Human Computer Interaction & Human Information Processing Models

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Introduction

- HCI Development Process
- Human Information Processing
- Information Processing Models
  - Case Study I:
  - Are Experts’ Information Processing different from Novices?
  - Case Study II:
  - Are Females’ Information Processing different from Males?
  - Case Study III:
  - Is Information Processing in VR different from Non-VR?
- Conclusion

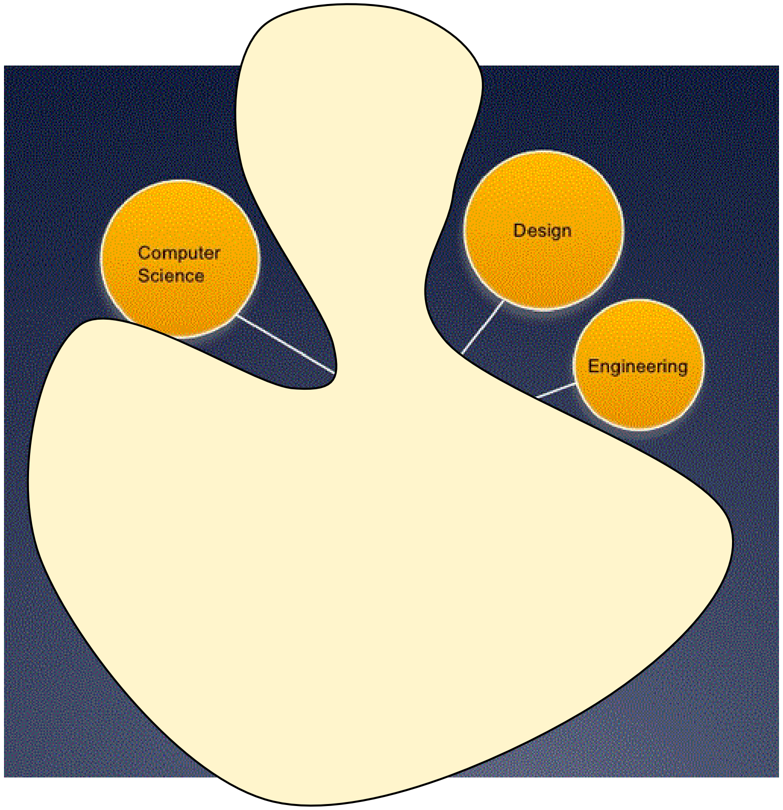
Human Computer Interaction

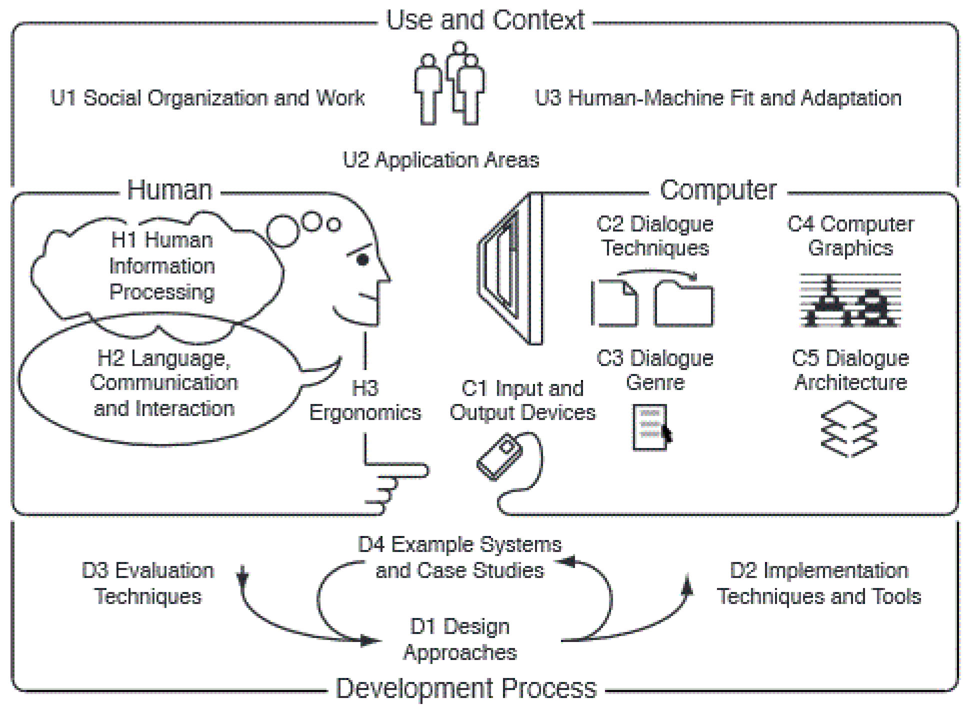
ACM SIG-CHI (2006)

HCI is a discipline concerned with the

- design,
- implementation
- and evaluation of interactive computing systems
- for human use and with the study of major phenomena surrounding them.
- HCI has **human** in its core but requires
- the **design of interaction** of
- human with computer technology.

HCI refers to the design and implementation of computer systems that people interact with.



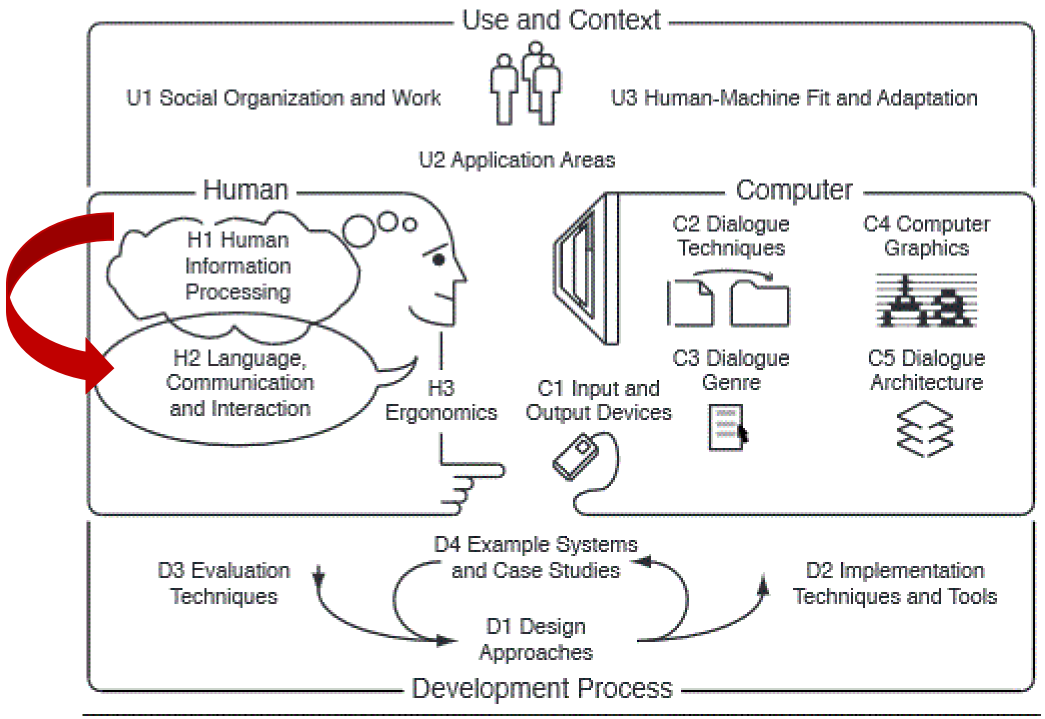


HCI (ACM-SIGCHI, 2006, http://old.sigchi.org/cdg/cdg2.html)

Characteristics of HCI
ACM SIG-CHI (2006)

- the **joint performance** of tasks by humans and machines;
- the **structure of communication** between human and machine;
- **human capabilities** to use machines (including the learnability of interfaces);
- **algorithms and programming** of the interface itself;
- **engineering** concerns that arise in designing and building interfaces;
- **the process** of specification, design, and implementation of interfaces; and design trade-offs.

HCI refers to the design and implementation of computer systems that people interact with.



HCI (ACM-SIGCHI, 2006, http://old.sigchi.org/cdg/cdg2.html)

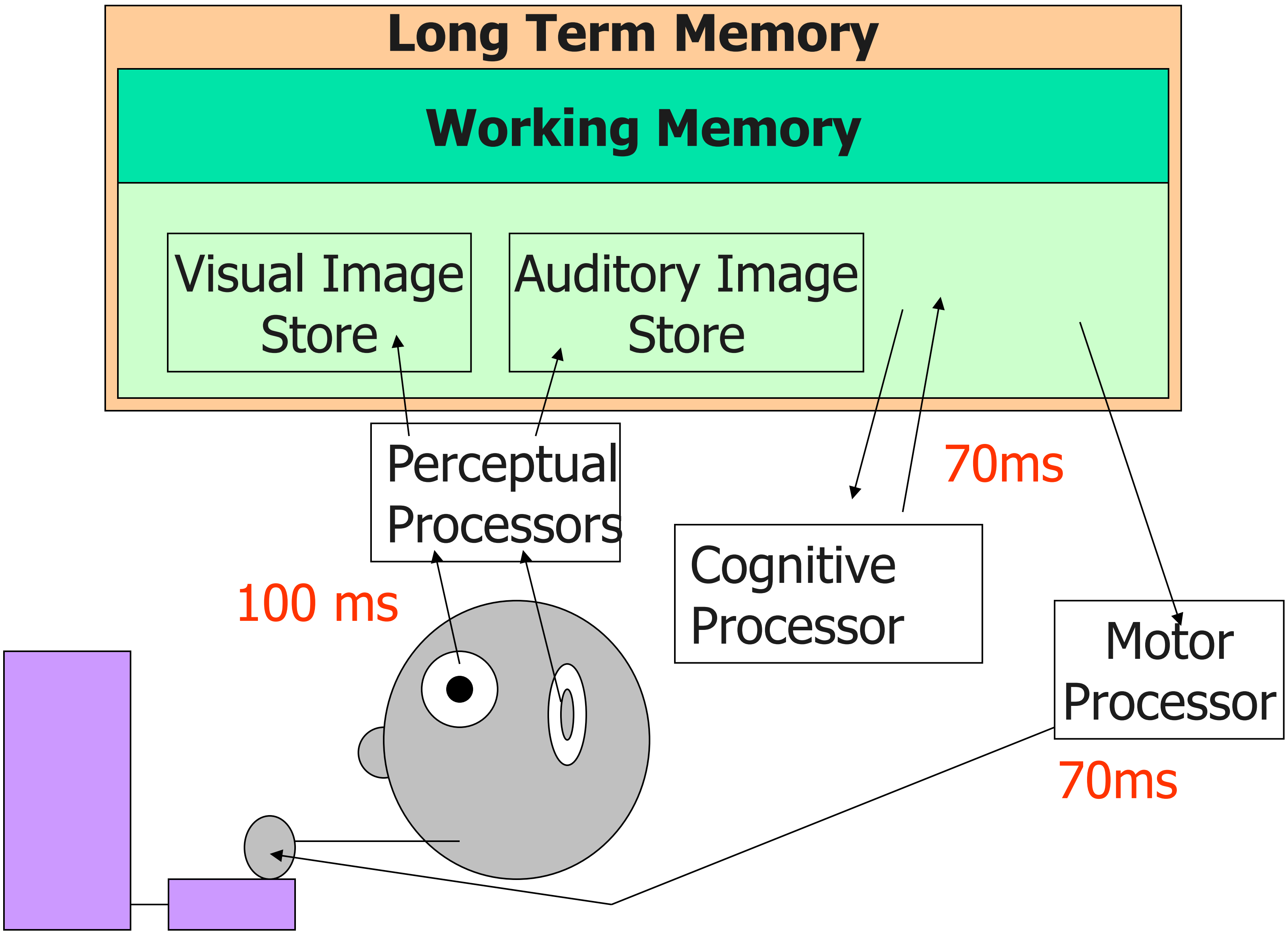
What do we need to know about **human** to design a display system?

- Input
  - Perceptual Systems
- Processing
  - Memories
  - Information Processes
- Output
  - Motor Systems
  - Speech

- Cycle times
- Decay Rates
- Storage Capacities
- Coding/Representation Schemes

- Both volatile and permanent memories
- Uses multiple representation schemes
- Has an attention and capacity component
- Has quantifiable cycle times
- Uses chunking and semantic recoding

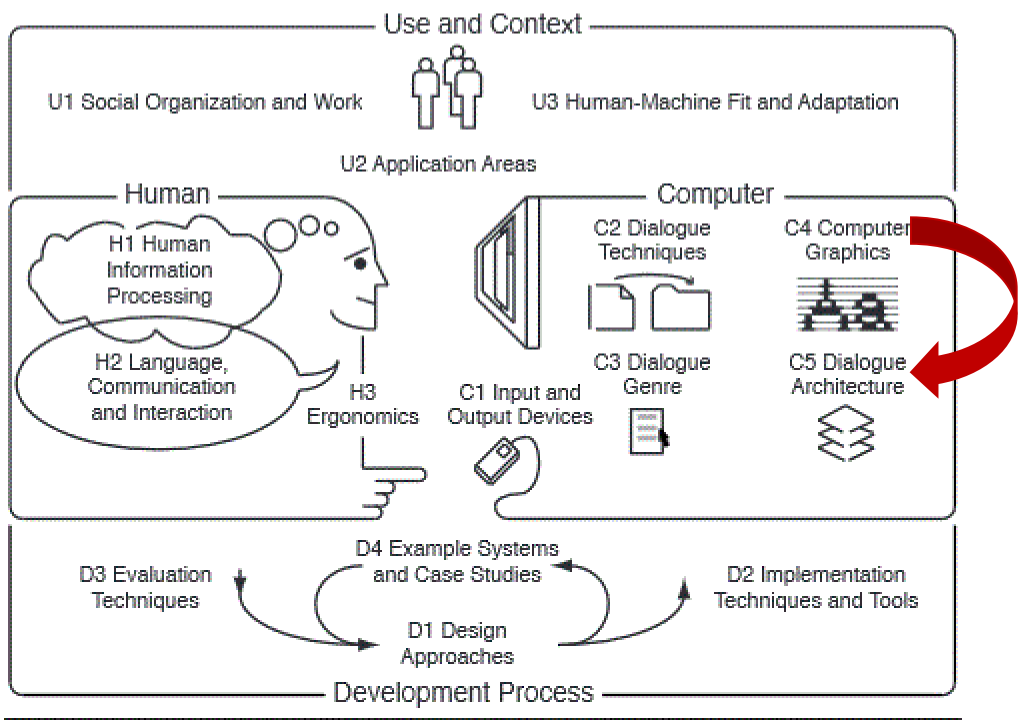
The Model Human Information Processor



Perceptual Processor

- The speed of the perceptual processor: ~100ms per cycle
  - Light blinks appearing within 100ms
    - look like a single brighter light
  - Light blinks in two locations within 100ms
    - look like motion of a single light
  - Auditory clicks occurring within 100ms
    - sound like one louder tone
  - Multiple taps occurring within 100ms
    - feel like one tap of greater pressure

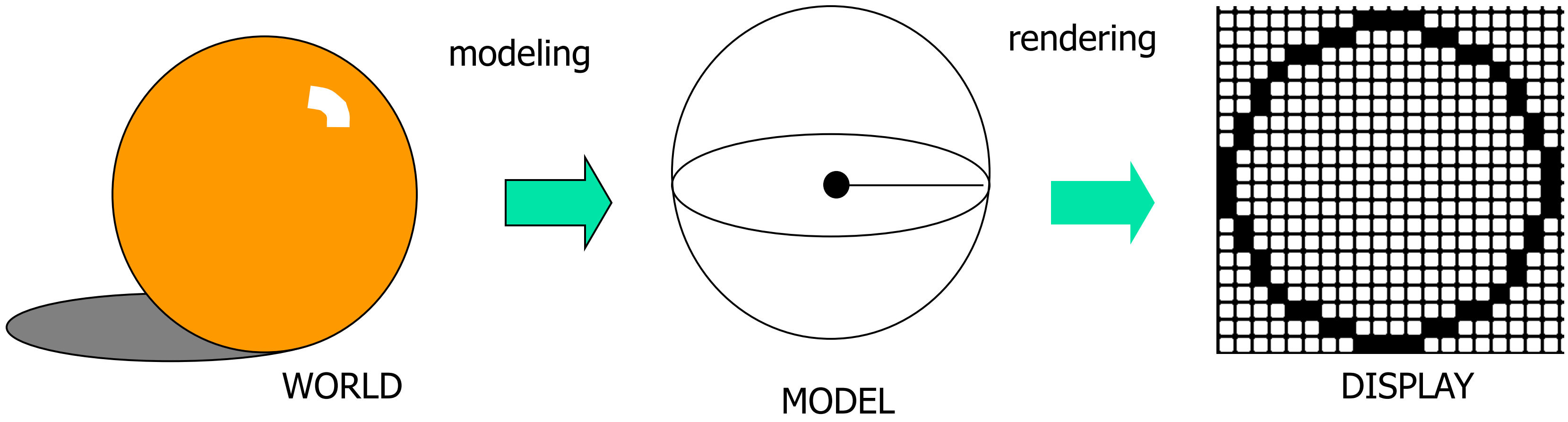
HCI



HCI (ACM-SIGCHI, 2006, http://old.sigchi.org/cdg/cdg2.html)

Perception of Computer Graphics

- Studies Computer Graphics
- "concerned with producing IMAGES (or animations) using a computer."



Raster Image & Pixel Value

- stored in a computer as an array of numerical values.

The array is called a **PIXEL MAP/ BITMAP**.

- Eye is unable to see the individual cells

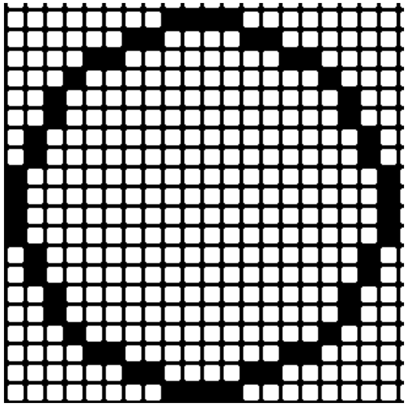
  Pixel:

  picture element

  Individual **cell**

8 bits/pixel=256 gray levels

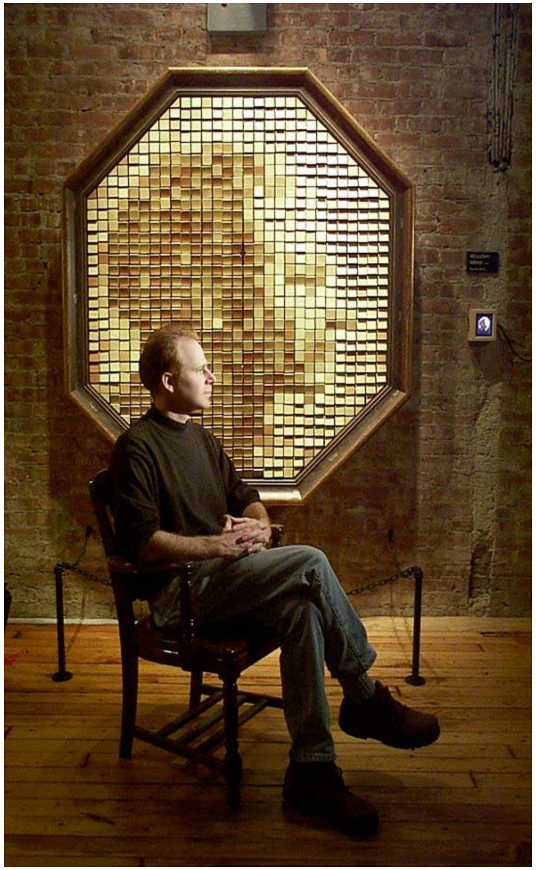
(01101110)



-one-bit-per-pixel image-

If there are only 2 pixel values,

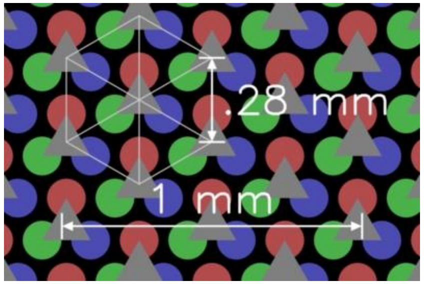
Then the raster image is called **bi-level**.

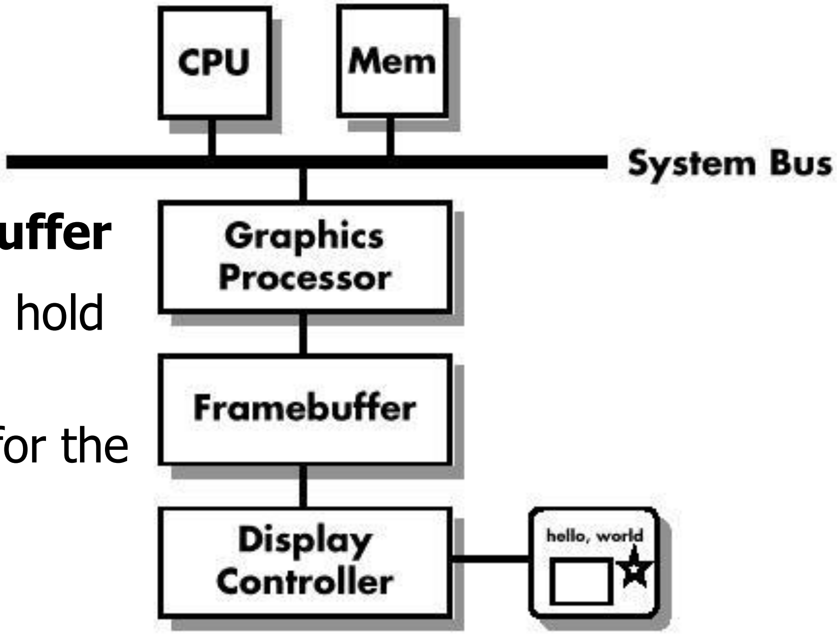


Each **pixel** has a ***pixel/colour value*** which describes how bright that pixel is, and/or what color it should be.

Raster Graphics System Architecture

- Each pixel in an image has a pixel/color value.
  - **Colour:** a combination of R,G,B light
    - Pixel value=(23,14,51) ordered triple written in the form (*r,g,b*)
    - Intensities of R,G,B
  - RGB
  - 0,1,1 =cyan (red off)
  - 1,0,1=magenta (green off)
  - 1,1,1= white
  - 0,0,0=black





•Raster displays are connected to a **frame buffer**

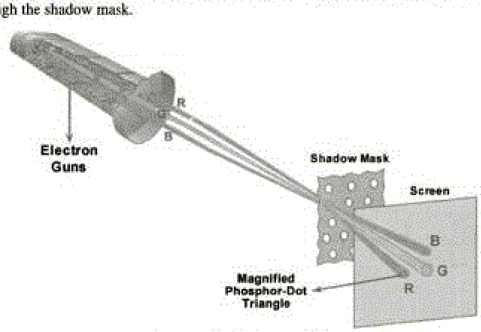
•A region of memory sufficiently large to hold all of the pixel values

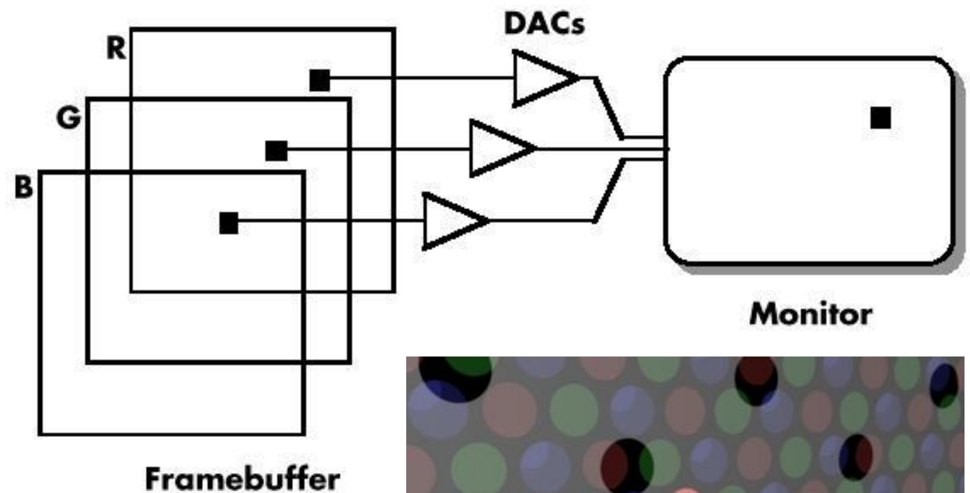
E.g., A graphics card holds the memory for the frame buffer

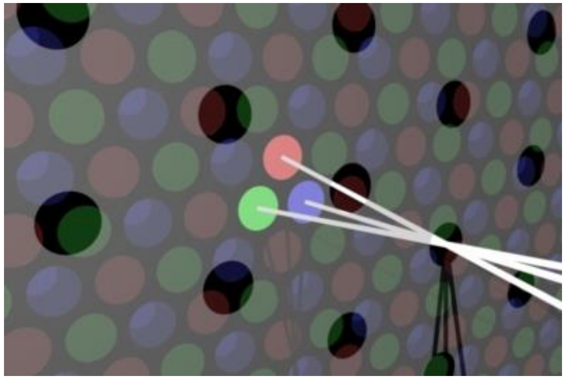
RGB Framebuffer

- In the **RGB** section, the CRT bias is controlled by the three **DAC** outputs: **Digital to Analog Converter**
  - RGB values are converted to actual voltage values (brightness)
  - fed to DAC using a pair of bits for each pixel (001101) –(for bluish green)
  - Light beams stimulate tiny phosphor dots at the proper address
  - RGB dots are so close to each other that humans see one composite dot
  - They quickly fade and must be refreshed (60 times per second) to prevent flickering

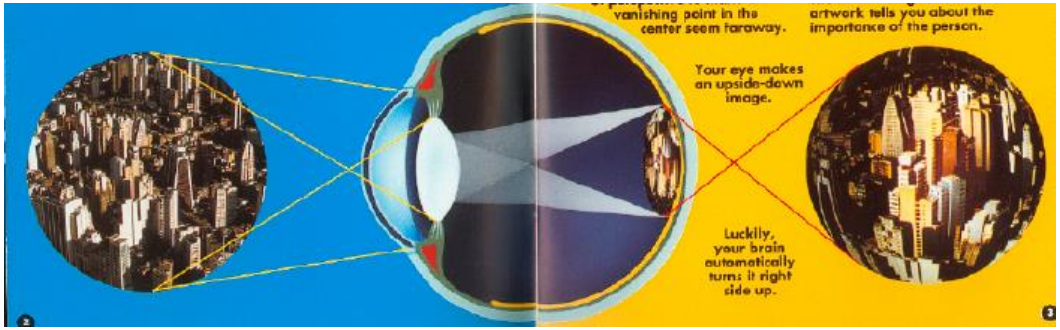
Shadow masking Shadow-mask method is commonly used in raster scan systems because they produce a much wider range of colours than the beam-penetration method. A shadow-mask CRT has three phosphor colour dots at each pixel position. One phosphor dot emits a red light, another emits a green light, and the third emits a blue light. This type of CRT has three electron guns, one for each colour dot, and a shadow-mask grid just behind the phosphor-coated screen. The three electron beams are deflected and focused as a group onto the shadow mask, which contains a series of holes aligned with the phosphor-dot patterns. When the three beams pass through a hole in the shadow mask, they activate a dot triangle, which appears as a small colour spot on the screen. The phosphor dots in the triangles are arranged so that each electron beam can activate only its corresponding colour dot when it passes through the shadow mask.

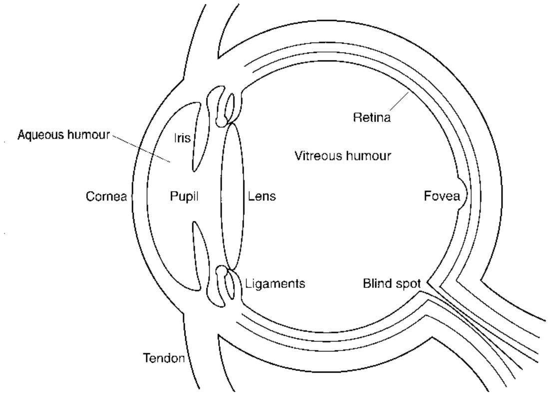






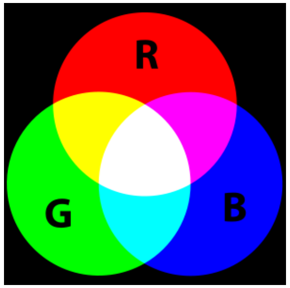
Human Vision I



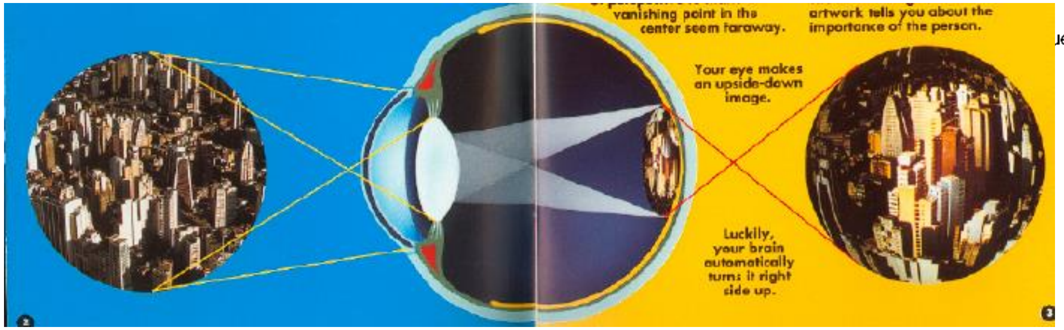


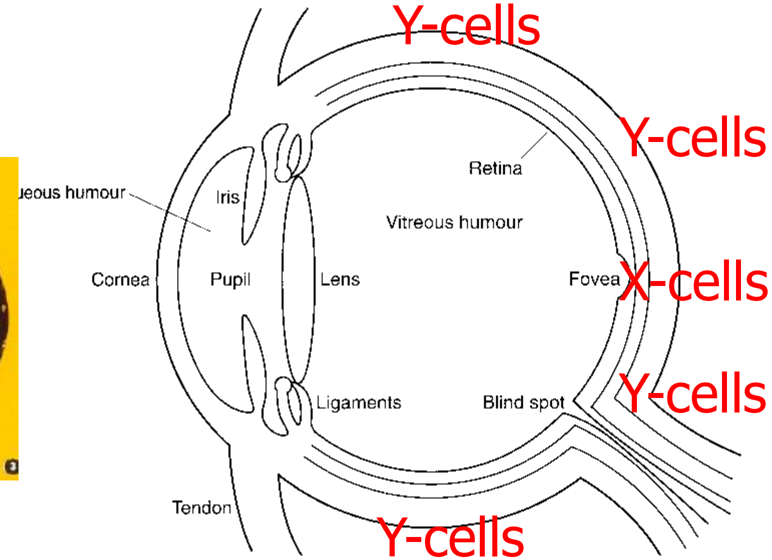
Retina contains two types of **photoreceptors**:

- Rods: are highly sensitive to light
  - Allow to see under low illumination
  - Are subject to light saturation
    - (temporary blindness when moving from dark room into sunlight)
  - +/- 12 million rods per eye, mainly situated near the edges of the retina
  - Rods dominate peripheral vision but less visual acuity
- Cones:
  - Allows colour vision under good light conditions
  - 3 different types of cones:
    - each sensitive to a different wavelength of light
  - +/- 6 million cones per eye, mainly concentrated on the **fovea**
    - When fixating on an object, object is displayed on fovea
  - Cones provide best visual acuity



Human Vision II

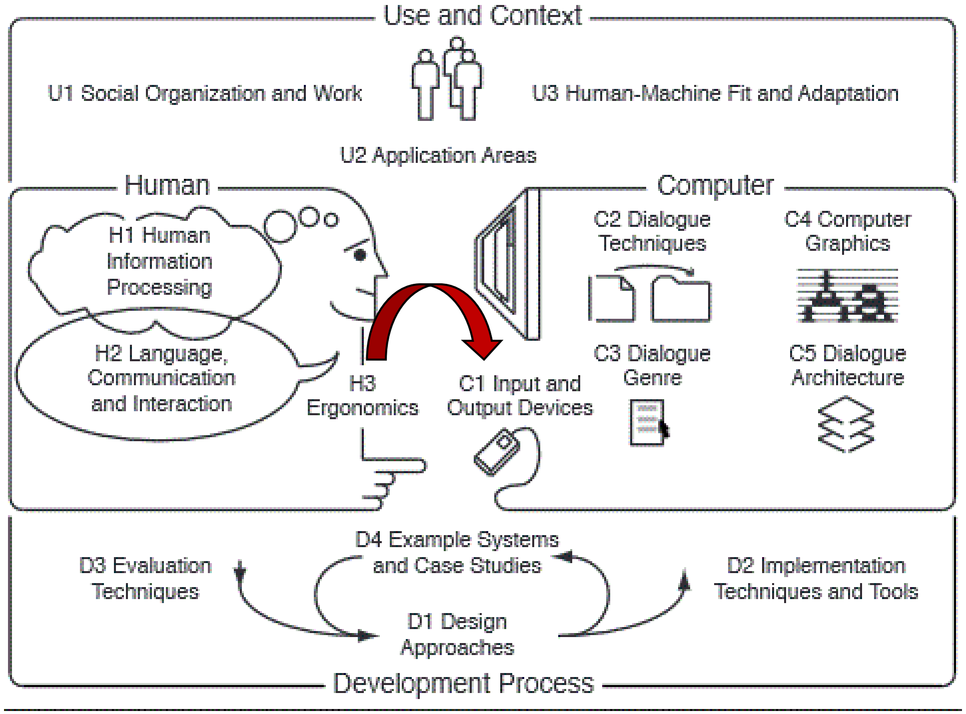




- Retina also has specialised **nerve cells**:
  - X-cells: responsible for detection of patterns
    - Concentrated in the fovea
    - Colour detection is good, when images are placed in front of the eye
  - Y-cells: responsible for detection of movement
    - Widely distributed

  <u>Consequence</u>:
    - No detection of changes in pattern in peripheral vision
    - But detection of movement in peripheral vision

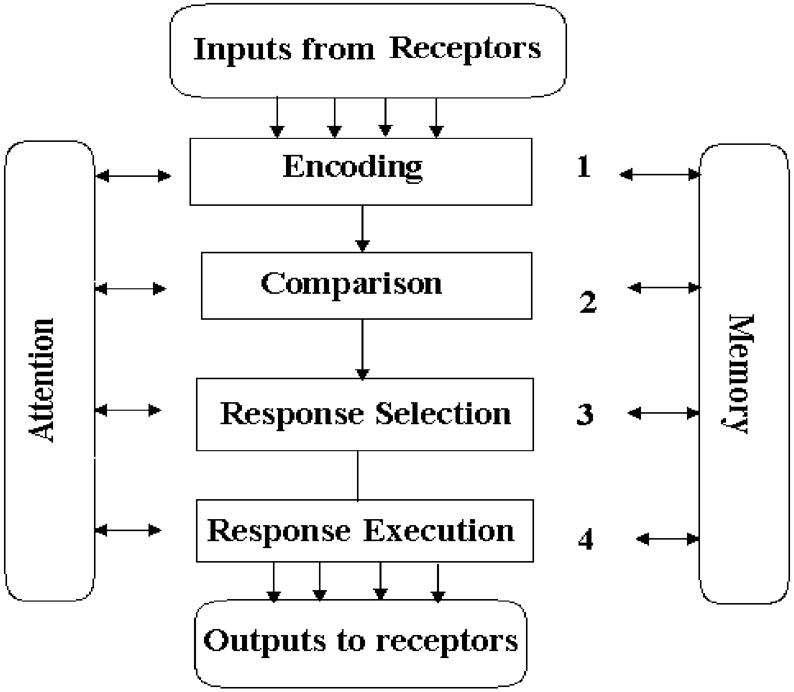
HCI



HCI (ACM-SIGCHI, 2006, http://old.sigchi.org/cdg/cdg2.html)

Stage Model of Human Information Processing

- Encoding –
  - information from environment into some internal representation
- Comparison –
  - internal representation with previous memorised representations
- Selection –
  - decision on appropriate response to encoded stimulus
- Execution –
  - organisation of response into action



The Stoop Effect

- Demonstrates automatic processing
- Shows how resources are limited

- In the next two slides –
- say the color of the letters
  - XYJFI – say "Red"
  - HQOP – say "Green"
- I'll time you

[redacted]

JCRTS

PJYTD

MCDRI

SQUR

PHENC

WFUB

YSCOP

YSVIE

SFTOW

OGSLEY

[redacted]

GREEN

BLUE

YELLOW

RED

YELLOW

GREEN

BLUE

GREEN

YELLOW

RED

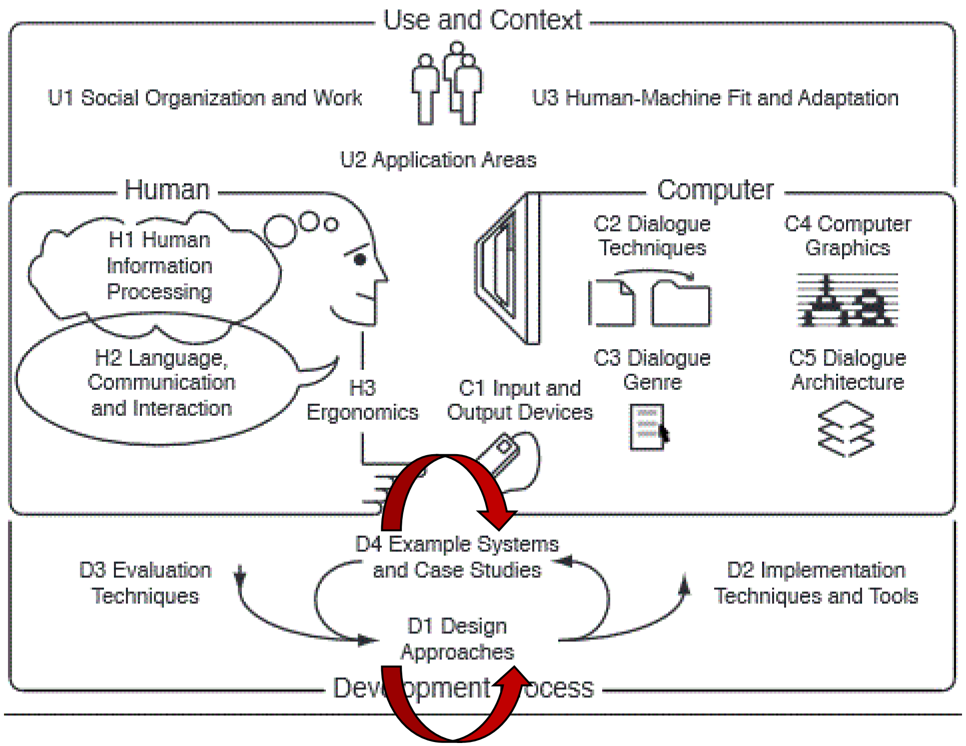
Putting It All Together

- Simple reaction time
  - 1 perceptual cycle + 1 cognitive cycle + 1 motor cycle
  - 100ms+70ms+70ms = 240ms
- Physical match
  - 1 perceptual cycle + 2 cognitive cycles + 1 motor cycle
  - 100ms+70ms+70ms+70ms = 310ms

CASE STUDIES

Human Information Processing Models

HCI



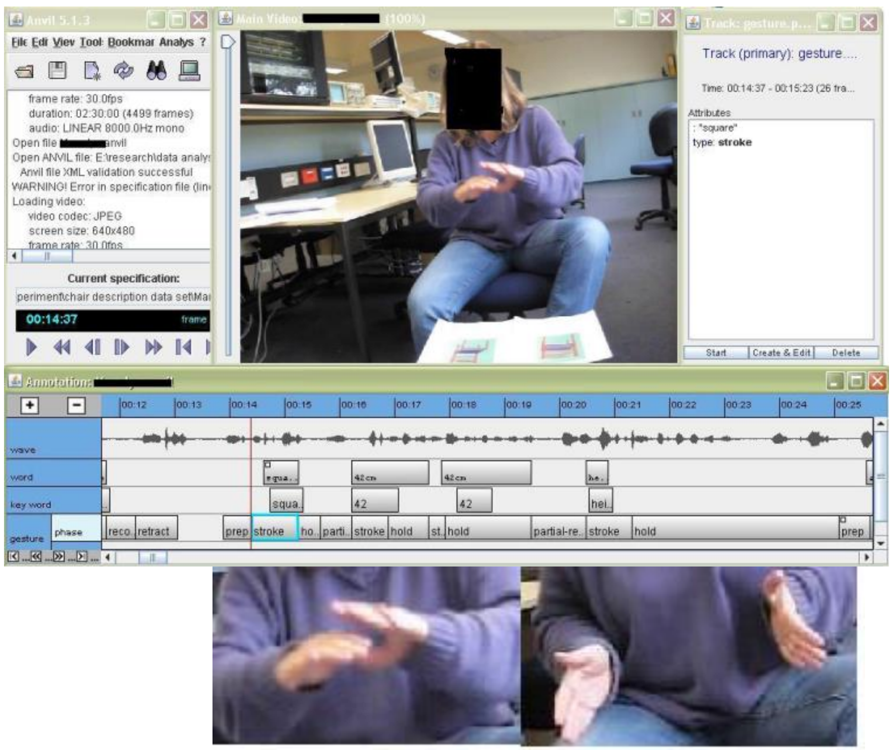
HCI (ACM-SIGCHI, 2006, http://old.sigchi.org/cdg/cdg2.html)

Protocol Analysis

- The primary empirical method for studying design

(Ericson and Simon, 1984)

- Design thinking is induced from the behaviour captured from the protocol including
  - **verbalisations (speech), drawings, and gestures**.
- **Critiques:**
  - PA does not address well the differences between internal and external representations (Chi, 1997)
  - There is a gap between the levels of description and humans' perception of what they are doing (Dorst, 1997)
  - Designer mentally constructs a design world (Schon, 1988, Trousee and Christiaans, 1996) beyond the entitites, attributes and relations, including **mental simulations** beyond the parameters of a state space (Schon, 1992, Dorst, 1997)


Anvil 5.1.3
Main Video: [redacted] (100%)
Track: gesture.p...
Track (primary): gesture....
Time: 00:14:37 - 00:15:23 (26 fra...
Attributes
: "square"
type: stroke
frame rate: 30.0fps
duration: 02:30:00 (4499 frames)
audio: LINEAR 8000.0Hz mono
Open file [redacted].anvil
Anvil file XML validation successful
Loading video:
video codec: JPEG
screen size: 640x480
Current specification:
00:14:37
Start
Create & Edit
Delete
Annotation: [redacted]
wave
word
key word
gesture
phase
reco.
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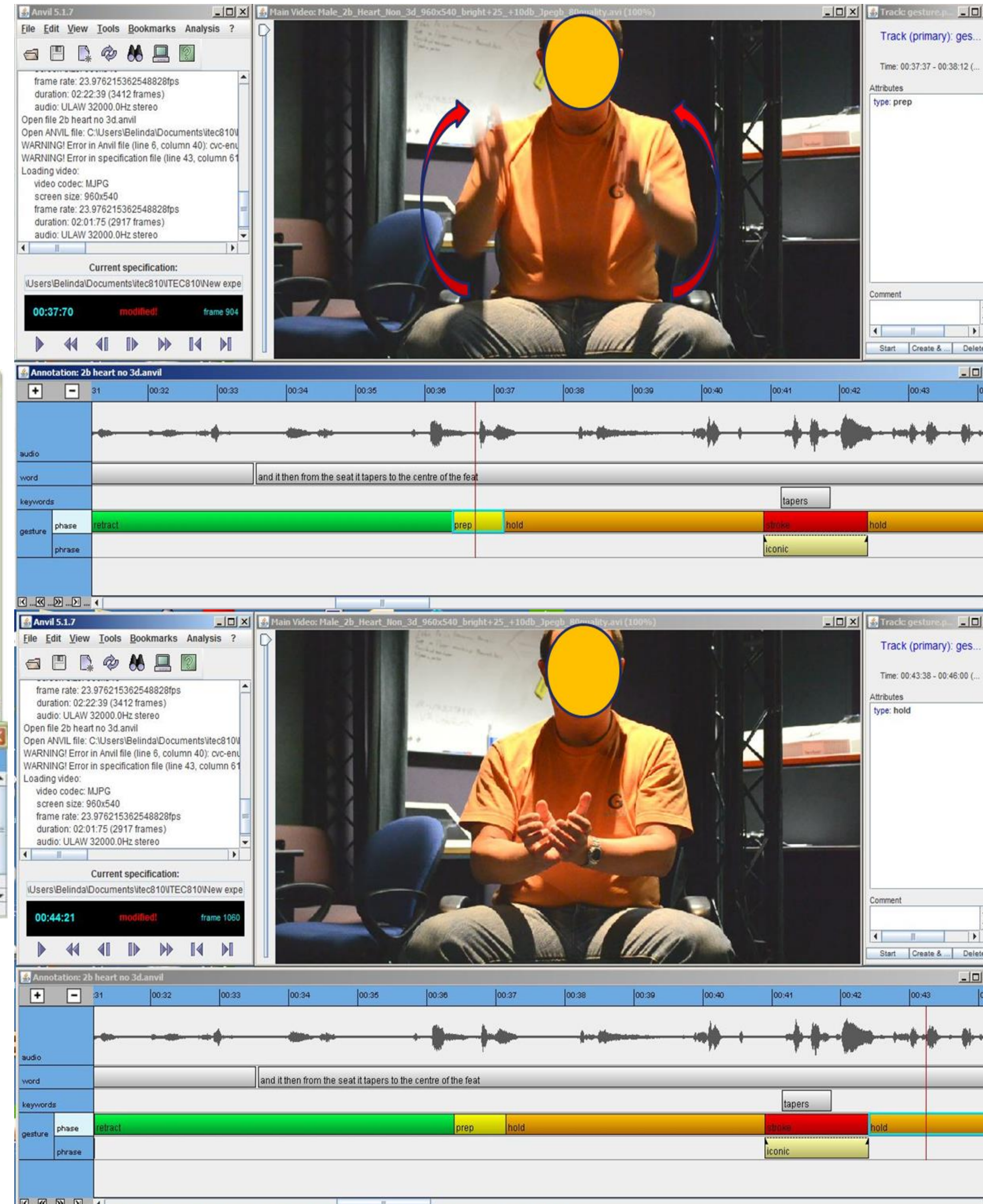
Anvil 5.1.7
File Edit View Tools Bookmarks Analysis ?
frame rate: 23.976215362548828fps
duration: 02:22:39 (3412 frames)
audio: ULAW 32000.0Hz stereo
Open file 2b heart no 3d.anvil
Loading video:
video codec: MJPG
screen size: 960x540
duration: 02:01:75 (2917 frames)
Current specification:
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00:37:70
modified!
frame 904
Track (primary): ges...
Time: 00:37:37 - 00:38:12 (...
Attributes
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audio
word
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retract
prep
hold
stroke
hold
iconic
00:44:21
modified!
frame 1060
Time: 00:43:38 - 00:46:00 (...
type: hold

Physical Actions

D-actions: drawing actions	M-actions: moves
Dc: create a new depiction	Moa: motion over an area
Drf: revise an old depiction	Mod: motion over a depiction
Dts: trace over the sketch	Mrf: move attending to relations or features
Dtd: trace over the sketch on a different sheet	Ma: move a sketch against the sheet beneath
Dsy: depict a symbol	Mut: motion to use tools
Dwo: write words	Mge: hand gestures

Perceptual Actions

P-actions: perceptual actions related to implicit spaces	P-actions: perceptual actions related to features	P-actions: perceptual actions related to relations
Psg: discover a space as a ground	Pfn: attend to the feature of a new depiction	Prn: create or attend to a new relation
Posg: discover an old space as a ground	Pof: attend to an old feature of a depiction	Prp: discover a spatial or organizational relation
	Pfp: discover a new feature of a new depiction	Por: mention or revisit a relation

Functional Actions

F-actions:Functional actions related to new functions	F-actions:Functional actions related to revisited functions	F-actions:Functional actions related to implementation
Fn: associate a new depiction, feature or relation with a new function	Fo: continual or revisited thought of a function	Fi: implementation of a previous concept in a new setting
Frei: reinterpretation of a function	Fop: revisited thought independent of depictions	
Fnp: conceiving of a new meaning independent of depictions		

Conceptual Actions

G-actions: Goals	Subcategories of G1 type goals:
G1: goals to introduce new functions	G1.1: based on the initial requirements
G2: goals to resolve problematic conflicts	G1.2: directed by the use of explicit knowledge or past cases (strategies)
G3: goals to apply introduced functions or arrangements in the current context	G1.3: extended from a previous goal
G4: repeated goals from a previous segment	G1.4: not supported by knowledge, given requirements or a previous goal

Retrospective Protocol Analysis

Segment no: 248	so I am going to have to segment this a little bit. Something has to be here and something back here. And I am not going to bisect the main space.				
Action type	index	class	Description (where, of what, among what?)	Dependency	
				index	On what
Drawing Dc	new	Circle 3			
Looking L1	old	Line 67			
Moves					
Perceptual Psg Prn1 Prn2	New New new	i-space l-relation g-relation	The rest space spatial rel (separate): the two spaces spatial rel (included): the new space is on the side of the building	New/ne w New/old	Dc, Psg Dc, L1
Functional					
Goals					

type	content	Source Seg/typ e	Trigger what?
Type 2 Type1.3	I am not going to bisect the main space of the building I am splitting the building on the side, not in the center	256	Type1.3 Prn1, Prn2

Case Study Example I:
Are Experts' Information Processing different from Novices?

- Analysis of design protocols of novice and expert designers, although based on a limited number of designers, have shown that there are **differences in the balance of cognitive actions** between the novice and the expert designers (Kavakli et al., 1999).
- The hypothesis:
  - the reason for the imbalance in cognitive activity between the novice and the expert designers in the conceptual design process is the **rate of information processing** driven by their relative experience in drawing production and sketch recognition.

Design Cognition

- Refers to the study of
- **Human Information Processing** in design (Eastman, 2001)
- **Design** was initially studied as
  - a type of problem solving (Newell, 1969)
  - a search space of possible solutions (Eastman, 1970)
    - Different from other forms of problem solving because it is ill-structured (Simon, 1973, and Akin 1986)
  - Researchers started to work on **design behaviour** and how mental resources were allocated within the structure of design tasks (Purcell & Gero, 1996, Akin & Lin, 1996).

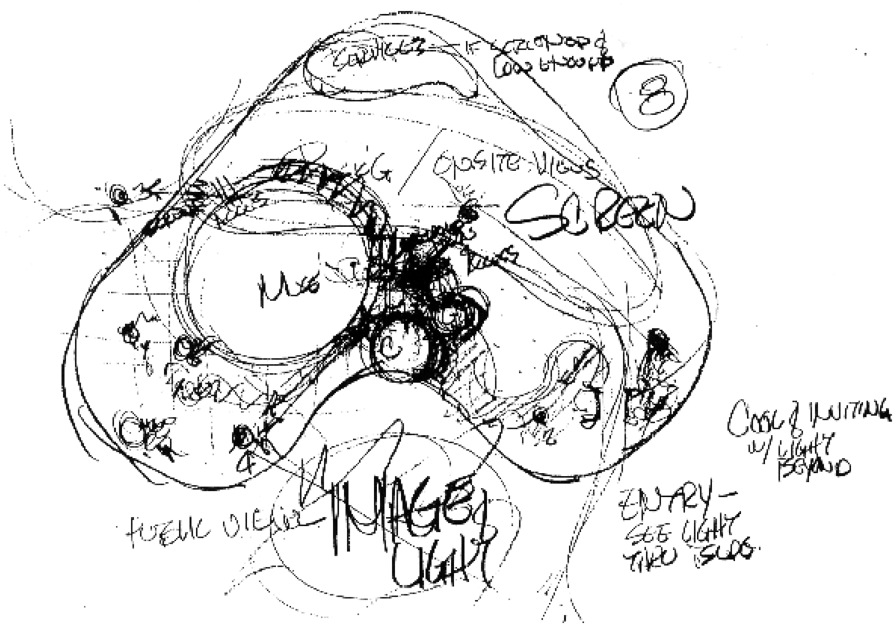
Structure of Design Information

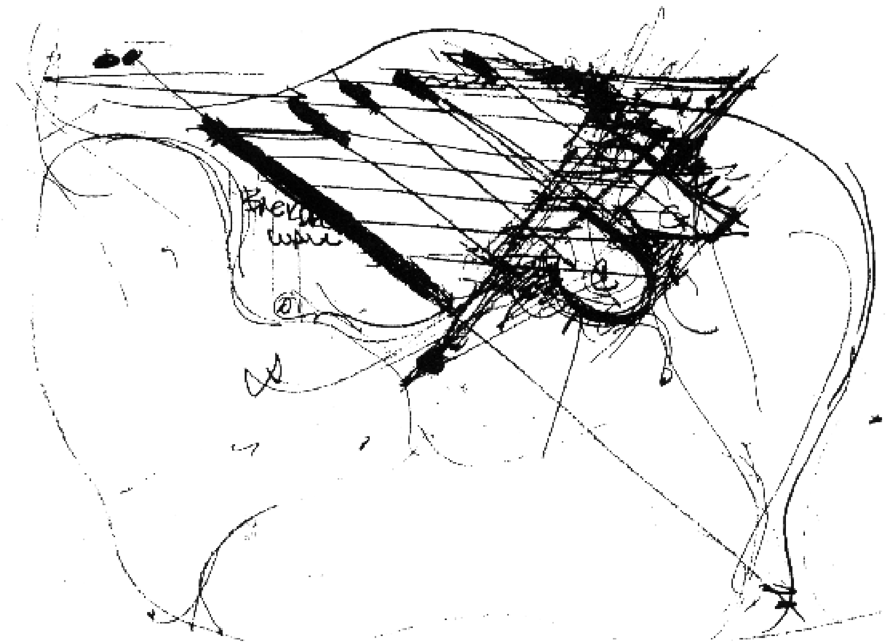
- **SBF** method (Takeda, Tomiyama et al, Goel, 1996) to distiguish between
  - Structure (form & geometry) of the solution
  - Behaviour (measurable performances into which the functions are translated)
  - Functions (general objectives, goals)
- Components, **features or attributes** are identified from the general **goals** (Akin, 1978).
- Mental imagery and knowledge representation are the foundations for better understanding the education of designers (Eastman, 2001).

Design protocols

- **Differences in Cognitive activity:**
  - the expert : 2,916 actions and 348 segments,
  - the novice: 1,027 actions and 122 segments.
- The expert's design protocol is **2.84** times as rich as the novice's in terms of actions.
- There were **2.85** times as many segments in the expert designer's session as in the novice's.
- **Differences in Productivity: (~3.25-3.5 times)**
  - the expert: **13 pages** and 7 design alternatives
  - the novice: **4 pages** and 2 design alternatives.
- The statistical results (chi squared test, $\chi^2 > c$, at 0.5% significance level):
- there are differences between the expert's and the novice's cognitive actions.
  - The strongest differences statistically are in **perceptual actions and goals.**

Sketches I

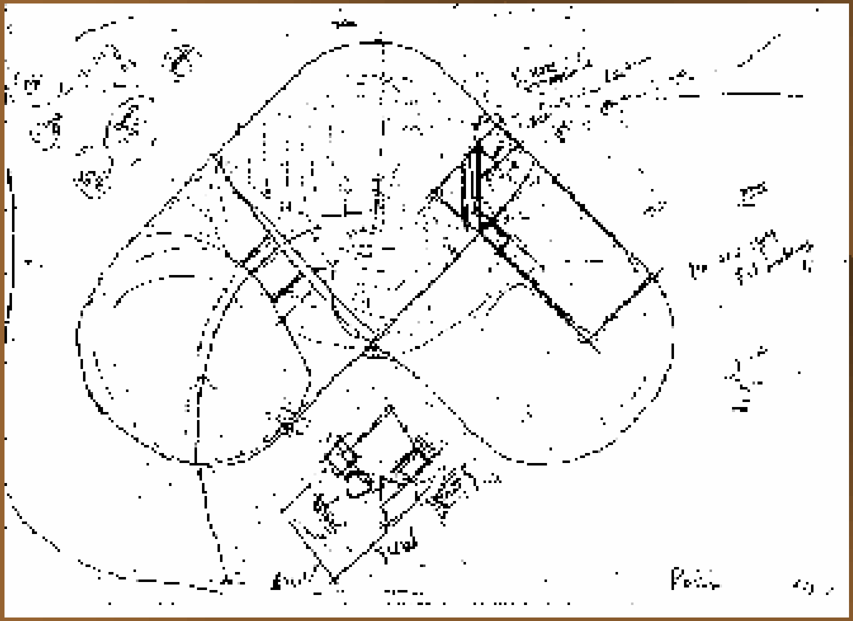


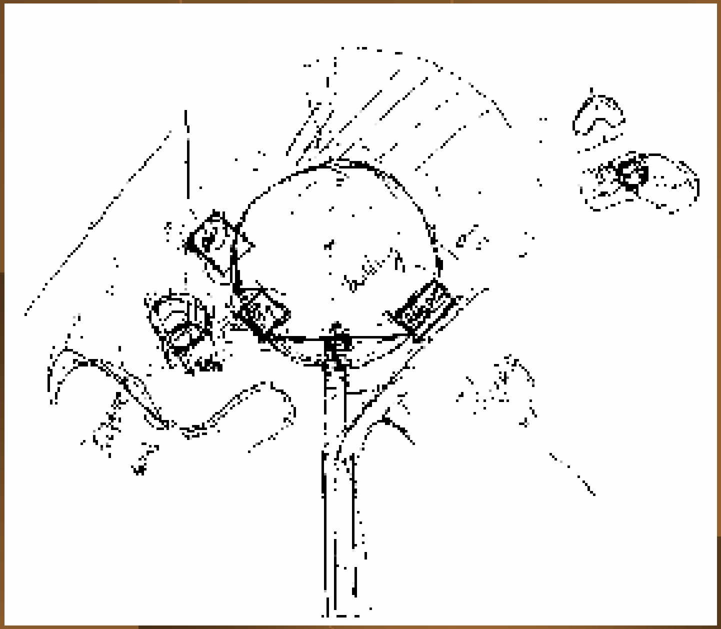


What are the cognitive actions corresponding to each design action?

Key Centre of Design Computing,
University of Sydney

Sketches II





ABLE 5. Action Categories.

Results

TABLE 5. Action Categories.

ACTIONS	Expert (%)	Novice (%)
Physical	38	45
Drawing	15	23
Looking	21	19
Moves	2	3
Functional	30	21
Perceptual	23	24
Conceptual	10	10
Goals	10	10

TABLE 6. Drawing Actions.

DRAWING ACTIONS	Expert (%)	Novice (%)
Depicting	54	62
Drawings (Dc)	40	42
Symbols (Dsy)	14	20
Modifying	31	23
Revising (Drf)	13	5
Overtracing (Dts)	11	15
Copying (Dtd)	7	3
Writing (Dwo)	15	15

TABLE 7. Functional Actions.

FUNCTIONAL ACTIONS	Expert (%)	Novice (%)
Revisited functions	42	33
Continual or revisited thought of a function (Fo)	41	32
Continual or revisited thought independent of depictions (Fop)	1	1
New functions	42	45
Associate a new depiction, feature or relation with a function (Fn)	30	32
Reinterpretation of a function (Frei)	11	11
Conceiving of a new meaning independent of depictions (Fnp)	1	2
Implementations	16	23
Implementation of a previous concept in a new setting (Fi)	16	23

TABLE 8. Perceptual Actions.

PERCEPTUAL ACTIONS	Expert (%)	Novice (%)
Implicit spaces	14	34
Discovery of a new space as a ground (Psg)	5	12
Discovery of an old space as a ground (Posg)	9	22
Features	22	25
Attention to the feature of a new depiction (Pfn)	9	11
Discovery of a feature of a new depiction (Pfp)	6	6
Attention to an old feature of a depiction (Pof)	7	8
Relations	65	41
Discovery of a spatial or organizational relation (Prp)	17	10
Creation of or attention to a relation (Prn)	28	21
Mention of a relation (Por)	20	10

TABLE 9. Goals.

GOALS	Expert (%)	Novice (%)
Goals to introduce new functions (G1)	62	75
based on the initial requirements (G1.1)	11	25
directed by the use of explicit knowledge or past cases (G1.2)	16	19
extended from a previous goal (G1.3)	17	7
not supported by knowledge, requirements or goals (G1.4)	18	24
Goals to resolve problematic conflicts (G2)	8	13
Goals to apply introduced functions in the current context (G3)	20	4
Goals repeated from a previous segment (G4)	11	8

Correlation Results in pages

Table 5. *Correlation coefficients of cognitive actions in pages*

expert-page	*Drawing*	*Looking*	*Perceptual*	*Functional*	*Goals*	*Moves*
Drawing	1.000					
Looking	0.864	1.000				
Perceptual	0.998	0.909	1.000			
Functional	0.998	0.951	0.998	1.000		
Goals	0.995	0.829	0.996	0.996	1.000	
Moves	0.975	0.635	0.968	0.978	0.975	1.000

novice-page	*Drawing*	*Looking*	*Perceptual*	*Functional*	*Goals*	*Moves*
Drawing	1.000					
Looking	0.968	1.000				
Perceptual	0.786	0.898	1.000			
Functional	0.744	0.828	0.670	1.000		
Goals	0.655	0.806	0.981	0.617	1.000	
Moves	0.951	0.862	0.680	0.504	0.529	1.000

Sketching as Mental imagery processing

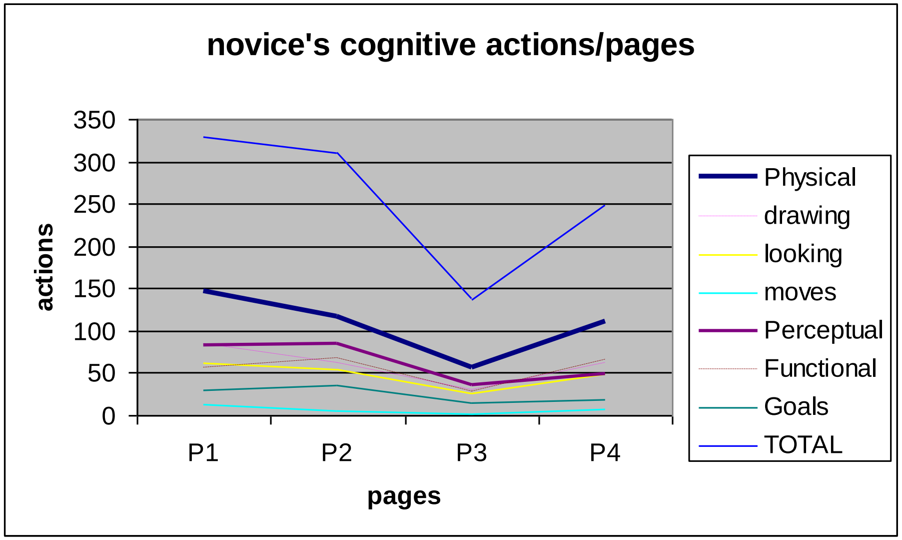
  - Imagery and perception share many of the same types of neural mechanisms (Farah, 1988, Finke, 1980, 1989) and all characterizations of imagery rest on its resemblance to perception (Kosslyn, 1995).
  - Given the apparent parallels between the uses of imagery and those of like-modality perception (Osherson, 1995), it is not surprising that imagery apparently shares some of the same processing mechanisms used in recognition (Finke and Shepard, 1986, Kosslyn, 1995).
  - **Modality-specific interference (Osherson, 1995):**
  - **Multisensory integration, also known as multimodal integration, is the study of how information from the different sensory modalities, such as sight, sound, touch, smell, self-motion and taste, may be integrated by the nervous system**
- Imagery and perception can often be considered functionally equivalent processes (Finke, 1980, Shepard, 1984).

FOR MORE INFO...

Kavakli, M., Gero, J.S., 2001: Sketching as mental imagery processing, *Design Studies*, Vol 22/4, 347-364, July, ISSN 0142-694X (118 citations) [ERA A*] **Impact Factor:** 0.983

Table A Correlation coefficients of cognitive actions across design depictions (Dc)

	Expert	*Novice*
Drf	0.03	0.34
Dts	0.58	0.98
Dtd	0.25	-0.75
Dsy	0.35	0.74
Dwo	0.32	0.75
L	0.81	0.99
Psg	-0.17	0.71
Posg	0.27	0.64
Pfn	0.45	0.66
Pfp	0.15	0.90
Pof	0.53	-0.27
Prp	0.74	0.98
Prn	0.70	0.28
Por	0.57	0.92
Fn	0.75	0.86
Frei	0.20	0.21
Fe	0.83	0.51
Fnp	0.31	0.60
Fop	0.68	0.21
Fi	0.24	0.26
G1-1	0.45	-0.29
G1-2	0.67	0.73
G1-3	0.44	0.21
G1-4	0.14	0.85
G2	0.34	0.38
G3	0.21	0.71
G4	0.19	0.58
Ma	0.31	-0.29
Mod	0.07	0.60
Moa	0.69	0.89



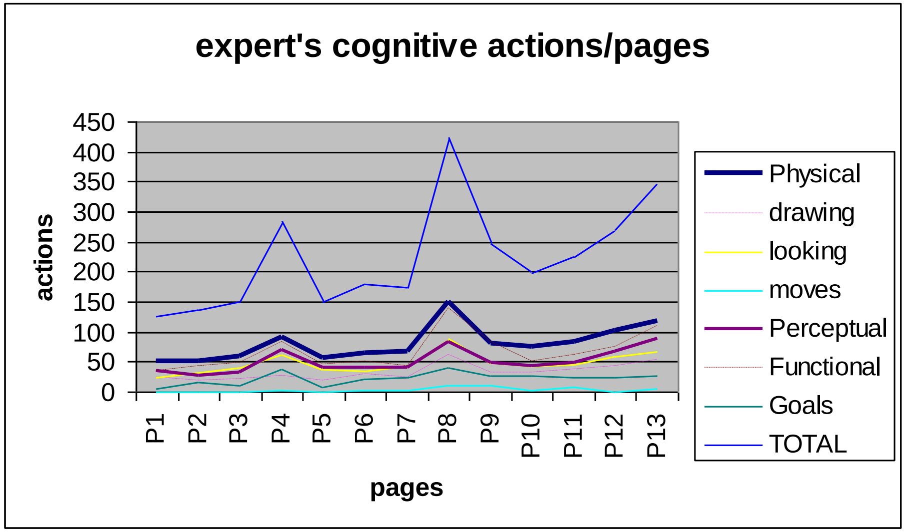


Table 6. *Primary Concurrent Actions Correlated with Depicting Drawings (Dc)*

Novice	Expert	Code	Cognitive Action	Novice	Expert
+	+	L	Looking at old depictions	0.99	0.81
+	~	Dts	Overtracing	0.98	0.58
+	~	Por	Mention of a relation	0.92	0.57
+	+	Prp	Discovery of a spatial or an organizational relation	0.98	0.74
0	+	Prn	Creation of a new relation	0.28	0.70
~	+	Fo	Continual or revisited thought of a function	0.51	0.83
+	+	Fn	Association of a new depiction with a function	0.86	0.75
+	~	Moa	Motion over an area	0.89	0.69
+	~	G1-2	Goals directed by the use of explicit knowledge or past cases	0.73	0.67
+	0	Dwo	Writing	0.75	0.32
+	0	Dsy	Depicting symbols	0.74	0.35
-	0	Dtd	Tracing over the sketch on a different sheet	-0.75	0.25
+	0	Psg	Discovery of a new space as a ground	0.71	-0.17
+	0	Pfp	Discovery of a new feature of a new depiction	0.90	0.15
+	0	G1-4	Goals not supported by knowledge, requirements or goals	0.85	0.14
+	0	G3	Goals to apply introduced functions in the current context	0.71	0.21

(+)strong positive correlation (-)strong negative correlation	(~) substantial correlation (0) weak/no correlation

13/5=2.6

Table 7. *Secondary Concurrent Actions Correlated with Depicting Drawings (Dc)*

Action Code	**Novice**	**Expert**	**Novice's Secondary Concurrent Actions**	**Expert's Secondary Concurrent Actions**
L	+	+	Dc, Dts, -Dtd, Dwo, Psg, Posg, Pfp, Prp, Por, Fn, G1-2, G1-4, G3, Moa	Dc, Prp, Por, Fo
Dts	+	~	Dc, Pfn, -Prn, Fi, G1-1, Ma	Dtd
Por	+	~	Dc, Dts, -Dtd, Dwo, L, Posg, Prp, Fo, G1.2, G1.4, G2, G3	L, Prp, Fo
Prp	+	+	Dc, Dts, -Dtd, Dwo, L, Psg, Posg, Pfp, Por, Fn, G1-2, G1-4, G3, Moa	Dc, L, Pof, Por, Fo
Prn	0	+		Dc
Fo	~	+	-Dtd, Pfn, Por, Frei, Fop, G1-3, G1-4, G2, G3	Dc, L, Prp, Por
Fn	+	+	Dc, Dsy, L, Psg, Pfp, Prp, -Pof	Dc
Moa	+	~	Dc, Dts, Dsy, L, Psg, Pfp, Prp, Fn, Fnp, Mod	Dc, Fn, Fop, G1-2
G1-2	+	~	Dc, Dts, Dwo, L, Psg, Posg, Prp, Prn, Por, -G1.1, G1.4, G4, -Ma	Moa
Dwo	+	0	Dc, Dts, L, Posg, Prp, Prn, Por, G1-2, G1-4, G2, G3	
Dsy	+	0	Dc, Psg, Pfp, -Pof, Fn, Fnp, Mod, Moa	
Dtd	-	0	-Dc, -Dts, -L, -Pfn, -Prp, -Por, -Fo, -Fi, -G1-4, -G3	
Psg	+	0	Dc, Dts, Dsy, L, Pfp, Prp, Fn, Fnp, -G1.1, G1-2, G4,-Ma, Mod, Moa	
Pfp	+	0	Dc, Dts, Dsy, L, Psg, Fo, Fi, G3	
G1-4	+	0	Dc, Dts, -Dtd, Dwo, L, Posg, Prp, Por, Fo, G1-2, G2, G3	
G3	+	0	Dc, Dts, -Dtd, Dwo, L, Posg, Pfn, Prp, Por, Frei, Fo, Fop, G1-3, G1-4, G2	

(+) positive strong correlation (-) negative strong correlation	(~) substantial correlation (0) weak/no correlation	**15/6=2.5**

Concurrent Cognitive Processing I

- **Primary concurrent actions:**
  - the cognitive actions that directly correlate with depicting drawings.
- **Secondary concurrent actions:**
  - the cognitive actions that highly correlate with the primary actions.

- (constant-4) **Strong correlations** in both design protocols:
- between **depicting drawings** (Dc) and
- **looking actions** (L),
- **discovery of a relation** (Prp),
- **association of a new depiction with a function** (Fn).

- (4+2): In addition to the constant-4, in the expert's design protocol:
- **creation of a new relation** (Prn)
- **revisited thought of a function** (Fo)
- there are weak correlations in these categories in the novice's design protocol.

FOR MORE INFO...

•Kavakli, M., Gero, J.S., 2002: The structure of concurrent cognitive actions: A case study on novice and expert designers, *Design Studies*, Vol 23/1, 25-40, January ISSN 0142-694X (140 citations) [ERA A*] **Impact Factor:** 0.983

Concurrent Cognitive Processing II

- There are **many actions that occur together** in the novice's protocol in parallel to depicting drawings.

- (4+11) In addition to the constant-4, **in the novice's protocol**:
  - overtracing (Dts),
  - writing (Dwo),
  - depicting symbols (Dsy),
  - discovery of a space as a ground (Psg),
  - discovery of a new feature of a new depiction (Pfp),
  - mention of a relation (Por),
  - motion over an area (Moa),
  - goals directed by the use of explicit knowledge or past cases (G1-2),
  - goals not supported by knowledge, requirements or previous goals (G1-4),
  - and goals to apply previously introduced functions in the current context (G3).
  - Tracing over the sketch on a different sheet is also strongly negative correlated with depicting drawings (Dc) for the novice.

Findings

- The experience and use of mental imagery cannot be conceived of as an independent, unitary facet of human cognition. Rather, it is associated with an array of related psychological phenomena (Slack, 1984).
- If the cognitive activities slow down at some point, this may be because of not only one activity, but also the other activities have different roles that proceed together.
  - There is a wide range of correlations in the performance of the tasks. If the novice's image generation is slow in the conceptual design process, this may be due to the cognitive activity slowing down.
  - In this case, we should look for its reason in the parallel processing of cognitive actions, rather than only in a certain group of cognitive actions.
- We have found evidence of the **coexistence of certain types of cognitive actions** in cognitive processes.
- We have also found **clues for structural organization** and systematic expansion in the expert's cognitive activity as opposed to the exhaustive search in the novice's.

Findings II

- There is a **considerable difference in the speed and rate of cognitive actions**:
- The speed of the cognitive processes in the expert's design protocol is much higher, and the rate of the cognitive segments and actions in the expert's design protocol increases on pages produced, while the novice's cognitive actions decrease.
- We have provided evidence that many cognitive actions coexist in the novice's design protocol in parallel to depicting drawings.
  - The expert's cognitive activity is based on a tree structure including a small group of concurrent actions in each branch (up to 5 in the primary and up to 6 in the secondary levels of cognitive processing).
  - However, in the novice's protocol, cognitive performance has been divided into many groups of concurrent actions with a tree structure including many concurrent actions in each branch with up to 13 in the primary and up to 16 in the secondary levels.
- The novice deals with 2.6 times as many concurrent actions as the expert. Whereas, the expert seems to have control of his cognitive activity and governs his performance in a more efficient way than the novice, because his cognitive actions are well organized and clearly structured.

Findings III

- The structural organization in the expert's concurrent cognitive actions may be the reason for the expert's relatively high performance compared to the novice's.
- While the expert’s highly focused attention might play a major role in his higher performance and productivity, the novice's widely distributed and defocused attention might play a major role in the higher rates of certain types of discoveries, by making remote associations available.
- This raises a question: may this unstructuredness in cognitive activity accidentally lead to certain type of discoveries?
  - In this case, can we talk about the positive affect of unstructuredness on discoveries, while it may also be the cause for the drop in the performance?
- **The structuredness in cognitive activity may govern the performance** in design process, while the unstructuredness may support the occurrence of certain type of discoveries, making remote associations accessible.
- This may explain the novice’s success in creating **novelty** and the experts’ success in **performance** called expertise.

Conclusion

We analyzed cognitive actions of designers using the retrospective protocol analysis method and found evidence of coexistence of certain types of cognitive actions in both novice and expert designers' protocols. The main difference between the two designers' protocols is the structure of concurrent cognitive actions. While the expert's cognitive actions are clearly organized and structured, there are many concurrent actions that are hard to categorize in the novice's protocol. We also found that the expert's cognitive activity and productivity in the design process were three times as high as the novice's.

Structured and organized acts govern performance in the design process.

If so,

how can we optimise cognitive processing and cognitive load?

Thank you!

- **We are all looking for an answer but in fact what drives us is the question**.
  - Future isn't written. It is designed.
- Questions?
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