Evaluating Visual Perception with Bouncing Motion

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While perception is of great importance to animation evaluation, the perceptual accuracy of human beings to physical motions is not well understood. We have designed a perceptual experiment and developed a novel interactive interface that supports to investigate human perception to bouncing motions. Specifically, we display a rigid ball falling and bouncing from a hill to detect a just noticeable range of plausible motions that loosely follow the law of physics. The experiment design and the interface are validated in piloting studies, providing insights to the theory of perception and physical simulation.

Additional Key Words and Phrases: Bounciness perception, Computer animation

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1 INTRODUCTION

Among the countless physical phenomena in everyday life, to what extent do people pay attention to them? The answer is not obvious. Thinking from the evolutionary perspective, while the world is constructed based on the law of physics, being precise on these information does not necessarily bring survival values. Human perception to physics is not always accurate. When it comes to producing visual media such as animation, following physical principles is increasingly emphasized as technology allows. However, immersive animation should be about creating great perception. Convincing and pervasive motions do not necessarily always follow the law of physics. Subtle changes to physics-based simulation may be hard to detect to most people, which introduces a range of plausible, but non-physical motions. With this range being specified, both computational and labour effort can be saved without jeopardizing the quality of simulation.

However, our understanding of such a range is limited due to the complicated nature of human perception. To explore people's perceptual accuracy to physical movements, we need to reduce the problem complexity by focusing on the basic cases. We consider a simple yet representative motion as a starting point - a rigid ball bouncing down a hill. We have designed and implemented a novel perceptual experiment interface to understand how changes in animated movement affect people's motion perception.

In the rest of the paper, we first review the related work on this topic and describe how we approach to find the range of plausible bouncing motions considering the coefficient of restitution. Then we detail the perceptual experiment designed for this problem and demonstrate the piloting result. We finally discuss the findings, limitations and future directions at the end.

2 RELATED WORK

Finding and evaluating plausible simulations to physical-based animations have been studied previously in the computer graphics area. Chenney and Forsyth have discussed the plausible solutions to multibody constraint problems [Chenney and Forsyth 2000]. O'Sullivan et al. have evaluated the visual quality of animations in which physical parameters have been distorted or degraded [O'Sullivan et al. 2003]. However, there is a lack of empirical studies on human perception to bouncing motions. An interesting question is whether there exists a range of bouncing motions that are plausible but not strictly physical.

There are two advantages of using bouncing motions as the starting point: (i) the bouncing motions are easy to implement and also can be easily perceived by people; (ii) the bouncing motions are well studied in the area of physics [Cross 1999, 2015].

The physics property that describes the bouncing motions is the **coefficient of restitution**. It describes how bouncy an object is when falling onto a surface. The larger the coefficient of restitution, the bouncier the object is when falling onto a surface.

Baseline bouncing motion: We assume that when two physical bodies are known, the coefficient of restitution between these two bodies is a constant. That is, in a physical simulation, given two known bodies, the bouncing motions between these two bodies should always be the same. If human perception is perfect to bouncing motions, only the motions with a constant coefficient of restitution should be perceived as plausible.

3 APPROACH

In this work, we investigate the possibility of a grey area of human perception to simulated bouncing ball motions. The two research questions (RQ) we are trying to understand are:

- **RQ1:** Is there a range of bouncing motions with coefficient of restitution changed along with time that is plausible?
- **RQ2:** If the answer to RQ1 is yes, what is the range of changes to the coefficient of restitution that keeps the motion plausible?

In the field of psycho-physics, a powerful experimental design used to measure the amount of a particular stimulation required to be perceivable at least half the time is called **just-noticeable difference (JND)**. To address our research questions, we have explored several JND experimental design methods, including one with the coefficient of restitution linearly varying with time, and one with the coefficient of restitution changing as a polynomial function of time. But in the end, we decide to manipulate the variation of the coefficient of restitution of each bounce (R_i) to create the non-physical simulation.

For each bounce i, we let $R_i = R_0 \times f$, where f is drawn from a uniform random distribution of the range $[1-\epsilon, 1+\epsilon]$, i.e., $f \sim [1-\epsilon, 1+\epsilon]$. The R_0 here is the coefficient of restitution of the physical bouncing simulation in the experiment, whose value is set

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to 0.8. The ϵ here is the variation of the coefficient of restitution that we are going tweak to create the non-physical simulation. Its initial value is 0.6. These two values are chosen heuristically. Here we further operationalize the research questions as whether there exists such an ϵ (> 0) with which people perceive the non-physical simulation as physical. We call this ϵ value as the JND value of ϵ.

The contributions of this work are as followed.

- We have developed a novel interface that can be used to conduct perceptual experiment with bouncing motions.
- An algorithm is designed to find the JND value of ϵ for the coefficient of restitution, which can be reused to find the plausible range of other physical simulation parameters, such as gravity and friction.
- We provide empirical evidence for understanding human perception.

4 INTERFACE IMPLEMENTATION

We have used PyBox2D[1] and Pygame[2] to implement our simulation system. PyBox2D is a 2D physics engine for games. We use it to implement the collision detection. Pygame is a set of Python modules for writing video games, which is used to render shapes and motions in our system. The code of the system is available online[3].

When the experiment starts, the system will display a welcome window. The participant needs to follow the instructions displayed on the window to finish the experiment. The experiment will end when the system finds the the JND value of ϵ of the participant.

We randomize the initial velocity of the ball and the shape of the hill among each trial. This aims to reduce the learning effect when doing the experiment. The learning effect here means that the participant may remember the trajectory of the ball which looks always physical.

4.1 Welcome window

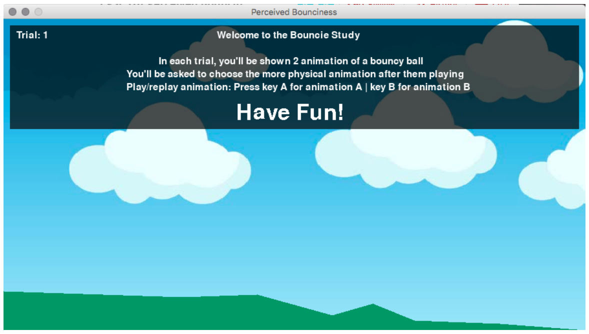
The welcome window is shown in Figure 1. It gives the participant the instructions to run the simulation system. In each trial, the participant will be shown two animations of a bouncy ball. After the two animations have been played, the participant will be asked to choose which one looks more physical. The system will record the participant's answer and then find the JND value of ϵ of the participant.

4.2 Animation running window

An animation running window is shown in Figure 2. It shows an animation where a ball is bouncing down along a hill. The participant is only allowed to play the other animation after the current animation is finished.

4.3 Choice window

A choice window is shown in Figure 3. It asks the participant to make a choice which one looks more physical between the two animations that have been played. After the participant inputs his/her choice, a new trail will start if the system is still not able to find the JND value of ϵ of the participant.



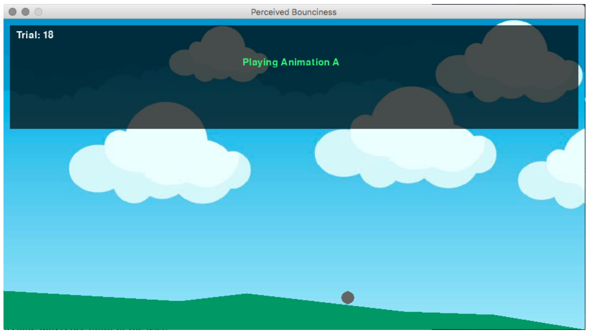
Trial: 1

Welcome to the Bouncie Study

In each trial, you'll be shown 2 animation of a bouncy ball
You'll be asked to choose the more physical animation after them playing
Play/replay animation: Press key A for animation A | key B for animation B

Have Fun!

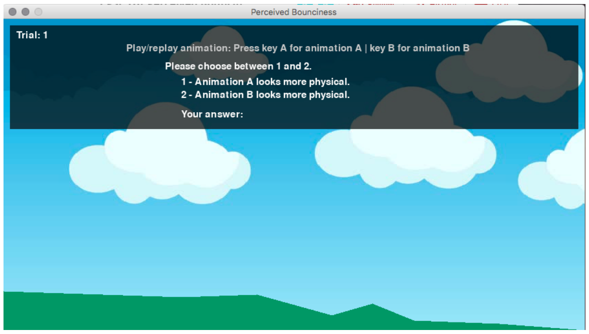
Fig. 1. Welcome window.



Trial: 18

Playing Animation A

Fig. 2. Animation running window.



Trial: 1

Play/replay animation: Press key A for animation A | key B for animation B

Please choose between 1 and 2.
1 - Animation A looks more physical.
2 - Animation B looks more physical.

Your answer:

Fig. 3. Animation running window.

5 STUDY DESIGN

We have designed a within subjects perceptual experiment to find a just-noticeable-difference point of distorted but perceptually plausible bouncing motions. The independent variable is the variation of coefficient of restitution ϵ, and the dependent variable is the identification rate to a non-physical motion when compared with a physical motion. In each trial, participants are first displayed two animations of a ball bouncing down a hill, with one of them being physical and

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[1] https://github.com/pybox2d/pybox2d
[2] https://www.pygame.org/news
[3] https://github.com/bicheng-xu/Perceived-Bounciness

one being distorted. Then we ask participants to choose one of the two animations that looks more physical.

Comparison Study: A difficulty arises from this setting is the uncontrollable contextual and narrative information that participants assumed on the ball. Another confounding variable is whether participants perceive the baseline motion to be plausible, that is, when ϵ equals to 0. We employ a comparison study design to eliminate these effects.

Criteria for plausible ϵ: The difficulty level of the comparison tasks depends on the variation of the coefficient of restitution, ϵ. As ϵ gets smaller, the non-physical motions get harder to be identified from the physical ones. We operationalize the difficulty of tasks by calculating the rate of wrong choices over total number of trials for a specific ϵ. For each ϵ value, we run k trials to get its error rate. Currently, we set $k = 6$. The next value of ϵ is determined by the error rate from the previous ϵ. If the error rate is less than a certain number, which is set to 0.4 in the current setting, then we say that the participant can tell the difference between the two animations. We use a bisection algorithm to find the the JND value of ϵ of the participant. The algorithm is described in Algorithm 1.

A consideration needed to take into account when using the bisection algorithm is that: once there is a mistaken choice, the algorithm always calculates within a wrong section. The bisection algorithm is sensitive to every choice made on the section. Balancing the risk of having false positives and true negatives, we assume that when the error rate is bigger than 0.4, the chosen ϵ is non-plausible. That is, the participant can not tell the difference between the two animations. Every time the error rate gets higher than the criteria, we reduce the possible range of f by half of its length, until the length is too short. Currently, the stopping criteria σ in Algorithm 1 is set to 0.01. By the end of the experiment, we expect to get the range of plausible bouncing motions for the participant.

Experiment procedure: Participants are first welcomed and introduced to the study interface. They are told that the ball is on the earth and one of the two motions is physical. Once they are ready to start, they press the keyboard to play motions and complete questions, guided by the text instructions. Each trial takes roughly 1 minute, and the number of trials depends on the initial ϵ value. After the stopping criteria is met, the experiment terminates. Then participants will be asked a few questions about whether they have used any heuristic throughout the experiment, and whether they feel the context of the ball has been changed over time.

The values of initial ϵ, k (the number of trials for each ϵ), and R_0 (the baseline coefficient of restitution), are heuristically determined with the objective to make sure the JND value of ϵ is smaller than the initial ϵ, while still keep the experiment finished in a reasonable time.

6 PILOT STUDY RESULT

We have conducted four piloting studies to evaluate the experiment procedure and design validity. Settings of pilots are similar to the real study. Two pilot participants are the authors themselves and two are other people who are not familiar with the experiment interface.

ALGORITHM 1: The bisection algorithm to find the JND value of ϵ

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Input: An initial $\epsilon$ value $\epsilon_0$, an initial step size $s_0 = \frac{\epsilon_0}{2}$, and a step size
       stopping criteria $\sigma$.
Output: The just-noticeable-difference $\epsilon$ value $\epsilon^*$.
$step\_size = s_0 \times 2$; $\epsilon = \epsilon_0$;
repeat
    Run the simulation with $\epsilon$;
    $step\_size = step\_size/2$;
    if the particepant can not tell the difference between the two animations
      then
        $\epsilon = \epsilon + step\_size$;
    else
        $\epsilon = \epsilon - step\_size$;
    end
until $step\_size < \sigma$;
$\epsilon^* = \epsilon$;
```

Result: The pilot results show that the interface supports the perceptual experiment execution. Participants performed the selection tasks well and the system is able to find the JND value of ϵ at the end of each study. Figure 4 shows how ϵ converges to the JND = 0.178 for one of the novel participants. The JND value of ϵ for the other novel participant is 0.497. Whereas the two authors each has a JND value of 0.066 and 0.12. These results might be biased, as both authors know the details of this study very well.

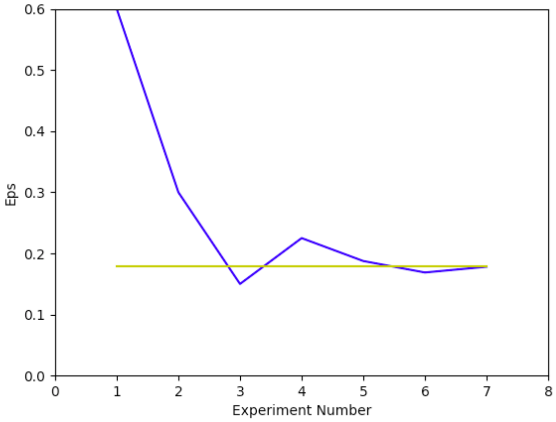

Fig. 4. Sample Piloting Result

Both the other two participants report that they have imagined different properties of the ball and the floor on different trials. One participant has been confused by the loosely specified contextual information. She thinks that both animations can be physical under different conditions. For example, if the floor is harder, then the first animation is more physical, while if the floor is softer, then the second animation is more physical.

The pilot results give insights to both of our research questions. First, there seems to be a range of plausible but non-physical bouncing motions to people's visual perception. Second, such range can vary to some extent from people to people. More data should be collected on new participants to further support these hypotheses.

7 DATA ANALYSIS AND ANTICIPATED RESULT

Inter-trial reliability: Even though we have set $k = 6$, the number of trials for each ϵ value, and set the plausibility criteria as error rate > 0.4, there still exists the possibility of passing the plausibility criteria by chance.

Narrative framing: At the end of the experiment, participants are asked whether they have used any heuristics and assumptions during the experiment. Qualitative data analysis should be conducted to participants with similar narrative assumptions, to figure out whether they have similar JND values of ϵ.

Plausible ϵ range: Human perception is too complicated to make an assertive conclusion on. We expect to find different JND values of ϵ for different individuals. But by doing the perceptual experiment on a reasonable sample size, we should be able to find a range of JND values of ϵ that covers the values of most participants.

8 DISCUSSION AND CONCLUSIONS

Summing up from the above, we have developed a novel interface and designed a perceptual experiment to find the range of bouncing motions that are plausible but non-physical to human perception.

Limitations and Future work: Our system has a couple of limitations. First of all, we do not control the contextual influence to participants' perception. Specifically, controlling participants' assumption on the physical properties of the ball and the ground is a very hard problem. Some participants may think the ball as a ping-pang ball, while others think it as a solid ball. That might lead to different expectations to the bouncing trajectory of the ball. A potential direction for the future work is to explore how participants tend to predict such trajectory under different assumptions.

Moreover, while this work only controls the coefficient of restitution for non-physical motions, there are other parameters such as gravity and friction that contribute to plausibility of the simulation. Future work should consider perceptual testing with different combinations of parameters.

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