Announcements

Presentation sign-ups due today (4/7).

Remember that signing up means listing a paper.

Tools for Thought

CIS 7000-001

Andrew Head & Danaé Metaxa

What is a tool for thought?

Explicit, fully committal definitions are rare in the HCI literature.

"Things that help us think."

Think: *define problems*, *solve them*, *understand the world*, *make decisions*, *do logic*, formulate *and review argument,* or more generally **produce new or refined knowledge from old**.

Things: *objects*, *representations*, *notations*, *languages*, *interfaces*, *custom*, *methods* [Appleton 2022]

Didn't we already have this lecture?

If our definition is "things that help us think" then...

- **Graphs** are a tool for thought [viz lecture]
- **Logo** is a tool for thought [ed tech lecture]
- **Twitter** is a tool for thought [social media lecture]
- **Figma** is a tool for thought [content creation lecture]
- **The mouse** is a tool for thought [input/output lecture]

Yes!

So why do we have another lecture talking about it?

Tools for thought as a way of framing HCI outcomes

With a "tools for thought" framing, we aspire to increase cognitive capacity to **achieve new outcomes not possible before**.

This involves helping people take on **complex problems**, **comprehend complex situations**, and come up with **solutions** previously beyond their reach [Engelbart 1962].

How do we do this?

Today

Extended cognition

Undefined, non-linear problem solving

Reverse centaurs

Where are we today?

Extended Cognition

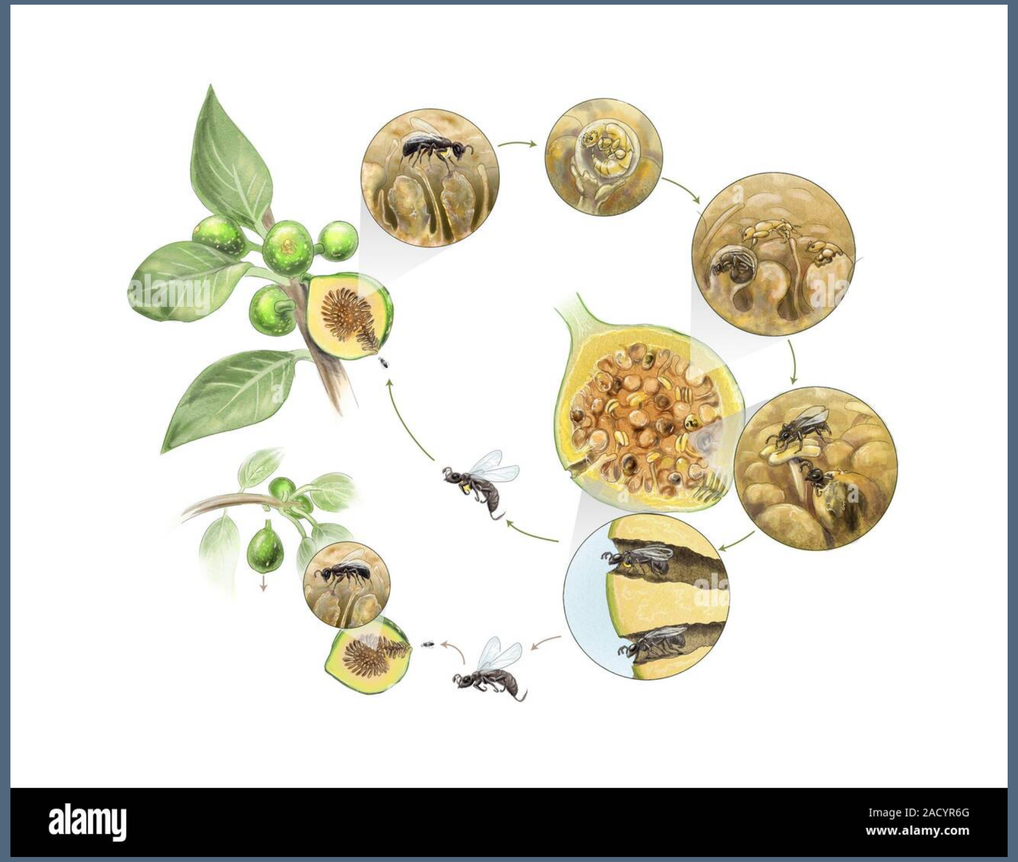
"Man-computer symbiosis"

[Licklider 1960]

Licklider envisions a future where a person-computer system can "think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today."

Long-term: Licklider expects computers to surpass humans in capacity to think.

Short-term: people need to work in symbiosis with computers.



Augmenting human intellect

[Engelbart 1968]

In 1968, Douglas Engelbart performs the "Mother of All Demos" in Silicon Valley.

The demo showed off the fruits of the labor of the Augmentation Research Center (ARC): precursors to many computer tools for thought: documents, hyperlinks, diagramming, remote collaboration, etc.

Augmenting human intellect

[Engelbart 1962]

To augment human intellect, we alter and connect a number of components:

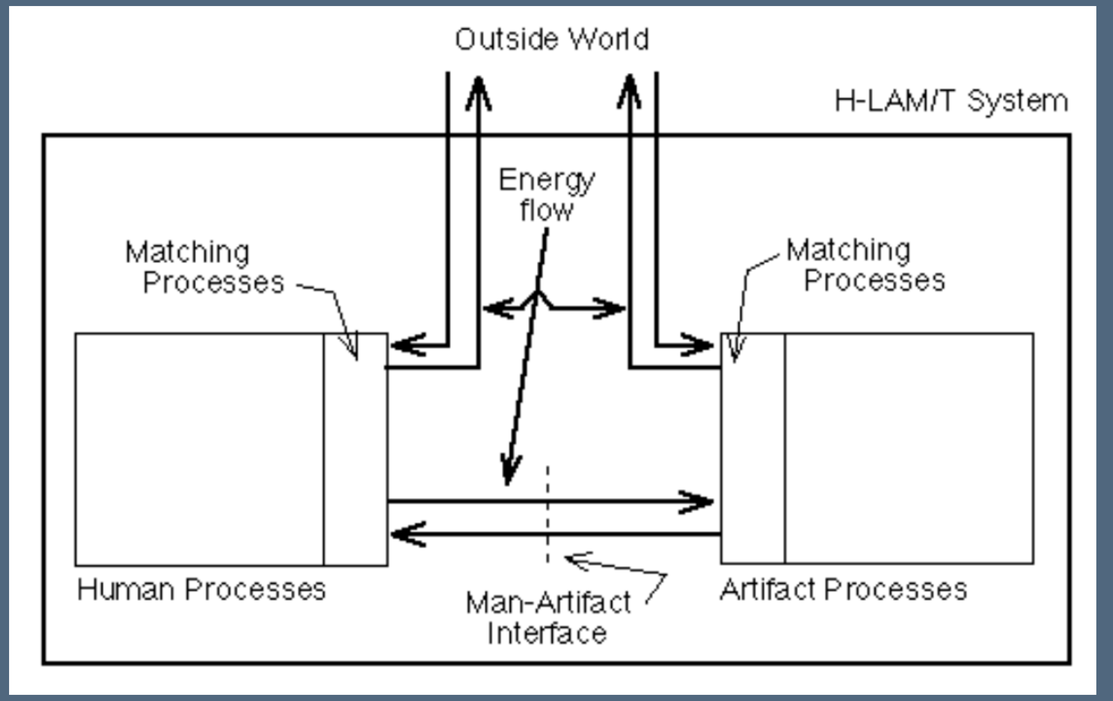
Human (H): self-explanatory

Artifacts (A): physical objects for manipulation of things, materials, and symbols

Language (L): how information travels between the world and the mind

Methodology (M): organization of activity

Training (T): conditioning for a human to develop skill with A, L, M.



What makes a good representation?

[Scaife and Rogers 1996]

Compute the following product:

$$\text{LXVII} \times \text{X} = ?$$

Try again with this one:

$$68 \times 10 = ?$$

Recall from before that picking the right representations can make cognitively demanding tasks trivial.

External cognition

[Scaife and Rogers 1996]

Scaife and Rogers name a few factors that make our graphical representations more effective:

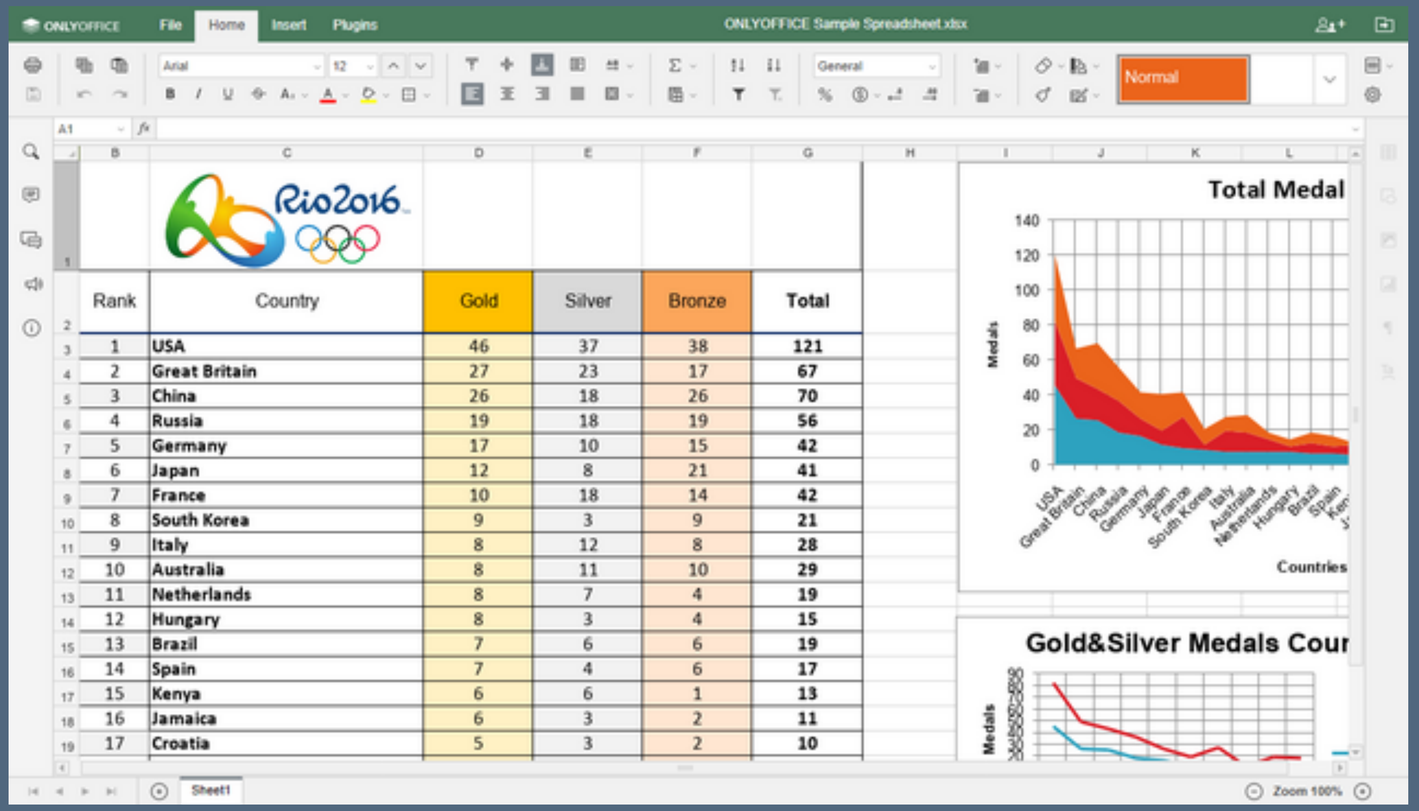
- **Computational offloading**: reducing the effort to solve a problem without affecting its underlying information content.
- **Re-representation**: casting a problem into a new representation that makes problem solving easier or harder.
- **Graphical constraining**: when visual aspects constrain the kinds of inferences that can be drawn about the represented world.

Computational offloading

[Scaife and Rogers 1996]

Reducing the effort to solve a problem without affecting its underlying information content.

Example: spreadsheet, maintains many computations that would otherwise need to be done individually.



Rank	Country	Gold	Silver	Bronze	Total
1	USA	46	37	38	121
2	Great Britain	27	23	17	67
3	China	26	18	26	70
4	Russia	19	18	19	56
5	Germany	17	10	15	42
6	Japan	12	8	21	41
7	France	10	18	14	42
8	South Korea	9	3	9	21
9	Italy	8	12	8	28
10	Australia	8	11	10	29
11	Netherlands	8	7	4	19
12	Hungary	8	3	4	15
13	Brazil	7	6	6	19
14	Spain	7	4	6	17
15	Kenya	6	6	1	13
16	Jamaica	6	3	2	11
17	Croatia	5	3	2	10

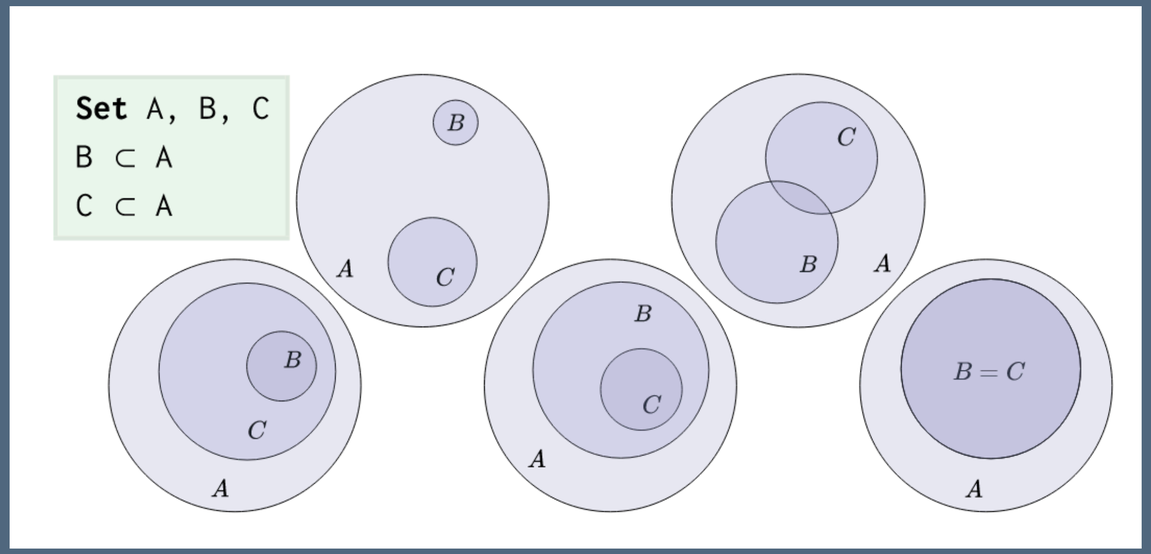
https://commons.wikimedia.org/wiki/File:OnlyOffice_spreadsheet_editor.png

Re-representation

[Scaife and Rogers 1996]

Casting a problem into a new representation that makes problem solving easier or harder.

Example: generating mathematical diagrams to convey relations between variables [Ye et al. 2020].



Re-representation

[Scaife and Rogers 1996]

Casting a problem into a new representation that makes problem solving easier or harder.

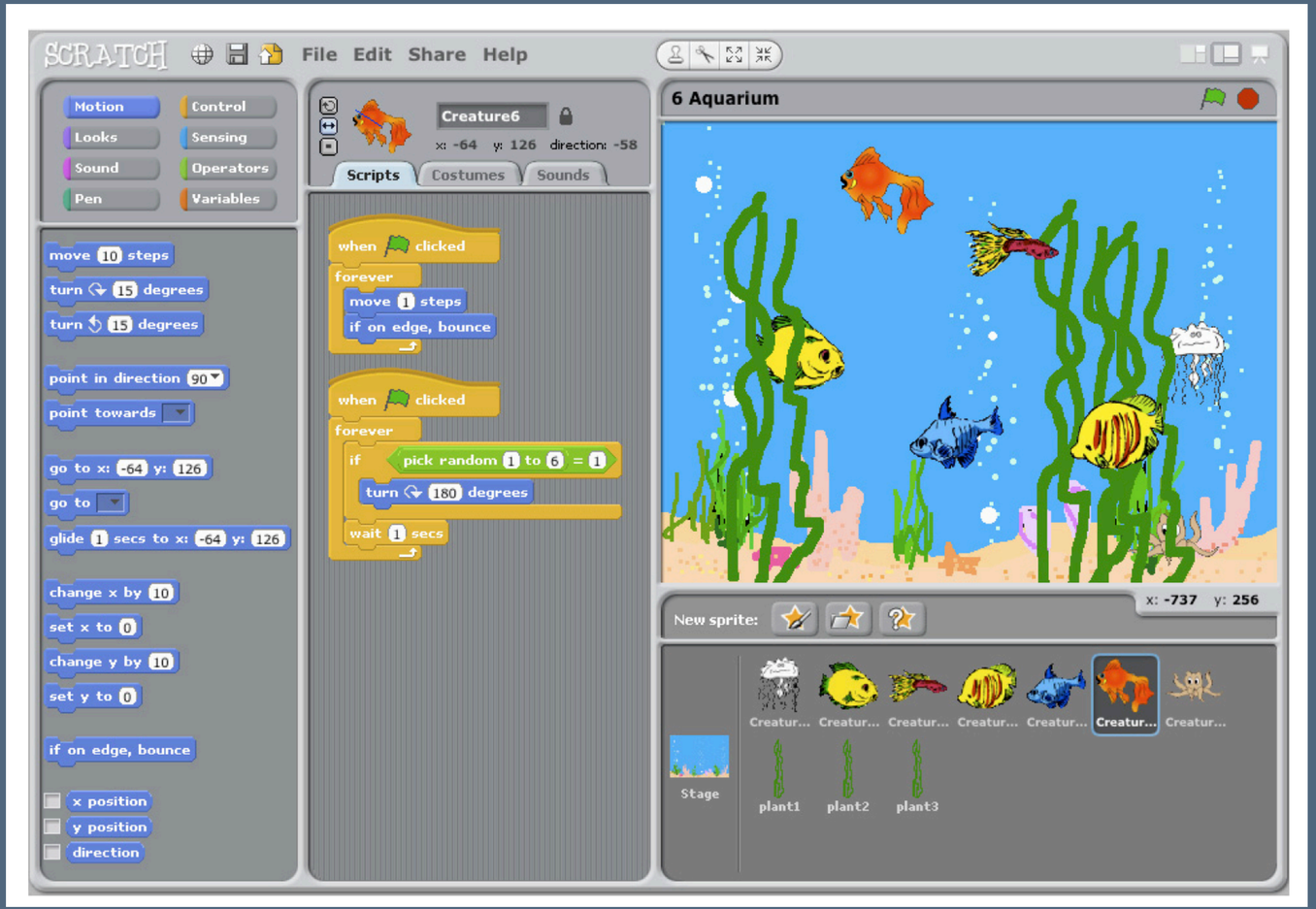
Example: visualizing hidden work of an LLM to invite inquiry into that work [Xie et al. 2024].

Graphical constraining

[Scaife and Rogers 1996]

When visual aspects constrain the kinds of inferences that can be drawn about the represented world.

Example: block-based programming languages constraining how a program can be constructed [Maloney et al. 2010].

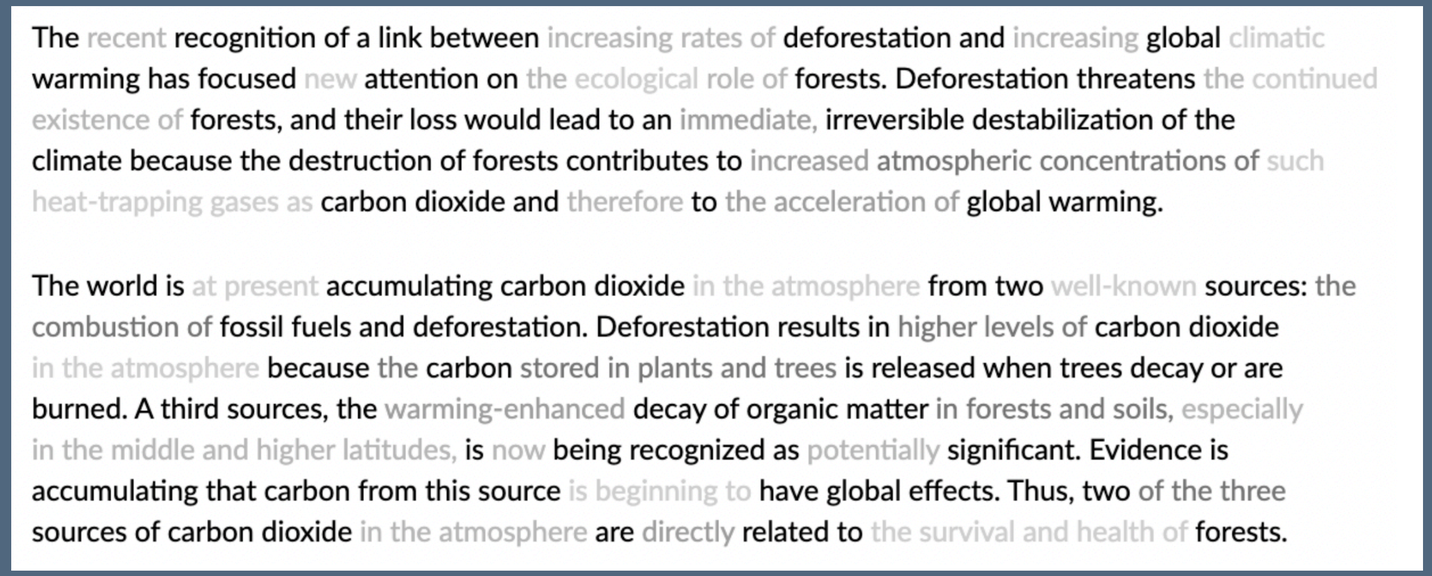


Graphical constraining

[Scaife and Rogers 1996]

When visual aspects constrain the kinds of inferences that can be drawn about the represented world.

Example: AI highlights that tell you what *can't* be skipped when skimming [Gu et al. 2024]



The recent recognition of a link between increasing rates of deforestation and increasing global climatic warming has focused new attention on the ecological role of forests. Deforestation threatens the continued existence of forests, and their loss would lead to an immediate, irreversible destabilization of the climate because the destruction of forests contributes to increased atmospheric concentrations of such heat-trapping gases as carbon dioxide and therefore to the acceleration of global warming.

The world is at present accumulating carbon dioxide in the atmosphere from two well-known sources: the combustion of fossil fuels and deforestation. Deforestation results in higher levels of carbon dioxide in the atmosphere because the carbon stored in plants and trees is released when trees decay or are burned. A third sources, the warming-enhanced decay of organic matter in forests and soils, especially in the middle and higher latitudes, is now being recognized as potentially significant. Evidence is accumulating that carbon from this source is beginning to have global effects. Thus, two of the three sources of carbon dioxide in the atmosphere are directly related to the survival and health of forests.

In summary, good representations...

[Scaife and Rogers 1996]

- Do the computation for us
- Cast into fluid, perceivable, manipulable representations
- Constrain the space of solutions

What makes a representation become a natural part of our thinking?

Extended mind hypothesis

[Clark and Chalmers 1998]

When the tools we use are heavily integrated into the way we process information, they might as well be part of our "mind."

For instance, consider a person with Alzheimer's, Otto, who relies on a notebook to look up where places are. Can we consider this notebook part of his cognition?

It is a **constant** in Otto's life

It is **directly available without difficulty**

He automatically **endorses** information from it

Extended mind hypothesis

[Clark and Chalmers 1998]

The extended mind hypothesis is an interesting provocation suggesting that if the coupling between a person and their artifacts is reliable, then perhaps it should be viewed as part of the same mind, working towards the same goal.

Sensemaking

Example sensemaking situation

You are planning a trip for you and your family.

Intended end result: a schedule of places and things to do

Starting point: a destination and set of vague constraints

How might you get to the intended result?

Come up with ideas

Collect information

Organize it

Reflect and iterate

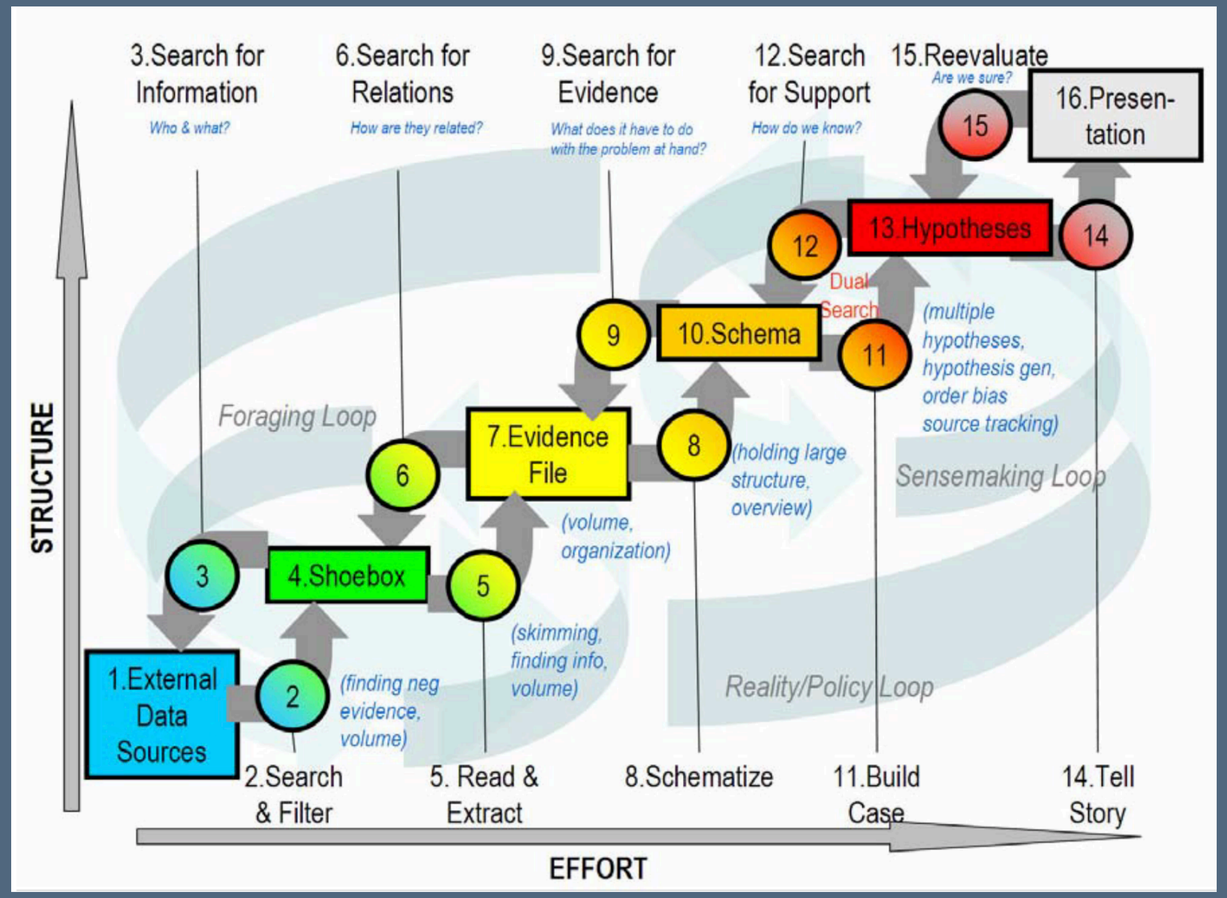
Share outcome

The sensemaking process

[Pirolli and Card 2005]

Derived from a cognitive task analysis of intelligence analysts.

Still, this framework has stood the test of time. It has appeared in derivative form in countless HCI papers and talks.



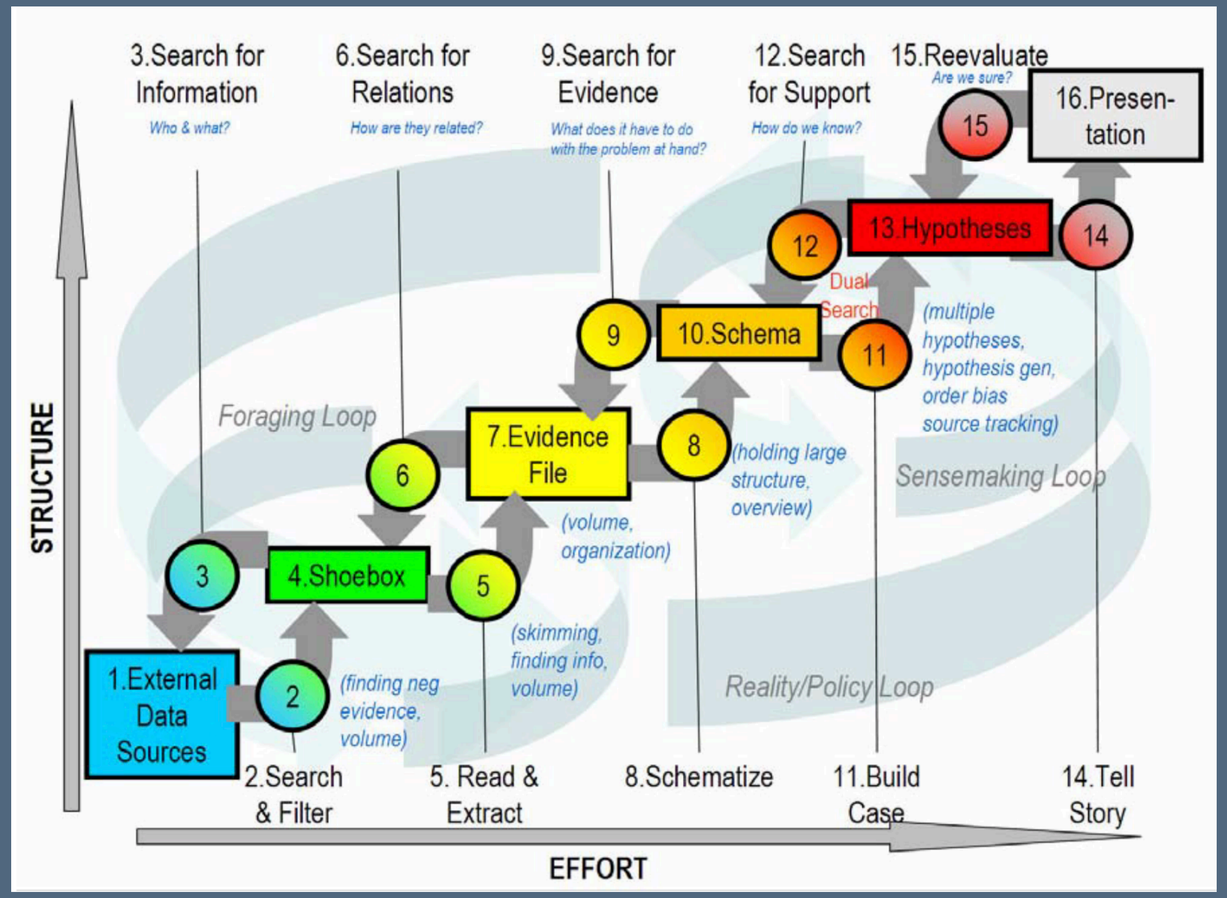
The sensemaking process

[Pirolli and Card 2005]

At its coarsest, described as:

1. Information
2. Schema
3. Insight
4. Product

Schema: set of learned templates for how best to interpret and process information



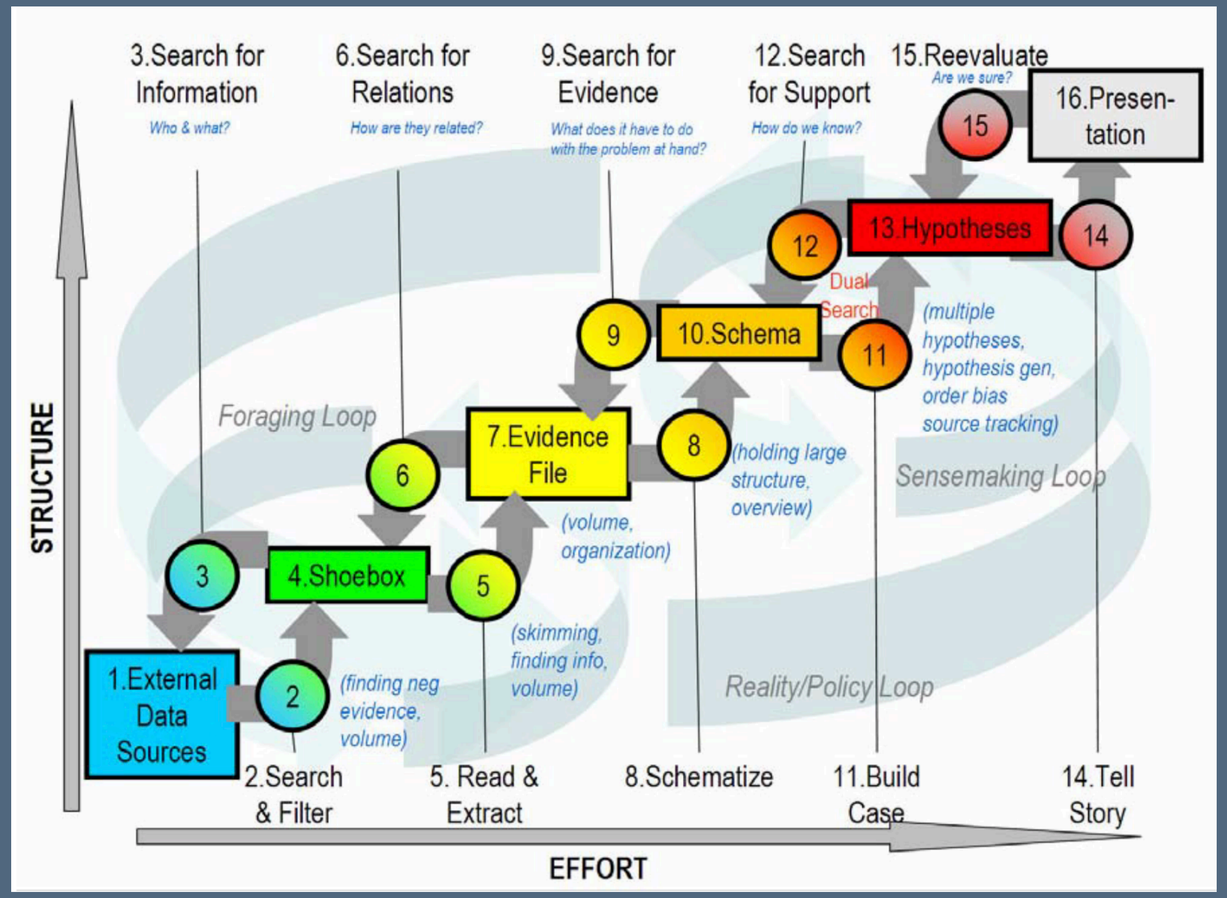
The sensemaking process

[Pirolli and Card 2005]

Loop 1. Foraging loop. Seek, search, filter, read, extract information, possibly into a schema.

Loop 2. Sense making loop. Iterative development of an understanding that fits the evidence.

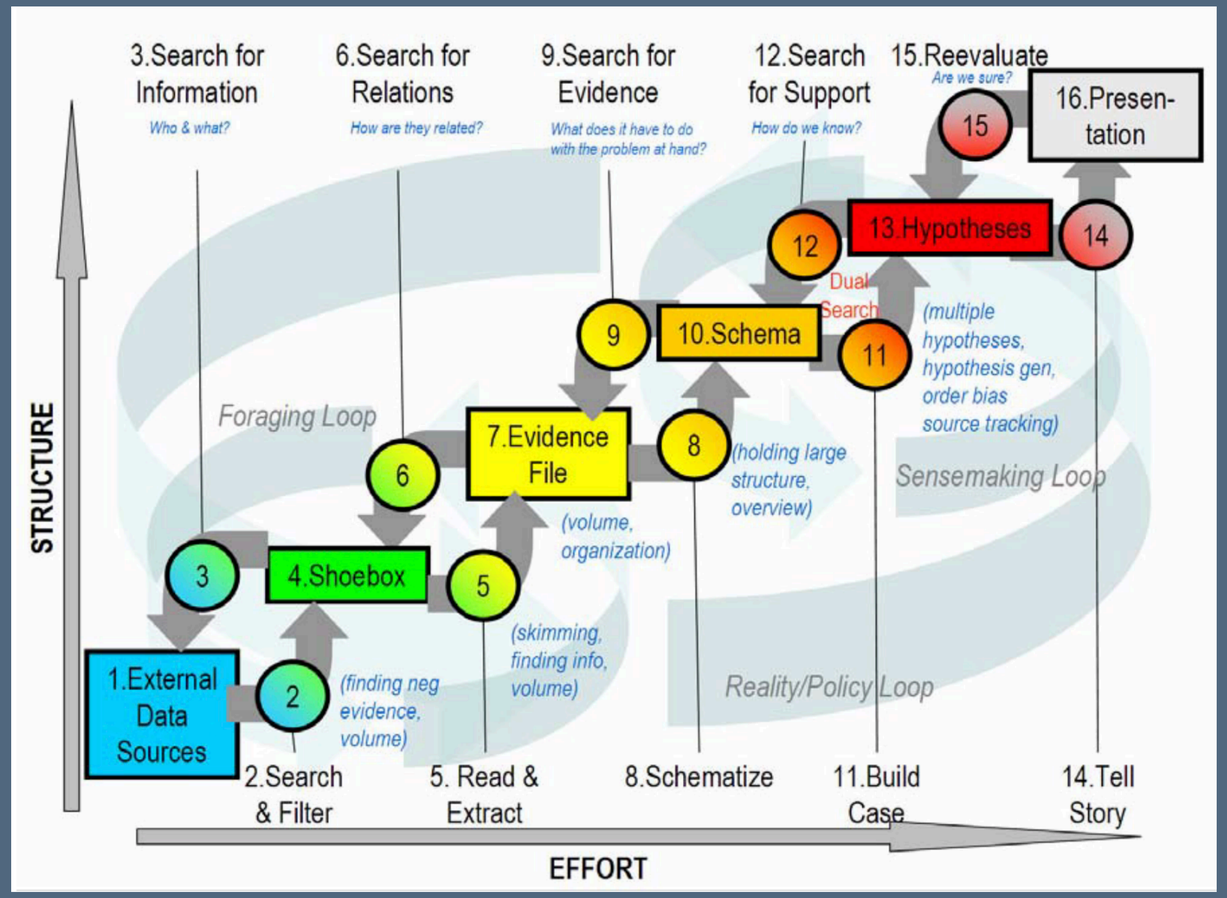
What interfaces do you use for sensemaking?



The sensemaking process

[Pirolli and Card 2005]

Sensemaking tools address some steps or transitions in the sensemaking process, lowering the barriers to foraging or synthesis.



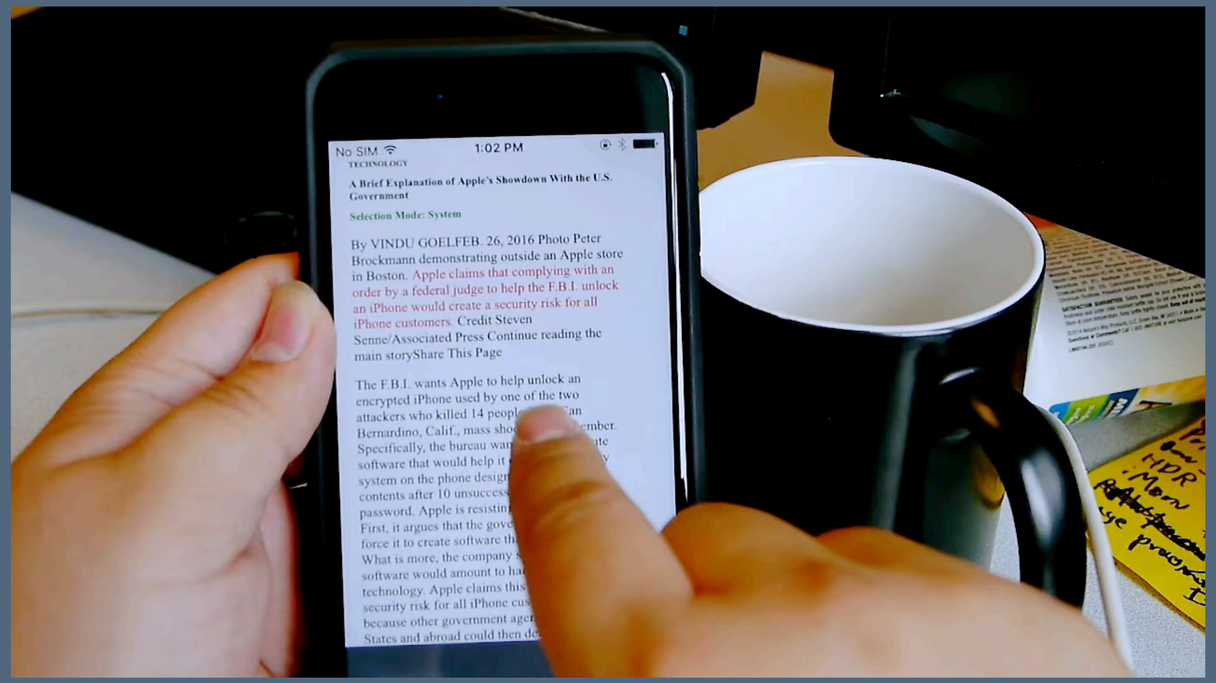
Search and Filter

[Chang et al. 2016]

Reduce cost of capturing information into the shoebox [Chang et al. 2016].

Support capturing on mobile phones using more easily executable input actions (long press with context window determined by pressure).

Reduce temptation to overinvest in precision at early stage (prohibit exact text selection).



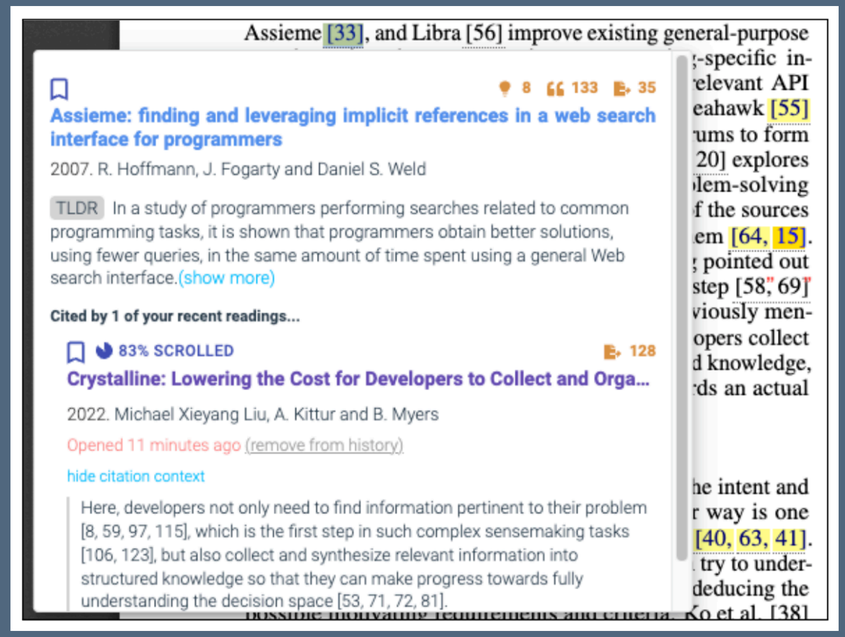
Search for Relations

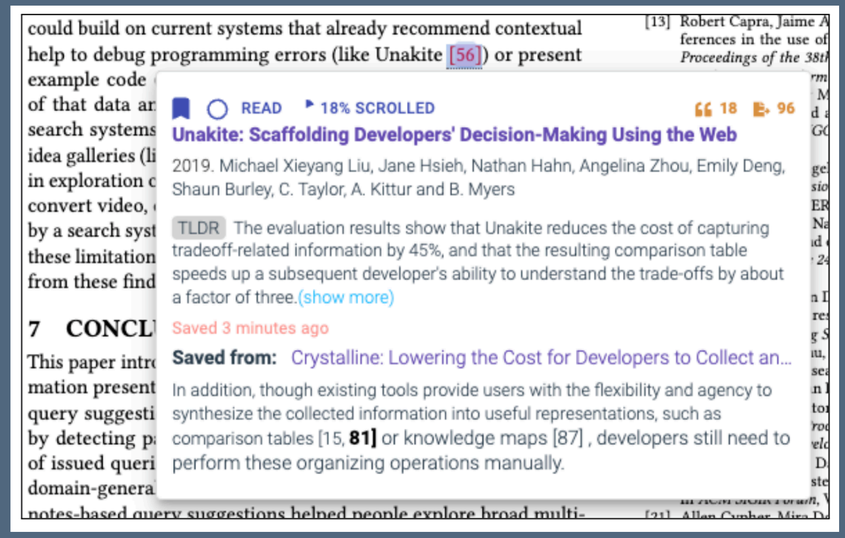
[Chang et al. 2023]

Put encountered information in context.

Augment the citation with information about who else cited this work and how else you have come across it in the past.

(At the same time, assist in decisions around searching for more citations).





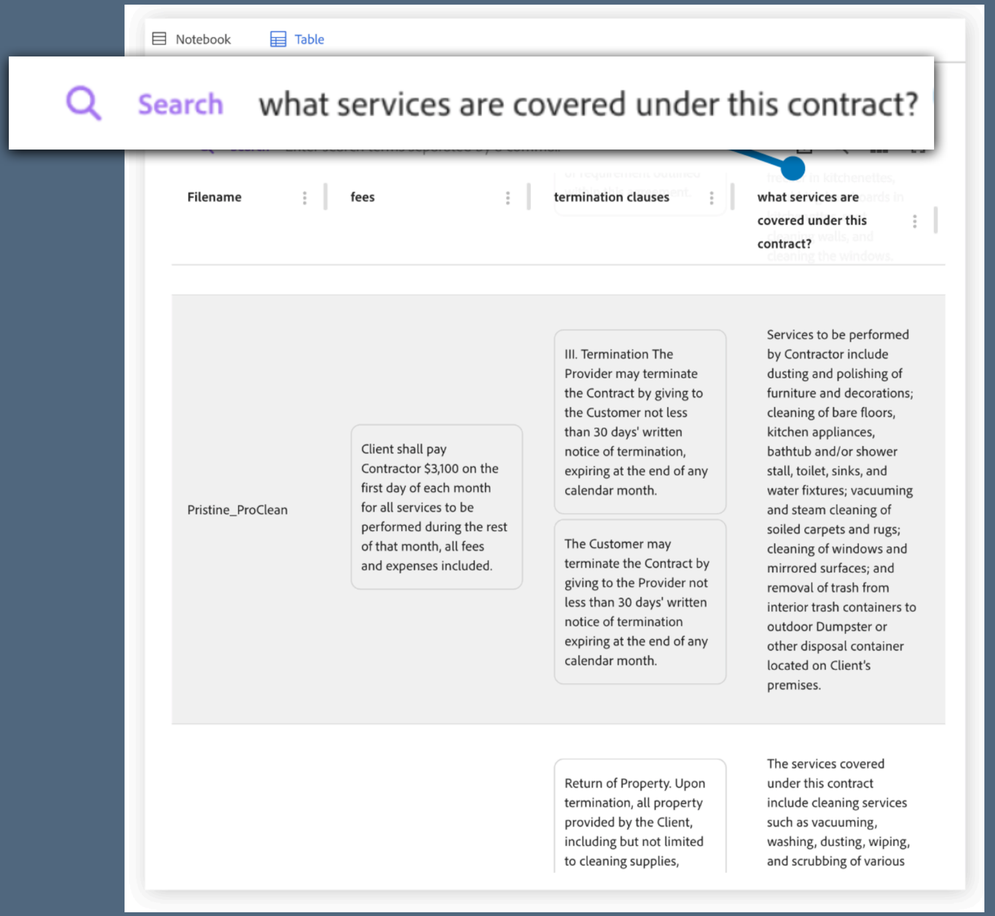
Schematize

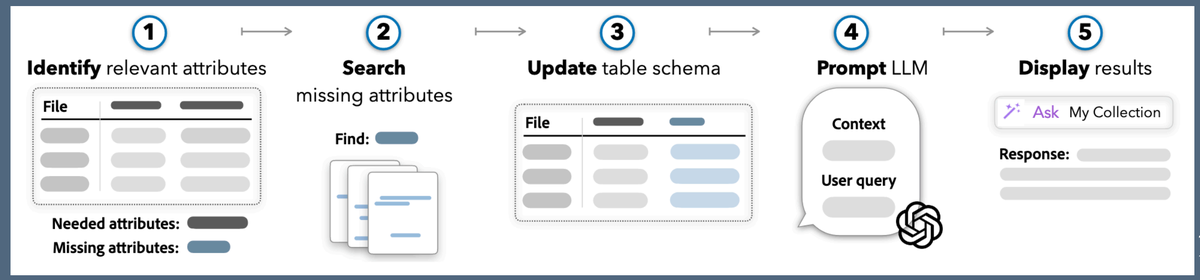
[Fok et al. 2024]

Fit found information into a meaningful structure.

Given a user query, extract information answering it from business documents. Place them in a table that supports more fluid comparison and synthesis.

Bonus: hooks back to the foraging step (can click on extractions to open them up in the original doc).



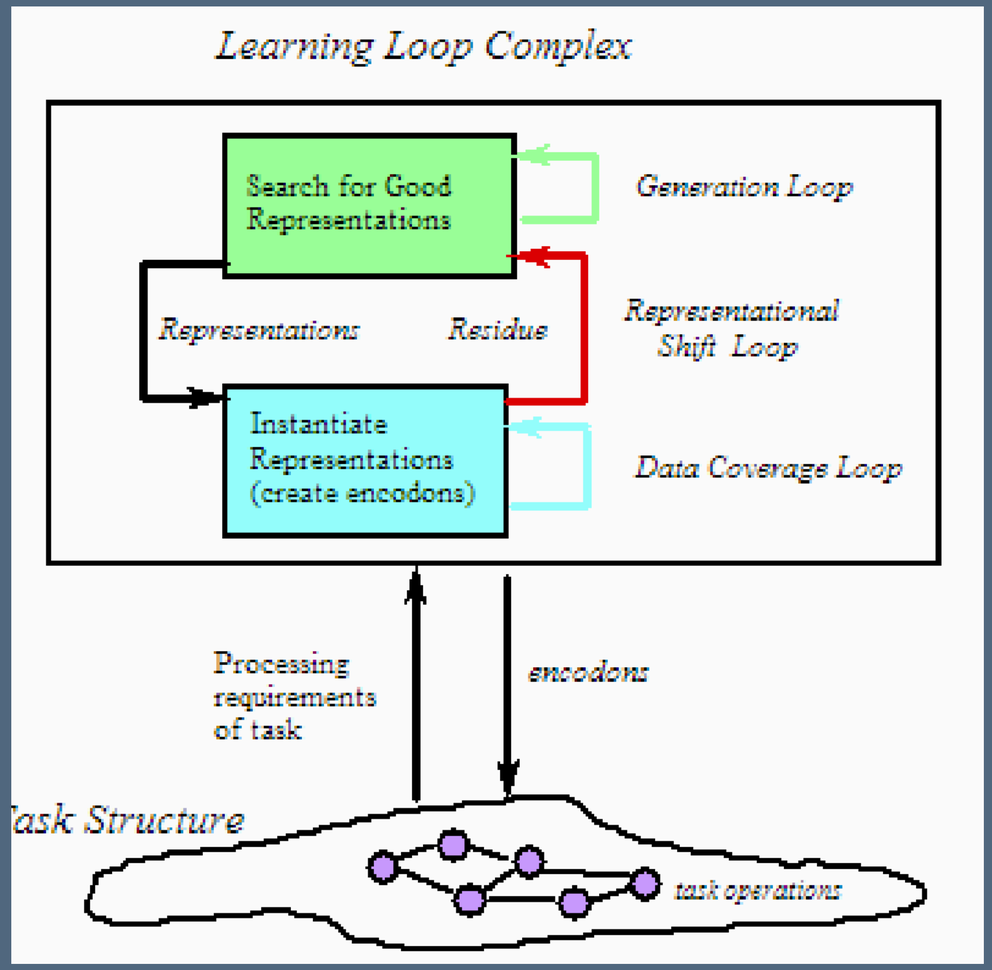


Surprise in sensemaking

[Russell et al. 1993 by way of Pirolli and Card 2005]

If sensemaking involves finding the right schema to fit information into, then there are problems if that schema is wrong.

When important information does not fit into our schema, we have **residue**. In some situations, it is important that we help people incorporate that residue.



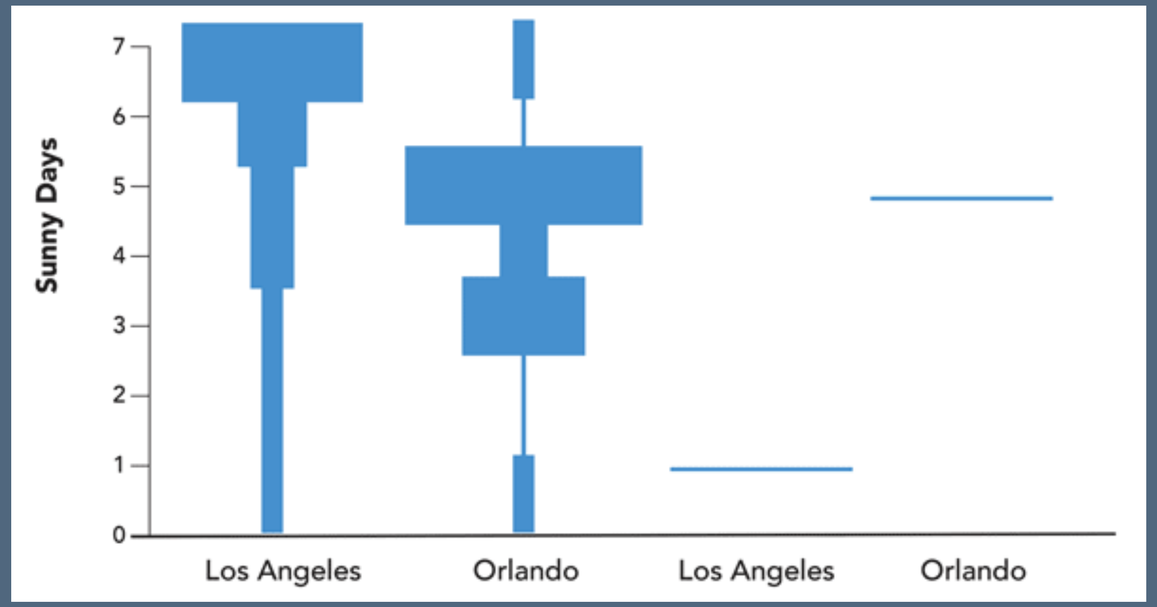
Showing the residue

[Kale et al. 2019]

Trying to keep someone from misreading the statistical model?

Show them examples in the form of hypothetical outcome plots.

Can improve readers' ability to infer the actual underlying trend in the data in low-evidence situations.



Showing the residue

[Dragicevic et al. 2019]

Trying to keep someone from misreading the statistical model?

Allow people to play around with the parameters and see how it affects the predictions.

Create a new medium of explorable multiverse reports, where parameters are baked into the document to permit this kind of information seeking.

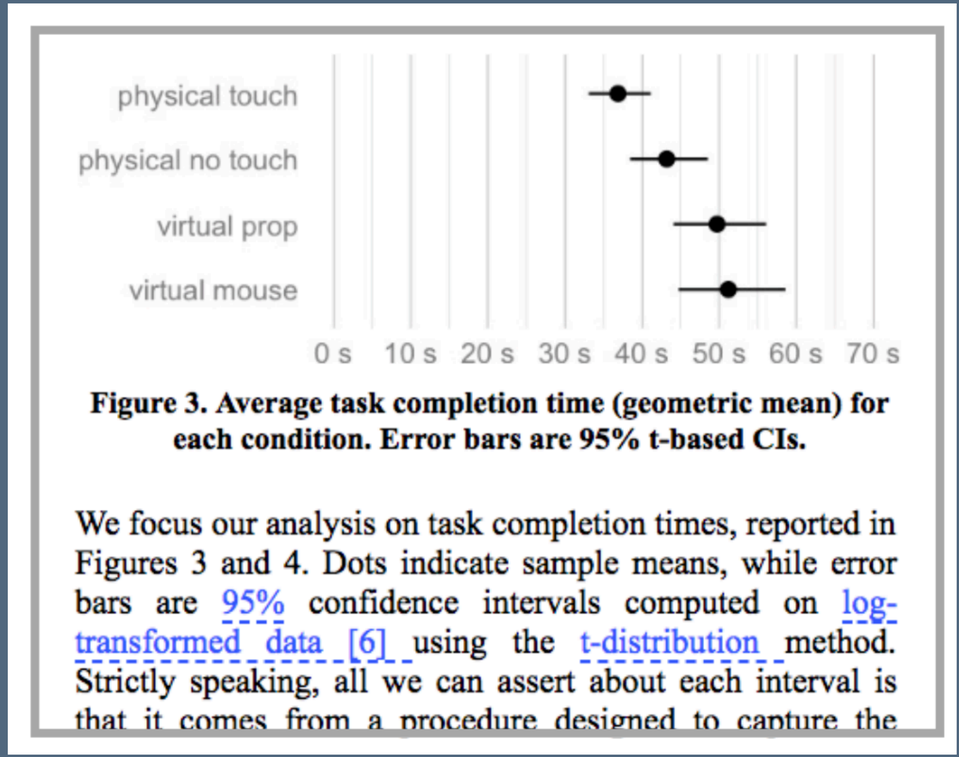


Figure 3. Average task completion time (geometric mean) for each condition. Error bars are 95% t-based CIs.

We focus our analysis on task completion times, reported in Figures 3 and 4. Dots indicate sample means, while error bars are 95% confidence intervals computed on log-transformed data [6] using the t-distribution method. Strictly speaking, all we can assert about each interval is that it comes from a procedure designed to capture the

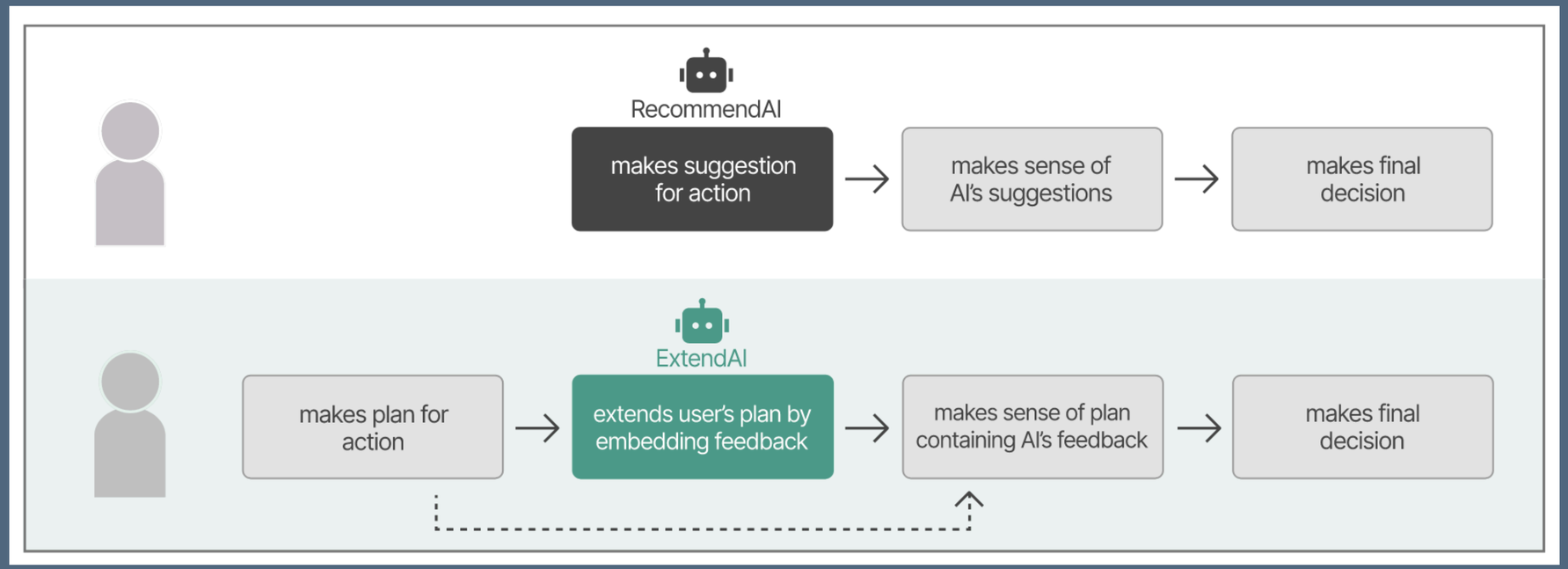
YOU READ THIS

Sensemaking with an AI

[Reichert et al. 2025]

Using an AI as a partner in making sense of information with an intent to make a high-stakes decision.

What model of interaction is better? *RecommendAI* or *ExtendAI*?



Reverse Centaurs

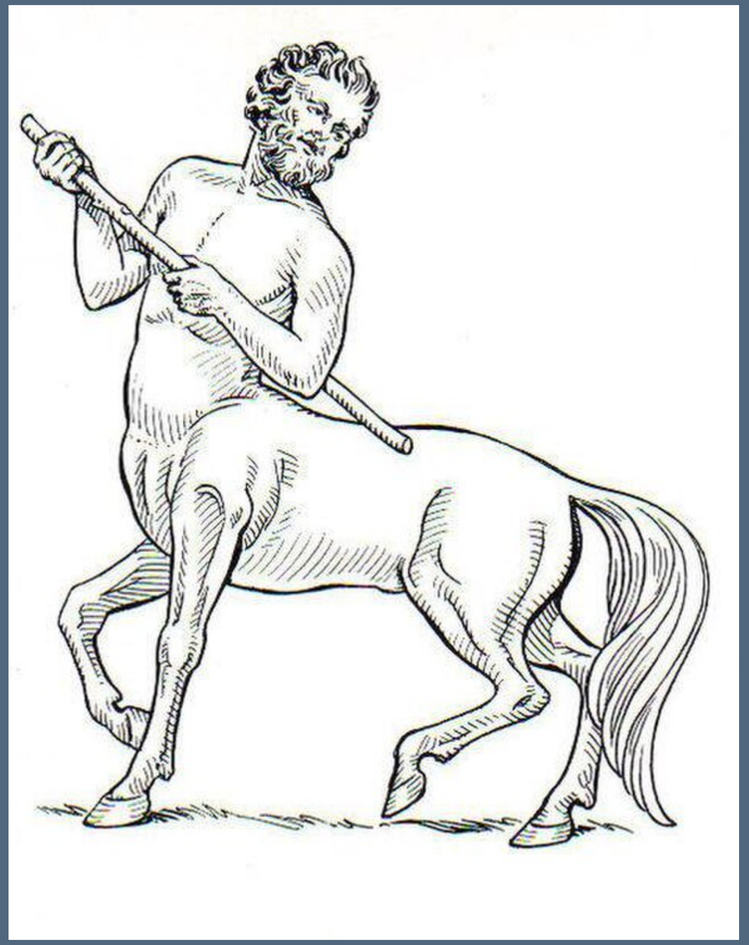
Centaurs

[adapted from Doctorow 2025]

Mind of a human, propulsion of a horse.

Used to describe human-AI interaction where the person **works towards their goals with the power of AI behind them**.

Example: While writing a new article, I used AI to produce a transcript of a bunch of MP3s I have of podcasts, and was able to search them for the perfect quote.



https://commons.wikimedia.org/wiki/File:Centaur_(PSF).jpg

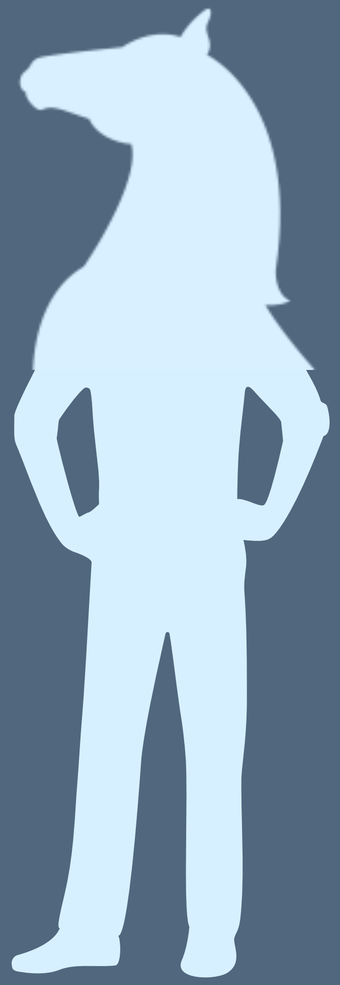
Reverse centaurs

[adapted from Doctorow 2025]

Mind of a horse, propulsion of a human.

Used to describe human-AI interaction where the **person's efforts are put to work in service of an AI**.

Example. Amazon warehouse workers fetching packages under the prescribed scheduling of the AI. A content creator who does not write themselves but rather fact-checks AI-generated drafts.

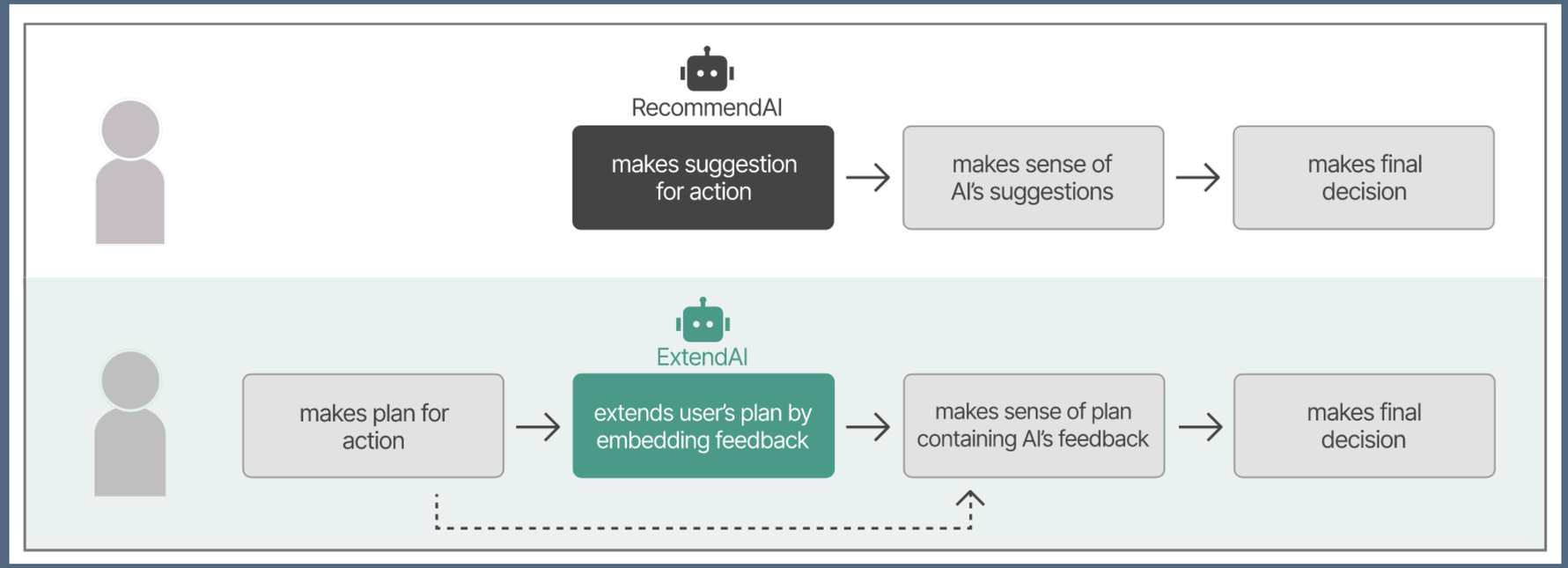


Sensemaking with an AI

[Reichert et al. 2025]

RecommendAI. Centaur or reverse centaur?

ExtendAI. Centaur or reverse centaur?



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After "Man-computer symbiosis"

[Licklider 1960]

"Man-computer symbiosis is probably not the ultimate paradigm for complex technological systems. It seems entirely possible that in due course, electronic or chemical machines will outdo the human brain in most of the functions we now consider exclusively within its province." - Licklider

This sounds like anticipating the reverse centaur in 1960. Not exactly a stirring vision of where this is all going.

What role should/must humans play in thought?

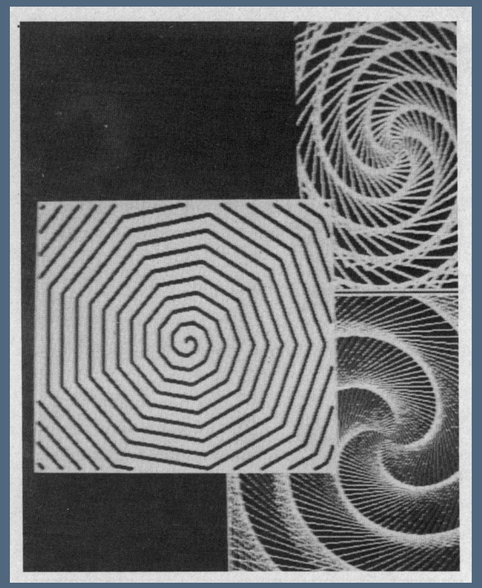
How far have we come?

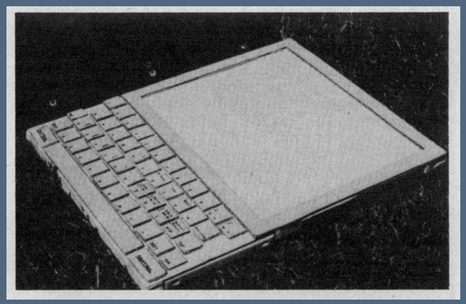
One more blast from the past

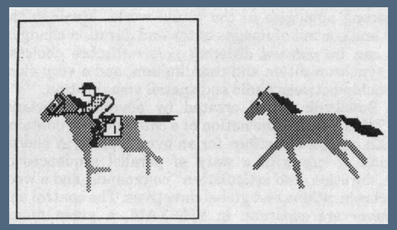
[Kay and Goldberg 1977]

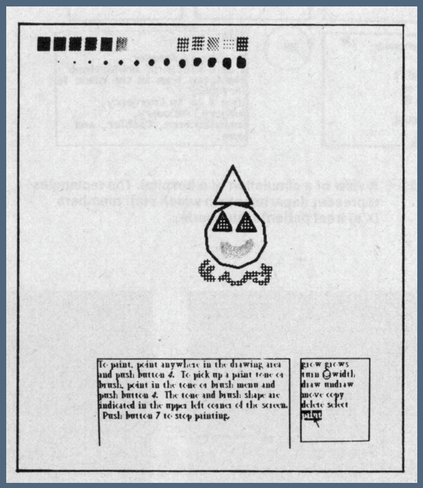
"Although thinking goes on in one's head, external media serve to material thoughts and, through feedback, to augment the actual paths the thinking follows."

Was Kay and Goldberg's vision transformative or not? Are there any parts we haven't achieved?









YOU READ THIS

Have we missed the goal?

Kay famously said that the computer revolution hasn't happened yet.

At the time, many of his visions around more malleable programming of the machines and adaptable experiences had, and they still haven't.

When asked, Engelbart apparently told one of his collaborators in 2006 that only "2.8 percent" of his vision had been achieved [Landau 2018].

Some challenges for tools for thought

[Matuschak and Nielsen 2019]

Developing tools for thought is something of a **public goods problem**. Software firms do not have much incentive to develop them, because it is costly to do well. Discovered software patterns can be easily copied.

And many good tools for thought are public goods. Think about language, writing, math notation, the spreadsheet design. They are universal, belong to no one, and thus can scaffold coordination between us all.

There is also an **expertise problem**. Matuschak and Nielsen posit that good tools for thought require domain experts working on real, cutting-edge problems, where tools for thought fall out of the experience as an aid to help them do their work.

Summary

Tools for thought are a wide category of tools where the common feature is their support for **production of new or refined knowledge from old knowledge**.

One kind of tool for thought is **representations**. These offload human computation, support problem-solving through manipulation, and helpfully constrain the space of solutions.

Sensemaking tools support thought as it evolves in messy, nonlinear, iterative projects. They help people arrive at appropriate schemas while foraging and making sense of information against those schemas.

Tools can either promote the human or AI as lead thinker, resulting in centaurs or **reverse centaurs**. A recent conversation for our community is how to advocate for centaurs where it seems more work is aimed towards reverse centaurs.

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