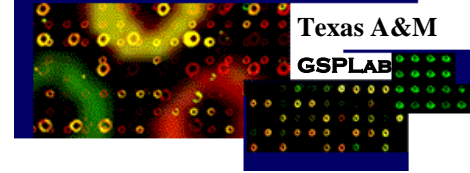


Scientific Epistemology: Knowledge Grounded on Phenomena

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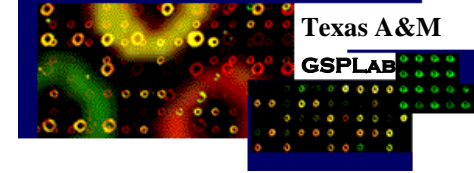
With Permission From My Mentor and Friend: Edward R. Dougherty
Department of Electrical and Computer Engineering
Center for Bioinformatics and Genomic Systems Engineering
Texas A&M University



Hume on the Nature of Causality

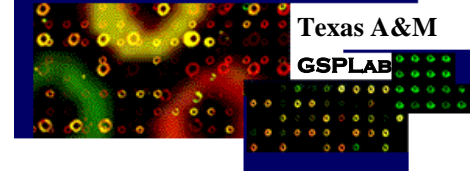
- **David Hume** (*Enquiry Concerning Human Understanding*, 1748): “When one particular species of events has always, in all instances, been conjoined with another, we make no longer any scruple of foretelling one upon the appearance of the other.... We then call one object, Cause; and the other, Effect. We suppose that there is some connexion between them; some power in the one, by which it infallibly produces the other, and operates with the greatest certainty and strongest necessity.”





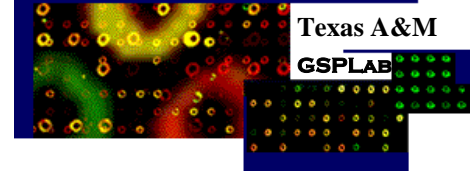
Causality and Understanding

- **David Hume:** “After a repetition of similar instances, the mind is carried by habit, upon the appearance of one event, to expect its usual attendant, and to believe that it will exist. This connexion, therefore, which we *feel* in the mind, this customary transition of the imagination from one object to its usual attendant, is the sentiment or impression from which we form the idea of power or necessary connexion. Nothing farther is in the case.”
 - No necessary connection can be concluded, no matter how often we observe events to be conjoined.
 - Induction cannot yield scientific theory.



Hume Demolishes Aristotelian Epistemology

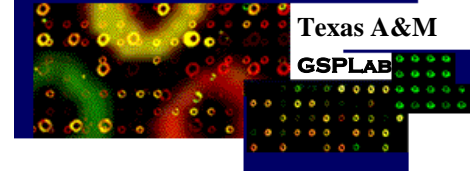
- **David Hume:** “If there be any relation among objects which it imports to us to know perfectly, it is that of cause and effect....The only immediate utility of all sciences is to teach us, how to control and regulate future events by their causes. Our thoughts and enquiries are, therefore, every moment, employed about this relation: Yet so imperfect are the ideas which we form concerning it, that it is impossible to give any just definition of cause, except what is drawn from something extraneous and foreign to it.
 - If the causality is the underpinning of science, then science has no ground of truth.



Hume Announces Modernity

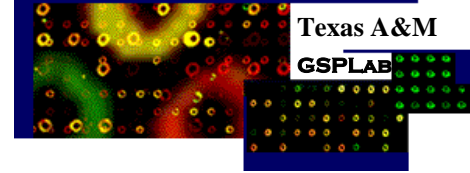
- **David Hume** (*Enquiry*): In reality, all arguments from experience are founded on the similarity which we discover among natural objects, and by which we are induced to expect effects similar to those which we have found to follow from such objects.... From causes which appear *similar* we expect similar effects. This is the sum of all our experimental conclusions.
 - Although he uses the word “causes,” there is expectation, not causality, so he really means “conditions,” – and modernity appears.





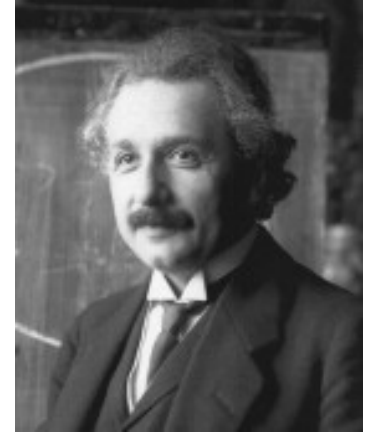
Hume on Natural Selection

- **David Hume** (*Philo*): “Every part of each form must be related to each other part of it and to the whole form; and the whole form itself must be related to the other parts of the universe — ... to every other form which is hostile or friendly towards it. A defect in any of those respects — as when...a heron becomes unable to escape hawks or to capture fish — destroys the form.... A chaos ensues, until through countless (though not infinitely) many re-arrangements there come to be, yet again, some forms whose parts and organs are so adjusted that they enable the forms to stay in existence while the matter in them continually changes.



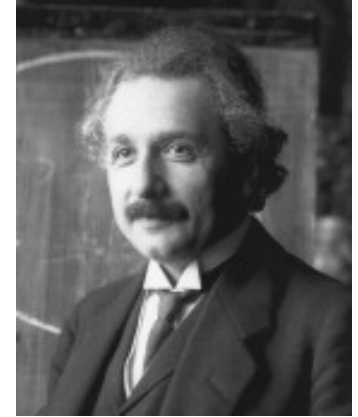
A Crushing Message

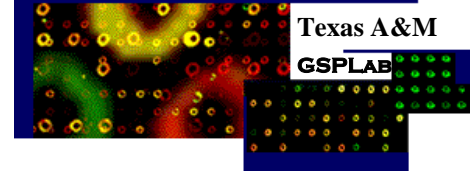
- **Albert Einstein:** “Man has an intense desire for assured knowledge. That is why Hume's clear message seems crushing: the sensory raw material, the only source of our knowledge, through habit may lead us to belief and expectation but not to the knowledge and still less to the understanding of lawful relations.”



Permanent Influence

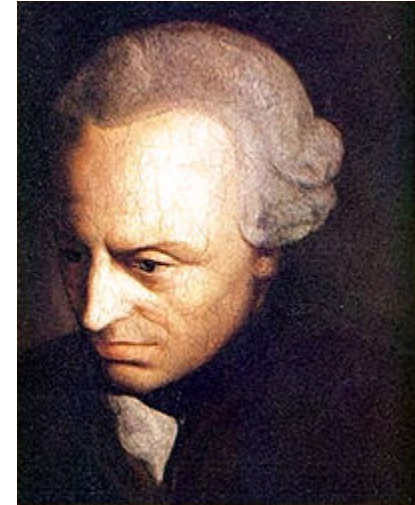
- **Albert Einstein:** “Hume saw that concepts which we must regard as essential, such as, for example, causal connection, cannot be gained from material given to us by the senses. This insight led him to a skeptical attitude as concerns knowledge of any kind. If one reads Hume's books, one is amazed that many and sometimes even highly esteemed philosophers after him have been able to write so much obscure stuff and even find grateful readers for it. Hume has permanently influenced the development of the best philosophers who came after him.”

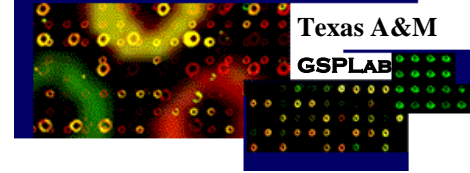




Kant: Understanding Imposes Causality

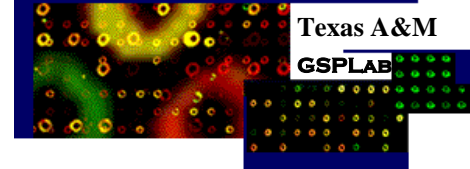
- **Immanuel Kant** (*Critique of Pure Reason*, 1786)
- Nature is experienced through the senses and concepts are formed from sensation via the categories of understanding.
 - We have knowledge of the *phenomena* (concepts of the understanding) but not of the *noumena* (the thing in itself).
 - The categories of understanding impose themselves on our perceptions so that Nature, as we see it, must conform to the categories.
 - Causality is imposed upon the phenomena in order that they be phenomena.





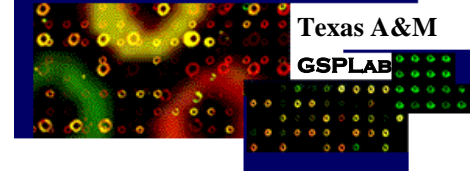
Limitation of Reason

- Reason is limited by the categories and the categories are applicable only to the phenomena.
 - Proofs of the existence of God are out – to wit, a conclusion regarding a first cause would have to apply the category of causality outside the phenomena and therefore is fallacious
 - But proofs about God's nonexistence are also out
 - Hume's attack on causality is circumvented because science is not about the noumena; it is about the phenomena, and there causality is imposed by the understanding
- Metaphysics is possible because its subject matter consists of the categories themselves. Mind can study mind, insofar as the categories are concerned.



Experimental Design: The Path of Progress

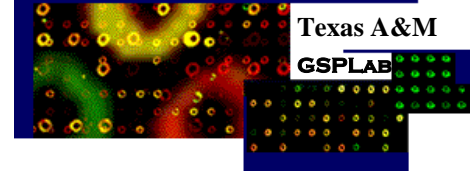
- **Immanuel Kant** (*Critique of Pure Reason*): It is only when experiment is directed by rational principles that it can have any real utility. Reason must approach nature with the view, indeed, of receiving information from it, not, however, in the character of a pupil, who listens to all that his master chooses to tell him, but in that of a judge, who compels the witnesses to reply to those questions which he himself thinks fit to propose. To this single idea must the revolution be ascribed, by which, after *groping in the dark* for so many centuries, natural science was at length conducted into the path of certain progress.



Transformation of Human Reason

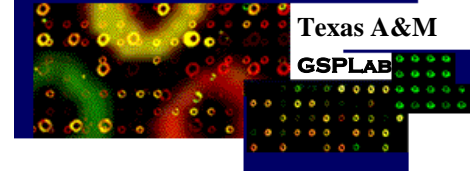
- **William Barrett (*Illusion of Technique*):**
“Kant...has more than a century of the new science to reflect upon, and he is the first philosopher to understand what has happened. The whole of his *Critique of Pure Reason* is not primarily an attempt to set up a system of idealistic philosophy; it is the effort, stubborn and profound, to grasp the meaning of the new science and its consequences for human understanding generally....What has happened is nothing less than the transformation of human reason itself.”





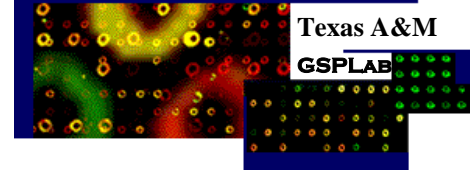
Reason Becomes ‘Legislative of Experience’

- **William Barrett** (*Illusion of Technique*): “What does Galileo do? He does not turn to the ‘irreducible and stubborn’ facts; rather, he sets up a concept [inertia] that can never be realized in actual fact.... Rationalism does not surrender here to the brute facts. Rather, it sets itself over the facts in their haphazard sequence; it takes the audacious step of positing conditions contrary to fact, and it proceeds to measure the facts in the light of these contrafactual conditions. Reason becomes ‘legislative of experience’ – this was the decisive point that Kant’s genius perceived as the real revolution of the new science.”



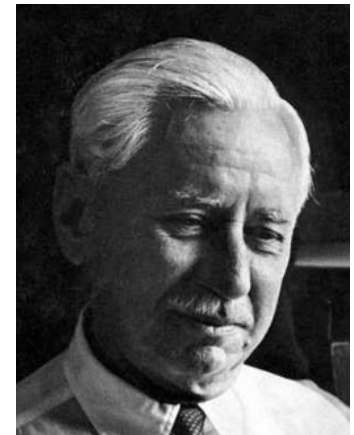
Kant on the Argument from Design

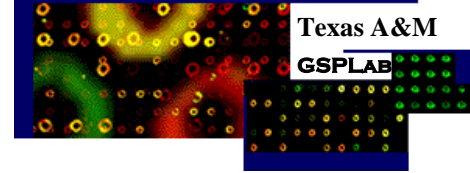
- **Immanuel Kant** (*Critique of Practical Reason*): “I see before me order and design in nature, and need not resort to speculation to assure myself of their reality, but to explain them I have to presuppose a Deity as their cause; and then since the inference from an effect to a definite cause is always uncertain and doubtful, especially to a cause so precise and so perfectly defined as we have to conceive in God, hence the highest degree of certainty to which this pre-supposition can be brought is that it is the most rational opinion for us men.”
 - The argument from design is not part of science. Nonetheless, Kant can accept the argument via reason in its speculative role.



Will Durant: The Ten Greatest Minds

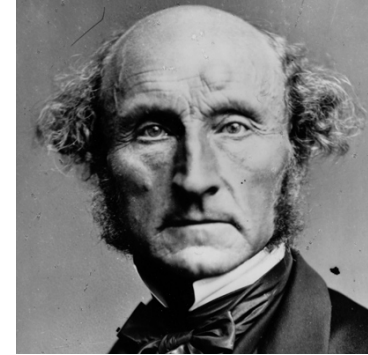
- **Will Durant:** “We shall seek for those men who by their thinking, rather than by their action or their passion, have most influenced mankind.
- The list:
 - Confucius
 - Plato
 - Aristotle
 - Thomas Aquinas
 - Copernicus
 - Francis Bacon
 - Isaac Newton
 - Voltaire
 - Immanuel Kant
 - Charles Darwin

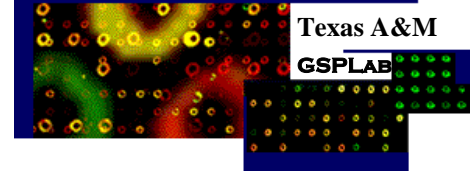




Mill on Causality

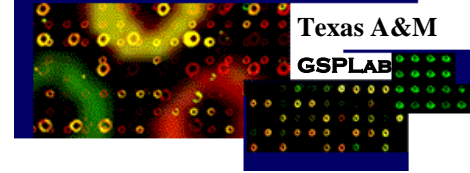
- **John Stewart Mill** (*A System of Logic, Ratiocinative and Inductive*, 1843): “The Law of Causation, the recognition of which is the main pillar of inductive science, is but the familiar truth that invariability of succession is found by observation to obtain between every fact in nature and some other fact which has preceded it, independently of all considerations respecting the ultimate mode of production of phenomena.”
 - Causality is nothing but invariable temporal succession.





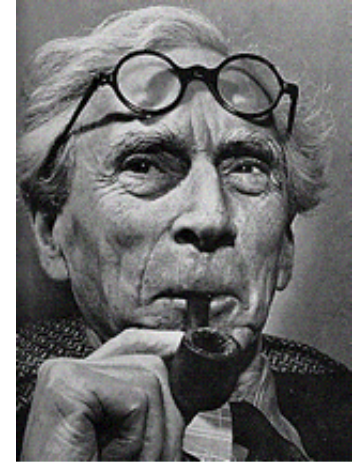
Knowing All of the Antecedents

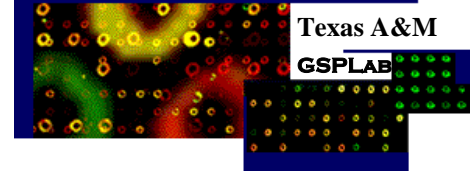
- **John Stewart Mill:** “The state of the whole universe at any instant, we believe to be the consequence of its state at the previous instant; insomuch that one who knew all the agents which exist as the present moment, their locations in space, and all of their properties, in other words, the laws of their agency, could predict the whole subsequent history of the universe, at least unless some new volition of a power capable of controlling the universe should supervene.”
 - An appeal to Laplace’s super intelligence – just as vacuous.



Russell on Causality

- **Bertrand Russell** (*On the Notion of Cause*, 1913): “The principle ‘same cause, same effect,’ which philosophers imagine to be vital to science, is therefore utterly otiose. As soon as the antecedents have been given sufficiently fully to enable the consequent to be calculated with some exactitude, the antecedents have become so complicated that it is very unlikely they will ever recur. Hence, if this were the principle involved, science would remain utterly sterile.”





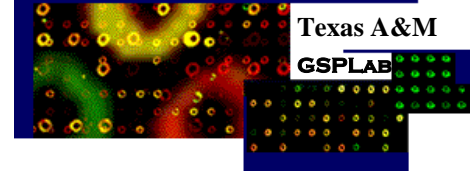
Causality Is Not Part of Scientific Theory

- **Bertrand Russell:** “In the motions of mutually gravitating bodies, there is nothing that can be called a cause, and nothing that can be called an effect; there is merely a formula. Certain differential equations can be found, which hold at every instant for every particle of the system, and which, given the configuration and velocities at one instant, or the configurations at two instants, render the configuration at any other earlier or later instant theoretically calculable....But there is nothing that could be properly called ‘cause’ and nothing that could be properly called ‘effect’ in such a system.”

Schrodinger on Causality

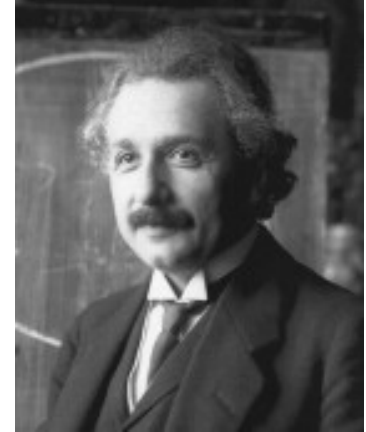
- **Erwin Schrodinger:** “It can never be decided experimentally whether causality in Nature is ‘true’ or ‘untrue.’ The relation of cause and effect, as Hume pointed out long ago, is not something that we find in Nature but is rather a characteristic of the way in which we regard Nature.”
 - Russell and Schrodinger follow in the wake of Hume’s criticism of causality as being neither logically nor empirically grounded.

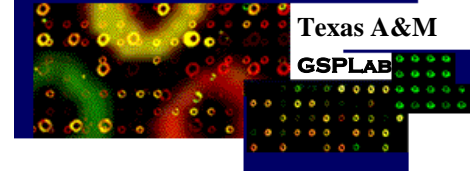




Einstein on Causality

- **Albert Einstein:** “I can, if the worst comes to the worst, still realize that the Good Lord may have created a world in which there are no natural laws. In short, a chaos. But that there should be statistical laws with definite solutions, e.g., laws which compel the Good Lord to throw dice in each individual case, I find highly disagreeable.”
 - Recall Windelband: “The highest principles for explaining the universe, and the general view of the universe based on these principles, form the problems of *metaphysics*.”

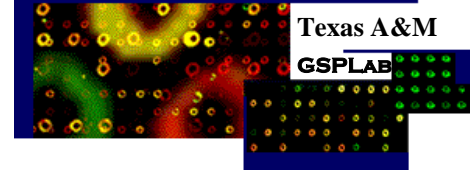




Constitution of Scientific Knowledge

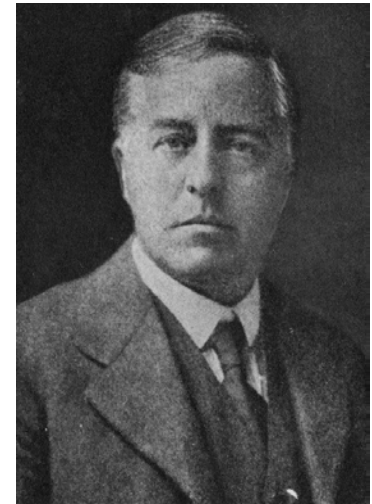
- **James Jeans** (*Mysterious Universe*): “The final truth about phenomena resides in the mathematical description of it; so long as there is no imperfection in this, our knowledge is complete. We go beyond the mathematical formula at our own risk; we may find a [nonmathematical] model or picture which helps us to understand it, but we have no right to expect this, and our failure to find such a model or picture need not indicate that either our reasoning or our knowledge is at fault.”

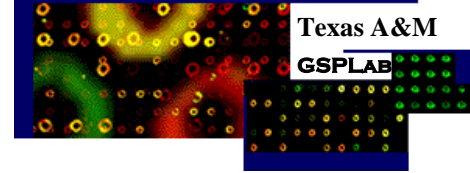




Scientific Knowledge \neq Everyday Knowledge

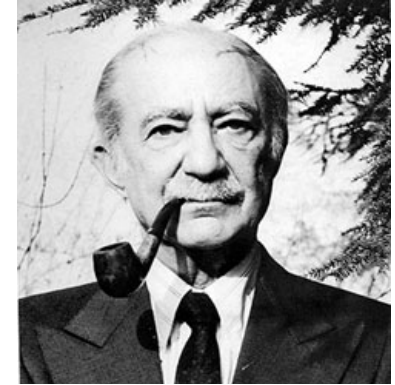
- **James Jeans:** “A mathematical formula can never tell us what a thing is, but only how it behaves; it can only specify an object through its properties. And these are unlikely to coincide *in toto* with the properties of any single macroscopic object of our everyday life.... We need no longer discuss whether light consists of particles or waves; we know all there is to be known about it if we have found a mathematical formula which accurately describes its behavior, and we can think of it as either particles or waves according to our mood and the convenience of the moment.”

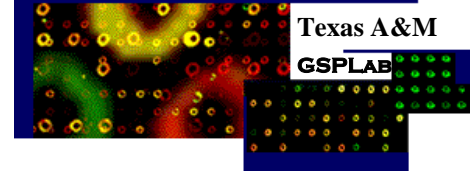




The Sacrifice of Intelligibility

- **Morris Kline:** “The insurgent seventeenth century found a qualitative world whose study was aided by mathematical abstractions. It bequeathed a mathematical, quantitative world that subsumed under its mathematical laws the concreteness of the physical world... What science has done, then, is to sacrifice physical intelligibility for the sake of mathematical description and mathematical prediction... Our mental constructions have outrun our intuitive and sense perceptions.”

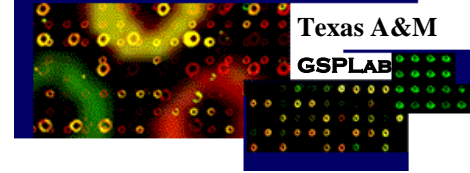




Going Beyond Everyday Language

- **Hannah Arendt** (*Between Past and Future*):
“Man can *do*, and successfully do, what he cannot comprehend and cannot express in everyday human language.”
- **Hannah Arendt**: “What defies description in terms of the “prejudices” of the human mind defies description in every conceivable way of human language; it can no longer be described at all, and it is being expressed, but not described, in mathematical processes.

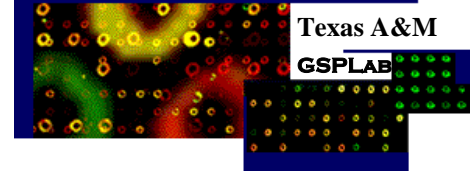




Objective Reality

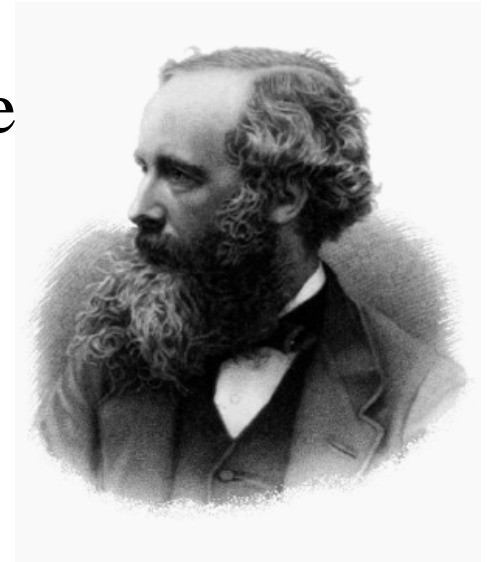
- **Henri Poincare:** “Does the harmony which human intelligence thinks it discovers in Nature exist apart from such intelligence? Assuredly no.... What we call `objective reality' is, strictly speaking, that which is common to several thinking beings and might be common to all; this common part, we shall see, can only be the harmony expressed by mathematical laws.”





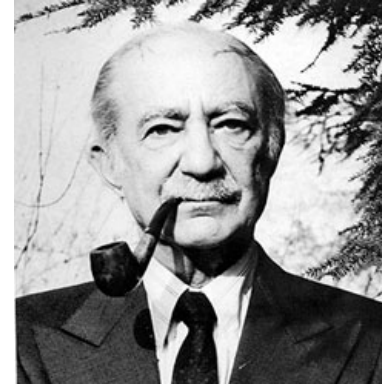
Maxwell's Regret

- **James Clerk Maxwell:** “If the results of mere speculation which I have collected are found to be of any use to experimental philosophers, in arranging and interpreting their results, they will have served their purpose, and a mature theory, in which physical facts will be physically explained, will be formed by those who by interrogating Nature herself can obtain the only true solution of the questions which the mathematical theory suggests.”



We Do Not Know

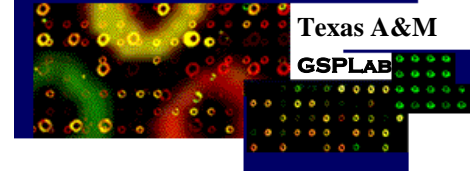
- **Morris Kline:** “We do not have any physical account of the knowledge of the electromagnetic waves as waves. Only when we introduce conductors such as radio antennae in electromagnetic fields do we obtain any evidence that those fields exist. Yet we send radio waves bearing complex messages thousands of miles. Just what substance travels through space we do not know.”



Observational Limitations

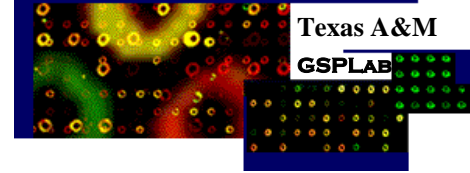
- **Uncertainty Principle:** The position and velocity of a particle are related in such a way that determining one of them with increased precision necessarily entails determining the other one with reduced precision.
- **Werner Heisenberg:** “We decide, by our selection of the type of observation employed, which aspects of nature are to be determined and which are to be blurred.”





Models Depend on Questions Asked

- **Werner Heisenberg:** “The most important new result of nuclear physics was the recognition of the possibility of applying quite different types of natural laws, without contradiction, to one and the same physical event. This is due to the fact that within a system of laws which are based on certain fundamental ideas only certain quite definite ways of asking questions make sense, and thus, that such a system is separated from others which allow different questions to be put.”



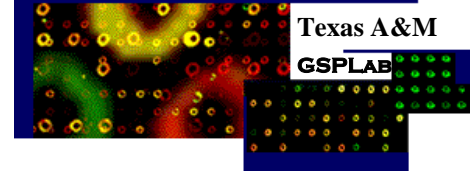
Free Creations of the Human Mind

- **Albert Einstein:** “Physical concepts are free creations of the human mind, and are not, however they may seem, uniquely determined by the external world. In our endeavor to understand reality we are somewhat like a man trying to understand the mechanism of a closed watch. He sees the face and the moving hands, even hears its ticking, but he has no way to open the case. If he is ingenious he may form some picture of a mechanism which could be responsible for all of the things he observes, but he may never be quite sure his picture is the only one which could explain his observations. He will never be able to compare his picture with the real mechanism and he cannot even imagine the possibility or the meaning of such a comparison.”

Elimination of Inherent Categories

- **Hannah Arendt:** “To understand physical reality seems to demand not only the renunciation of an anthropocentric or geocentric world view, but also a radical elimination of all anthropomorphic elements and principles, as they arise either from the world given to the five senses or from the categories inherent in the human mind.”
 - Bacon’s *Idols of the tribe*: “All perceptions, of both the senses and the mind, bear reference to man and not to the universe.”

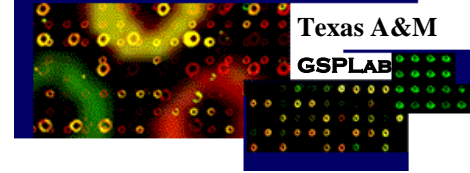




Unthinkable In Terms of Pure Reasoning

- **Hannah Arendt:** “The trouble, in other words, is not that the modern physical universe cannot be visualized, for this is a matter of course under the assumption that nature does not reveal itself to the human senses; the uneasiness begins when nature turns out to be inconceivable, that is, unthinkable in terms of pure reasoning as well.”





Models and Ordinary Experience

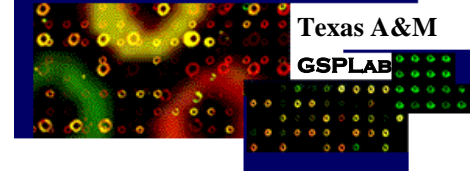
- **Erwin Schrodinger:** “As our mental eye penetrates into smaller and smaller distances and shorter and shorter times, we find nature behaving so entirely differently from what we observe in visible and palpable bodies of our surrounding that no model shaped after our largescale experiences can ever be 'true'. A completely satisfactory model of this type is not only practically inaccessible, but not even thinkable. Or, to be precise, we can, of course, think it, but however we think it, it is wrong; not perhaps quite as meaningless as a 'triangular circle', but much more so than a 'winged lion'.”

Prediction Grounds Scientific Knowledge

- **Richard Feynman:** “It is whether or not the theory gives predictions that agree with experiment. It is not a question of whether a theory is philosophically delightful, or easy to understand, or perfectly reasonable from the point of view of common sense.



The theory of quantum electrodynamics describes Nature as absurd from the point of view of common sense. And it agrees fully with experiment. So I hope you can accept Nature as She is – absurd.”



Reason and Prediction

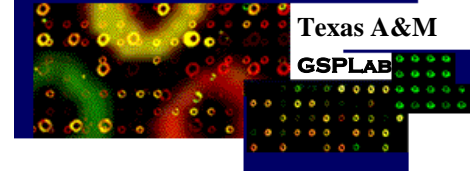
- **Hans Reichenbach** (*The Rise of Scientific Philosophy*): “If the abstract relations are general truths, they hold not only for the observations made, but also for observations not yet made; they include not only an account of past experiences, but also predictions of future experiences. That is the addition which reason makes to knowledge. Observation informs us about the past and the present, reason foretells the future.”



The Indispensible Tool

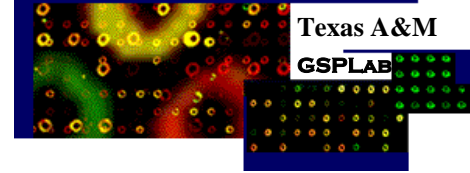
- **Will and Ariel Durant** (*Story of Civilization*): “Mathematics grew [in the 18th Century] because it was the basic and indispensable tool of all science, reducing experience and experiment to quantitative formulations that made possible precise prediction and practical control.”





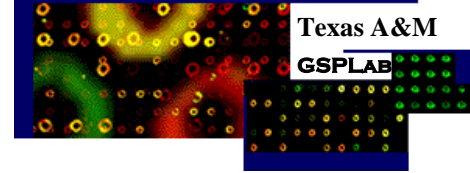
Scientific Theory

- *Mathematical model* consisting of variables and relations between the variables.
- *Operational definitions* relating the variables to observable (and measurable) phenomena.
- *Experimental design* to test predictions made by the model.
- A scientific theory is validated to the extent that predictions derived from it agree with experimental observations.



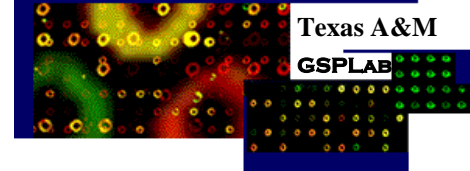
Scientific Statements

- Scientific statements are symbolic formulae that must be tied to observable phenomena via operational definitions.
- Reasoned statements about physical phenomena do not constitute scientific knowledge.
- Explaining data in a reasonable way is not science.
- Science does not fully trust reason; it trusts predictions.
- Science is not apologetics.



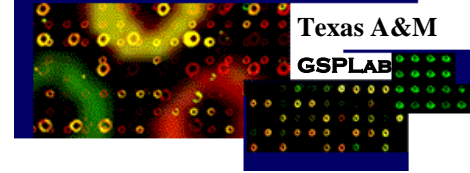
Non-scientific Statements

- Model \mathcal{A} matches *reality* better than model \mathcal{B} .
 - An Aristotelian view – one that is returning.
- More variables give a finer fit and therefore provide models closer to *reality*.
- An analog model is more *real* than a discrete model.
- A finely quantized model is better than a binary model because it is closer to *reality*.



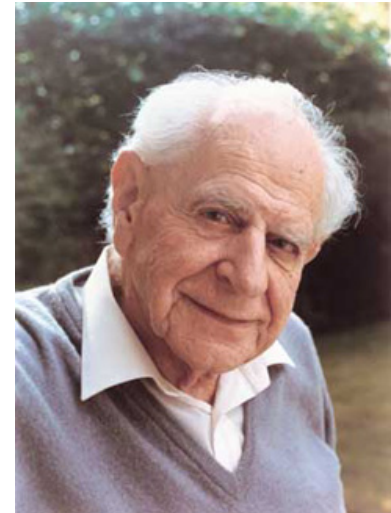
We Understand Mathematics, Not Nature

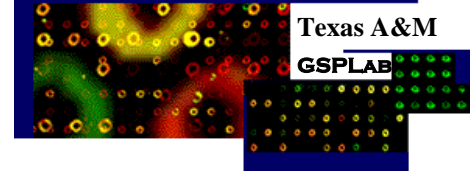
- We understand the mathematical model because it is a product of human intelligence.
- We do not understand Nature, nor should we expect to.
- Implicit in Feynman's comment is the existence of a set of statements whose predictive capability can be experimentally examined – independent of reason.
- Mental pictures are a step away from reality (Jeans) because they are not predictive.
 - Descartes: Clear and distinct ideas guarantee truth.



Science is Inter-subjective

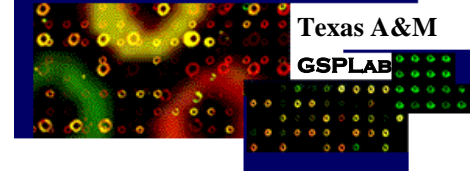
- **Karl Popper:** “The objectivity of scientific statements lies in the fact that they can be inter-subjectively tested.”
 - Inter-subjectivity demands that scientific knowledge not depend on reason, except within the strict rules of mathematics; otherwise, philosophical theories like Marxism could legitimately claim to be science. This would be “cult science,” open only to those who claim to understand empty phrases such as “dialectical materialism.”





Why Scientific Knowledge Is Mathematical

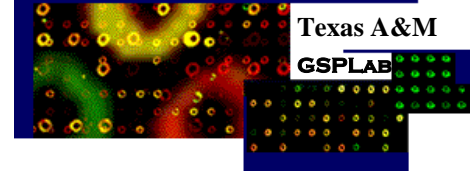
- Four reasons:
 - Scientific knowledge is based on quantitative measurements.
 - Scientific knowledge concerns relations and mathematics provides the formal structure for relations.
 - Validity depends on predictions. This requires a quantitative structure from which to generate predictions and a theory of probability in which to quantify the goodness of predictions.
 - Mathematics provides a formal language sufficiently simple so that both the constituting theory and the experimental protocols for prediction are inter-subjective.



Science Requires Observability

- **Erwin Schrodinger:** “It really is the ultimate purpose of all schemes and models to serve as scaffolding for any observations that are at all conceivable... There does not seem to be much sense in inquiring about the real existence of something, if one is convinced that the effect through which the thing would manifest itself, in case it existed, is certainly not observable.”
 - Without observable effects due to an object, the object is not a subject of scientific inquiry.

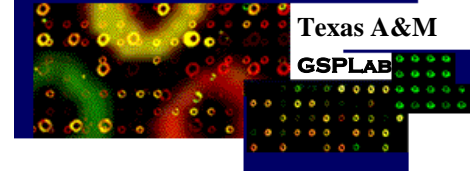




Verifiability

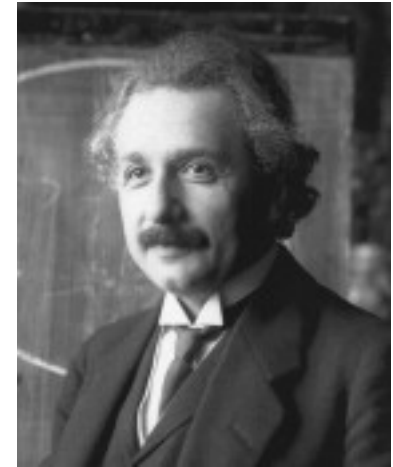
- **Hans Reichenbach:** “The reference to verifiability is a necessary constituent of the theory of meaning. A sentence the truth of which cannot be determined from possible observations is meaningless.”

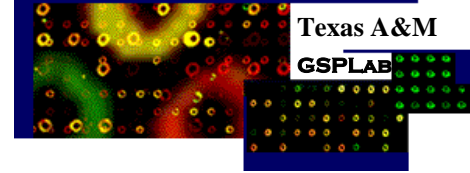




Scientific Validity Is Not an Absolute

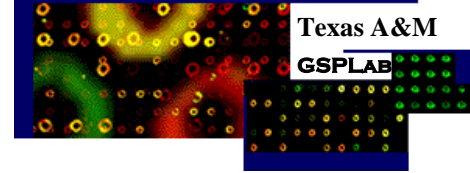
- **Albert Einstein:** “In order that thinking might not degenerate into metaphysics, or into empty talk, it is only necessary that enough propositions of the conceptual system be firmly enough connected with sensory experiences and that the conceptual system, in view of its task of ordering and surveying sense experience, should show as much unity and parsimony as possible.”
- The meaning of validity must be defined differently in different circumstances.





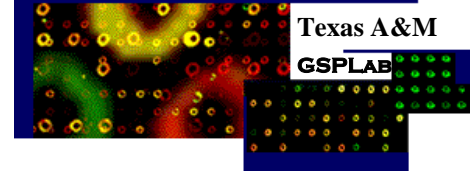
Validation Criteria

- A scientific theory requires formal specification of measurements that can be compared to predictions derived from the theory and the manner of comparison.
 - in particular, the choice of validity criteria and the mathematical properties of those criteria as applied in different circumstances.
- A scientific theory is inter-subjective, but the criteria underlying a particular validation are open to debate.
 - The mathematical model is valid relative to the validation criteria and to the degree that the requirements are satisfied, that is, to the degree to which predictions agree with observations.
- The rules of the game must be precisely specified.



The Meaning of Validity is Mathematical

- “There is no nonmathematical way to precisely describe knowledge regarding model validity. It depends on the choice of validity measurement and the mathematical properties of that measurement as applied in different circumstances. In all cases, the nature of our knowledge rests with the mathematical theory we have concerning the measurements. That cannot be simplified. If either the available theory or one’s familiarity with the theory is limited, then one’s appreciation of the scientific content of a model is limited.”
- Dougherty, E. R., Hua, J., and M. L. Bittner, “**Validation of Computational Methods in Genomics,**” *Current Genomics*, **8** (1), 1-19, 2007..



Muddled Science

- **Albert Einstein:** “Science without epistemology is – insofar as it is thinkable at all – primitive and muddled.”

