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The Influence of German-Speaking Émigrés on the Emergence of Cognitive Science as a New Interdisciplinary Field

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Abstract

During the 1950s, the scientific world experienced a shift in the study of the mind in what is now called the cognitive revolution. While common belief claims a rise of novel approaches, this is only partially true. A number of notions which built the foundation for cognitive studies were already present in the prior century in German schools. Research of developments of these traditions and concepts leading up to the cognitive revolution also showed that certain key figures in psychology and mathematics taught in Germany and by means of often forced emigration carried over the ideas that sparked in early German research centres. This article gives an overview of the development leading up to the cognitive revolution and the émigrés involved.

Introduction[1]

With the rise of National Socialism in Germany and neighbouring countries during the first half of the twentieth century, numerous academics and scientists were forced out of their positions and had to flee their home country. Subsequently, a large number of trained scientists migrated to North America.[2] Some of those who managed to integrate themselves in this new environment had a lasting influence on the natural sciences. Shortly after the Second World War, in the 1950s, North America became the scene for what we now call the cognitive revolution and from which, among other things, a new, interdisciplinary science arose — cognitive science.[3]

This article spotlights some of those individuals, their theories, and their contributions to the field. First, it will explain the scope and provide a brief history of cognitive science as well as its course today. Second, it will continue with brief historical accounts of contemporary psychology and of the development of the computer. Certainly, other disciplines also contributed a great deal to cognitive science, but the

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[1] I warmly thank Dr. Uwe Meyer at the University of Osnabrueck, Germany, as well as Dr. Frank W. Stahnisch at the University of Calgary, Canada, for their helpful comments on previous manuscript versions of this article. Furthermore, I extend my gratitude to the three external reviewers for *History of Intellectual Culture*, since their comments aided tremendously in improving the manuscript further.

[2] Mitchell G. Ash and Alfons Soellner, eds., *Forced Migration and Scientific Change* (Cambridge, UK: Cambridge University Press, 1996).

[3] Howard Gardner, *The Mind's New Science* (New York: Basic Books, 1985), 10–45.

merger of psychology with new advancements in computer science seems to be the primary development in the new science of mind.

Third, while going through milestones of these histories, the article will identify several individuals in these disciplines who shared the fate of emigrating to the United States from Central Europe.[4] It will examine at which European schools they were taught and where they migrated to in North America. Finally, the article will look at their work and involvement in specific university hotspots of cognitive science in North America, while showing that certain ideas that contributed to the creation of cognitive science build on concepts that sparked in early German centres of mathematics and psychology research. Many of these ideas were partially or fully transferred by these emigrating scientists to universities in North America such as Cornell University in Ithaca, New York; Princeton University in New Jersey; and Massachusetts Institute of Technology (MIT) and Harvard University in Cambridge, Massachusetts.

What Is Cognitive Science?

When we examine cognitive science, we must understand the history, the name, and the scope of this research field. However, we face a controversial conundrum. The scope of the field has fluctuated since its beginnings in the mid-twentieth century, and each scientist associated with it appears to have had a different opinion of what topics and methods are appropriate for the agenda.[5] Also, because cognitive science became an institutionalized discipline only in the late twentieth century, it is likely still subject to constant changes. While nowadays the scope appears to encompass all approaches to conceptualizing the brain and other, artificial, complex systems by combining methods and insights from several disciplines, the agenda has changed over time. The beginning of this endeavour is thus difficult to pinpoint, as are the first realizations that the fusion of disciplines is more than helpful and that we can learn much from comparisons with artificial machines and use them as tools for our benefit.

The recent history of cognitive science, however, starts in the late 1940s, when a number of conferences known as the Macy Conferences were held in New York to discuss and create a new science that at the time was called cybernetics. The mathematician and cofounder Norbert Wiener (1894–1964) defined cybernetics as "the scientific study of control and communication in the animal and the machine."[6] Later, in 1948, the founders of cybernetics participated in the famous Hixon Symposium on Cerebral Mechanisms in Behaviour at the California Institute of Technology, to discuss parallels between the human mind and machines. In the literature, however, the founding year is often given as 1956.[7] One could even go further, as the psychologist George A. Miller (1920–2012) has done, and refer to a specific day, 11 September 1956, where he and many other leading scientists from several disciplines gathered at the Symposium on Information Theory at MIT to discuss research that would later mark milestones in the creation of this novel research field.[8]

The groundwork for the developments that led to these meetings which revived the study of cognitive phenomena was laid out in the nineteenth century; certainly in the 1940s and 1950s, however, this interdisciplinary inquiry started coming together. In 1960 George A. Miller, together with the psychologist Jerome Bruner (1915–2016), founded the Harvard Center for Cognitive Studies — the first interdisciplinary

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[4] See Appendices 1 & 2 of this article for tables of contributing émigrés.
[5] See Allan Collins, "Why Cognitive Science," *Cognitive Science* 1, 1 (1977): 1–2; Donald A. Norman and David E. Rumelhart, *Explorations in Cognition,* (San Francisco: Freeman, 1975), 409.
[6] Norbert Wiener, *Cybernetics; Or, Control and Communication in the Animal and the Machine* (New York: MIT Press, 1961).
[7] Gardner, *The Mind's New Science*.
[8] George A. Miller, "A Very Personal History," talk to Cognitive Science Workshop (Cambridge, MA: MIT Press, 1979); *Edward A. Feigenbaum Papers* (Stanford University Libraries Online Collection, 1981).

research centre concerned with the problems that today constitute cognitive science. At that time, the American school of behaviourist psychologist Burrhus Frederic Skinner (1904–1990) was still very popular, and hardliners of this branch of psychology would clearly differentiate cognition both from internal processes such as motivation and emotion and from bodily action.[9] When choosing the name "cognitive" for their research centre, Bruner and Miller wanted to clearly set themselves apart from this behaviourist movement; they did not mean to imply studying cognition exclusively, and explicitly wanted to include motivation and emotion.[10] Thus, the name "cognitive studies," which literally would mean the study of knowledge while disregarding the motivational and emotional aspects of the mind, may seem misleading at first.

By the mid-1970s the holistic approach to cognitive science was clearly forming into its own academic discipline, and the revival of the study of cognition and mental phenomena had become immensely popular over the preceding two decades, in what became known as the cognitive revolution.[11] The term "cognitive science(s)" was coined by the chemist and cognitive scientist Hugh Christopher Longuet-Higgins (1932–2004) in 1973 and has since stuck with the discipline.[12] In 1977, the Alfred P. Sloan Foundation embarked on a multi-year program, investing millions into the strengthening and creation of institutions of cognitive science all over the United States.[13] George A. Miller, this time in cooperation with the linguist Samuel J. Keyser, in a report to the advisers of the Sloan Foundation defined cognitive science as the "study of the principles by which intelligent entities interact with their environments." They also identified anthropology, artificial intelligence, linguistics, neuroscience, philosophy, and psychology as the main contributing sub-domains, whose "richly articulated pattern of interconnection" and "common research objective: to discover the representational and computational capacities of the mind and their structural and functional representation in the brain bring forth the novel discipline of cognitive science."[14]

The importance of the influence of each of these sub-disciplines on cognitive science has changed through time and as Keyser and Miller's definition of the scope of cognitive science has been refined.[15] Most certainly, minor discrepancies, depending on which historian or cognitive scientist is consulted, will always occur. This breakdown into six disciplines, as well as the representational approach based on the mind-as-machine analogy, which relies on the implicit premise that cognitive processes are mere computations that can be done by the neurons of a brain as well as the hardware of a computer, are still relevant today.[16] Over the years, cognitive science has broadened its scope from original subjects of studies such as problem solving, language representation, deductive thinking, and memory to include motivation, emotion, volition, dreams, perception, human computer interaction, neuromodulation, machine learning, and more,

[9] Sven Walter, Introduction to the *Handbuch Kognitionswissenschaft*, eds. Achim Stephan and Sven Walter (Stuttgart: Metzler, 2013), 1–5.

[10] Bernard Baars, Interview with George Miller, in *The Cognitive Revolution in Psychology* (New York: Guilford Press, 1986), 200–23.

[11] Thomas Sturm and Horst Gundlach, "Urspruenge und Anfaenge der Kognitionswissenschaft," in Stephan and Walter, *Handbuch Kognitionswissenschaft*; Bernard J. Baars, *The Cognitive Revolution in Psychology* (New York: Guilford Press, 1986); Margaret A. Boden, *Mind as Machine* (Oxford: Clarendon Press, 2006), or Gardner, *The Mind's New Science*.

[12] Longuet-Higgins talked of the sub-domains as cognitive sciences, in their plural form, however proposed in the next sentence the singular form: "in view of the ultimate impossibility of viewing any of these subjects in isolation." Hugh Christopher Longuet-Higgins, "Comments on the Lighthill Report and Sutherland Reply," *Science Research Council* 1 (1973), 37.

[13] *Alfred P. Sloan Foundation: A Grantmaking History, 1934–2009* (New York: Alfred P. Sloan Foundation, 2009), 25–28.

[14] Samuel J. Keyser and George A. Miller, *Cognitive Science 1978* (Unpublished report of the State of the Art Committee to the Advisors of The Alfred P. Sloan Foundation, 1978), 3–6.

[15] Boden, *Mind as Machine*, 9–16; Gardner, *The Mind's New Science;* Collins, "Why Cognitive Science"; George A. Miller, "The Cognitive Revolution: A Historical Perspective," *Trends in Cognitive Science* 7, 3 (2003).

[16] Miller, "The Cognitive Revolution."

as well as giving rise in more recent years to further specialized fields such as neuroinformatics, psycholinguistics, computational linguistics, cognitive neuroscience, and neurophilosophy. The foundation for this approach to the study of the mind, however, was in no sense new, but had been around since the end of the nineteenth century, when the basis was laid for "one of the most exciting and fruitful areas of interdisciplinary research in the history of science,"[17] in Germany with the founding of psychology as an institutionalized discipline.[18]

Overview of the Contemporary History of Psychology

This article will not give an extensive account of the history of psychology or the founding of this discipline.[19] Nevertheless, a brief overview of the beginnings of experimental psychology is needed, through addressing points relevant to its development and influence on cognitive science. While the origin of cognitive science lies far in the past, with theoretical approaches to explaining phenomena of the mind dating back to Ancient Greece and Rome, empirical examinations did not appear until the mid-nineteenth century, in the laboratories of philosophy and physiology. Previously, matters of the mind had been mainly approached by philosophers. A group of German scholars, Jakob Friedrich Fries (1773–1843), Johann Friedrich Herbart (1776–1841), and Friedrich Eduard Beneke (1798–1854), however, tried to merge philosophy and physiology in order to conceptualize a scientific psychology.[20] The work of the physicist and physiologist Hermann von Helmholtz (1821–1894) built on these attempts. Helmholtz conducted experiments on severed frog legs, for example, where he measured the precise time for an impulse to travel along the nerves. He further conducted research on cognition, which showed that visual perception adjusted to prismatic distortions. Despite popular beliefs to the contrary, based on the works of Koenigsberg philosopher Immanuel Kant (1724–1804), empirical examination of certain aspects of human mental functioning, such as sensory perception, seemed possible. Helmholtz's work set the stage for further inquiries and the merged field of psychophysiology.[21] Also in Germany, the experimental physiologist Gustav Theodor Fechner (1801–1887) laid the groundwork for a mathematically based experimental psychology by studying how humans psychologically perceive differences in stimulation intensities. With his research proposal, he initiated the new research field of psychophysics.[22]

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[17] Keith Frankish and William M. Ramsey, eds., *The Cambridge Handbook of Cognitive Science,* 1; Sturm and Gundlach, "Urspruenge und Anfaenge."

[18] Boden, *Mind as Machine*; cf. Gardner, *The Mind's New Science*; Baars, *Cognitive Revolution*.

[19] For extensive histories of the development of psychology see Edwin Garrigues Boring, *A History of Experimental Psychology*, 2nd ed. (New York: Appleton-Century-Crofts, 1950); Raymond E. Fancher, *Pioneers of Psychology* (New York: Norton, 1979); Thomas Hardy Leahey, *A History of Modern Psychology*, 2nd ed. (Englewood Cliffs, NJ: Prentice Hall, 1994).

[20] David E. Leary, "The Philosophical Development of the Conception of Psychology in Germany, 1780–1850," *Journal of the History of the Behavioural Sciences* 14 (1973): 113–21; Adele Abrahamson and William Bechtel, "History and Core Themes," in *The Cambridge Handbook of Cognitive Science,* ed. Keith Frankish and William M. Ramsey (Cambridge, UK: Cambridge University Press, 2012), 9–28.

[21] Fancher, *Pioneers of Psychology*.

[22] John D. Greenwood, "Physiology and Psychology," in *A Conceptual History of Psychology* (New York: McGraw-Hill Higher Education, 2009); Gardner, *The Mind's New Science;* Duane P. Schultz, "Physiological Influences on Physiology," in *A History of Modern Psychology*, ed. Duane P. Schultz (New York: Academic Press, 1969); Wade E. Pickren and Alexandra Rutherford, "Subject Matter, Methods, and the Making of a New Science," in *A History of Modern Psychology in Context* (Hoboken, NJ: John Wiley, 2010); Jaan Valsiner, "The Mirror in the Making: Psychology as a Liminal Science," in *A Guided Science – History of Psychology in the Mirror of its Making*, ed. Jaan Valsiner (New Brunswick, NJ: Transaction, 2012); Jean Mandler and George Mandler, *Thinking: From Association to Gestalt* (New York: Wiley, 1964).

The Dutch ophthalmologist Franciscus Cornelis Donders (1808–1889) recorded in experimental studies that subjects reacted more quickly to simple-reaction tasks and took longer to react to choice-reaction tasks. This led to his proposal in the 1860s that one could even measure the duration of complex mental activities. These early, bottom-up approaches set the stage for a mechanistic view of the mind driven by an ideology of measurement and only being visibly challenged by the hermeneutic philosopher Franz Clemens Brentano (1838–1917) in the late nineteenth century. Brentano criticized the emerging mechanistic interpretation of the mind and completely rejected the idea that activities of the mind could be broken down into reductive knowledge sets. While psychology as a subject had then existed for almost five decades, a colleague of von Helmholtz and Fechner in Leipzig, Wilhelm Wundt (1832–1920), in 1879 was the first to create an institution solely dedicated to experimental psychology.[23] It was quickly followed by Georg Elias Mueller's (1850–1934) laboratories in Goettingen in 1881, and several institutions in Boston and Baltimore in the 1880s.[24] In 1873 Wundt also published the first textbook on experimental psychology, *Principles of Physiological Psychology,* which laid out the teaching canon for the new discipline.[25] His tremendous impact on popularizing psychology was in part due to the success of his many students. While Wundt, despite some reservations, used an introspective and partly subjective method in his experiments, his student Edward B. Titchener (1867–1927) rejected these reservations and relied solely on introspection.[26] For most of his working life Titchener taught at Cornell University in New York, where he continued Wundt's work through his school of psychology called structuralism, which aimed to explain conscious experience by breaking it down into small, basic elements of consciousness. Although gaining some publicity, this approach to studying the qualitative aspects of psychology seemed less popular in the United States than in Europe. [27]

Other national and international students of Wilhelm Wundt criticized Wundt's and Titchener's experimental approaches , as well as their theoretical foundation in the earlier philosophical school of associationism.[28] They also opened up higher mental processes to examination, which many of their scientific predecessors had deemed impossible by experimental research. This movement, mainly based at the University of Wuerzburg, became known as the Wuerzburg school of psychophysiology. The resulting criticisms led to a rethinking of experimental methods used in these schools to create a less subjective way of conducting empirical research. At the beginning of the twentieth century in Berlin a distinctly new approach to explaining perceptual phenomena was formulated. Known as the Gestalt movement, led by Max Wertheimer (1880–1943) and Wolfgang Koehler (1887–1967), this more holistic approach saw perception as determined by the configuration of the whole set of psychological and mental processes rather than their parts. Their line of studies evolved to incorporate problems of mental processes other than perception. In particular, the Gestalt school's approaches to problem solving became highly influential in the twentieth century.

Around the same time, Frederic Bartlett (1886–1969) conducted many experiments on memory at the University of Cambridge in England, from which he developed a theory that incorporated many social aspects, leading to a hierarchically ordered model of memory involving abstract patterns created by prior encounters of the subject with the environment. Another famous psychologist whose research continuously embraced cognitive processes, was the French Swiss Jean Piaget (1896–1980), who, beginning in the 1920s,

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[23] Greenwood, "Physiology and Psychology."

[24] James McKeen Cattell, "Early Psychological Laboratories," *Science* 67, 5 (1928), 543–8.

[25] See Wilhelm Wundt, *Principles of Physiological Psychology* (London: S. Sonnenschein; New York: Macmillan, 1904). Originally published as *Die Grundzuege der physiologischen Psychologie* in 1873.

[26] Fancher, *Pioneers of Psychology*, 171.

[27] Hornstein, Gail A., "Quantifying Psychological Phenomena," in *The Rise of Experimentation in American Psychology,* ed. Jill Morawski (New Haven, CT: Yale University Press, 1988), 1–25.

[28] Mandler and Mandler, *Thinking*; Gardner, *The Mind's New Science*.

studied the development of thinking in children.[29]

In America, the new discipline of psychology took a different turn. William James (1842–1910), a psychologist and philosopher, established a pragmatic approach to psychology in the late nineteenth century, as a counter-movement to Wundt's and Titchener's schools. He was more concerned with the functions of mental life rather than its structure or content. Subsequently his school became known as functionalism. Only a few decades later, however, his functionalist school was superseded by one of the major psychological movements of the twentieth century. This came in the form of John B. Watson's (1878–1958) behaviourism in 1913 and his subsequent trainees and followers. They proposed that psychology should be concerned less with the mind, and more with reactions posed to stimuli, redefining psychology to accommodate their dissociation from the study of consciousness to the study of behaviour.[30] Within this movement, which became known as behaviourism and encompassed most of the psychological research in America until the rise of cognitive psychology, were Karl Lashley (1890–1958), who would hold professorships at the universities of Minnesota, Chicago, and Harvard, and Edward Tolman (1886–1959), who studied for a time in Germany and for most of his career taught at the University of California at Berkeley. The prominence of the behaviourist approach, and later radicalization in related ideas by the work of psychologists such as B.F. Skinner in the United States, could lead to the assumption that the existence of cognitive states and cognitive processes were completely denied during this period of psychological research. However, especially in Europe, behaviourism was less influential elsewhere than in North America, and the schools of Wundt, Wuerzburg, and the Gestalt psychologists still enjoyed considerable influence in the West.[31] While this situation did not directly lead to a return to these ideas, progressions of those theories were partially reintegrated in the development of psychology in post-war America.

Cognitive psychology was essentially conceived during the 1950s, and with the emergence of cognitive science a new interest in the study of cognition emerged, which re-embraced the study of mental processes. Especially important were two works. George A. Miller's 1956 paper on memory, entitled *The Magical Number Seven, Plus or Minus Two*,[32] explored human working memory capability and showed that it is limited to around seven items, give or take two. Another ground-breaking work was by Jerome Bruner, who had been strongly influenced by Bartlett and Piaget. His 1956 *Study of Thinking* treated perception as a cognitive process. It set a clear break from stimulus-response patterns of behaviourists. Cognitive psychology was eventually defined in Ulric Neisser's (1928–2012) work under the same name.[33] From then on cognitive psychology and cognitive science became progressively institutionalized, and by 1970 cognitive psychology acquired its first journal. The émigré forerunners of this development from the foundational German schools will be discussed in the next section.

The Progression of Experimental Psychology from Leipzig to Wuerzburg in Germany

As mentioned previously, the first institute for experimental psychology emerged in Leipzig. Thus, it seemed natural that the training of a majority of psychologists could be traced back to Hermann von Helmholtz in Heidelberg and Berlin, or Theodor Fechner and especially Wilhelm Wundt in Leipzig. Wundt above all educated many scholars who continued work all around the world, including in the United States, Canada, Brazil, Russia, and Japan. Lists of his Leipzig graduate students show more than 110 doctoral

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[29] Gardner, *The Mind's New Science*, 109–27.

[30] John B. Watson, "Psychology as the Behaviorist Views It," *Psychological Review* 20, 1 (1913): 158–77.

[31] Sturm and Gundlach, "Urspruenge und Anfaenge."

[32] George A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *Psychological Review* 63, 1 (1956): 81–97.

[33] Ulric Neisser, *Cognitive Psychology* (New York: Appleton-Century-Crofts, 1967).

theses in psychology under his supervision being accepted between 1875 and 1919.[34] Among the most notable were Edward Bradford Titchener (1892), James McKeen Cattell (1886; 1860–1944), and Hugo Muensterberg (1885; 1863–1910), who all later worked in the United States, as well as Oswald Kuelpe (1887, 1862–1915) who helped to further develop the Wuerzburg school in psychology. Overall, Wundt advised an enormous number of students: at least 136 German-speaking graduate students and fourteen American and ten English graduate students and trainees.

Oswald Kuelpe's dissertation was accepted in Leipzig in 1887, under the title of *Zur Theorie der sinnlichen Gefuehle* (On the Theory of Sensory Feelings).[35] He had apparently developed the topic when studying under Georg Elias Mueller[36] — by this time the head of the recently established institute for experimental psychology in Goettingen — between 1883 and 1885.[37] Kuelpe was a very dedicated experimental psychologist and became a leading figure in the founding of the highly influential school of psychology in Wuerzburg in 1896.

While Fechner concentrated on combining mathematics with psychology in trying to establish an experimental psychological research program and helped to fund psychophysics, Helmholtz was not mainly concerned with psychological work. His studies on perception of space and his theory of unconscious inference made way for a molecular approach, which used of elemental units for the examination of psychological processes. The theory of unconscious inference claimed that not only do we read our environment, but also that our perception is affected by past, "interior" knowledge. Both Fechner and Helmholtz brought certain psychological phenomena into lawful relationships with physical data and research approaches, and they studied the relationship of the physical reality and conscious human experiences of this reality. Their younger colleague, Wilhelm Wundt, held experiments to test for simple processes by means of systematic self-observation. Together, their research programs began to steadily question the validity of theoretical mind-body dualism. As mentioned, his American student Bradford Titchener became a radical introspectionist, while Wundt retained reservations on the validity of this method throughout his academic career.[38]

Wundt, however, was certain that higher mental processes were too complex to be studied merely experimentally. Kuelpe disagreed with this approach. Together with his former student Karl Marbe (1869–1953), who had also studied under Hugo Muensterberg at Harvard, Hermann Ebbinghaus (1850–1909) in Hamburg, and Wundt in Leipzig, he established his own school of psychology in Wuerzburg in 1896. Although the setup of the institute resembled Wundt's laboratory in many ways, and the first experiments used a comparable method of introspection,[39] they quickly set themselves apart from the Leipzig school, and Marbe developed their own method of trained introspection, a combination of Franz Brentano's and Wundt's approaches.[40] Their findings showed that thinking was possible without an associated image or a conscious process — so-called imageless thought.[41] Wundt, however, continued to criticize their work, as he was not in a position to recognize their empirical methods. For example, the Wuerzburg psychologists asked subjects to describe their thought process while solving a complex philosophical or mathematical task. Wundt objected that the methods used in Wuerzburg were concerned only with qualitative aspects

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[34] Miles A. Tinker, "Wundt's Doctorate Students and Their Theses 1875–1920," in *Wundt Studies*, ed. Wolfgang A. Bringmann and Ryan D. Tweney (Toronto: C.J. Hogrefe, 1980).
[35] Oswald Kuelpe, *Zur Theorie der sinnlichen Gefühle* (Leipzig: University of Leipzig, 1887).
[36] Robert M. Ogden, "Oswald Kuelpe and the Wuerzburg School," *The American Journal of Psychology* 64, 1 (1951): 4–19.
[37] Edwin G. Boring, "Georg Elias Mueller: 1850–1934," *The American Journal of Psychology* 47, 3 (1945): 344–8.
[38] Fancher, *Pioneers of Psychology*; Baars, *Cognitive Revolution*.
[39] Gardner, *The Mind's New Science*.
[40] Edwin Garrigues Boring, *Psychologist at Large* (New York: Basic Books, 1961).
[41] Baars, *Cognitive Revolution*; Gardner, *The Mind's New Science*; Mandler and Mandler, *Thinking*.

and that their data was not scientifically quantifiable.

Kuelpe's and Marbe's work and research attracted many renowned psychologists such as Otto Selz (1881–1943), Karl Buehler (1879–1963), and Narziss Kaspar Ach (1871–1946). Ach received his PhD under Kuelpe in 1901, continued studies with Georg Elias Mueller in Goettingen and, after some eighteen years as a lecturer and professor in Marburg, Berlin, and Koenigsberg, succeeded Mueller as head of the psychology department in Goettingen in 1922.[42] The work of these psychologists associated with the Wuerzburg school was very important for development of the study of perception, thinking, memory, language, the relationship between knowledge and learning, and other mental processes, especially since they assumed that these phenomena arose from cognitive processes while not completely disavowing behaviouristic methods in their research approaches.[43] Their work was also important in that it carved out a place in psychology for the Gestaltist critics of behaviourism. This theoretical endeavour later facilitated the migration of their ideas across the Atlantic, where their work increasingly attracted attention during the 1950s.

The lack of international attention toward their ideas at the time, however, can be ascribed to the rise of behaviourism at the beginning of the twentieth century. It can be further attributed to the sudden "brain drain" of psychologists and neuroscientists from Germany after the rise of Nazism, as well as the lack of their translated works in America, which could in part result from the publishing prohibition in Nazi Germany.[44] Still, Titchener's popularization of Wundt's program in experimental psychology continued in North America, while Titchener even translated excerpts of Wundt's and Kuelpe's work. He further attracted graduate students, such as E.G. Boring (1886–1968) to Cornell University, to continue with the psychophysiological tradition. His research school, however, remained in many ways overshadowed by the new behaviourism, which John B. Watson had developed since the early 1910s.

In particular, Otto Selz's work on problem solving[45] proved to be relevant to later logic theory and bears similarities to a theory of human thought processing later published by Kurt Koffka (1886–1941), yet was barely present to Americans prior to the 1950s. Only the work of a few of his students crossed the Atlantic, such as Adrian de Groot (1914–2016; *Het Denken van den Schaker*[46] [1946; *Thought and Choice in Chess*, 1965], which the psychologist and computer scientist Herbert Simon [1926–2001] encountered and partially translated in the early 1950s), and Gestalt psychologist Karl Duncker (1903–1940; "On Problem-Solving" [1945]).[47] Selz himself was eventually dismissed from his position under the Nazi administration in 1933 and tragically killed in 1943 at Auschwitz. Kuelpe left Wuerzburg for Bonn (1909–1913) and later Munich (1913–1915) and was succeeded as the institute's head in Wuerzburg by Karl Marbe (1869–1953).

Karl Buehler probably did the most to popularize and pass on Wuerzburgian ideas of experimental psychology, although he was always open to other academic approaches, and the Wuerzburg period reflected only the early phase of his career. He followed Kuelpe to Bonn and Munich, and became a psychology professor in Vienna in 1922. Scholars interpret his work as having a great influence not only on

[42] David D. Cevonis, "Ach, N.," in *Encyclopedia of the History of Psychological Theories*, ed. Robert W. Rieber (New York: Springer, 2012), 1–2.

[43] Brett D. King and Michael Wertheimer, *Max Wertheimer & Gestalt Theory* (New Brunswick, NJ: Transaction, 2005); Sturm and Gundlach, "Urspruenge und Anfaenge."

[44] See, for example the related case of émigré psychologist Hugh Lytton in Erna Kurbegović's article in this special issue of *History of Intellectual Culture*, entitled, "From German Youth to British Soldier to Canadian Psychologist: The Journey of German Émigré Dr. Hugh Lytton (1921–2002)."

[45] Cf. Otto Selz, *Ueber Die Gesetze Des Geordneten Denkverlaufs* (Stuttgart: W. Spearmann, 1913).

[46] Adriaan Dingeman de Groot, *Het Denken Van Den Schaker* (Amsterdam: Noord-Hollandsche Uitgeversmaatschappij, 1946). For an English translation, see *Thought and Choice in Chess* (The Hague: Mouton, 1965).

[47] Karl Duncker, *Zur Psychologie des produktiven Denkens* (Berlin: Julius Springer, 1935). For an English translation, see Karl Duncker, "On Problem-Solving," *Psychological Monographs* 58, 1 (1945): 1–113.

psychologists but also on the Vienna Circle of philosophers and the Prague Linguistic Circle around the Russian linguist Roman Jakobsen (1896–1982) and Czech literary critic René Wellek (1903–1995). Buehler integrated a form of linguistic structuralism in his school of *Denkpsychologie*, which offered several paths toward a more interdisciplinary approach in psychology.[48]

Buehler's heated disagreement with Wundt on the introspective methods used to study complex thought processes in Wuerzburg brought keen scholarly attention to the work being done there.[49] Furthermore, Buehler was in no way intolerant of behaviourist approaches. In fact, through his strong encouragement of interdisciplinary psychological approaches, he proposed a connection of behaviouristics, as well as all introspective psychological methods, in *Die Krise der Psychologie 1927* (*The Crisis in Psychology*)[50] and *Sprachtheorie* 1934.[51] However, when he fled Germany with his renowned wife Charlotte Buehler (1893–1974) in 1938, despite being one of the most eminent psychologists at the time in Europe, he was unable to obtain a meaningful position after he rejected Edwin Garrigues Boring's invitation to come to Harvard in 1930. Moreover, ongoing disputes with the Berlin Gestalt psychology school led to continual aversions, and none of his former peers would recommend him for permanent positions in the United States. His ideas were only in part and indirectly transferred across the Atlantic, and almost two decades passed before some of his work was revived during the 1950s.[52]

While the relevance of their studies was not recognized until much later, the Wuerzburg professors did supervise many international and later acclaimed students. Among Kuelpe's students, for example, were the co-founders of Gestalt psychology, Max Wertheimer and Kurt Koffka — who had been especially influenced by Buehler during their time at Wuerzburg.[53] Among Buehler's students was Konrad Lorenz (1903–1989), Nobel Prize winner in physiology or medicine in 1973 and a major contributor to the anthropology of cognitive science. Positivist philosopher Karl Popper (1902–1994) and the American creator of purposive behaviourism Edward Tolman also had connections with Buehler. Furthermore, Egon Brunswik (1903–1955) and Paul Lazarsfeld (1901–1976) made major contributions to the psychological study of perception and sociology, respectively. The latter also participated in the Macy Conferences during the 1940s. Brunswik, who studied under Moritz Schlick (1882–1936) and Karl Buehler in Vienna, received his PhD in 1927 with the thesis *Structure-Monism and Physics.* He also met Fritz Heider (1896–1988) and Edward Tolman in the Austrian capital and came under the influence of the Vienna Circle.[54] Based on these influences he formed his own theory of perception, which can further be seen as a development of Helmholtz's unconscious inferences in that it also takes subconscious processes into account. According to Brunswik, the mind is an "intuitive statistician," that filters stimuli from its surrounding based on subconscious probabilistic calculations. After some delay, his theory was taken up by other psychologists and re-emerged in the study of cognition.[55] In 1935 Brunswik spent a year at Berkeley as a research fellow,

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[48] Adrian Brock, "What Ever Happened to Karl Buehler?" *Canadian Psychology/Psychologie Canadienne* 35, 3 (1994): 319–29.

[49] Cristina Massen and Juergen Bredenkamp, "Die Wundt-Buehler-Kontroverse aus Sicht der heutigen kognitiven Psychologie," *Journal of Psychology* 213, 1 (2015): 109–14.

[50] Karl Buehler, *Die Krise Der Psychologie* (Jena, Germany: G. Fischer, 1929).

[51] Thomas Sturm, "Buehler and Popper: Kantian Therapies for the Crisis in Psychology," *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 43, 4 (2012): 462–72.

[52] Walter B. Weimer, "The History of Psychology and Its Retrieval from Historiography: I. The Problematic Nature of History," *Science Studies* 4, 2 (1974), 235–58.

[53] Ibid.

[54] Edward C. Tolman, "Egon Brunswik: 1903–1955," *The American Journal of Psychology* 69, 3 (1956), 315–324.

[55] Gerd Gigerenzer and David Murray, "Tools=theories=data?" in *Psychology's Territories*, ed. Mitchell Ash and Thomas Sturm (Mahwah, NJ: Lawrence Erlbaum Associates, 2007).

where in 1937 with the help of Tolman, he returned as a visiting professor.[56] Brunswik married psychologist Else Frenkel (1908–1958) from Vienna in 1938 in California. She was a former student of Buehler and also had started working at Berkeley.

Important here is Heinz Werner (1890–1964), who had studied in Vienna between 1909 and 1914 and was immensely influenced by the Wuerzburg school. In 1921 Werner was appointed as an assistant professor in Hamburg, where he closely collaborated with William Stern (1871–1937) and Fritz Heider.[57] Most of his work was concerned with specific problems of psychological perception. After fleeing Germany in 1933 and emigrating to the United States, he continued working on perceptual problems and mental processes, although shifting his focus to developmental psychology.[58] He worked at the University of Michigan, then became a visiting professor at Harvard for one year in 1936, and later was hired at Clark University, Massachusetts. There, he rose through the academic ranks and was even appointed as chairman of the Department of Psychology — a position he kept until 1960.[59]

The Progression from Early Experimental Psychology to the Holistic Gestalt School in Berlin

Karl Buehler further exerted a considerable influence through his active membership in and later chairmanship of the German Society for Experimental Psychology, which had been founded in 1904 by Georg Elias Mueller, Oswald Kuelpe, and Ernst Meumann (1862–1915) from Zurich. Other early members were Friedrich Schumann (1893–1921) from Berlin, Robert Sommer (1864–1937) from Giessen, and Hermann Ebbinghaus, who at that time held a professorship in Breslau. Earlier, Ebbinghaus had turned to experimental psychology after being inspired by Fechner's empirical investigations in the third experimental psychology laboratory in Berlin, where he worked from 1879 to 1894. In Fechner's laboratory, Ebbinghaus explored the foundational principles of memory formation. Instead of using methods of introspection as in Leipzig, and rather than investigating memory possibly already associated with prior knowledge, he attempted to measure a subject's abilities to create memories.[60] One of his students, William Stern, is arguably credited with the creation of differential psychology.[61] When Carl Stumpf (1848–1936), instead of Ebbinghaus, was promoted in 1894 to head the philosophy department in Berlin, William Stern followed Ebbinghaus to Breslau, and later co-founded a psychology laboratory in Hamburg with Ernst Meumann.[62] In 1933 Stern was one of five full psychology professors in Germany to be dismissed through the Nazi civil service law.[63]

Carl Stumpf, whose interest in psychology was inspired by the philosopher Franz Brentano in Wuerzburg and Georg Elias Mueller's doctoral adviser Hermann Lotze (1817–1881) in Goettingen, taught all of the founders of Gestalt psychology in Berlin. In the Berlin Gestalt psychology, we see a clear re-

[56] Bernhard Wolf, "Theoretical Positions of Kurt Lewin and Egon Brunswik – Controversial or Complementary Points of View?" In *Lewin Legacy*, ed. Eugene Stiversand Susan Wheelan (Berlin, Heidelberg: Springer Verlag, 1986).

[57] Seymour Wapner and Bernard Kaplan, "Heinz Werner: 1890–1964," *The American Journal of Psychology* 77, 5 (1964): 513–17.

[58] See Roy D. Pea, "Werner's Influence on Contemporary Psychology," *Human Development* 25 (1982): 303–8.

[59] Herman A. Witkin, "Heinz Werner: 1890–1964," *Child Development* 36, 3 (1965): 306–28.

[60] Gardner, *The Mind's New Science*, 104–109; Fancher, *Pioneers of Psychology*.

[61] James T. Lamiell, "William Stern (1871–1938) and the 'Origin Myth' of Differential Psychology," *Journal fuer Psychologie* 14, 2 (2006): 253–73.

[62] Paul Probst and Wolfgang G. Bringmann, "Ernst Meumann und William Stern: Analyse ihres Wirkens in Hamburg (1910–1933) unter Beruecksichtigung biographischer und soziokultureller Hintergruende," *Geschichte Der Psychologie* 10, 1 (1993): 1–14.

[63] Mitchell G. Ash, "Émigré Psychologists after 1933: The Cultural Coding of Scientific and Professional Practices," in *Forced Migration and Scientific Change*, eds. Mitchell G. Ash and Alfons Soellner (Cambridge, UK: Cambridge University Press, 1996), 118.

emergence of Brentano's early holistic notions of the mind.[64] Brentano's and Lotze's philosophical influences on Stumpf led him to make no differentiation between epistemology and psychology and to argue that empirical psychology was necessary to explain higher philosophical concerns. This and Brentano's notion that the mind is not purely mechanistic reappeared in the Gestalt school through Stumpf's phenomenological approach to psychology. The Berlin Gestalt school formed one of the main traditions that retained a notable global following even during the behaviourist era. Arguably this derived from its distinct way of inspecting mental phenomena, as well as the emigration of nearly all of its contributing scientists from Central Europe to the United States. Begun through an observation by another one of Brentano's students, Christian v. Ehrenfels (1859–1932), the notion of Gestalt qualities made its way into psychology.[65] Otto Selz, in his theory of human thought processes, had already suggested that not all explanations for thinking processes are necessarily found in consciousness, but that instead the mind underlies automatic schemata to order thoughts and stimuli. However, not until the rising prominence of the Gestalt psychologist's research was it widely accepted that certain mental processes happen subconsciously.[66]

The founding of the school is mostly credited in literature to Max Wertheimer, the only one who wrote his doctoral thesis not under Stumpf, but rather under Kuelpe in Wuerzburg. The other prominent Gestalt psychologists — Kurt Koffka, Wolfgang Koehler, Adhémar Gelb (1887–1937), Johannes von Allesch (1882–1967), and Kurt Lewin (1890–1947) — all wrote their dissertations under Stumpf between 1906 and 1912. Karl Duncker, one of their most promising students, joined them in the early 1920s and later in 1926 received his MA from Clark University in Massachusetts, one of the leading institutions in American psychology at the time. This research stay in the United States was made possible through Koehler's year-long visiting professorship at Clark University, during which he invited Duncker to join him there. Duncker received his PhD in 1929 from Friedrich Wilhelm University of Berlin.[67] Another student of Koehler, Hans Wallach (1904–1998), received his PhD in 1934. Just as Ehrenfels had described a higher-level quality of a melody, which is more than the sum of its musical notes — its notes create a new phenomenon when arranged in a certain way — the Gestalt psychologists based most of their research on their interpretation of the heterogeneity of cognitive and psychological processes observed and perceived. The way that single functions and processes were perceived was determined by the configuration of the whole, such as the grouping of objects by similarity or proximity.[68]

Although the influence of Kuelpe and Marbe on Wertheimer was undeniable, in that he became interested in the study of mental processes, the Gestaltist approach yearned for a robust model that would account for a more holistic view and contrast with not only the work of the Wuerzburg School and Titchener's structuralism, but also, later, behaviourism. With their observation on apparent motion, they showed that different stimuli can produce subjectively identical experiences. Thus, in contrast to Titchener, whose theoretical bottom-up approach relied on breaking down mental processes into small elements, they pursued a top-down approach by observing the mental process and attempting to find each part's role in the process. Similarly, by arguing that some perceptual experiences cannot be broken down into smaller elements, they dismissed the behaviouristic account of atomic sensory elements, which gained them some recognition in America during the 1920s.

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[64] Gardner, *The Mind's New Science*.

[65] See Christian von Ehrenfels, "Ueber Gestalt Qualitaeten," *Vierteljahrsschrift fuer wissenschaftliche Philosophie* 17, 2 (1890), 249–92.

[66] Mandler and Mandler, *Thinking*, 235.

[67] Simone Schnall, "Life as the Problem: Karl Duncker's Context," *From Past to Future* 1, 1 (1999), 13–28.

[68] Gardner, *The Mind's New Science*, 111–29.

The Gestalt Theory Comes to North America

While some of its concepts are still relevant today, the Gestalt movement quickly died down after its arrival in America. Historian of psychology Michael Sokal interprets this demise of the Gestalt school as a result not of its scholars' ideas being disregarded when mainstream psychology took a different approach, but rather of them redirecting the mainstream toward Gestalt ideas.[69] Mitchell Ash attributes this development also to Gestalt psychologists' need to find jobs in applied sectors such as insurance psychology, industrial sociology, and the booming fields of socio-psychological testing, political psychology, and the psychology of advertising. The Gestaltists' numerous students (such as Heinrich Kluever [1897–1979] in Chicago, Norman Raymond Frederick Maier [1900–1977], and George Katona [1901–1981]) further incorporated their approach into expanded research programs in neuroscience, psychology, and economics. From their early work on perception, they soon applied similar concepts to different mental processes and problem solving. In contrast to the Wuerzburg school, the Gestaltists were more successful in integrating their school in America after their exile from Germany.[70] Kurt Koffka had left Berlin before Gestalt psychology became really successful, and from 1921 on he headed the psychological institute in Giessen, which August Messer (1867–1937) had helped to co-found in 1919.[71] During his time with Kuelpe in Wuerzburg, Koffka met the American psychologist Robert M. Ogden (1877–1959), who arranged for a visiting professorship at Cornell in 1924. After the Hessian government had continuously rejected support for the further institutionalization of psychology in Giessen, Koffka eventually accepted a professorship at Smith College in Northampton, Massachusetts, in 1927.

Ogden also tried to convince Wertheimer to join Cornell University in 1929, and Edward Boring invited him to become a visiting professor at Harvard a few years later. In 1933, Wertheimer fled Germany, after losing his position due to the infamous Law for the Re-establishment of a Professional Civil Service (*Gesetz zur Wiederherstellung des Berufsbeamtentums*) and acquired a professorship at the New York School for Social Science. One of his most influential American students was Abraham Maslow (1908–1970), who is best known for his hierarchy of needs.[72]

While Adhémar Gelb died of tuberculosis before he was able to emigrate to take up a position at the University of Iowa, Wolfgang Koehler became renowned for his problem-solving theory, which he developed while studying apes.[73] In 1922 Koehler was appointed to succeed Stumpf as the director of the psychological institute in Berlin. Later, he was several times offered a position at Harvard but remained in Berlin until 1935.[74] During that year, however, like many of his colleagues before, he emigrated to North America. He had repeatedly and openly voiced his disapproval of the Nazis' dismissal of Jewish academics.[75] In the United States he received a professorship at Swarthmore College in Massachusetts, where he remained until 1956, before moving to Dartmouth University in New Hampshire and serving as

[69] Michael M. Sokal, "The Gestalt Psychologists in Behaviorist America," *The American Historical Review* 89, 5 (1984): 1240–63.

[70] Mitchell G. Ash, "Under Nazism and After: Survival and Adaptation." In *Gestalt Psychology in German Culture, 1890–1967* (Cambridge, UK: Cambridge University Press, 1995): 323–4.

[71] Hans-Georg Burger, "Anfaenge und Bedeutung der experimentellen Psychologie in Giessen," *Giessener Universitaetsblaetter* 8, 1 (1975), 78–98.

[72] Greenwood, "Physiology and Psychology," 268–71, 527–8.

[73] Mitchell G. Ash, "Zur Geschichte des Berliners Psychologischen Instituts und der Zeitschrift 'Psychologische Forschung' vor und nach 1933," in *Psychologie im Nationalsozialismus*, ed. Carl F. Graumann (Berlin: Springer, 1985).

[74] Ibid.

[75] See Mary Henle, "One Man against the Nazis – Wolfgang Koehler," *American Psychologist* 33, 9 (1978): 939–44.

the president of the American Psychological Association in 1959.[76]

A year after his move to North America, Wolfgang Koehler invited his former assistant Dr. Hans Wallach from Berlin to work with him at Swarthmore. Contrary to the Gestalt psychologists' nativism, Wallach's research showed that learning could influence people's visual perception. He designed an experiment in which subjects viewed a rotating object through a device that exaggerated binocular disparity. After removing the device, subjects would report perceiving the rotating object as flattened. Wallach stayed at Swarthmore for most of his career, and had no aspirations to promote himself by visiting symposia or joining societies, which hindered early recognition of his work. Once a week between 1947 and 1957 he would travel to the New York School for Social Research as a visiting professor. He also worked at the Institute for Advanced Studies in Princeton for one year.[77] Wallach was not only a skilled researcher but also a formidable teacher. Among his students was the later very prominent cognitive scientist Ulric Neisser, who had gone to Swarthmore hoping to learn from Wolfgang Koehler.[78]

The younger Gestaltists, Kurt Lewin and Karl Duncker, despite Duncker's early death in 1940, exerted the most influence with their developments of Gestalt theory. Following the views of Wertheimer and Koehler, Duncker had been the Gestaltists' most promising student,[79] and his work on problem solving is regarded by Alan Newell (1927–1992) as major pioneering work for cognitive science.[80] Duncker briefly worked for Bartlett at the University of Cambridge in England, before following Koehler to Swarthmore College, where he worked on taste perception and the relationship between learning and thinking. Tragically, he lost a long struggle with depression and took his life in 1940.

Kurt Lewin, despite his background in Gestalt and himself a philosophy–psychology hybrid, soon went his own methodological way.[81] He cut the ties to Buehler and philosophers of science such as Ernst Cassirer (1874–1945) in Hamburg and Hans Reichenbach (1891–1953) in Berlin with whom he had shared a close intellectual connection. Lewin's theories differed quite significantly from ordinary Gestalt in the sense that they relied on concepts being mental by nature, rather than assuming the reduction to some physical entity. He also designed a phenomenological approach and adopted new mathematical tools such as topology and vector analysis. His work on child psychology, however, gained him the broadest recognition in America, even before 1933. After having rejected several offers of professorships from American universities in the past, when he was forced to leave Germany in 1933, out of need he accepted a mere research fellowship at Cornell University, through a recommendation from Robert Ogden. Two years later he moved to the Iowa Child Welfare Research Station, where he supervised Leon Festinger's (1919–1989) research and stayed for most of his life, until his final move to MIT in Cambridge in 1944.[82]

A brief elaboration is needed here on two earlier-mentioned psychologists who were influenced by Gestalt theory, Norman Raymond Frederick Maier and George Katona. Their continuation of experimental

[76] "*Former APA Presidents*," accessed 10 September 2017, http://www.apa.org/about/governance/president/past-presidents.aspx.

[77] Charles S. Harris, "Hans Wallach (1904–1998)," *American Psychologist* 56, 1 (2001): 73–74.

[78] George Mandler, *A History of Modern Experimental Psychology: From James and Wundt to Cognitive Science* (Cambridge, MA: MIT Press, 2007): 152–3.

[79] King and Wertheimer, *Max Wertheimer & Gestalt Theory*.

[80] Allen Newell, "Duncker on Thinking: An Inquiry into Progress in Cognition," in *A Century of Psychology as Science: Retrospections and Assessments*, eds. Sigmund Koch and David Leary (New York: McGraw-Hill, 1985).

[81] Ash, "Émigré Psychologists after 1933."

[82] Mitchell G. Ash, "Cultural Context and Scientific Change in Psychology – Kurt Lewin in Iowa," *American Psychologist* 47, 2 (1992): 198–207; Wolfgang Wildgen, "Kurt Lewin and the Rise of 'Cognitive Sciences' in Germany: Cassirer, Buehler Reichenbach," in *The Dawn of Cognitive Science – Early European Contributors*, ed. Liliana Albertazzi (Dordrecht: Springer, 2001), 299–332.

work in Michigan helped prevent the full suppression of German thought psychology.[83] Katona first studied under Georg Elias Mueller in Goettingen; his German psychological training and the influence of Gestalt led him to create novel economical models after his emigration to the United States. Maier first studied at the University of Michigan and spent two years with the Gestalt school in Berlin in 1925–1926.[84] He later worked for the behavioural scientist Karl Lashley in Chicago from 1929 to 1931. His time in Berlin inspired his combination of associationism and Gestalt principles in his theories of thinking and problem solving.[85]

Heinrich Kluever, who would later become a leading member of the cybernetics movement, had studied under Max Wertheimer in 1920–1923 as a graduate student in Berlin. After Kluever moved to the United States and received his PhD at Stanford, he befriended Karl Lashley in Minnesota during a visit there from 1924 to 1926, and joined Lashley in Chicago a few years later. He is best known for his research on frontal lobotomies in apes. His experimental research on vision during the 1920s and early 1930s, however, became especially influenced by the Gestalt school.[86]

On all the experimental and Gestalt psychologists, the influence of the Wuerzburg and Berlin schools left a lasting impression. Particularly the ideas and work paradigms of Helmholtz, Fechner, and Wundt markedly influenced the new generations of psychologists. Even though the Nazi regime forced out from Germany many of its psychological scientists and scholars, and the rise of behaviourism in the United States hindered the incorporation of all the ideas of émigré German-speaking psychologists in North America, their ideas and approaches in areas and disciplines relevant to modern cognitive science did not disappear, while they themselves were active and influenced university teachers of new generations of American students.

Some Contributions by Émigré Engineers and Information Scientists to the Technological Advances of the Modern Computer

The first efforts toward electronic computing machines started in the 1930s and advanced quickly during the Second World War, when several countries required higher computing power to aid their respective war efforts.[87] The diverse experiences of these endeavours were later brought together at the Macy Conferences in the United States. Also, the field of cybernetics was born, an important, if not (as some scholars have claimed) the most important discipline leading toward cognitive science.[88] Another important source for the field was the development of the study of artificial intelligence at Dartmouth College in 1956 before it merged more closely with psychology and neuroscience during the 1950s. When scientists like the émigré John von Neumann started analysing the relationship of mind and machine, the computer served not only as a tool for more efficient calculations and model generation, but also as an important analogy to complex cognitive systems.

The development of electronic computers, however, brings together the history of advances in engineering and in other fields such as mathematics and logic. As the nature of computers is split into

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[83] Herbert Simon, "Information-Processing Theory of Human Problem Solving," in *Handbook of Learning and Cognitive Processes*, ed. William K. Estes (Hillsdale, NY: Lawrence Erlbaum Associates, 1978), 271–95.

[84] Robert Pachella, "Experimental Psychology," in *Creating the Modern Michigan Psychology Department: The Chairmanship of Donald Marquis (1945–1957)* (Ann Arbor, Michigan: Psychology Department, 2010), 79–101.

[85] Mandler and Mandler, *Thinking*, 248.

[86] Frederick K. D. Nahm and Karl H. Pribram, "Heinrich Kluever — 1897–1979." In *Biographical Memoirs,* ed. National Academy of Sciences (Washington DC: National Academy Press, 1998), 289–305.

[87] Michael R. Williams, *History of Computing Technology* (Los Alamitos, CA: IEEE Computer Society Press, 1997), 209–406.

[88] Jean Pierre Dupuy, *The Mechanization of The Mind* (Princeton, NJ: Princeton University Press, 2000), 173.

hardware and software, so also are the origins of these two components split; these join together only in the first computers of the 1930s and 1940s.[89] Thus, the origins of artificial computation systems can be traced back to the sixteenth, seventeenth, and eighteenth centuries when the first mechanisms such as watches, and mechanical toys such as dolls were built to simulate physiological processes in the organic machine of the human body.[90] Also, early mechanical calculating devices were designed by Wilhelm Schickard (1592–1635) in 1623 and shortly thereafter by the French mathematician Blaise Pascal (1623–1663).[91] Further, an important predecessor to the computer age was the work of Charles Babbage (1791–1871). In his surprisingly accurate attempts at building a programmable machine for calculating mathematical polynomials,[92] he pioneered input models that could later serve as analogies to the functioning of the human mind.[93]

In the late nineteenth century, punched-card tabulators, developed by the American engineer Herman Hollerith (1860–1929), were used to semi-automate the tallying work of clerks in the United States census. Hollerith later laid the foundation for International Business Machines (IBM) with the creation of his Tabulating Machine Company in 1896. The Austrian mechanic Otto Schaeffler (1838–1928) used plug boards on the punched-card machines instead of direct soldering the connections to ease reprogramming.[94]

The astronomer Leslie Comrie (1893–1950) was the first to use these punched-card machines for a large-scale scientific calculation instead of bureaucratic or statistical purposes, when in 1928 he calculated the predicted movement of the moon while working at the National Almanac Office in London. As the calculations were based on the mathematician and astronomer Ernest William Brown's (1866–1938) *Tables of the Moon*, Brown paid Comrie a visit in London. Back in the United States, Brown introduced these methods of calculation to his former student and friend Wallace J. Eckert (1902–1971). Eckert proceeded to convince IBM to fund the establishment of a real computer bureau at Columbia University in New York, and in this way contributed to the increasing use of punched-card machines in scientific inquiries in North America.[95] In the century leading up to the 1930s, the demand for and use of mechanical calculation devices thus increased tremendously, driven by companies such as IBM in the United States and its German subsidiary DEHOMAG (Deutsche Hollerith Maschinen Gesellschaft [German Hollerith Machines]).[96]

Another step was needed, however, to build completely automated electronic computers. One of the major technological pioneers of modern computers was the German engineer Konrad Zuse (1910–1995) in Berlin, who designed the well-received "Z-machines" in the 1930s. During the Second World War, however, his work was isolated from newer American efforts to build serial computers at the Bell Telephone Laboratories in New York. Howard Aiken (1900–1973), at Harvard University and working cooperatively with IBM, continued to exchange information internationally with engineers other than Zuse,

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[89] Michael S. Mahoney, "The History of Computing in the History of Technology," in *The History of Computing*, ed. Thomas Haigh (Cambridge, MA: Harvard University Press, 2011), 113–25.
[90] Julien Offray de La Mettrie, *Man a Machine* (Chicago: Open Court, 1912).
[91] Michael R. Williams, *A History of Computing Technology* (Englewood Cliffs, NJ: Prentice-Hall, 1985), 119–29.
[92] Ibid.
[93] Christopher D. Green, "Was Babbage's Analytical Engine Intended to Be a Mechanical Model of the Mind?" *History of Psychology* 8, 1 (2005): 35–45.
[94] Heinz Zemanek, H. 1970. "Otto Schäffler: Wiener Pionier der Lochkartentechnik," *It — Information Technology* 12, 1–6 (1970): 133–4.
[95] Michael R. Williams, "Difference Engines from Mueller to Comrie," in *The History of Mathematical Tables: From Sumer to Spreadsheets*, ed. Martin Campbell-Kelly (Oxford: Oxford University Press, 2007), 123–44.
[96] Mark Priestley, *A Science of Operations* (London: Springer, 2011), 65; Paul Ceruzzi, *A History of Modern Computing*, 2nd ed. (Cambridge, MA: MIT Press, 2003), 18; Martin Campbell-Kelly et al., *Creating the Computer in Computer: A History of the Information Machine*, 3rd ed (Boulder, CO: Westview Press, 2016), 42–65; Herman Goldstine, "The Historical Background up to WWII," in *Computer – from Pascal to Neumann* (Princeton, NJ: Princeton University Press, 1973), 106–21.

and he and others advanced Babbage's previous work. Nonetheless, Zuse succeeded in building an automatically controlled computing machine in 1941, the Zuse Z3 (Figure 1), which received its information from a binary punched card. After the war Zuse visited the United States but never reached a major work agreement with IBM or Aiken.[97] As a parallel innovation (despite a feud between Aiken and the head of IBM, Thomas Watson [1874–1956]), in 1943 Aiken and IBM's cooperative project completed the Harvard Mark I, an electromechanical general-purpose computer (Figure 2).[98] Although the Mark I was more accurate, the Zuse Z3 was surprisingly faster and, due to its floating-point representation, more flexible.[99]

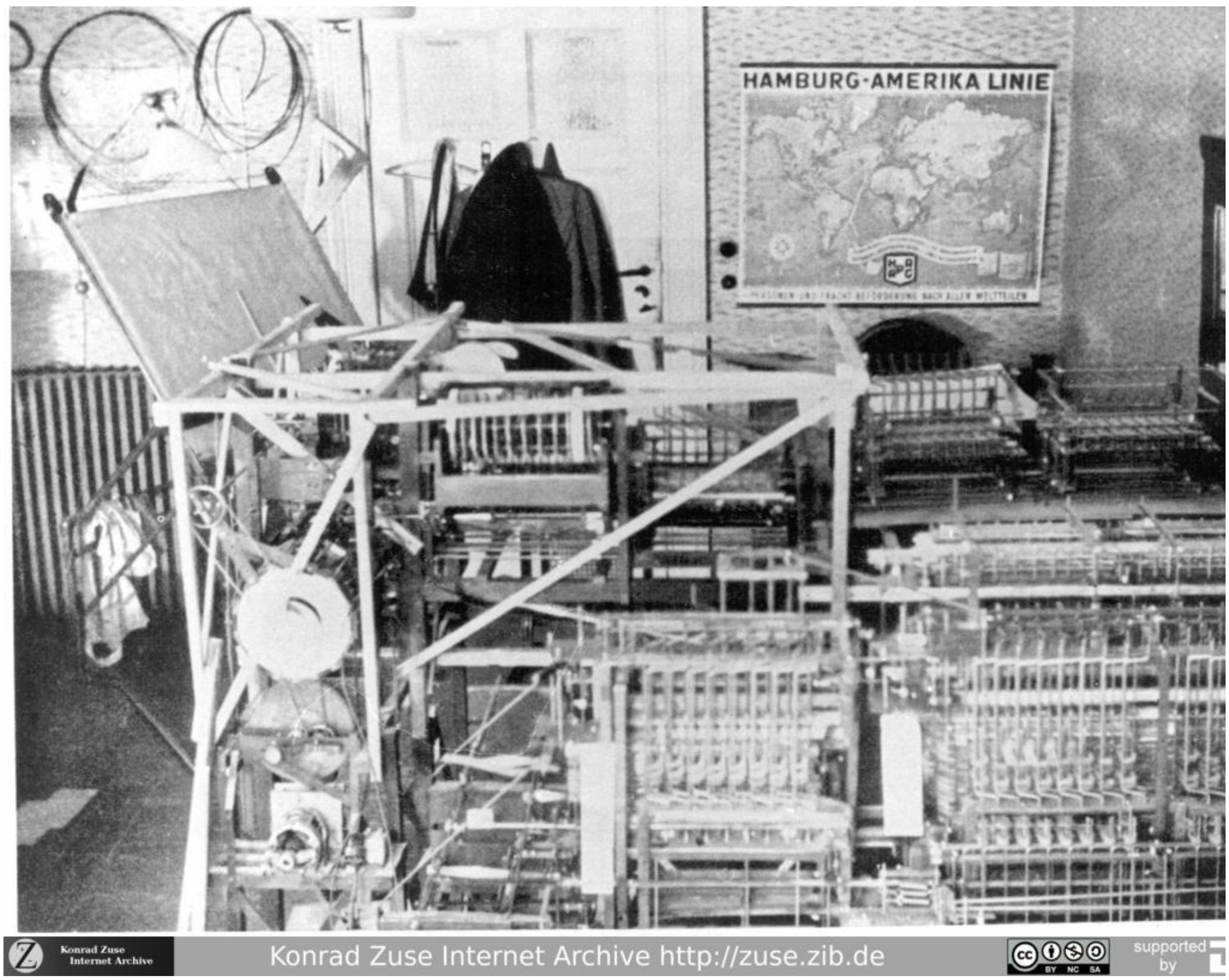

Figure 1: Konrad Zuse's prototype for the model Z1. Photographed in his parent's apartment, 1937.[100]

[97] Konrad Zuse, *Der Computer – mein Lebenswerk* (Berlin, Heidelberg, New York, Tokyo: Springer Verlag, 1984), 101–18.
[98] For details on the feud see Frederick Brooks Jr., "Aiken and the Harvard 'Comp. Lab,'" in *Makin' Numbers: Howard Aiken and the Computer*, eds. Bernard Cohen and Gregory W. Welch (Cambridge, MA: MIT University Press 1999), 139.
[99] Mark Priestley, *A Science of Operations – Machines Logic and the Invention of Programming* (London: Springer Verlag, 2011).
[100] Figure 1, from the Konrad Zuse Internet Archive,

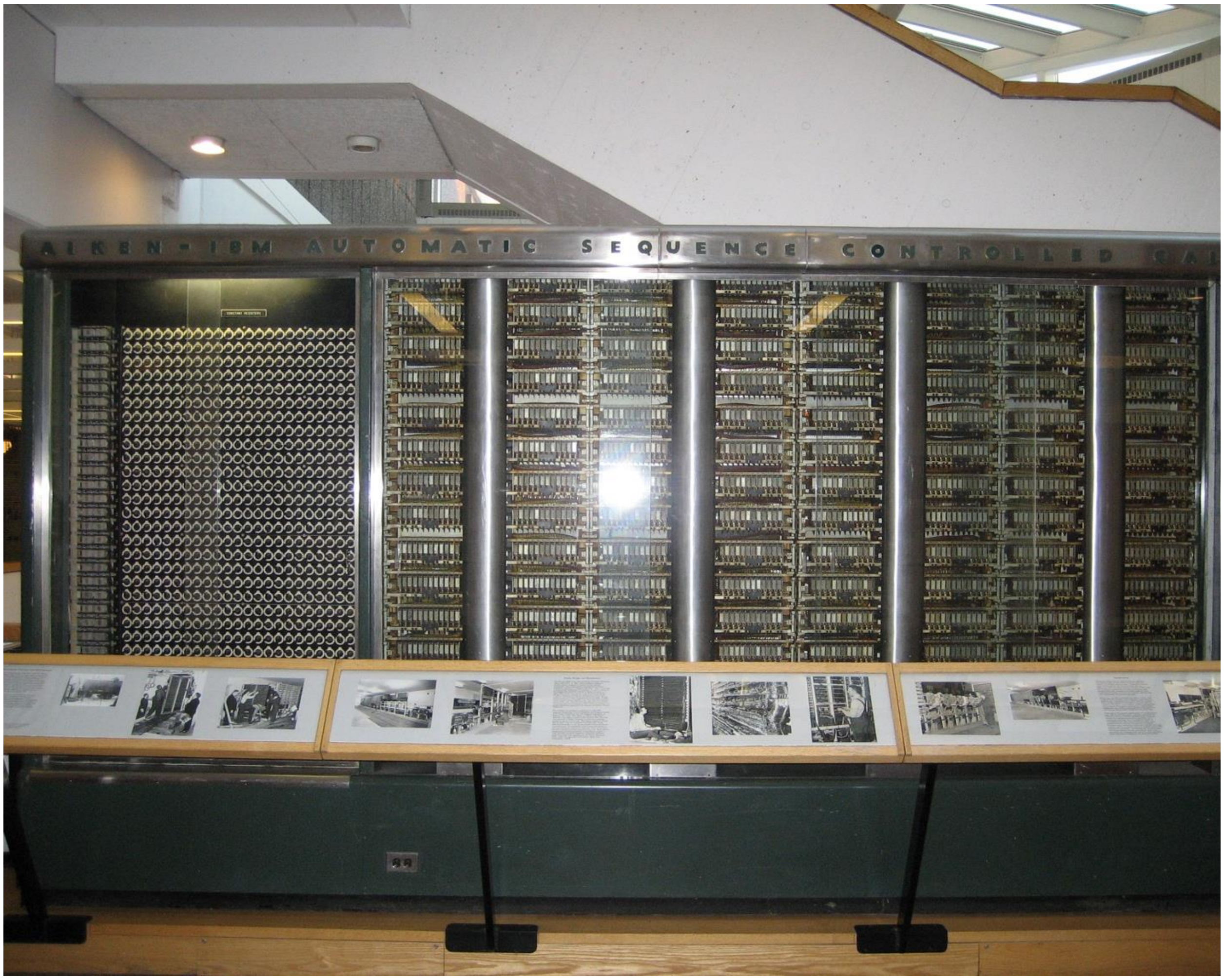

Figure 2: The Harvard Mark I[101]

The Mark I was followed by the development of the electronic computer Colossus in Great Britain, designed to solve the German Enigma code. It was based on electronic relay models but was not universally programmable. Such programmability had to await the construction of the Electronic Numerical Integrator and Computer (ENIAC) at the Moore School of Electrical Engineering at the University of Pennsylvania, with help of John von Neumann (1903–1957). Von Neumann's joining the group in 1944 accelerated the construction, completed in 1945. The work on the ENIAC inspired him to further experiment with the concept of a stored-program computer. Subsequently, he not only helped build the ENIAC but also started the design of a new machine called the Electronic Discrete Variable Automatic Computer (EDVAC),[102]

http://zuse.zib.de/digilibImage?fn=files/vb_dSKa5AwRFNsH/05/b0/80/9f-f47f-4a8a-8aa9-853f2bfd0a91/0/original/d12b5b936fe93f5ef4247ec8e3a5317d.jpg.

[101] Figure 2, *Harvard Mark I*, from "Wikimedia Commons," accessed 9 August 2018, https://commons.wikimedia.org/wiki/File:Harvard_Mark_I.jpg.

[102] Some people claim the design concept had already been established. See John Mauchly, "Amending the ENIAC Story," letter to the editor, *Datamation* (1979): 217–19.

which had quite significantly increased processing speed. His work on EDVAC stopped when communications between him and the Moore school broke off at the end of the war and he moved to the Institute of Advanced Studies in Princeton. The EDVAC was not completed until 1951.[103] Although the invention of these computers was essential for the development of the mind-as-machine analogy, more was needed to form a clear agenda for the new field of cognitive science.[104]

Mathematical Logic and John von Neumann's Contributions to Cognitive Science

This section will chiefly concentrate on John von Neumann (1903–1957), who was born in Hungary and spent some years studying in Germany, as his contributions were disproportionally large. Many contributions to procedural logic in the nineteenth and twentieth centuries proved to be essential for the later creation of the electronic computer. Among the first milestones were the binary algebra, defined by George Boole (1815–1864), and the functional calculus to prove sequential equations by Gottlob Frege (1848–1925). In 1854, Boole published his book *An Investigation of the Laws of Thought*,[105] an attempt at describing logical relations similar to the use of mathematics to describe numerical relations — the rules of Boole's formalism were to hold in an algebraic system with truth values of 0 and 1 — but it was not sufficiently expressive. Frege introduced a sufficiently expressive system in 1879; however, deduction in this system was not clear enough. Boole's earlier attempts culminated in the subsequent proof theories of Bertrand Russell and Alfred North Whitehead's *Principia Mathematica*, which was published in three volumes in 1910, 1912, and 1913. Each volume presented a system of natural relations between mathematics and logic by introducing a set of axioms and inference rules in symbolic logic, from which, in principle, all mathematical rules could be proven.[106]

In many ways, the beginnings of artificial intelligence can be further traced back to David Hilbert's (1862–1943) program in Goettingen, which was concerned with the philosophy and foundations of mathematics, in an attempt to formulate math in a completely logical basis. Hilbert began his work in Goettingen on formal logic around 1917, supported by his assistants Paul Bernays (1888–1977) and Heinrich Behmann (1891–1970).[107] His program changed its focus toward proving it impossible to make derivations from a contradiction.[108] Hilbert became one of the most renowned mathematicians at the time, and Goettingen attracted many international students and visitors. Among them were John von Neumann, Norbert Wiener (1894–1964), and Hermann Weyl (1885–1955) from Erlangen. Wiener, who received his PhD at the early age of eighteen at Harvard University, had previously studied logic with Russell at the University of Cambridge, and spent a good portion of the years 1924 to 1926 in Goettingen. There he also first met von Neumann, who had become very intrigued by Hilbert's work.[109]

However, in 1931, Kurt Goedel published his *Incompleteness Theorems*, which presented limits of provability in formal axiomatic theory. In Austria, Goedel had been associated with the Vienna Circle of philosophers of science, including Rudolf Carnap (1891–1971), who had originally introduced Goedel to

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[103] John von Neumann, *First Draft of a Report on The EDVAC* (Philadelphia: Moore School of Electrical Engineering, University of Pennsylvania, 1945).
[104] Sturm and Gundlach, "Urspruenge und Anfaenge."
[105] See George Boole, *An Investigation of The Laws of Thought* (1854) (New York: Dover, 1951).
[106] Pamela McCurdock, *Machines Who Think: A Personal Inquiry into the History and Prospects of Artificial Intelligence* (Philadelphia: Taylor & Francis, 2004); Priestley, A Science of Operations, 79–100.
[107] Paolo Macosu, "The Russelian Influence on Hilbert and His School," *Synthese* 137, 1 (2003): 59–101.
[108] Richard Zach, "Hilbert's Program Then and Now," in *Handbook of the Philosophy of Science, Philosophy of Logic*, ed. Dale Jacquette (Dordrecht: Elsevier B.V., 2007), 411–47.
[109] Stanislaw Ulam, "John von Neumann," in *John von Neumann – 1903–1957*, eds. John C. Oxtoby, Billy J. Pettis, and G. Baley Price (Providence, RI: American Mathematical Society, 1958), 1–49.

logic. This publication mostly ended all efforts by Hilbert and his group, as Goedel now proven that any system of axioms cannot prove its own completeness. Hilbert hence turned away from his research program on the foundations of mathematics and soon retired. Paul Bernays continued Hilbert's program. After being dismissed from his academic position in 1933 under the infamous Law for the Re-establishment of a Professional Civil Service, Bernays found refuge and work at the Eidgenoessische Technische Hochschule in Zurich, Switzerland, and also lectured at the Institute for Advanced Studies at Princeton in the United States.[110] Goedel continued working in Vienna until the political annexation of Austria by the Nazis in 1938, when he emigrated to Princeton as well.[111] Since 1933, Goedel had frequently visited the United States and gave many lectures at the Institute for Advanced Studies until his death in 1978.[112]

Von Neumann had left Goettingen in 1927 to pursue his own career as a lecturer in Berlin. Although he was eager to leave and lectured in Hamburg in 1929 and at Princeton from 1930 onward, he continually gave lectures in Berlin until his naturalization in America in 1933.[113] After the publication of Goedel's incompleteness theorems in 1931, John von Neumann quickly accepted that Goedel's proofs refuted the work he had done with Hilbert. Instead of continuing this work, von Neumann started discussing Goedel's incompleteness theorems in his lectures in Berlin. While Norbert Wiener spent some years teaching at MIT in Cambridge, von Neumann emigrated to North America, as a consequence of Adolf Hitler's (1989–1945) rise to power and became a faculty member at the Institute of Advanced Studies in Princeton in 1931, which was modelled after the German research institutes.[114] Both Wiener and von Neumann had close family ties to Europe. Wiener had married the German-born Margaret Engelmann, and both men encouraged bringing to North America a number of mathematicians and physicists, such as von Neumann's earlier colleague and friend, Oskar Morgenstern (1902–1977).[115] They also comforted and supported a number of German émigrés hosted at the Institute for Advanced Studies in Princeton, such as the theoretical physicist Albert Einstein (1879–1955), von Neumann's fellow high school student Eugene Wigner (1902–1995), Rudolf Ladenburg (1882–1952), and Hermann Weyl.[116] Wiener and von Neumann would become leading figures in the emerging field of cognitive science.[117]

Especially building on the catalyst machine developed by the Cambridge mathematician Alan Turing (1912–1954), von Neumann became increasingly interested in applications of game theory to the technological development of new computing machines. Neumann and Turing were among the first researchers to realize that the new representations used in the formalism of logic were the key to developing the new generation of electronic and universally programmable computers.[118]

Von Neumann's participation in war-related research became quite significant. His introduction to the ENIAC project had further sparked his interest in Turing's work, especially Turing's theoretical concept of a universal Turing machine. Historians are uncertain as to when von Neumann first took note of Turing's work, but very likely by 1938 at the latest von Neumann had encountered Turing's work on computability

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110 Henri Lauener, "Paul Bernays (1888–1977)," *Zeitschrift fuer allgemeine Wissenschaftstheorie* 9, 1 (Wiesbaden: Franz Steiner Verlag, 1978), 13–20.

111 For the naturalization of Goedel, see "*Memorandum from Mathematica*," Letter from Oskar Morgenstern, 13 September 1971).

112 John W. Dawson, *Logical Dilemmas* (Wellesley, MA: A.K. Peters, 1997).

113 Norman McRae, *John von Neumann* (New York: Pantheon Books, 1992), 136–50.

114 Steve J. Heims, *John von Neumann and Norbert Wiener* (Cambridge, MA and London: MIT Press, 1980).

115 On Mathematician Émigrés see Robin E. Rider, "Alarm and Opportunity: Emigration of Mathematicians and Physicists to Britain and the United States, 1933–1945," in *Historical Studies in the Physical Sciences* 15, 1 (1984), 107–76.

116 McRae, *John von Neumann*, 69.

117 Gardner, *The Mind's New Science*, 20–26.

118 Preface to *A History of Computing in the Twentieth Century – A Collection of Essays with Introductory Essay and Indexes*, eds. Nicholas Metropolis, Jack Howlett, and Gian Carlo Rota (New York: Harcourt Brace Jovanovich, 1980), xvi.

and held it in high esteem. Turing was well aware of von Neumann's work even prior to this discovery and the latter's work becoming well known.[119] This exchange of ideas eventually led to Turing's concept of creating a computer with a stored program (program data as well as instruction data in the same memory) and Neumann's idea to draw an analogy between computers and living organisms. Von Neumann first published on this analogy in his draft for the EDVAC in 1945. Already he had been discussing the subject with Wiener and neurophysiologists from Princeton during the war years.[120] These collaborations would lead to a fruitful interdisciplinary research program following the war — cybernetics. As British science journalist Andrew Hodges claimed, Turing and von Neumann had become the two main pioneers inherently connected with the invention of modern computing machines. They were the ones "assembling the necessary ideas for the digital computer out of the conjunction of Hilbertian rationalism and Second World War technology."[121] Certainly, von Neumann took his own path, and while gathering inspiration from numerous interdisciplinary sources such as the McCulloch-Pitts neural model, had frequently been the driving force behind novel ideas such as the mind machine analogy, which culminated in exciting scientific inquiries beyond his death in 1957.

Biology and the Machine — The Organism–Machine Model in Early Twentieth-Century Cybernetics

Several neurophysiologists in the early 1940s had argued that logical mechanisms resembled the anatomy of the central nervous system. Led by Chicago-based neuropsychiatrist Warren McCulloch (1898–1969)[122] and the logician Walter Pitts (1923–1969), who had been mentored by Rudolf Carnap,[123] they argued that neurons not only were the smallest and binary entities of the nervous system but functioned logically with respect to each other.[124] In conjunction with the mathematical work by Goedel, Boole, and von Neumann, this argument supported the research hypothesis that the human brain was merely a biological Turing machine, with finite information storage.[125]

Another approach which also struck comparisons between artificial and biological systems was cybernetics. The ideas underlying cybernetics in the beginning of the twentieth century can be seen as an attempt to combine biological and engineering assumptions into one research field. Again, Norbert Wiener, in discussions with mathematician Julian Biegelow (Bigelow) (1913–2003) and the physiologist Arturo Rosenblueth (1900–1970), compared organisms with machines around 1942. Von Neumann had become quite interested in neurophysiology and the biomedical community after reading the McCulloch-Pitts paper. His growing interdisciplinary interest in the years to come is clearly evident in the number of scientists from different fields that he was in contact with, such as the biochemist Sol Spiegelman (1914–1983), the chemist and biologist Alfred Lotka (1880–1949), and even chemist Karl Friedrich Bonhoeffer (1899–1957) in Germany and biophysicist Max Delbrueck (1906–1981) at the California Institute of

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119 Martin Davis, "Mathematical Logic and the Origin of Modern Computers," in *The Universal Turing Machine – A Half-Century Survey*, ed. Rolf Herken (Hamburg, Berlin: Kammerer und Unverzagt, 1988), 149–76; William Asprey, "The Origins of John von Neumann's Theory of Automata," in *The Legacy of John von Neumann*, eds. James Glimm, John Impagliazzo, and Isadore Manuel (Providence, RI: American Mathematical Society, 1990), 294.

120 Asprey, "The Origins of John von Neumann's Theory of Automata," 289–309.

121 Andrew Hodges, *Alan Turing: The Enigma* (New York: Simon and Schuster, 1983), 556.

122 Michael A. Arbib, "Warren McCulloch's Search for the Logic of the Nervous System," *Perspectives in Biology and Medicine* 43, 2 (2000): 193–216.

123 Neil R. Smalheiser, "Walter Pitts," *Perspectives in Biology and Medicine* 43 (2000), 217–26.

124 Warren S. McCulloch and Walter Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity," *The Bulletin of Mathematical Biophysics* 5, 1 (1943), 115–33.

125 Sturm and Gundlach, "Urspruenge und Anfaenge."

Technology.[126] Hence, the work by Wiener, Biegelow, and Rosenblueth was immediately and positively received by von Neumann at the end of the war.

In 1945, Howard Aiken, von Neumann, and Wiener organized a quite interdisciplinary meeting at Princeton. On the agenda were topics such as von Neumann's insights into computing machines, communication engineering as pursued by Wiener, and lectures by Rafael Lorente de Nó (1902–1990) and McCulloch about the organization of the brain.[127] Following this meeting at Princeton, a larger group formed around McCulloch, Pitts, Biegelow, Aiken, von Neumann, and Wiener and decided to engage in a permanent collaborative research program. McCulloch took on the administrative planning, and with the financial aid of the Macy Foundation he organized the first official conference in 1946, which hosted twenty-one cognitive scientists. This first Macy Conference aimed to bring together several disciplines to contribute to the understanding of the functioning of the human mind and brain. This initial conference kicked off a period of many meetings and discussions, eventually resulting in a merger of several disciplines into a new research field.[128]

For the first conference, McCulloch invited Wiener, Pitts, and von Neumann to represent mathematical engineering, Rosenblueth, de Nó, and Ralph W. Gerard (1900–1974) for neurophysiology, Lawrence Kubie (1896–1973) and Hank Brosin (1904–1999) for psychiatry, Gregory Bateson (1904–1980) for sociology, Donald Marquis (1908–1973), Heinrich Kluever, Kurt Lewin, and Molly Harrower (1906–1999) for psychology; Harrower was a former student of Kurt Koffka at Smith College. Following the suggestion of von Neumann, Kurt Goedel was also invited to pursue research into cybernetics.[129]

For the fourth conference, Wolfgang Koehler was invited, as he had become interested in neurophysiological studies of the visual cortex and had turned to McCulloch for help obtaining grant money. The members of the Macy Conferences had previously been sceptical of inviting Koehler as a guest speaker, to avoid controversy between different branches of Gestalt. Nonetheless, he was invited to speak on the second day of the fourth conference. His experiments had not progressed very far at this point and did cause controversy in the audience, but he was much better received when he could present more data at the Hixon Symposium a year later.[130]

Following these regular meetings, Wiener published his book *Cybernetics* in 1948, which underlined the parallels that he saw between the new computing machines and living organisms, such as the similarity of a binary computer to nerve structures. Until the last conference in 1953, the group remained relatively constant, inviting only a few guests to join and provide insights to interdisciplinary problems that could not be addressed by the inner community itself. Among them were the social psychologist Paul Lazarsfeld; Theodore Schneirla (1902–1968), a former student of N.R.F. Maier; and psychologist Heinz Werner, who presented "On The Development of Word Meaning" in 1950.[131] Wiener and his following did not succeed at permanently establishing this round of conferences; they were, however, an important stepping stone for a much larger purpose, as Frank Fremont Smith (1895–1975), medical director and later head of the Macy Foundation, announced in the program for the ninth conference.

> . . . there is a further, and perhaps more fundamental, aim which is shared by all our conference groups. This is the promotion of meaningful communication between

[126] William Asprey, *John von Neumann and the Origins of Modern Computing* (Cambridge, MA: MIT Press, 1990), 181; Lily Kay, "Cybernetics, Information, Life," in *Who Wrote the Book of Life?* (Stanford, CA: Stanford University Press, 2000), 104–15.
[127] William Asprey, *John von Neumann*, 181–9.
[128] Steve Heims, "Midcentury U.S.A.," in *The Cybernetics Group* (Cambridge, MA: MIT Press 1991), 1–13.
[129] Heims, *John von Neumann and Norbert Wiener*, 201–4; Heims, *Cybernetics Group*, 203.
[130] Heims, "Gestalten Go to Bits, 2: Koehler's Visits," in Heims, *Cybernetics Group*, chapter 10.
[131] Claus Pias, ed., *Cybernetics: The Macy Conferences 1946–1953* (Zurich and Berlin: Diaphanes, 2003).

> scientific disciplines. The problem of communication between disciplines we feel to be a very real and urgent one, the most effective advancement of the whole of science being to a large extent dependent upon it. Because of the accelerating rate at which new knowledge is accumulating, and because discoveries in one field so often result from information gained in quite another, channels must be established for the most effective dissemination and exchange of this knowledge.[132]

Other conferences at the time also endeavoured to bring together sciences and to strengthen interdisciplinary communication; all these culminated in the successful establishment of cognitive science as a field of study a few decades later.

Conclusion

Between 1900 to 1950, many ideas and technological developments came together in a new interdisciplinary approach. Although the direction was far from clear at the beginning, but the pioneers of cognitive science envisioned the kind of problems they wanted to solve. During the same year in which Wiener published his book *Cybernetics*[133] another major step was taken toward the creation of cognitive science as an interdisciplinary research field. Breakthroughs in many disciplines and the advances of the previous century had been eagerly taken up by contemporary academics. In September 1948 many leading scientists from different fields met at the California Institute for Technology.[134] Funded by the Hixon Foundation, it became known as the Hixon Symposium on Cerebral Mechanisms in Behavior. The discussions focused on comparisons of the mind as in the publications of von Neumann and McCulloch and a critique of behaviourism in Lashley's article. Notably, three of the six presented papers came from people closely associated with the previous cybernetics research group: von Neumann, McCulloch, and Kluever at the Institute for Advanced Studies in Princeton. Furthermore, half of the speakers were émigré scientists who were taught in the "old" German schools of psychology and mathematics: Kluever, Koehler, and von Neumann. Therefore, it seems natural that the then-modern school of behaviourism was rejected, and instead the focus was laid on the study of cognitive processes.

The ideas explored at the Hixon Symposium quickly caught on in the relevant scientific communities. While at the earlier conferences and meetings analogies between computers and the nervous system were explored, in 1956 the comparison of machines with cognitive systems in living organisms was first directly formulated. Herbert Simon, who had long promoted interdisciplinary approaches, synthesized the advances in cybernetics and the Gestaltists' work on problem solving into an innovative idea. In the summer of 1956, together with American psychologist John McCarthy (1927–2011), linguist Marvin Minsky (1927–2016), and philosopher of science Allen Newell, Simon gathered with programmers from IBM at Dartmouth, New Hampshire, to discuss new progress for the creation of thinking machines.[135] These attempts resulted in the creation of the field of artificial intelligence, as the term was later coined by John McCarthy. In September of the same year the Symposium on Information Theory took place at MIT. Here again scientists from different disciplines met, and many milestone theories of cognitive science were

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132 Frank Fremont-Smith, "Program for the Ninth Macy Conference, 1952," in Claus Pias, ed., *Cybernetics: The Macy* Conferences *1946–1953* (Zurich and Berlin: Diaphanes, 2003).
133 Wiener, *Cybernetics*.
134 Lloyd A. Jeffress, ed., *Cerebral Mechanism in Behaviour: The Hixon Symposium* (New York and London: Hafner, 1967).
135 Hunter Crowther-Heyck, *A New Model of Mind and Machine*, in *Herbert A. Simon — The Bounds of Reason in Modern America* (Baltimore and London: John Hopkins University Press, 2005), 184–214.

presented, such as Newell and Simon's Logic Theory Machine,[136] American linguist Noam Chomsky's (b. 1928) essay "Three Models for the Description of Language,"[137] and psychologist George Miller's paper on the seven-item capacity of human short-term memory. In the same year, Jerome Bruner published *A Study of Thinking*.[138]

What followed was a slow but steady development toward an interdisciplinary pursuit of the study of the mind. This period came to be called the cognitive revolution, headed by Ulric Neisser's *Cognitive Psychology* published in 1967, which returned to the psychological study of mental processes. Other émigrés scientists and physicians could not be mentioned here, despite their contributions to the wider research field of cognitive science. Rather, the article is limited to psychology and mathematics; thus, individuals such as the German-speaking émigré neurophysiologists Stephen Kuffler (1913–1980)[139] and Bernard Katz (1911–2003) were not examined in this article, as were some individuals who came at a young age and were mostly taught in American schools, such as Karl Pribram (1919–2015), a student of Lashley. Some years passed before the return to cognitive phenomena gathered pace and cognitive science was officially born as an institutionalized discipline in the 1970s. We have seen that many psychologists who were still present and active during the time had earlier studied experimental psychology as it was taught in Germany, where already from the beginning, cognitive processes constituted the main interests of the researchers. Especially in the laboratories of Leipzig and Wuerzburg, and in Gestalt psychology in Berlin the scholars contributed highly influential theories to the study of cognition. Their continuous investigation of these topics, even after their often troubled emigration to the United States, contributed substantially to the integration of their methods and ideas into the new interdisciplinary approach of cognitive science. This novel research field was long based on the mind-as-machine analogy, which was developed in the first half of the twentieth century, drawing especially on the work of these early cognitive psychologists and the rapid progression of the development of a digital computer, and to which many of the scholars from Central Europe contributed.

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[136] Allen Newell and Herbert Simon, "The Logic Theory Machine — A Complex Information Processing System," *IEEE Trans. Inform. Theory* 2, 1 (1956): 61–79.
[137] Noam Chomsky, "Three Models for the Description of Language," *IEEE Trans. Inform. Theory* 2, 1 (1956): 113–24.
[138] Jerome S. Bruner, *A Study of Thinking* (New York: Wiley, 1956).
[139] For a brief biography of Kuffler see Vincent von Hoeckendorf and Frank W. Stahnisch, "Stephen William Kuffler (1913–1980)," *Journal of Neurology* 263 (2015), 1258–60.

Appendix 1a: Psychologist émigrés contributing to cognitive science, in order of appearance.

Table 1a: Influential psychologist émigrés

Name	*Born*	*Place of Birth*	*Deceased*	*Place Deceased*	*Formal Discipline(s)*	*PhD Received in*	*Notable Teachers*	*Place of Work in Europe*	*Year Emigrated*	*Institutions Worked at in the U.S.A.*
Brunswik, Egon	1903	Budapest	1955	Berkeley, CA	psychology	PhD in Vienna	Moritz Schlick; Karl Buehler	University of Vienna; University of Ankara	1937	University of California, Berkeley
Buehler, Karl	1879	Meckesheim	1963	Los Angeles, CA	medicine; psychology	PhD in Freiburg; PhD in Strasbourg	Oswald Kuelpe; Karl Marbe	University of Bonn; University of Munich; University of Dresden; University of Vienna	1938	University of Southern California, L.A.
Duncker, Karl	1903	Leipzig	1940		psychology	PhD in Berlin	Wolfgang Koehler; Max Wertheimer; Kurt Koffka	University of Berlin	1938	Swarthmore College, PA
Heider, Fritz	1896	Vienna	1988	Lawrence, KS	psychology; philosophy	PhD in Graz	Alexius Meinon; William Stern	University of Munich; University of Berlin; University of Hamburg	1930	Smith College, Northampton, MA; University of Kansas, KS
Katona, George	1901	Budapest	1981	Berlin	psychology	PhD in Goettingen	G.E. Mueller	proposedly Goettingen	1933	University of Michigan; Harvard University, MA; Brooklyn College, NY; Clark University, MA;
Kluever, Heinrich	1897	Holstein	1979	Oak Lawn, IL	psychology	PhD at Stanford	Max Wertheimer	-	1923	University of Minnesota; Columbia University, NY; University of Chicago
Koehler, Wolfgang	1887	Tallin	1967	Enfield, NH	psychology; physics	PhD in Berlin	Carl Stumpf	Psychological Institute Frankfurt; Tenerife; University of Berlin	1935	Swarthmore College, PA; Dartmouth, NH
Koffka, Kurt	1886	Berlin	1941	Northampton, MA	psychology	PhD in Berlin	Carl Stumpf	University of Giessen	ca. 1924	Cornell University, Ithaca, NY; Smith College, Northampton, MA

Appendix 1b: Psychologist émigrés contributing to cognitive science, in order of appearance.

Table 1b: Influential psychologist émigrés

Name	*Born*	*Place of Birth*	*Deceased*	*Place Deceased*	*Formal Discipline(s)*	*PhD Received in*	*Notable Teachers*	*Place of Work in Europe*	*Year Emigrated*	*Institutions Worked at in the U.S.A.*
Lazarsfeld, Paul	1901	Vienna	1976	New York City, NY	mathematics	PhD in Vienna	Karl Buehler	Psychological Institute, Vienna	1935	University of Newark, NJ; Princeton University, NJ; Columbia University, NYC
Lewin, Kurt	1890	Mogilno	1947	Newtonville, MA	psychology; philosophy	PhD in Berlin	Carl Stumpf	University of Berlin	1933	Stanford University, CA; Cornell University, NY; University of Iowa, IA; M.I.T., MA
Neisser, Ulric	1928	Kiel	2012	Ithaca, NY	psychology	PhD at Harvard	George A. Miller; Hans Wallach	-	1933	Cornell University, Ithaca, NY
Wallach, Hans	1904	Berlin	1998	Media, PA	philosophy; Psychology	PhD in Berlin	Wolfgang Koehler; Max Wertheimer; Kurt Koffka	University of Berlin	1937	Swarthmore College, PA; New School for Social Research, NY; Princeton I.A.S., NJ
Werner, Heinz	1890	Vienna	1964	Worcester, MA	psychology	PhD Vienna	-	University of Hamburg	1933	University of Michigan; Harvard University, MA; Brooklyn College, NY; Clark University, MA;
Wertheimer, Max	1880	Prague	1943	New Rochelle, NY	philosophy; psychology	PhD in Wuerzburg	Carl Stumpf; G.E. Mueller in Berlin; Kuelpe in Wuerzburg	Psychological Institute Frankfurt; University of Berlin	1933	New School of Social Research, NY

Appendix 2: Mathematician and engineering émigrés contributing to cognitive science, in order of appearance.

Table 2: Mathematician and engineering émigrés

Name	Born	Place of Birth	Deceased	Place Deceased	Formal Discipline(s)	PhD Received in	Notable Teachers	Place of Work in Europe	Year Emigrated	Institutions Worked at in the U.S.A.
Bernays, Paul	1888	London	1977	Zurich, SWI	mathematics; physics; philosophy	PhD in Berlin	David Hilbert; Ernst Cassirer; Carl Stumpf; Hermann Weyl	E.T.H. Zurich; University of Goettingen	visits from 1935-36; 1959-60	visiting scholar at Princeton University
Goedel, Kurt	1906	Bruenn	1978	Princeton, NJ	mathematics; physics	PhD in Vienna	Moritz Schlick; Hans Hahn	University of Vienna	1938	Princeton University
Morgenstern, Oskar	1902	Goerlitz	1977	Princeton, NJ	political science	PhD in Vienna	-	University of Vienna	1938	Princeton University
von Neumann, John	1903	Budapest	1957	Washington, D.C.	chemical engineering; mathematics	PhD in Budapest	David Hilbert; Hermann Weyl	University of Berlin; University of Goettingen; University of Hamburg	1933	Princeton University; Los Alamos; University of Pennsylvania
Weyl, Hermann	1885	Elmshorn	1955	Zurich, SWI	mathematics; physics	PhD in Goettingen	David Hilbert	E.T.H. Zurich; University of Goettingen	1933	Princeton University