4M21 Software Engineering and Design
Human-Computer Interaction

Lecture 2/8

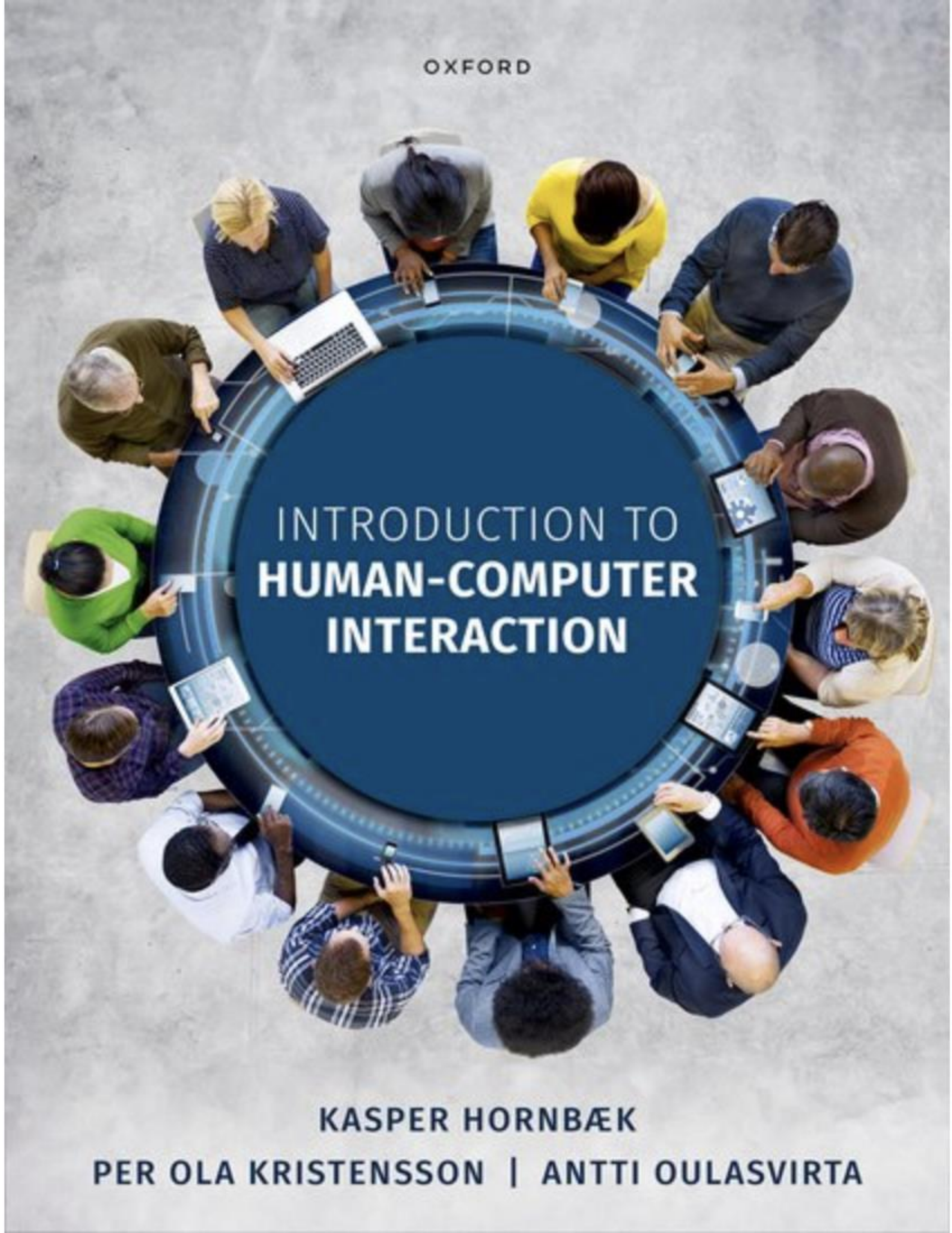
Professor Per Ola Kristensson

Department of Engineering

University of Cambridge

 Slides based on the textbook: Hornbaek, K., Kristensson, P.O. and Oulasvirta, A. 2025. *Introduction to Human-Computer Interaction*. Oxford University Press.

https://global.oup.com/academic/product/introduction-to-human-computer-interaction-9780192864543?cc=gb&lang=en&



Understanding People

Two scenarios

Perception: The two situations differ in terms of what users must be able to perceive. During driving, the user shares visual attention between the computer and the driving environment, the latter which is dynamically changing.

Two scenarios

Motor control: Many games require not only fast reflexes, but also the ability to intercept a fast-moving target that can be small and move erratically. Using a mobile device for non-gaming purposes mostly involves static targets selected with a very different input device, such as a touchscreen.

Two scenarios

Thinking: The gamer must keep track of several events, such as the current status of an enemy player in order to choose the next action. In contrast, selecting options from a mobile display is based on recognition of the icons and labels that most likely to lead to the target state.

Two scenarios

Needs: What kinds of desires and risks are associated with the two situations? Do people play games for different reasons from those they use social media? Not necessarily, as there are only a few basic psychological needs that can be pursued via both activities.

Two scenarios

Experience: Immersion in a virtual world is a desired quality in gaming, but not in mobile interaction, which places a greater emphasis on instrumental experiences, such as being satisfied in being able to complete tasks.

Two scenarios

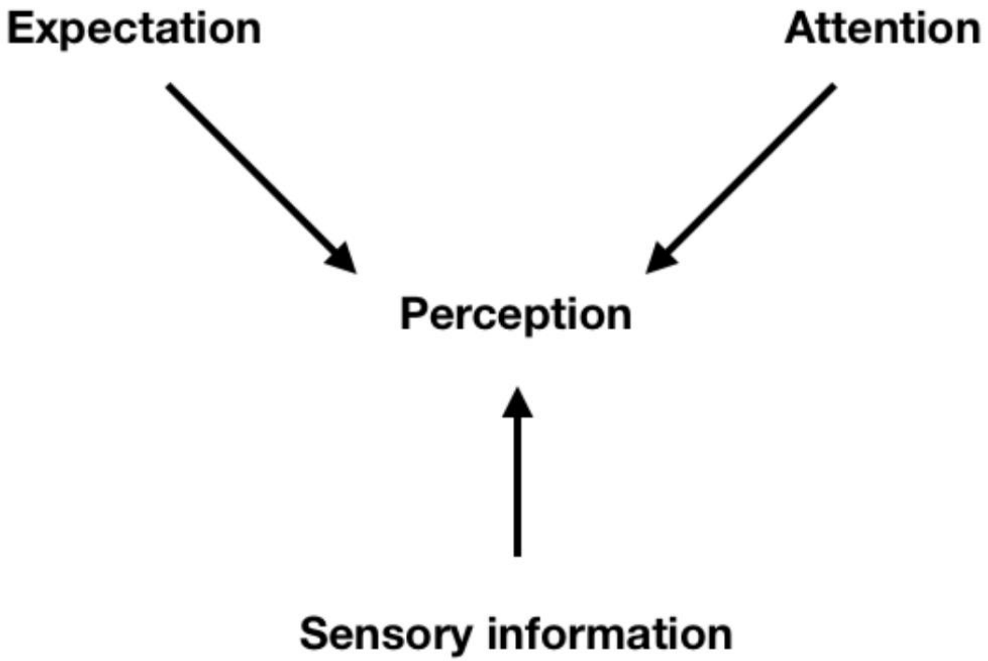
Communication: Competitive gaming is an extreme situation where two parties have conflicting goals. Both users must infer what the other party means or desires via the limited cues on the interface. Every so often, this requires intense communication and impromptu collaboration. Likewise, driving in this case co-occurs with the use of a mobile phone and thus shapes what is being communicated due to the user having to multitask.

Perception

- **Perception** serves a multitude of roles in human-computer interaction
- We regulate our actions in interaction via perception
- User interfaces communicate their state via perception
- In this example, perception has a decisive role in helping us find elements on the display, guide fingers, maintain awareness of the background, and control gait and walking

Three primary processes contribute to human perception

- Our perceptual experience of the world may appear like it is veridically (truthfully) reflecting the **sensory information** we receive
- However, it is a representation that our mind actively constructs
    - On the one hand, perception is affected by our **expectations** that draw from prior experiences
    - On the other hand, perception is shaped by how we deploy **attention** to sample information



Sensation and transduction

- **Sensation** is a physiological process that produces information about the environment for perception
- Sensation is required to form the integrated and actionable view that we need for interaction
- Sensation feeds perception
- From a biological perspective, sensation is about **transduction**
  - A sensory system transforms energy in one form, for example light or physical contact , to electro-chemical events in the brain that produce the experience of sensation

Transduction for human sensory modalities

- **Mechanosensitivity**
  - Example: kinaesthesia, the sense of own movement, and touch, hearing, and equilibrium
  - Physical contact energy is transduced, for example, via hair cells in the ear
- **Chemosensitivity**
  - Examples: gustation and olfaction
  - Chemical properties are transduced, such as taste buds on the tongue
- **Photosensitivity**
  - Example: the retina
  - Stimulation by photons is transduced
- Other means, less used in HCI
  - Thermal sensing, pain

Human sensory modalities in HCI

Sensory modality	Key characteristics	Design considerations
Vision	Fast, high bandwidth for parallel processing, field of view about 180 degrees	Visual, spatial, and lexical aspects of graphical displays, like contrast, acuity, use of color, visual primitives, symbols, and text
Hearing	Very fast (about 40ms faster reaction times than vision) but more serial presentation, 360 degrees	Properties of sound and voice, such as pitch, timbre, melody, and phrasing
Tactition	Fast but limited to areas of physical contact	Properties of haptic stimulation like amplitude and frequency of vibration

Windows of visibility

- **Visible spectrum of light**
  - We can only perceive a limited range in the spectrum of light, from about 380 to 780 nm
  - The rod and cone cells we have permit only trichromaticity, three chroma of color
- **Field of view**
  - Field of view is limited, to about 190 degrees horizontally and 125 degrees vertically
  - This sets limits to how large displays can be and how where they must be located in relation to our eyes
- **Contrast**
  - Perception of detail is limited
  - **Contrast** refers to difference in luminance and color that make something in the field of view to stand out from the rest
  - **Contrast sensitivity** refers to our ability to distinguish levels of contrast
- **Foveated vision**
  - The retinal image is limited and very non-uniform
  - It loses accuracy at the periphery

Windows of visibility

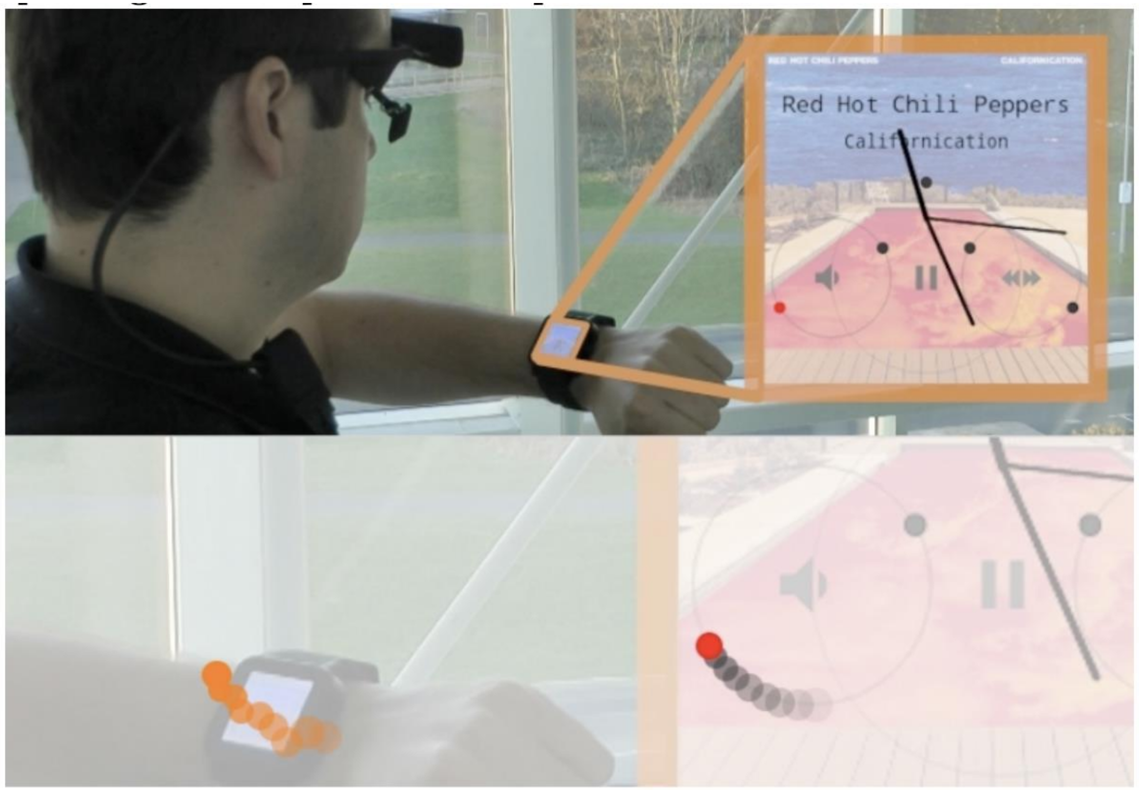
- Windows of Visibility can be used to understand how viewing conditions affect perceptual tasks in the wild
- For example, consider wanting to glance at the smartwatch while tying the shoelaces
- Using the Windows of Visibility, assess the situation:
  - What are key limits to the user's visual performance?

Eye movements

- The human oculomotor system controls eye movements using three main modes:
- **Fixations:** encode information about the visual scene consist of multiple micro-fixations, each a few tens of milliseconds
  - Eye trackers cluster micro-fixations into fixations of 200–400 milliseconds
- **Saccades:** move the gaze point in ballistic leaps that during which the scene is not perceived
  - They are ballistic, in the sense that the target of the saccade is not changed after the onset of the movement
  - They are also ’blind’: no information is sampled during a saccade
- **Smooth pursuit:** smooth tracking of moving targets, such as when following an animated character moving on the display
  - No saccades occur

Example: exploiting smooth pursuit for input

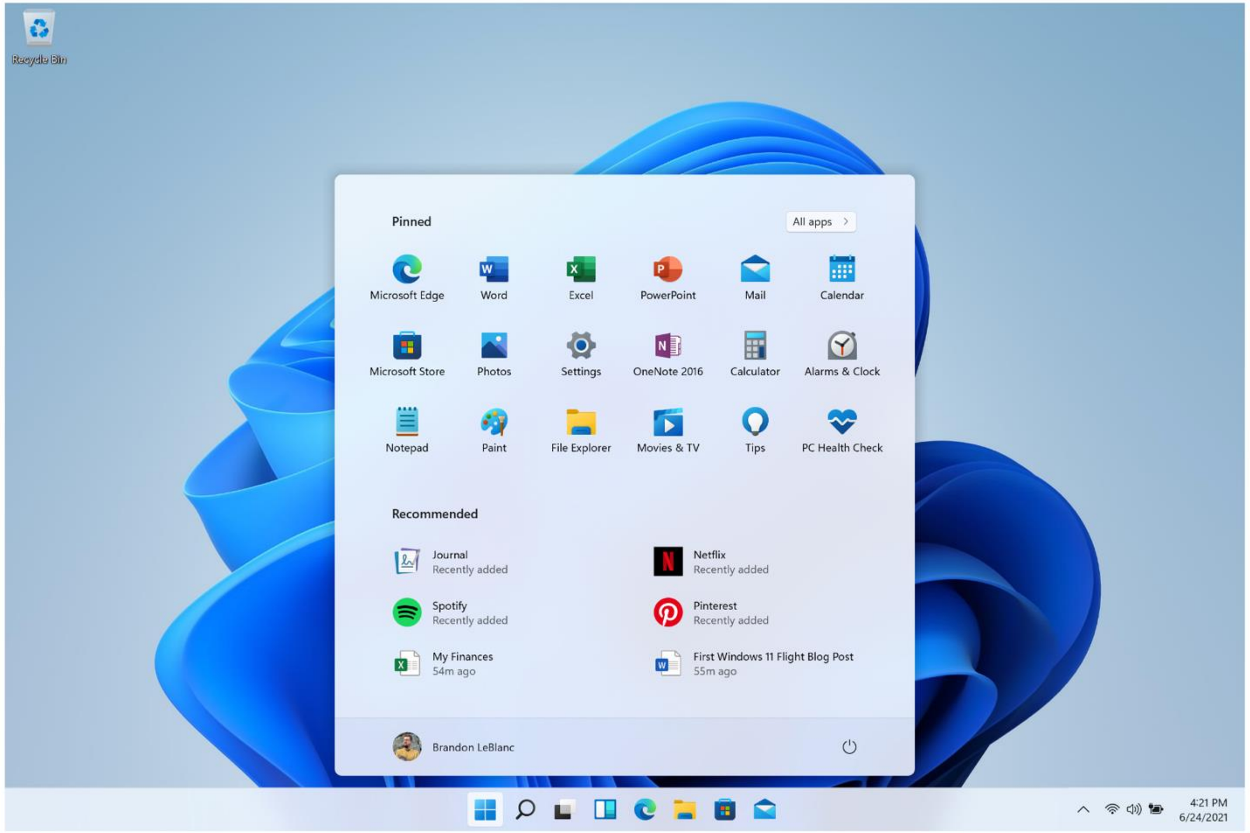
- *Orbits* is a selection technique that exploits smooth pursuit as an input modality
- The idea is to match the motion or trajectory indicated by a to-be selected widget
    - For example, user can raise the volume of a player on smartwatch by following the trajectory of a moving circle



A. Esteves, E. Velloso, A. Bulling, and H. Gellersen. Orbits: Gaze interaction for smart watches using smooth pursuit eye movements. In Proceedings of the Symposium on User Interface Software and Technology, pages 457–466, 2015.

Perceptual organization

- Perceptual organization refers to:
    1. The division of elements into figure vs. ground
    2. Their grouping into coherent regions
- In this example, the application window (*figure*) is clearly in front of the desktop wallpaper (*ground*)
- There are also many visual groups on the display
    - For example, the region of recommended apps forms a distinct region from the rest of what is presented in the window
    - Similarly, the icons on the horizontal task bar form a visual group

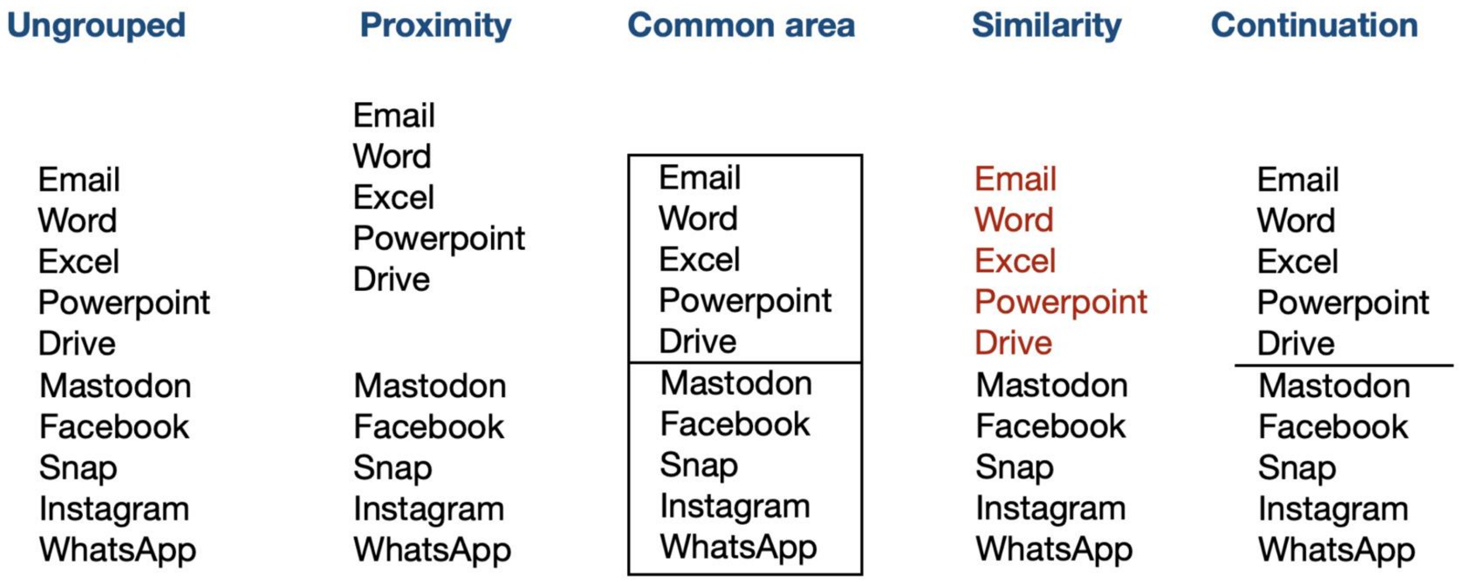


Perceptual organization

- **Figure/ground perception**
  - The organization of visual experience in a visuospatial hierarchy
  - Some objects belong to figure, or an object in front
  - Other objects belong to the background, or the ground
  - Graphical interfaces exploit figure/ground perception to show a display hierarchy
- **Regions**
  - The decomposition of a display into separate regions
- **Visual groupings**
  - The tendency of elements on a display to form visual groups

Common visual grouping rules (Gestalt laws)

- **Proximity:** the closer some elements are together and the farther apart they are from others, the stronger they are grouped together
- **Common area:** elements that located in the same closed region are grouped together
  Similarity: elements that are similar in color, size, orientation, etc. are grouped together
  Continuation: elements that are connected by continuation of flow are grouped together

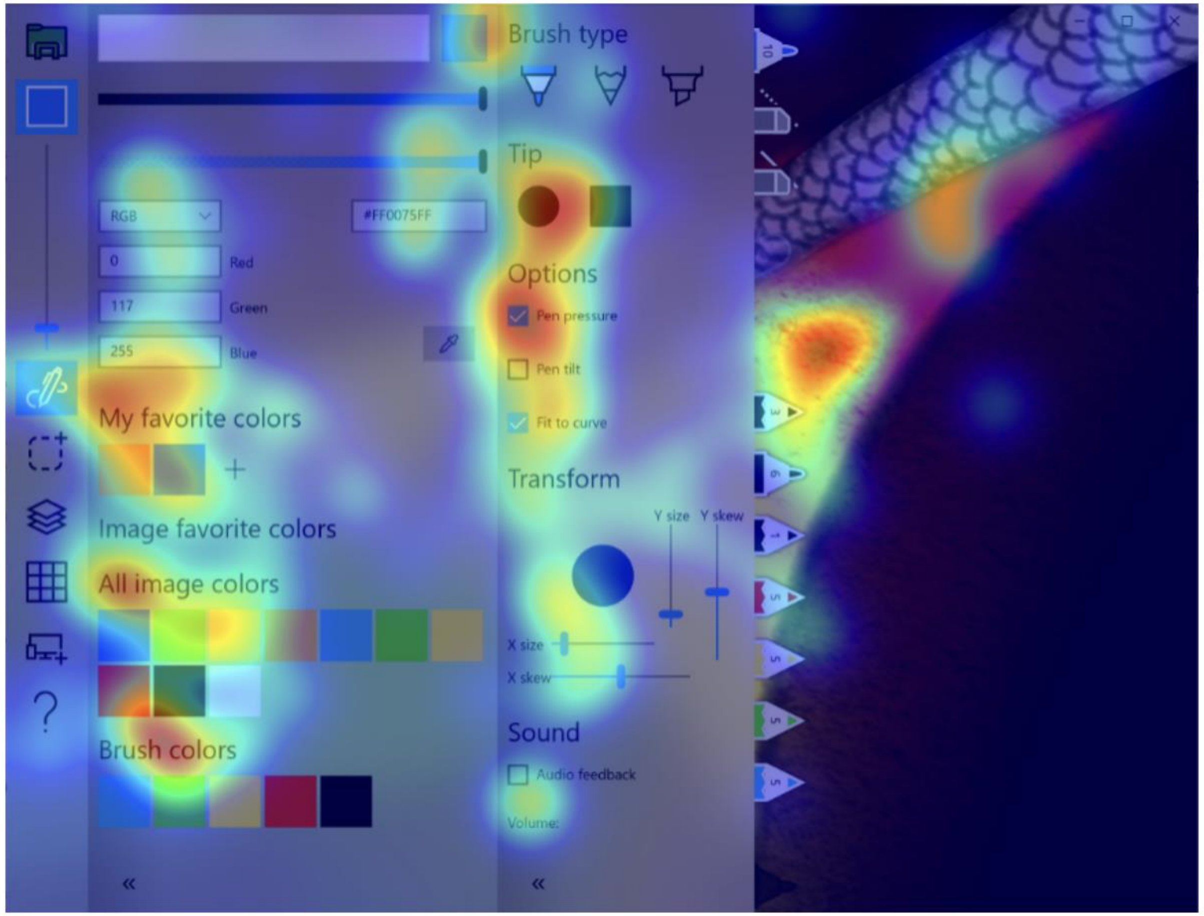


Visual attention

- **Attention** means the focusing of perceptual processing on a region or object in the perceptual field
- Visual attention is traditionally considered to consist of three processes:
  - Selective attention: the ability to shift attention to a desired object or location
  - Vigilance: the ability to sustain attention on something for a longer period
  - Divided attention: the ability to share attention between one or more objects, locations, or tasks
- **Change blindness** is a failure of a user to detect a change within the visual field due to visual disruption, such as a blink
- **Inattentional blindness** is a failure of a user to detect a change within the visual field even though there was no visual disruption
  - Instead the failure to detect the change is due to the user's attention being focused elsewhere

Visual saliency

- An example of eye tracking data on what people look at in a user interface
- Visual saliency denotes the probability with which visual features attract attention when we see a user interface for the first time
- Saliency depends on:
  - Distribution of visual features on the user interface
  - Expectations (prior experience to related designs)
  - Attentional strategies



Example: what makes a display cluttered?

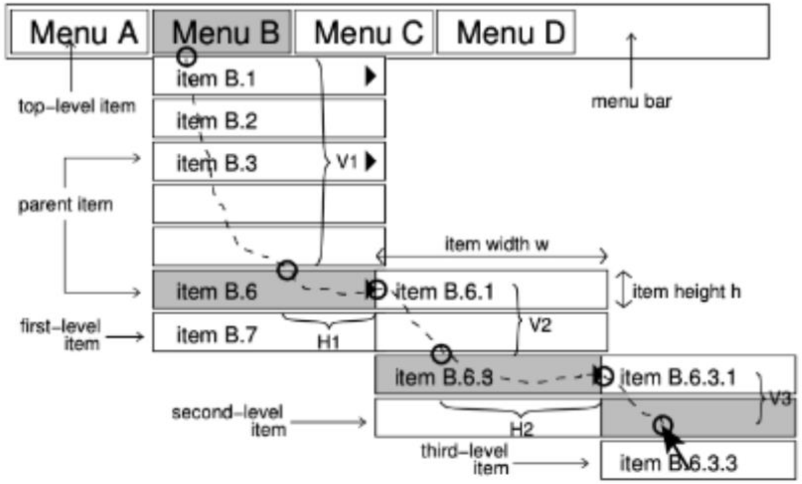
- Visual saliency can be used to explain and measure how cluttered a display is perceived to be
  - *Clutter* means that everything on the display attempts to be salient
- A simple test to understand if a display is cluttered: if you want to place a note on the display that should be noticeable, how would you design it?
  - Which color, size, or shape would you choose?
  - If the display is cluttered, you cannot select a visual feature that would make the note stand out in the display

R. Rosenholtz, A. Dorai, and R. Freeman. Do predictions of visual perception aid design? ACM Transactions on Applied Perception, 8(2):1–20, 2011.

Motor Control

Motor control

- From selecting an item on a menu to interacting with a large display at a distance, users rely on **motor control** to interact
- Human motor control refers to the regulation of all movement in a human, including integrating relevant internal and external sensory information to determine the necessary signals to trigger muscles to activate
- Motor control is critical for fundamental human tasks, such as balancing the body and pointing at and grasping an object



D. Ahlström. Modeling and improving selection in cascading pull-down menus using Fitts' law, the steering law and force fields. In Proceedings of the Conference on Human factors in computing systems, pages 61–70, 2005.

Examples of use of motor control in HCI

- Graphical layouts can be personalized to better match a user’s motor abilities
  - Depending on the amount of tremor, for example, selectable elements can be made bigger and reordered so that they can be better reached for users
- Target selection techniques use models of motor control to dynamically make objects on display more easily selected, for example, by changing their selection areas
- Keyboard layouts can be optimized using models of pointing
  - They demonstrate faster and less error-prone typing, yet at the expense of having to learn a new layout
- Input methods and devices can be compared for performance using metrics rooted in models of motor control, such as throughput

Elements of an HCI motor task

- **End-effector:** the body part that we use for something
- **Degrees-of-freedom:** how many ways we can translate an end-effector in 3D space
- **Open-loop:** movement without feedback
- **Closed-loop:** movement with feedback
- **Aimed movement:** the attempt to move an end-effector to a certain location
- **Interception task:** a task with both spatial and temporal demands, such as trying to catch a falling object
- **Speed-accuracy tradeoff:** the tendency that a higher speed results in a lower accuracy, and vice versa

Target acquisition: Fitts' law

- Fitts' law models the **movement time** (MT) it takes a user to acquire a target with **index of difficulty** (ID)

$$MT = a + bID$$

  - where $ID = \log_2(\frac{D}{W} + 1)$

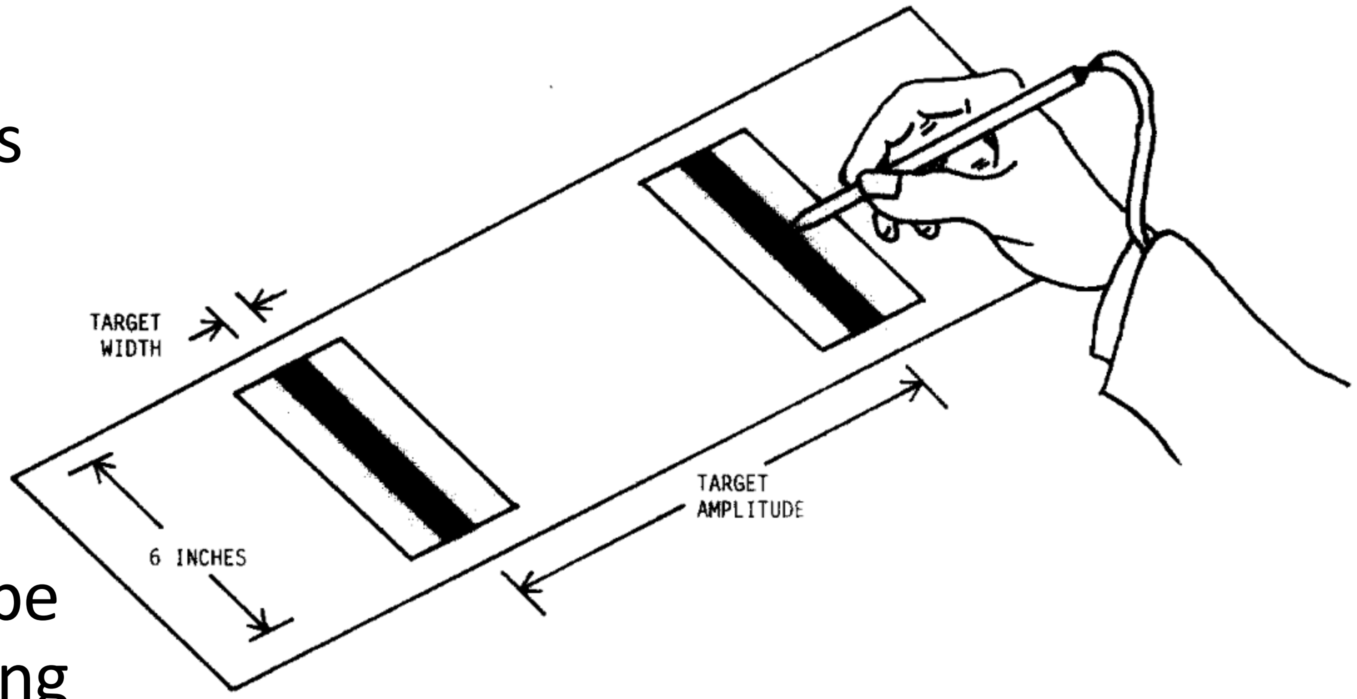
a and b are task-dependent regression coefficients

D and W are the distance and width to the target respectively

Fitts' experiment

- The experimental setup of Fitts manipulated movement *D* and target width *W* in a reciprocal tapping task

- The two metal plates were to be hit with a stylus in an alternating sequence as fast as possible



I. S. MacKenzie. Fitts' law as a research and design tool in human-computer interaction. Human-computer interaction **7**(1):91–139, 1992.

Throughput

- It is possible to use Fitts' law to compare input devices through a construct known as **throughput**, which allow us to assess the information capacity of users
- Throughput is the number of bits a user can communicate **independently** of a specific target
- One measure of throughput is the following:

$$TP = \frac{ID_{avg}}{MT_{avg}}$$

  - The downside is that it relies on an arbitrary average *ID*
- An alternative measure of throughput is:

$$TP = \frac{1}{b}$$

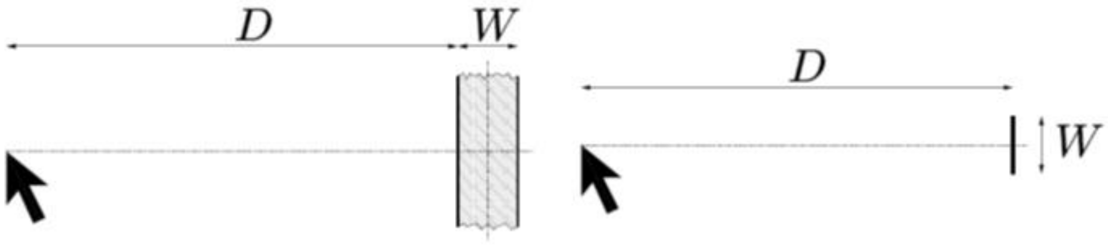
  - which relates throughput solely to the slope *b* of the line in Fitts' law
  - the downside is that it ignores any effect of the intercept *a*

Crossing

- A crossing task is a target acquisition task relaxes the stopping constraint of a pointing task (the *D* parameter)
- Experimentally, crossing has been demonstrated to adhere to the same mathematical formulation as Fitts' law
- Unlike pointing, crossing allows a user to select multiple targets in a single motion

(a) Pointing a target

(b) Crossing a goal



(a) Pointing: variability is allowed in the direction collinear to movement

(b) Crossing: variability is allowed in the direction orthogonal to movement

Steering

- A steering task is moving a cursor within a tunnel constraint
- In general, the time *T* it takes a user to steer a cursor through a tunnel is:

$$T = a + b \int_C \frac{ds}{W(s)}$$

where *a* and *b* are empirically determined parameters, *C* is the tunnel parameterized by *s* and *W*(*s*) is the width of the tunnel at *s*

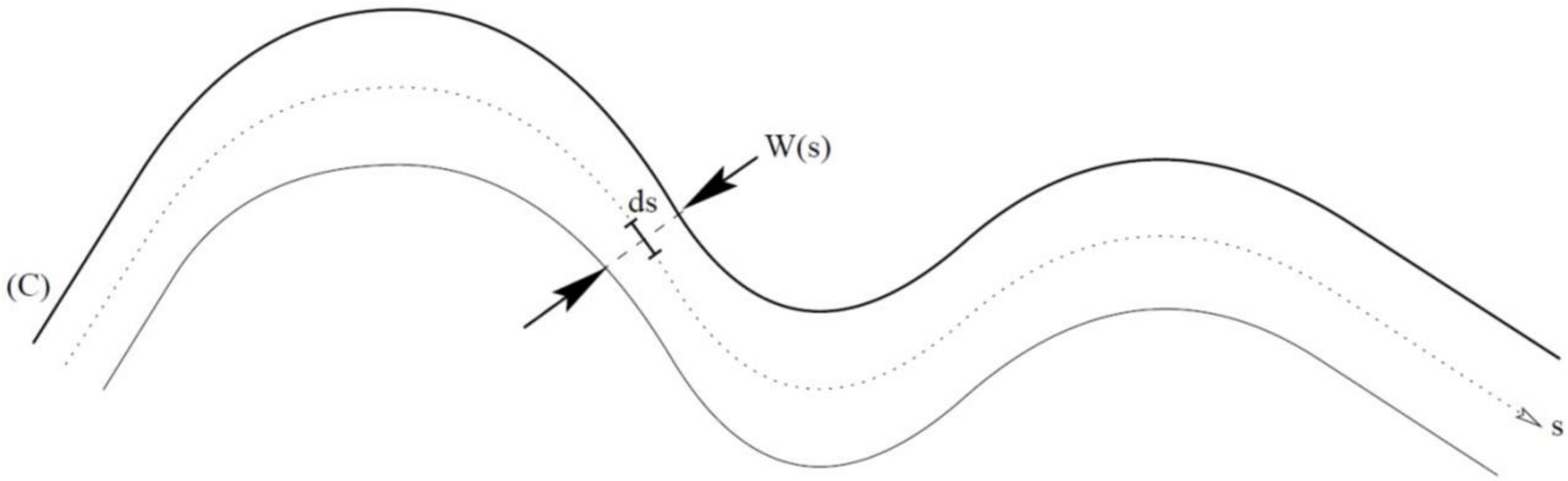
- Differentiating both sides of the above equation with respect to *s* yields:

$$\frac{ds}{dT} = \frac{W(s)}{b}$$

- which confirms that instantaneous movement speed is proportional to the width of the tunnel

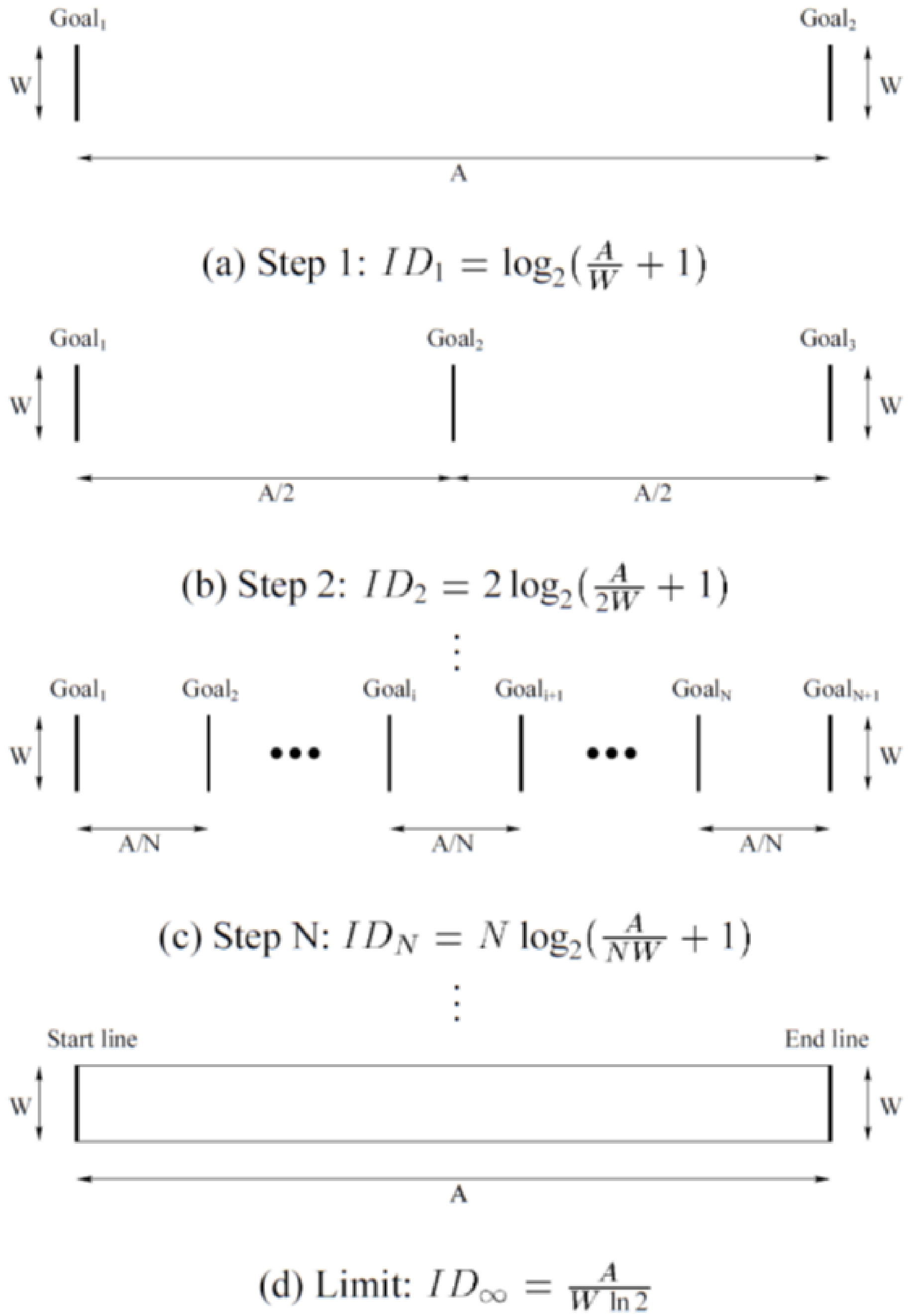
Index of difficulty for steering

- The index of difficulty for a parameterized curve *C* is:
- $ID_C = \int_C \frac{ds}{W(s)}$



Relationship with Fitts' law

- A steering task with constraints on both ends follows the same logarithmic relationship as Fitts' law
- By generalizing the number of *N* goals the user has to pass through, the constraints form a tunnel constraint
- Note that as *N* increases, the user must be more careful in passing through all the goals
- In the limit, the index of difficulty is no longer related to $\log_2(\frac{A}{W})$ but to $\frac{A}{W}$ directly
- In other words, in an *N* goal passing task, as *N* approaches infinity, the difficulty is no longer related to the logarithm of the distance (amplitude *A* in the figure) and the width (*W*)



(a) Step 1: $ID_1 = \log_2(\frac{A}{W} + 1)$

(b) Step 2: $ID_2 = 2\log_2(\frac{A}{2W} + 1)$

(c) Step N: $ID_N = N\log_2(\frac{A}{NW} + 1)$

(d) Limit: $ID_\infty = \frac{A}{W \ln 2}$

Simple reaction

- A simple reaction is when something appears on the display or in the environment, and the user must respond to it as quickly as possible
- Motor response refers to the elicitation of a motor movement appropriate to a presented event or stimulus
- The drift diffusion model is an evidence accumulation model for simple reactions
- Reaction time $RT = T_d + T_{er} += T_d + x + y$
  - where T_d is decision time and T_{er} is nondecision time
  - x is the time duration for perceptually encoding the stimulus (diffusion)
  - y is the time duration for the motor response

Choice reaction

- In a choice reaction task, instead of one response option, as in a simple reaction, *n* options are available
- When a cue appears, the user must execute the corresponding response as quickly as possible by pressing the associated key
- Each cue is associated to a single response, but cues can appear with different probabilities
- Choice reaction is open-loop: fingers are supposed to be on the associated keys to minimize any time to point at a response item

Open-loop decision time among *n* choices

- A user is presented with *n* choices and does not need to linearly scan the choices: it is an open-loop task
- The time *T* it takes a user to make such a choice is:

$$T = bH$$

  - where *b* is an empirically determined parameter
- *H* is the entropy inherent in the decision:

$$H = \sum_{i=1}^{n} p_i \log_2 \left(\frac{1}{p_i}\right)$$

  - where p_i is the probability of the *i*th choice

Hick-Hyman law: choice reaction

- If all the choices in the open-loop choice reaction task are equally probable, then we arrive at the **Hick-Hyman law**
- It states that the average choice reaction time *T* for *n* choices is:

$$T = a + b\log_2(n)$$

  - where *a* and *b* are empirically determined parameters
  - The *b* parameter controls how strongly *T* is influenced by additional choices

- If there is uncertainty on whether to respond or not the formula is:

$$T = a + b\log_2(n + 1)$$

  - No response is simply another choice

- When *n* = 1 we have a *simple reaction*
- When *n* = 2 we have a 2-alternative forced choice

Cognition

Cognition

Memory

"Powerpoint has image editing capabilities."

Attention

Searching for the icon, guiding finger to press it

Control

"What should I press now to edit a photo?"

Reasoning

"Could I edit the photo in Powerpoint and take a screenshot to store it?"

Decision-making

"I don't have time to learn this, can I ask Mary to do it?"

Cognitive capabilities relevant to HCI

- **Supervisory control:** adaptively deciding goals, allocating cognitive resources to tasks, and changing of course of action when required
    - For example, cognitive control is needed when a user decides to multitask by looking at their phone while driving
- **Memory:** forming, maintaining, and accessing beliefs about objects that are not directly perceivable
    - For example, long-term memory helps users locate previously seen icons faster
- **Attention:** selectively processing some part of the perceptual field
    - For example, deploying visual attention on a screen, or by sensing a tactile display by sweeping a fingertip on it
- **Reasoning:** applying transformation rules to beliefs to form new beliefs
    - For example, reasoning is needed to infer if software can do certain things in the case where one is not able to recall doing that earlier
- **Decision-making:** interaction often requires making decisions
    - For example, a user might decide to install application A and not application B because A appears to be more favorable with respect to features and costs

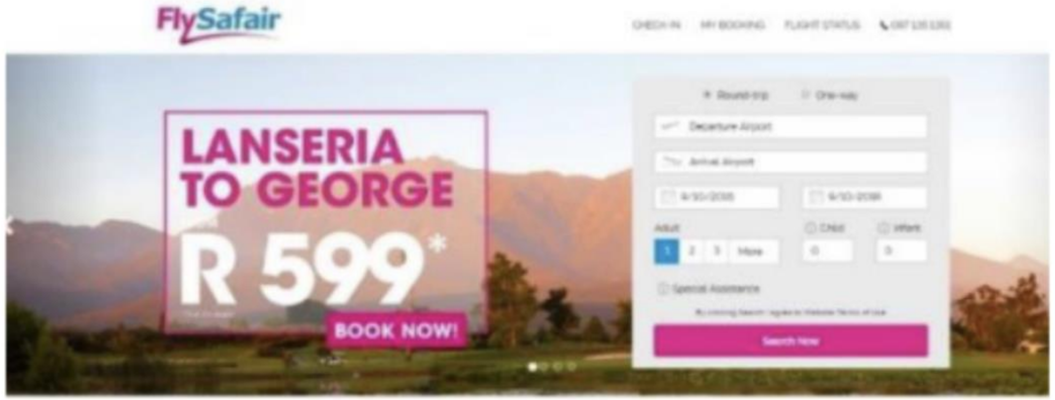
General Findings of Cognition

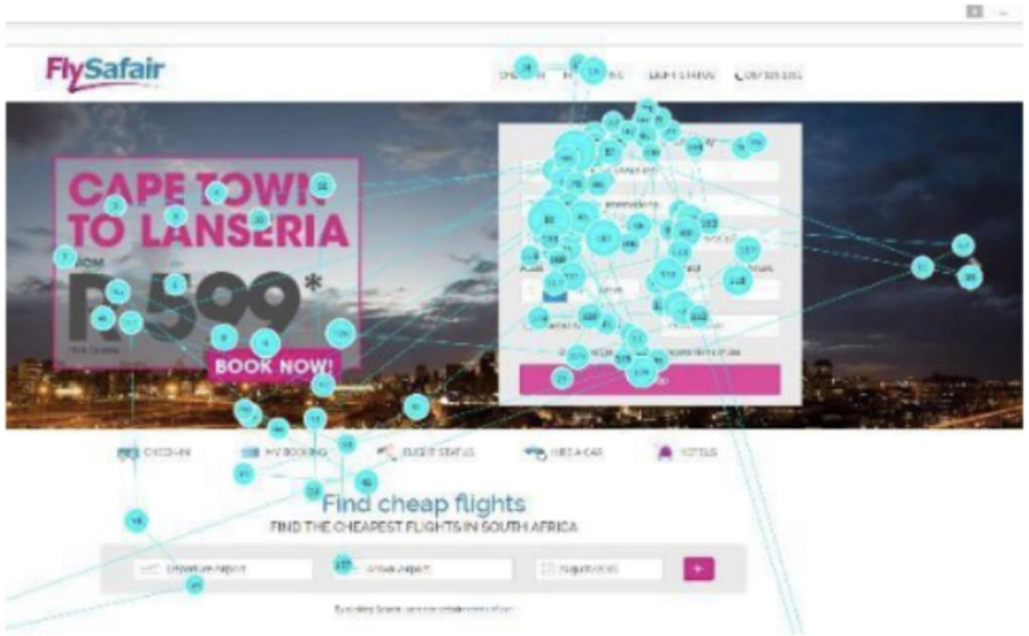
Cognition helps set goals and maintain focus

- A goal is some desirable state of affairs
  - In HCI, a goal often relates to something that people would like the computer to do for them
  - For example, a user’s goal could be to email a particular message to someone or to change privacy settings
- Goals, in turn, affect how cognition processes information
- Human memory, for example, is less about storing experienced events veridically—accurately
  - Rather it offers access to memories that may be useful for a given task
  - Goals set expectations about how the world is structured and what might happen next

Example: inattentional blindness

- That cognition is goal-oriented is well-demonstrated by the **inattentional blindness** effect
- When users are asked to focus on a task unrelated to a banner (bottom), they recall hardly any information about it
- However, according to eye tracking data, they looked at it





H. Gelderblom and L. Menge. The invisible gorilla revisited: using eye tracking to investigate inattentional blindness in interface design. In Proceedings of the Conference on Advanced Visual Interfaces, pages 1–9, 2018.

Cognition is limited

- Visual attention is spatially limited: people can extract more information from the foveal region and less from the periphery
- Working memory is limited: we can only keep a few mental representations active in our mind
- The typical working memory capacity that can be simultaneously maintained active in our mind is thought to be about 2–4 items
- Forgetting occurs in long-term memory: we cannot remember everything we have experienced and as a result we forget details of things we have attended
- Our capacity for abstract reasoning and planning is limited
  - We often resort to external aids, such as calculators and notes, to help us go beyond the limits posed by our own cognition

Cognition reasons based on internal models of reality

- Cognition has the ability to reason about things that are not directly perceivable
- This ability necessitates the construction of internal models of reality that can be used to formulate goals and plans
- An example of such an internal model is a **metaphor**
  - As an example in HCI, metaphors help users understand what to expect from a user interface
  - The desktop metaphor uses spatial concepts that are rooted in our everyday experience of physical worlds
  - For example, folders are on, not under, the desktop and folders can be moved into a bin when they are no longer required

Cognition is necessary for learning and adaptation

- Our cognitive, motor, and perceptual processes are **constantly adapting**—forming beliefs, trying new tactics, and fine-tuning
- This need is pronounced in HCI in that the systems people use and the way people carry out work keeps changing
- This phenomenon results in users having to continually formulate new plans and adapt to new ways of working with computer systems
- Hence cognition is not simply passively processing information from external environments and reacting to it
  - Instead, cognition takes actions and intervenes in order to facilitate its own functioning
- We use external aids, such as notes, calculators, and browsers to augment our abilities
- Over time, such dependencies affect the way we use cognition in interaction
  - For example, since the uptake of the graphical user interface, which relies more heavily on visual recognition, we have less need to use our long-term memory to store computer commands that would be typed in a command prompt

Cognition requires energy and effort

- **Mental effort:** the use of energy we need when controlling thinking to achieve our goals
- Mental effort is distinguished into two components:

1. **Task effort** refers to responses to increase computational demands
   - This can occur when we face novel environments, for example, when learning to use a new user interface
2. **State effort** refers to the energy required to protect performance from physiological fatigue, which can be caused by, for example, sleep deprivation

- Effort may sound like a negative concept in that effort is something that limits performance
  - However, it also serves a positive function: the feeling of effort protects us from overconsuming energy in less important activities

Needs and Motivations

Needs and motivations

- From the word processor to the Internet, interactive computer systems have changed the way we work, consume, and even lead our romantic lives
- However, in addition to technical limitations, are there human-related limits to a wider adoption of computing?
- What we **need** or **desire** as human beings is a defining factor in technology adoption and success
- At a high level, technology makes inroads into society in two ways:
  - Market-pull, which means that there is a market need for a solution
  - Technology-push, which means that new technology creates a new need in the market
- However, it is people and their needs that shape both pull and push factors

Psychological needs for interactive systems

Psychological need	Explanation
Relatedness	Need for social relationships
Meaning	Need for purpose and direction
Stimulation	Need for novel sensations and thoughts
Competence	Need for the ability to perform well in important activities
Popularity	Need for recognition by others
Security	Need for protection of self from harm

Self-determination theory (SDT)

- SDT starts with the idea of people as active organisms pursuing self growth, mastery, and fulfillment
- Psychological science has steered away from *deficit* needs and reinforcers and turned to *motivational* dynamics that underlie positive development, or self-growth
- Self-growth refers to the motivational mechanisms that drive us to improve our ability to act socially and psychologically
- People are seen as actively seeking new opportunities to master
    - As opposed to satisfying deficits

Needs according to self-determination theory

- **Autonomy:** the sense that actions are performed willingly, in alignment with one's self, and not directed by external forces
- **Competence:** the feeling of achieving mastery and controlling the outcomes of action
- **Relatedness:** the sense of reciprocal belonging in relation to other humans

Use of self-determination theory in HCI

- According to self-determination theory, motivations to act in a certain way develop over time in the interplay of environmental offering and rewards and basic psychological needs
- SDT enables us both to avoid solutions that do not satisfy any needs and to detect new opportunities for improving people's lives by fulfilling previously undiscovered needs
- SDT makes it possible to develop technology that better helps people achieve their goals and sustains their motivations
  - Assisting people to do so has been a key goal of technology in health care, for example, where an important goal is to use models of motivation to change behavior
- SDT allows us to analyze and classify user research by using models of needs and motivations to help see larger patterns in user reports and the essential drivers of what people want and do

Collaboration

Collaboration

- It is difficult to identify any complex activity that does not at some point involve other people
- Since collaboration is so common it is unsurprising that there are many collaborative systems, such as messaging services, videoconferencing, shared calendars, and so on
- There are many challenges in designing, building, deploying, and supporting collaborative systems and, as a consequence, many such systems have failed in the past
- Collaboration is not only the act of collaborating
  - It also involves activities that support collaboration, such as planning collaborative work, being aware of other collaborators’ goals and actions, and determining what to do next

Collaboration and cooperation

- **Collaboration** is “a mutually beneficial relationship between two or more parties who work toward common goals by sharing responsibility, authority, and accountability for achieving results”
- **Cooperation** means a *division of labor* is in place, each person is responsible for some part of problem solving
  - However, in cooperation, this division can be imposed to a particular participant, and thus there may not be a need to negotiate or establish a division of labor during the activity
- Collaboration emphasizes the joint construction of goals, understandings, and division of labor

D. D. Chrislip and C. E. Larson. Collaborative leadership: How citizens and civic leaders can make a difference, volume 24. Jossey-Bass, 1994.

Two-axis model of collaborative technology

	Synchronous	Asynchronous
Co-located	*Tabletop group interaction*	*Public display message board*
Remote	*Video conferencing*	*Email*

Additional factors of collaborative technology

- **Scale:** the number of participants involved in a collaboration is important as the larger the group, the more coordination is required
- **Communities of practice:** "…are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly"
  - The term refers to a concept of learning that describes how beginners learn the practices, tools, and norms of a community
- **Nascence:** The degree of coordination actions that are under development by the participants
  - A rigid system will involve few modifications while, for example, social apps allow users creative expressions or new ways of using media
- **Planned permanence:** the intended stability of a collaborative arrangement
- **Turnover:** the stability of the groups of participants

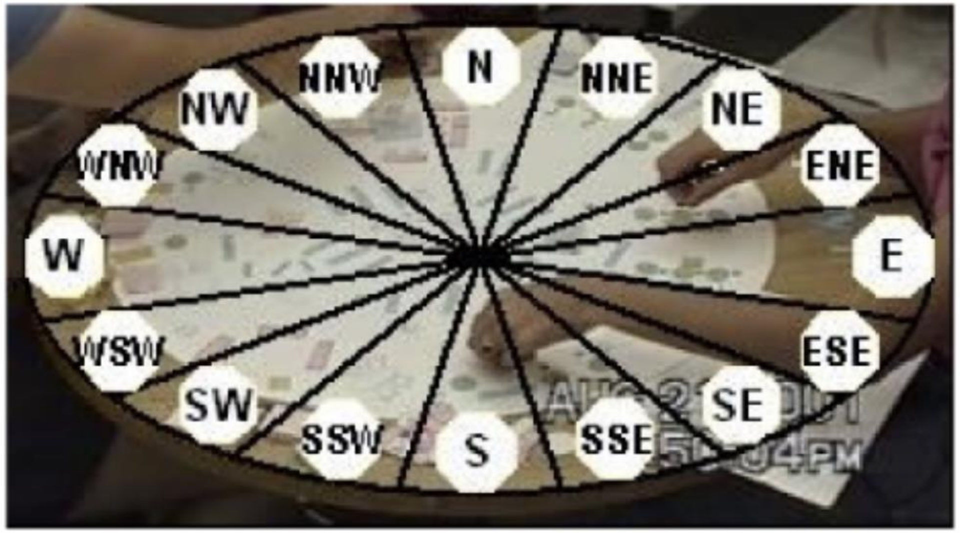
C. P. Lee and D. Paine. From the matrix to a model of coordinated action (MOCA): a conceptual framework of and for CSCW. In Proceedings of the Conference on Computer Supported Cooperative Work & Social Computing, pages 179–194, 2015.

Group interactions

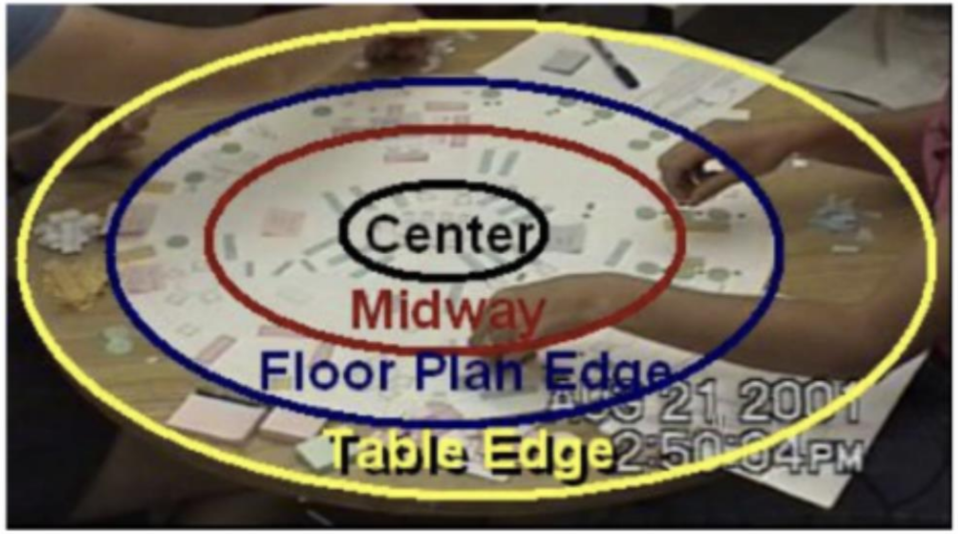
- **Task:** groups perform together to complete something
  - The objectives, constraints, and other properties of the task affect the behavioral patterns and interactions that emerge
- **Environment:** action takes place in some context, with particular resources, constraints, and so on
- **Individual attributes:** the group members' individual properties, such as personality traits, beliefs, and so on affect group interaction, behavioral patterns, and group structure
- **Group structure and relations:** facilitatory and impeding factors governing inter-relationships among group members, such as affection and power
- **Behavioral patterns:** constructs that shape the expected or routine way of interaction
  - Examples of such patterns are the assumed roles and divisions of labor within a group

Example: Territoriality when collaborating using tabletop displays

- A study recorded all tabletop activity and analyzed by zones
  - Personal territory: reserve an area for personal objects
  - Group territory: collaboration space
  - Storage territory: store task resources not in use, such as tools



16 directional zones



Four radial zones

S. D. Scott, M. S. T. Carpendale, and K. Inkpen. Territoriality in collaborative tabletop workspaces. In Proceedings of the Conference on Computer Supported Cooperative Work, pages 294–303, 2004.

Coordination

- **Articulation work:** describes activities that are extraneous to the work itself
  - It is about getting things done in work in a way that is situationally more appropriate
  - It is about deciding how tasks are carried out, for example, how tasks are scheduled, divided, managed, aligned, and organized into larger clusters
- **Awareness:** is a collaborator's ability to follow what others are doing, how their subtasks are progressing, and what they attend to
  - When collaboration is distributed in space and time, maintaining such awareness is challenging
  - When awareness breaks down, coordination of work becomes hard and prone to errors, and even conflict.
- **Boundary objects:** are objects that are shared among collaborators and helps them coordinate, share information, or coordinate

- Open access (PDF at link)
- Further reading:
  - Part II: Understanding People
  - Chapters 2–9