Design Cognition

CS 347

Maneesh Agrawala

Announcements

If you're a late add, make sure you're in a section

Discussants: turn in metacommentaries **before lecture** (not before section)

Quiz after lecture today — pencils!

Last time

Ubicomp seeks to embed itself in long-lived activities and goals.

- It does this across a number of domains, including: physical health, mental health and wellbeing, aging, and designing for neurodivergent populations

Often seeks to sense information about the user and their surrounding environmental context in **unobtrusive** ways

- **Commodity sensing:** hardware we have or might have soon, typically kept by a single user
- **Infrastructure-mediated sensing:** single-point sensors that connect to existing infrastructure rather than held by the user

Ubiquitous computing

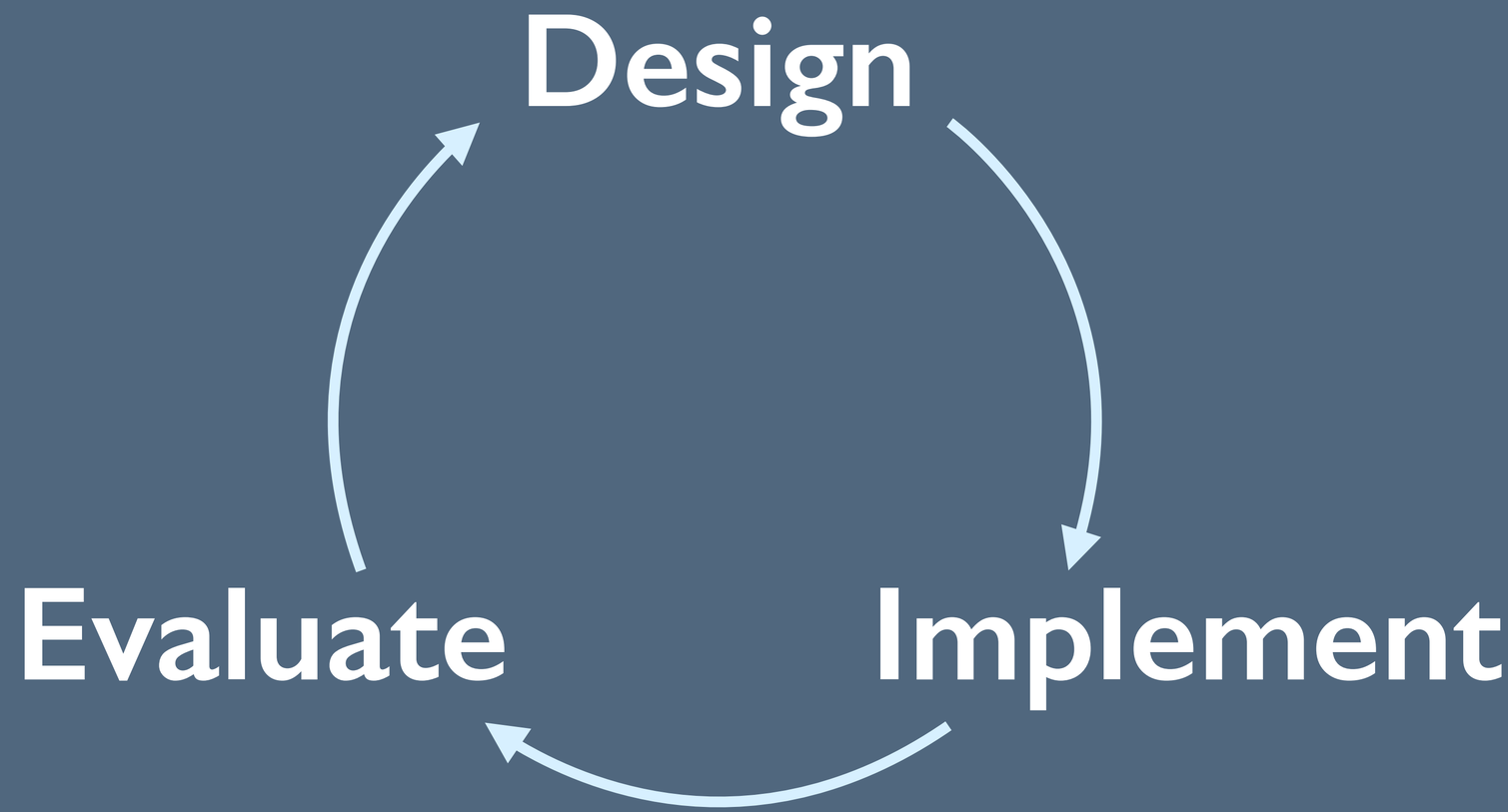
Unit 1

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

Design

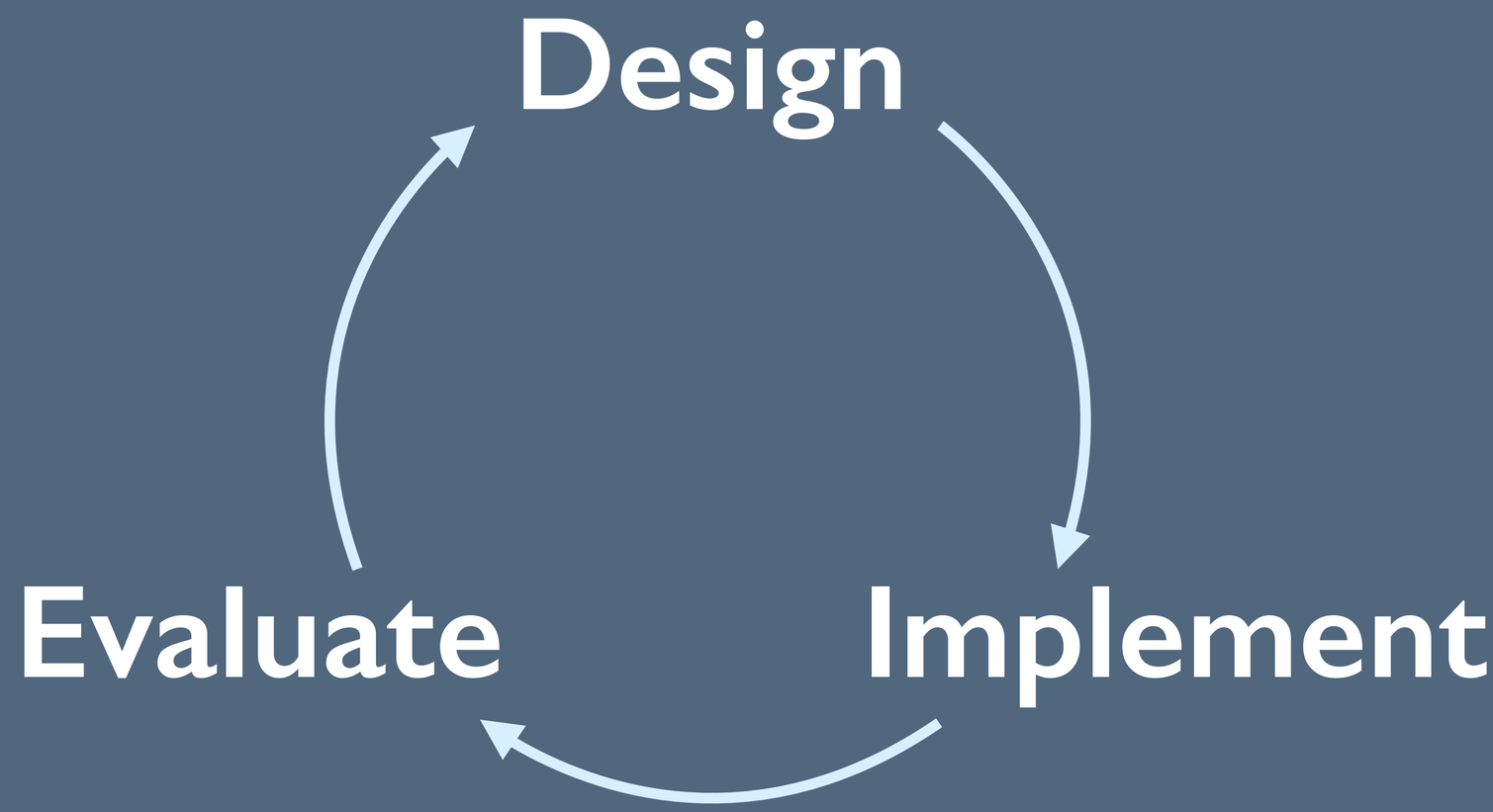
Unit 2

design cognition
design process
design tools

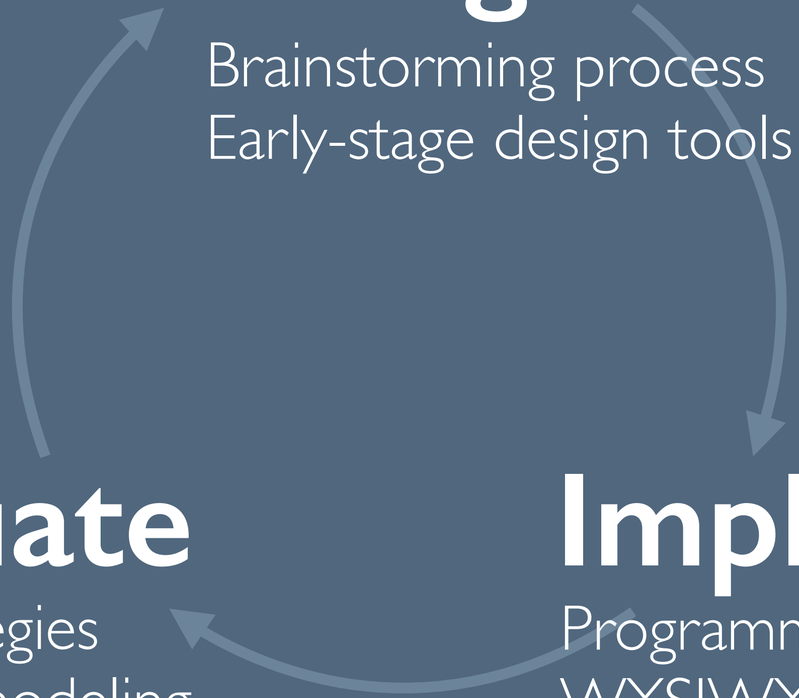

Design
Implement
Evaluate

Design is not a static process.

It can be studied, supported, and improved.



How might we facilitate and empower this process?


Design
Brainstorming process
Early-stage design tools
Implement
Programming tools
WYSIWYG design tools
Rapid prototyping tools
Evaluate
Study strategies
Cognitive modeling

Goal of the design unit

Refocus from the **process** of design to the **principles** that guide that process

Shift from obsequious adherence to a single prescriptive design process to an understanding of what each part of the process is trying to achieve

Result: apply the **right processes at the right time**, and develop entirely **new process innovations**

Today

Design cognition: how our thinking shapes our design process, and how our thinking shapes others' reactions to our designs

Three major themes of design cognition:

- Design Fixation
- Analogical transfer

} Processes directly impacting the designer

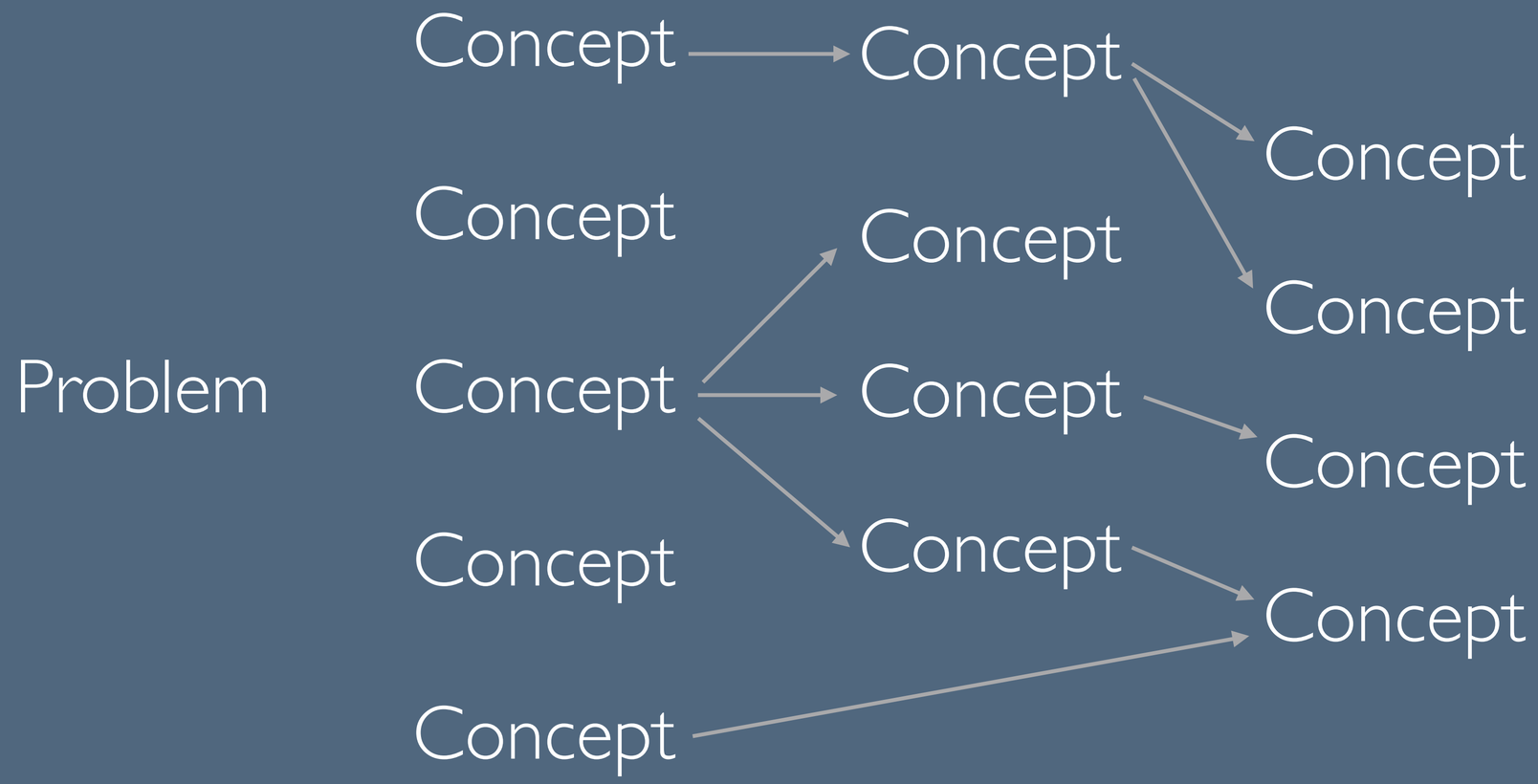
- Gulfs of execution and evaluation

} Processes indirectly impacting the designer through their effect on the user

Design Fixation

Ideal: open-minded ideation

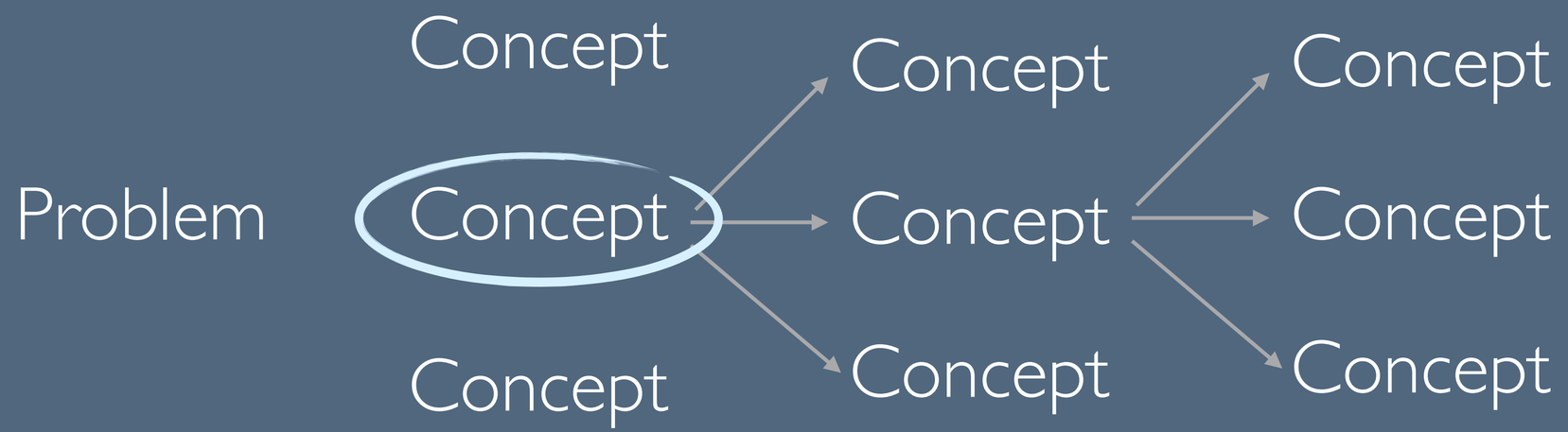
The **goal** is that the ideation process identifies many ideas, both proximal and distal



Reality: not enough breadth

In practice, we often myopically stay near proximal concepts that we've used before or that are surface-level similar

Why?



"I always liked this one anyway"

Design fixation

It cognitive psychology, **fixation** is when we introduce self-imposed barriers to problem solving [Maier 1931, Luchins 1942]

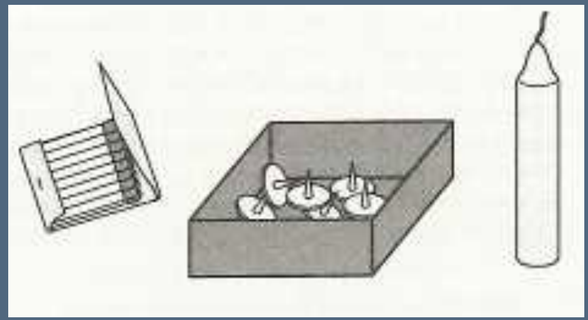
Design fixation is when we limit the breadth of our design process through adherence to a small set of concepts [Jansson and Smith 1991]

Design fixation takes hold both (1) unconsciously, when we're not aware, and also (2) consciously, even when we're aware that we're doing it.

Classic example of fixation

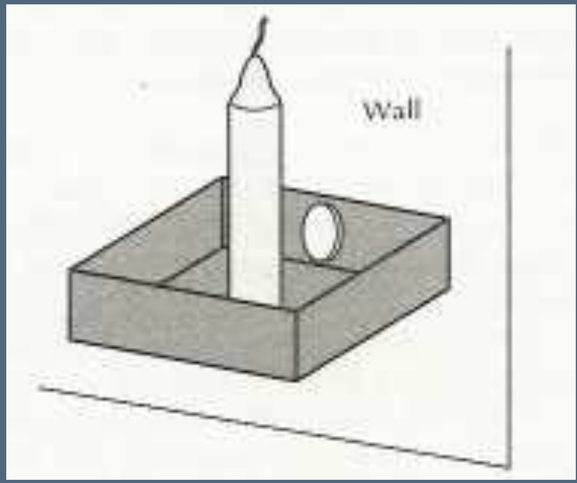
[Duncker and Lees 1945]

Goal: attach a candle to a wall so that the candle won't drip on the floor. You can only use (1) a book of matches, (2) a box of thumbtacks.



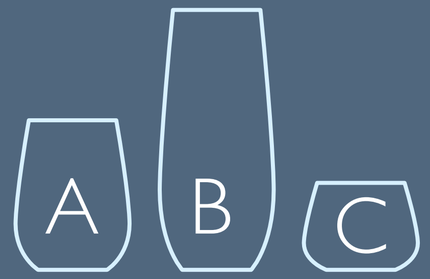
Designers are trained to question assumptions, and to creatively recombine the tools at their disposal.

However, we are biased toward using objects only in the ways we've seen them used before.



Classic example of fixation 2

[Luchins 1942]



Goal: measure a specific amount of water with the jars

Method: participants were given **practice tasks** that could be solved via a nontrivial algorithm B-A-2C

The **test problem** could be solved via the nontrivial algorithm (B-A-2C) but also very simply (A+C).

70% still used the nontrivial algorithm.

[Professor Layton]

The additional practice **should have made us better**. But, due to **fixation** on the approach we knew about, it made us **worse**.

Even worse, we fall in love with our own ideas

The IKEA Effect [Norton, Mochon, Ariely 2012]: **we place high value on things that we helped create**

> **Experiment:** One group of people build a piece of IKEA furniture, the control group get it pre-assembled. Both are asked how much they'd pay for the furniture.
>
> Those who assembled their own box were willing to pay a 63% premium over those who received the same furniture pre-assembled

Ideally, showing other peoples' ideas should positively influence our ideation. Instead, **we tend to ignore others' ideas**—unless the person who came up with them joins our design team. [Choi and Thompson 2005]

The harms of design fixation

Fixation anchors us in a small subset of the design space, preventing us from identifying the best solution

Knowing that it's happening doesn't help us escape it

What does help us escape it?

> Some designers and creative professionals practice **strategic forgetting**, where they intentionally don't capture ideas immediately, and trusting that good ideas will come back multiple times [Nicholas, Sterman, and Paulos 2022]
>
> Another approach might be…[advances the slide]

Analogical transfer

Where do good ideas come from?

It's often easy to translate a solution from one problem to another problem if the **surface features** of the problems are similar.

Worked-out textbook solution

Test problem following the exact same format

But, major innovations are not such simple copy-pastes. They require mapping **deep features** between problems.

Fitting a solar array in 1/10th the size for takeoff

Origami

[Zirbel et al. 2013]

How do bacteria mutate?

Slot machines

[Murray 2016]

Analogical transfer

Transfer across these deep structures is referred to as **analogical transfer**, as in **transfer via analogy**

How? We abstract problems and solutions we've encountered into **schemas** that drop out surface features and facilitate comparison

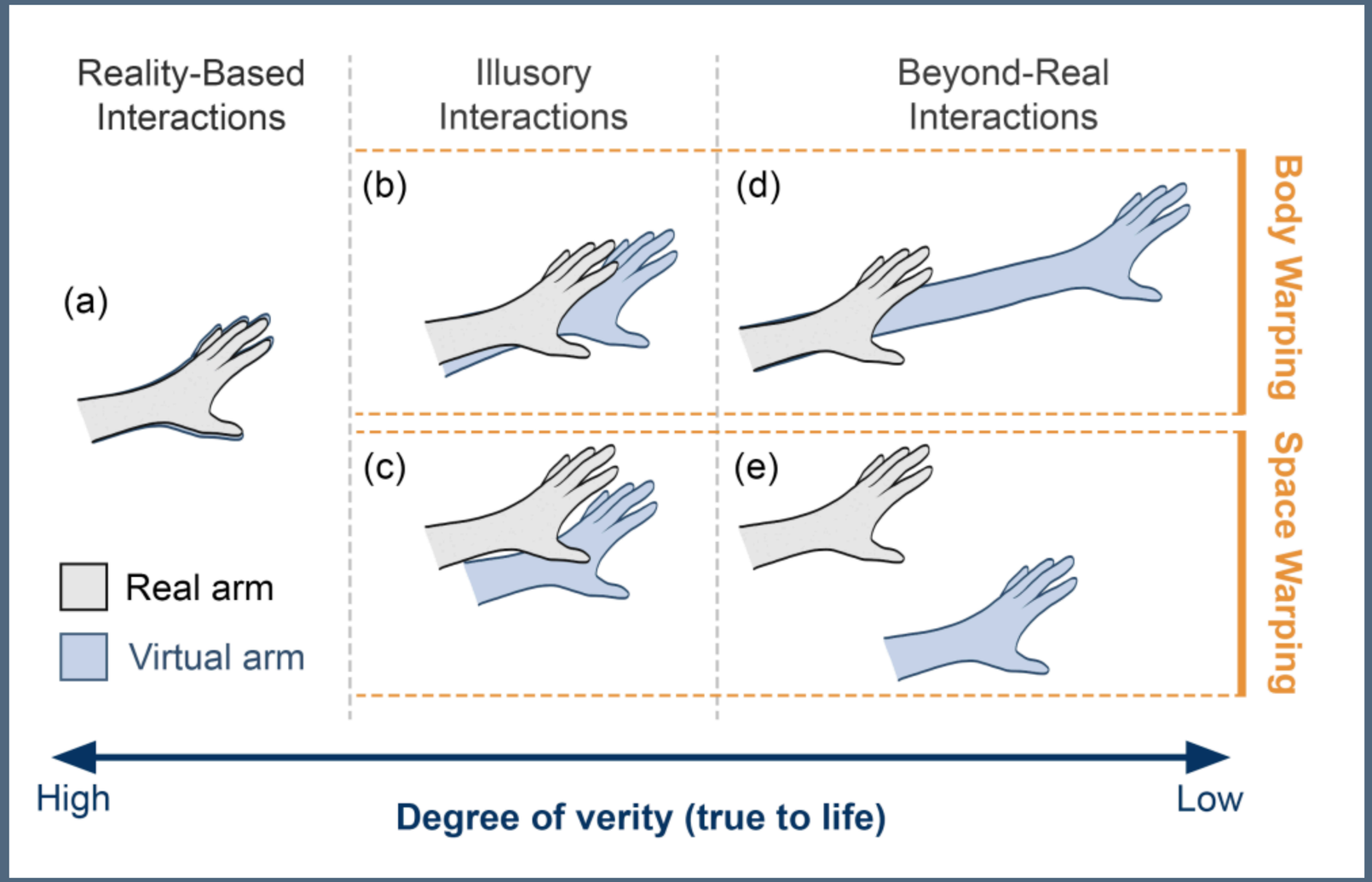
Example

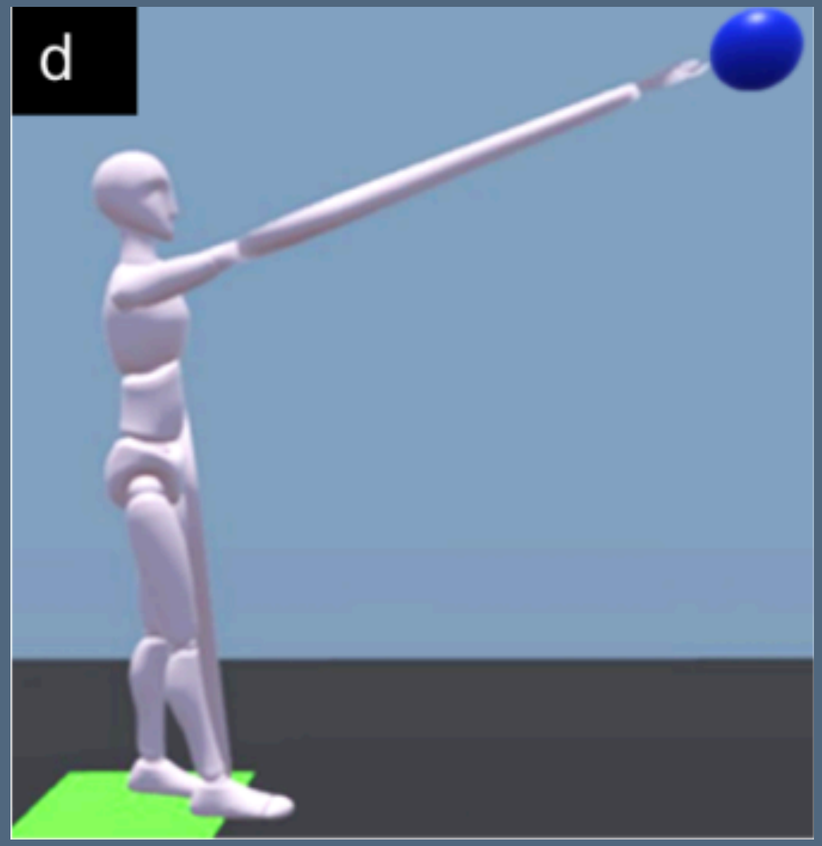
Problem: VR experiences are annoying to navigate and manipulate. How can we make VR better?

Surface feature transfer (boo): develop a laser pointer for VR

Deep feature, schema-based transfer (yay):

> **Social computing article:** "Beyond Being There" [Hollan and Stornetta 1992] says to create collaborative experiences better than "being there"
>
> **Schema:** Problem = adherence to reality is unsatisfying
> Solution = stop trying to be realistic
>
> **Result:** "Beyond Being Real" [Abtahi et al. 2022], create VR experiences that break from realistic self-representation





"Beyond Being Real"[Abtahi et al. 2022]

I'm a Giant: Walking in Large Virtual Environments at High Speed Gains [Abtahi et al. 2019]

Barriers to analogical transfer

For analogical structure mapping to work, it requires that we create the correct schemas and retrieve based on those schemas

Unfortunately, we are biased against deep structural comparisons due to fixation: we tend to focus on surface features

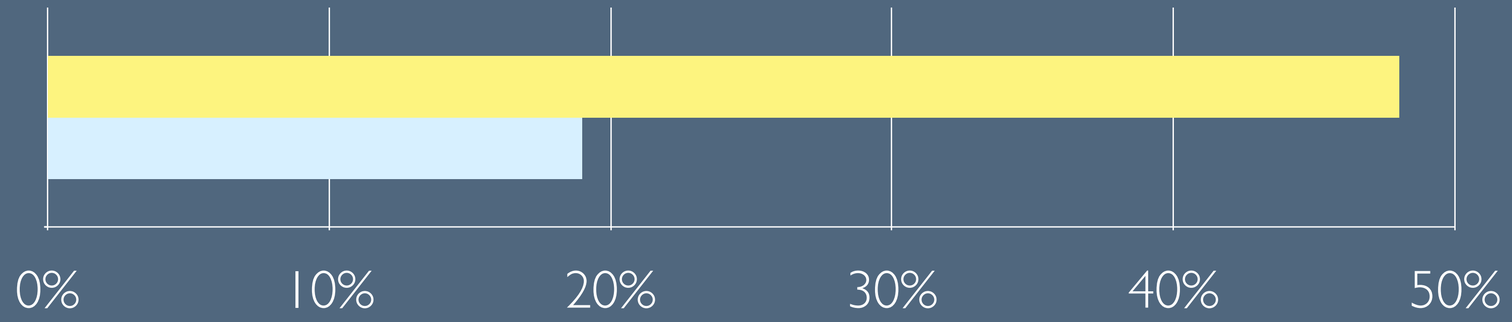
> **Study:** When learning probability, participants were asked to recall earlier problems that were relevant. 80% of the recalled problems were based on surface similarities (e.g., both about shopping lists) rather than the probability theory principles. [Ross 1984]

Without scaffolding, people don't identify deep features

Study: participants learning negotiation strategies

"Read these one at a time" vs "Compare these examples"

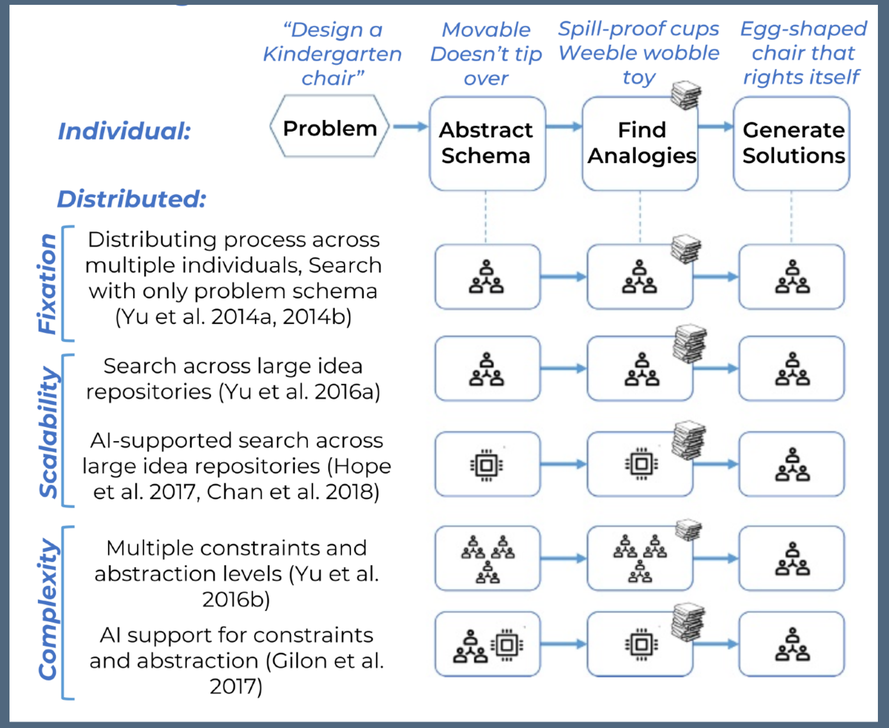
Measure: % of participants who correctly transfer the negotiation principle in the examples to a test case



Implications for design

Bad ideas are often a result of poor analogical transfer: applying surface features rather than deep features in retrieving relevant ideas

On the other hand, this raises opportunities: we can develop AI and crowdsourcing techniques to extract schemas at scale from existing ideas and aid application to new problems [Kittur et al. 2019]



YOU READ THIS

Gulfs of Evaluation and Execution

Goal: a cognitive account of why a design is poor

When people "don't get it", what's actually happening?

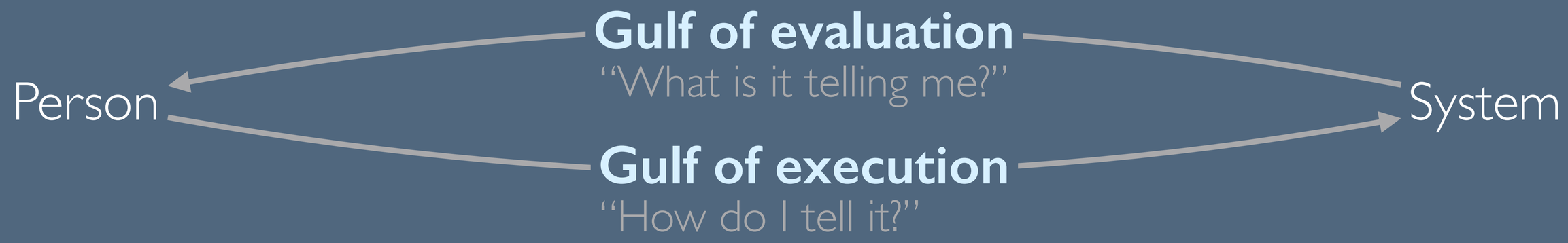
When people do get it can we say more than : "It just feels **natural**"

[Microsoft]

Gulfs between the person and the system

[Hutchins, Hollan and Norman 1985]

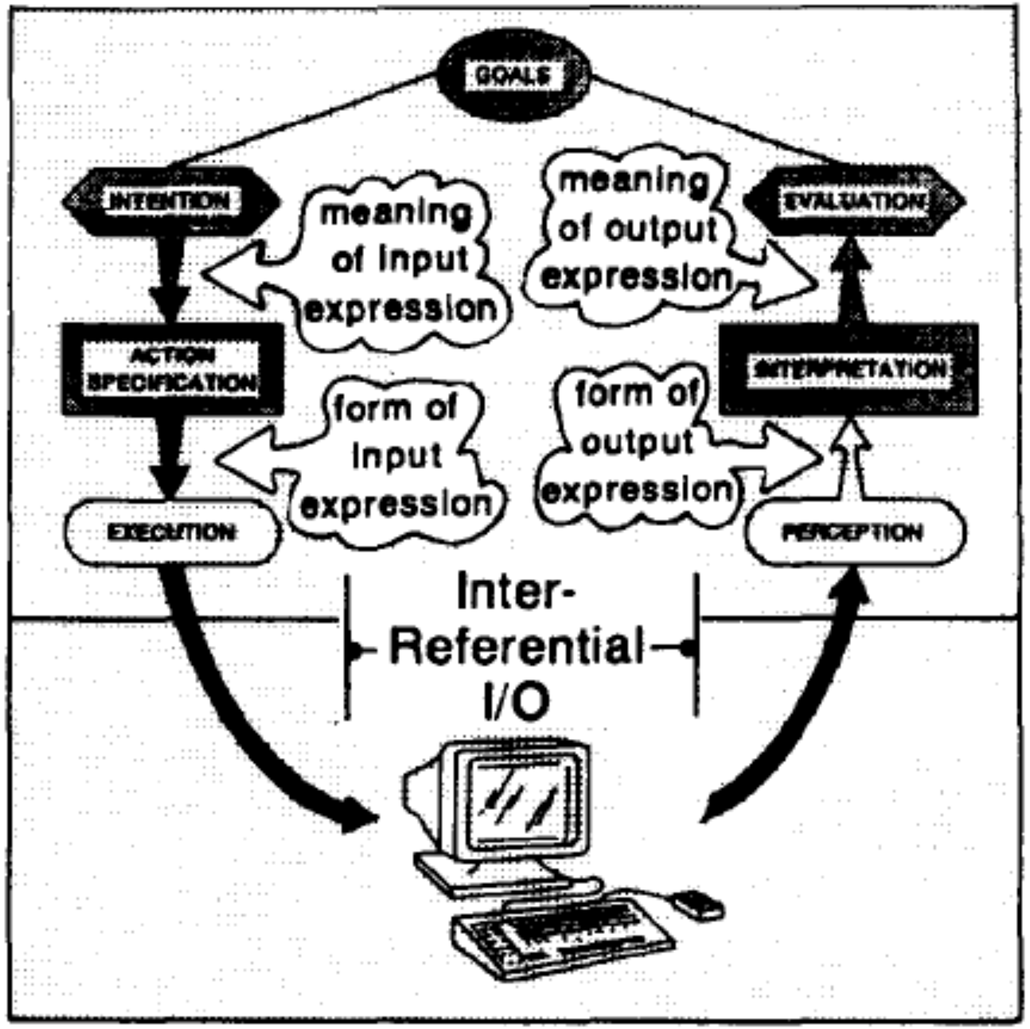
How many cognitive resources do I need to devote in order to translate from my goals to instructing the system and how do I interpret it's output?



Action cycle

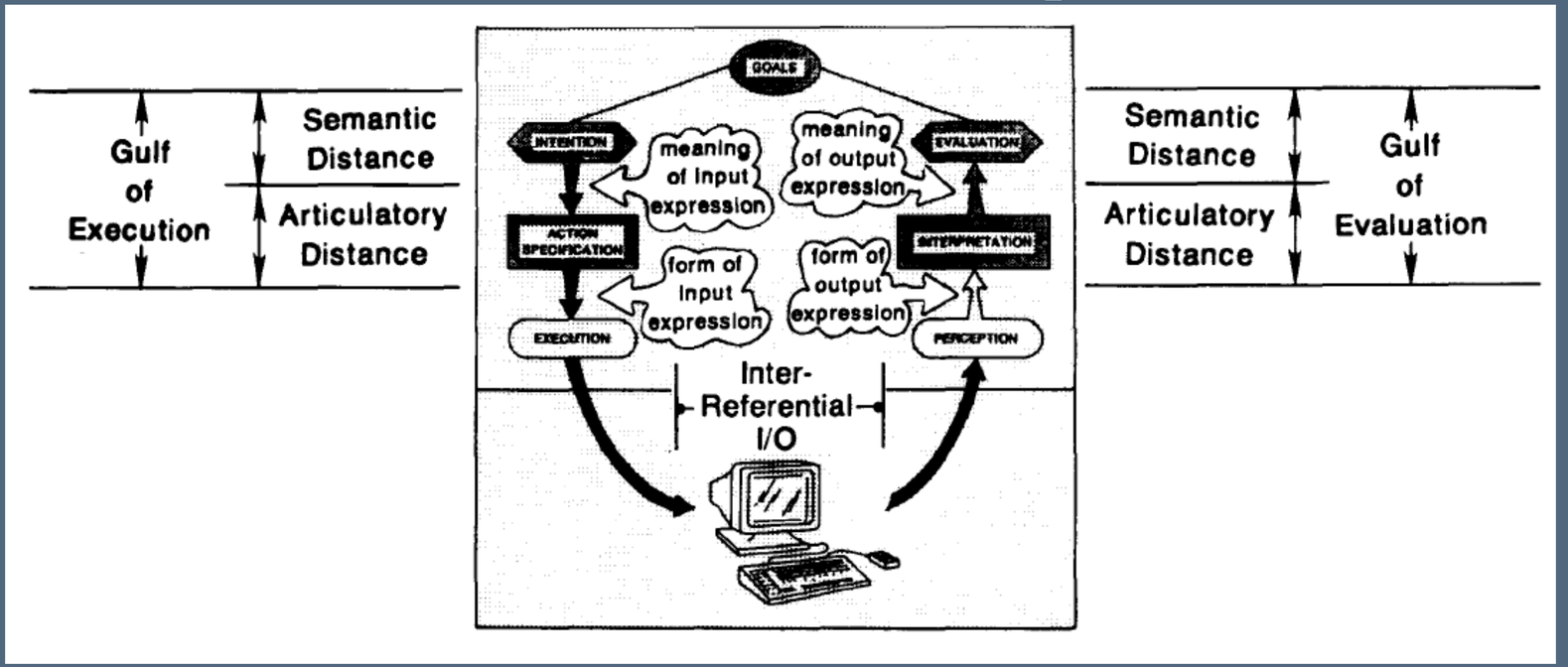
Action cycle

Gulf of Execution



Gulf of Evaluation

Semantic and Articulatory Distances



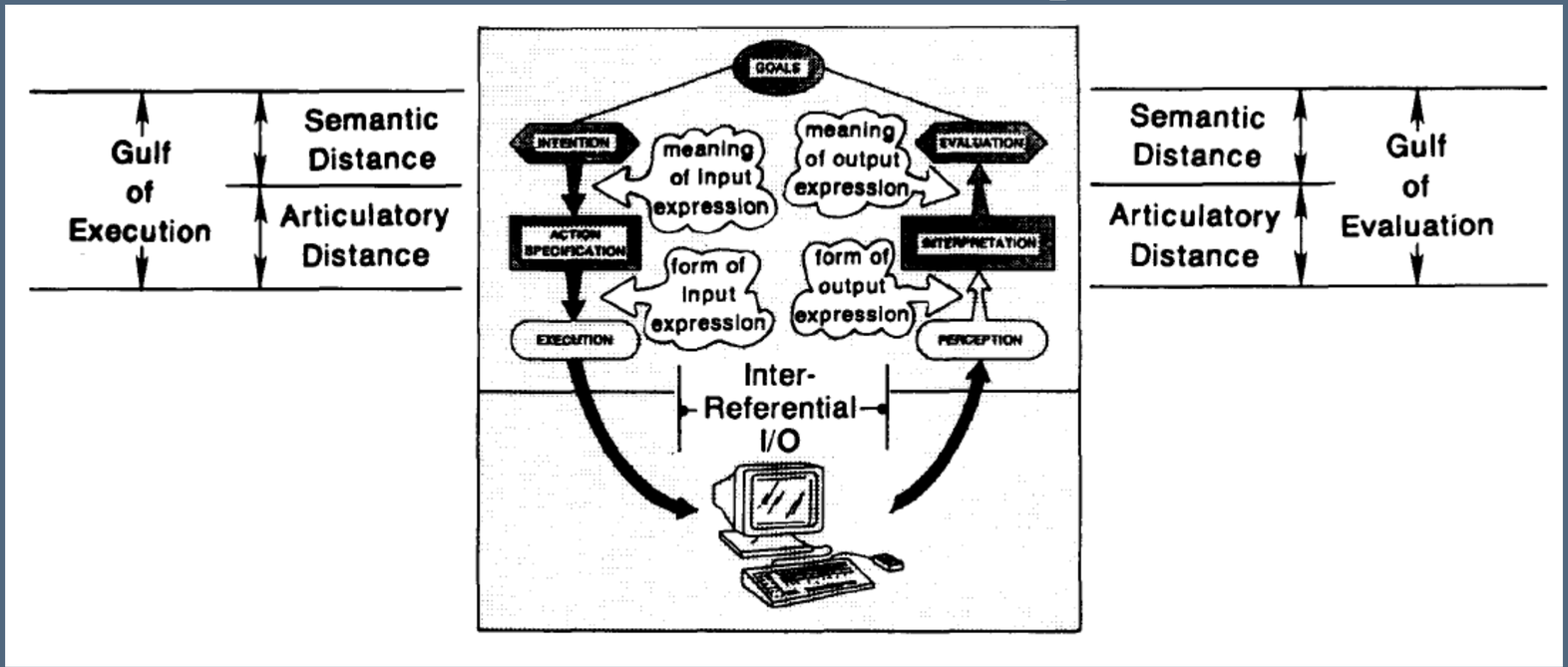
Semantic

Semantic distance reflects the relationship between the *user's intentions/goals* and the *meaning of expressions* in the interface/output language.

Articulatory

Articulatory distance reflects the relationship between the *physical form* of an expression in the interface/output language and its *meaning*.

Semantic and Articulatory Distances



Semantic

Is it possible to say what one wants to say?

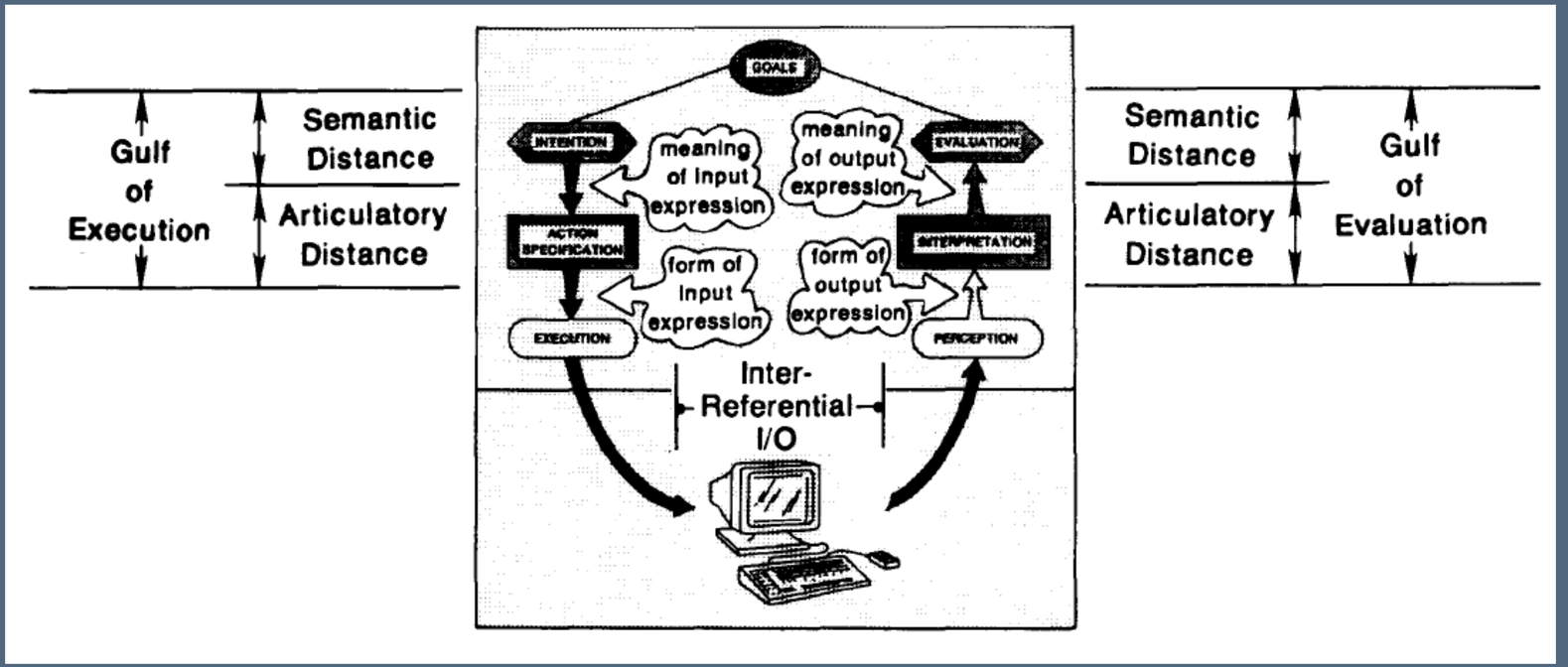
Can intentions be specified using interface expressions at matching level of detail?

Articulatory

Is form of expression similar to meaning of expression?

How difficult is it to produce the form of the expression?

Semantic Distance and the Gulfs



Gulf of Execution

Match interface language to level person thinks of the task (often interface is much lower)

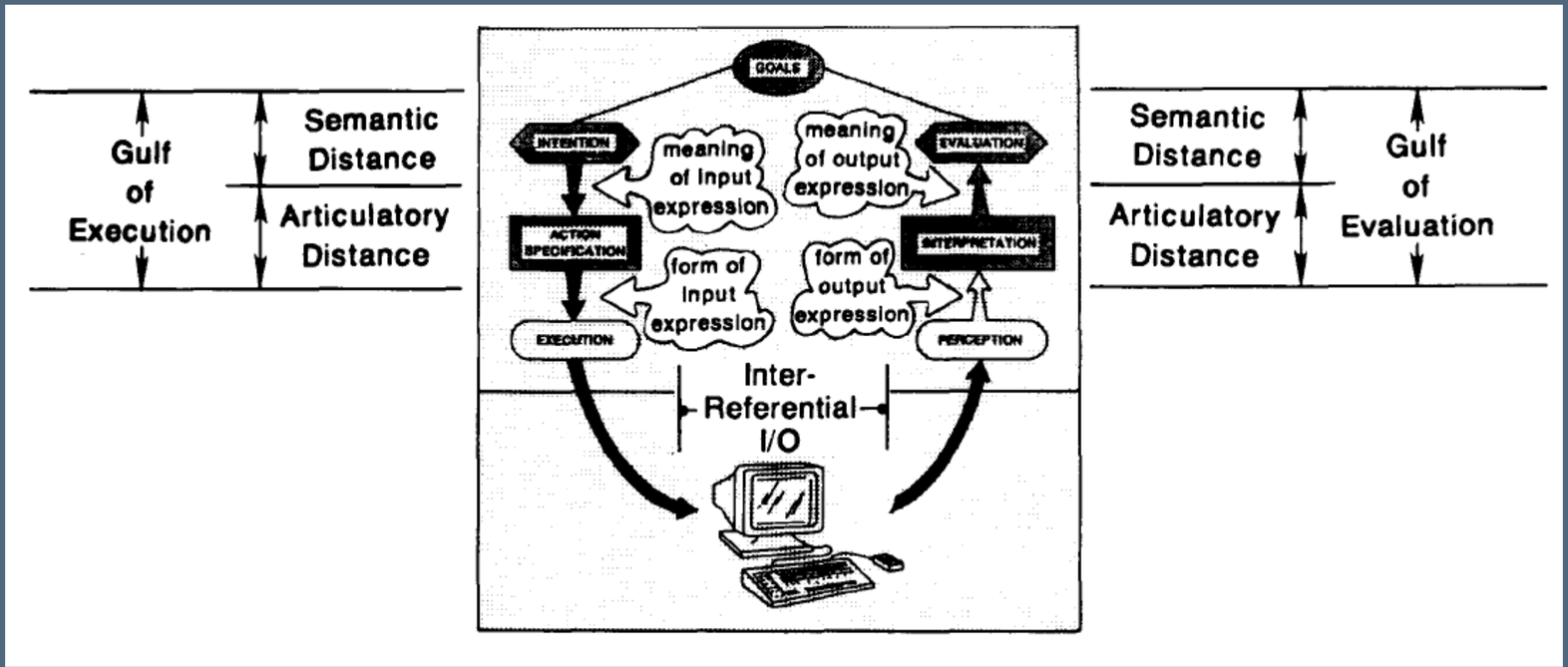
e.g., goal: draw star – draw star shape vs. draw sequence of line segments that form a star

Gulf of Evaluation

Match output language to the user's mental model to enable checking that goals have been met

e.g., goal: get mean of set of numbers – present table of values vs. present mean

Articulatory Distance and the Gulfs



Gulf of Execution

How similar are the intentions/goals to the interface language

e.g., goal: image placement — arrow keys nudging in PowerPoint vs. drag image to location

Gulf of Evaluation

Depict output language so that it is easier to parse the information relevant to goals/intentions

e.g., goal: find outliers in data — output graphical chart vs. table of numbers

Gulfs in practice

1. **Gestural interaction**: the gulf of execution may remain wide, because either the semantic distance is large (Which gesture am I supposed to use again?), or the articulatory distance is large (It's hard to get the gesture recognized.)

2. **AI+HCI tools**: even if end-user tools reduce the gulf of execution, they may not reduce the gulf of evaluation (How do I interpret the AI errors?) or the next gulf of execution (How do I tweak the prev. result?)

Direct manipulation

[Hutchins, Hollan and Norman 1985]

Modern GUIs often adopt a metaphor of acting directly on the object of interest: **direct manipulation**. This reduces the gulfs.

Rather than scripts and code input, we act directly on the object
Rather than interpreting code output, the object itself has changed.

So, rather than aiming for "natural" interfaces, we should ask: **which gulf is this interface closing, and how?**

Summary

These ideas help us fix the right problem rather than unreflectively following the design process.

Cognitive accounts can explain many challenges we face in design:

- **Design fixation:** unnecessarily focusing on a subset of the design space

They can also help us be precise about how to improve design:

- **Gulfs of execution & evaluation:** what needs to be reduced?
- **Analogical transfer:** what do we see as related inspiration?

References

Abtahi, Parastoo, et al. "Beyond Being Real: A Sensorimotor Control Perspective on Interactions in Virtual Reality." CHI Conference on Human Factors in Computing Systems. 2022.

Buxton, Bill. Sketching user experiences: getting the design right and the right design. Morgan kaufmann, 2010.

Choi, Hoon-Seok, and Leigh Thompson. "Old wine in a new bottle: Impact of membership change on group creativity." Organizational Behavior and human decision processes 98.2 (2005): 121-132.

Dell, Nicola, et al. ""Yours is better!" participant response bias in HCI." Proceedings of the sigchi conference on human factors in computing systems. 2012.

Duncker, Karl, and Lynne S. Lees. "On problem-solving." Psychological monographs 58.5 (1945): i.

Gentner, Dedre, Jeffrey Loewenstein, and Leigh Thompson. "Learning and transfer: A general role for analogical encoding." Journal of educational psychology 95.2 (2003): 393

Hollan, Jim, and Scott Stornetta. "Beyond being there." Proceedings of the SIGCHI conference on Human factors in computing systems. 1992.

Hutchins, Edwin L., James D. Hollan, and Donald A. Norman. "Direct manipulation interfaces." Human–computer interaction 1.4 (1985): 311-338.

Jansson, David G., and Steven M. Smith. "Design fixation." Design studies 12.1 (1991): 3-11.

Kittur, Aniket, et al. "Scaling up analogical innovation with crowds and AI." Proceedings of the National Academy of Sciences 116.6 (2019): 1870-1877.

References

Luchins, Abraham S. "Mechanization in problem solving: The effect of Einstellung." Psychological monographs 54.6 (1942): i.

Maier, Norman RF. "Reasoning in humans. II. The solution of a problem and its appearance in consciousness." Journal of comparative Psychology 12.2 (1931): 181.

Murray, Andrew. "Salvador Luria and Max Delbrück on random mutation and fluctuation tests." Genetics 202.2 (2016): 367-368.

Nicholas, Molly Jane, Sarah Sterman, and Eric Paulos. "Creative and Motivational Strategies Used by Expert Creative Practitioners." Creativity and Cognition. 2022.

Norton, Michael I., Daniel Mochon, and Dan Ariely. "The IKEA effect: When labor leads to love." Journal of consumer psychology 22.3 (2012): 453-460.

Ross, Brian H. "Remindings and their effects in learning a cognitive skill." Cognitive psychology 16.3 (1984): 371-416.

Zirbel, Shannon A., et al. "Accommodating thickness in origami-based deployable arrays." Journal of Mechanical Design 135.11 (2013).