Unit 1: Introduction

Cognitive*:* The earliest entries for the word "*cognitive*" in the *OED* take it to mean roughly *pertaining "to the action or process of knowing"*.

Cognitive science: the term

The term "*cognitive*" in "*cognitive science*" is "used for any kind of mental operation; cognitive process, or structure that can be studied in precise terms" (Lakoff and Johnson, 1999).

The term "*cognitive science"* was coined by Christopher Longuet-Higgins in his 1973 commentary on the *Lighthill report*, which concerned the then-current state of Artificial Intelligence research.

Cognitive Psychology:

Cognitive psychology is concerned with information processing, and includes a variety of processes such as attention, perception, learning, and memory. It is also concerned with the structures and representations involved in cognition. Cognitive psychology is one of the more recent additions to psychological research, having only developed as a separate area within the discipline since the late 1950s and early 1960s following the "cognitive revolution" initiated by Noam Chomsky's 1959 critique of behaviorism and empiricism more generally.

The core focus of cognitive psychology is on how people acquire, process and store information. There are numerous practical applications for cognitive research, such as ways to improve memory, how to increase decision-making accuracy, and how to structure educational curricula to enhance learning.

Cognitive science:

Cognitive science can be defined as the study of mind or the study of thought. We can also define it as the interdisciplinary study of *cognition*. **Cognition** includes mental states and processes such as thinking, remembering, language understanding and generation, visual and auditory perception, learning, consciousness, emotions, etc. It embraces multiple research disciplines, including *psychology*, *artificial intelligence*, *philosophy*, *neuroscience*, *linguistics*, *anthropology*, *sociology*, and *biology*. It relies on varying scientific methodology (e.g. *behavioral experimentation*, *computational simulations*, *neuro-imaging*, *statistical analyses*), and spans many levels of analysis of the mind (from low-level learning and decision mechanisms to high-level logic and planning, from neural circuitry to modular brain organization, etc.).

Some cognitive scientists limit their study to human cognition; other consider cognition independently of its implementation in humans or computers.

Cognitive science grew out of three developments: the invention of computers and the attempts to design programs that could do the kinds of tasks that humans do; the development of information processing psychology where the goal was to specify the internal processing involved in perception, language, memory, and thought; and the development of the theory of generative grammar and related offshoots in linguistics.

Cognitive science was a synthesis concerned with the kinds of knowledge that underlie human cognition, the details of human cognitive processing, and the computational modeling of those processes. There are five major topic areas in cognitive science: knowledge representation, language, learning, thinking, and perception.

Cognitive science differs from cognitive psychology in that algorithms that are intended to simulate human behavior are implemented or implementable on a computer

Cognitive science's approach to the study of mind is often contrasted with that of ***behaviorism***. The *behaviorist approach* to psychology seeks to describe and predict human behavior in terms of stimulus-response correlations, with no mention of unobservable mental states (including mental constructs such as symbols, ideas) or mental processes (such as thinking, planning, etc.) that might mediate these correlations. A behaviorist who would willing even to talk about the "mind" would view it as a "black box" that could only be understood in terms of its *input-output behavior*. Cognitive science in general seeks to understand human cognitive functions in terms of metal states and processes, i.e., in terms of *algorithm* that mediate between input and output.

The goal of cognitive science is to understand:

- the representations and processes in our minds that underwrite these capacities,
- how they are acquired, and how they develop, and
- how they are implemented in underlying hardware (biological or otherwise).

Stated more simply, the goal of cognitive science is to understand how the mind works.

Varieties of Cognitive Science:

Currently there are two major paradigms of computational cognitive science:

- Symbolic computational cognitive science
- Connectionist computational cognitive science

Symbolic computational cognitive science:

Here the concept is that the *mind* exists as a physically implemented "*symbol system*". A symbol system is any effectively computable procedure, i.e., a universal machine (which by Church's Thesis, could be a Turing machine, a recursive function, a general-purpose digital computer, etc.)

Connectionist computational cognitive science:

The "**connectionist**" (or "*neural network*", or "*parallel distributed processing*") approach to artificial intelligence and computational cognitive science can be seen as one way for a system to behave intelligently without being a "symbol system" and yet be computational. On this approach large numbers of very simple processors ("nodes") are connected in multiple ways by communication links of varying strengths. Input nodes receive information from the external world. The information is propagated along the links to and among intermediate nodes, finally reaching output nodes. Connectionist systems & techniques have been developed for learning features of natural language, for aspects of visual perception and for a number of other cognitive phenomena. The kind of information that the *symbol approach* would represent using various symbolic knowledge-representation techniques is, instead, "represented" by the strengths and connectivity patters of the links.

Cognitive science: a history

Like most approaches to the mind, cognitive science can be traced back to philosophical questions, especially about the nature of knowledge. For instance, Plato 's dialog Meno, where he investigates the source of knowledge, can be seen as a foundational text.

The modern culture of cognitive science can be traced back to the early cyberneticists; study of structure of regulatory system closely related to control theory & systems theory, in the **1930s and 1940s**, such as Warren McCulloch and Walter Pitts, who sought to understand the organizing principles of the mind. McCulloch and Pitts essentially invented the neural network, but did not have the computational tools to develop it into modern form.

Another precursor was the early development of the theory of computation and the digital computer in the **1940s and 1950s**. **Alan Turing and John von Neumann** were instrumental in these developments. The modern computer, or Von Neumann machine, would play a central role in cognitive science, both as a metaphor for the mind, and as a tool for investigation.

In 1959, Noam Chomsky published a scathing review of B. F. Skinner's book Verbal Behavior. At the time, **Skinner's behaviorist paradigm** dominated psychology: Most psychologists focused on functional relations between stimulus and response, without positing internal representations. Chomsky's work showed that in order to explain language, we needed a theory like his generative grammar; a particular approach to study of syntax in linguistic, which not only attributed internal representations but characterized their underlying order. This hugely successful theory would inspire much later cognitive science.

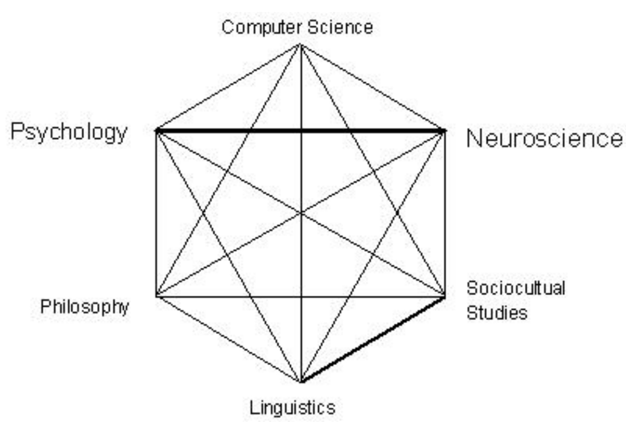
In the 1970s and early 1980s, much cognitive science research focused on the possibility of artificial intelligence. Researchers such as **Marvin Minsky** would write computer programs in languages such as LISP to attempt to formally characterize the steps that human beings went through, for instance, in making decisions and solving problems, in the hope of better understanding human thought, and also in the hope of creating artificial minds. This approach is known as "**symbolic AI**".

Eventually the limits of the symbolic AI research program became apparent. For instance, it seemed to be unrealistic to comprehensively list human knowledge in a form usable by a symbolic computer program. The late 80s and 90s saw the rise of neural networks and connectionism as a research paradigm. Under this point of view, often attributed to **James McClelland and David Rumelhart,** the mind could be characterized as a set of complex associations, represented as a layered network. Critics argue that there are some phenomena which are better captured by symbolic models, and that connectionist models are often so complex as to have little explanatory power.

Today a plurality of approaches exist, from connectionism, to a focus on dynamical systems models, to attempts to reintroduce symbolic models using tools from modern computer science such as **machine learning**. Machine learning is a scientific discipline that is concerned with the design and development of algorithms that allow computers to learn based on data, such as from sensor data or databases. A major focus of machine learning research is to automatically learn to recognize complex patterns.

Cognitive Science and Other Sciences

Cognitive science tends to view the world outside the mind much as other sciences do. Thus it too has an objective, observer-independent existence. The field is usually seen as compatible with the physical sciences, and uses the scientific method as well as simulation or modeling, often comparing the output of models with aspects of human behavior. Still, there is much disagreement about the exact relationship between cognitive science and other fields, and the interdisciplinary nature of cognitive science is largely both unrealized and circumscribed.



Philosophy:

Philosophy is the investigation of fundamental questions about the nature of knowledge, reality, and morals. It is the study of general and fundamental problems concerning matters such as *existence*, *knowledge*, *values*, *reason*, *mind*, and *language*. Philosophy is distinguished from other ways of addressing these questions by its critical, generally systematic approach.

Philosophy interfaces with cognitive science in three distinct but related areas. First, there is the usual set of issues that fall under the heading of philosophy of science (explanation, reduction, etc.), applied to the special case of cognitive science. Second, there is the endeavor of taking results from cognitive science as bearing upon traditional philosophical questions about the mind, such as the nature of mental representation, consciousness, free will, perception, emotions, memory, etc. Third, there is what might be called *theoretical cognitive science*, which is the attempt to construct the foundational theoretical framework and tools needed to get a science of the physical basis of the mind off the ground -- a task which naturally has one foot in cognitive science and the other in philosophy.

Psychological sciences: Psychology

Psychology is the study of mental activity. It incorporates the investigation of human mind and behavior & goes back at least to Plato and Aristotle.

Psychology is the science that investigates mental states directly. It uses generally empirical methods to investigate concrete mental states like *joy*, *fear* or *obsessions*. Psychology investigates the laws that bind these mental states to each other or with inputs and outputs to the human organism.

Psychology is now part of cognitive science, the interdisciplinary study of mind and intelligence, which also embraces the fields of neuroscience, artificial intelligence, linguistics, anthropology, and philosophy.

Biological sciences: Neuroscience

Neuroscience is a field of study which deals with the structure, function, development, genetics, biochemistry, physiology, pharmacology and pathology of the nervous system. The study of behavior and learning is also a division of neuroscience.

In cognitive science, it is very important to recognize the importance of neuroscience in contributing to our knowledge of human cognition. Cognitive scientists must have, at the very least, a basic understanding of, and appreciation for, neuroscientific principles. In order to develop accurate models, the basic neurophysiological and neuroanatomical properties must be taken into account.

Socio-cultural sciences: Sociology

Sociology is the scientific or systematic study of human societies. It is a branch of social science that uses various methods of empirical investigation and critical analysis to develop and refine a body of knowledge about human social structure and activity.

Linguistics

Linguistics is another discipline that is arguably wholly subsumed by cognitive science. After all, language is often held to be the “mirror of the mind”- the (physical) means for one mind to communicate its thoughts to another.

Linguistics is the scientific study of natural language. The study of language processing in cognitive science is closely tied to the field of linguistics. Linguistics was traditionally studied as a part of the humanities, including studies of history, art and literature. In the last fifty years or so, more and more researchers have studied knowledge and use of language as a cognitive phenomenon, the main problems being how knowledge of language can be acquired and used, and what precisely it consists of. Some of the driving research questions in studying how the brain processes language include:

(1) To what extent is linguistic knowledge innate or learned?

(2) Why is it more difficult for adults to acquire a second-language than it is for infants to acquire their first-language?

(3) How are humans able to understand novel sentences?

Computer Science: Artificial Intelligence

Artificial intelligence (AI) involves the study of cognitive phenomena in machines. One of the practical goals of AI is to implement aspects of human intelligence in computers. Textbooks define this field as “the study and design of intelligent agents”. Computers are also widely used as a tool with which to study cognitive phenomena. Computational modeling uses simulations to study how human intelligence may be structured.

Given the computational view of cognitive science, it is arguable that all research in artificial intelligence is also research in cognitive science.

Mathematics

In mathematics, the theory of computation developed by Turing (1936) and others provided a theoretical framework for describing how states and processes interposed between input and output might be organized so as to execute a wide range of tasks and solve a wide range of problems. The framework of McCulluch and Pitts (1943) attempted to show how neuron-like units acting as and- and or- gates, etc., could be arranged so as to carry out complex computations. And while evidence that real neurons behave in this way was not forthcoming, it at least provided some hope for physiological vindication of such theories.

<u>Descartes Mind Body Problem (Theory of dualism):</u>

<u>Dualism</u>: The term ***dualism*** is the state of being dual, or having a twofold division. Dualism doctrine consists of two basic opposing elements. Generally it consists of any system which is founded on a double principle. In philosophy of mind, **dualism** is a set of views about the relationship between mind and matter, which begins with the claim that mental phenomena are, in some respects, non-physical.

A generally well-known version of **dualism** is attributed to **René Descartes** (1641), which holds that the mind is a nonphysical substance. Descartes was the first to clearly identify the *mind* with consciousness and self-awareness and to distinguish this from the brain, which was the seat of intelligence. Hence, he was the first to formulate the *mind-body problem* in the form in which it exists today.

The **mind-body problem** can be stated as, "*What is the basic relationship between the mental and the physical?*" For the sake of simplicity, we can state the problem in terms of mental and physical events: "*What is the basic relationship between mental events and physical events?*" It could also be stated in terms of the relation between mental and physical states and/or processes, or between the brain and consciousness.

The mind-body problem is that of stating the exact relation between the mind and the body, or, more narrowly, between the mind and the brain. Most of the theories of the mind-body relation exist also as metaphysical theories of reality as a whole. While debates over the mind-body problem can seem intractable, science offers at least two promising lines of research. On the one hand, parts of the mind-body problem arise in research in artificial intelligence and might be solved by a better understanding of the relations between hardware and software.

The famous **mind-body problem** has its origins in Descartes' conclusion that mind and body are really distinct. The crux of the difficulty lies in the claim that the **respective natures of mind and body are completely different** and, in some way, opposite from one another. On this account, **the mind is an entirely immaterial thing without any extension in it whatsoever**; and, conversely, **the body is an entirely material thing without any thinking in it at all**. This also means that each substance can have only its kind of modes. For instance, the mind can only have modes of understanding, will and, in some sense, sensation, while the body can only have modes of size, shape, motion, and quantity. But bodies cannot have modes of understanding or willing, since these are not ways of being extended; and minds cannot have modes of shape or motion, since these are not ways of thinking.

Descartes was aware that the positing of two distinct entities-a **rational mind** and a **mechanical body**-made implausible any explanation of their interaction. **How can an immaterial entity control, interact with, or react to a mechanical substance?** He made various stabs at solving this problem, none of them (as he knew) totally convincing. But in the process of trying to explain the interaction of mind and body, Descartes became in effect a physiologically oriented psychologist: he devised models of how mental states could exist in a world of sensory experience-models featuring physical objects that had to be perceived and handled.

The basic steps in Descartes argument

- Reject any idea that can be doubted.
- Our senses deceive us (dreams).
- Our senses limit our knowledge (the wax example).
    - Knowledge is gained through the mind
- The only thing one cannot doubt is doubt itself.
- I doubt, therefore I think, therefore I am.

Descartes determined that the mind, an active reasoning entity, was the ultimate arbiter of truth. And he ultimately attributed ideas to innate rather than to experiential cause.

To further demonstrate the limitations of the senses, Descartes proceeds with what is known as the Wax Argument. He considers a piece of wax; his senses inform him that it has certain characteristics, such as shape, texture, size, color, smell, and so forth. When he brings the wax towards a flame, these characteristics change completely. However, it seems that it is still the same thing: it is still a piece of wax, even though the data of the senses inform him that all of its characteristics are different. Therefore, in order to properly grasp the nature of the wax, he cannot use the senses. He must use his mind. Descartes concludes: *And so something which I thought I was seeing with my eyes is in fact grasped solely by the faculty of judgment which is in my mind.*

Marr's Three Level of Information Processing:

In recent work in the theoretical foundations of cognitive science, it has become commonplace to separate three distinct levels of analysis of **information-processing systems**. David Marr (1982) has dubbed the three levels the *computational*, the *algorithmic*, and the *implementational*; Zenon Pylyshyn (1984) calls them the *semantic*, the *syntactic*, and the *physical*; and textbooks in cognitive psychology sometimes call them the levels of *content*, *form*, and *medium* (e.g. Glass, Holyoak, and Santa 1979).

David Marr presents his variant on the "three levels" story. His summary of "the three levels at which any machine carrying out an information-processing task must be understood":

- *Computational theory*: What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out? What is a concept? What does it mean to learn a concept successfully?

- *Representation and algorithm*: How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation? How are objects and concepts represented? How much memory (space) and computation (time) does a learning algorithm require?

- *Hardware implementation*: How can the representation and algorithm be realized physically?

As an illustration, Marr applies this distinction to the levels of theorizing about a well-understood device: **a cash register**.

At the ***computational level***, "the level of *what* the device does and *why*", Marr tells us that "what it does is arithmetic, so our first task is to master the theory of addition".

But at the level of ***representation and algorithm***, which specifies the forms of the representations and the algorithms defined over them, "we might choose Arabic numerals for the representations, and for the algorithm we could follow the usual rules about adding the least significant digits first and `carrying' if the sum exceeds 9".

And, at the ***implementational level***, we face the question of how those symbols and processes are actually physically implemented; e.g., are the digits implemented as positions on a ten-notch metal wheel, or as binary coded decimal numbers implemented in the electrical states of digital logic circuitry?

Putting a closer look to Marr's, we might see the three perspectives of *algorithm, content of computation,* and *implementation* as having something like the following questions associated with them:

- *Format and algorithm*: What is the syntactic structure of the representations at this level, and what algorithms are used to transform them? What is the real structure of the virtual machine? What's the program? From this perspective, the questions are explicitly information-processing questions. Further, it's this level of functional decomposition of the system which specifies the level of organization with which we are currently concerned, and to which the other two perspectives are related.

- *Content, function, and interpretation*: What are the relational or global functional roles of the main processes described at this level? What tasks are being performed by these processes, and why? These are centrally questions about the interpretation and global function of the parts and procedures specified in our algorithmic analysis.

- *Implementation*: How are the primitives of the current level implemented? By another computationally characterized virtual machine? Directly in the hardware? How much decomposition (in terms of kinds of primitives, structures, abilities, etc.) is there between the current level and what is implementing it? How much of the work is done by the postulated primitives of this level as opposed to being done explicitly by the analyzed processes? The shift from algorithm to implementation is thus centrally one of levels of organization or functional decomposition; i.e. of what happens when we try to move down a level of organization.

Turing response to Descartes

Mind, in Descartes's view, is special, central to human existence, basically reliable. The mind stands apart from and operates independently of the human body, a totally different sort of entity. The body is best thought of as an **automaton**, which can be compared to the machines made by men. It is divisible into parts, and elements could be removed without altering anything fundamental. But even if one could design an automaton as complex as a human body, that automaton can never resemble the human mind, for the mind is unified and not decomposable. Moreover, unlike a human mind, a bodily machine could never use speech or other signs in placing its thoughts before other individuals. An automaton might parrot information, but "it never happens that it arranges its speech in various ways, in order to reply appropriately to everything that may be said in its presence, as even the lowest type of man can do" (quoted in Wilson 1969, p. 13S).

Turing devised the test in the 1950's, as a hypothetical test to determine when a machine had been imbued with sufficient intelligence to pass for human. In the test, a human judge is placed with two computer terminals, one connected to another human, and the other to a machine. The judge then converses with each terminal, and if he is unable to determine which terminal is connected to the machine, the machine is said to have attained similar intelligence to a human.

This test is often presented as a product of the 20th century. However, René Descartes' *Discourse on Method*, written in 1637, contains the following passage, which bears a fair resemblance to the Turing Test:

If there were machines which had the organs and the external shape of a monkey or of some other animal without reason, we would have no way of recognizing that they were not exactly the same nature as the animals; whereas, if there was a machine shaped like our bodies which imitated our actions as much as is morally possible, we would always have two very certain ways of recognizing that they were not, for all their resemblance, true human beings.

The first of these is that they would never be able to use words or other signs to make words as we do to declare our thoughts to others. For one can easily imagine a machine made in such a way that it expresses words, even that it expresses some words relevant to some physical actions which bring about some change in its organs (for example, if one touches it in some spot, the machine asks what it is that one wants to say to it; if in another spot, it cries that one has hurt it, and things like that), but one cannot imagine a machine that arranges words in various ways to reply to the sense of everything said in its presence, as the most stupid human beings are capable of doing.

It seems that Descartes was able to conceive not only of a machine that might mimic a human in form, but also in action and speech, and he reasoned that the best way to differentiate this machine from a human being would be to engage it in conversation, and observe whether it conversed naturally, in the manner of a human being, or whether the conversation would be driven solely by rote and logic.

Thus the Turing Machine, a mathematical automaton model, developed by Alan Turing in 1940 was addressed by the Descartes in his *Discourse on Method*.

In “Computer Technology,” the section introducing Turing 1950, **Stuart Shieber**, well known to computational linguists for his research and to computer scientists, suggests that Turing played the role with respect to electronic computers that Descartes played with respect to mechanical devices, asking the same questions, only about different technology.

Application Related System in Cognitive Science

Major applications: decision making, education, human-machine interaction, intelligent systems. More,

- Neural Networks,
- Language Processing
- Machine Learning
- Machine Vision