北京大学 人工智能研究院
INSTITUTE FOR ARTIFICIAL INTELLIGENCE, PEKING UNIVERSITY

PKU-IAI Technical Report: PKU-IAI-2022-T-0001

Building Intuitive Physics Engine Enables AI to "Feel Magical"

Chenhao Zhou
Yuanpei College
Peking University
zhouch@stu.pku.edu.cn

Abstract

There are various magic performances making us surprised because of violation of our basic physics knowledge, and we tend to repeat the process in our mind to figure out how it was done. Human reactions to violation of physics law is inspiring to cognitive AI. This essay will take magic shows as example, focus on the violation of expectation (VoE) task in intuitive physics. We try to convince that causal generative model building is a proper mechanism for AI to solve VoE task, finally discussing the limits for the intuitive physics engine in AI.

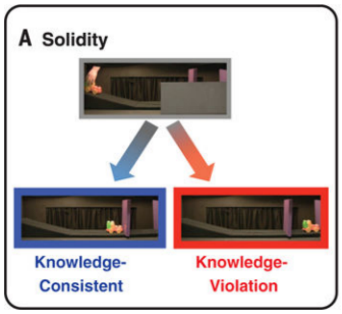
1 Introduction

Magic performance entertains audiences by showing physical impossible scene. Feeling surprised about the magic performance is humans general capability. Many researches in recent years have observed that even human infants can perceive the violation between the scene and their expectation, and engage in a series of behaviors that express surprise, such as gaze, quiver and so on[1, 7, 8]. Thus, violation of expectation (VoE) has become one of the six physical reasoning tasks[4] in intuitive physics. We will introduce it with the example of magics in Sec. 2

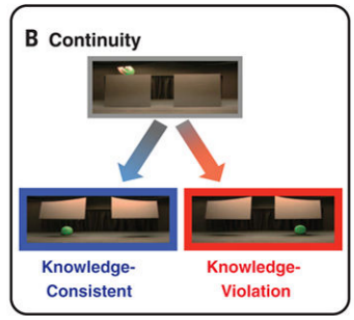
There are some VoE papers in physical reasoning, which are comparatively new and all propose their own datasets and approaches. Among them, we will focus on the simulation approaches which tend to be expressed as intuitive physics engines in Sec. 3, and furthermore in Sec. 4, trying to discuss the limitations on existing simulation methods.

2 Analysis of VoE: Magics

Violation of expectation (VoE) is a paradigm under causal reasoning, which came from the idea that human infants make expectations of physical events which determines their knowledge of causal links for transformations in physical interactions[3]. Stahl and Feigenson [9] show the infants a series of rough "magics" that violated expectations about object behavior or events that were nearly identical but did not violate expectations. Infants tend to respond when basic expectations are violated. For example, infants gaze when a ball appears to pass through a wall, suggesting the violation of expectations on the object solidity (Fig. 1a), and they gaze and quiver when an object hidden in one location is revealed in a different location, suggesting the violation of expectations on object continuity (Fig. 1b).



(a) **figure 1**. Violation of expectations on solidity.



(b) **figure 2**. Violation of expectations on continuity.

Figure 1: Parts of rough "magics" shown to infants.

Many jobs define that the goal in VoE is generally to train an agent to recognize the expected video as less 'surprising' than the surprising version. From our point of view, the perception of magic performance can be represented as combination of two parts: the perception of 'surprising' scene; and the reasonable reconstruction of expectation. Hence the 'surprise' happens under the violation of expectation, and it is believed that AI can feel surprised about magics when it gains the capability to recognize the violation of expectation.

3 Building Intuitive Physics Engine for AI

3.1 Arguments to support intuitive physics engine

There are some reasons why intuitive physics engine may be useful representations for cognitive AI. As shown above, the violation of expectation is tightly attached to the simulations in mind; and same as human intuitive physics system, neither is required to capture precise physic properties; simulation is roughly correct in both human mind and intuitive physics engine.

Besides, some physical illusions (also a part of VoE) are possible to be explained by the uncertainty involved in the reconstruction and prediction process of a physics engine. In Fig. 2, physics engine tend to create simplifying assumption that the bird's density is uniform, thus causing a general physical illusion.

3.2 Build intuitive physics engine

While building intuitive physics engine for AI to "feel magical" in a general scenes, involving some complex magics which contain several steps. All of these put forward higher requirements for the abstract feature extraction and generalization capabilities of the model.

Intuitive physics engine Mental simulators that to a certain degree capture the causal mechanisms at work in the world and can be evolved forward to predict and reason about objects' dynamics mechanically and spatially. Inspired by these features, in year 2013, Battaglia et al. [2] propose a framework based on the intuitive physics engine (IPE), which uses approximate and probabilistic simulations to make robust and fast inferences in complex natural scenes where crucial information is unobserved. It generates predicted states based on initial ones by recursively applying basic physical rules over short time intervals. And Monte Carlo stochastic simulations are used to represent the uncertainty about the scene's state. In a series of experiments it shows surprisingly consistency with probabilistic physics simulations.

Focus on VoE Smith et al. [6] present a new model, "Approximate Derenderer, Extended Physics, and Tracking" (ADEPT), which has two main components: a perception module that estimates an abstract, object-central representation from a raw image at each moment, and a reasoning module that maintains a belief about the scene's physical state, conditioning on past observations and using particle filtering. The perception module successfully extracts the abstract representations of object and accelerate computation. Several experiment based on VoE has shown that ADEPT did not just outperform a set of baseline models on differentiating scenes with physical violations from control scenes, but also did so in a more human-like manner.

Figure 2: Toy bird surprisingly stays balanced

4 Discussion: Limits on Intuitive Physics Engine

The existence of an intuitive physics engine remains a subject of ongoing inquiry. There are a series of limitations in physics simulation engine. First, there is still no definite evidence to imply that mental simulation is the sole underlying representation for all dynamic reasoning, even if the domain in which people can richly simulate physics in their minds turns out to be larger than some have argued. Secondly, though some dynamic tasks (such as most VoE tasks, which only involves more basic physical properties) can be solved quickly through qualitative reasoning in the absence of any quantitative simulation, some dynamic tasks (such as those involving wheels and other spinning objects) are difficult for humans to simulate[5]. Last but not least, even in inference tasks where physics engines can be useful for evaluating candidate hypotheses or explanations, there remains the difficult and separate problem of generating the right hypotheses in the first place.

References

[1] Spelke E. S. Wasserman S. Baillargeon, R. Object permanence in five-month-old infants. *Cognition*, 20(3):191–208, 1985. 1

[2] Peter Battaglia, Jessica Hamrick, and Joshua Tenenbaum. Simulation as an engine of physical scene understanding. *Proceedings of the National Academy of Sciences (PNAS)*, 2013. 2

[3] Merry Bullock, Rochel Gelman, and Renee Baillargeon. The development of causal reasoning. *The developmental psychology of time*, pages 209–254, 1982. 1

[4] Jiafei Duan, Arijit Dasgupta, Jason Fischer, and Cheston Tan. A survey on machine learning approaches for modelling intuitive physics. *arXiv preprint arXiv*, 2202.06481, 2022. 1

[5] Ethan Ludwin-Peery, Neil R. Bramley, Ernest Davis, and Todd M. Gureckis. Limits on simulation approaches in intuitive physics. *Cognitive Psychology*, 127, 2021. 3

[6] Kevin Smith, Lingjie Mei, Shunyu Yao, Jiajun Wu, Elizabeth Spelke, Joshua Tenenbaum, and Tomer Ullman. The fine structure of surprise in intuitive physics: when, why, and how much? *Annual Meeting of the Cognitive Science Society (CogSci)*, 2020. 2

[7] Kestenbaum R. Simons D. J. Wein D. Spelke, E. S. Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, 13(2): 113–142, 1995. 1

[8] Kinzler K. D. Spelke, E. S. Core knowledge. *Developmental Science*, 10(1):89–96, 2007. 1

[9] Aimee Stahl and Lisa Feigenson. Observing the unexpected enhances infants' learning and exploration. *Science*, 348(6230):91–94, 2015. 1