What is Cognitive Science?
Definition - 2 parts
• what is studied?
  – problems solved with “brains” / “minds”
• how is it studied?
  – interdisciplinary way

What is studied?
• problems solved by the mind/brain
  • So, what does the mind/brain do?

“It ought to be generally known that the source of our pleasure, merriment, laughter and amusement, as of our grief, pain, anxiety, and tears is none other than the brain. It is specially the organ which enables us to think, see, hear, and to distinguish the ugly and the beautiful, the bad and the good, pleasant and unpleasant… it is the brain too, that is the seat of madness and delirium, of the fears and the frights that assail us, often by night, but sometimes even by day; it is there where lies the cause of insomnia and sleep-walking, of thoughts that will not come, forgotten duties, and eccentricities…. ”

Hippocrates (circa 425 BC)

Sensation and Perception
• internalizing the physical world
  • light -> electromagnetic radiation - vision
  • sound -> sound pressure level - audition
  • chemical -> olfaction, gustatory, trigeminal
  • mechanical energy -> touch
  • temperatures -> “temperature sense”
  • gravity, acceleration, -> vestibular sense

Some problems solved by the brain and mind.
<table>
<thead>
<tr>
<th><strong>Other energy?</strong></th>
<th><strong>Cognition</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• infrared -&gt; rattlesnakes</td>
<td>• understanding</td>
</tr>
<tr>
<td>• echolocation -&gt; bats, porpoises, some birds</td>
<td>• thought</td>
</tr>
<tr>
<td>• magnetic sense -&gt; some birds</td>
<td>• planning and imagining</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Communication</strong></th>
<th><strong>Psychology</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• speech</td>
<td>• study of mind and behavior</td>
</tr>
<tr>
<td>• language</td>
<td>• questions</td>
</tr>
<tr>
<td>• gesture</td>
<td>– What can we know about the world?</td>
</tr>
<tr>
<td>• facial expression</td>
<td>– How do we learn and organize behavior?</td>
</tr>
<tr>
<td>• body language, posture</td>
<td>• methods</td>
</tr>
<tr>
<td>• gait</td>
<td>– scientific - empirical, hypothesis testing</td>
</tr>
</tbody>
</table>

| | • Cause effect : $x \rightarrow y$ |
| | • non-scientific - clinical, analytic, introspective |

<table>
<thead>
<tr>
<th><strong>How is the mind/brain studied?</strong></th>
<th><strong>Action</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Interdisciplinary approach</td>
<td>• manipulating the environment</td>
</tr>
<tr>
<td>• Which disciplines are useful?</td>
<td>• actively exploring</td>
</tr>
<tr>
<td></td>
<td>• navigation</td>
</tr>
</tbody>
</table>

| | • Emotion |
| | – fear |
| | – happiness |
| | – sadness |
| | – hmmm……. |
Neuroscience

- neural basis of:
  - perception
  - cognition
  - action

- structure and function of the nervous system
  - neuroanatomy
  - neurophysiology
  - neuropsychology

Neuroanatomy

- structure - neurons and neural tracts
  - staining/labeling dyes, tracer dyes, and histology
  - brain imaging - e.g., MRI

Neurophysiology

- functions - neurons
  - recording from single neurons (with stimulation)

Neuropsychology

- global functions of brain areas

  - lesions
    - strokes
    - controlled in animals
  
  - electrical stimulation of brain areas
    - pain control
  
  - neuroimaging - functional brain imaging
    - watch the brain while performing a task...
    - see what parts are active.....e.g., when you read?

Computer Science, Engineering, Robotics

- build machines that simulate (the functions of):
  - perception - vision, audition, etc.
  - cognition - thought, speech understanding
  - communication - language, task-interface
  - action - manipulation of objects (robots)

  - give insight into the problems

  - problems are difficult - any solution is interesting

  - Can machines perceive, think, be conscious?

Philosophy

- reason-based approach to understanding the mind, including:
  - perception
  - cognition
  - action

  - questions
    - What can the senses tell us? (Locke, Hume, Berkeley)
    - What is consciousness? (Decartes)

  - predates psychology (scientific method)
Nature of the cognitive science inquiry

- Cognitive science is a reverse engineering problem

- **Engineering**
  - have problem
  - design solution

- **Reverse Engineering**
  - have solution - human brain
  - understand the design - how does it work?

The Machine -> Brain

**Thought experiment**
- microwave
- battery pack
- time travel
- ...to Newton
- it cooks food....how?

Approach

- brain storming
  - well it might…
  - or, there might be a fire inside…
  - or .....

Philosophy

- test performance
  - what does it do well?... water, meat, etc.
  - how long does it take?
  - what materials work? ...paper, tin, etc.

- document, hypothesize, and retest

Psychology

- open cover and note structure
  - Lid off….
    - Structure ➔ Function

Neuroanatomy

- take it apart and see what is important
  - what parts do what?

Neuropsychology
• try to build model...
  – fly - birds, plane....

Engineering, CS, Robotics

Cognitive Science and the Microwave Problem

• Is Newton going to succeed?

• Are we going to succeed?

• Is it still worth doing?

When is the problem “solved”?

• When you can build one?
  – AI?
  – Cloning?

• When you understand enough to manipulate?
  – Scientific method, prediction and control

Recursion problem

• you are the machine you study….  
  – Measuring a ruler with a ruler?

• consciousness
  – What does it mean to “think”, “feel” etc….?

History

How do you find out about the brain/mind?

• development of ideas, hypotheses

• development of methods
The Beginnings - The Ancients

- 1st written mention of the brain (1700 BC)
- copy of surgical treatise (3000 - 2500 BC)
  - how to treat skull injury (from 48 cases)
  - each case -
    - This is an ailment I will treat
    - This is an ailment I will try to treat
    - This is an ailment I will not treat

- Egyptian (and perhaps universal) view
  - heart is the seat of mind and intellect
  - why?
    - physiological response

Alcemeon (Croton, Sicily) 450 BC

- 1st neuroscientist
- brain is the seat of perception and cognition
  - Why?
    - anatomical dissection
      - optic nerve - eye to brain
      - light bearing paths
      - physical manipulation of eye - phosphenes
      - fire/light in the eye

Hippocrates (Cos, Mediterranean) 452 BC

- physician
- scientific approach to medicine
- epilepsy -> the “sacred” disease
  - not possession

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Hippocrates (circa 425 BC)
Aristotle 450 BC

- **disciplines**
  - philosopher
  - leading biologist of the day
  - founder of comparative anatomy
  - founder of embryology
  - systematic study of animal behavior

- **work**
  - dissected 49 animals - snail to elephant
  - never a human
  - BLUNDER - heart not brain controls sensation

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Galen (129-199 AD) Pergamon

- **accomplishments**
  - 1st accurate detailed anatomy of the brain
  - ox versus human
  - lesion experiments
    - laryngeal nerve -> pigs vocalization

- **mistake (long-lasting)**
  - soul/mind is located in the ventricles of brain
    - Psychic pneuma (animal spirits)
    - SOUL - should not be material substance

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Death of Greek Science and Medicine

Beginning of Medieval Times

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Medieval Cell Doctrine (199-1200 AD)

- **ventricles**
  - cell 1 - lateral - common sense - multimodality
  - cell 2 - middle - reason, thought
  - cell 3 - memory

- **early church fathers**
  - nonmaterial nature of the soul
Evidence

"if we will (saith Aristotle in his Problems), enter into any serious thought, we knit the browses and draw them up; if we remember anything, wee hang downe the head and rub the hinder part, which sheweth very well that the imagination lieth before and the memory behinde . . . in the diverse petite chambers in the braine, which Anatomists call the ventricles"

A. du Laurens 1597 professor of medicine

Rebirth of Brain Science

Andreas Vesalius of Padua (1514-1564)

- greatest renaissance anatomist
- methods
  - dissection
  - human body and brain
- claims
  - ventricles - not the seat of the soul and mind
  - animals have ventricles too!

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• Thomas Willis (1664)
  – Cerebri Anatomie

Decartes, 1662
• mind-body problem
• soul is in the pineal gland
  – only part that is truly central
    • (not duplicated in both hemispheres)

Modern Era of Cortical Localization

Phrenology
• Founders
  – Franz Josef Gall (1776-1828)
  – J. C. Spurzheim (1776-1828)
• Theory of phrenology
  – Cortex is set of 35 intellectual-affective faculties
  – Detectable by bumps on the skull
• Methods
  – Examined skulls
    • (insane and criminals) vs (intelligent and accomplished)

• Broca (1824-1880)
  – confirms some localization of function
  – patient
    • “Tan” – the only word he could say
      – Broca’s aphasia
        • cannot speak
        • can understand language
    • autopsy
      – left frontal lobe damage
Phineas Gage
- 28 yrs old in 1848
- railroad worker
- a "most efficient and capable man"
- explosion - iron bar passes through the head
  - enters left cheek
  - passes through skull
  - exits the top of the head
- iron bar
  - 13 lbs, 3 ft. in length, 1.25 inches in diameter

Short term recovery
- Gage remained conscious, spoke within a few minutes
- Dr. John Harlow - town physician
  - Gage "perfectly rational"
  - explained how the injury happened as he was being examined and treated
- within 2 months Gage was pronounced "cured"
- coordination, movement, senses (with a small visual deficit in left eye), hearing, language - all normal

Long term recovery
- Gage underwent a personality change
  - "equilibrium between his intellect and his animal propensities has been destroyed"
  - "Gage is not Gage anymore"
    - drifted, drank, and was socially inappropriate
- died at age 38 - after seizure
- Implication --- ?

Neuroscience Methods in Mapping Brain to Function
- lesions
- direct brain stimulation
- neurophysiology - electrophysiology
- neuroanatomical - staining
- functional neuroimaging
- Neuropsychology
  - Lesions
    - Accidents
      - Gage, etc.,
    - Surgery
      - Intended - emotional disturbances, epileptic seizures
      - Unintended consequences
      - Corpus collosum, hippocampus, frontal lobe disconnect
    - Strokes
      - Clots in blood supply to the brain
      - Selective impairments
  - Lesions (continued)
    - Controlled lesions
      - Level 1 - Hensens-Munk (1886) - Seelenblindheit
        - Dogs - occipital cortex
      - Level 2 - Mishkin & Ungerleider (1980's) - "what" and "where"
        - "Where" Task - respond if anything appears at location y
        - "What" Task - object - respond if circle appears anywhere
        - Lesion in parietal lobe - 2 but not 1
        - Lesion in temporal - 1 but not 2
  - Lesions (continued)
    - Controlled stimulation
      - Wilder Penfield (1950's) - during brain surgery
      - Parietal cortex - map of the body in the brain

- Lesions (continued)
  - Controlled lesions
    - Level 1 - Hensens-Munk (1886) - Seelenblindheit
      - Dogs - occipital cortex
      - Navigation - ok - recognition impaired
    - Level 2 - Mishkin & Ungerleider (1980's) - "what" and "where"
      - "Where" Task - respond if anything appears at location y
      - "What" Task - object - respond if circle appears anywhere
      - Lesion in parietal lobe - 2 but not 1
      - Lesion in temporal - 1 but not 2
• Neurophysiology
  – recording activity from single neurons
    • while stimulating
      • classic examples
        – Letvin et al. (1959) What the frog’s eye tells the frog’s brain
          » Recorded from cells in the retinae
          » Responded to small moving spots of light
          » “Bug detectors?????”
        – Hubel & Wiesel (1962)
          » recorded from cell’s in cat’s occipital (visual) cortex
          » found a highly organized map of visual space

Hubel and Wiesel (1962)
- cells responsive to oriented lines
- orientations changed systematically
- binocular dominance columns
* topographic representation of space in visual cortex
* cortical magnification

• Neuroanatomy
  – staining and tracer dyes
    • anterograde - trace forward projections
    • retrograde - trace backward projections
  – Level 1 - structure
    • e.g., visual projections
  – Level 2 - function
    • oriented stripes and orientation-specific cells in visual cortex
    • 2DG - glucose-based dyes

• Neuroimaging
  – EEG - electroencephalogram
  – PET - positron emission tomography
  – MRI - magnetic resonance imaging
  – fMRI - functional MRI
**EEG - Electroencephalogram**
- surface electrodes on scalp
- excellent time resolution
- clinical tool
- spatial resolution less good
- Evoked potentials
  - VEP example
    - binocular system

**PET - Positron Emission Tomography**
- inject radioactive isotope with glucose
  - neural firing fueled by glucose
- subject engages in a task or activity
- imaging of brain
- advantage
  - spatial resolution excellent
- disadvantage
  - temporal resolution bad
  - invasiveness

**MRI - Magnetic Resonance Imaging**
- aligns spins of nuclei of atoms in brain with a BIG magnet
- zaps the alignment 90 degrees with a radio frequency pulse (resonance-matched magnet)
- spins “realign” with BIG magnet at different rates
- different tissues realign at different rates
  - white, gray, cerebrospinal fluid, bone, fat, blood, skin
- advantage
  - excellent spatial resolution
- NOTE- not functional imaging

**fMRI - Functional MRI**
- all of the above points
- plus - subject engages in a task
  - neurons active
    - hemodynamic response - extra blood flow
    - BOLD - blood oxygenation level dependent response
    - oxygenated blood in - deoxygenated blood out
    - MR properties of oxygenated and deoxygenated blood differ
- advantage
  - excellent spatial resolution
  - reasonable temporal - 1 brain image every 3 secs
  - noninvasive