Psychology's Movement Toward Cognitive Science

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Most accounts of the development of cognitive science in psychology focus exclusively upon the adoption by theorists of the computational theory of cognition and the representational theory of mind. Clearly the CTC/RTI began and remains central to cognitive science and its development in psychology. However, the progression between psychological schools of thought in this brief history emphasizes three trends: First, psychology progresses towards becoming a science and ultimately towards cognitive science by developing, evaluating, and integrating several important experimental methods. The development, evaluation and integration of experimental techniques together with a clear conception of their role in theory formation and testing constitute what I call and experimental tradition. Psychology develops an experimental tradition at first through the introduction of experimental methods from other sciences. Later as this tradition blossoms researchers become increasingly innovative and adaptive in their use of experimental methodology. Second, psychological schools of thought move from emphasizing conscious, qualitative aspects of mind and mental processes to emphasizing characterizations of the mind and mental processes in terms of informational processing. This change in emphasis does not merely represent a recognition by theorists of an important set of phenomena for understanding the mind and mentality—though it surely is—it represents a shift from phenomena ill-suited to the conceptual and experimental methods of the time to phenomena better understood and testable by those resources. Rather, it represents a shift towards those aspects of the mind best suited to the experimental tradition of the time. Third, psychologists develop and adapt experimental techniques in order to more reliably explore those elements of their information processing models not directly observable by experimenters. The development of experimental methodologies, the refinement of animal and other models, increased knowledge of human mentality, development, and physiology, as well as the development of technical ideas such as information and computation ultimately coalesce, allowing for the conceptual framing of cognitive phenomena as well as its systematic experimental investigation.

In discussing the development of physiology, I emphasize that physiology introduces a strong empirical and experimental emphasis to psychology. Indeed, many early psychologists receive their training from physiologists and anatomists. Consistent with that idea, I begin the discussion of the development of psychology towards cognitive science with the development of an experimental technique that has proven quite central to psychology—reaction time.

Reaction Times and Mental Chronology

Reaction time refers to the time it takes from the initial presentation of stimulus until the subject reacts. For instance, the time between a light flashing and a subject pressing a button is that subject's reaction time for that stimulus-response pairing. Reaction time measurement begins with Friedrich Wilhelm Bessel (1784-1846), a German astronomer and Gymnasium drop-out. Bessel becomes intrigued by a controversy regarding disparate observations of transit times between the astronomers Maskelyne and Kinnebrook, and later between Enckes and Gauss. Transit times are measurements of how long it takes stars to cross hairlines in telescopic observations. Transit times have significance because they indicate the time it takes the star to pass over the meridian of the observatory. Astronomers use transit times for a star to determine the coordinates of the star. Precise measurements of star coordinates are becoming increasingly important in the 1700s and 1800s, both for the astronomers and also because nautical tables of the time rely upon coordinate information for stars. Twenty years after the original dispute (1821), Bessel looks at the dispute using two approaches: First, Bessel analyzes the observations of different astronomers. Second, Bessel performs a simple experiment; he compares observational measurements between astronomers using the same equipment. Bessel determines that skilled astronomers will vary consistently in their observations of transit times. As a result, Bessel introduces the notion of an "involuntary constant difference," in describing his findings in the preface to the eighth volume of his *Astronomische Beobachtungen[1]* (1823).

In astronomy, the phenomena now commonly goes under the name introduced by John Pond (1767–1836) in 1933[2], as the "personal equation." It is not an exaggeration to describe Bessel's work as the first experimental quantitative measurement of reaction time. It eventually results in the first attempt to control both for reaction time and also for individual differences in scientific observation. In addition to the development of techniques to test reaction time, and a conception of it as a variable, experimental science benefits from the invention of improved measuring devices. In 1847 the German-born Swiss clock maker and inventor, Matthäus Hipp, builds a modified Chronoscope based upon the design of its inventor, Charles Wheatstone (1842). Wheatstone originally designed the Chronoscope for British Artillery applications, but the devices allow increased accuracy in temporal measurement over pendulum clocks and other measuring devices. Scientists and inventors follow Chronoscopes with other devices like the Chronometer and the Control Hammer Apparatus for better time keeping anc calibration.[3, 4]

Among those researchers who employ these devices, the German physiologist, Hermann Ludwig Ferdinand von Helmholtz (1821-1894), publishes his "On the Rate of Transmission of the Nerve Impulse[5]," in 1850. The Swiss astronomer Adolph Hirsch (1830-1901) publishes his

"Sur l'equation Personnelle dans les Observations Astronomiques (On Personal Equation in Astronomical Observations) and his "Experiences Chronoscopiques sur la Vitesse des différentes Sensations et de la Transmission Nerveuse (Chronoscopes Experiments on the Speed of Different Sensations and Nerve Transmission)"[6, 7] In the latter work Hirsch [8]

> …was the first (1) to use Hipp's chronoscope in scientific literature, (2) to study reaction time in connection to psychological interest, and (3) to study velocity of conduction in humans with appropriate techniques. Using Hipp's apparatus, Hirsch showed differences in time for manual response (1) to auditory, visual, and tactile stimulation; (2) between observers; (3) in Hirsch's own results when fresh and when fatigued; (4) according to the locus of tactile stimulation and the hand used for response; and (5) according to whether the stimulus was expected or unexpected. Moreover, observations made on one of his colleagues relate the conduction speed in nerves, from which he concludes that the differences in reaction time were due to the varying lengths of nerves. The speed of transmission in sensory nerves was evaluated by Hirsch at about 34 m/s. (p.261)

Researchers usually cite Franciscus Cornelis Donders (1818-1889) as the first researcher to use differences in human reaction time to infer differences in cognitive processing time. Building on the work of his graduate student, Johan Jacob De Jaager[9], and with an awareness of earlier work by Helmholtz and Hirsch, Donders uses the same subtraction method employed by Helmholtz, to make inferences about the times of various mental processes. In 1868, Donders publishes "On the Speed of Mental Processes,"[10] in which he shows that a simple reaction time is shorter than a recognition reaction time, and that the choice reaction time is longest of all. Using these times, Donders makes inferences as to the speed of mental processes through subtraction: recognition = (recognition reaction time - simple reaction time). Donders' results are an instance of mental chronometry, i.e., the study of the relative speed and temporal sequencing of mental process under some specified set of conditions. The ideas of subtraction, mental chronometry, and reaction time are now part of the central methodological framework of cognitive psychology. The next experimental technique, introspection, has a less venerable history.

		
Friedrich Wilhelm Bessel (1784-1846) From: http://en.wikipedia.org/wiki/File:Friedrich_Wilhelm_Bessel_%281839_painting%29.jpg	Hermann von Helmholtz (1821-1894) From: http://www.psych.ndsu.nodak.edu/mccourt/Psy460/historical%20and%20contemporary%20sensory%20science/young.JPG	Franciscus Cornelis Donders (1818-1889) From: http://commons.wikimedia.org/wiki/File:Donders,_F.C..jpg

Adolph Hirsch
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http://commons.wikimedia.org/wiki/File:Adolf_Hirsch_-_from_Svenskt_Portr%C3%A4ttgalleri_XX.png

Matthäus Hipp (1813-1893)
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http://www.twigsdigs.com/horology/heroes/portraits/hipp.htm

A chronoscope built by the Swiss inventor and clock maker Matthias Hipp in 1888. Early psychological and physiological researchers used chronoscopes to measure reaction times in their experiments. This chronoscope is accurate to 1/1000th of a second.

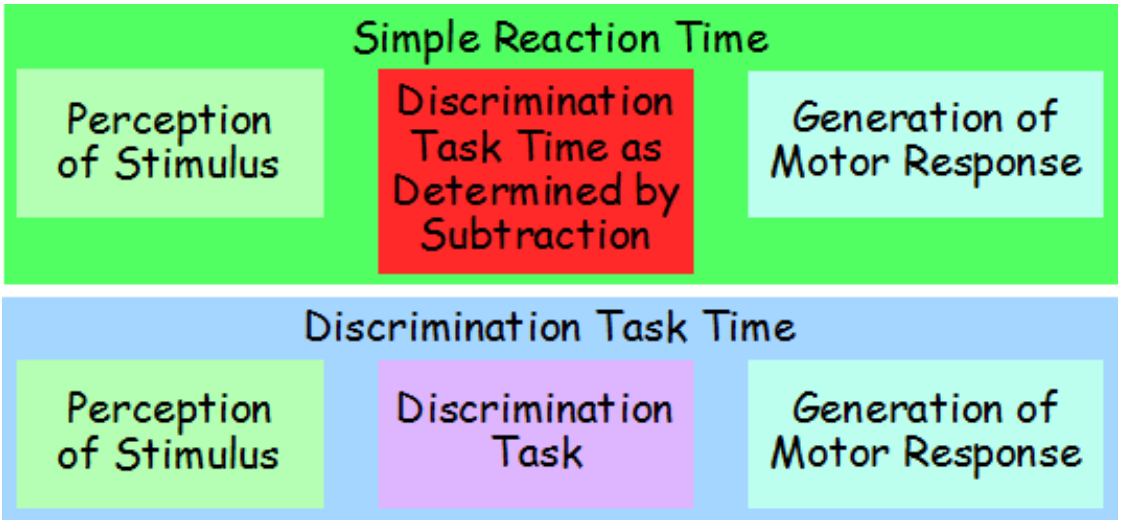


Diagram illustrating the subtraction technique. A researcher takes two tasks that differ only by one component task. In this case, the first task is a simple reaction task composed of a perception task and a motor response task. The second task is a discrimination task composed of a perception task, a motor response task, and the discrimination task. The researcher determines the mean time for subjects to complete each task. Subtraction of the simple reaction time from the discrimination task time to yield the time of the discrimination task alone.

Introspection and Introspection-Based Psychologies

The development of the categorization of phenomena as reaction time and the invention of devices for precise quantification of reaction time in experimentation represent a significant success in the development of an experimental tradition within physiology and what would eventually become psychology. The next example of the development of an operationalization (measurement procedure) proves less definitely positive. One difficulty theorist face in developing theories of mind lies in finding ways to categorize and measure qualitative conscious experiences. Some researchers turned to introspection, an individual's (seeming)

observations of their own conscious states such as beliefs, desires, emotions, and sensations as a means of gathering observations of such phenomena. The technique of introspection enters psychology through the work of Wilhelm Maximilian Wundt, (1832-1920) a German physician, psychologist, physiologist, and university professor. Wundt, Titchener, and Brentano are often portrayed together under the title of Introspectionist Psychology. However, as we will see, these theorists differ significantly in their theoretical perspectives as well as their use of introspection as a means of collecting data for experimental psychology.

		
Wilhelm Wundt (1832-1920)	Edward Titchener (1867-1927)	Franz Brentano (1838-1917)

Introspectionist Psychology: Voluntarism

Wundt creates the first laboratory explicitly dedicated to psychological research (as opposed to labs for teaching demonstrations) at the University of Leipzig in 1879. He also begins the first journal for psychological research in 1881. If Freud is the "father of Psychiatry," Wundt likely deserves the title of the "father of Experimental Psychology."

Wundt studies under the German anatomist Heinrich Müller and Helmholtz prior to writing his first book, *Contributions to the Theory of Sense Perception[11]* (1862). He follows this book with his second, *Lectures on Human and Animal Psychology[12]* (1863). Wundt has founded the first school of psychological thought by 1987, when he publishes *Principles of Physiological Psychology*.[13] Ironically, Wundt's success at training a new group experimental psychologists leads to a distortion of his own views. One Wundt's students, Edward Titchener (1867-1927), actively, but misleading, associates Wundt's view with Titchener's on view, structuralism. Wundt names his view voluntarism, and as we will see, it differs somewhat from the typical views attributed to structuralism.

Wundt equates mentality with consciousness, and holds that experimentation can help one to understand simpler conscious phenomena, but not more complex phenomena. For Wundt, one must employ historical analysis and naturalistic (non-experimental) observation to understand higher mental functioning. Essentially, Wundt limits psychology to studying what cognitive psychologists now call sensation (the processes and organs that sense or encode information in the environment such as smell and taste) and perception (the processes that operate to facilitate the interpretation, organization, and integration of sensory input). In adopting this theoretic framework, Wundt seeks to model his psychology primarily upon psychophysiology rather than atomistic psychology. Indeed, one way to understand Wundt construes his work as

an attempt to extend the approach of psychophysiology beyond the more basic applications of sensation order to capture many or even all of the processes of perception.

Wundt adopts two primary experimental techniques for studying simple conscious phenomena; introspection and reaction time. Reaction-time enters Wundt's experimental repertoire from Helmholtz and Donders. However, Wundt eventually abandons the use of reaction time as too unreliable. For Wundt introspection provides immediate observation of mental phenomena—direct observation unmediated by measuring and recording devices. Moreover, unlike many other psychologists who follow him, Wundt uses introspection in a highly constrained fashion in keeping with its use in physiology and psychophysiology. Subjects often provide only yes or no answers to signify whether they are experiencing a sensation. However, Wundt seeks to extend the reach of introspection to include the more abstract conscious processes associated with perception. Psychophysicists might investigate the minimum sensitivity to changes in color by asking subjects to introspectively judge whether two color patches are the same or different. However, Wundt seeks much more complex theoretic measurements from subjects. In order to gather data, therefore, Wundt trains subjects in introspection, ostensively so that the subjects can learn the appropriate categories. This training, however, introduces biases into the reports of subjects in that they now categorize and report their introspective experiences using Wundt's categories and following Wundt's instructions for applying those categories.

Wundt studies perception—the passive and involuntary combination of multiple sensations--and apperception--active voluntary perception involving attention. He seeks the fundamental constitutive elements of conscious mentality as well as the rules by which these elements combine into more complex experiences. In this way, Wundt follows the mental chemistry model of the mind that one finds in the British Empiricists. However, for Wundt attention and the will act as a sort of catalyst, making apperception active. Thus, Wundt differentiates himself from the British Empiricists, in part, because of his introduction of an active, volitional component to the mental chemistry account. Likewise, Wundt's exclusion of higher mental functioning from the domain of scientific studies of the mind differs from other atomists.

Wundt breaks mental elements into two categories; sensations and feelings. Sensations result from stimulation of the sense organs. Each sensation has an intensity value (ex. bright vs dim) and a modality (touch, taste, etc.). Each modality has associated qualities, such as sweet and sour for taste. Feelings are distinct from sensations but co-occur with sensations. Wundt proposes a tridimensional account of feelings in which feelings have values along three orthogonal (opposing and independent) dimensions; pleasantness-unpleasantness, excitement-calm, and strain-relaxation.

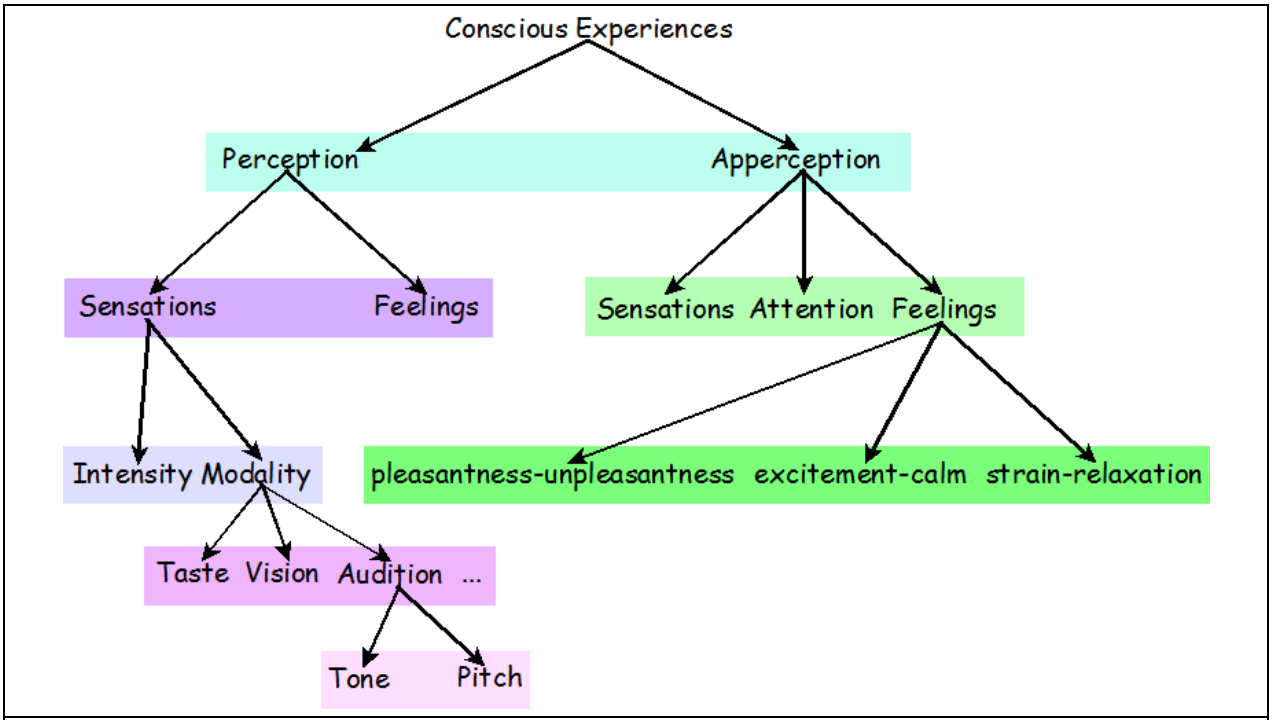


Diagram depicting Wundt's theory of conscious experience. Wundt divides conscious experiences into two kinds; passive perception and active apperception. Perception consists to two elements; sensations and feelings. Apperception consists of the elements of sensations and feelings together with attention. Sensations have two components (depicted on the right); intensity and modality. Each modality has qualities; in this case, audition has tone and pitch. Feelings (depicted on the left) vary along three orthogonal dimensions; pleasantness-unpleasantness, excitement-calm, and strain-relaxation.

Introspectionist Psychology: Structuralism

Edward Titchener (1867-1927) is an English student of Wundt who comes to Cornell University where he continues Wundt's general project of trying to identify the elements of simple human consciousness and their interactions. However, Titchener's views and methods differ significantly from Wundt's. Unlike Wundt, Titchener seeks to apply the lens of experimental psychology to higher order mental phenomena as well as simpler conscious phenomena. Titchener views experimental psychology as generating a morphological account of mental experiences—that is, an account of the elements and composite structure of conscious mental experiences. In his article, "The Postulates of a Structural Psychology,"[14] (1898), Titchener tells readers that,

> The primary aim of the experimental psychologist has been to analyze the structure of mind; to ravel out the elemental processes from the tangle of consciousness, or (if we may change the metaphor) to isolate the constituents in the given conscious formation. His task is a vivisection, but a vivisection which shall yield structural, not functional results. He tries to discover, first of all, what is there and in what quantity, not what it is there for. (p.450)

Likewise, Titchener differs from Wundt in that Titchener rejects the idea of an active volitional component of mental experiences. Titchener rejects as unscientific volitional, functional and teleological descriptions of mental processes at the psychological level. Instead, Titchener follows the British Empiricists in supposing that psychology should create an account of mental experiences in terms of structures created through the combination of basic elements through the mechanism of association. Similarly, Titchener holds that mental elements can only be known through their attributes. Titchener distinguishes three kinds of mental elements; sensations, images, and affections. Perceptions are composed of sensations, ideas are composed of images, and emotions are composed of affections.

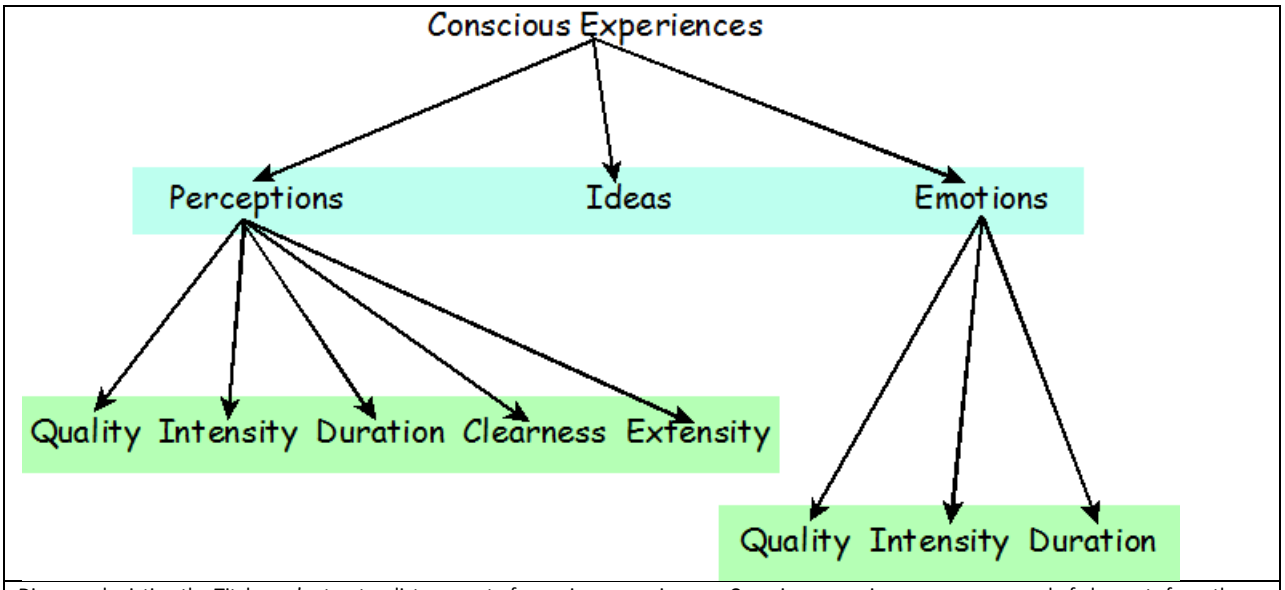


Diagram depicting the Titchener's structuralist account of conscious experiences. Conscious experiences are composed of elements from three categories (in blue); perceptions, ideas, and emotions. Each element has attributes (in green) that differentiates it and through which it is known. Perceptions and ideas have the attributes of quality, intensity, duration, clearness, and extensity. Emotions have the attributes of quality, intensity, and duration.

Titchener's use of introspection differs from Wundt's in that it requires subjects to actively probe or analyze their experiences to formulate reports. This requires extensive training. Titchener intends his training to cultivate an ability to observe and describe conscious experiences without the tincture of "stimulus error." Stimulus error occurs when subjects report their perceptions--reporting the meaning of the stimulus (or its conceptualization). For instance, if a subject saw an apple, the subject must report the hues, shapes, etc. of their experience—they should not report seeing an apple or a fruit. This combination of indoctrination into descriptive categories and active, even retroactive, analysis by subjects renders introspection even more methodologically problematic as an experimental tool.

In addition to the difficulties surrounding Titchener's use of introspection, he also ignores as irrelevant numerous research areas where significant progress is occurring. For instance,

Titchener discounts animal behavior and evolution, abnormal behavior, learning, development, and inter-subjective variation.

Introspectionist Psychology: Act Psychology

If you wish to find a true introspectionist villain, Franz Clemens Honoratus Hermann Brentano (1838-1917) probably best fits that description. In his major work, *Psychologie vom Empirischen Standpunkte*[15] or *Psychology from an Empirical Standpoint* (1874), Brentano coins the term "intentionality" to characterize his view that every mental act has an object to which it refers. For example, when someone sees an apple, they see it as an apple, an object, and not merely as a qualitative experience. Brentano tells readers:[16]

> Every mental phenomenon is characterized by what the Scholastics of the Middle Ages called the intentional (or mental) inexistence of an object, and what we might call, though not wholly unambiguously, reference to a content, direction towards an object (which is not to be understood here as meaning a thing), or immanent objectivity. Every mental phenomenon includes something as object within itself, although they do not all do so in the same way. In presentation something is presented, in judgement something is affirmed or denied, in love loved, in hate hated, in desire desired and so on. This intentional in-existence is characteristic exclusively of mental phenomena. No physical phenomenon exhibits anything like it. We could, therefore, define mental phenomena by saying that they are those phenomena which contain an object intentionally within themselves. (p.88-89)

Brentano also eschews the study of static simple conscious experiences, framing mentality in terms of acts, that is, in terms of the mind being directed towards an object in order to perform some function. Indeed, he holds that psychology should study mental processes in order to determine their function.

Though Brentano never practices experimental psychology, he does employ and advocate "phenomenological introspection," in his theorizing about the nature of the mind and its processes. In employing phenomenological introspection, the researcher either asks the subject to analyze temporally extended processes such as inferences, or performs such an analysis themselves. Though Brentano publishes very little, he influences many people, for instance, Freud.

The Downfall of Introspectionist Psychology

The reliance upon introspection as the sole measurement technique around which these researchers structure their experimental methodology ultimately dooms various variants of this movement in psychology. The methodological failures of introspective psychology include a

failure to control (eliminate) the implicit biases introduced by training subjects and allowing the much less reliable techniques of extended and retroactive introspective analysis. Though in many ways highly creative experimentalists, the major practitioners of the various schools of introspectionist psychology make little to no effort to assess introspection's calibration (ability to accurately record), or control for subject and experimenter bias. Instead, perhaps naturally, these researchers assume introspection is perfectly reliable across all of its methodological uses. Quite to the contrary, careful investigation reveals the relatively poor calibration of introspection. Moreover, introspection proves susceptible to massive subject and experimenter bias.

Behaviorists heavily criticize introspection as part of their rejection of the various forms of introspective psychology. The contemporary uses of introspection, as a result, are highly constrained and cross-validated. Indeed, Richard Nisbett and Timothy Wilson publish an influential literature review in 1977,[17] which still serves to highlight the perils of introspection. In the abstract for the review Nisbett and Wilson aptly summarize the concerns raised approximately fifty years of research (1925-1977) with regard to introspection as a measurement methodology for psychology:[17]

> Evidence is reviewed which suggests that there may be little or no direct introspective access to higher order cognitive processes. Subjects are sometimes (a) unaware of the existence of a stimulus that importantly influenced a response, (b) unaware of the existence of the response, and (c) unaware that the stimulus has affected the response. It is proposed that when people attempt to report on their cognitive processes, that is, on the processes mediating the effects of a stimulus on a response, they do not do so on the basis of any true introspection. Instead, their reports are based on a priori, implicit causal theories, or judgments about the extent to which a particular stimulus is a plausible cause of a given response. This suggests that though people may not be able to observe directly their cognitive processes, they will sometimes be able to report accurately about them. Accurate reports will occur when influential stimuli are salient and are plausible causes of the responses they produce, and will not occur when stimuli are not salient or are not plausible causes. (p. 231)

The failure of introspection as an operationalization, a measurement methodology for investigating the mind does not simply result from their over-reliance upon introspection. Ultimately, the atomist psychology proves a poor theoretical framework. The underlying metaphor of conscious mental elements interacting to create the dynamic changes of consciousness has no underlying basis in mental functioning or the mechanisms that subserve that functioning. Thus, the failure of the various schools of psychological thought that rely heavily upon introspection shifts the emphasis of psychological theorizing. Researchers move away from categorizing and explaining mental phenomena exclusively in terms of conscious qualitative experiences and towards other possible ways to categorize and model mental

phenomena. Specifically, researchers move toward understanding mentality through overt behavior and ultimately through the framework of information processing.

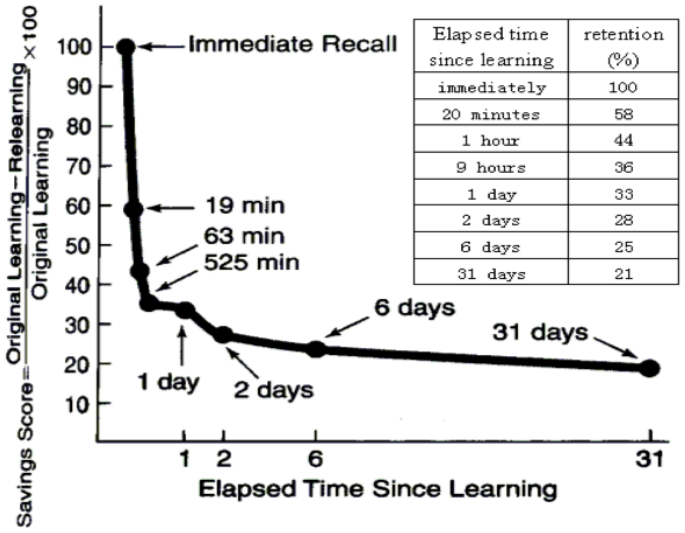
Ebbinghaus: The Quantified Study of Memory as a Process

Hermann Ebbinghaus (1850-1909), begins one of the first systematic studies of memory in 1879. He studies only the ability to memorize nonsense syllables by rote. He selects nonsense syllables since previous learning will not influence learning of these meaningless sounds. This choice represents one of his contributions to memory research, namely, that meaningfulness and relevance to the memorizer increases ease of memorization. Conversely, meaninglessness and irrelevance increase difficulties in memorization. Ebbinghaus might have used some of his students as subjects, but he seems primarily to use only himself as a subject. Thus, Ebbinghaus seems to have successfully avoided the biases inherent in self-experimentation. Equally important, Ebbinghaus successfully employs a quantitative operationalization (measurement procedure) for aspects for mentality by utilizing overt behavioral. He further manages to gain insight—insight expressed in non-behavioral categorizations like relevance and meaningfulness--into the functioning of memory through his experimental techniques. Ebbinghaus publishes his results in his book, *Über das Gedächtnis Untersuchungen zur Experimentellen Psychologie* [18] or *On Memory* (1885), which is later translated and published as *Memory: A Contribution to Experimental Psychology*[19] (1913).

In *On Memory* Ebbinghaus reports results that are the basis for the "learning curve" and the "forgetting curve." The learning curve shows that learning time, measured as number of repetitions, increases exponentially with the number of items memorized. Likewise, the increase in retention for each repetition decreases exponentially so as to approach complete retention asymptotically. The forgetting curve is similarly exponential, showing the forgetting decreases at an exponential rate, so as to approach complete failure of retention asymptotically. Specifically, $R = e^{-t/s}$ (where R = retention, t = elapsed time, and s = strength of original memory). Ebbinghaus also documents the serial position effect, viz. the recency and primacy effects (subjects are more likely to remember the last item in a series [recency] and the first item in a series [primacy]). Likewise, Ebbinghaus documents "savings." If one memorizes a list and then waits until recall is zero, one will still generally relearn the list at a faster rate despite the seeming lack of recall. Ebbinghaus terms the difference between the first and second memorization the savings.

Though Ebbinghaus is not prolific, does not identify himself with any psychological school of thought, and does not seek out pupils, his work spurs research on memory. Ebbinghaus' careful, well-designed experiments, his rigorous quantified results, statistical analysis, and systematic presentation prove extremely influential. Importantly, Ebbinghaus

Hermann Ebbinghaus (1850-1909)



Elapsed time since learning	retention (%)
immediately	100
20 minutes	58
1 hour	44
9 hours	36
1 day	33
2 days	28
6 days	25
31 days	21

Typical graph depicting data on savings.

(Left) Table from Ebbinghaus presenting data on savings.

Repetitions for the learning and recital of 6 series	Immediately successive repetitions for the sake of greater surety	Total number of repetitions used for the 6 series	After 24 hours the memorization of the series required	Thus the work saved by the total number of repetitions amounted to
104	294	398	41	63
101	285	386	39	62
114	324	438	46	68
109	309	418	38	71
m= 107	303	410	41	66 P.E.$_m$= 1.4

Functionalism

Most historians consider William James (1842–1910) the first figure in the first school of psychology in the United States--functionalism. Functionalism overlaps significantly with both structuralism and behaviorism. James' text, *The Principles of Psychology*[20] (1890), actually predates by two years Titchner's arrival a Cornell. *Principles,* a two volume, twelve hundred page text, makes James as famous and widely studied as Wundt. Functionalism, much like pragmatism, the philosophical movement with which James is also associated, has no central figure, nor a clear-cut doctrine. However, functionalists make important criticisms and contributions to other schools of psychological thought, and do share several common general commitments. (1) Functionalists oppose the search for the basic elements of thought that characterizes Wundt's and Titchener's views. In fact, *Principles* portrays mentality as a stream of consciousness incapable of analysis into elements. (2) Functionalists, in contrast to voluntarists and structuralists, think of the mind as dynamic, and mental processes as serving functions. (3) They view the function of mind through the lens of evolution. Thus, functionalists understand mental processes and behavior in terms of the general goals of adaptation and

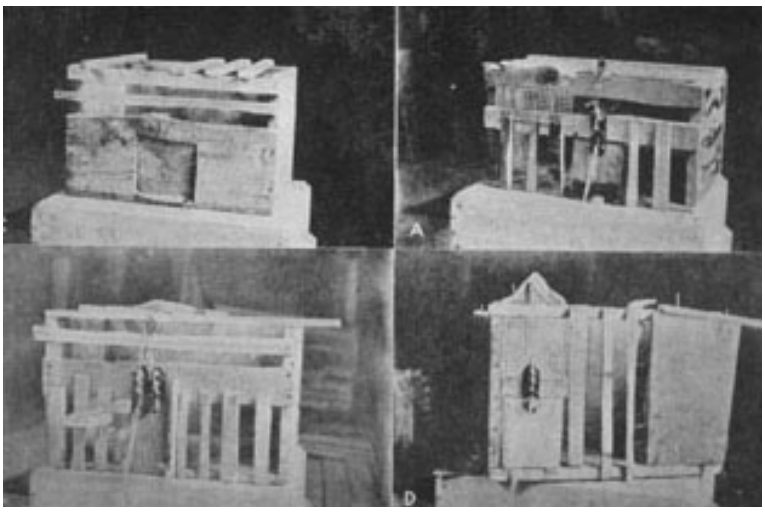
selectional advantage. (4) Unlike the rather rigid determinism of structuralism and behaviorism, functionalism tends to emphasize adaptation and differential responses driven by motivation. (5) Methodologically, functionalists tend to accept both introspection and behavioral observation as methodological tools. Though few early functionalists conduct experiments, later functionalists do conduct experiments. Functionalists also support psychological research on animals, children, and abnormal populations as a means to understand normal human mentality. (7) Finally, unlike Wundt, who views psychology's mission as pure basic research, functionalists tend to see psychology as a means to improve society and people's lives.

William James (1842–1910)

John Dewey (1859-1952)

The functionalists act as a counterweight to both structuralism and behaviorism. For instance, historians often cite John Dewey's "The Reflex Arc Concept in Psychology,"[21] (1896) as the beginning of functionalism. In this article Dewey criticizes the notion of the reflex arc as consisting of discrete stages; stimulus and response. He also anticipates challenges facing behaviorists by noting the difficulties in specify a context-free notion of stimulus and response, i.e., specifications capturing the relevant features of particular stimuli and responses as well as spcifications which predict the generalizations to future cases. Furthermore, the functionalist emphasis on practical applications in psychology, evolution, and diversity in methodology and research areas help to plant the seeds for cognitive science.

Edward Lee Thorndike (1874-1949)



Four of Thorndike's puzzle boxes.

Historians classify Edward Lee Thorndike (1874-1949) as a functionalist. However, much of his

work is arguably the first research on conditioning and is certainly the first work on operant conditioning. Thorndike publishes his dissertation, "Animal Intelligence: An Experimental Studyof the Associative Processes in Animals," in 1898--predating Pavlov's first public reference to conditioned reflexes by approximately a year. Thorndike republishes this work in 1911 as *Animal Intelligence*.[22]

Thorndike studies a number of animals, but he is most famous for his studies of learning in cats using homemade puzzle boxes (above). Thorndike puts a cat in a box, and lets it behave randomly until it stumbles upon the release mechanism. He repeats this procedure until the cat can release itself in negligible time. Thorndike then plots the decline in time to escape relative to times in the box, using this ratio to characterize learning by "learning curves." He formulates his generalized results in terms of the law of effect:[22]

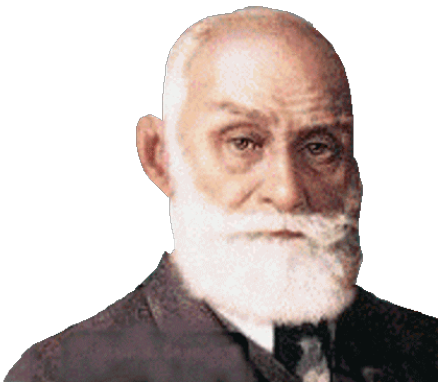
> The Law of Effect is that: Of several responses made to the same situation, those which are accompanied or closely followed by satisfaction to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they will be more likely to recur; those which are accompanied or closely followed by discomfort to the animal will, other things being equal, have their connections with that situation weakened, so that, when it recurs, they will be less likely to occur. The greater the satisfaction or discomfort, the greater the strengthening or weakening of the bond. (p.244)

Behaviorism: Pavlov's Discovery of Classical Conditioning

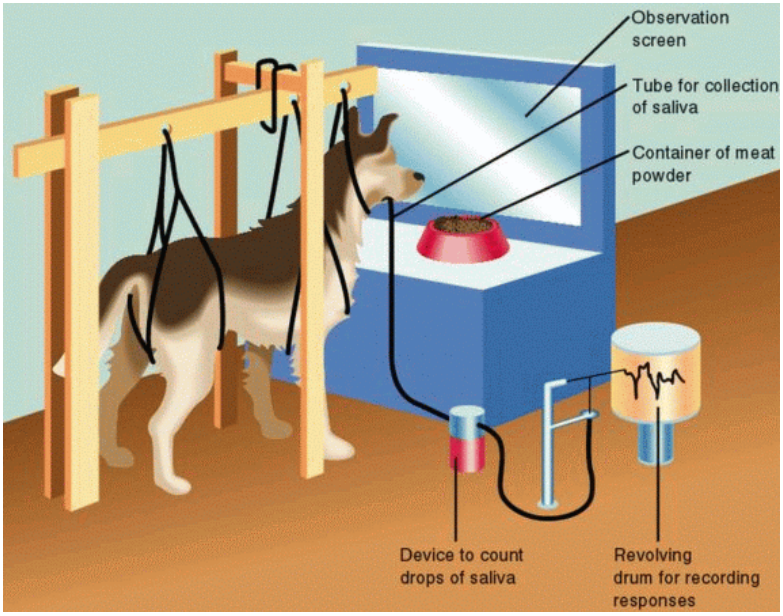
Ironically, it is Ivan Pavlov (1849-1936), a Russian physiologist studying digestion, who provides the key finding around which Behaviorism evolves--classical conditioning.

Pavlov's research includes the physiology and the neurophysiology of temperament, conditioning, and involuntary reflex actions; but the bulk of his work focuses on digestion. Pavlov's experimental research on digestion was innovative and sophisticated. Pavlov's techniques include surgical removal of components of the digestive system from animals to facilitate observations of their functions, lesioning nerve fibers to trace their function by observing the lesion's effects, and implanting fistulas (tubes or holes) draining into pouches to examine the organ's contents. In the 1890's Pavlov's lab is performing experiments on digestion using dogs. Specifically, Pavlov's group is studying the salivatory functions of dogs by surgically externalizing a salivary gland so that the saliva could be collected and analyzed. During their research Pavlov notices that the dogs begin to salivate before receiving food. He calls this phenomena "psychic secretion"[23] (p.7), and the lab begins to investigate this phenomena. The researchers realize that these "psychic secretions" result from associations

between the food and other stimuli. These investigations eventually reveal what Pavlov calls "conditioned reflexes," and we now call classical conditioning.



Ivan Pavlov (1849-1936)



Depiction of Pavlov's experimental apparatus for his studies of digestion. From http://www.simplypsychology.pwp.blueyonder.co.uk/classical-conditioning.html

A picture (left) of one of Pavlov's dogs complete with a fistula and collection chamber. From the Pavlov Museum in Russia. http://en.wikipedia.org/wiki/File:One_of_Pavlov%27s_dogs.jpg

Animation (left) depicting the elements and process of classical conditioning.

Pavlov first mentions his discovery in a lecture to the Society of Russian Doctors of St. Petersburg in 1899. Printed accounts of the research appear in a dissertation by Pavlov's student, Wolfson, and in a report to the 1903 Congress of Natural Sciences by Ivan Tolochinov,[24] Pavlov's collaborator. However, the discovery does not receive significant attention until Pavlov discusses it in his Nobel Prize acceptance speech in 1904. Pavlov's own account does not emerge until he publishes, *Conditioned reflexes: An Investigation of the Physiological Activity of the Cerebral Cortex*[23] in 1927.

As illustrated in the diagram above, classical conditioning works by associating a stimulus that triggers a specific response with a novel stimulus. Specifically, the unconditioned stimulus (US) is a stimulus that elicits a particular response called the unconditioned response (UR). The conditioned stimulus (CS) is paired with the unconditioned stimulus (US) repeatedly. The pairing of the conditioned stimulus (CS) and the unconditioned stimulus (US) elicits the unconditioned response (UR). This repeated pairing increases the association between the conditioned stimulus (CS) and the unconditioned response (UR) reflected in the increasing likelihood of the conditioned stimulus (CS) eliciting the response in and of itself, making the unconditioned response (UR) a conditioned response (CR).

Pavlov also discovers and studies extinction and spontaneous recovery. When one elicits the conditioned response using only the conditioned stimulus, the association between the conditioned stimulus and conditioned response weakness over time. This weakening is called extinction. After an association between a conditioned stimulus and a conditioned response reaches extinction, the conditioned stimulus can elicit a conditioned response at a later time without the intervention of additional conditional pairings; such cases are called spontaneous recovery.

Behaviorism: John Watson

John Watson (1878-1958) adapts the work of Pavlov into a general approach to psychology, which he presents in his 1913 paper, "Psychology as the Behaviorist Views It".[25] Watson embraces the idea of classical conditioning and sets the goal of psychological investigation as the prediction and control of behavior. Additionally, Watson explicitly rejects the project of analyzing conscious experience, and the methodological tool of introspection. Watson describes his view as follows:[25]

> Psychology as the behaviorist views it is a purely objective experimental branch of natural science. Its theoretical goal is the prediction and control of behavior. Introspection forms no essential part of its methods, nor is the scientific value of its data dependent upon the readiness with which they lend themselves to interpretation in terms of consciousness. The behaviorist, in his efforts to get a unitary scheme of animal response, recognizes no dividing line between man and brute. The behavior of man, with all of its refinement and complexity, forms only a part of the behaviorist's total scheme of investigation. (p.158)

While Watson emphatically distances behaviorism from introspectionist psychologies, there are strong similarities under the surface. Watson limits the appropriate phenomena of psychology to behavior, and sets the goals of behaviorism as prediction and control of behavior. However, in practice Watson's treatment of behavior is quite atomistic. Watson divides behavior into

four classes; explicit learned behavior such as riding a bicycle, implicit learned behavior such as a rumbling stomach when smelling someone else's dinner cooking, explicit unlearned behavior such as pulling your hand away when it is hurt, and implicit unlearned behavior such as sweating when it is hot. For the purposes of this class, this chapter focuses upon Watson's theoretical framework for the prediction and control of learned behavior. Watson hypothesizes that one can understand and explain explicit, complex learned behaviors--such as chess playing or language—as a series of simpler learned and unlearned behaviors performed in a sequence cultivated by imitation and classical conditioning. The environment, unlearned behaviors, and conditioning history explain the component simple learned behaviors. For instance, implicit learned behaviors (like a fear response) develop from simple conditioning and appropriate environmental ques. As Watson tells readers of his text, *Behavior: An Introduction to Comparative Psychology[26]* (1914):

> It is useless to ask young children to imitate acts as wholes where the elementary coördinates are lacking or are ill-formed. There must be complete mastery of simple habits,--a readiness to respond to a difficult and complex environmental setting in a variety of ways—the ability to change responses ever so slightly to meet the slightest change in a heretofore well-known object. In order to do this our stock in trade of acts must be much more numerous than the objects to which we respond. … Apparently new coördinations are not established by imitation either in man or in animal. What is new is the combination or method of grouping. Where imitation appears there are found always groups of flexible responses to every object worked with. (p.49)

If this general approach seems familiar, it should. Watson, in effect, proposes an atomistic theoretic framework for behavior; a set of elemental behaviors—unlearned

John Broadus Watson (1878-1958)

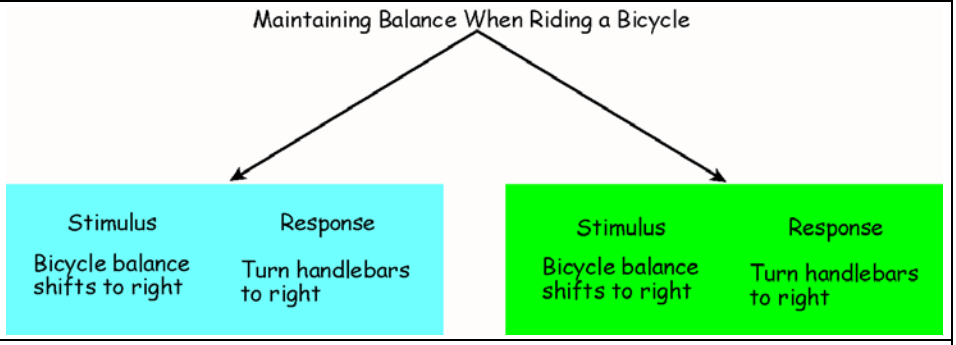


Diagram depicting how a more complex overt behavior, maintaining balance when riding a bicycle, might be analyzed into simpler overt behaviors.

behaviors—from which all the organism generates all learned behaviors through combination and through a process of association based upon contiguity and frequency.

Neo-Behaviorism

Historians classify the behaviorists that follow Watson as neo-behaviorists. One can find the general motivation behind the neo-behaviorist research in the above quote from Watson. On the one hand, Watson seeks to provide a highly mechanistic/deterministic account of the generation of behavior. On the other hand, Watson wants to use his account to explain complex, flexible behavior, including behavior in novel circumstances. Neo-behaviorists seek to expand the basic behaviorist framework to allow for increased flexibility and complexity. For instance, suppose that a researcher trains a rat to associate food with a blue box. Sometimes when presented with the box, the rat does not try to eat. Why doesn't the rat respond all the time? In other words, conditioned associations do not provide necessary conditions for the elicitation of behaviors. Even more problematic, the behaviorist has a difficult time predicting the range and quality of behavioral variation in response to environmental variation (or what psychologists often call stimulus generalization): Will the rat respond to the box when the researcher changes the color or the shape slightly? How much change to the box can occur before the conditioned response is no longer triggered?

Neo-behaviorists continue to view overt behavior as the central phenomena for psychology. They also hold that the prediction and control of behavior remains the central goal of psychology. Learning likewise remains central to psychology. Neo-behaviorists share Watson's conviction that researchers can easily and robustly transfer animal models of learning and perception to humans.

Neo-behaviorists commonalities go beyond Watson as well. For example, neo-behaviorists share Watson's general commitment to grounding psychology in observation. However, unlike Watson, neo-behaviorists seek to tie all theoretical terms—those that one can observe directly and those that one cannot directly observe--to operationalizations, i.e., the experimental operations for the measurement and/or application of those terms. Researchers call this view about the treatment of unobservable theoretical terms operationalism. Operationalists refer to the specification of a set of operations for a theoretical term as an operational definition. Watson and the neo-behaviorists see animal experimentation as essential to psychological research because of the continuity of animal learning and perception with human learning and perception. However, neo-behaviorists see additional value in animal experimentation because it allows for more rigorously controlled experiments.

Lastly, neo-behaviorists differ from Watson and one another in the manner in which they seek to extend behaviorism. Radical behaviorists like B.F. Skinner hold that the prediction and control of behavior must eschew internal, unobservable mental and physiological events.

Methodological behaviorists allow for appeal to internal states so long as those terms are tied to observation.

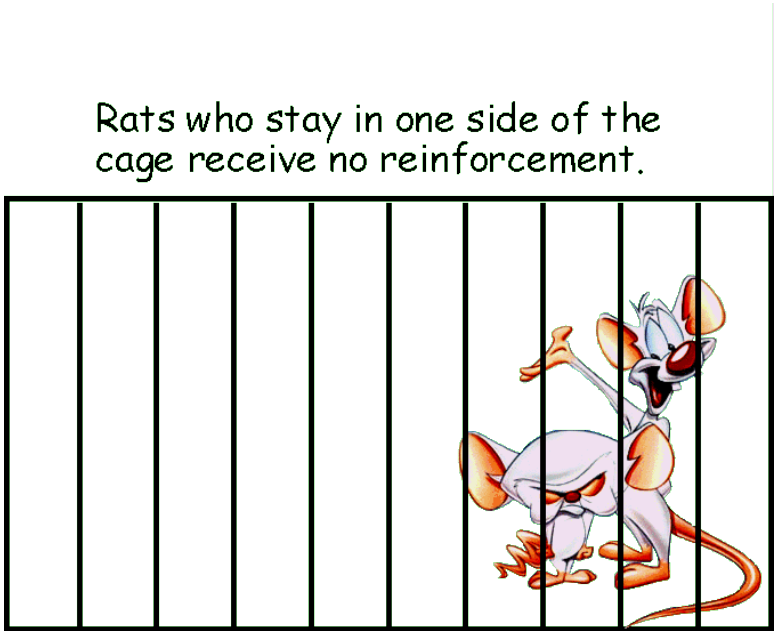
Neo-Behaviorism: Radical Behaviorism

Historians classify Burrhus Frederic "Fred" Skinner (1904-1990) as a neo-behaviorist, though Skinner is very strongly associated with behaviorism in the popular mind. Skinner's association with behaviorism is due in part to his theoretical approach. Like Watson, Skinner insists that theorists focus on predicting and controlling behavior. Likewise, Skinner also supposes that conscious mental states have no part to play in psychological theorizing, insisting instead that environment and conditioning history provide sole basis for the psychological understanding of human conduct.

However, Skinner's theoretical perspective diverges from Watson on several key points. Skinner adopts an approach called "functional analysis" that he traces to Ernst Mach. Functional analysis has a quite different meaning for Skinner than for the theorists we will discuss later. For Skinner functional analysis characterizes dependencies--not meticulously detailed step-wise causal relationships--between observable phenomena, i.e., between conditioning histories and environments. Specifically, Skinner understands functional analysis as a method for establishing relationships between stimuli and responses through the application of operant conditioning. Skinner's analysis is often called a "three-term contingency" analysis in that it characterizes the environmental features that act as a trigger for the behavior (sometimes called the discriminative stimulus), the response (the specific rigorously characterized behavior), and reinforcement (the consequence of the behavior that positively or negatively influences the probability of the behavior in the eliciting conditions). While Watson rejects Thorndike's law of effect as too subjective, Skinner creates a systematic, objective formulation of the learning paradigm--operant conditioning. Unlike Watson, Skinner does not understand behavior as something elicited by environmental stimuli. Rather, Skinner views behavior as active operations on the environment. Likewise, Skinner sees patterns of behavior emerging as a result of those behaviors being selected by contingent environmental reinforcement.

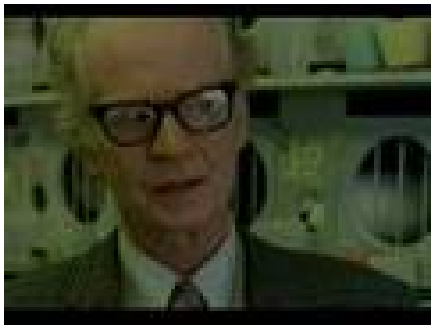
Skinner writes his famous book, *The Behavior of Organisms[27]* (1938), while at his first job at the University of Minnesota. In that book Skinner reformulates Thorndike's law of effect so that it describes environmental selection of behavior through the reinforcement resulting from the behavior. Skinner makes no reference to subjective states like desires, drives, etc. in characterizing reinforcement.

B. F. Skinner (1904-1990)

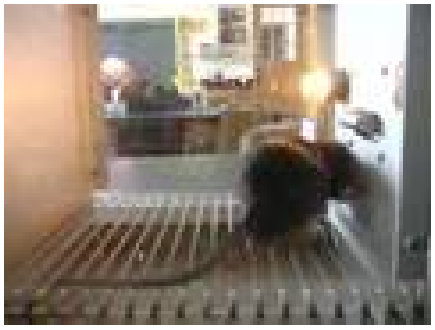


Animation depicting operant conditioning with negative reinforcement.

In operant conditioning a creature's behavior--often random behavior—receives either positive or negative reinforcement (rewarded or punished) from the environment through the behavior's consequences therein. The probability of the behavior occurring again in the presence of the relevant eliciting conditions increases or decreases in proportion to the number of behavior/reinforcement pairings. For example, as depicted in the animation above, a cage might be divided into two sections. Whenever a rat wanders into one section, experimenters administer an electric shock. Over time, the probability that the rat will, for instance, leave that section of the cage whenever placed there increases.



Video of Skinner discussing operant conditioning



Video of rat in a skinner box

Operant conditioning together with classical conditioning broaden the range of learned organism-environment interactions. Classical conditioning provides a mechanism whereby stimuli from the environment can elicit a response, i.e., stimuli cause organism responses. Operant conditioning provides a mechanism whereby behavior becomes part of the organism's repertoire as a function of its consequences, i.e., consequences elicit behaviors.

Part of the lore of cognitive science and behaviorism involves Skinner. In 1957 Skinner publishes a book entitled, *Verbal Behavior*,[28] based upon lectures originally given at the University of Minnesota, further refined at Columbia, and as the lectures William James. Skinner supposes that verbal behavior has no significant and essential differences from other sorts of behavior. For instance, he denies that verbal behavior results from an innate capacity. Skinner proposes to treat verbal behavior using his functional analysis method.

Noam Chomsky (1928-)
From:
http://laist.com/2011/05/06/palestine_and_israel_in_crisis_a_ta.php

In 1959 Noam Chomsky publishes a review of Skinner's book.[29] Often accounts of the development of cognitive science portray Chomsky's review as a refutation of behaviorism and the beginning of cognitive science. Chomsky's review represents an informed, articulate, and forward-looking indictment of the promise of Skinner's functional analysis as a methodology for investigating language. Few authors could hope improve upon Chomsky's articulate formulation of the task facing anyone who seeks to understand language and language acquisition:[29]

> We constantly read and hear new sequences of words, recognize them as sentences, and understand them. It is easy to show that the new events that we accept and understand as sentences are not related to those with which we are familiar by any simple notion of formal (or semantic or statistical) similarity or identity of grammatical frame. Talk of generalization in this case is entirely pointless and empty. It appears that we recognize a new item as a sentence not because it matches some familiar item in any simple way, but because it is generated by the grammar that each individual has somehow and in some form internalized. …
>
> The child who learns a language has in some sense constructed the grammar for himself on the basis of his observation of sentences and nonsentences (i.e., corrections by the verbal community). Study of the actual observed ability of a speaker to distinguish sentences from nonsentences, detect ambiguities, etc., apparently forces us to the conclusion that this grammar is of an extremely complex and abstract character, and that the young child has succeeded in carrying out what from the formal point of view, at least, seems to be a remarkable type of theory construction. Furthermore, this task is accomplished in an astonishingly short time, to a large extent independently of intelligence, and in a comparable way by all children. Any theory of learning must cope with these facts. (pp. 56-57)

Similarly, Chomsky's authoritative and tightly argued paper compels the reader's assent to his evaluation:[29]

> Anyone who seriously approaches the study of linguistic behavior, whether linguist, psychologist, or philosopher, must quickly become aware of the enormous difficulty of stating a problem which will define the area of his investigations, and which will not be

> either completely trivial or hopelessly beyond the range of present-day understanding and technique. In selecting functional analysis as his problem, Skinner has set himself a task of the latter type. (p.55)

However, as we shall see, Chomsky's insightful analysis reflects thinking among many theorists of the time—including behaviorists--with regard to many areas of research. Indeed, other neo-behaviorists seek to further extend the scope of behaviorism, not by finding new learning mechanisms, but by opening the black box in which Skinner's functional analysis places the mind.

Neo-Behaviorism: Hull's Methodological Behaviorism

Clark Leonard Hull (1884-1952) represents a bridge between behaviorism and cognitive psychology. Specifically, Hull and Tolman (next) come to view behavior as goal- oriented, and introduce "intervening variables" between stimulus and response in order to explain behavior. For Hull, unlike Tolman, experimenters must characterize intervening variables as primarily physiological. Hull articulates his vision for psychological theories in an early paper:[30]

> …sound scientific theory has usually led not only to prediction but to control; abstract principles in the long run have led to concrete application. With powerful deductive instruments at our disposal we should be able to predict the outcome of learning not only under untried laboratory conditions, but under as yet untried conditions of practical education. We should be able not only to predict what rats will do in a maze under as yet untried circumstances, but what a man will do under the complex conditions of everyday life. In short, the attainment of a genuinely scientific theory of mammalian behavior offers the promise of development in the understanding and control of human conduct in its immensely varied aspects which will be comparable to the control already achieved over inanimate nature, and of which the modern world is in such dire need. (p.516)


Clark Leonard Hull (1884-1952)

In his *Principles of Behavior*[31] (1943) Hull introduces a mathematical formulation to capture the relationship between environmental situations, intervening variables, and learned responses. The elements of this equation are as follows: Drive, D, (fueled by biological need), Habit Strength, ${}_{S}H_{R}$, (the connection between environmental situation and response measured as the number of pairings), and Reaction Potential, ${}_{S}E_{R}$, (the probability of the subject manifesting a learned response). These yield the equation: ${}_{S}E_{R} = {}_{S}H_{R} \times D$.

Hull operationally defines habit strength as the number of pairings between environmental situation and the response. Drive is operationally defined in terms of the length of deprivation.

Hull continues to introduce additional operationally defined variables to his basic framework throughout his career.

Neo-Behaviorism: Purposive Behaviorism

Like Hull, Edward Chace Tolman (1886-1959), espouses the use of intervening variables in the explanation of behavior. However, Tolman differs from Hull in that Tolman supposes animals have internal states characterizable in terms of their purpose, for instance, expectations and representations. In his article, "A New Formula for Behaviorism,"[32] (1922) Tolman explains his perspective to readers:

> The two essential theses which we wish to maintain in this paper are, first, that such a true non-physiological behaviorism is really possible; and, second, that when it is worked out this new behaviorism will be found capable of covering not merely the results of mental tests, objective measurements of memory, and animal psychology as such, but also all that was valid in the results of the older introspective psychology. And this new formula for behaviorism which we would propose is intended as a formula for *all* of psychology--a formula to bring formal peace, not merely to the animal worker, but also to the addict of imagery and feeling tone. (pp.46-47)

In several of his works Tolman develops and defends three important concepts; expectation, cognitive maps, and latent learning. In his 1932 book, *Purposive Behavior in Animals and Men*,[33] Tolman further refines his view, arguing against Watson that behavior should not be understood in terms of individual conditioned reflexes and their ordered chains. Rather, Tolman suggests that researchers need to understand behaviors as goal-directed acts in which component elements are organized to accomplish a purpose.

In *Purposive Behavior* and in an earlier paper, "Introduction and Removal of Reward, and Maze Performance in Rats,"[34] Tolman also argues that learning can occur without reward or punishment. Specifically, Tolman demonstrates that rats learn the location of food in a maze, and later utilize that knowledge, as a result of wandering around within the maze when they are not hungry. A phenomenon he calls latent learning (p.344).[33, 34]

In the first of an influential series of papers published in the *Journal of Experimental Psychology*,[35-39] (1946-1949) Tolman and colleagues argue that rats learn to negotiate radial mazes in virtue of their developing expectancies. Which they define as:[35]

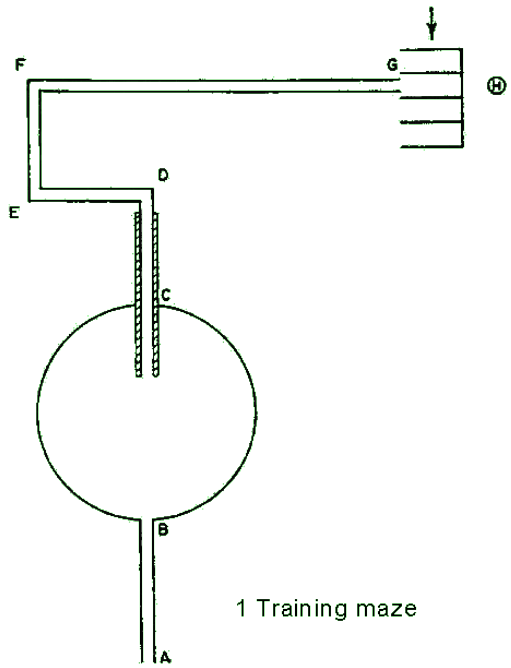
> When we assert that a rat expects food at location *L,* what we assert is that if (1) he is deprived of food, (2) he has been trained on path *P,* (3) he is now put on path *P,* (4) path *P* is now blocked, and (5) there are other paths which lead away from path *P,* one of which points directly to location *L, then* he will run down the path which points directly to location *L.*

When we assert that he does *not* expect food at location *L,* what we assert is that, under the same conditions, he will *not* run down the path which points directly to location *L.* (p.430)

In "Cognitive Maps in Rats and Men"[40] (1948) Tolman introduces the idea of a cognitive map:

Rather, the incoming impulses are usually worked over and elaborated in the central control room into a tentative, cognitive-like map of the environment. And it is this tentative map, indicating routes and paths and environmental relationships, which finally determines what responses, if any, the animal will finally release. (p.192)

Edward Chance Tolman (1886-1959)

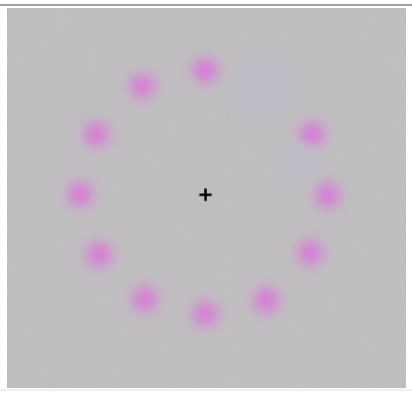


Animation showing 1 the original training maze, 2 the testing maze with the arm blocked, and 3 an overlay of both mazes showing how the choice of arm 6 by rats illustrates their knowledge of the relative position of the room where the food is located.

Gestalt Psychology

Historians general locate the start of Gestalt psychology to the 1912 publication of "Experimentelle Studien über das Sehen von Bewegung" or "Experimental Studies on the Perception of Motion"[41] by Max Wertheimer (1880-1943). Wertheimer conducted this research with his two research assistants, Kurt Koffka and Wolfgang Köhler. The emphasis of

their work is the study of perception, particularly the rules by which perceptual inputs are organized into meaningful wholes. Wertheimer articulates the central doctrines and insights of Gestalt psychology in his classic paper, "*Untersuchungen zur Lehre von der Gestalt"* or "*Laws of Organization in Perceptual Forms"[42]* (1923). Gestalt psychology contributes to the development of cognitive science in two ways. First, Gestalt psychology marks a shift in the study of perception away from pure physiology and psychophysiology towards the cognitive. Second, Gestalt psychologists argue that behavior is driven as much by insight and problem solving as by classical operant conditioning. The influence of gestalt psychologists manifests itself less through a theory than through an ever increasing body of perceptual and learning phenomena that resist explanation by either introspective techniques or by the reflexive techniques of behaviorists. For instance, Wertheimer articulates several basic principles by which perceptual forms seem to be organized in Laws of Organization, such as the factor of closure (below), but he does not offer an overarching framework for understanding vision.

		
Max Wertheimer (1880-1943)	Animated gif illustrating the phi phenomenon explored in "Experimental Studies on the Perception of Motion." In the phi phenomena properly sequenced lights give rise to the perception of motion.	Examples illustrating the law of closure in which objects grouped together in perception are seen as a whole.

Wolfgang Köhler (1887-1967), contributes greatly to the development of Gestalt psychology. However, it is through his book, *The Mentality of Apes[43]* (1917), that he makes his greatest contribution to the development of cognitive science. In his book Köhler describes the behaviors of various chimpanzees at the Prussian Academy of Sciences anthropoid research station. He argues that these animals seem to learn by insight and problem solving more than by Thorndike's trial and error. Among the researchers Köhler influences is a young Tolman, whose two review papers called "Habit Formation and Higher Mental Processes in Animals,"[44, 45] incorporate the idea of insightful learning, and analyze results of researchers who replicate and extend Köhler's experiments.

	
Wolfgang Köhler (1887-1967)	Pictures taken from *The Mentality of Apes* showing chimpanzees using various techniques like stacking boxes to reach suspended fruit.

The Mathematical Analysis of Communication and Control

As we will see in the chapters on the development of the formal treatment of computing and the development of computers, mathematical and techinical developments greatly facilitate the emergence of an information processing account of cognition. For now, we will consider only four figures central to the development of information theory and cybernetics. The work of these theorists plays a central role in early information processes accounts because the researchers intended their research to have wide applicability, including both artifical biological systems.

Norbert Wiener (1894-1964), a mathematician, represents an important influence as well as a general trend; after WWII research on human performance of skill-based tasks increases dramatically. These tasks lend themselves to characterization as information processing tasks. Wiener's 1943 article, "Behavior, Purpose and Teleology"[46] and his 1948 book, *Cybernetics: or Control and Communication in the Animal and the Machine*[47] represent one important and influential first step in this direction.

In *Cybernetics* and *Behavior* Wiener introduces such terms as "input" and "output" in outlining his interdisciplinary approach to the study of complex, goal-oriented systems. Cybernetics views such systems as complex systems interacting continuously with the environment through such mechanisms as communication, control, feedback, and self-organization.

Historians often cite the publication of "Behavior, Purpose and Teleology" together with the publication of "A Logical Calculus of the Ideas Immanent in Nervous Activity"[48] by Warren Sturgis McCulloch (1898-1969) and Walter Pitts (1923-1969) as the beginning of the Cybernetics movement in the 20th century.

In their paper McCulloch and Pitts show how, by interpreting neuronal activity as on-off (or binary), one can show how[48]

> The "all-or-none" law of nervous activity is sufficient to insure that the activity of any neuron may be represented as a proposition. Physiological relations existing among nervous activities correspond, of course, to relations among the propositions; and the utility of the representation depends upon the identity of these relations with those of the logic of propositions. To each reaction of any neuron there is a corresponding assertion of a simple proposition. This, in turn, implies either some other simple proposition or the disjunction or the conjunction, with or without negation, of similar propositions, according to the configuration of the synapses upon and the threshold of the neuron in question. (p.117)

From these results McCulloch and Pitts conclude:[48] "Thus, in psychology, introspective, behavioristic, or physiological the fundamental relations are those of two-valued logic." (p.131) In addition, McCulloch and Pitts show how logical functions could be computed by circuits created from neurons (see below).

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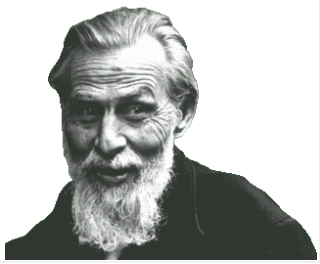
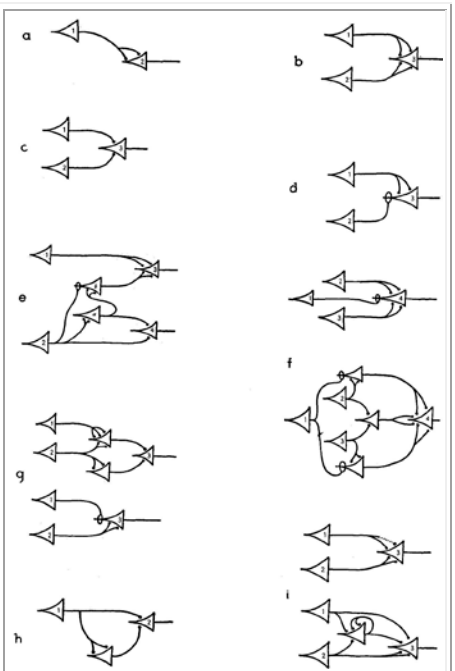
<td>  </td>
<td rowspan="2">  </td>
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<td>Norbert Wiener (1894-1964)</td>
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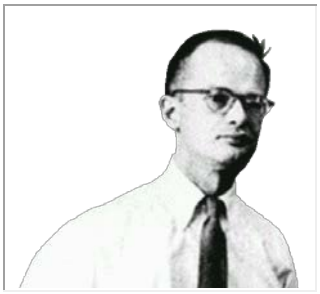
<td>  </td>
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<td>Walter Pitts (1923-1969)</td>
<td>Claude Shannon (1916-2001)</td>
<td>Diagram of neuronal circuits from McCulloch and Pitts</td>
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Claude Shannon (1916-2001), yet another mathematician, lays the foundations of information theory in his 1948 paper, "A Mathematical Theory of Communication."[49] The theory is specifically intended to address the problem of transmitting information over a noisy channel. However, it influences theories of perception and mental representation as well as adding to the general conception of information processing as a central feature of mentality.

These four men have an additional connection in that they were all at MIT in 1956, when one of the significant conferences in the development of cognitive science occurs—The Second Symposium on Information Theory. While there are a number of important conferences during this period in both the United States and Britain, many historians point to the MIT conference in particular.

Information Processing Psychology

Donald Eric Broadbent (1926-1993), an English experimental psychologist publishes his book, *Perception and Communication*,[50] in 1958. It outlines theories of selective attention and short-term memory using computer analogies. Among the contributions in Broadbent's book is his filter theory of attention and memory. On Broadbent's theory, the brain holds simultaneously presented sensory input in a short-term sensory memory acting like a recurrent circuit. These inputs can be retained through rehearsal, but will disappear once allowed to degrade. Input in the sensory memory can pass through a filter selecting for specific physical signal characteristics, at which point the input enters a limited capacity channel for additional processing. Once analyzed for meaning, it enters conscious awareness. Broadbent's model proves important in two respects: First, it suggests that the brain actively selects among information. Second, it suggests that the brain has real limitations in the amount of information it can process.

Donald Eric Broadbent (1926-1993)

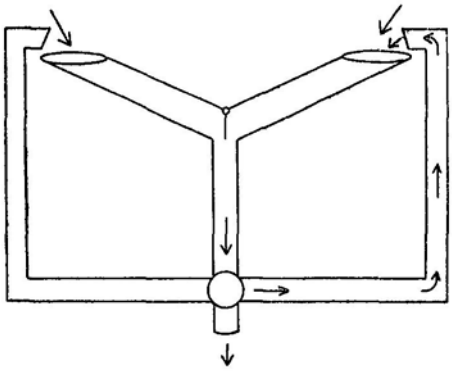

FIG. 2. The model modified to illustrate the theory of immediate memory as a recurrent circuit; or, in other terms, as a fading trace periodically revived by rehearsal.

A figure from Broadbent's "A Mechanical Model for Human Attention and Immediate Memory"[51] illustrating his theory.

George Armitage Miller (1920-), presents a paper at the 1956 MIT conference, "The Magical Number Seven, Plus or Minus Two,"[52] which he publishes later that year. The paper outlines experimental work by Miller and others showing that short-term memory (STM) has a capacity of seven items plus or minus two items. Miller also determines that chunking--linking individual items together--allows more complex items to be stored as single items, and improves recall. Miller's paper is framed within information theory.

In the paper's summary, Miller tells readers that

> ...the span of absolute judgment and the span of immediate memory impose severe limitations on the amount of information that we are able to receive, process, and remember. By organizing the stimulus input simultaneously into several dimensions and successively into a sequence or chunks, we manage to break (or at least stretch) this informational bottleneck. (p.95)

Miller goes on to co-found the Center for Cognitive Studies at Harvard and publishes an important book, *Plans and the Structure of Behavior*,[53] in 1960. *Plans* explores the potential of cybernetics in psychology through formulating many basic psychological process in terms of plans. They begin their first chapter by telling readers:[53]

> The authors of this book believe that the plans you make are interesting and that they probably have some relation to how you actually spend your time during the day. You imagine what your day is going to be and you make plans to cope with it. A Plan is any hierarchical process in the organism that can control the order in which a sequence of operations is to be performed. The image is all the accumulated, organized knowledge that the organism has about itself and its world. This chapter considers what modern psychology has to say about images and plans. (p.5)

Development as Inherently Cognitive

Jean Piaget (1896-1980), a Swiss "natural scientist" (that was his Ph.D. title) studies intellectual development in children as early as 1927. His research into development as well as his invention of experimental paradigms and demonstrations resist both introspective and behavioral explanation. Piaget suggests that the human intellect develops through a series of stages. According to Piaget's theory, humans progress through a series of developmental stages. Each stage represents a movement towards more abstract symbolic forms of reasoning, and is characterized by a particular schema or structure through which the person interacts with, and understands, the world.

Piaget considers himself an epistemologist, and writes an number of works in epistemology. His orientation in investigating development through schemas for understanding the world represents a European tradition with its origins in Kant. Similar research in other areas of development, for instance, in language acquisition, likewise challenge introspective and behaviorist perspectives both in terms of the breadth and robustness of development as well as regular timeframes in which development seems to occur.

Jean Piaget
(1896-1980)

Ulric Neisser
(1928-)

The Final Step

Ulric Neisser (1928-), a student of Miller, helps to catalyze and popularize cognitive psychology when his book, *Cognitive Psychology*,[54] is published in 1967. In that book, Neisser tells readers that[54] “Cognitive Psychology refers to all processes by which the sensory input is transformed, reduced elaborated, stored, recovered, and used.” (p.4) Neisser attempts to integrate work from areas like perception, thinking, concept formation, and linguistics within a general information-processing framework. For instance, Niesser characterizes the research project of the cognitive psychologists by telling readers that

> The task of a psychologist in trying to understand human cognition is analogous to that of a man trying to discover how a computer has been programmed. In particular, if the program seems to store and re-use information, he would like to know by what "routines" or "procedures" this is done. Given this purpose, he will not care much whether his particular computer stores information in magnetic cores or in thin films; he wants to understand the program, not the "hardware". By the same token, it would not help the psychologist to know that memory is carried by RNA as opposed to some other medium. He wants to understand its utilization, not its incarnation. (p.6)

Three years after Neisser publishes *Cognitive Psychology* the journal *Cognitive Psychology* comes into being in 1970. Needless to say, single events like Neisser's book or the founding of a journal do not mark a sudden transformation in psychology. Rather, such events are merely

indicative of widespread and temporally extended changes within psychology. Likewise, the cognitive psychology envisioned by Niesser in the above quote differs from the cognitive psychology and cognitive science we find today. For example, the idea that one can ignore the "hardware" in understanding the software has proven incorrect.

As we have seen, the development of cognitive psychology requires several factors to come together; the development of experimental methodologies, the refinement of animal and other models, and increased knowledge of human mentality, development, and physiology, and the development of technical ideas such as information and computation. The coalescing of these factors allows for the conceptual framing of cognitive phenomena as well as its systematic experimental investigation.

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