PSYCHOLOGY 354 MIDTERM EXAM
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Part I: Choose any TEN of the following terms, and write a short (2-3 sentence) definition for each. The definition should indicate what the term means, and should also indicate why the term is important to cognitive science. Remember, ONLY 10 DEFINITIONS are required. Each definition is marked out of 3 points.

Functional Analysis	Computational Level of Investigation	Primitive Process
Universal Turing Machine	Recursion	Strong Equivalence
"Gee Whiz" Connectionism	Distributed Representation	Multilayer Perceptron
Stigmergy	The Extended Mind	Physical Symbol System

Part II: Choose any ONE of the following questions, and write a short essay (3-4 pages) to answer it. Make sure that your answer is clear and concise, and also make sure that you deal with the question directly. Your answer will be marked out of 35 points.

1. Connectionist researchers argue that their networks have the same computational power as a universal Turing machine. Given this, discuss why we should explore connectionist cognitive science – why not just do classical cognitive science? If the two are the same computationally, what is connectionism buying us? Illustrate your answer with relevant examples from the lectures and from the readings.

2. What are the key differences between how classical cognitive science and embodied cognitive science treats the environment? What are the implications of these differences for cognitive science in general? Illustrate your answer with relevant examples from the lectures and from the readings.

3. Cognitive science is frequently characterized as being interdisciplinary. Describe its interdisciplinary nature, and explain why it is necessary. Illustrate your answer with relevant examples from the lectures and from the readings.

SAMPLE ANSWERS FOLLOW

General Comments

This midterm was written by 70 students. The average grade was 47.57 marks out of 65, which is a 73.19% average. This is slightly higher than expected (a typical average would be closer to 71% or 72). The maximum mark was 63/65, and the minimum mark was 3/65. A list of grades sorted by student ID is provided at the end of this document.

Sample Answers for Definitions

1. **Functional Analysis:** Functional analysis is one of the most common methodologies used in cognitive science. It involves trying to understand a complex phenomenon or function by decomposing it into a organized set of simpler subfunctions. It is common in experimental cognitive psychology, for example, when experiments are used to analyze 'memory' into a set of organized memories ('short term memory', 'long term memory'). Functional analysis seems to explain a function by describing as a set of other functions. This leads to a problem called Ryle's regress, in which functional analysis fails because it produces an infinite explosion of subfunctions. This has lead Cummins to propose a solution to this problem by having functional analysis try to subsume the bottom level of functions (explain them as simple machines, not as functions).

2. **Computational Level of Investigation:** At the computational level of analysis, a cognitive scientist is concerned with answering the question "What information processing problem is being solved by a system?" Usually, to answer this question involves some sort of formal analysis using mathematics or logic, because the answer requires creating a proof about the abilities or inabilities of a system. The computational level is important because it can be used to highlight limitations of information processing systems. For example, Minsky and Papert's proof that perceptrons could not learn to detect connectedness demonstrated a fatal limitation in that kind of neural network, and was a computational level analysis.

3. **Primitive Process:** A primitive process is part of the architecture, and is one of the basic building blocks that an information processor can use to perform calculations. A primitive process is basic in the sense that it cannot be broken down into simpler functions, but is instead built physically into the device. The architecture is the primitive programming language of the information processor. Primitive processes are important to cognitive science because one explains the functions of the architecture in terms of physical laws, and therefore finding all of the primitive processes of cognition provides a way to escape Ryle's regress. *(NB: Common problem for this term was not getting its importance across: materialism, escaping Ryle's regress, producing cognitive explanations.)*

4. **Universal Turing Machine:** A universal Turing machine is a general-purpose symbol manipulator – in fact, a kind of Turing machine -- that can imitate any other Turing machine. This is possible because the universal Turing machine is programmable. Turing machines exhibit a structure process distinction in that the symbols are on the ticker tape and the rules are in the machine. However, while some of their structure is a question to answer, other parts of their structure (data on the tape) describe another Turing machine to be simulated. The UTM is important to cognitive scientists because they are a prototypical example of a classical cognitive system. Also, they are powerful enough to solve problems central to human cognition, like dealing with the grammatical structure of human languages, while other devices like the finite state machine are not.

5. **Recursion:** Recursion results when some function can operate by calling itself. This idea arose in mathematics when the successor function was used to call itself to create the infinite set of integers. It is important because with recursion a finite system or a finite set of rules can be used to generate an infinite variety of behavior. Human language shows this kind of recursion; this is important because it means that models of cognition have to use recursion to model phenomena like language, and to show how a finite device like the brain can produce infinite behavior.

6. **Strong Equivalence:** Strong equivalence involves comparing a model like a computer simulation to a human subject. These two systems are strongly equivalent when they are identical at the computational, algorithmic, and architectural levels of analysis. That is, when they are solving the same problem, using the same program, and the same programming language they are strongly equivalent. Strong equivalence is important because it is required to say that the model is an explanation of human cognition. If the model is only weakly equivalent to the subject, then it is generating the right behavior for the wrong reasons, because it is using a different program and architecture to generate the correct answers.

7. **"Gee Whiz" Connectionism:** Gee whiz connectionism is a practice that was common when the connectionist revolution happened in the 1980s. Connectionist researchers trained their networks on classical problems, and then claimed 'gee whiz' they had an alternative theory. The problem with this is that it assumed that the networks were different from classical models, but did not collect data to support this view. This has led some researchers to develop methods to analyze the internal structure of trained networks to figure out the algorithm that has been learned. This is important because sometimes connectionist algorithms look very similar to classical ones.

8. **Distributed Representation:** This is the idea used by connectionist cognitive science that a property can be represented in a network by multiple

simple processors that are all active at the same time. An example of this is coarse coding where detectors have overlapping sensitivities to represent a property. This means that the location of a single target is represented by activity in several detectors that have overlapping receptive fields. This is important to cognitive science because examples like hyperacuity and color perception in the human vision system is represented in this way. This concept can also give the advantage of damage resistance and graceful degradation to a network, and is a new idea about representation that connectionism contributes to cognitive science.

9. **Multilayer Perceptron:** A multilayer perceptron is a prototypical network of modern connectionism. Like the simpler perceptron, it has a set of input units to represent environmental inputs, and a set of output units to represent responses to these inputs. However, it also has one or more layers of hidden units that stand as intermediate processors, and which are capable of detecting complex features present in the inputs. It is these hidden units that give the multilayer perceptron its exceptional power: to be an arbitrary pattern classifier, a universal function approximators, or to be equivalent in power to a universal Turing machine. The discovery of learning rules capable of training such powerful networks have led to the emergence of the connectionist alternative to classical cognitive science.

10. **Stigmergy:** Stigmergy is the notion that an agent's behavior is under environmental stimulus control. The agent reacts to changes in the environment, and thus acts on the environment again according to those changes. This is critical to embodied cognitive science because it explains and emphasizes the sentence-act processes critical to try might nest construction, as an example, such that the nest controls its own construction without the termites having to directly communicate with each other. *(NB: Much more than 'environmental influence' – a key element of the information processor, its control, has moved outside into the environment.)*

11. **The Extended Mind:** The extended mind is the belief that the mind is not confined within the agent, or the agent's skull, but leaks into the world. An example of this is cognitive scaffolding. My mind can be scaffolded in a notebook to lessen the cognitive effort taken to memorize everything. This is important to cognitive science because it challenges the Cartesian disembodied mind that is adhered to by classical cognitive scientists. In fact, it challenges the notion of where one should look if one is studying the mind! *(NB: According to this hypothesis, the mind doesn't just "interact" with the world – the world is literally part of the mind. You really need to make the point that the world 'constitutes' the mind.)*

12. **Physical Symbol System:** The concept "physical symbol system" defines "a broad class of systems that is capable of having and manipulating symbols, yet is also realizable within our physical universe" (Newell, 1980, p.

136). That is, it is a physical device that applies rules to manipulate symbolic expressions. Examples of physical symbol systems are modern digital computers, the universal Turing machine, and the production system. By hypothesis, the human brain is also a physical symbol system. One reason that physical symbol systems are important to classical cognitive science is because these systems show how finite physical mechanisms can bring to life an infinite variety of behavior. When classical cognitive scientists assume that human cognition results from a physical symbol system, they are proposing a materialist theory of cognition that refutes Cartesian dualism. An alternative reason that classical cognitive science endorses – and may be defined by -- the physical symbol system hypothesis: "the necessary and sufficient condition for a physical system to exhibit general intelligent action is that it be a physical symbol system" (Newell, 1980, p. 170). By necessary, Newell means that if an artifact exhibits general intelligence, then it must be an instance of a physical symbol system. *(Usually associated with classical cognitive science, but could be with others. Importance? Physical is critical – move from dualism to materialism within the classical camp!)*

Sample Answers for Essay Questions

1. Connectionist researchers argue that their networks have the same computational power as a universal Turing machine. Given this, discuss why we should explore connectionist cognitive science – why not just do classical cognitive science? If the two are the same computationally, what is connectionism buying us? Illustrate your answer with relevant examples from the lectures and from the readings.

The sample answer below was given 33/35. Really the point of this question was to get students thinking about the different levels of investigation, and how different theories might be compared at the different levels. The question states that these two schools of thought are weakly equivalent, and implies that other levels of investigation must be invoked to decide in favor of one school over the other. The sample answer given below starts this move with 'multiple realization' (I would have preferred many-to-one relationships, which are more general) and then proceeds with a solid argument in favor of connectionism with an appeal to strong equivalence.

1. The fact that connectionism and classical cognitive science each possess the same computational power is interesting because it poses questions about the importance of multiple realisation. Multiple realisation is the idea that implementationally, there are different paths to the same end goal - an accurate model of cognition. In order to evaluate implementation, however, the computational, algorithmic, and architectural levels of Marr's analysis should be first considered. The differences between the classical (serial and digital) ~~model of~~ and connectionist (parallel and biologically plausible) models of cognition is an example of weak versus strong equivalence.

The ability of the universal turing machines (UTM) to create an infinite number of responses through recursion is a classical cognitive science idea. This method of serially using rule governed processes calling themselves allows for classical cognitive science to answer any problem they can store on a ticker tape. Beneath the shell of the machine, a machine table governs the rules and sets the machine state so that the UTM can eventually reveal its response on the ticker tape. It is inspired by logicism and as such equates cognition with formal logic. The manipulations

of symbols the UTM performs is an example of this logicism. At the architectural level, the UTM is governed by a discrete tape memory, rules, and machine states. At the algorithmic level, these rules can be changed to suit the question and the machine states as well can have their meanings changed. The computational level is what connectionism claims to share with the classical cognitive science.

The parallel architectures and learning (rather than serial) rule) fuelled algorithms of a multilayered perceptron (same computational power as UTM) mean weak equivalence has been established between classical and connectionist cognitive machines; their internal workings differ in concept and execution, but they are able to generate the same output from the same input; they can accomplish the same tasks. This weak equivalence is the reason to continue doing both classical and connectionist cognitive science - just because the task is the same doesn't mean they are an accurate model of the cognition the mind does. Indeed, classical cognitive science may share this weak equivalence with the mind - both are capable of cognition, but the architecture and algorithmic equivalence needed to posit strong equivalence may be lacking. Indeed, this is the claim of the connectionist.

The connectionist flavor of cognitive science is neuronally inspired, that is, their cognitive models and machines are interested in being modelled after the processing that neuroscience has attributed to the brain. Their focus on learning, too, is similar in concept to what the brain does. Connectionism seeks to establish strong equivalence with the brain's cognition, and thus they seek to be both architecturally and algorithmically biologically plausible. We should continue connectionist cognitive science because it (embodied CS not withstanding) is the closest conceptual framework we have to how the brain physically operates (as according to neuroscience).

Although connectionism and classical cognitive science are the same computationally, this is not sufficient for the elimination of either. Connectionism's goal of strong equivalence is the reason for its importance of continuation. Its biologically plausible parallel processing as opposed to classical serial processing allow it to stand alone in cognitive science. To return to multiple realisation, cognitive science does not necessarily seek to have its models of brain matter - for them the strong equivalence will do. That is, without playing God, perhaps all that can be hoped for.

2. What are the key differences between how classical cognitive science and embodied cognitive science treats the environment? What are the implications of these differences for cognitive science in general? Illustrate your answer with relevant examples from the lectures and from the readings.

This question was answered by the majority of the students. The typical answer was to introduce the two schools, describe the disembodiment of one, the embodiment of the next, and to make a judgement call at the end (usually in favor of embodied cognitive science). I was most interested in the implications at the end, which were crucial for setting one answer apart from another. The sample answer below received a mark of 35/35; I liked it because it was an interesting and bold departure from the typical answer.

2. Key Differences in how classical and embodied cognitive science treat the environment.

The primary difference between classical and embodied schools of thought with respect to the role of the environment in cognition, is that classical cognitive science aims to rid explanation using phenomena external of the subject's experience, whereas, embodied cognitive science explains cognition by necessarily involving the external world's role. The implications of these two methodologies mean the difference between reasoning methods used, engineering modes used to model cognitive processes, and the overall complexity of explanations of cognition each produce.

Classical cognition originates from Descartes, who doubted the truth value of his perceptions in favour of his internal thought. This emphasis on nativism, that knowledge is innate to the mind, and not the product of experience, is the backbone of classical cognitive science. Its influence is apparent if we consider the classical sandwich, the sense-think-act cycle which puts thinking at the center of cognitive control, while its means of interaction with the external environment through sensing and acting are mediated by this disembodied mind. This view implies that the environment is merely a source of sensory input that a mind can act within, as a cognitive container. In contrast, embodied cognitive science embraces the sense-act cycle which eliminates the need for internal representations of thought. Embodied cognition therefore implies

that our interaction with the environment is what wholly defines cognition. As a result, embodied cognitive science's stance towards the environment means representation is not necessary to understanding cognition.

The implications of encorporating environment into cognition can be best demonstrated by Braitenberg's Laws of uphill analysis and downhill synthesis. By using environmental interaction to explain cognition, embodied cognitive scientists have essentially avoided the problem of trying to reason inductively about how a cognitive process functions. Instead, embodied cognitive science begins at the architectural stage, by defining the primitive processes and thus, functional architecture of a system, without needing to decompose its function first. This is because the primitive processes, which classical cognition aims to reveal with methods implementation, of functional analysis, describe the agent's embodiment and its affordances — "they are the biological programming of an agent, and therefore, are directly linked to the agents embodiment and situation. By starting off at this step, embodied cognitive science can use deductive (rather than inductive) tools to model and explain cognition. Compared to functional analysis, which requires reiteration and organization, processes which involve inductive reasoning, and as can be elucidated, provides an explanation which is overly complex, cognitive scientists have

all the tools necessary to begin to deductively explain cognition - no additional simplification is required.

The shift from inductive to deductive reasoning about cognition attributed to the environmental importance of each mode of thought also emphasizes a shift from cognitive models which are reverse engineered to those which are forward engineered. By including the environment as a necessary part of cognition, obstacles attributed to representation are no longer barriers in explaining cognition. For example, intentionality, or aboutness, which according to classical cognitive science, is a necessary feature of representations can be easily subsumed by embodied affordances. The biological relevance and rationality, paired alongside goals and desires of the agent, which Dennett lists under his intentional stance are all implied by an affordance.

It would seem as if classical cog. sci. takes the harder path to explaining cognition. Embodied approaches start from the bottom-up, limiting the additional complexity needed to explain phenomena. That being said, classical cognitive science still gains insight into cognitive explanations, but ultimately its endgoal is one in which embodied cognitive science seems to tackle head on.

3. Cognitive science is frequently characterized as being interdisciplinary. Describe its interdisciplinary nature, and explain why it is necessary. Illustrate your answer with relevant examples from the lectures and from the readings.

This was the second most popular question to answer. The sample answer below was given 33/35. Of the small number of students who answered this question, it was one of the few that highlighted the multiple levels of analysis from Chapter 2, which this question was supposed to be about. Most students, including the one who wrote this answer, felt the need to talk about the three schools of cognitive science as well. What I was hoping to see was the realization that Chapter 2 applies equally to each school, although differences between schools might alter important details at each level of analysis.

Raw Scores On Exam Provided At End Of Sample Answer 3

Essay # 3

The nature of cognitive science is interdisciplinary because it relies on multiple levels of analysis to explain cognition in the physical world. These multiple levels are often dominated by different professions such as psychology, philosophy, engineers, robotics, computer scienc, neuroscie + ecology. Rarely does one profession extend beyond a specific level of analysis and thus multiple disciplines are needed. This means that communication is essential in the productivity of cognitive science and thus places importance on having a cognitive vocabulary to allow multiple disciplis to work together though the comon goal of explaining human cognition. In this essay I will draw examples from multiple levels of investigation in all three schools of thought in cognitive scienc to illustrate the interdisciplinary nature of the feild.

The birth of cognitive science took form as Classical Cognitive Scienc, hence the term classical, which explains cognition as the preformenc of logic, comparing the brain to physical symbol systems. For such a statement to be made one must examine the rich history that allowed multiple disciplines to theorize this. Rooted in the cartesian philosophy classical cog sci accepts that the mind is disembodied and uses internal representations to process information. However this information was irrelevant to cognitive scienc until Boole was able to develop a system of formal logic using algebra. With formal logic available it wasn't long before theorys developed stating that perhaps the brain simply does logic, to create the superphenomna of cognition. Thus the computational and arguably algorithmic level of cegnitions were developed due to philosophy and logicism blending. Yet cognitive scienc could still not build

any models to represent cognition and thus could hardly be called a science. That is until Shannon, a philosopher and electrical engineer, who's interdisciplinary background allowed him to use logicism to build electrical circuits, and in doing so creating the architectural level of analysis and setting the grand for real cognitive science to take form. Now that the developments in philosophy, mathematics, and engineering had shown that thought could be mechanized into a device Classical cognitive science was born and began building physical symbol systems for the purpose of explaining cognition as disembodied within a machine, and simply the physical instance of logic. Clearly multiple disciplines are even rooted in the foundation of cognitive science.

Connectionist cognitive science also has an interdisciplinary nature. The Philosophy of Locke, tabula rassa, meaning blank slate, argues that humans are born with no innate knowledge and everything is learned. Empiricism is therefore responsible for the focus of connectionists on networks that can learn. Psychologists such as Pavlov who demonstrated classical conditioning then explained that learning takes place via the law of continuity, (Pairing Stimuli). Computer scientists can then take this information and build parallel distributed processing networks such as the multilayer perceptron which are initially useless, yet capable of learning any task. Through a learning rule (nonlinear) which exploits error correction and the law of continuity a network can be trained to respond with its output units to a specific stimuli received at its input unit. Neuroscientists can also verify the biological plausibity of the connectionists networks

by comparing them to the human brain. Neurons are analogs to units in multilayer perceptrons because sensory neurons, interneurons, and motor neurons are reflections of the input units, hidden units, and output units which hold information through distributed representations and can undergo parallel processing resulting from all-or none response to stimuli.

Embodied cognitive science has philosophical roots as the other two, but also relies on the disciplines of forward engineering, robotics, and ecology. Verum Factum means that the truth is what is built. This is why embodied cognitive scientist build behavior based robots and monitor them to infer behavior rather then attempting to do functional analysis on complex systems. Forward engineering results in the construction of robots which can complete a computation in the simplest possible way (such as the mating cricket). One could argue that embodied cognitive scientists build an archetype first, and then observe its algorithms and computations second. Also of note is that ecologists monitor this robotic behavior as simply responding to the environment, intern that the environment is literally a part of cognition.

The interdisciplinary nature of cognitive science is important both in its birth and, in its continuation. Developing theories of the mind related to mathematics, building these theories into robots, programming these robots, and observing how they interact the environment while comparing their circuitry to the neurons in the brain to determine biological plausibility is not a one man job. It is instead to attempt to train people in multiple disciplines in order to study the human mind. What is more plausible is ensuring

a common vocabulary exists between all these disciplines when studying the mind to prevent a communication breakdown which could ultimately result in a fracture of the disciple of cognitive science. Wether its classical, connectionist, or embodied schools of cognitive science, the fact of the matter is they all discuss cognition on conceptual and physical levels. These levels are usually inhabited by multiple disciplines because while the psychologist may study the software of the brain via computations, and algorithms, engineers and neuroscients, typicly build or compare these algorithms to physical mechanisms or organs. Ultimately the multiple levels used in study cognitive science make it necessary to have multiple disciplines united w a common language for cooperative scientific advancement.

Below is a table providing the raw score on the midterm (the mark out of 65) for each student sorted by student ID.

ID #	Current Quiz Total	Midterm Score Out Of 65
1253544	8	43
1297451	9	51
1297655	7	54
1299612	10	53
1302037	7	
1344228	0	26
1352842	9	51
1356002	0	
1388759	10	63
1392493	2	3
1394105	9	54
1407312	0	
1409975	0	36
1414049	9	48
1417394	8	54
1424168	10	43
1427453	6	49
1427945	6	
1431204	0	
1431259	10	
1431677	10	45
1442488	9	54
1444398	0	
1444803	10	52
1445467	9	40
1448758	8	41
1448789	0	
1458200	6	
1459682	9	53
1459965	8	57
1460361	7	39
1460445	10	45
1464311	10	47
1464878	10	38
1465400	2	
1465705	9	47
1466163	10	54
1466307	7	49
1467249	5	32
1467284	8	
1468515	8	38
1469409	10	49
1470069	6	
1470722	8	54
1471187	9	56
1473570	6	51

1474257	10	40
1476284	9	54
1477061	0	
1481550	6	43
1483991	7	47
1488894	8	53
1492468	10	50
1492846	7	46
1493114	8	50
1493675	5	39
1493830	8	46
1494516	7	57
1495281	0	
1496086	9	58
1496621	8	43
1496947	10	47
1497701	9	53
1500003	9	54
1501049	10	53
1501126	2	44
1502026	9	47
1503526	10	52
1503665	8	56
1503995	9	49
1504249	9	45
1506870	2	
1509141	10	49
1509181	0	32
1511967	7	47
1519628	9	53
1520448	7	39
1522027	4	46
1534322	6	46
1544040	6	48
1559316	10	59
1569410	7	52
1569722	8	47
1572653	10	57
1589212	10	60