Interstellar: The Tesseract and the Bulk

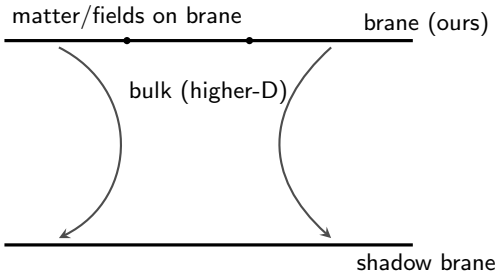
Honors Seminar, Dr. R. L. Herman

Based on Kip Thorne's *The Science of Interstellar*

November 13, 2025

From 4D Spacetime to a Higher-D Bulk

- **Bulk:**
  A higher-dimensional arena where our 4D universe (*brane*) is embedded.
- **Brane-world idea:**
  - Matter/fields live on the brane;
  - Gravity can propagate into the bulk.
- **Motivation (Interstellar):**
  - Speculation guided by GR;
  - Enables wormholes, gravity anomalies.



The Bulk

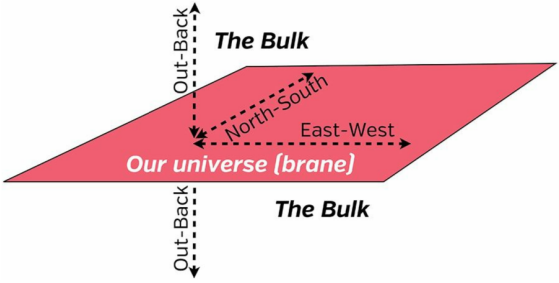


Figure: Our Universe in The Bulk - Fig 21.3, p. 188.

AdS Warping - Randall-Sundrum Theory

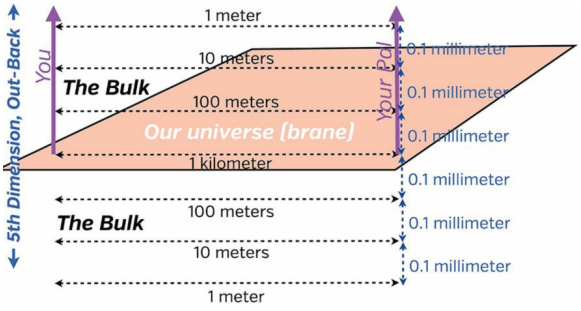


Figure: AdS warping of the bulk - Fig 23.5, p. 197.

AdS Sandwich

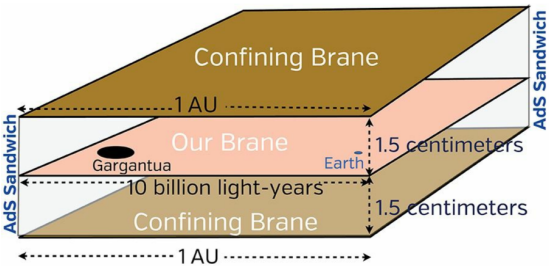


Figure: AdS sandwich - Fig 23.7, p. 199.

Dr. Brand's Blackboard with AdS Sandwich

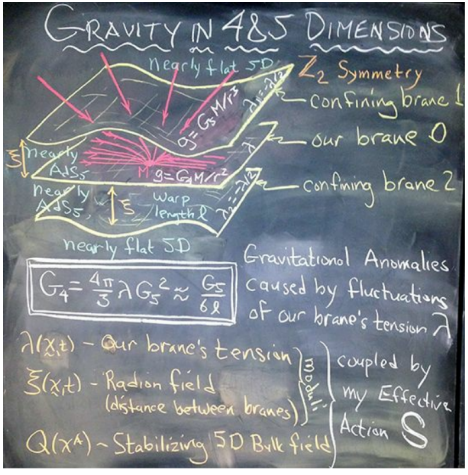


Figure: This blackboard features: AdS sandwich, gravitational field lines, and anomalies.

Dr. Brand's Equation, Fig 25.7, p. 220.

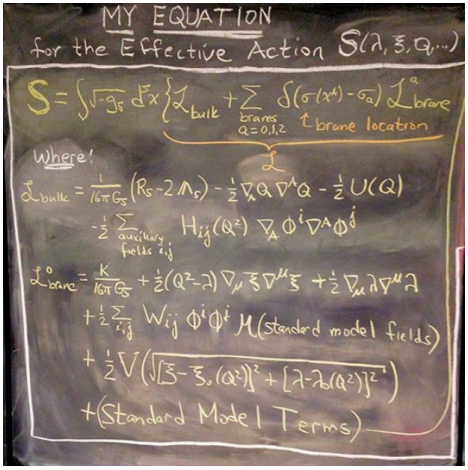
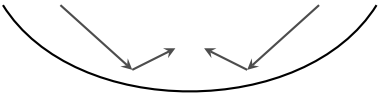


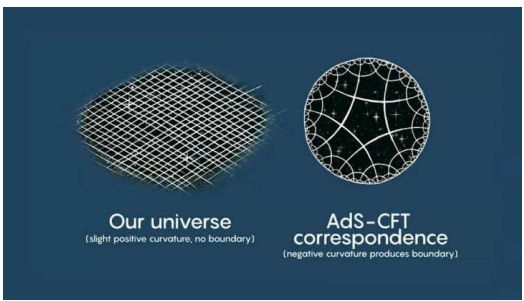
Figure: This combines known physics (Standard Model) with the bulk physics. Then, the system moves along the **path of least action**. [i.e.; it takes the "most efficient" trajectory out of all conceivable paths between the initial and final configurations.

Anti-de Sitter Geometry (Cartoon Cross-Section)

- **de Sitter (dS):**
  Positive curvature, expanding (closer to our observed cosmos).
- **Anti-de Sitter (AdS):**
  Negative curvature; geodesics and light rays "bend back" (reflective boundary).
- **AdS** is a mathematically convenient playground for dualities and holography.



AdS "bowl" (neg. curvature)

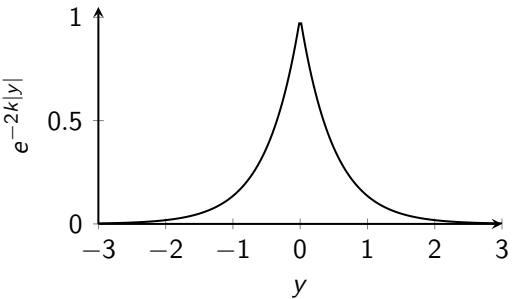


Randall–Sundrum Warped Geometry (skip for now)

Metric ansatz (schematic):

$$\boxed{\mathrm{d}s^2 \;=\; e^{-2k|y|}\,\eta_{\mu\nu}\,\mathrm{d}x^\mu \mathrm{d}x^\nu \;+\; \mathrm{d}y^2}$$

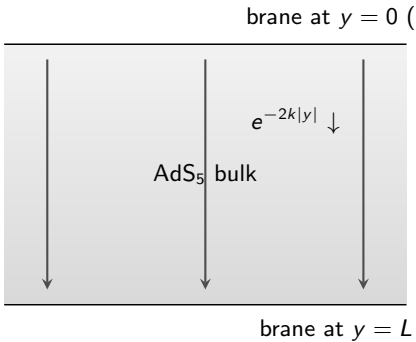
- y is the extra dimension; k sets the AdS curvature scale.
- The **warp factor** $e^{-2k|y|}$ exponentially redshifts scales away from the "Planck brane."
- Explains why gravity *appears* weak on our brane (leakage into the bulk).



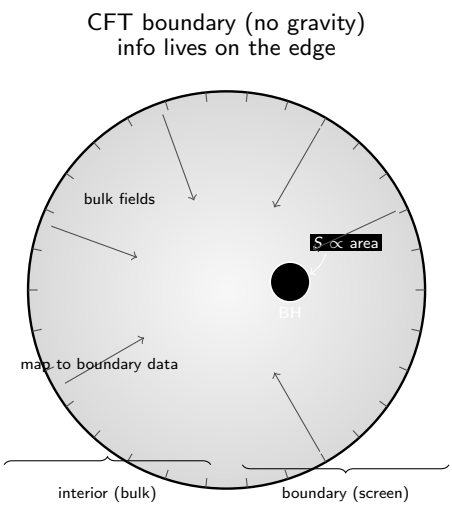
For illustration $k = 1$. Qualitative RS shape.

"AdS Sandwich": Two Branes Confining the AdS Bulk

- **RS picture:** Two branes at $y = 0$ and $y = L$;
  AdS_5 bulk between.
- **Our brane** The "IR brane" where physical mass scales are redshifted.
- The exponential warp can generate large hierarchy between Planck and electroweak scales; i.e., why the electroweak scale (around 100 GeV, relevant to particle masses and forces like electromagnetism and the weak interaction) is so much smaller than the Planck scale.



Why Black Holes Hint at Holography



Basic idea:

- Black hole entropy scales with **area**, not volume $\Rightarrow$ information lives on **surfaces**.
- In AdS/CFT: **bulk gravity** $\longleftrightarrow$ **boundary field theory**;

  the boundary "screen" encodes the interior.

Why this matters for Interstellar:

- If information can sit on boundaries, a structured **bulk** (your AdS sandwich) can target **boundary slices in time**.
- The tesseract scene = a localized bulk "scaffold" that makes those time-slices accessible (books/dust as boundary signals).

The BKL Singularities

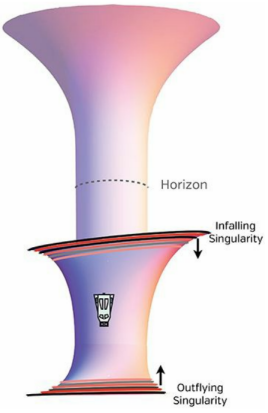


Figure: Infalling and Outflying singularities - Fig. 28.2, p. 249

The Appearance of the Tesseract

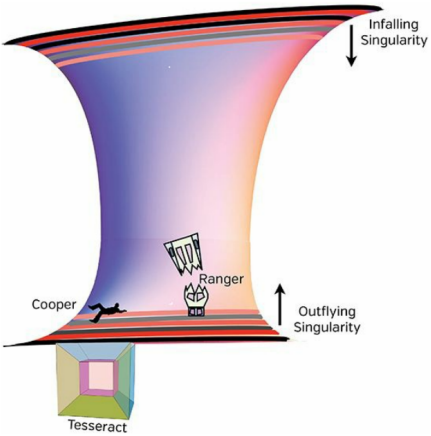
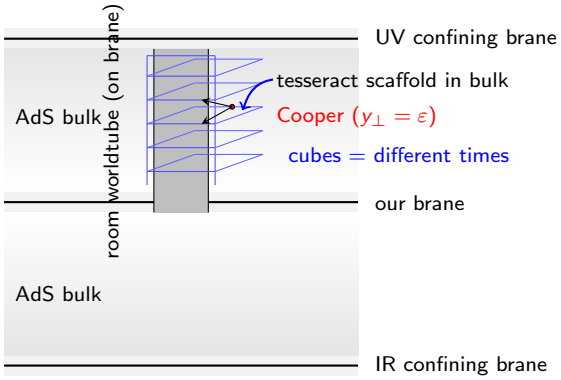


Figure: Our Universe in the Bulk - Fig 28.4, p. 251

Placing the Tesseract in an AdS Sandwich

- Three branes:
  UV confining (top),
  our brane (middle),
  IR confining (bottom).
- **Two AdS bulks:** Above and below our brane (negative curvature regions).
- **Tesseract:** Localized 4D scaffold extends a small distance ε into the *upper* bulk, *anchored* along the worldtube of Murph's room on our brane.
- **Cooper:** Point inside the scaffold at $y_\perp = \varepsilon$, moving through the lattice to access different time-slices on the brane.



Recall n-Dimensional Cubes

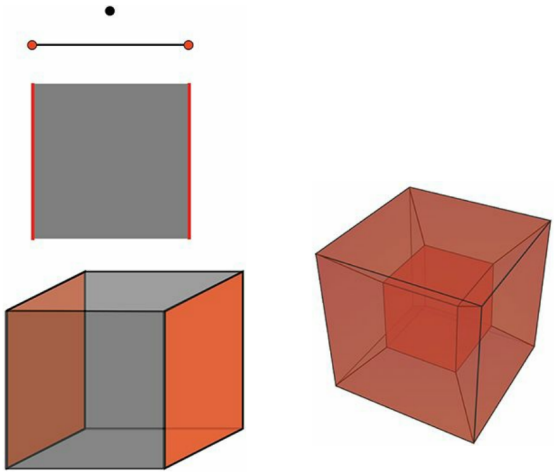
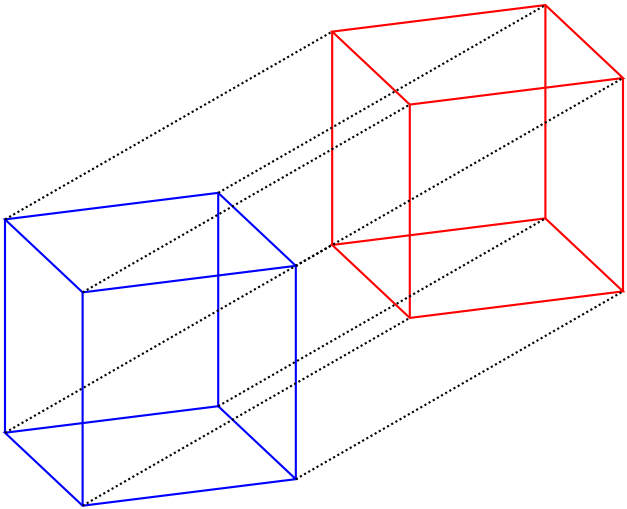


Figure: From point to line to square to tesseract. - Figs 29.1, 29.2, p. 253

Tesseract - Second Version



Cooper's Location in Tesseract

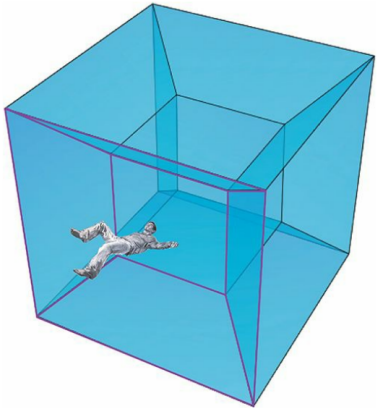


Figure: Cooper in 3D face of tesseract - Fig 29.3, p. 254.

Cooper Looking at Murph

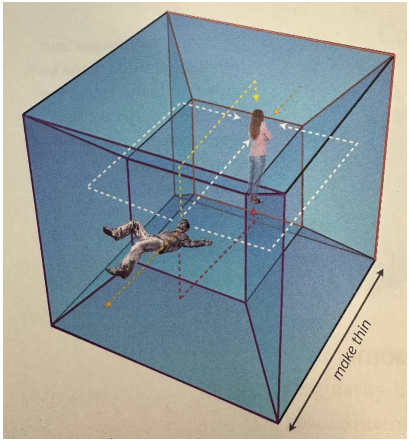


Figure: Cooper sees Murph through each wall of the tesseract - Fig 29.6, p. 256.

Cooper's Six Views

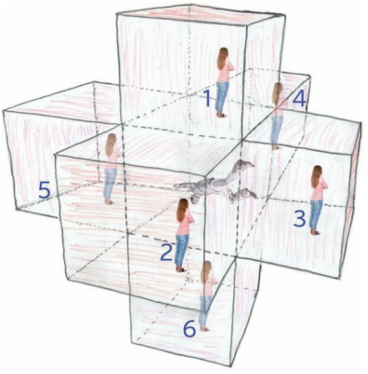


Figure: Cooper sees six Murphs - Fig 29.7, p. 256.

Inside the Tesseract

Figure: Cooper floating inside - Fig 29.8, p. 257.

Time Extrusions

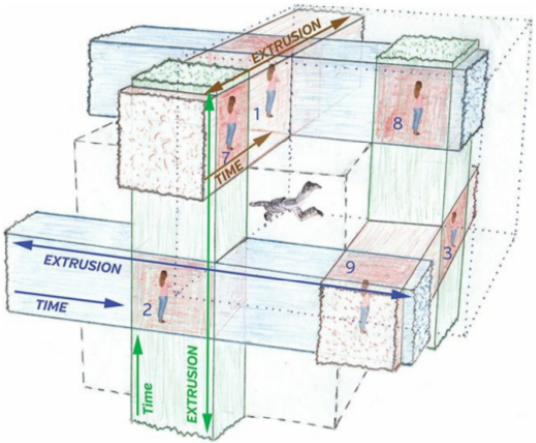


Figure: Extrusions in time from all bedrooms, intersecting in a bedroom - Fig 29.10, p. 256.

Film Extrusion

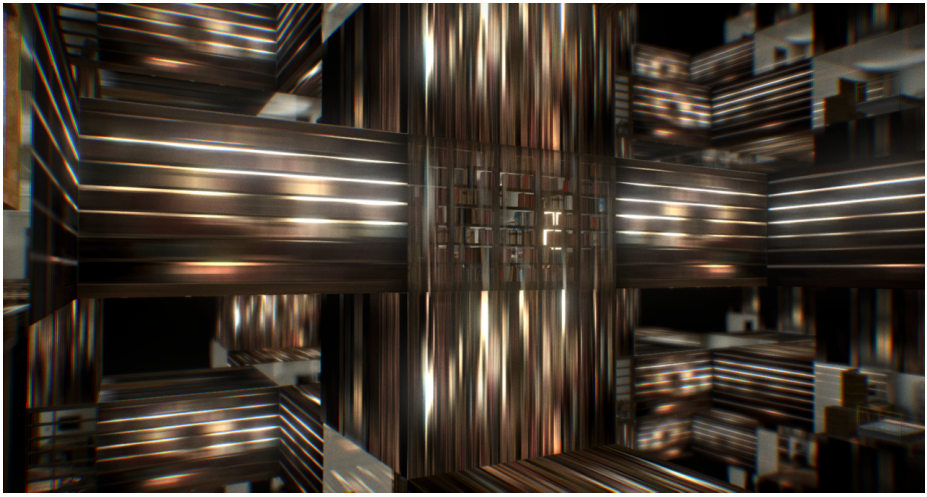


Figure: Film version of the extrusion.

The Lattice of Bedrooms

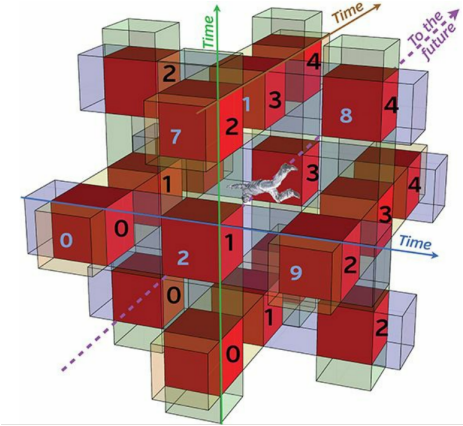
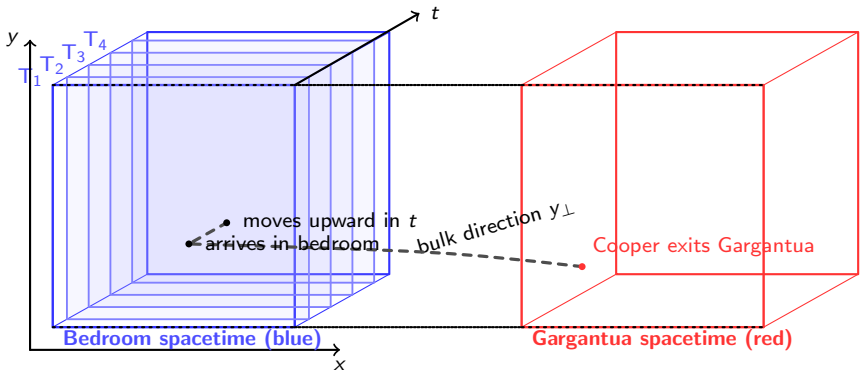


Figure: Lattice of bedrooms. Cooper's future direction is vioet arrow - Fig 29.13, p. 260.

The Bedroom

Figure: A shot of Murph's bedroom.

Gargantua → Bedroom via Bulk (Time-Stacked View)



Two brane-like spacetimes (red Gargantua, blue Bedroom) linked by the AdS bulk. Inside the blue region, stacked translucent layers represent Murph's bedroom at successive times T_1 to T_4. Cooper's trajectory passes through the bulk and ascends through the bedroom's time axis.

Tesseract: Film Image & Physics Mapping

Figure: Movie still: Cooper inside the tesseract lattice.

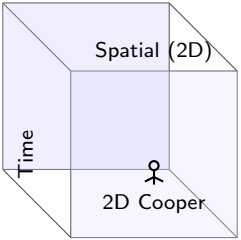


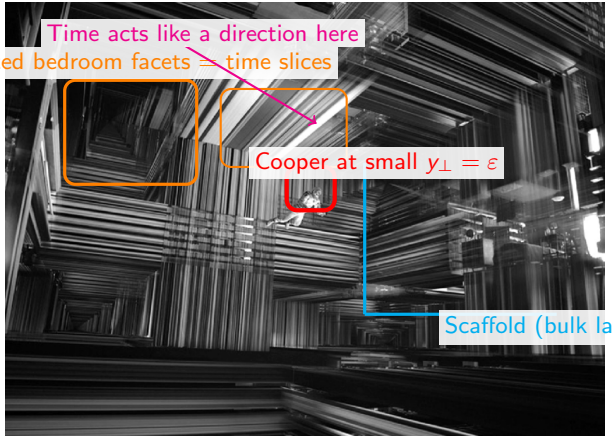
Figure: Flatland: stacked time-slices in a cube.

How the still maps to our model

- **Stacked rooms** = time slices of one location (Murph's bedroom).
- **Lattice walls** = engineered *scaffold* in the bulk that makes time navigable.
- **Cooper floating** = off-brane at small $y_\perp = \varepsilon$.
- **Moving through lattice** $\Rightarrow$ choosing different times.
- Fits inside an **AdS sandwich**: our brane in the middle; scaffold sits just above it in the bulk.

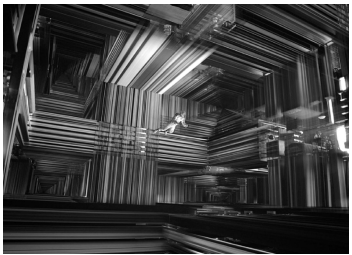
Key idea: For a higher-D being, *time is a direction*; for a lower-D observer, it appears as repeated "rooms."

Inside the Tesseract: What the Still is Showing

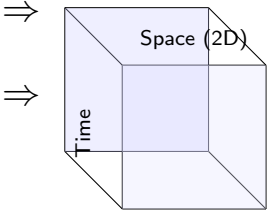


Stacked "rooms" are one location at many times; the luminous lattice is a scaffold built just off our brane in the bulk; Cooper floats at a small extra-dimensional offset and "aims" at different times.

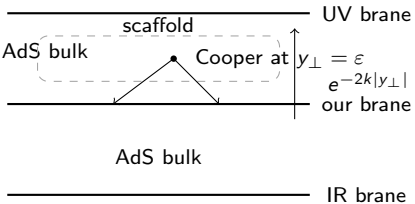
From Film Image to Geometry: Zoom Path



A) Film still Lattice = scaffold; Stacked rooms = time slices.



B) Flatland cube
Time becomes a spatial axis.



C) AdS sandwich (local)
Scaffold sits just off our brane in the bulk.

Read left→right: The film's lattice (A) is a 3-D projection of stacked time slices (B), realized physically as a local scaffold just off our brane inside an AdS bulk (C).

World Tubes

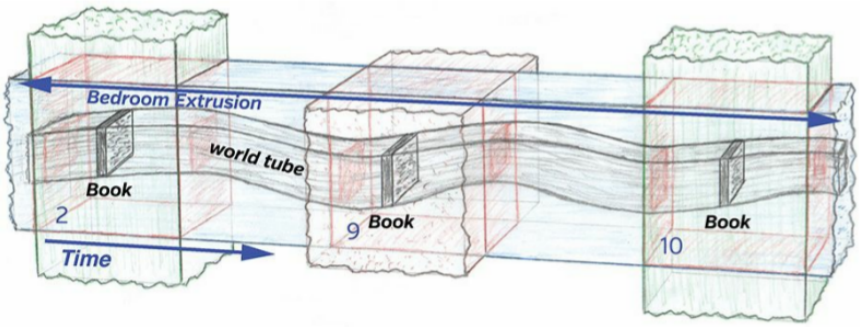


Figure: World tubes of books - Fig 30.2, p. 265.

Pushing Books Along its World Tube

Figure: Cooper facing books - Fig 30.1, p. 265.

From Inside the Tesseract 1

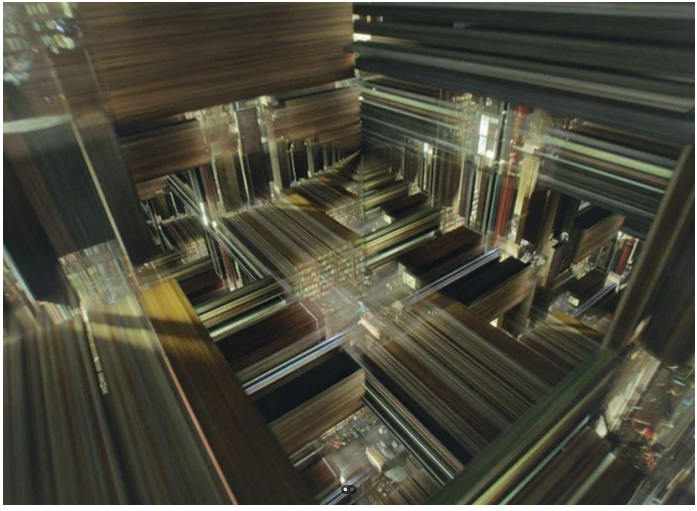


Figure: Bedroom

From Inside the Tesseract 2

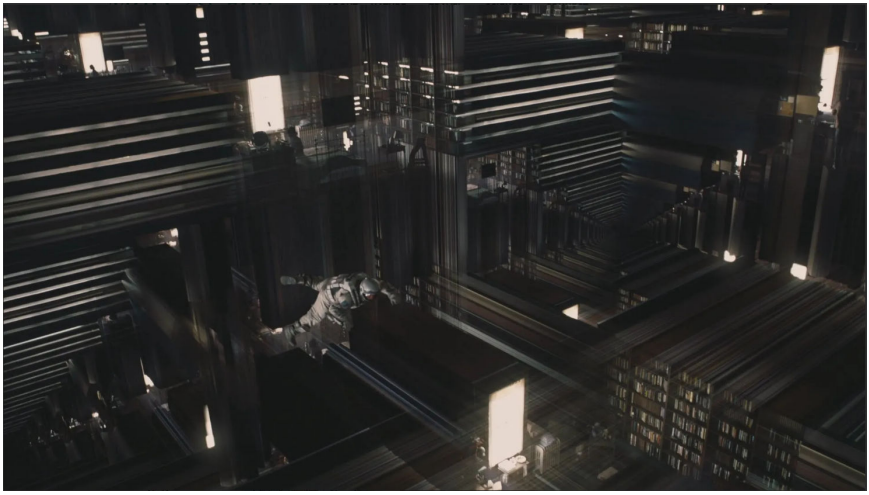


Figure: Bedroom

From Inside the Tesseract 3

Figure: Bedroom View

Media

Topics 1: Bulk & Branes; Anti-de Sitter (AdS) geometry; RS warping
Topics 2: Holographic principle; AdS/CFT; Interstellar's anomalies

- PBS Space Time: What is the Holographic Principle?
- Fermilab: What is Anti-de Sitter Space?
- MinutePhysics: Extra Dimensions
- Fermilab: What is Anti-de Sitter Space? (3–5 min)
- MinutePhysics: Extra Dimensions (2–4 min)
- PBS Space Time: What is the Holographic Principle? (7–10 min)
- Maldacena (1998): The Large N Limit of SCFTs and Supergravity (abstract-level skim)