place it within a spatial and temporal context. Yet contra Kant, it seems to be clear now that the categories of space and time are not given <u>a priori</u>, but are rather developed in early childhood anew for each individual. That is to say that although the categories of space and time are logically prior to any account of ordered change they are not ontogenetically prior.

Interestingly enough there appear to be cultural differences with respect to our constructions of space. In order to make those kinds of constructions amenable to scientific inquiry it is necessary to investigate cases in which the constructions fail to achieve their purposes, i.e. where we do misrepresent spatial relations. Gregory has investigated and depicted many of these misrepresentations. It turns out that people living in different environments do react differently to certain experimental situations. A particular kind of figure which typically will be misinterpreted by people of our western culture may be seen correctly by representatives of other cultures. The Zulus, for example, rarely encounter rectangular structures. They live in huts which are round, they plow their land in curved figures and even their possessions rarely have corners or straight lines. It turns out that they are less susceptible to illusions due to misinterpretation of perspective than we who are surrounded by rectangular rooms, houses, and many other straight and cornered objects (Gregory(1966)161-2).

In our spatial constructions we learn how to order objects according to the greatest likelihood of their possible arrangement in space. Generally we are very successful in this endeavor. Occasionally, however, we are deceived. It is then that the constructive nature of our perceptual system becomes evident. People living in a different kind of environment will learn to hold other features constant. They will therefore not be prone to the same deceptions as we are, though certainly they will encounter illusions characteristic of their respective kind of environment.

During early childhood we learn that there are objects and how they are located in space and time. In that process we coordinate our various sensory worlds, i.e. those of touch, taste, color, and sound. As a result of this coordination we learn to distinguish between entities which remain invariant with respect to a variety of these sensory modalities and those which do not. The former we call objects, the latter are entities of our own making, caused by the very activity of perception itself. For example, the afterimages we see after having stared into a lightsource will 'move' with us, but cannot be touched or smelled. To introduce a notion from systems theory: the afterimage is not *robust*, i.e. not amenable to independent multiple determination. A ball, however, is an object. As such, it can be felt, smelled, heard, and seen. What remains invariant with respect to those various sensations *is* the object 'ball', a robust entity, localizable in space and time.

A remarkable complex central nervous system is needed for the integration of the information coming from our various senses. In this process the brain has to relate together not only the three spatial dimensions but also color, movement, and other object-characteristics. Visual perception is thus always indirect and requires interpretation. It is therefore secondary to the senses of touch and taste whose activities result in immediate reflex action. Thus a hand will be withdrawn instantaneously without the interference of thought, once extreme heat is felt. Gregory calls these responses "primitive-pre-perceptual reactions *not to objects but to physical conditions*"(Gregory(1970)12,my italics). He points out that

> touch, taste,and temperature senses must have developed before eyes: for visual patterns are only important when interpreted in terms of the world of objects. But this requires an elaborate nervous system (ideed almost a metaphysics) if behavior is controlled by belief in what the object is rather than directly by sensory input.......
>
> Eyes give warning of the future, by

> signalling distant objects. It seems very likely that brains as we know them could not have developed without senses – particularly eyes – capable of *providing advance information*, by *signalling the presence of distant objects*....Eyes require intelligence to identify and locate objects in space, but intelligent brains could hardly have developed without eyes. Eyes freed the nervous system from the tyranny of reflexes, leading to strategic planned behavior and ultimately to abstract thinking (Gregory(1970)12-3,my italics).

Direct, immediate, non-theory-laden experience is confined to the primitive sensations of touch and taste. Vision which certainly – at least for human beings – is the most powerful of the senses removes us from the direct impact of the external world. It thus provides increased safety and foresight. The tremendous advantage resulting from a sophisticated eye-brain system has, however, its price. In removing us from the immediacy of experience, perception becomes inevitably theory-laden.

> Perception is not determined simply by stimulus patterns; rather it is a dynamic searching for the best interpretation of the available data. The data are sensory signals and also knowledge of the many other characteristics of objects. ....It seems clear that perception involves going beyond the immediately given evidence of the senses: this evidence is assessed on many grounds and generally we make the best bet and see things more or less correctly. But the senses do not give us a picture of the world directly; rather they provide evidence for the checking of hypotheses about what lies before us. Indeed, we may say that the perception of an object *is* an hypothesis, suggested and tested by sensory data......... When a perceptual hypothesis – a perception – is wrong we are

> misled, as we are mislead in science when we see the world distorted by a false theory. Perceiving and thinking are not independent: 'I see what you mean' is not a puerile pun, but indicates a connection which is very real (Gregory(1966)13-4).

In our everyday life perception is very reliable, so much so that one still needs arguments and scientific evidence to convince the empiricist - if he can be convinced - of the theory-ladenness of perception. Our success in making the best perceptual guesses, however, should not surprise us. It is the result of a long evolutionary process during which natural selection favored organisms which successfully integrated their various sensory systems. One of the most important evolutionary inventions was the addition of the second eye which allows us to perceive how objects lie in space. Our two eyes give slightly different projections which, together, result in stereoscopic vision. This adds depth information and allows us to judge correctly the three-dimensional relationships holding between external objects. Gregory points out that

> vision is essentially an <u>indirect</u> source of size and distance information: it is logically necessary that retinal images should be calibrated against direct measures, such as touching objects or walking towards them and recording the size change at the eye (Gregory(1970)104,his italics).

During ontogeny humans (and most likely also other highly developed mammals) learn to integrate their sensory capabilities such that they can locate stable objects within a stable space-time framework. Eventually they come to view themselves as being placed in a stable world independent of their own perceptual activities. This view comes so natural to us that we forget that it is a result of a constructive process during which we learned how to organize our experience. In interacting with the environing world we learned to distinguish between changes due to our own perceptual activities and those due to events occurring externally and independent of us. Thus we move from an extremely egocentric view of the world to a conceptual framework within which we can distinguish between subjects and objects. It was Piaget's great contribution to show that the subject-object distinction is not unproblematic or naturally given, but the result of a constructive process involving the coordination of our sensorimotor skills. As a result of an ever increasing web of coordinations we develop not only the subject-object distinction but also our space-time framework without which we could not distinguish between genuine and apparent changes.

I have argued that we cannot see the world 'as it really is' because the world is far <u>too</u> rich to be captured by one single perceptual or conceptual framework. In order to survive in this ever-changing universe we have to be able to react to those changes which are of immediate importance for us. Our physiological equipment assists in this task by severely restricting the kind of changes we can detect. Our eyes are sensitive only to visible light, and, not surprisingly, most changes which are of great immediate importance for us lie within its range.

In spite of these restrictions the patches of color which are received by the retina are still highly ambiguous and in need of interpretation. In particular it is important to distinguish between genuine "external" changes and those due to the act of perceiving itself; i.e. we need the distinction between subjects and objects. By actively exploring its environment the infant learns to form the concept of an object. The latter is a robust entity which remains invariant with respect to his perceptual activities. However, the formation of the concept of an object is by itself not enough to enable the young child to understand the changes an object may or may not undergo. For example, he will not know whether or not a ball which has rolled under the bed does or does not continue to exist. In order to gain this understanding he has to develop a concept of physical space. Within this space he learns to locate objects at varying distances utilizing stereoscopic vision, or changing parallax as the head moves.

2.3. THE CONSTRUCTIVE NATURE OF SCIENCE

Central to the present discussion is the fact that in order to account for change we have to assume something, an entity or process or structure that does not change. In a universe where everything was changing completely randomly so that there were no underlying structure or regularity detectable, knowledge about the external world would be impossible. It is safe to assume that our universe is not of this kind. Still, it is anything but easy to find the genuine invariant relationships holding between the ongoing processes. Doubtless our knowledge of these relationships has grown considerably. Still, we have to start with something, some presuppositions which may enable us to bring order into that otherwise erratic and incomprehensible world. All organisms have some perceptual - and the higher developed organisms also conceptual - equipment. This largely determines which kind of changes can be perceived and conceived and what is held to be constant.

Human beings - and on this planet they seem to be unique in <u>this</u> respect - have learned to explore different levels of reality. They have extended their perception by developing ever more sophisticated instruments and theories, exploring changes far beyond the range of visible light. It seems therefore natural to view science as an extension of perception and ask whether our understanding of perception can aid us in the understanding of the structure and dynamics of science.

The idea that science can be interpreted as an extension of perception is, of course, not new. It has been suggested, for example, by Bohm (Bohm(1977)) and also by Gregory who, indeed, has taken some substantial steps in the elaboration of this idea (Gregory(1970)).

Yet, as valuable as Gregory's approach is, he makes no attempt to put his insights into a wider philosophical perspective, in particular he does not discuss the profound epistemological and ontological implications connected with such an approach. This, incidentally, is not meant to be a criticism of Gregory's insightful work. Philosophy is a vast and demanding subject which requires many co-workers for the attainment of a full-fledged and satisfying interpretation. Any approach that succeeds in enriching philosophical discourse by applying scientific insights is valuable in its own right, for this way of doing philosophy is still all too rare.

Another important attempt to utilize scientific findings on perception for the understanding of science is due to Bohm who applies some of Piaget's profound insights (Bohm(1965)).

In the following discussion I will draw occasionally upon insights of Gregory and Bohm. Yet, the approach I have chosen differs substantially from theirs and therefore requires its own independent elaboration.

I have described the physiological limitations imposed on our naked eye observations. Scientists have managed to enlarge our access to the natural world by inventing scientific instruments which extend the power of our senses considerably. Telescopes and light microscopes are extensions in the most obvious way. Within the range of visible light these instruments provide us with more detailed information than we can obtain by naked eye observation. Modern science, however, is by no means restricted to the realm of visible light. Out of that ever-changing world which surrounds us scientists succeeded in bringing changes to our attention which are in principle not accessible to naked eye observation. For example, spectroscopy allows us to tune into the realm of the atom, whose frequencies, masses and other physical properties we can thus determine. It is important to realize that the scientist who wants to investigate the microstructure of a particular crystal, for example, faces essentially the same problem as evolution faced when designing our perceptual system. He has to make sure that he observes only those changes which are relevant for his specific purpose. He has to take great care that changes occurring at different levels of reality do not interfere with the kind of change he intends to investigate. For example, he has to make sure that changes in the atomic nucleus do not interfere with the measurement when he intends to measure the strength of chemical bonds.

Therefore scientific experimentation takes place in a tightly controlled environment. By applying a variety of instruments and techniques the scientist attempts to exclude possible disturbing factors. For example, he may create an artificial vacuum, keep the temperature constantly optimal, isolate the apparatus from undesirable radiation,etc. Fundamental for successful experimentation is also that he distinguish between changes internal to the apparatus and those external to it. As in the case of the young child he has to distinguish between changes caused by the activity of perceiving (i.e.measuring) and those germane to the external world. He also adopts various criteria of robustness by employing independent means of measuring the same process. In order to increase the reliability of his measurements, he might also repeat experiments several times and at various ranges of sensitivity. All these procedures are means for ensuring that he gets hold of something real. What remains invariant with respect to his activities, he will call an object. This could be any of the so-called theoretical entities, like genes, atoms, or pulsars, but holds as well for 'less' theoretical entities like cells, stars, or ecological communities. Once he has calibrated his instruments so that he can distinguish between 'genuine' change and 'noise', he can proceed with his investigation. It should be clear, however, that 'noise' is as real as any other phenomenon. Changes become 'noise' only with respect to the particular intentions of the observer. It follows that the observer is always part of the scientific picture.

We have seen that the same holds for our everyday perceptions. Here again things are invariant with respect to our activities. There is no absolute stability in this ever-changing world of ours. The best we can do, therefore, is to search for robust entities occurring at various levels of reality.

I have outlined the sense in which scientific exploration can be seen as an extension of perception. In order to "give more force" to this conception of science let me present some historical examples:

As a typical example for an invariant non-macroscopic entity I mentioned the chemical atom. We know now that this entity is not absolutely stable but can, under certain conditions, be split into subnuclear particles. With respect to chemical reactions, however, it remains invariant. The discovery of this invariance was of crucial importance for modern science and anything but easy to come by as the history of chemistry shows. The discovery of the chemical atom can indeed serve as a paradigm example that teaches us how difficult it is to find the proper invariants of physical changes. The properties of the chemical compounds at the beginning of a chemical reaction differ usually dramatically from those at the end of the reaction. For example, sodium is a highly reactive metal and chlorine a dangerous aggressive gas. The combination of both elements leads to the formation of that harmless salt, sodium chloride, with which we season our food. Over many centuries chemists searched for the entities which remain invariant in the course of chemical reaction. In pre-modern chemistry it was held that certain "principles" or "spirits" perservere through chemical change. Mercury, sulphur, and salt were examples of such principles. It turned out that this conceptualization did not lead to a successful chemistry, for there <u>are</u> no qualitative principles which remain invariant during chemical change. The joint contribution of Lavoisier and Dalton led to the first successful conceptualization of chemical change. What remains invariant in the course of chemical reaction is (a) the weight of the compounds, i.e. the weight of the compounds on the left hand side of a chemical equation equals the weight of those on the right hand side of the equation; and (b) the identity and proportionality of the chemical atoms, i.e. the same number and kind of chemical atoms is to be found on both sides of the chemical equation.

For a modern chemist those identities appear to be rather trivial, almost analytic. He has forgotten what a great intellectual accomplishment lay behind those discoveries. In his forgetfulness he resembles the adult who cannot recall how he dicovered what objects were and for whom it is now "obvious" that we see 'the world 'as it is'.

The empiricist believes that if we only observe carefully enough and put our preconceptions aside we will discover the lawful relationships holding in the universe. Certainly - one should think - there cannot be any more straightforward relation than the equality of the weight before and after chemical reaction. Why, then, did it take so long for scientists to discover this relationship? Was it merely a caseof closing one's eyes to the obvious? It can easily be shown that this empiricist view is false for there were perfectly good reason's in the 18th century to deny the preservation of weight during chemical reaction:

During the 17th and 18th century most chemists believed in the corporeal nature of heat and also attributed weight to it like to all other matter. Heat, however, can pass through reaction vessels. Given those beliefs it was perfectly reasonable to deny the conservation of mass during chemical reaction. If at the end of a chemical reaction it was found that the resulting compounds were heavier than those present at the beginning of the reaction, this gain of weight could and was frequently attributed to heat particles which had been absorbed during the reaction. Lavoisier claimed that it was the newly discovered gas oxygen which caused the increase in weight after combustion. He did, however, also believe in the materiality of heat. In order to reconcile both views he was forced to postulate a weightless material fluid which he named 'caloric'.

Empiricists may want to scold Lavoisier for employing such an obscure concept as a 'weightles fluid of heat'. Yet, as I have indicated, the introduction of this metaphysical' entity did a most valuable service to chemistry. It made it possible to postulate the conservation of weight during chemical change.

Building upon Lavoisier's profound insights Dalton could propose his atomic theory. For it was only if weight was preserved through chemical change that the concept of a chemical atom could serve as a useful tool for chemical analysis, because the various atoms could be distinguished only by their repective weights.

Corpuscular theories had been popular among chemists for a very long time. Yet those theories had been of little value in actual scientific research because they did not specify any macroscopically ascertainable properties. By individuating atoms by their atomic weights Dalton hit upon a property which indeed distinguishes, in fact defines, chemical atoms. After hundreds of years of conjecturing what remains invariant through change, Lavoisier and Dalton found an invariant which is useful in chemical analysis and makes predictions of chemical reactions possible. Modern chemistry knows of more invariants of this kind, for example the preservation of electric charge or symmetry conservation in quantum chemistry.

In our context it is useful to compare the achievements of Lavoisier and Dalton with that of a young child which first hits upon properties of objects which enable her to identify the object under changing conditions - in fact it let's her "grasp" what an object is - . Later she may discover many more properties and thus improve her understanding of "what the world is all about". Once she reaches a certain age the world <u>is</u> for her a world of well-defined objects located in space and time. She can predict and understand many changes and thus orient herself in that complex world of ours.

By hitting upon the first and most fundamental invariance in chemical change Lavoisier and Dalton jointly constructed the "objects" of chemistry. Later, researchers were to add many more such properties which led to the improvement of our understanding of that elusive world of chemical change.

We have seen that Gregory emphasizes the relationship between intelligence and sensation. In order to perceive a world of objects we do not only need senses but also brains that integrate the information coming from those various organs of sensation. It is the brain which constructs for us a world of objects within which we can orient ourselves.

Science also employs a variety of scientific instruments and theories which interpret the incoming information and structure it with respect to the purpose of the investigation. Instrumentation and theories together often succeed in providing us with an adequate picture of otherwise inaccessible realms of reality. The fact that scientists always work with a whole network of theories is well known to philosophers of science and is usually referred to as the Duhem-Quine thesis. This thesis states that if a scientifictheory predicts a certain outcome of an experiment, and if it turns out that this prediction is erroneous , then it is not justified to claim that the theory which led to this particular prediction is false. For any of the numerous other theories might be at fault, and this makes it impossible to locate the error.

This thesis has been of great concern to many philosophers of science, in particular to Popperians whose methodology prescribes to abandon refuted theories. This, of course, presupposes that we can locate the theory which is at fault and numerous attempts have been made to find a way to locate error.

The present approach emphasizes that we organize our experience with the goal of finding invariant relationships in the world. This means for science that we have to coordinate our various theories and instruments until they all fit together and jointly let us conceive of stability in an otherwise instable world. The Duhem-Quine thesis fits therefore nicely into the framework I am developing here. Indeed, I intend to present a stronger version of this thesis and will argue that it is conceivable that we may operate with a set of true theories and nevertheless arrive at false predictions. In other words the search for criteria by which we can eliminate false theories may be in vain, for there may be no false theory which needs to be eliminated. Needless to say, I do not intend to refute the laws of logic. What is at stake here is the fact that it is <u>in principle</u> impossible for us to be aware of all the implicit assumptions inherent in our conceptual frameworks. In order to make my point I will construct an historical example.

I mentioned above that during the 18th century many scientists believed that heat was a material fluid which had weight. Parallel to this tradition there existed another tradition which held an early version of "our" kinetic theory of heat, i.e. heat was thought to be caused by the motions of the corpuscles; it did not therefore contribute to the weight of the substance. Now let us assume that sometime at the beginning of the 18th century, i.e. <u>before</u> the discovery of oxygen, a chemist holding the kinetic theory of heat, comes up with the "bold conjecture": Weight remains invariant during chemical reaction. He puts his hypothesis to a test and hits upon a chemical reaction which involves what <u>we</u> would call oxidation. At the end of the reaction he uses his scale and sees that the products are heavier than the compounds with which he began. Being a good Popperian he abandons the true theory, i.e. that weight does not change during chemical reaction.(2)

A modern reader may protest and declare that the true theory (i.e. weight remains invariant during chemical change) was never refuted because the experiment was not conducted properly. The vessel remained open during the course of the reaction and gas was absorbed from the atmosphere. This is doubtlessly true. Yet, we cannot blame the 18th century chemist for something he simply could not have known. What was missing in his conceptual framework was the concept of a gas which has weight and may participate in chemical change.

This example highlights what I consider to be the central problem of scientific knowledge, which is that we have to realize that we often do not know what we are talking about. We discover certain puzzling phenomena and deem them to be in need of explanation. However, what is or is not considered to be a problem depends on our conceptual framework. If this framework is too poor and does not reflect genuine invariant relationships in the world, our problems may turn out to be pseudoproblems, reflecting merely our own ignorance, never capturing anything real.

2.4. HOW TO FIND INVARIANCE IN AN EVER CHANGING WORLD

A powerful conceptual framework which orders our experiences and lets us predict future changes is needed for a successful science. Yet, such a framework, as desirable as it may be on the one hand, is as dangerous on the other. Consisting of a set of mutually reinforcing theories and practices, it defines what is possible and easily leads to dogmatism. Being caught within its explanatory power we are in danger of forgetting that our framework <u>is</u> a construction, that the world is far too rich to be captured by any one framework alone.

The best known example of such a powerful conceptual prison was the closed universe of Aristotelian mechanics and Ptolemaic astronomy. It is also an excellent example for the distortion of our worldview due to our position as perceivers. Being inside the closed Aristotelian universe, the world seems to turn around <u>us</u>. Is there any way to get <u>outside</u> this universe, to get a different perspective which will put us into our proper and not all too important position?

We have seen how the second eye adds depth to our perception. By seeing two slightly different images stereoscopic vision is introduced which enables us to see the same object from two different positions. This makes it possible to distinguish between phenomena which are dependent and those which are independent of our personal involvement as perceivers.

The question arises whether we can create such a stereoscopic vision also with respect to our conceptual framework. Can we add a "second eye" which gives us a different view and lets us distinguish those features that are robust and independent from those that are merely due to our position as perceivers?

In order to demonstrate that this is possible I have invented a story, you might call it a thought experiment.

Imagine a group of scientists driving in a car through North

America. The car is a special vehicle, indeed. It is driven by a robot. The scientists sit in the back of the car. Their compartment is completely isolated from the outside world. There are no windows and the compartment is hermetically sealed. The car is set on cruise control, say 50 mph. The only information our scientists have comes from data about the car itself. They can continuosly monitor the amount of gas the car needs on their trip. Whenever the car drives up the hill the increase in gas shows up on a little sceen. Because of the constancy of speed the board computer will plot correctly the increases and decreases in altitude.

The scientists will begin their trip on the east coast, cross the Appalachians, then descend into the wide North American plains. After a long drive they will note a dramatic increase in gasoline consumption as the car drives up into the Rocky Mountains. And on goes their trip, up and down several mountain ranges until eventually the car descends to the Pacific Coast. We can imagine our scientists to criss - cross North America, coming up eventually with a correct profile of the continent.

Let us further postulate that our scientists have never been outside the vehicle. They have never seen mountains or valleys, nor have they experienced rain or wind. Our world is for them a "theoretical entity", and their knowledge about it is bound to be painfully indirect. We who with our God's eye view can observe them as well as the beautiful world of which they are almost totally ignorant will sometimes have empathy for them, for their methods are anything but unproblematic.

For occasionally their car will drive through a storm which will increase their gas consumption, and on their screen 'mountains' appear where there are none. (We will assume that they call those peaks on the screen 'mountains' although they don't know what mountains really are). Perhaps our scientists have a more refined methodology and will repeat the trip several times thus being able to distinguish between peaks that appear always on the screen, and those that appear only occasionally. The latter they will dismiss as noise, irrelevant disturbances of unknown origin. Although this methodology improves the reliability of their measurements it is still anything but certain that the peaks of gas consumption they are measuring are always due to real mountains. For there are some winds that blow regularly in a certain area and will be encountered whenever they drive through it. Let us assume such a wind blows in the North American plains leading our scientists to believe that there is a large mountain range right in the middle of Nebraska. Are they ever going to find out that they are being misled? We could imagine that they may accidentally discover an instrument which measures wind but not altitude. By utilizing more than one mode of perception they could test the robustness of their object hypotheses and distinguish between those peaks on their screen which are caused by real mountains and those that are caused by wind. (Of course, the concept 'wind' they could only develop <u>after</u> having realized that the concept 'mountain' does not suffice for accounting for all the peaks they see on the sceen. And 'wind', of course, like 'mountain' would mean something entirely different for them than for us.) What will happen if they do not accidentally discover an instrument that measures wind? Will they forever be caught in their conceptual prison and believe that there is a mountain range in the center of Nebraska? That, of course, may happen. Yet, there is an additional possibility which may liberate them from their ignorance. They can change speed! Let us remember that by keeping the speed constant they could detect mountain peaks through measuring the increase in gas consumption. If they repeat their trip, but this time drive 70 instead of 50 mph, they may discover that there is something peculiar about those mountains in Nebraska. Assuming that the increase in gas consumption resulting from the higher speed is not the same depending whether it is caused by driving up a hill or by hitting the wind, the shapes of the respective curves will differ. By comparing the curves derived from driving across the continent with various speeds the scientists will realize that they are dealing with different phenomena.

By creating a stable framework against which external changes can be measured, regularities of the external world manifest themselves. We can, however, never be sure to which degree these regularities depend on real features of the external world and to which degree they depend on the pecularities of the framework (i.e. the particular speed) we have chosen. As long as we remain within that framework we might not be capable of detecting error, and all our methodologies may mislead us.

For imagine our scientists driving at 50 mph, attempting to induce regularities from the observation of all those peaks they find on the screen. Not knowing that some of those peaks are caused by entirely different phenomena they may arrive at completely erroneous generalizations. Or consider what could happen if the scientists were to follow Popper's prescription. They might propose a bold conjecture, say, concerning the incline of the mountain peaks. Let us assume that this hypothesis is correct. Then they will put their hypothesis to test. Driving through the "mountains" of Nebraska they will note that their conjecture does not hold, and will consequently abandon the correct hypothesis. For they do not know that they are dealing with two entirely different phenomena. In other words, the refutation of a hypothesis may not mean that the hypothesis is false, but that we are dealing with more than one phenomenon.

By introducing a second framework we may be lucky and can tease apart those different phenomena. We may realize that the conflation of the phenomena was due to the pecularities of our chosen framework. By intoducing a second framework (i.e. different constant speed) new features of the world may manifest themselves, and it will become clear that we were misled through our own activities as perceivers.

Two dimensional pictures are inherently ambiguous, and many different interpretations can be compatible with the received information. By adding the second eye, we can exclude many of these interpretations. Our two conceptual frameworks give us stereoscopic vision and increase the robustness of our conceptual hypotheses.

2.5. SOME HISTORICAL EXAMPLES

When Copernicus moved from the geocentric to the heliocentric world picture, he gave us a "second eye" which made it possible to distinguish between the robust features of the universe and those which were due merely to our particular position on the planet earth. It turned out that what seemed to be the central and most obvious phenomenon of the universe, i.e. its circular motion around the earth was a mere illusion caused by our own position as perceivers. Other phenomena, however, which were heretofore unrelated, became of crucial importance within the new world view. For example, somewhere in the cycle or epicycle of all the planets there occurred one with a period of 365 days. The appearance of this same period in different places is a unexplained coincidence within the Ptolemaic account. Within Copernicus' heliocentric system, however, these separate epicycles diappear. The revolution of the earth around the sun takes care of all those otherwise unexplained and unrelated phenomena. Thus, what is and is not a genuine phenomenon becomes redefined through the shift from Ptolemaic to Copernican astronomy. The integration of otherwise unexplained coincidences leads to a much more powerful and unified view of nature. Copernicus himself was impressed with the integrative aspects of his new world picture:

> I found at length by much and long observation, that if the motions of the other planets were added to the rotation of the earth and calculated as for the revolution of that planet, not only the phenomena of the others followed from this, but also it so bound together both the order and magnitude of all the planets and the spheres and the heaven itself, that in no single part could one thing be altered without confusion among the other parts and in all the universe. Hence for this reason in the course of this work I have followed this system....(3)

In science as in perception we find that progress is achieved through the integration of various previously unrelated phenomena or sensations. The child has to learn how to correlate the information coming from his various organs of sensation. This integration takes place in the brain. As a result he experiences objects located in space and time. In science as well we have to learn how to correlate the information we receive through our senses and measuring instruments. Only a powerful conceptual framework makes such an integration possible.

Einstein's theory of relativity constitutes perhaps the most powerful intellectual integration ever achieved in the history of science. In this theory the properties of space, time, and mass which appeared previously to be independent of each other cease to be absolutes. Instead they become correlated in a general space-time framework. For example, in classical mechanics, mass was thought to be a property of objects independent of the space-time framework. In relativity theory, however, mass is seen to be a relation between an object and the coordinate system. Due to this relationship the relative velocities and potential energies contribute to the mass balance.

As a result of this reinterpretation of the classical concepts, Einstein succeeded in integrating the laws of mechanics, optics, electrodynamics, and also attempted to incorporate gravitation within a general and extremely powerful conceptual framework.

This integration was achieved by inquiring into what remains invariant with respect to observers moving in different frames of reference, and, interestingly enough, Einstein referred to his theory originally as Invariantentheorie.(4) David Bohm who has emphasized the importance of invariance in both, perception and physics, characterizes relativity theory as follows:

> In Einstein's theory of relativity, the notions of space, time, mass,etc., are no longer regarded as representing absolutes, existing in themselves as permanent substances or entities. Rather, the whole of physics is conceived as dealing with the discovery of what is relatively invariant in the everchanging movements that are to be observed in the world, as well as in the changes of points of view, frames of reference, different perspectives,etc., that can be adopted in such observations.(Bohm(1965)185).
>
> ......Einstein's major steps were based on setting aside such ideas of an absolute, and on extending into broader domains the notion of the laws of physics as invariant relationships (e.g., so as to include velocities comparable to that of light). In doing this he was led also to drop the notion of fixed quantities of substances, having constant masses. Instead, mass was seen to be only a relatively invariant property, expressing a relationship between energy of a body and its inertial resistance to acceleration, along with its gravitational properties. Further developments in modern physics, including quantum theory and the studies of the transformations of the so-called "elementary" particles....suggest that the notion of permanent entities constituted of substances with unchanging qualitative and quantitative properties may have to be dropped altogether, and that physics will be left with nothing but the study of what is relatively invariant in as wide as possible a variety of movements, transfomations of coordinates, changes of perspective, etc.,(Bohm(1965)218).

Bohm's remarks lead us back to the ontological issues I discussed in chapter one. There I argued that we should replace the old epistemological question 'how can we know the world' by the new question 'how can the world be such that we can know it'. In chapter two I explored the similarities between science and perception and argued that the old demarcation between 'subject' and 'object' cannot be absolute, for what we call an 'object' is as much part of our own perceptual and conceptual background as it is part of the external world. If this view is not to desintegrate into a purely subjectivist conception of knowledge we need a new and different kind of ontology. In the next chapter I will explore such an alternative and will argue that a metaphysics of processes interlocks smoothly with the epistemological model I am developing. However,before presenting this alternative it will be necessary to reflect upon the most widely accepted contemporary metaphysics, namely reductionism. This worldview has been dominating western science ever since the desintegration of the Aristotelian world picture. What led to its adoption? Are the reasons which convinced the pioneers of modern science still valid in light of the scientific findings of the 20th century? What are the presuppositions upon which reductionism rests? What picture of human beings and their intellectual capacities results from the adoption of reductionism?

Only after having discussed those questions will we see what is required for a new alternative metaphysics, only thereafter can we attempt to present a comprehensive picture of a world within which knowledge becomes possible and where the development and integration of our intellectual capacities leads to an ever better understanding of this elusive universe.

NOTES TO CHAPTER TWO

1. Gregory expounds some of Helmholtz' views and sees his own work as an extension of Helmhotz' ideas about perception (Gregory(1970)32).

2. This artificially contrived example should not be taken too seriously.Chemists were well aware that during "calcination" as the oxidation of metals was called, the weight of the substances increased, and they would have never proposed a conjecture denying the obvious.

3. Copernicus, De Revolutionibus, Letter to Pope Paul III, quoted from (Burtt(1932)50).

4. This information was given to Stephen Toulmin by Gerald Holton. See (Toulmin(1972)90).

CHAPTER III

TO BE OR TO BECOME, THAT IS THE QUESTION

3.1. REDUCTIONISM: ITS MERITS AND ITS PROBLEMS

To reduce the material of experience to order, to explain macroscopic diversity in terms of microscopic simplicity, to reveal the permanent stability of the real behind the seeming irregularity of the apparent, this has been the explicit goal of science during the past three centuries. Ever since the advent of the mechanical philosophy, the ideal of scientific explanation has been to reduce all that diversity and complexity which is so characteristic of the world we inhabit to causal interaction between ultimate entities of matter. This ideal is exemplified by the famous remark of Laplace, that a powerful intelligence acquainted with the position and motion of the atoms at any moment could predict the whole course of future events. This Laplacian image implies that in some sense the present already "contains" the future.

Modern science has all but abandoned the underlying assumptions of this reductionist framework. Instead of impenetrable hard atoms contemporary physicists explore elementary particles that exist only for extremely brief durations of time. The concept of materiality applying to those entities is far removed from what was called material in the 17th or 18th century. Even the law of the conservation of matter itself, so much at the heart of a mechanistically conceived universe, has been replaced by the law of the conservation of energy. Most importantly, however, the Second Law of Thermodynamics demonstrates the existence of irreversible processes, a result which is in conflict with the very foundation of dynamics, for the latter makes no distinction between the future and the past. The dynamical equations of classical mechanics - and also of quantum mechanics - are invariant with respect to the time parameter. Contrariwise, irreversible processes, such as diffusion, heat conduction, decay of nuclear particles, chemical reaction, depict an obvious directedness of time: in a closed system entropy always increases until a state of thermodynamic equilibrium is reached. It has been stated by many distinguished physicists, most poignantly perhaps by Poincaré: Thermodynamics and dynamics are incompatible.(1)

Yet, it is thermodynamics which is increasingly considered to be the fundamental physical theory, particularly with respect to the lifesciences. Living things 'feed' on negentropy. In open, non-equilibrium systems living substances extract energy from their environment and transform it into highly complex molecular structures. The formation of order from chaos, the transformation of negentropy into increasingly higher levels of complex organization, is characteristic of evolutionary processes.

The strong reductionist orientation so evident in much contemporary theorizing in biology, sociology, and philosophy appears therefore to be a rather remarkable phenomenon which deserves explanation. David Bohm has made this point succinctly:

> Physics has really totally abandoned its earlier mechanical basis.. Its subject matter already, in certain ways, is far more similar to that of biology than it is to that of Newtonian mechanics. It does seem odd, therefore, that just when physics is thus moving away from mechanism, biology and psychology are moving closer to it. If this trend continues, it may well be that scientists will be regarding living things and intelligent beings as mechanical, while they suppose that inanimate matter is too complex and subtle to fit into the limited categories of mechanism (Bohm(1969)34).

The mechanistic approach against which Bohm's criticism is directed forms part of the general philosophical outlook of reductionism. This philosophy alleges that whatever the ultimate entities of nature turn out to be, they and the relationships between them determine the properties and relations of observable phenomena. "In between" observables and ultimate entities, scientists have identified a series of intermediate entities such as cells, molecules, atoms,etc. According to the reductionist program, upper level entities or phenomena are to be identified with entities, properties, and relations located on the next lower level. If any and every science does its job and reduces the phenomena of its concern to relations or properties belonging to entities on the next lower level then we will eventually have created a scientific edifice going all the way down from ecology and anthropology to molecules, atoms, and ultimately to elementary particles. It is acknowledged that such a complete reduction will never actually be accomplished, yet, scientists and philosophers have been content to voice their conviction that such a reduction ought to be possible, at least "in principle".

Adherents of the reductionist point of view further claim that the actual course of the history of science has confirmed the value of the reductionist program. They hold that science progresses by giving an increasingly more precise description of upper level phenomena in terms of lower level entities, properties, and relations.

Indeed, the remarkable integration of several previously separated scientific specialties seems to support reductionist claims. The paradigm cases of alleged reduction are: the reduction of chemistry to quantum physics, the reduction of phenomenological thermodynamics to statistical mechanics, the reduction of Mendelian genetics to molecular genetics. To pursue scientific progress along reductionist lines means to reduce a scientific theory which accounts for the relationships between macrostates, properties, processes and events, to a different theory describing the same phenomena in terms of microstates, properties, processes, and events. In other words theory reduction parallels ontological reduction.

Thus reductionism can be seen as an important tool for the unification of science, a central aim of 20th century science and philosophy. In order to attain the goal of unification reductionism makes normative claims with respect to the direction scientific research should take. This philosophy advises the scientist to search for deeper levels of reality and to dismiss higher levels of organizational complexity as mere epiphenomena of underlying entities and processes. Thus phenomena are to be described entirely in terms of properties of isolated objects. It is the task of science to search for a progressively more refined specification of these objects, which means to describe them in terms of lower level entities which in turn are hopefully describable in terms of entities on even a lower level of the scale, leading to whatever will turn out to be ultimate and real.

We see that reductionism is indeed a powerful philosophy which offers an intuitively plausible ontology and provides scientists with a heuristic which has shown remarkable successes in the past. Thus it is not surprising that the younger biological and social sciences followed the lead of the physical sciences and adopted reductionist research strategies.

> The whole magnificent movement of modern science is essentially of a piece, the later biological and sociological branches took over their basic postulates from the earlier victorious mechanics, especially the all-important postulate that valid explanations must always be in terms of small, elementary units in regularly changing relations. To this has likewise been added, in all but the rarest cases, the postulate that ultimate causality is to be found in the motion of the physical atoms (Burtt(1932)30).

3.2. THE HISTORICAL SOURCES OF REDUCTIONISM

In view of the many facets of reductionism, its positive as well as negative features, it seems hardly possible to give a fair evaluation by merely looking at contemporary arguments in favor or against this philosophy. I will therefore turn to some historical sources and ask the question: Why did men like Galileo and Kepler, Descartes and Newton adopt reductionism?(2) Are the reasons which led them to embrace this metaphysics still valid in light of contemporary science, or are there good grounds for starting afresh and rethinking our most fundamental philosophical premises? I will begin my historical assessment by letting one of the founding fathers of modern reductionism speak for himself. In two famous passages in the <u>Assayer</u> Galileo develops his distinction between primary and secondary qualities.

> Now I say that whenever I conceive any material or corporeal substance, I immediately feel the need to think of it as bounded, and as having this or that shape; as being large or small in relation to other things, and in some specific place at any given time; as being in motion or at rest; as touching or not touching some other body; and as being one in number, or few, or many. From these conditions I cannot separate such a substance by any stretch of my imagination. But that it must be white or red, bitter or sweet, noisy or silent, and of sweet or foul odor, my mind does not feel compelled to bring in as necessary accompaniments. Without the senses our guides, reason or imagination unaided would probably never arrive at qualities like these. Hence I think that tastes, odors, colors, and so on are no more than mere names so far as the object in which we place them is concerned,

> and that they reside only in the consciousness. Hence if the living creature were removed, all these qualities would be wiped away and annihilated (Galileo(1623)274).
>
> To excite in us tastes, odors, and sounds I believe that nothing is required in external bodies except shapes, numbers, and slow or rapid movements. I think that if ears, tongues, and noses were removed, shapes and numbers and motions would remain, but not odors or tastes or sounds. The latter, I believe, are nothing more than names when separated from living beings, just as tickling and titillation are nothing but names in the absence of such things as noses or armpits (Galileo(1623)276-7).

Galileo's distinction between the primary and secondary qualities was to revolutionize man's view of nature and of himself. Indeed it created modern science. By divesting nature of the qualitative features and insisting that the "real" equals the measurable Galileo put science on a secure foundation which was to be called "scientific objectivity".

The idea that reality is caught up in the mathematical harmony underlying the world of the senses is of course much older and can be traced back to Plato and to Pythagoras. But whereas the older traditions emphasized the acquisition of knowledge through introspection and mystic insight, Galileo, Kepler, and Newton emphasized the usage of measurement and the careful collection of data. Yet, their empiricism was of a peculiar kind. It did not deal with the wholeness of human experience but rather stipulated that only particular types of observation should rightfully be called scientific. These were the ones which were amenable to mathematical treatment. Thus it became the main goal for science to disentangle among the characteristics of an object those which are quantifiable. The scientific experiment became the main tool for the achievement of this goal. Within the experimental situation the phenomena become simplified in such a way that the assignment of numerical values to properties of objects becomes possible. By varying one parameter at a time and keeping the others constant a lawlike relationship is sought between the properties of the object under investigation and the changing experimental conditions.

The belief that the world of matter is a world fundamentally possessing mathematical characteristics, also necessitated the introduction of new concepts into scientific discourse. Concepts like space and time, mass and energy were the new categories within which the quantifiable features of objects became expressible. Those concepts had been either non-existent or else of rather minor importance in scholastic science which had been content to concentrate upon the qualitative features of the physical world (Burtt(1932)26). For expressing non-mathematical relationships in the natural world the old Aristotelian categories such as essence, substance, form, and matter sufficed.

It was notably Galileo who emphasized that in order to apply the science of mathematics to the phenomena we have to recast our way of apprehending the natural world. Necessarily we have to experience the world by means of the senses but it is only through mathematical demonstration that scientific certainty is to be reached and the hidden rational order of the universe revealed. Therefore we have to reinterpret what our senses tell us and must give primacy to reason. This - Galileo tells us - is the prime achievement of the Copernican revolution:

> I (cannot) ever sufficiently admire the outstanding acumen of those who have taken hold of this opinion (that the earth moves) and accepted it as true: they have through sheer force of intellect done such violence to their own senses as to prefer what reason told them over that which sensible experience plainly showed them to be the contrary. For the arguments against the whirling of the earth...are very plausible...and the fact that the Ptolemaics and Aristotelians and all their disciples took them to be conclusive is indeed a strong argument of their effectiveness. But the experiences which overtly contradict the annual movement are indeed so much greater in their apparent force that, I repeat, there is no limit to my astonishment when I reflect that Aristarchus and Copernicus were able *to make reason to conquer sense* that, in defiance of the latter, the former became mistress of their belief (Galileo(1632)328,my italics).

Copernicus had removed the earth from the center of the universe, Galileo went one step further in diminishing the realm of man by denouncing his most vivid experiences as secondary and unreal. The world of color and sound, of taste and of fragrance was shoved aside in favor of a universe hard, cold, colorless, silent and dead, a world of quantity, a world of mathematically computable motions in mechanical regularity. After the great Newtonian intellectual conquest the mathematical science of physical nature was firmly established. Nature came to be thought of as essentially a realm of masses, moving according to mathematical laws in space and time under the influence of definite and computable forces.

The mind of man had come in touch with a new realm of being, and saw from now on only in mathematical mechanics the possible key to all the secrets in nature. The view man held of himself and of his place in the universe had fundamentally been altered. Before the scientific revolution man was thought to dwell in the center of the universe, and he was also believed to be the measure of all things which God had created for his enjoyment.

With the overthrow of the medieval world picture man forfeited the spiritual security of the man-centered universe in favor of absolute, non-humane knowledge as it was exemplified in the realm of mathematics. Let us again turn to Galileo for an illustration of this point.

> The human understanding can be taken in two modes, the intensive or the extensive. Extensively, that is with regard to the multitude of intelligibles, which are infinite, the human understanding is as nothing even if it understands a thousand propositions; for a thousand in relation to infinity is zero. But taking man's understanding intensively, in so far as this term denotes understanding some proposition perfectly, I say that the human intellect does understand some of them perfectly, and thus in these it has as much absolute certainty as Nature itself has. Of such are the mathematical sciences alone; that is geometry and arithmetic, in which the Divine intellect indeed knows infinitely more propositions, since it knows all. But with regard to those few which the human intellect does understand, I believe that its knowledge equals the Divine in objective certainty, for here it succeeds in understanding necessity, beyond which there can be no greater sureness (Galileo(1632)103).

Due to the staggering achievements of scientists like Copernicus, Kepler, Galileo, and Newton, man seemed to have come closer to the fulfillment of that old Platonic ideal of absolute, divine mathematical knowledge.

Yet, the success of mathematical physics also had its prize. It required the cutting up the wholeness of man's experience into two realities, the pseudoreality of the secondary qualities and the genuine reality as exemplified by the quantifiable features of experience. This distinction which had proven to be so fruitful for the advance of science on the one hand, erected barriers between the experience of vision and the object we are supposed to see on the other. Man cannot help but experience the world as a realm of sound and color, fragrance, and taste. Those experiences are now pushed aside as mere epiphenomena of the real underlying primary qualities, and it became the central occupation for natural philosophers to find a method leading directly to the primary qualities without being influenced by these deceitful secondary qualities which were attributed to our untrustworthy senses.

It was thought that the primary qualities were attributes of matter itself. Matter was composed ultimately of absolutely hard, indestructible particles, equipped with those primary characteristics which were essentially mathematical in nature. All changes are to be regarded as separations, associations, and motions of these permanent atoms. It was thought that the varied motions of the atoms were operating upon the senses, thereby causing us to perceive the secondary qualities. Human sensory perception was thus inevitably linked with deception and the question arose how certain knowledge of the real corporeal world could be possible at all. It was held that the mind is located inside the brain; there it receives information about the external world by means of the unreliable senses and is therefore prone to be mislead.

Now, as all those features which are most intense to man are being classed as secondary and ignoble, man appears to be outside the real world. His memory and purpose are irrelevant with respect to that great mathematical drama outside, of which he is, at best, a semi-real effect.

Having isolated ourselves from the experiental continuum we are left in the position of spectators witnessing a universe that exists outside and away from ourselves. We are left to wonder how all these great scientific achievements are possible, how knowledge can safely leap the sensed gap between world and mind.

Thus the scientific revolution resulted in the banishing of man from the great world of nature. Modern scepticism and man's alienation from nature are a direct consequence of the destruction of the integrity of our experience of reality,

> ...the world of science, the real world, is no more seen....as a finite and hierarchically ordered, therefore qualitatively and ontologically differentiated whole, but as an open, indefinite, and even infinite universe, united not by its immanent structure but only by the identity of its fundamental contents and laws...This, in turn implies the disappearance - or violent expulsion - from scientific thought of all considerations based on value, perfection, harmony, meaning, and aim, because these concepts, from now on merely subjective, cannot have a place in the new ontology.....
>
> Modern science broke down the barriers that separated the heavens and the earth, and ...united

> and unified the universe,...But...it did this by substituting for our world of quality and sense perception, the world in which we live and love and die, another world - the world of quantity, of reified geometry, a world in which, though there is a place for everything, there is no place for man (Koyré(1965)23).

3.3. REDUCTIONISM AND THE PROBLEM OF 'BECOMING'

We have seen how the acceptance of reductionism resulted in deep epistemological problems which have been occupying philosophers during the past three hundred years. How is it possible that man's mind, which is in contact with the outside world only through the 'window' of the unreliable senses can have knowledge about this world? What is the nature of the human mind that it can know? Are man's conceptualizations of the world necessarily correct or are they, too, subject to change and improvement? What - if knowledge is so problematic - is the status of all those laws which are being discovered by scientists and which enable them to predict and control natural events?

It is clear that we cannot expect answers to these well known epistemological problems to arise within the framework of the reductionist philosophy itself. In the one-level ontology of reductionism there is no place for man and his quest for knowledge. If reality is nothing but the sum total of the movements of the ultimate entities in space and time, living things including man himself are but semi-real effects of this great and strange happening. In order to introduce an observer into such a universe he has to be artificially superimposed without being rooted in the metaphysical system itself. The gap between the observer and the observed has traditionally been bridged by postulating a guarantor who warrants that man's claim to knowledge is not a mere illusion. Thus Descartes' God who is not a deceiver provides the ultimate legitimation for those clear and distinct ideas upon which the rationalist framework rests. The empiricist, too, needs a guarantor whose benevolence has equipped human beings with reliable organs of sensation without which genuine knowledge would be impossible. Even the Kantian who has resigned himself to the belief that we live and die in the prison of our conceptual frameworks has to rely on a benevolent God who created these very frameworks to fit the world. Without this belief, he, too, would have to submit to utter scepticism.

The increasing acceptance of the theory of evolution has brought another kind of guarantor into the epistemological debate. It is said that the fact of evolution itself is assurance enough that we can put trust in the reliability of our organs of sensation as well as in the power of the human mind. Those faculties have been selected by the external world and if they would not 'fit' this world, i.e. reflect it truthfully, our species would not have survived as long as it did.

Yet, to propose an evolutionary justification for our claim to knowledge sharpens the conflict rather than to alleviate it. For it is hard to see how any theory of biological evolution can ever be reconciled with an ontology which asserts that nothing genuinely new can ever come into being, and which has eliminated life altogether from its conceptual model of the real.

In order to understand living things we have to think about them in thermodynamic rather than in dynamic terms. Living things feed on negentropy and thereby sustain their complex non-equilibrium structures. The conceptual relationships between thermodynamics and dynamics are, however -as we have seen above - anything but clear, indeed these sciences are probably incompatible.

Prigogine has recently called thermodynamics the science of becoming and dynamics the science of being (Prigogine(1980)). Thus, we should not be surprised about the difficulties in reconciling both sciences, for we are facing - although in different guises - the old philosophical problem which set the Greek mind on fire: how can we reconcile Being with Becoming?

It is most noteworthy that one of the oldest conceptual problems has surfaced again after having been relegated to the status of a pseudoproblem at the beginning of the scientific revolution. With the discrediting of the old Aristotelian science, the distinction among the various kinds of change was also abandoned. Of the various types of change only 'locomotion' was retained. Indeed, the movements of the planets and the stars and the inquiry into the laws of falling bodies stood at the center of the scientific interest of this period.(3) Believing that living things are nothing but aggregates of minute, solid particles, it was thought that they, too, followed the universal laws of motion and would eventually yield to scientific investigation based upon the laws of dynamics. Thus dynamics became the universal science.

The problem of understanding the intricacies of living things, in particular their apparent goal-directedness, was "solved" by postulating that organisms are nothing but complicated machines which can be understood on the same terms. Like most metaphors, this one, too, can be of value within a limited context but can actually harm our understanding if applied outside its legitimate range of application. Thus it did good service to Harvey, who by comparing the heart with a pump discovered the circulation of the blood. To say, however, that living things are nothing but machines, i.e., to take that metaphor quite literally, is misleading, to say the least. Machines do not develop, they do not grow, they do not evolve. None of these characteristics which are so crucial for the understanding of the phenomena of life are to be found in human artifacts. I have called the machine metaphor 'most unfortunate', because taken out of the appropriate context it obliterates the real conceptual issues and gives the impression that we understand more than we actually do. In particular it hides the fact that from within the reductionist framework the phenomena of becoming cannot be accounted for. Yet, these features are most important for the understanding of living things, their development and evolution.

The problem of 'becoming' is by no means restricted to the biological sciences, although they appear there most conspicuously. Even in the heart of theoretical physics we find conceptual problems associated with the phenomena of qualitative (i.e., non-dynamic) change. Thus it is a notorious problem for quantum mechanics to account for the lifetime and decay of a particle. Yet any atom will eventually decay, once it has been brought to an excited energy level.

> The clearest example of the predictive incompleteness of quantum mechanics is the disintegration law of radioactivity. To take the example of an atom of a member of a radioactive series: its lifetime is certainly a part of the description in the theory, in fact an essential part of a test statement in the theory; but the statement cannot be derived within the theory (Post(1971)280).

In spite of its universality the problem of 'becoming' has resisted conceptual clarification. This, however, should not surprise us. For as long as we lead the investigation on the basis of a reductionist framework, we are excluding the solution a priori. Why this is so can easily be seen once we understand the source of the exclusion of the phenomena of 'becoming' in favor of those of 'being':

The question of how a thing can change without losing its identity was one of the deepest conceptual puzzles which occupied the Presocratic philosophers. They argued that once a thing has changed, it is not the same thing anymore; how, then, can change be possible? The two bold answers given to that difficult problem are associated with the names of Herakleitus and Parmenides. Herakleitus argued that the whole question was a non-issue in the first place, for there are no things, only processes. Change is inevitable, the apparent stability of the world a mere illusion.

Parmenides answer was no less daring and counterintuitive. He argued that what is cannot come out of what is not (Cornford(1912)153). Change is logically impossible for any thing - for any being. The plurality of phenomena is only apparent; anything that is claimed to be real must also be ultimate. Being must not be allowed to spring from not-being. Needless to say, this answer was not very convincing, either. The dominance of change in the world of our experience is too obvious to be argued away. Nevertheless, it was Parmenides' and not Herakleitus solution which was eventually adopted, though in a different guise.

The Atomists Leukippos and Demokritos proposed a most ingenious solution to the seemingly unsolvable puzzle. They declared that things do not change intrinsically, although they change their position in the void. Things are nothing but aggregates, arbitrarily formed in the coming together of independent individual atoms. The coming into being and perishing of all things is nothing but the aggregation or dissipation of a set of atoms, moving mechanically in the void.

> We are thus left with a conceptual model of the real, in which perfect clarity of conception triumphed, and which, accordingly, held the field in science till yesterday. The Gods and the immortal soul have vanished in the dance of material particles. <u>Physis</u>, though the name may be retained, has lost all its ancient associations of growth and life. there is no such thing as 'growth'; nothing but the coming together and separating of immutable atoms. All motion had once been the inherent property of the living thing, the proper expression of its inward life. Now the life is wrung out of matter; motion, no longer a spontaneous activity, lies not within, but between, the impenetrable atoms. Instead of life, nothing is left but the change of space relations (Cornford(1912)158).

At the foundation of atomism lies the denial of becoming. The atomistic solution to the problem of change remains in essence Parmenidian, in that it accepts the immutability of 'being', and explains 'becoming' as nothing but mixing. Parmenides' doctrine that 'out of what is in truth one, a plurality cannot come, nor yet a unity out of what is really many' was adopted by Leukippos (Cornford(1912)155), and has ever since then provided the foundation of any atomistic metaphysics.

We must therefore not be surprised that our atomistic-reductionistic ontology cannot accomodate qualitative change. <u>It was never meant to</u>! This, of course, was always known to many philosophers and scientists. For example W.Thomson and also Helmholtz observed in the 19th century that atomism cannot "explain" any properties except those which are attributed gratuitously and a priori to the atom itself (Santillana(1941)19). The postulate that what is in the whole must necessarily be in the parts results in the denial of the coming into being of new properties and leads to all the epistemological and conceptual puzzles I have been alluding to. Yet, the hold of the atomistic metaphysics on the mind of most philosophers and scientists is still as strong as ever and many of them will even claim that all the modern scientific evidence is in favour of the atomistic way of looking at the world:

> Atomism is the recurrent image that has dominated scientific thought for over two thousand years. If anything were more remarkable than its purely a priori origin, it would be its enduring through the ages as a strict matter of faith, its capacity

> for drawing new life from seemingly unrelated discoveries, and its ultimate vindication (Santillana(1941)17,my italics).

3.4. A WORLD IN FLUX

Is Santillana correct in his conviction that modern science confirms the atomistic view of the universe? Is it not rather the case that whenever we have discovered new, immutable entities, they turn out to be nothing but the result of violent processes which in their interaction restrict themselves and give the superficial appearance of stability?

> The real constitution of things
> is accustomed to hide itself
>
> Herakleitus

The seemingly eternal features of the universe have turned out to be long lasting only with respect to the life-span of human beings. Stars are born, evolve, and pass away, matter dissolves and looses its solidity. Rocks are nothing but atoms in motion, atoms - once eternal by definition - disintegrate into electrons, protons and neutrons. The identity of these elusive entities, however, gets lost in the

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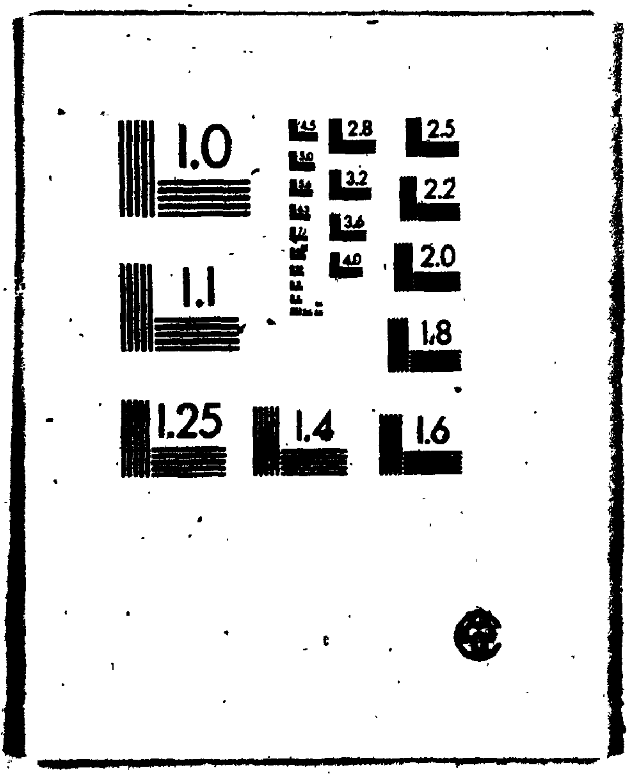


whirl of subnuclear particles which physicists have to postulate in order to accomodate all those strange properties of matter, they have discovered with their mighty particle accelerators.

> The unseen connexion of opposites is in fact stronger
> than other more obvious types of connexion
>
> Herakleitus.

What used to be regarded as an independent permanent substance - the material particle - turns out not to be sufficiently unchanging to be treated as a thing existing in isolation in its own right, but is rather to be regarded as a changing system in a changing environment. The seeming stability of matter is due to the ongoing electrical interaction between a positively charged nucleus and the negatively charged electron. It is this interaction that structures the electrons into a dynamic state of equilibrium in which they become strong electric fences, creating the apparent solidity of the ground on which we stand.

> Men do not know how what is at variance
> agrees with itself.
> It is an attunement of opposite tensions
> like that of the bow and the lyre
>
> Herakleitus.

The whole of the world that we take in with the senses is structured as objects because of the nature of the forces in or between them. Thus it becomes our task to comprehend the interaction of those forces and realize that things are not essentially separate but cohere in a subtle and often elusive way. The universe in flux between tensional opposites is symbolized by Herakleitus through the image of a flame for

> the quantity of fire in a flame burning steadily appears to remain the same, the flame seems to be what we call a "thing". And yet the substance of it is continually changing. It is always passing away in smoke and its place is always taken by fresh matter from the fuel that feeds it (Burnet(1930)145).

The image of the flame as the symbol of existence demonstrates dramatically the differences between an atomistic and a process view of the universe. In the atomistic view we look at the world of change and declare it to be mere illusion. If we want to gain knowledge we have to delve behind the appearances and search for the ultimate entities of matter. In the process view we acknowledge that the world is continuously in flux. What we need to explain is why we experience stability at all, why we conceive of objects as stable entities enduring through time. Thus, the atomists conceive of the universe as an essentially timeless entity in which qualitative change becomes a mere illusion. The world is inherently stable. It is us who - because we are deceived through sensation - give the appearance of change to an essentially stable universe. Adopting a process metaphysics, however, we cannot conceive of any eternal stability. If things appear to be stable, then <u>this</u> is due to our activity as perceivers.

The history of western science and philosophy has essentially been a story demonstrating the success of the atomistic conception of the universe. With some notable exceptions, such as Herakleitus, the Alchemists and Whitehead, philosophy and science have been carried forward by timeless reductionism. This is mainly due to the fact that atomism is much more amenable to mathematical treatment. And central to the progress in physics during the past three hundred years has been the application of ever more sophisticated mathematical techniques.

The other major factor which contributed to the neglecting of the process view is the fact that until the second half of the 19th century the world indeed appeared to be much more stable than it appears to us now. Wherever we turn now, we seem to be surrounded by evolutionary changes. Darwin's theory of evolution and the discovery of the Second Law of Thermodynamics are but counterpoints in a change of worldview which has been going on for the past one hundred years. Meanwhile we got used to the idea that the universe itself is evolving, and that the stability of the atom is elusive. Instead of finding stability and security, wherever we look, we discover evolutionary processes leading to diversification and increasing complexity. Today stability seems to be the exception and dynamic change the rule. Yet this fundamental change in our vision of the universe has still not been fully assimilated. We are still carrying the same metaphysical presuppositions with us which helped the pioneers of modern science to get it off the ground.

3.5. HOW TO CREATE STABILITY IN AN UNSTABLE WORLD

It has been only very recent that the emerging new paradigm is gaining more impetus, and a burgeoning literature is ample evidence that a new 'Evolutionary Vision' - to use a term coined by Boulding(4) - is emerging. The fusion of new results in the thermodynamics of irreversible processes, in systems theory, in ecology, and in evolutionary theory seems to be close to a critical point at which the new paradigm will come fully to the open and substantially alter even our deepest metaphysical beliefs. This view is voiced by Nobel Prize winner Ilya Prigogine, who speaks of his

> conviction that we are in a period of scientific revolution - one in which the very position and meaning of the scientific approach are undergoing reappraisal - a period not unlike the birth of the scientific approach in ancient Greece or of its renaissance in the time of Galileo (Prigogine(1980)XIII).

It is clear that a fundamental restructuring of our metaphysics must be accompanied by an equally substantial change in our epistemology. A new way of conceiving of the structure of the world is bound to lead to a new conception of human beings, their relationship to this world, and their role as perceivers and actors in it. In the present thesis I am sketching an epistemology which is based on the assumption that the world - and this includes the human observer - constitutes a matrix of mutually interacting processes. It would be far beyond the scope of a dissertation, however, to develop a fully fledged philosophical system which encompasses all the relevant scientific and philosophical issues. Thus, the present work should rather be seen more as a scouting out of a possible way of constructing such a system than as a full-fledged philosophical system in its own right. Needless to say, I also do not claim that this is the only way to proceed. At the present stage, however, where the philosphical community still appears blissfully unaware that such a new world view is in the making, it might already be worthwhile to bring this new approach to its attention by explaining a new way of looking at human beings and their relationship to the environing world.

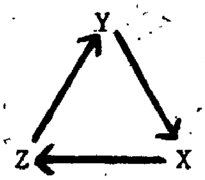
Let me begin by discussing the most fundamental distinction which holds when we look at the world conceived as a flux of interacting processes.

Natural processes can be distinguished by the kind of thermodynamic system within which they operate. Depending on whether or not systems can accept or dissipate energy from their surroundings, they are called open or closed systems, respectively. Open systems can exchange energy (or matter or information) with other systems, the latter are said to form their environment. In contrast, a closed system does not permit energy (or matter or information) to leave, neither can it accept any; thus, strictly speaking, closed systems have no environment and are therefore not found in nature, although it is assumed that the universe as a whole constitutes one gigantic closed system. When we talk about closed systems, we are referring to systems which - at least for the purpose of investigation - are insulated from their environment in such a way that it becomes permissible to neglect the always existing exchange of energy.(5) In order to have a truly closed system, we would need a perfect insulator; in practice, however, there does not exist such a thing. The internal energy of a perfectly isolated system would remain constant forever, which is just another way of stating the principle of the conservation of energy.

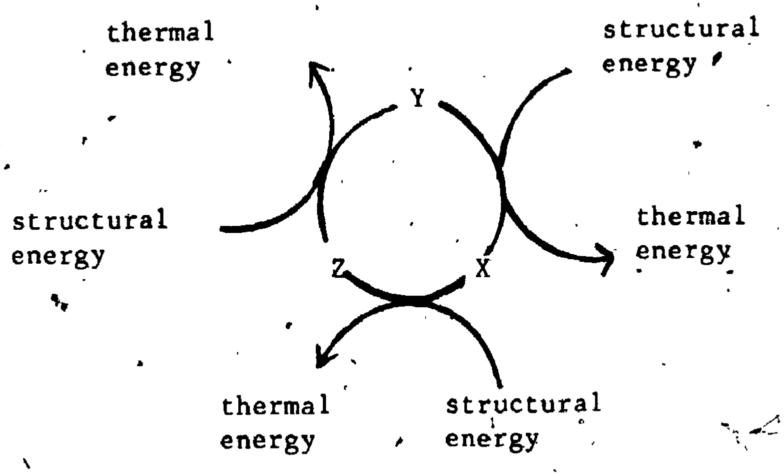
A closed system will tend towards thermodynamic equilibrium which is the state in which entropy reaches its maximum value. Thus, Clausius stated in 1865: "The entropy of the universe tends to a maximum".(6) Equating entropy with disorder, we can say that the thermodynamics of isolated systems evolves towards the state of maximum disorder. Within the closed system a variety of complex physical interactions take place. Depending on the temperature of the system, different physical aggregates may form. The formation of certain types of ordered structures in physics is a consequence of the laws of thermodynamics applied to <u>closed</u> systems at thermal equilibrium. Ice crystals or various forms of liquid water are examples of such equilibrium structures.

Let us now shift our interest to open, non-equilibrium systems which are of central importance for the present inquiry. The energy of an open system can be changed by a flow of heat or other types of energy across its boundary. Thus it can gain energy from, or lose energy to its environment. Processes occurring in open systems can interact in such a way that they form structures of a very different kind, compared to the equilibrium structures we discussed above. The most important of these non-equilibrium structures are living things. Living systems are characterized by an internal decrease of entropy and an appearance of order from the chaotic thermal movements of the molecules. Such a system needs permanent interaction with the environment in order to maintain its existence. Streams of energy, matter, and information pass through it, and it is fed by negative entropy derived from the environment. Thus, the increase in and the maintenance of the organization is paid for by entropy increase in the surround. There is an essential difference between the laws for systems at equilibrium and those for systems far from equilibrium. The former tend to maximal entropy production, the latter "feed" on negative entropy. Thus it appears that living matter tends to flout the Second Law of Thermodynamics. It follows that from the point of view of thermodynamics organisms are highly improbable arrangements of matter.

Intensive theoretical and experimental research into the nature of open, far from equilibrium systems has led in recent years to much better understanding of those systems. In particular the work of Prigogine and his co-workers have provided a foundation for the understanding of systems which form and maintain themselves far from thermodynamic equilibrium. These open systems are called 'dissipative structures' because they convert structural energy into thermal energy by irreversible processes. This thermal energy is then dissipated into the environment. It has been shown that these structures can form spontaneously in open chemical reactions far from equilibrium. Under specific experimental conditions a new molecular order appears that is stabilized by the exchange of energy with the outside world. Dissipative structures are characterized by their ability to stabilize their organization by "feeding" upon negentropy extracted from the environment. Both substance and energy of these structures are constantly being lost; yet through their capability to extract new energy from their environment, they can constantly replace the losses they are suffering, and thus maintain their precarious existence. In other words, those structures show a remarkable autonomy (although by no means independence) from their environment. This autonomy is made possible through the non-linear autocatalytic mechanisms which characterize dissipative structures. A fairly elementary example would be the system



(X,Y,Z, being certain chemical compounds). The autonomy of the system (X,Y,Z) is caused by the cross-catalytic mechanism by which Y produces X, X produces Z, and Z in turn produces Y.(7) If we also want to show the relation with the external environment we would enrich our diagram in the following way:



This diagram might help us to understand in which sense a dissipative structure (X,Y,Z) is autonomous from and in which sense it is dependent on the environment.

Dissipative structures renew themselves continuously, they absorb energy which serves to maintain and improve their self-organization. In virtue of the autonomy of dissipative structures, members of these structures, i.e. molecules, can be characterized in two(!) different ways. On the one hand they are simply molecules like any other molecules, and the normal structural description of chemical entities applies to them. On the other hand a molecule which participates in the maintenance of a dissipative structure has also a function, which is to contribute to the ongoing self-renewal of the dissipative structure. This characterization brings out most clearly the difference between equilibrium structures and dissipative structures. The former are merely aggregates of matter, structuring themselves in the way determined by the temperature of the system. The molecules or crystals making up those structures form a pure collection of individual elements without any overall systems organization.

What marks off the dissipative structure is that its components have not only a structure qua molecules but also a function qua member of a coherent and interrelated organization. The stability of the system, i.e. the possibility of its survival under conditions where it is thermodynamically unstable, constitutes a constraint on the variety of possible configurations of the molecules making up the system. The two ways in which order can arise in physical systems can thus be described best by saying that equilibrium structures display architectural order which is determined by equilibrium conditions, whereas dissipative structures also display functional organization which insures the integrity of the system under conditions where it is thermodynamically instable.

We have seen that far from equilibrium, chemical systems that include autocatalytic mechanisms may lead to dissipative structures. Those structures are distinguished through their functional organization which enables the system to act as a whole. The symbolic aspect of matter, i.e. the existence of the genetic code, constitutes the most dramatic exemplification of the functional aspect inherent in dissipative structures. The carriers of the information contained in the genes, i.e. the polynucleotide molecules known as DNA, are from the structural point of view simply linear macromolecules with certain physical properties, like molecular weight, conformation,etc. From the point of view of the biological system, however, this particular macromolecule fulfills a specific function, i.e. it instigates the production of a different molecule, say, an enzyme, which is needed for the maintenance of the organism. Pattee points out that the structural and functional descriptions of the same macromolecule

> are complementary in the sense that neither model can be reduced or derived from the other by any logical process within the rules of the two models. We cannot study the structure of DNA from the purely objective chemist's point of view and derive the genetic code or any corresponding protein function, nor can we look at the behavior of an enzyme from a purely functional point of view and derive any chemical property of the corresponding DNA molecule (Pattee(1981)120).

Within a substance metaphysics we cannot account for the differences between the living and the non-living. The reason for this is straight-forward: There is no difference in substance; the building blocks for life and non-life are identical. Once, however, we adopt a process metaphysics we begin to study processes in their interaction, and we realize that there is, indeed, a fundamental difference between the living and the non-living, or rather between the dissipative structures and the equilibrium structures. As we have seen this difference turns out to be a difference in organization between structural organization in equilibrium structures on the one hand, and functional organization in dissipative structures on the other. Thus life turns out to be a phenomenon of self-organization, whereby the living system manages to conserve its properties despite continuous turnover of all the components.

The idea that stability is not due to underlying stable material entities but rather a result of organization, is intimately tied to the process view which asserts that stability appears as a result of the ongoing interaction of forces which mutually restrict each other. To understand the natural world we must therefore investigate the possible interactions among processes leading to increasing complex organization in the realm of the living and to increasing disorder in the realm of the non-living. In the 'thing' metaphysics life appears as an ultimately meaningless superstructure over inanimate matter. In the process metaphysics we are interested in the organization which makes it possible for a system to be a whole, autonomous unit that is alive.

We have seen that living things are dependent on the environment from which they extract energy and into which they drain entropy. The greatest problem for any living thing is to survive in this inherently hostile environment. This is the problem of adaptation. It is important to note that it makes sense only to speak of adaptation in the case of living things. To say that a crystal is adapted to its environment is rather trivial, because the crystal cannot help but being "adapted". If we take it away from the conditions under which it is thermodynamically stable and put it into a situation where it is instable, it will begin to decay towards the direction determined by the thermodynamic course of events. A crystal is wholly at the mercy of its environment, it has no autonomy. Only systems which have the possibility of being non-adapted can <u>improve</u> their adaptation. This happens in evolution. There we find as the science of palaeontology demonstrates an evolutionary thrust towards higher and more complex forms of organization. Yet, in evolution species not only undergo changes themselves, they also change the environment within which they live. It is obvious that the appearance of life on earth has changed our planet in a most fundamental way. The earth as it is presenting itself to us now has certainly little in common with the barren rocks and dead waters of the prebiotic times. In cultural and scientific evolution as well we are facing an ever increasing complexity of societal, instrumental, and conceptual structures. We are likewise confronted with an environment which has been profoundly affected and transformed by the human actor. It is therefore tempting to view human cultural evolution as a continuation of biological evolution. It should be clear that this is not meant to be a reductionist view in the sense that cultural evolution ought to be reduced to biological evolution. Those claims have no place in the nonreductionist framework of a process metaphysics. What we can attempt to find, however, are common patterns of organizational complexity and development.

Let us therefore try to understand what is meant by functional complexity and organization in the realm of the living and ask the question of how this increasing complexity is related to the phenomenon of adaptation. In other words, what we have to understand is, how autonomous living things can and do relate to their environment. This, of course, is the great epistemological question in its most general form. It is hoped that by gaining insight into the relationship between the living and the not-living we can prepare the way for a better understanding of how human beings, dissipative structures in their own right, organize their own experience, and can gain knowledge about this strange non-equilibrium world within which they live and which they transform.

NOTES TO CHAPTER THREE

1. Quoted from Prigogine (1980),157.

2. It may appear strange to list Descartes' name among those who favored atomistic reductionism. Yet, Descartes only denied the existence of a vacuum, Cartesian substance remains particular and thus ultimately akin to atomism.

3. It is, however, by no means the case, that the mechanical philosophy was the only important scientific tradition of the time. In fact, various hermetic traditions remained influential during the whole period of the scientific revolution, and most major scientists pursued alchemical as well as 'modern' mechanical research. See(Bonelli(1975),West(1961)).Yet, the very fact that history has been rewritten so as to obliterate those "non-scientific" influences on all the major figures of the time, demonstrates the tremendous influence of the mechanical philosophy upon philosophers, scientists, and historians. The mechanical philosophy was never fully and wholeheartedly accepted, yet, we are conditioned to believe that it constitutes the only genuine scientific outlook.

4. An impressive discussion of the sources and ramifications of this "Evolutionary Vision" is to be found in a book with the same title, edited by the late Erich Jantsch (Jantsch(1981)).

5. Genuine closed systems have hardly any practical interest. In practice we always want to do something with the system or get something out of it. Adiabatic processes,for example, occur in systems closed with respect to heat transfer, but they are open in the sense that they permit an exchange of energy in order to perform work.

6. Quoted from Prigogine (1980)78.

7. Examples of such primitive dissipative structures are given in Prigogine (1980)120-3.

CHAPTER IV

A WORLD OF HIERARCHIES

4.1. STRATEGIES FOR SURVIVAL

In chapter one I proposed that we should replace the old question "how can we know the world" by the new question "how can the world be such that we can know it". In order to answer the latter question I suggested that we should employ metaphysics constructively and create a system within which metaphysics and epistemology mutually support one another.

In chapter two I developed a view of science as an extension of perception, arguing that the constructive features of our perceptual and conceptual frameworks make it possible for us to distinguish between changes which are relevant for a particular purpose and those which are irrelevant and are seen as mere "noise". Only against a fixed framework can regularities be detected and predicted.

In chapter three I investigated the widely accepted metaphysics of reductionistic atomism and concluded that this metaphysics is not suitable for our purpose, i.e. that it is incomprehensible how human beings could have knowledge in a universe of that kind. Turning to a process metaphysics I argued that modern science lends at least as much support to this latter view as to the former. Indeed, in light of the increasing realization of the importance of irreversible processes, there are good grounds for believing that a process view provides a better conceptualization of the universe than the old atomistic metaphysics. I then proceeded to give a somewhat more detailed account of such a universe of processes based mainly upon insights derived from Prigogine's important work on dissipative structures.

I will now weave the various threads of argumentation together and develop an epistemology based upon the process metaphysics which I outlined in the last chapter. In order to do this it is necessary to look in some detail at the organization and the evolutionary changes a dissipative structure may undergo. Thereafter I will view the observer as a dissipative, i.e. order creating, structure, and raise the question of how the observers' capacities can be improved in his interactions with the external world.

Let us recall that dissipative structures are very precarious entities which exist far from thermodynamic equilibrium. They can continue to exist under those conditions only because of their capacity to extract energy from the environment and transform it into high-energy biomolecules, which can be utilized for the maintenance of their structure. This kind of system is continuously threatened by a possible decay into thermal equilibrium, and we can easily imagine a natural selective mechanism favoring those structures which succeed in delaying that decay.

The most important "inventions" dissipative structures have made with respect to their future survival are a) the development of a genotype and b) the development of hierarchical organization. One may summarize the principle which lies behind the invention of the genotype by pointing out that it doesn't matter how well constructed a phenotype is, sooner or later it is bound to succumb to the Second Law of Thermodynamics. However, it is possible to defeat death and gain potential immortality if one succeeds in finding a mechanism by which the <u>information</u> of how to construct a new dissipative structure can be passed on. The invention of the genotype indeed makes a virtue out of the inevitable evil, i.e. death. It is only through the dissolution of the old and generation of the new individuals that genotypic changes can be introduced into a population of organisms. However, the capacity of the genotype to change, i.e. to undergo mutation and reassortment, is a necessary prerequisite for the occurrence of evolutionary change. The genotype codifies all the biological information necessary for the construction of a new phenotype; that is to say, it also contains all the information necessary for hierarchical organization.

Still, in spite of the relationship between phenotypic hierarchical structure and genotypic codification of this structure, it is well worth considering both features separately. For, although all living things are made up of a genotype and a phenotype which displays hierarchical organization, both types of inventions made by dissipative structures are utilized in various degrees by different species. Therefore it is useful to distinguish between two rather different evolutionary strategies.(1) Let me call the first strategy the 'population strategy'. Organisms adopting this kind of strategy leave their individual members rather underdeveloped. Members of these species multiply very fast. This makes it possible for the population to adapt to changing environmental conditions by letting many of its members die. Those few that survive can, however, make up for that loss in a brief period of time. Bacteria are a paradigm example of organisms utilizing the 'population strategy'.

The other kind of strategy I have been alluding to puts more emphasis on the survival of the individual organism. Here it is the individual member of the species that can adapt to a variety of heterogeneous environments. Those individuals tend to have longer lifespans, less progeny, and, most importantly, the species they belong to display in their evolutionary history an ever greater thrust towards complex hierarchical organization.

Within the present context we are only interested in the latter kind of strategy. When we talk about evolutionary progress, about the 'tree of evolution', leading from relatively primitive to highly complex organisms, we have undoubtedly those species in mind that adopted the 'individualistic strategy'. If we are interested in progress through evolution, in particular progress which leads to the development of ever greater capabilities of individuals, clearly then we have to look closer at the characteristics of hierarchical organization. This I will do in the next section.

In order to prevent misunderstandings, let me emphasize, however, that there exists no single species which adopts only one of those strategies. In reality we always find a mixture. Yet, as I indicated above, some species, i.e. the more primitive organisms, employ predominantly the 'population strategy', whereas other kinds of species, for example warmblooded creatures put greater emphasis on individual survival. The difference between a virus on the one hand, and <u>homo sapiens</u> on the other demonstrates strikingly to what divergent results the adoption of different strategies may lead to.

4.2. CONTROL HIERARCHIES

Before turning to the hierarchical organization of living organisms I will discuss a more familiar example, and will elaborate on some basic concepts of hierarchical structures in terms of human social organization. It should, however, be clear that human organization is <u>not</u> the best example of complex organization. Humans are rather underdeveloped in their understanding and handling of complexity. They have still much to learn from natural systems, whose admirable coordination is still only insufficiently aped in our own attempts to construct complex organizational ~~hierarchies~~.

The type of hierarchy I am going to describe next, is called a <u>control hierarchy</u>. Later I will also discuss a different kind of hierarchy, the <u>structural hierarchy</u>. Both terms I borrowed from Pattee upon whose insights I will frequently draw in the following discussion. See (Pattee(1972),(1973),(1981)).

Let me begin my elaboration of hierarchical controls by looking at the regulation of the traffic flow in a large city. There we find as a very basic control device a traffic light. In certain time intervals such a light will change from red to green. The function of the light is to safeguard the passage of automobiles, bicycles, and pedestrians. In a large city with much traffic those lights have also another function. They are to regulate the speed of the traffic flow in order to maximize the volume of traffic the city streets can handle. In order to fulfill this function the periods various traffic lights are on red or green have to be regulated and coordinated. On the main arteries of the city we will find many such coordinated traffic lights. If the regulatory system is sophisticated enough, then the various arteries will also be coordinated so as to optimize some parameter or set of parameters, such as maximizing traffic flow, increasing fuel economy without foregoing safety, etc.

The system I have been describing is distinguished by several levels of organizational control. On the most fundamental level we encounter the individual traffic light which controls only the traffic going into one particular direction. The next level of control is constituted by a set of traffic lights at the crossing of two streets. They are coordinated and jointly control this particular crossing. On the next higher level various of these crossings are coordinated, i.e. the input of the individual set of lights is determined by the demands of the whole artery. The next higher level of control consists then in the determination of which speeds should be permitted on each individual artery in order to maximize the coordination of the traffic in various parts of the city. Like most hierarchies, this one, too, is open-ended, and we can conceive of many more levels of organizational control. In practice, however, we do not find these levels, because - as I indicated above - we are still not very good in handling many-levelled systems, and often enough a single traffic accident can jam the whole system.

Each level of control determines the values of the parameters by which the next lower level is to operate. For example, the time intervals an individual traffic light operates on red or green are determined by higher level goals, such as the desired speed of the traffic on the main street.

The principle of hierarchical organization enables us to correlate functionally the higher level goals of a system with the practical activity of the members standing at a very low level of the hierarchy. Thus, a general who directs his troops in a war has to be sure that his ideas get translated into activities on the battlefield. it is unlikely that the general and the common soldier will ever meet. They are not joined through personal acquaintance but through a hierarchical network of commands that filters through the various levels of a military hierarchy.

In order to have a hierarchy we need at least two levels. Both levels are coordinated through the controls which the upper level exerts upon the lower level. What happens in a control situation is that the upper level puts constraints on the degrees of freedom available to the lower level. For example, a control device like a traffic light might constrain the traffic on the side streets, and thereby selectively favor the traffic on the main street.

Let us now return to the discussion of living things and their hierarchical organization. How are we to characterize the various levels of control and which kind of constraints guide the multitude of chemical reactions in such a way that they can be of use to the organism?

The most fundamental constraints which every living system has to face is given by the fact that it has to survive under non-equilibrium conditions. I pointed out above that the invention of a genotype and the development of hierarchical organization can be understood as responses to this threat to survival. Any possible genotypic and phenotypic change is thus constrained by the necessity to keep the system going in spite of its non-equilibrium nature. In the course of evolution living things have succeeded in improving their survival capacities to a remarkable degree. Those improvements are to be found almost exclusively in their phenotypic organization. The organization of the genetic system, i.e. the DNA-RNA-protein succession, has apparently remained unchanged for most of evolutionary history. This is not surprising, for a change on such a fundamental level would in all likelihood be lethal for the organism within which it occurred. In contrast to the stability so evident in genetic organization, phenotypic organization has undergone dramatic changes. This is amply documented by the diversity of living species, both, past and present.

Living things can extract energy from their environment and can improve or relax constraints on the thermodynamic course of events. By developing ever more hierarchical levels of control they have succeeded in controlling and channelling the energy intake which keeps the system going. Thus life thrives even under the most adverse conditionsin the deep seas, the burning deserts, or the frozen arctic. This amazing feat is accomplished through the controlled intake of structural, and dissipation of thermal energy.

How do these controls function? What are the "traffic lights" directing the energy flow within a cell? The molecules which are responsible for the orderly progression of biochemical reactions are called enzymes. They are catalysts whose function it is to accelerate a certain chemical reaction. By influencing the rate of chemical change, the catalyst ensures that the required chemical reactions occur at the right time and at the right place. From a structural point of view enzymes are merely molecules like other molecules (in the same vein traffic lights are nothing but physical structures). What distinguishes the enzyme molecule from other molecules is that it also has a function, which is to contribute to the overall maintenance of the dissipative structure. The enzyme which controls the lower level reactions is in turn controlled by constraints originating at the next higher level of control.

In order to understand this control mechanism, we have to realize that the enzymatic capacity of the molecule only arises within a certain context.(2) Both enzyme and substrate molecules may exist within the same solution without any reaction taking place. Only under certain well defined environmental conditions will the enzyme molecule fold in such a way that an active site is formed which was not present previously. This optimal configuration can then react with a suitable substrate molecule. Thus the activity of the enzyme molecule can be controlled by regulating the thermodynamic conditions of the surroundings. These conditions in turn may be controlled by a variety of other chemical reactions, including the one which is to be controlled. In the latter case we speak of a feedback situation. There the consequences of the action of a system are referred back to the system as part of its input, thereby influencing its subsequent output. In living things we find many more levels of control often connected in feedback circuits, leading to a staggering complexity which is still not fully understood. This is, of course, not the place to discuss these most interesting cybernetic mechanisms in detail. Rather, the brief excursion into this exciting science is meant to bring some basic features of hierarchical organization into focus.

Hierarchical organization is a means for creating stability in an otherwise chaotic world. This created stability is internal to the system, and caused by mutual interactions of a great number of processes. External to the system we find a basically hostile surrounding. This is due to the fact that the system is not in equilibrium with its environment. To create and preserve internal stability in spite of the ever present threat of thermodynamic decay, and in spite of the ongoing turnover of the components internal to the system, has been a continuous challenge to living organisms during their long evolutionary history. Those organisms which adopted the 'individualistic strategy' evolved towards greater and greater complexity. In the course of this evolution more and more levels of hierarchical control have been superimposed upon the older organizational structures. As a result of this thrust towards hierarchical organization, the sensitivity of the internal controlling and regulating devices increased dramatically.

The term used to describe the regulation of the internal environment is <u>homeostasis</u>. Many physiological variables, such as core body temperature and the pressure, ph, and glucose concentration of blood are subject to homeostatic regulation.(3) It is absolutely essential for the organism to keep those kind of variables under strict control. If some external disturbance drives such a variable outside its normal limits, the commencing change itself will activate a mechanism which opposes the external disturbance. The reason for the importance of this internally created stability is that it is only under stable, well defined conditions that the biochemical reactions necessary for the maintenance of the organism can take place. In order to keep these essential variables constant it is necessary for other variables to vary. Thus, the constancy is a dynamic stability, brought about through various processes which mutually interact and through this interaction create stability.

4.3. STRUCTURAL HIERARCHIES

After having elaborated on the distinguishing characteristics of a control hierarchy, I will now turn to the discussion of the other kind of hierarchy which is to be found in our universe of processes; this is the structural hierarchy.

At the various levels of this hierarchy we find different equilibrium structures such as atoms, molecules, crystals, and solids. This kind of hierarchy can be characterized as a hierarchy of forces, the strongest forces being responsible for the smallest or lowest level structures. One can also characterize this hierarchy by ordering its levels according to time scales of interaction. Thus the strongest forces which hold together the atomic nucleus are associated with the shortest time intervals of interaction, whereas larger time intervalls indicate weaker forces and are characteristic of larger structures.(4)

The various forces operating at different levels of the hierarchy operate almost independently of each other. If this were not the case, knowledge in our universe would be impossible. If every process were to interact with every other process no invariant features could be detected. Every observation would change the entities of its concern; experiments could not be repeated, the world would be a complete chaos. Instead of such constraintless interactions of processes we find a parsimony of interactions as a result of which the world appears hierarchically ordered.

> The world is a large matrix of interactions in which most of the entries are very close to zero, and in which, by ordering those entries according to their order of magnitude, a distinct hierarchic structure can be discerned (Simon(1973)23).

Thus we can investigate a chemical reaction without having to analyze the interattions within the atomic nucleus; neither do we have to take the changes in gravitational attraction into account, which may be due to the proximity of some planets. The slower motions of the higher level appear to be constants with respect to our measurement, whereas the faster lower level motions are averaged out (Pattee(1972)5). It is because of this "layered" structure that we can search for law-like relationships on one level and still neglect the forces of the upper and lower levels. Nevertheless, some interactions between the various levels do take place, they crop up as "disturbances" or "noise". In other words the levels are not fully separate, they are only "nearly decomposable", to use a term due to Simon (Simon(1973)11).

In our universe of processes we find no absolute stability. Yet, this does not mean that we cannot discover genuine regularities. Due to the fact that not all processes interact with one another, a hierarchy of entities appears. Entities on one level interact almost exclusively with other entities on the same level. We can therefore attempt to discover the relationships holding between those entities. The entities themselves are, of course, processes, stable only from the perspective of a particular level within the hierarchy. Thus the "objects" which surround us are stable only with respect to our everyday experiences, i.e. to the natural modes of perception which are our evolutionary heritage. Once we point a ray of electrons towards a table, say, we will discover different levels of reality. On this level we cannot see the table anymore; likewise in our everyday reality we do not see the atoms. This does not mean that our table, or the atoms, or the nuclear particles are unreal; it does mean, however, that in a universe of processes we find many levels of reality.

From the point of view of a "things" metaphysics this appears to be absurd. There can be only one particular object at the same space-time location. Thus, if our table is made up of atoms, then it is the latter which are real; if the atoms are made up of nuclear particles, then those are real, and so on down the reductionist scale.

We can however, find different <u>processes</u> at the same space-time location. Some of these processes will interact with each other, other's won't. As a result of this constrained interaction, stabilities appear at various levels of our structural hierarchy.

4.4. HOW TO HAVE KNOWLEDGE IN A WORLD OF PROCESSES

If we are to have knowledge in this strange world of processes, then we have to find means to focus upon one level at a time without being too much distracted by upper or lower level phenomena.

Scientific knowledge is always concerned with invariant relationships between "objects". In our world of processes objects are processes themselves and are stable only with respect to particular modes of interaction. If we change the conditions of experimentation, for example by using x-rays instead of visible light, we will be confronted with different objects located at a different level of the structural hierarchy.

Therefore it becomes the central epistemological problem of how to tease the various levels of the hierarchy apart such that they become amenable to scientific investigation. If we were to experience everything there is all at once, we would be utterly confused and incapable of accomplishing even the simplest task. The problem thus becomes how to <u>restrict</u> our access and let us perceive only one level at a time. In other words, we have to learn how <u>to control the conditions of our experience</u>.

The problem of how to constrain our cognitive access to the world has been most beautifully solved in the course of evolution. By restricting our visual experience to that small range of frequencies, the visible light, we experience mainly those features of the natural world which are of crucial importance if we are to survive the exigencies of existence. However, these natural restrictions are not enough, we need further constraints imposed by intelligent brains which let us stabilize our experience of the world and construct out of fleeting two-dimensional patterns a stable three-dimensional world within which we can orient ourselves and act in a meaningful manner.

We have seen that not all processes which constitute the world interact with each other, and that the appearance of structural hierarchies is a result of these selective interactions. In view of the fact that processes almost exclusively interact with other processes of similar frequencies (i.e. similar energy levels), stabilities do appear, although - needless to say - those stabilities are only relative to the perspective of a particular level of the hierarchy. This, however, does not minimize their importance. On the contrary, all objects which surround us are real in precisely this sense. We as physical entities are also "objects" on the same level of the hierarchy. We have to operate with and on those objects, and it is the task of our perceptual and conceptual framework to search out those aspects of the external world which are invariant with respect to our own cognitive activities, and belong to robust entities which we call 'objects'.

Being physical entities ourselves it is of crucial importance for us to control our interaction with other potentially dangerous physical objects. Following Gregory, I showed in chapter two that the sensations of touch and taste give more direct, less theory-laden experience of those entities. However, if we were to rely on those sensations exclusively, we would be in great physical danger. The importance of our visual and also auditory experience is that it enables us to learn about the environment without physically interacting with it. Being removed from potentially dangerous objects we gain safety, but our experience also becomes inevitably theory laden. Neither colors nor sound are robust,neither remains invariant in a variety of contexts. Therefore these sense impressions have to be calibrated against touch which presents us with more reliable properties such as size and shape. By coordinating various modes of sensation the child learns to distinguish between robust entities and those which are only a byproduct of the process of perception itself. By placing those robust entities within a space-time framework he begins to understand the world, and can make predictions about the future location and behavior of objects.

In chapter two I elaborated on some of the constructive characteristics inherent in perception and conception. Now, after having discussed the structural and control hierarchies, we can understand these constructive features much better as a means of controlling the conditions of our experience. Indeed, we can view the establishment of perceptual and conceptual control as the continuation of the evolutionary process which is distinguished through the development of ever more hierarchical levels of control. By stabilizing the internal environment, dissipative structures can survive even under adverse environmental conditions. By stabilizing the conditions of their own experience, higher developed organisms learn to orient themselves and act in a meaningful manner. The former process is entirely genetically determined, whereas the latter also involves individual learning during ontogeny. In our further development as cultural beings we learn how to attach names to things and handle these names in a language. Our linguistic capability enables us to select relevant details of objects and situations. What is or is not relevant, however, is largely determined by the cultural context. Myths, fairy tales, and metaphysical presuppositions alike provide us with a framework of basic categories through which those facts gain coherent meaning.

Thus, physiological homeostasis secures internal stability, perception lets us conceive of stable objects in a three-dimensional world, and culture provides us with our basic concepts which sustain the order in the universe for us.

It is now necessary to look in some greater detail at these conceptual control hierarchies and see if we can detect the same organizational pattern as we did in the previous examples.

4.5. A COGNITIVE CONTROL HIERARCHY

We have seen how by means of a control hierarchy stabilities are created. The best example is the phenomenon of biological homeostasis, where a multitude of interacting processes creates a stable environment within which certain specific properties of enzyme molecules emerge. Likewise I want to view our perceptual and conceptual frameworks as controlling devices which stabilize our experience of the world in such a way that we can distinguish between genuine stabilities which characterize robustness and those phenomena which are only a byproduct of our own cognitive activities.

Nowhere is the importance of control more evident than in modern science. Experimentation can only be conducted in a tightly regulated environment. As in homeostasis, we let certain parameters vary in order to keep others constant. This constancy is a necessary prerequisite for the understanding of lawful change. By means of a measurement we connect our theoretical conceptions _of_ the world _to_ the world. A measurement apparatus is part of the external world in the sense that it is a physical entity which interacts with other physical entities. The same apparatus is, however, also linked to our theoretical world. Our theoretical preconceptions determine what we intend to measure, and the results of a measurement will have to be interpreted according to these preconceptions. In other words, the measurement apparatus has not only a physical structure but also a function, which is to link the external world in a meaningful way to our theoretical world. Likewise, entities participating in a dissipative structure, besides possessing a structure _qua_ physical entities, also have a function _qua_ members of an organization; this, of course, is a distinguishing characteristic of a dissipative structure. In other words, I view the linkage of the external physical world to our internal theoretical world in the same way as the incorporation of physical structures into the organization of a control hierarchy.

The measurement apparatus itself is not a controlling device, but it is incorporated into a cognitive control hierarchy in the sense that the scientist has to control the conditions under which the measurement apparatus can fulfill its function. Only if the experimental setup itself does not produce disturbances can stable conditions be produced. Thus the scientist may have to create a vacuum, use ultra-pure reagents, isolate the apparatus against radiation, etc. He also has to calibrate the measurement apparatus itself in order to be able to distinguish between the ever present 'noise' and the actual measurement results. Which parameters the scientist will have to vary and which he keeps constant, against which disturbances he has to protect the experimental apparatus and which he considers harmless, which kinds of measurements are appropriate and which are unnecessary, all these factors are to be determined by the next level of the control hierarchy. At this level we find a cluster of scientific theories and models which guide the scientist in his activities. There, for example, we can watch him drawing figures of molecular orbitals, there, on paper, he lets electrons "attack" a particular chemical bonding, there he calculates the energies involved in the reactions, etc. In other words, at this level of control all his theoretical knowledge is harnessed and applied to a particular problem. The scientist also uses general principles or laws which help him to direct his activities. For example, the Principle of Le Chatelier will tell the chemist how to influence an experiment, and direct it towards the desired outcome (LeChatelier's principle states that a system in equilibrium reacts to a stress in a way that counteracts the stress and establishes a new equilibrium (5)). If the scientist is faced with the common problem of how to recreate a particular puzzling phenomenon under controlled laboratory conditions, then he may have to manipulate a host of parameters before this goal can be accomplished. Only after having learned how to control the situation, can he proceed with further scientific investigations, and pose more detailed questions which in turn may necessitate new experimental arrangements.

It is clear that the theories which the scientist adopts determine which parameters he varies, which he holds constant, and which experimental arrangement he chooses. Theories, however, are not self-authenticating. By means of theories we establish relationships between various observable properties; yet among the various observable properties only very few are deemed to be suitable for scientific investigation. Thus the question arises by what criteria does the scientist decide which observables are worthy of scientific investigation. Why does he prefer to deal with properties such as charge, temperature, pressure, instead of color or smell?

In order to understand the level of control which determines which observables are of scientific significance and which can be neglected, we have to consider the role mathematics plays in modern science. A modern scientific theory can be viewed as an algorithm, a set of rules telling the scientist how to calculate testable results, using observed data as a starting point. In order to utilize the power of mathematical reasoning it is necessary for the scientist to confine his attention to those properties which are capable of measurement and calculation. Once mathematical relationships have been established, the horizon of scientific inquiry can be widened.

It becomes therefore the primary task for the scientist to single out those properties which can be measured, and thereby turn a given scientific problem into a question for mathematics.

This method was pioneered by Kepler and Galileo. They geometrized the heavens and turned the problem of motion into the problem of geometrical bodies moving in geometrical space. According to Galileo "the book of nature is written in geometrical characters"(Galileo(1623)238). In order to read this book it becomes necessary to isolate the phenomena from their natural contexts, and study only the aspects of such phenomena which are measurable. "When the philosopher-geometer wishes to recognize in the concrete world the effects demonstrated in the abstract he must cut down the encumbrances of matter".(6) Only by applying mathematical reasoning to a nature which has been stripped of the deceptive secondary qualities can scientific progress be achieved. Without mathematical reasoning, however, human thought becomes "an aimless wandering through a dark maze".(7) In a similar vein Kepler said that just as the ears are made for sound and the eye for color, the mind of man is meant to consider quantity and it wanders in darkness when it leaves the realm of quantitative thought.(8)

By substituting for the real experienced world a world of geometry, Galileo and Kepler succeeded in erecting a vast body of mathematical theory upon the results derived through measurement. The mathematical method of Kepler and Galileo was so successful that their successors followed their pioneering thought. As a result of the increasing mathematization of nature knowledge gets ever more detached from surface appearances and from our everyday intuitions. For the colorful, qualitatively determined facts of common experience are repugnant to the precision of measure and therefore to the application of mathematical rigor. Another impressive example of the power of mathematical analysis is given by Newton's study of spectral colors. Newton succeeded in transcending the realm of quality by interpreting the phenomena of light on a quantitative basis.

The application of mathematics to physics has proven to be so successful that often physics has been considered to be coextensive with mathematics. Thus, Newton's teacher Isaac Barrow states that

> the attempt to speak of the mathematician as dealing with an ideal or intelligible realm as opposed to the realm of sensible objects is mistaken: it is, the sensible realm, so far as it is intelligible, especially so far as it reveals quantitative continuity, that is the object of all science. Thus physics, so far as it is a science is wholly mathematical, likewise all of mathematics is applied in physics, hence we may say that the two sciences are co-extensive and equal (9).

The claim that mathematics and physics are coextensive would in all likelihood be considered to be too strong in light of the many esoteric mathematical theories of today. Yet, the fundamental importance of the progress in mathematics for the progress of science can hardly be overestimated. Without probability theory Boltzmann could not have laid the foundation for statistical thermodynamics, without the tensor calculus Einstein could not have developed the theory of relativity.

So far we have been discussing three levels of the cognitive control hierarchy: the level of experimental control, the level of theory control, and the level of mathematical control. We still need to add one more fundamental level before we can understand how, by means of a system of controls, we succeed in stabilizing our experience of the world and make it amenable to scientific investigation. It is clear that one more level is needed, because scientists do not simply measure whatever can be measured or count whatever can be counted. If they were to proceed in such a way they would never find meaningful correlations. Scientists do not count the leafs on a tree or the blades of grass in a meadow. When they begin their investigation they have already a very definite idea of which questions are worth investigating and what sorts of answers are acceptable.

Questions and answers are verbal formulations, hence for them to be connected to experience, experience must be categorized. This categorization of the world is taught to us in a social context at a very early age. We are therefore unaware that we hold such beliefs and do not question the way we cut up the world. Already through the learning of a language our thoughts are guided into definite directions. We have learned in early childhood how to correlate our various modes of experience and have acquired the concept of an object. The people who surround us name those objects and in naming they also interpret. The child is encouraged to see the world as his parents do and the older he gets the more natural the adopted categorization of the world appears. Small children ask all kinds of "silly questions". They have not yet learned what socially is considered to be an acceptable question or answer. Once they have adopted the belief system of their elders they can function appropriately in the social environment within which they grew up.

If the young scientist is to function appropriately in his field, he also has to be socialized and learn the concepts, techniques, and standards of his science. This learning takes place within the social context of the scientific community. After many years of an often demanding apprenticeship he will have learned to see the world as his peers do. He can understand their questions, judge proposed answers, and contribute his own. The aspiring scientist learns how to categorize his scientific world as implicitly in a social context as he learned to categorize the everyday world when he was still a child. Therefore he is usually unaware that he holds any metaphysical beliefs. Yet, these beliefs are nevertheless powerful and constitute the uppermost level of the cognitive control hierarchy. Historically those beliefs are related to our common sense conceptualizations. There we learn that the world is made up of objects: tables, rocks, people, plants, and animals. We then transfer the concept of an object to the invisible realm. However, once we begin to inquire into what lies behind the phenomena, we are facing the problem that we have learned how to categorize the world in the context of our everyday life but that there is no <u>a priori</u> justification for assuming that the same categories are also suitable for the understanding of different realms of reality. When we apply the concepts gained in everyday discourse to different areas of reality, we are making a metaphysical decision. We hope that our conceptualizations are powerful enough to capture true relationships holding in a realm to which we have no direct access. We believe that there are objects which make up the world, and we use concepts such as resistance, impedance, attraction, acceleration, force, field, pressure, and law. All these concepts bear witness to their origin in everyday language.

Once divested from their everyday use, however, concepts gain new meanings, and eventually bear little resemblance to the original conceptions from which they descended. Nevertheless, they do cut up our experience in certain specific ways which indicate their origin, and this ,indeed, is unavoidable. Nature does not dictate how she ought to be categorized, and therefore science has to start with metaphysical presuppositions. Like a man who throws an iron hook attached to a rope across an abyss, hoping it will catch hold on a tree so that he can pull himself onto the other side, so do we impose our metaphysical presuppositions upon nature, hoping that the iron hook will catch hold, that some of our questions may turn out to be meaningful.

A metaphysical system helps human beings to understand otherwise unexplainable phenomena in terms of familiar concepts. Thereby it gives meaning to the world in which they live and instills a sense of direction into their daily activities. It determines which kind of questions they can ask meaningfully and which are obsolete. The concept network which constitutes a metaphysics allows men to focus their ideas ,and check whether or not they are consistent. It organizes and categorizes their perceptions of the world, and it relates their activities to the events with which they are confronted in their lives. In summary, a metaphysical system's underlying categorization of the world gives meaning to man's thought and 'actions.' Metaphysics seems to be a universal category of culture, as all people try to understand the unknown by the known and extend metaphorically the concepts of daily life into the realm of the unknown. Whether we talk about atoms or fields, spirits or forces, the goal of explanation seems to be identical, ~~namely~~ to reduce the unknown to the familiar, and to extend one's perceptions into areas not accessible to human sensory peception. A leading anthropologist describes this connection in the following way:

> The quest for explanatory theory is basically the quest for unity underlying apparent diversity; for simplicity underlying apparent complexity; for order underlying apparent disorder; for regularity underlying apparent anomaly. Typically, this quest involves the elaboration of a scheme of entities or forces operating 'behind' or 'within' the world of common-sense observations. These entities must be of a limited number of kinds and their behavior must be governed by a limited number of general principles. Such a theoretical scheme is linked to the world of everyday experience by statements identifying happenings within it with happenings in the everyday world.
>
> ....each category of being has its appointed function in relation to the world of observable happenings. The gods may sometimes appear capricious to the unreflective ordinary man. But for the religious expert charged with the diagnosis of spiritual agencies at work behind observed events, a basic modicum of regularity in their behavior is the major premiss on which his work depends. Like atoms, molecules, and waves, then, the gods serve to introduce unity into diversity, simplicity into complexity, order into disorder, regularity into anomaly (Horton(1976)132-34).

In view of the structural similarities between the metaphysical systems of so-called "primitive" people and our own highly refined scientific conceptualizations, is it still justified to presume that western science is more likely to give us a better picture of reality than the systems of belief adopted by other cultures? Or is it merely a matter of cultural bias that we prefer western science to other models of the universe? Some anthropologists, social scientists, and philosophers subscribe to this view, and epistemological relativism is gaining increasing acceptance. I do not think that we have to give up hope for the improvement of science, and I believe that we have good grounds for holding that western science is cognitively superior to other belief systems. For, although a metaphysics constitutes the highest level of cognitive controls, it is not the only one. The levels of mathematical and experimental controls are, as we have seen, also of utmost importance, and these levels are missing in non-scientific belief systems. A metaphysics categorizes the world. Thereby it constrains our imagination and in doing so it creates conceptual order, a necessary prerequisite if we want to orient ourselves in that stultifying diversity so characteristic of the natural world. The utilization of the power of mathematical reasoning puts additional constraints upon our ideas of reality. It is this constraint which is missing in the belief systems of people who have not adopted the scientific outlook of western science. I dare to conjecture that if "primitive" people were to mathematize their world of spirits, forces, and gods, they, too, would eventually come up with a successful science.

It is necessary to constrain metaphysical conceptions in order to arrive at clear conceptual models suitable for conducting science.

Atomism is a paradigm of such a model. Originally atoms were thought to be little impenetrable pieces of homogeneous matter with none but spatial properties - tiny geometrical solids, out of which all bodies, of whatever shape or size could be built up. In the Cartesian version of atomism (10) we find, indeed, only one propery, that of extension and only one oosmological law - that of a constant quantity of movement. Again and again in the history of science we find a change in the ultimate properties the atoms are alleged to have. Our 'modern' atoms, which are, of course, not the chemical atoms, but the elementary particles, exhibit novel properties such as charge and spin. In spite of all these differences in the conception of what the ultimate entities of matter are supposed to be, there runs a common metaphysical thread through the diversity of conceptualizations: any atomic analysis reduces the data to the sum total of the atomic, elementary components. It thereby explains changeable things in terms of non changeable entities. The properties of those entities are measurable quantities, because only on these, the primary qualities, can the science of numbers and extension operate. Thus the atomistic metaphysics claims that qualitative differences are simply differences in quantity - more or less of the same stuff in a given space. The postulate of atomism is: what is in the whole must necessarily be in the parts, and it is this metaphysical postulate which serves to weld observed measurable quantities and mathematical theory together. The atomistic conception of the universe proved to be invaluable for the progress of science. It exemplifies the fruitful marriage between mathematics and metaphysics, producing the desired offspring: quantifiable properties.

Yet, the atomic analysis of global events and actions, that is, the pattern of reducing experience to the sum total of the atomic, elementary components should not be identified with mathematical treatment in general. Different problems demand different mathematical treatments. Which mathematical analysis is appropriate cannot be determined a priori, but has to depend on the nature of the change we attempt to explain. The frequent employment of atomistic analyses in areas where they seem to be out of place (for example in the social sciences), is most likely due to the desire to apply the ready made mathematical tools of atomistic analysis. Already d'Alembert warned agains this misuse of mathematical techniques:

> It is often the desire to be able to make use of methods of calculation which determines the choice of principles, whereas the principles themselves should first be sought without thinking in advance to bend them forcibly to methods of calculation. Geometry which should only obey physics, when united to the latter, sometimes commands it.(11)

Once we have put mathematical fetters on our imagination, we need to apply one more set of constraints, i.e. we have to control our interaction with nature. We have to deal with nature in an artificially controlled environment. The rich, colorful and messy world within which we live is not suitable for mathematical treatment. We have to simplify the phenomena in experiments, so that those characteristics of them that vary quantitatively together with the mode of their variation may be seized and precisely defined.

Thus we are facing a cognitive control hierarchy within which several levels of constraints channel our thoughts and activities in such a way that an intelligible order appears. Only against this created stability can genuine invariant relationships manifest themselves, can we get some understanding of the structural stabilities which characterize the hierarchical constitution of our universe of processes.

Like any complex control hierarchy, the cognitive control hierarchy displays also an intricate network of feedback cycles which mutually interact and thereby improve the working of the hierarchy as a whole. For example, an improvement in scientific instruments may lead to more refined experimental results which may indicate weaknesses in the existing theoretical framework. In order to devise a better theory a more powerful mathematical apparatus may be needed. The new mathematical apparatus may in turn frame new theorems which need to be investigated theoretically and experimentally.

Thus we may say that science can be improved at all levels, but it is only through the interaction of these levels that new knowledge can be gained, that the art of interrogating nature can be improved.

4.6. SUMMARY

In this chapter I proposed to view knowledge as an hierarchical system of controls imposed upon our experience. It is this nexus of interrelated controls which makes it possible to conceive of a world of stable objects located within a n-dimensional space-time framework. In reality - so my position goes - there is no absolute stability in the world of processes we inhabit. Yet, there are relative stabilities, due to the fact that not every process interacts with every other process. If we want to have knowledge about this kind of universe, it has to be knowledge about the invariant relationships holding between these local stabilities (called objects) occurring at various levels of reality. If we want to gain this kind of knowledge we are faced with the problem that we have to tease the various levels of the structural hierarchy apart so that we can deal with one at a time, and can relegate the others to the status of 'noise'. This means that we have to learn how to improve the "tuning" of our scientific instruments, and it also means that we need a powerful conceptual framework which allows us to differentiate between a host of intrinsically diverse changes. The other major problem we are facing is given by the fact that we continuously interact with very many processes, and therefore potentially disturb what we want to observe "objectively". Our own position as observers may mislead us into believing that we observe genuine invariant relationships which are characteristic of the external world, whereas in truth our very act of perceiving, conceiving, experimenting may disturb what we want to achieve. Thus it becomes a central aim of the knowledge seeker to disentangle his own activities from those which he intends to record. On the traditional account this has been called 'scientific objectivity'. This notion seems to be out of place in a world of processes. This, however, does not mean that science is merely subjective, that every conceptualization should be allotted an equal voice in its claim to knowledge. In fact the fundamental ideas behind the conception of 'objectivity' can very well be captured in the present systems account. In order to show how this can be done, let me draw your attention to the concept of a catalyst.

A catalyst is a substance which participates in a chemical reaction but which is not being used up in the reaction, i.e., it does not affect the overall stoichiometry. Without the presence of the catalyst the reaction in question would either not occur at all or at an extremely slow rate. We encountered the notion of catalysts in this chapter when I discussed the biochemical control hierarchies and the role enzyme molecules play in it. In fact a catalyst is a control device par excellence. It is its job to steer a particular chemical reaction into one specific direction.

We may view the various levels of our cognitive control hierarchy as controlling devices similar to catalysts. Their job is to steer our thoughts and activities into new and fruitful directions. Without them no research could take place at all. We have to categorize before we can think, we have to measure and calculate before we can make precise predictions. Yet those cognitive activities must not interfere with the tasks they are supposed to accomplish. As in the case of the catalyst, they will ideally leave no trace, only then will we have knowledge of genuinely invariant relationships holding in the world.

However, at a certain stage in history we cannot know how deeply our views of the world are colored and distorted through our perceptual, conceptual, and instrumental biases. Yet, in hindsight we can clearly discern a pattern of development leading from a highly anthropocentric view of the universe towards a conception where we increasingly succeed in disentangling ourselves from what we are experiencing.

Copernicus demonstrated that what seemed to be the central and most obvious phenomenon of the universe, namely its circular motion around the earth, was a mere illusion caused by our own position as perceivers. Galileo demonstrated with his distinction between the primary and secondary qualities that the naive Aristotelian realism was mistaken, and that our experience is colored by our organs of sensation. From then on science was searching for robust properties, i.e., properties which remain invariant with respect to the modes of observation. Mathematics turned out to be a superb tool in helping us to distinguish between the subjective, fleeting, and colorful experiences of everyday life and those observations which remain invariant with respect to the activities of the observer. It helped us to transcend the realm of quality and break through into the realm of physical, that is quantitatively determined, reality. Yet we are still burdened with a further profound metaphysical conception which - if the central tenet of this thesis is sound - distorts our conception of reality. This is the view that the world is made up of objects, and that it is the task of science to determine the properties of these objects. This conception of the universe results in a fundamentally reductionistic outlook, because there can be only one object at the same space-time location. Thus we are lead to believe in a one-level world and denounce all the complex manifestations of matter as mere illusions which ought to be ultimately reducible to the fundamental entities of nature. If the world, however, is a world of processes, then the apparent stability of objects is the result of our selective attention to one particular level of the structural hierarchy.

Our perceptual and conceptual frameworks stabilize the conditions of our experience in such a way that only one particular level of reality manifests itself at a time. If we could live in and experience different levels of reality, we would need different conceptual and perceptual frameworks and we would observe an utterly alien world; if protons could speak they certainly would report of a very strange universe with different "objects" possessing obscure properties. In this sense, then, objects bear also the mark of the perceiver, or, to put it in a different way: objectively speaking objects do not exist.

NOTES TO CHAPTER FOUR

1. I am indebted to Professor Hooker who first brought the population strategy' to my attention.

2. For an insightful discussion of the context dependency of enzymatic activity see Grobstein(1973).

3. For discussion and examples of homeostatic regulation see Hardy(1976).

4. For a more detailed discussion of the structural hierarchies see Pattee(1972)3-5.

5. For application and further elaboration of the Principle of Le Chatelier see any textbook in chemistry, for example Mortimer(1979), whose definition I adopted.

6. quoted from Bellone(1980)22.

7. quoted from Bellone(1980)184.

8. quoted from Butterfield(1973)90.

9. quoted from Burtt(1932)151, my italics.

10. It may appear strange to list Descartes' name among those who favored atomism. Yet, Descartes only denied the existence of a vacuum. Cartesian substance remains corpuscular, and thus ultimately akin to atomism.

11. Quoted from Santillana(1941)8.

CHAPTER V

THE DYNAMICS OF EVOLUTIONARY CHANGE

5.1. AN OUTLINE OF WADDINGTON'S EVOLUTIONARY THEORY

In this thesis I have proposed to view the constructive characteristics of our perceptual and conceptual frameworks as necessary prerequisites for knowledge if we assume that we live in a universe of processes. In such a universe the observer has to learn how to control the conditions of his own experience in order to arrive at genuine knowledge about invariant relationships holding at different levels of reality. The development of level upon level of hierarchical control leads to an improvement of the observers' capacities to direct his interactions with the world. This development has culminated in modern science where man has learned to penetrate even into areas of reality which will forever remain inaccessible to any natural (i.e. non-instrumental) mode of perception.

I have compared the resulting cognitive control hierarchy with the system of hierarchical controls we find in living organisms. They, too, have to face the challenge of having to create stability in an unstable world. This led me to suggest that we should view the evolution of the cognitive control hierarchies as a continuation of the evolutionary process which is distinguished by an increase in complex hierarchical organization. I want to devote the last chapter of this thesis to an investigation into the pattern of evolutionary change common to both biological and scientific evolution.

The question arises if we can find a model of evolutionary change which applies to biological and cognitive evolution alike. Once we possess such a model we can transfer insights from biology to epistemology. The kind of model needed for this purpose has to give an explanation why in the course of evolution we find a thrust towards more and more complex organizational structures. The same model must, however, also explain why this trend towards organizational complexity is by no means universal to all species. What are the parameters which determine if a population of organisms remains virtually unchanged during vast periods of time or if it undergoes substantial changes in phenotypic structure and appearance? The model should further explain why the increase in organizational complexity constitutes 'progress in evolution', i.e. it should give an account of the advantages a species gains by improving its cybernetic adjustments rather than remaining on a simpler level of organization.

It is clear that the standard neo-Darwinian account of evolution is not suitable for the task at hand, because it does not deal with phenotypic organization at all, neither does it assign any meaning to the idea of 'progress through evolution'.

Fortunately, however, there exists a different model which was proposed by the distinguished embryologist and evolutionary theorist

C.H.Waddington. He refers to his theory as a "post-neo-Darwinian paradigm", and argues that neo-Darwinian theory ought to be amended by imbedding it into a wider framework of concepts among which the concept of the phenotype is to play a central role. I have expounded Waddington's theory elsewhere (Hahlweg(1981)). This paper is included as an appendix to this thesis. There the reader can also find a discussion of some of the shortcomings of neo-Darwinian theory, in particular it is shown that within the framework of neo-Darwinism the concept of long-term evolutionary progress is meaningless. In this chapter I will restrict myself to expounding Waddington's theory only in so far as it is relevant for the purpose of the present inquiry.

Central to Waddington's conception of evolutionary change is the concept of the phenotype. Phenotypes are - to use the terminology employed in this thesis - dissipative structures. They exist far from thermodynamic equilibrium and have to maintain their precarious existence through continuous extraction of energy from and dissipation of entropy into their environment. Phenotypes which possess a high degree of hierarchical organization are capable of adjusting to changing environmental circumstances. This adabtability is due to the fact that phenotypes are processes, or, rather, are made up of a network of interacting processes which mutually stabilize the organisms internal environment. A change in environmental conditions can, to a certain degree, be accomodated by changing the interactions between a variety of processes, i.e. by changing the course of development the organism follows. Phenotypes are always developing. From conception to death the organism undergoes developmental change.

It is this capacity to change which makes it possible for organisms to adjust to changing conditions. The existence of internal conditions of stability as exemplified by the phenomena of homeostasis and homeorhesis (homeorhesis=stabilization of a developmental pathway) makes it possible for a species to survive under severe environmental conditions.

Phenotypic plasticity is also of crucial importance for the evolutionary process. During the course of evolution, the environment of a population of organisms undergoes change. Organisms which are already endowed with ontogenetic variability can more easily adapt to a changing environment than those more highly specialized organisms which can only make a living within a restricted homogeneous niche.

Waddington emphasizes that natural selection operates upon the ontogenetic plasticity of a population. If a population of organisms live in a homogeneous environment, phenotypic variability does not convey any selective advantage to the members of the population. There will therefore be no selective pressure favoring the improvement of the capacity to adapt. If, however, the population faces a heterogeneous environment, those members of the population whose adaptability surpasses that of other members will have an edge in evolution and will pass on more progeny. The capacity to adapt is, of course, genetically determined and, thus, in effect we find that organisms which adjust their developmental pathways successfully during development are also more likely to leave more progeny with similar capacities. Put another way, organisms experiencing a changing environment will utilize their capacities to adapt and those organisms which excel in adaptability will leave more progeny than other less adaptable phenotypes. A homogeneous environment, on the other hand, does not present new challenges and therefore no selection for greater adabtability will take place. This brings us to an understanding of why the thrust towards improved hierarchical organization is by no means universal to all species. The environment of many species has remained virtually unchanged during vast periods of time. There was therefore 'no incentive' for them to improve their adaptave capacities. Once, however, the previously stable environment does change, many species will become extinct. Being not endowed with sufficient adabtability, they cannot cope with a sudden environmental change. Our century provides dramatic examples of the disastrous effect a changing environment can have on many species. Due to man's interference into previously ecologically stable systems, many species have become extinct within the last few decades alone. Other more adabtable species, however, do very well under the changed environmental conditions. Rats or pigeons, for example, show remarkable success as city dwellers, and have adapted their lifestyle to the new circumstances.

Waddington emphasizes that 'progress in evolution' means 'progress in adabtability' and not 'progress in adaptation'. All species, past and present, were, and respectively are, adapted to their natural environment. It makes no sense to claim that a contemporary species is better adapted to its habitat than, say, the dinosaurs were to theirs. Hence, there can be no long-term progress in adaptation. We do, however, find progress in adaptability. The improvement in hierarchical organization, specifically the development of sophisticated nervous systems and perceptual organs is evident in the palaeontological record which shows that the further back in time we go, the more primitive the various life-forms become.

Let me, however, remind the reader of the'population strategy' which I discussed briefly in 4.1. Here, too, we find an improvement in adabtability, but the capacity to adapt to environmental change is a property of a population of organisms, not of individuals. The individuals may, indeed, be highly specialized and survive only within a very limited range of environmental fluctuations. But due to the fast reproductive rate and to the always existing variety in the gene-pool, such a population can survive as a whole and adapt to new circumstances. Bacteria are a good example of this strategy. I will not further elaborate on the population strategy because it is of little interest for the present context, which is devoted to the understanding of complex systems.

So far organisms have been treated as essentially passive entities which are at mercy of the whim of an often capricious environment.(1) This is, however, by no means a satisfying account and does no justice to the intricacies of evolutionary change. Organisms do not merely suffer selective pressures exerted by the environment, but also penetrate new environments and in doing so change them. This holds particularly for higher developed organisms. Due to their sophisticated perceptual systems, they can explore new environments, feed on different resources, disturb existing ecological balances, destroy the niches of some organisms and create new niches for others. Ecologist Richard Levins describes this interdependence between environment and organism in the following way:

> Organisms (a) select their environment actively, (b) modify their environment by their own activity, (c) define their environment in terms of relevant variables, (d) create new environments for other organisms, (e) transform the physical nature of an environment input as their effects percolate through the development network, (f) determine by their movements and physiological activity the effective statistical pattern of environment, and (g) adapt to the environmental pattern that is partly of their own creation. Further, each part of the organism is "environment" to the other parts.
>
> The conclusion of (d),(f), and (g) that organisms adapt to and create statistical patterns of environment finally suggests that the utilization of resources by populations not only uses up ecological opportunities but also creates new ones: The variability in resource level may itself behave as a resource.
>
> ......The traditional separation of the world into organism and environment as mutually exclusive classes.......leaves us with the task of then connecting them. A more dialectical approach emphasizes the mutual interpenetration of organism and environment (Levins(1979)766).

Living things change the environment which they inhabit and thereby inadvertantly effect the selective pressures they will suffer. This feedback between organisms and environment can be held responsible for the exponential growth curve we notice when observing the increase in complexity evident in the palaeontological record. There we find that the first traces of one-celled organisms appear some 3.5 billion years ago. And it took life another three billion years for the development of primitive plants and animals!(2) Since then evolution proceeded in an ever increasing speed: It was only 400 million years ago that plants conquered the land and vertebrates the oceans. The geological record shows that within only another 200 million years amphibians and mammals evolved. Man appeared some 1.8 million years ago, and as recently as 100.000 years ago Neanderthal man thrived in what was to become Europe. It is thought that the behavioral capacities of Neanderthal man were not markedly different from our own.(3) Thus, evolution - the problem-solving process - had created man - the problem-solver.

This pattern of exponential growth is to be understood on the basis of a continuous interplay between organisms and the environment they inhabit. It seems that each adaptive advance of a population of organisms generates a series of environmental changes which influence the selective pressures exerted upon many species. In order to survive in this changing environment species have to find new ways of adapting, and these adaptive advances in turn generate new changes. This feedback situation has led not only to the change of old but also to the creation of new environments (i.e. new ecological niches), and is ultimately responsible for the richness and diversity of ecological systems. The earth as we know it is to a large degree a result of the activities of living things exerted over the past three billion years. The recent appearance of homo sapiens has resulted in further dramatic changes of the environment. More than any other species, man has left his trace on the face of this planet. This human impact, however, is not due solely to biological but mainly to cultural evolution. Here, too, we find an exponential growth of the human capacities to adapt to a variety of environments with its concomitant impact on the ecology of the earth. Let me sketch the exponential growth curve evident from the archaeological and historical record:(4)

Of the 100.000 years since the appearance of Neanderthal man

90.000 were devoted to a nomadic lifestyle of hunting and gathering. Only 10.000 years ago systematic agriculture seems to have been introduced and only 6000 years ago the first great civilizations appeared. Writing seems to have been introduced as recently as 5000 years ago in Mesopotamia, and the development of science proceeded very slowly during the following 4000 years. Only since the time of the Renaissance has science advanced at an ever increasing pace leading to a situation in the 20th century where we hardly can cope physically, emotionally, and philosophically with the ever new discoveries and inventions which though bettering our lives on the one hand, also deplete our physical and cultural resources.

We are facing the paradoxical situation that the more successful organisms become in stabilizing their internal environment (physiologically, perceptually, and conceptually), the more likely they are to destabilize the external physical and/or cultural environment. Thereby new selective pressures are created, which demand even greater adabtability on the part of the organism. There exists always the danger that a species eventually cannot cope with the environmental fluctuations it has partly helped to create, and will be forced into extinction. This, of course, is the foremost danger which the most adabtable of all species, i.e., *homo sapiens*, is facing. The disruptions which have been imposed by humans onto the ecology of this planet, have been dramatic, particularly during the past few decades, and there exists the real danger that the survival of mankind itself may eventually be threatened. We may not be able to cope with the disruptions of the physical and cultural environment for which we are largely responsible ourselves.

The cognitive evolution culminating in modern science is superimposed upon the much slower biological evolution. Both evolutionary processes, however, show the same exponential growth curve, both are characterized by the development of highly complex hierarchical organization, and both lead not only to the adaptation to a particular environment, but also increasingly to the transformation of it. Waddington's model of evolutionary change accounts satisfactorily for the dynamics of biological evolution. In the light of the striking similarities in the growth curves of biological and cultural evolution, it appears promising to apply his model also to cognitive evolution. This is particularly appropriate in view of my characterization of science as an extension of perception.

I have argued that in both perception and science we have to stabilize the conditions of our own experience, and that this creation of stability can be understood according to the same organizational principles which account for the stability of phenotypic organization. Waddington also emphasizes the importance of phenotypic stability (both, homeostatic and homeorhetic) for the evolutionary process. He argues that in the course of evolution the cybernetic mechanisms responsible for internal stability are constantly improved. This leads to greater phenotypic adaptability and thereby to progress in evolution. Similarly, scientific progress results in ever greater adabtability of the human species.

I will now proceed and give a more detailed account of how the cybernetic feedback mechanisms which distinguish Waddington's evolutionary model find their equivalent in the realm of scientific development.

5.2. THE ROLE OF THE GENOTYPE AND ITS EQUIVALENT IN SCIENTIFIC EVOLUTION

When moving from a discussion of biological to a discussion of scientific evolution, it has to be made clear which characteristics of both processes are identical, and which are contingent on the particular system we are investigating. In this thesis I am searching for the organizational patterns underlying biological and scientific evolution. Moving from one realm to the other means therefore to detect those categories which are functionally equivalent in both. Waddington expresses his theory in terms of three fundamental conceptions: the genotype, the phenotype, and the environment. The various cybernetic correlations between these categories account for the changes an evolutionary system may undergo. I will therefore begin my inquiry by searching for the equivalents of these notions in the realm of scientific change.

Let me begin by investigating the conception of the genotype. We are obviously not interested in the particular physical structure which serves as a carrier of the genetic information (i.e.the DNA). Neither are we interested in the way this information gets translated into the physical appearance of the phenotype (i.e. the DNA-RNA-protein succession). What is important, however, is to define the fundamental functions the genes play in the evolutionary process. There we find that the genotype plays two roles without which evolution could not take place. The genotype serves as a generator of variety, and it transmits information from one generation to the next. The generation of new variety occurs throug mutation and recombination of DNA-molecules. The transmission of information is taking place by means of the various mechanisms of inheritance.

In the realm of science we also need to transmit knowledge, and we likewise have to find ways of introducing novel concepts. Human language plays a fundamental role in both processes. Scientific knowledge is linguistically formulated and is passed on to other scientists by means of oral presentations, textbooks, journals, etc. In the course of scientific evolution new concepts have to be introduced and old ones are continuously reinterpreted.

The similarities between the functions of the genotype and that of human language have also been emphasized by Stephen Toulmin (Toulmin(1972)). He bases his model of scientific evolution on the neo-Darwinian theory of evolution. This theory, however, does not deal with the appearance and development of phenotypic hierarchical organization and can give no meaningful account of long-term evolutionary progress. (For a discussion of this point see section 6.3. of the appendix to this thesis). Toulmin's refusal to take the thrust towards hierarchical organization seriously is based upon the fact that a species can develop either more progressively (i.e. in direction of greater complexity), can remain stable or can even regress to a less complex organizational pattern. Toulmin sees the same features in the development of science and feels thus that we can dispense with the notion of long-term progress altogether. Yet, the fact that species or cultures can either increase, decrease or remain invariant in their organizational complexities does not mean that we don't need an explanation of why complex organization occurs in the first place and why and in which sense we might want to attribute the notion of progress to the increase in structural complexity.

Indeed, Toulmin tries rather to deemphasize the features of organizational and structural complexities, claiming that the employment of these concepts leads to static and non-evolutionary views about culture and the scientific enterprise. However, it seems to me, as I have repeatedly emphasized in the course of this thesis that the central question of biological and scientific evolution is: How is it possible that highly structured entities (organisms, societies, conceptual systems) can change over time without loosing their functional capacities? Instead they manage to improve these and subsume new or altered functional abilities under new regulatory systems. The answer I have been proposing on the basis of Waddington's theory is that by means of a control hierarchy a special kind of stability can be created. It is distinguished not by internal rigidity but by its capacity to adjust itself if this is demanded by changing environmental circumstances.

It is the great merit of Waddington's theory that it places the development of phenotypic plasticity into the center of evolutionary theorizing, and it is this feature which makes his theory important for the understanding not only of biological but also of epistemic organization. In view of the fact that Toulmin's model lacks precisely those characteristics which are of central importance for the present inquiry, I will not further discuss it. I do, however, side with him in his assessment of the functional equivalence of human language and the language of the genes.

By whatever means new concepts are introduced into science, be it through operational definition, reclassification, or reinterpretation, one mechanism for the generation of new concepts seems to be of particular importance. As it has often been pointed out (5), scientific language grows through the employment of metaphors. Concepts such as attraction, resistance, repulsion, force, and even the concept of a scientific law were transferred from everyday discourse into the realm of science. The capacity of language to grow by means of metaphorical extension makes language not only important as a means of communication but also as a means of introducing novelty. Because, once divorced from their everyday use, those concepts gain new meanings and eventually separate completely from their source in common language. For example, the notion of a scientific law has little in common with the conception of divine law from which it descended.

Realizing how rich the potential of language is for the generation of novel expressions we need not search for linguistic equivalents of 'mutations'. Mutations are a biophysical way of introducing novelty, metaphorical extension is a linguistic means of accomplishing the same feat. What is important is that by means of either process novelty can be introduced into the genotype or into language respectively.

At this stage of the discussion the question may arise whether we have to propose that concepts are introduced randomly just as mutations are. It is in fact one of the main objections against evolutionary accounts of science, that science is a teleological endeavor, whereas biological evolution proceeds without intentionality playing a role. This objection is based upon a misunderstanding of both the biological processes and the sense in which functional equivalence holds between the creation of novelty in biological and in scientific evolution. Let me elaborate: When we say that mutations occur randomly, we do not thereby proclaim that there are no physical laws governing the changes on the molecular level. On the contrary, no scientist doubts that those changes are governed by physical laws holding at the molecular level. Mutations can be considered to occur at random only with respect to the eventual benefits or damages they may convey to the organism within which they take place. Turning from biology to science we find that scientists reason mostly rationally and teleologically. The concepts which they introduce fulfill a specific well-defined role in the conceptual framework within which they operate. Yet, the introduction of those concepts can also be seen as being random or undetermined with respect to the actual structure of the physical world. For it is this structure which scientists attempt to unravel. They hope that the new concepts may capture essential features of this unknown entity out there. But they cannot know beforehand if they will be successful. In this sense, then, the eventual success or failure of a conceptual novelty is irrespective of (i.e.random with respect to) human intentions but depends on the nature of the world alone. Thus, once again, we see that properly interpreted, the analogy between biological and scientific evolution is much stronger than perceived by many philosophers.

5.3. THE ROLE OF THE PHENOTYPE AND ITS EQUIVALENT IN SCIENTIFIC EVOLUTION

After having discussed the role of the genotype and its linguistic equivalent in science, I will now take a closer look at the notion of the phenotype. Already in the last chapter I compared the organization of knowledge with phenotypic hierarchical organization. This comparison is suggestive once we realize that in a universe of processes we have to learn how to stabilize the conditions of our own experience. Living organisms, being dissipative structures, have to create internal stability in order to survive under non-equilibrium conditions.

The necessity of creating stability in an inherently instable world becomes also evident in perception. We learn as children how to correlate our various modes of perception in such a way as to create a stable background against which genuine invariant relationships holding in the external world can manifest themselves. I discussed some of these constructive characteristics of our perceptual frameworks in chapter two, relying mainly upon insights derived from Gregory and Piaget. In the same chapter I argued that we should view science as an extension of perception. In science, as well as in perception, stability is not simply 'given'. It has to be constructed. In perception this construction happens on a subconscious level, in science we consciously construct the conditions under which we can observe regularities. I emphasized that we should regard the goal of science to be that of finding invariant relationships holding in the world. In order to accomplish this task we have to coordinate our various theories and instruments until they all fit together and jointly lead to a construction of a stable background against which genuine changes become observable. What I am suggesting is that the whole spectrum of scientific activities can be understood from this point of view. Even the most menial task in the laboratory gains significance if it is seen from the present perspective. From the careful cleansing of vessels with special reagents to the calibration of measurement instruments, from the storage of chemicals at a specific temperature to the computation of ranges of acceptable errors, every single scientific activity can be understood as contributing to the one desired goal: the creation of stable experimental conditions which allow us to observe new genuine invariant relationships holding in the external world. Each of these tasks involves the employment of a host of theories which have to be brought together and coordinated in order to achieve success. Thus, if by means of those activities we control experience, by means of the cluster of theories we control our activities. Hence, so I argued in chapter four, the creation of experimental stability is to be understood as involving a hierarchy of controls in the same sense as the control hierarchies involved in <u>homeostasis</u> and <u>homeorhesis</u> stabilize the internal environment of living things.

I further argued that we need at least two more levels of hierarchical control in order to account for the complexities involved in scientific inquiry. Those further constraints are imposed on our scientific reasoning through the availability or non-availability of a powerful mathematics and the deep-rooted metaphysical beliefs we subscribe to.

Mathematics controls the construction of theories in the sense that it restricts meaningful scientific discourse to quantifiable properties. (Modern developments in topology may lead to a loosening of this requirement; this, however, would merely confirm my claim that the development of new mathematical systems can enlarge our access to the external world.)

On the highest level of the control hierarchy reside our often unconsciously held metaphysical beliefs. Yet, the fact that many scientists are unaware of their ontological commitments makes the latter no less powerful. On the contrary "the most effective....control is that which is not noticed; which is not overt or formal; which is, as it were 'closer to us than breathing, nearer than hands or feet'" (Feyerabend(1965)259).

A metaphysics specifies which kind of entities are fundamental for a science. Any macroscopic change will then be explained in terms of changing relations between those entities. These may be elementary particles in nuclear physics, genes in evolutionary biology, individual human beings in sociological theory. Once a scientist has committed himself to see those entities as basic, he will view all other phenomena as derivative. He will employ a mathematics suitable for dealing with the entities in question, and he will deny the autonomy of phenomena which cannot be described in terms of the accepted metaphysics. The ongoing discussion in evolutionary theory about the existence or non-existence of group selection exemplifies such an ontological dispute among scientists.(6)

By subscribing to a particular metaphysics (consciously or unconsciously) the scientist delimits the range of problems which he will consider to be worthy of scientific investigation. Thus, the old proble of 'becoming' appears to be a pseudo-problem within an atomistic-reductionistic ontology. This issue I discussed in some detail in chapter three. There, however, I also indicated that a new scientific outlook is in the making which tends to see the world as a world of processes and which places 'becoming' before 'being'.

Metaphysical issues, instead of having been buried forever by the positivists, are emerging in many areas of science, and it is becoming increasingly clear that they play a major role in the determination what is considered to be the subjectmatter of a particular science. Thus, we may say that a metaphysics steers our thoughts and actions into certain directions, and thereby constitutes the most remote but also perhaps the most powerful level of control.

I have described scientific knowledge as a system of hierarchical controls by means of which we create stability in a world of processes. This compares with phenotypic organization where also homeostatic and homeorhetic stability is created in order to ensure the survival of organisms in an inherently instable world.

Progress in evolution means in Waddington's theory progress in adaptability. This is accomplished through the development of new and refinement of old hierarchical controls. Likewise I view progress in science as deriving from our increased capacity to control our interactions with the world. Thereby we manage to gain access to areas of reality which were previously beyond our instrumental and/or theoretical and/or conceptual capacities.

5.4. SOME REMARKS ABOUT SCIENTIFIC THEORIES

Before turning to the discussion of the dynamics of this evolutionary change, it is, however, appropriate to make a digression and discuss in somewhat more detail the role scientific theories play within the present approach.

The issues relating to the nature and status of scientific theories can be seen as constituting the pivot around which philosophy of science turns. Are theories true? Are they probable? Are they mere instruments for gaining knowledge? Can they be verified? Can they be falsified? These are central questions for philosophy of science and, although I will certainly not attempt to provide answers to all of them, it appears nevertheless to be necessary to clarify the specific role of scientific theories within the present framework, in particular the question of what theories tell us about the nature of the world.

In the traditional realist position (I do not discuss instrumentalism, because it purports that theories tell us nothing about the actual structure of the world) it is held that the terms employed within a theory refer to actual entities existing in the world, and that, if the theory is true, it will represent the actual relationships between those entities. If we had a complete science, all scientific theories jointly together would fully descibe the nature of the universe. Put in a different way: scientific theories are seen as constituting a "mirror of nature". to use a term coined by Rorty (Rorty(1979)). The reality reflected by the mirror would be a reality free from the distortions of our organs of sensations. It woud, indeed, constitute a complete image of 'objective' reality. It is interesting to note that the metaphor of the 'mirror of nature' does imply that objective knowledge of this kind is impossible, because we cannot look into a mirror without seeing ourselves! Such a mirror, if it existed, would be useless, for we would not be allowed to glance into it. But perhaps this means stretching the metaphor too far, and I will rather proceed and present a new metaphor suitable for the universe of processes I have been describing.

In this universe we find many levels of reality, furthermore there are always new levels added to it, due to the capacity of dissipative structures to form new stabilities. Relative stabilities, however, is all we can find in this world. Everything is constantly changing, though at different rates. Therefore, depending which level of reality the observer tunes into, he will see different stabilities and observe the invariant relationships holding between them. All the observer can come to know are those invariant relationships. In order to gain this knowledge it becomes necessary for him to tease the various levels of reality apart and observe one level at a time, i.e. he has to restrict his access to reality. This restriction is either built into our organs of sensation (we see only within a small range of the electromagnetic spectrum!) or has to be constructed in the laboratory. There the scientist performs a great number of activities which are meant to ensure that he only deals with one level of reality at any given time. Thus he purifies his reagents, calibrates his measurement apparatus, stains tissues,etc. In order to perform these activities a host of scientific theories has to be marshalled. They direct the scientist's activities and should therefore be seen primarily as guides to action.

The analogue which comes to my mind when thinking about theories as guides to action is the metaphor of a geographical map: Scientific theories guide our explorations in the laboratory in the same way as geographical maps guide our explorations into new and foreign territories. It should be clear that geographical maps are not, and are not meant to be "mirrors of reality". Indeed as such they would be useless. Geographical maps only depict those invariant features of the external world which are of direct concern to the user. There are, indeed, very many different kinds of maps:

We are all familiar with road maps. They show the main road connections between towns and cities. They inform us about the distances between those locations and the kind of highway which connects them. They may also give information about approximate driving times, road conditions, etc.

A related kind of map is geared specifically to the tourist. Those maps indicate the most scenic drives, places of interest and perhaps even specialty restaurants.

A very different kind of map is a geological map. It depicts information about the geological eras during which the rocks or sediments of a given geographical location have been formed or deposited. Such a map will also indicate other important geological features such as the range of former glaciation, fissures and faults in the earth crust or landslides.

There are many more types of maps and I need not delve further into the matter. What is important for the present purpose is to point out the similarities between maps and scientific theories: A scientist who employs a cluster of scientific theories in designing his activities in the laboratory, concentrates upon a very small aspect of reality. The various theories help to bring this aspect into focus. In the same vein a map only gives us information about a very limited aspect of reality. The art of mapmaking is to select the relevant information for a specific purpose. The art of the scientist is to select among the large array of scientific theories those which can guide him in his or her daily activities.

The design of a map is based upon an ontology which is indicated somewhere at the bottom or top of the map. There we find a symbolic representation of all the possible kinds of information the map can provide. For example, we find color codes for the various kinds of geological formations in a geological map, symbols for castles or museums in a tourist map, symbols for four-lane highways or gravel roads on a road map. Information which is not depicted by means of these symbols cannot be found on a map. Thus, by looking at a map's ontology we can find if it can guide us in our respective purpose. Unfortunately scientific theories contain their ontology only implicitly. If scientists were as explicit about their ontology as mapmakers are about theirs, much confusion could be avoided.

There exist very many different maps for the same geographical location. Similarly, we can find very many levels of reality described by a host of different theories. All of those maps and all of those theories can rightfully claim to capture some of that vastness which constitutes physical reality.

All the information contained in any particular map could in principle be extracted from the map and expounded in propositional form. Similarly, all the deductive consequences of a particular theory or set of theories can in principle be stated in propositional form. Traditional philosophy of science assumes that theories ought to be evaluated on the basis of the truth-or falsity content of these propositions. The present approach emphasizes that this is not only utterly impracticable (for reasons such as the Duhem-Quine problem) but is not even desirable, because a cluster of theories is more than a set of true and/or false propositions. It is most importantly a guide to action. We cannot evaluate a map by looking at its truth content alone. Too much detail may make the map useless. Occasional misinformation on the other hand may not do much harm if balanced by a good and clear design.

Indeed, the history of science demonstrates that it is not always true theories which provide good guidance to the scientist. Aristarchus' true theory (i.e. that the earth moves around the sun) proved to be barren for over eighteen centuries until it was reintroduced in an entirely different context by Copernicus. See (Kuhn(1970)75). On the other hand, the false caloric theory of gases proved to be extremely fruitful and guided scientists for many decades during the 18th and 19th century.(7)

I do, however, not mean to imply that it does not matter whether the theories we use in our day to day activities as scientists are true or false. Surely in the long run true theories are more likely to provide good guidance than false ones. Similarly, maps which contain errors will often mislead the user. What I am arguing is that theories are primarily guides to action, and that there is no necessary connection between the truth of a theory and its fruitfulness. Furthermore, it is impossible for a scientist at a certain stage of his research to judge whether or not all the theories he employs are correct. It is, however, possible, indeed, necessary in order that scientific research can proceed at all, to judge theories on their basis of fruitfulness.

It seems to me that philosophers of science by concentrating almost exclusively on the propositional content of individual theories have missed the most essential characteristic of the scientific enterprise, namely that science is primarily an activity geared towards the accomplishments of certain well-defined tasks. A scientist may utilize a theory even if he or she is convinced that this theory is false. but if there is no better theory available, he will use it anyway for heuristic purposes. It is better to have a bad map than no map at all!

In recent years a shift in perspective has been occurring among some philosophers of science. In particular Larry Laudan's much discussed Progress and its Problems emphasizes that science is to be seen primarily as a problem-solving activity. Still, Laudan's book relates only tangentially to the present approach. His work is devoted to methodology, an issue which I have bracketed in this dissertation. Laudan still equates epistemology with methodology, a conflation against which I argued in chapter one. He therefore does not discuss at all the ontological issues which are central to my approach.

In spite of my insistence that scientific theories are primarily guides to action, it should be clear that I am not proposing an instrumentalist view of science. Maps, too, are guides to action, and they can fulfill this function only because they do depict genuine invariant relationships holding in the world. It is, however, as impossible to evaluate theories on the basis of their truth content, as it is impossible to evaluate maps on theirs. We select maps on the basis of their capacity to guide us to our destination. Likewise we choose to employ theories which can serve as guides to action. In doing so we indirectly select for truth. There seems to be no way to verify or falsify individual theories. We always are dealing with a cluster of theories. If there are serious shortcomings hidden somewhere in that nexus of theories, sooner or later they will manifest themselves just as misinformation contained in an otherwise useful map eventually will show up. But this will only happen if we travel a new, previously untried road. Likewise a scientific theory may prove to be successful for a very long time until eventually a daring scientist endeavors to try a new path. This happened to Newtonian mechanics and Einstein was the scientist who decided to take a new and daring sideroad. It turned out that he had to map out this new territory for himself, for the well-tried theory could not serve anymore as a useful guide to action in these new lands.

5.7. THE ROLE OF THE ENVIRONMENT AND ITS EQUIVALENT IN SCIENTIFIC EVOLUTION

Let me now return to the main topic of the present chapter, namely the discussion of Waddington's cybernetic model of evolutionary change and its application to the elucidation of scientific progress. Let me recapitulate the main results of the previous discussion which has centered around the notions of the genotype and the phenotype.

I argued that human language should be seen as being equivalent to the notion of the genotype. All beliefs, rational as well as irrational are contained in the pool of propositions shared by a community of scientists. The individual scientist has only a very limited access to this pool, in the same vein the individual organism possesses only some of the genotypic information which belongs to the gene-pool of the population. It is the function of the genes to store information and transmit it to the next generation. Similarly it is the function of language to communicate information from one individual to the next. Furthermore, the genotype serves as a generator of novelty. In the biological case this generation takes place through mutation and reassortment. In language we find also various means of introducing conceptual novelty, the most important of which seems to be metaphorical extension.

Phenotypes are individuals which undergo development during every moment of their existence. Similarly, scientific practice is always changing. We control our activities in the laboratory by means of a cognitive control hierarchy. The goal of this activity is to create constancy in a world of flux. Phenotypes are also hierarchically organized. This organization creates stability which makes it possible for the organism to survive in a world of flux. By improving their cybernetic regulatory mechanisms, organisms gain increased adaptability, i.e. instead of being merely adapted to one particular environment, they can survive in an heterogeneous environment. By improving their old and developing new hierarchical levels of cognitive control, scientists learn to extend their perception into areas previously inaccessible to scientific investigation. For example, the understanding of radioactive decay created a host of applications in many sciences, indeed it even led to the formation of new specialties. Be it in archeology, geology, or chemistry, the utilization of this knowledge has led to new profound insights and opened up realms of reality previously inaccesssible to the human investigator.

How are we to understand the selection processes which lead to an improvement of the 'tuning' of the cognitive control hierarchy? Who does the selecting? These are the issues which now have to be dealt with. In order to do this it is necessary to search for the equivalent conception in science of the third fundamental category employed in Waddington's theory, namely the notion of the environment.

It will prove useful for the following discussion to distinguish between three different kinds of environments which can impinge upon a population of phenotypes. First, there is the internal environment of an organism in the sense that every cell, tissue, or organ constitutes the environment to every other cell, tissue, or organ. Internal selection may lead to the elimination of an organism without it ever experiencing the selective pressures of the external environment. Thus, a change occurring in the genome may never have the chance to be tested in the external world if this change proves not to be viable because of an incompatibility internal to the organism.

Second, there are the forces of the external environment which exert selective pressures upon organisms. Availability of food and water, range of temperatures, predator distribution, may serve as examples of those forces.

Third, we find the environment upon which the organisms act and which they transform through their activities. These changes may percolate through the ecological system and eventually impound upon the very population of organisms which was the original source of this disturbance.

In the realm of science we can also distinguish between three different kinds of environments, each of which has a selective impact upon scientific practice. The three kinds of selective forces are exerted by a) the scientist, b) the scientific community, and c) the wider social and cultural context. What remains to be shown is which kind of pressures the different environments exert, and how the interaction among those forces leads to the dynamics of scientific evolutionary change.

Let me begin by discussing the kind of selections made by the individual scientist and show how they contribute to the increasing adaptability of the human species. It is, of course, not the scientist's intention to select for greater adaptability; this is rather a concomitant result of the scientist's endeavors which are directed at far more practical goals. Neither does he, strictly speaking, search for truth, although, needless to say, he hopes to find true theories. But as there is no method available to direct him to this elusive goal, he has to concentrate on more manageable tasks and hope that by means of down to earth practices he will eventually also contribute to the development of theories which with increasing precision describe genuine invariant relationships holding in the universe. The scientist's work (at least the experimental scientists), is in fact as practical as that of any craftsman or engineer.

The major problem the scientist is facing at the beginning of an investigation is to find means by which to translate an elusive and ill-defined problem into a definite, well circumscribed task which can be pursued in the laboratory. For it is usually not the case that the data which he has at his disposal at the beginning of his research provide the kind of information suitable for universal generalizations. They have to be processed and refined before they may yield useful information and point to new avenues of research. Most importantly, the scientist does never know for sure if he is dealing with one specific phenomenon or a set of interrelated changes which produce the appearance of regularity but in reality have to be teased apart and investigated separately.

To gain control over our experience, to distinguish genuine from spurious phenomena, to tease various levels of reality apart, this is, as I have repeatedly emphasized in this thesis, the central task of the scientist. If he is successful, he will at the end of a research project come up either with a comphehensive theory accounting for the phenomena he has studied or - much more likely - he will have to content himself with presenting a new and better defined set of data which can serve as a starting point for future investigations. He selects his theories and instruments with this goal in mind, and if he is successful this reflects upon the adequacy of the various experimental procedures and theoretical conjectures which he employed during his often long and laborious research.

I will now demonstrate by means of an example how this down- to earth practical work also eventually leads to scientific progress which appropriately can be called 'progress in adaptability':

Suppose a scientist has the task of investigating the crystalline structure of a certain chemical substance. Let us further assume that it is known that this substance crystallizes in two different lattices. What the scientist wants to find out is under which conditions each of these lattices is being formed and by means of which procedures the crystallisation can be instigated.

The chemist attempts to synthesize the substance under consideration and employs a variety of procedures suitable for this purpose. Most of the time the result of the synthesis will be amorphous or polycrystalline material, occasionally, however, he will also get the desired single-crystalline substance. He may even discover that under certain circumstances the substance crystallizes in a different, heretofore unknown modification.

After having explored the methods by means of which the substance can be synthesized in crystalline form, the scientist will submit his results for publication. He will carefully describe the experimental setup, the measurement apparatus, and elaborate on the various procedures used for gaining and purifying the crystals. He will indicate the range within which they are thermodynamically stable and which precautions had to be taken to prevent their dissolution. At the end of the publication he will also make a few remarks of a more theoretical nature. He will point out that lattice A formed under conditions C1 after synthesizing the substance by means of chemical reaction R1. He will also emphasize that the substance could not be induced to crystallize in lattice B after having employed the same chemical synthesis. A different procedure had to be adopted, and the scientist will attempt to correlate the different chemical reactions with the occurrence of different lattices. He may point out that both types of reactions are known to involve different reaction pathways. Reaction R1 is distinguished from reaction R2 by a different transition state. Thus the chemist puts forward the hypothesis that the transition states determine whether the substance crystallizes in lattice A or B.

This conjecture may arise the interest of other scientists working on similar problems. They may have been working with different substances but have also been wondering what determines the formation of a particular crystal structure.They will now utilize the alleged hypothesis as a guide to action, and begin systematically to synthesize a series of similar substances by means of the same reaction pathways. (The similarity will be judged according to the electronic configuration of the molecules under consideration.)

Let us assume that eventually a pattern emerges which gives support to the chemist's conjecture. There will be exceptions, of course, but this is to be expected. After all, the scientists still don't know for certain what the genuine invariants are. The findings will again be published in a journal, and the procedures which led to the published data will be described in great detail.

Now the ground is prepared for the presentation of a new, more detailed and more informative conjecture: A scientist may link the different transition states to symmetry conservation of the molecular orbitals (i.e. he may link the phenomena to rules such as proposed by Woodward and Hoffman). The alleged hypothesis will state that transition state A leads to a more densely packed lattice than transition state B, and he will suggest that this is due to the symmetry of the molecular orbitals, i.e. to quantum mechanical relationships. This conjecture is far more powerful because it correlates not individual substances or compounds but is expressed on the general level of quantum chemistry. The scientists may now attempt to synthesize other compounds known to possess identical quntum mechanical transition states, and investigate if the conjecture holds true even among compounds of a very different chemical nature. Due to the existence of clear and unambiguous decision procedures it can be established if crystals of the predicted structure have been synthesized. Needless to say, this does not establish the truth of the theory but certainly shows its fruitfulness. A theoretical framework has been found which correlates a great number of substances and their crystal lattices.

The example demonstrates nicely how theory and practice are intimately interwoven in the actual research situation. We need reliable data in order to make intelligent theoretical guesses. These in turn will suggest new experiments as a result of which we will gain new, better specified data. This cycle will continue until we are satisfied that we have reached a level of theoretical sophistication and practical control powerful enough to capture genuinely invariant relations holding in the external world.

This interplay between theory and practice has often been observed, yet philosophers have insisted that practice is subservient to theory and that improved practice is only a byproduct of theoretical investigation. I prefer to turn this evaluation around and view improved theories as a byproduct of our increased capacity to control the conditions of our experience. Prima facie, this appears to be a spurious quibble. If theory and practice are but two sides of the same coin, why should it matter which side is given priority? But it does matter! Two sides of the same coin may designate the same value but one side may display obscure, ambiguous characters. The other side may, however, show engravings clearly etched and easily readable. Certainly we would prefer the latter side if it were our task to ascertain the value of the coin. The coin stands for scientific progress, the obscure side for scientific theories, and the clearly readable side for scientific practice.

There are simply no definite unambiguous criteria by means of which we can assess the value of an alleged scientific theory. We do, however, possess definite criteria which allow us to evaluate scientific practice. The young scientist learns during his apprenticeship how to apply these criteria, and he knows that his future research will be evaluated according to these standards. If he publishes a paper he invites criticism and careful assessment by his collegues. Characteristically they will first criticise his practice before turning to the discussion of the merits of his theoretical conjectures. They will ask questions such as: Could the data which he published have reliably been derived by means of the measurement instruments he described or do they lie outside the limits of accuracy characteristic of these instruments? Were the procedures the scientist employed acceptable or did they rest on dubious assumptions? Was he justified in utilizing the last decimal place in computing his findings or does he pretend to a degree of accuracy not attainable with the experimental setup he employed? Does the correlation of his results by means of a mathematical formula depict a genuine invariant relationship or does this correlation merely indicate wishful thinking on part of the scientist? These and similar questions may be asked by other members of the scientific community, and they may bestow severe penalties upon him if he is judged to have sinned against the professional standards accepted by the community at large. If his work, however, is judged to have been well performed and the alleged data appear to be reliable, then the scientific community may turn to the discussion of his theoretical conjectures.

So far I have been discussing two of the three kinds of "environments" which exert selective pressures on the cognitive control hierarchy by means of which we direct our research activities. First, I discussed the selections performed by the scientist who chooses theories, instruments, and procedures to guide him in his activities. Second, I discussed the selection which is exerted by the scientific community and which centers around the evaluation of scientific practices. I argued that scientific theories are selected only subsequently and then as guides to action for future research.

In order to understand the dynamics of evolutionary change suggested by Waddington's theory, it is now necessary to turn to the discussion of the environment upon which the scientist acts and which is transformed through these activities.

Modern technology is based upon science, and technology - needless to say - changes the world. By means of technology we create new goods, build better houses, battle diseases, and fly into outer space. But we also create new problems, such as air, water, and noise pollution. These problems now occupy a multitude of researchers in all areas of the physical and social sciences. Thus science should be viewed not only as a problem solving but also as a problem creating activity. The exponential growth we have been observing in the development of science is a direct outcome of this feedback interaction. We are facing the paradoxical situation that the more problems we solve, the more we also create.

5.8. CONCLUSION

I have reached the end of the discussion of Waddington's model of evolutionary change and have shown how it can elucidate scientific progress. I have discussed the functional equivalents in science of the biological notions of genotype, phenotype, and environment. I also have demonstrated that the same feedback connection holds in both evolutionary models. Let me recapitulate in a few sentences:

The language of the genes finds its equivalent in human language. It serves to transmit information and is also the generator of conceptual novelty.

Phenotypes are hierarchically organized. They find their equivalent in the cognitive control hierachies which I discussed in chapter four. These hierarchies create internal stability (be it physiological, perceptual, or conceptual), which makes it possible for organisms to survive in an heterogeneous environment.

Progress in evolution is equated with progress in adaptability. It is only through interaction with the environment that a species' adaptability can be tested. Likewise it is only through scientific practice that we make contact with the external world and can check the fruitfulness of our scientific theories.

The environment selects upon the phenotype and only indirectly upon the genotype. Similarly the scientist and the scientific community select for scientific practice and thereby indirectly select those theories which have proven to be useful guides to action.

Scientific knowledge gets translated into technological application. Technology transforms the world and creates new problems which have to be dealt with scientifically. The more powerful science becomes, i.e., the more levels of reality it penetrates, the more profound changes it can effect in the environment. Let me mention nuclear energy as an example. Thus we are facing the problem that the better we become in problem solving, the "better" we also become in problem creating.

I began this dissertation by discussing Bacon's and Descartes' vision of scientific progress. Those thinkers expressed a fundamental optimism about the possibility of gaining undubitable knowledge. They believed that there exists a perfect method which once discoverd would enable man to gain new knowledge in a systematic fashion. They further held that the advance of science would automatically lead to concomitant societal progress, eliminating poverty and other plagues of mankind forever. Man had forfeited his dominionover nature at the Fall, science would help him to reestablish this role once again.

I have argued that Bacon and Descartes believed rightly that scientific progress is possible. We have learned with remarkable success how to penetrate most hidden aspects of nature and have established instrumental and conceptual control over realms of reality forever inaccessible to our natural modes of perception. However, this knowledge was not gained through the application of one single perfect method. Rather it came about as a result of much tinkering and guessing and the employment of a variety of procedures and standards by means of which we can judge and compare scientific practice.

I have further argued that the concept of control is fundamental for the understanding of human knowledge, and that this is so because we live in an unstable universe, a universe of processes, where we have to learn how to control the conditions of our own experience. Only against a fixed perceptual and conceptual framework can genuine invariant relationships manifest themselves.

The evolution of science can be compared with biological evolution. Living things have conquered the water, the land, and the air. Homo sapiens has more than any other species contributed to the transformation of the earth. By applying scientific knowledge to practical matters we continuously impress new changes onto our environment. We thereby create new problems which in turn have to be dealt with by scientists. It appears now to be most doubtful if we will ever catch up with the problems we have created ourselves.

The growth of scientific knowledge has thus not led to a concomitant societal progress. Rather it has turned out that science feeds on its own problems, that it not only leads us to new important and exiting discoveries, but also to the destabilization of nature, culture, and society. It seems we are far removed from the Paradise Bacon and Descartes envisioned. Adam and Eve were not kicked out of Paradise for nothing!

NOTES TO CHAPTER 5

1. The term 'capricious environment' was coined by Lewontin (Lewontin(1966)). A capricious environment fluctuates randomly with respect to the adaptive capabilities of a population of organisms. Lewontin couches his discussion within an information theoretic framework. For a discussion of this framework and some of its implications see Wimsatt(1980).

2. The data on the geological record were taken from (Mayr(1978)).

3. For relevant information see Binford,S.R.&Lewis,R.(1969).

4. For the information on the archeological data I relied on (Piggot,S.(ed.)(1961)).

5. For example by (Jaynes(1976)) and (Barnes(1974)).

6. For a detailed account of which kind of issues are at stake see (Sober & Lewontin (1982)).

7. For a detailed exposition and discussion of the history of the caloric theory see (Fox(1971)).

APPENDIX*

AN INQUIRY INTO THE THOUGHT OF C.H.WADDINGTON

6.1. THE PROBLEM OF GOALDIRECTEDNESS IN EVOLUTIONARY PROCESSES

To understand the nature of evolutionary change is one of the most important challenges modern science is facing. Not only is the development of a powerful theory of evolution necessary for the understanding of the origin of the diversity and complexity which distinguishes living things, but such a theory is likely to have also repercussions of a more general nature. For evolutionary processes are not restricted to the realm of biology alone, Human cultures, too, display diversity and complex organizational structures. They, too, undergo change which is called 'evolutionary'.

The question arises: should we view the notion "the evolution of culture" just as a way of describing the increase in cultural complexity over time, which seems to suggest some vague analogue to biological evolution, or should we not rather assume that both evolutionary processes are to be accounted for by similar mechanisms of change? In other words, can we find a frame of reference such that the whole of evolution can be described in one fundamental set of terms?

The latter case would be of great philosophical importance, for so far no theoretical system which attempted to describe the cultural activities of man has given a convincing account of the relationshsip between the biological and the cultural heritage.

Biological evolution is the best researched and understood of all evolutionary processes. It constitutes a blueprint for all evolutionary systems and we might therefore hope to find help in our attempt to understand the dynamics of societal change by looking to the theory of biological evolution.

In the enterprises of science and society we deal with human beings, i.e. conscious actors who create their world according to 'rational' principles, who increase their knowledge and adjust their solutions of problems to the everchanging world. The non-human organisms, however, do not seem to know of such an adjustment. Their lives and actions are determined by genes which prescribe their activities. The appearance of design and purposiveness which is so evident in the world of all living organisms seems therefore to be just an illusion. The gap between the conscious human actor, adjusting his decisions to the changing world and those other living organisms, blindly directed towards 'goals' which they neither want nor don't want seems to be unbridgeable.

If this is the case then the theory of biological evolution might prove incapable of serving as a model for a problem solving process which deserves this name. Thus, if we claim that evolution has solved problems such as that of flying we speak only metaphorically for the concept of genuine problem solving seems to demand more than trial-and-error processes. It demands an interaction between the actor and his objects because an activity is purposive only if it exhibits sensitivity and persistence toward a goal as a result of directive correlation.

The question arises: do the concepts of persistence and sensitivity really presuppose a conscious human or divine actor, that is to say a being who acts intentionally towards a goal? Is it not rather possible that we are imposing an unduly anthropomorphic connotation on the concept of purposiveness? It seems to me that it could be said that any system which interacts with the environment in such a way that it adjusts itself to external stresses so that it reaches an end which is of value for itself, exhibits purposive behavior. In this context one often points to a self guiding-missile as an example of a purposive non-human entity. Yet this example is misleading because, after all, the missile was designed by human beings for a purpose set by them. What we need is a system which designs itself in a non-random fashion.

It is generally held that biological evolution is not such a system because there is no direct interaction between the environment and the genes which mutate randomly.

The biologist C.H.Waddington has developed a theory which brings purposiveness back into the realm of evolutionary change. This reopens the possibility that we may find a mechanism responsible for the characteristics of evolutionary systems and common to all of them. Hence, the philosophical implications of Waddington's approach can hardly be overestimated.

Before we can proceed in our task and expound the Waddingtonian concept of evolution, it will be necessary to give a brief account of the development and content of the prevailing neo-Darwinian concept of evolution. This will provide us with a basis for the understanding of Waddington's criticism of the received view. it will also facilitate the understanding of the Waddingtonian approach which, after all, is based upon concepts derived from population genetics.

6.2. THE RECEIVED VIEW OF EVOLUTIONARY CHANGE

In his On the Origin of Species, published in 1859, Darwin developed an evolutionary theory which was to account for the origin of organic diversity, both palaeontological and neontological. Although the idea that living things had in the course of time changed their form and function as a result of a gradual, continuous process did not originate with Darwin, he was the first to conceive of evolution as a two step process, the first step consisting in the production of variation, and the second, of the sorting of this variability by natural selection. Assuming Malthus' doctrine of 'excessive reproduction' and applying the principle of natural selection Darwin succeeded in giving an account for the phenomenon of adaptation: assuming that the organism will always leave more offspring than the environment can maintain, it follows that only a certain proportion of the progeny will survive. Those will be the ones which are fittest relative to a given environmental condition. However, if always the best, the fittest, survive, and if there is a difference in inherited variation among individuals, the species will by necessity steadily improve.

The awe-inspiring fit of the organisms to their environment had been the chief evidence of a Supreme Designer and had convinced the majority of Darwin's contemporaries that organic diversity would forever elude scientific enquiry. However, the simple mechanism proposed by Darwin enabled him to reject 'final causes' and vitalism, thereby opening the realm of organic change to scientific investigation.

Yet, a full application of Darwin's concepts was only possible after the theory was reconciled with Mendelian genetics: Mendel's discovery that different pairs of traits behave in inheritance independently of one another led to the postulate of a microstructure which was thought to account for the diversity observed in the macroscopic realm. The 'genes', as those microentities were soon to be called, were conceived of as being segregated and independently assorted entities. These entities were thought to determine the presence or absence of specific characters in the resulting organism. On this model, variation between individual organisms is due to changes in the underlying discrete units of inheritance, and evolution has to be considered in terms of changes in frequencies of individual genes in populations of organisms.

We see that this way of looking at living things is essentially based on an atomistic metaphysics, and the 'founding fathers' of the neo-Darwinian theory - Haldane, Fisher, and Wright - did indeed utilize the possibility of algebraic treatment which makes atomistic concepts so useful for scientific investigations.

The discovery of the DNA double helix by Crick, Franklin, and Watson and the deciphering of the genetic code provided a deeper understanding of the chemical nature of the gene, the mechanism of directed protein synthesis and the concept of mutation. Errors in the replication of DNA are reponsible for the occurrence of gene mutations and are thus the ultimate source of genetic variability. However, contrary to the original Darwinian conception, most of the genetic variation in populations arises not from new mutations at each generation but from the reshuffling of previously accumulated mutations.

Organisms which persevere best in the respective environment will leave more progeny and thereby perpetuate their genotype. Natural selection will operate upon individual 'characters' exhibited by the organisms. The phenotype is conceived as a mosaic of individual gene controlled characters upon which natural selection will operate thereby directly effecting the genotype. Thus the phenotype is viewed as being the genotype's way of ensuring the production of another genotype. And natural selection is conceived of as not being a merely negative force that eliminates the unfit but as a positive constructive force that accumulates the beneficial. When treating the theory mathematically a selective coefficient is attached to a certain allele or genotype. This indicates the relative number of offspring which would be left, on the average, by a large number of individuals of that type forming part of an infinite population. The coefficient is conceived as being a measure of 'fitness'. Thus the term fitness indicates the success of a genotype in transmitting genetic information to the next generation. Natural selection is conceived of being a stochastic process favoring or rejecting certain gene frequencies. The ultimate source of genetic variability are micromutations which transform a gene into 'newer' version and which occur at random. That is to say, their occurrence is unrelated to the demands of the environment.

If a population becomes geographically divided, the 'gene-flow' will be interrupted and new mutations will effect only the separated subpopulations. Different changes occurring in the environment will subject the populations to different selective pressures. In the course of time we might find two new species distinct from each other and adapted to different environmental conditions.

It is thought that in view of the time available for the evolutionary process, mutation, recombination, selection, and geographical isolation quite adequately account for the diversity of life. This confidence in the explanatory power of the neo-Darwinian theory of evolution was voiced by the well-known palaeontologist Simpson: "it seems that the problem of evolution is now essentially solved and the mechanism of adaptation is known".(1)

6.3. PROBLEMS WITH THE RECEIVED VIEW

In spite of Simpson's confidence there remains a group of distinguished biologists, physicists, and philosophers who stubbornly maintain that the problem of evolution is far from being solved and that the remaining conceptual problems deserve serious attention.(2)

The issues around which the controversy centers can be characterized by the slogans 'Does evolution depend on random search?' and 'Is the "survival of the fittest" a tautology?'.

The accusation that the time available for creating the diversity and complexity we find in the world of living things was by far too short to account for the fantastic variety and complexity we find in the living world in terms of random mutation and natural selection alone, comes mainly from physicists and mathematicians interested in the evolutionary process. Murray Eden, for instance, speaks about the negligible chance that "a child arranging at random a printer's supply of letters would compose the first twenty lines of Vergil's Aeneid" (Eden(1967)6).

The alleged tautologism of the neo-Darwinian theory is based upon the fact that it defines fitness in terms of leaving offspring. Taking this definition for granted 'the survival of the fittest' becomes a vacuous statement.

I do not intend to delve in any greater detail into these long standing issues. Let me, however, point out that both problems are created by the fact that the idea of long-term progress is a meaningless concept within the neo-Darwinian framework. When neo-Darwinians talk about progress they refer to progress in adaptation. If, say, a prey species solves the problem of running faster it will constitute progress for this species because its members will be more successful in escaping predators. Hence, the progress for one species results in many new problems for other species. If, in the course of many succeeding generations the predators in turn will change in such a way that they will be more

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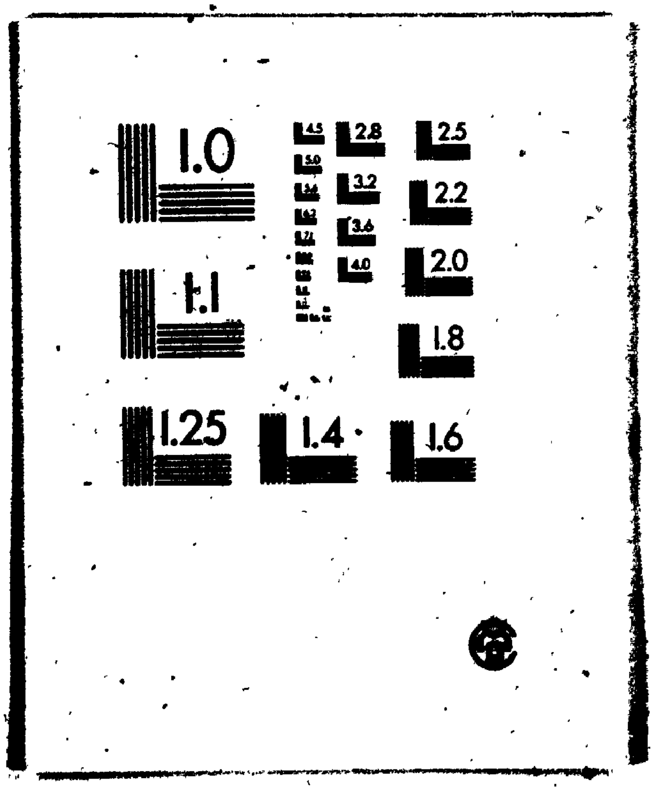

successful in their hunting capabilities they also will have created problems for a host of other species, including the one which "started" the succession of problem-creating by problem-solving. Indeed, solutions to a problem which originally constituted progress for the species may eventually lead to its extinction. If we define fitness in terms of leaving more progeny we can indeed consider only a very brief period, in which we assume that no other environmental changes take place.

> By fitness is simply meant the probability of survival and reproduction....It follows from this definition that fitness can be compared only in a specific environment or range of environments (Maynard Smith(1972)84).

The impossibility of accounting for long-term progress in adaptation becomes even more evident if we consider that all species past and present were, respectively are, adapted. A species which managed to survive for many millions of years must have been adapted to its environment.

Do we have to conclude that the idea of progress through evolution is a meaningless concept or might we not want to amend the neo-Darwinian conception of evolution in such a way that our intuitions about evolutionary progress become justified?

Neo-Darwinists themselves seem to feel that something is lacking within their shared framework. Maynard Smith, for instance, proposes to replace the phrase 'the survival of the fittest' by 'the survival of the adaptively complex'(Maynard Smith(1972)84).

It was suggested that in order to account for the evolutionary processes which involve human activities, we need a model of evolution as a system which designs itself in a non-random fashion. In light of the criticisms of the neo-Darwinian interpretation of evolution such a system seems to be also a <u>desideratum</u> for the biological process of evolution. Such a system would not only answer the objections against 'random search' and the alleged tautologism but would also account for progressive changes over long periods of time.

Waddington's 'Theory of the Phenotype' fulfils this demand. In doing so it brings back into biological reasoning the concept of puposiveness without, however, employing either the idea of a divine designer nor mysterious vital forces. Waddington voices his contention that the concept of design is central for an understanding of the process of evolution and that neo-Darwinism fails in this respect in the following way:

> The neo-Darwinian paradigm, of selection acting on genes, is good enough when we are considering situations in which fitness is related rather directly to the qualitative nature of primary gene products...(in these cases) it is probably justifiable to follow the neo-Darwinist prescription, and leave out of account any effect of the environment in modifying the phenotype on which selection acts. Where this prescription fails to pass muster is just in problems of evolutionary adaptation at the organ or even tissue level. Moreover, they are the problems which have philosophical implications. It is doubtful if anyone would have ever felt any need to resist the notion of evolution if all it implied was that the exact chemical constitution of haemoglobin gradually changed over the ages.

> The importance of the theory of evolution, as part of man's thinking about the universe in which he finds himself, is that it offered an alternative to the notion of an Intelligent Designer....It is where it comes into conflict with the Theory of Intelligent Design that the Theory of Evolution becomes something of general human importance, rather than a mere piece of technical specialized expertise; and it is just in these areas of conflict that the neo-Darwinist paradigm is misleading. The success of neo-Darwinism, pepped up as necessary with a shot of stochasticism in explaining the evolution of the haemoglobins, nuclear histones, or histo-compatibility loci...will be largely beside the point when we are considering Evolution as a relatively new, major component of man's thinking about his place in the universe (Waddington(1975)VI,VII).

6.4. THE WADDINGTONIAN ALTERNATIVE

Let us now turn to C.H.Waddington's account of evolution and see if and in which sense his 'Theory of the Phenotye' solves the alleged problems.

Waddington approaches the problem of evolutionary change from the viewpoint of an embryologist. As such, he is mainly concerned with the development of the organism through time. The developing organism presents a picture of increasing complexity from the moment of the formation of the zygote to the adult stage. Each cell in the body (with exception of the gametes) contains the same genetical information, i.e. an identical set of chromosomes. Yet the organism is made up of vastly different tissues and organs: liver, kidney, muscle, brain, to name but a few. The embryologist observes that the originally homogenous egg plasm becomes more and more structured as time goes on. It is important to realize that although originally each part of the egg has the same potential for developing into any of the later structures, once a 'decision' has been made a certain pathway will be followed, that is to say that the differentiation into different tissues and organs is irreversible. Thus, "the causal structure of an animal can be represented as a set of branching developmental paths, along which a certain part of the egg moves during the development" (Waddington(1941a)14).

If we want to characterize these developmental pathways we have to stress on the one hand the remarkably coordinated sequence of events and, on the other, the capability of the pathways to get readjusted if the coordination is interrupted by externally or internally acting factors. This becomes evident through the well-known capacity of many developing systems to react, especially in the early stages of development in a regulative, restorative manner to injuries, traumas or accidental losses of parts.

The organism is not only protected to some degree against external interferences, but also against genetic disturbances. Thus, inbreeding which diminishes the genetic diversity of natural populations often produces organisms which exhibit major malfunctions. This property of the genotype to absorb a certain amount of its own variation without exhibiting any alterations in development, is called by Waddington the "buffering of the genotype", examples of which are the phenomena of dominance and epistasis. The appearance of the phenotype thus does not exhibit a genuine 'mapping' between genetic and phenotypic diversity and we find that "identical phenotypes may have different genotypes, and identical genotypes may give rise to different phenotypes"(Waddington(1975)VI).

We have seen that the pathways along which the embryonic development proceeds are rather resistant to modification. Waddington refers to this property as the 'canalization' of development. Thus the initially rather homogenous egg plasm will differentiate into various distinct tissues without any intermediate tissues to be found, and we find canalization for brain, liver, muscle, and many other tissues which in turn will form functionally adaquate organs. The development of those organs is also canalized; an example is the hypertrophy of one organ of a pair when the other is removed. That is to say when we speak of canalization we refer to the constancy of a functional performance which - so to speak - the developmental pathways have as their 'goal'. In this sense we can also say that the whole phenotype is canalized, i.e. that in spite of differences in the genetic endowment and those occurring during ontogenesis the development of different individuals will lead to almost identical phenotypes.

> The individuals that are phenotypically almost identical, looking alike as two peas, contain wildly different genotypes, each a sample drawn from the populations' highly heterogeneous gene pool. The uniformity of the wild-type is a phenotypic uniformity, a result of the canalization of development, which conceals the heterogeneity of the phenotypes and of the epigenetic environments (Waddington(1974)36).

The canalization of development ensures the optimal performance of the phenotype in spite of varying environmental conditions. It can therefore be said that the developmental pathways exhibit purposive behavior as defined in the first part of this essay. That is to say the pathways show persistence and sensitivity towards a goal, whereby the goal is a function valuable for the organism. The fact that the organism can reach its goal in spite of environmental and genetical disturbances exemplifies persistence and sensitivity.

However, the appearance of purposiveness during embryological development will hardly be controversial even among biologists working within the neo-Darwinian framework.(3)

In order to illustrate the sense in which it can be said that the evolutionary process itself exhibits goal-directedness(4) let me present the following analogy. Let us visualize groups of soldiers having the task to dig trenches in order to approach in a relatively safe manner hostile positions. In order to achieve this aim several considerations come into play. The trenches have to be deep enough to provide protection but not so deep that one cannot jump out of them if necessary. The speed of digging is also important for if the soldiers don't reach their goal in time all their efforts might be in vain. Furthermore, let us assume that the soldiers have not worked together previously. We can therefore expect that their cooperation will improve as time passes on. Some groups of soldiers might consist of fast learners, not only in the sense of learning their individual tasks but in the sense of learning how to cooperate, putting each man at the right time at the place best suited for him. We can assume that those groups of soldiers learning how to cooperate fast and in the most efficient way will be those favored by 'natural' selection – an analogy which we might take quite literally in a wartime situation.

Our soldiers stand for populations of genes, the trenches for the developmental pathways. Natural selection will favor those gene-populations which cooperate best in bulilding the developmental pathways of the 'right' depth ('right' is, of course, defined relative to some function performed in the environment). If the entrenchment of the pathways is too deep or too shallow the organisms bearing those genes may become extinct. Too deep an entrenchment means insufficient flexibility in adjusting the trenches if necessary; Too shallow a trench will bear the danger that the organisms will be ill affected by even minor genetic or environmental changes.

We assumed that the soldiers, unskilled at first, improved in their performance and learned how to cooerate best. On the gene-level this improvement will occur over many generations, that is to say that gene-populations which cooperate best will produce phenotypes which will leave more progeny. Any further improvement will be preserved in the gene pool.

Our analogy between a team of soldiers and a 'team' of genes lacks still an essential component. Our soldiers operate towards a goal and their activities and successes will be assessed in relation to this goal. If our metaphor is to be of any value we have to postulate that there are goals to be achieved by evolution. We also have to demand that the slow improvement in cooperation among the genes can and will be continuously assessed relative to the goal which is, of course, an environmental demand. In other words there has to be a <u>feedback</u> connection between the goal set by the environment and the gene pool. It is this point which is crucial for the understanding of Waddington's theory because it is here that we inevitably have to employ the concept of the phenotype.

Phenotypes show a remarkable capability of adjusting themselves to changing environmental conditions. If we expose our muscles to heavy work they will grow in size, if we walk bare foot we will grow calluses. On the traditional view it is thought that those characters acquired during the lifetime of an individual are irrelevant for evolutionary changes. After all, we know that there is no information flow from proteins to nucleic acids but only from nucleic acids to proteins. But, as Waddington points out

> The acquirement of an adaptive modification in response to an environmental stress cannot be due simply to a plasticity of the phenotype to which the genotype is quite irrelevant. The adaptive modification, like all other characters of the developed animal, must be an expression of the hereditary potentialities with which the zygote was endowed (Waddington(1961)287,288).

If the adaptive modification is of value to the animal then we should expect that evolution will favor genotypes which endow their possessors with the capacity to react adaptively with their surroundings. In other words, natural selection will favor organisms with greater <u>adaptability</u>.

> We are suggesting that all natural selection is in fact a selection for the ability of the organism to adapt itself to the environment in which it finds itself (Waddington(1957)104).

The characters of an adult organism are always the result of processes of development. If a population persists in some unusual environment by forming a suitable adaptive modification, natural selection will favor those genotypes which cooperate best and facilitate the acquisition of these characters. Thus, the exposure to the changed environmental conditions over many generations will result in changes in the developmental system and will lead to a "tuning of the canalized pathways" (Waddington(1961)285).

It is because the capacity of organisms to respond to environmental stresses during development is itself a hereditary quality that we can speak about a feedback between the environment and the genotype. That is to say, that the environment has not only a negating, i.e. selecting effect but also a positive or — as we might want to say — instigating effect. To say it in Waddington's words:

> The environment not only determines the selective forces, but also co-operates with the genotype in the specification of the phenotype (Waddington(1957)104).

6.5. EXPERIMENTAL EVIDENCE

Waddington buttresses his interpretation of the evolutionary process with numerous examples and experiments. Especially illuminating are his experiments on 'Genetic Assimilation' and his interpretation of the 'Evolution of eggs'.

The evolution of eggs has always posed a major problem for evolutionary accounts based upon natural selection. The eggs produced by animals belonging to different phyla and families of the animal kingdom differ from one another as strikingly and fundamentally as do the adults. It is difficult to conceive of a natural selective mechanism operating upon the characteristics of the hatched animal, but not on the differentiation occurring within the developing egg. That is to say that the repatterning of the egg structure has to be a consequence of natural selection operating on the adult animal. In other words,"from the point of view of evolution, it is the hen which comes before the egg" (Waddington(1951)174). The hatched animals are subjected to a variety of environmental stresses. Selection for the ability to respond adaquately to those stresses will in the course of many generations generate animals which will repond better, i.e. more specifically to specific environmental conditions. Natural selection will lead to an adjustment of the developmental pathways which are responsible for these specific reactions.

> We may.....conceive that it may not be beyond the powers of natural selection, once a given new adult type of pattern has been evolved, to improve

> the developmental system by which it is brought into being and in the course of this improvement to alter the organization of the ripe ovum from which the whole process starts (Waddington(1951)174).

That is to say that the plasticity of the phenotype is a precondition for the survival in changing environmental conditions. Genotypes which endow their possessors with the capacity to react adaptively with their surroundings will be favored by natural selection. To say it metaphorically: they enable the organism "to see a goal" and meet a specific environmental demand.

An especially illuminating example of the appearance of purposiveness in evolution is provided by the phenomenon of 'Genetic Assimilation', a novel evolutionary process which was predicted and experimentally verified on the basis of the Waddingtonian concept of evolution. To illustrate this phenomenon I will describe one of the numerous experiments performed by Waddington.(5)

waddington manipulated the environment in which Drosophila larvae live by adding a high concentration of sodium chloride to the medium. These larvae possess anal papillae which play a role in regulating the osmotic pressure of the body fluids. The increase in the salt concentration resulted in an increase of the size of these papillae in successive generations of animals. No artificial selection was made, the selection pressure being entirely due to the natural selection exerted by the harsh environment. After many generations of larvae had been exposed to the modified medium an enlargement of the papillae occurred even if the animals were raised on a medium with low sodium chloride content.

> We have obtained a result which is effectively the same as would have resulted from the direct inheritance of acquired characters but which has been produced, not by the mechanisms which are usually thought of in connection with Lamarck's hypothesis but by a population-genetical mechanism which involves selection (Waddington(1959a)49).

In the initial stages of the experiment the increase in the size of the papillae occurred proportional to the increase in salt content. Animals which were most successful in acquiring this character, i.e. which showed a high degree of adaptability survived and left progeny. Further selection resulted in an improvement of the developmental pathways responsible for this particular responsiveness. Eventually the 'acquired' character occurred irrespective of the exact extent of stimulus which the organism had met in its early life. That is to say that the developmental pathways had become canalized. Finally the particular modification which had been selected for appeared even in the absence of the stress. This shows that the response to the environmental stress had become genetically assimilated.(6)

6.6. THE DYNAMICS OF PROGRESSIVE CHANGE

We have seen that 'acquired' characters exert influence on the direction in which evolutionary change proceeds. Indeed, by selecting

> for both capacity to respond and type of response to environmental stresses,....we found evidence for the existence of a 'feedback' between the conditions of the environment and the phenotypic effect of gene mutations. The 'feedback' circuit is the simple one, as follows: (a) environmental stresses produce developmental modifications; (b) the same stresses produce a natural selective pressure which tends to accumulate genotypes which respond to the stresses with co-ordinated adaptive modifications from the unstressed course of development; (c) genes newly arising by mutation will operate in an epigenetic system in which the production of such co-ordinated adaptive modifications has been made easy (Waddington(1959a)56).

The correlation between the plasticity of the phenotype on the one hand and its capability to respond specifically to long lasting environmental pressures provides a basis for the understanding of the complexity we find in the world of living things. The existence of a 'feedback' mechanism between the environment and the genome can provide us with a better understanding why natural selection will favor organisms which are not only adapted but also adaptable. The plasticity of the phenotype is not only valuable for the immediate survival of a particular species living in an heterogeneous environment but is also a precondition for long-term directional changes as exhibited in the canalization of development. The capability of organisms to acquire characters if exposed to a new environment presupposes a highly heterogeneous gene pool. The experimental findings of T.Dobzhansky showed that natural populations are genetically much more heterogeneous than had been thought previously. He proposed that the evolutionary changes as codified in the genome should be considered not so much as a consequence of changes in sigle, identifiable genes, but rather as the result from alterations of the proportions in which many different genes are present in the gene pool of a population. Organisms which react adaptively with the environment thereby expose a genetic potential which previously had been concealed in the old environment by dominance and epistasis. Canalization for acquired characters therefore requires a highly heterogeneous gene pool and fails in inbred populations. This has been amply verified by numerous experiments.

A changing environment will pose specific problems to the organism. It will not 'ask' for an overall improvement. Yet, the developmental pathways which are responsible for particular functions are intrinsically interrelated. Environmental pressures which, say, promote the development of a more powerful muscular system will thereby also require an increase in the consumption of oxygen. Thus, the blood-circulatory system might have to be improved. This change, in turn, will have repercussions on the structure of many other organs. Hence, the selective pressures operating towards an improvement of one particular function may result in the 'rebuilding' of the species.

In order to adapt to a changing environment the organisms will often have to change their behavior adequately. The genes which determine the modification of the developmental pathways must therefore be correlated with those responsible for the behavioral adjustment. For example "Kettlewell has shown that melanic moths do in fact tend to settle on darker areas of trees more frequently than would be expected by chance. It is clear, however, that here again selection will be operating not on isolated components, behavior on one side and developmental and physiological response on the other - but on an interlocking system in which behavior and other aspects of function mutually influence one another"(Waddington(1959a)57-58).

Thus, the solution to an environmental problem as codified in the developmental pathway and in the behavior of the organisms cannot be seen in isolation from either the rest of the developmental processes nor from the environment in which the organisms live.

Yet, higher organisms do not just 'behave' in a perfectly determined manner but they also choose and modify the environment in which they live. This leads us to the consideration of the complex problems involved in the evolution of the ecosystem which poses such questions as: "how did the London sparrow cope with the success of the petrol engine in driving off the streets, all those horses, with their offerings of dung full of delicious seeds"(Waddington(1969)117). The feedback situation in which an animal's behavior largely determines the kind of selection pressure to which it will be subjected is characterized by Waddington in the following way:

> Behavior is one of the factors which determines the magnitude and type of evolutionary pressure to which the animal will be subjected. It is at the same time a producer of evolutionary change as well as a resultant of it, since it is the animals behavior which to a considerable extent determines the nature of the environment to which it will submit itself and the character of the selective forces with which it will consent to wrestle. This 'feedback' or circularity in a relation between an animal and its environment is rather generally neglected in present-day evolutionary theorizing (Waddington(1959b)204).

6.7. SUMMARY

Profeesor Waddington presents us with a picture of the evolutionary process which is based upon the existence of two interlocking feedback systems. Because of their behavioral adaptability animals can choose new environments and in doing so change them. This in turn, creates new demands for a host of other species. Because of their phenotyic adaptability organisms can - within certain limits - survive in spite of changing environmental conditions. If the selective pressures remain constant for a long period of time, the developmental pathways which are responsible for the adequate reactions will be changed in such a way that the organism will develop in the "right" direction, even in the face of minor genetic or short-term environmental pressures. That is to say that natural selection has "dug the trenches of the proper depth", a process also labelled the 'tuning' of the canalized pathways. As the result of its "labor" natural selection will accumulate those populations of genes best coordinated relative to the "goal". Hence, natural selection does not only act as a sieve which eliminates the harmful and accumulates the beneficial but it also has an instigating effect upon the developing organism. Organisms which live in unchanging environments will not experience this "push" from their surroundings and are therefore not likely to change.

The flexibility and directedness which characterizes the developmental processes has its counterpart on the behavioral level in the appearance of purposive activities. Animals endowed with highly dveloped sense organs coordinated by a complex nervous system will be able to act purposively and adjust their activities according to the prevailing environmental conditions. The capability to learn from one's experience is most highly developed in the human animal. Indeed, human beings do not necessarily have to experience their environment but can rely upon their judgements when contemplating a proper course of action.

The appearance of design is omnipresent in the world of living things. It is a result of the development of systems which can interact with their environment and in doing so increase their problem solving capabilities. In moving from the neo-Darwinian to the Waddingtonian paradigm we switch from 'progress in adaptation' to 'progress in adaptability', from 'random search' to 'goal-directedness'. Or to say it in Waddington's own words:

Whereas the import of the previous evolutionary theories can be sloganized in Jacques Monod's phrase 'Chance and Necessity', the (new) paradigm would substitute slogans such as 'Learning and Innovation' or, if you like a more with-it-jargon, 'Recompiling and Heuristic Search'(Waddington(1975)VI).

NOTES TO THE APPENDIX

* The material presented in the appendix constitutes a slightly revised version of a previously published paper (Hahlweg(1981)).

1. Quoted from Wolsky (1976)2.

2. For an extensive criticism of the neo-Darwinian theory from the viewpoint of a biologist see Wolsky(1976), and the writings of Lewontin, Portmann, and Waddington. The criticism brought forward by mathematicians and physicists are nicely summarized in Moorhead, Kaplan (eds.)(1967). For criticism based upon philosophical considerations see Grene(1974).

3. The neo-Darwinian view on this matter is well summarized in Mayr(1968).

4. Waddington's response to E.Mayr's article (see footnote 3) is illuminating in this context. See Waddington(1968)55-6.

5. For a detailed account of Waddington's experiments on 'Genetic Assimilation' see Waddington(1941b;1952;1953;1959a;1961). The following experiment is described in Waddington(1959a), reprinted in Waddington (1975)46-9.

6. G.C.Williams questions the relevance of Waddington's experiments for biological evolution on the basis that they involve artificial selection. (He refers to experiments in which the eggs of <u>Drosophila</u> were subjected to ether vapor in sublethal doses. A few of the survivors developed into the abnormal bithorax phenotype. These phenotypes were selected for, and the treatment was repeated in successive generations. Eventually some eggs in the selected line produced the bithorax phenotype even without exposure to the ether, i.e. genetic assimilation had occurred.) Williams' explanation of these experiments is: "He (Waddington) produced an extreme but simple kind of degenerative evolution. He was selecting for specific kinds of inadequacies in the mechanisms of developmental canalization"(G.C.Williams(1966)77).

Aside from the fact that artificial selection is a commonly accepted practice in many laboratories, the example I present in this essay shows that 'genetic assimilation' can be a source of evolutionary change which is of survival value for the organisms.

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