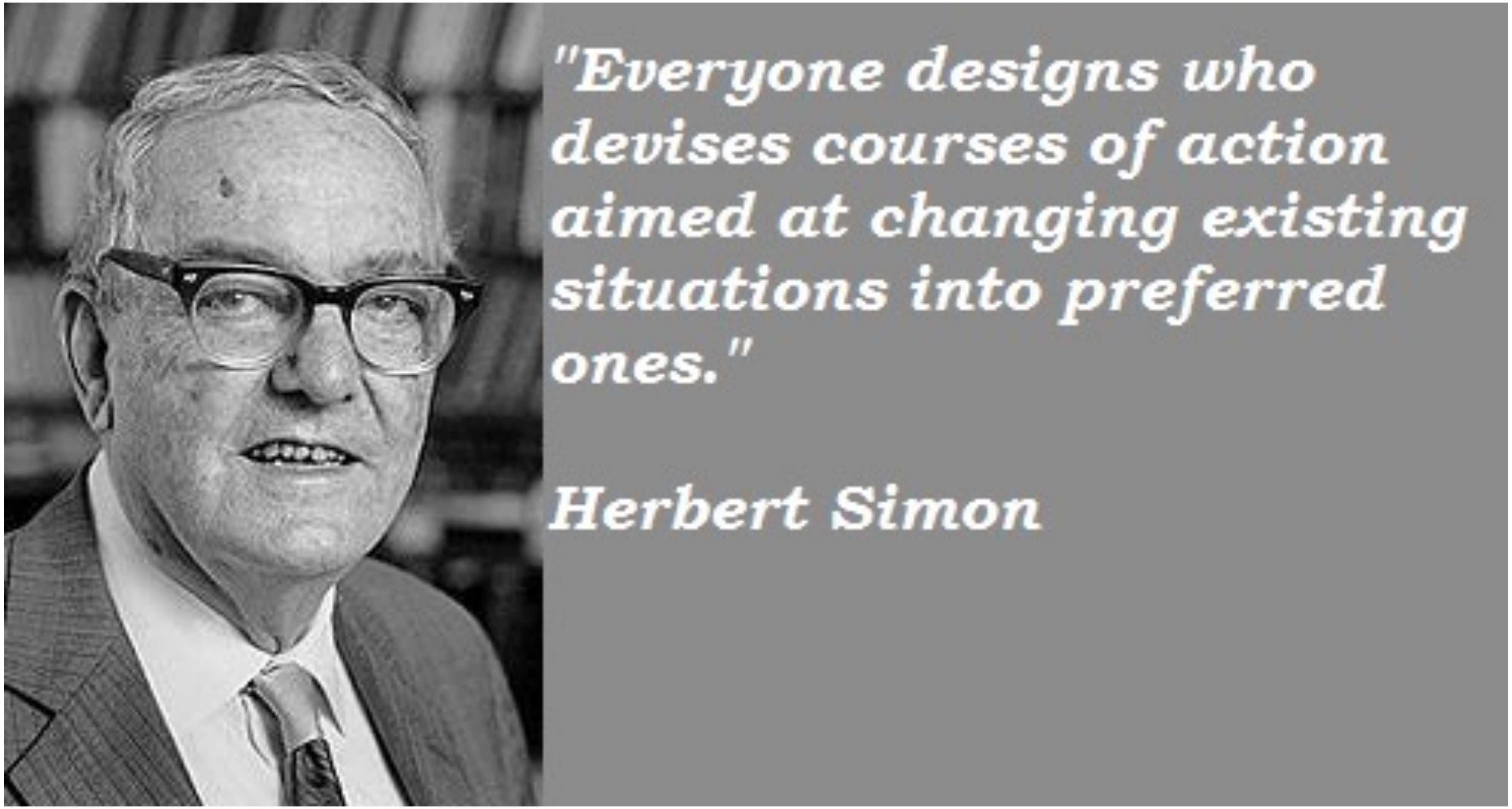
Research Methods: Methods in Design and Engineering

Hans Gellersen

Learning Goals

- Understand
  - How research in design and engineering fields (incl. computer science) is different from research in ‘classic’ sciences
  - Design and evaluation as the main methodological concern
  - Different types of experimental research for different purposes
- Be able to
  - Discuss the relationship between design and research
  - Identify different types of experiments

Research in Design Fields



https://article1000.com/herbert-simon-administrative-behaviour/

“The Sciences of the Artificial”

Understanding the Natural and the Artificial Worlds

About three centuries after Newton we are thoroughly familiar with the concept of natural science most unequivocally with physical and biological science. A natural science is a body of knowledge about some class of things objects or phenomena in the world: about the characteristics and properties that they have; about how they behave and interact with each other.

Natural science is knowledge about natural objects and phenomena. We ask whether there cannot also be "artificial" science knowledge about artificial objects and phenomena.

Simon, Herbert A. 1996. *The Sciences of the Artificial* (3rd ed.)

Research in Design Fields

Scientific Tradition	Design/Engineering Tradition
Aim: Understanding the world	Aim: Changing the world
Concerned with knowledge and whether its true (validity)	Concerned with artefacts and solutions to problems
Discoveries	Products and inventions
Models, theories and laws	Processes, rules, heuristics
Know-that: propositional knowledge	Both “Know-that” and ”know-how”: procedural knowledge

Research in Design Fields

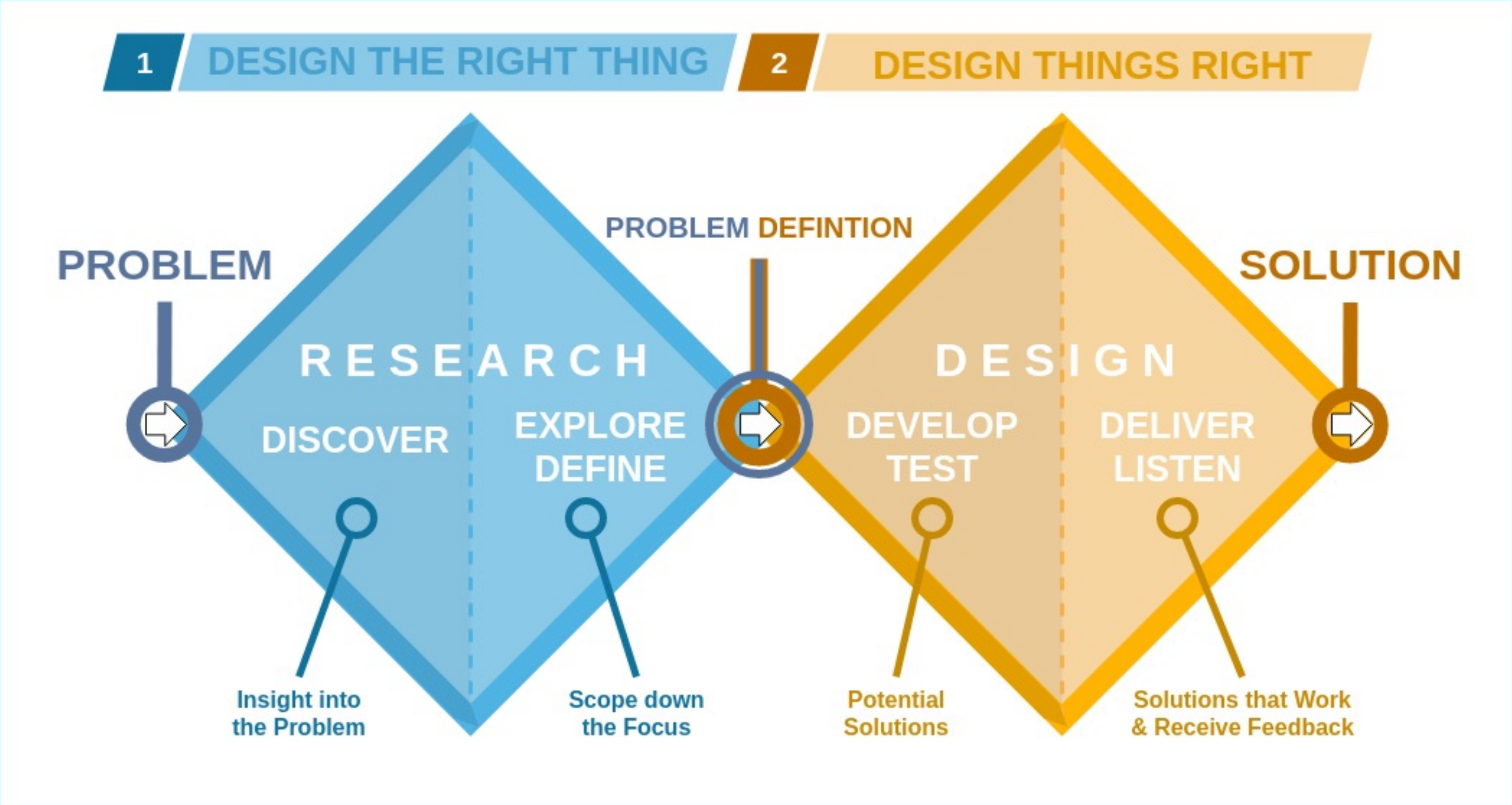
- Creation of artefacts plays a central role
  - “Build what you study, study what you build”
  - Making prototypes to explore specific aspects of the product/system
- Design and evaluation is the central methodological concern
  - Using methods to systematically explore and evaluate possible designs
- Experimental research
  - Experimental as opposed to theoretical: conducted “in the world” as opposed to “in the head”
  - Investigating “things” that are at an experimental stage: novel unfinished, not fully understood, or speculative in nature

“Research” versus “Design”

Doing Research	Work done with the intention to produce knowledge for use by others
Doing Design	Work done with the intention to produce a feasible solution to improve a given situation

Research for Design (RfD)	Doing research as part of doing design Using methods to generate knowledge needed for the design
Research through Design (RtD)	Doing design as part of doing research Designing artefacts/prototypes to (help) generate knowledge

Research for Design



Double Diamond

Design Process Model

“Design Research” Method

- Purpose
  - Study ideas and problems by creating solutions/manifestations
  - Learning via making
  - Answer design questions, e.g. What’s an effective way to achieve X
- Defining characteristics
  - Detailed description of the artefact, and/or its development
  - Demonstration and evaluation
  - Generates how-to knowledge, but the artefact itself is often seen as the primary research contribution

"Design Research" Example

Lancaster University

MixFab: A Mixed-Reality Environment for Personal Fabrication

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ABSTRACT

Personal fabrication machines, such as 3D printers and laser cutters, are becoming increasingly ubiquitous. However, designing objects for fabrication still requires 3D modeling skills, thereby rendering such technologies inaccessible to a wide user-group. In this paper, we introduce *MixFab*, a mixed-reality environment for personal fabrication that lowers the barrier for users to engage in personal fabrication. Users design objects in an immersive augmented reality environment, interact with virtual objects in a direct gestural manner and can introduce existing physical objects effortlessly into their designs. We describe the design and implementation of *MixFab*, a user-defined gesture study that informed this design, show artifacts designed with the system and describe a user study evaluating the system's prototype.

Author Keywords

personal fabrication; direct manipulation; 3D printing; mixed-reality; 3D modeling

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation: User Interfaces - Interaction styles

General Terms

Design; Human Factors

INTRODUCTION

Personal fabrication of 3D objects has been spurred by rapid advances in printing tools and techniques. The quality, speed,

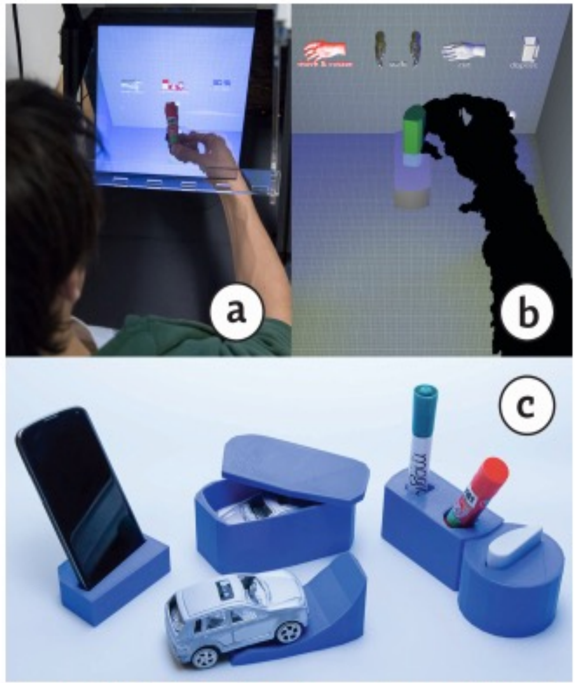


Figure 1. MixFab: mixed-reality environment for personal fabrication. (a) a user positioning a physical object in the MixFab prototype system, (b) screenshot of a user manipulating a virtual object, (c) 3D printed objects created with the system.

- A visionary UI for 3D product modelling
  - Manually shaping a virtual block into an object to be 3D printed
- Detailed description of the experimental system and its operations
- Walkthrough from user perspective, on fully worked example
- User study, demonstrating that users can produce artefacts in short time

“Design Research”: Use in Computing

- Research based on the creation of artefacts is the norm in computing
  - Artefacts: systems, algorithms, techniques, …
- Computer scientists and engineers would not think of this as a method
  - It is just implicit that the research involves construction of something
  - If they think of this as method, then they would call it ”experimental”
- A main focus is on technical detail to convey how-to knowledge
  - Reproducibility of the artefacts (e.g. algorithm)
- The artefact as such, or the process of making it can contribute knowledge
  - More commonly, other methods are used to evaluate the artefact and generate knowledge about it (e.g. experiments)

“Design Research”: Pros and cons

- \+ By definition creative: always scope for proposing new research
- \+ Good for what’s best understood by making it
- \+ Tangible outcomes to build on, in addition to know-how

- \- High demand on researchers in terms of technical skills
- \- Resource-intensive: build the subject of your research before you can study it
- \- High expectations on evaluation to be recognized as research
- \- How best to evaluate is often hard to determine

Design v. Research – Key points

- Research in design fields is characterised by a combination of research work and design work
- The creation of artefacts and prototypes plays a central role
  - Researchers study what they build
- Empirical research is concerned with rigour and reproducibility of method, and originality and significance of research findings
- Research in design fields is also concerned with rigour in technical detail, and novely and significance of the practical outcome

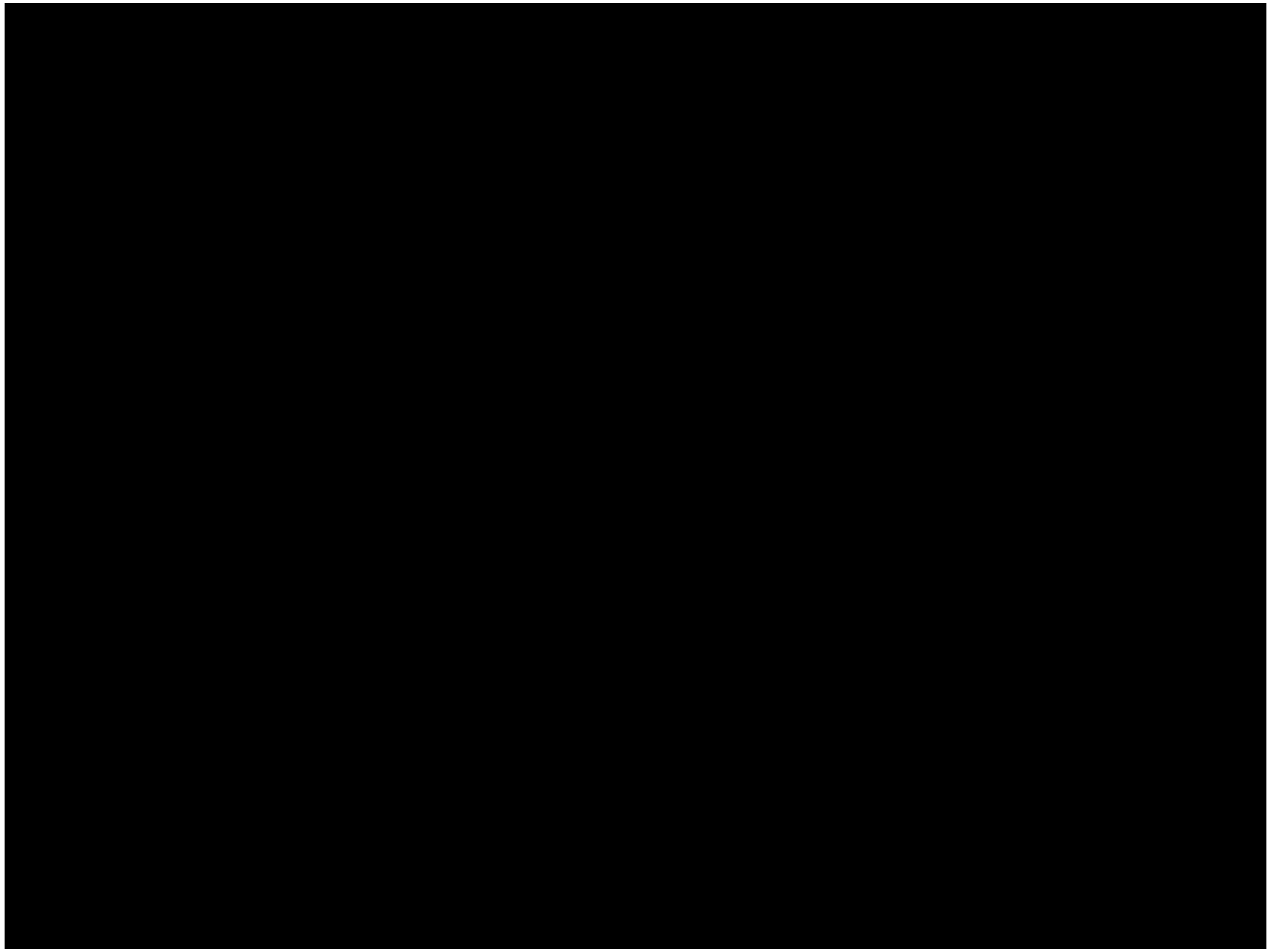
Experimental Research

Type	Focus
Proof of Concept	Demonstrating feasibility
Trial experiment	Analysing the performance of a system
Field experiment	Observing system performance in the real world
Controlled experiment	Assessing effects of system design choices
Comparative evaluation	Evaluation of alternatives, or against a baseline

Demonstration

- Purpose
  - Proof of concept
  - Demonstrating that something is feasible
  - Demonstrating novel capabilities of a system
- Characteristics
  - “Demo or Die”: minimal expectation to show that X works
  - No actual experiment
  - Effective for conveying technical advances

The Mother of all Demos



Douglas Engelbart, 1968

ACM/IEEE Computer Society's

Fall Joint Computer Conference

https://www.youtube.com/watch?v=fhEh3tEL1V4

Trial experiments / Tests

- Purpose:
  - Find out how well a prototype or system works
  - Characterise the performance of a system
  - Evaluate how it performs against some criteria

- Characteristics
  - Experimental in using test runs with parameter variation
  - Simulation is a common form of trial-experiment

Trial Experiments

Lancaster University

OpenLIDS: A Lightweight Intrusion Detection System for Wireless Mesh Networks

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ABSTRACT

Wireless mesh networks are being used to provide Internet access in a cost efficient manner. Typically, consumer-level wireless access points with modified software are used to route traffic to potentially multiple back-haul points. Malware infected computers generate malicious traffic, which uses valuable network resources and puts other systems at risk. Intrusion detection systems can be used to detect such activity. Cost constraints and the decentralised nature of WMNs make performing intrusion detection on mesh devices desirable. However, these devices are typically resource constrained. This paper describes the results of examining their ability to perform intrusion detection. Our experimental study shows that commonly-used deep packet inspection approaches are unreliable on such hardware. We implement a set of lightweight anomaly detection mechanisms as part of an intrusion detection system, called OpenLIDS. We show that even with the limited hardware resources of a mesh device, it can detect current malware behaviour in an efficient way.

Categories and Subject Descriptors

1. INTRODUCTION

Wireless Mesh Networks (WMNs) are self managing networks in which radio nodes participate in transmitting traffic from others to reach a destination, which they could not reach themselves. They are becoming increasingly popular as a way of providing Internet access in a cost efficient way [9, 18, 26]. In these deployments, clients connect to a mesh device, which routes their traffic via other wireless mesh routers in order to reach a mesh node with an Internet uplink. WMNs will typically use IEEE 802.11 to communicate between the wireless mesh routers, and a subset of these routers will have connectivity to the wider Internet.

In many cases, WMNs are operated by the community that uses them, and the hardware for the mesh devices are consumer-level wireless access points that run a customised version of the Linux operating system. These devices are cost-effective, but are usually constrained in processing and memory resources. Cost-effectiveness in a community network is crucial, as more expensive hardware could prevent users from contributing.

By generating malicious traffic, malware infected computers use valuable network resources and put other systems at risk. A fundamental tool in defending against malicious

- A (then) new intrusion detection system
  - How to detect intrusion in resource-constrained networks
- Use of trial-experiments to evaluate system performance
  - Generating test traffic
  - Measuring CPU utilization, packet drop rate, etc

Field experiments

- Purpose
  - Observing how well a systems works under real-world conditions
    - e.g. noisy, imperfect infrastructure
  - Evaluating system behaviours that are not internal to the system but relative to the system’s surrounding and context

- Characteristics
  - Testing in the context of use, “in situ”
  - Research in “Living Laboratories” or “In the wild”
  - Less control but high ecological validity

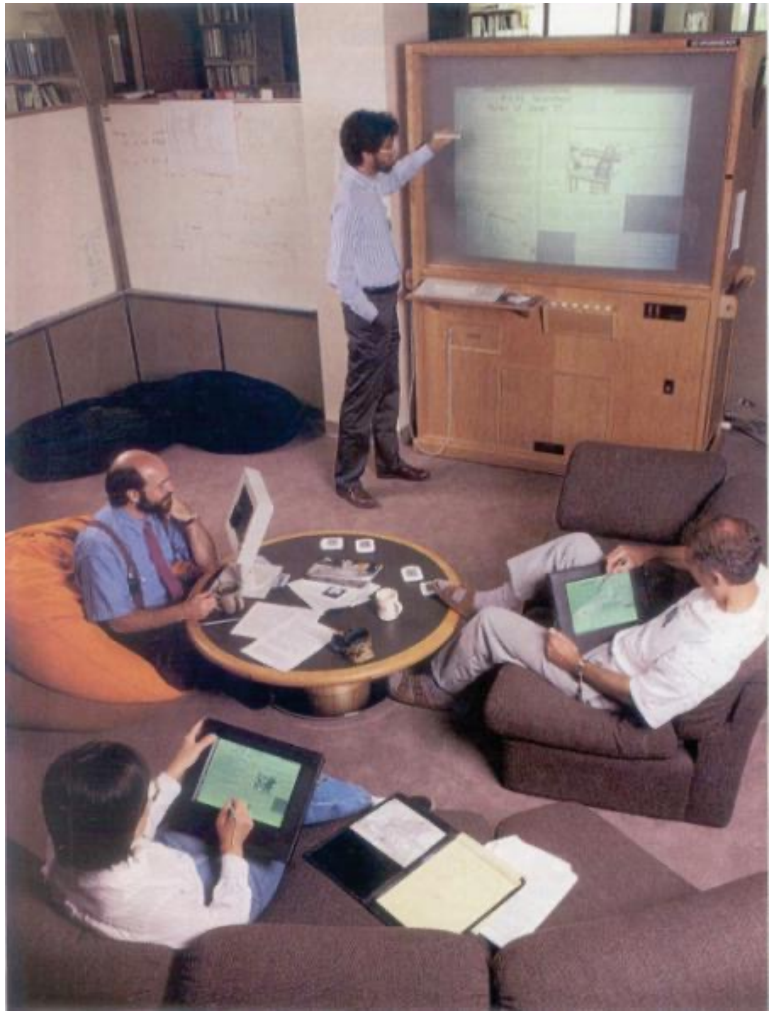
Living Lab: Ubiquitous Computing Project

Lancaster University

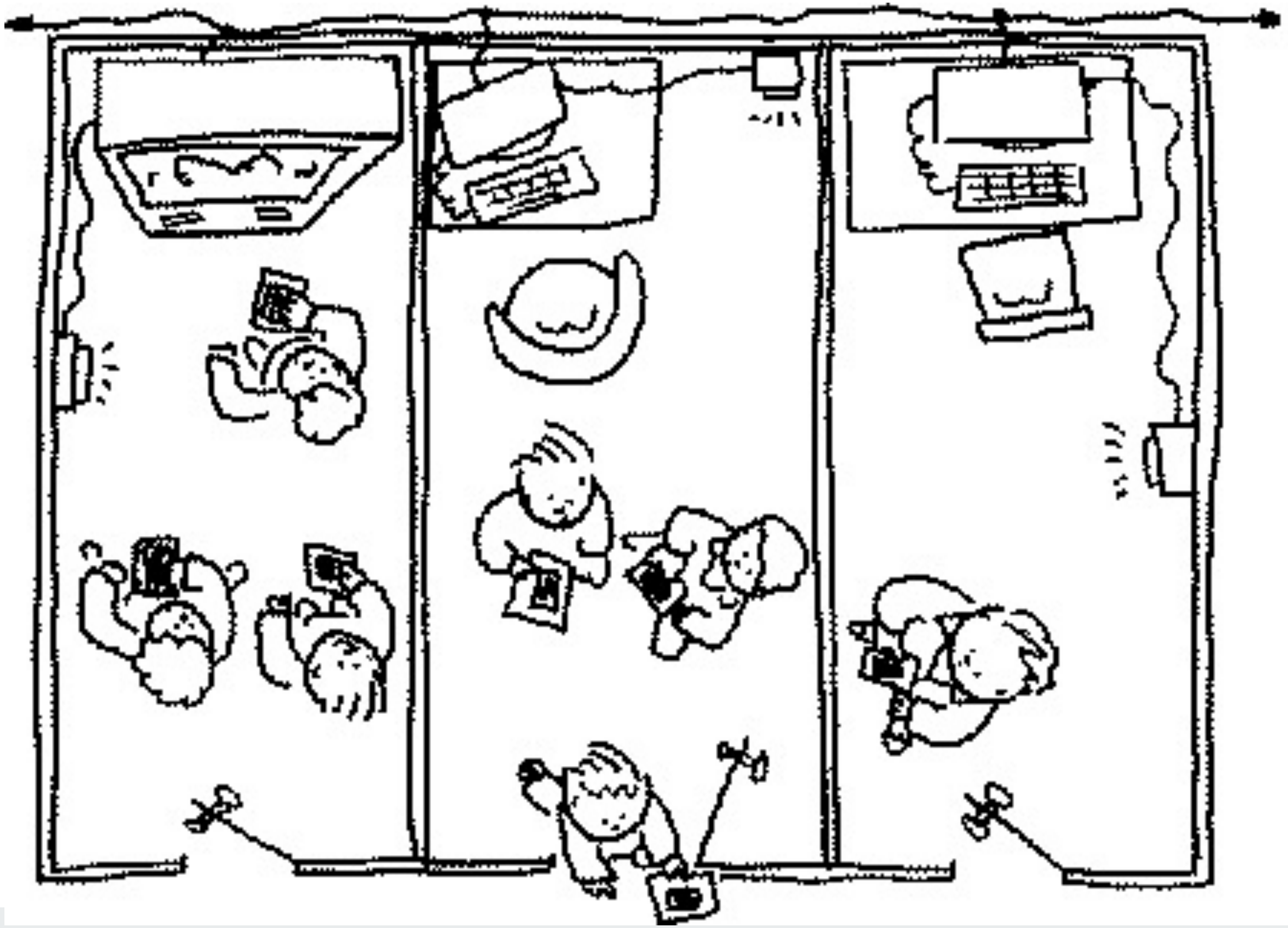
An Overview of the ParcTab Ubiquitous Computing Experiment

Roy Want, Bill N. Schilit, Norman I. Adams, Rich Gold, Karin Petersen, David Goldberg, John R. Ellis and Mark Weiser

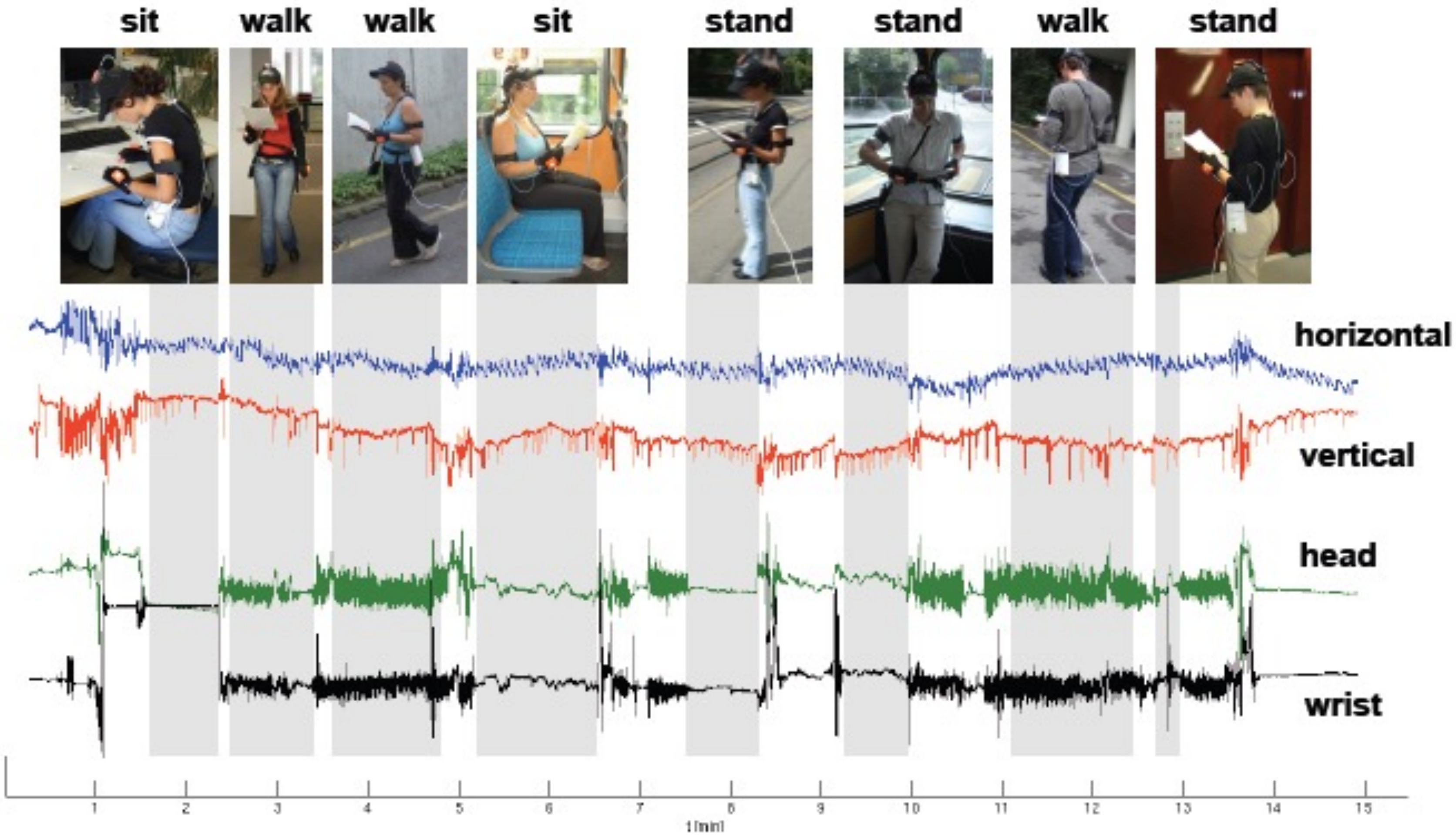
The PARCTAB system integrates a palm-sized mobile computer into an office network. The PARCTAB project serves as a preliminary testbed for Ubiquitous Computing, a philosophy originating at Xerox PARC that aims to enrich our computing environment by emphasizing context sensitivity, casual interaction and the spatial arrangement of computers. This paper describes the Ubiquitous Computing philosophy, the PARCTAB system, user-interface issues for small devices, and our experience in developing and testing a variety of mobile applications.



Living Lab: ParcTab Experiment



Fieldwork experiment: Example



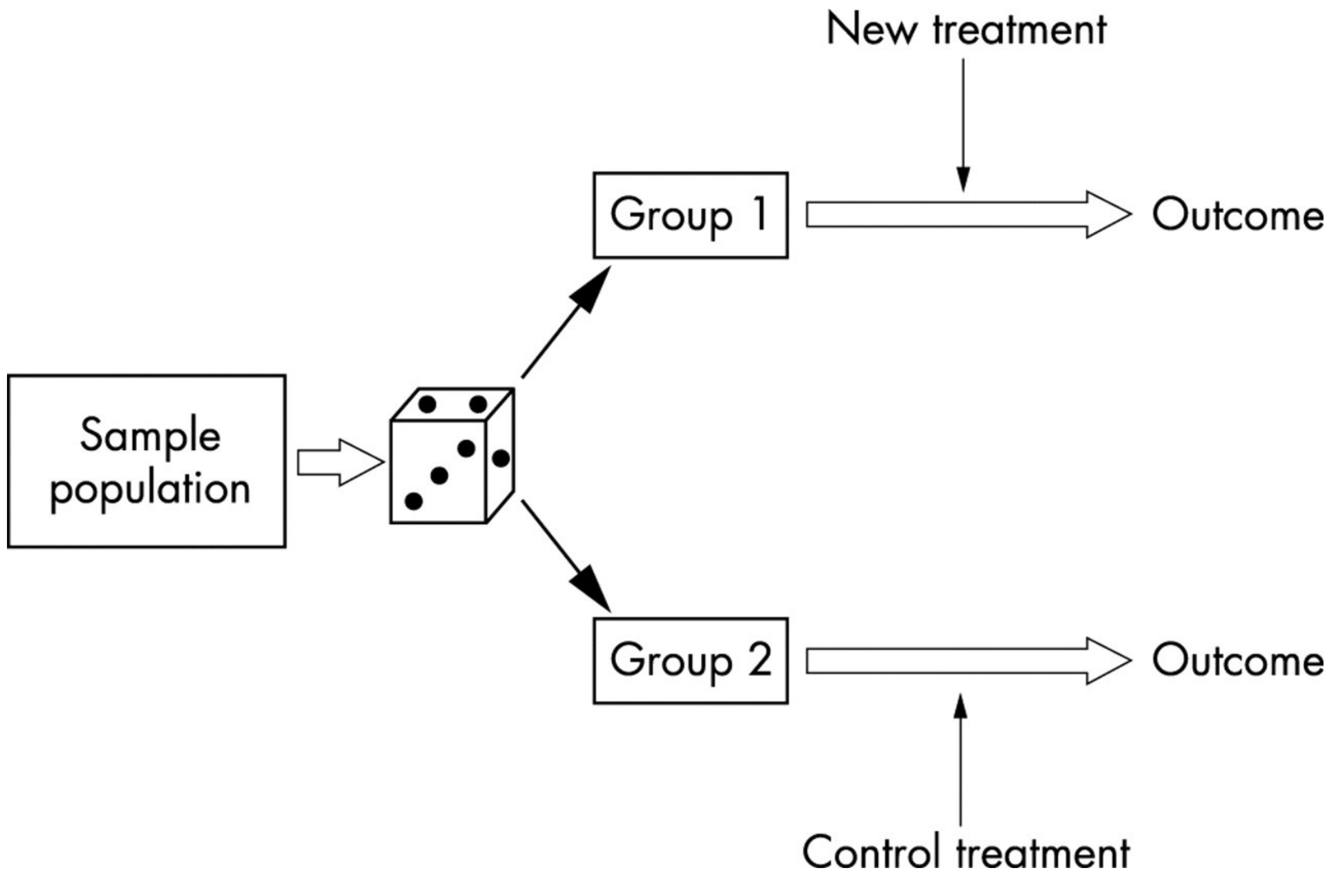
- Detecting when people read, from eye movement signals (EOG)
- Data collection “in the wild”, under varying conditions

Controlled Experiment

- Purpose
  - Study how one thing has an effect on another
  - Get specific evidence of cause-effect relationships
  - Answer causality and comparative questions

- Defining characteristics
  - Reduction to observation of specific variables
  - Control to limit confounding factors
  - Repetition: repeated runs/trials to gain sufficient evidence

Controlled Experiment: Example



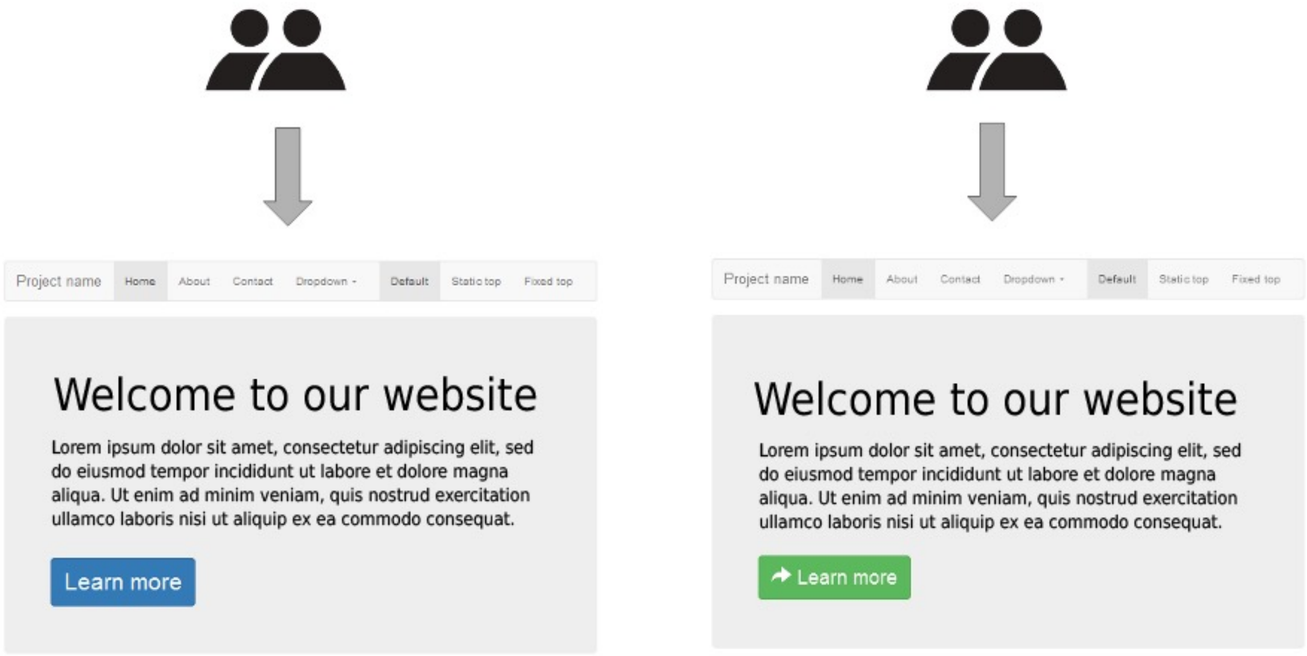
- Randomised Control Trial (RCT)
- Hypothesis-testing (confirmatory)
- Preregistration, to clearly separate from hypothesis-generation (exploratory)

Comparative experiment

- Purpose:
  - Comparison of competing solutions
  - Comparison of a new solution against a baseline
  - Comparison under different conditions

- Characteristics
  - Factorial design
  - No need to form a hypothesis as the purpose is to evaluate differences
  - Avoiding bias is a main concern (choice of data sets, test scenarios, participants, tasks, etc)

Comparative experiment: Example



Click rate: 52 % 72 %

A/B test

"Bucket testing"

Experimental Research – Key Points

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- Experimental research has a broad scope.
- Not all experiments have independent variables (factors)
- Not all experiments have a hypothesis