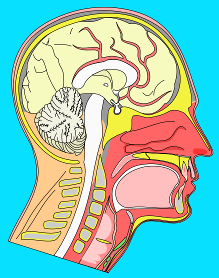


A Comparison of Human and Computer Information Processing

Brian Whitworth © 2007

Introduction

- Some things are easy for people, but have been found surprisingly difficult for computers:
  - Pattern recognition
  - Intelligent conversation
  - Visual ambiguity
  - Language contexts
  - Spatial processing
  - Self-reference

How can 3 lbs of "wetware" do what super-computers still struggle to do?

Pattern Recognition

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

A 3 year old can recognize all these as "A"s

Computers struggle to do this

A different kind of processor

"*As yet, no computer-controlled robot could begin to compete with even a young child in performing some of the simplest of everyday activities: such as recognizing that a colored crayon lying on the floor at the other end of the room is what is needed to complete a drawing, walking across to collect that crayon, and then putting it to use. For that matter, even the capabilities of an ant … far surpass what can be achieved by the most sophisticated of today's computer control systems.*" (Penrose, 1994, p45).

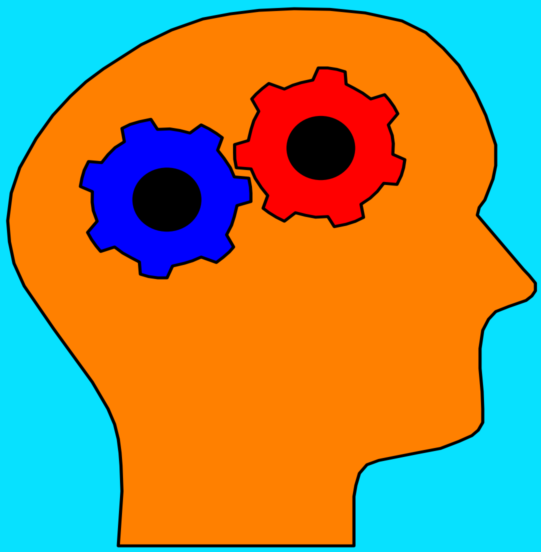
When "smart" computers try to do what people routinely do, they often appear "dumb"

Vive la difference!

- *The brain is a different kind of processor*
- *This impacts:*
  - *Computer design*: Computers that use a different type processing.
    - *HCI design*: Computers that work well with people

*A **systems theory** approach (Bertalanffy, 1968) can contrast computer & human information processing*

The brain as an information processor



- 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

Von Neumann computers

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

1. *Control*: Centralized
2. *Input processing*: Sequential
3. *Output processing* : Exclusive
4. *Storage*: By location
5. *Initiation*: Input driven
6. *Self processing*: Minimal

Information processing need not work this way

Issue 1. Centralized control

- All processing *ultimately originates from and returns to a central processing unit (CPU),* even if that unit delegates work to sub-processors
- 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:

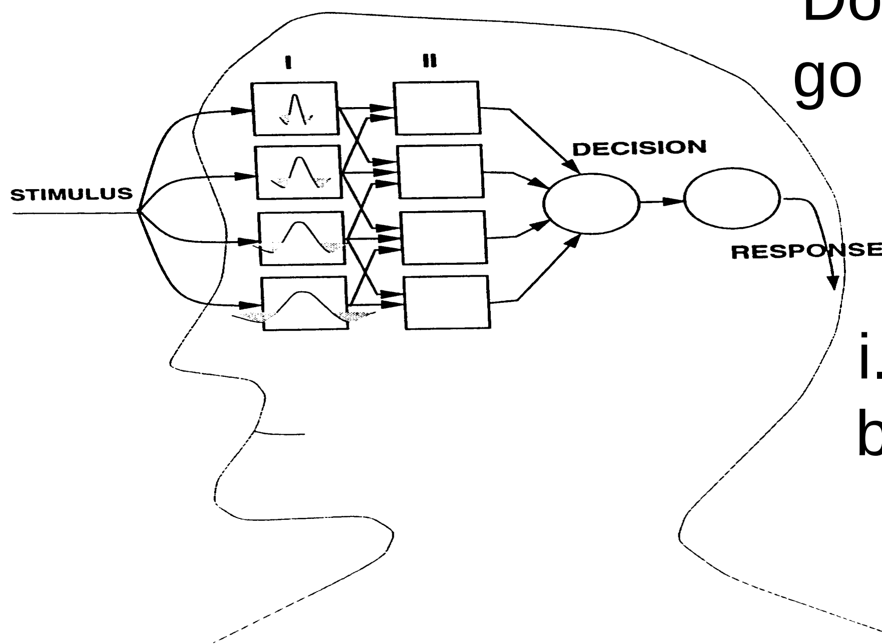


FIGURE 5 Channels. Center-surround receptive fields of ganglion cells and lateral geniculate cells occur in a wide range of sizes. Their outputs are processed in size-specific "channels" for several stages (I, II) before signals processed by receptive fields of different size combine. (Reproduced with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

No 13

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

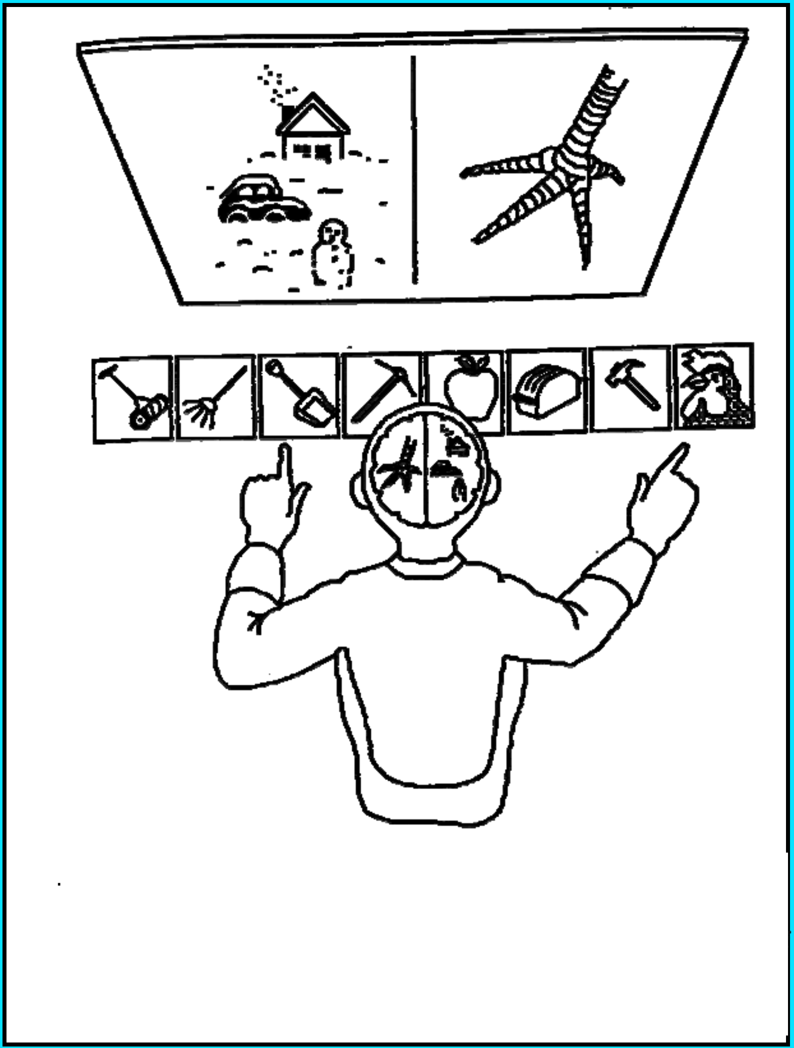
  Note: The hemispheres connect to the mid-brain, so the brain is not really “split”
- Each hemisphere then has its own input & output!

  Can each hemisphere act of its own accord?

  i.e. do they have autonomy?

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. subject shown a bee then points to a key



Multi-processing at the highest level

“It does not compute” ?

- 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
- When ***verbally*** asked why the left hand (controlled by RH) chose a shovel, the subject’s LH (which saw a chicken foot) would make something up (e.g. “Because you need the shovel to clean up after chickens”)

- “It does not compute” seems not an option for human information processing. *It just forms the best available hypothesis*

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

The brain has successfully implemented decentralized 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
  - We have a "*society of mind*" (Minsky, 1986)

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

Computer autonomy examples

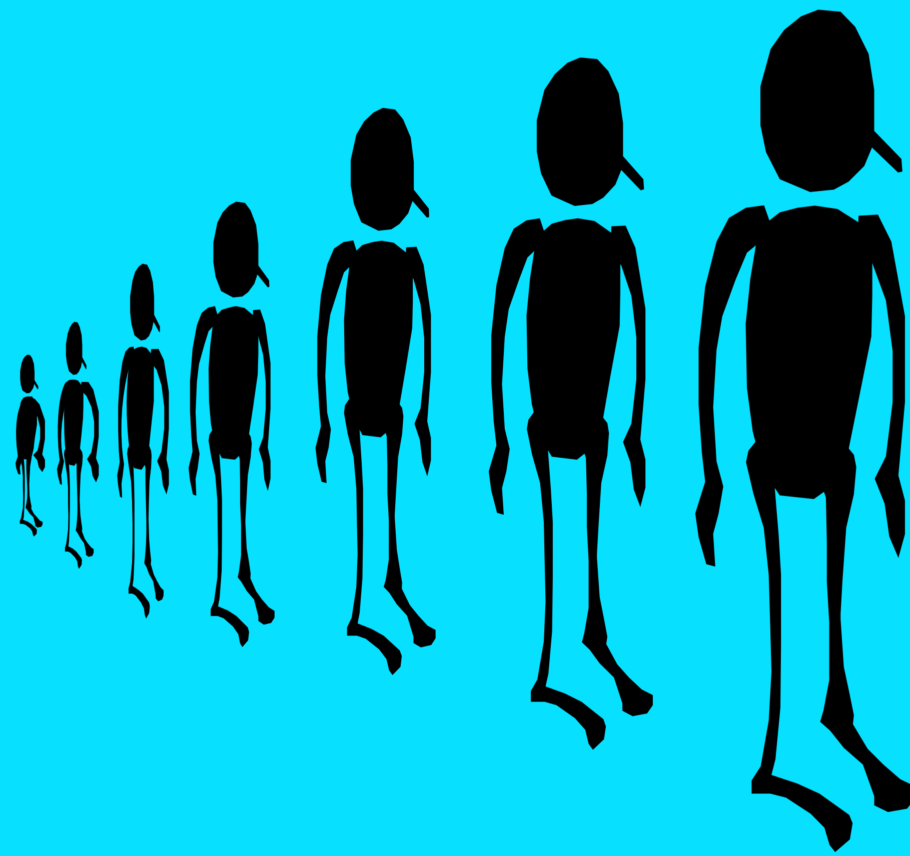
- Printers with no Off switch
- Self-maintaining systems -
  Automatic disk defragmentation
- Networks with no-one in charge (eg WWW)
- Space shuttle launch - several computers vote independently on a complex decision!

Design principles

- Multiple subsystem processes imply
  - **Multi-media design:** many sub-systems need many inputs to process
  - **Attention management.** How can multiple autonomous sub-systems get common focus?
    - Design computers with both upward (*distraction*) and downward (*concentration*) control of system focus (attention*)*
    - Design interfaces to manage the user's attention.

Issue 2. Sequential processing

Input instructions are processed one after another rather than simultaneously (in parallel).



Do people process sequentially?

Computer processing

- While computers use pipelining and hyper-threading, most computer processing is sequential due to cable and port line limits.
- While supercomputer arrays do some parallel processing, the brain has *massively parallel processing*
- The optic nerve has millions of lines, and human retina cell already process boundary data before the signals leave the eye.

Neurons are slow

- Neuron event - 1/1,000 second (Refractory period)
- Computer event - 1/1,000,000,000 second
- Humans recognize complex patterns/sentences in 1/10th second, faster than computers
- The brain’s hardware allows only 100 sequential steps - pattern and sentence recognition in 100 lines of code? Impossible!

How can slow components give a fast response?

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

Issue 3. Exclusive output processing

- *Exclusive output processing* “locks” output for sole access, e.g. two documents sent to a network printer at the same time come out one after the other, not interleaved.
- Databases use exclusive control to avoid the deadly embrace of a double lock.
- Process input *one* way, to give *one* result
- *Replacing* old systems with newer (over-write them) *as each has single level control*

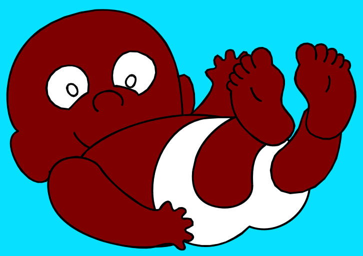
Is the brain a single level output system?

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

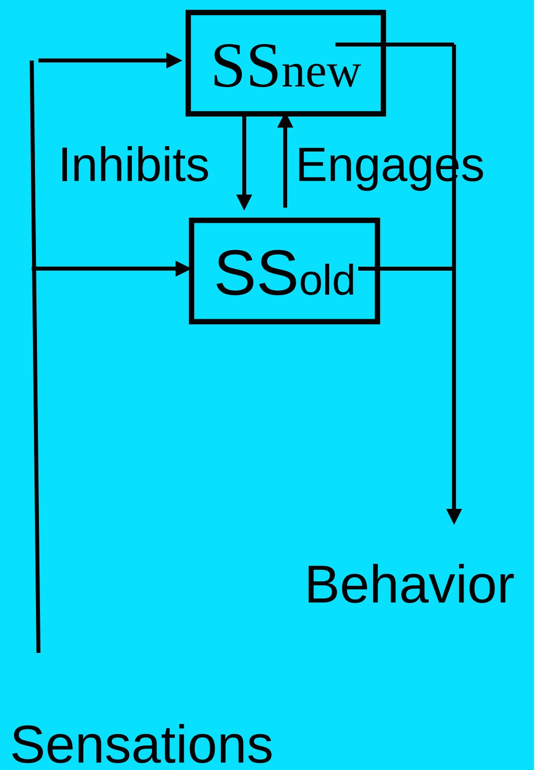
Blindsight

- 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!

Older systems are overlaid, not replaced.

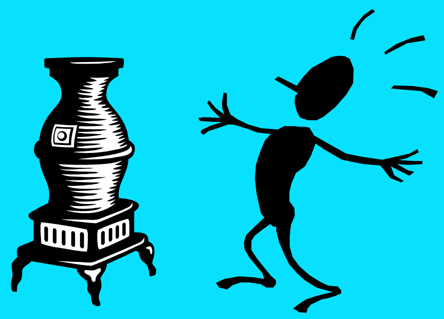
Conclude

- 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

computer 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)
- Overlay simple and reliable systems, rather than replace them (e.g. DOS vs Windows)

Issue 4. Access by location

- ***Location based storage*** stores/recalls information by numbered memory locations, e.g. a disk's side, track and sector. *It works like a* physical filing cabinet
- Computers can duplicate data by duplicating storage (e.g. RAID 0), but this is costly, so one computer "fact" is usually stored in one place, & damaging that location destroys the data held there.
- Since storage capacity depends linearly on the number of locations, such systems can report "memory full".
- Computers only simulate ***access by content*** by indexes, hashing or pointers

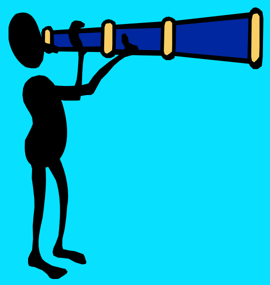
Is human memory like a big filing cabinet?

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

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?

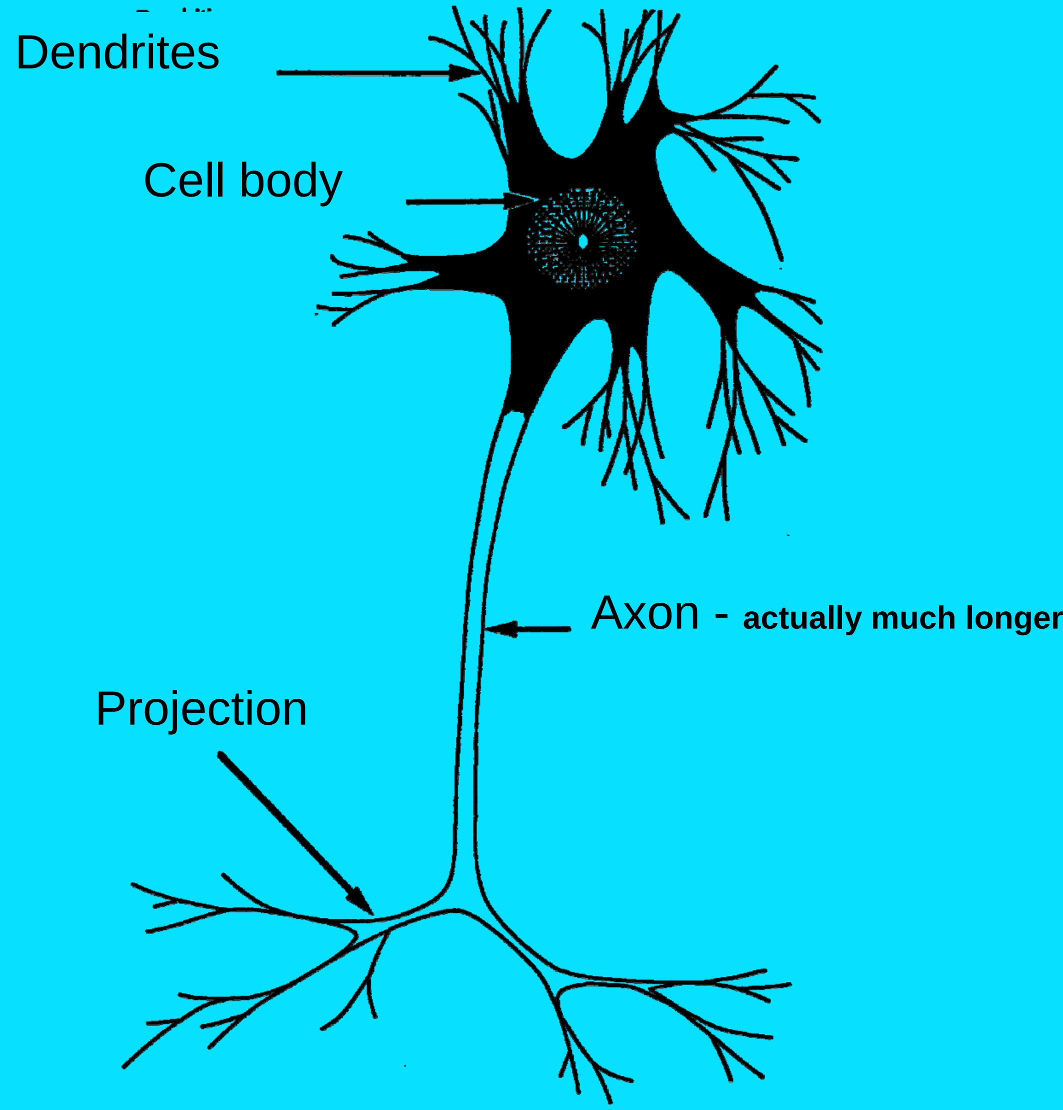
The answer to all these and many other searches may be the same memory

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

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 the connections?**

Neurons



Connectivity

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

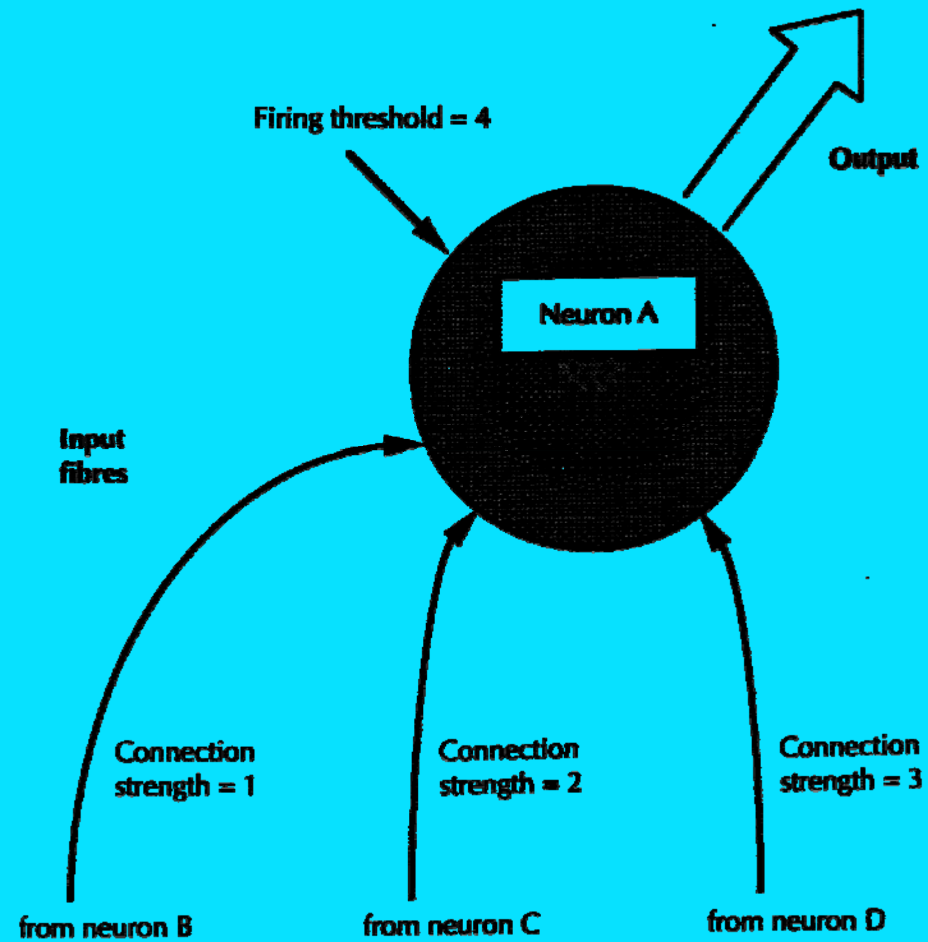
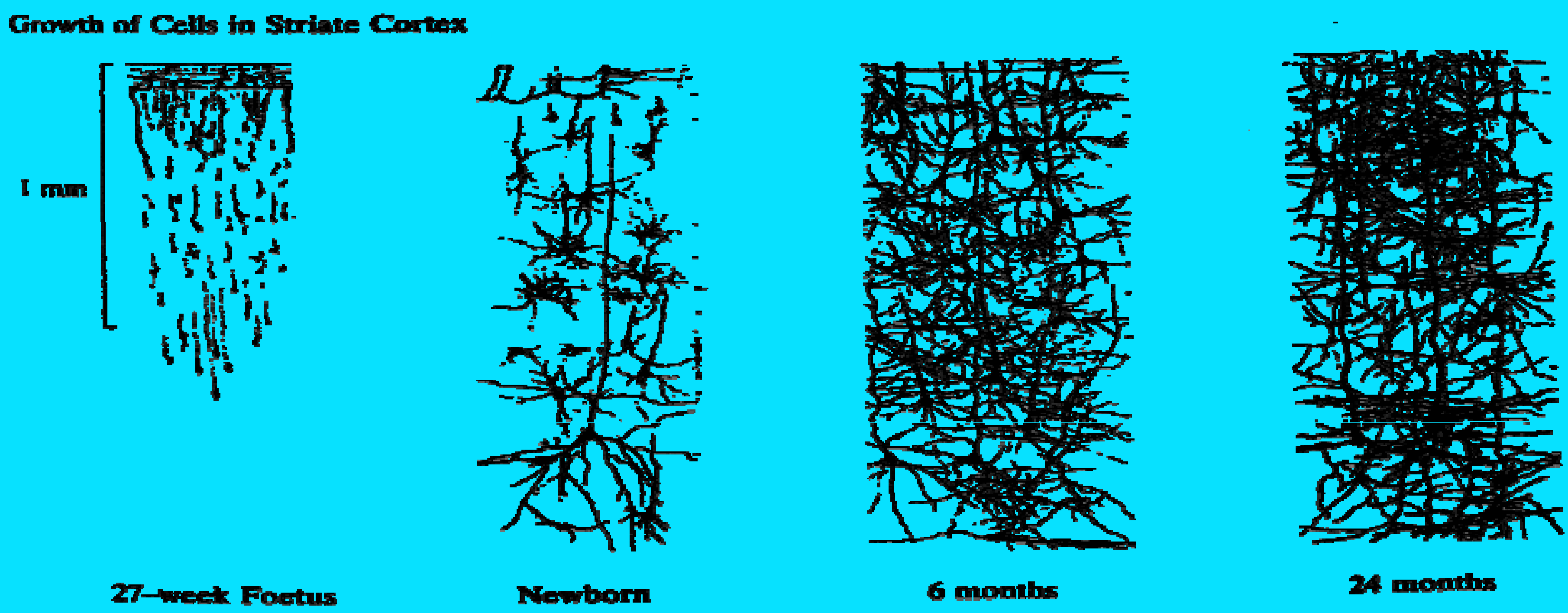


Figure 10.1 The neuron fires a discharge along its output fibres when the weighted sum of its inputs exceeds its threshold.

Example



(**Gregory:** 1998, p105)

Massive interconnection

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

(**Gregory:** Brain development)

Advantages

- *Virtually unlimited capacity* - no "brain full" messages
- Losing a neuron doesn't entirely lose a memory
- *Access by content is flexible*
  - 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

Design Example - Hypertext

- *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

People like to “search” by connections

Issue 5. Input driven

- *Input driven processing* means input initiates processing, which then generates output,
  - i.e. a computer system's output is determined by its input.
  - In Jackson Structured Programming program code derives from input and output specifications.
- Without input, the system waits (i.e. is *passive*)

Does human behavior = input + process?
(just as flour = wheat + milling?)

Input driven system (IPO)

Input → **Process** → **Output**

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

The world creates sensation - which reflects reality

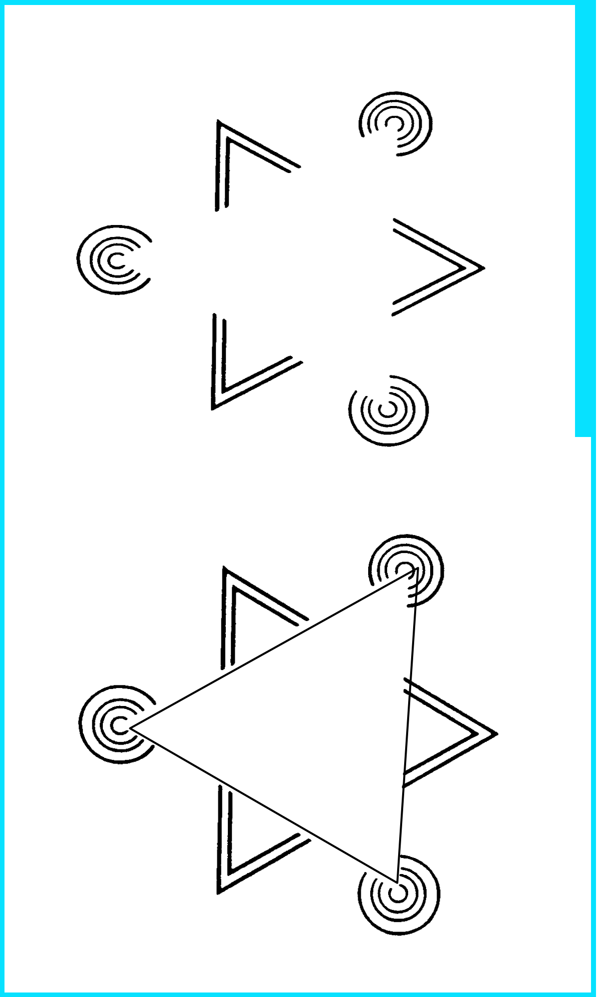
The curse of context

Read this sign:

- Word meaning creates sentence meaning
- Sentence meaning also affects word meaning
- One-way processing cannot handle context effects, where the whole alters what creates it
- See Hofstadter’s Goedel, Escher and Bach

Brain is process driven

- Process driven systems can *alter their own input*:
  - *Retinal* signals go to the lateral geniculate body (LGB) relay station, then to the *visual cortex*.
  - But there are more neural projections ***from*** the visual cortex ***to*** the LGB i.e. the opposite way.
  - The brain is clearly not just an input processor.
- That *final* processing can alter its own *initial* processing data, allows people to deal with context effects

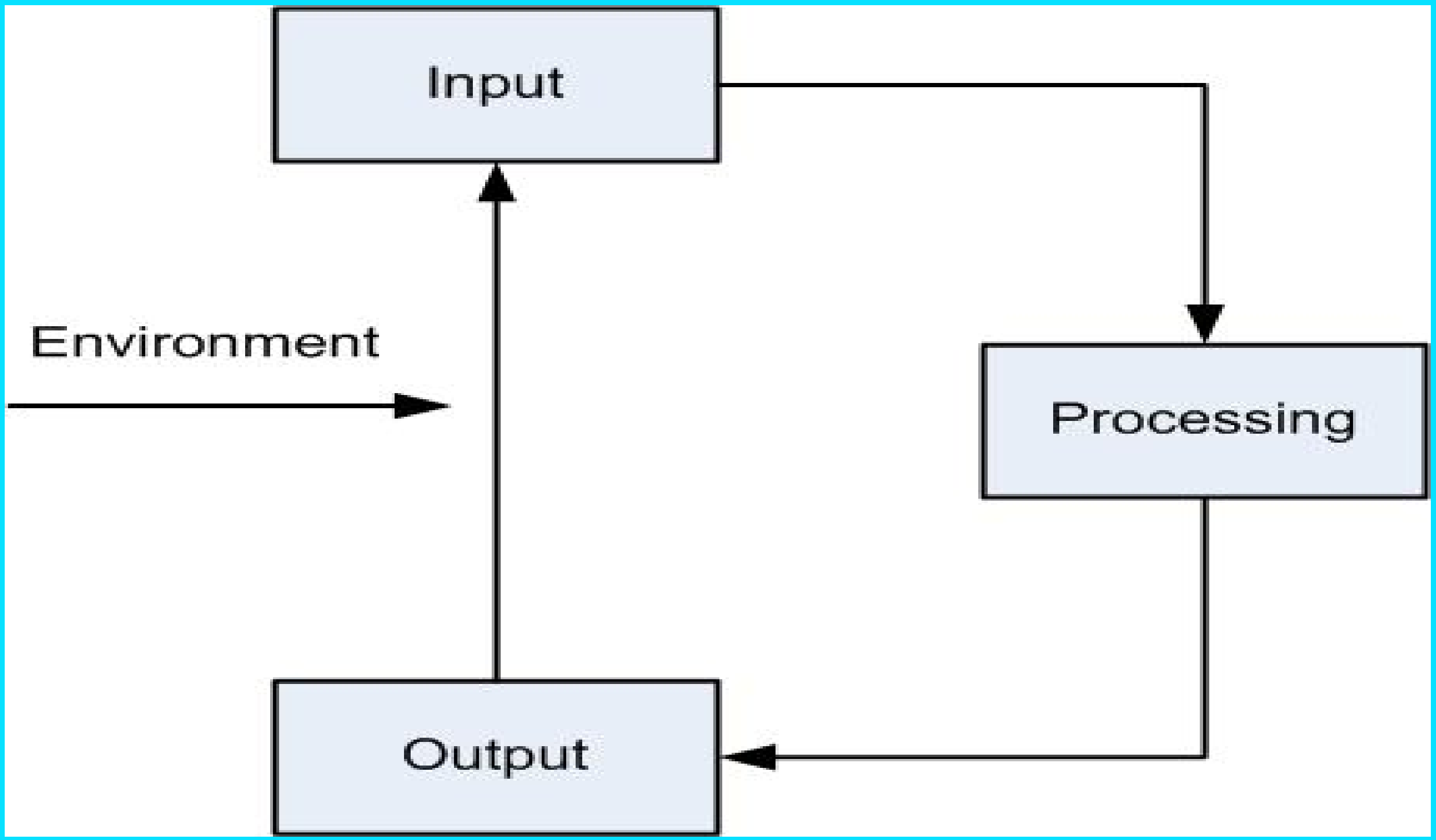


Kanizsa's triangle

The two perspectives

- Psychology theory has two approaches to sensory input:
  - *Objectivist*. For behaviorists Watson, Hull, and Skinner a real world creates sensations, which reflect external reality.
  - *Constructivist*. Others like Piaget and Chomsky suggest people construct rather than derive the “world”, and interpret sensations to see *a* world not *the* world (Maturana & Varela, 1998).
- People are not passive to input - we *anticipate*, *expect* and *imagine* things that have not occurred,
- In sensory deprivation studies people hallucinate i.e. imagine or create perceptions - we **must** process
- Without something to process people are ***bored, but*** *computers are not*

Process driven system (POI)



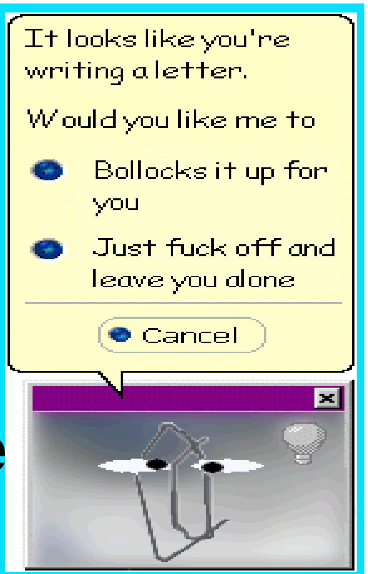
We create/construct *our* "world"

Gregory: Homeostasis

Design principles

- *Develop active feed-forward loops that enable purposes and expectations*, e.g. web-bots that trawl the Internet with a purpose.
- *Design for user driven feedback loops. P*eople become bored when passive.
- Interactive web sites are more interesting because we feel we are in charge (Langer, 1975).
- Was the Back Button the greatest software invention of the last decade?

Issue 6. Self-Processing



- ***Self processing:*** **a system can process its processing, i.e. "itself". Must process the entire feedback loop, not just another's output**
- **A "clever" system can be unaware of itself, e.g. Mr. Clippy's Bayesian logic analyzed *your* actions, but not *his* actions. Even if told a thousand times to go away, he happily offered again to "help". "Smart" software should be smart enough to recognize rejection..**

Mr. Clippy, like most ''intelligent'' software today, could not process itself

Human self-processing

- Computers don’t name themselves, but people do. How can a self conceive of itself? People think on their thinking. How can a process process itself?
- Can highly interconnected but autonomous brain sub-systems like the frontal cortex do this?
- Can people reprogram their neurons, with goals like ‘To be more patient”?
- Can computer systems change themselves, and recursively change their own processing?

Design principles

- A person's "ego" or "I" strongly affects their actions. Groups arise when a group's "identity" creates member self identity (Social Identity Theory Hogg, 1990).
- Interfaces that recognize and remember their interaction relationship, i.e. polite computing
- Social computing "bots" that recognize the common good "we", as well as the individual "I" identity

Summary

The brain contrasts the Von Neumann design principles:

1 *Control*: Decentralization maximizes flexibility.

2. *Input*: Massively parallel processing maximizes processing

3. *Output*: Overlaying primitive/advanced sub-systems gives the benefits of both.

4. *Storage*: Use interconnectivity to store a lifetime's data.

5. *Initiation*: Process driven interaction can hypothesize and predict life.

6. *Self-processing*: Developing concepts of self and group allows social activity and social synergy

Brain system specification

- Operational from the first component
- Cannot “delete” earlier versions
- Can’t be “rebooted” if it fails
- Must respond in real time
- Indeterminate, ambiguous & complex input
- Complex & undefined output
- Must adapt its processing to a changing environment

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.

The brain is an excellent processing design

Computing design trends

- *Autonomous computing*: Autonomous parts with simple rules can create “emergent” systems.
- *Massively parallel computing*: Take parallel processing to the limit.
- *Overlaid computing*: Combine simple but fast and complex but slow systems.
- *Neural net computing*: Systems that use the power of interconnections.
- *Process-driven computing*: Systems with goals.
- *Self-aware computing*: Systems that reflect and learn.

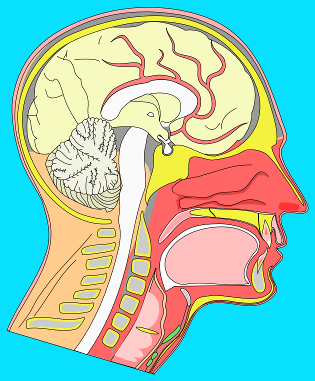
Will humanized computers also get their weaknesses?

e.g. Marvin the depressed robot in “Hitchhikers Guide to the Galaxy”?

Human-Computing Design

- *Attention flow management:* Where do users look?
- *Parallel inputs:* Multimedia design.
- *Immediate engagement:* What are the “first impressions”?
- *Link management:* How are idea links connected?
- *User feedback: How d*oes the system respond?
- *Socially aware software: How d*o s/w agents interact?
- The last decade’s runaway IT successes *support people* (cell-phones, Internet, e-mail etc)
- Clever stand alone computer (Sony dog) struggle.
  cf a Sony dog with cuddly fur and puppy dog eyes.

Conclusion



- The brain is a *sophisticated information processor* (not “primitive”) for its demands
- Computers doing what people do could have *the same faults as people*
- People plus computers is the best of both worlds
  i.e. people + computers > people *or* computers
- *People are the senior partner*
  *i.e. h*uman-centred computing
- Goal: ***human-computer excellence***
  not computer excellence

More

- http://brianwhitworth.com/papers.html
- http://brianwhitworth.com/braincomputer.pdf
  Paper forthcoming in Paganini, M., 2007, Encyclopedia of Multimedia Technology and Networking

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