What is cognitive science?
What is this class about?

Shorter version

Experimental approaches to understanding the structure of human thought.
What is this class about?

Longer version

An introductory course on the use of various behavioral measures (accuracy, reaction time, etc...) to understand the structure of the human mind. Our goal is to use experiments to test alternative theories of cognitive function and to better understand the motivation and structure of human behavior. We will learn a basic set of skills for using computers to run experiments, collect data, analyze it, and communicate the outcome to others.
What is human cognition?

The study of how the mind (or mind/brain) works. The study of how people think, learn, and solve problems.
Examples

- How do people learn effective behavior through interaction with their environment?
- What are the stages of information processing the mind goes through to solve problems?
- How does the architecture of the mind interact with experience to determine what we know?
- How does human memory work? In what ways is human memory like computer memory? In what ways is it not?
- What is the format or "representation" of information that the mind uses?
- Can we develop theories that allow us to predict and explain human behavior? Can information we derive from these investigations enable us to build better artificial intelligence systems to solve problems?
A tale of two magnets
Scientific inference

Observations

Theory
Scientific inference

- Natural Behavior
- Just ask people questions
- Test/quizzes (more controlled performance measures)
- Reaction Time (RT)
- Eye tracking
- Physiological measures (Galvanic skin response, heart rate)
- Brain measures (fMRI, EEG, MEG)
- Lesion studies/surgical interventions
Scientific inference

• Theories of information processing, inspired by modern computers

• Mind-as-a-computational device

• Build computational theories of the way we think the mind works, test the implication of those theories in new experiments, refine theories when needed.
The science of the mind

Environment

**Stimuli** that are perceived by the body and nervous system

Behavior
The science of the mind

Environment

**Stimuli** that are perceived by the body and nervous system

**Cognitive mechanisms** (i.e., representations + processes)

Behavior
The science of the mind

Environment

**Stimuli** that are perceived by the body and nervous system

**Cognitive mechanisms** (i.e., representations + processes)

Behavior

**Predicts**

**Theory**
The science of the mind

Environment

Stimuli that are perceived by the body and nervous system

Cognitive mechanisms (i.e., representations + processes)

Behavior

Describes

Theory

Predicts
The science of the mind

Environment

**Stimuli** that are perceived by the body and nervous system

**Cognitive mechanisms** (i.e., representations + processes)

Behavior

**Model**

**Implements**

**Generates**
The science of the mind

Stimuli that are perceived by the body and nervous system

Cognitive mechanisms (i.e., representations + processes)

Behavior

Environment

Manipulates

Oberves

Experiment

Refines

Generates

Implements

Model
What is cognitive science?
Cognitive Science

"Cognition, as defined by Ulrich Neisser, involves all processes by which sensory input are transformed, reduced, elaborated, stored, recovered, and used."

"Science is the art of acquiring knowledge in such a manner that coherent structures of understanding can be erected on the basis of a critical evaluation of evidence."
What is a mind?

This has been debated for thousands of years. If you don’t have an immediate answer, don’t feel bad. Various proposals have been thrown around from by Plato, Buddha, Aristotle, Zoroaster…. ancient Greek, Indian, and Islamic philosophers, and even several folks at NYU.
What do minds do?

Minds encompass our thoughts, which are mental processes that allow us to deal with the world. These include not only explicit wishes, desires, and intentions, but also unconscious processes.
What is a mind?

Does MIND = BRAIN?

We know that we can’t have a mind or thoughts without a brain, but does that mean that minds and brain are synonymous?
A “slippery slope” argument can convince us that minds are not literally brains, but encompass anything that is organized as representational states that accurately reflect aspects of the world.
The Brain/Mind Riddle

What is common to the various entities (person 1, person 2, cat 1, cat 2, robot, etc.) that look at this scene of two cylinders and a sphere and agree upon what is viewed?
The question: What is common to observers viewing the same scene and who agree upon what is viewed?

• Can’t literally be neurons. My neurons are my own, and you can’t borrow them to solve your own problems.

• Is it the literal organization of the human nervous system? We know (or at least believe) that cats have a very similar visual system and view the world much like we do. Is it the mammalian visual system? What about other animals?

• What about artificial systems formed of computers and video cameras that can accurately recognize the scene as well?

• The key to minds is not their physical substrate, but the relations that states of the system have to one another, and to the external environment.
Minds as computers

• Minds aren’t human neurons or cat neurons or robot parts. They are dynamic, continually evolving systems that relate ongoing internal (i.e., mind) states and external (i.e., world) states.

• Correspondences can be made between two systems by describing what they do, independent of their exact physical substrate.

• We can describe these correspondences through the language of computation, simply because the THEORY OF COMPUTATION offers formal insights into how ostensibly dissimilar systems can be formally identical.
Goals for this semester

• To explore (experimentally) how the brain represents and processes information in solving tasks

• We have to formulate hypotheses about how the mind might function, then design experiments to test these hypotheses

• This will involve testing various theories of cognitive function that can be formalized as computer programs or algorithms

• We are licensed to do this due to the fundamental idea that the mind can be understood as an organization system that evolves according to particular rules, steps, or procedures
A couple of good examples...
ON THE GENESIS OF ABSTRACT IDEAS

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Previous work has shown that Ss can learn to classify sets of patterns which are distortions of a prototype, even when they have not seen the prototype. In this paper it is shown that after learning a set of patterns, the prototype (schema) of that set is more easily classified than control patterns which are also within the learned category. As the variability among the memorized patterns increases, so does the ability of Ss to classify highly distorted new instances. These findings argue that information about the schema is abstracted from the stored instances with very high efficiency. It is unclear whether the abstraction of information involved in classifying the schema occurs while learning the original patterns or whether the abstraction process takes place at the time of the first presentation of the schema.

When a man correctly recognizes an animal he has never seen before as a dog, he has manifested an ability to generalize from previous experience. What has he learned that allows him to make the classification successfully? This question has been discussed in various forms since Aristotle. Some philosophers suggest a process of abstraction in which S builds up a representation of a figure (e.g., triangle) which is different from the instances he has seen. Others have denied the reality of such com-

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1 This research was supported in part by National Science Foundation Grant GB 3939 to the University of Oregon. A preliminary
How do people represent categories?

“Bird”

There are different versions of the theory, which go like this: Concepts are a summary representations based on typical properties or central tendency of a category, or an ideal image.

Earliest alternative, but now not the only, or the most popular theory.

Prototype theory?

computation

Ideal bird?
1. **Instructions**: You will see stimuli from Category A or B. Please indicate which category you think is correct.

2. **Training phase**: Participants see stimuli one at a time. For each item, they respond “A” or “B”. Feedback (the correct answer) is received during training.

3. **Test phase**: Participants may respond to additional stimuli. No feedback is given.
Category A or B?

A
Category A or B?
Category A or B?

B
Category A or B?
Category A or B?
Category A or B?
Training period is done. Now for testing…
Items seen during test period (after training)  
(Posner & Keele, 1968)

After training, participants were tested on:
-- the prototypes (new)
-- some pattern distortions (old)
-- some pattern distortions (new)

Result:
( Accuracy for prototype = Accuracy for old distortions )

> Accuracy for new distortions

Suggests that some form of abstract representation is learned, like an “ideal image” or prototype. But also exemplars aren’t lost/forgotten
The capacity of visual working memory for features and conjunctions

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Short-term memory storage can be divided into separate sub-systems for verbal information and visual information1, and recent studies have begun to delineate the neural substrates of these working-memory systems2-4. Although the verbal storage system has been well characterized, the storage capacity of visual working memory has not yet been established for simple, supra-threshold features or for conjunctions of features. Here we demonstrate that it is possible to retain information about only four colours or orientations in visual working memory at one time. However, it is also possible to retain both the colour and the orientation of four objects, indicating that visual working memory stores integrated objects rather than individual features. Indeed, objects defined by a conjunction of four features can be retained in working memory just as well as single-feature objects, allowing sixteen individual features to be retained when distributed across four objects. Thus, the capacity of visual working memory must be understood in terms of integrated objects rather than individual features, which place significant constraints on cognitive and neurobiological models of the temporary storage of visual information5.

To measure the capacity of working memory for simple features, we used a variant of the sequential comparison procedure developed by Phillips6. Subjects viewed a sample array and a test array on each trial, separated by a brief delay, and then indicated whether the two arrays were identical or differed in terms of a single feature. The accuracy of this discrimination was assessed as a function of the number of items in the stimulus array (the set size) to determine how many items could be accurately retained in working memory. In addition, control experiments were conducted to ensure that performance truly reflected the capacity of visual working memory and was not influenced by verbal working memory or by limitations in perception, memory encoding, or decision processes.

The first set of experiments examined working memory capacity for simple colours (Fig. 1a). The sample array consisted of 1–12 coloured squares and was presented for 100 ms. This was followed by a 900-ms blank delay interval and then a 2,000-ms presentation of the test array, which was either identical to the sample array or differed in the colour of one of the squares. Performance was nearly perfect for arrays of 1–3 items and then declined systematically as the set size increased from 4 to 12 items. According to the method for estimating memory capacity described by Pashler7, the capacity estimate was not influenced by verbal working memory. In this condition, only colour could vary between the sample array and the test array, and the observers were instructed to look for a colour change. In a second condition, only orientation could vary, and the
Get ready...
Did anything change?
Get ready…
Did anything change?
Results and analysis

Performance nearly perfect for 3 items, starts to drop at 4

Remembering two features per item is no harder than one feature
four slot theory

visual short term memory

[Diagram showing object memory and slots]
A detection theory account of change detection

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Previous studies have suggested that visual short-term memory (VSTM) has a storage limit of approximately four items. However, the type of high-threshold (HT) model used to derive this estimate is based on a number of assumptions that have been criticized in other experimental paradigms (e.g., visual search). Here we report findings from nine experiments in which VSTM for color, spatial frequency, and orientation was modeled using a signal detection theory (SDT) approach. In Experiments 1-6, two arrays composed of multiple stimulus elements were presented for 100 ms with a 1500 ms ISI. Observers were asked to report in a yes/no fashion whether there was any difference between the first and second arrays, and to rate their confidence in their response on a 1-4 scale. In Experiments 1-3, only one stimulus element difference could occur \((T = 1)\) while set size was varied. In Experiments 4-6, set size was fixed while the number of stimuli that might change was varied \((T = 1, 2, 3, \text{ and } 4)\). Three general models were tested against the receiver operating characteristics generated by the six experiments. In addition to the HT model, two SDT models were tried: one assuming summation of signals prior to a decision, the other using a max rule. In Experiments 7-9, observers were asked to directly report the relevant feature attribute of a stimulus presented 1500 ms previously, from an array of varying set size. Overall, the results suggest that observers encode stimuli independently and in parallel, and that performance is limited by internal noise, which is a function of set size.

Keywords: feature judgment, visual short-term memory (VSTM), signal detection theory, change blindness, high-threshold theory, capacity limitations

Introduction

A critical aspect of any creature’s ability to function effectively within a changing environment is the facility to efficiently utilize information from a variety of sensory sources in both its present and its immediate past. The high evolutionary value of such information is implied by the ability of human observers to store various perceptual dimensions, such as spatial frequency, orientation, and hue, with a high degree of fidelity and stability over extended periods of time (Magnussen & Greenlee, 1992; Magnussen, Greenlee, Asplund, & Dyrnes, 1991; Magnussen, Greenlee, & Thomas, 1996; Regan, 1985). It has been shown, for instance, that observers are readily able to detect spatial frequency changes for time periods of upwards of 60 s that are smaller than the Nyquist frequency associated with the spacing between adjacent cones on the fovea (Magnussen, Greenlee, Asplund, & Dyrnes, 1990; Regan, 1985).

In a typical visual short-term memory (VSTM) experiment, conditions present leads to a monotonic decrease in the sensitivity of observers to differences between the two displays; although for experiments employing suprathreshold stimuli, this decrease is typically only observed after set size has reached around three to four elements (Luck & Vogel, 1997; Pashler, 1988; Vogel, Woodman, & Luck, 2001).

A prominent class of VSTM model proposes that the performance decline associated with increasing set size is caused by a fundamental limit of the number of items that can be encoded, either because the capacity of VSTM itself is limited (Cowan, 2001; Luck & Vogel, 1997; Pashler, 1988; Vogel et al., 2001), or because of a bottleneck in the number of items that can be attended to during the encoding process (Rensink, 2000).

This type of model assumes that VSTM is restricted in storage capacity to only a few items, \(C\) (often estimated to lie in the range of 4 to 5), within a set size \(N\) (Pashler, 1988). The probability that a suprathreshold change will be reported \((H)\) is then
Color judgement experiment

The probe stimulus was assigned one of 30 possible colors, chosen from the palette. Data were collected from participants over a single session, consisting of 64 trials. The order of trials within all blocks was counterbalanced for each participant.

As in Experiments 1-3, set size was varied (N = 2, 3, 4) for color and spatial frequency and orientation (where “1” indicated a very confident response, “2” somewhat confident, “3” somewhat unconfident, and “4” very unconfident). If an observer incorrectly indicated the presence or absence of a change, an auditory tone was sounded.

The importance of accuracy, rather than speed, was emphasized to all participants. Before data collection began, participants were instructed that their task was to determine whether the two stimuli were identical. They were informed that their task would be to report the color of the probe stimulus. They were also informed that the probe stimulus would appear 1500 ms after the presentation of the stimulus, which consisted of a color array within a 252-element identical array.

In all other respects, the properties of the probe stimulus were identical to those of the stimulus elements. The probe stimulus was assigned one of 16 spatial frequency values, which were equally spaced in a linear fashion, such that the inner and outer diameters of the annulus were 0 and 252, respectively. The lower spatial frequency was assigned to the stimulus elements, and the upper spatial frequency was assigned to the probe Gabor. In all other spatial frequency experiments, equidistant values were assigned to ensure all the presented spatial frequencies were equally spaced between 0 and 2 pixels/cycle. The spatial frequency values, CLUT values, and matched spatial frequencies are as specified for orientation experiments. The spatial frequency was varied (π = 0.125, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, 3.25, 3.5, 3.75) in all previous spatial frequency experiments. The appearance time for each trial was 100 ms, and the trial order was randomized.

Fractional values were rounded to the nearest integer. The probe stimulus was assigned to ensure all the presented spatial frequencies were equally spaced between 0 and 2 pixels/cycle. The spatial frequency was varied in all orientation experiments, as indicated in Figure 2. The appearance time for each trial was 100 ms, and the trial order was randomized.

Gabors, and the colors were highly saturated. The procedure for the color judgement experiment, as that used in Experiments 1-3, is as follows. The probe stimulus consisted of a color that varied between the 16 colors or a white square.

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Get ready…
What color was it?
Results

As set size increases, approximately linear increase in error

**Color**

![Graph showing judgement error as a function of set size for color perception.](image)

**Orientation**

![Graph showing judgement error as a function of set size for orientation perception.](image)
more continuous resource than slots..

slot model

continuous resource model

error-prone encoding
Well-designed studies that get at underlying representations/computations
Now, time for the in-class activity
Acknowledgements

- Initial version of many of these slides are from Todd Gurecks