Exploring how the geometry of the representation space influences curiosity-based exploration

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How does geometry influence exploration behaviors?

In human spatial awareness...

- 3D Projective geometry structures **information integration and planning**
- **Subjective perspectives** can be taken on this internal representation space

Methodology

- **Agent** a looks for an **object** O using **observations** $y_o \in Y$.
- Agent's **"internal world model" space** X is a group structured space, where a group acts on it. **We compare spaces structured by Euclidean Geometry vs Projective Geometry**.
- The agent plans its actions m by taking perspectives on its **internal G-space** X, corresponding to the choice of **a group action**.
- **Beliefs** P_X about the position of object O = **probability measure** on the internal space.
- Uncertainty of observations = **Markov Kernel** $P_{Y|X}$. Updated beliefs $P_{X|y_o}$ are computed using Bayes' rule.

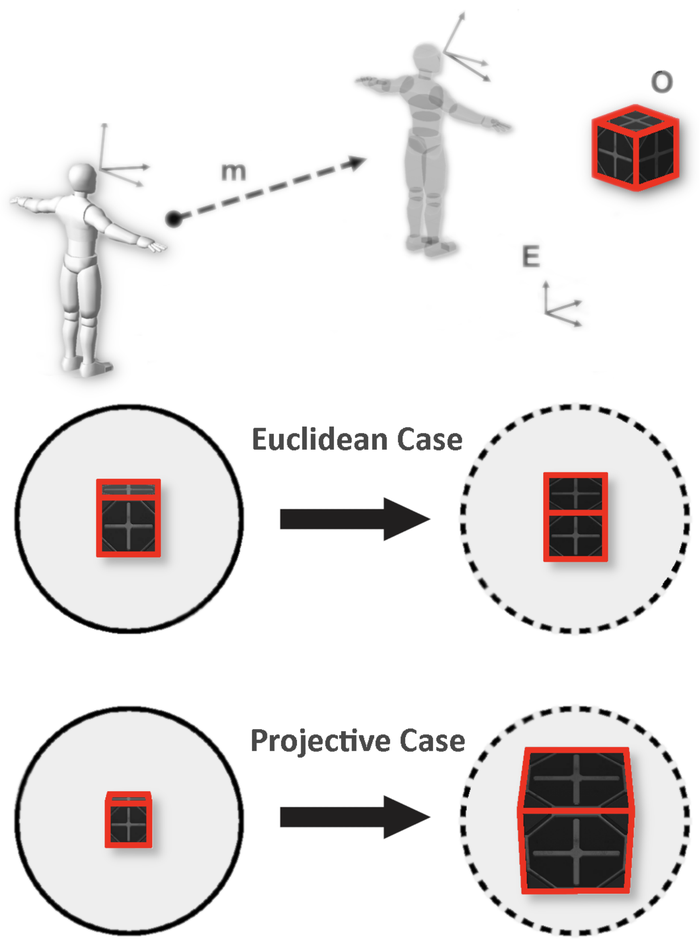
Epistemic value and exploration algorithm

- Epistemic value/curiosity C = **divergence** H **between prior and posterior beliefs** (from Active Inference)

$$C(P_X) := \mathbb{E}_{P_Y}\left[H(P_{X|Y}|P_X)\right] \tag{1}$$

- **A broader belief distribution yields a greater epistemic value**
- The agent **maximizes** at each step the epistemic value of the posterior beliefs.

Setup of toy model



*Approaching a point in projective geometry **magnifies** the surrounding space.*

Results & discussion

I. Geometry can induce a drive to approach the object

Euclidean case : the agent **stays still**

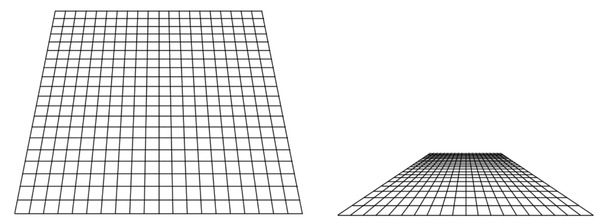
Viewpoint doesn't affect the **broadness of beliefs**: epistemic value is **constant** w.r.t. movement

Projective case : the agent **approaches** the object

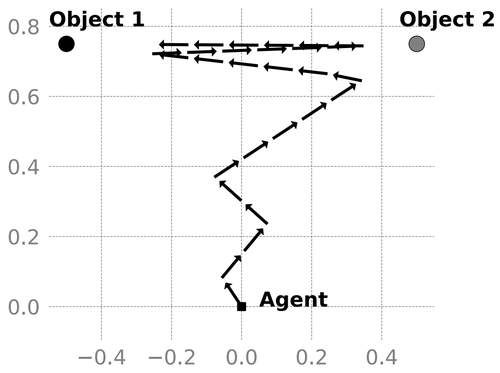
Getting closer **magnifies** the belief distribution = broader beliefs = epistemic value increases as evidence becomes more valuable

II. Exploration behaviors in multi-object projective settings

- **Observing** an object **weakens the drive** to approach it as **the epistemic value decreases** (the belief distribution narrows with evidence)
- **Projective geometry** : **approaching** the object **increases the epistemic value** (surrounding space is magnified = broader beliefs)
- Strong projective deformation = **amplified magnifying** = higher drive to approach. This drive may compensate the decrease in epistemic value from the observations.
- Altering the **magnitude of the projective effect** results in **different exploration behaviors**

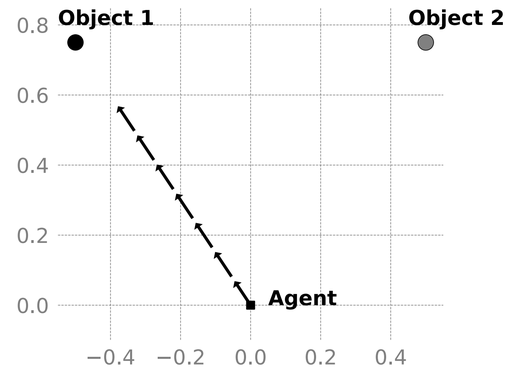


*Weak vs strong projective deformation of the euclidean grid. The **magnifying effect** on approach is **amplified with greater deformations.***



***Weak projective deformation** = **lower drive** to approach = quick oscillation between objects*

***Moderate projective deformation** = low-frequency oscillation*



***Strong projective deformation** = the **drive to approach prevails** over the decrease in epistemic value (very low-frequency)*

Conclusion

- **Projective geometry** generates an **epistemic drive to approach an object**
- The **magnitude of projective deformations** can be interpreted as **modulating the agent's focus on a target.**

1. Rudrauf et al., The Projective Consciousness Model: Projective Geometry at the Core of Consciousness and the Integration of Perception, Imagination, Motivation, Emotion, Social Cognition and Action, 2023
2. Rudrauf et al., "Modeling the Subjective Perspective of Consciousness and Its Role in the Control of Behaviours", 2022
3. Williford, Bennequin, and Rudrauf, "Pre-Reflective Self-Consciousness & Projective Geometry", 2022
4. Rudrauf, Bennequin, and Williford, "The Moon Illusion Explained by the Projective Consciousness Model", 2020