


1. Brain vs Computer

An Overview

Aim

Compare how computers process information vs how the brain process the senses?
Define the main differences

To discover the principles of human-computer interaction (HCI)

(LINK: Nervous system)

Human vs computer centered

- The brain has changed little in last 3 million years
  - Under development for many millions of years
  - Rigorously beta tested, at great cost
- Computer systems have been around for 60 years
  - Change drastically every three years
- Should IS adapt to people, or people to IS?

To develop effective HCI systems, we must understand the human system as well as the computer system

Introduction

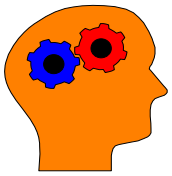
- Why are things easy for people, often surprisingly difficult for computers?
  - Pattern recognition
  - Intelligent conversation
  - Ambiguity
  - Context effects
  - Self-reference
- How can 3 lbs of "wetware" even compete with a super-computer, let alone better it?

Example: Pattern Recognition

Any three year old can recognize all these

A few of the variances on the letter 'A' to be found in the Letraset Catalogue

Is the brain a computer?



- Neurons transmit/receive electrical impulses
- Neurons are on/off devices
- Threshold effect allows logic gates (McCulloch & Pitts, 1943)
- The brain has input/output
- 10^{12+} (thousand billion) neurons per head – more than there are people in the world, or stars in the galaxy

(LINK: Digital)

Von Neumann computers

Computers were designed by Von Neumann according to certain practical principles:

1. *Control*: Centralized
2. *Processing*: Sequential
3. *Input/Output*: Exclusive processing
4. *Storage*: By address
5. *Initiation*: Input driven
6. *System type*: Predictable/closed

Information processing need not work this way

(**LINK:** Von Neumann)

Issue 1. Centralized control

- All processing is via a *central processing unit* (CPU)
- Computers need a CPU for *control* reasons - otherwise they would not know where they were
- If the CPU fails, the *whole system* fails ("hangs")
- Distributed control, as the brain seems to have, is much more difficult to do than centralized control

Example:

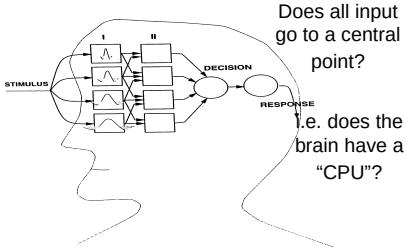


FIGURE 5 Channels. Center-surround receptive fields of ganglion cells and lateral geniculate cells occur in a wide range of sizes. Their outputs are processed in size-specific "channels" for several stages (I, II) before signals processed by receptive fields of different size combine. (Reproduced with permission of G. Sperling.)

N-L3

Does all input go to a central point?

I.e. does the brain have a "CPU"?

Cortical hemispheres

- The brain hemispheres divide up the job of seeing Each hemisphere only receives half the visual field
  - Left visual field (both eyes) --> Right Hemisphere
  - Right visual field (both eyes) --> Left Hemisphere
- The two parts are combined via the corpus callosum - 800 million nerves connecting the hemispheres
- In most people
  - the left hemisphere does language processing
  - The right hemisphere does spatial processing
  - the left hemisphere controls the right side of the body
  - The right hemisphere controls the left side of the body

The "Split-Brain"

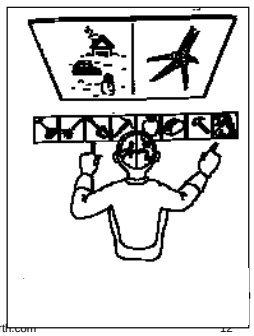
- For some seriously epileptic patients the corpus callosum was cut, giving "split-brain" subjects
  Note: The hemispheres connect to the mid-brain, so the brain is not really "split"
- Each hemisphere can then have its own input and output!
  Can each act of its own accord?

(**LINK:** Split brain)

The results - No "CPU"!

- Spoken & right hand responses matched right field images
- But left hand responses matched left field images
- Each H did its own processing
- Also matched "sounds like" e.g. shown bee and points to a key

(**LINK:** Language areas in the brain; Language-Processing Areas In The Brain)



Multi-processing at the highest level

"It does not compute" ?

- When asked why the left hand (controlled by RH) chose a shovel in response to the chicken foot, subjects would make something up (e.g. "Because you need the shovel to clean up after chickens")
- The RH directed the left hand choice (based on the snow picture which it alone saw). The LH, which controls speech, didn't see the snow picture, and is disconnected from the RH, so it had no idea why the shovel was chosen, *so it formed the best available hypothesis*
- In general "it does not compute" is not an option for human information processing

Subsystem autonomy

- Each hemisphere has a degree of *autonomy, i.e.* it can receive/process/respond without direction
- Each hemisphere keeps the other "informed" via the corpus callosum
- Who is "in charge"? Neither
- For language tasks the LH may dominate, but for say spatial tasks it is usually the RH. Each hemisphere decides itself whether to act

(LINK: Mind & Brain, Luria on mind and brain)

Brain has successfully implemented shared not centralized control

Advantage - *Adaptability*

- The appropriate specialist sub-system (SS) can autonomously take charge of the situation:
  - advanced special service teams facing high challenges work this way (facing a cliff, the climbing expert controls, in a water-crossing, the water expert takes charge
  - CSMA/CD (ethernet) networks are more efficient than central polling networks for the same reason – each can take what they need
  - We have a "*society of mind*" (Minsky, 1986)

Brain is a multi-part system without central control where somehow choices are made!

IS autonomy examples

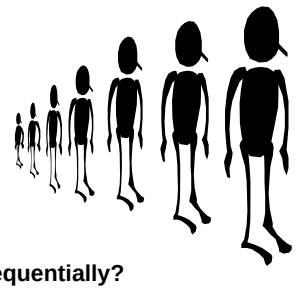
- Printers with no Off switch
- Self-maintaining systems - Automatic disk defragmentation
- Object orientated programming - each object has autonomy
- Networks with no-one in charge (eg WWW)
- Space shuttle launch - several computers vote independently on a complex decision!

Design principles

- Multiple I/O channels and multiple processes require **multi-media design** or **multi-process design**
- A common focus for multiple sub-systems (*attention)* is expensive – design to *manage the user's attention e.g.* One sub-system can affect another (e.g distractors vs attractors of attention). See Lesson HCI2, Attention, for more detail
- Different sub-systems may learn in different ways so people prefer different processing styles (e.g. right vs left brained people) – *design for multiple styles* (See Lesson HCI8, Learning)

Issue 2. Sequential processing

- Task instructions are processed one after another



Do people process sequentially?

Neurons are slow

- Neuron event - 1/1,000 second
- Computer event - 1/1,000,000,000 second
- Humans recognize complex patterns/sentences in 1/10th second, faster than computers
- Brain's hardware allows only 100 sequential steps - pattern recognition in 100 lines of code? Impossible!

(**LINK:** Refractory period)

How can such slow components give such a fast response?

Slow components - fast responses!

Ali Baba is inside one of forty jars, which one?

- *Sequentially*:
  Very fast slave checks jar 1, then jar 2 ..
- *Parallel*:
  40 very slow slaves each check their jar

Who will win?

The parallel advantage

"It is odds on that a machine - or organ - with sluggishly functioning components and a parallel mode of operation would be able to thrash a computer with high speed components but a sequential mode of operation"

Copeland, 1993

Design principles

- At a base level, **all sense channels are processed** e.g. process the entire visual field
- Filling sensory fields with simple input gives a "fuller" sense experience, and avoids a feeling of being in empty space e.g visual backgrounds, surface "feel", mood music, colors
- See Lesson HCI3 Perceptions for more detail

Issue 3. Single IO processing

- Process input *one* way, giving *one* result, vs process in different ways, with different results
- *Exclusive* output control (eg "lock"printer or database), vs output directed by many *influences*
- *Replacing* old systems with newer (over-write them) *vs adding* new functions to older ones

Is human I/O processing singly sourced?

The case of Phineas Gage

- A speeding iron rod smashed the middle and left lobes of his cerebrum
- Within minutes was conscious and speaking
- Showed disturbed behavior
- Lived for 13 years, died of unknown causes

Performance degrades but system does not "crash"

Reliability

"How could a mechanism composed of some ten billion unreliable components function reliably while computers with ten thousand components regularly fail?"

Von Neumann

Blindsight

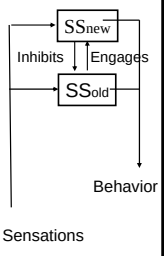
- Amnesic patients re-solve jigsaws faster but say: "I have never seen this before"
- People "know" things they are unconscious of
- Newborn babies "swim" when put in water
- Infant reflexes re-appear with brain damage
- Aphasic subjects (who cannot speak) can still swear & sing!

(LINK: Subliminal perception)

Older systems are overlaid, not replaced.

Conclude

- Advanced (later) sub-system SS_{new} *overlays* and inhibits SS_{old}
- If SS_{new} fails, SS_{old} can take over again
- SS_{new} is more complex, & takes longer but gives better results
- As SS_{old} is simpler & **faster,** it *may act before SS_{new} can inhibit it in situations it recognizes, and where speed is important*



Example

Puts hand on stove:

- Pulls away **(reflex spinal action)**
- Aaaggh! **(instinctive cry)**
- Puts burned hand in water **(physical response)**
- Who left that on! **(emotional response)**
- Remember to turn off stoves **(intellectual plan)**

Multi-level processing - every level has a role

IS example: Operating systems

- **Word:** "The selected floppy disk drive is not in use. Check to make sure a floppy disk is inserted." Retry. Cancel. **Civilized**
- **Windows:** "A:\ is not accessible. The device is not ready." Retry. Cancel. **Simple**
- **DOS:** "Not ready reading drive A. Abort, Retry, Fail?" **Basic**
- **Kernel:** "Parity error cluster 17340056A …" **Primitive**

Different "levels" of system response sophistication

Design principles

- Design for *both* simple and long term complex responses (e.g. color and design layout vs meaning and logical structure)
- Simple processing precedes complex, so short term reactions can preempt long term ones, e.g. must recognize an object before knowing what it means.
- Long term processing can also direct short term processing (expectations)
- See HCI4, Recognition, and HCI5 Space

Issue 4. Access by address

- Data is stored in specific locations
- Removing the location removes the data
- Data is *accessed by its address (ABA),* not *accessed by its content (ABC)*
- A physical filing cabinet is *access by address*
- Computers have *limited* ABC by indexes, hashing or pointers eg indexes store a data *key field* (like telephone number or address) *plus address*

(LINK: Engram)

Is human memory just a big filing cabinet?

Lashley's "engram" search

- 100 rats taught a maze. Surgically removed a different cortical area in each.
- Found: Destroying *any* 10% of cortex produced little effect. Any more, and performance degraded.
- Conclusion of 33 years of ablation studies*:*

No special cells (or locations) for special memories

(LINK**:** Lashley)

Human memory

- What did you have for dinner last night?
- When did you last have fish?
- Have you been to Northcote Rd?
- Do you remember John Davis?
- Do you know any red-haired women?

The answer to all these and many other searches may be the same memory

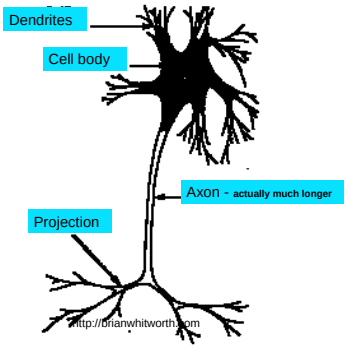
People appear to have any number of "indexes" into any given memory - unlimited access by content

(LINK: Memory and context; Memory and context)

Memory and connections

- Seem to be 1,000 to 1,000,000+ neurons per memory
- Each neuron connects to 1,000 - 10,000 others
- Over 10^{15} interconnections!
- One memory involves many neurons
- One neuron involves many memories
- **Can a memory be stored in these connections?**

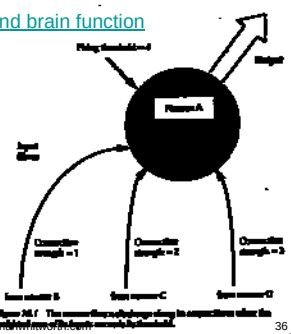
Neurons



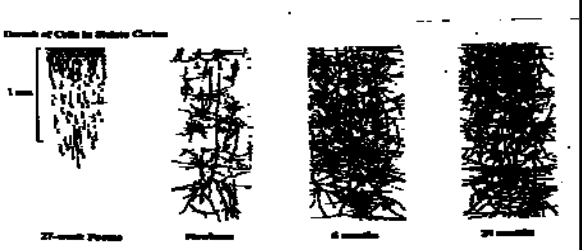
Connectivity

LINK: Neural connectivity and brain function

- Any input set can activate neuron's threshold
- Neurons can inhibit other neurons



Example



(**Gregory:** 1998, p105)

Massive interconnection

"The mass of processes, structures and interactions possible within this [maze] beggars both description and mathematization. The fascination is almost akin to terror …"(Rose, 1976)

(**LINK:** Brain development)

Advantages of ABC

- Virtually unlimited capacity - no "disk full" messages
- Flexible access
  - cf what is your SS/customer/ tracking number?
  - Imagine a file with as many indexes as there are data elements in the record
- Disadvantage: Imperfect recall as there are so many connections

People like to "search" by connections

Design Example - Hypertext

- People access information via flexible associations
- *Hypertext* links any word in a document to any other document, or a part of the same document
- It succeeds because it works as human memory works - anything can connect to anything else
- Hypertext is above all **flexible** (like people)
- HTML (Hypertext Markup Language) was successful for the same reasons
- See HCI8 Integration

Issue 5. Input driven

- Input activates processing
- Processing requires input
- Without input, the system waits (i.e. it is *passive*)

Does behavior = input + process
as flour = wheat + milling?

Input driven system (IPO)

Input ⇨ **Process** ⇨ **Output**

Input defines processing, processing defines output, in a one-way sequence

(**LINK:** Sensation)

The world creates sensation - which reflects reality

The curse of context

Read this sign:

- Such context effects are usually useful
  - Word meaning creates sentence meaning
  - Sentence meaning also affects word meaning
- One-way processing cannot handle context effects, where the whole alters the part that creates it:
  - "Hit me" (Blackjack) vs "Hit me" (in boxing)

Active systems

- Active systems alter their own input:
  - From the *retina*, signals go to the lateral geniculate body (LGB), which is largely a relay station, and thence to the *visual cortex*.
  - But the neural projections ***from*** the visual cortex ***to*** the LGB are at least as many as from the LGB to the cortex
- That *final* processing can alter its own *initial* processing data, allows people to deal with context effects computers find difficult

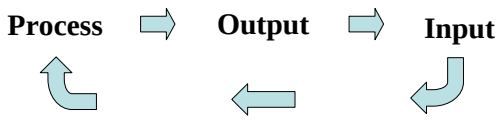
Brain is process driven

- 100x more inter-neurons than sensory/motor neurons
- Motor neurons develop before sensory ones, embryos move before sensory cells are connected
- Actions generate input - e.g. where one looks

Brain is process driven cont

- We are not passive to input - we anticipate, expect and imagine things that have not occurred,
- In sensory deprivation studies people start to imagine or create perceptions - we **must** process *actively*
- Without something to process we are ***bored***

Process driven system (POI)



We create/construct our "world"
- if we process differently the world changes

Design principles

- Steady states (homeostasis)
- "Purpose" (teleological behavior)
- Context - via top down processing
- Feedback loops
- Must design with what people **do** in mind
- People find web sites more interesting when they can interact with them, i.e. act upon them
- See Lesson HCI7 Interactivity

LINK: Homeostasis; Homeostasis

Issue 6. Predictable

- **Computer's state + input --> next state, etc**
  - i.e. "perfect" predictability
- **Universal determinism (Laplace)**
  - the state of the universe's atoms predicts its next state
  - lawful systems are always predictable
- **Neurophysiological determinism**
  - All actions derive from the action of neurons
  - people are predictable, and have no choice or free will

(**LINK:** Logical positivism, Logical positivism)

Is the brain as predictable as a computer?

Chaos theory

- Chaos theory describes complex systems, i.e. those whose parts are **highly interconnected**
  - May be essentially unpredictable (eg complex weather systems Lorenz, 1963)
  - *Minute* input changes may have *big* effects ("butterfly effect")
  - Self-adjust to "steady states"
  - Sometimes have "catastrophes" (eg avalanche)

Lawful systems can be unpredictable

Examples

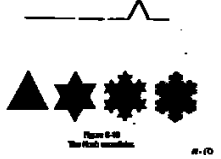
- Quantum uncertainty:
  - Cannot predict an electron's position
  - Causality fails for lawful sub-atomic events
- Arithmetic is inherently **incomplete** - it contains lawful statements that both true and false (Gödel, 1962)
- Logically valid statements may be undecidable:

"Everything I say is a lie"

(**LINK:** Gödel)

Unpredictability involves recursion

- Structures that repeatedly self-reference are **recursive**
- Recursive patterns are called **fractals**, e.g. Koch Snowflake These patterns are common in Nature e.g. snowflake, cauliflower
  - Fractal pictures look like landscapes, animals and plants
  - Each part potentially defines the whole e.g. holograms, genes, cells



Recursion: Simplicity in complexity

Recursion in the brain

- The human brain can *process its own processing* - our evolution may involve just this feature
- People can think about their own thinking, analyze their own analysis - how can an analysis process analyze itself?
- Each person, or self, has a concept of themselves - how can a self form a concept of itself?
- The human brain seems to satisfy a system specification that is impossible

Design principles

- People can learn context effects, e.g:
  - Purpose is contextual to behavior
  - Sender is contextual to a message
  - Group is contextual to an individual
- People want to know the context of a web site (its purpose, who runs it, their background, etc)
- People may use (adapt) your web site in un-expected ways. Expect and allow this to happen
- See Lesson HCI8 Learning for more information

Brain system IS specification

- Operational from the first component
- Cannot "delete" earlier versions
- Can never be "rebooted" if it fails
- Must respond in real time
- Indeterminate, ambiguous & complex input
- Complex & undefined output
- Able to analyze/change its own program

Nature's solution

An advanced chaotic system which is unpredictable but not random, complex but not slow, adaptable but not unreliable, structured but not unchangeable, receptive but not input defined, and can provide unlimited responses to potentially infinite variability in real time.

We can learn a lot about system design from the brain

Summary

The brain seems to be designed according to the following principles (follow up lesson in brackets):

1. *Control*: Decentralized (HCI2)
2. *Processing*: Parallel (HCI3)
3. *Input/Output*: Multiple sources (HCI4,HCI5)
4. *Storage*: Multiply stored (HCI6)
5. *Initiation*: Process driven (HCI7)
6. *System type*: Chaotic, open (HCI8)

Conclusions

- Systems designed the way people work are:
  - more likely to be accepted
  - more likely to be effective
  - easier to learn
- **Base IS design on human design**, base computer primitives on psychological ones
- HCI systems aim to fit in with human nature

Homework

- Read the following to keep up:
  - Nervous System- an overview
  - Split Brain - understand the hemispheres and the corpus callosum
  - Lashley - understand what he tried to do with his rats
  - Brain Development - note how the corpus callosum *grows* to join the hemispheres

Next: Attention

- How do we know what is important?
- How do we know where to look, unless we have already looked there?
- What determines what we attend to?

References

Alligood, K. T., Sauer, T. D. & Yorke, J. A. (1997). Chaos: An Introduction to Dynamical Systems: Springer.

Barrow, J. D. (1999). Impossibility: The limits of science and the science of limits. London: Vintage.

Bertalanffy, L. v. (1968). General System Theory. New York: Geore Braziller.

Calvin, W. H. (1996). The Cerebral Code: Thinking a Thought in the Mosaics of the Mind. Cambridge, Massachusetts: The MIT Press.

Capra, F. (1996). The Web of Life. New York: Anchor Books, Doubleday.

Casti, J. (1997). Would-be Worlds: How simulation is changing the frontiers of science. New York: John-Wiley and Sons.

Copeland, J. (1993). Artificial Intelligence. Oxford: Blackwell Publishers.

Godel, K. (1962). On Formally Undecidable Propositions. New York.

Hochberg, J. (Ed.). (1998). Perception and Cognition at Century's End. New York: Academic Press.

Lorenz, E. N. (1963). Deterministic nonperiodic flow. Journal of the Atmospheric Sciences, 20, 130-141.

Maturana, H. R. & Varela, F. J. (1998). The Tree of Knowledge. Boston: Shambala.

McCulloch, W. S. & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. Bulletin of Mathematical Biophysics, 5, 115-33.

Minsky, M. L. (1986). The Society of Mind. New York: Simon and Schuster.

Homework – To Read

- Read on the basic three-part structure of the brain
  - http://en.wikipedia.org/wiki/Central_nervous_system
  - http://en.wikipedia.org/wiki/Human_brain
  - Nervous system http://en.wikipedia.org/wiki/Nervous_system
  - The split brain http://en.wikipedia.org/wiki/Split-brain
- Language and the brain
  - http://thebrain.mcgill.ca/flash/d/d_10/d_10_cr/d_10_cr_lan/d_10_cr_lan.html
  - http://en.wikipedia.org/wiki/Broca%27s_area
- How the brain connects and develops
  - http://www.answers.com/topic/neuronal-connectivity-and-brain-function
  - http://faculty.washington.edu/chudler/dev.html
- How does the mind connect to the brain?
  - http://en.wikipedia.org/wiki/Mind
  - http://www.answers.com/topic/luria-on-mind-and-brain

OTHER LINKS

- What is digital?
  - http://en.wikipedia.org/wiki/Digital
  - http://en.wikipedia.org/wiki/Von_Neumann
- Positivism:
  - http://en.wikipedia.org/wiki/Kurt_G%C3%B6del
  - http://en.wikipedia.org/wiki/Logical_positivism
  - http://cscs.umich.edu/~crshalizi/notabene/logical-positivism.html
- Response time and subliminal perception
  - http://en.wikipedia.org/wiki/Refractory_period_%28physiology%29
  - http://watarts.uwaterloo.ca/~pmerikle/papers/SubliminalPerception.html
- Memory and the brain
  - http://en.wikipedia.org/wiki/Engram_%28neuropsychology%29
  - http://en.wikipedia.org/wiki/Karl_Lashley
  - http://en.wikipedia.org/wiki/Context-dependent_memory
  - http://www.answers.com/topic/memory-and-context
- What are sensations? http://en.wikipedia.org/wiki/Sensation_%28psychology%29
- Homeostasis:
  - http://www.answers.com/topic/homeostasis
  - http://en.wikibooks.org/wiki/Human_Physiology/Homeostasis