HeedVision

Attention Awareness in Collaborative Immersive Analytics Environments

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Follow along & ask questions

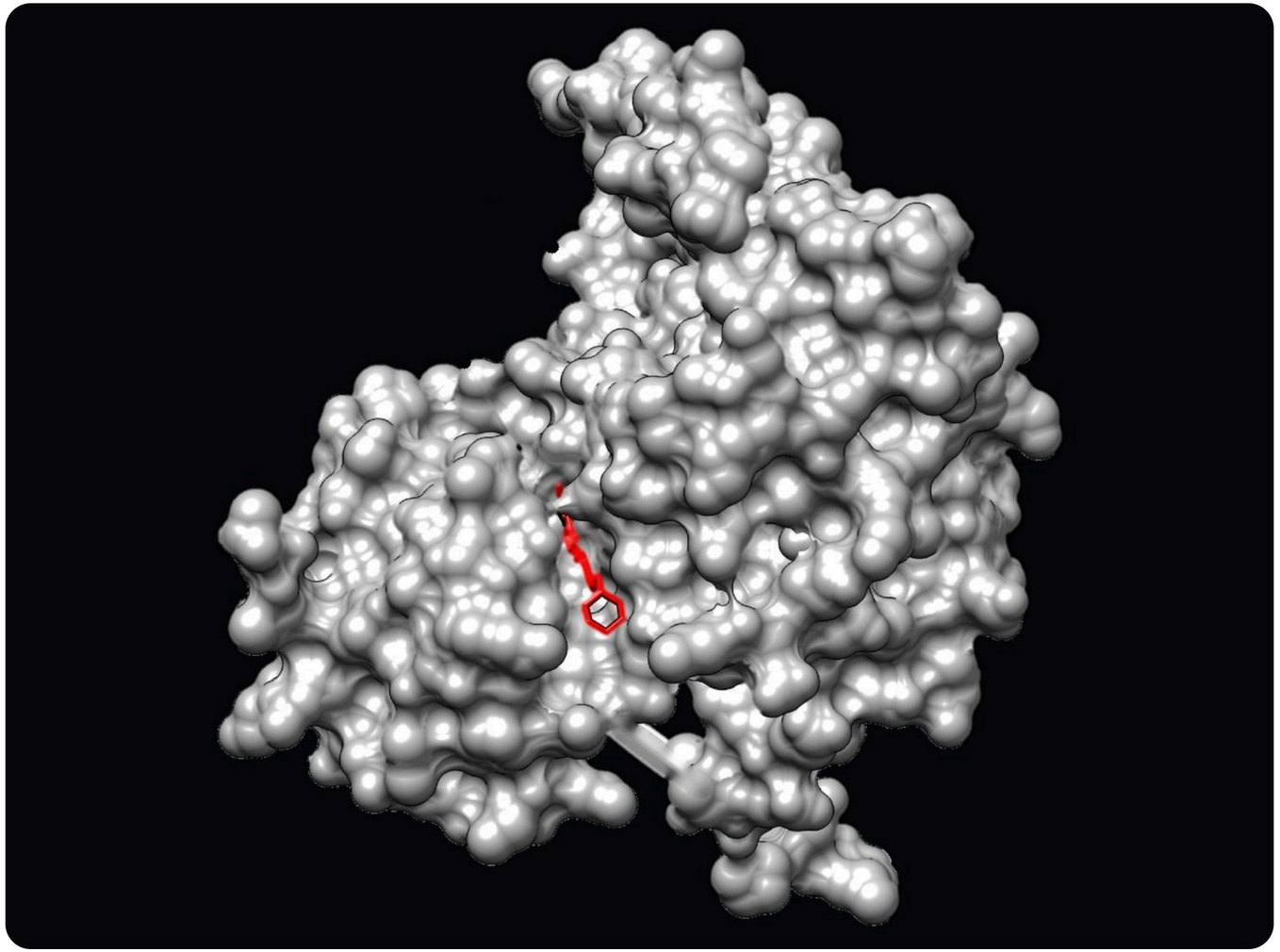
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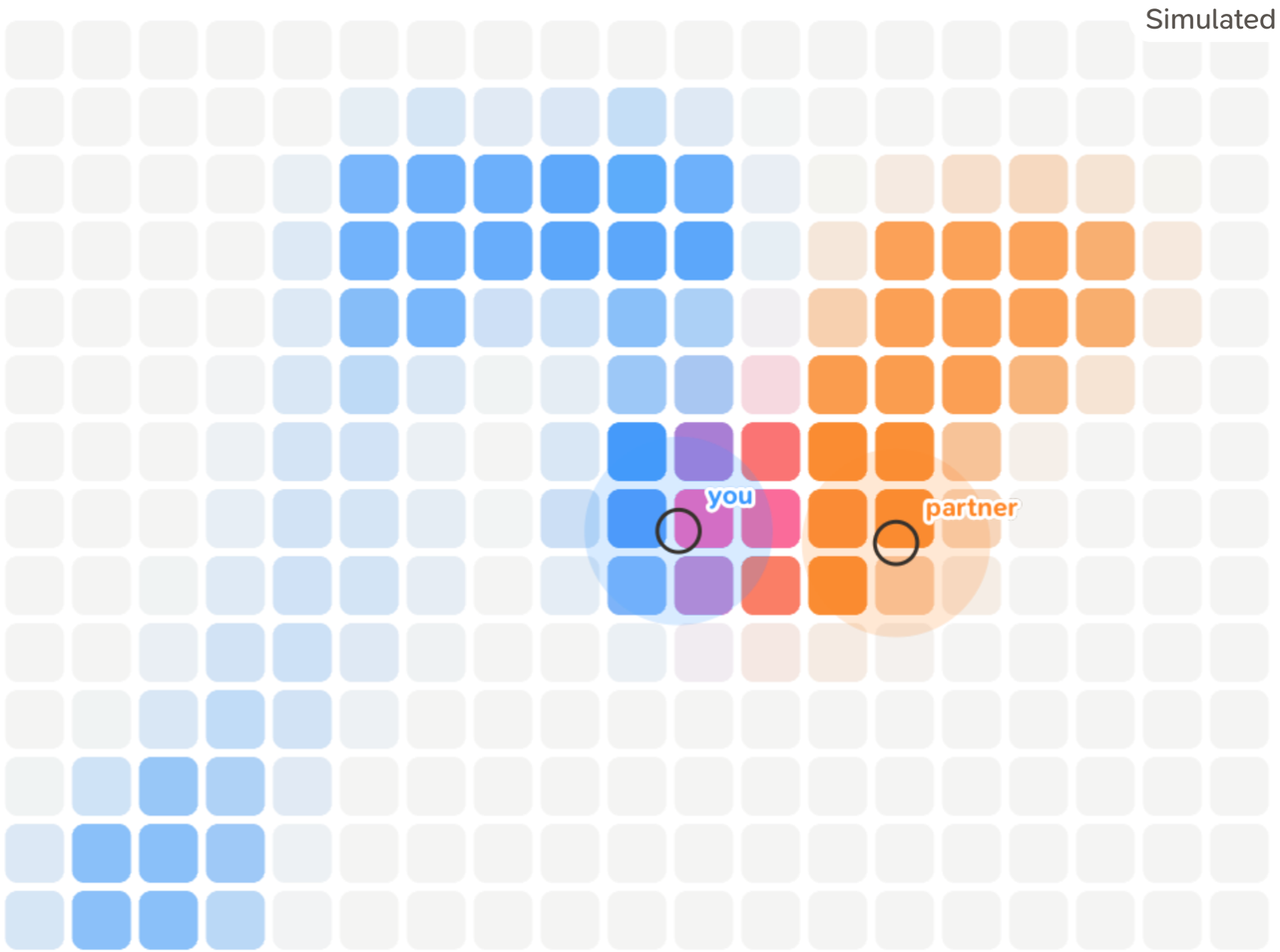
Searching a 3D space together

- **Few reference points.** One bump looks much like the next.
- **Hard to describe.** Positions are difficult to put into words.
- **Too much for one person.** So you bring in a colleague.



Example: O'Connor et al., multi-user VR for molecular dynamics, Science Advances 2018. Image: Human CHK2 in complex with benzimidazole carboxamide inhibitor, BaptisteGrandGrand, Wikimedia Commons, CC BY-SA 4.0. Adapted: labels removed, background changed; adaptation CC BY-SA 4.0.

Who looked where?



- **Group awareness.** The ability to perceive the activities of collaborators in a shared space.
- **Harder in immersive 3D.** Multiple viewpoints, distributed spatial attention, real-time coordination.
- **What if the space remembered?**

Gutwin and Greenberg call this workspace awareness: an up-to-the-moment understanding of others' interaction with a shared workspace (CSCW 1998, CHI 1998).

1

Idea

From one viewer to many

Collaborative attention-aware visualization



Capture

Distinguish between users while tracking attention simultaneously.

RQ1

How should the attention of multiple viewers on a visualization be captured in real time?



Record

Identity-aware accumulators, with sum, maximum, difference and count.

RQ2

How should the attention of multiple viewers on a visualization be recorded over time?



Revisualize

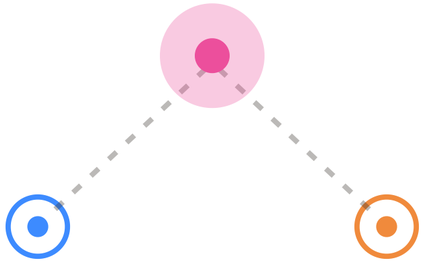
Encode both attention intensity and user identity.

RQ3

How should the attention of multiple viewers on a visualization be displayed?

Kinds of collective attention

Joint



Both look at the same thing.

Distributed



They split up the space.

Sequential



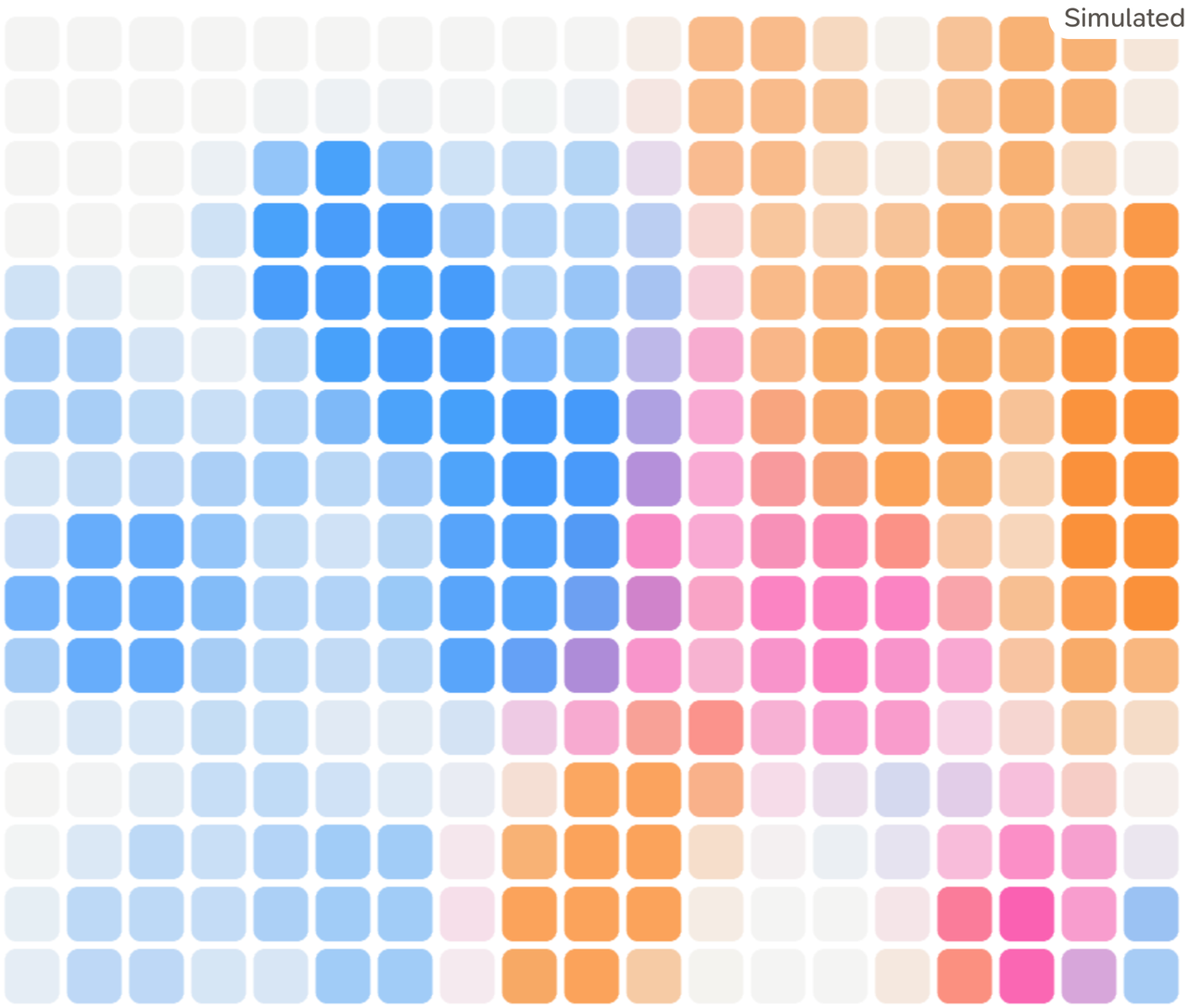
One builds on where the other looked.

Cumulative



Everything the team has covered.

Recording collective attention



- **Count.** Number of analysts who attended.
- **Sum.** Total collective attention.
- **Maximum.** Highest individual attention.
- **Difference.** Balance of attention between members.
- **Per user.** Blue you, orange partner, pink both.

Display: a design space

Embedded in the vis

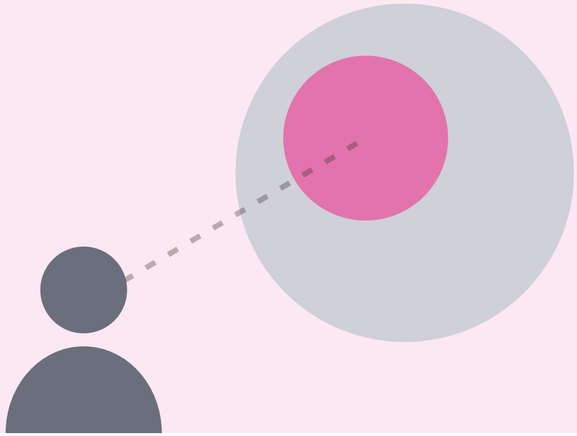
Separate view

Triggering

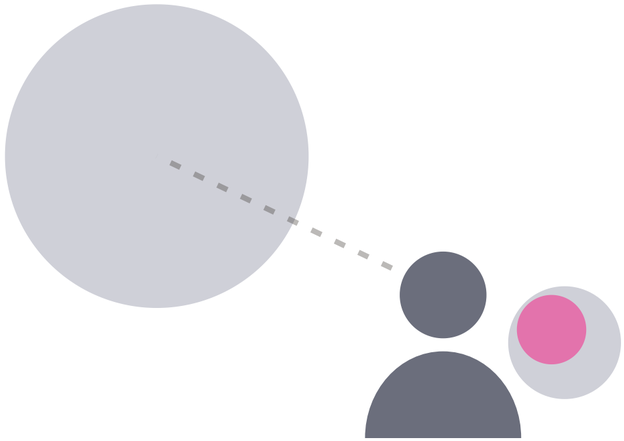
World space

World · embedded

HeedVision

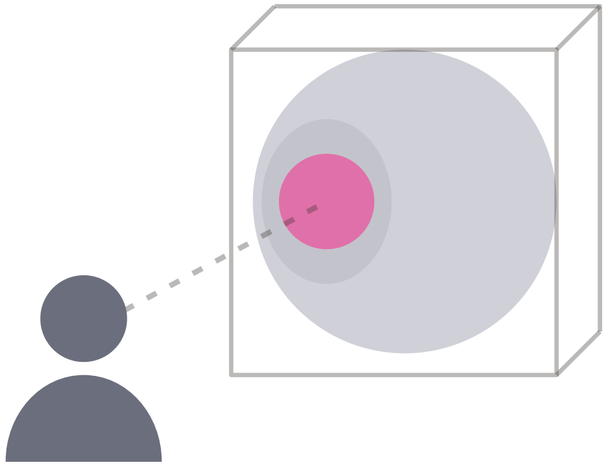


World · separated

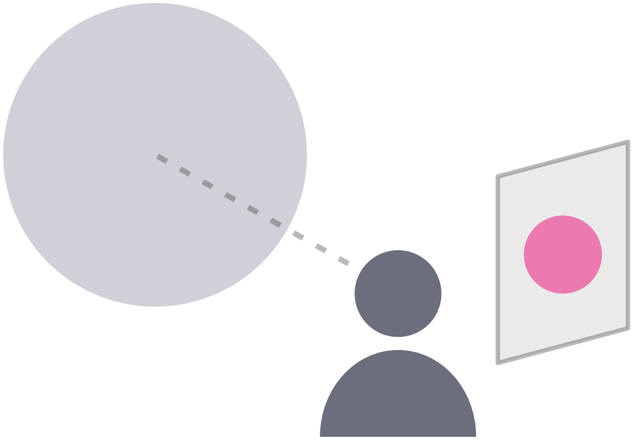


Camera space

Camera · embedded



Camera · separated



Always on

risks Midas touch

Explicit

you ask to see it

Implicit

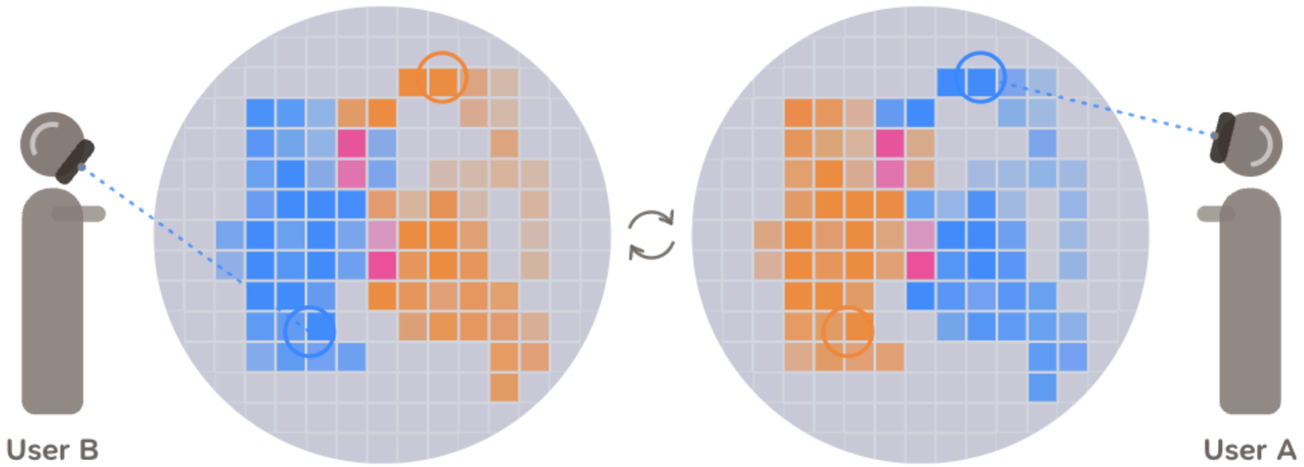
the system decides

2

System

One corner built and evaluated

HeedVision: colour per user

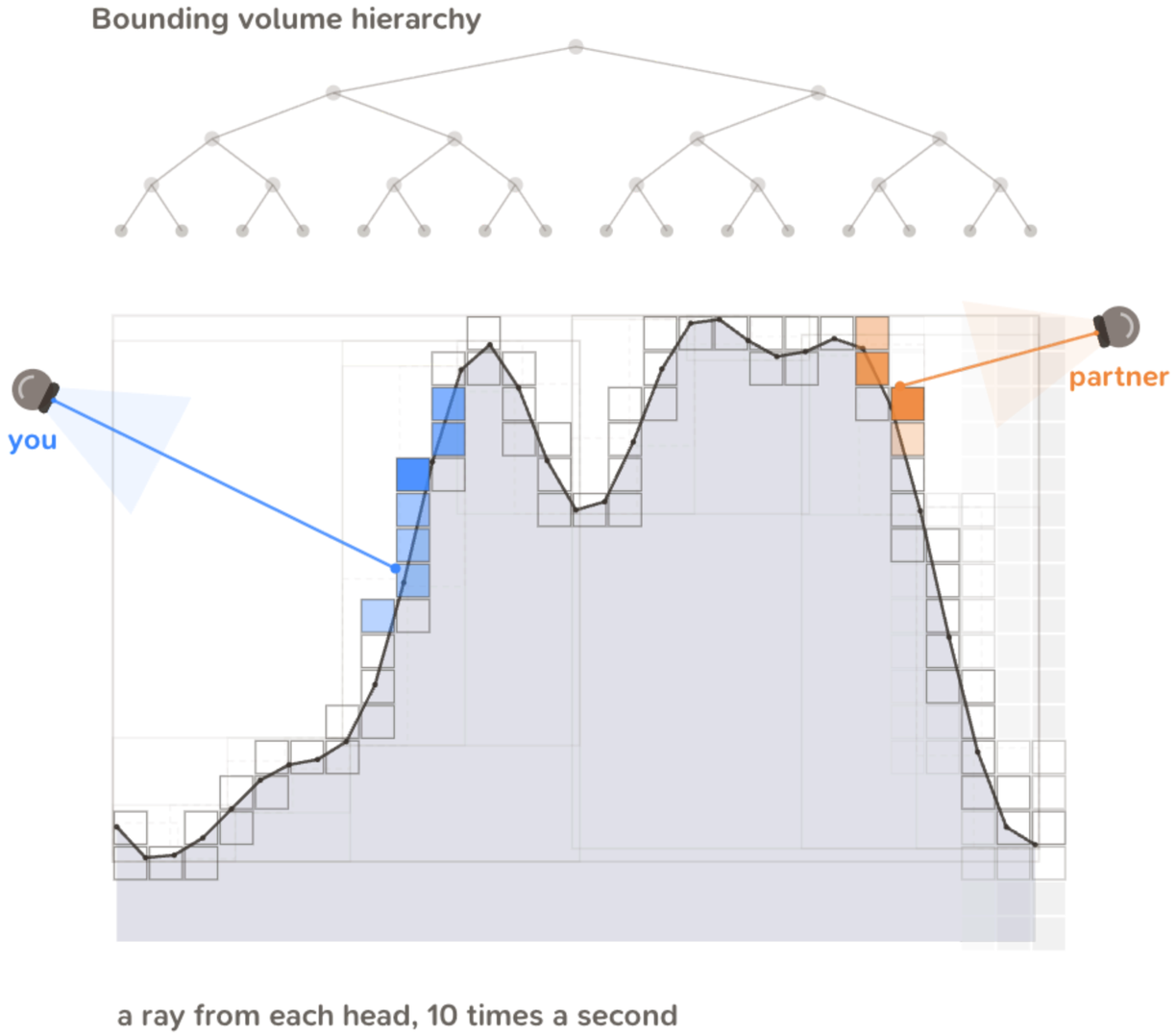


Each headset shows a copy of one shared scene

Trail shown

- **WebXR.** React Three Fiber, on headsets like the Meta Quest 3.
- **Explicit.** Point at a chart and press a controller button to show or hide attention.
- **Per headset.** Blue is you, orange your partner, pink both.
- **Opacity and decay.** More attention, more opaque. It fades when you look away.

Voxels collect the attention



- **Wrap the chart.** A bounding volume hierarchy around its geometry.
- **Keep voxels that touch it.** Boxes rule out empty cells.
- **A ray from each head, at 10 Hz.** It hits the nearest voxel, which gains that person's attention.

Display: a design space

Embedded in the vis

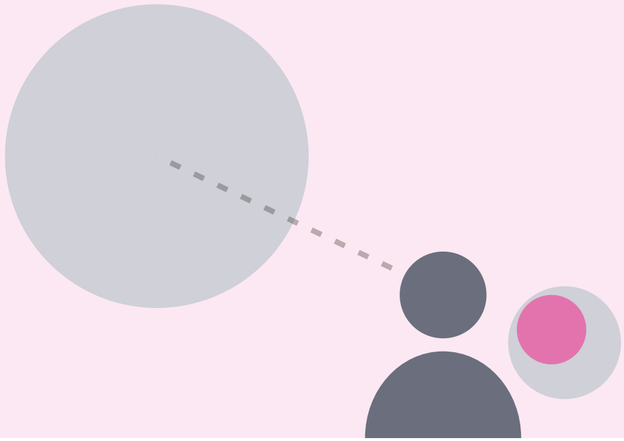
Separate view

Triggering

World space

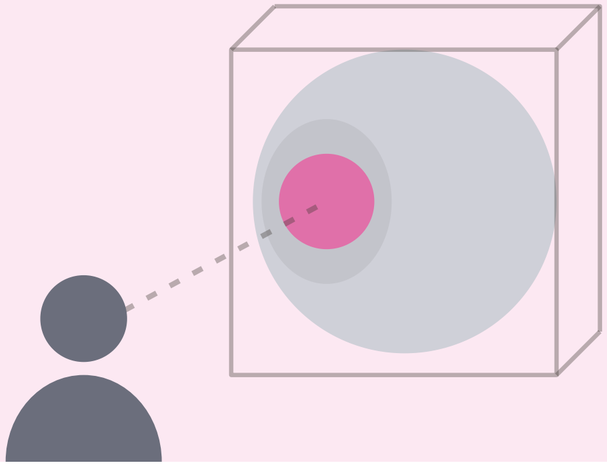
World · embedded

World · separated Prototype

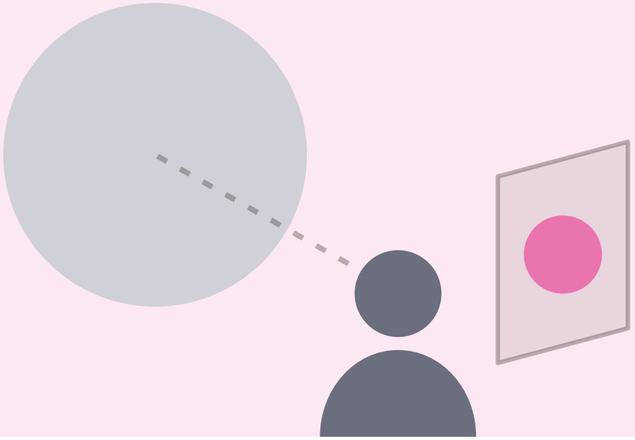


Camera space

Camera · embedded Prototype



Camera · separated Prototype



Always on

risks Midas touch

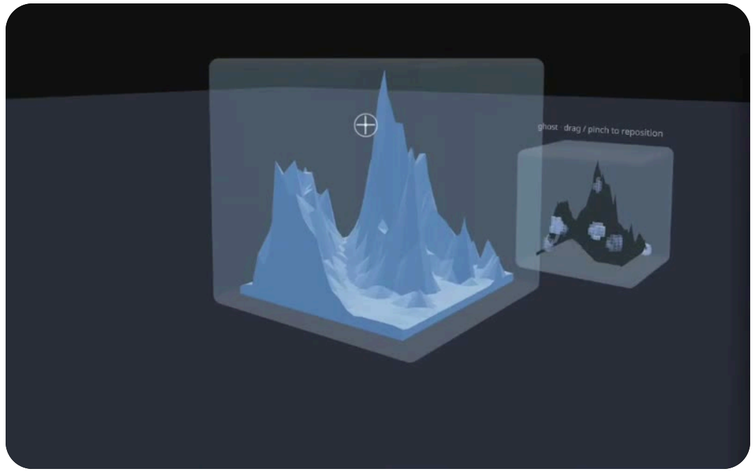
Explicit

you ask to see it

Implicit

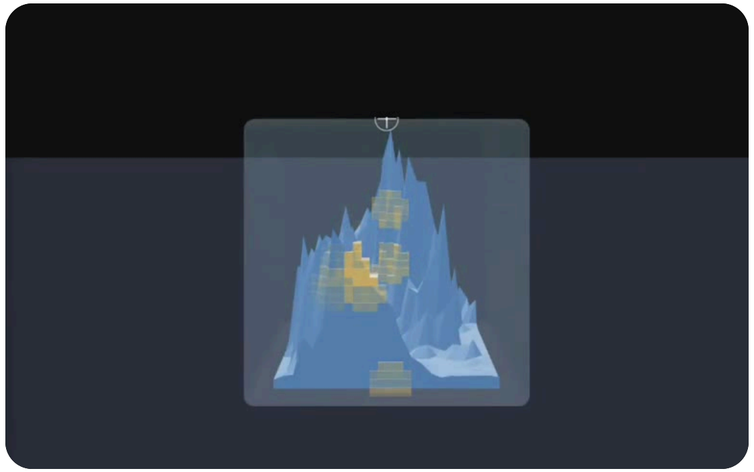
the system decides

The other three quadrants



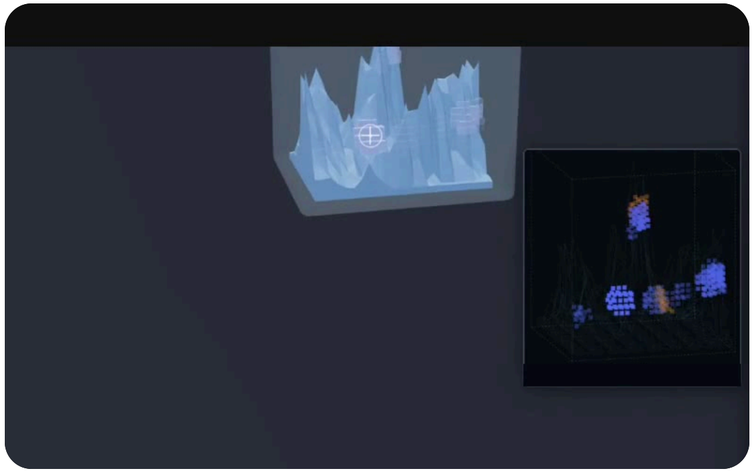
World, separated

A movable miniature



Camera, embedded

Attention on the bounding box



Camera, separated

A 2D panel beside the data

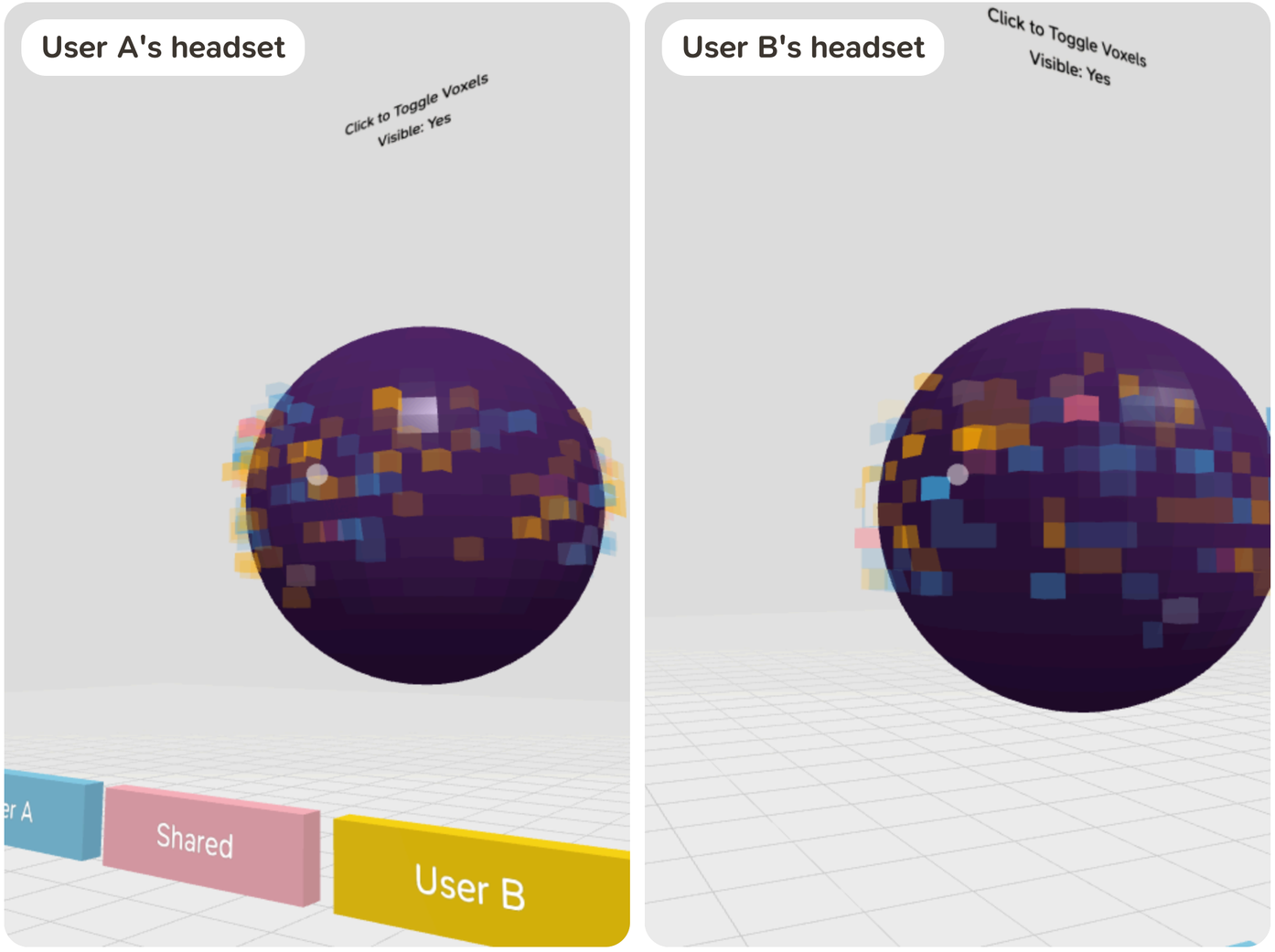
Proofs of concept: VR only, synchronized locally between browser tabs. Not formally evaluated.

3

Study

Does it help?

A treasure hunt, in the real system

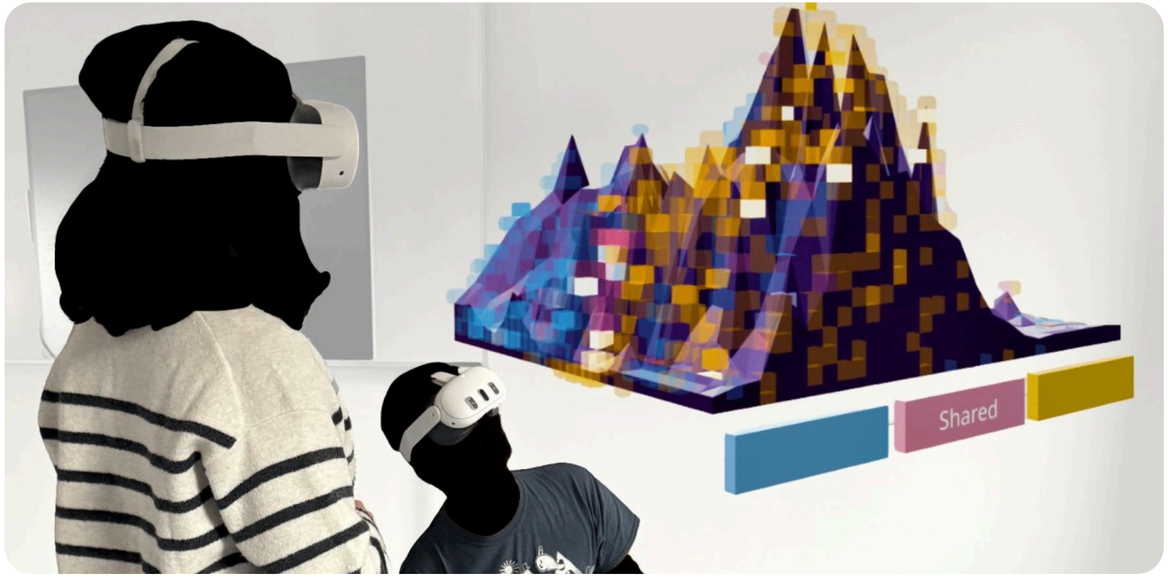


Live demo Drag a view to move that person · click the sphere to hide or show their voxels

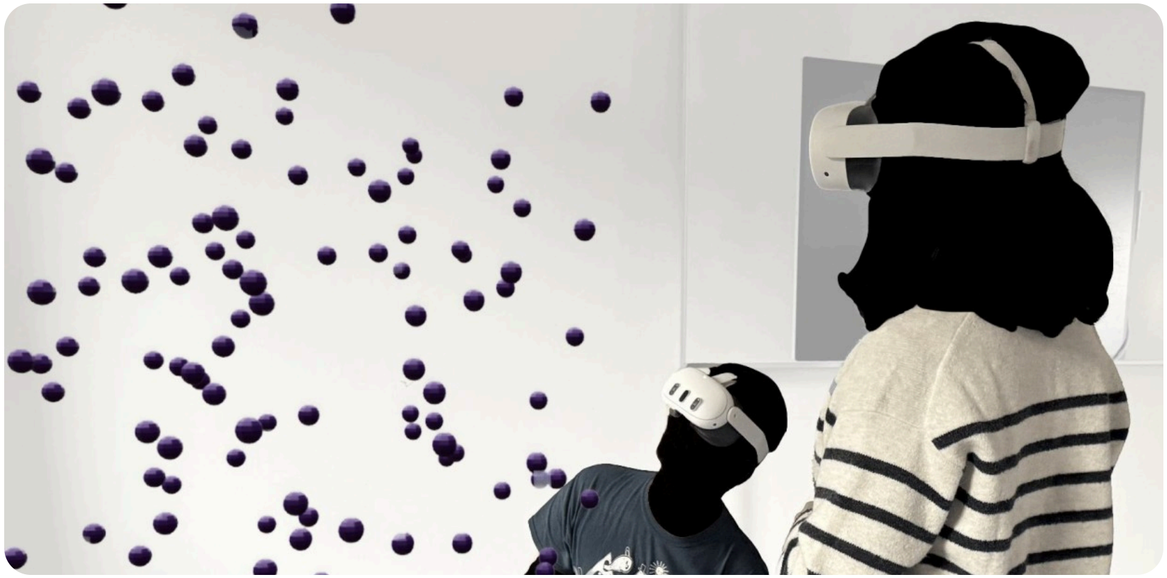
Reset

- **8 co-located pairs.** 16 participants, shared AR on Meta Quest 3, 10-minute sessions.
- **Targets.** 5% of voxels.
- **Visible up close.** From the correct angle, within 10 cm.
- **With CAAV.** Voxels show where each person has looked.

Two visualizations, with and without CAAV



Terrain × CAAV



Scatter × No-CAAV

- **2 × 2 design.** Visualization × CAAV.
- **4 pairs per condition.** Counterbalanced.
- **Analysis.** Bootstrap 95% CIs, Hedges' *g*.

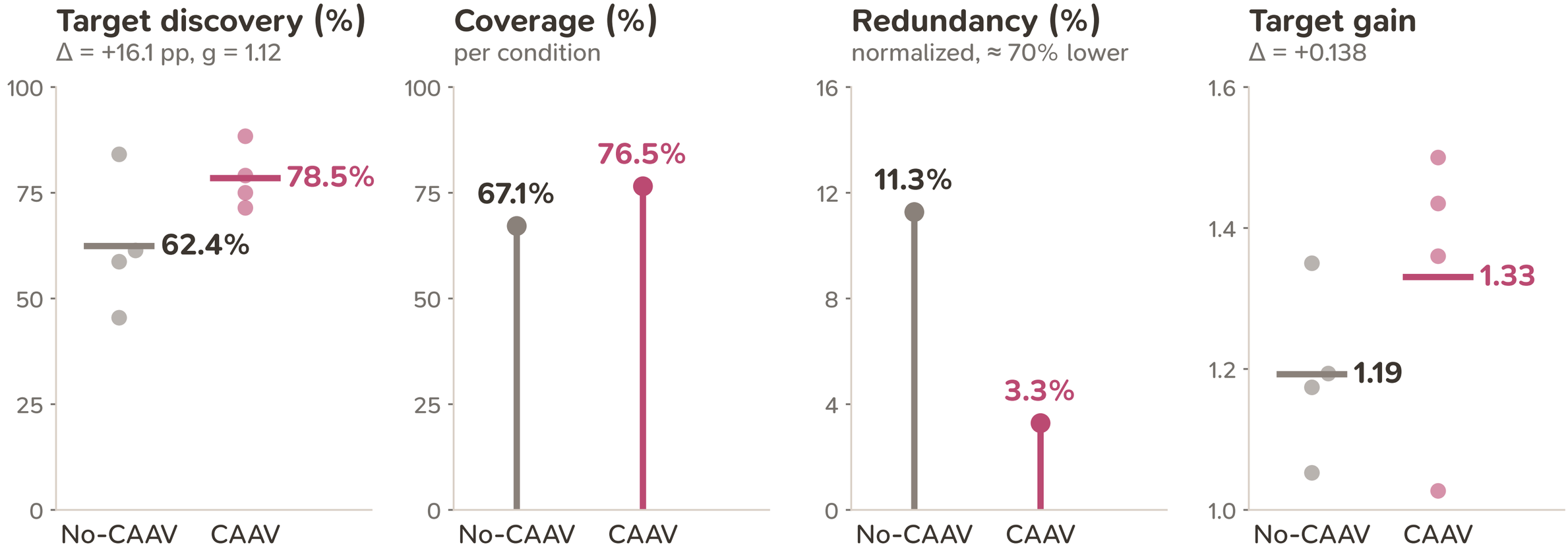
- **Discovery, coverage.** % targets, % space.
- **Coverage efficiency.** Discovery ÷ coverage.
- **Redundancy.** Normalized Shannon entropy.
- **Target gain.** Pair ÷ mean individual.

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Results

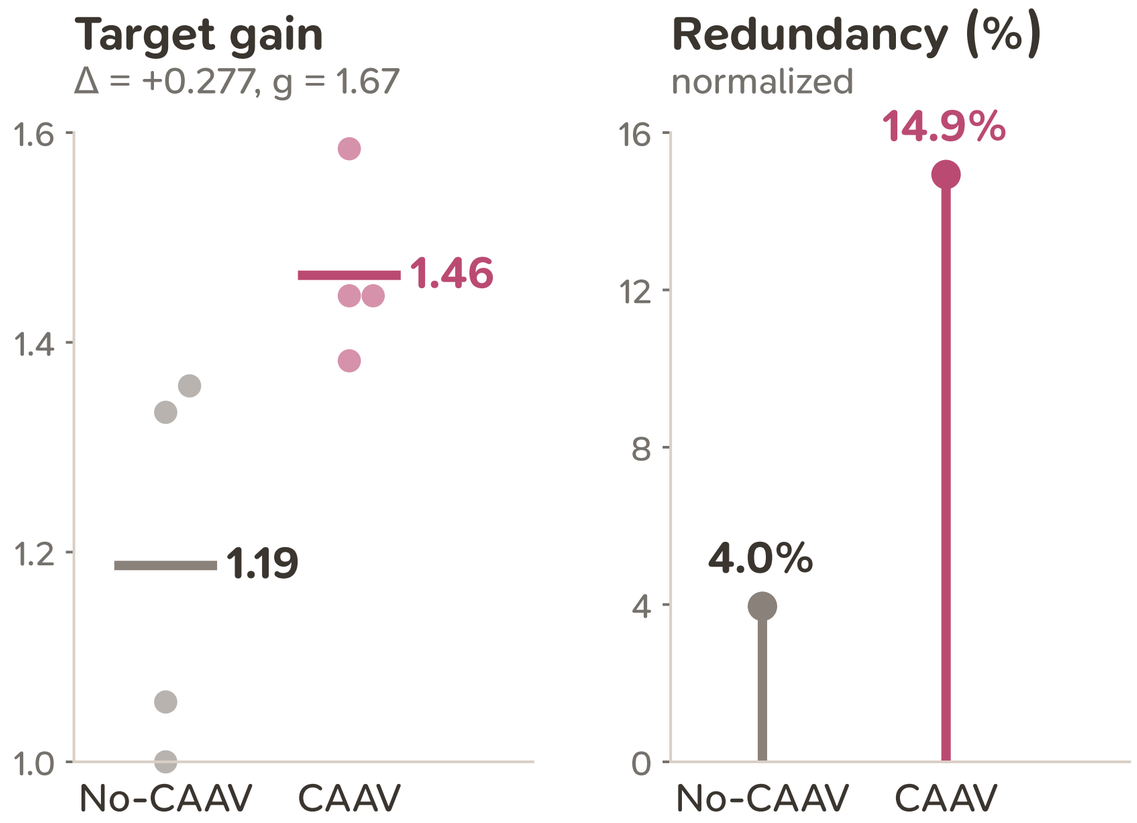
It depends on the space

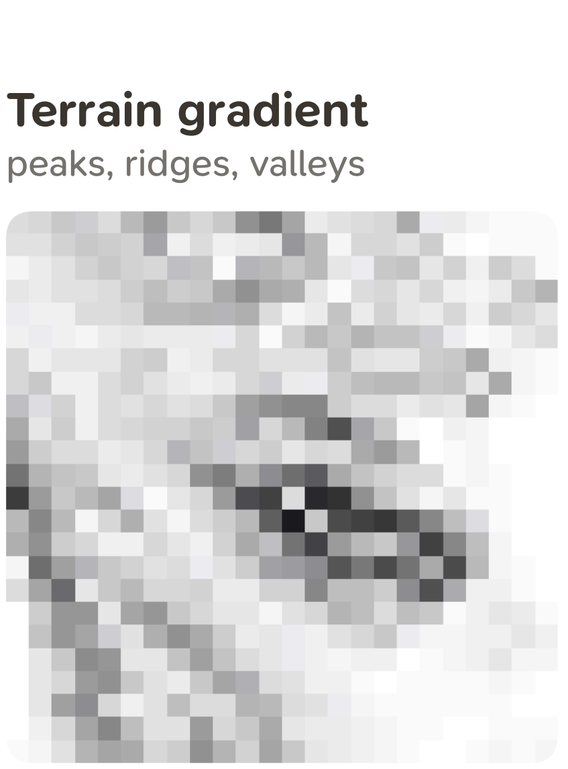
Scatterplot: directional benefits

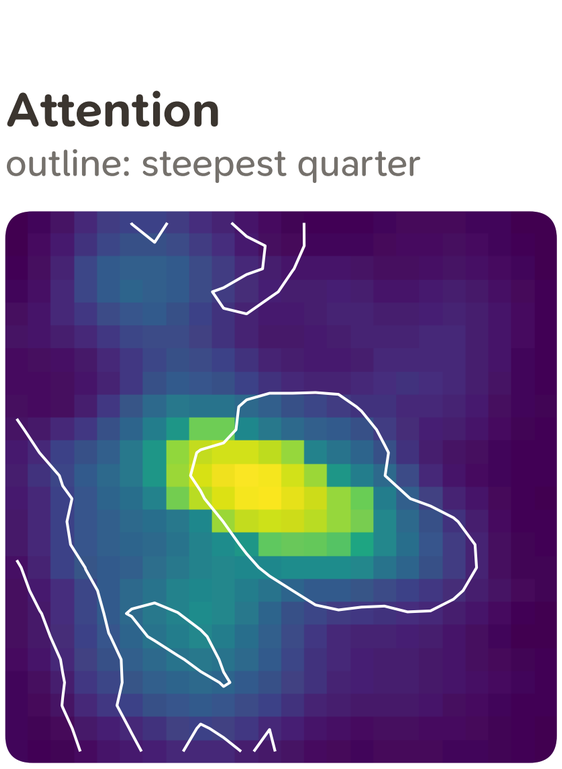


Dots: pairs. Bars: means. Targets Δ = +16.1 pp, BCa 95% CI [−0.012, +0.293], g = 1.12. Redundancy BCa CI [−0.172, −0.002], exact p = 0.257: directional. Coverage efficiency 1.027 vs. 0.920. Redrawn from Figs. 7, 8 and the text.

Terrain: largest gain, more redundancy







Target gain Δ = +0.277, BCa 95% CI [0.112, 0.450], g = 1.67, p = 0.029. Targets 26.0% vs. 19.6%, coverage 24.6% vs. 18.8%: CIs span zero. Gradient and attention: Pearson r = 0.490, Spearman ρ = 0.561, both $p < 0.0001$. Redrawn from Figs. 8, 9 and the text.

Six strategies

Spatial division

We cut the space into top and bottom, and one search for top another search for the bottom.

P3

Systematic search

I took one half and systematically searched through it.

P12

Visual feedback

Used the voxel system to avoid redundant searches.

P14

Verbal coordination

We tried to coordinate verbally by describing positions relative to the Scatter structure.

P13

Landmark navigation

We used landmarks and described roughly in which area we found the targets.

P10

Physical synchronization

We placed the Scatter in the same location in the room using the yellow triangle.

P6

Top row, in pink: the coordination patterns that came with CAAV conditions.

By condition, and a clear preference

Strategy	Scatter No-CAAV	Scatter CAAV	Terrain No-CAAV	Terrain CAAV
Spatial division	2	4	3	2
Landmark navigation	2	0	3	5
Systematic search	0	4	1	2
Verbal coordination	3	0	1	1
Visual feedback	0	2	0	5
Physical synchronization	2	0	0	0

we have no verbal communication during the condition where we have [CAAV]

P8

93.8%

preferred CAAV conditions

81.3% strongly agreed it improved collaboration.

75.2%

of the session with attention shown

All participants used the toggle.

24%

lower overall workload

NASA TLX, 2.79 vs. 3.69 of 7.
On terrain, directionally higher.

74.38

mean SUS

SD 19.79. Benchmark 68.

Participant counts per strategy, by pair. Participants may appear under more than one strategy.

Limitations and future work

Limitations

- **Scale.** Voxels get expensive at high resolutions or with many users.
- **Proxy.** Head orientation is coarser than eye tracking.
- **Scope.** Synchronous, co-located pairs, in visual search.
- **Baseline.** Only no attention visualization.
- **Awareness.** Measured through proxies, not directly.

Future work

- **Tasks and teams.** Diverse tasks, larger teams, selective sharing.
- **Baselines.** Shared gaze rays, pointer trails, manual markers, minimaps.
- **Prototypes.** The other three quadrants, in networked AR.
- **Semantic attention.** Recording at the level of data elements.
- **Settings.** Remote and asynchronous collaboration.

Takeaways

- **CAAV effectiveness depends critically on visualization context.** Initial evidence, in visual search.
- **Scatterplots.** Reduced redundant exploration, and emergent coordination strategies.
- **Terrain.** A large coordination gain, even as attention visualization sometimes interfered with natural coordination cues.

Thank you for your attention



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One more thing: the code is open source

- **caav.** A small library for adding these techniques to your own three.js and WebXR scenes.
- **Try it.** heedvision.arvindchee.nu/toolkit
- **Source.** github.com/arvindcheenu/caav, MIT License.

