Perceptual Evaluation of Cartoon Physics: Accuracy, Attention, Appeal

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Abstract

People have been using stylistic methods in classical animation for many years and such methods have also been recently applied in 3D Computer Graphics. We have developed a method to apply squash and stretch cartoon stylisations to physically based simulations in real-time. In this paper, we present a perceptual evaluation of this approach in a series of experiments. Our hypotheses were: that stylised motion would improve user Accuracy (trajectory prediction); that user Attention would be drawn more to objects with cartoon physics; and that animations with cartoon physics would have more Appeal. In a task that required users to accurately predict the trajectories of bouncing objects with a range of elasticities and varying degrees of information, we found that stylisation significantly improved user accuracy, especially for high elasticities and low information. To assess attention, many simulated objects were shown to participants on which words appeared at random, the task being to speak and remember them. Our results do not confirm that attention can be directed in such a scenario using cartoon physics. However, a game with cartoon physics was chosen to be more appealing almost twice as often as one with no stylisation applied. We conclude that stylised motion can be a valuable tool to improve physically based animations.

CR Categories: I.3.7 [Computing Methodologies]: Computer Graphics—Animation; J.4 [Computer Applications]: Social and Behavioral Sciences—Psychology;J.2 [Computer Applications]: Physical sciences and engineering—Physics;

Keywords: Computer animation, Perceptual validation, Cartoon Animation

1 Introduction

The need for stylised motion has long been established by traditional hand drawn cartoon animators and it is documented that Disney artists in particular have employed a well defined set of rules for enhancing the quality of animations [Thomas and Johnston 1981]. Techniques such as squash and stretch are believed to add a life-like quality to animated objects, making their motions more interesting to behold and often drawing focus to important events occurring in animation. As the quality and accuracy of physics engines increases, there has been some demand for going beyond just accurate physics and incorporating artistic variations such as cartoon deformations to real-time interactive physics simulations e.g. Cel Damage by Pseudo Interactive® and Electronic Arts®. A number of papers have been published on simulating cartoon physics using a range of different approaches from simple geometrical deformations to complex physically based models of elasticity. In this paper we present the results of a number of experiments that were performed to address the question of whether and to what degree stylisation contributes to the quality of a real-time interactive simulation.

1.1 Contributions

Our main contribution in this paper is to validate some well known assumptions that stylised behaviour has the potential to significantly affect a user's perception and response to a scene. In particular, we address the question of whether stylisation can increase the user's accuracy in understanding and predicting object motion, whether stylised animation can significantly attract the attention of the viewer to significant objects in the scene, and whether the overall appeal of the animation as a whole is noticeably increased by stylisation. These three criteria are tested within a system, presented previously in [Garcia et al. 2007] which enables real-time interactive cartoon physics. We believe that the results of such a study will help in advocating the usefulness of cartoon-type stylisations of motion in interactive real-time applications such as games.

2 Previous work

There is a large body of work in the literature of non-photorealistic rendering that advocates stylisation in rendering to increase the effectiveness of images in communicating information, ideas or emotional impact upon the user. A strong parallel can be drawn with stylisations that are applied, not to the appearance of objects, but to their dynamic properties and behaviours. Lasseter [1987] is amongst the first to raise the topic in the field of Computer Graphics, outlining how Disney's principles of traditional animation can be applied to computer generated 3D animation. Lasseter states that the main goals in traditional animation should be to put ideas across clearly and unambiguously to the audience, and to present something that will be entertaining to the audience. From, this we infer three criteria that may be of particular relevance to judging the quality of animations. These are: *Accuracy*, which relates to the clarity and quality of the information that is being communicated to the audience, *Attention* which could be seen as a measure of how much of the most relevant information in the scene is being communicated to the user, and *Appeal*, which relates to the entertainment value of an animation.

Since Lasseter's paper, a number of authors have proposed techniques for applying mainly squash and stretch behaviours to computer animated objects [Opalach and Maddock 1994; Faloutsos et al. 1997; Wyvill 1997; Terzopoulos et al. 1987]. More recently real-time cartoon-style physics with squash and stretch has been discussed by Chenney et al. [2002] who used a geometric model of deformation and this was extended by Garcia et al. [2007] who presented a physically-based model for interactive real-time cartoon

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deformations.

Beyond squash and stretch there has been a small but diverse number of papers dealing with applying other dynamic characteristics of traditional animation in computer graphics. Wang et al. [2006] use a cartoon animation filter that automatically applies anticipation and follow-through motions to animation data. Motion lines combined with squash and stretch have been applied by Collomosse et al. [2003] to create cartoon animation from video. View-dependent geometry [Rademacher 1999] and Expressive deformations [Noble and Tang 2006] have been proposed to stylise views of animated objects towards improving staging and appeal.

The major motivation for all of these approaches in traditional and computer generated animation is that they have the potential to add qualities such as personality and appeal or to draw focus and accentuate important events. The process is naturally tied in to perception of motions and what has not heretofore been well established is a conclusive measure of how much particular stylisations add value to normal animation; or whether there is any real justification for stylisation to exist in interactive computer animation. The fact that such studies are not well known is unsurprising. There is a limited body of work which deals with evaluating the quality of animations in general, let alone stylised animations.

Although relatively new in Computer Graphics, the perception of movement has been well discussed in the Psychology literature. Kaiser and Proffitt [1987] presented a series of experiments that investigated the ability of people to discriminate between accurate and dynamically anomalous collisions whilst Clement [1982] demonstrated that naïve intuitions concerning simple physics problems were highly inaccurate. Proffitt and Gilden [1989] showed that people are reasonably good at detecting dynamic anomalies in relatively simple particle motion, but are less competent with extended body systems with larger dimensions of visual information.

Barzel [1996] proposed that such uncertainties in the perception of physics could be exploited in computer graphics towards various ends, for instance in the form of intentional deviations from physically accurate collision response in order to tune a simulation to fit certain initial and goal states [Chenney and Forsyth 2000; Popovic et al. 2000]. However, in order to do so effectively, it is important that we have dependable measures of how well users are able to understand dynamic cues and to detect anomalies in animation. Towards this end, O'Sullivan et al [2003] proposed measures to determine the fidelity and plausibility of physically based simulations. Intentional changes to the normal "accurate" simulation of dynamic objects are described as *aesthetic distortions*, introduced to achieve a desired goal. This is distinguished from *unavoidable distortions* which are necessitated by the inability of the system to deal with fully accurate simulation due to computational load or limits in the level of resolution of the models used. Stylistic animation fits well into the class of aesthetic distortions and, although their work primarily targeted the latter types of distortion, there appears to be no reason why similar studies cannot apply equally well to stylised physics.

Recently, a study of perception of computer generated dynamics was presented by Nusseck [2007], who used a computer simulation of a virtual ball bouncing to study the correspondence between users' ability to estimate the balls elasticity and to predict its future path. In this paper, we recreate their experiments as one component of a suite of tests to determine the degree to which stylisation adds to the quality of automatically generated physically based animation.

The stylization algorithm we employ in this paper is built upon a deformable object simulation engine. The physically based modeling of deformable objects was first introduced in Computer Graphics by Terzopoulos et al. [1987]. Our efforts, as many others before, are driven towards solving this problem with the additional constraint of real-time framerates for potential use in interactive applications such as computer games, surgery simulations, and cloth and hair simulations. Such approaches usually focus on providing a plausible solution at interactive rates instead of a fully accurate one. Many approaches have been proposed to deal with this problem including: mass-spring systems [Baraff and Witkin 1998], mesh-free methods [Liu 2002; Müller et al. 2005], finite element methods [Etzmuß et al. 2003], finite differences [Terzopoulos et al. 1987], finite volumes [Teran et al. 2005], boundary element methods [James and Pai 1999], geometrical constraints [Teschner et al. 2004]. Our technique is based on the Finite Element Method (FEM) (see [Bathe 1996]). The models based in FEM are usually accurate but slow, although some approaches like co-rotational formulation (see [Müller and Gross 2004]) or modal analysis (see [Choi and Ko 2005; Barbič and James 2005]) try to solve this limitation. For further information on deformable simulation we recommend the survey by Nealen et al. [2006]. Although some work has been done in controlling deformable object animations (see [Irving et al. 2004]), to our knowledge, our previous work (see [Garcia et al. 2007]) is the only other work that deals with stylising physically based deformable model simulation.

3 Elastic model used

In this section we summarise our approach and briefly introduce how the simulation of the scene's deformable objects is performed for stylised and non-stylised objects. The co-rotational formulation of the finite element method is used for real-time simulation of soft bodies. A detailed description of this technique can be found in [Müller and Gross 2004; Etzmuß et al. 2003]. To improve performance, the optimisations described in [Garcia et al. 2006] and [Garcia et al. 2008] have been implemented.

The model employed is characterised by the following features. Tetrahedral elements are used to discretise the space. We use a linear constitutive equation which means that the stress and the strain are linearly related. A linear strain tensor is also used. This is only valid for measuring small displacements because it is not invariant to rotations. We use the co-rotational formulation to solve this problem. In this approach the element rotations are computed at each simulation step and then the internal forces are calculated in the un-rotated configuration and then the forces are rotated again:

$$f_e^{in} = R_e K_e (R_e^t x_e(n) - x_e(0)) \tag{1}$$

where f_e^{in} is the element internal forces, R_e is the element rotation, $x_e(n)$ is the position of the element nodes at an instant n, $x_e(0)$ is the initial position of the element nodes and K_e is the matrix that relates the node displacements with the internal forces (stiffness matrix). To grant the model stability we compute the state of the nodes using an implicit integration schema at each simulation step.

Henceforth we refer to the engine that uses the algorithms described above as the Normal Physically-based Simulation (NPS) engine, and this is used as the reference model against which we compare the stylised motions. In our experiments we stylise the animations of some objects using the squash and stretch principle described by Lasseter [1987]. To do this we use an algorithm for interactive real-time cartoon physics which runs on top of the NPS engine. We refer to the engine that uses this approach as the Cartoon Physics Simulation (CPS) engine.

The deformations computed using the non-stylised algorithms are controlled using a technique based on plasticity forces. In this way, any kind of desired non-physically based deformation can be applied to the tetrahedral mesh (see [Garcia et al. 2007] for more details). Using the algorithm to control the deformation of the physically based simulated objects, the technique described by Chenney [2002] to control the level of squash and stretch was used. We extend their approach by adding elastic body physics and with a few modifications to the deformation variables.

Our algorithm basically consists of the following steps:

1. The velocity of the center of mass is computed v_c.

2. Depending on the modulus of the velocity, the scale factor s is computed:

$$v_\alpha = \begin{cases} |v_c| - \alpha, & if |v_c| - \alpha > 0 \\ 0, \end{cases} \tag{2}$$

$$s = \frac{|v_\alpha| s_m s_c + 1}{|v_\alpha| s_c + 1} \tag{3}$$

   where s_m is the maximum stretch factor, s_c is rate of stretch, v_c is the mass center velocity, v_α is a threshold velocity used to compute the scale factor s and α is a threshold value. s_c, s_m and α are defined bye the user.

3. To compute the stretch deformation gradient S on the undeformed configuration, a rotation R_v is applied to the model to align with the velocity as in [Chenney et al. 2002].

$$S = \begin{bmatrix} s & 0 & 0 \\ 0 & \frac{1}{\sqrt{s}} & 0 \\ 0 & 0 & \frac{1}{\sqrt{s}} \end{bmatrix} R_v \tag{4}$$

4. Our model uses the Cauchy strain tensor to measure the deformations. This tensor is not invariant to rotations so, by using the polar decomposition, the rotations are removed from the matrix leaving a pure scale-shear matrix.

5. Finally, the control deformation forces are calculated using the technique described in the previous section.

The squash process is analogous so it will not be described in this paper, but some considerations must be taken into account:

- The squash process starts with a collision. The user must define which collisions are going to be squashed.
- When a squash is going to take place, the system controls the velocity and the rotation of the object. This is done by applying forces to modify angular and linear momenta of the object.

To accelerate the collision detection phase we use a bounding sphere hierarchy. Thus our 3D objects are represented simultaneously by three separate abstraction layers: a surface model used in rendering, a sphere tree used to speed up the collision detection stage and a tetrahedral mesh used to animate the object (see Fig. 1).

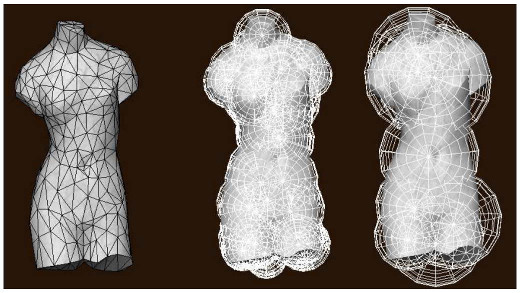

Figure 1: *Multi-layered representation of objects used in our approach shown here with respect to a venus model. Pictured is the polygon mesh used for rendering (left) and two levels of the hierarchical sphere tree for collision detection (center and right). In addition to this, there is a tetrahedral model used in animation (not shown here).*

4 Experiments

The stretch physics engine was evaluated through the three criteria: Accuracy, Attention and Appeal. First, we tested whether tuning the physics with the stylised stretch algorithm helps the user to estimate the movement of an object more easily. Then, we tested if the attention of the user is attracted when animating objects with stretch. Finally, we tested if the animations made using the algorithm are more appealing to the user. Each of the different criteria was validated using a different experiment, which will be described in this section.

A group of 24 participants were recruited for the experiment: 12 females and 12 males. All the experiments were run together in the same session. The first experiment run was the appeal test (experiment number 3). The other two experiments were run in counterbalanced order each time.

All the experiments were run on a DELL XPS710 with an Intel® Core™ 2 Extreme QX6700 2.13GHz processor, 2GB of RAM memory, dual NVIDIA® GeForce® 7950 GX2 graphics cards and a 30” screen .

Data analysis of all the experiments was performed with the help of the software tool STATISTICA from STASFOT ®

4.1 Experiment 1

This experiment was designed to examine whether stretching objects along their trajectories gives cues to the users to estimate the trajectory of an object, helping him them to perform certain tasks. To do so, the experiments proposed by Nusseck *et al.* [2007] to predict the trajectory of a bouncing ball were reproduced using the NPS and CPS engines.

4.1.1 Scenario

The scenario was built using our physically based engines for the simulation and *Coin3D* for the rendering. In this experiment the ball falls vertically from a fixed starting position onto a small platform. This initial platform is inclined at 63 degrees so that the ball acquires horizontal velocity after colliding into it. A second platform is placed following the first one. The second platform is horizontal and much larger than the first. The ball can bounce on this platform until it reaches the edge. At this point there is a paddle, which the participant can move along the x-axis using the mouse to catch the ball. The overall scene is similar to Nusseck *et al* and can be seen in Fig. 5.

The vertical distance between the ball’s starting point and the first hitting point is 355 units. The second platform is placed 5 units below. The width of the second platform is 180 units. The paddle width is 20 units and it can be moved within a range of 180 units. Finally the ball radius is 5 units. The stylised ball was stretched by 80% when it reached its maximum velocity.

The ball casts a shadow at all times, which is caused by a light placed at the top of the scene. The ball is animated using 6 different restitution coefficients ($R_1 = 0.7,\ R_2 = 0.75,\ R_3 = 0.8,\ R_4 = 0.85,\ R_5 = 0.9,\ R_6 = 0.95$) which control the output velocity of the ball after the collision. These coefficients are used to simulate the different range of elasticities. Usually only one bounce onto the second platform takes place except when the ball is animated using R_1 (where two bounces take place) and R_6 (where no bounces take place). R_1 and R_6 were not taken into account in the result analysis. We have used 6 different elasticities instead of nine, as in Nusseck *et al*, because the balls are simulated using both NPS and CPS.

The ball deforms when a collision occurs and the deformation is controlled using our FEM based algorithm. These deformations are driven using the same *Young* modulus and *Poisson* ratio, without considering its restitution coefficient. This means that all the balls are going to have the same deformation behaviour. Air resistance is not taken into account during the simulation.

4.1.2 Task

The simulation starts when the user presses the start button. At certain points, the simulation is stopped and the user is asked to place the paddle where the ball is going to fall. When the participant has done this, he should press the button again, after which point, the participant can no longer move the paddle, which becomes red to indicate this.

4.1.3 Experiment description

In this experiment 3 factors were tested:

- 6 possible elasticities ($R_1,\ R_2,\ R_3,\ R_4,\ R_5,\ R_6,$)
- 3 different stopping points:
  - Far point: The ball is stopped when it reaches its highest point after the first collision point
  - Mid point: The ball is stopped in its second collision. This case never happens with R_6
  - Near point: The ball is stopped in its highest point after the second collision. This case never happens with R_6
- 2 animation engines (NPS and CPS)

Participants performed all cases twice in random order. Before each simulation started, the platform was placed either at its right-most or left-most possible position, chosen randomly.

4.1.4 Results

In Experiment 1, we examined whether participants' trajectory prediction accuracy increases when the stretch principle is used. Accuracy was measured as the absolute value of the distance between the paddle and the centre of the ball when it reaches the level of the floor. In each experiment, three variables were modified: the ball stopping point, the restitution coefficient and the stylisation. The experimental data obtained was analyzed using a three factor (elasticities, stopping points and animation engines) ANalysis Of VAriance (ANOVA) followed by a post hoc analysis which was performed using the Newman-Keuls test. As presented below, the results of this analysis showed that participants estimated the trajectory of the deformable bodies better when stylisation was performed. We found main effects for the three variables.

Stopping point main effect: the less information the participants have the less accurate their predictions are. Therefore, better results were gathered when the ball stopped at the near point, worse results were obtained at mid stopping point and the worst results were obtained when the ball was stopped in the third stopping point. These results were statistically significant ($F(2, 46) = 127.46, p < 0.00001$).

Elasticity main effect: the bounce of the ball also affects the accuracy ($F(3, 69) = 25.503, p < 0.00001$). With higher elasticities (bigger bounces) worse errors were obtained. R_5 was significantly different to all other restitution coefficients ($p < 0.0002$) having the least accurate results.

Stylisation main effect: stylisation also affects the results collected significantly ($F(1, 23) = 12.839, p < 0.002$). We found that with the cartoon physics, the accuracy increased.

We also found interactions between stylisation and the other two factors: stopping points ($F(2, 46) = 20.805, p < 0.00001$) and elasticities ($F(3, 69) = 5.3843, p < 0.005$).

Stylisation/Stopping point interaction: stylisation is particularly important when the user has less information. When the ball was stopped in the far stopping point, the cartoon physics increased the participants' accuracy. This result is particularly significant in comparison with the others stopping points ($p < 0.002$). On the other hand, the differences obtained between the stylised and the non-stylised simulations when the ball was stopped at the mid position and the near position were not significant.

Stylisation/Elasticity interaction: when the ball bounces are bigger (higher elasticity) the stylisation also helps to reduce the error. For R_5 and R_4 the animations driven using the CPS engine received significantly better ratings than for the NPS engine ($p < 0.001$). The results obtain for R_4 were improved with stylisation, approaching the same results obtained with R_3. It was also found that the stylisation did not affect the accuracy recorded for R_2 and R_3.

Fig. 6 summarises the results described above.

4.2 Experiment 2

The aim of the second experiment was to check if the CPS attracts the attention of the participants more than the NPS.

4.2.1 Scenario

In this experiment the screen is divided into four. Each viewport shows the same scene: two side walls and some moving obstacles. These obstacles have the same movement in the four scenes.

Three balls fall one after the other at dispersed intervals from the top of the screen in every viewport during the simulation. Each of the three balls appears at the same instant in the four scenes, and just the starting x-axis position of the ball changes from one viewport to the other. The movement of the balls in two viewports is controlled using NPS and in the other two using CPS. Which scene shows CPS balls and which shows NPS balls is chosen randomly each time. The balls were stretched by 80% of their initial size when they reached their maximum velocities.

Five unit radius balls are used. The height of the walls is 220 units and they are separated by 90 units. Fig. 2 shows the layout of the experiment.

Randomly, one ball in every viewport has a three letter word appear on it for half of a second. 60 words were taken from the 2000 most commonly used English words[1]. A maximum of 24 words are shown per simulation.

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[1] The list was develop by Rob Waring and can be downloaded from http://www1.harenet.ne.jp/ waring/vocab/wordlists/vocfreq.html

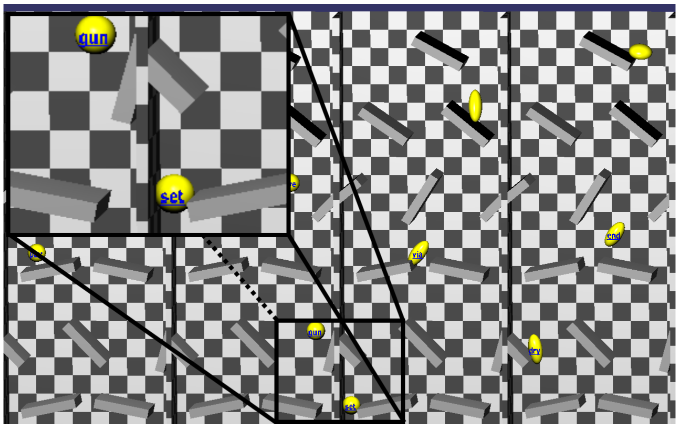

Figure 2: *Experiment 2 layout. As can be seen in this figure a 3 letter word appears in front of some balls*

4.2.2 Task

The participants are asked to read with a clear voice as many words as they can. These words are recorded and when the simulation ends they are also asked to write down the words that they remember.

4.2.3 Experiment description

The user is placed in front of the 30” screen with his eyes at the same height as the centre of the screen and 110cm away from it.

The participants are asked to run the experiments 3 times.

4.2.4 Results

These experiments were run to check if the attention of the participants was concentrated on the objects animated using the CPS engine. The premise was that a users’ gaze would be attracted by the squash and stretch and this would lead to them reading more of the words that appeared upon the stylised balls. We have not found evidence proving that users focus their attention more on the stylised animation than on the normal ones. Two capacities were measured: the participants’ attention and the participants’ memory. In both tests the results gathered were similar.

In the memory test, taking the average of 3 runs, the participants remembered 7.3 words that were shown over a non-stylised ball (52%) and 6.7 words that were shown over a stylised ball (48%). No differences in results were statistically significant. Taking the average of the 3 runs, results would indicate that the participant saw the same number of words (10.4) in both cases.

4.3 Experiment 3

In this experiment we tried to measure the appeal of the cartoon-like physics simulation, tested within a game scenario. The participants play two games and then they simply decide which game they like better.

4.3.1 Scenario

This section is subdivided in two parts. In the first one the background is described and then the elements of the game (the enemy bugs and the participants’ space ship).

The game takes place in a scene textured with a checker-tiled background as shown in Fig. 3:

- The user can move the ship only on a plane ($z = 0$)
- Participants can move themselves in a square limited by four walls. Each wall is 200 units wide initially.
- The scene shrinks by 10% of its initial area each 5 seconds. To let the user know the scene is going to shrink the walls blink for 1 second before they are resized.
- The top view of the scene is shown to the user
- When users are touched by an enemy, they lose a life and they are advised by a screen message.
- When the user loses 3 lives, the game ends and their score is shown. The user gets 60 points for each second he survives.

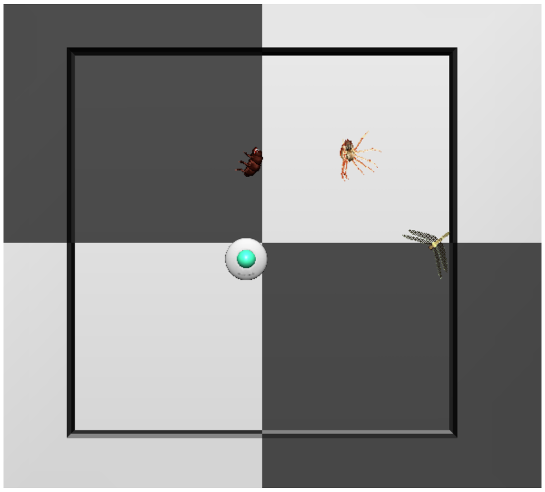

Figure 3: *Experiment 3 layout.*

The user controls the movements of a space ship:

- The space ship is the spherical object shown in Fig. 3 and in Fig. 4.
- It has a 5 unit radius.
- It is controlled with the mouse like pointer.
- The ship is allowed to collide with the walls without loss of life.

The enemies are bugs (see Fig. 4):

- 5 different models were used. In each run 3 of those are chosen randomly.
- The bugs bounce on the walls and undergo deformations similar to the balls in previous experiments. To be sure that the bugs do not stop moving the bug velocity after colliding into a wall is predefined.
- In one of the two games played by the user the bugs are animated using normal physics and in the other they are animated using cartoon-like physics. The stylised bugs were stretched by up to 60% of their initial sizes

4.3.2 Task

The following task was given to each individual:

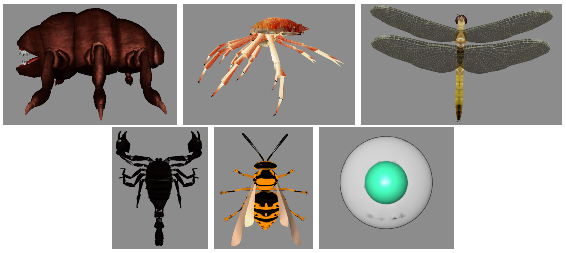

Figure 4: *Experiment 3 elements. The bottom right figure shows the space ship used the others show bugs used*

- Participants should keep their space ship safe from some bugs that move across the scene and bounce off walls. They should avoid colliding into these creatures.
- Every time that a collision takes place the users lose a life. They have 3 lives and when they lose all of them the game is over.
- After playing two games participants are asked to choose which game they prefer.

4.3.3 Experiment description

The participants were asked to play two games and then to choose which game they prefer. In one of the games the bugs are animated following a physically based behaviour and in the other game the bugs are animated using the cartoon-physics behaviour. One game differs from the other in the bugs used and in the algorithm used to animate them. Which bugs are used and which type of animation is run first are randomly chosen each time. As in the previous one the experiment was run three times per participant.

4.3.4 Results

The appeal of the stylisation was measured using Experiment 3. Results indicate that users found the Cartoon physics to be significantly more appealing than the normal physics. The participants chose the stylised animation 63% of the time, which means that the CPS engine was chosen almost twice as often as the NPS engine.

5 Conclusions

In this paper we have studied how a simple animation principle such as squash and stretch [Lasseter 1987] can be used to stylise a physically based simulation and how this affects the three criteria of: Accuracy, Attention and Appeal.

Probably the most interesting results were the ones gathered in the accuracy test. We conclude that stretching the objects in the trajectory direction can improve a participant's precision in carrying out a specific a task. The results indicate that stylisation can be particularly useful in situations were the users have a more difficult task, for example when a bare amount of information is given or when the trajectories of the object are longer, such as in the higher elasticity cases.

The results gathered for the attention test do not prove that the participants' attention can be driven by stylising the movements of the animated objects. This was an unexpected result and it could be due to different factors. The users might have been too concentrated in the task omitting other details in the scene. When a ball shows a word, other balls simultaneously show a word in the other viewports. We think that the participants mainly focus their attention in the viewports which are in the centre of the screen.

In this set of experiments we have also discovered that stylisation has an important effect on the animation's appeal. From the results previously detailed, it can be concluded that cartoon physics could be a useful technique to increase the appeal of many applications and can also help the user to perform certain tasks.

6 Future work

We have found that for some applications, it can be worthwhile to incorporate the squash and stretch principle. As future work we plan to add other principles of animation as outlined by Lasseter [1987] to interactive stylised physics simulations and evaluate their effect on the user using our threee criteria. For instance, motion retiming might be used to add dramatic effect and focus or alternatively to communicate dynamic properties such as the weight of an object or the amount of friction or resistance against its movements.

Unexpected results were obtained when measuring attention. We are working on the design of further experiments to test if the attention of the user could be driven by stylising the animation. These might include experiments using an eye-tracker to measure the amount of time spent fixating on stylised objects over others.

Another compelling area of further study would be the effect of combining stylised rendering with stylised behaviours. Artists often employ effects such as motion lines and motion blur to provide additional cues about the dynamic properties of objects, whilst bold lines or strokes are a well-known technique for communicating weight, smoothness or focus. Furthermore, there has been a number of papers discussing the physically based generation of sounds using computer automated processes. It seems obvious that these too might be usefully stylised to add informational and emotional content to animations. It would be interesting and highly useful if there were a defined measure to determine if various multi-modal cues such as these, could be combined in a constructive way to add attention, appeal and accuracy to interactive animations.

Acknowledgements

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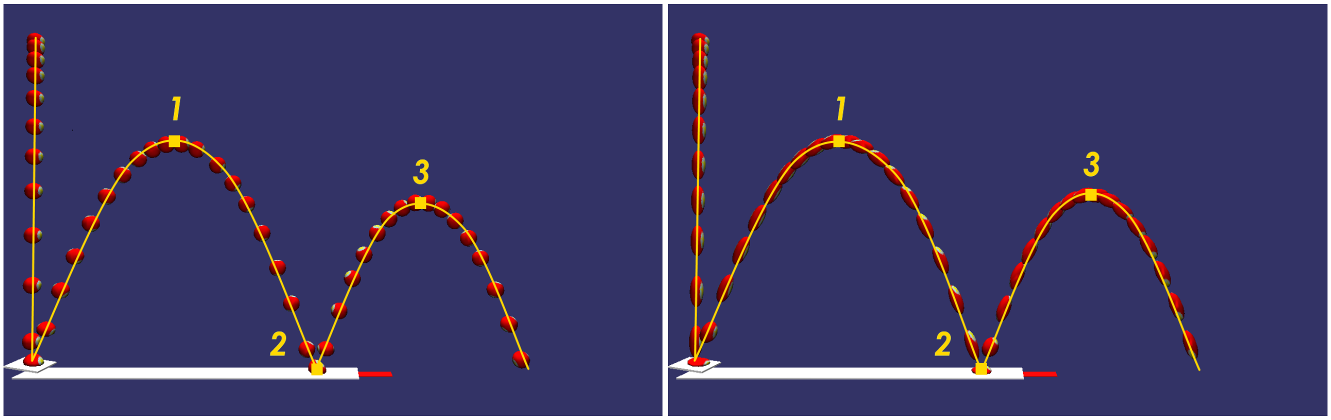
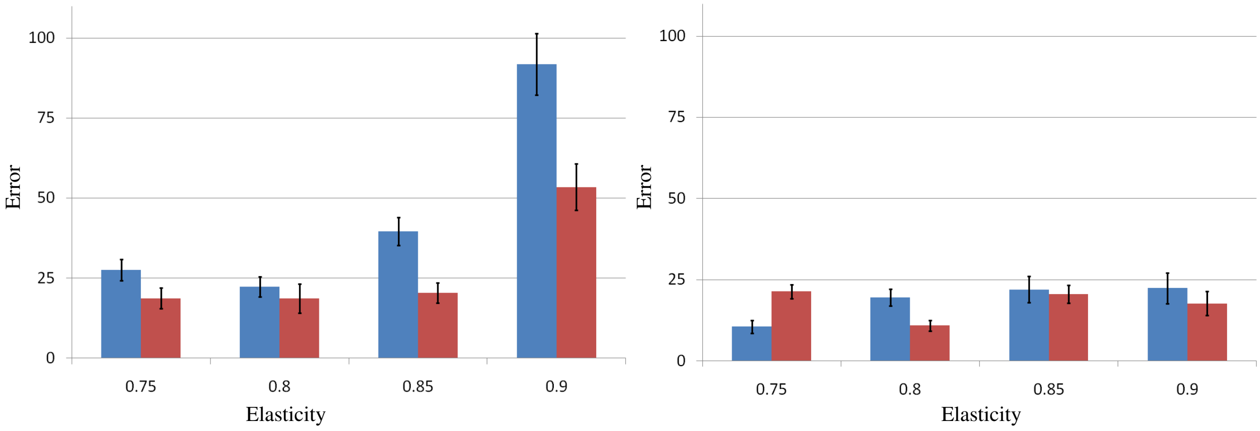
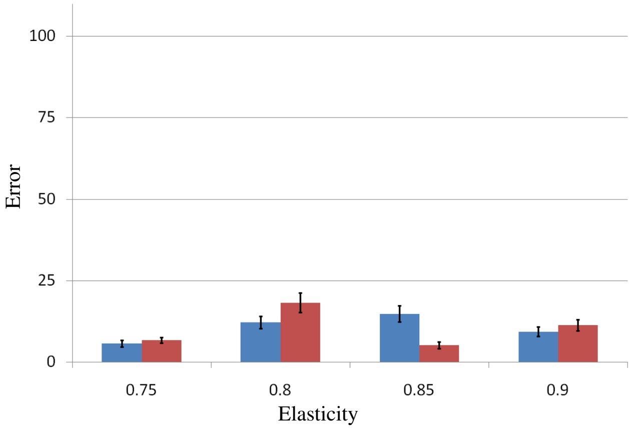


Figure 5: *Experiment 1 layout. These two figures show the layout of Experiment 1, showing the stopping points used: point 1 is the far stopping point, point 2 is the mid stopping point and point 3 is the near stopping point. The figure on the left shows a normal simulation and the figure on the right shows a stylized simulation.*



(a) Far stopping point

(b) Mid stopping point



(c) Near stopping point

🟦 Normal simulation 🟥 Cartoon like simulation

Figure 6: *These graphics show the results gathered in Experiment 3*