Communications
Design Group SF

RESEARCH AGENDA AND FORMER FLOOR PLAN

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Premise

New **representations of thought** — written language, numerals, mathematical notation, data graphics — have been responsible for some of the most significant leaps in the progress of civilization, by expanding humanity's collectively-thinkable territory.

Definition

A *representation* captures some aspect of a concept or phenomenon in a human-understandable form, thereby enabling a person to perceive and think about it.

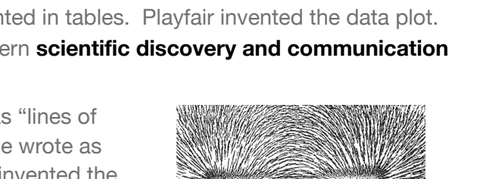
For example, a piece of music can be represented as a verbal description or as a page of music notation (*symbolic*); a waveform plot or spectrograph (*visual*); an audio recording or click track (*aural*), the pattern of finger movements while playing the piano (*tangible*), or the experience of walking around an orchestra (*spatial*).

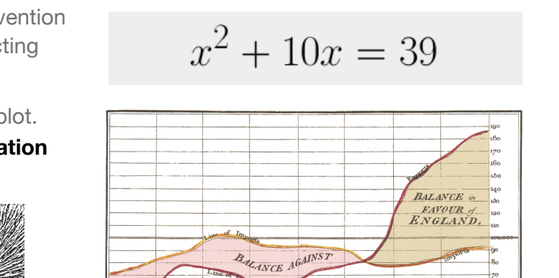
Parables

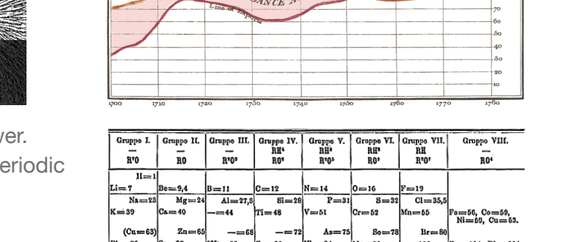
37
x 43
101
148
1591

$$x^2 + 10x = 39$$

- Before the 14th century, multiplication was considered a highly abstract concept, only for the mathematical elite. Once place-value Arabic numerals replaced Roman numerals, multiplication and division became mundane. It was this representation which made universal **arithmetic literacy** possible.
- Before the 17th century, mathematical calculation was described in prose. The invention of algebraic notation made mathematical structure visible, and allowed for abstracting beyond numbers. This representation was the birth of **modern mathematics**.
- Before the 19th century, data was presented in tables. Playfair invented the data plot. Without this form of representation, modern **scientific discovery and communication** would be inconceivable.
- Faraday's representation of magnetism as "lines of force" inspired Maxwell's theory, which he wrote as twenty differential equations. Heaviside invented the language of vector analysis specifically to rewrite Maxwell's equations in four simple lines. This representation was the birth of **electrodynamics**.
- Dalton's elements were a grab-bag, with no coherent framework or predictive power. Mendeleev found a way to represent the patterns of chemical properties with a "periodic table". This representation enabled, for the first time, a theory of **chemistry**.







Why representations matter

These representations weren't mere scientific "discoveries". Each of them essentially *enabled all subsequent scientific breakthroughs thereafter*. A powerful new form of representation affects everything, forever.

Opportunity

The **dynamic medium** now exists. But dynamic representations of thought do not. Humanity is using the dynamic medium merely to emulate and extend static representations from the era of paper.

The dynamic medium hosts artifacts that are:

- computational (*capable of simulation*)
- responsive (*stimuli determine behavior*)
- connected (*can exchange information with other such artifacts*)

medium
author → material → reader

Dynamic material is the "stuff" that an author creates in the dynamic medium, to communicate to a reader.

Today, this might be called "software", but the distinction between software, hardware, wetware, etc will break down soon. More importantly, the focus is on human communication — modeling and understanding a concept — not the engineering of a system.

Dynamic authoring is creating dynamic material.

Today, this might be called "programming", but again, the focus is on capturing and conveying an idea to a person, not the engineer problem of "making it work". This certainly doesn't mean "writing code".

Dynamic sketching is improvised authoring in realtime, "at the speed of thought". Creating working dynamic material in seconds.

Today, this is not possible.

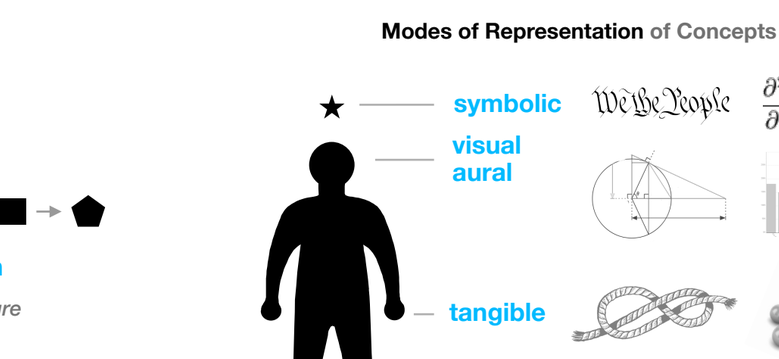
Intention

Use the dynamic medium to reinvent the representations of thought. Invent a way of thinking — imagining, understanding, creating, explaining — via dynamic representations that engage **all modes of thought** and **respect the whole human being**.

Modes of Thinking

intuition	reason
association	*procedure*
pattern-matching	*logic*
metaphor, analogy	*analysis*

Modes of Representation of Concepts



Strategy

The representations of thought are reflected in the representations used to communicate. Bring each **mode of human communication** into the dynamic medium, reinventing it around the whole person.

Modes of Communication of Representations

conversing	presenting	reading	browsing	writing
person-to-person	*person-to-people*	*media-to-person*	*media-to-person*	*person-to-media*

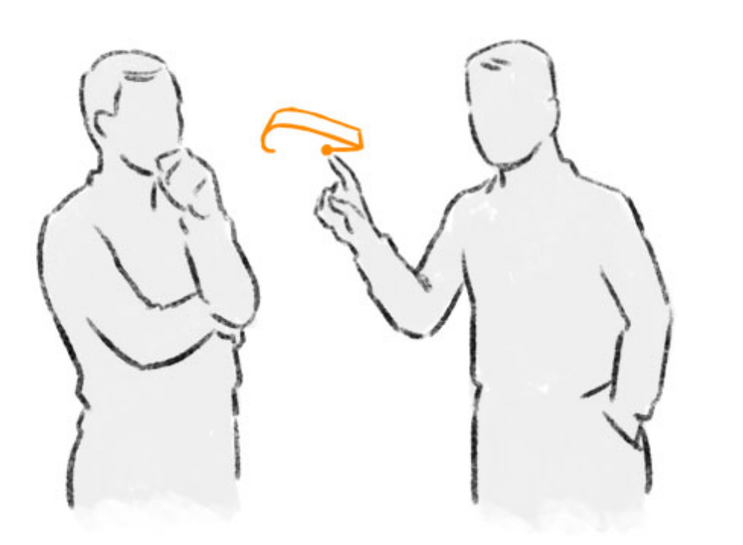
Representations used in external communication (*languages, notations, imagery, metaphors*) are also those used **internally**.

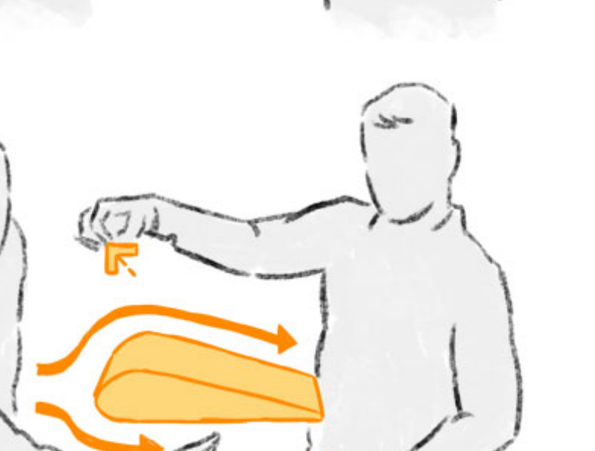
thinking
person-to-self

By upgrading the forms of external communication, we enable more powerful internal representations, which enable more powerful thoughts.

Face-to-face

Dynamic Conversation
I see what you're saying





illustrations by David Hellman

Mode of communication

- *Conversation* means person-to-person, face-to-face, realtime, improvised.

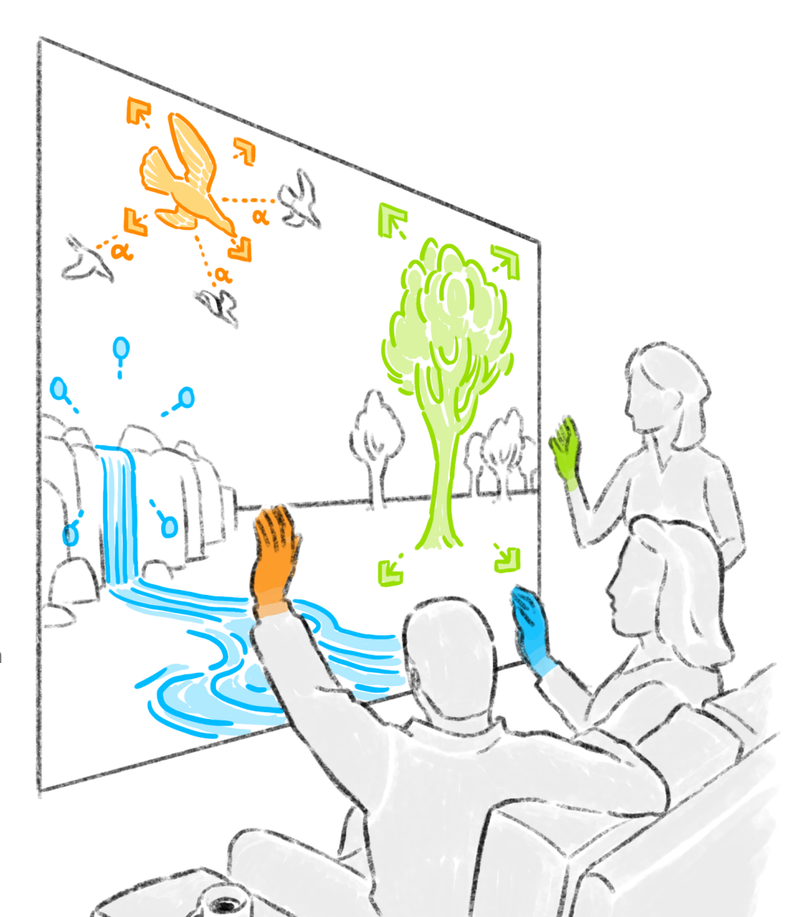
Today

- Concepts are represented with spoken words, hand-waving, static sketches.
- One person's "picture in the head" can't be seen by the other. Miscommunication is the norm.
- People explain and convince through reasoning and rhetoric, not evidence and explorable models. Words are terrible at representing systems.

Vision

- A medium in which every conversation is naturally **show-and-tell**. People can depict as easily as describe.
- **Dynamic sketching.** As two people are talking about how an aircraft wing generates lift, they quickly and naturally improvise dynamic simulations to explore and explain, as if sketching on a whiteboard. (Today, "programming" such things takes hours. This needs to come down to **seconds** in order to fit into a realtime conversation.)
- The medium encourages **evidence-backed** representations over guesses.
- The **context** of every representation can be seen. A conversation is an exploration of a visible data space rather than a string of anecdotes.
- The participants' focus remains on **each other** and the concepts represented, not the implementation of the representations.
- Long-term — entire conversations taking place through improvising and manipulating visual-tactile representations intermixed with scattered words and sounds. A genuinely new language that would be unintelligible to someone today.

Dynamic Creative Play
friends, drinks, and dynamic authoring



Mode of communication

- Friends hanging out in the evening, casual, playful, realtime, improvised, shared experience.

Today

- Most activities where friends focus together on the same thing are **passive** (watching TV) or **non-creative** (playing games).
- Programming is **isolating**, even in groups. People stare at laptops, focused on their own private worlds.
- Code is **anti-social**. A program cannot be immediately understood and modified by a casual onlooker.

Vision

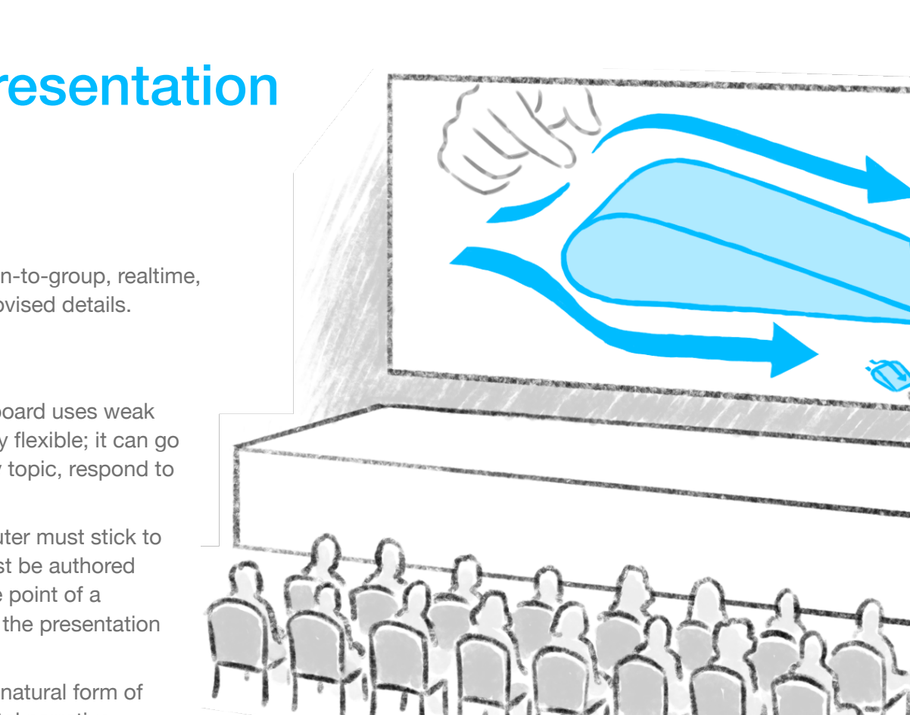
- Friends authoring together for fun, in a casual, shared space. (Creating dynamic playable "murals", perhaps.) Similar to playing with LEGO or model trains.
- Everyone is focused on the **same thing**.
- Everyone can **see** what everyone else is making.
- Everyone can **understand** how everyone else is making it.
- Everyone can "jump in" and **participate** in what others are making.

Rationale

- If the dynamic medium is to be the foundation of a new literacy, people must be able to author **casually and socially**. Authoring shouldn't feel like "work", it shouldn't be isolating, and implementations must be immediately understandable and modifiable by onlookers.

Presenting

Dynamic Presentation
show and tell



Mode of communication

- *Presentation* means person-to-group, realtime, prepared outline but improvised details.

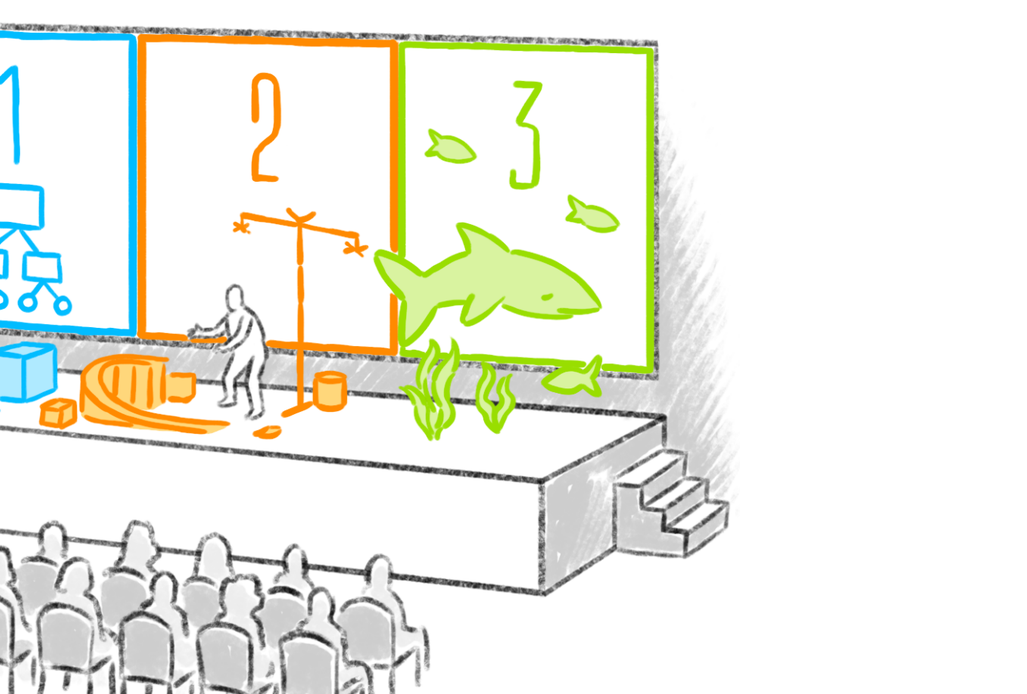
Today

- A presentation at a blackboard uses weak representations, but is fully flexible; it can go in any direction, cover any topic, respond to any question.
- A presentation at a computer must stick to the script. All material must be authored ahead of time. What's the point of a living, dynamic speaker, if the presentation itself is completely static?
- In the verbal medium, the natural form of explanation is the anecdotal narrative. Lies are indistinguishable from truth.

Vision

- Every presentation is naturally **show-and-tell**. By default, referents are shown rather than described. The shown material carries the **primary representations** of the concepts presented, not secondary "visual aids". It is not possible to understand the presentation by just listening.
- The material is **dynamic** — the speaker speaks while interacting with dynamic representations. The audience listens to the presenter while watching dynamic behavior. The presentation may almost feel like a "dialog" between the speaker and their material.
- The material is **sketched from scratch**, on the spot, like on a blackboard. In the same way that a presenter improvises their words, they also improvise all their other representations. Digressions and discussions are exactly as show-and-tell as the prepared line.
- The medium encourages **evidence-backed** presentations, where all evidence and connections are directly visible by the audience. Less anecdotal narrative, more tours around the data space.

Dynamic Stage
explaining with the body



Mode of communication

- A *stage* is the **spatial environment** in which a presentation takes place.

Today

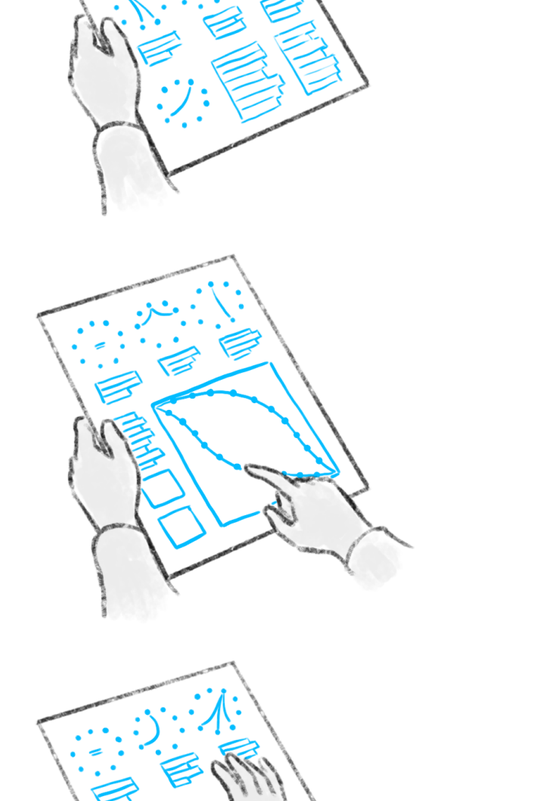
- The audience sees a generic stage which contributes nothing to the explanation of concepts. The presenter's material does not involve stage design.
- By contrast, a play uses the stage as a set, where each part of the space carries meaning, supports the story, and can be interacted with. (Improv theater and pantomime take place on a dynamically-sketched set, although the audience's imagination is required.)

Vision

- The stage is a **medium** — a canvas — and participates in the presentation by hosting **human-scale representations**.
- **Concept space is mapped to physical space.** Different areas of the stage represent different concepts. The presenter builds up a conceptual space and a visible space in parallel, and then navigates in that space while discussing. The presenter physically moves around the stage as the message moves between topics. Connections between concepts can be seen as connections across physical space.
- The **outline** of the presentation is manifest in the layout of the stage. At all times, the audience can see what the presenter has already presented, and what they have yet to present. Instead of the presentation being "one fleeting thing after another", the audience sees a tour through a visible, well-structured space.
- The stage is a **dynamic** medium, and the presenter sketches and interacts with human-scale dynamic representations. In addition to sketching space during the presentation, the presenter can **download environments** authored at home.

Reading

Dynamic Reading
this is not a printing press



Mode of communication

- *Reading* means media-to-person, solitary, deliberate, prolonged, contemplative.

Today

- Concepts are represented with words, words, words. The author's "picture in the head" is rarely transferred well to the reader.
- The author explains and convinces through reasoning and rhetoric, not evidence and explorable models. Words are terrible at representing systems.
- Material is mass-produced, one-size-fits-all. Every reader sees the same thing.

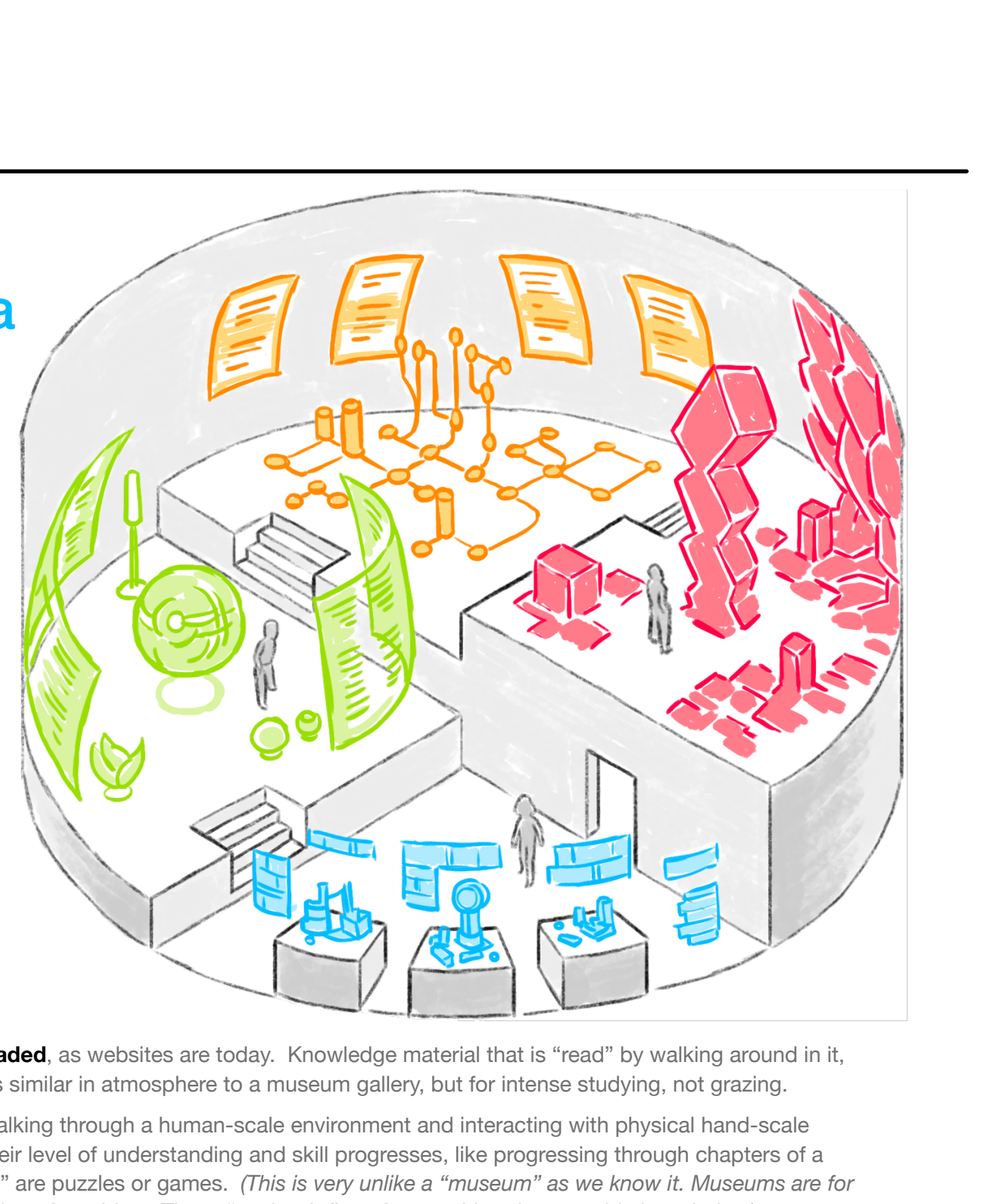
Vision

- A thoroughly **multi-channel** form of written communication. A fine-grained mixture of words, notations, and visual representations. Show and tell.
- **Skimmable.** Get the gist in 5 seconds. Get "enough of an understanding to make associations with later" in 60 seconds. Go deeper in particular areas as needed.
- **Transformable.** View many different representations of the same knowledge, without an author having created them beforehand.
- **Explorable.** Assertions and explanations are backed by data and models. Adjust premises and assumptions, and see consequences.
- **Context-sensitive.** Not one-size-fits-all, but unique for every reader and every reading. Reflects the reader's prior understanding and current needs.
- **Interrogable.** Have a dialog with the material. Get clarifications and examples, without an author having anticipated the questions.

Hypothesis

- With a better form of writing, concepts that today take hours to understand can be understood in seconds. What today takes weeks can take hours. What is impossible today, because it would take more than a lifetime to synthesize, becomes possible.

Dynamic Spatial Media
books you walk around in



Mode of communication

- Like reading — media-to-person, personal, prolonged, contemplative — but human-scale, and experienced with the body.

Today

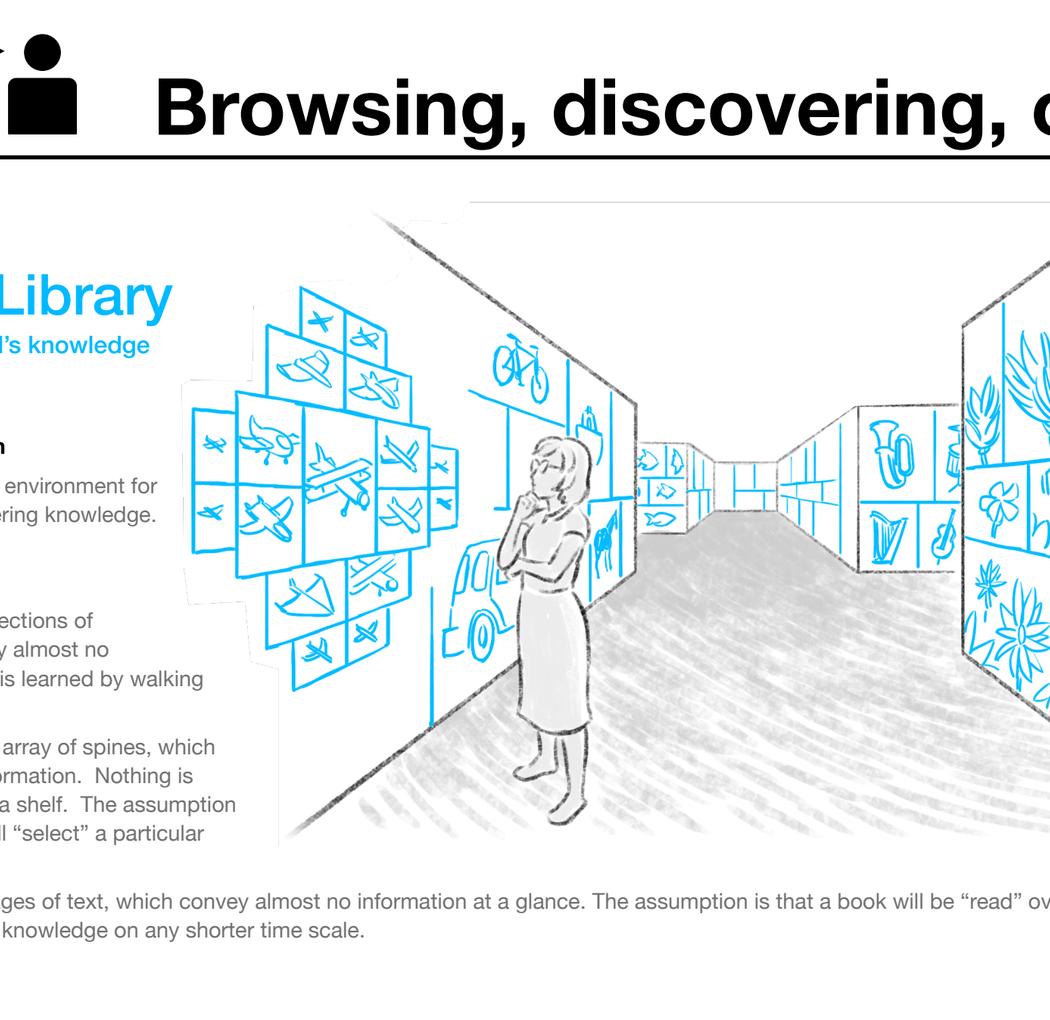
- The primary objects for acquiring knowledge — books and computer screens — confine representations to a tiny rectangle.
- Representations use a tiny fraction of the visual field. Peripheral vision and visual scanning are wasted. Eyes are damaged by constant up-close focus.
- Representations are flat and intangible. Tactile understanding is wasted; the hands are neglected.
- Readers are immobile. Spatial understanding is wasted; the body is neglected and damaged.

Vision

- Walkable environments that are **published and downloaded**, as websites are today. Knowledge material that is "read" by walking around in it, engaging with it visually, tangibly, and spatially. Perhaps similar in atmosphere to a museum gallery, but for intense studying, not grazing.
- **Spatial textbooks.** A person learns linear algebra by walking through a human-scale environment and interacting with physical hand-scale objects. The learner progresses through the space as their level of understanding and skill progresses, like progressing through chapters of a textbook. "Examples" are interactive objects, "exercises" are puzzles or games. *(This is very unlike a "museum" as we know it. Museums are for gazing in wonder, or gaining a superficial lay-understanding of a subject. These "textbooks" are for acquiring deep, usable knowledge.)*
- **Spatial research papers.** Scientific findings are published as physical environments that the reader walks through.
- And so on. The focus is on the **spatial representation of usable knowledge**. The goal is not to invent the "spatial web" for its own sake, but to invent powerful new representations of thought which may require such a medium.

Browsing, discovering, connecting

Dynamic Library
walk through the world's knowledge



Mode of communication

- A *library* is a walkable environment for browsing and discovering knowledge.

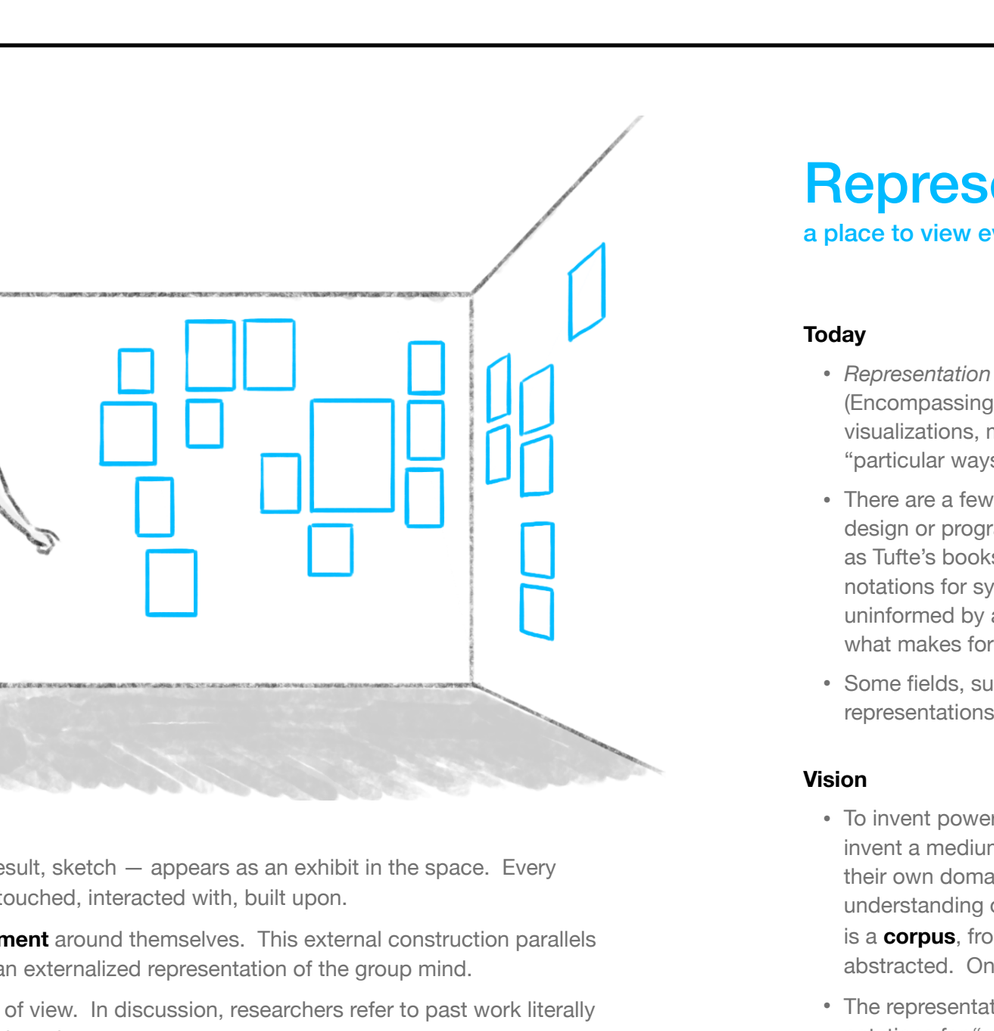
Today

- A library consists of sections of shelves, which convey almost no information. Nothing is learned by walking around the space.
- A shelf consists of an array of spines, which convey almost no information. Nothing is learned by looking at a shelf. The assumption is that the browser will "select" a particular book to read.
- A book consists of pages of text, which convey almost no information at a glance. The assumption is that a book will be "read" over many hours, and does not provide knowledge on any shorter time scale.

Vision

- The branches of knowledge are represented by distinct areas that feel **inviting, approachable, and tempting**, like the lands at Disneyland. Simply walking around the space gives one an **spatially-anchored overview** of the branches of knowledge and how they are connected. Wandering into the Anthropology section gives one a basic grounding in anthropology, and invites deeper exploration.
- Material provides knowledge at **all distance scales**: 12 feet away (overview of topic), 6 feet, 3 feet, 1 foot (standard reading), ½ foot (fine details).
- Material provides knowledge at **all time scales**: ½ second ("get" what the material is about), 10 seconds (understand the gist), 3 minutes (enough knowledge to later make connections back to), hours (deeper studying), days, etc.
- Engaging at the more zoomed-out scales requires **no deliberate action** other than simply walking by.
- Conceptual **connections** between knowledge can be seen visually, and explored.
- Material is **dynamic and multi-channel**. Knowledge is represented in many different forms, including dynamic tangible objects.

Research Gallery
every idea is on display



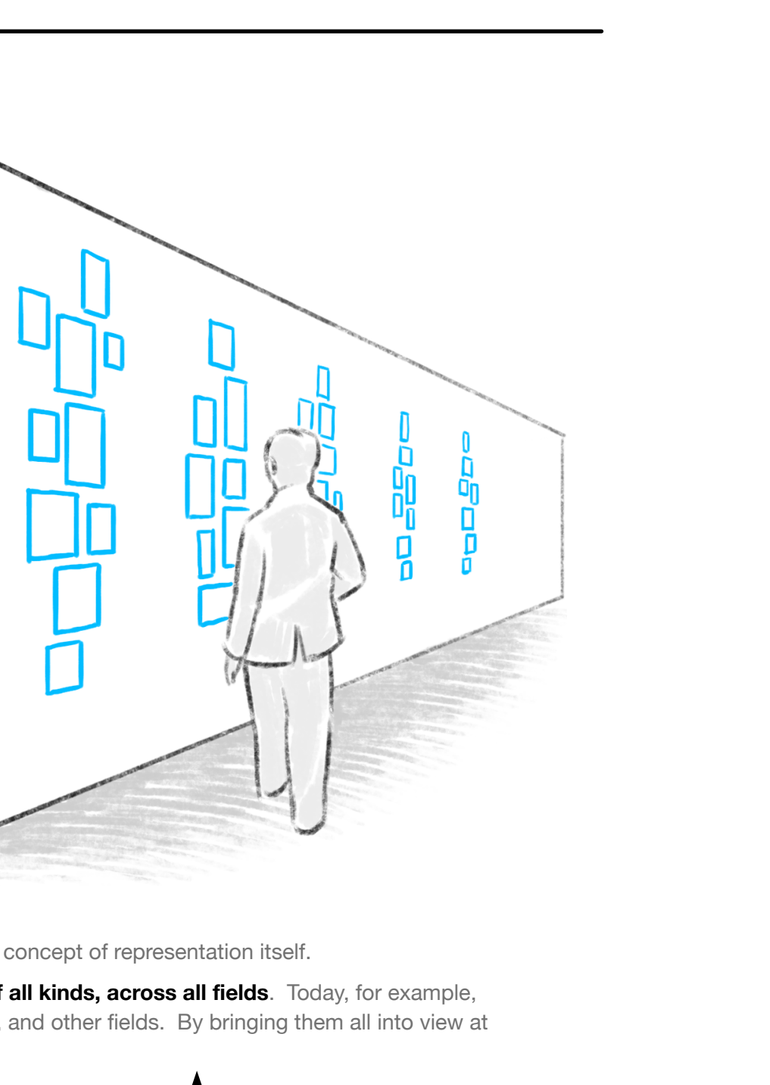
Today

- In most research environments, no representation of the group's output is **displayed in the space**. Ideas, prototypes, discoveries, and analyses are buried in hard drives, code repositories, websites, group lore.
- A researcher can't make use of **prior work** unless they happen to recall it via mental association, then spend the effort to bring it up.
- A **visitor** can't see and learn from the group's work. A visitor learns more from a website or paper than by visiting the group itself.
- As the group **turns over**, past work is forgotten and lost.

Vision

- Every artifact the group produces —every prototype, demo, tool, design, figure, result, sketch — appears as an exhibit in the space. Every concept has a **physical presence**; it can be spotted, pointed to, walked over to, touched, interacted with, built upon.
- As researchers work, they feel like they are **constructing an intellectual environment** around themselves. This external construction parallels and reflects the internal construction of their understanding. The environment is an externalized representation of the group mind.
- Researchers make **connections** between ideas by seeing both ideas in their field of view. In discussion, researchers refer to past work literally by pointing to it, instead of with vague verbal descriptions. Ideas are spatially anchored.
- New researchers are **immersed** in the history and ways-of-thinking of the group in a more direct way than casual conversation. Researchers "come of age" by physically exploring the space, interacting with the artifacts, and asking questions about them.
- The space is a form of **publication**. Visitors browse and explore the space, and come away with a deep and usable understanding of the group's work. The space is designed to teach and disseminate, in the way that a research website should be.

Representation Gallery
a place to view every point of view



Today

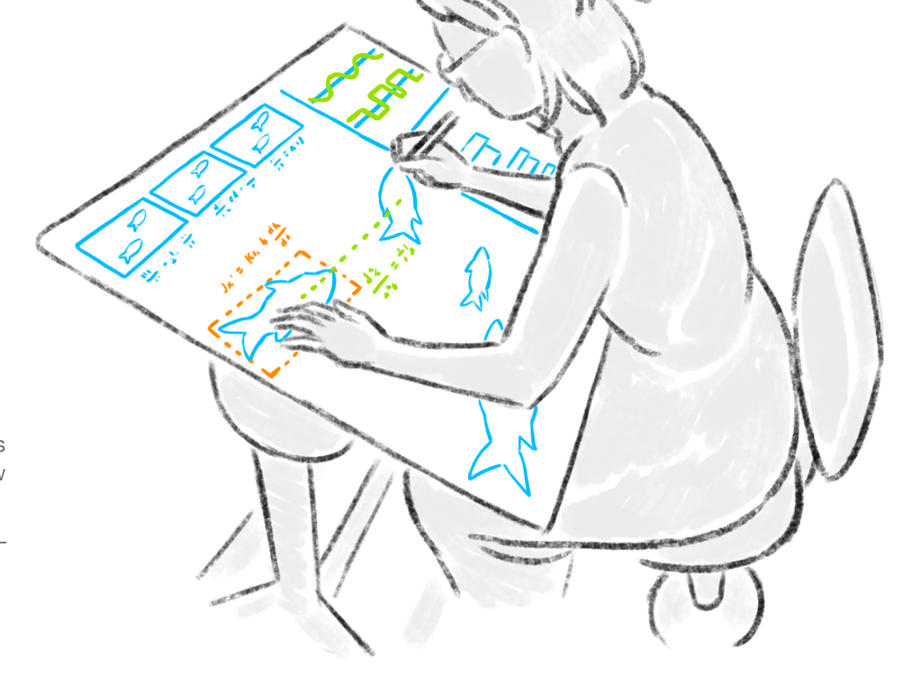
- *Representation design* isn't yet a recognized field of study. (Encompassing the design of languages, notations, visualizations, models, metaphors, transforms, and all other "particular ways of viewing and working with a concept".)
- There are a few established subfields, such as visualization design or programming language design, with resources such as Tufte's books. But most representations (for example, notations for systems biology circuits) are designed ad hoc, uninformed by any sort of design theory or understanding of what makes for effective notation.
- Some fields, such as semiotics, study a theory of representations, but don't seem useful for designing new ones.

Vision

- To invent powerful dynamic representations, and especially to invent a medium and tools where domain workers can design their own domain-specific representations, a deep understanding of representations will be helpful. An initial step is a **corpus**, from which powerful ideas can be recognized and abstracted. Only by seeing many representations of something can one come to see the concept of representation itself.
- The representation gallery is a spatial environment that brings together representations **of all kinds, across all fields**. Today, for example, notations for "events in time" are scattered across music, digital logic, chemistry, comics, and other fields. By bringing them all into view at once, the viewer sees common patterns, cross-pollinates ideas, and begins synthesizing the beginnings of a design theory.
- The gallery emphasizes **generalization** (going up from specific examples to an abstracted pattern), **instantiation** (going down from an abstraction to specific examples), and **analogy** (diverse examples of the same pattern).

Writing

Dynamic Authoring
direct manipulation of dynamic behavior



Mode of communication

- *Authoring* is person-to-media, deliberate, prolonged.

Today

- Static material — illustrations, films, books — is created by directly manipulating a literal representation of the artifact.
- Dynamic material is created by "writing code" — blindly manipulating symbols. The author sees and manipulates indirect symbolic representations, and must imagine how they give rise to dynamic behavior.
- "Blindly manipulating symbols" is a holdover from pencil-and-paper mathematics. Programming emulates paper.

Vision

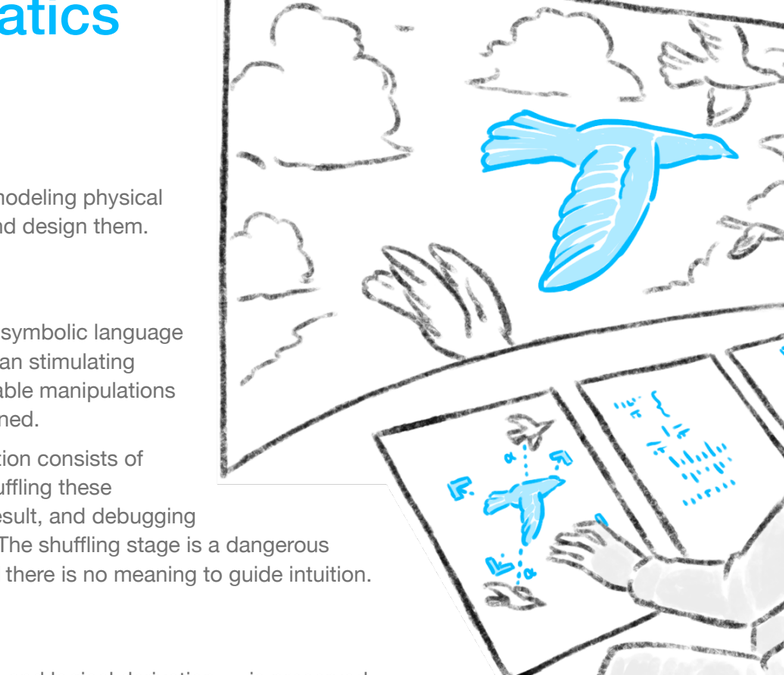
- The author **sees the dynamic behavior** they're creating, and sees it as they're creating it. The primary representations are behavior or data representations, not representations of a system structure.
- The author sees **multiple representations** of behavior — multiple levels on the "ladder of abstraction", multiple instances of abstractions, multiple views and transforms, each offering its own perspective and insights.
- The author **explores** the representations — transforming, measuring, searching, looking at them from many perspectives.
- The author creates the material by **directly manipulating representations of behavior and data**, instead of manipulating a structure. Manipulation takes place in the data domain.

Rationale

- The envisioned new form of thinking centers upon creating and exploring dynamic representations. Thinkers must be able to create these representations with as little indirection as possible, so the dynamic medium can function as an extension of the mind.

Creating new knowledge

Dynamic Mathematics
the direct manipulation of meaning



Mode of communication

- *(Applied) mathematics* is a set of tools for modeling physical systems, in order to understand, predict, and design them.

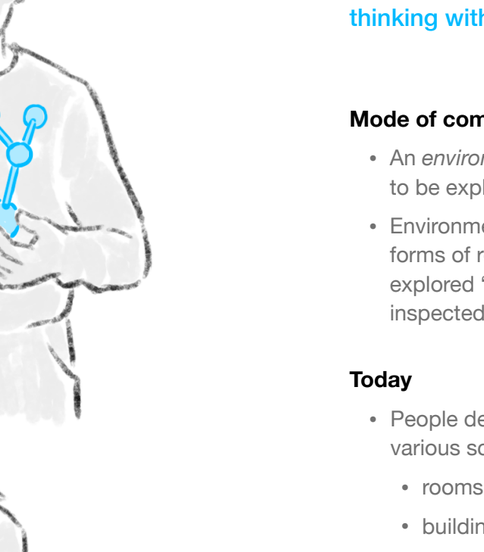
Today

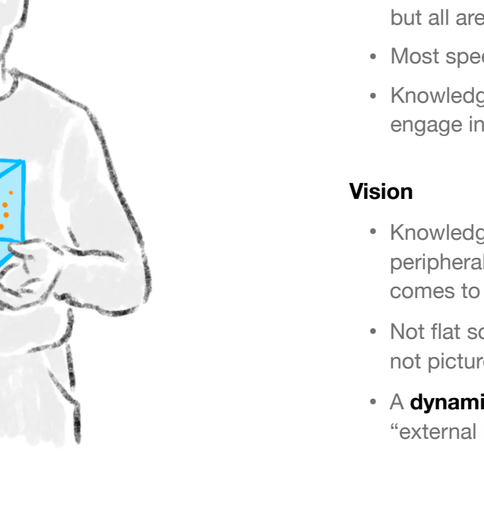
- Representations are opaque. Notation is a symbolic language which is designed more for bookkeeping than stimulating intuition. Behavior, relationships, and available manipulations mostly cannot be seen; they must be imagined.
- Manipulation is blind. Mathematical derivation consists of encoding meaning into symbols, blindly shuffling these symbols, interpreting a meaning from the result, and debugging when the interpretation reveals nonsense. The shuffling stage is a dangerous wasteland where missteps are invisible and there is no meaning to guide intuition.

Vision

- The essence of mathematics — abstraction and logical derivation — is preserved. The **interface of mathematics** — notation and methods, the "seeing" and "manipulating" — is wholly reinvented for the dynamic medium.
- The activity of mathematics is no longer transforming symbolic expressions, but creating and exploring a **constellation of interconnected multimodal representations.** All forms of understanding — linguistic, visual, tactile, spatial — are in use at all times, at all levels of abstraction.
- Representations, even abstract ones, remain connected to the modeled system. **Physical meaning is ever-present** — it never gets lost and must be reinterpreted. The constellation is built by moving around a "ladder of abstraction" rooted on the modeled system.
- Representations are **evocative**. Their appearance and affordances suggest potential connections and relationships, and collectively bring out perceivable patterns. Feeling is ever-present — negligible terms feel negligible, related terms feel related.
- **Approximation and assumption** are first-class operations, supported by error estimation and dependency tracking. Thinkers easily and eagerly simplify models and incorporate prior intuition, never losing sight of the validity of their approximations and contingency of their results.
- **Context, context, context.** Every result is a point within a more general space, and is always seen as such.

Dynamic Objects-To-Think-With
thinking with the hands, not staring at screens





Mode of communication

- An *object* is a representation that's designed to be inspected and manipulated with the hands.

Today

- Almost all representations used in intellectual work — both when authoring material for readers, or as intermediate scratch work while figuring things out — are flat and intangible. Ink on paper, or pixels on a screen.
- Handheld objects as thinking tools (slide rules, chemical models, architectural models) are rare, and are becoming extinct by virtualization. Only virtual representations are dynamic.
- Unlike representational art, which has always included both painting and sculpture, symbolic communication (writing, numbers, maps, data graphics) evolved solely as marks on a surface. A handheld representation of an abstract symbolic concept (such as an equation) is practically unimaginable.

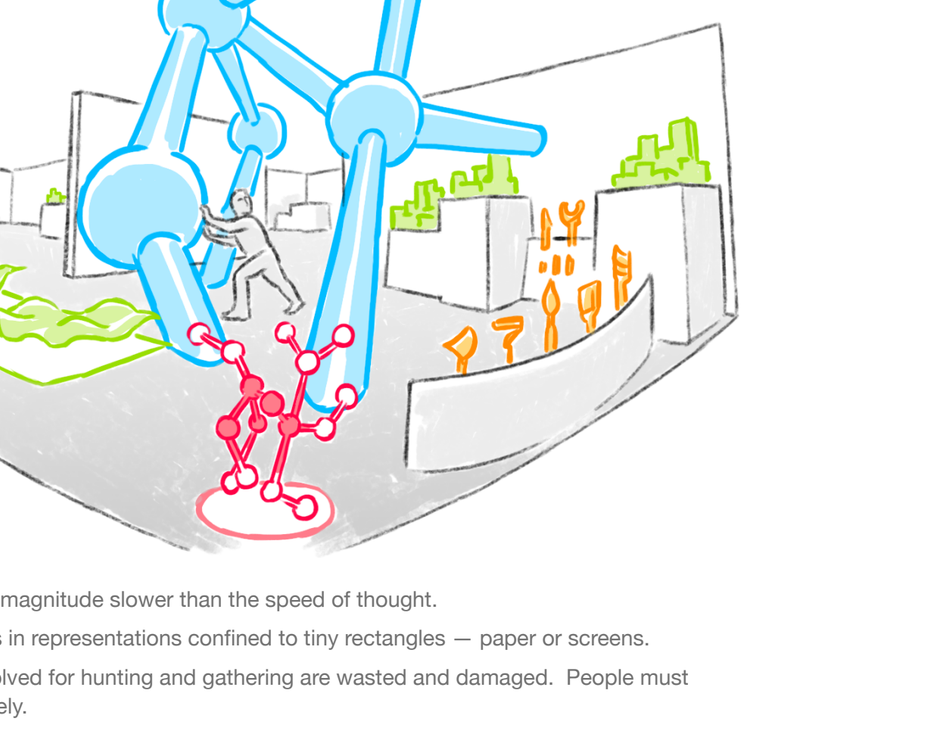
Vision

- Thinkers work with handheld representations which are **felt and manipulated by the fingers**.
- A **dynamic** tactile medium. In the same way that a computer screen can *visually* represent almost anything, a dynamic object can "shape-shift" to *tangibly* represent almost anything.
- In addition to "literal" representations such as chemical or architectural models, objects can represent **abstract spaces** such as scatterplots, and even **symbolic concepts** such as algebraic equations.

Hypothesis

- Playfair's invention of data graphics was transformative because it tapped into capabilities of the human visual system which had gone unused in intellectual work. It may be similarly transformative to tap into the profound capabilities that enable a person to tie a shoelace or make a sandwich, and bring them to bear on more abstract thinking.

Dynamic Environments-To-Think-In
thinking with the body, not staring at screens



Mode of communication

- An *environment* is a representation that's designed to be explored and manipulated with the body.
- Environments and objects are complementary forms of representation. Environments are explored "from the inside", and objects are inspected "from the outside".

Today

- People design environments for knowledge work at various scales:
  - rooms *(blackboards, storyboards, sticky note boards)*
  - buildings *(design of an office)*
  - neighborhoods *(design of a university)*

  but all are static. Making a change takes from hours to months, orders of magnitude slower than the speed of thought.
- Most speed-of-thought work (such as deriving an equation or algorithm) is in representations confined to tiny rectangles — paper or screens.
- Knowledge work is paralyzing — workers sit, immobile. Bodies which evolved for hunting and gathering are wasted and damaged. People must engage in artificial "exercise" to prevent their bodies from atrophying entirely.

Vision

- Knowledge workers look around, move around, and work with **human-scale spatial representations**. Representations take advantage of peripheral vision, visual scanning, spatial orientation, and sense of scale. Complex systems are understood in the same way that a person comes to understand their neighborhood.
- Not flat screens. Real environments for embodied work, such as woodshops and kitchens, surround the worker with **physical tangible tools**, not pictures.
- A **dynamic** spatial medium. A spatial environment with the flexibility and responsiveness of a computer screen, which a worker can use as an "external imagination".

Principles

These thirteen projects are avenues through a single city. The goal is to invent a medium of thought that's driven by the following interrelated principles.

The human being is sacred.

A way of living that reduces the human experience to sitting at a desk staring at tiny rectangles — that reduces the human body to an eye interpreting symbols and fingers gripping a pen or mashing a keyboard — is debilitating to mind and body, wasteful of the vast human potential, and deeply unethical. This way of living is a consequence of static media. It's a result of a culture that has contorted itself around the limitations of marks on paper.

The dynamic medium provides the opportunity to invent an ethical form of knowledge work. Representations can exercise the entire range of human faculties — all senses, all forms of movement, all forms of understanding — instead of straining a few and atrophying the rest.

Every one of these projects is about *designing a thinking medium to fit the human, instead of deforming the human to fit the medium.*

The medium is an external imagination.

The purpose of a thinking medium is to bring thought outside the head, to represent concepts in a form that can be seen with the senses and manipulated with the body. (This is, for example, how paper enabled complex mathematical derivations, logical argumentation, navigation...) In this way, the medium is literally an extension of the mind.

However, static media are extremely limited in what they can conveniently represent, so much thinking is still trapped inside the head. (For example, the behavior of mathematical expressions, variable values in a computer program, connections and references between books in a library...) The dynamic medium has the potential to represent such concepts directly, to bring them out in the open, where the entire range of human faculties — all senses, all forms of movement, all forms of understanding — can be brought to bear on them.

Every one of these projects is about *designing a medium that externalizes as much thought as possible — an external imagination.*

The material must show and tell.

Static media favor language. On paper, abstract concepts and dynamic phenomena are easier to *describe* than *depict*. As a result, the culture has evolved expressive and powerful linguistic representations (for example, mathematical derivation, logical argumentation), while non-linguistic abstract representations are little more than baby-talk. Concepts poorly suited to language remain barely thinkable.

The dynamic medium offers the potential for thinkers to fluidly read and write rich *multimodal* representations, where all forms of human understanding — linguistic, visual, tactile, spatial — can be brought to bear simultaneously. The culture can start to develop a *dynamic multimodal literacy*.

Every one of these projects is about *designing a medium for multimodal representations — show and tell.*