INTRODUCTION
TO
PHILOSOPHY OF SCIENCE

The aim of philosophy of science is to understand what scientists did and how they did it, where history of science shows that they performed basic research very well. Therefore to achieve this aim, philosophers look back to the great achievements in the evolution of modern science that started with the Copernicus with greater emphasis given to more recent accomplishments.

The earliest philosophy of science in the last two hundred years is Romanticism, which started as a humanities discipline and was later adapted to science as a humanities specialty. The Romantics view the aim of science as interpretative understanding, which is a mentalistic ontology acquired by introspection. They call language containing this ontology "theory". The most successful science sharing in the humanities aim is economics, but since the development of econometrics that enables forecasting and policy, the humanities aim is mixed with the natural science aim of prediction and control. Often, however, econometricians have found that successful forecasting by econometric models must be purchased at the price of rejecting equation specifications based on the interpretative understanding supplied by neoclassical macroeconomic and microeconomic theory. In this context the term "economic theory" means precisely such neoclassical equation specifications. Aside from economics Romanticism has little relevance to the great accomplishments in the history of science, because its concept of the aim of science has severed it from the benefits of the examination of the history of science. The Romantic philosophy of social science is still resolutely practiced in immature sciences such as sociology, where mentalistic description prevails, where quantification and prediction are seldom attempted, and where implementation in social policy is seldom effective and often counterproductive.

Positivism followed Romanticism. Many Positivists were physicists, who took physics as the paradigm of the empirical sciences, and several wrote histories of physics. Positivism is practiced in behaviorist

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psychology, but has negligible representation in any of the social sciences. The term "theory" in the Positivist philosophy of science means language referring to entities or phenomena that are not directly observable. On this meaning the term includes the Romantic concept of "theory", which refers to the covert and introspectively acquired mental experience rejected by behaviorists. Theory is also defined in opposition to observation language, which serves as the logical reduction basis that enables theory language to be both empirically acceptable and semantically meaningful. Positivism originated as a reaction against Romanticism, and purported to be more adequate to the history of science, even if its reductionism agenda made it remote from the practice of basic research.

Pragmatism followed Positivism. The contemporary Pragmatism's ascendancy over Positivism was occasioned by philosophers' reflection on the modern quantum theory in microphysics. There have been numerous revolutionary developments in science, but none since Newton's mechanics has had an impact on philosophy of science comparable to the development of quantum theory. Its impact on philosophy has been even greater than Einstein's relativity theory, which occasioned Popper's effective critique of Positivism. Initially several of the essential insights of contemporary Pragmatism were articulated by one of the originators of the quantum theory, Heisenberg, who reinterpreted the observed tracks of the electron in the Wilson cloud chamber, and who also practiced scientific realism.

Many years later Heisenberg's ideas were taken up and further developed by academic philosophers in several leading American universities, and it is now the ascendant philosophy of science in the United States. Contemporary Pragmatism contains several new ideas. Firstly by introducing reciprocity between truth and meaning the Pragmatists philosophers, following the physicists Einstein and Heisenberg, dispensed with the naturalistic observation-theory semantics, thereby undercutting the observation-language reduction base essential to Positivism. Pragmatists substituted a relativistic semantics for the Positivists' naturalistic primitive observation semantics, thereby revising the meanings of "theory" and "observation", to recognize their functions in basic research science. Secondly by relativizing semantics, they also relativized ontology thereby removing it from the criteria for scientific criticism. The intended outcome of this development was recognition of the absolute priority of empirical criteria in scientific criticism, in order to account for physicists' acceptance of quantum theory with its distinctively counterintuitive ontology of duality. A related outcome was a new philosophy of science with which to reexamine retrospectively the previous great achievements in the history of

science. Feyerabend for example found that Galileo had revised his observation language when defending the Copernican heliocentric theory, something unthinkable to the Positivists.

The implications of ontological relativity are fundamentally devastating for both Romanticism and Positivism, both of which are defined in terms of prior ontological commitments. For the Pragmatist no ontology may function as a criterion for scientific criticism, because ontological commitment is consequent upon empirical testing, and is produced by a nonfalsifying test outcome that warrants belief in the tested theory. Neither "theory", "law" nor "explanation" are defined in terms of any prior ontology, semantics, or subject matter, but rather are defined in terms of their functioning in basic research: "theory" is any universally quantified statement proposed for empirical testing; "scientific law" is any empirically tested and currently nonfalsified theory; "explanation" is a deduction concluding to either a description of particular events or to another universal law statement. Thus the Pragmatist can accept but does not require the Romantic's mentalistic description, and he can accept but does not require the Positivist's nonmentalist description.

As the contemporary Pragmatism has been achieving its ascendancy, a new approach – computational philosophy of science – has emerged as a specialty in a new school of psychology called "cognitive psychology." Computational philosophy of science is less a new philosophy and more a new analytical technique enabled by the computer, and its appearance was not occasioned by a new revolutionary development in science; quantum theory is still the touchstone for contemporary philosophy of science. Cognitive psychology considers its subject to be conceptual representations, and there emerged a psychologistic turn, which was occasioned in part by rejection of the nominalist philosophy of language that some philosophers such as Quine have carried forward from Positivism into Pragmatism. But nominalism is not integral to Pragmatism; conceptualism is perfectly consistent with the contemporary Pragmatism. The computational approach is a new analytical technique occasioned by the emergence of computer technology compatible with the contemporary Pragmatism, much as the symbolic logic was once a new analytical technique compatible with Positivism and produced Logical Positivism. The computational analytical technique has already yielded many interesting re-examinations of past revolutionary episodes in the history of science. Its promise for the future – already realized in a few cases – is fruitful contributions to the advancement of contemporary science. A computational Pragmatist philosophy of science clearly seems destined to be the agenda for the twenty-first century.

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Organizational Overview

There are four basic topics in modern philosophy of science:

1 The institutionalized value system of modern science, also called the aim of science.
2 Scientific discovery, also known as new theory development.
3 Scientific criticism, especially the criteria used for the acceptance or rejection of theories.
4 Scientific explanation, the end product of basic science.

Theories, laws and explanations are linguistic artifacts. Therefore philosophy of language is integral to philosophy of science. There have been several philosophical approaches to language and to science in the twentieth century: Romanticism, Positivism, contemporary Pragmatism, and psychologistic computational philosophy of science. The last is more a technique than a philosophy.

The following discussion therefore begins with a brief overview of each of the philosophical approaches, and then proceeds to the examination of the elements of philosophy of language. Finally with this background the four topics are examined in the order listed above.

Romanticism

The earliest of these philosophies is Romanticism, which is still widely represented today in the social sciences including neoclassical economics and sociology. This philosophy had its origins in the German Idealist philosophies of Kant and Hegel, although the Idealist philosophies are of purely antiquarian interest to philosophers of science today. But contemporary Romantics carry forward the Idealist thesis that there is a fundamental distinction between sciences of nature and sciences of culture. According to the Romantics any valid and "causal" explanation of human behavior must describe the mental experiences – the views, values and motivations – of the human agents studied by social science. Access to these mental experiences requires introspection by the social science researcher, who if he does not share in the same culture as his subjects, at least shares in their humanity. The resulting interpretative understanding yields the "theoretical explanation" of observed behavior. Thus in the Romantic philosophy the semantics of the terms "theory" and "explanation" represent culture understood as shared mental experience, and these terms

mean something quite different from their meanings both in the natural sciences and in other philosophies of science.

The Romantics' philosophy of scientific discovery is based on introspection. Furthermore some Romantics advocate Max Weber's *verstehen* thesis of criticism, and require that explanations be validated by empathetic plausibility, so that they "make sense" in the scientist's vicarious imagination. When Romantics apply empirical criteria, it is often for survey research, where the survey responses are articulate expressions of the subject's mental state, often including his erroneous beliefs. The verbal survey responses are subject to the researcher's interpretative understanding. There may occur a conflict between the *verstehen* judgment and the empirical survey findings, and different Romantics will decide differently as to which to choose with some rejecting the empirical data out of hand. And when the empirical data are not survey data describing mental states, but instead are measurements of nonverbal behavior or demographics, then the absence of mentalistic descriptions supplying interpretative understanding will occasion the Romantics' rejection of valid empirical findings. Romanticism has its distinctive philosophical theses in philosophy of language and therefore in the four basic topics in philosophy of science.

Positivism

Positivism originated in the British Empiricist philosophers including notably David Hume, although these Empiricist philosophies are of largely antiquarian interest to philosophers of science today. The French philosopher Auguste Comte founded Positivism in the late nineteenth century. Apart from Behaviorist psychology there is only a residual representation of Positivism today in either science or philosophy of science. Positivists believe that all sciences share the same methodological concepts and philosophy of science, and their ideas are based on examination of the natural sciences. This view evolved into the Logical Positivist Unity of Science agenda. The Positivists are therefore very critical of the Romantics' introspective mentalistic view of theory and explanation in social science.

Positivism enjoyed its widest acceptance in physics during the apogee of Newtonian physics. Yet the Positivists were critical of Newton's theory, and their aim was to develop permanent foundations for Newtonian physics in observation by eliminating all of its theoretical components. Positivism later saw a revival after the First World War as Logical Positivism, which was advocated by a group of physicists and philosophers known as the

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"Vienna Circle." The Logical Positivists wished to imitate the physicists' use of mathematics in philosophy, and attempted to apply the Russellian symbolic logic to this end. They were also influenced by the success of Einstein's relativity theory in physics, which convinced them that physics is becoming more theoretical instead of less theoretical. Therefore they revised the original Positivist agenda from eliminating all theory to justifying theory accepted by contemporary physics. The justification was to be accomplished by using the Russellian symbolic logic to relate theoretical terms to observation language, an agenda known as logical reductionism.

Contemporary Pragmatism

In the middle of the twentieth century there emerged a new philosophy in the United States that was a reaction against Positivism. Called contemporary Pragmatism, it is currently the ascendant philosophy of science in academic philosophy in the United States as well as in many other countries. Pragmatism had an earlier representation in the classical Pragmatists - Pierce, James and Dewey - in the United States, but while some aspects of the classical Pragmatism have been carried forward into the new, the new contemporary Pragmatism is largely the product of philosophical examination of the quantum theory in microphysics developed in Europe the 1920's rather than a gloss on the classical Pragmatists. Physicists have offered several ontological interpretations of the modern quantum theory. Many have accepted one called the "Copenhagen interpretation." There are two versions of the Copenhagen interpretation, both of which assert the thesis of "duality", which says that the wave and particle properties of the electron are two aspects of the same entity, rather then separate entities that are always found together. One version called "complementarity" advanced by Bohr, says that the mathematical expressions of the theory must be viewed instrumentally instead of realistically, that only the ordinary language used for macrophysics can be used to express duality, and that the terms "wave" and "particle" are complementary because the semantics of the two terms make them mutually exclusive. The other version advanced by Heisenberg also contains the idea of duality, but says that the mathematical expression is realistic and descriptive, and does not need Bohr's complementarity. Basically the two versions differ in their philosophy of language. Heisenberg's philosophy of language was due to the influence of Einstein, and it has been incorporated

into the contemporary Pragmatist philosophy of language pioneered independently by Quine.

The Romantic and Positivist philosophies of science have been historically opposed to one another, but in comparison to the contemporary Pragmatist philosophy they are much more similar to one another than to the contemporary Pragmatism. The contemporary Pragmatist philosophy of science is distinguished by a new philosophy of language, which replaced the traditional naturalistic view of the semantics of descriptive terms with an artifactual view. The outcome of this new linguistic philosophy is that ontology, semantics, and truth are mutually determining unlike the simpler unidirectional relation found in earlier philosophies including classical Pragmatism. It thus revolutionized philosophy of science by relativizing the semantics and ontology of language and their relation truth.

While the contemporary Pragmatism emerged as a critique of Positivism, the Logical Positivists' emphasis on analysis of language and their nominalist referential theory of meaning have been carried forward into the contemporary Pragmatism, which continues in the Analytic tradition. The Analytic philosophers took the "linguistic turn" in philosophy, in search of the objectivity they believed lacking in both earlier Positivism and especially Romanticism. In their linguistic philosophy they adopted nominalism and rejected concepts, ideas, and all other mentalistic views of knowledge. Their adoption of nominalism was also motivated by their acceptance of the Russellian symbolic logic, in which ontological claims are indicated by the logical quantifier in the predicate calculus. The ontology expressed by the Russellian predicate calculus does not admit attributes or properties except by placing predicates in the range of logical quantifiers, thereby making them reference subsisting entities. Thus all predicates are either uninterpreted symbols or logically quantified terms referencing either mental or Platonic abstract "entities." Hence the Logical Positivists regard all philosophers as either Nominalists or Platonists. Some Pragmatist philosophers of science today continue to accept the Positivists' referential theory of the semantics of language, but this nominalism it is not essential to the contemporary Pragmatism.

Computational Philosophy of Science

Philosophers and scientists have long desired to have a "method" of routinizing scientific research, so that progress no longer depends on mysterious intuition or inexplicable genius. Francis Bacon (1561-1626)

thought he had such a method, an inductive method, which he set forth in his *Novum Organon*. John Stuart Mill (1801-1873) thought he also had such a method that he had set forth as his canons of induction in his *A System of Logic*. Neither was successful, but techniques have evolved considerably since their times. Recently and largely independently of academic philosophy of science, there has emerged a new approach in philosophy of science, which consists of developing computer systems for the creation of new scientific theories. These computer systems also apply criteria for selecting a subset of their developed theories for output as acceptable theories. This is a new technical approach that has replaced both the symbolic logic and the Logical Positivists' agenda. However, this technical approach has become a specialty in a new area of psychology known as "cognitive psychology", also known as "artificial intelligence." The originator of this approach is Herbert Simon, a Nobel laureate economist and a founder of artificial intelligence. A more recent name of the specialty is "computational philosophy of science" originated by Paul Thagard in his *Computational Philosophy of Science* (1988), which he defines as normative cognitive psychology.

This new technical agenda has ended up as a specialty in psychology, because the computational philosophers of science reject the residual Positivist nominalism in contemporary Pragmatism. The cognitive psychologists regard the subject of their investigations to be mental representations. Nominalism is not essential to the contemporary Pragmatism. But in other respects this cognitive-psychology approach may be viewed more as a technique than a philosophy. Before discussing the four topics in philosophy of science mentioned above, consider firstly the elements of philosophy language.

Synchronic Metalinguistic Analysis

Firstly some preliminaries: Philosophers of science divide language into two types: *object language* and *metalanguage*. Metalanguage is the discourse used to describe an object language, which in turn is the language used to describe some domain of the real world. The language of science is typically expressed in an object language, while the discourse of philosophy of science is typically in an appropriate metalanguage. Furthermore language may be viewed either *synchronically* or *diachronically*. The synchronic view is static, i.e. limited to a point in time like a photograph. The diachronic view exhibits change in a discourse or language over time.

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If the transitional process of change through time is described, then the diachronic view is also *dynamic*. Otherwise it is a *comparative static* view containing only "before" and "after" snapshots. Linguistic analysis offers four successive perspectives on language, which are increasingly inclusive: (1) *syntax*, (2) *semantics*, (3) *ontology*, and (4) *pragmatics*.

Syntax

Syntax is the minimally inclusive perspective, and its object is the most obvious part of language. *Syntax is the system of symbols in linguistic expressions considered in abstraction from the meanings associated with the symbols.* It is what remains after the removal of pragmatics, ontology, and semantics, and it consists of the forms of expression, so its perspective is said to be "formal." Since meanings are excluded from the syntactical perspective, the expressions are also said to be *semantically uninterpreted*. Syntax includes the physical sound symbols, but in science most of the language used is written, and written syntax consists of the visible ink marks on paper. Examples are the sentences of colloquial discourse, the formulas of pure or formal mathematics, the expressions of symbolic logic, and the instruction code in computer languages such as **FORTRAN**, **BASIC**, **C**, or **LISP**.

Syntactical Rules

Syntax is not quite as stark as some ancient inscriptions that are completely undecipherable to a field archeologist, because in addition to the uninterpreted inscriptions, there are rules that pertain to them. These are syntactical rules, and they are of two types: *formation rules and transformation rules*. Typically in the written languages of science the elementary symbols in the syntactical structure of an expression are organized serially and horizontally, and are often called "concatenated strings." However vertical or multidimensional positioning may also be significant in syntactical constructions, as in schematic diagrams or numbers arranged in matrices. Syntactical construction is governed by "*formation rules*", which are expressed in a metalanguage, since they are rules about language.
    Formation rules enable construction of grammatical sentences or well-formed formulas from more elementary syntactical symbols. The native

speaker of a colloquial language can routinely produce grammatical sentences, but the linguist's task of formulating explicit formation rules for a natural language is more difficult. Linguists apply syntactical formation rules to small elements of language such as sound phonemes and the written alphabet. But for the analysis of scientific texts philosophers are content with such elements as words and terms. Artificial languages such as those of mathematics and computer systems are typically more regular, and their rules are less complex than those of colloquial discourse. Grammatically correct expressions in these artificial languages are conventionally called "well formed formulas." When there exists a comprehensive set of formation rules for a language, it becomes possible to develop a type of computer program called a "generative grammar", which can generate grammatically correct expressions or well formed formulas for a language. These computer programs input, process, and output object language, while the coded instructions constituting the computer program are statements in a metalanguage. When a computerized generative grammar is used to produce new scientific theories in an object language for an empirical science, the computer system is called a "*discovery system.*"

Transformation rules change well-formed formulas or grammatical sentences into other such formulas or sentences. For example there are transformation rules for colloquial language that change a declarative sentence into an interrogative sentence. But the discourse of science is expository, and philosophy of science therefore principally considers the declarative sentence in descriptive discourse. Furthermore transformation rules are of greater interest to logicians than to philosophers of science, who are more interested in formation rules for generative grammar discovery systems. Logical inferences are said to be made by transformation rules, but logic rules are intended not only to produce new grammatical sentences but also to guarantee truth transferability from one sentence to another.

Semantics

Semantics is consideration of the meanings associated with syntactical structures, and therefore includes the syntactical perspective. Language viewed in the semantical perspective is said to be a "*semantically interpreted.*" In comparison to syntax the topic of semantics has been more philosophically controversial, and it is in the area of semantics that philosophy of language and philosophy of science have exhibited the greatest amount of change in recent decades. There is now a post-Positivist

view, which has been developed most extensively to date in the contemporary Pragmatist philosophy. And it is also a post-Romanticist view. But for purposes of contrast consider firstly a stereotypically generic version of the traditional Positivist view of semantics.

Traditional Positivist Semantics

On the traditional Positivist view descriptive terms receive their semantics *ostensively* unless they are given their meanings *contextually* by explicit definitions. In the simple case of primitive terms such as "black" the child's ostensive acquisition of meaning was thought to consist of his pointing his finger at an instance of perceived blackness in some black thing such as a raven bird, and then hearing the word "black." A French or German word would presumably have served equally well. There have been various theories about what cognitive processes are involved in this supposedly primitive perception, but the outcome of the process was thought to be the acquisition of primitive sensations or sense data. Most notably the sensation thus acquired is thought to be identical for all persons. And the concept serves as an elementary and atomistic building block for the construction of larger units of language such as sentences. Then from the early experiences that "this raven is black" or "some ravens are black", the learner may acquire more extensive experience with ravens that may occasion the generalized belief that "all ravens are black."

What is fundamental to this traditional view is the naturalistic philosophy of the semantics of language, the thesis that the semantics of descriptive terms is determined by the nature of human perception or other cognitive processes and/or by the nature of the real world itself. Different languages are conventional in their vocabulary symbols and in their syntactical structures and rules, but on the naturalistic thesis nature determines that the semantics is the same for all persons who have had the same kinds of experiences that occasioned their having acquired their semantics by simple ostension. Furthermore the naturalistic semantics of a descriptive term is invariable through time and in different contexts. This *meaning invariance* is a property of terms thought to have only an ostensively acquired semantics.

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The Positivist Analytic–Synthetic Semantical Dichotomy

In addition to the descriptive terms that have primitive and simple semantics, the traditional view also recognized the existence of terms that have complex semantics. A type of sentence called a "definition" reveals the composition in a complex meaning. The defined term or *definiendum* has a compositional semantics that is exhibited by the defining terms or *definiens*. Terms having complex semantics also occur in sentences called "analytical" or just "analytic", while the terms having simple and primitive semantics occur in sentences called "synthetic", thus giving rise to the *analytic-synthetic* distinction. But this difference is not merely a distinction; it also alleges a dichotomous separation between the simple and complex types of descriptive terms. An example of an analytical sentence is "all bachelors are unmarried." The semantics of the term "bachelor" is compositional, because the idea of being unmarried is included as a part of the complex meaning of the idea of bachelorhood due to the definition of "bachelor", thus making the phrase "unmarried bachelor" redundant. A closely related claim traditionally made of the analytic sentence is that it is an *a priori* or self-evident truth, a truth known by reflection on the inclusive relation of the meanings of its constituent terms. Contemporary Pragmatists reject the thesis of *a priori* truth.

The Positivist Theory-Observation Semantical Dichotomy

Another example of compositional semantics is the Positivists' thesis of "*theoretical terms*." Stock examples of theoretical terms found in the natural sciences are terms such as "neutrino" and "prion." The Positivists considered theoretical entities such as neutrinos and prions to be postulated entities as opposed to observed entities. They called terms that reference observed entities and that receive their semantics ostensively "*observation terms*", and they called the sentences containing only such terms "*observation sentences*." They called terms that reference postulated entities and that therefore cannot receive their semantics ostensively "*theoretical terms*." And they called sentences containing any such terms "*theory sentences*" or just "*theories*." They also believe that theoretical terms are meaningless unless these terms receive their semantics from observation terms, because on the nominalists' referential philosophy of meaning, terms purporting nonexistent entities are meaningless. Therefore the Logical Positivists proposed a type of sentence which they called the "*reduction*

sentence", also called "correspondence rule" or "bridge principle", which purportedly enables theoretical terms to derive their semantics deductively from observation terms by the symbolic logic. Both the reduction sentence and the definition exhibit composition in the semantics of their descriptive terms. But while the definition determines the whole meaning of the defined term, the reduction sentence determines only part of the meaning of the theoretical term, because the theoretical term will receive additional meaning as the scientific theory containing it is further developed. The problem of reduction, however, is a problem that the Logical Positivists themselves finally agreed they could never solve, because they could not exclude meaningless theories from those accepted by scientists.

Contemporary Pragmatist Semantics

The development of the contemporary Pragmatist philosophy was occasioned by the development of the modern quantum theory in physics, and it 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 the development of an artifactual thesis that relativizes semantics. The rejection of the naturalistic thesis in philosophy of language is not new to linguistics, but it is as fundamentally opposed to the Positivist philosophy as the rejection of the parallel postulate is to Euclidian geometry. The artifactual thesis of the semantics of language is that semantics of any term is determined in its context of statements believed to be true for any reason. *Three notable consequences of the artifactual thesis are (1) the rejection of the Positivist observation-theory dichotomy, (2) the rejection of the Positivist thesis of meaning invariance for descriptive terms, and (3) the rejection of the Positivist analytic-synthetic dichotomy.*

Rejection of the Positivist Observation-Theory Dichotomy

More than thirty years after Heisenberg, one of the developers of the modern quantum theory, had said that he could "see" the electron in the Wilson cloud chamber, philosophers began to reconsider the concept of observation, an idea that had previously seemed obvious. Today on the Pragmatist view there are no observation terms that receive their meanings by simple ostension. Rather every descriptive term is embedded in a

connecting "web of beliefs", to use a phrase of Quine, which constitutes the context determining the term's meaning. A unilingual dictionary is a listing of a subset of these beliefs for each univocal lexical entry. It is necessary to know much about what the speaker believes about ravens even just to recognize it as a raven, much less perhaps also to view it as some kind of omen. Contrary to the Positivists, observation terms are not uncontaminated by theory context. Furthermore ostension cannot fully determine the semantics of the word "raven" even in its belief context. All descriptive terms have a residual vagueness that can never be completely eliminated, but can be reduced by the addition of clarifying context. The vagueness is a manifestation of the empirical underdetermination of language. *All descriptive language is empirically underdetermined by reality.*

Rejection of Positivist Meaning Invariance Thesis

One of the motivations for the Positivists' maintaining the observation-theory dichotomy is the belief that science offers a kind of knowledge that is permanently valid and true. In the Positivist philosophy it is observation that was presumed to deliver this certitude, while theory is subject to revision sometimes revolutionary in scope. When the observation-theory dichotomy is rejected, the foundation for this permanence crumbles, and the Positivists' observation language becomes subject to semantical change or *meaning variance*. A revolutionary change in theory, such as the replacement of Newton's theory of gravitation with Einstein's, has the effect of changing the semantics of all the language common to both the old and new theories including what the Positivists called observation language.

Rejection of the Positivist Analytic-Synthetic Dichotomy

On the traditional view analytic sentences are those the truth of which could be known *a priori*, i.e. by reflection on the meanings of the constituent descriptive terms, while synthetic sentences require empirical determination of their truth status, and can only be known *a posteriori*. Thus to know the truth status of the analytic sentence "All unmarried men are bachelors" it is unnecessary to take a survey of unmarried men to determine how many men are bachelors, because the meaning of bachelor is determined by the context constituting the definition of bachelor as an

unmarried man. But on the artifactual thesis of the semantics of language all descriptive terms are contextually determined, such that all declarative and universally quantified sentences may be called analytic. Yet their truth status is not thereby known *a priori*, because they are also synthetic. Therefore when any universally quantified declarative sentence is accepted as true, it can be used analytically for a partial analysis of its constituent descriptive subject term. Thus "All ravens are black" is as analytic as "All bachelors are unmarried men", so long as one believes that all ravens are black, because the meaning of "raven" include the idea of blackness, just as the meaning of "bachelor" includes the unmarried state. Normally in science the reason for belief is the empirical adequacy demonstrated by an empirical test such as an experiment. *All universally quantified statements believe to be true are both analytic and synthetic, and can be called "analytical hypotheses."*

Traditional Romanticist Semantics

On the Romanticist view the Positivist semantics is acceptable for the natural sciences, but it is deemed inadequate for research in the cultural sciences of human action. Human action has meaning for the human actors; it is purposeful and motivated for them. Therefore the semantics for the cultural sciences explaining human action is the subjective meaning that the action has for the actor. The researcher's access to and sharing of this meaning requires the aid of introspection, even if its acquisition also involves the actor's overt linguistically expressed reporting. The resulting meaning is called interpretative understanding. In the cultural sciences both the actor's utterances and all his other voluntary actions require interpretative understanding. When applied to linguistic tests, the acquisition of such human understanding is called hermaneutics. The validity of the sharing is based in their shared humanity, and where the researcher lives in the same society or group, it is also based in their shared culture.

Some Romantics deny that interpretative understanding can change. Von Mises, the Austrian economist, maintains that economics is a permanent, a priori, and purely deductive science, which he calls praexology, and which he says is developed entirely from introspectively and intuitively self-evident propositions. But this is a minority view. Many more cultural science researchers admit to cultural change and its constituent meaning change on the part of the actors. And since this meaning change

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can happen in the actors, it can happen in the researchers also, since their practice of cultural science research is also human action. However, the cultural science researchers' examination of cultural change is simply comparative in the sense that it is not a componential semantical analysis.

Semantical Rules

Just as there are syntactical rules, so too there are semantical rules. In the contemporary Pragmatist philosophy of science the semantical rules describe the meaning of a descriptive term by exploiting the analytic-synthetic character of universally quantified statements believed to be true. If it is believed that all ravens are in fact black, then the statement "All ravens are black" is a semantical rule describing part of the meaning of the term "raven." The idea of blackness is a component part of the complex idea of raven, as is revealed by the redundancy in the phrase "black raven."

Semantical rules are statements in a metalanguage, since they are about language. The semantical rules can be expressed in the style of a Tarskian sentence using single quotation marks for object language and double quotation marks for metalanguage. Consider the traditional Tarskian formulation: "'All ravens are black', if and only if all ravens are black." This conditional sentence only expresses the truth condition for the universal affirmation. On the other hand a semantical rule in the Tarskian style would read: "The concept black is a component part of the concept raven, if and only if 'all ravens are black' is believed to be true." Like the universal affirmation, this statement analyzes the composition of the meaning of "raven."

Univocal and Equivocal Terms

The definitions in a unilingual dictionary are semantical rules. Usually each lexical entry in the unilingual dictionary offers several meanings for a descriptive term, because terms are routinely equivocal with several alternative meanings. Even the English language, which has a very large vocabulary, economizes on words by giving each word several different meanings, which are distinguished in context. There is always at least one semantical rule for each univocal use of a descriptive term. The descriptive term is univocal if none of the predicates in the several statements functioning as semantical rules can be related to one another by a

universally quantified negative statement. 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 are parts of different meanings for the term "X", and "X" is equivocal. Otherwise A and B would be different parts of the one meaning complex associated with the univocal term "X." Furthermore some of the structure of the meaning complex associated with the univocal term is revealed if the predicates in the statements can be related to one another in universally quantified affirmations, such that some of the statements in the list form a deductive system. Thus if the predicate terms "A" and "B" in "Every X is A" and "Every X is B" were related in the statement "Every A is B", then one of the statements in the list could be logically derived from another. Awareness of the deductive relationship and the consequent display of structure of the meaning complex associated with the term "X" makes the meaning of "X" more coherent. The dictionary meanings are only minimal descriptions of the meanings of univocal descriptive terms. Such terms may have many semantical rules, when many characteristics apply universally to a given subject term. Thus there are multiple predicates that universally characterize ravens, characteristics which are known to the ornithologist, and which may fill a page of his reference book about birds.

Relativized Semantics

As said above, all the statements believed to be true and predicating characteristics universally of ravens are semantical rules describing the complex meaning of "raven." But if a bird watcher captures a bird specimen that looks like a red raven, 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 a red nonraven bird, or he must decide not to continue to believe "All ravens are black" and that he holds a nonblack raven bird. In either case a semantical change must occur. Because semantics is relativized to a system of beliefs, it has an artifactual nature, which means that a decision is involved. Color could be made a criterion for species identification instead of the ability to interbreed, although many other beliefs would also then be affected in violation of Quine's principle of minimum mutilation of the web of beliefs.

The decision is also ontological. If the decision to reject the belief "All ravens are black" becomes conventional, then the phrase "red raven" becomes a literal description for a type of existing birds. Red ravens

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suddenly populate many trees in the world, however long ago nature had evolved red ravens. But if the decision is to continue to believe "All ravens are black", then there are no red ravens in existence. In that case the phrase "red raven" is a metaphor like "vulpine man", and the reader or listener is left to surmise from context and supply from imagination what the poet might have had in mind by his phrase "red raven." But if the reader-supplied metaphorical meaning later becomes conventional, much less trite, then the metaphor has become a dead metaphor, and "red" becomes at least in part equivocal with a new literal meaning, as with the two literal meanings for "running" in "running title" and "running turtle."

The bird watcher's scientific discovery requires that all the ornithological reference books be updated either to include a new species of red-colored bird or to exclude the characterization that all ravens are black. The availability of the choice is due to the artifactuality of the semantics of language and to the ontology the relativized semantics describes. As it happens, since color is not conventionally definitive of animal species, especially if the birds of different color can interbreed, the books will probably not announce a new species, but instead will note that red ravens have been observed. These semantical and ontological details may seem rather pedantic, if not quite bird-brained, but semantics and ontology have been controversial in science and philosophy. For example in 1905 Einstein's relativity theory changed the semantics of the familiar term "simultaneity" in a way that many of his cohorts in physics had found difficult to accept. And today economists still argue whether or not consumer credit card borrowing limits are money, a decision that is hugely consequential for a banker's legally required minimum reserve requirements. Our linguistic decisions alone neither create nor annihilate reality. But they do change our characterization of it into kinds according to the degree that the current state of our semantics discriminates the sometimes profuse and sometimes paltry manifold of attributes, whereby physical things manifest themselves to us.

Clear and Vague Meaning

Terms are univocal or equivocal; meanings are clear or vague. Clarity is increased for a descriptive term by the addition of universal statements to the list of statements believed to be true and containing it as a common subject term, and also by the addition of universal statements believed true and relating the predicates in the list. The universal statements may be

either affirmative or negative. Affirmative statements offer clarity by adding information and in some cases by exhibiting semantic structure. Negative statements offer clarity by contrast and by exhibiting equivocation. Vagueness remains to the extent that such clarification is lacking. Vagueness can never be eliminated completely, since it is the absence of information, but it is reduced by the addition of universal statements accepted as true. Inevitable vagueness is a manifestation of the empirical underdetermination of language.

Analysis of Semantical Change vs "Holism"

Semantical change was vexing to the contemporary Pragmatists, when they first accepted the artifactual thesis of the semantics of language. When they threw out *a priori* analytic truth they mistakenly also rejected analyticity. And when they accepted the contextual determination of meaning, they mistakenly took an indefinitely large context as the smallest unit of language that can be examined. This context was typically construed either as consisting of a whole explicit theory with no criteria for individuating theories, or even more vaguely as a "paradigm" consisting of a whole theory together with many associated pre-articulate beliefs and tacit skills. This is a wholistic (or "holistic") semantical thesis. On the wholistic view a new theory that succeeds an old theory that has been falsified by empirical testing must completely replace the old theory together with all its observational semantics and ontology. This view is typically associated with the historian of science Thomas Kuhn, who wrote a popular monograph titled *Structure of Scientific Revolutions* in 1962, and also with the philosopher of science, Paul Feyerabend. This wholism creates a problem for the decidability of empirical testing in science, because complete replacement deprives the two theories of any semantical continuity, such that they cannot describe the same phenomena or address the same problem. If a new theory must completely replace an old one, such that there can be no semantical continuity, how can the new theory be said to be an alternative to the old one, much less be a better one?

However, it is not necessary to accept the wholistic view of semantics, because rejection of the analytic-synthetic dichotomy and its *a priori* truth claim do not imply the rejection of analyticity. The contextual determination of meaning implies only that the dichotomy need be rejected, not analyticity as such. As discussed above, universally quantified empirical (i.e. synthetic) statements believed true for any reason are also analytic

statements used as semantical rules for semantical analysis. And the analysis consists of exhibiting the composition and structures of meanings by revealing their component parts. Therefore when a semantical change occurs due to a change in some of the beliefs in the context of a system of beliefs, some parts remain common to both the old and new meanings, while the semantical change consists in dropping some parts and in adding some new ones. The meaning parts that endure through the change from one theory to a later one are those occurring in the statements of empirical test design, which do not change. Furthermore since every predicate term has a semantical rule describing its complexity, the web of beliefs contains elementary components that may be called "semantic values." These semantic values are the smallest distinguished features of the real world that are recognized by the language at the current time. The introduction of new semantic values produces partial semantic incommensurability between old and new descriptive discourse, such that discourse after the introduction of the new semantic values cannot be fully commensurated with the old discourse about the same subject.

Semantical State Descriptions

A state description is a synchronic display consisting of a list of universally quantified statements containing both the currently nonfalsified theories addressing one problem and the test design statements that define the problem. The theories may be nonfalsified because they have not been tested. And the state description may be augmented with falsified theories for new theory development, so that it is a cumulative state description; old theories have scrap value consisting of language that may be recycled. The state description is a semantical description, because the universally quantified statements believed to be true at the given point in time, function as semantical rules exhibiting the component parts of the composite meanings associated with their common univocal descriptive subject terms. Furthermore a state description is for a scientific "profession", which consists of the persons who are attempting to solve the scientific problem. On this definition a profession is a much smaller group than the academicians in the field of the problem, while at the same time it is not restricted to academicians. A diachronic display consists of two state descriptions representing two chronologically successive states sharing a set of common descriptive terms. Both synchronic and diachronic displays are static analyses; the diachronic display enables a comparative static analysis.

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State descriptions are the beginning and ending points for a dynamic analysis, which describes the transition from one state to the next.

Scientific Realism

Academic philosophy has often been a comfortable and remunerative haven from reality. Even more than insane schizophrenics, inane academics need reality checks. In particular pedantic philosophers need be told that there is a real world existing independently of human cognition, and that it is the first object of human cognition. Realism is not a conclusion that can be proved logically either by science or in any other way. But all persons are experientially aware of reality from the awakening of consciousness. That awareness is a primordial *prejudice*. One is reminded of Bertrand Russell's "proof" for realism: after announcing his intent he simply raised his hands. Nothing spoken, but enough said. This awareness grows in sophistication with the acquisition of language including in due course the acquisition of the language of science. The advancement of science is the increasing adequacy of human knowledge of the real world. For the empirical scientist the consciousness of reality becomes astute when theory reveals reality, and acute when reality refutes theory. A falsifying test outcome is no time for Cartesian doubt that the first object of human knowledge is the recalcitrant real world. Such is the basis for scientific realism. *Scientific realism is the thesis that the most critically empirically tested and currently nonfalsified theory, i.e. a scientific law, in science is the most adequate available description of reality.*

Relativized Ontology

Ontology is the third of the metalinguistic perspectives after syntax and semantics. *Ontology pertains to the real world as linguistically characterized. In the context of science the characterizing language has meanings associated with the descriptive terms in empirically tested and nonfalsified universal statements believed true.* When scientific realism is joined with semantics relativized to universally quantified statements believed to be true, the result is the thesis that Quine calls "ontological relativity". Scientific realism pertains indiscriminately to all empirically warranted statements, but ontology is the distinctive characterization of reality claimed by the semantics of an individual statement. It may be added

that no realistic claim is made by what a particular scientific discourse does not describe. Silence is vagueness. As mentioned above, if one maintains the empirically warranted belief expressed in substantive language that all ravens are black, then both raven entities with their black attribute are real, and red ravens are not real. Historically philosophers and scientists believed that they knew very well just what is real however much they disagreed among themselves, and they brought their preconceptions to the criticism of scientific theories. This presumption led them to reject out of hand many new and empirically acceptable theories that did not conform to their ontological preconceptions. Eventually philosophers of science recognized that often the prevailing ontological preconceptions used by scientists to criticize new theories have been nothing more than ontologies described by previously accepted theories. Scientific realism lets the scientists do the ontologizing instead of the philosopher.

Relativized ontology is the thesis that each empirically tested and nonfalsified set of universally quantified statements believed to be true defines its own ontology. It may be added that this applies to the universally quantified language presumed true in order to conduct the empirical tests, because it is empirical language having definitional force. Ontological issues depend on prior decisions about semantical rules, which in turn enable characterization of evidence operative in empirical testing. Subordinating ontological claims to such universally quantified statements believed true due to their empirical warrant is an outcome of the relativistic semantics, because the relativized semantics produces relativized ontology. Quine called this "ontological relativity", although Quine imposed a nominalist ontology due to his acceptance of the Russellian predicate calculus notational conventions.

Relativized ontology effectively makes all referential terms theoretical terms, because it makes all entities posited entities. The referencing of an entity is by means of the descriptive semantics that is described by the universally quantified statements characterizing it and believed true. Thus the relativized semantics makes ontological commitment no less relative whether the postulated entity is an elephant, an electron, or an elf. Beliefs that enable us to make successful predictions routinely are deemed more empirically warranted than those not so warranted, and the entities, properties or any other manifestations of reality postulated in those successfully predicting beliefs are invested with greater ontological commitment than alternatives. It is to those manifestations that are most empirically consequential and about which we have the most characterizing information, to which we make our strongest ontological commitments. If

the postulate of elves enabled us to predict economic fluctuations more accurately and reliably than humans, then we would accept busy elves as real entities, and would busy ourselves about them, as we have done with elephants and electrons for other types of predictable consequences. And when we find our belief in elves to be empirically inconsequential, we reject the reality of elves, as we reject the reality of possessing demons once thought responsible for sickness.

As it happens, "demon" is not part of contemporary ontology, but it could have been otherwise. Just as the meaning of "atom" has evolved since the time of Democritus, the meaning of "demon" might too have evolved to become as beneficial as the modern meaning of "bacterium" – had empirical testing regulated its evolving semantics.   Then today scientists might materialize (i.e. visualize) demons with microscopes, and physicians might write incantations (i.e. prescriptions), so pharmacists might dispense antidemonics (i.e. antibiotics) to exorcise them. But terms such as "materialize", "incantation" and "antidemonics" would have acquired a new semantics in more empirical contexts. As Quine observed in his "Two Dogmas" in 1952, we can preserve our belief in any statement positing anything, if we are willing to make sufficiently drastic redistribution of truth values elsewhere in our web of beliefs – the set of related beliefs that we use as semantical rules to describe our semantics and associated ontologies. And ontologies based on scientific realism are those for which beliefs are regulated by empirical science.

Causality

The ideas of cause and effect are ontological categories, because they are about the real world that exists independently of human cognition, which is not to say independent of human actions in the real world such as measuring. The causal relationship is expressed in the nontruth-functional conditional statement that makes a universal claim that is believed to be true. The causal dependency asserted to exist between what is described by the antecedent and consequent clauses is never proved or permanently established, but its tested and nonfalsified status warrants the belief in the assertion and thus in an ontological commitment. When in the progress of science the theory is falsified, it is made clear thereby that the universality of the claim is not valid, and that a more adequate characterization of the specific causal relation is needed, if it is retained at all.

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Pragmatics and Theory Language

Pragmatics is the fourth and the most inclusive of the metalinguistic perspectives. Pragmatics pertains to the language user's use of his language understood as semantically interpreted syntax and associated ontology. The controlling pragmatics of basic science is described in the statement of the aim of science: *to create explanations by the development and empirical testing of theories that are laws because they are not falsified when tested.* Explanations and laws are accomplished science; theories are work in process at the frontier of development.

Scientific theories are universally quantified semantically interpreted syntactical structures proposed for testing. This is the definition of theory language 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 the Positivist observation-theory dichotomy. The Positivist observation-theory dichotomy is based on the semantical thesis that observation sentences have a naturalistic semantics acquired by observation, and that theory language has no semantics unless and until it is logically related to observation statements with reduction sentences. But when the observation-theory dichotomy falls, so too must the semantical basis for identifying theory language.

Today the contemporary Pragmatists have replaced the semantical basis for identifying theory language with a pragmatic one: theories are hypothetical because they are untested and are proposed for testing. Actually all universally quantified statements are hypothetical in the sense that they cannot be incorrigibly true and beyond revision. But theories are those statements that are selected as relatively more hypothetical and more likely to be revised when testing shows revision is needed. Empirical testing is the pragmatics of theory language in science. After its test outcome is known, the theory is no longer a theory. The test outcome transforms the theory into either a law or a falsified discourse. Furthermore at some later time a law may revert to a theory to be tested again. For about three hundred years Newtonian mechanics had been received as paradigmatic of scientific law in physics. But Newton's theory of gravitation was tested again in the famous Eddington eclipse experiment of 1919, after Einstein had proposed his alternative general relativity theory. For a brief time early in the twentieth century Newton's "theory" was actually a theory again.

The term "theory" is thus ambiguous in contemporary usage. Both the traditional and the pragmatic meanings continue to be used. In the traditional sense we still speak of Newton's "theory" of gravitation. In the

pragmatic sense it is now falsified physics in basic science, although it is still used by engineers whose applied-science purposes can accept its known error. But this knowledge of the error means that Newtonian mechanics is no longer either a hypothesis for testing or our law-based explanation of the physical universe. Hanson recognized this difference between the pragmatic and traditional meanings of "theory" in his distinction between "research science" and "almanac science."

Pragmatic Definition of the Language of Test Design and Observation

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 a prior agreement about the semantics needed to identify the test subject, to set up the test apparatus, to perform the test operations, and to characterize the test's initial conditions and outcome. This is done with the 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*. Both types of language are believed to be true, but for different reasons. Test-design statements are presumed true with definitional force for executing the test, while the advocates of the theory propose the theory statements as true with sufficient plausibility for testing with an expected nonfalsifying outcome. The descriptive terms common to both the test-design statements and the theory statements thus have their semantics determined jointly by both sets of universally quantified statements.

Observation sentences are test-design sentences and test-outcome sentences with their logical quantification changed from universal to particular quantification for executing the test and for reporting its observed outcome. To describe an individual test execution, the test-design statements have their quantification changed from universal to particular, and are then called observation statements for describing the concrete test. This is a pragmatic sense of observation language, because it depends on the use of the language and not on the semantics. Unlike the Positivists the Pragmatists recognize no inherently observational semantics. The statement predicting the test outcome is a statement of the tested theory with its quantification made particular for the individual test. After the test is performed, the statement reporting the test outcome also has particular quantification for the individual test and is observation language. Whether

or not the actual test outcome agrees with the theory's prediction, both the prediction statement and test-outcome statement have the same vocabulary, and their semantics are the same in so far as their descriptive semantics is definable by reference to the universally quantified test-design statements. Herein lies independence of the test from the theory. Herein also lies the semantical continuity throughout the test for each of the terms common to the test design and the theory regardless of the test outcome, because the parts of the complex semantics defined by the test-design statements are unchanged throughout the test. The statement reporting the test outcome is an observation statement describing what was observed in the test execution. But the prediction statement is not as such an observation statement; it is only incidentally an observation statement when the test outcome is nonfalsifying, such that the prediction is the same as the test-outcome statement. All scientists define the semantics of their observation language when they formulate and accept test designs. Feyerabend had hit upon an important historical insight when he said that in defending the Copernican heliocentric theory Galileo had created his own observation language.

Semantic Individuation of Theories

Theory language is defined pragmatically, but theories are individuated semantically. Theories may be individuated in either of two ways. *Firstly different theory expressions are different theories because they address different subjects*. Theory expressions may be different theories, because they are unrelated; their subjects individuate them. Different theory expressions having different test designs are different theories, because the test-design language identifies the subject of the test. *Secondly different theory expressions are different theories because each makes contrary claims about the same subject*, where different claims usually means different predictions. They have different semantics. Occasionally there is more than one theory proposed for empirical testing with the same set of test-design statements. Since the proposals are all universally quantified and are proposed for testing, they are all instances of theory language. While they have the same test-design statements and therefore all address the same subject, they are not the same theory, because they make contrary claims about the same subject.

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Diachronic Comparative Static Semantical Analysis

There has been much confusion due to philosophers' failure to recognize principles for the individuation of theories. Many philosophers state that theories are not falsified by empirical tests, because all theory choice is comparative, and because scientists retain a falsified theory until a better theory is developed and tested with a nonfalsifying outcome. But when it is said that scientists retain a falsified theory, the response of the scientists is not adequately described. What should be said is that when the scientist tries to save the theory by making adjustments to it, he has made a new theory. When the adjustments are not merely *ad hoc*, but are attempts to modify the universal claims of the theory even in relatively minor ways, in order to enable it to survive a previously falsifying test design, then the original theory has been discarded and a new theory developed.

Theories modified to produce improved predictions while retaining the same test design are different theories. If a change of the test-design has the effect of reducing semantical vagueness or measurement error, the outcome of the empirical test with the modified design may or may not be a falsification of the previously tested and nonfalsified theory. But modified test designs that produce improved predictions produce different theories, which in turn results in a new state description. When the universal statements or equations in either the new theory or test design are used as semantical rules for semantical analysis, the change in meaning of the descriptive terms common to both state descriptions are exhibited by comparison between the two successive state descriptions. Universal statements that are the same in both state descriptions exhibit semantical continuity, while those that have changed or replaced exhibit semantical change. As noted above, such comparison is not possible with a wholistic (or "holistic") view of semantics.

Mathematical Language in Science

The stereotypic "All ravens are black" categorical type of statement is not typically the form used explicitly in the object languages of science. The object language of science is more often expressed either in colloquial language or in mathematical language. Colloquial discourse is often implicitly universal with universality intended. In such cases the grammatical form may lack definite articles or quantifiers, and may be without a copula explicitly containing a form of the verb "to be." Colloquial

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language is often called the "informal" language of science. The informal colloquial expressions can be transformed into the categorical form although usually at the expense of awkward style.

A mathematical language for science is an object language for which the syntax is supplied by mathematics. The syntax includes the notational symbols and the formation and transformation rules. Whenever possible the object language of science is mathematical rather than colloquial. This preference is not due to an aesthetic appreciation for deductive elegance. Mathematical syntax is preferred, because measurement quantification of the subject of discourse enables the scientist to quantify the error in his theories, after estimates are made for the measurement errors by repetition of the measurements.

Universal Quantification in Mathematical Language in Science

Mathematical language in science is universally quantified when descriptive variables have semantics but no associated numerical values. It is particularly quantified when numeric values are associated with the descriptive variables either by measurement or by calculation from measurement values. Like the categorical statements, the mathematically well formed formulas, usually equations, are explicitly quantified logically as either universal or particular, even though the explicit indication is not with such logical quantifiers as "every", "all", or "no." Universal quantification is changed to particular quantification in mathematical language, when measurements are made for an ongoing empirical test situation and are associated with the descriptive variables in the equation. When an equation is particularly quantified logically by association with measurement values, it may be said to describe a *numerical measurement instance*. In the case of quantum theory the situation is distinctive by the fact of duality, which means that not all the variables such as those representing momentum and position can have specific values simultaneously. But realizing a value for any one of them makes the logical quantification particular. Quantification is also changed similarly, when numeric values are associated with descriptive variables by computation with the equation and measurement values. When an equation is particularly quantified logically by association with such computed values, it may be said to describe a *numerical empirical instance*, since the referenced instance has not been measured. This occurs when an equation is used to make a quantitative prediction, and the numerical empirical instance is the

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predicted value intended to be compared with a measurement value for the same phenomenon in an empirical test.

Semantics of Mathematical Language in Science

The semantics for a descriptive variable is determined by the context consisting of statements and/or equations believed to be true. The semantics-determining statements include measurement language describing the subject measured and the measurement procedures and any employed apparatus. Like the Positivist "operationalist definitions" the statements setting forth the measurement procedures and apparatus contribute meaning to the descriptive term. But unlike the operationalist definitions, each statement does not constitute a separate definition for the measured subject, thereby making the term equivocal. Instead different measurement procedures contribute different parts to the one univocal meaning of the descriptive term, unless and until the different procedures are found to produce different measurement values, where the differences are greater than estimated measurement error. Semantics for the descriptive variables in the theory is also supplied by the equations of the theory itself, such that the structure of their meaning complexes is in part mathematical.

Ontology of Mathematical Language in Science

In the categorical proposition the quantified subject term references individual instances and also describes the attributes that enable identifying the instances, while the predicate term only describes attributes. In an older vocabulary the same idea is expressed by saying that the subject term has personal supposition, while the predicate has only simple supposition. Both categorical statements and colloquial discourse have been called the "thing language", because the instances referenced are "things" or "instantiated entities." Attributes manifest the things of which they are aspects, and enable classification of the manifested things into kinds. The things thus classified and the attributes thus manifested the ontology of the categorical proposition believed to be true. The ontological claim is made explicit by the term "is" in the copula.

However, the ontological claim made by the mathematical equation is not about instances that are things or entities. *The individual instances referenced by the mathematical equation are numerical measurement*

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instances. The measurement instances are related to thing instances and their attributes by the colloquial statements describing the measured subject, the metric, and the measurement procedures including any apparatus, which typically occur in the test design language.

Aside on the Ontological Issue in Quantum Theory

An ontological issue in modern quantum theory in microphysics is about whether or not microphysical waves and particles are two aspects of the same entity. The affirmative view is called the "duality" thesis. Its advocates cite the de Broglie equation relating both wave and particle properties, and also note that the mathematical expression for the wave function can be transformed into the mathematical expression for the matrix mechanics. One version of the negative view is called the "pilot wave" thesis, which affirms the separate reality of wave and particle, and says that they always found together as exhibited in the Young two-slit experiment. Other versions deny the reality of either the wave or the particle. This ontological issue cannot be resolved by appeal to the mathematically expressed theory, because the mathematics says nothing about entities. It only references numerical measurement instances. Bohm was correct in maintaining that the interpretation issue of the quantum theory is in the informal language of physics, and not in the theory's mathematics. The issue about entities is supplementary to the mathematically expressed and empirically tested quantum theory. This ontological issue has therefore continued for many decades, as each side advocates its preferred informal language and associated ontology to address the question of individual entities. The issue is a variation on the ontological problem of the red raven.

Dynamic Diachronic Metalinguistic Analysis

Turn next to the dynamic diachronic metalinguistic analysis, the examination of the processes of how the language of science changes through time from one language state to a later one. *Language changes in science result from the two basic types of research functions: theory development and theory testing.* The linguistic changes are not merely incidental to the performance of basic research, since the product of basic science is new language consisting of theories hopefully yielding laws and explanations. A change of state description is produced whenever a new

theory is proposed, and whenever a proposed theory is tested by the most critically empirical test that can be applied at the current time. If the test outcome is a falsification, the proposed theory is eliminated from the current state description. When the test outcome is not a falsification a theory has become a new law in the state description.

The Institutionalized Aim of Science

The preceding sections have discussed the archetypal twentieth-century philosophies of science: Romanticism, Positivism, Pragmatism, and Psychologism. And they have also discussed the basic perspectives of language: syntax, semantics, ontology, and pragmatics. Finally consider next the four topics in philosophy of science in the light of these previous discussions beginning with the institutional aim of science.

Issues about the aim of science are the most fundamental, because they profoundly affect all the other topics. And as it happens the literature of philosophy of science offers a variety of proposals for the aim of science. The Positivists had proposed that science should achieve firm foundations either by relying on observation language exclusively or by limiting theoretical terms to those that are related by logical reduction to an observation language serving as a reduction base. Neurath, a proponent of the unity of science agenda, proposed that all sciences including the social sciences aim at logical reduction to physics, which in turn is to be reduced to observation. On the other hand Romantics in the social sciences maintain that the sciences of nature differ fundamentally from the sciences of culture, which are the social sciences. They propose that science aims at vicarious imputation of subjectively based interpretative "understanding", so that an explanation "makes sense" to the social scientist due to his personal experiences as a participant in shared human nature and, when possible, participation in the same culture as the social agents he is studying. Some of them advocate the philosophy of Weber, in which this understanding called "*verstehen*" is not only a source for the requisite mentalistic ontology, but is also a basis for validation. Most fundamentally Romantics who do not altogether reject the aim of prediction and control in cultural sciences, subordinate it to interpretative understanding.

Most of the more recent proposals in academic philosophy of science arise from reflection on episodes in the history of the natural sciences. Popper, reflecting on the development of relativity theory by Einstein, proposed that the aim of science is to produce tested and nonfalsified

theories having greater information content than their predecessors. Kuhn, reflecting on the development of the much earlier Copernican heliocentric theory, proposed that small incremental changes extending the prevailing theory defines the institutionalized aim of science, which he called "normal" science, and that scientists do not consciously aim to produce revolutionary new theories. Feyerabend, reflecting on the development of the quantum theory, proposed that each scientist has his own aim, and that anything institutional is an impediment to science. His philosophy of science is an early variation upon the then-emerging Pragmatist ideas, but it is also a quite idiosyncratic version. Thagard, reflecting on the wave theory of sound and on other more recent developments in natural science, proposed that scientists choose theories that maximize what he calls "explanatory coherence", which he defined in terms of empirical adequacy, breadth of explanation, simplicity of explanation, and analogy with established explanations. He developed his computerized cognitive system **ECHO,** to simulate the realization of this aim in various episodes of theory choice in the history of science.

The contemporary Pragmatist philosophy is now the ascendant view in academic philosophy. It evolved from an examination of the development of quantum theory in physics in the 1920's and from a consequent critique of Positivism. However, the mature articulation of the contemporary Pragmatism did not come to fruition until the early 1970's. Today Pragmatists view modern empirical science as a cultural institution having its distinctive system of views and values. The institutionally regulated activities of research scientists may be described succinctly in a statement of the aim of science, which the contemporary research scientist seeking to maximize his success may employ as what some social scientists call a *rationality postulate*. The Pragmatist rationality postulate for the practice of research in the empirical sciences is the following statement of the aim of science:

> **Scientists aim to construct explanations by developing theories that satisfy the most critically empirical tests that can be applied at the current time. Such satisfactory theories may be called scientific laws.**

This statement is explained by examining the second, third, and fourth topics in philosophy of science as three sequential steps. It can be rephrased to describe the successful achievements in the history of science, so as not to impute motives to scientists whose personal objectives and psychological

experiences often cannot correctly be described in a statement of the conscious aim of science. The statement rephrased in terms of successful outcomes instead of a conscious aim reads as follows:

> **Science achieves explanations by developing theories that satisfy the most critically empirical tests that can be applied at the current time. Such satisfactory theories may be called scientific laws.**

Institutional Change

Change of institutions is different from change within institutions. In the history of science successful researchers in basic science have routinely failed to understand the reasons for their success, and have often formulated or accepted erroneous philosophies of science to explain their successes. One of the most historically notorious such misunderstandings is Newton's "*Hypotheses non fingo*", his denial that his monumental theory of gravitation is a hypothesis. In due course such false practices and beliefs become suspect, as successful developments are achieved in spite of the erroneous proscriptions and prescriptions. As Feyerabend noted in his *Against Method*, successful scientists have often broken prevailing methodological rules. The successful and institutionalized practices of scientific research had firstly to evolve through trial and error before they could be examined, analyzed, and formulated into new philosophies of science. The rationality postulate is therefore a postulate in the sense of a hypothesis, and what is rational today will likely be seen tomorrow as superstition, as both science and philosophy of science continue to evolve. Not surprisingly there exists what may be called a cultural lag between the evolution of science and the development of philosophy of science, since the latter depends on the former. For example over thirty years passed between the development of the modern quantum theory and the consequent emergence of the contemporary Pragmatist philosophy of science. The evolution in science that involves a revision of the rationality postulate amounts to an *institutional change*. Such changes do not occur rapidly or easily, and are usually intergenerational due to the magnitude of the adjustment.

Not only is there a cultural lag between science and philosophy, there are also cultural lags among the several sciences. Philosophers of science have preferred to examine physics and astronomy, because these have been

the most advanced of the sciences since the historic Scientific Revolution, which started with Copernicus. Many other sciences have tended to lag behind physics and astronomy with the social and behavioral sciences farther behind than the natural sciences other than physics and astronomy. The result has been the survival of philosophical superstitions in the lagging sciences, especially to the extent that they have looked to their own less successful histories to formulate their own philosophies of science. For example sociologists and many neoclassical economists continue to use a Romanticist philosophy of science, and believe that cultural sciences or sciences of "human action" are fundamentally different from the natural sciences. In addition, the behaviorist school of psychology continues to use the Positivist philosophy of science. In the contemporary perspective these sciences are institutionally retarded, because they impose prior ontological commitments – either mentalistic or nonmentalistic - as criteria for scientific criticism.

Institutional change in science must be distinguished from change within the prevailing institutional matrix of the aim of science and the criteria for scientific criticism. Philosophy of science is principally concerned with the latter. It has less to say about the former except retrospectively, because institutional change is unique and distinctively historical. Its occurrence can be recognized retrospectively, because it is seen to involve not only a change in formerly accepted explanations in science, but also a change in the prevailing concept of the nature of science itself. Contrary to philosophers such as Kuhn, the existing institutional matrix is not identified with the prevailing scientific explanations. There have been revolutionary developments in science such as Darwin's theory of evolution that had no effect on the institution of basic science, however great the impact Darwin's theory had on the science of biology and on the macrosociety. In fact it is the enduring stability of the institution of science through even dramatic revolutionary changes that makes philosophy of science possible and useful to the practitioner of basic research science.

Scientific Discovery

Recall the distinctively Pragmatist meaning of the term "theory" as universally quantified statements proposed for testing. The topic of scientific discovery is the problem of creating new theories that will pass empirical testing with nonfalsifying outcomes. There have been other ideas about discovery depending on the meaning of "theory." Positivist

philosophers' discussion of this topic consisted of induction, which yields empirical generalizations, and of the human creative processes, which yield theories. But they could offer no explanation as to how scientists create theories. For Positivists the term "theory" refers to sentences containing "theoretical terms", which describe unobserved entities. Such entities can be microphysical particles such as electrons or mental states such as ideas. For Romantic social scientists and philosophers the creative process consists of the imputation of vicariously based ideas and motives that "make sense" to the social scientist because he can recognize them in his personal experience. Thus the social sciences are cultural sciences in which the term "theory" refers to language describing the mental states experienced by the subjects of their social theories. On the contemporary Pragmatist view there is no separate class of vocabulary called "theoretical terms", as the Positivists thought, nor do mental experiences warrant uniquely labeling discourse about it "theory", as the Romantics thought. For the contemporary Pragmatist philosophers "theory" is defined pragmatically instead of semantically; it is any universally quantified discourse proposed for empirical testing. Thus the problem of scientific discovery is essentially that of analyzing and proceduralizing the creation of such statements that are empirically testable and hopefully when tested are not falsified.

As mentioned above both *theory development* and *theory testing* change the state description of the language in the science, and thus offer a dynamic diachronic view. Theory creation introduces new language into the current state description, while falsification eliminates language from the current state description. The most significant work addressing the problem of scientific discovery has been the relatively recent development of computerized discovery systems. These systems, also called "artificial-intelligence" systems, describe the transition from an inputted state description to an outputted one generated by the computer system and representing a later language state. To be useful *every discovery system must contain procedures both for theory creation and for theory selection.* Different computer systems created by different developers implement different strategies in their system designs for the discovering. If the discovery system is a generative grammar, then only the descriptive vocabulary from the initial state description is inputted to the system. But whatever the system design, the input information is from an initial state description, and the output information is the terminal state description. There are issues in the philosophy of science literature as to just what the state descriptions are describing. On the cognitive psychology agenda, the state descriptions represent in individual's psychological state consisting of

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mental representations. On the linguistic analysis agenda, the state descriptions represent the shared semantics of a language-using community constituting a scientific profession. On either interpretation, however, the input state description represents the knowledge available for future discovery, and the output state description is the one or several new theories that constitute the discovered knowledge.

The sources of language for the input state description is crucial for a discovery system. In his *Introduction to Metascience* (1976) Hickey distinguished three types of theory development that are relevant to input language: (1) theory extension, (2) theory elaboration, and (3) theory revision. Firstly theory extension is based on a currently nonfalsified theory that is used to address the scientific problem under investigation. The extension could be a simple addition of statements to make a general theory more specific for a new problem. This process involves minimal change.

Secondly theory elaboration is the correction of a currently falsified theory by the addition of new factors or variables in a manner that changes the theory's predictions while preserving the theory's universal quantification so it is not merely *ad hoc*. The input language consists of factors or variables that represent anything that seems plausible for solving the problem, and the amount of vocabulary inputted to a mechanized discovery system could be large. This theory-development strategy amounts to a fishing expedition in search for a correcting factor or variable.

Thirdly theory revision is essentially a reorganization of the constituent information in existing theories. The source of input for theory revision consists of the descriptive vocabulary from all the currently nonfalsified theories addressing the problem at hand. The nonfalsified theories need not have been tested empirically. Since the problem is unsolved, it does not have any theory that is tested and not falsified. The descriptive vocabulary from recently falsified theories may also be included as inputs to make an accumulative state description. Rejected theories have scrap value. The size of the input state description is relatively small. Yet it must be large enough to supply sufficient information for the development of a new theory. The new theory is typically very different from previous theories. This output is most likely to be called "revolutionary." Hickey's **METAMODEL** system has been used for both theory elaboration and theory revision, often combined in the same input.

The revision can also be the patterning of a proposed solution to the new problem by analogy with an existing explanation. Thagard's reconstruction of the development of the theory of sound waves on analogy with water waves by means of his **PI** system might be taken as an example

of mechanized theory revision. This source of input for analogy, however, is potentially very large, and this strategy has not been used in any mechanized system for developing a contribution to the current state of any science, although there are many examples of the use of analogy in the history of science.

To date discovery systems that have actually produced new theories for a scientific profession have had certain characteristics. Firstly researchers working in their own specialized scientific field of application have developed the effective discovery systems, while neither academic philosophers nor cognitive psychologists have such a track record. Cognitive psychologists have been content to apply their discovery systems to the replication of past episodes in the history of science, rather than apply their systems to the current state of a science and actually produce new theories. Their efforts to date have been like a stage play in perpetual rehearsal with no performance. Secondly the discovery procedures used in the systems are typically described as merely the mechanized automation of theory-developmental practices already used in the scientific field of application. Thirdly the input descriptions contain numerical data, and the mechanized discovery procedures applied to the input data incorporate statistical-analysis procedures. Fourthly and finally the scientific fields of application have been the social sciences. Statistical inference procedures are commonly used in the social sciences to discover relations among data, thus making these sciences obvious opportunities for the first useful discovery systems.

Scientific Criticism

The philosophical discourse on scientific criticism has little to say about the specifics of experimental design. Instead it pertains to the criteria for the acceptance or rejection of theories. The only criterion acknowledged by the contemporary Pragmatists is the empirical test. Whenever in the history of science there has been a conflict between the empirical criterion and any nonempirical criteria for the assessment of new theories, eventually it was always the empirical criterion that governed theory selection. Contemporary Pragmatists accept scientific realism and ontological relativity, and therefore reject all prior ontological criteria and subordinate ontological commitment to empirical criticism.

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The Logic of Testing

The universally quantified statements of the theory in an empirical test can be cast into a conditional proposition in the form "If A, then C." The antecedent clause "A" represents the set of universally quantified statements describing the antecedent conditions, those of the test-design for the test. When the test is executed the logical quantification of "A" is changed to particular quantification to describe the individual test situation, and it is regarded as true, if the test is executed in compliance with its test design. *The empirical test is conclusive only if it is executed in accordance with its test design.*

The consequent clause "C" represents the set of universally quantified statements describing the predicted outcome of the execution of a test. Its logical quantification is changed to particular quantification to describe the predicted outcome of the individual test. Another statement, "O", which also has particular quantification, describes the observed outcome from execution of the test in the same vocabulary that is used in the prediction statement "C." The logic of the test is the nontruth-functional *modus tollens* argument form, according to which the conditional hypothetical statement expressing the theory is falsified if the statements "C" and "O" are not accepted as saying the same thing, i.e. if the prediction is wrong.

The *nontruth-functional* conditional logic implements Popper's falsificationist philosophy of scientific criticism. The conditional statement expressing the tested theory asserts not merely a conjunction, but a *dependency* between the phenomena described by the antecedent and consequent components. This claimed dependency cannot be conclusively established or verified on the basis of the truth-values of the component statements except in the case of falsification. The truth table for the truth-functional Russellian logic therefore is not the logic of empirical testing in science. When the antecedent clause is false, the test is invalid due to a failure to comply with its test design. For purposes of comparison truth-functional and nontruth-functional truth tables appear as follows:

Truth-Functional Truth Table			Nontruth-Functional Truth Table		
A	**B**	**A ⊃ B**	**A**	**B**	**If A, then B.**
T	T	T	T	T	Not Falsified
T	F	F	T	F	Falsified
F	T	T	F	T	Invalid Test
F	F	T	F	F	Invalid Test

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Empirical Decidability and Semantics

The decidability of empirical testing is not absolute. Popper had recognized that the statement reporting the observed test outcome, which he called a "basic statement", requires prior agreement among the cognizant scientists, and that it is not incorrigibly true. Normally the semantics is such that if a test has a nonfalsifying outcome, the semantics is unchanged with the universally quantified statements of both the theory and the test design contributing to the meanings of the terms common to both kinds of statements. But when the outcome is a falsification, there is a semantical change produced for those who accept the outcome as a falsification of the theory. The test-design statements continue to control the semantics of the terms common to the theory and test design by contributing their parts of the meaning complex of each of the common terms. But the parts of the meaning complex contributed by the theory statements are excluded from the semantics of those common terms, at least for those who previously believed in the tested theory but no longer do as a result of the test.

In the event of falsification, there is also a different semantical change produced for those who do not accept the outcome as a falsification of the theory. Such a dissenting scientist has reconsidered either the test-design statements or the report of the test outcome. If he challenges the test outcome, then he has merely questioned whether or not the test was executed in compliance with its agreed test design, and the test may be repeated to answer his challenge to validity.

But if he challenges the test design itself, then he has changed his mind about the test design, and has thereby changed the semantics involved in the test in a fundamental way. The semantical change produced for such a recalcitrant believer in the theory consists in the theory statements controlling the meanings of the terms common to the theory and test-design statements. In that case the parts of the meaning complex contributed by the test-design statements are the parts excluded from the semantics of at least one and probably several of the terms common to the theory and test-design statements. This amounts to attacking the test design as if it were falsified, and letting the theory define the subject of the test – a role reversal in the pragmatics of the test design and theory language, that redefines the problem under investigation. Popper rejects such a response to a test, calling it a content-decreasing stratagem, and he admonishes the scientist to stick to his problem and refrain from criticizing everything. 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, and may take exception

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to a measurement procedure or other aspects of the test design. *Empirical tests are conclusive decision procedures only for the scientists who agree on which language is proposed theory and which language is presumed test-design.*

Empirical Underdetermination

Another factor affecting decidability of empirical testing is the empirical underdetermination of language, with the result that empirical criteria cannot always result in unambiguous theory choice. Mathematically expressed theories use measurement data containing some measurement error, which is a manifestation of empirical underdetermination. Scientists like measurement and mathematically expressed theories, because they can measure the amount of error in the theory. But separating the measurement error from the prediction error made by the equation constituting the theory can be problematic. Repetition of the measurement procedure enables estimation of the degree or range of measurement error. If the prediction made by the equation exhibits an error that is large relative to the estimated measurement error, then the theory is deemed conclusively falsified. Otherwise the theory is either untestable or the test design is inadequate for the theory. If there are several theories yielding prediction errors that are different but small relative to one another, and are also small enough to be within the estimated range of measurement error, then the inescapable empirical underdetermination inherent in language has imposed undecidability in the choice of alternative theories for the given test design. The problem of empirical underdetermination also occurs in the testing of qualitative theories. In such cases the empirical underdetermination is manifested as conceptual vagueness. All concepts have vagueness, which can be reduced but can never be eliminated. *Empirical tests are conclusive to the extent that measurement error and vagueness are small relative to the effect produced in the empirical test.*

Given the dilemma of having several alternative theories that are not falsified by empirical test due to empirical underdetermination, philosophers have proposed nonempirical criteria that may be operative in theory choice. But no such nonempirical criteria enable scientists to predict which alternative nonfalsified theory will make more reliable predictions, when the degree of empirical underdetermination is reduced by improved observation practices or test designs. And when scientists are confronted by such dilemmas, better observation practices with test designs having added

clarifying information or more accurate measurements are in order. The existence of several alternative theories that have survived an empirical test without having been falsified is thus endemic to science. In the social sciences that use statistical techniques for testing this is a common outcome, but it also happens in natural sciences. Einstein had described this situation in physics as an "embarrassment of riches." The resulting multiple explanations are equally scientific. Different scientists may have distinctive reasons, such as aesthetic, circumstantial, or strategic reasons, for preferring one alternative explanation to another. Thagard has noted three such criteria implemented in his **ECHO** system, his artificial-intelligence system specifically for theory selection. He finds that the most important criterion is breadth of explanation, followed by simplicity of explanation, and finally analogy with previously accepted theories. Where the empirical criteria are not decisive, theory selection becomes more of a professional career decision for the scientist rather than a purely scientific one. For example knowing what a profession currently likes to see in new theories helps getting a paper published in the refereed literature. Thagard considers these selection criteria to operate as inference to the "best" explanation. But contemporary Pragmatists are inclined to exclude all such nonempirical criteria from the aim of science, because while relevant to persuasion, they are irrelevant to evidence. They are like the psychological criteria that trial lawyers use to select and address juries in order to win lawsuits, but have nothing to do with courtroom evidence rules.

Scientific Pluralism

Language is always empirically underdetermined by the real world, such that there is always the possibility of the development of a new theory that is empirically equal to or superior to currently accepted explanations of the same subject. This empirical underdetermination may be due to errors of measurement or to the residual vagueness always present in descriptive variables and terms, and it is often reduced by development of more adequate observation practices and technologies for test designs. The undecidability of the resulting empirically adequate multiplicity of scientific explanations is recognized by the Pragmatist thesis of "scientific pluralism." *Scientific pluralism is the undecidability among alternative laws and consequently explanations due to the empirical underdetermination of language.*

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Nonempirical Linguistic Constraints

The constraint imposed by empirical test outcomes, the empirical constraint, is an institutionalized cultural value that is not viewed as an obstacle to be overcome, but rather is a condition to be respected for the advancement of science. There are other constraints that are viewed as impediments that must be overcome for the advancement of science. Some of these impediments are purely circumstantial. They may be sociological, dogmatic, financial, political or academic. These impediments are external to science. There are two other nonempirical constraints that are internal to science in the sense that they are inherent in the nature of language. They are *the cognition constraint and the communication constraint.*

The cognition constraint inhibits a theorist's ability to construct new theories, and it is manifested as what is often mundanely referred to as lack of imagination. Semantical rules are not just rules; they are also linguistic habits that enable fluency in both thought and speech. The rules are such that the meaning of a descriptive subject term is determined by the set of universally quantified statements believed to be true. Thus given the belief in certain universally quantified statements, the meanings of their constituent descriptive terms are determined. Conversely given the established meaning of a descriptive term, certain conventions and beliefs are sustained, with the result that change of belief is made difficult by the need to change linguistic habits. Accordingly the more revolutionary the revision of beliefs, the greater the impeding force of the cognition constraint imposed by psychological habit. And if a new syntax is required such as an unfamiliar mathematics, then the semantical restructuring of the affected meaning complexes is even greater. This follows from the relativistic semantics, which is opposed to the thesis that language is neutral in the sense of being merely a passive instrument for thought. It is noteworthy that the use of discovery systems circumvents this problem, because the machines have no linguistic habits; they mechanically apply a generative grammar to inputted linguistic symbols.

The communication constraint is similar to the cognition constrain; it is merely the impediment to understanding a new theory relative to those currently known due to prevailing linguistic habits. The scientist must learn the new theory well enough to restructure the composite meaning complexes associated with the descriptive terms common to both the old theories he already knows and new theory to which he had recently been exposed. And it may be noted that the scientist viewing the computerized discovery system

output experiences the same communication impediment with the machine that he would have were the outputted theories developed by a fellow human scientist.

If the differences between the old and new theories are very great, some members of the affected scientific profession are unwilling or unable to accomplish the learning adjustment required, and they become the rear guard defending the older conventional wisdom. In the meanwhile the developers and advocates of the new theory, who have mastered the new theory's semantics, assume the role of the *avant garde* until the new theory's acceptance has become sufficiently widespread that it has become the new conventional wisdom appearing in the textbooks. This is the conversion process described by Kuhn in revolutionary transitional episodes. However, contrary to Kuhn the transition does not involve a complete semantical discontinuity. Rather involves an extensive restructuring of the new theory's semantical description of the domain common to both old and new theories as described by the semantics in their shared test design statements.

Scientific Explanation

Whether viewed heuristically or historically the ultimate aim of basic science is the production of explanations. One of the most obvious characteristics of an explanation is that it consists of language. Thus it may be said that basic science produces a linguistic artifact. This is what distinguishes basic or pure science from applied science and technology. Applied science and technology produce nonlinguistic real products, such as engineered buildings, medical clinical therapies, and social policies affecting human activities. So long as a tested theory has not been falsified, it is accepted as a scientific law, which may occur in an explanation. Thus in the contemporary Pragmatist philosophy of science "explanation" is defined as follows: *An explanation is a deduction containing one or several scientific law statements concluding to statements describing particular events or to universal statements.* Laws and theories are distinguished pragmatically. *A law statement is a former theory that has been tested by the most critical test design currently possible and is not yet falsified by the executed empirical tests.*

The statements or equations of an explanation, like those of a theory, are law statements that are universally quantified logically. And the litmus test of the law's universal claim is the prediction of future events or of currently unavailable evidence for past events in an explanation. Prediction

is the guarantee that the law is not *ad hoc* to its development sample. Furthermore a motivating and social justification, which is external to basic science, is the control that is often yielded by basic science's power of prediction. Such control enables applied science and technology, which fundamentally distinguishes applied science from basic research science.

Summary

This introduction started with discussion of four types of philosophy of science – Romanticism, Positivism, contemporary Pragmatism, and psychologistic computational philosophy of science. It then took up philosophy of language – syntax, semantics, ontology, and pragmatics. And it finally considered the four topical areas of philosophy of science – the aim of science, discovery, criticism, and explanation. To facilitate an integrated understanding of these three discussions, the following recapitulation picks up the stick from the other end, as it were, and structures the whole discussion around the four topical areas.

Aim of Science:

On the Romantic philosophy the natural and cultural sciences have different aims. Romanticists do not object to the Positivist view of the aim of the natural sciences. In fact it supplies Romantics with a stereotypic misunderstanding of natural science. But Romantics maintain that the aim of the cultural sciences of human action consists of interpretative understanding in terms of the conscious views, values, norms and motives of human subjects. Thus they require a mentalistic ontology for the cultural sciences. And they also deny that explanation in cultural science aims at prediction and control.

On the Positivist philosophy the natural and social/behavioral sciences have the same aim. That aim is to enable prediction and ideally control of phenomena by means of language either expressing or founded upon direct observation. Positivists reject a nonobservable mentalistic ontology for social sciences.

On the contemporary Pragmatist philosophy the aim of science is explanation that enables prediction and ideally control of the real world. Like the Positivists they maintain the aim of science is the same for all sciences, but unlike the Positivists and the Romantics they reject commitment to any ontology prior to empirical testing, whether mentalistic

or nonmentalistic. Pragmatists permit but do not require mentalistic or nonmentalistic ontologies.

On the cognitive psychology view the aim of science is whatever they find in history; they do not characterize it. Philosophically they are eclectic. They reject Behaviorism, which is Positivism in psychology, yet they distinguish observation terms, as those that are inputted to the system, from theoretical terms, as those that are generated and outputted by the system. Like the Romantics they view the subject of their psychological investigations as mental representations, but contrary to the Romantics they equate human concepts to the data structures in their computer systems. And unlike Positivists they are not nominalist. Within these parameters they select criteria for scientific criticism according to what is needed for their systems to replicate the particular historical episodes that they simulate mechanically.

Discovery:

The Romantics' concept of scientific discovery for cultural science is based on their concept of scientific theory, which they define in terms of the mental states experienced by the social actors whose actions they investigate. Acquiring this kind of knowledge is believed to require introspection by the researcher. The Romantics therefore deny that social theory can be developed exclusively by analysis of empirically acquired social statistics, and they have a Luddite attitude toward computational theory development with mechanized discovery systems.

The Positivist' concept of scientific theory is also distinctive. They dichotomize observation language and theory language. The latter contains descriptive terms referencing entities that have never been observed, and thus given their nominalism they presume that theory language is not meaningful until reductively related to the observation language. Discoveries expressible exclusively with observation terms are called empirical generalizations. Generalizations are the product of induction resulting from recognition of similarities in repeated direct observations. The Positivists offer no explanation for the discovery of theories except to note that theories are free creations of the imagination and are not generalizations based in observation.

The contemporary Pragmatists' concept of theory differs from both the Romantics' and the Positivists' concept, because the Pragmatists reject associating theory with any prior ontology. They define theory functionally as any universally quantified discourse proposed for testing. This concept

lends itself to computer processing, since any output from the discovery system is considered to be theory proposed for further empirical testing.

Finally the cognitive psychologists' principal concern is with the development of computerized systems, with the objective of characterizing, proceduralizing and mechanizing the psychology of the discovery process.

Criticism:

The Romantics require as a criterion for scientific criticism in cultural sciences, that the language describe a mentalistic ontology. Language that does not conform to this prior ontological criterion is rejected out of hand as "atheoretical" and as unsuitable for cultural science notwithstanding valid empirical findings. Some Romantics furthermore require Weber's *verstehen* criterion that the theory be empathetically or vicariously plausible in the personal experience of the researcher. Such theories are said to "make sense."

The Positivists maintain that empirical generalizations are always provisional, and must be tested empirically. The early Positivists such as Mach viewed theories as temporary expedients relegated to less than scientific status, to be replaced later by empirical generalizations based on direct observations as science progressed. The later Positivists such as Carnap were more accepting of theories, but conditioned the acceptance of theories not only on the confirming outcome of scientists' empirical test, but also conditioned the theory's meaningfulness on the philosophers' logical reduction to an observation language.

The contemporary Pragmatists give absolute authority to the outcome of empirical testing as the criterion for theory acceptance and selection, so long as the observed effect is large enough to be distinguishable from error due to the empirical underdetermination of language. They view falsification as conclusive. They deny that an empirical test outcome can establish a theory, but they accept nonfalsification as warranting belief in the theory's ontological claims. The empirical underdetermination manifested by measurement error or conceptual vagueness results in undecidability, such that more than one theory may be empirically nonfalsified. This scientific pluralism permits the scientists to choose among the alternative tested and nonfalsified theories on the basis of other criteria, such as simplicity or familiarity.

Cognitive psychology will consider any criteria for scientific criticism that their cognitive systems can successfully use to simulate historical episodes in the progress of science. These have included empirical

adequacy, breadth of explanation, simplicity of explanation, and analogy with established explanations.

Explanation:

The above mentioned considerations flow through to the topic of scientific explanation. For the Romantics explanation in cultural science is interpretative understanding. Knowing the social actors' misunderstanding is deemed more important than connecting their intentional action to its unintended consequences. Romantic explanation is discourse having the required mentalistic ontology.

The Positivists on the other hand are committed to an observational ontology traditionally called phenomena, sense data, or sensations. They typically reject the mentalistic ontology of the Romantics. On their philosophy scientific laws are either empirical generalizations containing only observation terms, or they are theories confirmed by empirical testing and found meaningful, because their theoretical terms have been logically related to a suitable observation-language reduction basis.

The contemporary Pragmatists define scientific law as language that was formerly theory, because it has been empirically tested and has not yet been falsified. And since nonfalsification warrants belief, the law and the explanations in which it is used describes its own ontology.

The cognitive psychologists view an explanation as either the output of a cognitive discovery system or a primitive term in a theory-selection system, which is applied to a problem in basic research science. Cognitive psychologists construe an explanation as a conceptual representation.