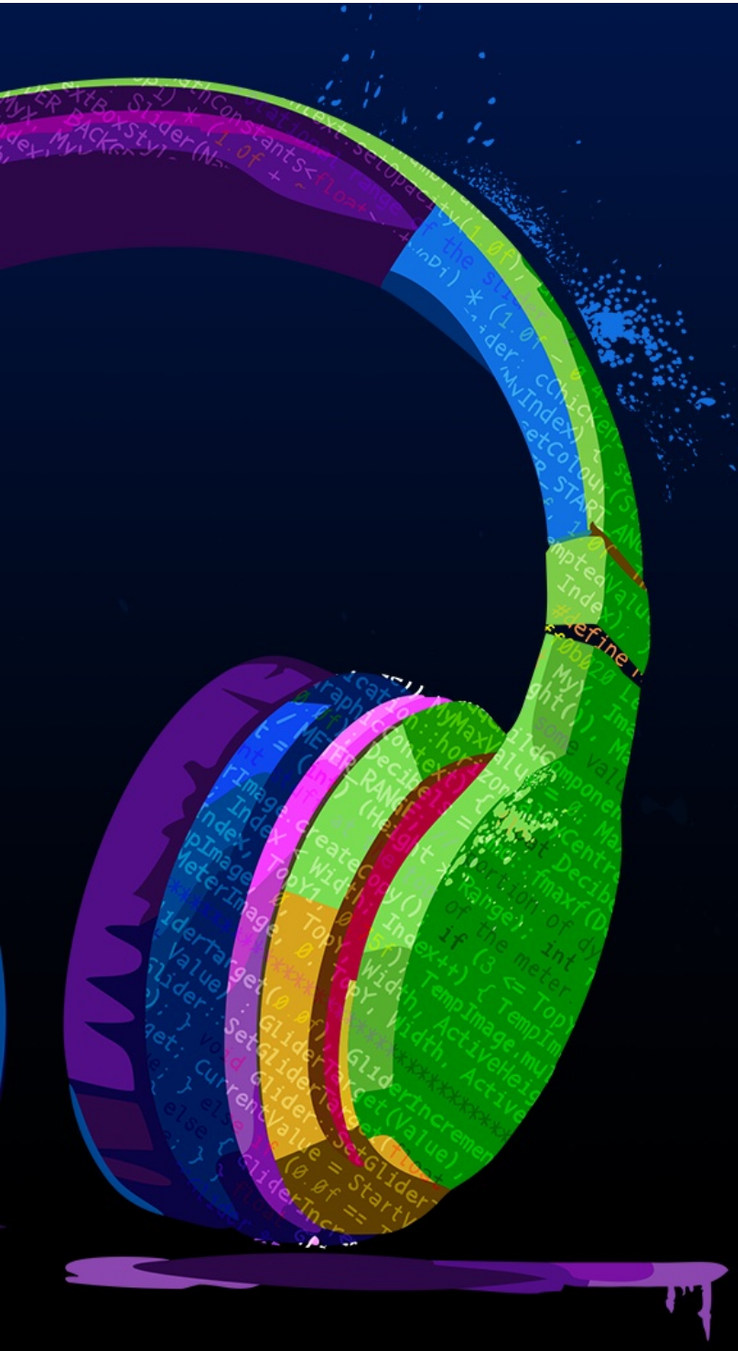


ADC24 Bristol

KEYNOTE:
SONIC CARTOGRAPHY

NAVIGATING THE ABSTRACT SPACE-TIME OF SOUND

CARLA SCALETTI


Oculus
Development Kit 2

```
#include <cmath>
#include <vector>

std::vector<float> comb_filter(const std::vector<float>& input,
float delay_samples, float feedback_coefficient) {
    int num_samples = input.size();
    std::vector<float> output(num_samples);
    std::vector<float> delay_buffer(delay_samples);

    for (int i = 0; i < num_samples; ++i) {
        // Calculate output sample
        output[i] = input[i] + feedback_coefficient *
delay_buffer[i % delay_samples];

        // Update delay buffer
        delay_buffer[i % delay_samples] = input[i];
    }

    return output;
}
```

Sonic cartographers

Creating maps

- Sound designers
- Audio engineers
- Musicians

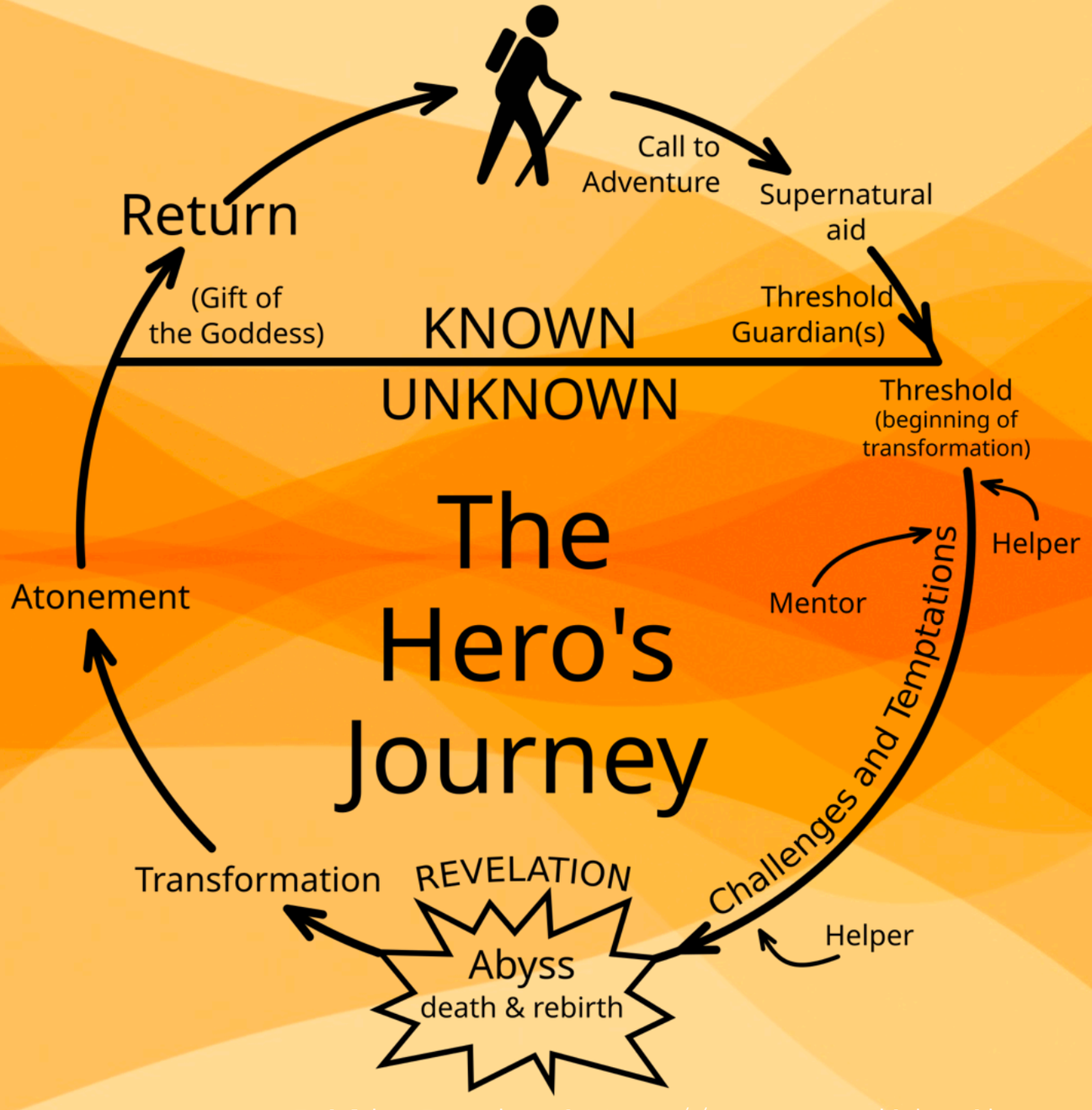
Depiction of Ptolemy employing a quadrant, from Giordano Ziletti's Principles of astrology and geography according to Ptolemy, 1564. Public Domain

History of cartography

Maps *may* predate language…

- Sharing Maps
- Maps in the form of Stories
- Stories in the form of Songs

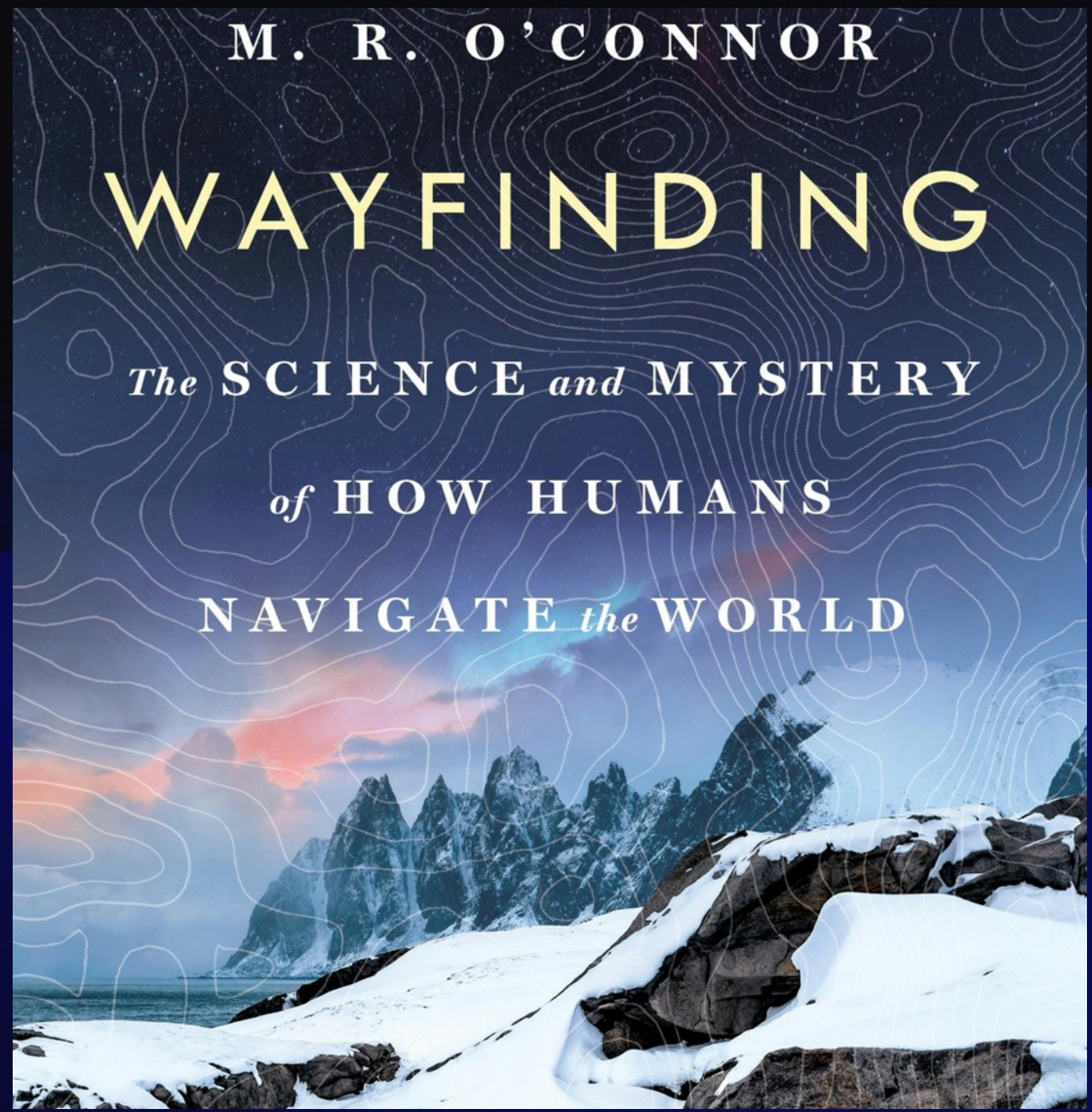
Image generated using Canva with the prompt:
'Paleolithic men and women around a fire'



“By associating stories with specific places and encoding navigation information within the sequences of songs or stories, they made it easier to recall them through reciting those oral maps”

M.R. O’Connor *Wayfinding*

Image from CUNY TV
https://www.youtube.com/watch?v=q2VXvcF_W1U



Extending networks

Distributed collective cognition

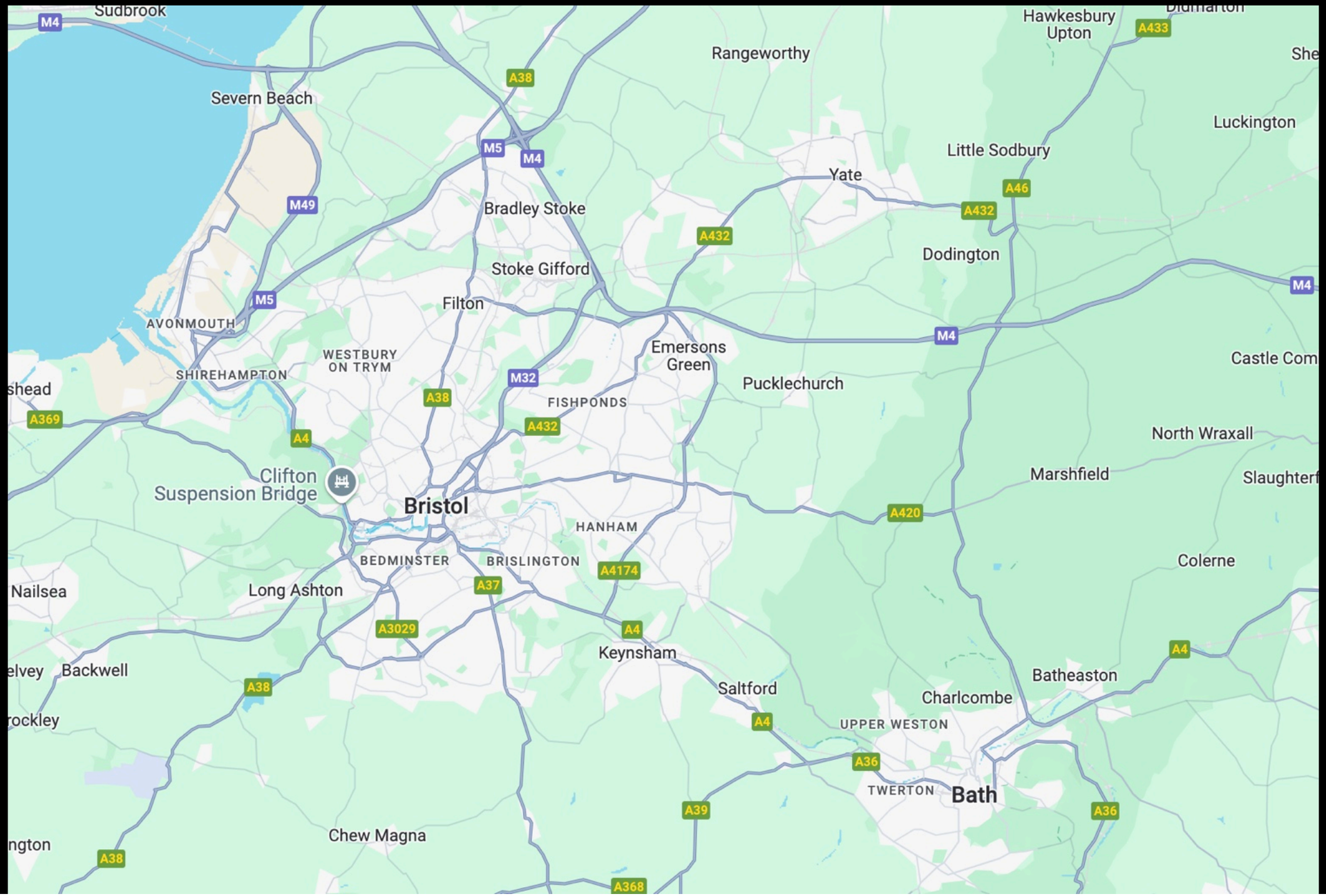
- Learn things you have never directly experienced
- Hierarchies of maps constructed by combining simpler maps
- Distributed cognition

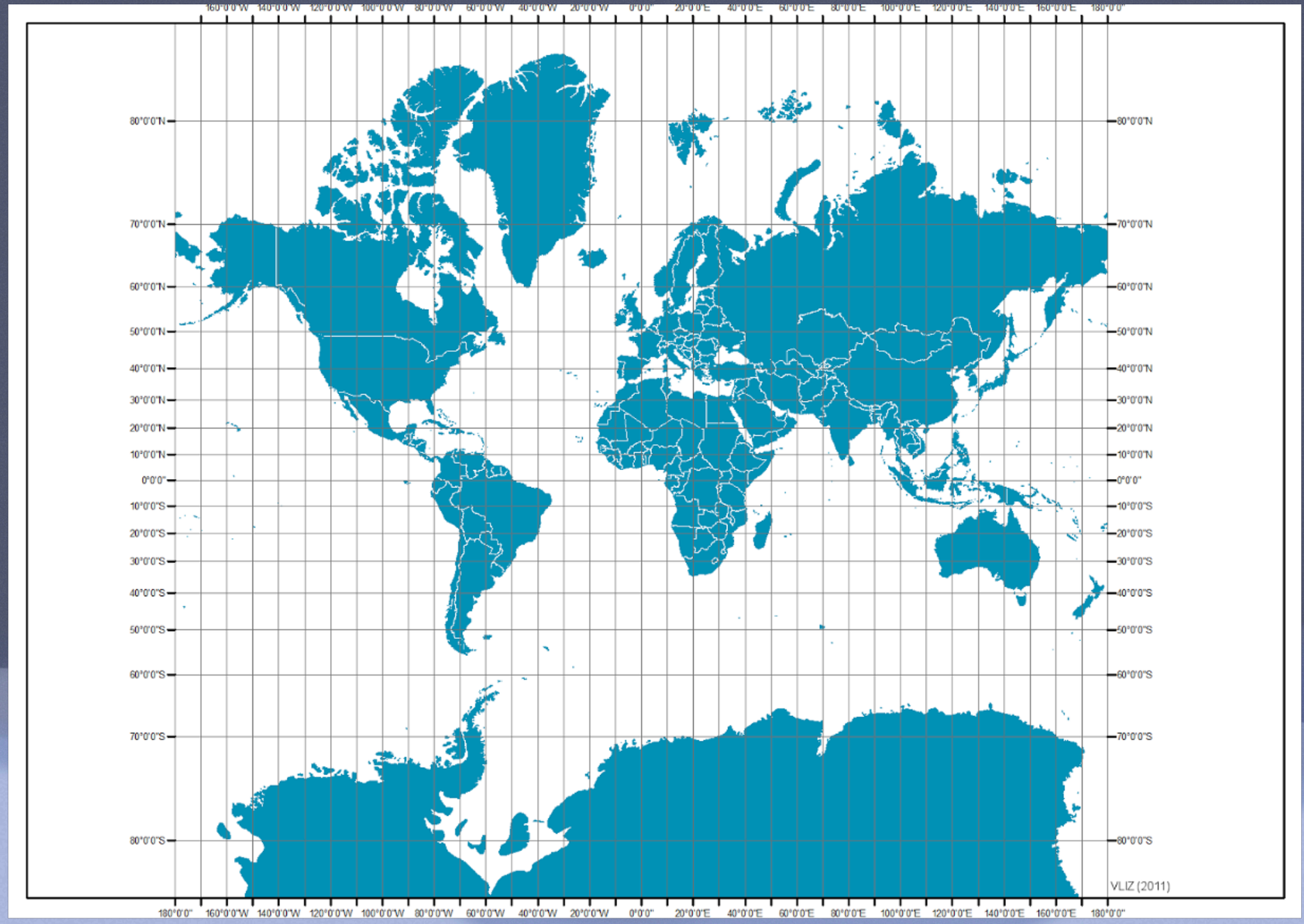
Canva:'Paleolithic men and women around a fire'

Imagining maps

Events that haven’t happened

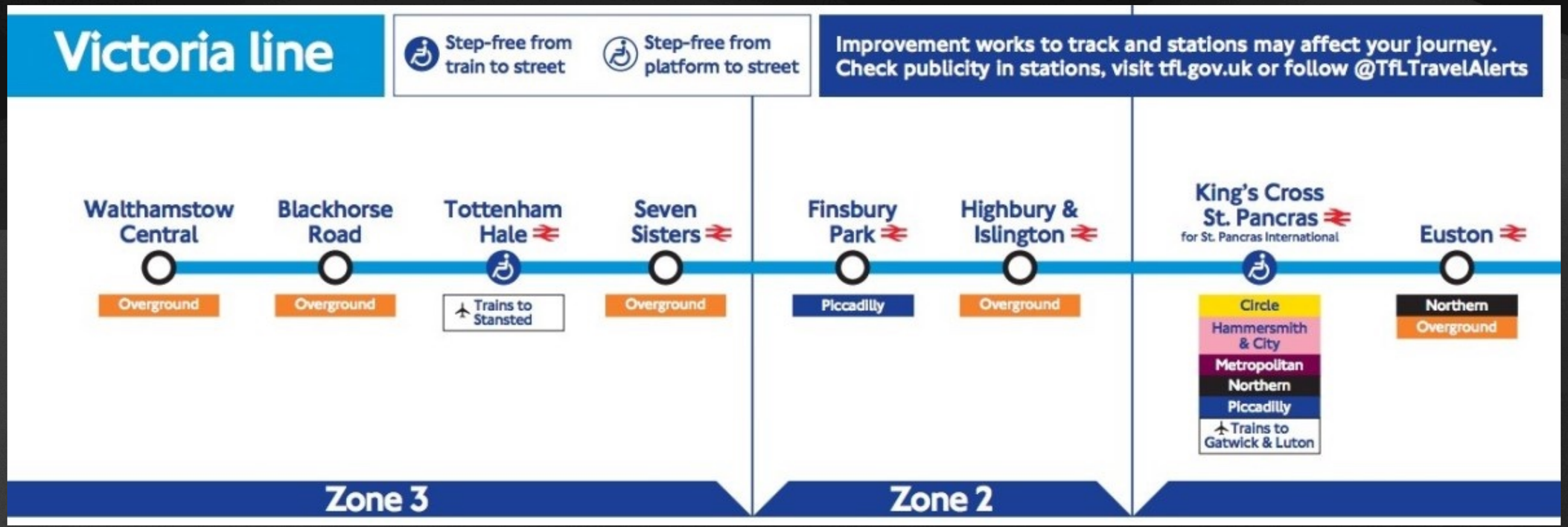
- Places that don’t exist
- Events that never happened


Sudbrook
M4
Severn Beach
M49
M5
AVONMOUTH
SHIREHAMPTON
WESTBURY ON TRYM
A369
A4
Clifton Suspension Bridge
Bristol
A38
M5
M4
Rangeworthy
Bradley Stoke
Stoke Gifford
Filton
M32
FISHPONDS
A432
Emersons Green
Pucklechurch
HANHAM
BEDMINSTER
BRISLINGTON
A4174
A37
Long Ashton
A3029
Nailsea
Backwell
A38
Keynsham
A4
Saltford
A4
A36
UPPER WESTON
TWERTON
Bath
A39
A36
Chew Magna
A368
A38
Hawkesbury Upton
A433
Luckington
Little Sodbury
Yate
A46
A432
Dodington
M4
M4
Castle Com
North Wraxall
Marshfield
A420
Slaughterf
Colerne
A4
Batheaston
Charlcombe



The Underground

Schematic Metro Maps



https://content.tfl.gov.uk/victoria-line-cld-archive.pdf

The map designer sacrifices some information in favor of preserving what the map maker thinks will be important to the users of the map.

The map is not the territory

A map is a way to reason about something in another domain

Nature can never be completely described, for such a description of Nature would have to duplicate Nature

Lao Tzu (mapped by Archie J Bahm)

Joseph Goguen (1941-2006) UCSD

A user interface can be considered as a representation of the underlying functionality to which it provides access…as mappings, or morphisms…which should preserve as much structure as possible.

Goguen, J. (1999). An Introduction to Algebraic Semiotics, with Application to User Interface Design. In: Nehaniv, C.L. (eds) Computation for Metaphors, Analogy, and Agents. CMAA 1998. Lecture Notes in Computer Science(), vol 1562. Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-48834-0_15

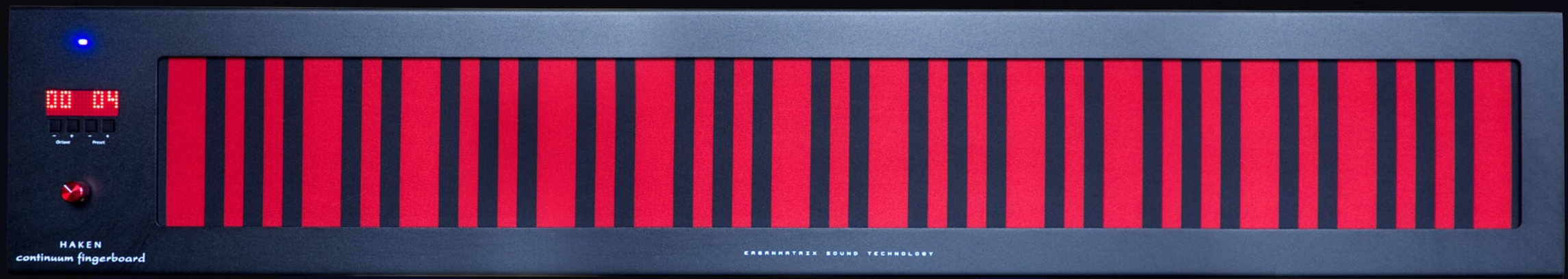
Art of interface design

Selecting which elements & relations to map

Preserve the most important elements, connections, and relations

Such that sequences of actions & chains of reasoning in the source domain

Also make sense in the target domain (and vice versa)

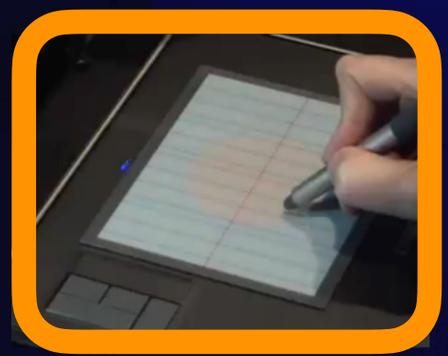


hakenaudio.com

Continuum fingerboard

1400 mm to pitch
127 mm to timbre
30 mm to amplitude

An instrument is a map of a musical space



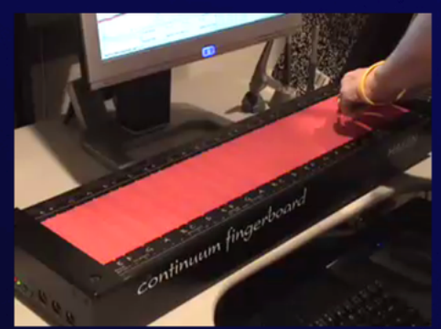


Image generated by Canva in response to the prompt: ‘GUI of an audio plugin’

Jacques Attali
French economist
Author of *NOISE*

…each instrument, each tool… implies an imaginable and explorable universe.

Jacques Attali in *Noise: the political economy of music*

Wayfinding

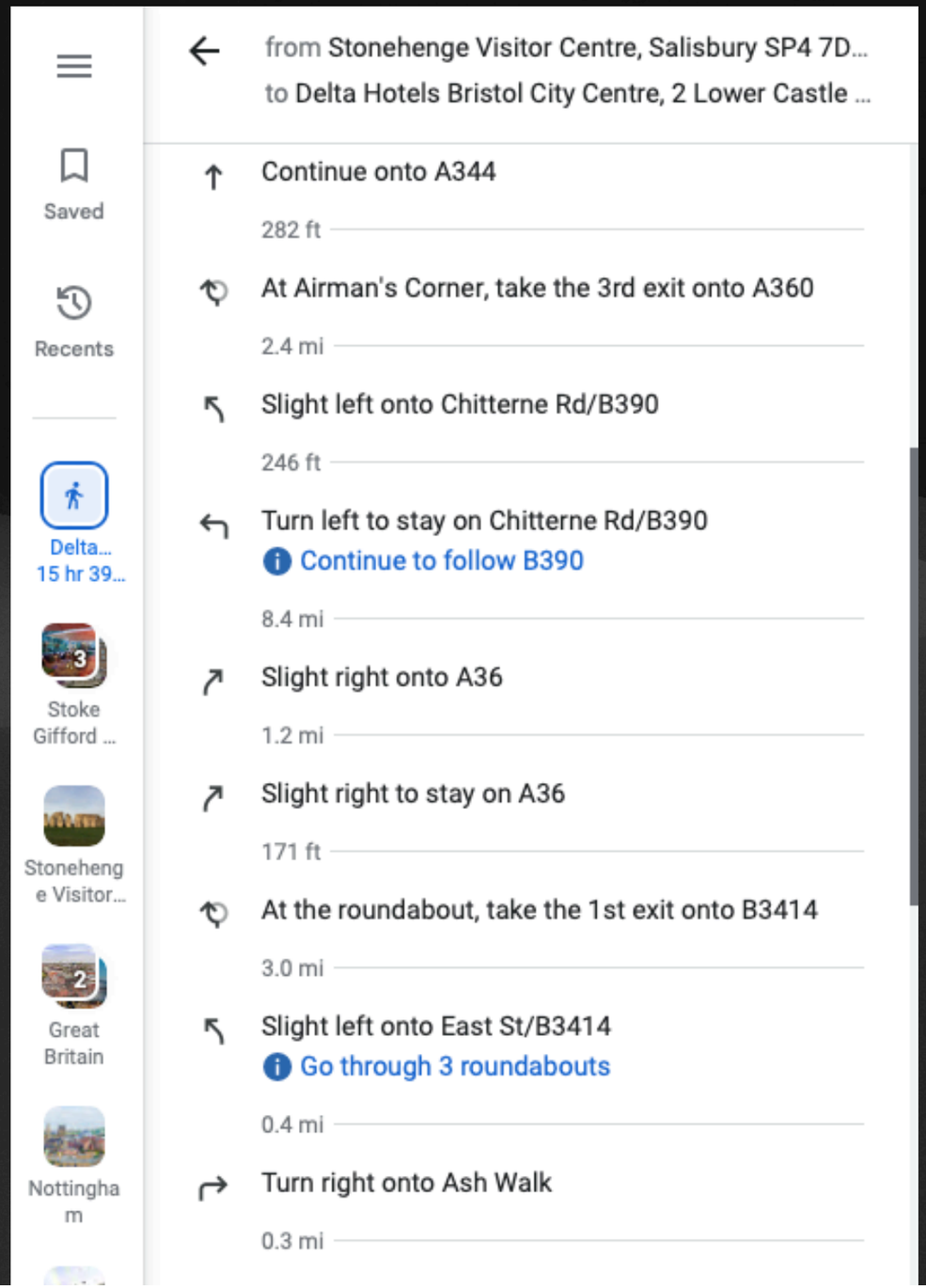
Why do people get lost?

- Route-following
- Survey-knowledge

Route-following

Series of actions taken at specific decision points

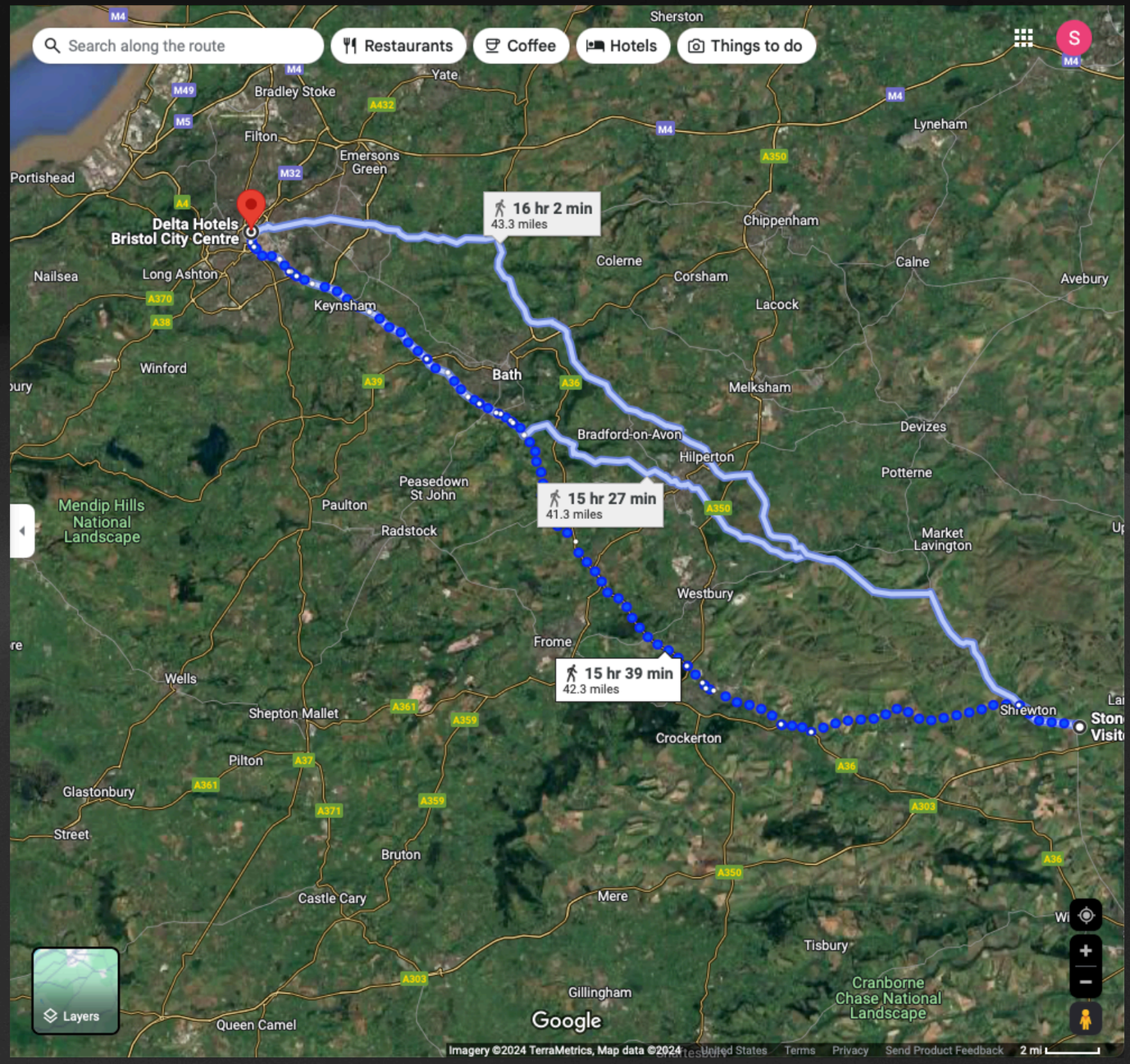
- Turn left or right at specific landmarks
- Self frame-of-reference (egocentric)
- Easily acquired without effort
- Harder to find alternate routes

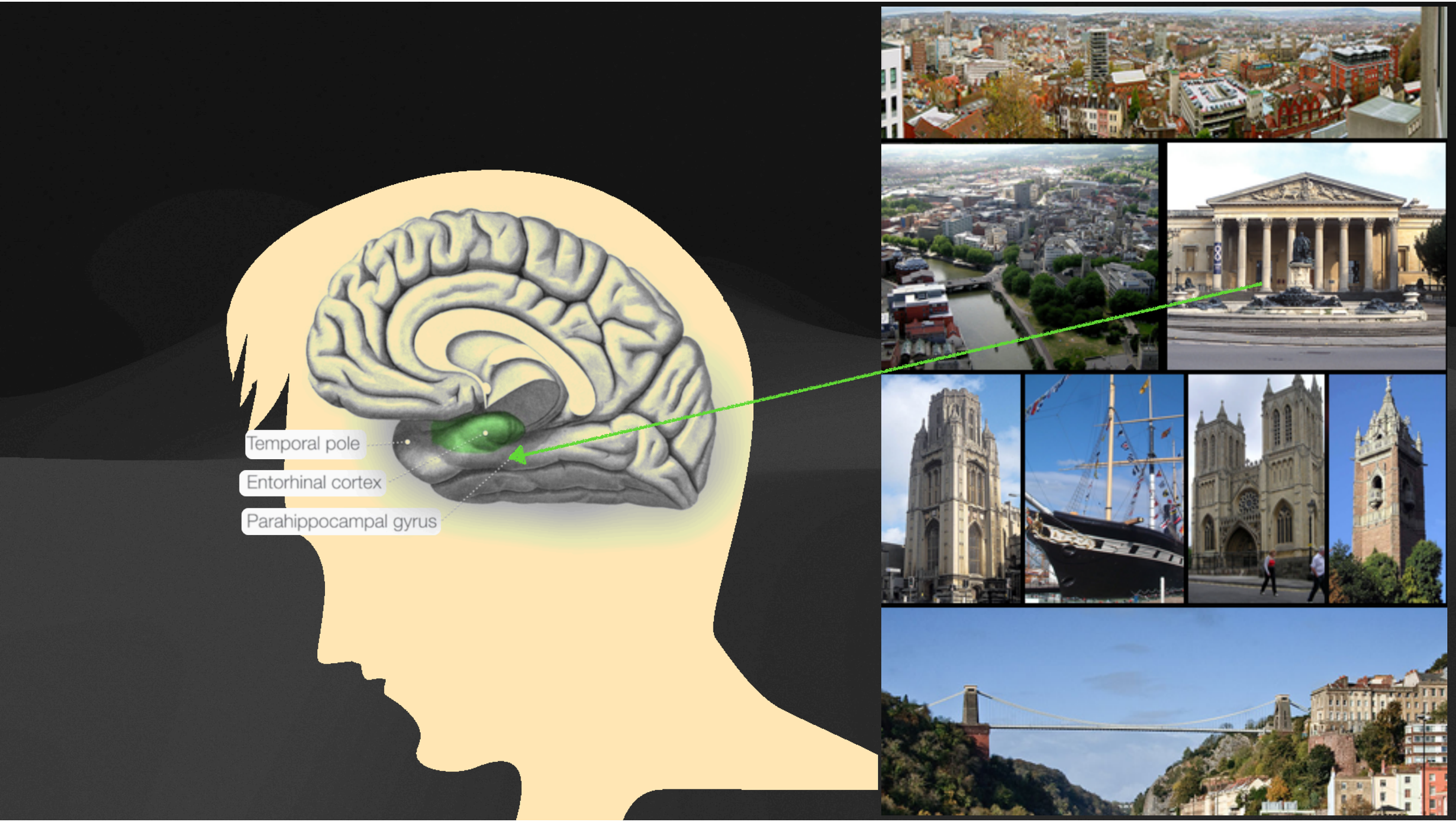


Survey-knowledge

Birds-eye point of view

- Cardinal directions, angular degrees, straight-line distances, geospatial cues
- Allows for finding new trails and shortcuts
- Requires effortful attention to acquire
- People who employ survey knowledge rarely get lost




Temporal pole
Entorhinal cortex
Parahippocampal gyrus

Wayfinding
Audio space

- *Using* tools (Route-following)
- *Creating* the tools (Survey-knowledge)

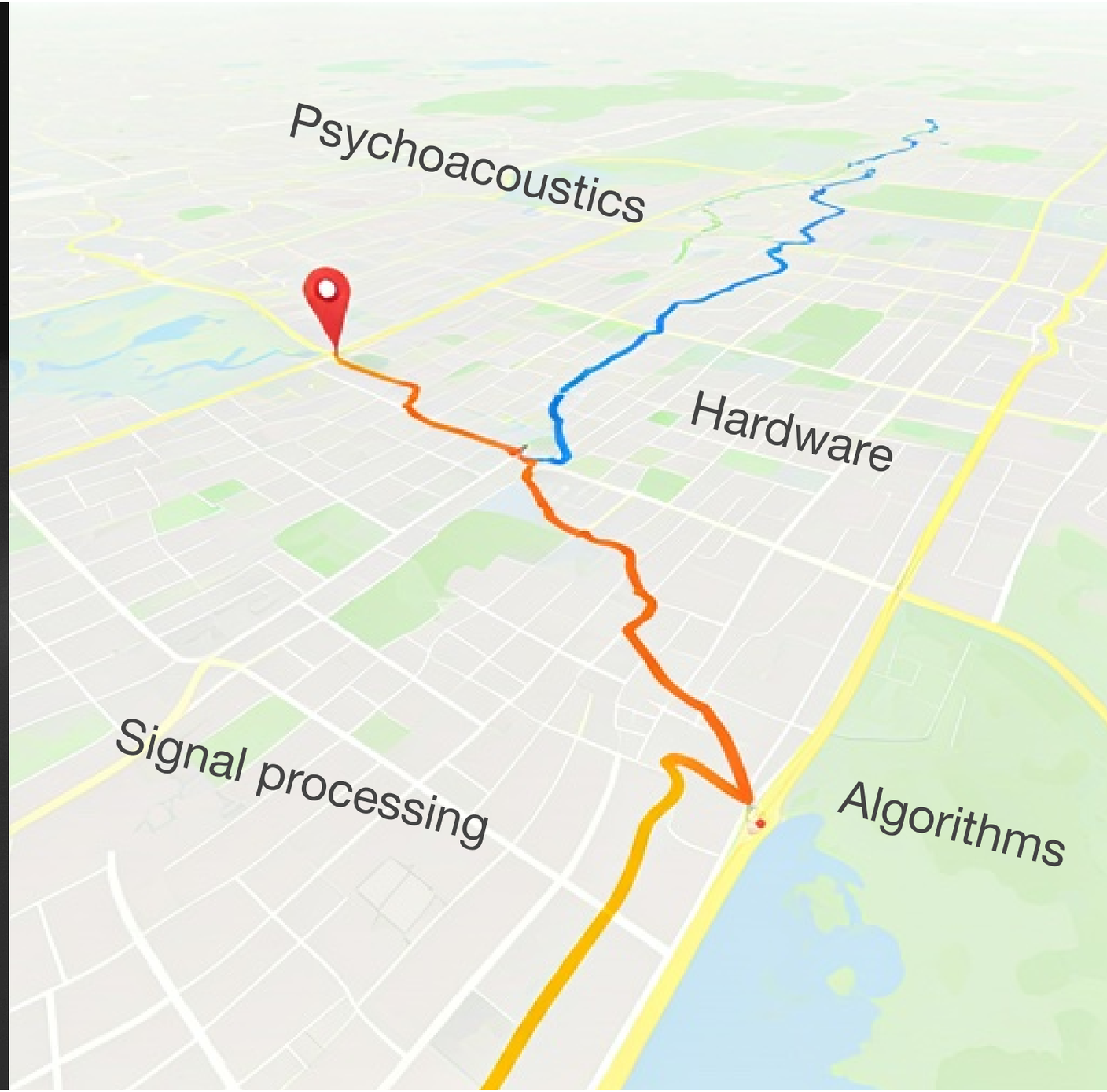
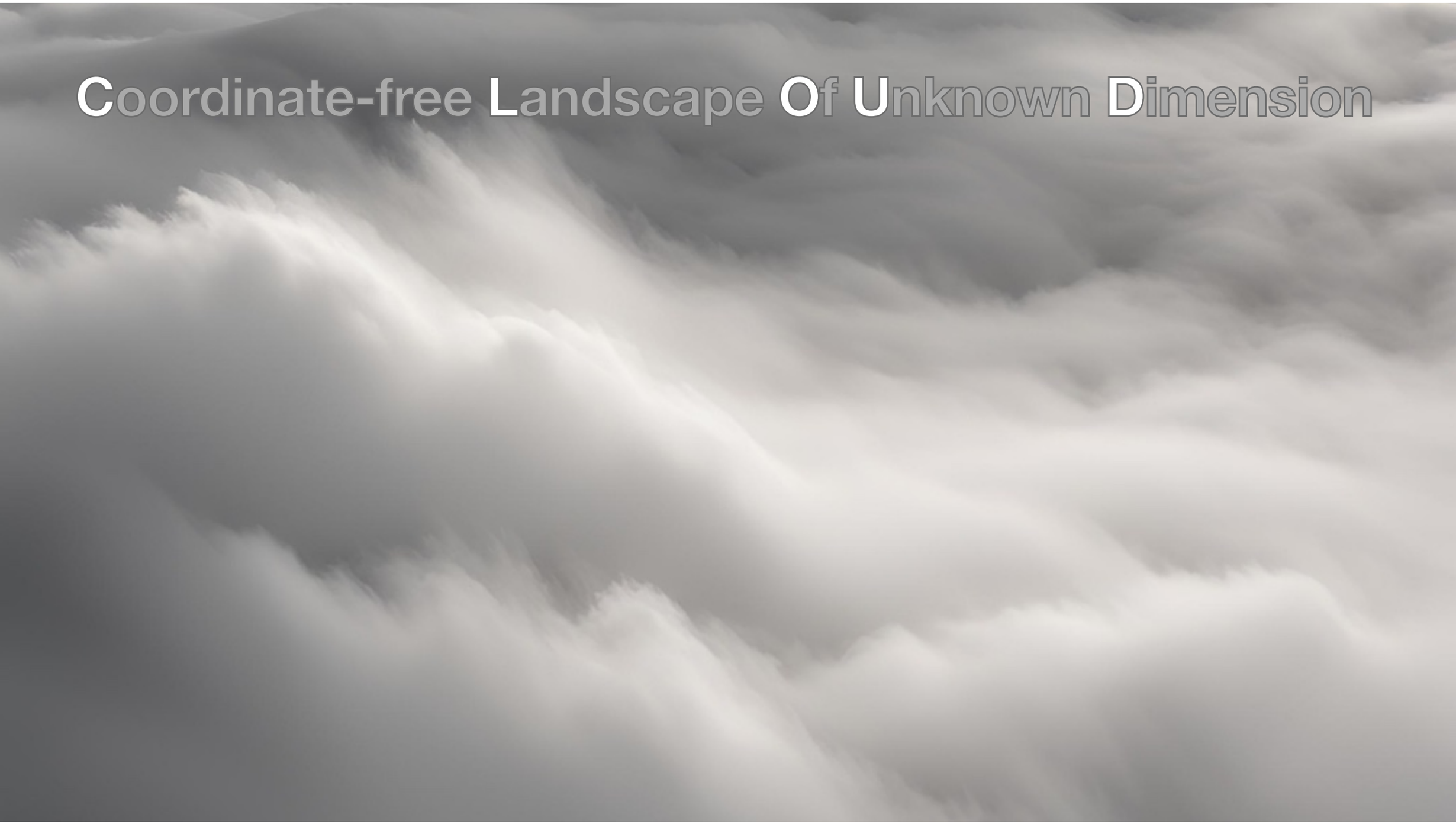


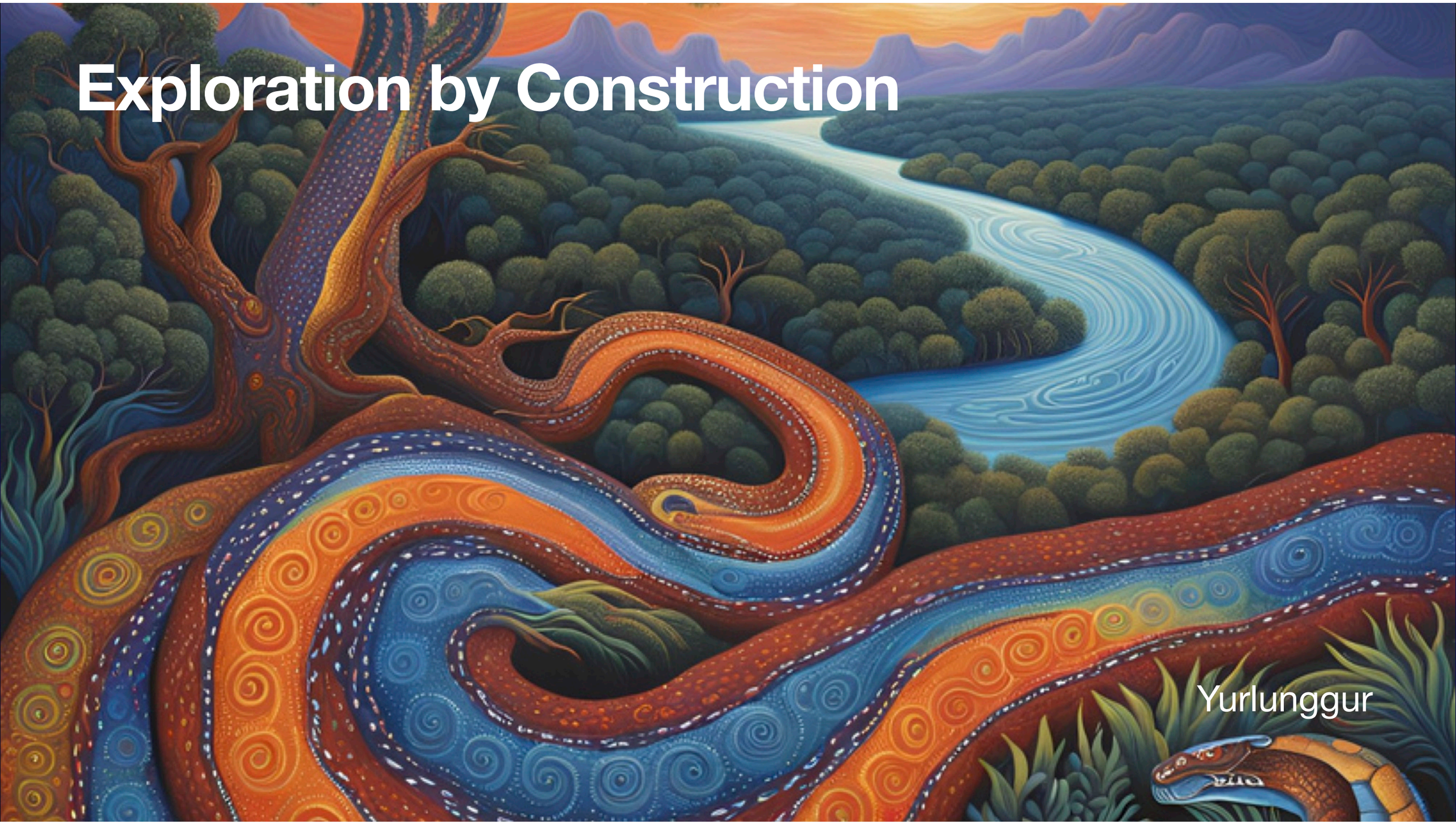
Imagen3: please create a map showing three alternative routes


Coordinate-free Landscape Of Unknown Dimension


CLOUD

Explore the universe by creating it…

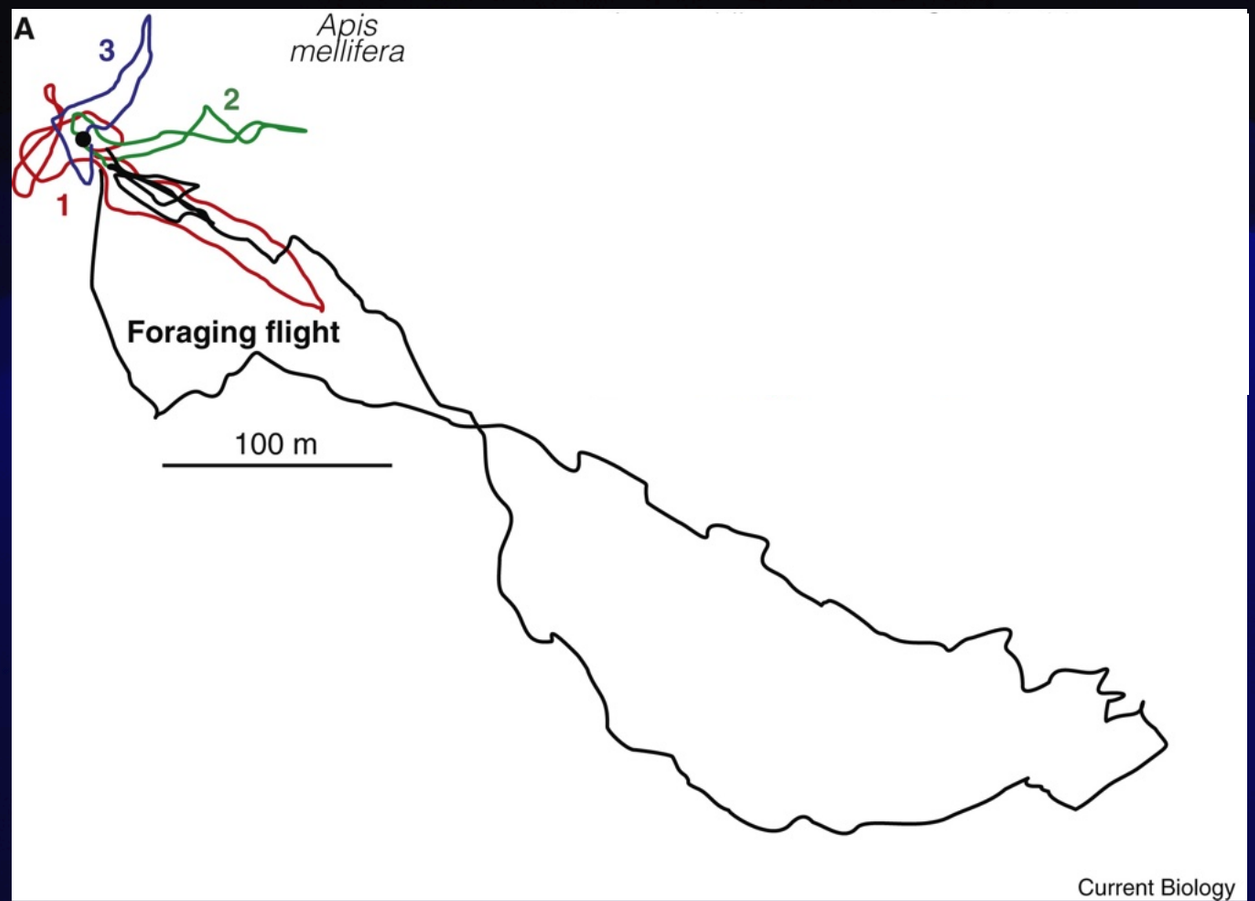
Exploration by Construction



A third wayfinding strategy?

Recursive Construction

- Insect flights
  - Short round trips in each direction
  - Longer trips built from the smaller ones



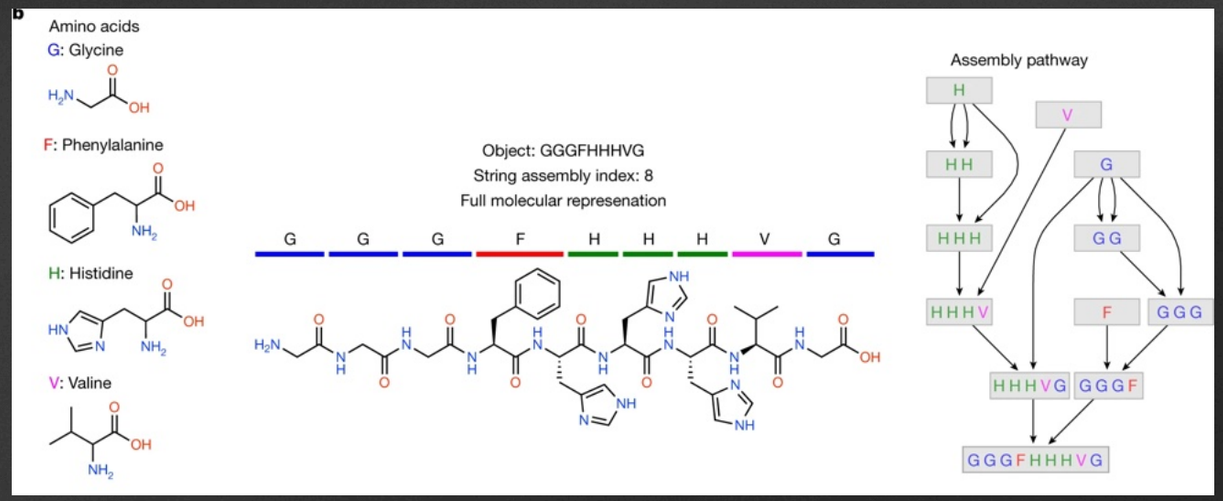
Thomas S. Collett, Jochen Zeil, Insect learning flights and walks Current Biology,Volume 28, Issue 17, 2018

Assembly Theory

Life on Earth emerged through a series of self-assembling chemical reactions

Sara Walker
Astrobiology
ASU

Complex systems are built from simpler components through a process of **recursive construction**

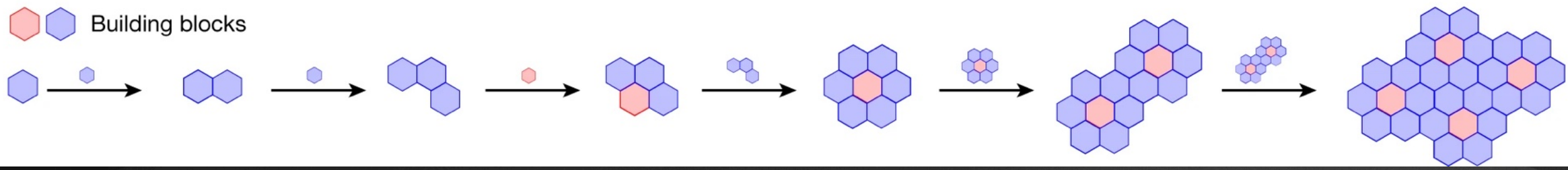


Lee Cronin
Digital Chemistry
University of Glasgow

Sharma, A., Czégel, D., Lachmann, M. et al. Assembly theory explains and quantifies selection and evolution. *Nature* (2023). https://doi.org/10.1038/s41586-023-06600-9

Assembly Theory

Exploration by construction



- Break it down into its constituent, elementary building blocks
- Recursively recombine these sub-assemblies to form new structures
- Add the new structure into the assembly pool for reuse in future assemblies

Sharma, A., Czégel, D., Lachmann, M. et al. Assembly theory explains and quantifies selection and evolution. *Nature* (2023). https://doi.org/10.1038/s41586-023-06600-9

Ideas in the air

Cambrian explosions of ideas

- Past events shape what options are available on the current step
- New ideas build on previous infrastructure
  - Geoff Hinton could not have re-ignited interest in neural nets
  - If Fei-Fei Li had not created ImageNet* *first*

Imagen3: Cambrian Explosion of Ideas

* ImageNet is a publicly-available database of over 14 million annotated images

The Cloud

Boundary of the known & unknown

“We do something quite heroic. Every day, we try to bring ourselves to the boundary between the known and the unknown and face the cloud.”

"Why truly innovative science demands a leap into the unknown"

Stuck in the CLOUD

…I felt like a pilot flying through the mist, and I lost all sense of direction.

Professor Uri Alon
Design Principles in Biology
Weizmann Institute of Science
Winner, Nakasone HFSP award for a breakthrough at the frontier of life science

https://www.youtube.com/watch?v=F1U26PLiXjM

“Why truly innovative science demands a leap into the unknown"

Improvisation

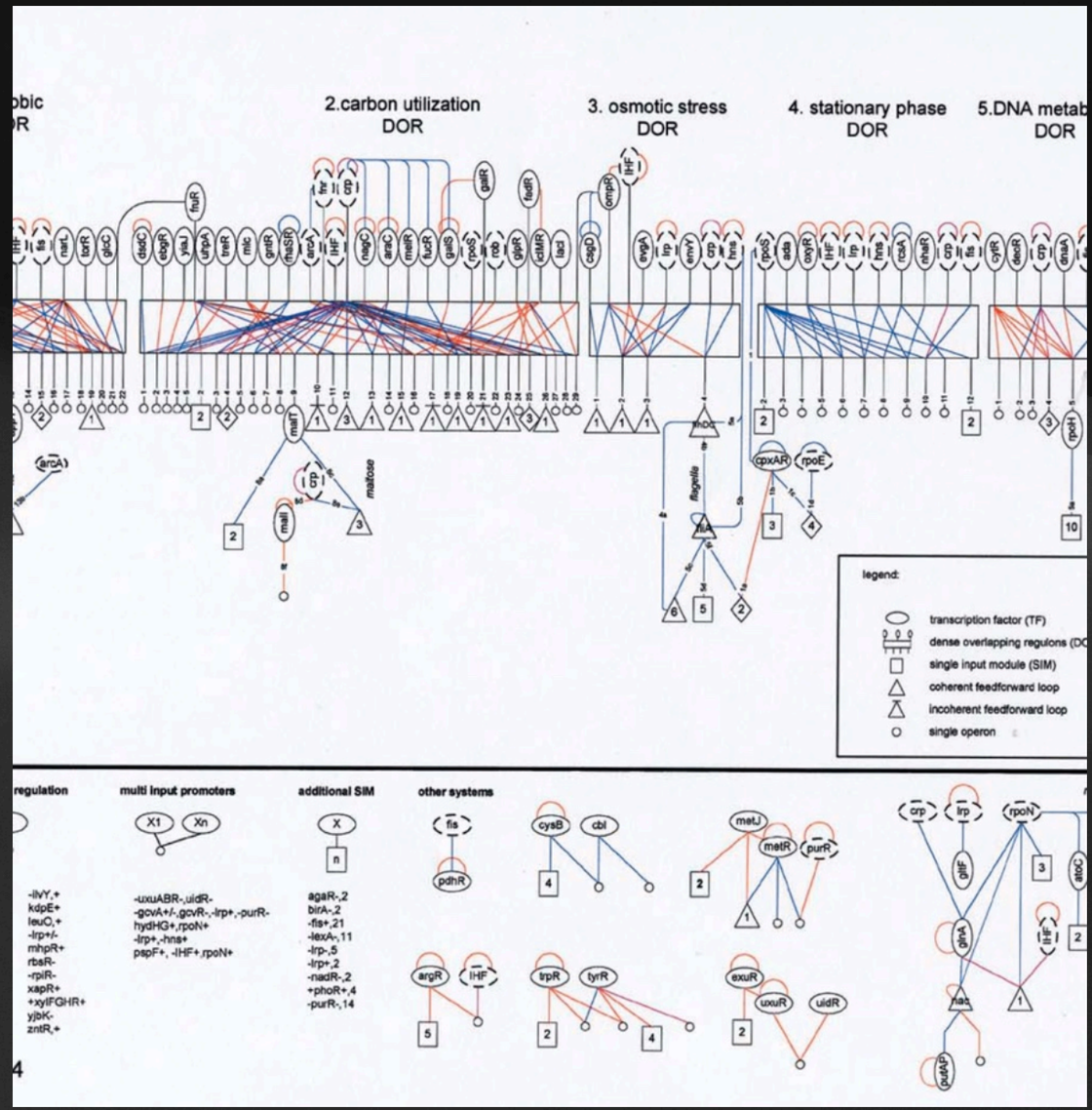
You're going to fail…miserably.

You *are* going to get stuck.

https://www.youtube.com/watch?v=F1U26PLiXjM

Exploration through Construction
Yes, and…

- Student1: Let's just draw this on a piece of paper, this network
- Uri: Yes, and let's use a very *big* piece of paper
- Student2: Let's use a *gigantic* architect's blueprint kind of paper, and I know where to print it

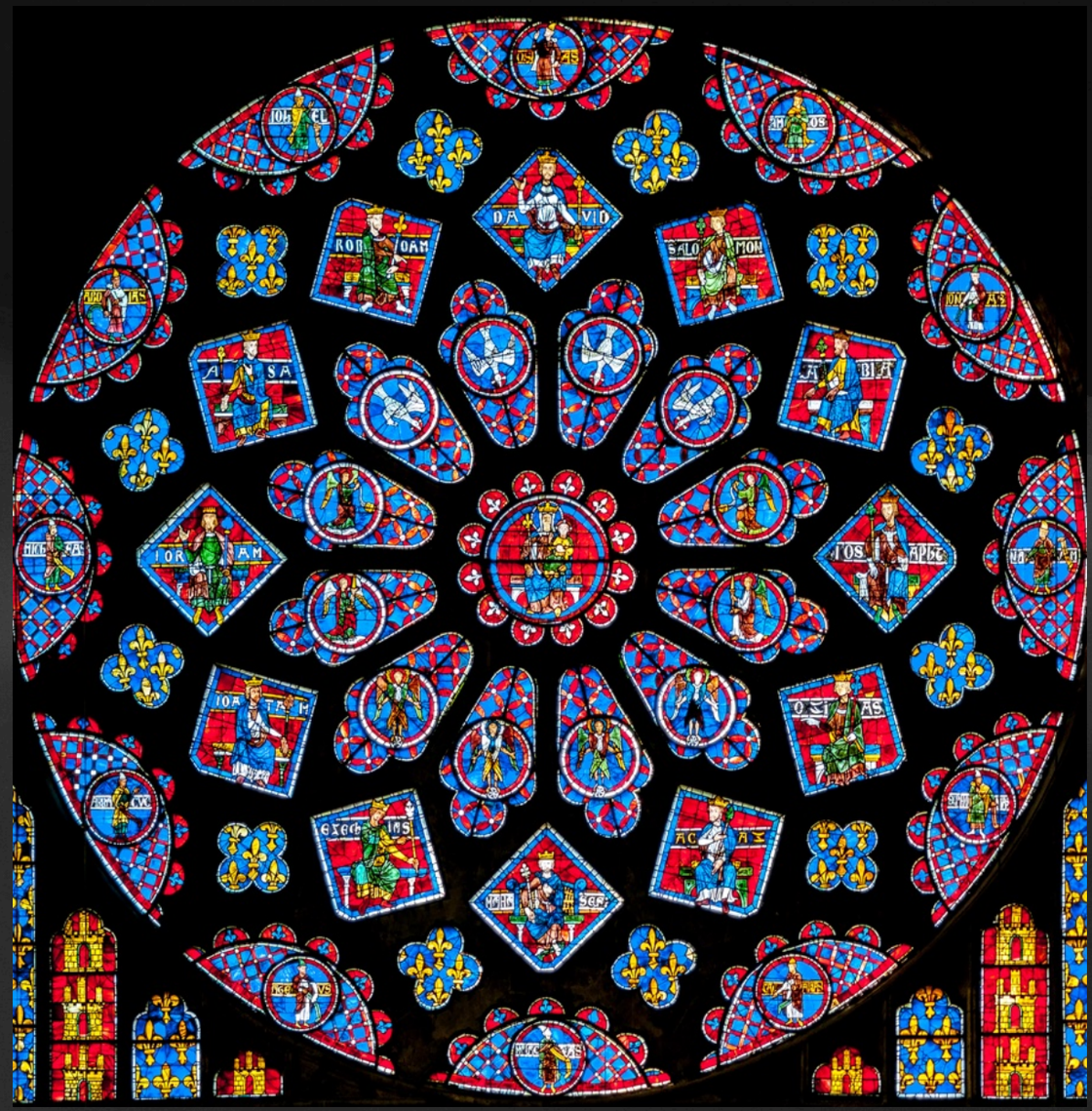


Shen-Orr, S., Milo, R., Mangan, S. et al. Network motifs in the transcriptional regulation network of Escherichia coli. Nat Genet 31, 64–68 (2002). https://doi.org/10.1038/ng881

“Why truly innovative science demands a leap into the unknown"

Network motifs

- Elementary circuits, recursively recombined to form more complex networks
- How cells interact with a changing environment
- *Explore-by-construction* strategy

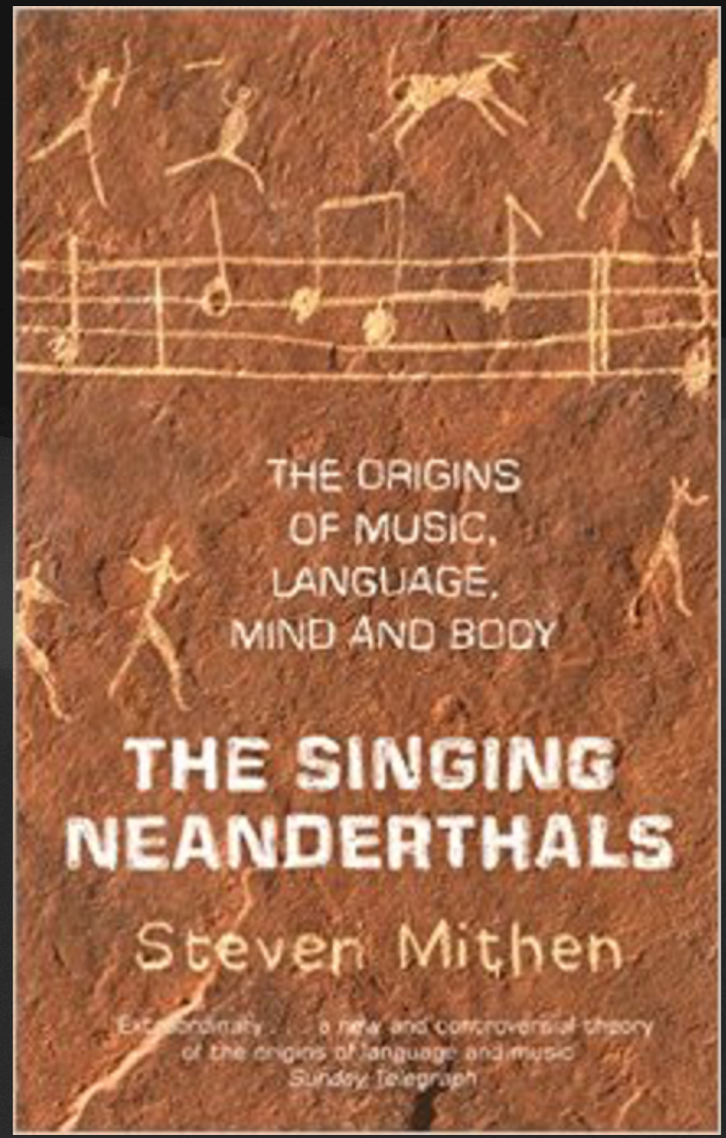


Chartres Rosette Nord Photo by PtrQs CC

Cognitive Fluidity

Exploration by Construction

- Domain-specific modules
- Recursive re-combinations of domain-specific modules



Brains made for navigation

- Memory
- Imagination
- Prediction
- Simulation

Imagen3: “Please combine an astrolabe with a brain”

London taxi drivers

“The Knowledge”

- Significantly larger hippocampus
- Size was positively correlated with driving experience

Eleanor A. Maguire
University College London

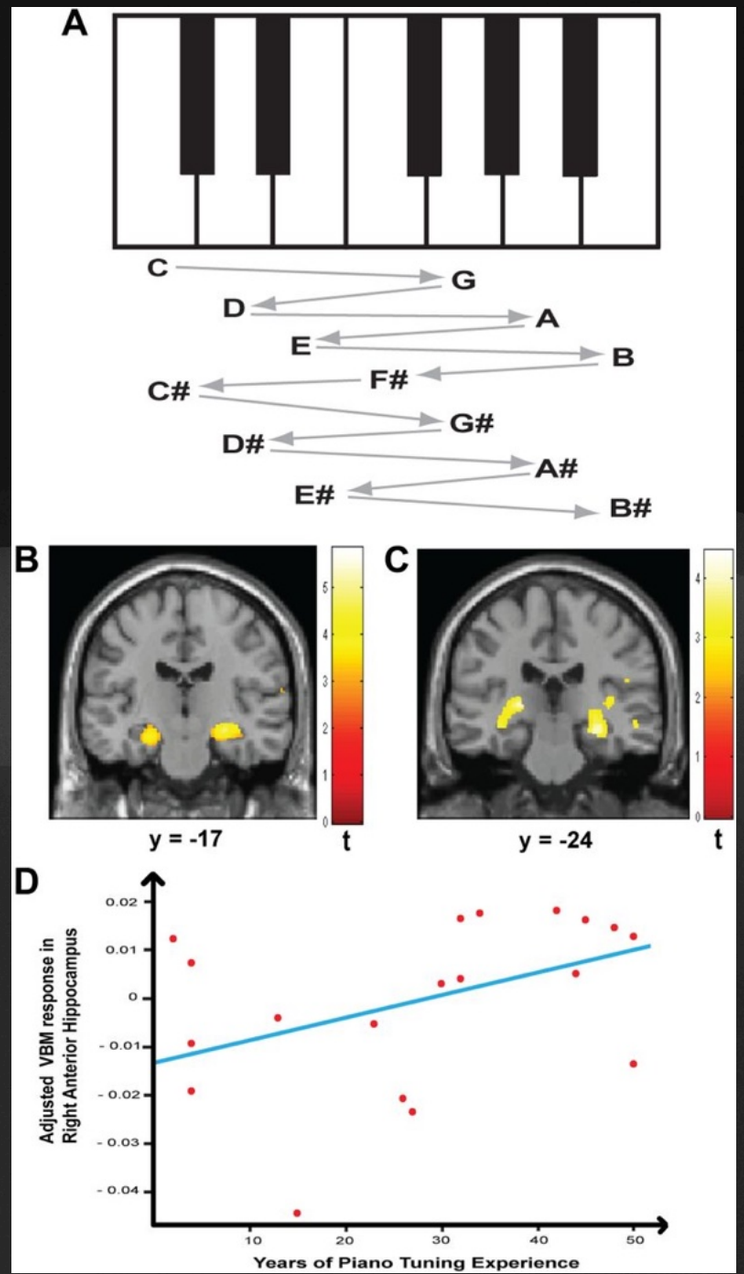
“Navigation-related structural change in the hippocampi of taxi drivers”
Eleanor A. Maguire et al *PNAS* (2000)

London piano tuners

Navigating the Auditory Scene

- Skilled exploration of complex soundscapes
- Similar neural architecture to that used for navigation in *physical* space

Tim Griffiths
Professor of Cognitive Neurology
Newcastle University
University College London



Navigating the Auditory Scene: An Expert Role for the Hippocampus
Sundeep Teki, +6, Timothy D. Griffiths
Journal of Neuroscience (2012) doi.org/10.1523/JNEUROSCI.0082-12.2012

"Patients with hippocampal amnesia cannot imagine new experiences"
Demis Hassabis et al. PNAS 2006

Recalling vs Imagining

"Hippocampal Amnesia"

- Recalling *prior* experience
- Imagining *new* experience

Demis Hassabis, PhD
Cognitive Neuroscientist
University College London

Eleanor A. Maguire
Cognitive Neuroscientist
University College London

"Patients with hippocampal amnesia cannot imagine new experiences"
Demis Hassabis et al. PNAS 2006

Construction system of the brain

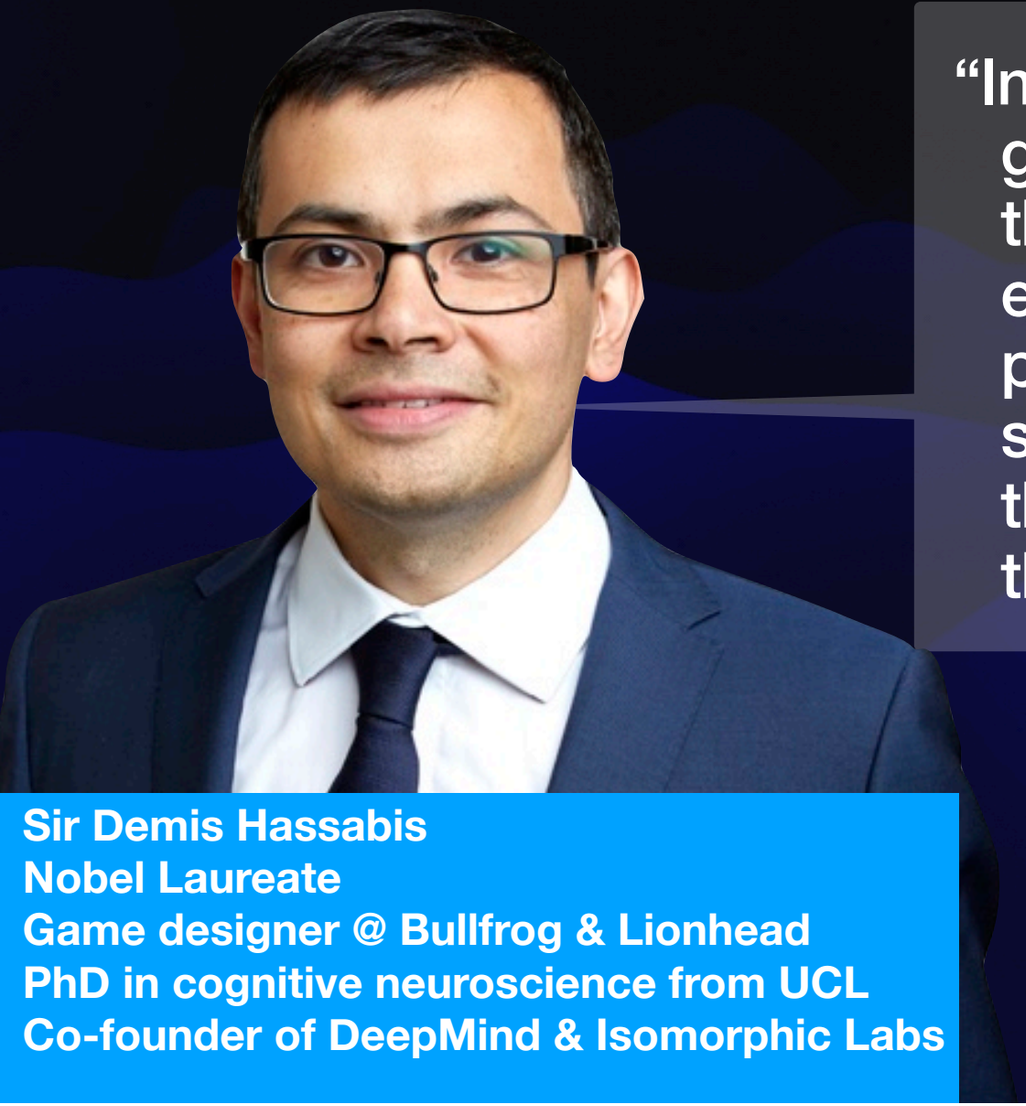
Complex scenes *constructed* out of smaller elements

- Recalling *prior* experience
- Imagining *new* experience
- Both are *constructive* processes

Demis Hassabis, PhD
Cognitive Neuroscientist
University College London

Eleanor A. Maguire
Cognitive Neuroscientist
University College London

Mind as Simulation Engine



Sir Demis Hassabis
Nobel Laureate
Game designer @ Bullfrog & Lionhead
PhD in cognitive neuroscience from UCL
Co-founder of DeepMind & Isomorphic Labs

"In humans, the use of this constructive process goes far beyond simply predicting the future, to the general evaluation of fitness for purpose. For example, a scriptwriter … who is writing a passage in a film … may play out the whole scene using their construction system, not with the idea of predicting the future, but instead for the purpose of evaluating its aesthetic suitability.

The best way to predict the future is to create it.

Variously ascribed to: R Bradbury? A Kay? P Druker? A Lincoln?

Delphic Sibyl, Michelangelo (1509) Public Domain

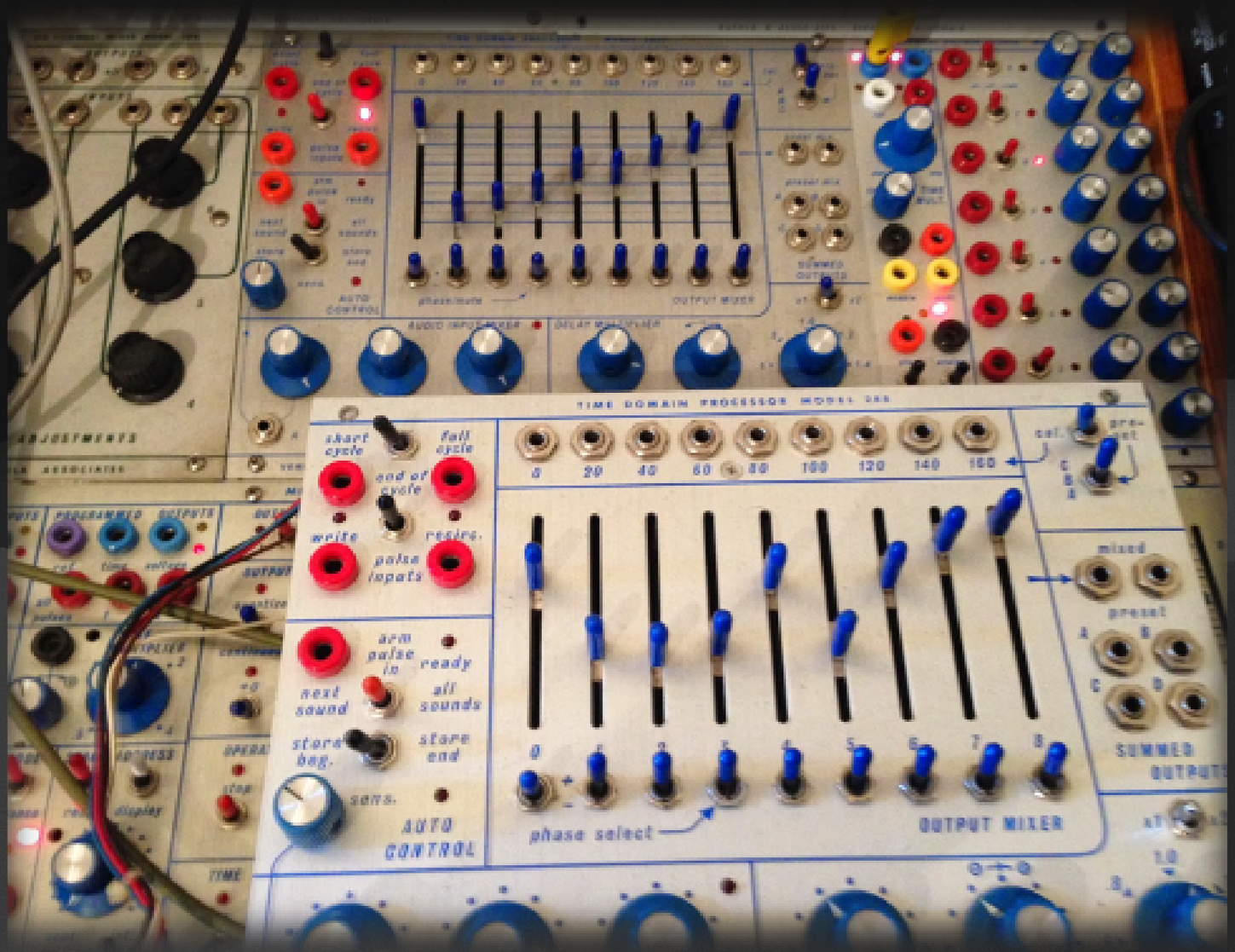
Symbols ➡ Physical reality

Mappae Mirabilis

- Humans can imagine maps of what does not yet exist
- Coders can *make* it exist!

Imagen3: software moving a mechanical arm


Once upon a time


short cycle
full cycle
end of cycle
write
pulse inputs
resinc.
arm pulse in
ready
next sound
all sounds
store bag.
store end
sens.
AUTO CONTROL
phase select
OUTPUT MIXER
mixed
preset
SUMMED OUTPUTS

Music N

A map that reflects the worldview of the map *maker*

- Models of Instruments & Scores
- Far from interactive or real-time

Jacques Attali

…each tool… implies an imaginable and explorable universe.

The dream

Unobtainium?

- No distinction among live audio, recorded audio, synthesized audio, processed audio
- Sound structures (not necessarily notes played on instruments)
- Interactive controls with immediate audio feedback
- For live, interactive performances

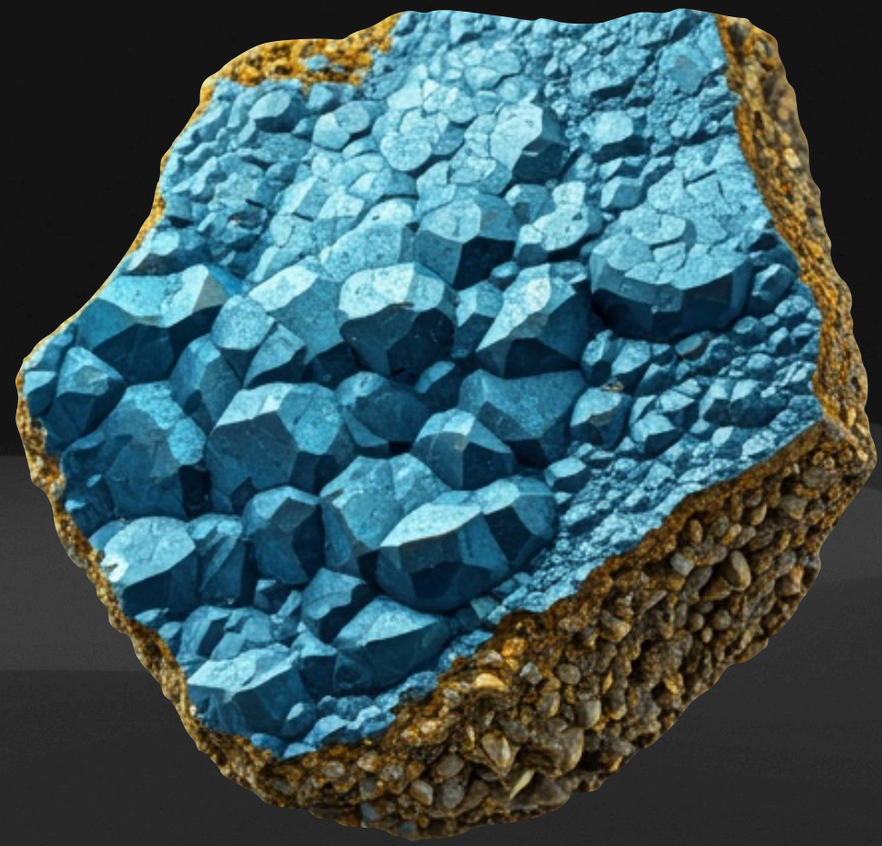
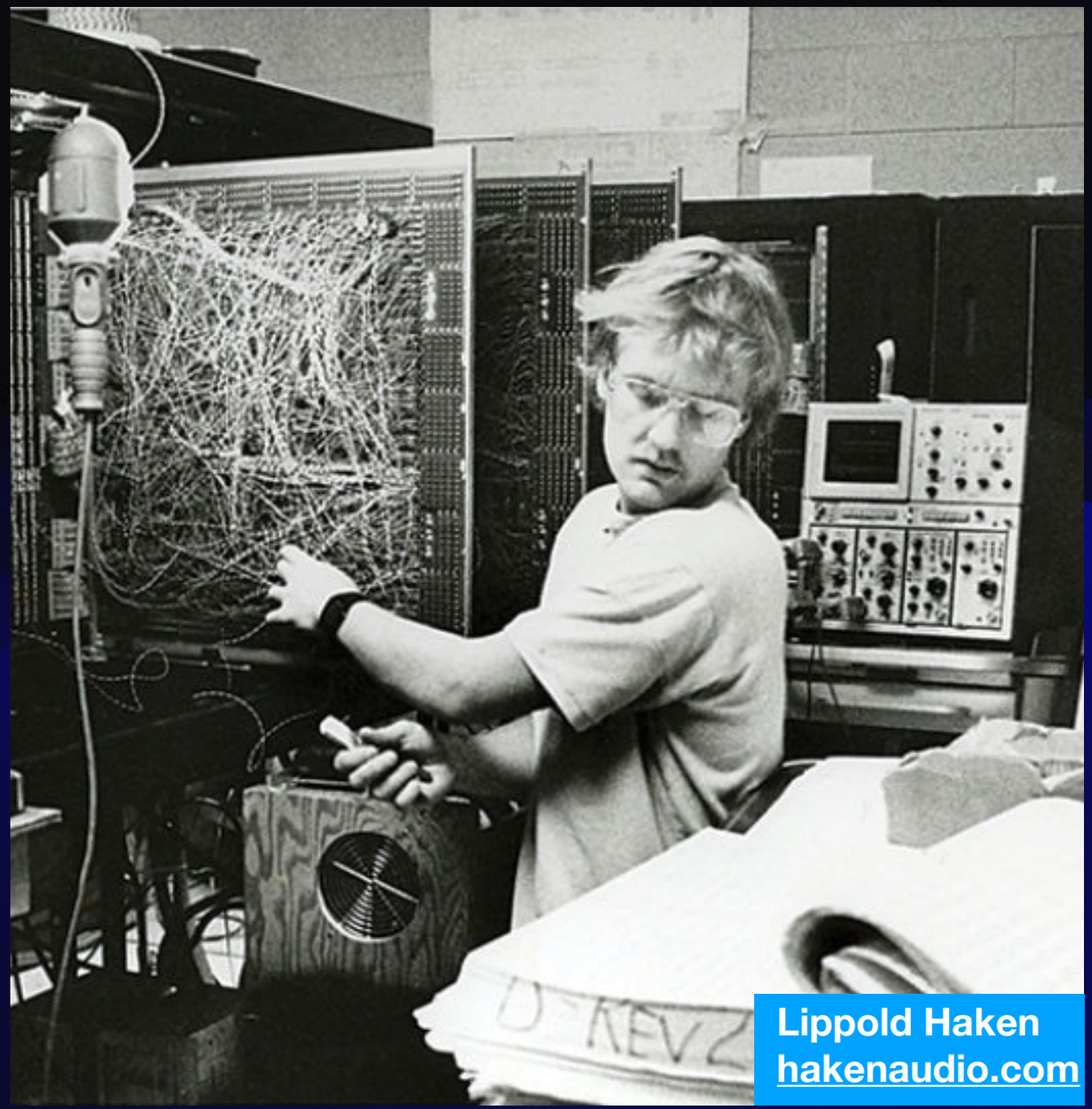


Imagen3: A piece of the valuable “unobtanium" from Avatar

CERL Sound Group

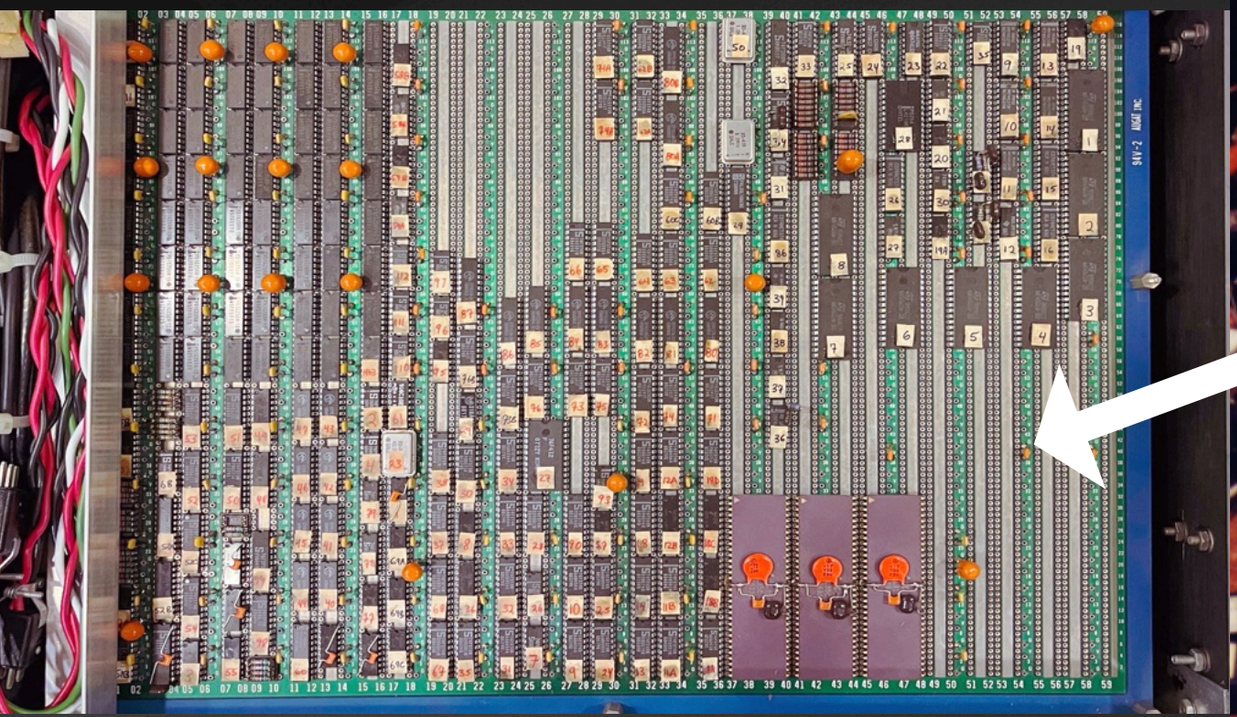
aka CERL Music Group



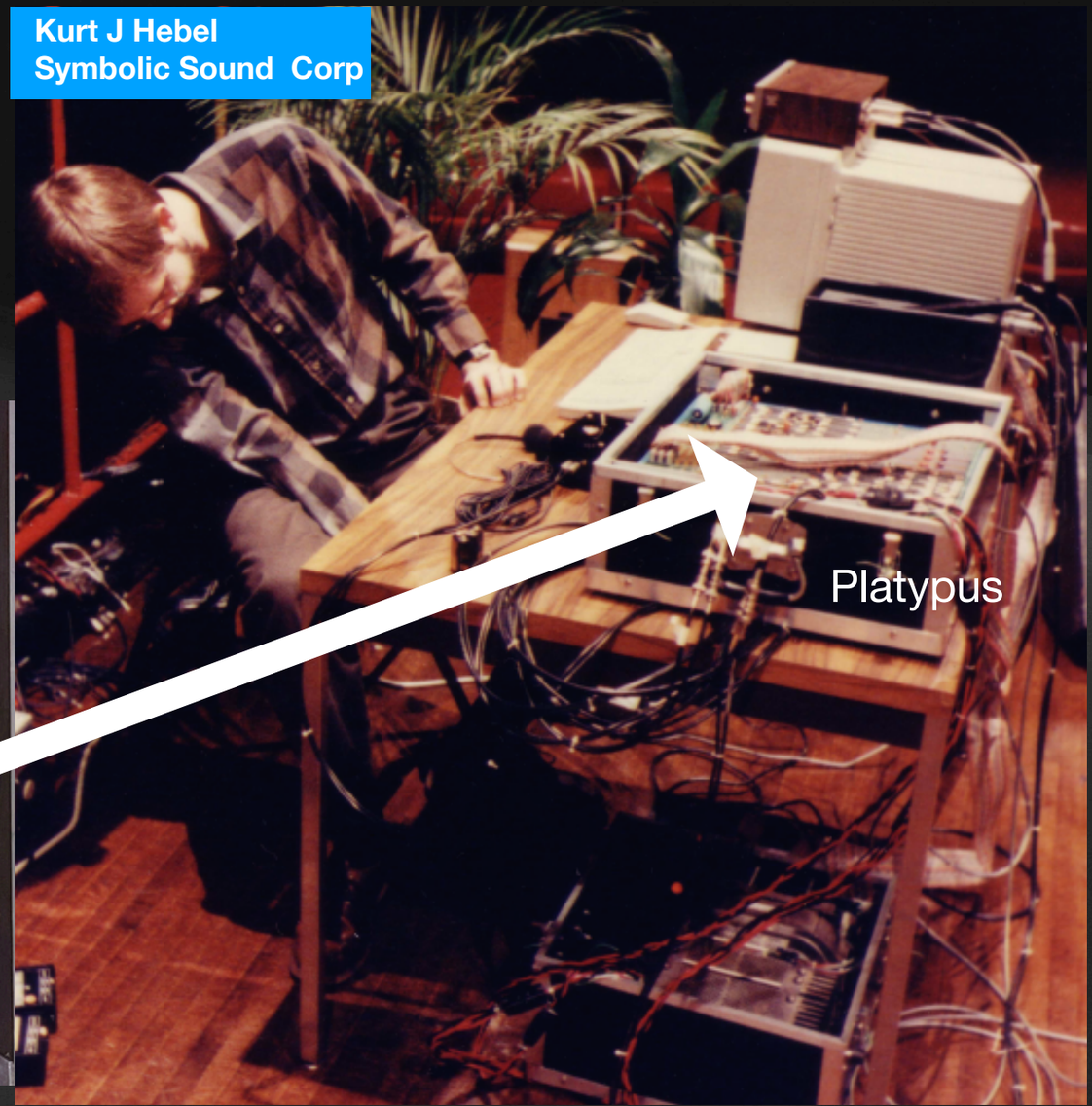
https://uiaa.org/2010/09/10/in-the-time-of-plato/

Platypus

Haken & Hebel (1984)



Platypus (top view)



SCSS

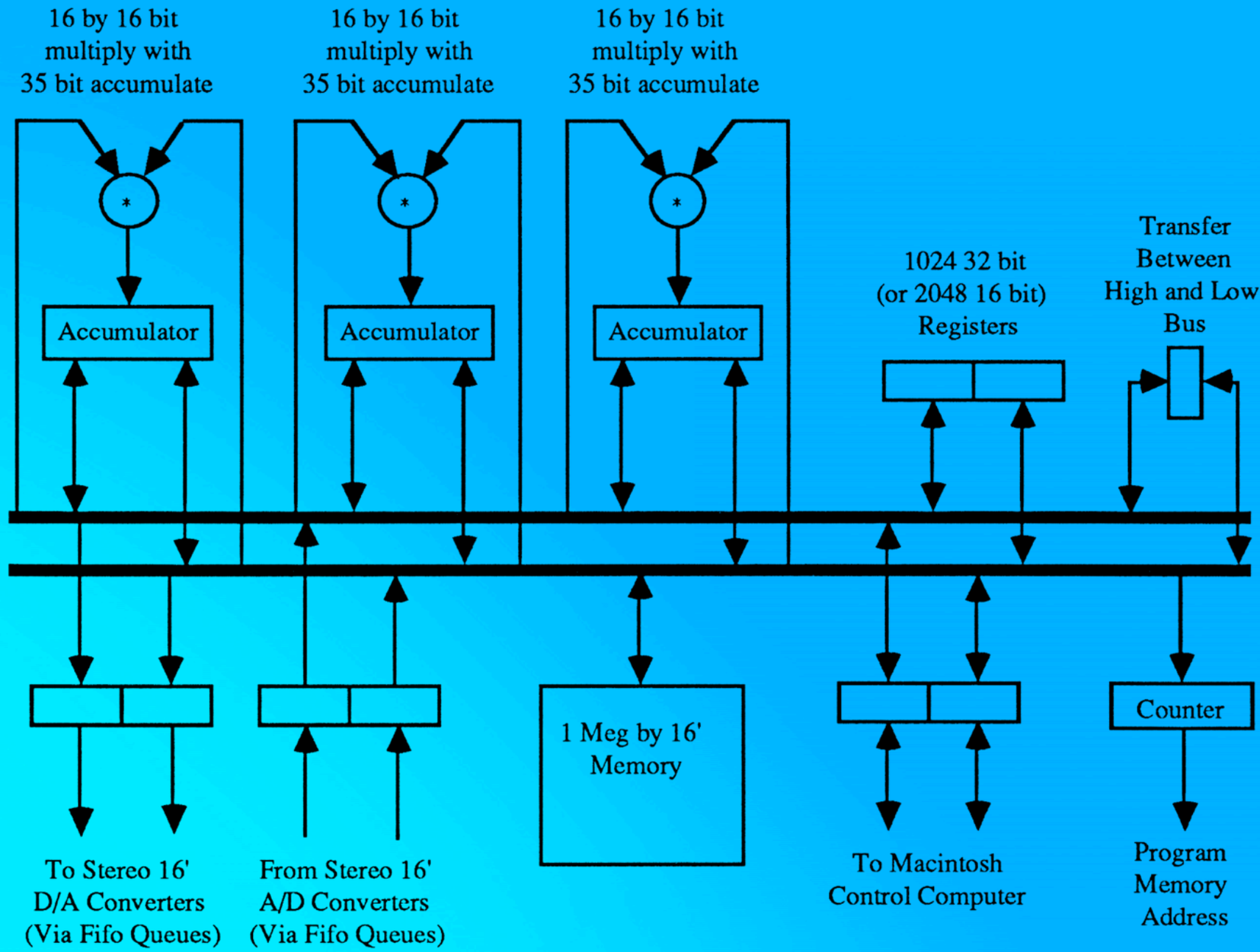


Figure 21. A Block Diagram of the Platypus Digital Signal Processor.

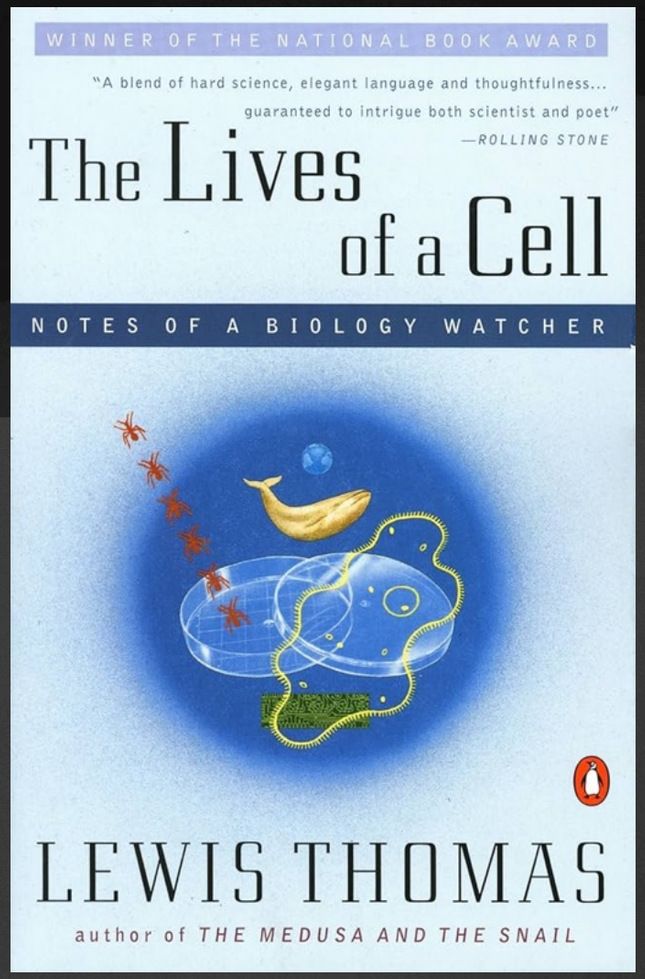
Very Long Instruction Word (VLIW)

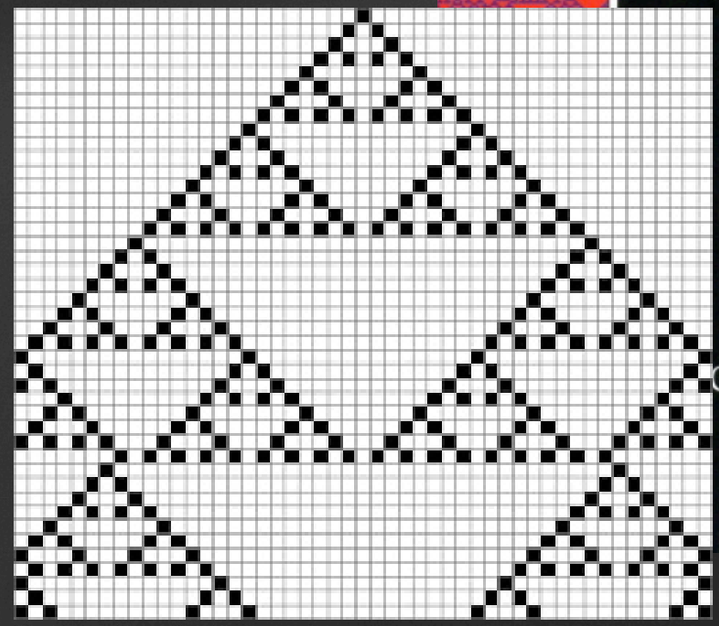
Instruction-level parallelism

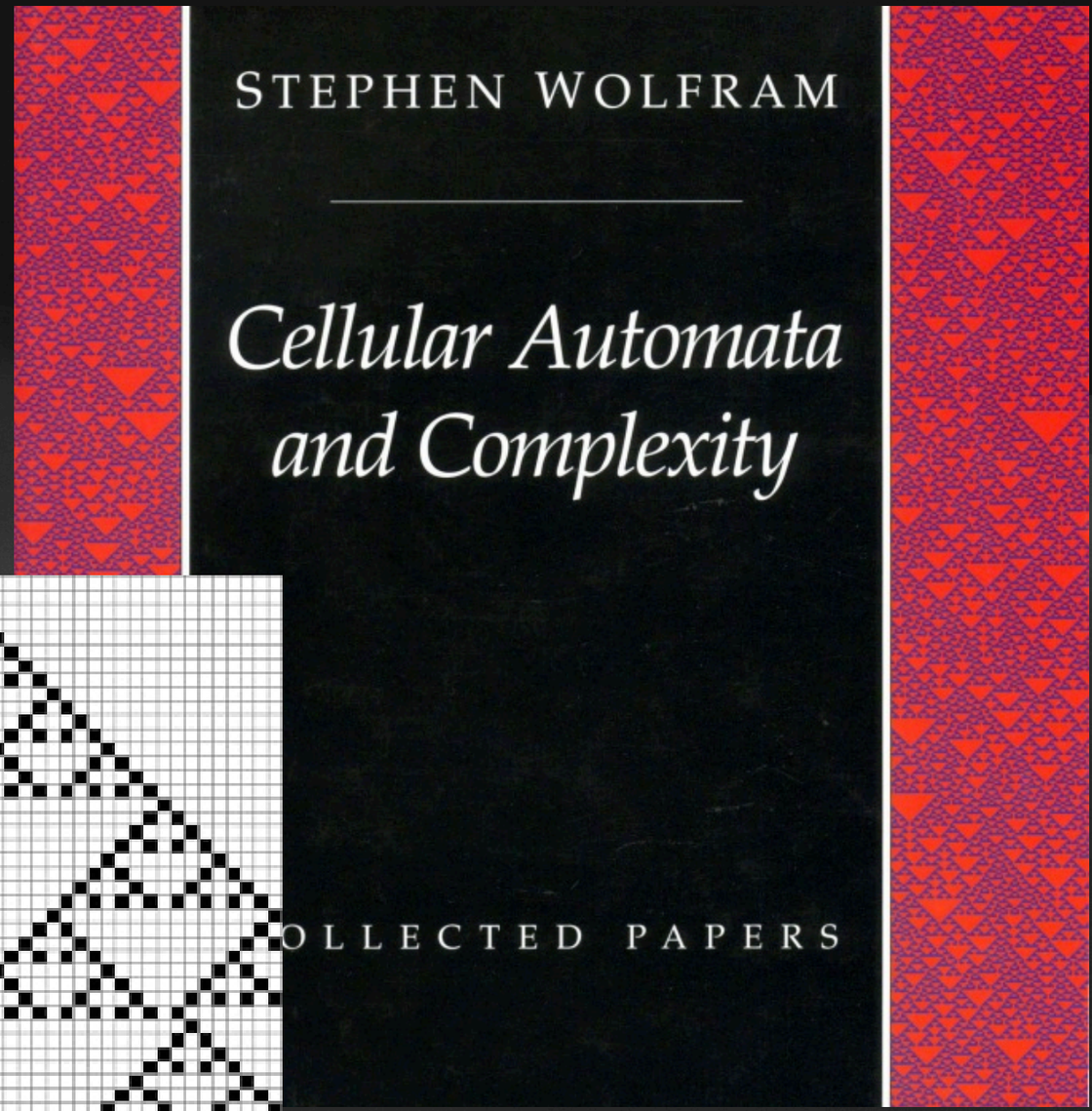
```
assembleUsing: anAssm
    "Return the microcode to increment the stack pointer and push a stereo sample from one of the waveforms stored in memory."

    anAssm defineOffset: #incr toBe: 1;
           defineOffset: #phase toBe: 2;
           defineOffset: #waveNbr toBe: 3.

    anAssm    assembleCodeFromArray: #(
           addrhH = phaseH, multp0 = phase;
           addrlH = waveNbrH, addrL = waveNbrL, read;

    "Increment the phase and the stack pointer."
           multx0H = incrH, multy0L = incrL, add;
           product0, multx2H = oneOneH, multy2L = oneOneL, add;
           phase = multp0, product2;

    "Put stackptr in base, and place the sample from the lookup table (copied to both high and low halves of the word) onto the top of the stack."
           baseH = multp2L, lotohi;
           nop;
           TopL = dataL, TopH = dataL, lotohi;

    "Restore the base to the original class, and jump back to the control loop."
           baseH = multp2H, jumpnextL = ctrlLoopL;
           nop;
)
```

sunSurgeAutomata

…the transformation of inanimate, random matter in chaos into the improbable, ordered dance of living forms



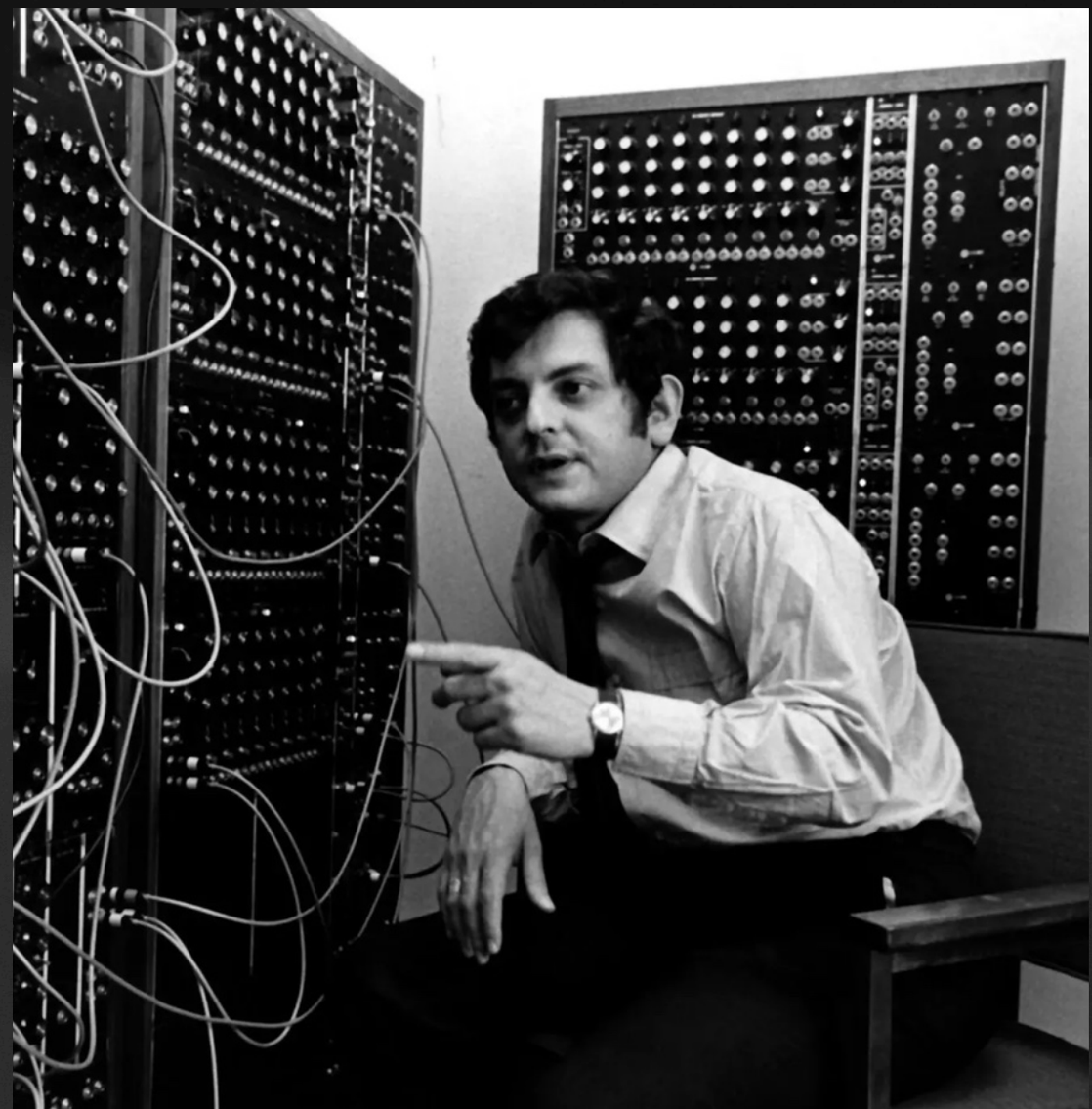




Power vs Control

Joel Chadabe, author & composer

- Control
  - Low-level details
- Power
  - Articulating a vision
  - Delegating the implementation



Joel Chadabe (1938-2021)


What do you do when you
could do anything?

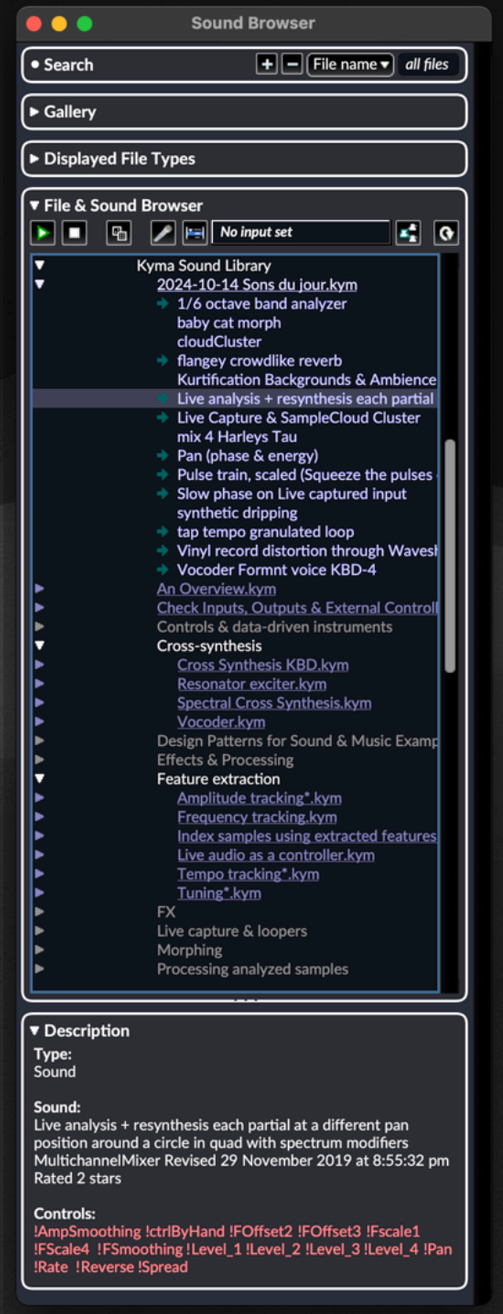
Explore by recursive construction

Assembly Composability Construction Recombinance

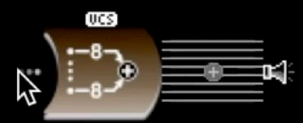
Kyma

κύμα = wave

- Updatable, searchable database of Sound objects
- Recombined in new ways
- Save new assemblies back into the database



A Sound contains a trace of its history

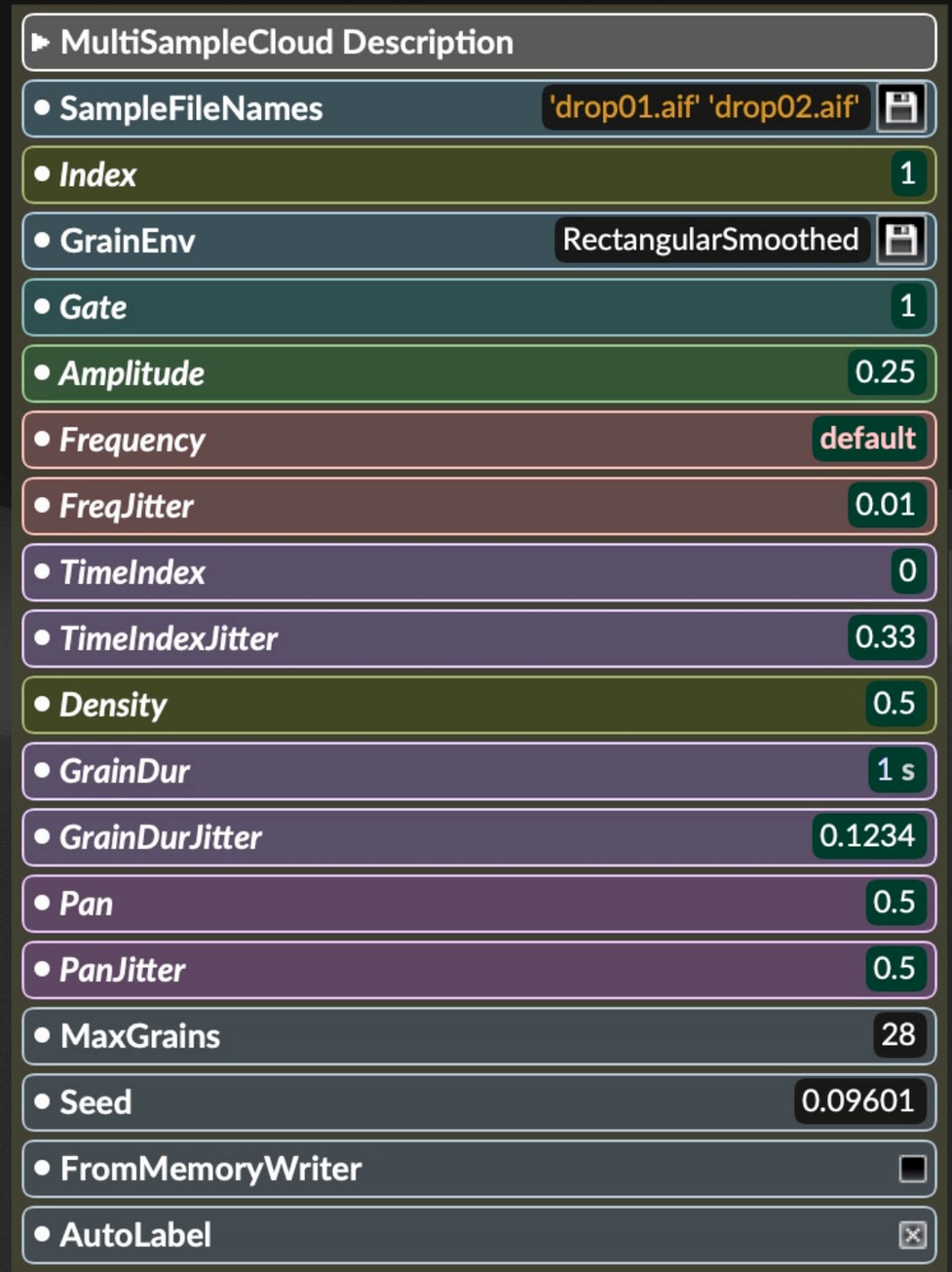


Live analysis + resynthesis each partial at a different pan position around a circle in quad with spectrum modifiers

Parameters

To minimize external dependencies

- State & Control are internal
- Minimize external dependencies
- Any Sound can be substituted for any other



Parameters

Run-time variables

- !EventValue
- Virtual Control Surface
- External stream of control

Parameters

Signals as parameters

- “Voltage control”
- Signal output of another Sound

Parameters

Combining data streams

Capytalk — a functional reactive programming language

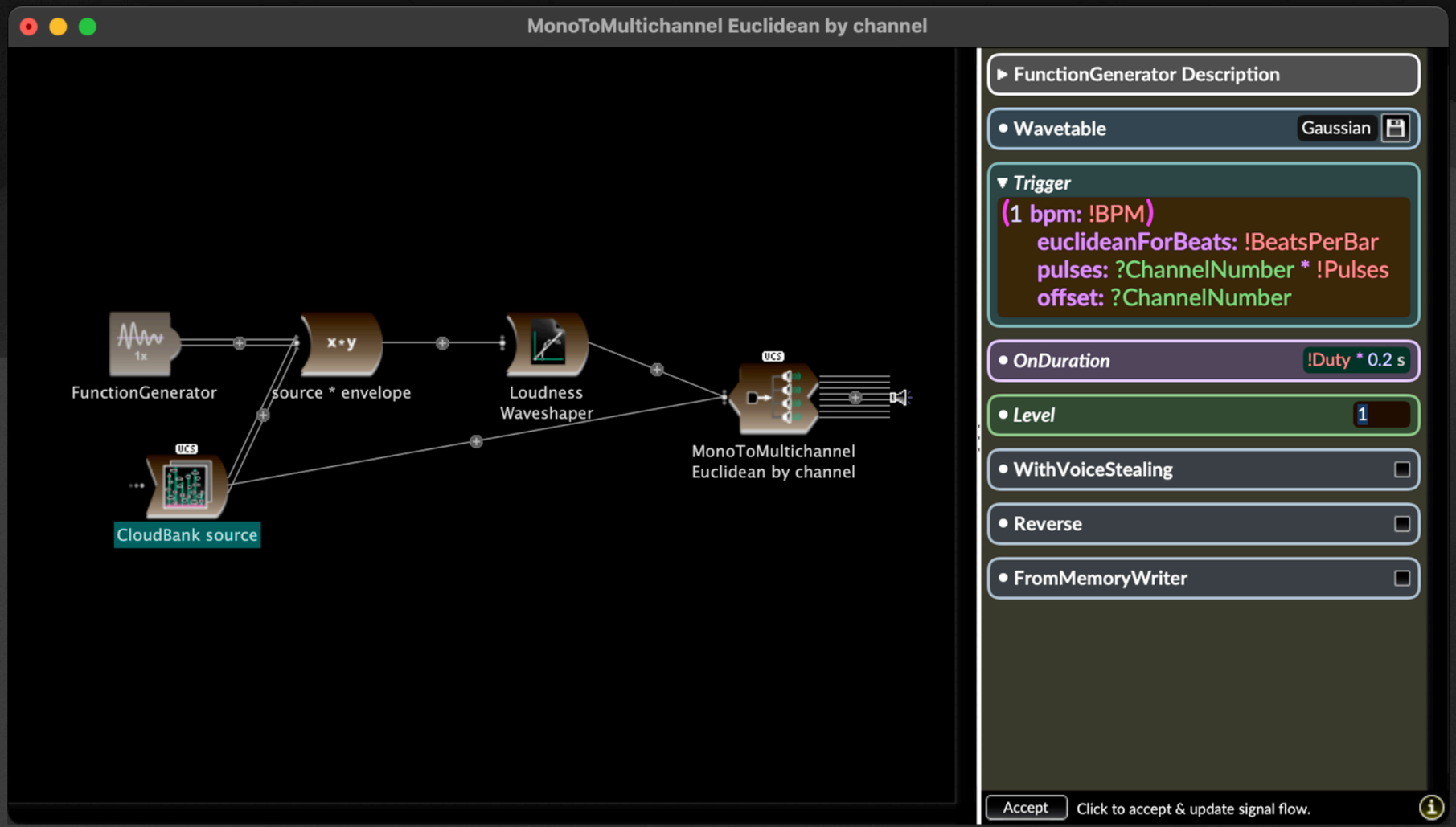
Parameters

Compile-time variables

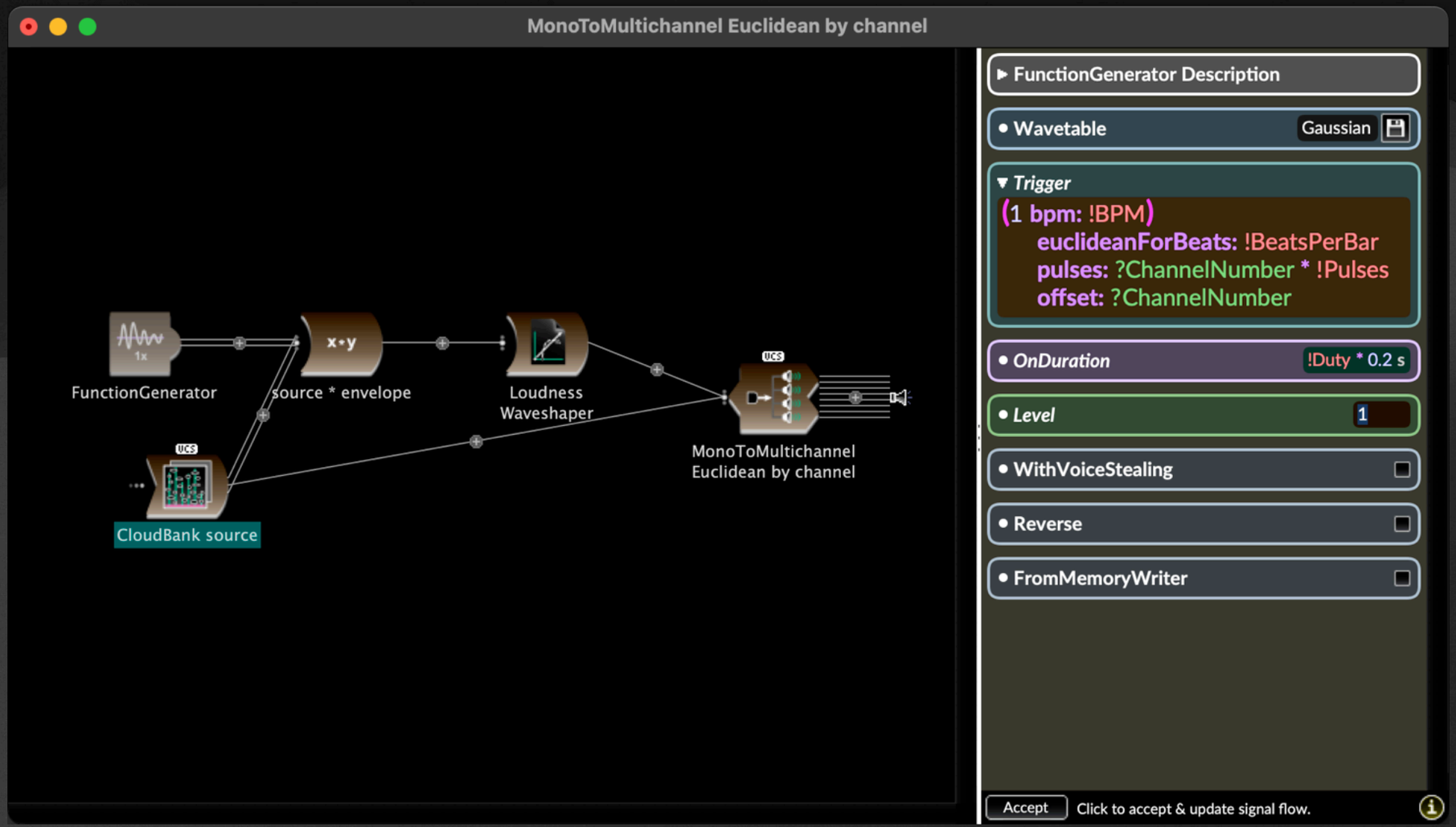
- ?CompileTimeVariable
- Mapped in an “environment” module

Variables in Parameter Fields

Explorable space

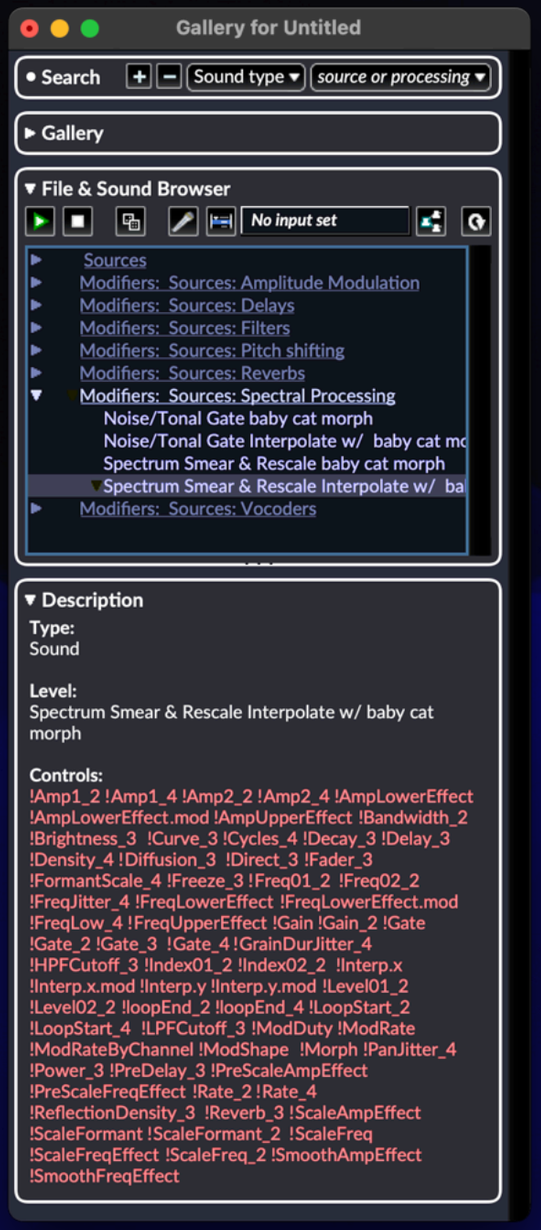


Meta Sounds


MonoToMultichannel Euclidean by channel
FunctionGenerator
source * envelope
Loudness Waveshaper
MonoToMultichannel Euclidean by channel
CloudBank source
FunctionGenerator Description
Wavetable
Gaussian
Trigger
(1 bpm: !BPM)
euclideanForBeats: !BeatsPerBar
pulses: ?ChannelNumber * !Pulses
offset: ?ChannelNumber
OnDuration
!Duty * 0.2 s
Level
1
WithVoiceStealing
Reverse
FromMemoryWriter
Accept
Click to accept & update signal flow.

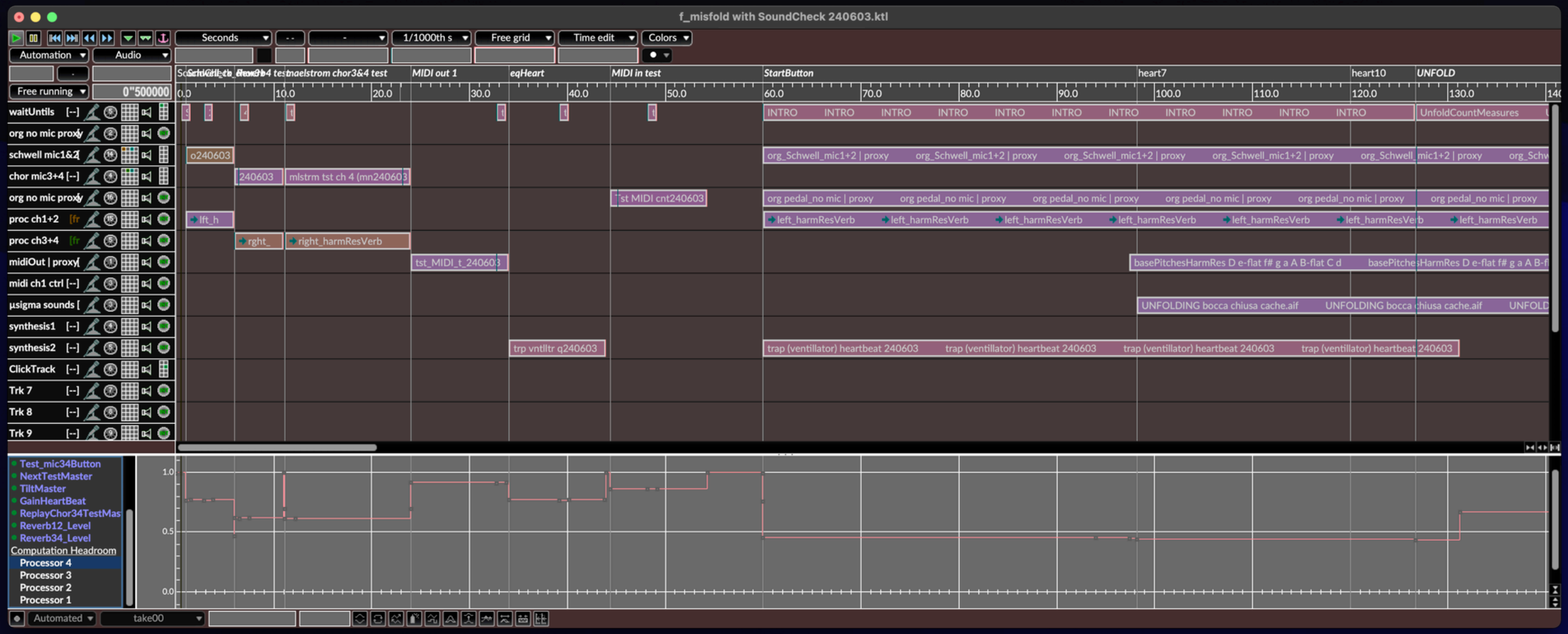
Galleries

Exploring the assembly space algorithmically

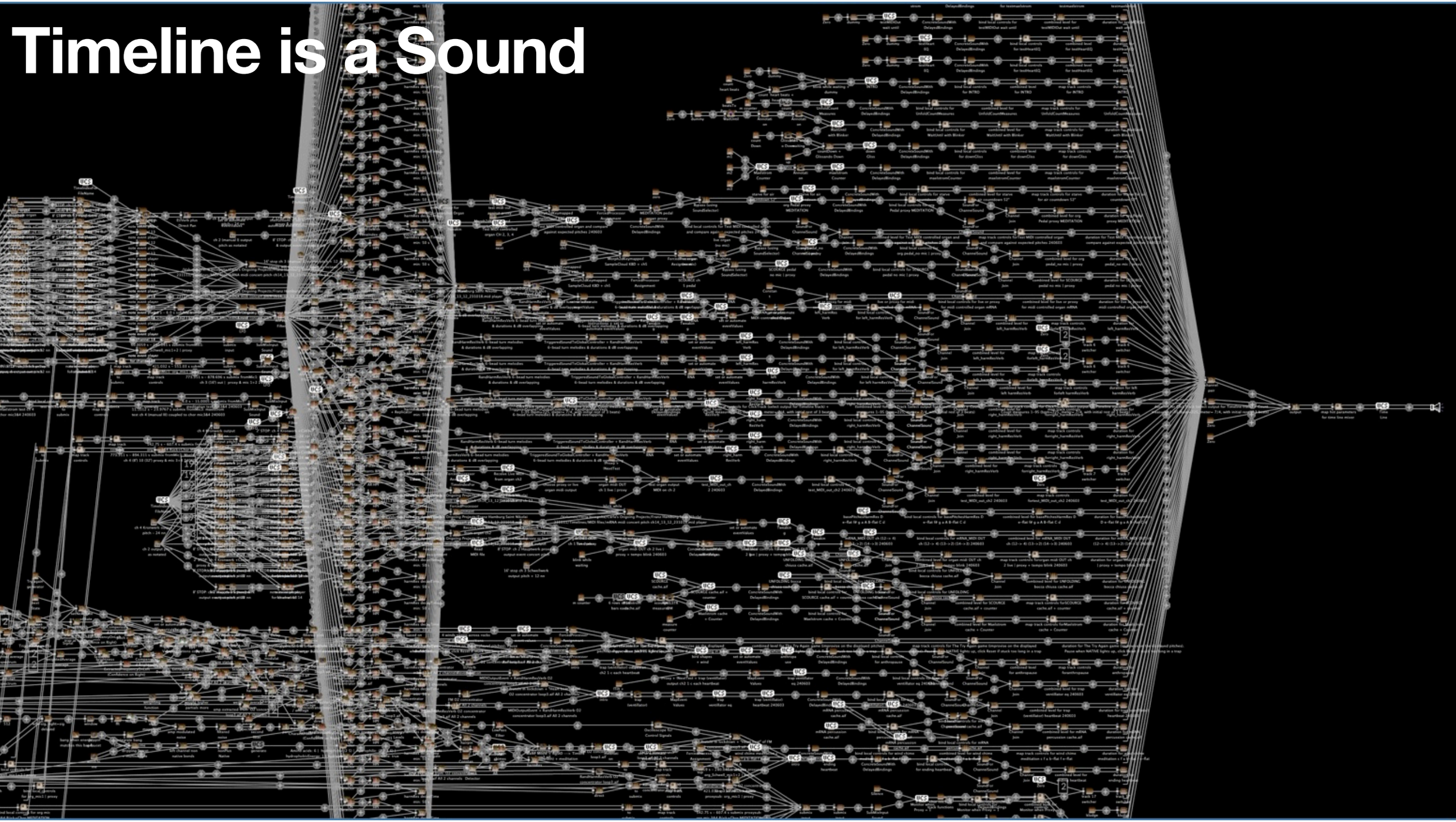


A different interface on the same structure

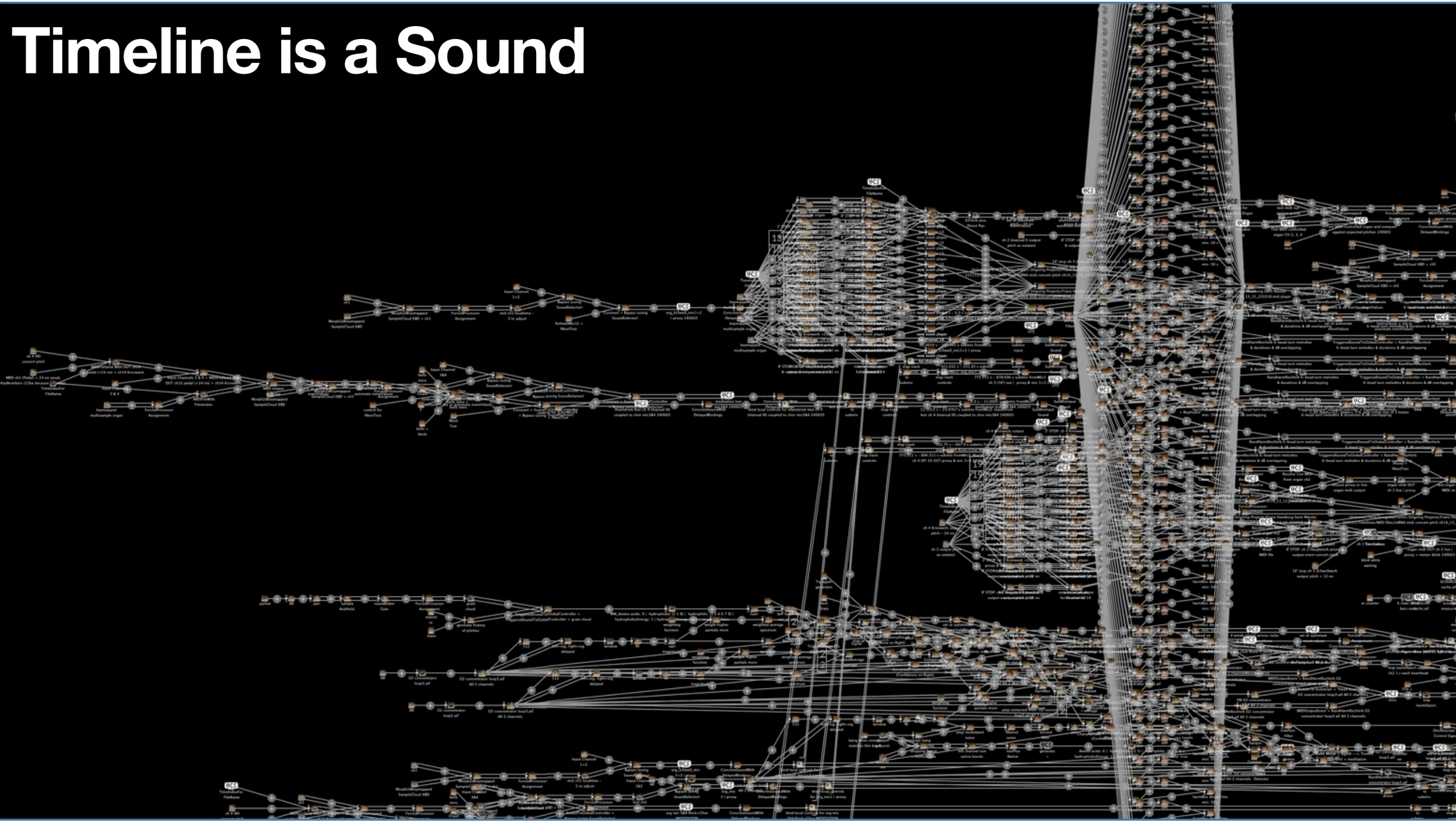
Timeline Preserves start & duration and hides signal flow



Timeline is a Sound



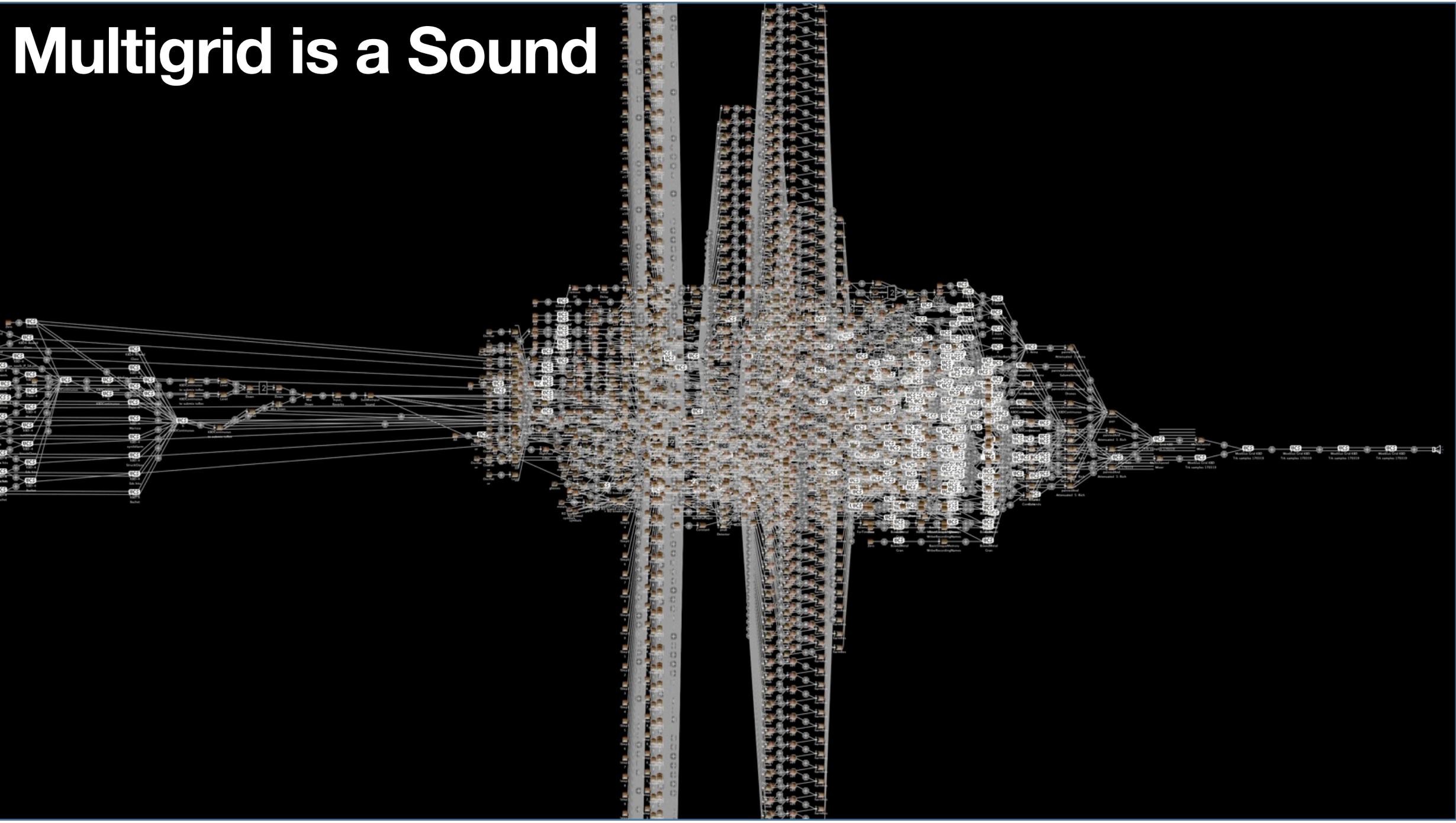
Timeline is a Sound



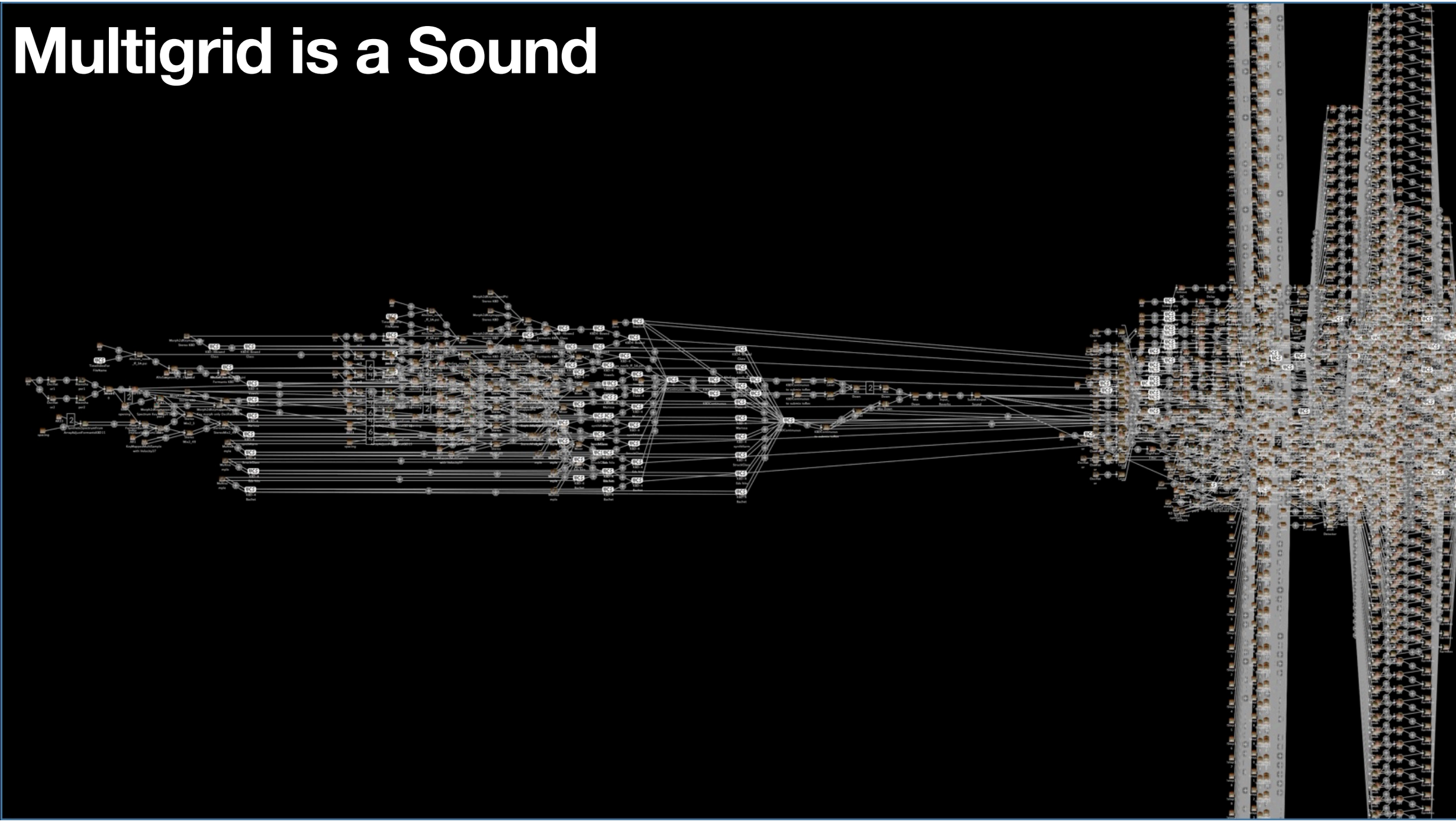
Yet *another* view of the same structure

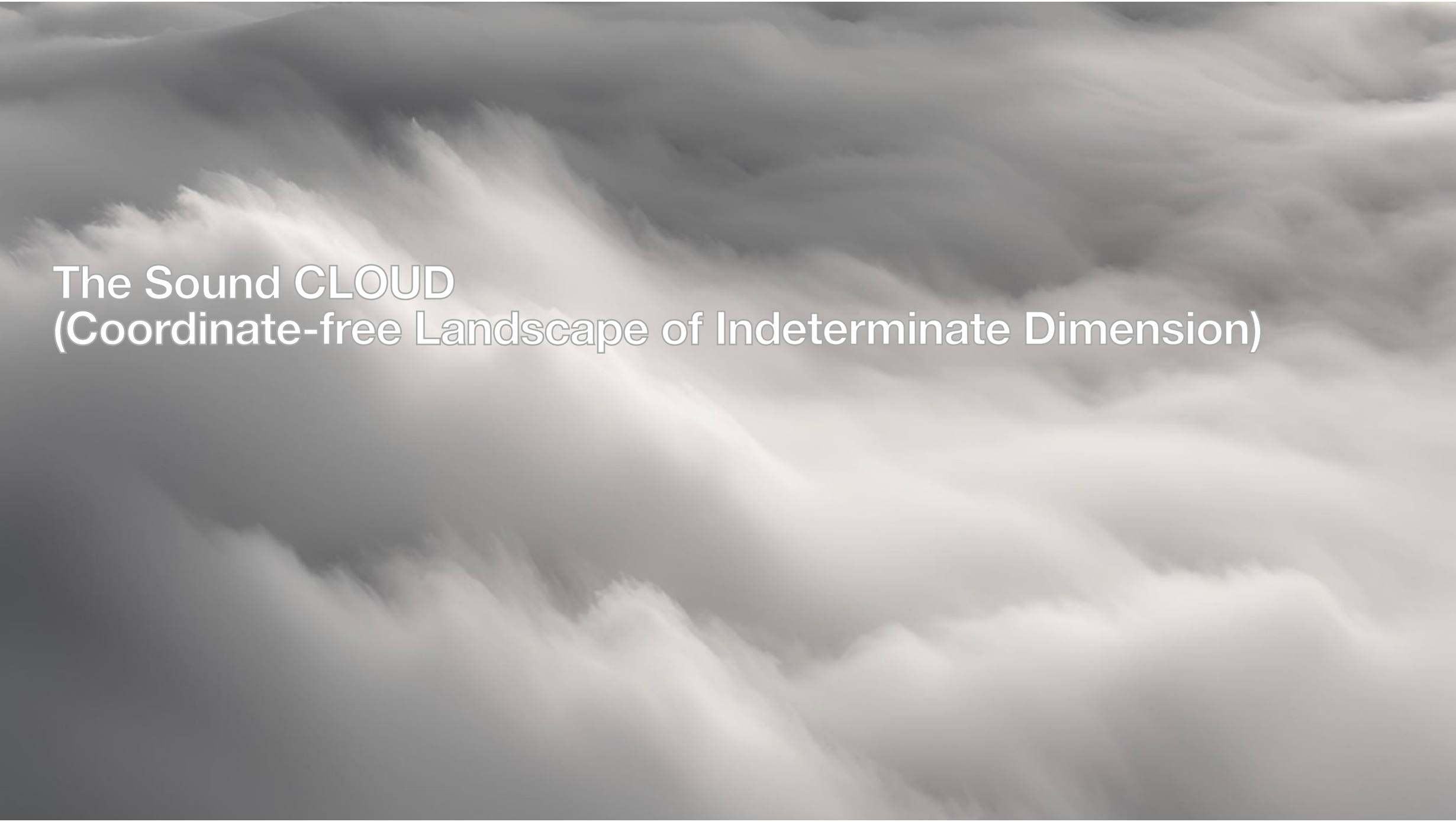
Multigrid shows the active Sounds in each track of a mix

Multigrid is a Sound



Multigrid is a Sound

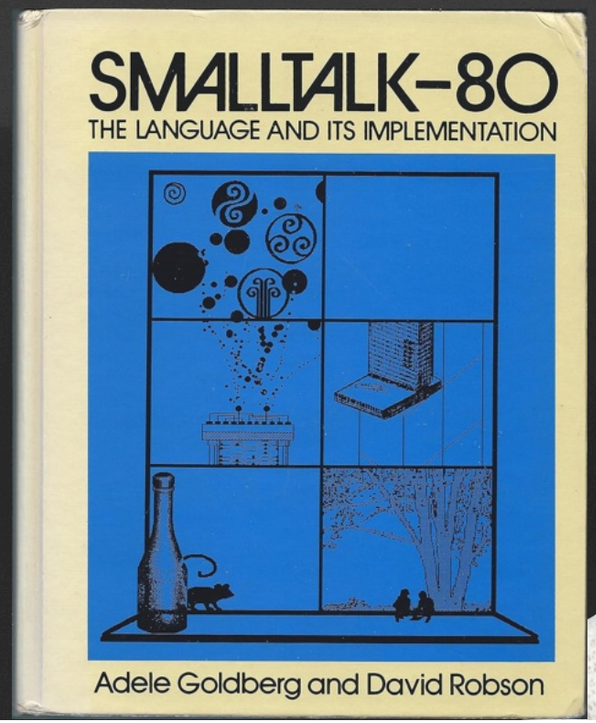



The Sound CLOUD
(Coordinate-free Landscape of Indeterminate Dimension)

Smalltalk programming language

Invites exploration through recursive Construction

- Extensive library of reusable code modules
  - Objects
    - Internal state is hidden
- Live coding
  - Replace any Object with another Object without breaking the rest of the system
  - Extreme late binding of messages
  - Incrementally modify the system while it’s running



Adele Goldberg
Smalltalk co-developer

Python

C

Clojure

C++

A programming language is a map and reflects the worldview of the language designer

Java

Rust

Smalltalk

Haskell

Assembly language

Co-evolution

Hardware & software

People who are really serious about software should make their own hardware

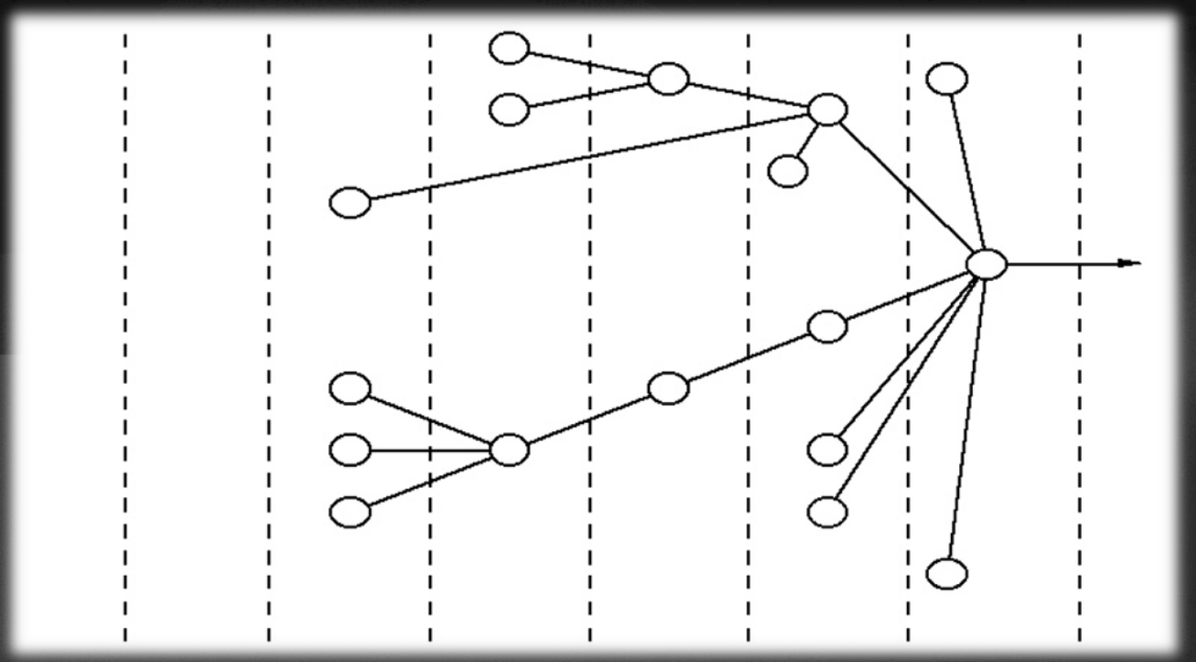
Alan Kay — Turing Award Laureate (2003)
Director of the Smalltalk project at Xerox PARC
Squeak, Disney, Future of Computing

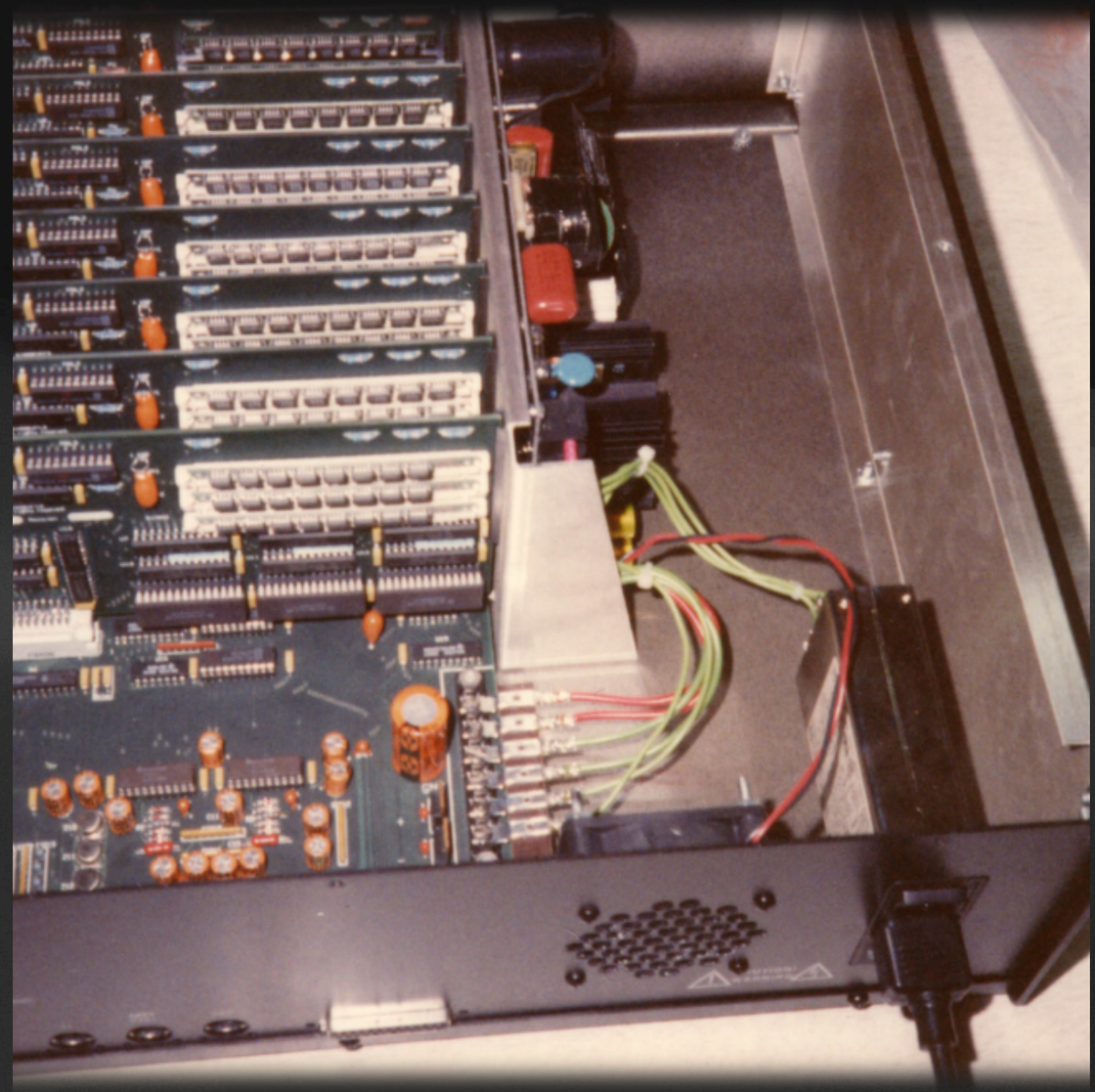
A Platypus evolves into a Capybara

Canva: platypus and capybara in dreamtime

Multiple processors

Distributed Computation





APU migration…

Platypus

Capybara

Capybara 33

Capybara 66

Capybara 320

Pacarana

Paca

Pacamara Ristretto

Canva & Imagen hallucinations…

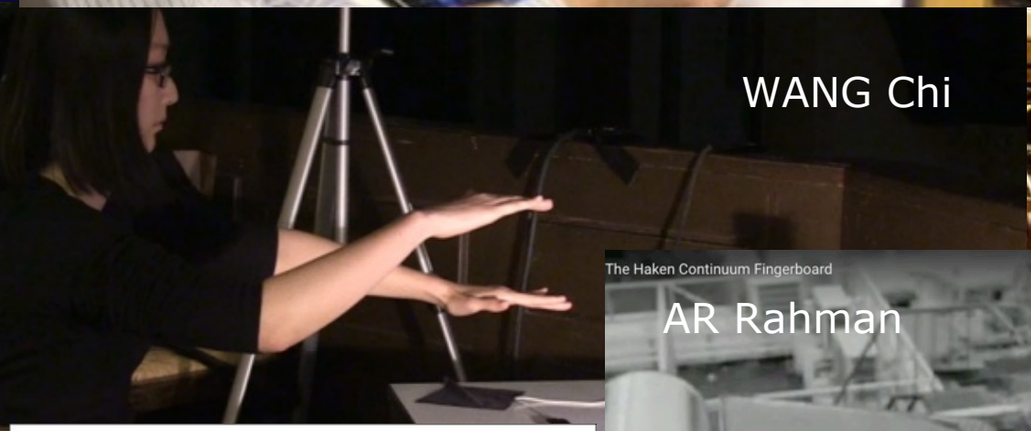
Operating system migration…

The Smalltalk interpreter (virtual machine) is also a Map

Franz Danksagmüller

Jeffrey Stolet

Ben Burtt



WANG Chi

John Paul Jones

Imagen3: person in a cloud

Embrace the cloud

A breakthrough is near…

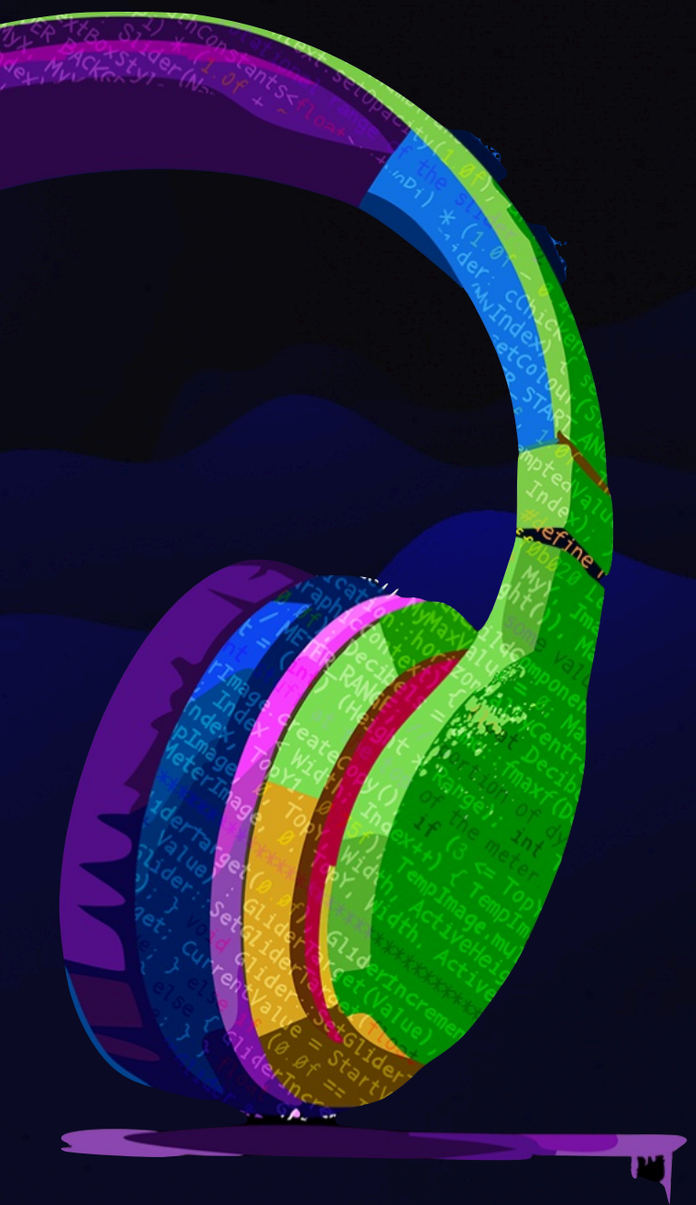
Imagen3: person hugging a cloud

Solidarity

It's best to walk into the unknown together

If you'd like to explore the risky paths needed to get out of the cloud, you need other emotions — solidarity, support, hope —that come with your connection from somebody else…

…in science, it's best to walk into the unknown together.



Yes, and…

Bing: person talking with a globe

An LLM is a map

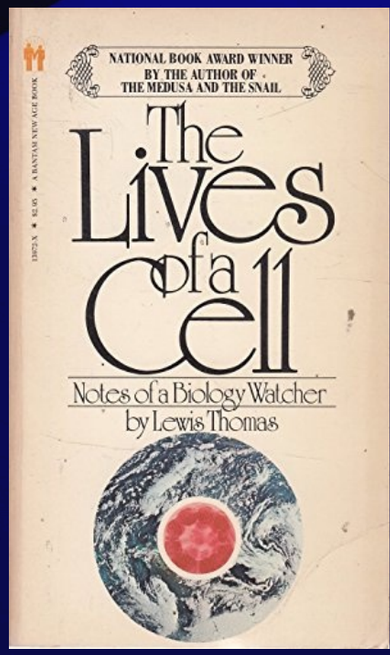
Exploring a high-dimensional semantic vector space

- Breaks them down into constituent parts (words, sub-words, “Tokens”)
- Embeds the tokens as numerical vectors in a high-dimensional semantic vector space
- Recursively recombines sub-assemblies to form complex structures in the semantic space representing the meaning of phrases, sentences, or documents
- At each step, the new structures are added to the pool of available representations, allowing for the construction of increasingly complex semantic structures

Canva: everyone in the world as one mind

“We are becoming a grid, a circuitry around the Earth.

“The great mass of human minds around the earth seems to behave like a coherent living system



Lewis Thomas, The Lives of a Cell (1974)

“Mitigating the risk of extinction from AI should be a global priority alongside other societal-scale risks such as pandemics and nuclear war.”

Geoffrey Hinton
Emeritus Professor of Computer Science, University of Toronto
Demis Hassabis
CEO, Google DeepMind
Sam Altman
CEO, OpenAI
Dawn Song
Professor of Computer Science, UC BerkeleyMedia Lab
Eric Horvitz
Chief Scientific Officer, Microsoft
et al…

https://www.safe.ai/

Public Domain: iconic photo of President Franklin D. Roosevelt

The map is not the territory

Language, alone, is not enough

Imagen3: the map is not the territory

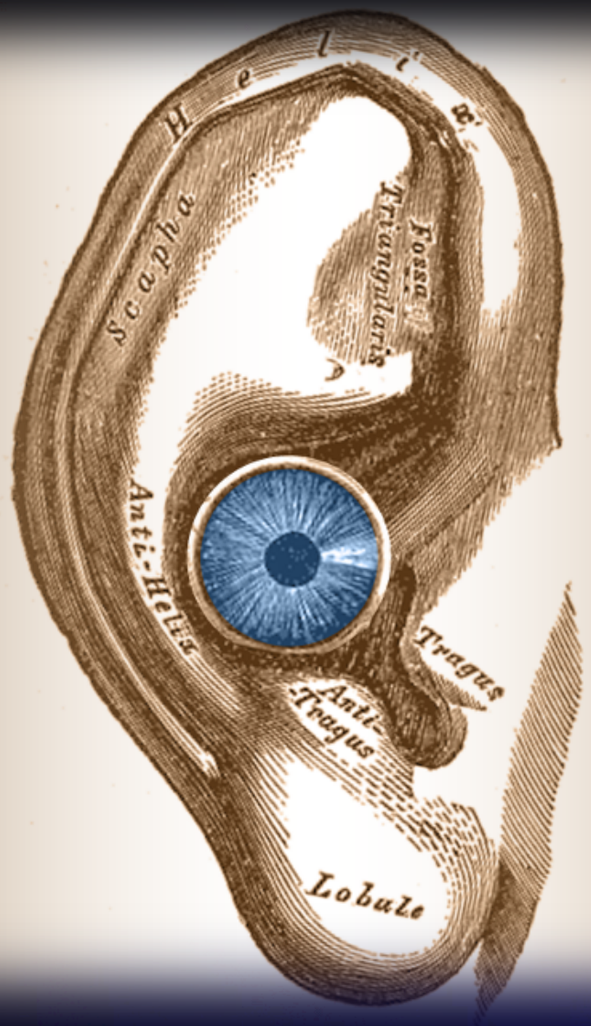
Spatial intelligence

aka navigation ➡ maps

"…visual spatial intelligence is so fundamental, it's as fundamental as language, possibly more ancient and more fundamental in certain ways…" — Fei-Fei Li

- World Labs
  - Large World Models (LWMs) trained on 3d Visual Spatial data

The a16z Podcast, Sep 20, 2024
https://www.youtube.com/watch?v=vIXfYFB7aBI


Helix
Scapha
Fossa Triangularis
Anti-Helix
Tragus
Anti-Tragus
Lobule

Why are we driven to do this work?

Real-time audio computation is challenging

Sonic cartographers

Sound and music are profoundly meaningful

- You face the cloud
- You imagine maps of that infinite space
- You turn that map into symbols
- You map those symbols to reality

Imagen 3: Map with ears

Yes, and…