Neuroscience and Psychophysical Evidences on the Existence of Human Intuitive Physics Engines

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Abstract

Human beings leverage their capabilities of intuitive physics to predict the unfolding of physical events, gain a comprehensive understanding of complicated physics scenarios, and seamlessly interact with the tangible world. An intriguing question involving this realm is whether humans possess Intuitive Physics Engines (IPEs) to draw physical inferences. We delve into the neuroscience findings concerning the human brain, as well as the outcomes of psychophysical experiments simulating IPEs, aiming to assert that humans definitely employ their IPEs when comprehending and engaging with authentic physics scenes.

1 Introduction

Intuitive physics is defined as the knowledge underlying the human ability to understand the physical environment and interact with objects and substances that undergo dynamic state changes, making at least approximate predictions about how observed events will unfold [5]. It plays an important role not only in people's thinking about hypothetical situations but also in their interactions with real objects [8]. For example, humans employ their intuitive physics to swiftly generate rough predictions about various physics scenarios when presented with static images, including instances like object collisions, falling objects, pendulum dynamics, and numerous other scenes which involve rich physical knowledge.

Nevertheless, it remains unclear how humans employ their intuitive physics to interact with the physical world. Some researchers argue that the human capacity for intuitive physics is closely linked to vision and memory, where visual attention and memory are automatically drawn toward physically relevant features [3, 11]. Early perspectives modeled the process of employing intuitive physics as constructing specific structures, *e.g.*, decision trees [1] and lists of rules [9]. A recent explanation introduces Intuitive Physics Engines (IPEs), akin to making inferences using a physical software engine, the kind of simulators that power modern-day animations and games [2, 6]. This enables humans to make quantitative but approximate judgments about the physical world.

There is still a lack of consensus regarding the existence of IPEs in human brains. In this paper, we endeavor to demonstrate the existence of the IPE by scrutinizing two key aspects. In Sec. 2, we present recent discoveries in neuroscience, revealing distinct regions in the human brain, separate from the vision center, that become active when individuals observe physical events unfolding. Moving on to Sec. 3, we draw upon psychophysical experiments from various sources to exemplify that the performance of probabilistic models designed to simulate the IPE exhibits a strong correlation with human performance, indirectly suggesting that humans understand the physical world through mechanisms strikingly similar to IPEs.

2 Neuroscience Findings

In addressing the question of whether the human brain possesses an IPE, a pivotal consideration is to ascertain whether there exists a specific region or a family of regions in the human brain essentially engaged in physical inferences and recruited more for physical inference than for other similarly difficult prediction or perception tasks [4]. If an IPE does indeed exist in the human brain, these regions, which involves knowledge of physics, should operate independent from the region that governs human vision. This implies that the human process of perceiving the physical world encompasses not only pattern recognition within physical scenes, but also the real-time reconstruction of perceptual scenes achieved through internal representations of objects and their physically pertinent attributes, along with the forces acting upon objects. The latter process is considerably more intricate and demands abilities that surpass the capabilities of the brain's vision center.

To address this inquiry, neuroscience experts delved into the regions of the human brain involved in physical inference [10]. They presented videos of Jenda-style block towers to 12 subjects, asking them either to predict where the blocks would land if the tower toppled, or to guess if the tower had more blue or yellow blocks. Through these experiments, researchers discovered that when subjects attempted to predict physical outcomes, the most responsive brain regions included the premotor cortex and the supplementary motor area, which are the brain's action planning areas (See Fig. 1). It can be concluded that individuals utilize specific parts of their brains, primarily dedicated to planning actions rather than processing visual information, to employ their intuitive physics and make physical predictions.

Furthermore, they also confirmed that these regions are distinct with the vision centers simply by having subjects watch movie clips without requiring them to answer any questions [10]. As scientists monitored the brain activities of these subjects, they observed that the more physical content in a clip, the more the key brain regions were activated. This more precisely demonstrated that humans employ IPEs to engage in activities related to intuitive physics, rather than relying solely on vision centers of their brains for pattern recognition and feature extraction from the physical scenes to inform their their intuitive physics knowledge for making physical predictions.

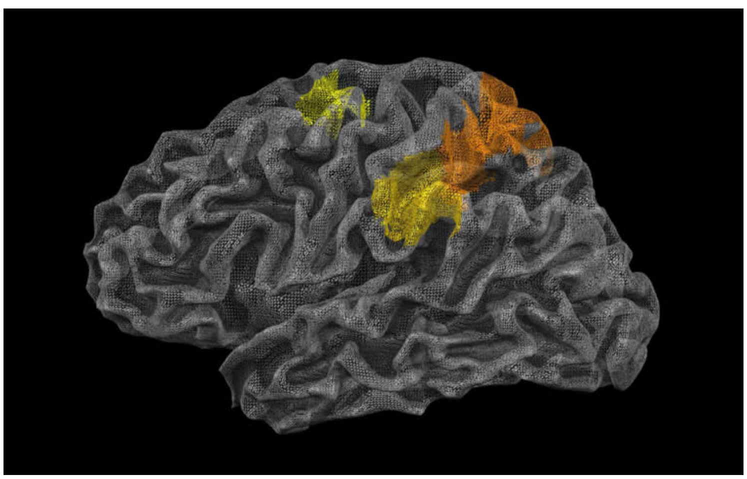

Figure 1: The location of IPE in the brain is highlighted [10].

3 Psychophysical Experiments

Another computational method for examining the existence of IPEs is to construct probabilistic models that resemble the expected IPEs. These models are trained with a diverse range of data involving designed psychophysical tasks. Subsequently, the performance of the model on these tasks is tested to evaluate its correlation with human responses. It is worth noting that our primarily focus lies in assessing the correlation of the performances between the computational models and humans, rather than the absolute capabilities of the constructed models. If performance of the models, which accomplish tasks in ways similar to the IPEs, can exhibit a highly correlation with human behavior, we can have confidence that human brains employ mechanisms analogous to IPEs for making physical predictions and interacting with the physical world.

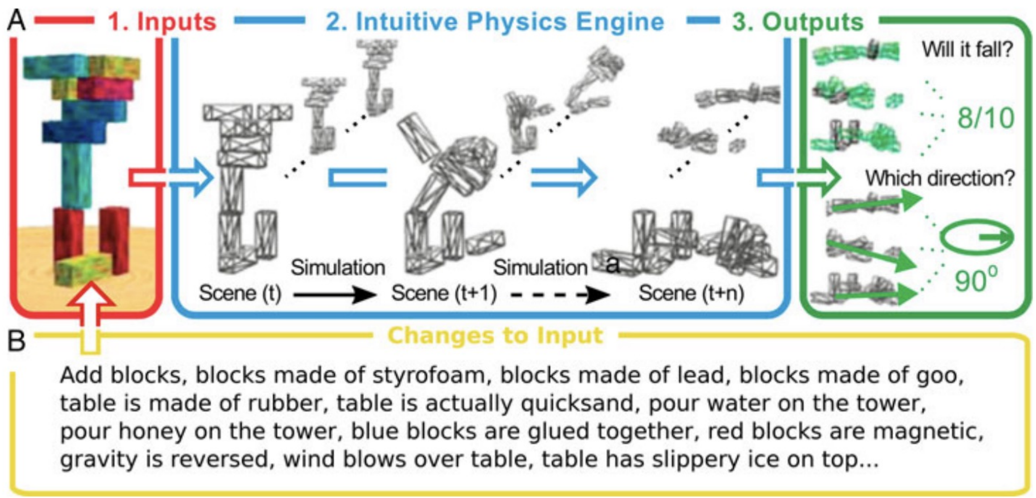

Figure 2: The intuitive physics-engine approach to scene understanding, illustrated through tower stability [2, 7].

Battaglia et al. [2] first introduced the architecture of the IPE (See Fig. 2) and designed psychophysical experiments to validate the correlation between human performance and model predictions. The core of the computational IPE is an object-based representation of a 3D scene, which quantitatively encodes variables required to capture the motions and interactions of many objects. The authors devised five psychophysical tasks which featured complex configurations of objects and require multiple kinds of judgments in different output modalities and graded predictions. Detailed information about these tasks can be found in [2]. The results of the experiments showcased a substantial correlation between the model's and participants' average judgments. For instance, one of these experiments assessed each subject's judgments regarding whether a tower of 13 blocks would topple over 60 different tower scenes, repeated six times over separate blocks of trials. With specific experimental configurations, the performance of humans and models exhibited an expected correlation coefficient of 0.92. This provides psychophysical evidence that humans employ their intuitive physics with mechanisms akin to IPEs.

Lerer et al. [7] delved deeper into the comparison between human performance and model predictions by proposing a deep convolution network-based system (PhysNet) to predict the stability of block towers from simulated images. Undoubtedly, the results achieved by PhysNet are quite impressive. It demonstrates a certain level of correlation with human performance, and even surpasses human abilities on synthetic images. Nonetheless, there are limitations associated with this architecture. The correlation is not as strong as that observed with IPEs. Additionally, the vast amount of data required for training Physnet poses a considerable challenge, and its ability to generalize to other tasks is also constrained [6]. From my perspective, the outstanding performance of PhysNet is mainly attributed to the remarkable feature extraction capabilities of convolution networks. The fact that the correlation between human performance and PhysNet is weaker than that demonstrated by IPEs indirectly underscores the reliability of IPEs in elucidating the mechanisms of how human employ intuitive physics to understand physical scenes.

4 Conclusion

The question of whether there exists an IPE in the human brain governing activities involving intuitive physics remains a subject of controversy. The complexity of the human brain makes providing a definitive answer to this question a formidable task. In this paper, we have taken preliminary steps towards arguing that the IPE unequivocally exists in the human brain, playing a pivotal role in comprehending physical scenes and making accurate physical predictions. However, further interdisciplinary scientific research is still imperative to offer a more reliable explanation of IPEs. We hold the expectation that studies aimed at confirming the existence of IPEs and simulating them through various methods will make significantly contributions to advancing research in the domain of physical inference and cognitive reasoning.

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