

INTRODUCTION TO PHILOSOPHY OF SCIENCE

Chapter I - Overview

1.01 Aim of Philosophy of Science

The aim of contemporary philosophy of science is to formulate principles of basic-science research practices by investigating successful episodes in the history of science, and then to advance contemporary basic science by applying the principles.

This introductory ebook is a concise summary of the contemporary pragmatist principles of philosophy of science.

1.02 Computational Philosophy of Science

Achievement of the aim of philosophy of science is facilitated today by computerized discovery systems in a new specialty called “computational philosophy of science”. Computational philosophy of science is the design, development and application of computer systems that simulate episodes in the history of science. The resulting mechanized procedures formulate and implement principles for contemporary philosophy of science. Application of the computer systems aims to facilitate the advancement of contemporary basic-science research. Computational philosophy of science gives the philosopher a contributing role in the work of the scientist.

1.03 Two Perspectives on Language

Philosophy of language supplies the analytical framework that integrates contemporary philosophy of science. Philosophers distinguish two perspectives in philosophy of language called “object language” and

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“metalanguage”. Object language includes most of ordinary discourse together with the language of the sciences, which is about the domains of reality that the particular sciences investigate.

Metalanguage is language about object languages. Much of the discourse in philosophy of science is in the metalinguistic perspective. Important metalinguistic terms include “theory”, “law”, “observation report” and “explanation”. And the computer instructions coded in the discovery systems are also metalinguistic expressions, because these systems input, process and output the object languages of the sciences.

1.04 Dimensions of Language

Using the metalinguistic perspective, philosophers analyze the object languages of science in terms of four aspects that Rudolf Carnap called “dimensions”. They are syntax, semantics, ontology, and pragmatics.

Syntax refers to the structure of language, as is often represented by ink marks on paper. Syntactical symbols include terms such as words and mathematical variables, and also sentences and mathematical equations assembled from the terms. Syntactical rules enable construction of grammatical expressions such as sentences and equations by concatenation or other arrangements of terms.

Semantics is the meanings associated with syntactical symbols. Syntax without semantics is systematic but literally meaningless. The addition of meanings to syntactical symbols makes the syntax “semantically interpreted”.

In the metalinguistic perspective belief in the truth of semantically interpreted universally quantified sentences makes the sentences “semantical rules” that are used for analyzing the complex meanings of their component subject terms. The lexical entries in a common unilingual dictionary function as semantical rules.

Ontology is the aspects of extralinguistic reality that are described by semantically interpreted sentences believed to be true due to empirical testing. “Empirical” means based on experience, i.e., conceptualized sense stimuli.

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Pragmatics in philosophy of science pertains to how scientists use language, namely to create and test theories, and thus to develop the scientific laws that are operative in scientific explanations.

1.05 Classifications of Functional Topics

Basic-science research practices can be classified into topics that pertain to certain functions performed in basic research. They are also the principal topics typically discussed in the philosophy-of-science literature.

Aim of basic science is to develop explanations, which are the institutionalized objective and the products of basic-science research.

Discovery pertains to the processes of developing new theories. Pragmatists define theory language pragmatically as universally quantified statements including equations that are proposed for empirical testing. Empirical testing is the pragmatics of theory language.

Criticism pertains to the decision criteria for the evaluation of theories. Pragmatists accept only the empirical criterion for evaluation of theories.

Explanations for individual events are enabled by scientific laws, which are theories that have been tested empirically and not falsified by the tests.

1.06 Classification of Modern Philosophies

Twentieth-century philosophies of science may be classified into three generic types. Each type has several representative authors with different but similar philosophical ideas. These generic types of philosophy are *romanticism*, *positivism* and *contemporary pragmatism*.

There are philosophical issues in all four of the functional topics listed above, which originate in the different philosophies of language characteristic of these three modern philosophical traditions. *Each of the three modern philosophies uses different concepts for such metalinguistic terms as “theory” and “explanation”.*

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Chapter II – Three Modern Philosophies

This chapter sketches the three generic types of twentieth-century philosophy of science in terms of the four functional topics mentioned above. Philosophy of language will be taken up in Chapter III. Then all these elements will be integrated together to complete the synthesis in Chapter IV.

2.01 Romanticism

Romanticism has no representation in the natural sciences today, but is still widely represented in the social sciences including economics and sociology. It originated with the eighteenth-century German idealist philosophers including notably Immanuel Kant. The idealist philosophies are of purely antiquarian interest to professional philosophers of science today, but contemporary romantics carry forward the thesis that there is a fundamental divide between sciences of nature and sciences of culture. Romantics default to the positivist philosophy for the natural sciences, but they reject imitating the positivist philosophy of the natural sciences for the social sciences.

Aim of science:

For romantics the aim of the social sciences is “interpretative understanding” of “human action”, by which is meant explanation of social interaction in terms of the culturally shared subjective mental states – ideas and motives – of members of social groups.

Discovery:

Because romantics define “theory” as language describing subjective ideas and motivations, some of them furthermore view the development of theory in the social sciences as involving the social scientist’s introspective reflection on his own experienced ideas and motivations. They thus attempt to understand by imputation the subjective mental states of the social members whose social interactions they seek to explain. Some social scientists call such attempts to relive vicariously the experiences of the social members “substantive reasoning”.

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The romantics therefore deny that social theory understood as interpretative understanding can be developed by data analysis exclusively or by observation of external behavior alone. Romantics oppose their view of the aim of science to the positivists' view including notably that of the behaviorists such as B.F. Skinner. The former say they explain consciously purposeful and motivated "human action", while the latter say they explain publicly observable "human behavior".

Criticism:

The romantic criterion for criticism is "interpretative understanding" of conscious motivations, which are deemed to be the underlying causes of observed human action. Causality is an ontological concept, and all romantics impose their mentalistic ontology as a prior ontological criterion for criticism, while making empirical or statistical analyses at most optional and supplementary.

Furthermore many romantic social scientists demand the criterion that a social theory "make sense" in the particular investigator's own introspectively recognized subjective personal experience.

Explanation:

The romantics maintain that only "theory" that describes subjective motives can "explain" conscious human action. The motives are the causal factors identified in "causal" explanations, which are also therefore called "theoretical" explanations. Observed regularities cannot "explain", even if they enable correct predictions.

2.02 Positivism

Positivism was a reaction against romanticism, but more recently it has been relegated to history of philosophy. Positivists hark back to the eighteenth-century British empiricist philosophers including notably David Hume. But it was not until the late nineteenth century that positivism got its name from the French philosopher Auguste Comte, who also founded sociology.

Positivism's last incarnation was the "neopositivists", who attempted to use the symbolic logic developed by Russell and Whitehead early in the twentieth century. They had fantasized that the Russellian truth-functional

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symbolic logic could serve philosophy, as mathematics has served physics, and they called themselves “logical positivists”.

Contrary to the romantics, positivists believe that all sciences including social sciences share the same philosophy of science. And the positivist ideas about science are based upon their examination of the physical sciences.

Aim of science:

Positivists believed that the aim of science is to produce explanations that have a foundation in objectivity supplied by observation. This is called a “foundationalist agenda.” Early positivists recognized only empirical laws for valid scientific explanations, but later positivists also recognized hypothetical theories in valid scientific explanations, if the theories could be logically related to language used to report observations.

Discovery:

Positivists define empirical laws as universally quantified statements containing only observation terms describing observable entities and phenomena. They believed that empirical laws are inferentially produced by inductive generalization based on repeated observations.

In contrast positivists define theories as statements containing theoretical terms, which do not describe observable entities or phenomena. They believed that theories are the products of creative imagination, but left the creative process for developing theories unexplained.

Criticism:

The positivists’ criterion for criticism is publicly accessible observation. They deny that either empirical laws or theories can be permanently validated empirically, but they require that the laws be founded in observation as a condition for the objectivity needed for true science. They maintain that observation language is incorrigible and not subject to revision.

Theories on the other hand are subject to revision, but are nevertheless indirectly and tentatively warranted by the empirical laws, when the laws are logically implied by the theories.

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Explanation:

Positivists and specifically Carl Hempel advocated the “covering-law” model of explanation, according to which predictions of observable individual events are deductively derived from observation-language statements together with universal or “covering” empirical laws. This form of explanation has also been called the “nomological-deductive” model.

Positivists also maintained that theories explain laws, when the theories are premises from which the empirical laws are deductively derived as theorems by the mediation of “correspondence rules”, which are also called “bridge principles”. Correspondence rules are sentences that relate the theoretical terms in a theory to the observation terms in the empirical laws.

2.03 Contemporary Pragmatism

In the middle of the twentieth century there emerged a new academic philosophy in the United States that has been critical of logical positivism. Now appropriately called “contemporary pragmatism”, it is currently the ascendant philosophy in American academia.

Pragmatism had earlier versions in the classical pragmatists, notably those of Charles S. Peirce, William James and John Dewey. Some theses in classical pragmatism such as the importance of belief have been carried forward into the new. Especially important is John Dewey’s pragmatic philosophy of science, which says that the logical distinctions and methods of scientific inquiry develop out of the scientist’s successful problem-solving processes.

The origin of the contemporary pragmatist philosophy of science is Werner Heisenberg’s reflections on the language in his quantum-theory revolution in microphysics. There have been various alternative ontologies proposed for the quantum theory in modern microphysics. Most physicists have accepted one that has ambiguously been called the “Copenhagen interpretation”. There are two versions of the Copenhagen interpretation, and both assert a thesis called “duality”, which says that the wave and particle properties of the electron are two aspects of the same entity, rather than two separate entities always found together.

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One of those versions is called “complementarity”, which was proposed by Niels Bohr, founder of the Copenhagen Institute for Physics. His version says that the mathematical equations of quantum theory must be viewed instrumentally instead of descriptively, because only the language of classical Newtonian physics can describe physical reality. Instrumentalism is the doctrine that scientific theories are not descriptions of reality, but are merely useful instruments that enable prediction. The quantum theory says that the electron has both wave and particle properties, but in classical physics the semantics of the terms “wave” and “particle” are mutually exclusive – a wave is spread out in space while a particle is a concentrated point. Therefore Bohr maintained that description of the electron as both “wave” and “particle” is a necessary semantic inconsistency that he called “complementarity”.

Heisenberg, a colleague of Bohr at the Copenhagen Institute, proposed his own version of the Copenhagen interpretation. His version also contains the idea of duality, but he said that the mathematical expression of the quantum theory is realistic and descriptive rather than merely instrumentalist. And since the equations describing both the wave and particle properties of the electron are mathematically consistent, there is in no need for Bohr’s complementarity inconsistency.

The two versions differ in their philosophy of language. Bohr’s philosophy is a naturalistic view of semantics, which requires what he called the “forms of perception”. Heisenberg’s philosophy is the artifactual view of semantics, in which the equations of his uncertainty relations supply the context that defines the concepts that the physicist uses for observation. Heisenberg’s philosophy of language was due to the influence of Albert Einstein, and it has been incorporated into the contemporary pragmatist philosophy of language.

Heisenberg’s linguistic philosophy as incorporated into the contemporary pragmatist philosophy may be summarized in three theses:

Thesis I: Relativized semantics.

In "Quantum Mechanics and a Talk with Einstein (1925-1926)" in his *Physics and Beyond* Heisenberg relates that on the day in April of 1925, when he presented his matrix-mechanics quantum theory to the prestigious Physics Colloquium at the University of Berlin, Einstein, who was in the

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assembly, afterward invited him to his home that evening. In their conversation Einstein said that he no longer accepts the positivist view of observation including such positivist ideas as operational definitions, because *the theory describes what the physicist can observe*.

The idea that theory determines what is observed contradicts the fundamental positivist thesis that there is a dichotomous separation between observation language and theory language. Positivists believed that the objectivity of science requires that the vocabulary used for incorrigible observation must be uncontaminated by the vocabulary of speculative and provisional theory.

Then in the next chapter titled "Fresh Fields (1926-1927)" in the same book Heisenberg reports that Einstein's discussion with him in Berlin had later occasioned his own reconsideration of observation. He then recognized that classical Newtonian physical theory had led him to conceptualize the observed track of the electron in the Wilson cloud chamber as having a definite position and velocity.

Recalling Einstein's statement that the semantics of observation is determined by physical theory, Heisenberg reconsidered what is observed in the cloud chamber. He then rephrased his question about the electron tracks in the cloud chamber using the concepts of the quantum theory instead of the classical Newtonian theory. He reports that he asked himself: Can the quantum mechanics represent the fact that an electron finds itself approximately in a given place and that it moves approximately at a given velocity? In answer to this newly formulated question he found that these approximations could be represented mathematically. He then developed this mathematical representation that he called the "uncertainty relations", the historic contribution for which he was awarded the Nobel Prize in 1932.

Later Russell Hanson expressed Einstein's thesis that the physical theory describes what the physicist can observe by saying that observation is "theory-laden" and Karl Popper likewise by saying that observation is "theory-impregnated".

Furthermore Paul Feyerabend recognized employment of relativized semantics to create new observation language, and he called that practice "counterinduction". Feyerabend found that Galileo practiced counterinduction in the *Dialogue Concerning the Two Chief World Systems*

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(1632), where Galileo reinterpreted apparently falsifying observations in common experience by using the concepts of the heliocentric theory instead of the concepts of the geocentric theory. Likewise Heisenberg practiced counterinduction in 1926 to reinterpret the observed electron track in the Wilson cloud chamber using quantum concepts instead of classical concepts.

Like Einstein, pragmatists say that the theory decides what the scientist can observe. Thus semantics is relativized in the sense that the meanings of descriptive terms used in observation reporting are not just names or labels for phenomena, but rather are determined by the context in which they occur.

Most notably that context includes theories that proponents believe are true. The significance is that the acceptance of a new theory superseding an earlier one and sharing some of the same descriptive terms, produces a semantical change in the shared descriptive terms used for observation reporting. Thus Einstein for example changed the meanings of such terms as “space” and “time”, which occur in both the Newtonian and relativity theories. And Heisenberg changed the meanings of the terms “wave” and “particle”. Feyerabend calls the semantical change due to the relative nature of semantics, “meaning variance”.

Thesis II: Empirical underdetermination.

Einstein recognized that a *plurality of alternative empirically adequate theories could be consistent with the same observational description*, a situation that in his autobiography he called “an embarrassment of riches”.

Measurement error and conceptual vagueness, which can be reduced indefinitely but never completely eliminated, exemplify the empirical underdetermination that is inherent in all language, and that permits this observational ambiguity and theoretical pluralism. Additional context including law language and/or improved test-design language contributes additional semantics to the observational description in the test designs, thus reducing but not eliminating empirical underdetermination. And such additional semantics for test designs that refines the definition of the problem may occasion retesting of theories previously tested and not falsified. Willard van Quine called this thesis “empirical underdetermination”, the label by which the thesis is known today.

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Thesis III: Ontological relativity.

In his discussions about Einstein's special theory of relativity in *Physics and Philosophy* and in *Across the Frontiers* Heisenberg describes the "decisive step" in the development of special relativity. That step was Einstein's rejection of Hendrik Lorentz's distinction between "apparent time" and "actual time" in the Lorentz-Fitzgerald contraction. Lorentz took the Newtonian concepts to describe real space and time. In his relativity theory Einstein took Lorentz's "apparent time" as physically real time, while altogether rejecting the Newtonian concept of absolute time as real time. In other words the "decisive step" consisted of Einstein's taking the relativity theory realistically, and *letting his relativity theory define the ontology of the physically real.*

Then in his "History of Quantum Theory" in *Physics and Philosophy* Heisenberg describes his use of the same strategy in his discovery experience for quantum theory. There he states that his thinking about the uncertainty relations consisted of turning around a question. Instead of asking himself how one can express in the Newtonian mathematical scheme a given experimental situation, he asked whether only such experimental situations can arise in nature as can be described in the formalism of his quantum theory. The new question is an ontological question about what exists in physical reality.

Again in "Remarks on the Origin of the Relations of Uncertainty" in *The Uncertainty Principle and Foundations of Quantum Mechanics* Heisenberg explicitly states that a Newtonian path of the electron in the cloud chamber does not exist. And still again in "The Development of the Interpretation of the Quantum Theory" in Pauli's *Niels Bohr and the Development of Physics*, Heisenberg says that he inverted the question of how to pass from an experimentally given situation to its mathematical representation. There he concludes that only those states that can be represented as vectors in Hilbert space can exist in nature and be realized experimentally. And he immediately adds that this conclusion has its prototype in Einstein's special theory of relativity, when Einstein had removed the difficulties of electrodynamics by saying that the apparent time of the Lorentz transformation is real time.

Like Heisenberg in 1926, the contemporary pragmatist philosophers let the scientist rather than the philosopher decide ontological questions.

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And the scientist does so on the basis of empirical adequacy demonstrated in empirical tests. Many years later Quine called this thesis “ontological relativity”, the label by which the thesis is known today.

Ontological relativity did not begin with Heisenberg much less Quine. Copernicus and Galileo practiced it when they both interpreted heliocentrism realistically and accepted its ontology to the fateful chagrin of Pope Urban VIII. Heisenberg’s Copenhagen interpretation still prevails in physics today. But should future superior test designs and experiments result in falsification of his Copenhagen interpretation and in the survival of, say, David Bohm’s alternative subquantum hypothesis, then physicists’ practice of ontological relativity would make the subquantum hypothesis the prevailing ontology in future microphysics.

In view of the above background description of the contemporary pragmatist philosophy of language, a few of the more salient aspects of the pragmatist concepts of the four functional topics are summarized as follows:

Aim of science:

For the contemporary pragmatists the aim of basic science is explanation. Wherever possible the explanation should enable prediction and ideally control by applied science including new engineering technologies, medical therapies and social policies.

Discovery:

Contemporary pragmatism is consistent with computerized discovery systems, which aim to proceduralize and mechanize new theory development, in order to advance contemporary science.

Contemporary pragmatists *define* theory language and observation language pragmatically. Theories are universally quantified statements that are *proposed* for empirical testing. Scientific laws are former theories that have been tested with nonfalsifying test outcomes. Test-design statements are universally quantified statements that are *presumed* for empirical testing in order to identify the subject for empirical testing and to execute the test. Observation language is particularly quantified test-design and test-outcome statements with their semantics defined in the test-design language. Unlike positivists, pragmatists do not recognize any natural observation semantics.

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Contemporary pragmatists *individuate* theories semantically. Two theory expressions are different theories either if *the expressions have different test designs so they identify different subjects*, or if *the expressions make contrary claims about the subject defined by the same test design*.

Criticism:

Contemporary pragmatists recognize the empirical criterion as the *only* valid decision criterion that yields scientific progress.

Thus on the pragmatist philosophy a priori semantics and ontologies can never trump the empirical criterion for criticism. Ontologies are only accepted a posteriori based upon empirical adequacy as demonstrated by empirical test outcomes.

Thus contrary to romantics, pragmatists *permit* description of subjective mental states in social science theories and explanations, but *never require it as a criterion for criticism*.

Pragmatists recognize the nontruth-functional hypothetical-conditional form of statement expressing proposed theories, and they recognize the *modus tollens* falsifying argument for empirical testing of the theories. Unlike the logical positivists pragmatists do not recognize truth-functional conditional logic in science.

Explanation:

Pragmatists recognize the hypothetical-conditional form of statement expressing scientific laws and the *modus ponens* nontruth-functional deductive logic for explaining individual events.

Laws are explained in the sense that a set of related laws form a deductive system partitioned into dichotomous subsets of explaining antecedent axioms and explained consequent theorems.

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Chapter III - Philosophy of Language

Many if not most of the central concepts and issues in philosophy of science are in philosophy of language. Therefore the following selected elements of philosophy of language are discussed in the context of their relevance for philosophy of science.

3.01 Synchronic and Diachronic Analysis

To borrow some terminology from Ferdinand De Saussure's classic *Course in General Linguistics* language analysis may be viewed either synchronically or diachronically. The synchronic view is static, because it exhibits the state of a language at a point in time like a photograph. In computational philosophy of science the state of the language for a scientific problem is displayed synchronically in a semantical state description, in which statements of either inputted theory language or outputted laws are viewed as semantical rules that describe the meanings of their constituent descriptive terms.

The diachronic view on the other hand exhibits two chronologically successive states of the language for the same problem, and shows semantical change over the interim period. If the transitional process between the two successive language states is described, then the diachronic view is dynamic like a motion picture. Otherwise the diachronic view is a comparative-static semantical analysis like "before" and "after" photographs.

3.02 Object Language and Metalanguage

Philosophers of science distinguish two perspectives, object language and metalanguage. Object language is used to describe the real world. Metalanguage is used to describe object language. The language of science is typically expressed in the object-language perspective, while much of the discourse in philosophy of science is in the metalinguistic perspective.

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3.03 Dimensions of Language

The metalinguistic perspective offers four dimensions of language, which serve well as an organizing framework for philosophy of language. They are **A. syntax, B. semantics, C. ontology and D. pragmatics.**

A. SYNTAX

3.04 Syntactical Dimension

Syntax is the most obvious part of language. It is residual after the removal of pragmatics, ontology, and semantics. And it consists only of the forms of expression, so it is often said to be formal. Since meanings are excluded from the syntactical dimension, the expressions are also said to be semantically “uninterpreted”, and since the language of science is usually written, syntax consists of visible ink marks on paper or more recently displays on computer screens. Examples of syntax include the sentence structures of colloquial discourse, the formulas of pure or formal mathematics, and the computer source codes such as FORTRAN or LISP.

Syntax is the system of linguistic symbols considered in abstraction from their associated meanings.

3.05 Syntactical Rules

Syntax is a *system* of symbols. Therefore in addition to the syntactical symbols, there are also rules for the system called “syntactical rules”. These rules are of two types: formation rules and transformation rules.

Formation rules order concatenations of such syntactical elements as mathematical variables, mathematical operator symbols, descriptive terms, syncategorematic terms, and the various reserved words, variables and operator symbols of computer source codes. Concatenations (or matrices) that comply with the formation rules for a language are said to be “grammatical” expressions. Grammatically correct expressions in mathematics have been called “well-formed formulas” and grammatical

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computer source-code instructions are called “compiler-acceptable” or “interpreter-acceptable” code.

Formation rules are expressions in metalanguage that regulate the construction of grammatical expressions out of more elementary symbols.

When there exists an explicit and adequate set of syntactical formation rules, it is possible to develop a type of computer program called a “generative grammar”. A generative grammar produces grammatically correct expressions from inputs consisting of more elementary syntactical symbols. The generative-grammar computer programs input, process, and output object language, while the source-code instructions constituting the computer system function as metalinguistic expressions.

A generative grammar is a computer system that applies formation rules to more elementary syntactical symbols, in order to produce grammatical sentences or well-formed mathematical expressions.

When a computerized generative grammar is used to produce new scientific theories in the object language of a science, the computer system is called a “discovery system”. Typically the system also contains an empirical test for the selection of a limited subset of generated theories for output.

A discovery system is a computerized generative grammar that generates and empirically tests scientific theories as its output.

Transformation rules change grammatical sentences into other grammatical sentences. For example there are transformation rules for colloquial language that change a declarative sentence into an interrogative sentence. But the object language of science is typically expository, and philosophy of science therefore principally considers the declarative mood in descriptive discourse.

Transformation rules are of greater interest to logicians and mathematicians than to contemporary philosophers of science, who today are more interested in formation rules for generative-grammar discovery systems. Transformation rules are used in logical and mathematical deductions. Logic and mathematical rules are intended not only to produce new grammatical sentences but also to guarantee truth transferability from

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one set of sentences or equations to another, often by the transformation rule of substitution that makes the logic extensional.

Transformation rules are expressions in metalanguage that change grammatical expressions into other grammatical expressions.

In 1956 Herbert Simon developed an artificial-intelligence computer system named **LOGIC THEORIST**, which operated with his “heuristic-search” system design. The system developed deductive proofs of the theorems in Alfred Whitehead and Bertrand Russell's *Principia Mathematica*. The symbolic-logic statements are object language for this system. But Simon denies that formal logic itself is an appropriate metalanguage for the design of such systems.

3.06 Mathematical Language

The syntactical dimension of mathematical language includes the mathematical symbols and the formation and transformation rules of the particular branch of mathematics. Whenever possible the object language of science is mathematical rather than colloquial, because measurement enables the scientist to quantify the error in his theory, after estimates are made for the range of measurement error usually by repeated execution of the measurement procedure.

Mathematical language in science is object language for which the syntax is supplied by mathematics.

3.07 Logical Quantification in Mathematics

Like categorical statements, mathematical equations are explicitly quantified logically as either universal or particular, even though the explicit indication is not by means of the syncategorematic logical quantifiers “every”, “some” or “no”. An equation is universally quantified logically when none of its descriptive variables are assigned numeric values. Universally quantified equations may contain mathematical constants in empirical theories or laws. An equation is particularly quantified logically by associating measurement values with any of its descriptive variables, and it may then be said to describe an *individual measurement instance*.

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When numeric values are associated with descriptive variables by computation with measurement values in other descriptive variables in the same mathematical expression, the equation may be said to describe an *individual empirical instance*. In this case the referenced instance has not been measured but depends on measurements associated with other variables in the same equation.

Individual numerical empirical instances are calculated when an equation is used to make a quantitative prediction. The individual numerical *empirical* instance is the predicted value. It is compared with an individual numerical *measurement* instance, which is the test-outcome value made for the same variable in the execution of an empirical test. The individual numerical empirical instance made by the predicting equation is not said to be empirical because the predicting equation is correct, but because the predicting equation makes an empirical claim, which may be falsified by an empirical test.

Mathematical expressions in science are universally quantified when descriptive variables have no associated numerical values, and are particularly quantified when numeric values are associated with any of the descriptive variables.

B. SEMANTICS

3.08 Semantical Dimension

Semantics is the second of the four dimensions, and it includes the syntactical dimension. Language viewed in the semantical metalinguistic perspective is said to be “semantically interpreted syntax”, which is to say that the syntactical symbols have meanings associated with them.

Semantics is the meanings associated with syntactical symbols.

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3.09 Nominalist vs. Conceptualist Semantics

Both nominalism and conceptualism are represented in contemporary pragmatism. There are several variations of nominalism, but all nominalist philosophers advocate a two-level semantics, which in written language consists only of syntactical structures and the ontologies that are referenced by the structures. The two-level semantics is also called a referential theory of semantics, because it excludes any mid-level mental representations variously called ideas, meanings, significations, concepts or propositions. Typically on the nominalist view language referencing nonexistent fictional beings or entities is semantically nonsignificant, which is to say literally meaningless.

In the alternative view known as the three-level semantics, terms symbolize meanings, which in turn signify attributes and reference ontologies that include entities and attributes. This is called a conceptualist theory of semantics, which is emphatically *not* to say that there are concepts but nothing real conceptualized. Nominalism was common among many positivists, although some like the logical positivist Rudolf Carnap maintained a three-level semantics. In his three-level semantics descriptive terms symbolize what he called “intensions”, which are concepts or meanings viewed in simple supposition, and the intensions in turn signify properties and reference what he called “extensions”, which are the individual entities having the properties.

While the contemporary pragmatism emerged as a critique of neopositivism, some philosophers carried the positivists’ nominalism into contemporary pragmatism. Pragmatist philosophers such as Willard van Quine adopted nominalism and rejected concepts, ideas, meanings, propositions and all other mentalistic views of knowledge due to his fidelity to the Russellian predicate calculus. However, in his book *Word and Object* Quine defines “stimulus meaning” as a disposition by a native speaker of a language to assent or dissent from a sentence in response to present stimuli. And then he adds that the stimulus is not just a singular event, but rather is a “universal”, which he called a “repeatable event form”.

Nominalism is not essential to the contemporary pragmatism, and most contemporary pragmatists such as Russell Hanson, Thomas Kuhn and Paul Feyerabend have opted for the three-level semantics.

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Also computational philosophers of science such as Herbert Simon and Paul Thagard, who advocate the cognitive-psychology interpretation instead of the linguistic-analysis interpretation, reject both nominalism and behaviorism. Behaviorism is positivism in the behavioral sciences. They recognize the three-level semantics, and furthermore believe that they can model the mental level with computer systems.

In his book *Mind: Introduction to Cognitive Science* Thagard states that the central hypothesis of cognitive science is that the human mind has mental representations analogous to data structures and cognitive processes analogous to algorithms. Cognitive psychologists claim that computer programs using data structures and algorithms applied to the data structures can model the mind's concepts and its cognitive processes with the concepts.

3.10 Naturalistic vs. Artifactual Semantics

While the issue of nominalism vs. conceptualism is peripheral to contemporary pragmatism, the issue of naturalistic vs. artifactual thesis of semantics is central. The contemporary pragmatist philosophy of science is distinguished by a new philosophy of language, which has replaced the traditional naturalistic thesis with the thesis that the semantics of language is artifactual.

The naturalistic thesis is an absolutist semantics according to which the semantics of descriptive terms is acquired ostensively and is fully determined by nature. Thus descriptive terms function as names or labels for perceptions, primitive sense data or sensations. Then after the meanings for descriptive terms are acquired ostensively, the truth of statements constructed with the terms is ascertained empirically.

On the artifactual thesis sense stimuli contribute to semantics that is conceptualized by the linguistic context consisting of a set of beliefs that has a defining role for the concepts. The artifactual thesis revolutionized philosophy of science by relativizing both the semantics and ontology to belief. The outcome of this new linguistic philosophy is that *ontology, semantics, and belief are all mutually and simultaneously determining and thus interdependent*, unlike the simpler unidirectional relation affirmed by the naturalistic thesis with its foundational absolutes.

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The artifactual thesis of the semantics of language is that the semantics of every descriptive term is determined by its context consisting of universally quantified statements believed to be true, such that ontology, semantics and belief are all mutually and simultaneously determining.

3.11 Romantic Semantics

On the romantic view the positivist semantics is deemed acceptable for the natural sciences, but is deemed inadequate for understanding human action in the behavioral and sociocultural sciences. Human action considered by the social sciences has subjective meaning for the members of a group or society, because it is purposeful and motivating for their social interactions. Therefore the semantics for these sciences explaining human action must include the subjective meaning that the action has for the social-group member.

Romantics call the resulting subjective meaning “interpretative understanding”, and the social member’s voluntary actions require such interpretative understanding, which is shared by both the social member and the social scientist. And if the researcher participates in the society or group he is investigating, the validity of his vicariously imputed interpretative understanding is enhanced by his personal experiences as a member in the group or society.

3.12 Positivist Semantics

According to the positivist philosophy the ostensibly acquired meanings of descriptive terms used for reporting observations are primitive, simple and fully determined by nature. These meanings were variously called “sensations”, “sense impressions”, “sense perceptions” or “sense data” by different positivists.

For example in the case of a primitive term such as “black” the child’s ostensive acquisition of meaning might involve his pointing his finger at a present instance of perceived blackness in some black entity such as a raven bird. And then upon hearing the word “black” in repeated cases of various black objects, he associates the word with his experienced perceptions of the

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color black. And from the several early experiences expressible as “That raven is black” the young learner may eventually conclude by inductive generalization “All ravens are black.”

3.13 Positivist Thesis of Meaning Variance

What is fundamental to this naturalistic philosophy of semantics is the thesis that the semantics of observation terms is fully determined by human perception. Thus different languages are conventional in their vocabulary symbols and in their syntactical structures and rules. But nature makes the semantics of observation terms the same for all persons who have the same perceptual stimuli that occasioned their having acquired their semantics in the same circumstances by simple ostension. Thus the natural semantics of a descriptive term used to report observations is invariable through time and is independent of different contexts in which it may occur. Positivists view this meaning invariance as the basis for objectivity in science.

3.14 Positivist Analytic-Synthetic Dichotomy

In addition to the descriptive observation terms that have primitive and simple semantics acquired ostensively, the positivist philosophers also recognized the existence of certain terms that acquire their meanings contextually and that have complex semantics. The initial distinction between simple and complex ideas can be found in the *Essay Concerning Human Understanding* by the seventeenth-century British empiricist philosopher John Locke.

The first type of term having complex semantics that the positivists recognized occurs in the definition. The defined subject term or *definiendum* has a compositional semantics that is exhibited by the structured meaning complex associated with the several words in the defining predicate or *definiens*. For example “Every bachelor is a never-married man” is a definition.

The second type occurs in the analytic sentence, which is an a priori or self-evident truth, a truth known by reflection on the interdependence of the meanings of its constituent terms. Analytic sentences contrast with synthetic sentences, which are a posteriori, i.e. empirical, and thus have

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independent meanings for their terms. The positivists view the analytic-synthetic distinction as a fundamental dichotomy between the two types of statements. A similar distinction between “relations of ideas” and “matters of fact” can be found in Hume’s *An Enquiry Concerning Human Understanding*.

An example of an analytic sentence is “All bachelors are unmarried”. The semantics of the term “bachelor” is compositional and is determined contextually, because the idea of never having been married is by definition included as a component part of the meaning of “bachelor” thus making the phrase “unmarried bachelor” redundant. As in Quine’s paper “Two Dogmas of Empiricism” contemporary pragmatists reject the thesis of a priori truth, and maintain that all sentences are empirical and that their constituent terms are descriptive.

3.15 Positivist Observation-Theory Dichotomy

Positivists alleged the existence of “observation terms”, which are terms that reference observed entities or phenomena. Observation terms are deemed to have simple and primitive semantics and to receive their semantics ostensively and passively. Positivists furthermore called the particularly quantified sentences containing only such terms “observation sentences”. For example the sentence “That raven is black” uttered while the raven is being viewed by the speaker of the sentence, is a paradigmatic observation sentence.

In contrast to observation terms there is a third type of term having complex semantics that the positivists called the “theoretical term”. The term “electron” is a favorite paradigm for the positivists’ theoretical term. The positivists considered theoretical entities such as electrons to be postulated entities as opposed to observed entities like elephants. And they defined “theory” as sentences containing any theoretical terms. Rudolf Carnap maintained that the definition determines the whole meaning of the defined term, while the theory determines only part of the meaning of the theoretical term, because the semantics of a theoretical term will receive additional meaning as scientists further develop the scientific theory containing it.

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Nominalists furthermore believe that theoretical terms are meaningless, unless these terms logically derive their semantics from observation terms. On the nominalists' view terms purporting either unobserved entities or phenomena not known observationally to exist have no known referents and therefore no semantical significance or meaning. For example the term "centaur" is a meaningless term, since the centaurs have never been observed and are deemed to be mythical. For nominalists theoretical terms in science receive their semantics by logical connection to observation language, a connection that positivists called "logical reduction to an observation-language reduction base". Without such connection the theoretical terms are presumed to be meaningless.

Both the post-positivist Karl Popper and the logical positivist Carl Hempel have noted that the problem of the logical reduction of theories to observation language is a problem that the positivists have never solved. Positivists cannot exclude what they considered to be meaningless theories from the theories currently accepted by scientists.

In summary for the positivists the definition, the analytical sentence and the theory all exhibit composition in the semantics of their constituent terms.

3.16 Contemporary Pragmatist Semantics

The development of the contemporary pragmatist philosophy was occasioned by reflection on the development of quantum theory in physics. Pragmatism contains a new philosophy of language with a new metatheory for semantics.

The fundamental postulate in the contemporary pragmatist philosophy of language is the rejection of the naturalistic thesis of the semantics of language and its replacement with the artifactual thesis that relativizes all semantics and ontology to linguistic context consisting of some set of related beliefs. The rejection of the naturalistic thesis is not new to linguistics, but it is fundamentally opposed to the previously prevailing positivist philosophy and also to other older philosophies such as Aristotelianism. As an entry guide to the pragmatist philosophy, consider the following analogy illustrating relativized semantics and ontology.

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3.17 Pragmatist Semantics Illustrated

Our linguistic system is analogous to a mathematical simultaneous-equation system. The equations of the system are a constraining context that determines the numerical values of the variables in a solution set for the equation system. If the system is mathematically underdetermined, there is an infinitely large number of numerical solution sets for the system. In pure mathematics this mathematical underdetermination of the equation system can be eliminated and the system can be made uniquely determinate by adding equations until there are just as many variables as there are equations. Then there is only one unique solution set of numerical values for the system.

When applying such a mathematically uniquely determined equation system to reality as in science or engineering, the pure mathematics is made to function as the syntax for a descriptive language, when the numerical values of the descriptive variables are measurements. But the measurement values make the mathematically uniquely determined equation system *empirically underdetermined* due to measurement errors, which can be reduced indefinitely but never completely eliminated. Then even for a mathematically uniquely determined equation system there is still an infinitely large number of possible valid numerical solution sets falling within even a narrow range of measurement errors.

Analogously the statements consisting of universally quantified statements believed to be true are a constraining context that determines the semantics of the descriptive terms in the belief system. The semantics of the descriptive terms in any semantical “solution set”, as it were, are relativized to one another by the system of universal statements believed to be true. But the semantics acquired from sense stimuli always contains some vagueness. Due to the vagueness the system is empirically underdetermined and admits to an indefinitely large number of relativized semantical sets for the system. Adding more statements to the belief system reduces this empirical underdetermination by adding clarity, but the residual vagueness can never be completely eliminated. Our semantics captures determinate mind-independent reality, but the cognitive capture with our semantics can never be exhaustive. There is always residual vagueness in our semantics. Vagueness and measurement error are both manifestations of empirical underdetermination.

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The relativized semantics in turn produces relativized ontology, because ontology is the determinate features of reality that are described by the relativized semantics. Mind-independent reality imposes the empirical constraint on our falsifiable belief systems, while our access to mind-independent reality is by language-dependent relativized semantics. Thus ontology is not absolute and there are no referentially fixed terms. Descriptive terms are always referentially fuzzy, since their semantics always has residual vagueness.

Three notable consequences of the artifactual thesis of relativized semantics are firstly the rejection of the positivist observation-theory dichotomy, secondly the rejection of the positivist thesis of meaning invariance for the descriptive terms in language used for reporting observations, and thirdly the rejection of the positivist analytic-synthetic dichotomy.

3.18 Rejection of the Observation-Theory Dichotomy

One of the motivations for the positivists' accepting the observation-theory dichotomy is the survival of the ancient belief that science in one respect or another has a permanent, incorrigible and objective foundation. In the positivists' version of this foundational agenda observational description is presumed to deliver this certitude, while theory language is subject to revision sometimes revolutionary in scope. The positivists were among the last to believe in any such eternal verities.

More than a quarter of a century after Heisenberg said he could observe the electron in the Wilson cloud chamber, philosophers began to reconsider the concept of observation, a concept that had previously seemed *prima facie* obvious. On the pragmatist view there are no observation terms that receive isolated meanings merely by simple ostension, and there is no distinctive semantics for identifying language used for observational reporting. Instead every descriptive term is embedded in an interconnected system of beliefs, which Quine calls the "web of belief", some part of which constitutes a relevant context for determining any given descriptive term's meaning. A unilingual dictionary is a minimal listing of a subset of relevant beliefs for each univocal lexical entry.

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3.19 Rejection of Meaning Invariance

When the observation-theory dichotomy is rejected, the language that reports observations becomes subject to semantical change or what Feyerabend called “meaning variance”. The statements of theory contribute meaning parts to the semantics of descriptive language used to report observations, such that a theory revision changes the semantics of the relevant observational description.

The semantics of every descriptive term is determined by the term’s linguistic context consisting of universally quantified statements believed to be true, such that a change in any of those beliefs changes some parts of the constituent terms’ meanings.

In science the linguistic context consisting of universally quantified statements believed to be true may include both theory and test-design statements, which jointly determine the semantics for particularly quantified statements that report observations.

3.20 Rejection of the Analytic-Synthetic Dichotomy

On the positivist view the truth of analytic sentences can be known a priori, i.e., by reflection on the meanings of the constituent descriptive terms, while synthetic sentences require empirical investigation to determine their truth status, such that their truth can only be known a posteriori. Thus to know the truth status of the analytic sentence “All bachelors are unmarried”, it is unnecessary to take a survey of bachelors to determine whether or not any such men are married. However, determining the truth status of the sentence “All ravens are black” requires an empirical investigation of the raven bird population.

On the alternative pragmatist view the semantics of all descriptive terms are contextually determined, such that all universally quantified affirmations believed to be true are analytic statements. But their truth status is not thereby known a priori, because they are also synthetic, i.e., known by experience. This dualism implies that when any universally quantified affirmation is accepted as empirically true, the sentence can be used analytically such that the meaning of its predicate displays a partial analysis

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of the meaning of its subject term. To express this analytic-empirical dualism Quine used the phrase “analytical hypotheses”, although he was a nominalist and restricted the phrase to translation hypotheses. Such a restriction is unnecessary.

Thus “All ravens are black” is as analytic as “All bachelors are unmarried”. The meaning of “bachelor” includes the idea of being unmarried and makes the phrase “unmarried bachelor” redundant. Similarly so long as one believes that all ravens are in fact black, the meaning of “raven” includes the idea of being black, as evidenced by the fact that the belief makes the phrase “black raven” redundant. In science the reason for belief is often empirical adequacy demonstrated by a nonfalsifying empirical test outcome.

All universally quantified affirmations believed to be true are both analytic and synthetic.

3.21 Semantical Rules

The above discussion leads immediately to the idea of “semantical rules”, a phrase borrowed from Carnap but with a new meaning. In the contemporary pragmatist philosophy semantical rules are statements in the metalinguistic perspective, because they are about language. And their constituent terms are in logical supposition, because the statements are about meanings. Each semantical rule describes part of the descriptive subject term’s meaning complex by exploiting the analytic-synthetic dualism in universally quantified affirmations believed to be true.

For example if it is believed that all ravens are in fact black, then in the metalinguistic perspective the statement “All ravens are black” is a semantical rule describing part of the meaning of the term “raven”, as indicated (to repeat) by the redundancy in the phrase “black raven”. The component parts of a meaning complex in a semantical rule are always understood by the user, because he must have previously understood and believed the universal statement that makes the complex include the component part. Thus the user understands the meaning component “black” in the meaning complex for “raven”, because he had previously understood and accepted the statement “Every raven is black”. Otherwise there is no

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question of understanding the component, because “black” would not be a component of “raven” for that user.

Hickey had firstly set forth his thesis of componential semantics in 1976 in his *Introduction to Metascience: An Information Science Approach to Methodology of Scientific Research*.

A semantical rule is a universally quantified affirmation accepted as true and viewed in logical supposition in the metalinguistic perspective, such that the meaning of the predicate term displays some component parts of the meaning of the subject term.

3.22 Componential vs. Wholistic Semantics

Semantical change was vexing to the contemporary pragmatists, when they first accepted the artifactual thesis of the semantics of language. When they rejected a priori analytic truth, many of them mistakenly also rejected analyticity altogether. And when they accepted the contextual determination of meaning, they mistakenly took an indefinitely large context as the elemental unit of language for consideration. This elemental context was typically construed either as consisting of a explicitly stated whole theory with no criteria for individuating theories, or even more inclusively as a “paradigm” consisting of a whole theory together with many associated pre-articulate skills and tacit beliefs. This is the wholistic (or “holistic”) semantical thesis.

On this wholistic view therefore a new theory that succeeds an alternative older one must completely replace the older theory including all its observational semantics and ontology, because its semantics is viewed as an indivisible unit. In his *Patterns of Discovery* Russell Hanson attempted to explain such wholism in terms of Gestalt psychology. And the historian of science Thomas Kuhn, who wrote a popular monograph titled *Structure of Scientific Revolutions*, explained the complete replacement of an old theory by a newer one as a “Gestalt switch”. The philosopher of science Paul Feyerabend also tenaciously maintained wholism, but attempted to explain it by his own understanding of Benjamin Lee Whorf’s thesis of linguistic relativity also known as the “Sapir-Whorf hypothesis”. In his *Against Method* Feyerabend proposes semantic “incommensurability”, which he says is evident when an alternative theory is not recognized to be an alternative.

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He cites the transition from Newtonian to Einstein's relativity physics as an example of such incommensurability.

Any wholistic semantical thesis such as notably Feyerabend's semantic incommensurability thesis creates a pseudo problem for the decidability of empirical testing in science. It implies complete replacement of the semantics of the descriptive terms used for test design and observation. And complete replacement deprives the two alternative theories of any semantical continuity, such that their language cannot even describe the same phenomena or address the same problem. In fact the new theory cannot even be said to be an alternative to the old one, much less a more empirically adequate one. Such empirical undecidability due to alleged semantical wholism would deny the history of science both production and recognition of progress.

But the thesis of componential semantics resolves the wholistic semantical muddle in the linguistic theses proffered by Hanson, Kuhn and Feyerabend. It is not necessary to accept the wholistic view of semantics, because the pragmatists' rejection of the analytic-synthetic dichotomy with its a priori truth claim need not imply the rejection of analyticity as such. The contextual determination of meaning implies only that the analytic-synthetic dichotomy need be rejected, not analyticity itself.

Therefore when there is a semantical change in the descriptive terms in a system of beliefs due to a revision of some of the beliefs, some component parts of the terms' complex meanings remain unaffected, while other parts are dropped and new ones are added. For empirical testing in science the component meaning parts that remain unaffected by the change from one theory to a later alternative one include those parts determined in the statements of test design. Therein lies the semantical continuity that enables empirical testing to be decidable.

Thus a revolutionary change in scientific theory, such as the replacement of Newton's theory of gravitation with Einstein's, has the effect of changing only part of the semantics of the terms common to both the old and new theories. It leaves the semantics supplied by test design language unaffected, so it was possible for Arthur Eddington to test both Newton's and Einstein's theories of gravitation simultaneously with the same celestial photographic observations in his 1919 eclipse test. Thus contrary to Feyerabend there is no semantic incommensurability between these theories.

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Furthermore there is no historical evidence that the advocates of Einstein's relativity theory had failed to recognize that Einstein's theory is an alternative to Newton's.

3.23 Componential Artifactual Semantics Illustrated

The set of affirmations believed to be true and predicating characteristics universally and univocally of ravens are semantical rules describing component parts of the complex meaning of the term "raven". But if a field ornithologist captures a red bird specimen that exhibits all the characteristics of a raven except its black color, he must make a decision. He must decide whether he will continue to believe "All ravens are black" and that he holds in his birdcage some kind of red nonraven bird, or whether he will no longer believe "All ravens are black" and that the red bird in his birdcage is a red raven. Thus a semantical decision must be made. Color could be made a criterion for species identification instead of the ability to interbreed, although many other beliefs would also then be affected, an inconvenience that is typically avoided as a disturbing violation of the linguistic preference that Quine calls the principle of "minimum mutilation" of the web of belief.

Use of statements like "All ravens are black" may seem simplistic for science, if not quite bird-brained. But as it happens, a noteworthy revision in the semantics and ontology of birds has occurred recently due to a five-year genetic study launched by the Field Museum of Natural History in Chicago, the results of which were reported in the journal *Science* in June 2008. An extensive computer analysis of 30,000 pieces of nineteen bird genes revealed that contrary to previously held belief falcons are genetically more closely related to parrots than to hawks, and furthermore that falcons should no longer be classified in the biological order originally named for them. As a result of the new genetic basis for classification, the American Ornithologists Union has revised its official organization of bird species. And the bird watchers' field guide has also been revised accordingly. Now well-informed bird watchers will classify, conceptualize and observe falcon sightings differently, because some parts of the meaning complex for the term "falcon" have been replaced with others, namely the genetic description.

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Our semantical decisions alone neither create, annihilate nor change mind-independent reality. But semantical decisions change our mind-dependent linguistic characterizations of mind-independent reality and thus the ontological realities the semantics reveals.

3.24 Semantic Values

For every descriptive term there are several semantical rules with each one's predicate describing a component part of the common subject term's meaning complex. A linguistic system therefore contains elementary components of meaning complexes that are shared by many descriptive terms, but are not uniquely associated with any single term. These may be called "semantic values". Semantic values describe the most elementary ontological features of the real world that are distinguished by a language at a given point in time, and are the smallest elements in any meaning complex at the given point in time. What the language user's conventionalized semantics is unable to capture at that time constitutes the empirical underdetermination of the language.

Semantic values are the elemental component parts distributed among the meaning complexes associated with the descriptive terms of a language at a given point in time.

3.25 Univocal and Equivocal Terms

The definitions in a unilingual dictionary function as semantical rules. They are universally quantified logically, and are always presumed to be true. Usually each lexical entry in a dictionary such as the Oxford English Dictionary offers several different meanings for a descriptive term, because terms are routinely equivocal. Even the English language, which has a very large vocabulary, economizes on words by giving them several different meanings, which the fluent English-speaking listener or reader can usually distinguish in context. There is always at least one semantical rule for the meaning complex for each univocal use of a descriptive term, because to be meaningful, the term must be part of the linguistic system of conventional beliefs and eligible for a lexical entry in a dictionary.

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A descriptive term's use is univocal, if no universally quantified negative statement accepted as true can relate any of the predicates in the several universal affirmations functioning as semantical rules for the same subject term. Thus if two semantical rules have the form "Every X is A" and "Every X is B", and if it is also believed that "No A is B", then the terms "A" and "B" signify parts of different meanings for the term "X", and "X" is equivocal. Otherwise "A" and "B" would signify different parts of the one meaning complex associated with the univocal term "X".

A definition in a unilingual dictionary functions as a semantical rule. But the dictionary definition is only a minimal description of the meaning of a univocal descriptive term, and it is not the whole description. Terms have many semantical rules, when many characteristics apply universally to a given subject. Thus there are multiple predicates that universally characterize ravens, characteristics which are known to the ornithologist, and which may fill a paragraph or more in his ornithological reference book.

3.26 Signification and Supposition

The signification of a descriptive term is its meaning, and terms with two or more alternative significations are equivocal in the sense described immediately above. The concept of supposition enables identifying additional ambiguities that are not due to differences in signification that make equivocations, but instead are due to differences in representing ontology. Univocal terms having the same signification have different supposition, because they describe differences in ontology due to their having different functions in the sentences containing them.

The subject term in the categorical proposition is said to be in "personal" supposition, because it references individual entities, while the predicate term is said to be in "simple" supposition, because the predicate signifies an attribute but does not reference the individual entities having the attribute. For this reason the predicate in the categorical proposition is not logically quantified with any syncategorematic terms such as "all" or "some". For example in "Every raven is black" the subject term "raven" is in personal supposition, while the predicate "black" is in simple supposition. So too for "No raven is black".

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Unlike semantical rules that describe signification, the supposition of descriptive terms in object language depends only on the role of the terms in a statement containing them and not on the truth of the statement. Thus the suppositions of the subject and predicate terms are the same in the statement “Every raven is orange”, which is believed to be false, as they are in the statement “Every raven is black”, which is believed to be true.

Both personal and simple suppositions are types of “real” supposition, because they are different ways of talking about extralinguistic reality in the object-language perspective. They operate in expressions that are object language and thus describe and reference ontologies as either attributes or the individuals identified by their attributes.

Real supposition is contrasted with “logical” supposition, in which the meaning of the term is referenced in the metalinguistic perspective exclusively as a meaning, i.e., only semantics is referenced and not ontology. The meaning has universality in cognition that it does not have in extralinguistic reality. For example in “Black is a component part of the meaning of raven”, the terms “raven” and “black” in this statement are in logical supposition. Whenever a universally quantified affirmation is used in the metalinguistic perspective as a semantical rule for analysis in the semantical dimension, both the subject and predicate terms are in logical supposition. Similarly to say in explicit metalanguage “‘Every raven is black.’ is a semantical rule” to express “Black is a component part of the meaning of raven”, is again to use both “raven” and “black” in logical supposition. Furthermore just to use “Every raven is black” as a semantical rule to exhibit its meaning composition without actually saying it is a semantical rule, is also to use the sentence in the metalinguistic perspective and in logical supposition. The difference between real and logical supposition in such a sentence is not indicated syntactically, and depends on the intent of the writer or speaker. Lexical entries in dictionaries are in the metalinguistic perspective and in logical supposition, because the dictionary’s function is to describe meanings.

In all the above types of supposition the same univocal term has the same signification. But another type of so-called supposition proposed in ancient times is “material supposition”, in which the term is referenced in metalanguage as a linguistic symbol in the syntactical dimension with no reference to a term’s semantics in object language. An example is “‘Raven’ is a five-letter word”. In this example “raven” does not refer either to the

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individual real bird as in real supposition or to the universal concept of it as in logical supposition. Thus material supposition is not supposition properly so called, because the signification is different from the term's object-language signification in the semantical dimension. It is actually an alternative meaning and thus a type of equivocation.

3.27 Aside on Metaphor

In the last-gasp days of decadent positivism some positivist philosophers invoked the idea of metaphor to explain the semantics of theoretical terms. The theoretical term was the positivist's favorite hobbyhorse. But the semantics of theories is unproblematic for contemporary pragmatists. In his "Posits and Reality" Quine said that all language is empirically underdetermined, and the only difference between positing microphysical entities (like electrons) and macrophysical entities (like elephants) is that the statements describing the former are more empirically underdetermined than the latter. Thus contrary to the neopositivists the pragmatists admit no qualitative dichotomy between observation terms and theoretical terms.

As science and technology advance, concepts of microphysical entities like electrons are made less empirically underdetermined, as occurred with the development of the Wilson cloud chamber. While philosophers of science now recognize no need to explain theoretical terms by metaphor or otherwise, metaphor is nevertheless a linguistic phenomenon often involving semantical change and it can be analyzed and explained with componential semantics.

It has been said that metaphors are both true and false. In a speaker's conventional or "literal" linguistic usage the entire meaning complex is associated with the univocal predicate term. But in a speaker's metaphorical linguistic usage only some selected part or parts of the entire meaning complex are associated with the univocal predicate term, and the remaining parts of the meaning complex are intended to be excluded. If the excluded parts were included, then the metaphorical statement would be false. But the speaker implicitly expects the hearer or reader to suspend from consideration the excluded parts of the predicate's conventional semantics, while the speaker or writer uses the component part that he has selected for describing the subject truly.

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Consider for example the metaphorical statement “Every man is a wolf.” The selected meaning component associated with “wolf” that is intended to be predicated truly of “man” might describe the wolf’s predatory behaviors, while its fur and tail, which are conventionally associated with “wolf”, are among the excluded meaning components for “wolf” that are not intended to be predicated truly of “man”.

A listener or reader may or may not succeed in understanding the metaphorical predication depending on his ability to select the applicable parts of the predicate's semantics intended by the issuer of the metaphor. But there is nothing arcane or mysterious about metaphors, because they can be explained in literal (i.e., conventional) terms to the uncomprehending listener or reader. To explain the metaphorical predication of a descriptive term to a subject term is to list those affirmations intended to be true of that subject, and which together may substitute for the predicated metaphor, setting forth just those parts of the predicate's meaning that the issuer intends to be applicable.

The explanation may be further elaborated by explicitly listing separately the affirmations that are not viewed as true of the subject, but which are conventionally associated with the predicated term when it is predicated literally. Or these may be stated as universal negations stating what is intended to be excluded from the predicate's meaning complex in the particular metaphorical predication, e.g., “No man has a wolf’s tail.”

A semantical change occurs when the metaphorical predication becomes conventional, and this change to conventionality produces an equivocation. The equivocation consists of two literal meanings, the original one and a new meaning, which is now a dead metaphor. As a dead man is no longer a man, so a dead metaphor is no longer a metaphor. A dead metaphor is a meaning from which the suspended parts in the metaphor have become conventionally excluded to produce a new literal meaning.

A metaphor is a predication to a subject term that includes only selected parts of the meaning complex conventionally associated with the predicate term, so the metaphorical predication is a true statement, while intentionally excluding the remaining parts in the predicate’s meaning complex that would make the metaphorical predication a false statement.

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3.28 Clear and Vague Meaning

Terms are either univocal or equivocal, but meanings are more or less clear and vague, such that the greater the clarity, the less the vagueness. Vagueness is empirical underdetermination, and can never be eliminated completely, since our concepts can never grasp any reality exhaustively. But vagueness is reduced by the addition of predicates in both universal affirmations and universal negations accepted as true.

Adding semantical rules increases clarity by elaboration. Thus if the list of universal statements believed to be true are “Every X is A” and “Every X is B”, then clarification by elaboration with respect to a descriptive term “C” consists in adding to the list either the statement “Every X is C” or the statement “No X is C”. Clarity is thereby added by elaborating the meaning of “X”, and vagueness remains to the extent that such clarification is absent.

Adding universal statements believed to be true that relate any of the univocal predicates in the semantical rules for the same subject increases clarity by increasing coherence. Thus if the predicate terms “A” and “B” in the semantical rules “Every X is A” and “Every X is B” are related in the statements “Every A is B” or “Every B is A”, then one of the statements in the list can be logically derived from the others. Awareness of the deductive relationship and the consequent display of structure of the meaning complex associated with the term “X” makes the complex meaning of “X” more coherent, because the deductive relation makes it more semantically integrated. Clarity is thereby added by exhibiting semantic structure in a deductive system, and vagueness remains to the extent that such clarification is absent.

These additional universal statements relating the predicates may be negative as well as affirmative. Additional universal negations offer clarification by separating parts thus exhibiting equivocation. Thus if two semantical rules are “Every X is A” and “Every X is B”, and if it is also believed that “No A is B”, then the terms “A” and “B” signify parts of different meanings for the term “X”, and “X” is equivocal. Clarity is thereby added by the negation, and vagueness remains to the extent that such clarification is absent.

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3.29 Semantics of Mathematical Language

Both test designs and theories often involve mathematical expressions. Thus the semantics for the descriptive variables common to a test design and a theory may be supplied by mathematical expressions, such that the structure of their meaning complexes is partly mathematical. The semantics-determining statements in test designs for mathematically expressed theories may include mathematical equations, measurement language describing the subject measured, the measurement procedures, the metric units and any employed apparatus and/or instruments.

Some of these statements may resemble Percy Bridgman's "operational definitions", because the statements describing the measurement procedures and apparatus contribute meaning to the descriptive term. But as Carnap says contrary to Bridgman, each operational definition does not as such constitute a separate definition for the measured subject, thereby making the term equivocal. Instead descriptions of different measurement procedures contribute different parts to the univocal meaning of the descriptive term, unless the different procedures produce different measurement values, where the differences are greater than the estimated measurement error. Furthermore pragmatists do not accept Bridgman's naturalistic philosophy of the semantics of language, nor need they accept his nominalism.

The semantics for a descriptive mathematical variable is determined by its context consisting of universally quantified statements and/or mathematical expressions believed to be true.

3.30 Semantical State Descriptions

The above discussions in philosophy of language have tended to focus on descriptive terms such as words and mathematical variables, and then on statements and equations that are the theories and laws constructed with the terms. For computational philosophy of science there is an even larger unit of language, which is the state description for the object-language inputs and outputs of mechanized discovery systems.

In concept an input state description is a listing of the statements or equations of the several currently untested theories addressing the same

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unsolved problem at a given point in time and functioning as semantical rules. It represents the frontier of research for the specific problem. The state description is a synchronic semantical display and is thus static. The initial state description is the source of inputs to a discovery system, and the terminal state description contains the output from a discovery system run. Each discovery system and both its input and output state descriptions address only one problem identified by the test design, and thus represent only one scientific profession.

In concept a discovery-system design is a generative grammar that produces sentences or equations from terms or variables. Therefore an input state description for a discovery system may be reduced for system input so that the description consists exclusively of descriptive terms or variables drawn from the untested theories without actually listing the statements or equations containing those terms and variables. Furthermore such a reduced input state description may profitably be supplemented with the descriptive terms and variables from previously falsified theories thus making it a cumulative state description, although it still represents available information at a point in time. Descriptive terms salvaged from falsified theories have scrap value consisting of terms that may profitably be recycled through the theory-developmental process.

Since proponents of theories believe that the theories they advocate are true and do not expect them to be falsified, the statements and/or equations constituting the several theories in the state description are semantical rules. Each alternative theory has its distinctive semantics for its constituent descriptive terms. A term shared by several alternative theories is thus partly equivocal, but it is also partly univocal due to the shared test-design statements, which are also semantical rules.

A state description for a scientific profession is a synchronic display of the semantical composition of the meanings of the descriptive terms in a list of the alternative theories functioning as semantical rules and addressing a single problem defined by a common test design.

3.31 Diachronic Comparative-Static Analysis

A diachronic display consists of two chronologically successive state descriptions for the same problem and therefore addressed by the same

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scientific profession. Since state descriptions consist of semantical rules, changes in meanings through time are exhibited by comparison between the two chronologically separated state descriptions. The comparison is called a comparative-static semantical analysis, which consists of two state descriptions representing two chronologically successive language states sharing a common subset of descriptive terms. In computational philosophy of science the comparative-static semantical analysis is the comparison of a discovery system's input and output state descriptions. However after the system is run, the output is of principal interest.

3.32 Dynamic Diachronic Analysis

The above discussions have described the synchronic and comparative-static diachronic perspectives. Both are static, because they refer to points in time. The dynamic diachronic metalinguistic analysis on the other hand consists of two state descriptions representing two chronologically successive language states sharing a common subset of descriptive terms, it exhibits a process of linguistic change over a period of time from one language state to a later one.

Such changes in science are the result of two functions in basic research, namely theory development and theory testing. A change of state description into a new one is produced whenever a new theory is proposed or whenever a theory is eliminated by a falsifying test outcome.

3.33 Computational Philosophy of Science

Computational philosophy of science consists of developing computerized discovery systems that simulate noteworthy scientific advances in the history of science. Its practitioners thus proceduralize explicitly the production of theories by replicating the past results of successful scientists, with the ultimate aim of developing new theories in a contemporary science by applying the mechanized procedures to its current state description. The discovery systems created by computational philosophers of science represent dynamic diachronic metalinguistic analyses. They proceduralize the transitional process explicitly with the system's computer design, in order ultimately to accelerate the advancement of a science by mechanizing the transition. The systems typically include empirical criteria for selecting a subset of the developed theories for output

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as tested and nonfalsified theories either for use in explanations as laws or for future predictive testing.

In this computer age computational philosophy of science is inevitable. Notwithstanding dismissive obstructionism by latter-day Luddites computational philosophy of science is the future that has arrived. It is destined to achieve ascendancy in twenty-first-century philosophy of science among those who are opportunistic enough to master the necessary system-development skills and the requisite working competence in an empirical science. The variety of competencies may require collaborative interdisciplinary efforts. By the year 2100 the enhanced capacity of computer hardware and the enhanced capacity of the computer systems designs in computational philosophy of science may be expected to transform the practices of basic research in unimaginable ways.

Computational philosophy of science consists of developing computerized discovery systems that simulate noteworthy scientific advances in the history of science, in order to proceduralize explicitly the past achievements of the successful scientists, and then to apply the mechanized procedures to the current state description of a science for the development of new theories that advance the science.

3.34 An Interpretation Issue

There is ambiguity in the literature as to what a state description represents. On the linguistic analysis interpretation the state description represents the language state for a language community constituting a single scientific profession. Computational philosophy of science so interpreted is a technique for a specialized type of linguistic analysis, and is neither a separate philosophy nor a psychologicistic agenda. It is compatible with the contemporary pragmatism and is closely related to computational linguistics.

On the cognitive psychology and artificial intelligence interpretations the state description represents the individual scientist's cognitive state consisting of mental representations. The originator of the cognitive-psychology interpretation is Herbert Simon, one of the founders of artificial intelligence. In his *Scientific Discovery: Computational Explorations of the Creative Processes* Simon says that he seeks to investigate the psychology of discovery processes, and to provide an empirically tested theory of the

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information-processing mechanisms that are implicated in that process. He states that an empirical test of the systems as psychological theories of human discovery processes would involve presenting the computer programs and some human subjects with identical problems, and then comparing their behaviors. But Simon admits that his book provides little in the way of detailed comparison with human performance. And in discussions of particular applications involving particular discoveries, he says that in some cases the historical discoveries were actually performed differently than the way that the systems performed the rediscoveries.

The academic philosopher Paul Thagard, who follows Simon's interpretation, originated the name "computational philosophy of science" in 1988 in his book *Computational Philosophy of Science*. Hickey admits that it is a more descriptive name than the name "metascience" that he had proposed in the 1970's. Thagard defines computational philosophy of science as "normative cognitive psychology". To date the cognitive-psychology systems have successfully replicated developmental episodes in history of science, but the relation of their system designs to systematically observed human cognitive processes is still speculative. On either interpretation, however, the input represents knowledge available for potential future discovery, and the output sets forth the one or usually several new theories, which may be accepted either as laws or as theories subject to predictive testing.

C. ONTOLOGY

3.35 Ontological Dimension

Ontology is the metalinguistic dimension after syntax and semantics. Semantically interpreted syntax describes ontology most realistically, when the statement is either experimentally or experientially warranted empirically. In science ontology is most realistic when described by the semantics of either a scientific law or an observation report. However even the semantics of falsified theories display less realistic ontology due to the theories' known lesser truth.

Ontology is the semantically described aspects of reality.

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3.36 Metaphysical and Scientific Realism

In his *Mind, Language and Society: Philosophy in the Real World* realist philosopher John R. Searle, a critic of cognitive science, refers to metaphysical realism as “external realism”, by which he means that the world exists independently of our representations of it. And he denies that realism can be justified, because any attempt at justification presupposes what it attempts to justify. In other words all arguments for metaphysical realism are circular, because realism must simply be accepted.

Similarly in “Scope and Language of Science” in *Ways of Paradox* the realist philosopher Willard van Quine writes that we cannot significantly question the reality of the external world or deny that there is evidence of external objects in the testimony of our senses, because to do so is to dissociate the terms “reality” and “evidence” from the very application that originally did most to invest these terms with whatever intelligibility they may have for us. And to emphasize the primitive origin of realism Quine writes that we imbibe this archaic natural philosophy “with our mother’s milk”. He thus affirms what he calls his “unregenerate realism”.

Hickey joins these contemporary realist philosophers. He maintains that metaphysical realism, the thesis that there exists mind-independent reality accessible to human cognition, is the primal prejudice. And he affirms that it is a correct prejudice. Contrary to Descartes, metaphysical realism is neither a conclusion nor an inference nor an extrapolation. It cannot be proved logically, established by science, or validated in any discursive manner. If anything is immediately self-evident, it is the imposing, intruding and recalcitrant otherness of mind-independent reality.

Metaphysical realism is the thesis that there exists mind-independent reality that is accessible to human cognition.

Quine furthermore adds that the notion of reality independent of language is derived from our earliest impressions, and is then carried over into science as a matter of course. He writes that realism is the robust state of mind of the scientist, who has never felt any qualms beyond the negotiable uncertainties internal to his science.

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Scientific realism is the thesis that the most critically tested and currently nonfalsified theory offers the most empirically adequate description of reality at the current time.

3.37 Ontological Relativity Defined

Further understanding of scientific realism, however, requires consideration of ontological relativity. When metaphysical realism is joined with relativized semantics, the result is ontological relativity. We cannot step outside of our knowledge and compare our knowledge with reality, in order to validate a correspondence. Thus while we can distinguish our semantics from the ontology it describes, as we do when we distinguish real and logical suppositions, we cannot separate ontology from semantics. Ontology is mind-independent reality as our language-dependent semantics describes it, and we describe reality with the concepts in our language. The ontologies described by our artifactual semantics are just as relative as the describing semantics.

Prior to the contemporary pragmatism philosophers had identified realism with one or another particular ontology, which they viewed as the only true ontology on the assumption that there can be only one true ontology. But science has produced revolutionary changes. And as the advancement of science has produced new theories with new semantics exhibiting new ontologies, prepragmatist scientists and philosophers found themselves attacking a new theory and defending an old theory, because they had associated realism with a displaced ontology associated with a falsified and displaced theory. As Feyerabend notes in his *Against Method* scientists have criticized a new theory using the semantics and ontology of a previously accepted and now falsified theory. Such a perversion of scientific criticism is still common in the social sciences where romantic ontologies are invoked as criteria for criticism.

With ontological relativity realism is no longer uniquely associated with just one particular ontology. The ontological-relativity thesis does not deny mind-independent metaphysical realism, but it distinguishes mind-independent reality from ontology described by language-dependent semantics. It thus enables admitting change of ontology without denying metaphysical realism.

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On the contemporary pragmatist view metaphysical realism is logically prior to and presumed by all ontologies as the primal prejudice, while the choice of an ontology is based upon the empirically tested adequacy of the theory describing the ontology. Thus ontological relativity leaves ontology to the scientist with his explanatory scientific laws rather than to the metaphysician. And increased empirical adequacy of new scientific law yields increased realism in the ontology that the new law describes.

Ontological relativity in science is the thesis that the semantics of a scientific law and its constituent descriptive terms describe reality.

A scientific law is a tested and nonfalsified universally quantified statement that prior to its empirical testing was a theory.

3.38 Ontological Relativity Illustrated

Ontological relativity can be illustrated by the semantical decision about red ravens mentioned in the above discussion about componential artifactual semantics. The decision is ontological as well as semantical. For the bird watcher who found a red raven-looking bird and decides to reject the belief “All ravens are black”, the phrase “red raven” becomes a description for a type of existing birds. Once that semantical decision is made, red ravens suddenly populate many trees in the world, however long ago nature had evolved such avian creatures. But if the decision is to persist in believing “All ravens are black”, then there are no red ravens in existence, because whatever kind of bird they are, the red birds are not ravens. The availability of the choice illustrates the artifactuality of the relativized semantics of language and the consequently relativized ontology that the relativized semantics reveals about reality.

Relativized semantics makes an ontology no less relative whether the posited entity is an elephant, an electron, or an elf. Beliefs that enable us routinely to make successful predictions are deemed more empirically adequate than those not so successfully predictive. And we invest the entities, attributes or any other manifestations of reality posited by those successfully predicting beliefs with our ontological commitments. Thus if positing evil elves conspiring mischievously enabled predicting the collapse of stock-market price bubbles more accurately and reliably than the

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postulate of euphoric humans speculating greedily, we would accept those busy elves as real entities, and would busy ourselves about them, as we have done with elephants and electrons for successful predictions about elephants and electrons. And when in due course we find our belief in evil elves to be empirically incorrect, we then reject our ontological commitment to the conspiring elves, as today we reject the reality of possessing demons once thought responsible for sickness.

As it happens, today we do not find ontological claims about possessing demons to be empirically adequate for medical practice. But it could have been otherwise. The semantics of “atom” has changed greatly since the days of the ancient Athenian philosophers Democritus and his mentor Leucippus. It has since evolved under the regulation of basic research in physics. Similarly the semantics of “demon” might too have evolved to become as beneficial as the modern meaning of “bacterium” – had empirical testing regulated an evolving semantics and ontology for “demon”.

Both the ancient and the modern physicians may observe and recognize some of the same obvious symptoms for a certain infectious bacterial disease in a patient, thus giving some continuity to the semantics of “demon” through the ages. But their medical diagnoses, practices and remedies would be quite different. If the semantics and ontology of “demon” had evolved under the regulation of increasing empirical adequacy, then today scientists might materialize (i.e., visualize) demons with microscopes, and physicians might write incantations (i.e., prescriptions), and pharmacists might dispense antidemonics (i.e., antibiotics) to exorcise (i.e., to cure) possessed (i.e., infected) sick persons. But terms such as “materialize”, “incantation”, “antidemonics”, “exorcise” and “possessed” would also have acquired new semantics in the more empirically adequate contexts than the ancient medical beliefs. Thus the meaning of “demon” would have been purged of what we now find empirically to be inadequately realistic about demons.

3.39 Causality

Cause and effect are ontological categories described by tested and nonfalsified nontruth-functional hypothetical-conditional statements. The nontruth-functional hypothetical-conditional statement claiming a causal

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dependency is an empirical statement, and is therefore never proved and may always be falsified in the future. But ontological relativity means that a statement's empirical adequacy warrants belief in its ontological causality claim.

When in the progress of science the causal claim is empirically falsified by testing, it is made evident thereby that the causality claim is less adequately realistic than previously hypothesized. A scientist has not confused cause with antecedent, until the occurrence of a falsifying test outcome has shown that the consequent phenomenon has failed to follow upon realization of the antecedent conditions. Philosophers and scientists who seek permanent and eternal causes are innocent of the history of science.

Causal claims based on statistical correlations can also be schematized as nontruth-functional hypothetical-conditional statements subject to empirical testing and thus expressing causal ontological claims. The scientist does not know that a correlation is not causal, until the correlation is falsified empirically.

3.40 Ontology of Mathematical Language

In the categorical proposition the logically quantified subject term references individuals and describes the attributes that enable identifying the referenced individuals, while the predicate term describes only attributes without referencing any instantiated individuals manifesting the attributes. The referenced extramental real things and their semantically signified extramental real attributes constitute the ontology described by the categorical proposition that is believed to be true due to its experimentally or otherwise experientially demonstrated empirical adequacy. This ontological claim is expressed explicitly by the copula term "is" as in "Every raven is black".

However, the ontological claim made by the mathematical equation in science is not just about instantiated individuals or their attributes. The individual instances referenced by the variables in the mathematical equation are instances of individual measurement results, which are acquired by measurement operations that produce numeric values for the descriptive variables. Individual measurements are made by the scientist, and the

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individual measurement instances are related to reality by nonmathematical language, which may include description of the measured subject, the metric, and the measurement procedures including any apparatus described in test-design language. Calculated and predicted descriptive variables also make ontological claims until falsified empirically.

D. PRAGMATICS

3.41 Pragmatic Dimension

Pragmatics is the metalinguistic dimension after syntax, semantics and ontology, and it presupposes all of them. Specifically it pertains to the uses or functions of language understood as semantically interpreted syntax and described ontology. The regulating pragmatics of basic science is set forth in the statement of the aim of science, namely to create explanations containing scientific laws by the development and empirical testing of theories, which are deemed laws when not falsified by the currently most critical empirical test. Explanations and laws are accomplished science, while theories and testing are work in process at the frontier of basic research. Understanding pragmatics therefore requires understanding the concepts of theory and testing.

Pragmatics is the uses or functions of language understood as semantically interpreted syntax and described ontology.

3.42 Semantic Definitions of Theory Language

For neopositivist philosophers the term “theory” refers to universally quantified sentences containing “theoretical terms” that describe unobserved phenomena or entities. Early positivists had rejected altogether the atomic theory of matter in physics, because the atoms were deemed unobservable. These early positivist philosophers’ idea of discovery consisted of induction, which yields empirical generalizations rather than theories.

Later the neopositivists believed that they could validate the semantical significance of theoretical terms referencing unobservable

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microphysical particles such as electrons, and thus admit theories as valid science. But for discovery of theories they invoked human creative processes and offered no description of the processes of theory creation.

For romantic philosophers and romantic social scientists “theory” means language describing subjective mental experiences such as ideas and motivations. The theory creation process is typically portrayed as consisting firstly of introspection by the theorist upon his own personal subjective experiences. Then secondly it consists of imputing vicariously his introspectively experienced ideas and motives to the social members under investigation. Thus the social scientist can recognize or at least imagine these ideas and motives in his own personal experience, such that the motives “make sense” to him.

3.43 Pragmatic Definition of Theory Language

Unlike positivists and romantics, pragmatists define theory language pragmatically instead of semantically.

Scientific theories are universally quantified statements including mathematical expressions that are proposed for empirical testing.

This is the definition of “theory” in the contemporary pragmatist philosophy of science. It contains the traditional idea that theories are hypotheses, but the reason for their hypothetical status is not due to either the positivist observation-theory dichotomy or the romantics’ requirement of referencing subjective mental states. Contemporary pragmatists have replaced such semantical concepts for identifying theory language with the pragmatic definition based on the function of theories in science.

Theories are hypothetical because they are proposed for testing.

All universally quantified statements are hypothetical in the sense that they are empirical, and thus are not provable, incorrigibly true, or beyond revision. But theories are those statements that are regarded as relatively more hypothetical, because scientists believe they are more likely to be productively revised, if a falsifying test outcome shows revision is needed. After a theory is tested, it ceases to be a theory, because it is either scientific law or rejected language, except for the skeptical scientist who wants further

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predictive testing. Theories may have lives lasting many years due to problems formulating or implementing decisive test designs. Or as in a computerized discovery system with an empirical decision procedure, they may have lives measured in milliseconds.

Empirical testing is the pragmatics of theory language in science. After a conclusive test outcome, the tested theory is no longer a theory. The conclusive test outcome makes the theory either a scientific law or falsified discourse.

Romantic social scientists adamantly distinguish theory from mathematical and statistical models. Many alternative supplemental speculations about motives can be appended to the model that is tested, but it is the model that is empirically tested and not the various supplemental discourses. Pragmatically the language that is tested empirically is theory, such that when the model is proposed for empirical testing, the model has the status of theory.

Sometime after initial testing and acceptance, a scientific law may revert to theory status to be tested again. Centuries after Newton's law of gravitation had been initially accepted as scientific law, it was tested in 1919 in the famous Eddington eclipse test of Einstein's alternative general relativity theory. Thus for a brief time early in the twentieth century Newton's theory was pragmatically speaking actually a theory again.

The term "theory" is ambiguous in contemporary usage. There are both archival and pragmatic meanings. In the archival sense we still may speak of Newton's "theory" of gravitation. But in the pragmatic sense Newton's "theory" is now falsified physics in basic science and is no longer proposed for testing, although it is still used by aerospace engineers who can exploit its lesser realism and truth. Knowledge of its error means that Newtonian mechanics is neither a hypothesis for testing nor is it our currently most empirically adequate and thus most realistic universal law for explaining space, time, motion and gravitation.

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3.44 Pragmatic Definition of Test-Design Language

Pragmatically theory is universally quantified language that is proposed for testing, and test-design language is universally quantified language that is presumed for testing.

Accepting or rejecting the hypothesis that there are red ravens presumes a prior agreement about the semantics needed to identify a bird's species. Similarly the empirical test of a scientific theory presumes prior agreement about the semantics needed to identify the test subject. This semantics includes but is not limited to the language for describing the design of any test apparatus, the testing methods including any measurement procedures, the characterization of the test's initial conditions, and the characterization of the observed outcome resulting from the test execution. The universally quantified test-design statements contribute these meaning components to the semantics of the descriptive terms common to the test design and the theory.

Both theory and test-design language are believed to be true, but for different reasons. Experimenters testing a theory presume the test-design language is true with definitional force for identifying the subject of the test and for performing the test. The advocates proposing or supporting a theory believe the theory statements are true with sufficient plausibility to warrant testing with an expected nonfalsifying outcome. Both the theory statements and the test-design statements contribute component parts to the complex semantics of the descriptive terms that they share.

Often test-design concepts describing the subject of a theory are either not yet formulated or are too vaguely conceptualized to be used for effective testing. They are concepts that await future scientific and technological developments that will enable formulation of an executable and decisive empirical test. Formulating a test design capable of evaluating the empirical merits of a theory decisively often requires considerable ingenuity. Eventual formulation of specific test-design language enabling an empirical decision supplies the additional semantics that sufficiently reduces the disabling vagueness.

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3.45 Pragmatic Definition of Observation Language

After scientists have formulated and accepted a test design, the universally quantified language describing the design determines the semantics of its observation language. To describe an individual test execution and its outcome, the test-design statements have their quantification changed from universal to particular, and are thus made observation statements. This is a pragmatic concept of observation language, because it depends on the function of such language in the test. Contrary to positivists, pragmatists reject the thesis that there is any inherently or naturally observational semantics.

If a theory's test outcome is not a falsification, the tested theory is deemed empirically warranted. The status of the tested theory is then changed to scientific law, and it continues to contribute its semantics to the meaning complex associated with the descriptive terms in the language used for reporting observations. And the test outcome may be described in terms of the law, a former theory.

Observation sentences are test-design sentences and test-outcome sentences with particular logical quantification for describing an individual test execution including reporting the explained test outcome.

3.46 Observation and Test Execution

For the execution of a test, the statements *predicting* the test outcomes are the statements of the theory having semantics defined by the theory's universal statements with their logical quantification made particular for the individual test execution. For a mathematically expressed theory this particular logical quantification is accomplished by assigning measurement values to the theory's descriptive variables that are needed to calculate a value for the theory's prediction variable, and then calculating the predicted numerical value.

For the execution of a test, the statements *reporting* the observed test outcomes are the statements of the test design having semantics defined by the test-design's universal statements with their logical quantification made particular for the individual test execution. For a mathematically expressed theory this particular logical quantification is accomplished by assigning

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measurement values to the theory's prediction variables describing the test outcome for comparison with the predicted values. Both the prediction and test-outcome statements must share the same descriptive terms.

The statements reporting the test outcome are observation statements describing what was observed as a result of the test execution. But the prediction statements are not as such observation statements. They are only incidentally observation statements, when the test outcome is nonfalsifying. A nonfalsifying test outcome is a predicted effect that is larger than the estimated measurement error and that is not obscured by semantical vagueness, such that the prediction is deemed to be the same as what the test-outcome statements describe.

Scientists prefer repeatable controlled experiments. When possible, measurement values are the result of repeated measurement instances, in order to produce a statistical inference that enables an estimate of measurement error and a mean average value for a mathematical variable. A conventional measure of dispersion about the mean such as the standard deviation may serve as an estimate of measurement error.

The test outcome may have semantical consequences. If the test outcome is nonfalsifying, the semantics of the terms common to theory and test design does not change for the theory's advocates whose belief in their theory was vindicated. But if the test outcome is falsifying, then by prior agreement it is the theory that is falsified. And the semantical outcome is that the falsified theory statements no longer contribute to the semantics of the terms common to the test design and theory for the theory's advocates.

But the semantical contributions made by the test-design statements are unaffected by either test outcome for all who continue to accept the test design. Herein lies the semantical continuity throughout the test. Thus contrary to Kuhn and Feyerabend there is no complete replacement of semantics of statements used to report an observed test outcome much less any alleged semantic incommensurability.

3.47 Scientific Professions

In computational philosophy of science a "scientific profession" means the researchers who at a given point in time are attempting to solve

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the same scientific problem as defined by a test design. On this pragmatic definition, a profession is a much smaller group than the academicians in the field of the problem, while by no means restricted to academicians.

3.48 Semantic Individuation of Theories

Theory language is defined pragmatically, but theories are individuated semantically.

Theories are individuated semantically in either of two ways. Firstly different expressions are different theories, *because they address different subjects*. Different theory expressions having different test designs are different theories, because the test-design statements are semantical rules that define the subject of a theory. Furthermore the different theory expressions are different for different scientific professions, because they address different problems. In fact pragmatically what is theory for one profession is not theory for another.

Secondly different expressions are different theories, *because each makes contrary claims about the same subject*. The test-design language defines the subject. Contrary claims are different descriptions and make different predictions. Occasionally there is more than one theory proposed for empirical testing with the same set of test-design statements. Since the alternative theories are all universally quantified and proposed for testing, they are all instances of theory language, but they have different semantics and are therefore different theories.

There has occasionally been confusion due to philosophers' failure to recognize semantic principles for the individuation of theories. Some philosophers state that theories are not rejected due to empirical falsification, because a scientist will "save" a falsified theory by modifying it, so that there is no longer a falsifying test outcome. But when the scientist tries to "save" the theory by making adjustments to it, he has *ipso facto* rejected the tested theory and has made a new theory with his modifications. The original theory has been discarded and a new theory has been developed, when the adjustments are not merely *ad hoc* particularly quantified statements citing individual instances as exceptions, but instead are modifications to theory's universally quantified statements that alter its semantics, even if in relatively minor ways.

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Chapter IV – Philosophy of Science Topics

The preceding chapters have offered generic sketches of the principal twentieth-century philosophies of science, namely romanticism, positivism and pragmatism. And they have discussed the elements of the contemporary pragmatist philosophy of language for science, namely the object language and metalanguage perspectives, the synchronic and diachronic views, and the syntactical, semantical, ontological and pragmatic dimensions of language.

Finally at the expense of some repetition this chapter integrates those discussions into the four functional topics briefly examined in the overview chapter, namely the institutionalized aim of basic science, scientific discovery, scientific criticism, and scientific explanation.

4.01 Institutionalized Aim of Science

Over the last three hundred years empirical science has evolved into a social institution with its own distinctive and autonomous professional subculture of shared views and values. The institutionalized aim of science is the cultural value system that regulates the scientist's performance of basic research. Idiosyncratic motivations of individual scientists are of less interest to philosophers of science, except when such idiosyncrasies have initiated an institutional change.

The literature of philosophy of science offers a variety of proposals for the aim of science. The three modern philosophies of science mentioned above set forth different philosophies of language, which influence their different concepts of all four of the functional topics.

4.02 Positivist Aim

The positivists proposed a foundational agenda. Early positivists such as Ernst Mach initially proposed that science should aim for firm objective foundations by relying exclusively on observation and on empirical

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generalizations that summarize individual observations. Theories were deemed temporary expedients and viewed as less than truly scientific.

After the acceptance of Einstein's relativity theory by physicists, the later "neopositivist" philosophers acknowledged the essential role that hypothetical theory must have in the aim of science. Between the World Wars the neopositivist Rudolf Carnap and his fellow members of the Vienna Circle group attempted to justify the role of theories in science by relating the theoretical terms in the theories to the observation terms that they believed are a foundational reduction base.

These neopositivists were also called "logical positivists", because they attempted to use the symbolic logic developed by Bertrand Russell and Alfred N. Whitehead, in order to accomplish the logical reduction. These neopositivists fantasized that the Russellian symbolic logic could serve philosophy as mathematics serves physics. In fact the Russellian truth-functional logic does not capture the hypothetical logic of empirical testing in science, and is no longer seriously considered by philosophers of science.

The neopositivist agenda was statements of these philosophers' aim rather than the aim for science itself. Scientists did not use symbolic logic or seek any logical reduction for theoretical terms. The decline and eclipse of positivism was in no small part due to the disconnect between the philosophy and the practices of scientists.

4.03 Romantic Aim

The romantics have a subjectivist social-psychological reductionist agenda for the social sciences. This is a statement of the aim of social sciences that is embraced and enforced by many social scientists. Both romantic philosophers and romantic scientists maintain that these sciences of culture differ fundamentally in their aim from the sciences of nature. They view the aim of the social sciences as the development of explanations in terms of subjective social-psychological motives, in order to explain observed social-interaction in terms of purposeful human action in society.

Some romantics call this type of explanation "interpretative understanding" and others call it "substantive reasoning". Using this concept of the aim of science they often say that an explanation must "make

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sense” to the social scientist due to the scientist’s personal experiences, especially when he is a participant in the same culture as the social members he is investigating.

Examples of these romantics are sociologists like Talcott Parsons and his followers, who advocate variations on the philosophy of the sociologist Max Weber, in which this vicarious understanding called “*verstehen*” is a criterion for criticism that trumps empirical evidence. This criterion has severely retarded the evolution of sociology into a modern empirical science in the twentieth century.

The economist Trygve Haavelmo and the neoclassical econometricians supply another example. They do not reject the aim of prediction and policy formulation using econometric models, but nonetheless subordinate the selection of “explanatory” variables in their econometric models to the description of subjective motives set forth in the maximizing rationality postulates that economists heroically impute to the participants in economic activities.

4.04 More Recent Ideas

Most of the twentieth-century post-positivist proposals for the aim of science arise from examination of important episodes in the history of the natural sciences rather than from the speculations and agendas of philosophers.

Albert Einstein’s idea was influenced by reflection on his relativity theory for his concept of the aim of science, which he set forth as his “programmatically aim of all physics” stated in his “Reply to Criticisms” in Schilpp’s *Albert Einstein*. The aim is the comprehension as complete as possible of the connections among sense impressions in their totality by the use of a minimum of primary concepts and relations. Its achievement is the representation of the multitude of concepts and theorems close to experience as theorems logically derived from and belonging to a basis, as narrow as possible, of axioms and fundamental concepts, which themselves can be chosen freely. Thus the aim of science is the logical unity of the world picture, a coherence agenda. He found statistical quantum theory to be incomplete according to his aim.

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Thomas Kuhn, reflecting on the development of the Copernican heliocentric theory in his *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* and his *Structure of Scientific Revolutions* assigned institutional status to the prevailing theory, which he called the “consensus paradigm”. He proposed that small incremental changes extending the consensus paradigm define the institutionalized aim of science, which he called “normal science”, and that scientists neither desire nor aim consciously to produce revolutionary new theories, which he called “extraordinary science.” Kuhn therefore defines scientific revolutions as institutional changes in science.

Karl Popper was an early post-positivist philosopher of science and a critic of the romantics. Reflecting on the development of Einstein’s relativity theory in physics he proposed in his *Logic of Scientific Discovery* that the aim of science is to produce tested and nonfalsified theories having greater universality and information content than their predecessor theories addressing the same subject. The English-language title of his book notwithstanding Popper denies that discovery can be addressed by either logic or philosophy, but instead is the proper subject for psychology.

Norwood Russell Hanson reflecting on the development of quantum theory states in his *Patterns of Discovery* that inquiry in research science is directed to the discovery of new patterns in data for new explanatory hypotheses for deductive explanation. Following C.S. Peirce he calls this “abduction”, but does not propose any procedure for discovering the new patterns.

Paul Feyerabend also reflecting on the development of quantum theory proposed in his *Against Method* that each scientist has his own aim, and that anything institutional is a conformist impediment to the advancement of science. He said that historically successful science is literally anarchical, and he therefore proposed “revolution in permanence”.

4.05 Aim of Maximizing “Explanatory Coherence”

Paul Thagard developed his computerized cognitive system **ECHO**, an acronym meaning “Explanatory Coherence by Harmony Optimization”, in order to explore the operative criteria in theory choice by mechanically simulating noteworthy past episodes in the history of science.

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James Cornman initially proposed the “best explanation” idea and called it “explanationism”. It refers to an explanation that aims to maximize explanatory coherence of one’s overall set of beliefs. Thagard’s system described in his *Conceptual Revolutions* simulated the realization of the aim of maximizing “explanatory coherence” by replicating various episodes of theory choice. He applied his system **ECHO** to several revolutionary episodes in the history of science including (1) Lavoisier’s oxygen theory of combustion, (2) Darwin’s theory of the evolution of species, (3) Copernicus’ heliocentric astronomical theory of the planets, (4) Newton’s theory of gravitation, and (5) Hess’ geological theory of plate tectonics.

In reviewing his historical simulations Thagard reports that **ECHO** found the criterion making the largest contribution historically to explanatory coherence in scientific revolutions is explanatory breadth – the preference for the theory that explains more evidence than its competitors. But he adds that the simplicity and the analogy criteria are also historically operative although less important. He maintains that the aim of maximizing explanatory coherence with these criteria yields the “best explanation”.

4.06 Contemporary Pragmatist Aim

The principles of the contemporary pragmatism including its philosophy of language evolved through the twentieth century beginning with the autobiographical writings of Werner Heisenberg, one of the central participants in the historic development of quantum theory. His philosophy of language was summarized above in Chapter II in the form of three central theses, which are not repeated here.

The institutionally regulated activities of research scientists may be described succinctly in the pragmatist statement of the aim of science, which the contemporary research scientist seeking success in his research may consciously employ as what some social scientists call a “rationality postulate”. Such a pragmatist rationality postulate may be expressed as follows: Scientists aim to construct explanations by developing theories that satisfy the most critically empirical tests that can be applied to the theories at the current time, and which are thereby regarded as scientific laws that function in scientific explanations. This statement is more elaborately

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explained in terms of the other functional topics as sequential steps in the development of explanations.

The institutionalized aim can also be expressed so as not to impute motives to the successful scientist, whose personal psychological motives may be quite idiosyncratic. Thus the contemporary pragmatist statement of the aim of science may be phrased in terms of the successful outcome instead of a conscious aim imputed to scientists:

The successful outcome of basic-science research is explanation, which is achieved by developing theories that satisfy the most critically empirical tests that can be applied to the theories at the current time, and which are thereby regarded as scientific laws that function as premises in deductive explanations of events.

4.07 Institutional Change

Institutional change in science must be distinguished from change within the institutional constraint defined by the aim of science. Philosophy of science is concerned both with changes within the institution of science and with historical changes of the institution itself. But institutional change can only be recognized retrospectively due to the distinctively historical uniqueness of each episode and also due to the need for emergent conventionality for new basic-research practices to become institutionalized.

In the history of science institutionally deviate practices, innovative instruments and unconventional concepts that yielded successful results were initially recognized and accepted by only a few scientists. As Feyerabend emphasized in his *Against Method*, in the history of science successful scientists have often broken the prevailing methodological rules. The successful departures eventually become conventionalized, and by the time they appear in reference manuals, encyclopedias and student textbooks the institutional change is complete.

But adequate understanding of successful departures from institutionalized basic research is elusive. Successful researchers have often failed to understand the reasons for their unconventional successes, and have formulated or accepted erroneous methodological ideas and philosophies of science to explain their successes. One of the most historically notorious

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such misunderstandings is Isaac Newton's "*hypotheses non fingo*", his denial that his law of gravitation is a hypothesis.

It is noteworthy that the contemporary pragmatist statement of the aim of science is itself a postulate in the sense of an empirical hypothesis. Therefore it is destined to be revised at some unforeseeable future time, when due to some future developmental episode, basic science practices are revised. Then some conventional practice deemed rational today will some time in the future likely be dismissed as superstition.

4.08 Philosophy's Cultural Lag

As mentioned above adequate understanding of successful departures from institutionalized basic research is elusive even for philosophers. Not surprisingly there exists a time lag between the evolution of the institution of science and developments in philosophy of science, since the latter depends on the realization of the former. For example more than twenty-five years passed between Heisenberg's philosophical reflections on the language of his uncertainty relations in quantum theory and the consequent emergence and ascendancy of the contemporary pragmatist philosophy of science in academic philosophy.

Due to the regulating role of the aim of science, any cultural evolution in science that involves a modification of the aim of science amounts to a greater or lesser institutional change, when it becomes conventionalized. Some such changes seem to occur with lengthy time lags due to such impediments as intellectual mediocrity, risk aversion or vested interests in the received conventional philosophical wisdom.

4.09 Cultural Lags among Sciences

Not only are there cultural lags between the practices of science and philosophy of science, there are also cultural lags among the several sciences. Philosophers of science have preferred to examine physics and astronomy, because historically these have been the most advanced sciences since the historic Scientific Revolution benchmarked with Copernicus. Many other sciences have tended to lag behind physics and astronomy with

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the newer social and behavioral sciences lagging farther behind than most of the natural sciences.

Naïve sociologists and economists are blithely self-confident in their ersatz philosophizing about basic social science research, often adopting prescriptions and proscriptions that contemporary philosophers of science view as erroneous, anachronistic and retarding. The result has been the emergence and survival of retarding philosophical superstitions in these lagging sciences, especially to the extent that they have looked to their own less successful histories to formulate their amateurish philosophies of science.

As mentioned above, sociologists and economists continue to enforce a romantic philosophy of science, because they believe that sociocultural sciences must have fundamentally different philosophies of science than the natural sciences. Similarly behaviorist psychologists continue to impose the positivist philosophy of science. On the contemporary pragmatist philosophy these sciences are institutionally retarded, because they erroneously impose prior semantical and ontological commitments as criteria for scientific criticism. Pragmatists recognize only the empirical criterion for scientific criticism.

4.10 Scientific Discovery

The functional topic after the aim of science is discovery. “Discovery” refers to the development of new theories, and is the first step toward realizing the aim of science.

The problem of scientific discovery for contemporary pragmatist philosophers of science is to describe and to proceduralize the development of universally quantified statements for empirical testing with nonfalsifying test outcomes.

Much has already been said in the above discussions of philosophy of scientific language about the pragmatic basis for the definition of theory language, about the semantic basis for the individuation of theories, and about state descriptions. That will not be repeated here. Of special interest in the present context is the mechanized development of new theories.

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4.11 Discovery Systems

As a creative event, the development of an empirically successful theory has a reputation for mystery. In the "Introduction" to his *Models of Discovery* Nobel laureate Herbert Simon says that dense mists of romanticism and downright knownothingness generally have always surrounded the subject of scientific discovery and creativity. Therefore the most significant development addressing the problem of scientific discovery has been the relatively recent computerized discovery systems in computational philosophy of science. The discovery system explicitly describes the transition from an input language state description containing currently available information to an output language state description containing the newly generated and tested theories.

The discovery systems do not merely implement an inductivist strategy of searching for repetitions of individual instances, notwithstanding that statistical sampling theory is employed in some system designs. The system designs are mechanized procedural strategies that search for patterns in data or linguistic input information. They thus implement Hanson's thesis in *Patterns of Discovery* that in a growing research discipline inquiry is the discovery of new patterns in data.

Every useful discovery system to date has contained procedures both for constructional theory creation and for critical theory evaluation. Theory creation introduces new language into the current state description to produce a new state description, while falsification eliminates language from the current state description to produce a new state description. Thus both theory development and theory testing enable a discovery system to offer a dynamic diachronic description of linguistic change in science.

The ultimate aim of the computational philosopher of science is to facilitate the advancement of contemporary sciences by participating in and contributing to the successful basic-research work of the scientist.

4.12 Types of Theory Development

In his *Introduction to Metascience* Hickey distinguished three types of theory development. They are theory extension, theory elaboration and theory revision.

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Theory extension is the use of a currently tested and nonfalsified explanation to address a new scientific problem. The extension could be as simple as adding statements to make a general explanation more specific for the problem at hand.

A sophisticated strategy for theory extension is analogy. In his *Computational Philosophy of Science* Thagard developed a strategy for mechanized theory development, which he says consists in the patterning of a proposed solution to a new problem by analogy with an existing explanation for a different subject. Using his system design based on this strategy his discovery system called **PI**, an acronym for “Process of Induction”, reconstructed development of the theory of sound waves by analogy with the description of water waves. Since the input is an existing explanation for a different subject, the input state description does not consist of untested theories already proposed to solve the problem at hand.

In his *Mental Leaps: Analogy in Creative Thought* Thagard explains that analogy is a kind of nondeductive logic, which he calls “analogic”. It firstly involves the “source analogue”, which is the known domain that the investigator already understands in terms of familiar patterns, and secondly involves the “target analogue”, which is the unfamiliar domain that the investigator is trying to understand. Analogic is how the investigator understands the targeted domain by seeing it in terms of the source domain, and it involves a “mental leap”, because the two analogues may initially seem unrelated. But the act of making the analogy may reveal new connections between them.

It may be noted that if the output state description generated by the system is radically different from anything previously seen by the affected scientific profession, the members of the profession may experience the communication constraint with colleagues that is usually associated with a theory revision.

Theory elaboration is a correction of a currently falsified theory to create a new theory by the addition of new factors or variables that correct falsified universal statements and erroneous predictions. The correction is not merely *ad hoc* referencing individual exceptional cases, but rather changes universally quantified statements. Except perhaps for description of the additional correcting variable, the new theory usually has the same test design as the old theory that is the basis for elaboration.

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For example Gay-Lussac's law for gasses could be elaborated into Boyle's gas law by the introduction of a variable for the volume quantity and a constant coefficient for the particular gas. Similarly Friedman's macroeconomic quantity theory might be elaborated into a Keynesian liquidity-preference function by the introduction of an interest rate, to account for the cyclicity manifest in an annual time series describing over several decades the calculated velocity parameter.

The **BACON** discovery system, named after the English philosopher Francis Bacon (1561-1626) who thought that scientific discovery can be routinized, is a set of successive and increasingly sophisticated discovery systems that make -quantitative empirical laws and theories. **BACON** was designed and implemented by Pat Langley in 1979 as the thesis for his Ph.D. dissertation written in the Carnegie-Mellon department of psychology under the direction of Herbert Simon. A description of the system is in Simon's *Scientific Discovery: Computational Explorations of the Creative Processes*.

The system uses Simon's heuristic-search design concept, which may be construed as a sequential application of theory elaboration. Given sets of observation measurements for two or more variables, **BACON** searches for functional relations among the variables. **BACON** has simulated the discovery of several historically significant empirical laws including Boyle's law of gases, Kepler's third planetary law, Galileo's law of motion of objects on inclined planes, and Ohm's law of electrical current.

Theory revision is a reorganization of currently existing information to create a new theory. It might be undertaken after theory elaboration has failed to correct a previously falsified theory. The data source for the input state description for mechanized theory revision consists of the descriptive vocabulary from the currently untested theories addressing the problem at hand. The descriptive vocabulary from previously falsified theories may also be included as inputs to make an accumulative state description, because the vocabulary in rejected theories can be productively cannibalized for their scrap value. The new theory is most likely to be called revolutionary if the revision is great, because theory revision typically produces greater change to the current language state than theory elaboration.

In the early 1970's Hickey tested his **METAMODEL** discovery system by synthesizing the Keynesian macroeconomic theory from variables and U.S. statistical data available prior to 1936, the publication year of

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Keynes' *General Theory of Employment, Interest and Money*. The applicability of the **METAMODEL** for this theory revision is already known in retrospect by the fact that, as Nobel laureate econometrician Lawrence Klein said in his *Keynesian Revolution*, all the important parts of Keynes theory can be found in the works of one or another of his predecessors. Hickey's **METAMODEL** discovery system is a combinatorial procedure for theory revision, a system design that Simon calls a "generate-and-test heuristic-search design". It might be said that this system design implements Feyerabend's principle of "theory proliferation" at electronic speed. The mechanized proliferation is a tsunami of options that the system constructs and tests empirically in its run.

Hickey also used his discovery system to develop a macrosociometric institutional model of the American national society with seventy-five years of historical time-series data. To the shock, chagrin and dismay of the academic sociologists the model was not a social-psychological theory. Due to their a priori ontological commitment to romanticism the communication constraint rendered them invincibly obdurate, and they furthermore exhibited a Luddite attitude toward mechanized theory development.

4.13 Examples of Successful Discovery Systems

Examples of some successful discovery systems that are in use include Sonquist's **AID** system (1961), Hickey's **METAMODEL** system (1976), and Litterman **BVAR** system (1980).

Sonquist developed his **AID** system as a doctoral dissertation at the University of Chicago. He described it as a discovery strategy in his *Multivariate Model Building: Validation of a Search Strategy*. The system has long been used at the University Of Michigan Survey Research Center. Now known as the **CHAID** system Sonquist's discovery system is available commercially in SAS and SPSS statistical packages, and is by far the most widely used of all the discovery systems yet created.

Hickey was a graduate student at the University Of Notre Dame at South Bend, Indiana, but the philosophers have a reform-school culture and told him to get reformed or get out. He got out and then developed his **METAMODEL** discovery system at San Jose College in California. In the more than thirty years since Hickey first developed his system, he has

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applied his discovery system for economic analysis at Kraft Foods, Brown & Williamson Company, Quaker Oats Company, U.S. Steel Corporation, Allstate Insurance Company, TransUnion LLC, and the State of Indiana Department of Commerce.

Litterman developed his **BVAR** system as a doctoral dissertation at the University of Minnesota, and today economists at the Federal Reserve Bank of Minneapolis use his system for macroeconomic analysis.

4.14 Scientific Criticism

The functional topic after the aim of science and discovery is criticism. The philosophical literature on scientific criticism has little to say about the specifics of experimental design. Most often it pertains to the criteria for the acceptance or rejection of theories and the decidability of empirical testing.

The only criterion acknowledged by contemporary pragmatists is the empirical test. Contemporary pragmatists accept relativized semantics, ontological relativity and scientific realism. They therefore reject all prior ontological criteria for scientific criticism such as the romantics' mentalism. The empirical criterion is what separates the empirical sciences from their origins in natural and moral philosophy, not to mention science-fiction literature. Whenever in the history of science there has been a conflict between the empirical criterion and any nonempirical criteria for the evaluation of new theories, eventually it is the empirical criterion that ultimately decides theory selection. The empirical criterion is the necessary condition for "progress" in basic science.

In the past philosophers and scientists had used their ontological preconceptions as criteria for the criticism of scientific theories including preconceptions about causality or specific causal factors. This presumption led them to reject out of hand new and empirically acceptable theories that did not conform to these ontological preconceptions. In his *Against Method* Feyerabend noted that the ontological preconceptions used by scientists to criticize new theories have often been earlier theories' semantical and ontological claims elevated to criterion status.

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The only criterion for scientific criticism acknowledged by contemporary pragmatists is the empirical criterion.

4.15 Logic of Empirical Testing

The universally quantified theory statements in an empirical test can be schematized as a nontruth-functional hypothetical-conditional statement, i.e., as a statement with the logical form “If A, then C.” The hypothetical-conditional statement itself represents the set of one or several universally quantified theory statements that describe the causal dependency of the phenomena described by “C” upon the phenomena described by “A”. The hypothetical-conditional statement is thus the theory-language context that contributes meaning parts to the complex semantics of the theory’s descriptive terms including the terms common to the theory and test design.

The antecedent “A” also includes the set of universally quantified statements of the test design that describe the initial conditions that must be realized for execution of an empirical test of the theory, and which also describe the test outcome independently of the theory’s predictions. These statements also contribute meaning parts to the complex semantics of the terms common to theory and test design, and do so independently of the theory’s claims. The universal logical quantification indicates that any execution of the experiment is but one of an indefinitely large number of possible test executions especially if the test is repeatable at will.

When the test is executed, the logical quantification of “A” is changed to particular quantification to describe the realized initial conditions in the individual test execution, and it is always presumed to be true or the test execution is rejected as invalid.

The consequent “C” represents the set of universally quantified statements of the theory that describe the predicted outcome of every execution of a test design. Its logical quantification is also changed to particular quantification to describe the predicted outcome in an individual test execution. In a mathematically expressed theory, “C” may simply be a dependent variable in the equation of the theory. When no value is assigned, it is universally quantified. When the calculated prediction value of the variable is assigned in the individual empirical test execution, it is particularly quantified.

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Another particularly quantified statement, “O”, describes the observed test outcome of an individual test execution. The report of the test outcome, “O”, has the same vocabulary that is used in the prediction statement “C”. But the semantics of the terms in “O” is determined exclusively by the universally quantified test-design statements rather than by the statements of the theory, and thus its semantics is independent of the theory’s claims. In an individual predictive test execution “O” represents observations made and data collected after the prediction is made, and it too has particular logical quantification to describe the observed outcome resulting from an individual execution of the test.

If “A” is false in an individual test execution, then regardless of the truth of “C” the test execution is simply invalid due to a failure to comply with its test design, and the status of the theory remains unknown. Contrary to the logical positivists the truth table for the truth-functional Russellian logic is therefore not applicable to testing in empirical science, because a false antecedent, “A”, does not make the hypothetical-conditional statement true. A false antecedent “A” is irrelevant to the truth status of the theory.

The empirical test is conclusive only if it is executed in accordance with its test design.

If “A” is true and the consequent “C” is false, as when the theory conclusively makes an erroneous prediction, then the theory is falsified. Falsification occurs when the statements “C” and “O” are not accepted as saying the same thing within the range of vagueness or measurement-error manifestations of empirical underdetermination. This logic of the test is the *modus tollens* argument, according to which the conditional-hypothetical statement expressing the theory is falsified, when one denies the consequent clause of the hypothetical conditional. This is the falsificationist philosophy of scientific criticism advanced by C.S. Peirce, the founder of pragmatism, and also advocated by Karl Popper.

If “A” and “C” are both true, the hypothetical-conditional statement expressing the tested theory asserts a causal dependency between the phenomena described by the antecedent and consequent clauses. The hypothetical-conditional statement does not assert merely a Humean constant conjunction. Causality is an ontological category describing a real dependency, and the causal claim is asserted on the basis of ontological relativity due to the empirical adequacy demonstrated by the nonfalsifying

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test outcome. This is also true when the conditional expresses a numerical correlation. But the empirical adequacy and therefore the causality claim are never absolute or final. Because the nontruth-functional hypothetical-conditional statement is empirical, empirical adequacy and the causality claim are always subject to future testing, to future falsification, and to future revision.

On the pragmatist philosophy a theory that has been tested is no longer theory, once the outcome is known and the test execution is accepted as correct. If it has been falsified, it is merely rejected language. But if it has been tested with a nonfalsifying test outcome, then it is empirically warranted and thus deemed a scientific law. The law is still hypothetical because it is empirical, but it is less hypothetical than it had been as a theory proposed for testing. The law may thereafter be employed in an explanation or in test designs for testing other theories.

For example the engineering documentation for the Tevetron particle accelerator at Fermilab near Chicago, Illinois is based on previously tested science. The science in that engineering is not what is tested when the particle accelerator is operated for experiments, but rather it is presumed true for the experiments performed with the accelerator.

4.16 Test Logic Illustrated

For example consider the simple case of Gay-Lussac's law for gasses in an enclosed container as a theory proposed for testing. The container's volume is fixed throughout the experimental test, and is not represented by a variable. The theory is $(T'/T)*P = P'$, where the variable **P** means gas pressure, the variable **T** means the gas temperature, and the variables **T'** and **P'** are incremented values for **T** and **P** in an experimental test.

The statement of the theory may be schematized in the hypothetical-conditional form "If A, then C", where "A" includes $(T'/T)*P$, and "C" states the calculated prediction value of **P'** after temperature is incremented from **T** to **T'**. The theory is universally quantified, because it claims to be true for every execution of the experimental test. And the semantics of **T**, **P**, **T'** and **P'** are mutually contributing to the semantics of each other for believers in the theory, since each variable can be expressed mathematically as a function of all the others.

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The test-design statements are also included in “A”. They describe the experimental set up and initial conditions to be realized for execution of a test. These include description of the equipment used including the container, the heat source, the instrumentation used to measure the magnitudes of heat and pressure, and the units of measurement for the magnitudes involved, such as the pressure units in atmospheres and the temperature units in degrees Kelvin. And they describe the procedure for performing the experiment. This test-design language is universally quantified and also contributes to the semantics of the variables **P**, **T** and **T'** in “A”.

The procedure for performing the experiment must be executed as described in the test-design language, in order for the test to be valid. The procedure will include firstly measuring and recording the initial values of **T** and **P**. For example **T** = 200 degrees Kelvin and **P** is 1.6 atmospheres. Then the measurement value for **T** is incremented to **T'**, which might be 400 degrees Kelvin, and this incremented measurement value is recorded. A description of the execution of the procedure and the recorded magnitudes are expressed in particularly quantified language for this particular test execution.

The test outcome consists of measuring and recording the resulting observed incremented value of **P'**, which may be denoted **P''** and is represented by particularly quantified statement “O”. The universally quantified test-design statements also in “A” define the semantics of “O”. The test executions would also likely be repeated to estimate the range of measurement error in **P**, **P'**, **T**, **T'** and **P''**. A mean average value would be calculated for each of these variables to estimate measurement errors. Deviations from the mean average value indicate the amounts of measurement error, and statistical standard deviations could summarize the dispersion of measurement errors about the means.

The mean average of the measures value **P''** is compared to the mean average of the value **P'** to determine the test outcome. If the values of **P'** and **P''** are within the estimated range of measurement error, i.e., are sufficiently close to 3.2 atmospheres as to be within the measurement errors, then “C” is deemed true, and the theory is sufficiently warranted empirically to be called a law, as it is today.

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4.17 Semantics of Empirical Testing

Much has already been said about artifactual semantics, componential semantics and semantical rules. In the semantical discussion below these concepts are brought to bear upon empirical testing and test outcomes.

Normally the semantics of a tested theory is such that if a test has a nonfalsifying outcome, then the semantics is unchanged for the developer and advocates of the tested theory. Prior to the test they had proposed the theory in the belief that it would not be falsified, and it consequently functions as a set of one or several semantical rules. Thus the universally quantified statements of both the theory and the test design are accepted as true, and after the nonfalsifying test outcome, each set of statements continues to contribute parts to the complex meanings of the terms common to both of them, as before the test.

But when the test outcome is a falsification, there is a semantical change produced in the theory for the developer and advocates of the tested theory who accept the test outcome as a falsification. The unchallenged test-design statements continue to contribute semantics to the terms common to the theory and test design by contributing their parts to the meaning complexes of each of the common terms. But the component parts of the meanings contributed by the falsified theory statements are excluded from the semantics of those common terms for the proponents who no longer believe in the theory due to the falsifying test outcome.

4.18 Test-Design Revision

The decidability of empirical testing is not absolute. Popper had recognized that the statements reporting the observed test outcome, which he called a “basic statements”, require prior agreement by the cognizant scientists, because they are subject to future revision and thus are not incorrigibly true.

For the scientist who does not accept a falsifying test outcome of a theory, a different semantical change is produced than if he had accepted the test outcome as a falsification. Such a dissenting scientist has either reconsidered the test-design statements or rejected the report of the test outcome. If he has rejected the outcome of the individual test execution,

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then he has merely questioned whether or not the test was executed in compliance with its agreed test design. Sometimes this is called “attacking the data”. If the test is repeatable at will, then repetitions of the test will likely answer the challenge to its validity.

But if he has challenged the test design itself, then he has thereby changed the semantics involved in the test in a fundamental way. This change amounts to rejecting the test design as if it were falsified, and letting the theory define the subject of the test and the problem under investigation – a role reversal in the pragmatics of test-design language and theory language. Then the theory’s semantics characterizes the problem, and the test design is deemed inadequate thus making the test design and the test execution irrelevant.

Popper rejects such a dissenting response to a test, calling it a “content-decreasing stratagem”, which is in fact what it is given the semantical outcome for the test design. He admonishes that that the fundamental maxim of every critical discussion is that one should “stick to the problem”. But the dissenting scientists may decide that the design of the falsifying test is a misconception of the problem that the tested theory is intended to solve, especially if he developed the theory himself and did not develop the test design. The semantical change produced for such a recalcitrant believer in the theory affects the meanings of the terms common to the theory and test-design statements. The parts of the meaning complex contributed by the test-design statements are then the parts excluded from the semantics of one or several of the terms common to the theory and test-design statements.

Empirical tests are conclusive decision procedures only for those scientists who agree upon which language is proposed theory and which language is presumed test design, and who furthermore accept the test-design and also the test execution outcomes with the test design.

4.19 Empirical Underdetermination

An important factor affecting the decidability of empirical testing is the empirical underdetermination of language with the result that empirical criteria cannot always result in unambiguous theory-testing decisions. Two manifestations of empirical underdetermination are conceptual vagueness

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and measurement error. All concepts have vagueness that can be reduced indefinitely but never be eliminated completely. Mathematically expressed theories use measurement data that contain some measurement error in all but the simplest cases that are not typically found in science. Measurement error can be reduced indefinitely but never eliminated completely.

Scientists prefer measurements and mathematically expressed theories, because they can measure the amount of error in the theory, when the theory is tested. But separating measurement error from a theory's prediction error can be problematic. Repeated execution of the measurement procedure enables estimation of the degree or range of measurement error. A test is conclusive to the extent that the measurement error is small relative to the predicted outcome.

Empirical tests are conclusive only to the extent that empirical underdetermination is manifestly small relative to the effect predicted in an empirical test.

4.20 Scientific Pluralism

All language is always empirically underdetermined by reality. Empirical underdetermination explains how two semantically alternative empirically adequate theories can have the same test-design language. It may occur that there are several semantically different theories yielding prediction errors that are different from one another but with differences that are small enough to be within the range of the estimated measurement error. In such cases empirical underdetermination due to the given test design has imposed undecidability on the choice among the alternative individual theories.

The problem of empirical underdetermination is also manifested as conceptual vagueness. For example to develop his three laws of planetary motion Johannes Kepler, a heliocentrist, used the measurement observations of Mars that had been collected by Tycho Brahe, a geocentrist. Thus both these astronomers not only used the same test-design semantical contributions for the meanings in their observational concepts for identifying the planet Mars and for measuring its celestial movements, but they also used the same astronomical measurement data. In those days no test-design observations or measurements were informative enough to enable an

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empirical decision between the two cosmologies, and for many years both cosmologies were empirically adequate.

Kepler nonetheless believed in the heliocentric cosmology, and this belief made the semantic parts contributed by the heliocentric cosmology become for him component parts of the semantics of the language used for celestial observation, thus displacing the geocentric cosmology's semantical contribution. Then hypothesizing with the heliocentric clarifying contributions to the celestial semantics, he developed his planetary laws for Mars.

Thus as Hanson said in *Patterns of Discovery*, observation language is "theory-laden". And as Feyerabend noted in *Against Method*, Galileo practiced "counterinduction". Galileo believed in the heliocentric cosmology, and counterinduction enabled him to create a new observation language, as did Kepler. By using heliocentric concepts in his *Dialogue* he revised and clarified apparently falsifying observational evidence alleged by the Aristotelian geocentrists. Similarly in 1926 Heisenberg had practiced counterinduction for describing the electron tracks in the cloud chamber, and he then developed his uncertainty relations.

But like geocentrism and heliocentrism in Galileo's day, alternative empirically adequate theories due to excessive empirical underdetermination are all more or less true. An answer as to which theory is truer must await further development of additional observational information that clarifies the inadequate test-design concepts. But there is never any ideal test design with "complete" information, with no vagueness or no measurement error. Pragmatist recognition of undecidability among alternative empirically adequate scientific explanations due to empirical underdetermination is called the thesis of "scientific pluralism".

Scientific pluralism is the coexistence of empirically adequate alternative explanations due to undecidability among alternative laws, permitted by test-design language that is too underdetermined empirically.

4.21 Scientific Truth

What is truth! Truth is a property of descriptive language. Furthermore as Jarrett Leplin maintains, truth and falsehood are properties

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admitting to more or less. They are not simply dichotomous, as they are represented in two-valued formal logic. Tested and nonfalsified statements are more empirically adequate, have more truth, and have ontologies that are more realistic than falsified statements. Falsified statements have recognized error, and may simply be rejected unless they are still useful for their lesser realism and lesser truth. As the classical pragmatists believed, what has utility has truth.

Popper said that the famous eclipse test of Einstein's theory of gravitation in 1919 "falsified" Newton's theory and thus "corroborated" Einstein's. Yet the U.S. National Aeronautics and Space Administration (NASA) today uses Newton's laws to navigate interplanetary rockets and satellites through our solar system. Thus it must be said that Newton's "falsified" theory is not completely false or it could never be used, even for nineteenth-century ballistics.

Popper said that science does not attain truth. Contrary to Popper, contemporary pragmatists believe that with such an idea, truth has been misconceived. Theories are falsified by empirical tests, but it need not be said with Popper that truth is unattainable for scientists. Advancement in empirical adequacy is advancement in truth. And a theory with more truth is a theory with a more realistic ontology.

4.22 Nonempirical Criteria

Given the dilemma of having semantically alternative explanations that are tested and not falsified due to empirical underdetermination in the test designs, philosophers have proposed nonempirical criteria that they believe have been operative historically in explanation choice. But no such nonempirical criterion enables a scientist to predict reliably which alternative nonfalsified explanation will survive new empirical testing, when in due course the degree of empirical underdetermination is reduced by improved test design.

Test designs are improved by developing more accurate measurement procedures having less measurement error and/or by adding descriptive information that reduces the vagueness in the characterization of the subject for testing. Such test-design improvements refine the characterization of the problem addressed by the theories.

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When empirical underdetermination makes testing undecidable, different scientists may have personal reasons for preferring one alternative explanation to another. In such circumstances selection may be a decision for the career scientist rather than an investigative decision. The scientist is speculating on future science and also seeking professional acceptance. Knowing what a journal editor and his selected referees currently like to see in submissions helps getting a paper published in the peer-reviewed literature, which is an academic status symbol with the more prestigious journals paying out more brownie points for the accumulation of academic remuneration, promotion and tenure. Academic journal editors and their selected referees are nearly always the risk-avoiding rearguard rather than the risk-taking avant-garde. They are the established “authorities” who defend the received conventional wisdom in which they and their journals have a reputation-based vested interest.

4.23 The “Best Explanation” Criteria

As noted above, Thagard’s cognitive-psychology system **ECHO** developed specifically for theory selection has identified three nonempirical criteria. His simulations of past episodes in the history of science indicate that the most important criterion is breadth of explanation, followed by simplicity of explanation, and finally analogy with previously accepted theories. Thagard considers these nonempirical selection criteria as inferences to the “best explanation”.

The breadth of explanation criterion seems similar to Popper’s aim of maximizing information content. In any case there have been successful theories in the history of science, such as Heisenberg’s uncertainty relations, which do not have any of these characteristics. And as Feyerabend noted in criticizing Popper’s view in *Against Method*, Aristotle’s physics identified four causes, material, formal, efficient and final, while Newton’s only identified one kind of cause, the efficient cause. Aristotle’s explanations therefore may be said to have greater breadth, but his physics was less empirically adequate.

Contemporary pragmatists acknowledge only the empirical criterion. They exclude all nonempirical criteria from the aim of science, because while relevant to persuasion to make theories appear “convincing”, they are irrelevant to evidence. They are like the psychological criteria that trial

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lawyers use to select and persuade juries in order to win lawsuits in a court of law, but which are irrelevant to courtroom evidence rules for determining the facts of a case.

4.24 Nonempirical Linguistic Constraints

The constraint imposed upon theorizing by empirical test outcomes is the empirical constraint. It is a regulating institutionalized cultural value that is not viewed as an obstacle to be overcome, but rather as a condition to be respected for the advancement of science. The only other cultural constraint that must be respected is the moral constraint, which is a criterion external to the institution of science, and which cannot be judged either by science or by philosophy of science.

However, there are other kinds of constraints that are retarding impediments that must be overcome for the advancement of science. Some of these nonempirical impediments are purely circumstantial like those mentioned above. They are external to science. But there are two other nonempirical constraints that are internal to science in the sense that they are inherent in the nature of language, which science must use. These two constraints may be called the “cognition constraint” and the “communication constraint”.

4.25 Cognition Constraint

The cognition constraint inhibits a scientist’s ability to construct new theories, and it is manifested as what is often mundanely referred to as lack of imagination, creativity or ingenuity. Semantical rules are not just rules. They are also linguistic habits that enable fluency in both speech and thought.

As mentioned above, given belief in some universally quantified affirmative statement, the predicate in that affirmation determines part of the meaning complex of its subject term. Conversely given the conventionally established meaning of a descriptive term, certain related beliefs are sustained with the result that change of belief is made difficult by the need to change meanings that are reinforced by linguistic fluency. In his book *Concept of the Positron* Hanson identified what he called a “conceptual

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constraint” that operated as a semantical impediment to the discovery of the positron.

This thesis is opposed to the neutral-language thesis that language is merely a passive instrument for thought. Language is not merely a passive instrument for thought. It has a formative influence on thought. The formative influence of language on thought is recognized by the Sapir-Whorf hypothesis and specifically Benjamin Lee Whorf’s thesis of linguistic relativity set forth in his “Language, Mind and Reality” reprinted in *Language, Thought and Reality*.

Accordingly the more revolutionary the revision of beliefs, the more constraining the semantical structure and psychological conditioning on the creativity of the scientist who would develop a new theory. And if a new syntax is required such as an unfamiliar mathematics, then the semantical restructuring of the affected meaning complexes is all the more demanding.

It is noteworthy that the use of computerized discovery systems circumvents this problem, because the machines have no linguistic habits. They strategically yet mindlessly apply mechanized procedures to object-language syntactical inputs, which may be counted as one of their virtues.

4.26 Communication Constraint

The communication constraint is similar to the cognition constraint. It is the impediment to understanding a new theory relative to those currently conventional. The impediment is both cognitive and psychological. The scientist must cognitively learn the new theory well enough to restructure the composite meaning complexes associated with the descriptive terms common both to the old theory he already knows and to the new theory to which he is exposed. And this involves overcoming existing linguistic fluency enabled by psychological habit, which reinforces existing beliefs.

This learning process suggests the conversion experience described by Kuhn in revolutionary transitional episodes, because the new theory must firstly be accepted as true however provisionally for its semantics to be understood, since only statements believed to be true can operate as semantical rules. If testing demonstrates the new theory’s superior empirical

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adequacy, then the new theory's acceptance will eventually make it the established conventional wisdom.

If the differences between the old and new theories are very great, some members of the affected scientific profession may be unwilling or unable to accomplish the required learning adjustment. They become the rearguard who cling to the received conventional wisdom, which is challenged at the frontier of research, where there is much conflict that produces confusion due to semantic dissolution. In the meanwhile the developer together with the more opportunistic and typically younger advocates of the new theory, who have been motivated to master the new theory's language in order to exploit its perceived promise, assume the avant-garde role.

It is noteworthy that contrary to Kuhn and especially to Feyerabend the transition does not involve a complete semantic discontinuity much less any semantic incommensurability. And it is unnecessary to learn the new theory as though it were a completely foreign language. For the terms common to the new and old theories, the component parts contributed by the new theory replace those from the old theory, while the parts contributed by the test-design statements remain unaffected by the change. Thus the test-design language component parts shared by both theories constitute common and commensurating semantics providing semantical continuity and enabling characterization of the same subject of both theories independently of the distinctive claims of either theory. The shared semantics in the test-design language also facilitates learning and understanding the new theory, however radical the new theory may be. Or if excessive empirical underdetermination for the present prohibits a decisive test design, the currently vague characterizations of the subject of the theories enable semantical continuity, such as it is.

It may be noted that the scientist viewing the computerized discovery system output experiences the same communication impediment with the machine output that he would were the outputted theories developed by a fellow human scientist.

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In summary both the cognition constraint and the communication constraint are based on the following semantical fact:

Given the conventionally established meaning of a descriptive term, certain implied beliefs are reinforced by habitual linguistic fluency with the result that the term's conventional meaning impedes a change in those beliefs.

4.27 Scientific Explanation

Explanation is the ultimate aim of basic science. There are other types such as the historical explanation, but only explanation in basic science is of interest in philosophy of science. When some course of action is taken in response to an explanation such as a social policy, a medical therapy or an engineered product or structure, then the explanation is utilized in applied science.

The logical form of the explanation in basic science is the same as that of the empirical test. The universally quantified statements constituting a set of one or several scientific laws in an explanation can be schematized as a nontruth-functional hypothetical-conditional statement in the logical form "If A, then C". But while the logical form is the same for both the test and the explanation, the deductive arguments are different.

The deductive argument of the explanation is the *modus ponens* argument instead of the *modus tollens* logic used for testing. In the *modus tollens* argument the hypothetical-conditional expressing the proposed theory is falsified, when the antecedent clause is true and the consequent clause is false. On the other hand in the *modus ponens* argument for explanation both the antecedent clause and the hypothetical-conditional statements are accepted as true, such that affirmation of the antecedent clause concludes to a valid affirmation of the consequent clause.

The schematic form of an explanation is: "If A, then C." "A is affirmed." "Therefore C is affirmed." The statement "If A, then C" represents the universally quantified law statements. "A is affirmed." is the particularly quantified statements describing the realized initial conditions that cause the explained phenomenon. "Therefore C is affirmed." is the

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particularly quantified statements affirmed deductively and describing the explained individual effect, which may be a prediction of the event.

In the explanation the statements in the hypothetical-conditional schema express scientific laws accepted as true due to their empirical adequacy as demonstrated by nonfalsifying tests. The antecedent statements describing the initial conditions in the explanation together with the law statements jointly constitute the *explicans* or explaining language. And the logically consequent language is the *explicandum* describing the explained phenomenon.

A scientific explanation is a modus ponens deduction with one or several explaining universally quantified law statements expressible as a nontruth-functional hypothetical-conditional schema together with particularly quantified antecedent language describing initial conditions, which jointly conclude to particularly quantified consequent language describing the explained event.

It has also been said that theories “explain” laws. Neither untested nor falsified theories occur in an explanation. Explanations consist of laws, which are formerly theories that have since been tested with nonfalsifying outcomes. Proposed explanations are merely untested theories.

Since all the universally quantified statements in the nontruth-functional hypothetical-conditional schema of an explanation are laws, the “explaining” of laws means that a set of logically related laws forms a deductive system partitioned into dichotomous subsets of explaining antecedent axioms and explained consequent theorems.

Note: BOOK I is available as an ebook titled *Philosophy of Science: An Introduction*.