4M21 Software Engineering and Design
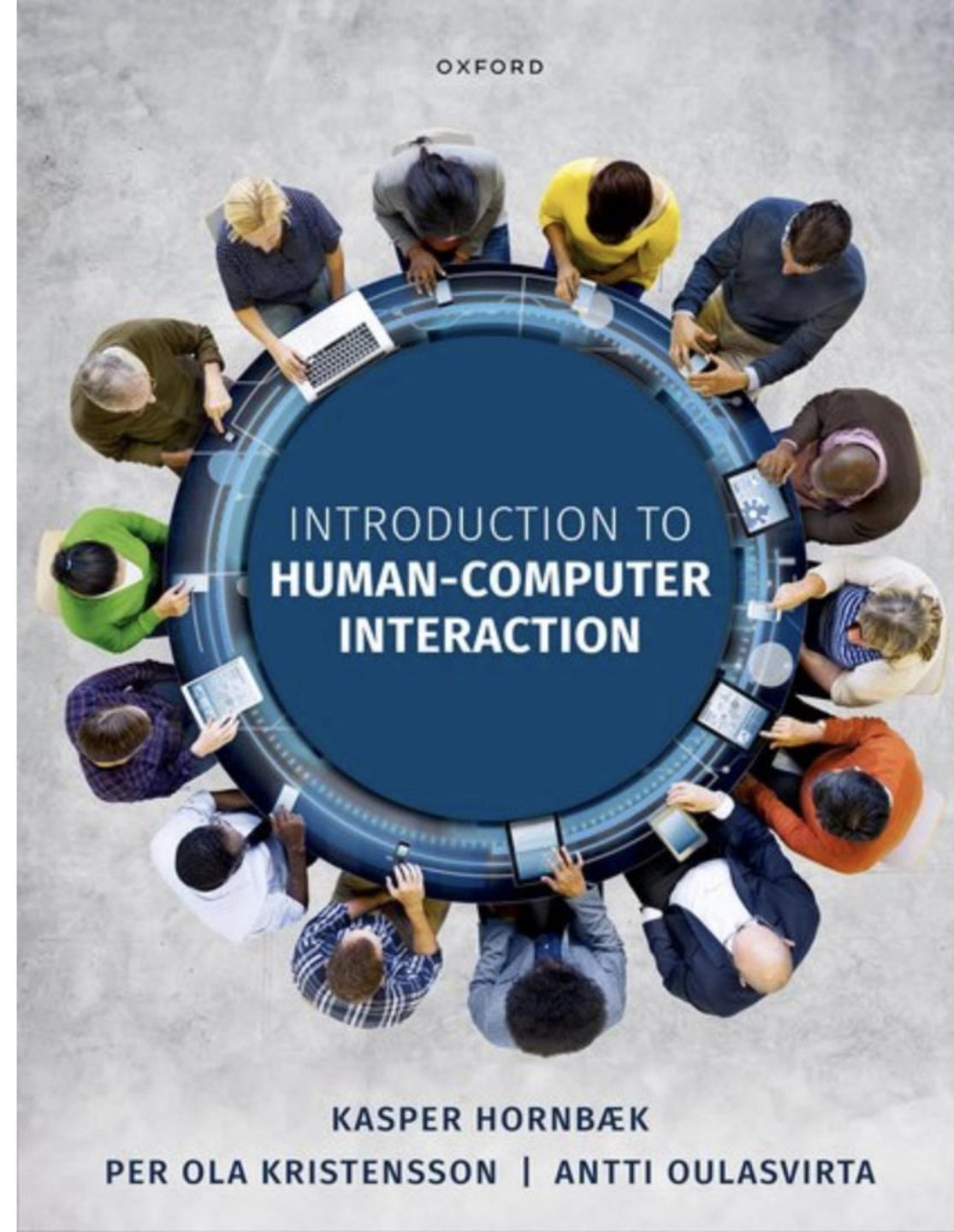# Human-Computer Interaction

Lecture 1/8

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

INTRODUCTION TO
HUMAN-COMPUTER
INTERACTION

KASPER HORNBÆK
PER OLA KRISTENSSON | ANTTI OULASVIRTA

A computer is a tool

- From fishing nets to drilling machines, **tools** are vital to human ability
- Tools amplify our physical abilities and are central to many intellectual activities, such as writing, mathematics, and accounting

- **A computer is a tool**
  - Computer programs decompose complex activities into sequences of much simpler operations
  - However, computers would be useless tools if they did not offer some way for people to control them
  - A **user interface** enables interaction with a computer

Challenges in HCI: humans are complex

- Humans are complex biological and social organisms
- A human being is capable of conscious thought and has developed language abilities, capabilities for fine motor movements, and generally excellent abilities to learn to develop, use, and adapt tools to achieve goals
- Several of such fundamental abilities are sufficiently well-understood to apply them in HCI, such as central aspects of human motor control
- However, many open questions remain, such as those related to experience and language

Challenges in HCI: individual differences

- HCI must account for individual differences
- There are large individual differences in computer use
- Not only in terms of performance, but in terms of what is considered interesting or culturally appropriate
- For example, an expert on HCI for development described the challenges faced in non-Western contexts as follows:
  - "We need to address the everyday problems of people. Most people don't know how to scroll, navigate. We need to do basic HCI work to make text larger. Also, time of day is the most prominent thing on [a phone's] screen. Let's replace that with the amount of airtime you have left. We need to improve upon what we built yesterday rather than doing novel interventions or focusing on the future."

Challenges in HCI: computers are complex

- The computer is the most complex tool humans have devised
- A modern computer relies on an elaborate stack ranging from transistors, logic gates, microcontrollers, and memory chips to operating systems, software drivers, software libraries and toolkits, applications, and ultimately user interfaces
- Modern computers typically rely on multiple cores to perform computations in parallel and retrieve data from sources with indeterminate delays, such as information from networks
- Designing systems with this level of complexity is inherently challenging

Challenges in HCI: understanding systems

- HCI involves people interacting with computers in complex contexts where they attempt to carry out a variety of goals

- HCI requires a **systems approach**

- This means taking the full socio-technical context into account that the specific HCI activities are situated in

- In HCI, even if we often focus on a subsystem, successful deployment relies on the ability to understand and relate observations to their wider, system-level context

Challenges in HCI: design is hard

- The purpose of HCI is, ultimately, to impact the **design** of applications, interaction techniques, systems, or services so that users can achieve their goals in an **effective, efficient, safe, and satisfactory** manner
- **There is no perfect design**—design is about identifying tradeoffs and generating suitable solutions that each trade off certain characteristics in exchange for others, such as a user's speed for accuracy
- Design requires creating new ideas
  - In design fixation, a designer maintains an early identified solution despite being inferior to other possible designs
  - It is hard to let go of old ideas and generate new ideas that are also valuable
  - Even experienced designers suffer from design fixation
- To arrive at a design is a complex process where it is easy to introduce mistakes early in the process, such as accidentally injecting faulty user requirements based on misunderstandings, which later are exceedingly difficult to correct

HCI is hard

- HCI requires a unique combination of skills that almost no student receives from basic education
    - The skills cover software development, such as understanding software architectures and programming user interfaces
    - Analytical skills, such as formal modeling of a user's performance
    - Design practice, for example, interaction design, service design, or product design
    - User research skills, such as carrying out and analyzing experiments, conducting interviews, and engaging in field studies

Types of research in HCI

- **Empirical problems**
  - Developing accounts of phenomena in interaction grounded on empirical data
  - An empirical research problem is generally motivated by a lack of understanding of some aspect of interaction
  - For example, an empirical problem is to understand how people discover and learn to use features in an interface, or to understand the consequences of social media on relationships
- **Conceptual problems**
  - Explaining previously unconnected phenomena occurring in interaction by reference to theoretical constructs
  - Conceptual problems involve hypotheses, explanations, theories, and models
  - For example, conceptual problems may concern reconciling different views of what privacy is, or to build a theory of what it means for users to feel immersed in virtual reality
- **Constructive problems**
  - Tackling the knowledge needed for constructing interactive systems for some stated purpose in human use of computing
  - This understanding does not need to be expressed formally in terms of models
  - Constructive problems may just as well concern visions for building brain-computer interfaces or guidelines that help designers create accessible user interfaces

HCI practice

- Hundreds of thousands of professionals around the world engage daily in designing, implementing, and evaluating interactive systems

- HCI practitioners hold different and continually evolving professional titles, such as interaction designer, usability specialist, HCI specialist, user interface engineer, user researcher, behavioral analyst, and user experience designer

- HCI practice has itself been a focus of HCI research

What do HCI practitioners do? (1/2)

- Many HCI practitioners work to create an understanding of users and their activities
  - This may involve the analysis of the tasks that users do or the collection of empirical data that focuses on the activities and work of users
  - To inform practical decisions, they perform requirements gathering, benchmarking against competitors, task analysis, and user studies in the real world
  - **Empirical research** forms the basis of their methodology
- Most actively contribute and often drive constructive activities
  - They design and prototype interactive systems, such as mockups or sketches
  - A user interface designer may use digital tools to sketch wireframes of graphical user interfaces
  - The design of those tools has a significant impact on their work and, thereby, the world
  - They use methods from **design and engineering**, including those for wireframing, sketching, and prototyping

What do HCI practitioners do? (2/2)

- HCI practitioners also evaluate interactive systems from the user's perspective, for example, by testing the systems with users or by doing expert reviews
  - Many of these methods have roots in behavioral and social sciences, especially psychology and sociology
  - They rely on **evaluation** methods
- HCI practitioners engage with other professionals, for example, marketing professionals and software developers, as well as other stakeholders including representatives of clients and end-users
  - Occasionally the structure of such engagements is systematized into a process model
  - Often success in such engagements is outside any process and defined by one's ability to **communicate and persuade**
  - Such soft skills are important to influence decision makers and opinion leaders in relevant organizations

# Fundamental Concepts

Fundamental concepts
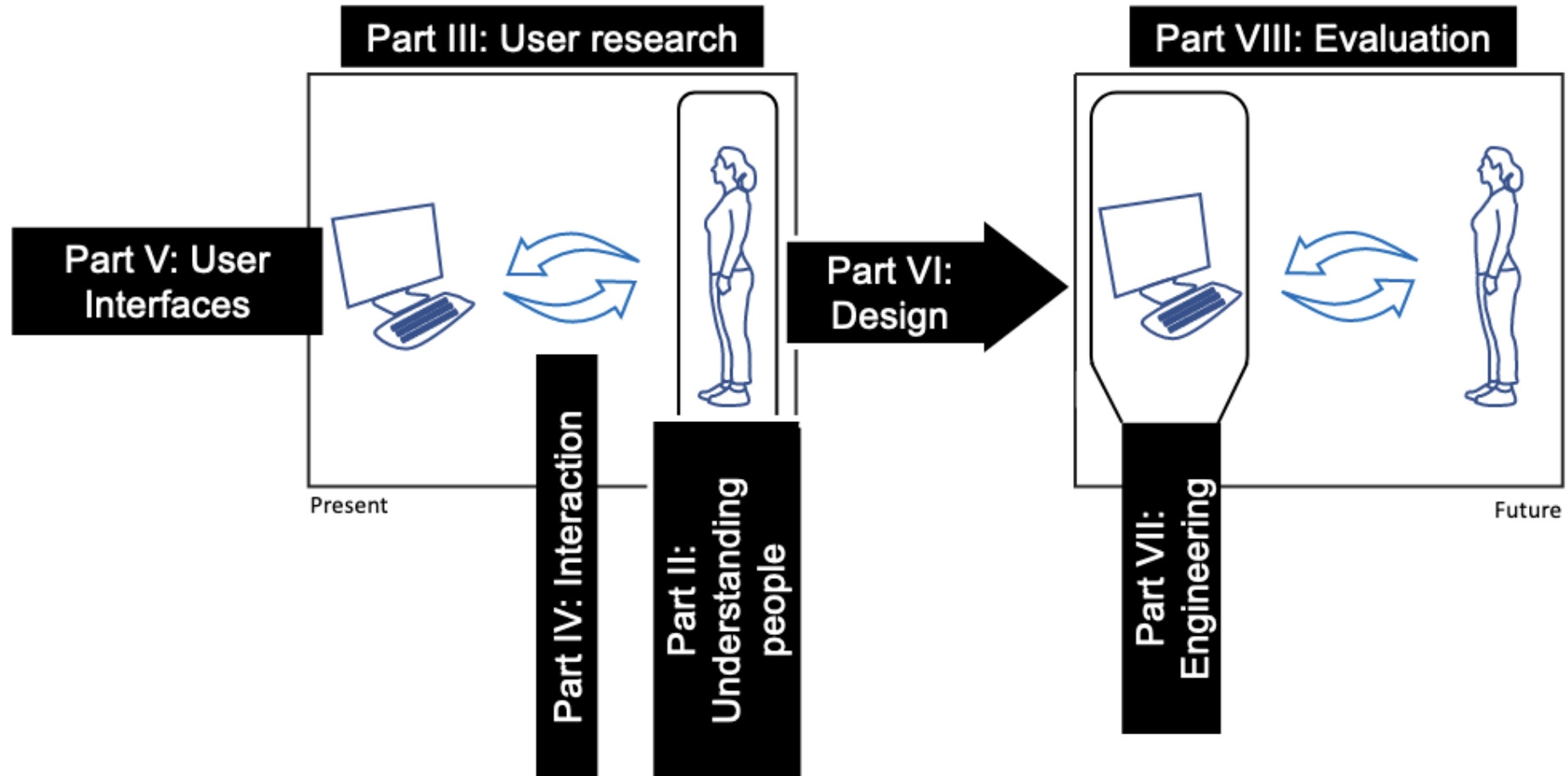
Human-centered (1/2)

- HCI focuses on the people who use an interactive system or are affected by its use
  - This focus is often called being **human-centered** to contrast it with a focus primarily on the technology itself
  - Human-centeredness distinguishes HCI from many other technical disciplines
- Being human-centered has three immediate and deep implications:
  1. A requirement to understand users, including their needs and motivations
  2. A requirement to engage with people as part of research and design
  3. A requirement for an ethical consideration of how an interactive system may directly or indirectly affect people

Human-centered (2/2)

- Systems should *match* people, rather than requiring people to match the system
- We strive for the best possible understanding of people
- We engage with people as part of any research and design with the goal of understanding people's *specific* concerns and practices
- Implies a particular ethical stance towards people
  - This stance means that the primary rationale for any practical decision should be rooted on understanding of the people using or affected by the system
  - There is a responsibility to avoid harm and try to find the best possible solution for people

# How theories of HCI shed light on interaction
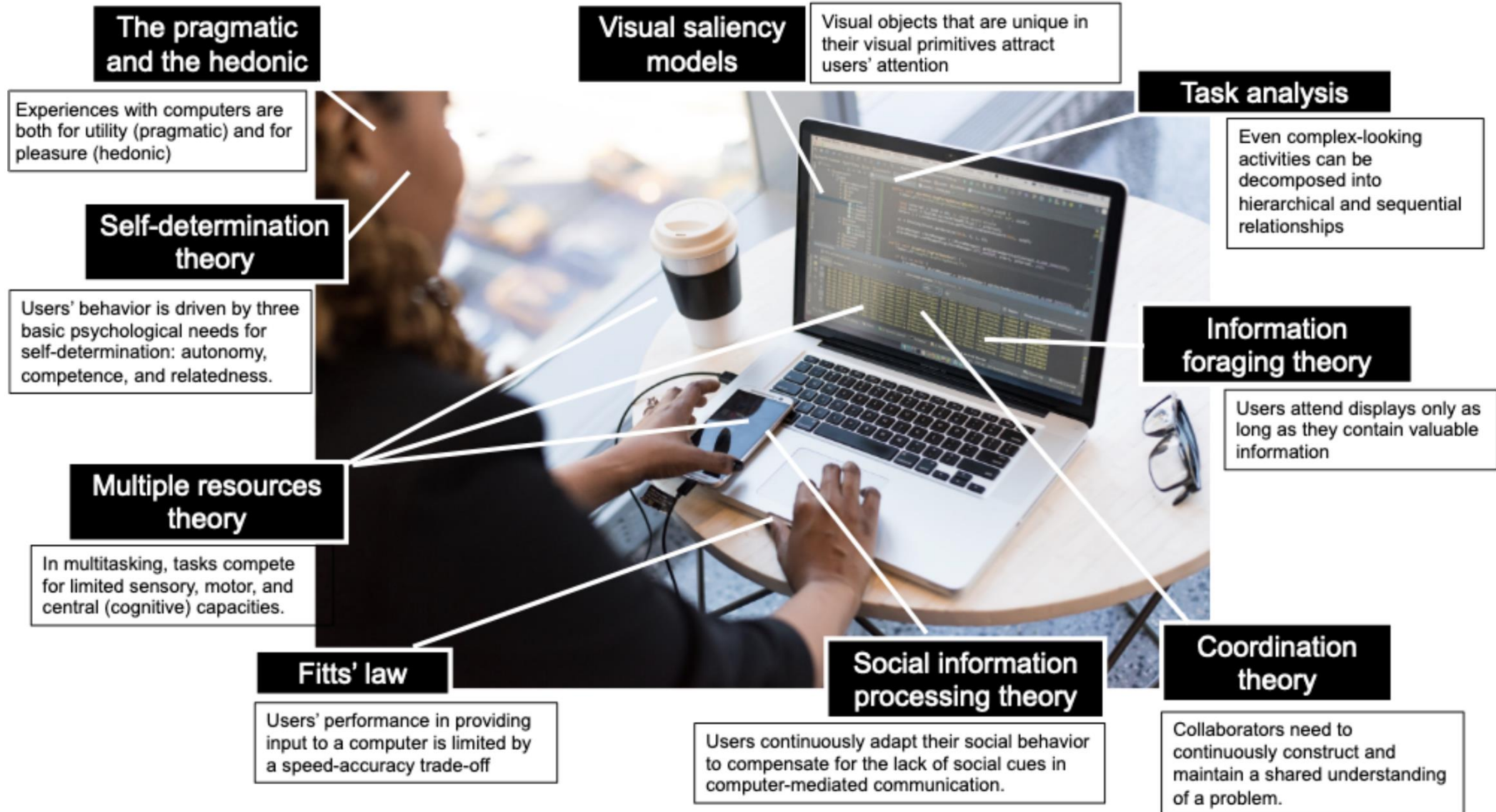
Interaction

- **Interaction** refers to the reciprocal influence between people and an interactive system that takes place through the user interface
  - It is not a property of the system design nor that of the user, but something that **emerges** when they influence each other
- The interactive relationship between human and computer can be complex, because it is not singularly defined by the user nor the computer
  - However, interaction is often more complicated than this because it is also affected by specific activities and the context of use
  - This is a pervasive aspect of HCI that even concerns the most mundane consideration
- Interaction often involves co-adaptation between people and computers
  - Such co-adaption can happen without hands-on contact, through changing work practices, or by fundamentally changing values or habits
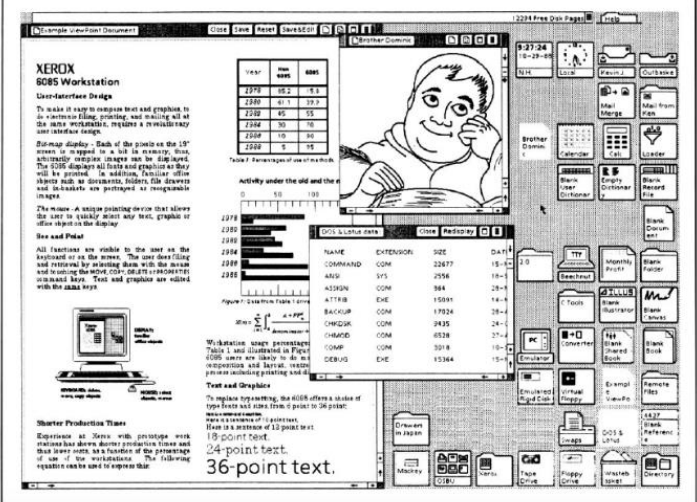
User interfaces

- A **user interface** refers to those parts of an interactive system that the user comes into contact with or that in other ways shape the users' perception of the system
- Design is almost invariably concerned not only about the user interface but also the broader system
- The user interfaces that HCI studies are continuously changing
  - The 1970s and the early 1980s saw a lot of work on command-line interfaces, for example, research on the naming of commands and the syntax of command-line arguments
  - The 1980s show pioneering work on the Xerox Star, a personal computer with a graphical user interface using the desktop metaphor
- Despite continuous developments, research on user interfaces can draw lessons from previous work
- For example, spoken-dialogue systems build on work on command-line interfaces, augmented reality interfaces contain menus that are similar to those of graphical user interfaces, and so on

Sensorama, U.S. Patent, 1962, provided one of the first virtual reality experiences
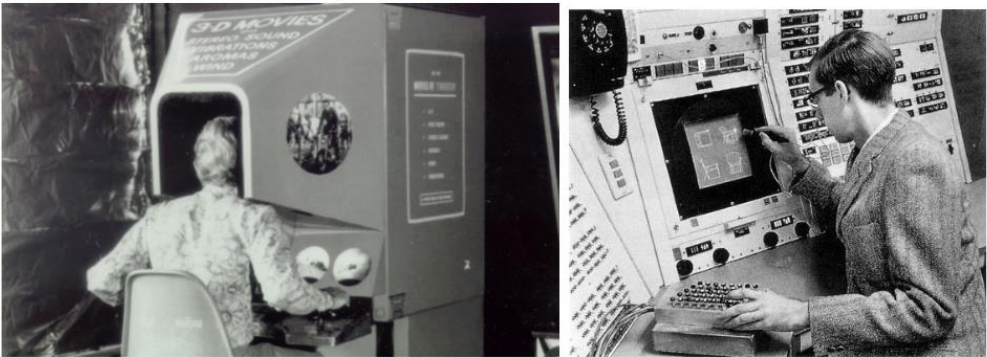
Sketchpad, published in the journal *Simulation* in 1964, is one of the earliest graphical user interfaces

The Hypertext Editing System, developed around 1969, enabled users to follow hypertext links by selecting them with a pen

The Xerox Star, presented around 1981, presented a graphical user interface with the familiar desktop metaphor

Design

- HCI aims to change the world by designing human-centered systems
- **Designing** is a process of arriving at a plan, specification, prototype, system, or service—a design
- Design can involve a user interface and relevant parts of the underlying interactive system but also a service

- Design is about envisioning things as they *could* be

Engineering

- **Engineering** refers to using technical principles, such as mathematics, science, and technical know-how, to realize a design that best meets a given set of expectations
- Several **emergent** qualities of an implementation are important to users, including the performance, safety, robustness, and explainability of a system
- When HCI researchers are engaged with such engineering problems, they need to integrate their understanding with the theory and practice of engineering and computer sciences
- While there are many engineering and technical challenges in creating interactive systems, HCI focuses on those challenges that matter to people
- Early HCI research discovered that software design that assumes that users will make errors tends to work more reliably
    - This had deep implications on the design of software architectures
    - For example, allowing users to reverse their actions—providing an undo feature—can be surprisingly difficult to implement well, demonstrating that such concerns are not simply features to be added later on

Evaluation (1/2)

- **Evaluation** refers to an application of some systematic methodology to attribute some human-related value to an artifact, prototype, system, or process
  - Examples of such attributes include performance, experience, and safety or ethical aspects, such as an avoidance of bias or harm
- Verification, validation, and testing are variants of evaluation
  - **Verification** means ensuring that the design meets all requirements and constraints imposed for the design task
  - **Validation** means ensuring the design is fit for its intended purpose
  - **Testing** (such as usability testing) refers to carrying out evaluation by means of trying something out in realistic conditions

Evaluation (2/2)

- HCl evaluations almost always **use multiple methods**
- In HCl, we need to arrive at robust, generalizable, and reproducible findings that practical decisions can be based on
- It is often naïve to expect a single or just a few evaluation methods to be sufficient, because these methods complement each other
- Practitioners deploy a plurality of evaluation methods ranging from ethnographic studies and interviews to studying log files, conducting controlled experiments, and analyzing computational models
- In HCl practice, evaluation is closely coupled with iterative design
  - Most design processes incorporate evaluation as an ongoing activity throughout all design, build, and deployment activities

Why HCI Matters

Interactive systems are difficult to use (1/3)

- HCI was born out of the realization that interactive systems are difficult to use

- As interactive systems begun to be used by non-computer experts, it became increasingly clear that many users had difficulties in understanding how to provide input and how to interpret output

- We have all used interactive systems that exhibited unexpected behavior and difficult-to-understand instructions, requiring us to work around stumbling blocks or give up using the system altogether

Interactive systems are difficult to use (2/3)

- A study found that frustrating episodes with computers occur frequently due to error messages, faulty network connections, long download times, and hard-to-find features
  - Shockingly, about half of the time spent on the computer was lost to such incidents
- These challenges may seem minor, but over time, they compound and can have unexpected and unfortunate downstream consequences
- For example, consider how poorly some user interfaces support aging users, some of whom may struggle to use computers for even basic tasks
  - Such struggles are known to affect users' willingness to use computers, and, thereby, also their ability to benefit from computers, with negative effects on their ability to participate in society

Interactive systems are difficult to use (3/3)

D. A. Norman. The psychology of everyday things. Basic books, 1988.

- The door to the left signals it needs to be pushed but actually needs to be pulled

- There is no hint on how to open this door

- A sliding door, but this is so unclear there is a sign to point this out

The egocentric fallacy

- People are complex, beyond intuition, and not all people are alike
- It is an **egocentric fallacy** to assume that others are like us—to attempt to explain other people by reference to one's own experience
- You are often *not* the user
- Intuition can only go so far and is often misleading
- A good example is HCI research on mental models
  - People have vastly different beliefs about how calculators work and these beliefs can explain errors and issues they have when using calculators
  - For instance, many people think that they need to press "clear" (or the equivalent) multiple times when using a calculator

It is the right thing to do

- Being human-centered is a value of its own
- We have a responsibility to take the needs and abilities of other people seriously when designing technology
- In the words of designer Dieter Rams: "Indifference towards people and the reality they live in is the one and only cardinal sin in design"
- HCI has the potential to have a positive impact on the world, and HCI research can cause less bias, less frustration, and greater well-being
- In a classic book, Landauer (1995) argued that computers are difficult to use and that this is why, at the time of writing, they failed to improve the productivity of the companies that invest in them
  - Landauer (1995) argues that a duty of HCI is to improve computers

T. K. Landauer. The trouble with computers: Usefulness, usability, and productivity. MIT press, 1995.

HCI is profitable

- HCI also has financial value when done correctly, as it can help open up and conquer new markets, increase productivity, and lower costs

- Investments in HCI pay off

- Analysis of investment return has found several-fold returns for every investment that a company make in HCI

- User interfaces and interaction design constitute a significant part of nearly all technology projects

- In 1992, Myers and Rosson found that 48% of the software code was related to the user interface
  - This means that getting anything relating to the user interface right early is important and that fixes to the user interface that are only discovered when the interactive system is deployed are very costly

B. A. Myers and M. B. Rosson. Survey on user interface programming. In Proceedings of the Conference on Human factors in computing systems, pages 195–202, 1992.

HCI invents the future

- HCI is well-positioned to invent the future
- Systems, products, and services go through constant life cycles of market introduction, growth, maturity, and decline
- Competition and changing demand create a need for existing systems, products, and services to evolve or be replaced with new alternatives
- HCI is critical to discovering ways to use new products, enjoy new services, and manage new systems

Market-pull and technology-push

- **Market pull:** sensing there is market demand for a new offering
  - HCI with its rich plurality of human-centered research methods is eminently suitable for capturing users' needs and wants and framing such findings as actionable design know-how
- **Technology push:** new technology is injected into the market and thus generates new demand for something that was previously unavailable
  - There are many visions and research discoveries in HCI that have changed how we view computer use, such as ubiquitous computing, tangible interfaces, and virtual and augmented reality

Douglas Engelbart's *mother of all demos*: a vision of using computers to augment the human intellect that predated collaborative and distributed writing, among many other things (1968)

The *Dynabook* created by Kay and Goldberg: a vision predating tablets, and containing many ideas for creative and programmable use of media (1977)
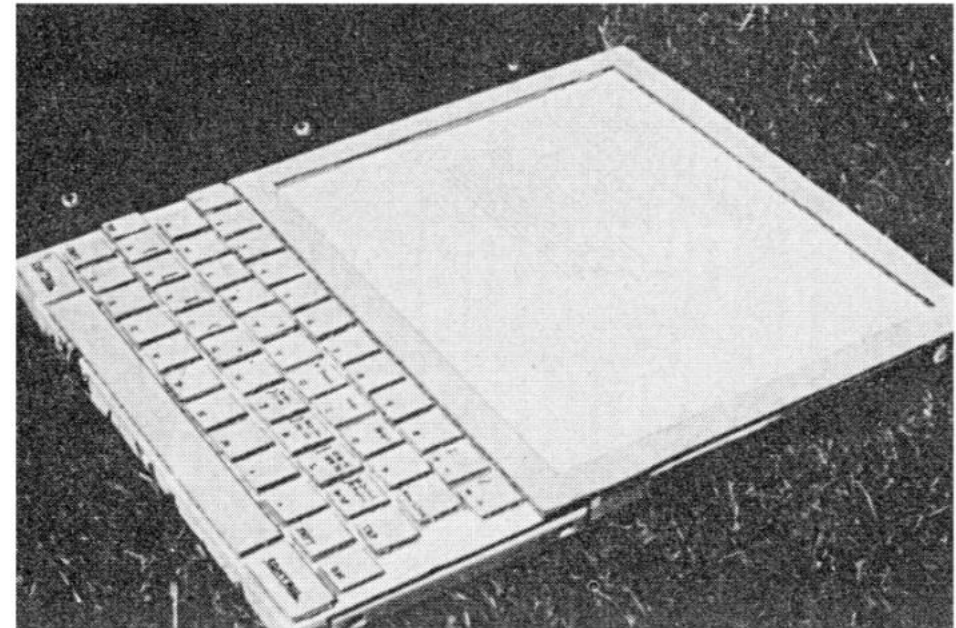
Approach

Principles

- We focus on **principles and skills**

- By *principle* we refer to a foundational idea or rule that explains or controls how something happens or works in human-computer interaction

- For example, Direct Manipulation is a principle for organizing the interaction with graphical user interfaces
  - The principle states that computational objects must be presented on a display and acted on by the user through direct, reversible, and incremental actions with immediate feedback

Pluralism in methods and theories

- All methods are limited and consequently we will cover a range of different research approaches and methodologies
- We will cover the views of science, design, and engineering as ways of knowing in HCI
- HCI phenomena can be studied from many perspectives, all of which are relevant
  - This is a form of **theoretical pluralism**
  - HCI phenomena span eye movements, emotional reactions, aesthetic experiences, social interactions, and organizational structures
  - It spans behaviors at the millisecond level to changes in the use of interactive systems over decades
  - It spans individuals, groups and societies

Essential insights supported by research

- We focus on essential insights in HCI
  - Rather than analyzing current user interfaces or enumerating the vogues of HCI research as found in present-day research
- We have distilled those principled insights that we think will hold and be valuable to academics and practitioners for decades
- We have picked those essential insights that we believe are supported by evidence, possibly in other areas of scholarship than HCI
- We will explain empirical findings relating to principles, insights, and methods

Optimism that HCI problems are solvable

- Many of the world's most successful systems are based on HCI research
  - Mobile devices, Wikipeda, search engines, extended realities, and computer games, etc.
- Current key technologies—such as e-commerce systems, social media, augmented reality, text input and editing—have been shaped by HCI
- For a surprisingly large number of problems in HCI we actually have suitable methods or actionable insights
  - Frequently there are known answers in HCI
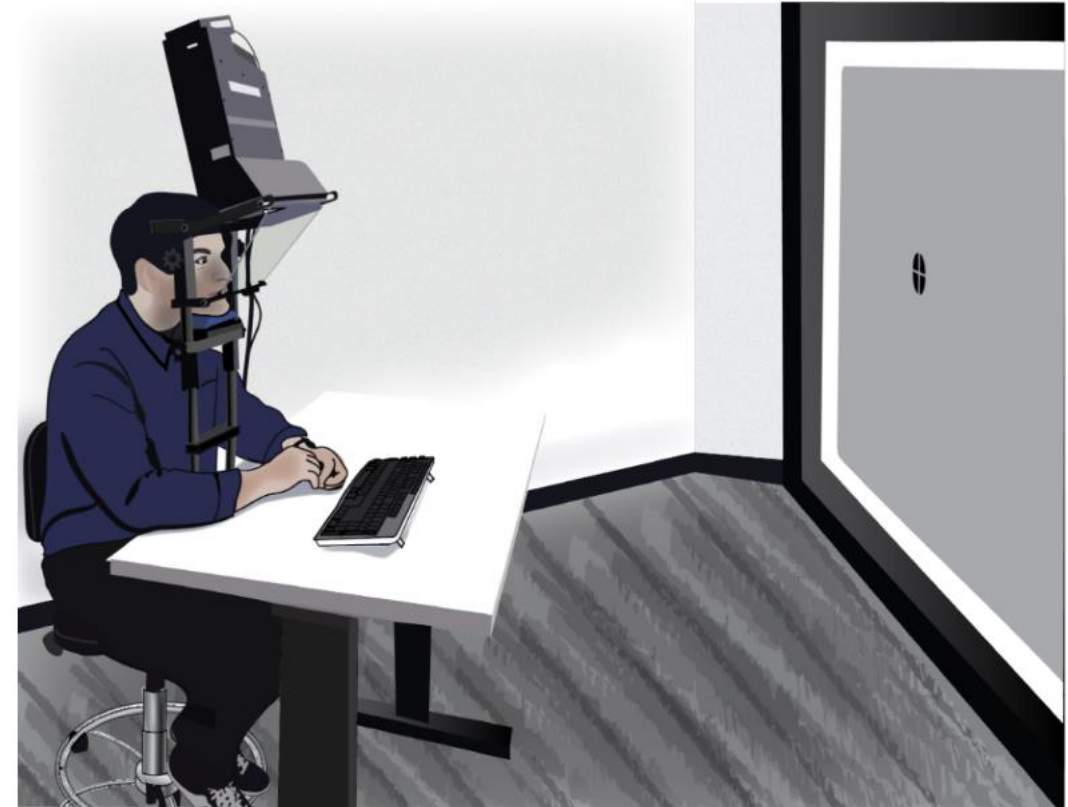 - This does not mean that HCI, like any technology, is always the answer

Economic impact of HCI

HCI/UXD: Large Economic Impact

B. Shneiderman. Revisiting the astonishing growth of human–computer interaction research. IEEE Computer, 50(10):8–11, 2017.
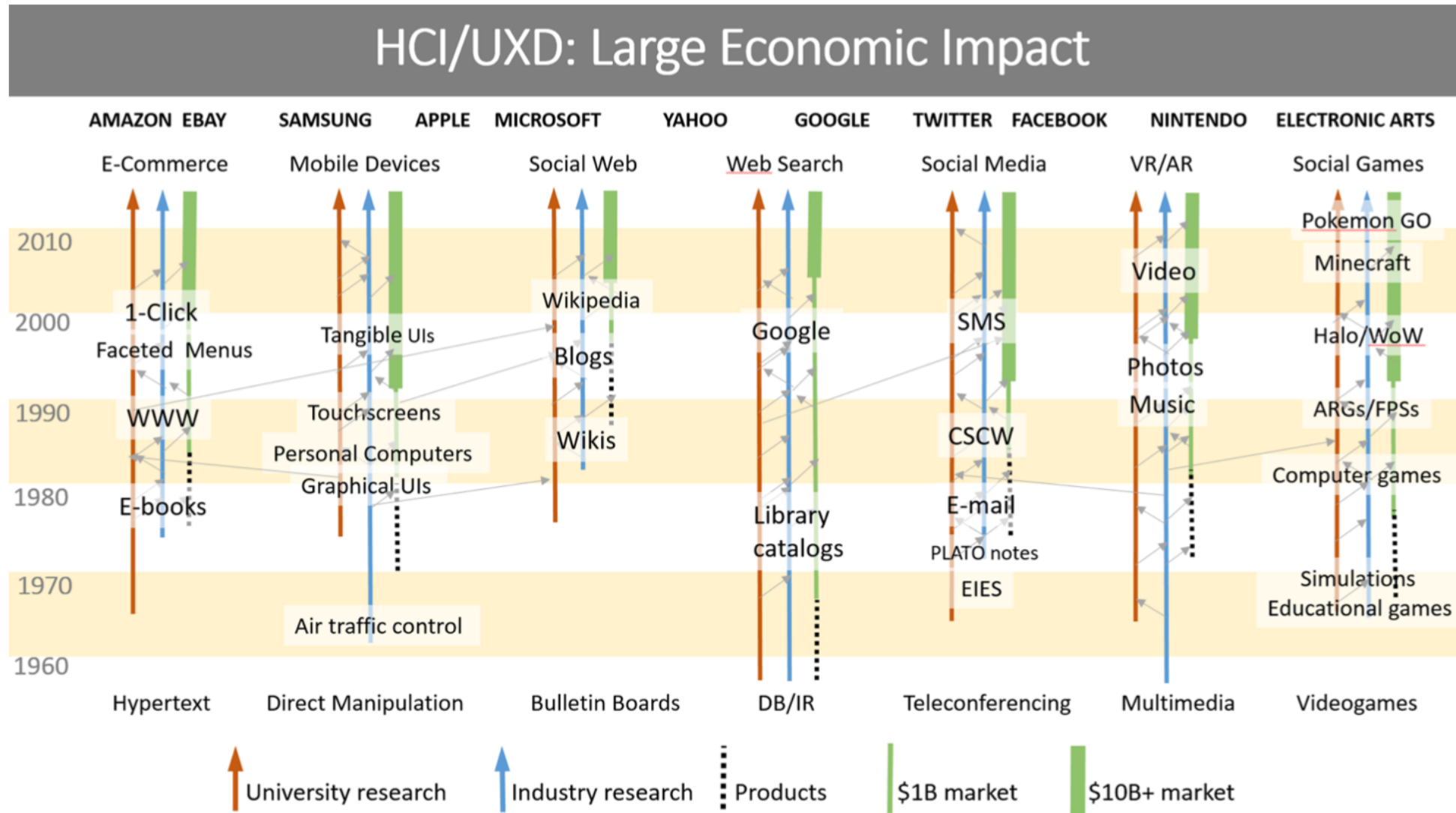
HCI Examples

Understanding people: can Fitts' law explain gaze-based selection tasks?

- Fitts' law is a model that is frequently used to calculate the average movement time it will take a user to select a target
  - Does Fitts' law also accurately predict target selection tasks when users are using an eye-tracker?
  - The literature around this topic is divided as Fitts' law is meant to describe movements under continuous control while eye gaze moves in ballistic motions due to a phenomenon known as saccades—rapid eye movements from one point to another
- The researchers find that difficult to reach targets follow Fitts' law but easy to reach targets can be reached using a single saccade in near constant time

I. Schuetz, T. S. Murdison, K. J. MacKenzie, and M. Zannoli. An explanation of Fitts' law-like performance in gaze-based selection tasks using a psychophysics approach. In Proceedings of the Conference on Human Factors in Computing Systems, pages 1–13, 2019.
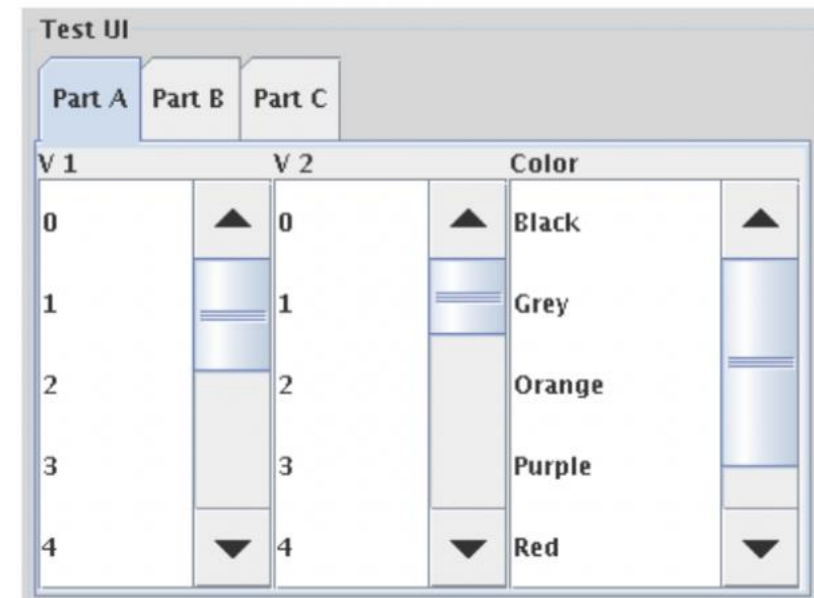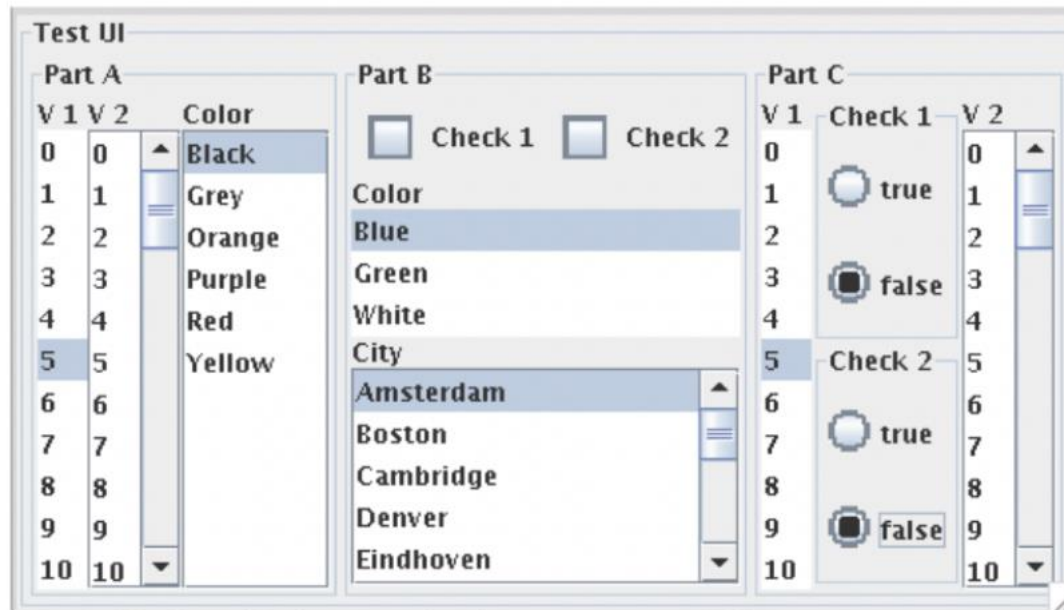
User research: ethnography of system administrators

- Thanks to extended immersion to the lives of the participants, ethnographic research can illuminate technically specialized user groups
  - One such group is system administrators
- To understand their practices, the researchers observed web and database administrators for 25 days, a total of over 100 hours of recorded materials
  - They followed a mixed-methods approach consisting of diaries, interviews, and observation
- The paper showed that the work of system administrators includes hours of troubleshooting complex information, tools, and organizational knowledge
  - Yet, existing tools that sysadmins use do a poor job supporting such tasks
- Most importantly, the tools are opaque, leading to system adminstrators creating their own custom-made tools

R. Barrett, E. Kandogan, P. P. Maglio, E. M. Haber, L. A. Takayama, and M. Prabaker. Field studies of computer system administrators: analysis of system management tools and practices. In Proceedings of the ACM Conference on Computer Supported Cooperative Work, pages 388–395, 2004.

Interaction: generating user interfaces based on users' abilities

- Supple++ is an example of a computational method developed in HCI that can improve graphical user interfaces to better fit a user's unique motor abilities

- Supple optimizes a custom interface based on series of motor tasks

K. Z. Gajos, J. O. Wobbrock, and D. S. Weld. Automatically generating user interfaces adapted to users' motor and vision capabilities. In Proceedings of the Annual ACM Symposium on User Interface Software and Technology, page 231–240, 2007.

User interfaces: *Botanicus Interactus*

- Interaction does not necessarily need to be limited to artificial objects, such as displays

- An example is *Botanicus Interactus*, which allows interaction with living and artifact plants

- It works by exciting the plant with an electrical signal at multiple frequencies that span a range of 0.1 to 3 MHz
  - Since the electrical signal path inside the plant varies by frequency, it is possible to infer touch locations by analyzing the frequencies which have affected the signal using machine learning methods

I. Poupyrev, P. Schoessler, J. Loh, and M. Sato. Botanicus interacticus: interactive plants technology. In ACM SIGGRAPH 2012 Emerging Technologies, 2012.
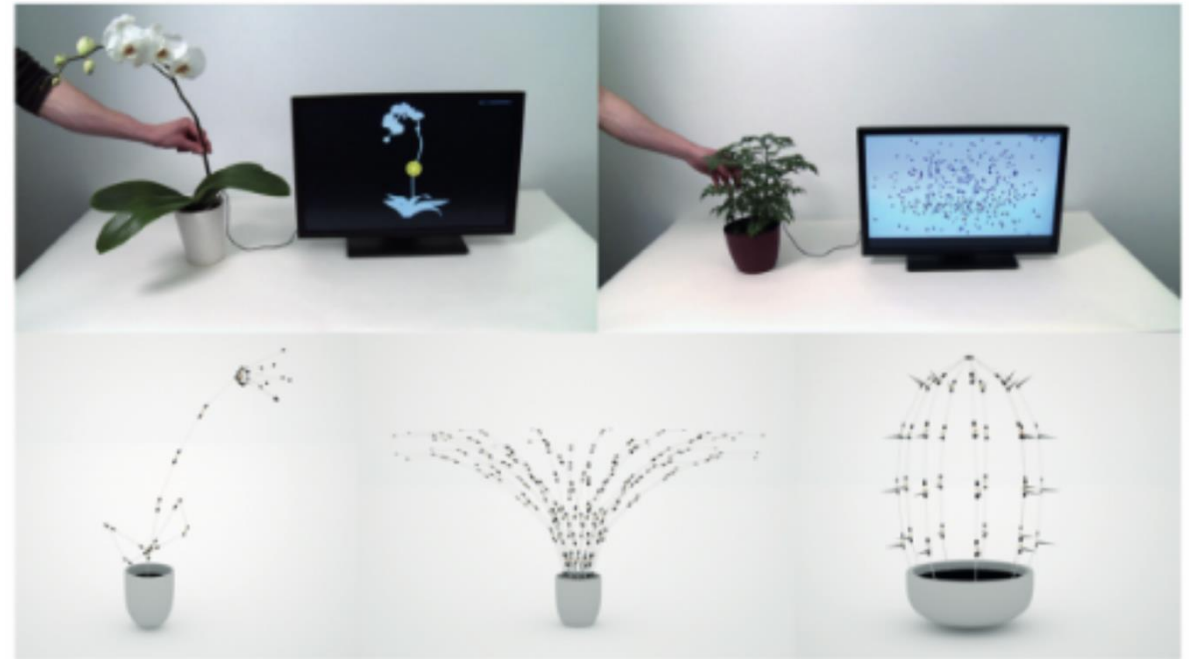
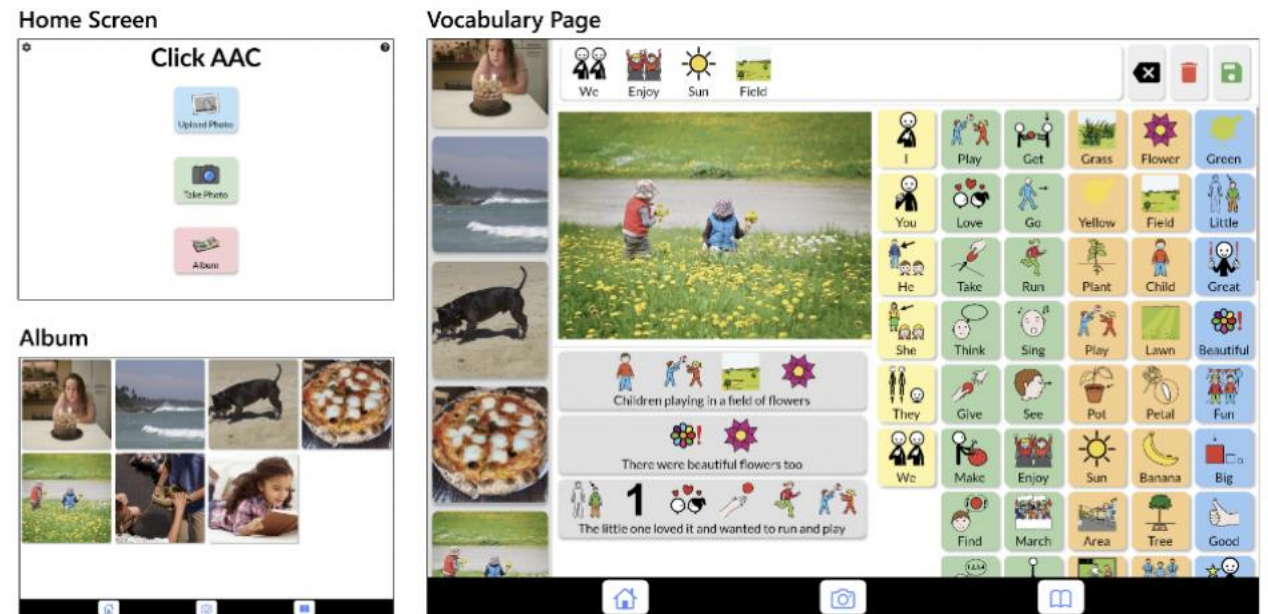# Design: value-sensitive design of AI algorithms

- Intelligent systems are often developed in an algorithm-centric manner
- To help develop algorithms in a human-centric manner, researchers used a value-sensitive design approach for a socialization algorithm for WikiProjects
  - In WikiProjects, members can seek and help collaborators, organize joint activities, and manage social interactions to collectively decide edits to Wikipedia
  - However, these communities were suffering from unwarranted reverts and edit wars
- The study recruited specific users in each stakeholder group and worked with them to evaluate the different algorithmic prototypes, using both qualitatively and quantitatively using ratings
- The study exemplifies how value-sensitive design calls for situating an algorithm as part of a system rather than as merely a relationship to data, like a traditional machine learning research

H. Zhu, B. Yu, A. Halfaker, and L. Terveen. Value-sensitive algorithm design: Method, case study, and lessons. Proceedings of the ACM on human-computer interaction, 2 (CSCW):1–23, 2018

Engineering: why Alice and Bob can't encrypt

- The availability of security technology does not guarantee that security is established
  - For this to happen users have to be able to achieve their goal of security and this is only possible if the interfaces that they have to interact with are usable
- The study explored the reasons why end-users are unable to use the graphical user interface for the encryption program Pretty Good Privacy (PGP) 5.0
  - PGP enables users to encrypt and decrypt text as a means for secure communication, for instance, by email
- The user study asked 12 educated participants experienced with email to use PGP to send secure email
  - Only one third of the participants were able to correctly sign and encrypt an email
  - A quarter of the participants also exposed the secret key by inadvertently sending it in an unprotected email they believed had been correctly encrypted
- Following basic user interface design principles is insufficient to ensure usable security

Whitten, Alma, and J. Doug Tygar. Why Johnny Can't Encrypt: A Usability Evaluation of PGP 5.0. USENIX security symposium. Vol. 348. 1999.

Evaluation: using an app to reach AAC professionals in the field

- Augmentative and alternative communication (AAC) is a field investigating techniques and approaches for enabling nonspeaking individuals with motor disabilities to communicate

- The study proposes a symbol communication device that uses computer vision to generate symbols for photos

- The researchers evaluated the app by finding AAC professionals through a public app store

- This enabled the researchers to carry out in-depth interviews with AAC professionals, reporting on the usefulness of the app for their users *in-situ*

Fontana de Vargas, Mauricio, Jiamin Dai, and Karyn Moffatt. AAC with Automated Vocabulary from Photographs: Insights from School and Speech-Language Therapy Settings. *Proceedings of the ACM SIGACCESS Conference on Computers and Accessibility,* 2022.

Summary

- Computing is a powerful tool: interactive systems and user interfaces help control and tame it

- Human-computer interaction is concerned with people, creating technology, and understanding interaction

- Essential activities in HCI are understanding people, studying what users need and want, designing and engineering interactive systems, and evaluating their benefits for users

- HCI is important because *you are not the user*
  - HCI offers a disciplined approach to some hard problems faced in design and innovation

Reflective exercises

1. Can you identify the user? Identify three relevant user groups for the following systems: (1) a mobile phone app allowing users to view timetables for buses in their city; (2) an online banking website; (3) an educational website that teaches children early stage mathematics; and (4) a C++ compiler (a piece of software that translates program code into machine code)

2. Analyze the bottleneck. Think about a product or service you frequently use and consider a feature or function you find annoying or frustrating. Why do you find this feature or function annoying? What are you trying to achieve? Why is it difficult to achieve? What are the assumptions that the product or service is making that cause the bottleneck? Can you think of all the relevant factors that determine the function or feature? Can you think of a redesign that might work better? Why do you think that your redesign would solve the problem? How would you test your assumptions?

3. Approaches to a problem. HCI is pluralistic, but what does this mean in practice? Consider being responsible for a multidisciplinary effort to improve the usefulness and usability of a social media application. How might the following disciplines contribute to such effort: (1) psychology, (2) computer science, (3) design?

- Open access (PDF at link)
- Further reading:
  - Chapter 1: Introduction to human-computer interaction