Descriptive vs. Generative Scientific Theories

by Dag Forssell 2004
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The spectacular progress we have seen in the physical sciences in the last 400 years, compared to previous millennia, is largely due to a historic shift from descriptive science to generative science.

By a generative theory we mean a postulated organization of functional components with well defined, quantified interactions. Operating by itself as a model or in simulation, this organization generates action which validates or disproves the particular theory. Other terms used to describe the two kinds of theory are Empirical versus Fundamental, where empirical means derived from data using correlations or statistics (without any understanding of underlying reasons) and fundamental means derived from basic ideas, or laws of nature.

This comparison of descriptive and generative science in the fields of astronomy and psychology illustrates the well-known scientific revolution in astronomy and suggests that a similar upheaval is overdue in psychology and related fields.

The starting point for the modern era of physical science was the Copernican idea of a Sun-centered universe. Copernicus's model was adopted and promoted by Galileo, who among other things carried out meticulous studies of acceleration, thereby establishing the basic methods of modern physical science. The model of the solar system was later refined by Kepler and the laws of nature that govern it defined by Newton, completing the conversion of astronomy from descriptive to generative. Replacing the previous descriptive, "cut-and-try" approach to physical science, this sequence of developments laid the foundation for our contemporary, generative, physical and engineering sciences.

As new theories have been proposed and tested in the physical sciences, numerous scientific revolutions have followed, but as Thomas Kuhn explains in *The Structure of Scientific Revolutions*, textbooks don't usually explain or even mention previous concepts, so students are left with the impression that science is a matter of accumulating facts, where of course all new facts must fit previous facts. Not so. Numerous upheavals have taken place in physical science in the last 400 years.

DESCRIPTIVE ASTRONOMY

Concept
Formalized by Greek astronomer Ptolemy (approx. 87–150 AD) in one of the world's oldest scientific works, the *Almagest*, the basic concept was that the Earth was an immovable object at the center of the universe. The idea that the Sun and all the other heavenly bodies rise in the East and revolve around the Earth seemed obvious and was accepted by scientists and lay people alike.

Study
You study the description of each heavenly path and master the tools of this science—the geometry and mathematics of circles and epicycles.

Description and interpretation
Descriptions assume that we experience reality directly through our exquisite senses—in living color and stereophonic sound. What we observe in the heavens is what is going on.

Prediction and testing
You predict future positions by projecting forward from current observations, using the descriptive mathematical tools. Because of the great regularity of the heavenly movements, such projections were very accurate. Lunar eclipses could be forecast years in advance. Ptolemy's descriptive model must be said to have been quite successful.

Limitations and complications
Ptolemy's descriptive mathematics provided no explanation for the phases of the moon or planets. About eighty epicycles (read fudge-factors) were defined by Ptolemy to make the basic geometric descriptions hang together.

Use
Heavenly constellations were noted, named and invested with significance by the Ancient Egyptians, from whom we have inherited Astrology. The model served as the basis for development of the calendar and was helpful for navigation at sea. The Catholic church accepted Ptolemy's circles and spheres and concluded that the planets are supported and carried by perfect crystal spheres as they revolve around the Earth.

To learn more
The University of St. Andrews web site:
http://www-gap.dcs.st-and.ac.uk/~history/Mathematicians/Ptolemy.html
is one good source of information on Ptolemy.

DESCRIPTIVE PSYCHOLOGY

Concepts
Basic concepts have included sequences of stimulus and response.

Behaviorists believe the environment determines what we do. Cognitive psychologists believe the brain issues commands for particular actions.

In both cases, explanations focus on output—on particular actions. Both these beliefs are at present almost universal among scientists and nonscientists alike.

Study
You study a vast number of theories put forth by a multitude of psychologists. You master the tools of statistics, which can provide an illusion of causal relationships and thus an illusion of understanding.

Description and interpretation
Descriptions assume that we experience reality directly through our exquisite senses—in living color and stereophonic sound. What we observe and describe is objective truth.

Prediction and testing
You predict future behavior basically by saying: "I've seen this before—I'll see it again." Due to the great variety of conditions and individuals, such predictions have an extremely poor track record.

Comparison with a working model has never been required. No psychological theories have ever been disproven or discredited.

Limitations and complications
The field of psychology is extraordinarily fragmented. The focus is on behaviors, which are classified and discussed, but no functional, physical explanations are offered for even the simplest phenomena.

Use
Descriptive psychological ideas of many different kinds are used throughout our culture. They are part of our language and pervade education, politics, management etc.

People have long used unverified concepts from these descriptive sciences to feel they are explaining events.

To learn more
We live in a culture dominated by descriptive sciences of psychology. Umpteen books on various psychologies are published every year. Findings are regularly reported on the evening news.

GENERATIVE ASTRONOMY

Origin

Polish astronomer Nicolaus Copernicus (1473–1543) proposed the Sun-centered alternative to the Earth-centered Ptolemaian model. Copernicus distributed a handwritten book called *Little Commentary* to other astronomers already in 1514. His major work *On the Revolution of the Heavenly Spheres* was published in 1543. Copernicus work (still descriptive, featuring some epicycles, but on the right track) was championed by Galileo Galilei (1564-1642), who found evidence supporting the concept, such as phases of Venus and moons of Jupiter using the newly invented telescope. Johannes Kepler (1571-1630), using observations collected by Tycho Brahe (1546-1601), found that if planetary paths were elliptical, not circular, they would fit the data—doing away with the need for epicycles. Finally, Isaac Newton (1642-1727), formulated the laws of motion and gravity, which, when operating on heavenly bodies interacting in the mechanism we call the Solar system, generate the elliptical motions observed in the heavens. The 200-year conversion of astronomy from a descriptive to a generative science was complete.

Postulates

Copernicus's *Little Commentary* states seven axioms, which suggest the structure of the universe:

1. There is no one center in the universe.
2. The Earth's center is not the center of the universe.
3. The center of the universe is near the sun.
4. The distance from the Earth to the sun is imperceptible compared with the distance to the stars.
5. The rotation of the Earth accounts for the apparent daily rotation of the stars.
6. The apparent annual cycle of movements of the sun is caused by the Earth revolving round it.
7. The apparent retrograde motion of the planets is caused by the motion of the Earth from which one observes.

GENERATIVE PSYCHOLOGY

Origin

Developed by William T. (Bill) Powers (1926–). Bill was trained by the U.S. Navy as an electronic technician to service control (servo) systems. After WW II, he obtained a B.S. degree in physics. An interest in the important subject of human affairs led him to enroll in a graduate program in psychology, but he left after one year because his proposed Masters Degree thesis, involving control by rats, was not acceptable to the Spencian psychologists then in charge. He began his development of Perceptual Control Theory (PCT) in the early 1950s by applying control engineering and natural science to the subject of psychology. His major work *Behavior: the Control of Perception* was published in 1973.

In this work, Powers proposes a structure of our nervous system, complete with mechanisms in some detail and, most important, functional interactions between the various elements and clusters of these mechanisms. The result is a coherent whole that can be tested to see if it functions in a way that rings true when compared to our observations of the real thing—human beings and animals. PCT lays a foundation for a new beginning, a new way to think about and perform research in psychology and related fields.

Postulates

Philip J. Runkel spells out postulates of Perceptual Control Theory (PCT) in *People as Living Things*, (page 57):

1. Causation in the human neural net is circular and simultaneous.
2. Action has the purpose of controlling perception. Controlling perception produces repeatable consequences by variable action.
3. A controlled perception is controlled so as to match an internal standard (reference signal). Every internal standard is unique to the individual, though two individuals can have very similar standards.

One of the deductions one can make from these postulates is that particular acts are not, in general, predictable.

Note:

As discussed in *Big Bang* (2004) by Simon Singh, page 22 ff, and *The Structure of Scientific Revolutions* (1970, 1996) by Thomas Kuhn, page 75, Aristarchus of Samos (circa 310-230 BC), proposed a heliocentric solar system. On pages 34-35 and 68-69, *Big Bang* features informative overviews of the evidence for the earth-centered model and the sun-centered model in Aristarchus' era and as of 1610 AD, after Galileo's observations. I leave it to another student of PCT to present a similar overview of the evidence for descriptive versus generative psychology.

Generative astronomy, continued

Postulates, continued
Newton's three laws of motion and law of gravity suggest the dynamic physical states of and interactions between moving objects:

Motion:
1. Every body will remain at rest, or in a uniform state of motion, unless acted upon by a force.
2. When a force acts upon a body, it imparts an acceleration proportional to the force and inversely proportional to the mass of the body and in the direction of the force.
3. Every action has an equal and opposite reaction.

Gravity:

> Every particle attracts every other particle with a force that is proportional to the product of their masses and inversely proportional to the distance between them.

The structure and functional interactions allow the scientific model to generate action by itself. This can be compared to actual observations as well as used to predict future states of the heavens.

Study
You grasp the idea and generative model of the solar system by studying the mechanism and dynamic physical relationships between moving objects.
You realize that the concept of an Earth spinning around its axis while revolving around the Sun is counter-intuitive, but once the mechanism and the quantifiable physical interactions have been studied, it is not particularly difficult to visualize and understand.

Description and interpretation
You realize that appearances in the heavens can be very deceiving. What looks obvious to the intuitive observer may be better explained by a very different mechanism operating in ways that are not readily apparent and can only be inferred from various observations, interpreted through the framework of a proposed mechanism.

Generative psychology, continued

Postulates, continued
These postulates are summarized and amplified on page 129:

> Perceptual control theory claims that behavior controls perception—at every time, in every place, in every living thing. The theory postulates that control operates through a negative feedback loop—neurally, chemically, and both. The theory postulates the growth of layers of control both in the evolution of the species and in the development of individuals of the "higher" animals. Those are the crucial postulations of invariance in PCT. They are asserted to have been true for the single cells floating hither and thither a billion years ago, which might have had only two layers of control, and they are asserted to be true for you and me with our many layers. They are asserted for all races, nations, sexes, and indeed all categories of humans—and indeed all categories of creatures. Furthermore, if one creature is found reliably to violate any one of those postulations (and yet go on living), the theory will immediately be revised.

Study
You grasp the idea and generative model of PCT by reading the basic text, studying tutorials that explain control in detail, by experiencing physical control systems, and by studying informative simulations you can run on your own Windows computer.
You realize that the concept is counter-intuitive, but once the mechanism and the quantifiable physical interactions have been studied, it is not particularly difficult to visualize and understand.

Description and interpretation
You realize that our various sensors merely originate neural signals when "tickled" by various physical phenomena in a physical reality we as humans will never know, but certainly do our best to draw conclusions about. You realize that everything you see, hear, touch and smell is made up of neural signals in your nervous system. The sights and sounds you enjoy are fabricated by your nervous system and "displayed" in your mind. You never experience reality directly.

Generative astronomy, continued

Prediction and testing
You build a model of the Solar System, either a physical model or a simulation of the physics, implemented in a computer program. You make sure that you program functional interactions correctly with regard to the laws of nature, such as Newton's laws of motion. You predict by allowing the model to operate by itself, generating future positions. You test these predictions against the best possible observations of the motions of heavenly bodies. You expect agreement as closely as you can measure, or you modify your model.

Predictions based on contemporary astronomy routinely match observations to the limit of measurement. Rockets launched into space have found their targets.

Consequence
Copernicus's theory was not compatible with the existing, predominant Ptolemaian theory. It ultimately gave rise to a scientific revolution, which took a long time to play out. Once you understand the mechanism of the Solar system, Newton's laws of motion and gravity and accept the generative model, you reject all the explanations inherent in the old, descriptive astronomy, though not necessarily all of its observations. You may retain some of its language, such as "The Sun rises in the East." You realize that if you are interested in moving beyond the scope of simple observation, such as calculating trajectories and forces required for space travel, the old descriptive astronomy would have been utterly useless. You recognize that the physical model and mechanisms implied by the descriptive science, such as the stars revolving around the Earth in 24 hours, was not physically feasible. You recognize that accepted phenomena of the old science, such as the epicycles, planets moving in small circles as they move in big circles, were illusions.

Use
The transition from descriptive to generative physical science laid the foundation for the engineering progress we have enjoyed for the last 400 years.

Generative psychology, continued

Prediction and testing
You build a model of an organism, either a physical model or a simulation of the physics, implemented in a computer program. You make sure that you program functional interactions correctly with regard to the laws of nature, as known from physics, kinetics, neurology, etc. You predict by allowing the model to operate by itself, generating activity on its own. You test these predictions against observations of actual, living organisms operating by themselves. You expect very close agreement, or you modify your model.

Tests to date shows correlations above .95, often around .98, between the model and the actual person.

Consequence
Powers's theory is not compatible with existing, predominant psychological theories. It causes a scientific revolution, which will take a long time to play out. Once you understand the mechanism of perceptual control and recognize that control is the pervasive, defining quality of living things, you reject the basic concepts of descriptive psychologies, though not necessarily all of their observations. You have little choice but to continue using the languages of contemporary psychologies, such as "What are you doing," because that is part of our current culture and language. (PCTers might say "What are you controlling for.") You realize that if you are interested in moving beyond the scope of repeating observations, such as developing harmonious management programs or effective educational programs, descriptive psychologies have severe limitations. You realize that the physical mechanisms implied by descriptive science, such as super-computer brains issuing commands, are not feasible in a rapidly varying environment. You recognize that many widely held ideas, such as people controlling their behavior, or responding to stimuli, are illusions.

Use
PCT, seen as an overall organizing principle for living organisms, lays a foundation for a fresh review of the life sciences, promising great progress in the future.

Generative astronomy, continued

Limitations

By the time the transition from an Earth-centered to a Solar-centered astronomy was complete, the evidence for the Solar system was compelling to those who looked at the evidence. However, at that time there was much detail left to be worked out, such as detailed equations that portray the movement of the moon relative to the Earth, and astronomers are still uncovering wonders of the universe. Newtonian physics has been extraordinarily successful, but we still don't have any explanation that tells us how gravity works. But we have no doubt that it does.

Willingness and ability to understand

If you were raised at an age and in a society where everybody *knew* that the Earth rests at the center of the universe, and somebody suggested the idea of a Sun-centered universe. What would you make of it?

Would you have been willing and capable of making the effort to grasp the model? Might you have found the idea strange and obviously false?

Acceptance

The basic Sun-centered model of our local universe is widely accepted today. You most likely take it for granted because you learned the concept already in kindergarten. It was not intuitively obvious, was it?

To learn more

The Internet features numerous web sites about Copernicus, Galileo, Kepler and Newton. *On the Shoulders of Giants*, edited by Stephen Hawking, (2002) features the full text of *On the Revolution of the Heavenly Spheres* by Copernicus, *Dialogues Concerning Two Sciences* by Galileo , *Harmony of the World*, book five, by Kepler, and *Principia* by Newton.

For information on the numerous scientific revolutions in the natural sciences, see Thomas Kuhn's *The Structure of Scientific Revolutions*.

Generative psychology, continued

Limitations

PCT is a natural science in its infancy. Evidence that living organisms control their perceptions is compelling to those who examine it, and this makes all the difference for our understanding of behavior. Detailed simulations show how a hierarchy of control systems can work. Some levels of control in people can be clearly demonstrated. The postulated higher levels are by no means definitive. How perception works at the various levels is unknown; thus wonders of perception remain to be uncovered. But there can be no doubt that we control our perceptions.

Willingness and ability to understand

You have been raised in a culture where everyone *knows* that we react to stimuli in our environment and control our actions. Now someone suggests that you don't react, you oppose disturbances. You don't control your actions, you control your perceptions. Your brain does not issue commands, it sets reference signals. What would you make of it?

Are you willing and capable of making the effort to grasp the model? Might you find the idea strange and obviously false?

Acceptance

The basic PCT model of how living organisms control their internal worlds will hopefully be widely accepted fifty years from now. Children most likely will take it for granted because they will learn the concept already in elementary school.

To learn more

People as Living Things; The Psychology of Perceptual Control by Philip J. Runkel introduces the theory and shows its implications for numerous aspects of human experience, thereby illustrating its significance and challenging crucial contemporary notions of how humans and human relationships can work. This is a very good place to start. The book refers to other PCT literature and points to web sites where you can download tutorials and simulations. See http://www.livingcontrolsystems.com.