This is proof version of:
Hohol, M. (2021). Cognitive science: an interdisciplinary approach to mind and cognition. In B. Brożek, M. Jakubiec, P. Urbańczyk (Eds.), Perspectives on interdisciplinarity (33–55), Krakow: Copernicus Center Press.

Mateusz Hohol
Copernicus Center for Interdisciplinary Studies,
Jagiellonian University in Krakow

Cognitive science: an interdisciplinary approach to mind and cognition[1]

Introduction

The mind is usually considered to be machinery which computes inner representations and employs them to act. These representations could refer to both physically existing objects, or events occurring in the proximal surrounding, and hypothetical entities (Fodor, 1975). For instance, when perceiving an object characterized by meowing, having whiskers, tail, four paws, and fur, we immediately categorize it as "cat," and reach out to pet it (unless we do not like cats). What is more, categorizing the object as a cat allows us to use our prior knowledge and say that it is a mammal and a vertebrate, that it occupies terrestrial niches, and could be our companion. Thus, one could define cognition as mental activity

[1] This is the English and expanded version of a chapter (Hohol, 2019) published in the online handbook edited by Piotr Urbańczyk and Marek Jakubiec.

(e.g., categorization) sandwiched between perception (e.g., visual) and action (e.g., petting or verbal behavior).

Although the computational-representational approach to mind and situating cognition between perception and action have been challenged (see e.g., Chemero, 2009), they are characteristic of the early stage of so-called cognitive science (henceforth, CogSci). CogSci is usually described as an interdisciplinary enterprise which aims to understand how the mind works. In the present chapter, I will focus on the interdisciplinarity of CogSci by tracking and tracing its history. At the outset, I will outline the collaboration of various disciplines since the dawn of CogSci in the 1950s to 1980s (this period is usually called classic CogSci). Then, I will take a closer look at some of the newer faces of interdisciplinarity in CogSci. These considerations will be illustrated by case studies of computer simulations in classic CogSci and more recent research on cognitive metaphors, respectively. Finally, I will describe recent controversies related to interdisciplinary studies of mind and cognition.

The interdisciplinarity of classic computational cognitive science

Although philosophers have investigated the nature of mind and cognition since ancient times, they did so purely theoretically, usually making use of introspection and anecdotes. Experimental studies have only been conducted since the 20th century, when psychology became an independent field (Gardner, 1985). It was perhaps Jean Piaget who was the first researcher to conceptualize the individual development of knowledge structures as building and transforming inner representations. His studies conducted in the period covering the 1920s-1950s involved a broad spectrum of topics, from the cognitive origins of morality, through language up to mathematical cognition (Piaget, 1926). His works from this period were not, however, widely known in the United States, where behaviorism, avoiding the concept of mental representation, predominated in experimental psychology.

In the United States, the cognitive revolution started in the mid-1950s (Bechtel, Abrahamsen, & Graham, 1998; Gardner, 1985; Miller, 2003) and gave rise to the discipline known today as CogSci. This name, given at the University of California San Diego in La Jolla, gained popularity later and in the 1970s other terms, such as cognitive studies at Harvard University and information-processing psychology at Carnegie Mellon University, were used in tandem (Miller, 2003). However, such semantic issues are not our concern here. A traditional date considered to mark the advent of CogSci is September 11, 1956, when a group of researchers interested in the information theory and related disciplines met at the symposium organized at the Massachusetts Institute of Technology. Its participants included, among others, Allen Newell and Herbert Simon, who presented their theorem proving computer program (Newell, Shaw7 & Simon, 1958); Noam Chomsky, who outlined his model of language build on the generative grammar approach (see Chomsky, 1980), and George Miller (1956), who presented results of studies on the limits of short-term memory.

The latter of CogSci's founding fathers, George Miller (2003), confessed after many years that he left the symposium "with a conviction, more intuitive than rational, that experimental psychology, theoretical linguistics, and the computer simulation of cognitive processes were all pieces from a larger whole and that the future would see a progressive elaboration and coordination of their shared concerns" (p. 143). Although according to the traditional view early CogSci comprised psychology, linguistics, and computer science (or artificial intelligence) and supported by

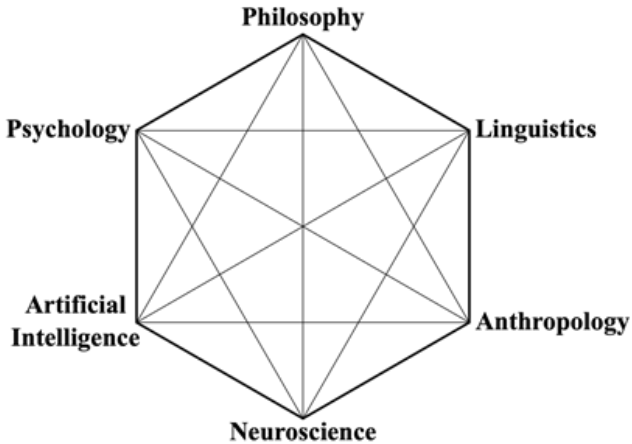

Figure 1. The structure of cognitive science (modeled on Wikipedia; CC BY--SA 3.0). According to the traditional view, CogSci on the grand scale is the product of interdisciplinary collaboration between, or joint efforts of, (experimental) psychology, philosophy (of mind), linguistics (mathematical and theoretical), neurobiology (or neuroscience), artificial intelligence (or computer science in general), as well as anthropology (both cultural and biological). They constitute nodes in the above diagram. These academic fields can interact at a smaller scale, creating more specific research interdisciplinary programs, represented by lines of the diagram. The most important of such programs are psycholinguistics and neurolinguistics, studying respectively psychological and neural mechanisms of language and communication (Aitchison, 2011; Ingram, 2007), cognitive neuroscience, interested in neural foundations of cognitive processes (Gazzaniga, 1995), computational neuroscience, modeling neural processes and its products (namely cognition and behavior) by using algorithms, artificial neural networks, and other computer tools (Churchland & Sejnowski, 1994; Miłkowski, 2013), the philosophy of artificial intelligence (Clark, 2007), neurophilosophy, undertaking the traditional philosophical problems in neuroscientific terms (Churchland, 1986), and finally, cognitive anthropology, where cognitive processes are elucidated using anthropological methods (Hutchins, 1995).

neuroscience, anthropology, and philosophy (Figure 1), Miller claims that the first three disciplines were "central," while other three "peripheral" (ibid.). However, this does not mean that neurobiologists were not active in their labs, anthropologists did not conduct fieldwork, and philosophers did not think thoroughly in their armchairs in the pioneering years. Miller's main message is they did not work together as closely as experimental psychologists, linguists, and computer scientists.

Case study 1: Collaboration of computer scientists and psychologists within classic computational CogSci. The main goal of a computer simulation is mapping the causal structure of a simulated phenomenon by implementing crucial component parts and operations involved in a phenomenon of interest (whether it is a hurricane, stock exchange, or human cognition). This task requires, in turn, experimentally investigating and understanding the phenomenon of interest. Only then is a modeler able to recreate general regularities (and sometimes even laws) and select initial conditions constituting the phenomenon. Computer simulations of cognitive processes realized by the founding fathers of CogSci implemented interdisciplinary collaboration. Newell and Simon (1976), as well as other modelers, were particularly interested in problem-solving, both by flesh-and-blood human beings and artificial systems. To achieve relevance they implemented psychological data, e.g., verbal protocols collected under laboratory research on problem-solving (Ericsson & Simon, 1984). Solving geometric problems is a representative example. Greeno's (1978) computer program called Perdix taken into account verbal protocols obtained from students facing with Euclidean problems. Thanks to this strategy, Greeno decided to abandon the modern, purely formal, approach to geometry and implemented a more intuitive strategy, where the content of a diagram could constitute the relevant resource for proving by the artificial engine. Geometry Tutor Expert was another psychological data-driven theorem-proving program. Its developers incorporated the results of experimental studies on the use of heuristic rules to predict further inferences based on contextual diagram properties and previously accepted statements (for more details about these and other theorem-proving programs see the chapter of Hohol, 2020). Notably, the rules of transformation in various early problem-solving programs also implemented the results of linguistic studies (see Chomsky, 1980).

Close collaboration between psychologists, linguists, and computer scientists resulted in the emergence of an approach refining the computational-representational approach to cognition sketched at the beginning of the chapter. According to Newell and Simon (1976), cognition-as-representation-processing not only happens in humans but also in all cognitive systems, including artificial ones. These researchers proposed the so-called physical symbol system hypothesis claiming that any physical system (no matter whether it is biological, like the human brain, or silicon circuits, like a computer) manipulating symbols step-by-step according to well-defined rules "has the necessary and sufficient means for general intelligent action" (ibid., p. 116). Note that, "a symbol" is understood here as amodal (namely, deprived of any perceptual content), language-like (i.e., resembling rather logic tokens than natural language ones), and arbitrary (this means that its processing involves only purely syntactic properties, not the structural similarity to its referent; see also (Fodor, 1975; Jackendoff, 2002). In other words, Newell and Simon's hypothesis states that if a physical system manipulates symbols it is a cognitive system; and conversely, if a system is cognitive, it is a physical system manipulating symbols. According to the hypothesis, geometric theorem proving programs (see Case study 1) implemented in computer hardware could be dubbed cognitive systems in the same systems as flesh-and-blood geometers.

One could ask which component parts of physical systems are directly involved in constituting cognition? On the one hand, classic computational CogSci intentionally avoided this question, since it considered cognition as a function of the system that is explanatory autonomous from the system's physical structure. On the other hand, the founding fathers of CogSci assumed that higher cognitive functions are implemented in the prefrontal cortex, while sensorimotor cortices are not directly involved in cognition (recall the amodal nature of symbols). According to this view, the process of object categorization looks as follows (in a nutshell). First, the perception of an object involves preprocessing in sensory areas (e.g., occipital lobe for visual perception). Second, information is transmitted to the prefrontal cortex, where cognition takes place (e.g., categorization through testing proximity to the prototype or evaluating whether a perceived object meets necessary and sufficient conditions to be a category member). Finally, the results of cognitive processing serve as a trigger of action initiated in motor cortices. Importantly, stage one (processing in sensory cortices) and stage three (motor cortices activity) cannot be called cognitive.

The physical symbol system hypothesis stimulated interdisciplinary research on the computer simulation of cognitive processes. Clearly, particular disciplines delivered basic outputs. Computer science, for instance, delivered tools for computational modeling, linguistics – for analyzing symbolic transformations, and psychology – for the experimental study of human behavior. Only interdisciplinary collaboration between them allowed, however, a more comprehensive view on cognition. What is important, the information flow between computer science and psychology was bidirectional. On the one hand, experimental psychology delivered data informing and constraining modelers' efforts. On the other hand, the results of computational simulations could serve as a source for building predictions for further psychological experiments (see Churchland & Sejnowski, 1994).

The interdisciplinarity of more recent cognitive science

The situation where CogSci was mainly constituted by psychology, linguistics, and computer science began to change at the end of the 1970s. According to Bechtel, Abrahamsen, and Graham (1998), at this time CogSci expanded "vertically into the brain and horizontally into the environment" (p. 77). New methods of measuring brain activity gained in popularity, cognitive scientists placed more research emphasis on the impact of the surrounding world – both physical and social – on cognition. Proponents of classic computational CogSci argued that external factors could be ignored, at least in the early stages of research (see Vera & Simon, 1993). Last, but not least, the change was also motivated by highlighting the problems of the classic computational CogSci. The so-called symbol grounding problem described by Steven Harnad (1990) is one of the most serious of them.

The symbol grounding problem is the following: "How can the meanings of the meaningless symbol tokens, manipulated solely on the basis of their (arbitrary) shapes, be grounded in anything but other meaningless symbols?" (Harnad, 1990, p. 335). The problem could also be expressed more intuitively. Is a total novice able to learn a foreign language with only a dictionary at their disposal? Since each word is defined by other words in a standard dictionary, and she does not understand these words, the simple answer is no. To learn something, a novice has to have at her disposal something linking at least some words with their referents. Returning to a more technical formulation, to solve the symbol grounding problem, the meaning of at least some mental symbols (representations) should be grounded in something other than the purely syntactic properties of arbitrary symbols. For instance, some representations should be structurally similar to their referents (Gładziejewski & Miłkowski, 2017). In this way, the concept of "cat" could be defined not as a list of abstract features but rather as resembling cats we interact with. Another problem associated with the physical symbol system hypothesis is a lack of details about where concepts come from. Thus, an alternative proposal should not only solve the symbol grounding problem but also elucidate the origins of our concepts.

Embodied cognition (resp. grounded cognition) offers an alternative that promises to meet the above criteria. This approach emerged from the interdisciplinary collaboration of all six disciplines indicated in Fig 1 in the 1980s. Its main assumption says that cognitive processes are deeply rooted in our bodies and bodily interaction with the surrounding world. Higher cognition is not sandwiched between perception and action but directly involves sensorimotor cortices. Although embodied cognition is far from being a single theory – it is a paradigm containing a wide spectrum of different and sometimes even incoherent ideas (see Wołoszyn & Hohol, 2017) – more and more researchers agree that our cognition cannot be elucidated without recourse to the body (Chemero, 2009; Clark, 1999; Davis & Markman, 2012; Johnson, 2012; Lakoff & Johnson, 1980; Wilson, 2002). More precisely, proponents of embodiment claim that the detailed structure of our bodies shape, or at least constrain, the concepts we have at our disposal. This view has been adopted in studies on many kinds of concepts, e.g., social and emotional (Carr et al., 2018), mathematical (Hohol et al., 2018), or religious (Barsalou et al., 2005). Let us look at the contribution of the constituting disciplines of cognitive science to the idea of embodiment.

The term embodied cognition appeared in philosophy for the first time at the end of the first half of the 20th century, in the milieu of the French phenomenologists. One of them, Maurice Merleau-Ponty, highlighted in his book “Phenomenology of perception” (1945/2002) that the body could be considered as a cognitive organ interacting with the world and giving meaning to our linguistic expressions. This philosophical idea was adopted by cognitive linguists in the 1980s who emphasized the interactive nature of our concepts. Zoltan Kövecses (2006), who belongs to the research tradition of cognitive linguistics, outlines the following elucidation:

> As an example, take the conceptual category of TREE. How can the body play any role in our understanding of what tree is? For one thing, we understand a tree as being upright. This comes from how we experience our own bodies; namely, that we experience ourselves as being erect. For another, we see a tree as tall. The aspect of tallness only makes sense with respect to our standard evaluation of the body’s relative height. A tree is tall relative to our average human size. In this way, categories of mind are defined by the body’s interaction with the environment (s. 11).

The idea of embodied cognition has also been elaborated within psychology. The theory of perceptual symbols by Lawrence Barsalou (1999, 2020) is one of the best empirically corroborated incarnations of embodiment in this field. Contrary to amodal theories, Barsalou claims that there is no single area of the brain specialized in conceptual processing or higher thinking in general. Instead, concepts are encoded in the areas primarily responsible for perception and motor control (thus the theory could be dubbed perceptual and motor symbols). There are two main technical terms: “simulator,” and “simulation.” According to Barsalou (2020), “whereas the entire body of accumulated knowledge for a category constitutes a simulator, using the simulator to construct a conceptualization on a specific occasion constitutes a simulation" (p. 9). Let us return to our category of "cat." Whenever we encounter a cat, both cortical and subcortical structures of the brain processing the cat's properties are activated in order to encode these properties in the appropriate modalities. At the same time, these modality-specific activations are integrated into association structures (e.g., the parietal cortex). Thus the perception of a cat triggers processing in terms of how it looks (visual cortex), smells (olfactory cortex), and moves (motor cortex). Moreover, our brains process some motor opportunities associated with a cat (e.g., grooming). Last, but not least, emotional areas responsible for rewards accompanying a cat are also activated. All these signals are integrated into association areas. The following interactions with cats make this distributed pattern of activation superimposing, and after many such episodes, a simulator of "cat" became more robust. Thus, the concept of "cat" is not implemented in the brain as a list of features or as an idealized prototype, but rather as an exemplar copy saturated by perceptual and motor features (see Figure 2). When well-established, a simulator could be used to make predictions or reasonings about cats in the process of simulation. This process involves the reenactments of all the brain areas associated with the primary experience of a cat. What is important, this process could be run to represent the cat even in its absence. In this way, we can think about cats (this includes imagine them) even when there is no physical exemplar of the cat in front of us. Finally, as Barsalou (2020) claims, "one form of concept composition results from binding multiple simulators to multiple perceived entities in the world and then relating them together with a relational simulator" (p. 9). Thus, simulators are not completely fixed, but they could be combined in various ways.

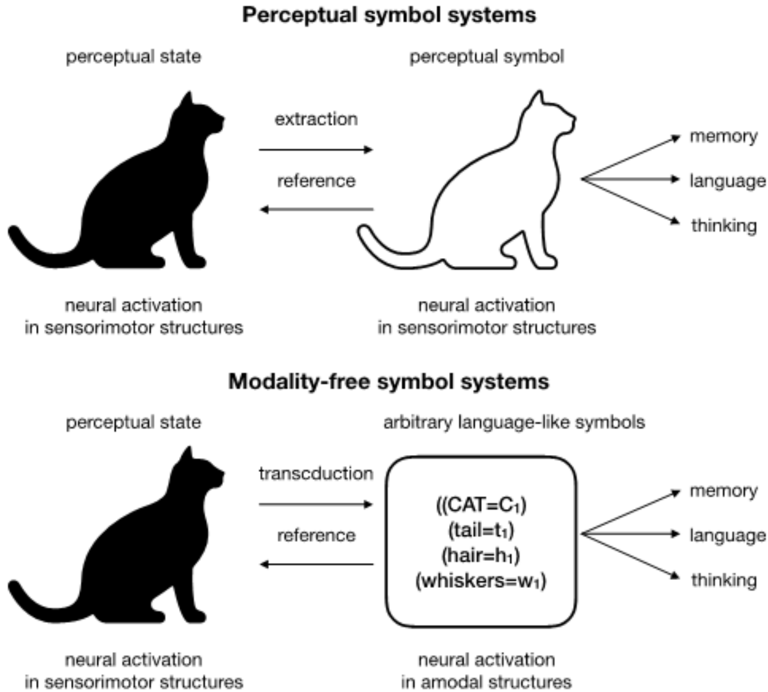

Figure 2. Theory of perceptual symbols (top) vs. physical symbol system hypothesis (down). It is modeled on Barsalou, 1999, p. 578–579. Barsalou's theory of perceptual symbols assumes that mental representations of categories, e.g., concept "cat", are analogous to perceived objects and emerge through extraction from perceptual (and motor) states. Cognition is grounded in perception and action through simulations (of reenactments) of interactions with exemplars, occurring in sensorimotor structures of our brains. On the other hand, the physical symbol system hypothesis proclaims that mental representations of categories occur in the process of the transduction of percepts to an amodal format. The conceptual processing does not involve sensorimotor structures, at least directly, but it is implemented in amodal structures of the brain. The theory of perceptual symbols is one of the best-known incarnations of the embodied CogSci, while the physical symbol system hypothesis is characteristic of classic computational CogSci.

Although the theory of perceptual (and motor) symbols grew out of psychology (Barsalou, 1999) it has been extended to other disciplines and has become a platform for successful interdisciplinary collaboration within CogSci. While the first empirical test of the theory involved behavioral experiments, neuroscientific methods were also successively used. For instance, Simmons and his colleagues (2007) found that visual structures of the brain are not only active during direct color perception but also during cognitive tasks including verification of object features performed by the participants. More literally, visual structures were not only activated when the participants perceived a yellow taxi but also when they thought about a yellow taxi. Barsalou's theory was also developed in terms of computational models (Pezzulo et al., 2011) and widely discussed on the ground of the philosophy of mind (e.g., Prinz, 2004). However, many theorists and empirical researchers noted that, although the theory of perceptual symbols convincingly elucidates the processing of concrete concepts (e.g., "cat"), abstract concepts ("democracy," "love," "prime number") constitute a severe challenge to it. Thus, other theories, expanding the idea of embodiment have been developed. In Case Study 2, I outline one of them, namely the theory of conceptual metaphors (Lakoff and Johnson, 1980), that emerged within linguistics but soon launched interdisciplinary studies.

Case study 2: Interdisciplinary studies on metaphor within embodied CogSci. In the book entitled "Metaphors we live by" (1980), the linguist George Lakoff and the philosopher Mark Johnson stated that "our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature" (p. 3). According to these authors, a metaphor means "understanding and experiencing one kind of thing in terms of another (ibid., p. 5), wherein "understanding and experiencing" indicate that this is not only about a linguistic level, but also a prelinguistic level of cognition. Lakoff and Johnson's main tenet is that all abstract concepts are structured by concrete concepts thanks to metaphorical mappings. Ordinary metaphorical thinking occurs when we talk that she "experienced ups and downs," and "got into trouble," but then "got out of trouble," and finally (and fortunately) "lift her spirit." Another story full of metaphors is: "his diploma exam turned out to be very hard", "he tried to defend his thesis," but "he fell on the battlefield." In consequence, "he boiled with anger," but then he calmed down and understood "he should approach the exam once again." Importantly, the metaphors present in the above expressions are not linguistic conventions but the way our mind conceptualizes abstract domains. To this end, we use concrete concepts as "weight," "ascension," "falling," "boiling," and "approaching" to understand and express our experiences in the social (e.g., academic) domain. The theory of cognitive metaphors is embodied since it emphasizes that even very abstract concepts are grounded in our action and perception. Lakoff and Johnsons' idea triggered interdisciplinary collaboration in at least two aspects. First, it has been applied to the analysis of evidently distinct fields as poetics (Lakoff & Turner, 1989), philosophy (Lakoff & Johnson, 1999), politics (Lakoff, 2002), law (Brożek, 2020), and even mathematics (Lakoff & Núñez, 2000). Second, the assumption that our abstract concepts are rooted in sensorimotor experience has been investigated not only through analysis of discourse and communication but also by using a large toolkit of CogSci methods. Experimental psychologists have tested some metaphors in behavioral experiments. For instance, Casasanto and Boroditsky (2008), investigated whether metaphorical representations as "a long lecture" or "a too-short coffee break," also occur at the cognitive level. They asked participants to observe nonverbal stimuli, i.e., lines or dots, and then to reproduce their duration or spatial shift. The researchers found that when participants made decisions about duration, they could not ignore spatial information, but not vice versa. As they concluded, this result indicates that the metaphorical mapping of space and time is not only a matter of linguistic convention but runs at the level of embodied mental processing. There are also dozens of studies indicating other abstract cognitive domains are processed via metaphorical mappings. For instance, we unconsciously think about such abstract entities as numbers in terms of objects occupying the place in a spatial continuum resembling a number line (e.g., Cipora et al., 2016). There are also neuroscientific findings in line with the theory of cognitive metaphors. For instance, some neuroimaging studies found that the processing of highly metaphorical linguistic expressions activates sensorimotor structures primarily responsible for perception and motor control (Gallese & Lakoff, 2005; Pulvermüller, 2002). Last, but not least, elements of Lakoff and Johnsons' theory have been further developed with the use of computational models (e.g., Indurkhya, 1987; Kintsch, 2000).

Challenges of the interdisciplinary study of mind and cognition

One may correctly notice that nowhere have I defined what is interdisciplinarity but rather talked about interdisciplinary collaboration within CogSci or collaboration among representatives of disciplines constituting CogSci. These uses at least partly resonate with the common meaning of the interdisciplinarity. It is not my goal to analyze the various variants of interdisciplinarity and related concepts in detail, such as multidisciplinarity, crossdisciplinary, or transdisciplinarity (see e.g., Alvargonzález, 2011; Ash, 2019). Instead, I would like to introduce a frequently used distinction between weak and strong interdisciplinarity in CogSci (Gardner, 1985). The former, weak interdisciplinarity, refers to the interdisciplinary collaboration between scientists (e.g., psychologists and philosophers) whose goal is to gain deeper insight into some aspects of cognitive processing, but without any ambition of setting out a novel conceptual framework and study methods. Here, everyone comes to the joint enterprise with their own background and methods (e.g., a psychologist with behavioral experiments and the philosopher with conceptual analyses) and these academics try to do something together. On the contrary, the strong form of interdisciplinarity means the coordination of joint research efforts in order to establish a novel theoretical framework and methods of investigation. Here, everyone comes with their own background and methods but, over time, often gradually, these differences blur. This novel framework should be characterized by the integration and unification of its constituents (see Miłkowski, 2016, 2017). The majority of academics have noticed that classic computational CogSci is characterized by interdisciplinarity in a weak sense (e.g., Bechtel, Abrahamsen & Graham, 1998; Gardner, 1985). Thus, we should talk rather about cognitive sciences in the plural rather than as a single discipline.

However, there is no consensus about the ultimate purpose of CogSci. A traditional view is that the ambition of its founding fathers was to lay the foundations of a strong interdisciplinary CogSci. more than 60 years after the pioneering symposium at MIT one could assume the boundaries of psychology, neuroscience, computer science, linguistics, philosophy, and anthropology are blurred. Recently, Rafael Núñez and his collaborators (2019) investigated this assumption in a data-driven way. Analyzing many indicators, they concluded that CogSci is not interdisciplinary today in a strong sense. The authors found that instead of the new framework, CogSci teaching curricula at US research universities are dominated by one of the fields (most often psychology or neuroscience). Moreover, students learn about the other CogSci fields separately and without integrative contexts. In addition to educational indicators, Núñez and colleagues investigated the content of the top journal in the field called Cognitive Science. They found the published papers are dominated by those from experimental psychology, and the contribution of anthropology is only marginal. On the other hand, other researchers claim that the situation where experimental psychology and neuroscience are central does not have to mean the end of cognitive science. Moreover, at least some of CogSci's founding fathers have explicitly claimed that they had no ambition of building a strongly interdisciplinary enterprise (see Gentner, 2019).

The situation becomes even more complicated when we take into account the fact that contemporary researchers called and/or calling themselves cognitive scientists not only use methods and concepts of "the founding disciplines" fruitfully (namely, psychology, computer science, linguistics, neuroscience, anthropology, and philosophy), but also fields such as evolutionary biology, comparative ethology or sociology. There are many reasons to be skeptical that this will someday lead to strong interdisciplinarity, but some voices emphasize the fact that such pluralism is not a vice but rather a virtue of CogSci (see Miłkowski & Hohol, 2020; Miłkowski, Hohol & Nowakowski, 2019 for discussion). Moreover, many valuable research programs where two or more disciplines meet have emerged within this globally weakly interdisciplinary CogSci. Cognitive neuroscience and computational neuroscience (see Fig 1) constitute particularly fine examples of building unified frameworks and using original methodologies in order to obtain a deeper understanding of our minds.

References

Aitchison, J. (2011). The articulate mammal: An introduction to psycholinguistics. In *The Articulate Mammal: An Introduction to Psycholinguistics*. London-New York: Routledge.

Alvargonzález, D. (2011). Multidisciplinarity, interdisciplinarity, transdisciplinarity, and the sciences. *International Studies in the Philosophy of Science*, *25*(4), 387-403. https://doi.org/10.1080/02698595.2011.623366

Anderson, J. R., Boyle, C. F., & Yost, G. (1985). The geometry tutor. *Proceedings of the International Joint Conference on Artificial Intelligence*. Los Angeles: IJCAI.

Ash, M. G. (2019). Interdisciplinarity in historical perspective. *Perspectives on Science*, *27*(4), 619-642. https://doi.org/10.1162/posc_a_00318

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*(4), 577-660. https://doi.org/10.1017/S0140525X99002149

Barsalou, L. W. (2020). Challenges and opportunities for grounding cognition. *Journal of Cognition*, *3*(1), 1-24. https://doi.org/10.5334/joc.116

Barsalou, L. W., Barbey, A. K., Simmons, W. K., & Santos, A. (2005). Embodiment in religious knowledge. *Journal of Cognition and Culture*, *5*(1-2), 14-57. https://doi.org/10.1163/1568537054068624

Bechtel, W., Abrahamsen, A., & Graham, G. (1998). The life of cognitive science. In W. Bechtel & G. Graham (Eds.), *A companion to cognitive science* (pp. 2-104). Malden: Blackwell Publishers.

Brożek, B. (2020). *The legal mind: A new introduction to legal epistemology*. Cambridge: Cambridge University Press.

Carr, E.W., Kever, A., & Winkielman, P. (2018). Embodiment of emotion and its situated nature. In A. Newen, L. de Bruin, &

S. Gallagher (Eds.), The Oxford Handbook of 4E Cognition (pp. 529-552), Oxford: Oxford University Press.
Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition*, *106*(2), 579-593. https://doi.org/10.1016/j.cognition.2007.03.004
Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: The MIT Press.
Chomsky, N. (1980). *Rules and representations*. New York: Columbia University Press.
Churchland, P. S. (1986). *Neurophilosophy: Toward a unified science of the mind/brain*. Cambridge, MA: The MIT Press.
Churchland, P. S., & Sejnowski, T. J. (1994). *The computational brain*. Cambridge MA: The MIT Press.
Cipora, K., Hohol, M., Nuerk, H.-C., Willmes, K., Brożek, B., Kucharzyk, B., & Nęcka, E. (2016). Professional mathematicians differ from controls in their spatial-numerical associations. *Psychological Research*, *80*(4), 710-726. https://doi.org/10.1007/s00426-015-0677-6
Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences*, *3*(9), 345-351. https://doi.org/10.1016/S1364-6613(99)01361-3
Clark, A. (2007). Artificial intelligence and the many faces of reason. In S. Stich & T. Warfield (Eds.), *The Blackwell guide to philosophy of mind* (pp. 309-321). Hoboken, NJ: Blackwell. https://doi.org/10.1002/9780470998762.ch13
Davis, J. I., & Markman, A. B. (2012). Embodied cognition as a practical paradigm: Introduction to the topic, the future of embodied cognition. *Topics in Cognitive Science*, *4*(4), 685-691. https://doi.org/10.1111/j.1756-8765.2012.01227.x
Ericsson, K. A., & Simon, H. A. (1984). *Protocol analysis: Verbal reports as data*. Cambridge, MA: The MIT Press.
Fodor, J. A. (1975). *The language of thought*. Cambridge, MA: Harvard University Press.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: the role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, *22*(3-4), 455-479. https://doi.org/10.1080/02643290442000310

Gardner, H. (1985). *The mind's new science: A history of cognitive revolution*. New York: Basic Books.

Gazzaniga, M. S. (1995). *The cognitive neurosciences* (M. S. Gazzaniga, Ed.). Cambridge, MA: The MIT Press.

Gentner, D. (2019). Cognitive science is and should be pluralistic. *Topics in Cognitive Science*, *11*(4), 884-891. https://doi.org/10.1111/tops.12459

Gładziejewski, P., & Miłkowski, M. (2017). Structural representations: causally relevant and different from detectors. *Biology and Philosophy*, *32*(3), 337-355. https://doi.org/10.1007/s10539-017-9562-6

Greeno, J. G. (1978). A study of problem-solving. *Advances in Instructional Psychology*, *1*, 13-75.

Harnad, S. (1990). The symbol grounding problem. *Physica D: Nonlinear Phenomena*, *42*(1-3), 335-346. https://doi.org/10.1016/0167-2789(90)90087-6

Hohol, M. (2019). Nauki kognitywne. In P. Urbańczyk & M. Jakubiec (Eds.), *Interdyscyplinarność w naukach humanistycznych i społecznych*. Copernicus College: https://www.copernicuscollege.pl/podreczniki/interdyscyplinarnosc-w-naukach-humanistycznych-i-spolecznych.

Hohol, M. (2020). *Foundations of geometric cognition*. London-New York: Routledge.

Hohol, M., Wołoszyn, K., Nuerk, H.-C., & Cipora, K. (2018). A large-scale survey on finger counting routines, their temporal stability and flexibility in educated adults. *PeerJ*, *6*(e5878). https://doi.org/10.7717/peerj.5878

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: The MIT Press.

Indurkhya, B. (1987). Approximate semantic transference: A computational theory of metaphors and analogies. *Cognitive Science*, *11*(4), 445-480. https://doi.org/10.1016/S0364-0213(87)80016-2

Ingram, J. C. L. (2007). *Neurolinguistics: An introduction to spoken language processing and its disorders*. Cambridge: Cambridge University Press.

Jackendoff, R. (2002). *Foundations of language: Brain, meaning, grammar, evolution*. Oxford: Oxford University Press.

Johnson, M. (2012). *The meaning of the body*. Chicago: University of Chicago Press.

Kintsch, W. (2000). Metaphor comprehension: A computational theory. *Psychonomic Bulletin & Review*, *7*(2), 257-266. https://doi.org/10.3115/981436.981442

Kövecses, Z. (2006). *Language, mind, and culture: A practical introduction*. Oxford: Oxford University Press.

Lakoff, G. (2002). *Moral politics: How liberals and conservatives think*. Chicago: University of Chicago Press.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to western thought*. New York: Basic Books.

Lakoff, G., & Núñez, R. (2000). *Where mathematics comes from*. New York: Basic Books.

Lakoff, G., & Turner, M. (1989). *More than cool reason: A field guide to poetic metaphor*. Chicago: More Than Cool Reason: A Field Guide to Poetic Metaphor.

Merleau-Ponty, M. (2002). *Phenomenology of perception*. New York: Psychology Press.

Miłkowski, M. (2013). *Explaining the computational mind*. Cambridge, MA: The MIT Press.

Miłkowski, M. (2016). Integrating cognitive (neuro)science using mechanisms. *Avant*, *6*(2), 45-67. https://doi.org/10.26913/70202016.0112.0003

Miłkowski, M. (2017). Unification strategies in cognitive science. *Studies in Logic, Grammar and Rhetoric*, *48*(1), 13-33. https://doi.org/10.1515/slgr-2016-0053

Miłkowski, M., Hohol, M. (2020). Explanations in cognitive science: Unication versus pluralism. *Synthese*. Online first. https://doi.org/10.1007/s11229-020-02777-y

Miłkowski, M., Hohol, M. Nowakowski, P. (2019). Mechanisms in psychology: The road towards unity? *Theory & Psychology*, *29*(5), 567-578. https://doi.org/10.1177/0959354319875218

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81-97. https://doi.org/10.1037/h0043158

Miller, G. A. (2003). The cognitive revolution: A historical perspective. *Trends in Cognitive Sciences*, *7*(3), 141-144. https://doi.org/10.1016/S1364-6613(03)00029-9

Newell, A., Shaw, J. C., & Simon, H. A. (1958). Elements of a theory of human problem solving. *Psychological Review*, *65*(3), 151-166. https://doi.org/10.1037/h0048495

Newell, A., & Simon, H. A. (1976). Computer science as empirical inquiry: symbols and search. *Communications of the ACM*, *19*(3), 113-126. https://doi.org/10.1145/360018.360022

Núñez, R., Allen, M., Gao, R., Miller Rigoli, C., Relaford-Doyle, J., & Semenuks, A. (2019). What happened to cognitive science? *Nature Human Behaviour*, *3*(8), 782-791. https://doi.org/10.1038/s41562-019-0626-2

Pezzulo, G., Barsalou, L. W., Cangelosi, A., Fischer, M. H., McRae, K., & Spivey, M. J. (2011). The mechanics of embodiment: A dialog on embodiment and computational modeling. *Frontiers in Psychology*, *2*(5). https://doi.org/10.3389/fpsyg.2011.00005

Piaget, J. (1926). *Language and thought of the child*. New York: Harcourt.

Prinz, J. J. (2004). *Furnishing the mind: Concepts and their perceptual basis*. Cambridge, MA: The MIT Press.

Pulvermüller, F. (2002). *The neuroscience of language: On brain circuits of words and serial order*. Cambridge: Cambridge University Press.

Simmons, W. K., Ramjee, V., Beauchamp, M. S., McRae, K., Martin, A., & Barsalou, L. W. (2007). A common neural substrate for perceiving and knowing about color. *Neuropsychologia*, *45*(12), 2802-2810. https://doi.org/10.1016/j.neuropsychologia.2007.05.002

Vera, A. H., & Simon, H. A. (1993). Situated action: A symbolic interpretation. *Cognitive science*, *17*(1), 7-48.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*(4), 625-636. https://doi.org/10.3758/BF03196322

Wołoszyn, K., & Hohol, M. (2017). Commentary: The poverty of embodied cognition. *Frontiers in Psychology*, Vol. 8. https://doi.org/10.3389/fpsyg.2017.00845