Hunter College's SCI 111: Brains, Minds, and Machines

This course is intended for first-year students and has no prerequisites. It has been approved by The City University of New York as a Scientific World course, which means that it is accepted to fulfill a science distribution requirement. It is taught as a small lecture course that meets for 75 minutes twice a week for 14 weeks. There is a midterm, a final, and 8 assignments that require extensive reading and writing.

The course is designed around three central questions:

- What is in your head?
- How does that make you behave?
- How could we build a machine like that?

As the course progresses, there is a strong emphasis on material produced by interdisciplinary collaboration and thoughtful experimental design. At Hunter, this course regularly invites several early-career (recent graduates, post-doctoral students, and Ph.D. students) guest lecturers with substantial expertise in a particular area. Each of them addresses one of the topics below from their own perspective. (There is also always a guest lecture on free will by Dr. Phil Zeigler that the students invariably praise.)

Given its breadth and target population, the course is designed with a spiral curriculum, that is, material is repeatedly introduced at deeper levels. Thus, it introduces some basic vocabulary and processes in lecture 1, extends those ideas in lecture 2, and lays the groundwork for a scientific approach in lecture 3. The next set of lectures goes into greater depth on cognitive neuroscience (lectures 4 and 5), cognitive psychology (lectures 6 and 7), and artificial intelligence (lectures 8 and 9). The remainder of the material focuses on three essential cognitive abilities: vision (lectures 10-15), navigation (lectures 16-18), and language (lectures 19-21). Each ability is viewed in turn from the perspective of how the brain, the mind, and a computer address it. Vision, about which the most is known, is addressed first generally and then focuses on the task of face recognition.

Catalog information: SCI 111 (The SCI prefix denotes an interdisciplinary science course; for administrative purposes only, it is hosted by Hunter College's Department of Computer Science.)
This course addresses current knowledge about how human brains, human minds, and artificially intelligent machines think. Students will learn about groundbreaking work that will provide insight into people, the apps they rely on, and the robots in their future. Highly recommended for students considering any science major, and for students interested in problem solving.

Lecture 1: Welcome to a new science

Course overview including requirements and expectations
Cognitive neuroscience probes neural mechanisms in the brain
Cognitive psychology observes and measures intelligent behavior
Artificial intelligence simulates intelligent human behavior
Science: what it is, how it makes progress, and the roles of experimentation, creativity, skepticism in science

Lecture 2: An introduction to 3 disciplines

Cognitive neuroscience, including the large-scale anatomy of the human brain
Cognitive psychology, including the challenges of experimental design
Artificial intelligence, including the Turing test and the rational computational agent

Lecture 3: Science as a process[1]

Science as an iterative process
What an experiment is and how it contributes to knowledge
The differences among a hypothesis, a theory, and an over-arching theory
Scientific arguments as explanation and predictors
Science as a community of people who work together
When to trust an idea
Why and how it is important to support science funding

Lecture 4: The neuron

What neuroscience is
Axons, dendrites, and synapses
Electrochemistry and the action potential cycle
Why disequilibrium is important to brain function
Action potentials and neurotransmitters

Lecture 5: The brain

Gross brain anatomy and modularity
How to detect neuron or brain region activity: microelectrodes, EEG, MEG, PET, fMRI
Connectivity
The principles of integration and segregation, including fROIs
The relationship between activity and function

Lecture 6: The origins of cognitive psychology

What psychologists mean by "the mind"
Evolution of basic cognitive science principles: subject, reaction time, savings, classical conditioning
Evolution of cognitive science experimental design from analytic introspection to a controlled experiment
How experiments on human subjects and on animals can reveal what is going on in our minds

Lecture 7: Psychology and cognition

The range of human percepts and what psychologists believe about perception
Kinds of attention and its relationship to perception
Kinds of memory and evidence about them
Experiments that support these claims

Lecture 8: The computer

Perception as peripheral devices
How data, instructions, and percepts are represented in a computer
Hardware components of a computer: circuitry, CPU, memory
What a program is and how it is executed
Fundamental differences between a computer and the human brain

Lecture 9: Artificial intelligence

What AI is and its major achievements
Algorithms and computational models
Why real-world AI is a hard problem
What it means for a machine to learn
Introduction to artificial neural networks

---

[1] Much of this material is drawn from a highly-recommended source: Understanding Science. 2018. University of California Museum of Paleontology. 3 January 2018 <http://www.understandingscience.org>.

Lecture 10: Vision in the brain
Sensory responses in the eye
How sensory information is distorted
How light is transformed to a signal to the brain
Feature detection
Visual pathways to the brain

Lecture 11: Face recognition in the brain
Why face recognition is challenging
Human skill at face recognition
Where and how the brain processes faces

Lecture 12: Vision in the mind
Why perception is hard
How (un)trustworthy perception is
Theories about how perception "works"
Theories on object perception: Helmholtz, Gestalt, regularities, Bayesian inference
Experience-dependent plasticity
How knowledge and motion impact perception

Lecture 13: Face recognition in the mind
Observations as people recognize faces
How parts impact face recognition
What an average face is and how we acquire one
Quantification of facial similarity
How prototypes and anti-faces impact recognition
Prosopagnosia

Lecture 14: Vision in the computer
An introduction to computer vision and graphics
Significant applications of computer vision
How light becomes an image for a computer: texture, depth, shading, stereo, motion
Why a computer has to recover shape and what clues it can use to do so
Challenges in computer vision: edges, attitude, perspective, occlusion, highlights, reflection, video
Comparison of the ways images are formed in the brain, the mind, and the computer

Lecture 15: Face recognition in the computer
Applications of automated face recognition
Face databases and their role in performance testing
Feature-based face recognition: Kanade, face space
Principal components analysis and faces: eigenfaces, compaction, recognition
Viola-Jones algorithm
Deep networks: DeepFace, FaceNet
Rapid object detection and categorization: HMAX
Key remaining challenges

Lecture 16: Navigation in the brain
Head-direction cells
Place cells and grid cells
How (extensive) navigation experience changes our brains
Where our brains treat paths and distances

Lecture 17: Navigation in the mind

Imagery and perception
Virtual reality experiments
Labeled graphs and cognitive maps
Landmarks and fast, efficient shortcuts
Evidence for neural correlates during navigation
Many uncertainties still abound about how people navigate

Lecture 18: Navigation in the computer

How robots navigate
Challenges in robot navigation: localization, sensor error, actuator error
Decision making: reactivity, deliberation
Autonomous robot navigation: probabilistic SLAM
Cognitive robotics: SemaFORR

Lecture 19: Language in the brain

Where the brain processes language
Time course of understanding: evidence that word recognition is temporal and relies on semantic primitives
How auditory cues and data support the construction of a semantic map for language in the brain

Lecture 20: Language in the mind

The chronology of word learning/understanding in young children
The role of impaired patients in understanding concept semantics
The role of fMRI in understanding concept semantics
The current theory of concepts
Some open questions in the field

Lecture 21: Language in the computer

Natural language understanding requires a belief system, which in turn requires knowledge
Illusion of understanding from formulaic responses: ELIZA
Understanding as a text-based pattern matcher: Watson
Understanding as a semantic storehouse: NELL
Synthetic therapy

Lecture 22: Conclusions

Physiology determines animal cognition
The differences between perception (stimuli), consciousness (what we are aware of), and storage (memory)
The differences between how people process information and how computers do
The ways that brains, minds, and machines can help us understand intelligence

Sample homework questions

Read http://www.newyorker.com/magazine/2015/05/18/lighting-the-brain
What does VNS stand for and what does it do?
What is optogenetics and how does Deisseroth use it?
What is an opsin and how does he use one?
What has Deisseroth contributed thus far to science?

Read about S.F.: http://www.edublox.com/memory-techniques-memory-challenges.htm
Read about Jonathan Foer:
http://www.nytimes.com/2011/03/13/books/review/book-review-moonwalking-with-einstein-by-joshua-foer.html?pagewanted=all&_r=0).
Both S.F. and Foer appear to have improved their working memory. What did they do and did it really work?

Watch the following two videos:
The humanoid final at Robocup 2015 https://www.youtube.com/watch?v=iNLcGqbhGcc
Video of Cobot Executing Tasks: http://www.cs.cmu.edu/~coral/projects/cobot/
Write 300 words on the differences between the tasks these robots are doing, what they have achieved, and what surprised you.

How well do you recognize faces? Take the test at http://www.faceblind.org/facetests/ff/ff_intro.php
Snapshot and report your results. Explain to what degree you think they truly reflect your ability and why.
Members of The Center for Brains, Minds, and Machines and faculty at The City University of New York have provided inspiration, advice, and support during the development of this course. Particular thanks go to Joshua Blumberg, Martin Chodorow, Ellen Hildreth, Nancy Kanwisher, Tomaso Poggio, Andrew Polsky, Sandeep Prasada, William Sakas, Mike Wiest, and Phil Zeigler.