

# HCI Foundations and Frontiers

CS 347 | Stanford University  
Maneesh Agrawala

# HCI Foundations and Frontiers

CS 347 Stanford University

How will the future of human-computer interaction evolve? This course equips students with the major animating theories of human-computer interaction, and connects those theories to modern innovations. We will examine foundational work in design theory, cognitive theory, ubiquitous computing, and human-centered AI. We will consider how these foundations have in turn led to research advances in virtual/augmented reality, automated design tools, accessibility and collaborative support. Unlike other courses in HCI this will primarily be focused on conceptual understanding rather than implementation and design practice. Students read and discuss multiple papers per week. Prerequisites: For CS and Symbolic Systems undergraduates and masters students, CS147 or CS247. No prerequisite for PhD students or students outside of CS and Symbolic Systems.

Foundations and frontiers

Foundations and frontiers

Foundations and frontiers (-tiers, -tiers, -tiers)

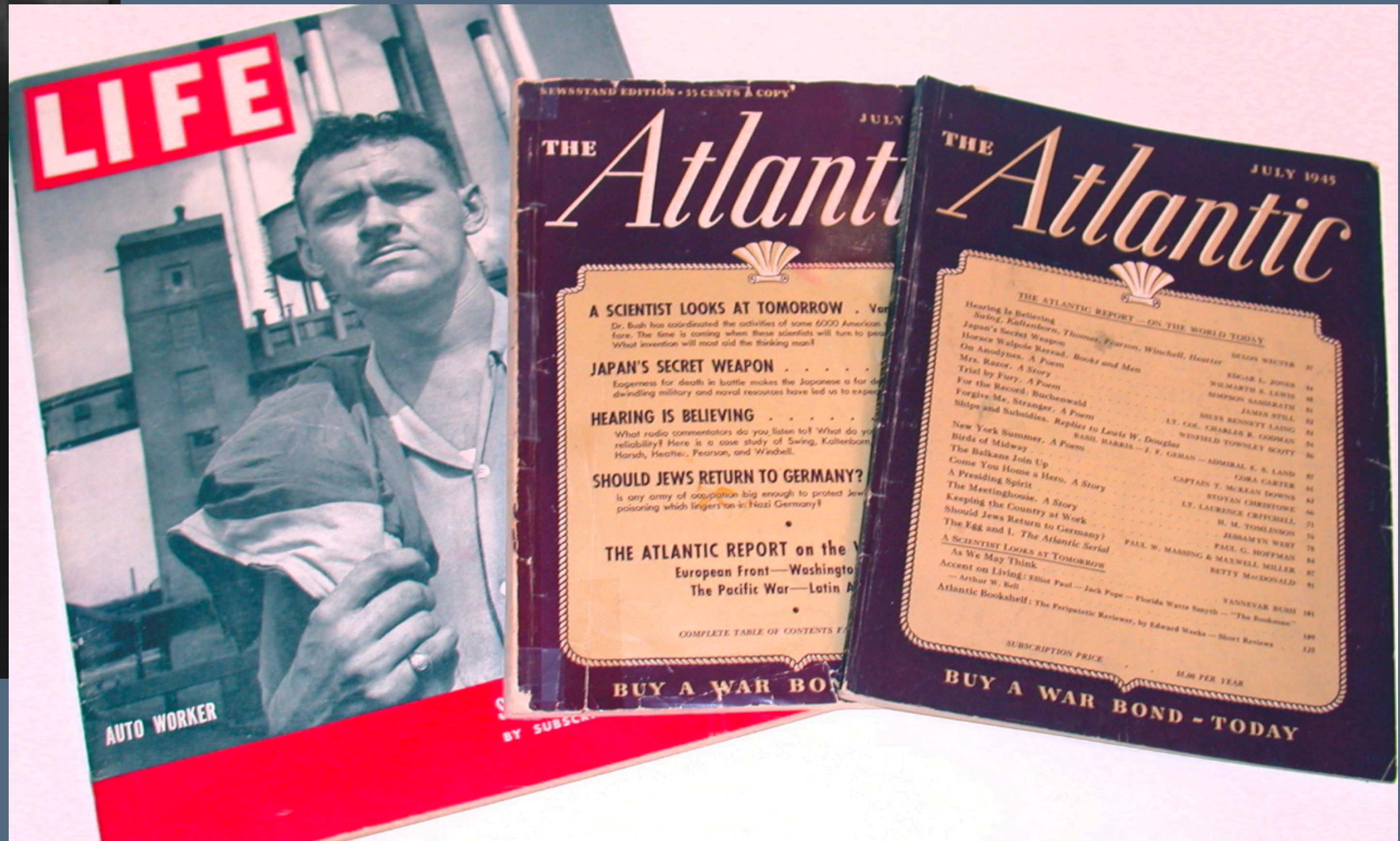
Foundations and frontiers!

CS 347

CS 347

CS 347 (seven, seven, seven)

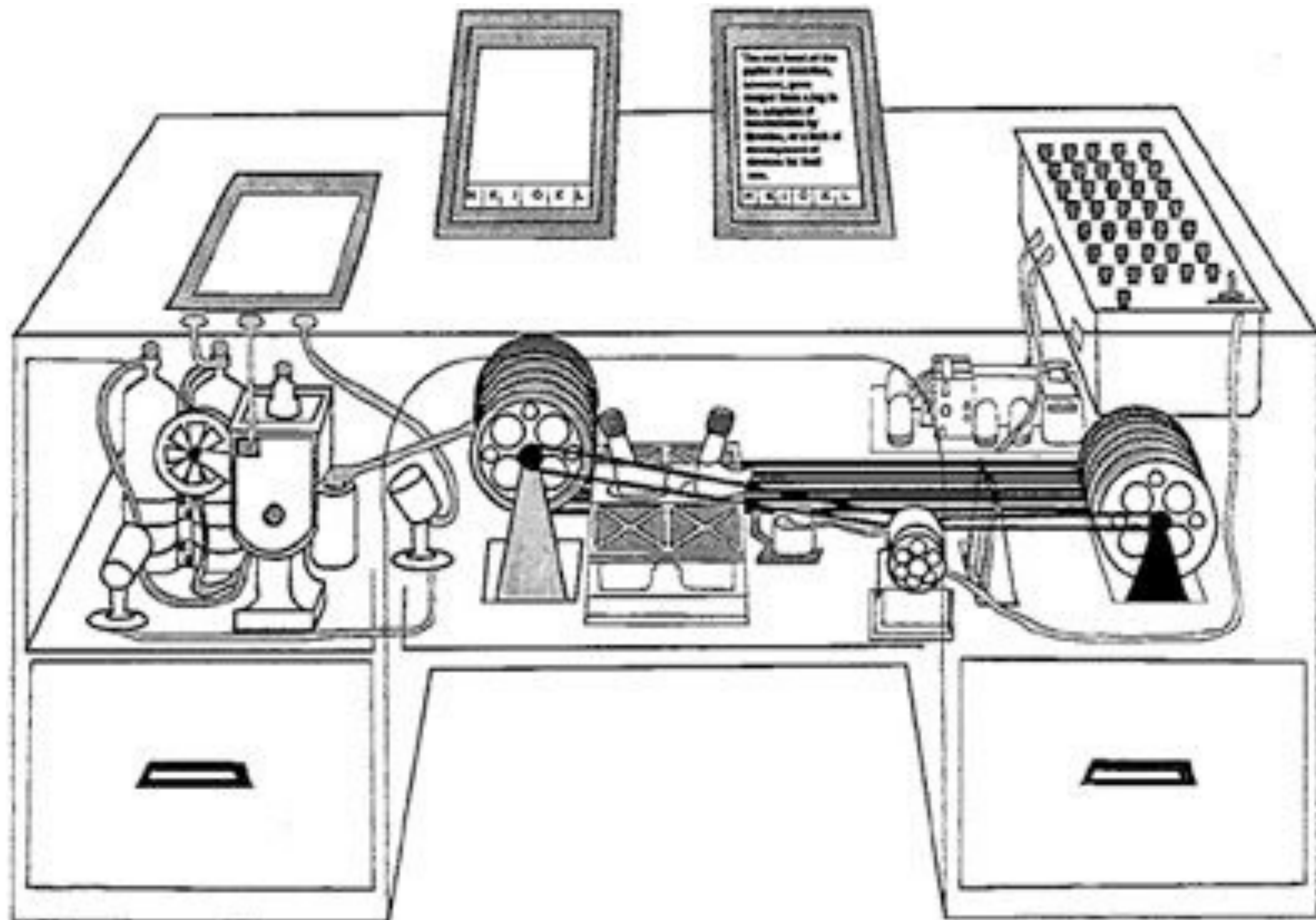
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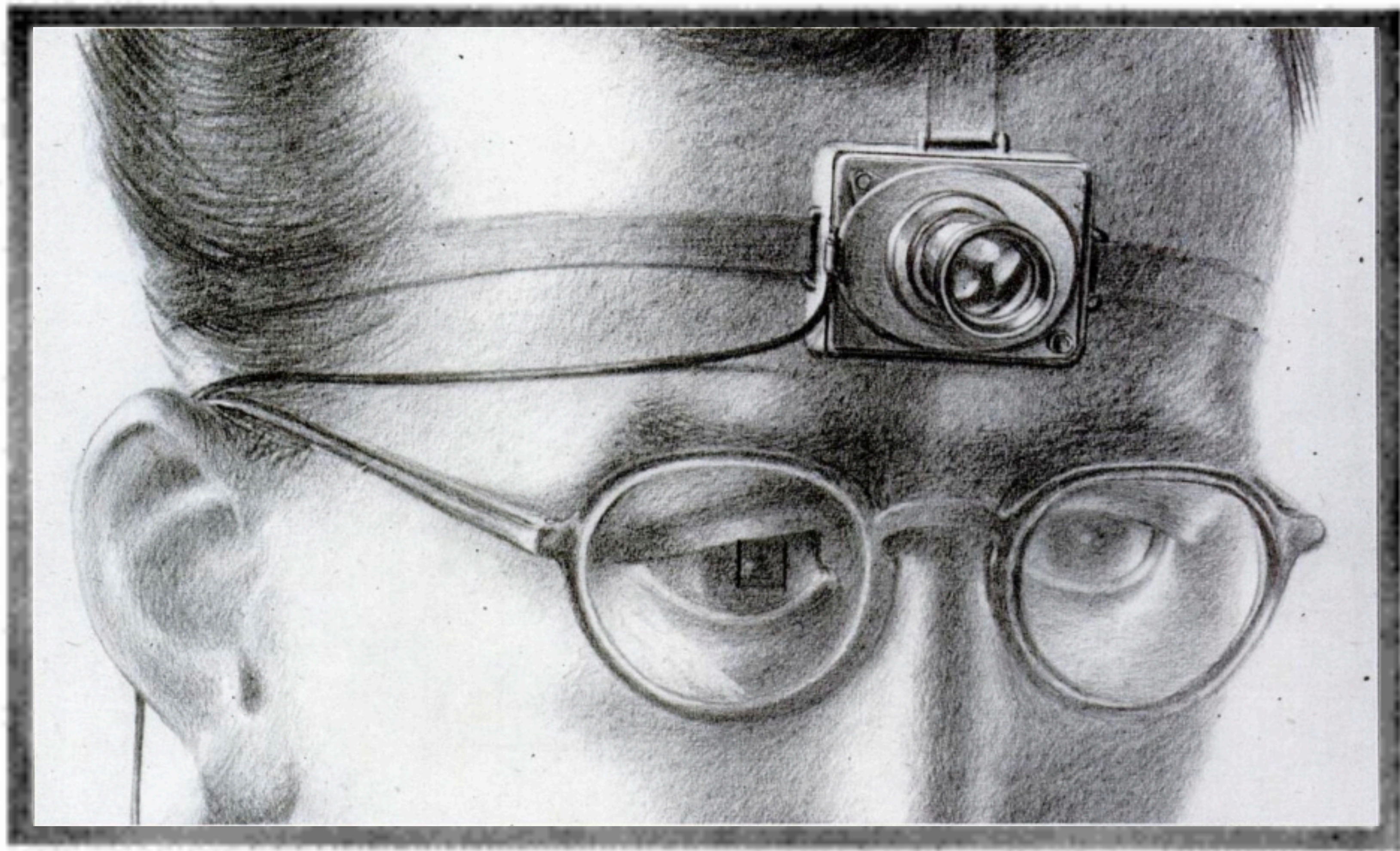


As we may think.

Vannevar Bush, 1945.

First appeared in The Atlantic, later that year a condensed version in Life





A scientist of the future records experiments with a tiny camera fitted with universal-focus lens. The small square in the eyeglass at the left sights the object (*LIFE* 19(11), p. 112).



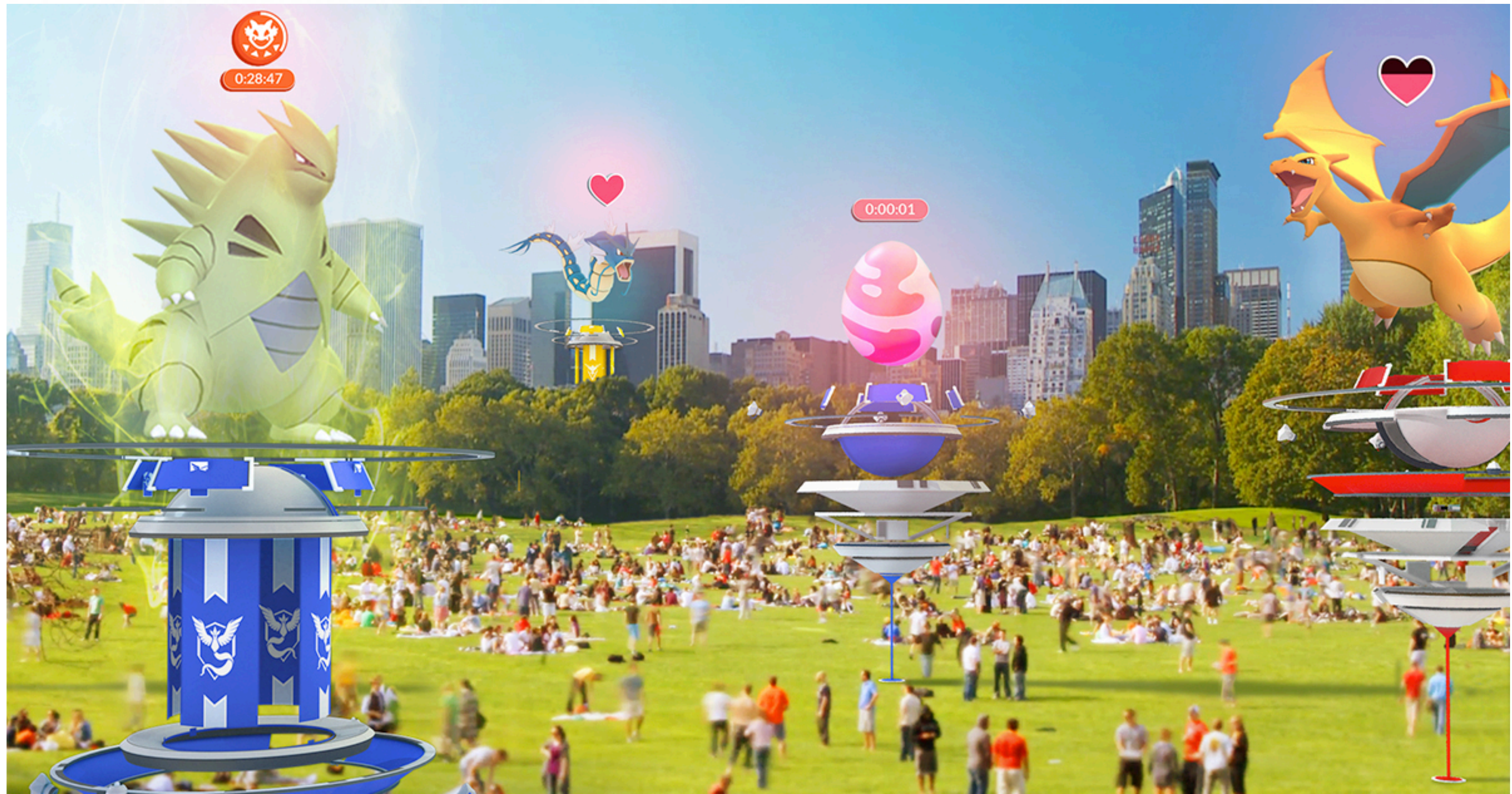
[image from  
Wired]

A scientist of the future records experiments with a tiny camera fitted with universal-focus lens. The small square in the eyeglass at the left sights the object (*LIFE* 19(11), p. 112).



[image from  
apple]

A scientist of the future records experiments with a tiny camera fitted with universal-focus lens. The small square in the eyeglass at the left sights the object (*LIFE* 19(11), p. 112).



A scientist of the future records experiments with a tiny camera fitted with universal-focus lens. The small square in the eyeglass at the left sights the object (*LIFE* 19(11), p. 112).

“Wholly new forms of encyclopedias will appear, ready-made with a mesh of associative trails running through them.”

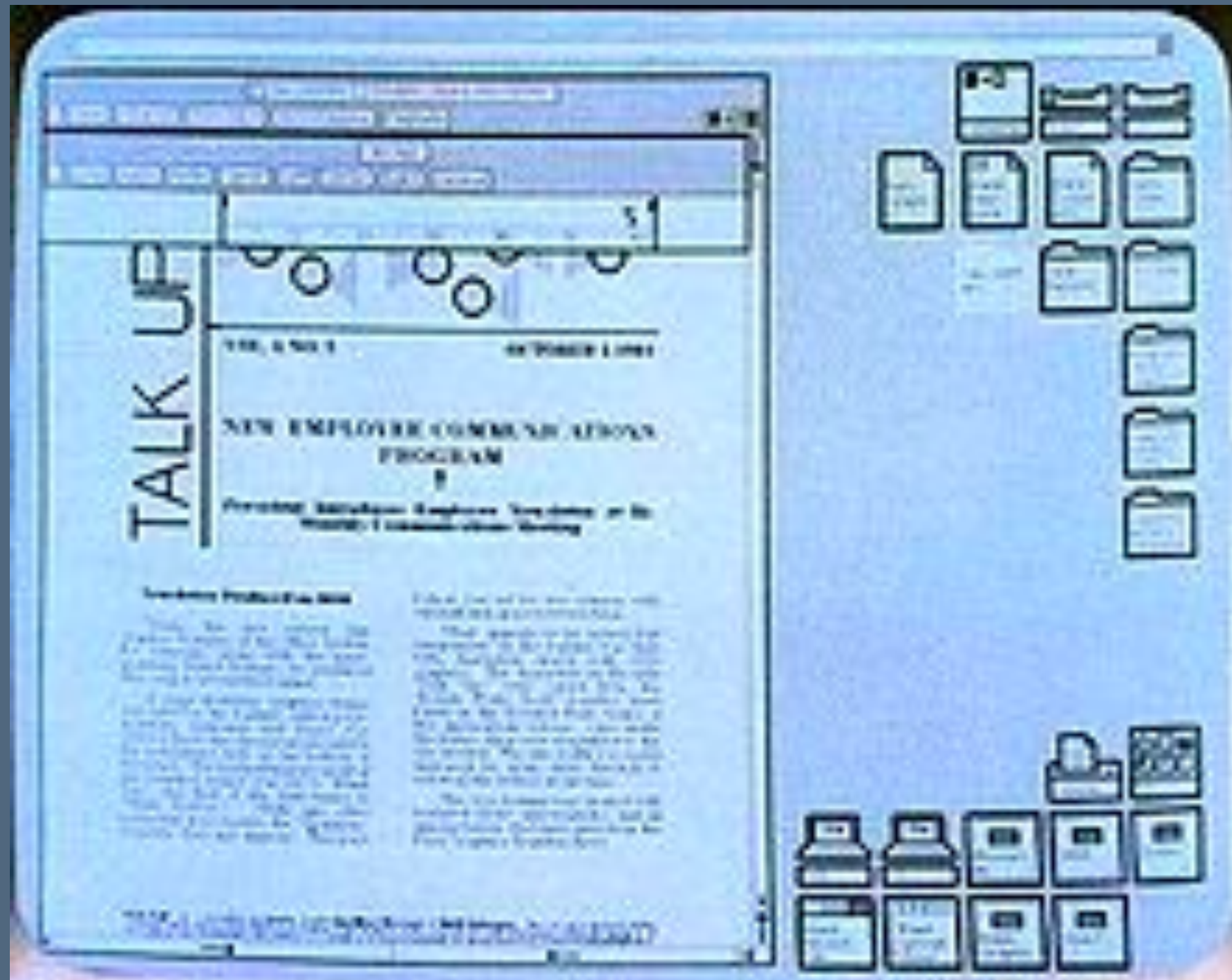
“Wholly new, it is not ready-made with trails running through them.”



# WIKIPEDIA

The Free Encyclopedia

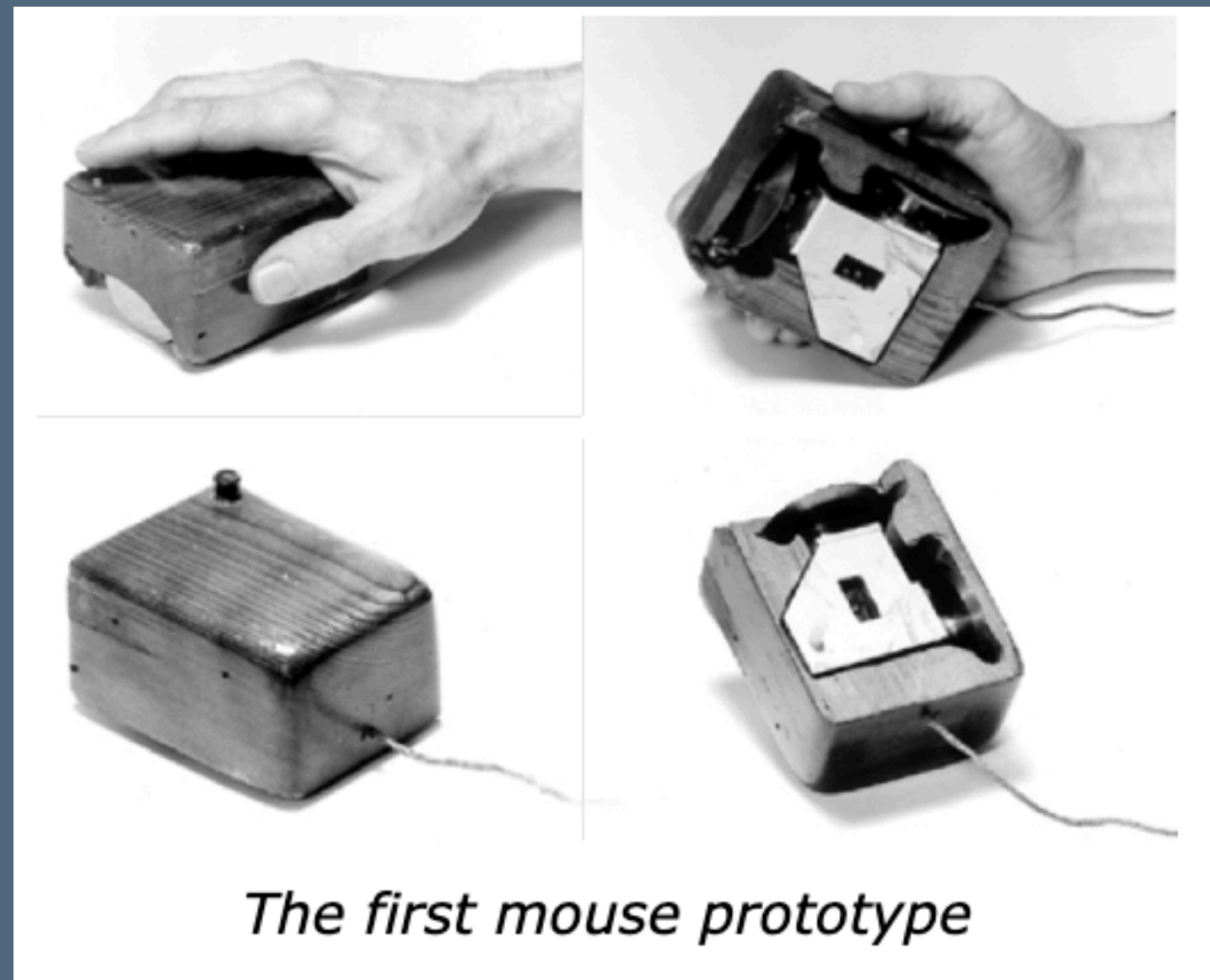
Xerox PARC. 1973.  
The Xerox Alto.



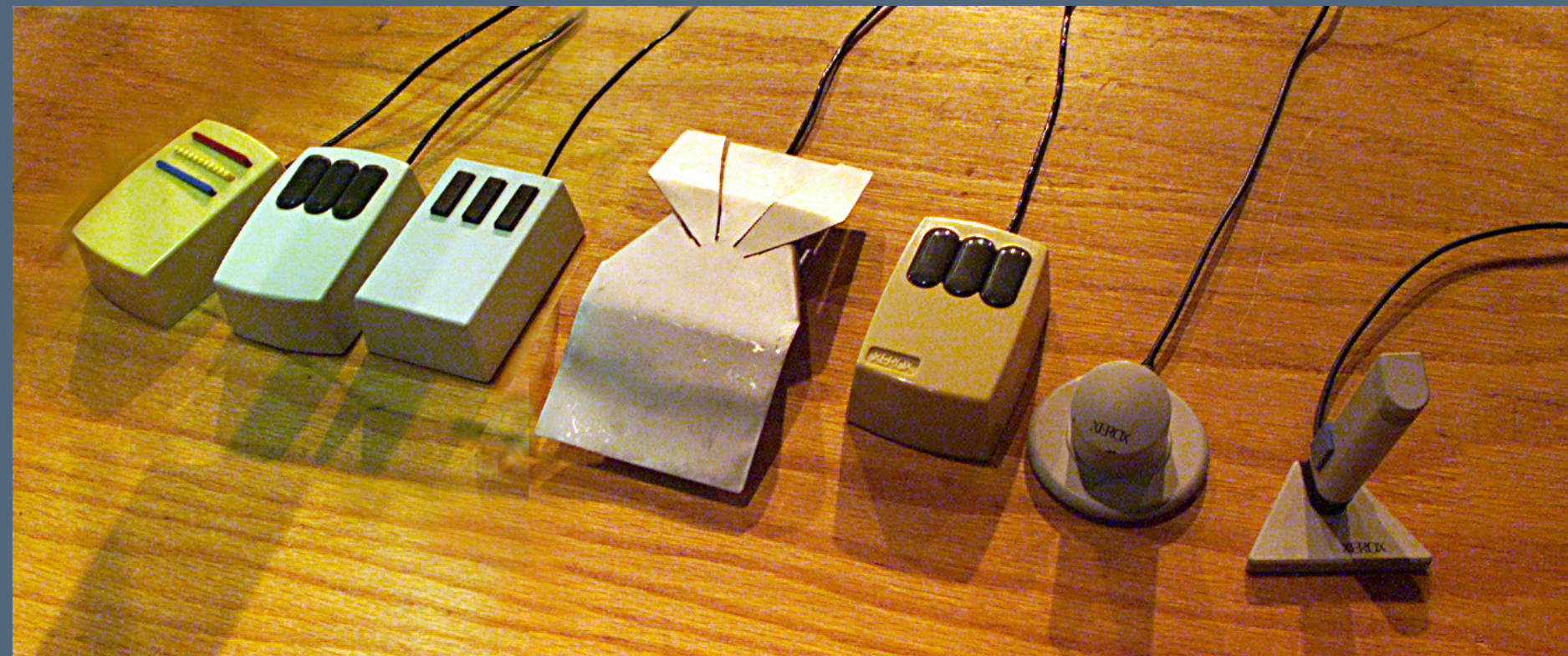
Modern MacOS desktop



Engelbart 1963-64  
First mouse prototype



Card, English and Burr. 1978.  
Evaluation of mouse, rate-controlled  
isometric joystick, step keys, and text  
keys for text selection on a CRT.



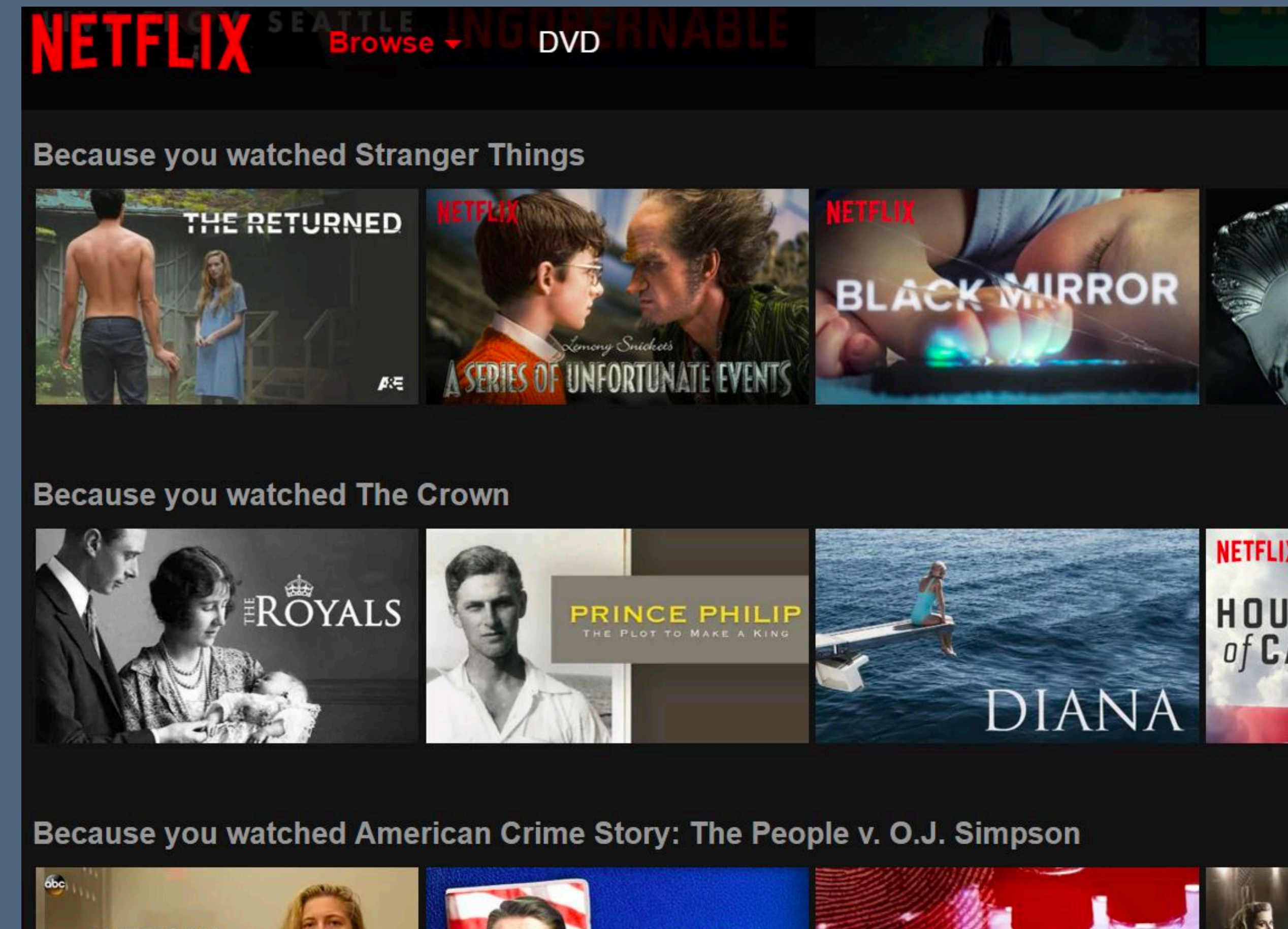
Modern mouse



Resnick et al. 1994. GroupLens:  
an open architecture for  
collaborative filtering of netnews.



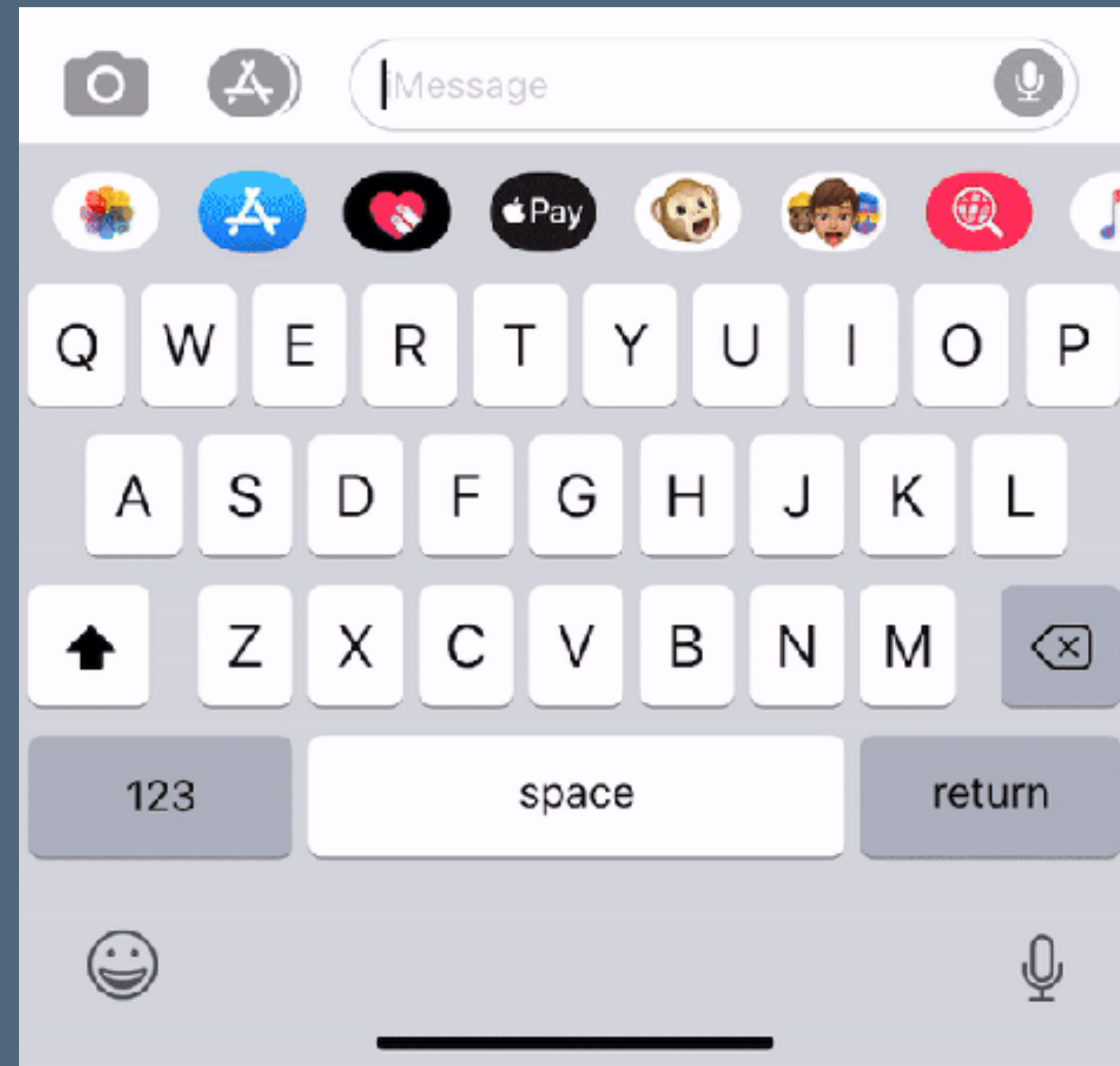
Modern recommender systems  
[image from HBS]



Zhai and Kristensson. 2003.  
Shorthand writing on a stylus  
keyboard.



Swipe keyboards (iOS, Android)  
[image from 9to5mac]



Consolvo et al. 2008. Activity sensing in the wild: a field trial of UbiFit Garden.



Modern fitness trackers  
[image from Apple]





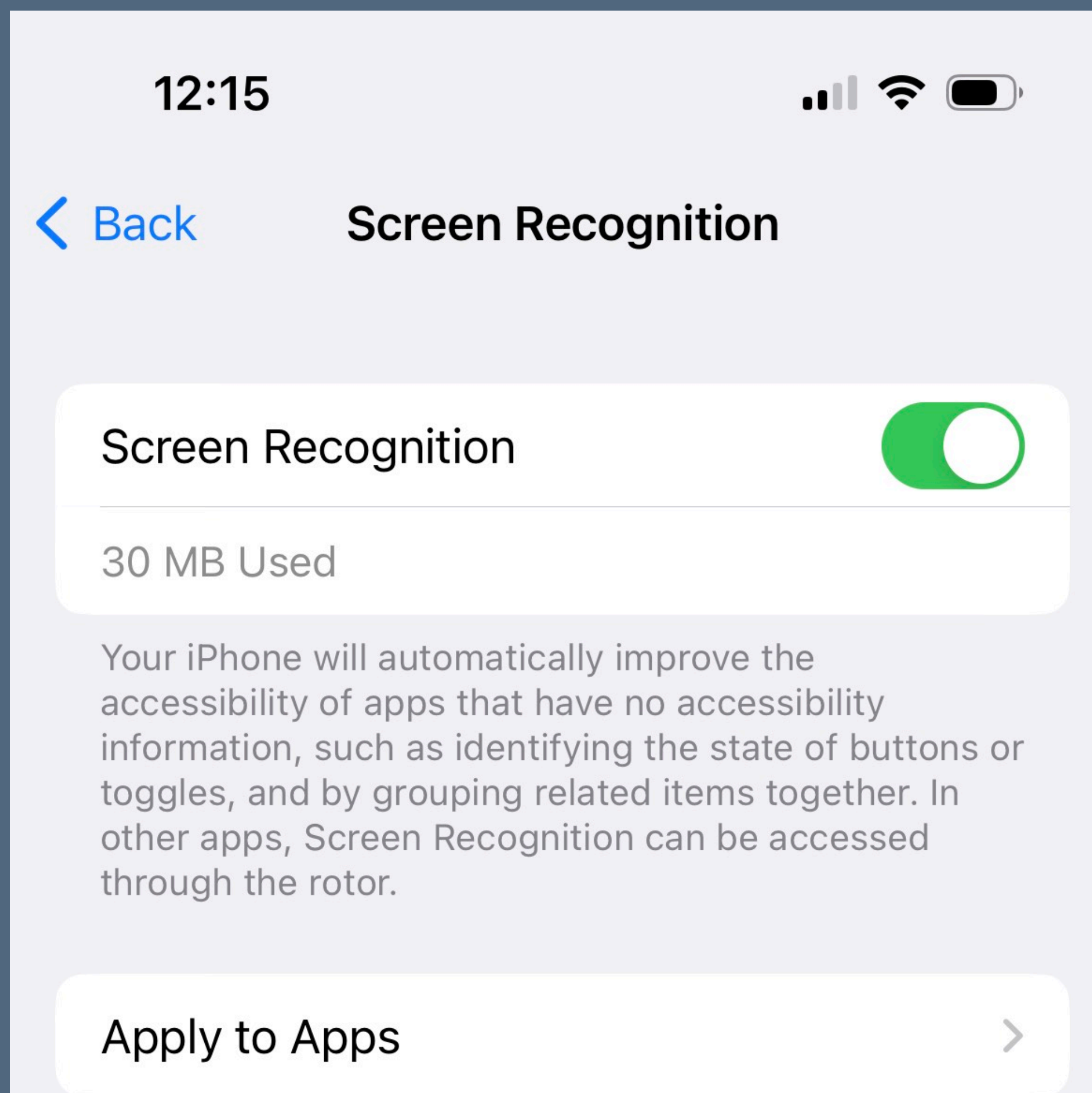
Laput et al. 2018. Ubicoustics: Plug-and-Play Acoustic Activity Recognition



Apple Watch handwashing detection 2020

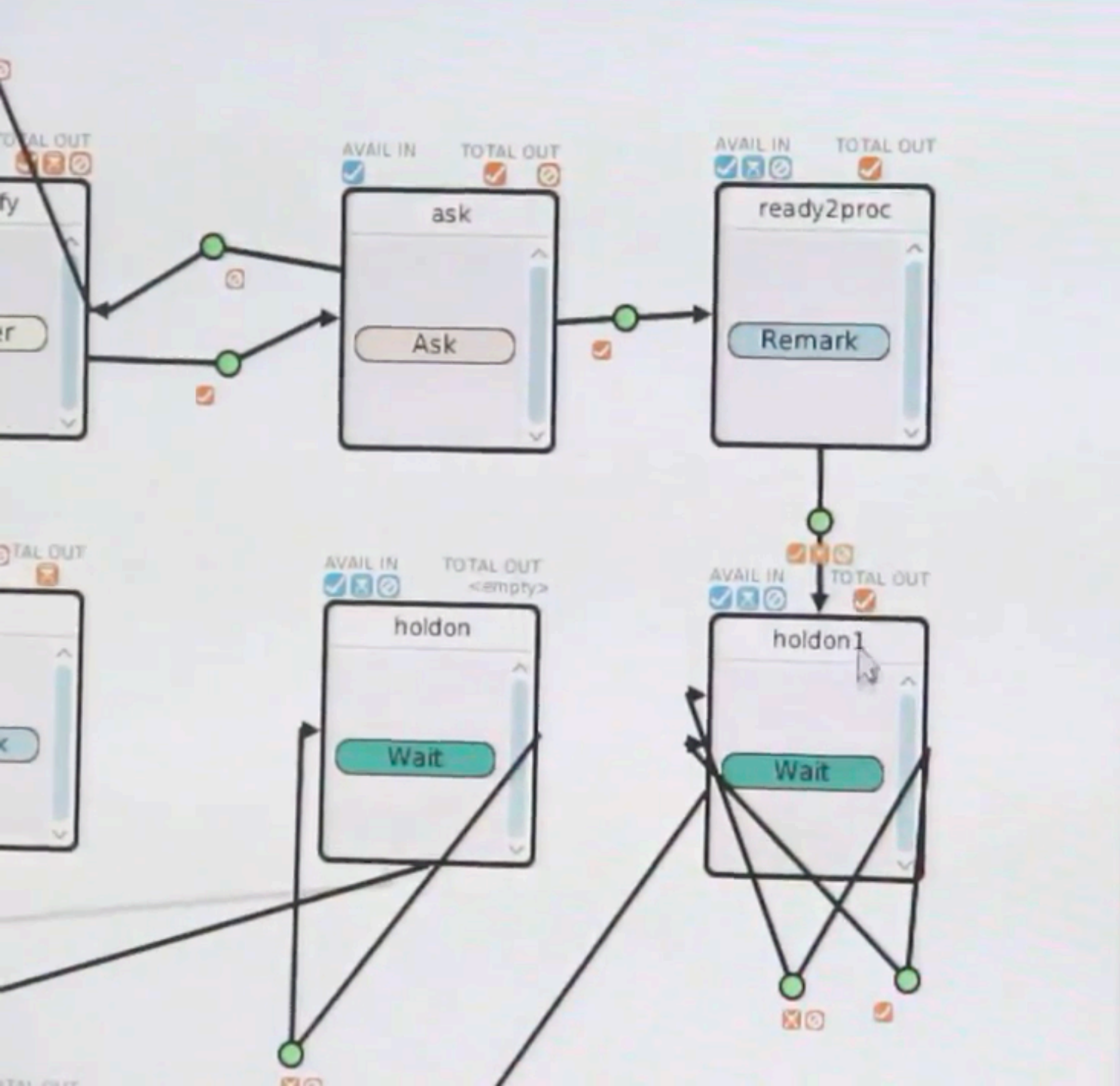
Zhang et al. 2021. AI-powered screen reader accessibility.

iOS Screen Recognition





# What's next? And why?



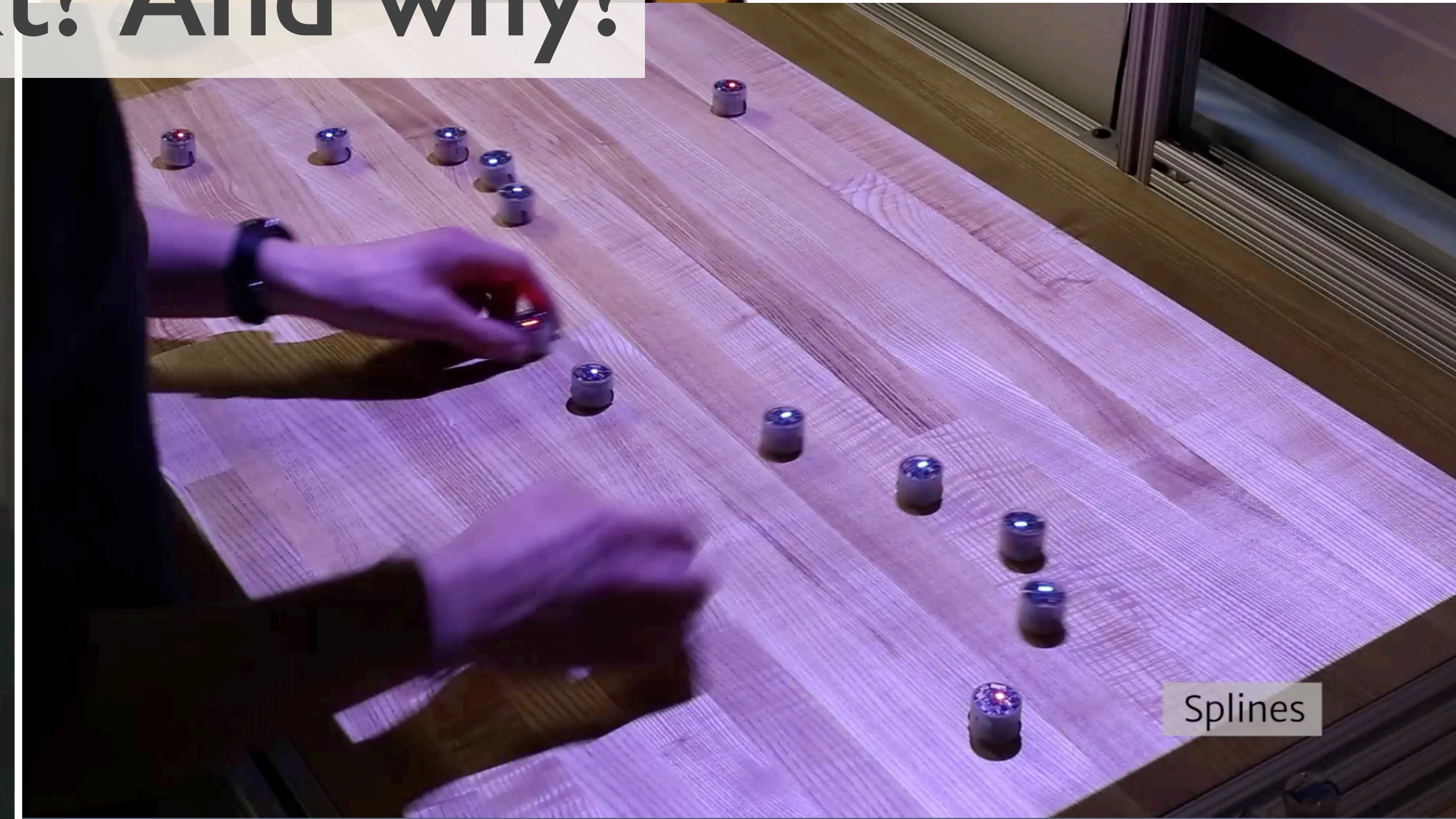
⚠️ Branch conditions insufficient (See grayed-out transitions. Are you using else statements appropriately?).

- Task-Related Errors
- Farewell Flubs
- Turn-taking Flubs

There is a sequence of microinteractions starting from give, in which the ROBOT speaks twice in a row.

There is a sequence of microinteractions starting from help, in which the ROBOT speaks twice in a row.

GAZE\_INTIMACY (RESOLVED) In give, robot might use GAZE\_INTIMACY in Remark and GAZE\_REFERENCE in Handoff at the same time.



Splines

*“How about a virtual reality headset that uses blockchain technology to securely store user data and personalize the VR experience using deep learning algorithms? The headset would be able to analyze a user's brain activity and eye movements in real-time to continuously adapt the VR content to their preferences and interests. It would also use blockchain to store a record of the user's interactions within the VR world, allowing them to seamlessly switch between devices and pick up where they left off. This technology would revolutionize the way we experience virtual reality, making it more immersive and personalized than ever before.”*

## **Why is this a bad idea?**

(ChatGPT prompt: “Generate a tech product idea that is full of technobabble about VR, blockchain, and deep learning”)

# This class

Envisioning and understanding  
the future of interaction  
between people, society, and technology

# This class

Teaches foundational theories  
and modern frontiers

# Learning goals

# This is not like other HCI classes.

Your goal is **not** just to **design** an alignment between people and technology.

Your goal is to articulate, critique, and generate entirely new ideas about that relationship.

# Foundations and frontiers

You will learn the major theories and concepts that underpin HCI

You will engage in critical analyses of these theories and concepts, apply them, and extend them



**START**

# Ubiquitous computing

Unit I

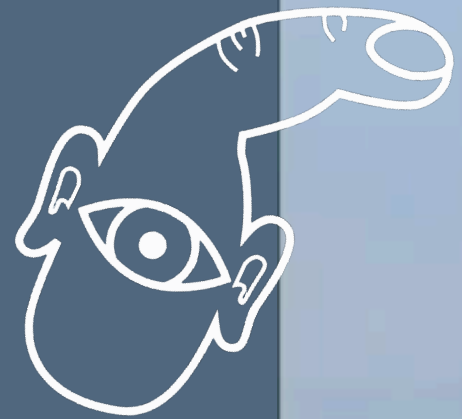
ubiquitous and tangible computing  
input and output  
activity, health, and behavior



Mobile phone's  
model of a person

[O'Sullivan and Igoe 2004]

# The future of interaction?



“...this vision, from an interaction perspective, is *not visionary*. It's a timid increment from the status quo, and the status quo, from an interaction perspective, is actually rather terrible.” – Bret Victor

<http://worrydream.com/ABriefRantOnTheFutureOfInteractionDesign/>



vs. "Pictures Under Glass"  
[Victor 2011]



# Why is this so terrible?

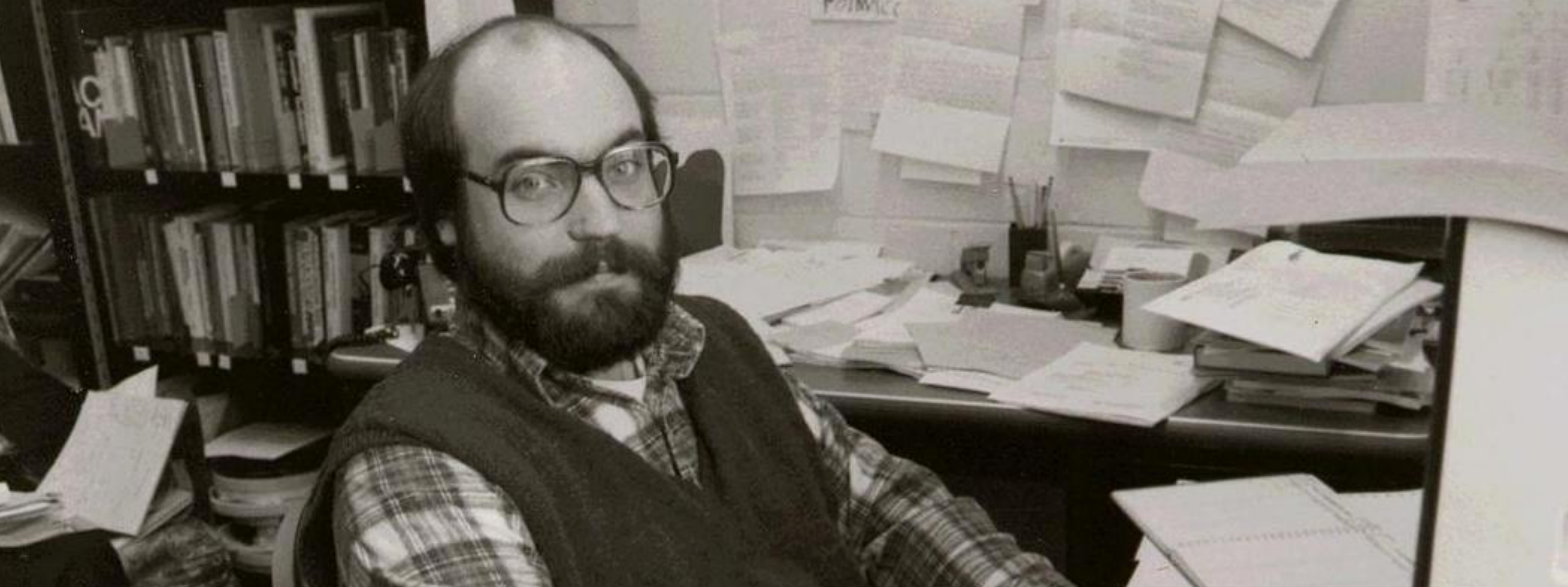
[Hutchins 1995, Dourish 2004; Klemmer, Hartmann, Takayama 2006]

Our cognition leverages **embodiment**—our bodies:

We learn through interaction with the world

We leverage the environments around us to make us smarter

We communicate our intent through much broader mechanisms than just our fingertips: consider musicians, dancers, construction workers, professors on stage trying to get your attention



The Computer for the 21st Century  
Mark Weiser, 1991  
You will read this for our next class

“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.”  
– Mark Weiser

[Weiser 1991]

# Ubiquitous Computing [Weiser 1991]

**Ubiquitous computing:** a vision in which computers “**vanish into the background**” rather than focus our attention on a single box

This vision requires interactive systems to become reactive, context-aware, ambient, and embedded in everyday activities

# Activity recognition [Laput et al. 2015]



Detecting ambient EM signals transmitted through body using commodity smart watch

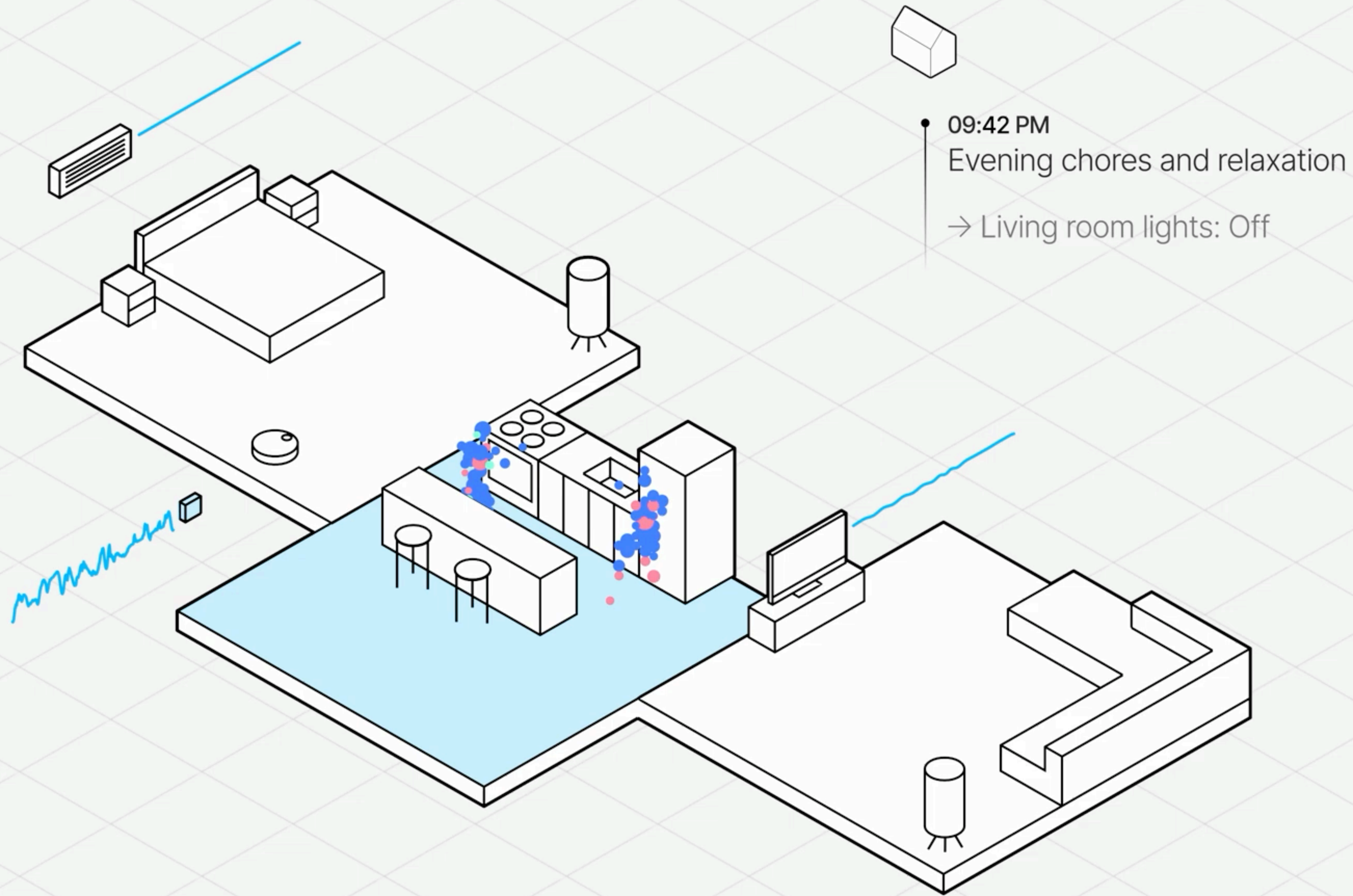
# Context-aware computing

Collect information about the user's environment, and use it to customize their computing experience

Some types of context: location, social surroundings, activity, ...

## **Towards a Better Understanding of Context and Context-Awareness**

Anind K. Dey and Gregory D. Abowd



Ivan Poupyrev's Archetype AI: <https://www.youtube.com/watch?v=LTb0HomVI8Y>

# Programmable objects

[Jin et al. 2019]



one side: 45 min  
both sides: 90 min

Photochromic inks change color when exposed to lights of a specific wavelength

# Privacy [Chen et al. 2020]



Wearable microphone jamming: ultrasonic speakers are read as white noise by mics

Wearing the bracelet means the speakers move, so we get better coverage

# Ubiquitous?

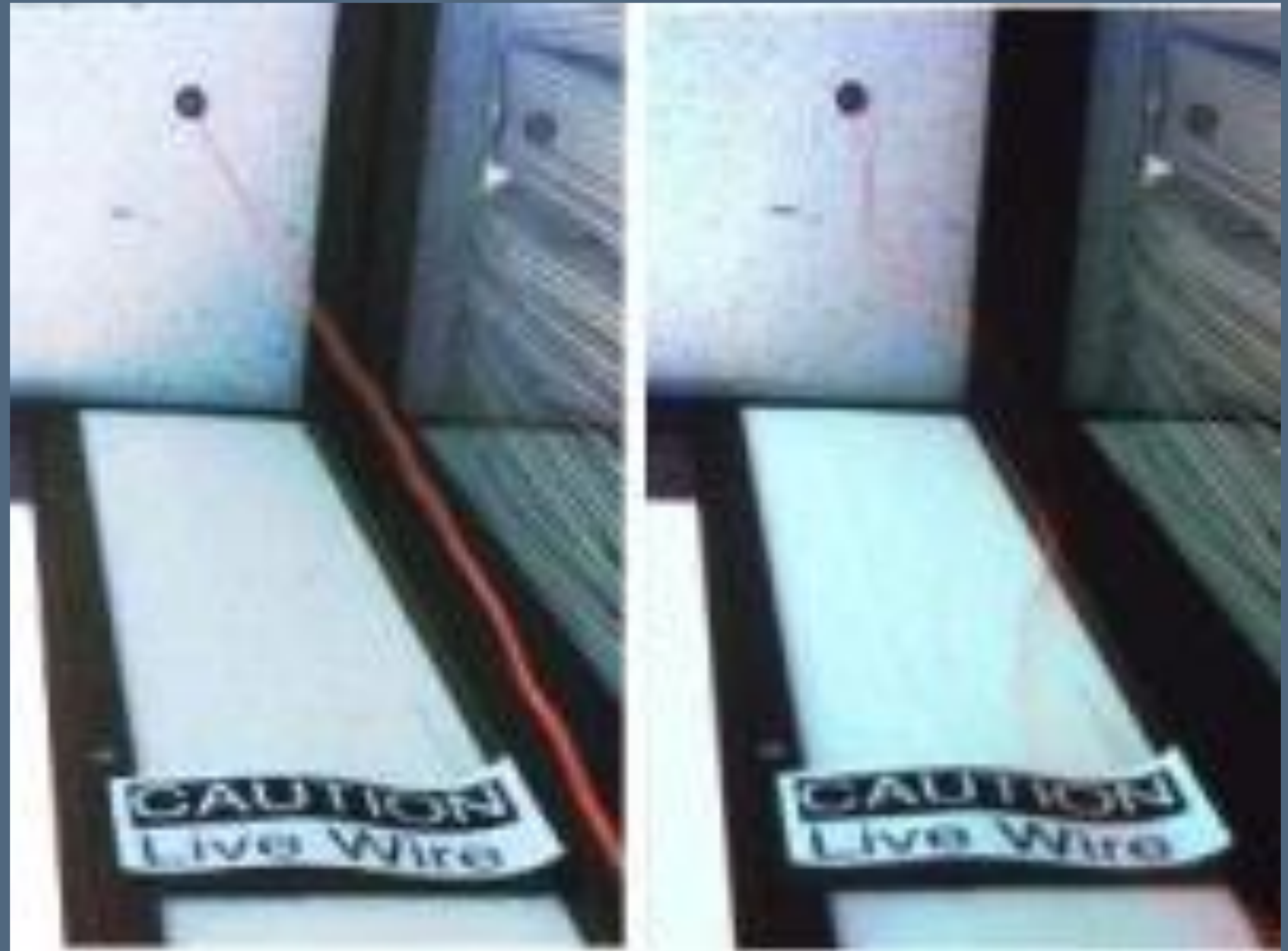


# Ubiquitous?



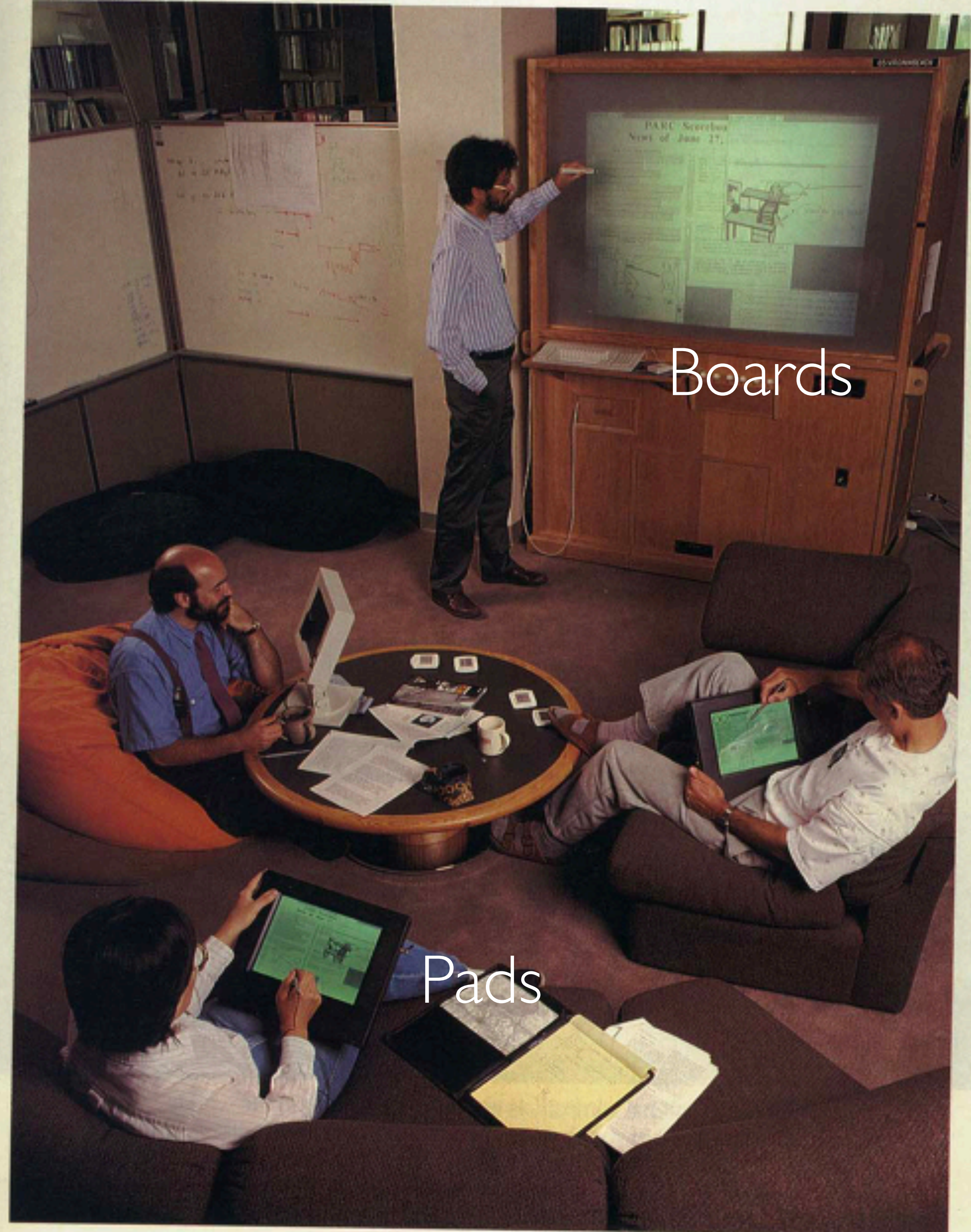
# Ubicomp is backgrounded

What Weiser calls one of the first “calm” technologies: Live Wire, a wire on a stepper motor, monitoring net traffic [Jeremijenko 1995]





Tabs



Boards

Pads

Weiser envisioned ubiquitous computing devices at three scales: tabs, pads, and boards.

# Tabs

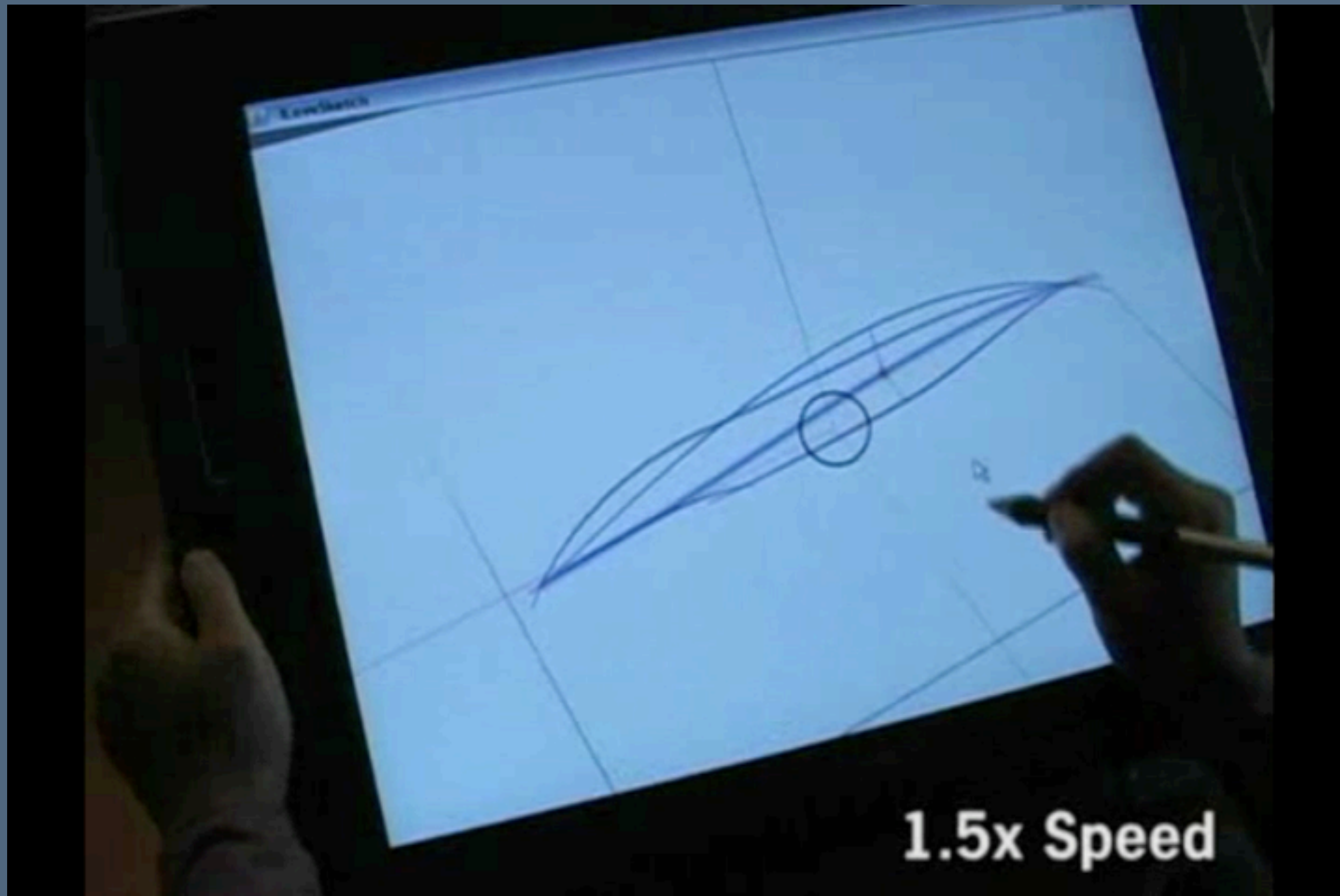


Most similar to today's smart watches

Significant  
Otter: sharing biosignals with romantic partners [Liu et al. 2021]

# Pads

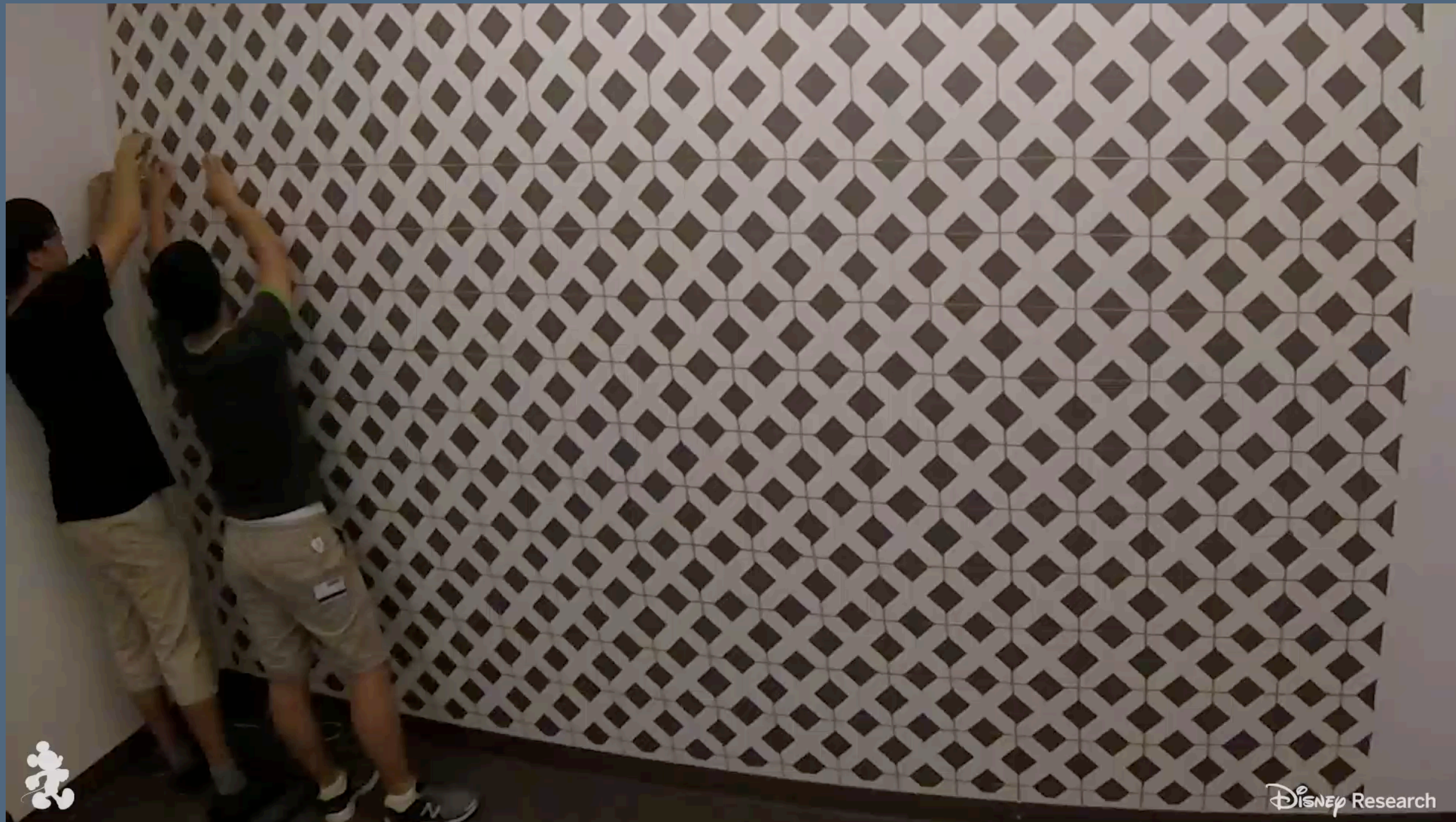
Most similar to today's tablets



[Bae, Balakrishnan, and Singh 2008]

[Hinckley et al. 2010]

# Boards



Create a grid of conductive diamonds similar to a phone screen

Sense the columns and scan the rows to ID the touch location

[Zhang et al. 2018]



# Tangible computing

# Tangible Computing

Directly-manipulable physical interfaces to data and computation

'Pure' form of ubicomp in that there is no computer to be seen

You will read this for our next class

## **Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms**

**Hiroshi Ishii and Brygg Ullmer**

MIT Media Laboratory

Tangible Media Group

20 Ames Street, Cambridge, MA 02139-4307 USA

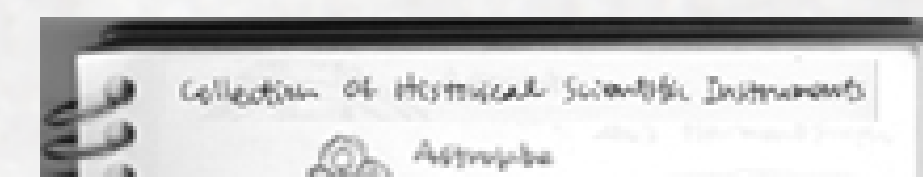
{ishii, ullmer}@media.mit.edu

### **ABSTRACT**

This paper presents our vision of Human Computer

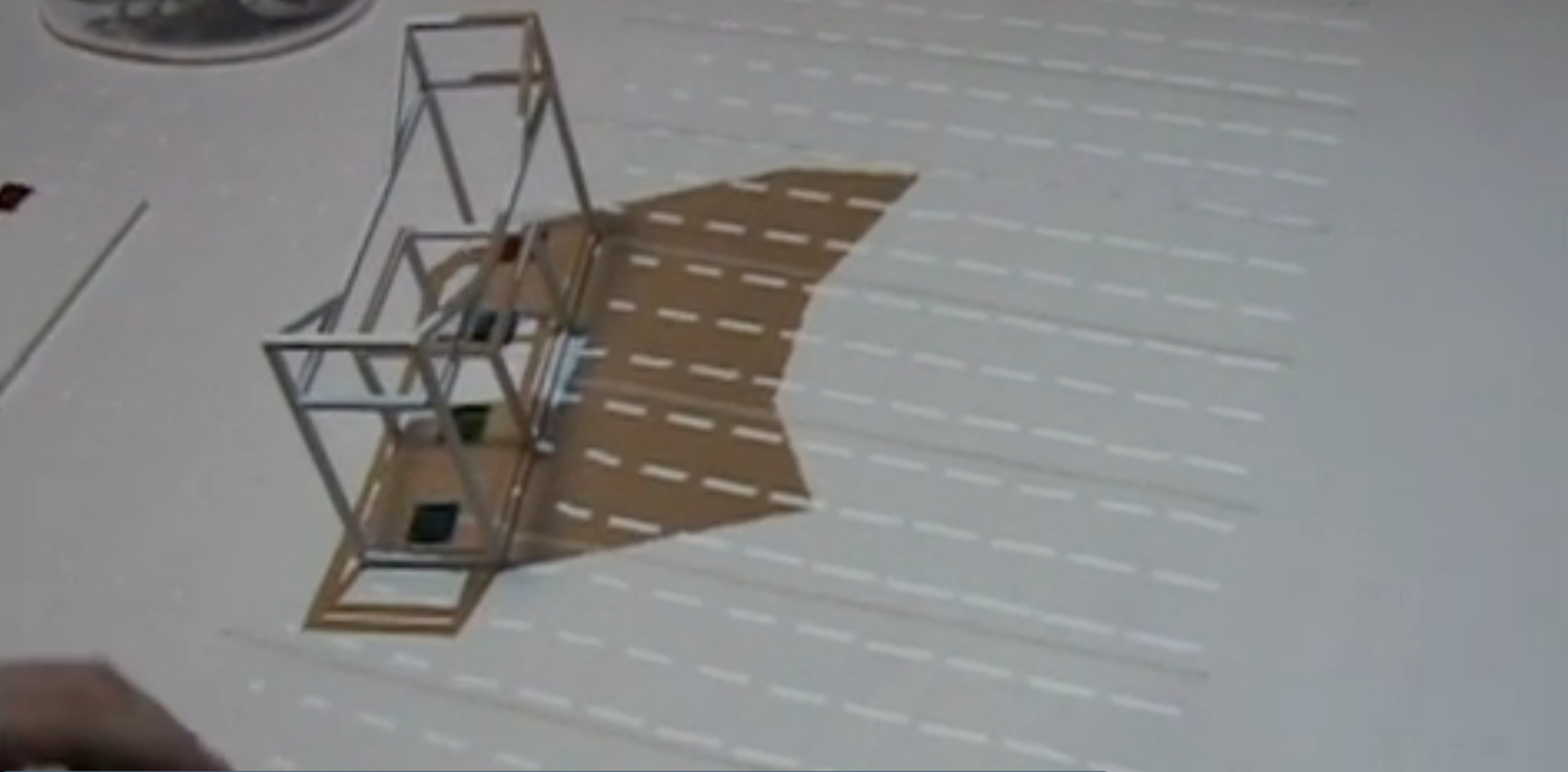
### **BITS & ATOMS**

We live between two realms:

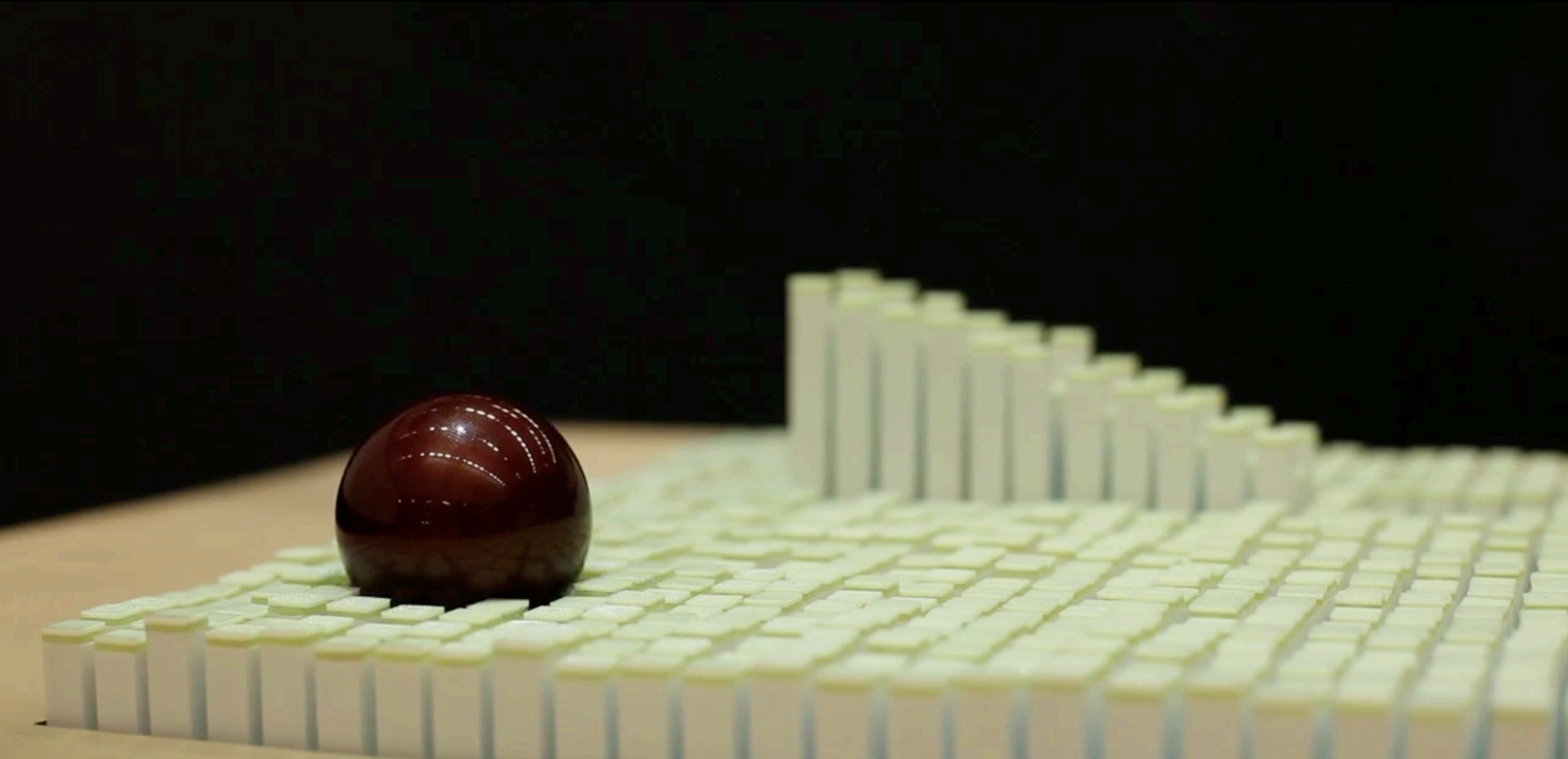


A close-up photograph showing a person's hands interacting with a physical wireframe model of a building structure. The model is made of thin, light-colored rods and is held in a way that allows the user to adjust its form. The background is a plain, light-colored wall. The lighting is soft, highlighting the metallic texture of the rods and the skin of the hands. The overall scene suggests a hands-on, tangible design process.

Urp: a luminous-tangible workbench for urban planning and design.  
Underkoffler, Ishii. CHI '99.



Urp: a luminous-tangible workbench for urban planning and design.  
Underkoffler, Ishii. CHI '99.



Follmer, Leithinger, Olwal, Hogge, Ishii. inFORM: Dynamic Physical Affordances and Constraints through Shape and Object Actuation. UIST '13. Object Motion  
Through Shape Change

# Questions you ought to be asking

Why do, and don't, we have elements of the ubiquitous and tangible computing visions in our lives today, thirty years later?

What are resilient challenges or mistaken assumptions, and what challenges might we actually be able to tackle?

# Yesterday's tomorrows

[Bell and Dourish 2007]

Ubiquitous computing is driven not by a technological goal, but by a shared vision of the future.

However, this vision is a future as imagined in 1991.

What should the future of ubicomp be, from today's perspective?

# Where we go from here

week 1	Ubicomp
week 2	Ubicomp/Design
week 3	Design
week 4	Social and Collaborative Computing
week 5	Human-Centered AI
week 6	Cognition / Visualization
week 7	Programming Tools / Content Creation
week 8	TBA
week 9	Methodology
week 10	History

**How this class works**

# Class activity 1 of 3: Readings

# Yes, you are reading in a Computer Science class.

There will be two papers to read for each class day.

This will take substantial time. It will get faster as the course proceeds and you get more used to reading papers.

If you are reading off-campus, use the Stanford library proxy linked at the top of the syllabus webpage.

# Commentaries

After reading the papers for each class, you will reflect on the main ideas in each paper and submit a written commentary.

These commentaries serve as a mechanism to drive deeper reflection on the concepts in each paper.

Commentaries are **due at 5pm the day before lecture.**

We will drop the four lowest commentary grades at the end of class: meaning, you **may drop four readings'** worth of commentaries

We will be using these commentaries to drive discussion during each lecture

# Do's: writing a strong commentary

**Do:** engage with the core contributions —

**Step 1 (Reflection):** State the main point but then **reflect on why the ideas in the reading made sense from the authors' perspectives.**

**Step 2 (Synthesis):** How effectively does it convince you of that argument? **How could the argument be even more persuasive, on its own terms?**

**Step 3 (Future work):** What are the implications of the argument? **Given the ideas presented in the paper, what would you want to work on, or how would you modify those ideas?**

# Don'ts: writing a strong commentary

**Do not:** stop after just disagreeing with what the authors wrote

**Step 1 (Reflection):** We get lots of commentaries that are mostly summary. Don't stop here. We've all read the paper. 1–2 sentences max.

**Step 2 (Synthesis):** It's easy to just lob criticisms and negativity. Too many commentaries are just lists of complaints. Instead, focus on: what's at the core of this idea, and why is it holding sway? What might be a better version of this idea, if you're unconvinced?

**Step 3 (Future work):** Too few commentaries cover this! Instead, ask yourself: what are applications of these ideas, and what follow-up ideas might be worth exploring?

~~“This paper has so many problems:”~~

“This paper inspired me to develop an idea:”

# Example Length

I enjoyed learning about how the researchers used different approaches and compared-and-contrasted them in order to see how various tools categorized the importance of different graphical sections. I was most interested by the difference between Ground Truth BubbleView clicks and Predicted Importance projections. Specifically, I thought it was interesting that many of these graphics were magazine-esque layouts, with background images that projected the theme, but often didn't have super specific information, and large amounts of text in various sizes, colors, and placements. With BubbleView, it seemed that lots of people would click on the text, as well as these background images, but Predicted Importance often thought that the background image wasn't too important. I thought this finding reiterated how important it is to choose background images that are intentional, and not just filler images to make the page important. If people's attention goes there more than we'd expect, it's crucial to spend time choosing images that accentuate your points rather than distract the reader.

One experience this reminded me of is other AI tools and algorithms that I have seen on social media sites, specifically those that try to decide the important areas of an image that should be showcased when cropped. Specifically, I remember similar cropping / importance algorithms being used on Twitter / X. However, these tools turned out to be extremely problematic, often cropping the images to focus on those who are white, thin, and female. Many articles dived into understanding this, and users themselves tested by adding photos with underrepresented populations vs. more privileged groups and saw the ethical issues themselves. Many tech people wrote articles (ex. [Twitter's Photo-Cropping Algorithm Favors Young, Thin Females](#) Links to an external site.), as well as Twitter themselves ([Sharing learnings about our image cropping algorithm](#) Links to an external site.). The biases present in this algorithm were deeply connected to general biases in AI, and I would have loved to see the article dive into that possibility more. They do not touch on any biases in their training data, or any edge cases they see that might need further exploration.

Overall, I felt that future work for this article relies on more than just making the tool open source for people to explore themselves. Certain fonts, text patterns, and images grabbed the attention of the user greatly, and a guide to those recommendations would make these learnings even more applicable to the average designer. Although these guides of design tips may exist now, I am sure that at the time of the release of this article, these suggestions would have really changed how people presented media online.

# First readings for Wednesday

## The Computer for the 21st Century

Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence

by Mark Weiser

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

Consider writing, perhaps the first information technology. The ability to represent spoken language freed information for long-term storage freed memory from the limits of individual memory. The technology is ubiquitous in many countries. Not

is approachable only through complex jargon that has nothing to do with the tasks for which people use computers. The state of the art is perhaps analogous to the period when scribes had to know as much about making ink or baking clay as they did about writing.

The arcane aura that surrounds personal computers is not just a "user interface" problem. My colleagues and I at the Xerox Palo Alto Research Center think that the idea of a "personal computer itself is misplaced and that the vision of laptop machines, dynabooks and knowledge navigators" is only a step toward achieving the technology that will make

The idea of integrating computers seamlessly into the world at large runs counter to a number of present-day trends. "Ubiquitous computing" in this context does not mean just computers that can be carried to the beach, jungle or airport. Even the most powerful notebook computer, with access to a worldwide information network, still focuses attention on a single box. By analogy with writing, carrying a super-laptop is like owning just one very important book. Customizing this book, even writing millions of other books, does not begin to capture the real power of literacy.

Furthermore, although ubiquitous computers may use sound and video in addition to text and graphics, they do not make them "multimedia" or "multimedia" in the sense that

PAPERS

## Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms

CHI 97 \* 22-27 March 1997

Hiroshi Ishii and Brygg Ullmer  
MIT Media Laboratory  
Tangible Media Group

20 Ames Street, Cambridge, MA 02139-4307 USA  
{ishii, ullmer}@media.mit.edu

### ABSTRACT

This paper presents our vision of Human Computer Interaction (HCI): "Tangible Bits." Tangible Bits allows users to "grasp & manipulate" bits in the center of users' attention by coupling the bits with everyday physical objects and architectural surfaces. Tangible Bits also enables users to be aware of background bits at the periphery of human perception using ambient display media such as light, sound, airflow, and water movement in an augmented space. The goal of Tangible Bits is to bridge the gaps between both cyberspace and the physical environment, as well as the foreground and background of human activities.

This paper describes three key concepts of Tangible Bits: interactive surfaces; the coupling of bits with graspable physical objects; and ambient media for background awareness. We illustrate these concepts with three prototype systems - the metaDESK, transBOARD and ambientROOM - to identify underlying research issues.

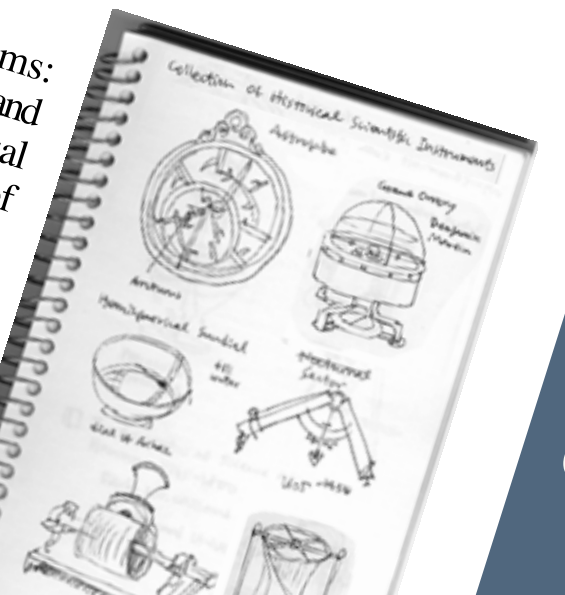
### Keywords

tangible user interface, ambient interface, augmented reality, and periphery

### BITS & ATOMS

We live between two realms: our physical environment and cyberspace. Despite our dual citizenship, the absence of these parallel existences leaves a great divide between the worlds of bits and atoms. At the present, we are torn between these parallel but disjoint spaces.

We are now almost constantly "wired" so that we can be here (physical space) and there (cyberspace) [14]



# Class activity 2 of 3: Discussion

# Yes, there is human-human interaction in a CS class.

You will join a weekly discussion section

You will dig into themes that arose in commentaries and in class

Discussions run Wednesdays, Thursdays and Fridays (**start this week**)

# Discussion sections

**80min, once per week**

Section 1: Wed 3:30-4:50pm

Section 2: Wed 5:00-6:20pm

Section 3: Thu 10:30-11:50am

Section 4: Thu 12:00-1:20pm

Section 5: Fri 9:30-10:50am

Section 6: Fri 11:00-12:20pm

# Required section application

**Submit section application by 11:59 tonight for priority placement**

Link to application is on syllabus page of the course website:

<http://cs347.stanford.edu/syllabus>

We will use this application to assign you a section and discussant date

# Being a discussant

For one paper, you will be the **discussant**, responsible for helping drive effective in-class discussion.

Discussants have two goals

1. Summarize the commentaries on one paper into a meta-commentary before your section in the form of a slide deck:

- Major themes in your section's commentaries, including quotes

- Your response to each of these themes, to kick off discussion

2. Use slide deck to help launch discussion in section (20 min per discussant)

- In section share a theme, deliver your response to it, and discuss!

# Class activity 3 of 3: Quizzes

# Five in-class quizzes

Cover the lecture content, every two weeks

Each quiz will cover content spanning from the lecture day of the previous quiz up until, but not including, the current quiz's day

e.g., Quiz 1, at the end of Week 2, will cover today through the first lecture of Week 2

e.g., Quiz 2, at the end of Week 4, will cover the lectures from the same day as Quiz 1, through the first lecture of Week 4

Comprehensive final quiz during final lecture time

All quizzes are closed-book, will ask you to recognize and apply the concepts from lecture

# Quiz Timeline

week 1

week 2

Quiz

week 3

week 4

Quiz

week 5

week 6

Quiz

week 7

week 8

Quiz

week 9

week 10

Quiz 2x

No Final Exam

# Prereqs and background

**Most important:** are you prepared to dive deep into foundational HCI theories and critique/discuss them?

Helpful:

Depth in at least one of (computer science, social science methods, design, STS)

Experience in human-computer interaction (e.g., CS 147, CS 247)

Required:

CS or SymSys HCI track undergraduate and masters: CS 147 or CS 247

PhD or other programs: no prereqs

# Grading

30% Paper commentaries

60% First four quizzes 10% each, final quiz 20%

10% Participation (discussant, section, class)

# Introductions

# Maneesh Agrawala

Professor of Computer Science

HCI/Graphics/Visualization

Office hours: Thu 2-3pm,  
*CoDa E362*



# TAs



Jiaju Ma  
PhD CS



Jean-Peic Chou  
PhD CS



Yujie Tao  
PhD CS

# Contact us

Email: [cs347@cs.stanford.edu](mailto:cs347@cs.stanford.edu)

Readings, policies, entertainment: [cs347.stanford.edu](http://cs347.stanford.edu)

Assignment submission: [canvas.stanford.edu](http://canvas.stanford.edu)



Questions?

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