Automatic 2.5D Cartoon Modelling

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***Abstract*—2.5D cartoon modelling is a recent technique used for modelling 2D cartoons in 3D, to enable 2D cartoons to be rotated and viewed in 3D. Automatic modelling is essential to efficiently create 2.5D cartoon models. However, existing approaches to 2.5D modelling are based on manual 2D drawings by artists, which is inefficient and labour intensive. In this paper, we present a framework for automatic 2.5D cartoon modelling from 3D models, which provides an automatic approach to constructing 2.5D cartoon models. Our experiments show that the proposed method is efficient and automatic.**

I. Introduction

The term "2.5D" is often used to describe techniques used in video games and animations to simulate 3D scenes using only 2D elements. These include games based on isometric tiles and parallax scrolling where the viewing angles are often fixed. Some other 2.5D methods [4], [2] provide for viewpoint changes, but these methods are relatively limited as they rely heavily on information manually provided by the artists, and thus are inefficient and labour intensive. Recently, Rivers et al. [10] proposed a novel solution for full 3D rotation of 2D drawings, called "2.5D Cartoon Models", which combines interpolation and rendering methods. More importantly, it retains 2D stylistic strokes while rotating in 3D, thereby enabling presentation of elements that are impossible to define using current 3D techniques.

Currently, the building process for such models requires the user to have sufficient drawing abilities and could take a great amount of time and effort as the user actually needs to manually draw a number of 2D cartoons from different views. Defining a curve in 2.5D normally requires much more work than defining it in 2D vector graphics, because a regular 2.5D cartoon model is often defined in 3 or more different 2D planes. The manual process makes the creation of 2.5D cartoon models not only inefficient but also labour intensive. Therefore, an automatic system that allows users to quickly build up a 2.5D model is essential for improving the usability of such models.

In this paper, we propose a framework to automatically construct 2.5D cartoon models from existing 3D models. Some examples are shown in Figure. 1. If a 3D model does not currently exist, then one built using Image-Based Reconstruction methods is also appropriate. The 3D model will then be segmented and converted to a 2.5D model. The overall system framework is shown in Figure. 2. Creating a new 2.5D cartoon model using our system requires very few human operations, and normally take less than 3 minutes. In contrast, creating a similar model manually from scratch requires the user to put in a lot of effort and is very time consuming. On the other hand, our system does not fully take over the role of the artist. Instead, it is a tool to help artists sketch up a 2.5D model, which helps to quickly build models by modifying the sketches.

The paper is organized as follows. Related work is surveyed in Section II. 2.5D cartoon models are described in Section III.

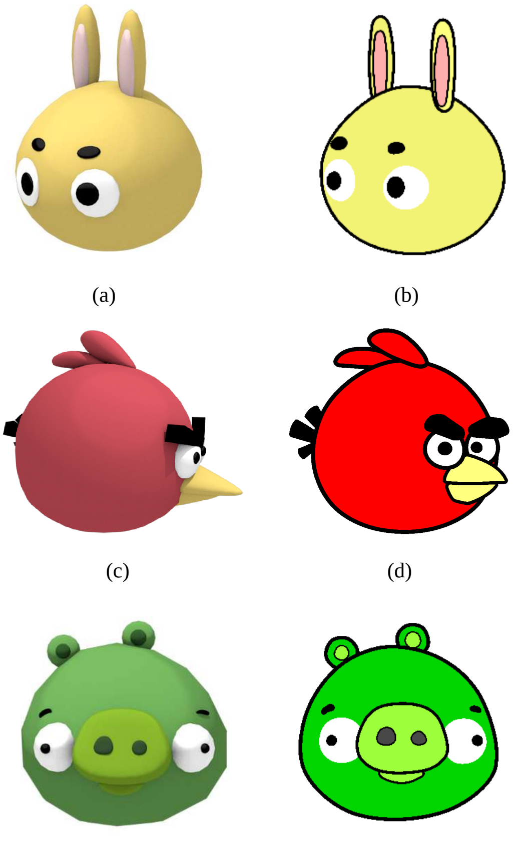


Fig. 1. (a): A 3D model of little rabbit 'Ruby'. (b): 2.5D cartoon Ruby. (c): A 3D Angry Bird. (d): 2.5D cartoon bird. (e): A 3D pig. (f): 2.5D pig.

The proposed automatic 2.5D modelling system is presented in Section IV. Experimental results are in Section V and conclusions are in Section VII.

II. Related Work

Many games, animations and applications utilize techniques for simulating 3D scenes using 2D elements. A large number of 2.5D games have emerged during the last decade, including Isometric-Tiles based games such as “Diablo II”, and Parallax-Scrolling games such as “Super Mario”. Most 2.5D techniques fix the viewing angle to a single position, i.e. they can only simulate a 3D scene at a fixed orientation and lack the ability to rotate and view the scene from any other angle in 3D. This technique may be traced back to the 1800’s [5].

Some recent applications provide 3D rotation for 2D elements. Di Fiore et al. [4] proposed an approach for animation production that generates key frames by interpolating hand-drawn views. Bourguinon et al. [2] presented another approach using 2D strokes manually drawn on 3D planes. These two methods give the artists less freedom than the 2.5D Cartoon Models recently presented by Rivers et al. [10]. The latter is a novel approach for rendering 2D cartoons in 3D. Rivers’ 2.5D model, though, is created purely by manual means. We will take a deeper look at it in Section III. In this paper, we aim to provide an automatic 2.5D modelling technique based on this model.

Recent methods for Image-Based 3D Reconstruction provide good performance and are easier to apply. Using these, one can produce good quality 3D models from photographs taken using hand-held cameras. For the Middlebury Benchmark [11], the most accurate method proposed so far is by Furukawa et al. [6]. The approach of Heip et al. [9] also has good accuracy. We utilize image-based 3D reconstruction approaches to acquire 3D model.

The 3D mesh segmentation benchmark [3] evaluates several approaches to 3D mesh segmentation based on comparisons of human-generated and computer-generated segmentations. The evaluated methods include Randomized Cuts [7], Fitting Primitives [1] and Shape Diameter Function [12]. This comparison allows us to select the most appropriate segmentation approach for our system.

III. The 2.5D Cartoon Model

We now briefly describe the 2.5D cartoon model [10]. Normally a 2.5D cartoon model contains several billboards, each of which is defined in one or more views using one stroke per view, and also has one 3D anchor position, as shown in Fig. 3. The shape of the billboard in a new view is then determined by doing simple 2D interpolation between the corresponding user drawn strokes in existing views.

A. Advantages

The main advantage of Rivers’ model over 3D meshes is that it preserves geometrical cartoon stylistic elements, and not just the appearance style, as provided by Toon-Shading. For example, no matter the viewing angle, Bugs Bunny’s ears are always facing the camera [10]. To present this geometric element in a 2.5D cartoon model, one just draws the ears as they face the camera in all views. This advantage is achieved by defining the shape of the model in each view separately, and editing a shape in one view will not affect its appearance in other user drawn views.

Another advantage is that downgrading an object from 3D to 2.5D also reduces the data size needed to define that object. For example if a 2D point is defined by 2 variables and a 3D vertex is defined by 3 variables, the data size of a 2.5D rabbit model Ruby, as shown in Figure 4, is only 6% as big as the 3D one. The difference may be even larger as we have ignored the link infomation, which 2.5D points usually have 1-2 links and 3D vertexes often have more than 2 edges.

B. Limitations

There are several limitations to Rivers’ 2.5D models. The one that cause the most issues is the simple interpolation technique used to determine stroke shapes in views that are not key views. The simple interpolation may lead to strange shapes in interpolated views, which may also cause different parts of

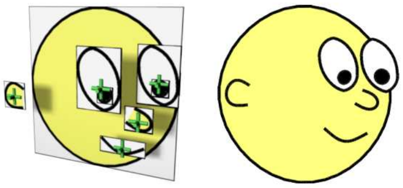
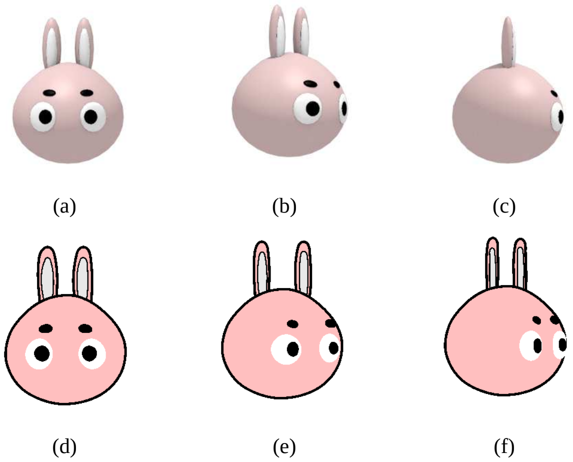


Fig. 3. A picture demonstrating the principle of the River’s 2.5D cartoon models. This simple head model is constructed using 9 billboards, each billboard contains one stroke as its boundary line, a 3D anchor position and a filling colour.



(a)
(b)
(c)
(d)
(e)
(f)

Fig. 4. The front, 45 degree and right view of 3D model (top row) and 2.5D model (bottom row) of ’Ruby’. The 3D model is rendered using Toon-Shading. In order to show the advantages of Rivers’ structure the 2.5D Ruby has been manually edited based on an automatically generated sketch, and we changed the positions of eyes and ears in a side view. The eyes can still be seen even when facing 90 degrees sideways, and the ears appear always facing the camera.

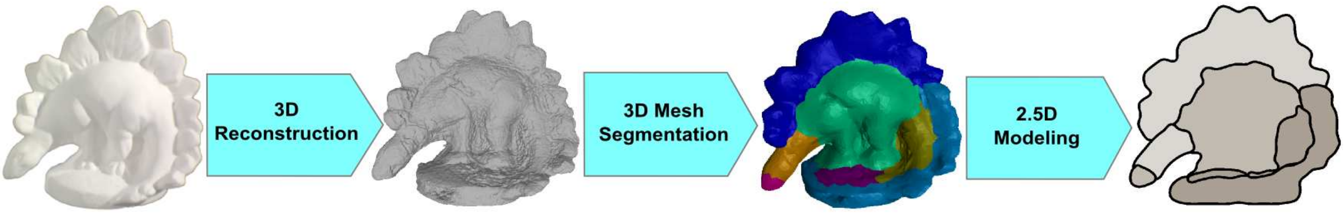


Fig. 2. The overall system framework.

a model to dettach from each other during rotation. At this moment the only way to solve this problem is to define more key views. In Rivers' work, three more key views were defined to make the Alien's arm looks right, as shown in Figure 5. The more views need to be defined the more work artists have to do. While using our system the artist can simply add another line to the commands to generate a new 3D consistent key view, without any extra work.

C. The manual creation process

Normally the user starts from one view position, draws the main part of the cartoon object, changes to another view position and draws the same parts again, then keeps changing to different views as more parts are added to the model. This process may cost an experienced artist tens of minutes to create a little bear, for example [10]. Thus a method to automatically generate 2.5D models would be very beneficial.

The goal of this paper is to automatically generate 2.5D cartoon models. Rivers' 2.5D cartoon model relies on artists during the drawing process to:

i) analyse the spatial and spectral characteristics of the object

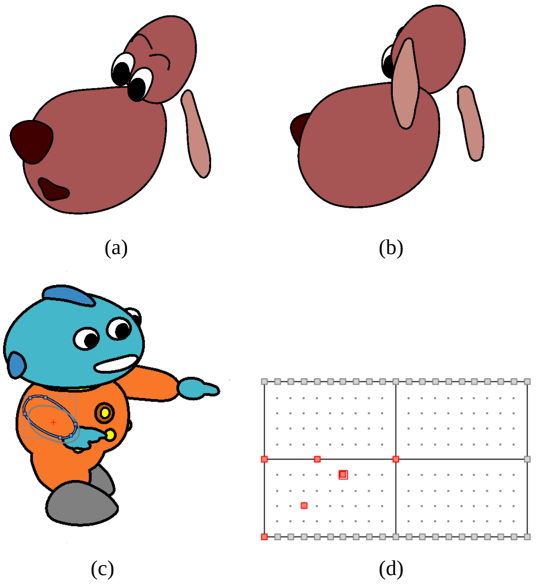


Fig. 5. Notice the ears of the 'Dog' model (a)(b) in Rivers' work [10]. Three more key views (c) are pre-defined to make the arm of the 'Alien' (d) looks right.

ii) segment the object into parts based on those characteristics, and

iii) create a 2D stroke for each part in each view.

Therefore, to automate the 2.5D model construction, we need to simulate the drawing process of human artists by automating each of the steps described above.

IV. Automatic 2.5D Modelling System

Our approach to automatic 2.5D model creation consists of several steps. A 3D model of the desired object should already exist, or constructed from images using Image-Based Modelling methods such as [6]. Segment 3D mesh into several parts using a 3D mesh segmentation method. The segments are then converted into strokes for creating the 2.5D model. The following sections discuss each step.

A. 3D Information Collection

3D information is important for 2.5D modelling, since human artists often use spatial information to segment objects when they create strokes. Also, this information is required to provide 2D object boundaries for creating strokes in any required view. To gather this information, we can construct a 3D model of the object using image-based 3D reconstruction methods. Plausible options include open source software PMVS [6] and Bundler [13], or ready models built manually before.

B. Segmentation

Once we have constructed a 3D model for an object, we can then simulate manual segmentation based on the 3D information. To this end, the segmentation approach should mimic the segmentation by artists and provide similar results. We investigate a set of 3D mesh segmentation techniques and utilize SDF [7], that produces results similar to those of humans. The actual algorithm used in this work will be discussed in Section V.

C. Parts Refinement

After the 3D mesh segmentation, we cannot yet expect the parts are ready to use, because cutting off a 3D mesh from another one makes holes in both parts. If there are multiple holes on a part, from some view angles the camera may see the background through the model. This is not a very rare case, for example if two arms are cut off, in side views the chest will be seen through. The strokes built by parts having a hole on them will lead to wrong billboard shapes.

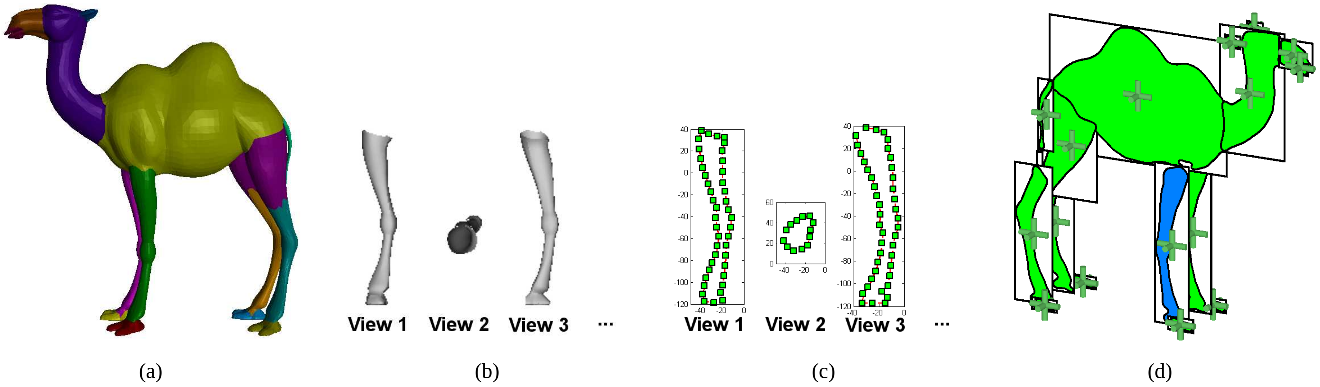


Fig. 6. The process of billboard reconstruction: (a)segmented mesh. (b)the right-front leg part from different views. (c)2D control points of the part. (d)final 2.5D model, with the right-front leg marked out.

To solve this problem, we refine parts using a simple 3D hole filling method, which chooses each time the best pair of adjacent border edges and adds a face between them. Several implementations are available, such as the remeshing filter in MeshLab[1].

D. 2.5D Model Construction

Once we have segmented the object, we can then convert the segments into strokes to compose 2.5D models in Rivers' framework. Specifically, we create 2D boundaries of each part in each view and then convert the boundaries to strokes.

Firstly, we capture the silhouette of a part in a view by projecting the part into an plane that is normal to the view direction. Once the silhouettes are captured, they are converted into strokes as follows. For each silhouette captured, points on the silhouette are sampled, each of which has a 2D position. These points are rearranged to preserve the right order according to their neighbourhood relationships and linked into strokes. We then create 2.5D models using these strokes.

The 2.5D model construction process is demonstrated in Fig. 6.

E. Summary of the Method

The proposed framework for 2.5 cartoon modelling is summarised in Algorithm 1. The algorithm takes a set of images as input, and the output is a 2.5D cartoon model consisting of a set of billboards.

V. Implementation and Experiments

As described in Section IV, our approach requires 3D information of objects. In this experiment we have used existing 3D models such as those provided by Strecha et al. [14] and Chen et al. [3].

Our implementation of 3D mesh segmentation is based on Shape Diameter Function [7] since it has good performance for simulating 3D object segmentation by humans (ranked 2 in Chen's benchmark [3]) and is open sourced.

Algorithm 1 CartoonModelling(I)

```
Initialise $B \leftarrow \emptyset$, $P \leftarrow \emptyset$
$M \leftarrow ImageBasedReconstruction(I)$
$S \leftarrow MeshSegmentation(M)$
for all $s \in S$ do
    for all $v \in Views$ do
        $c \leftarrow CreateContour(s, v)$
        $p \leftarrow SamplePoints(c)$
        $P \leftarrow P \cup p$
    end for
    $b \leftarrow CreateBillboard(P)$
    $B \leftarrow B \cup b$
end for
return $B$
```

Rivers et al. parameterised the view angle space to a 2D grid containing 440 viewpoints. We normally choose the front, left and up views to construct 2.5D models.

We compare models built by our system with models manually created by humans. To make the comparison more convincing, we select the models originally provided by Rivers et al. [10]. As shown in Fig. 7, our system has successfully created models that are close to the fully manually created ones. Comparison of pure 2D and 2.5D scenes of Angry Birds[2] are shown in Figure.10.

The outputs of our implemented system have the same format as Rivers' system, thus models built by our system are ready to be loaded directly into Rivers' drawing software. This makes it very easy to do further manual modifications.

VI. Discussion

Rivers' structure is good for presenting abstract cartoons, but not suitable for models that have long thin shapes, such as tables and chairs. This is because of the limitations of Rivers' structure as discussed in III-B. Complex objects that are not combined by round shapes, normally need more key views to make them look right during rotation. Having many key

[1] meshlab.sourceforge.net

[2] A famous mobile game created by Rivio.

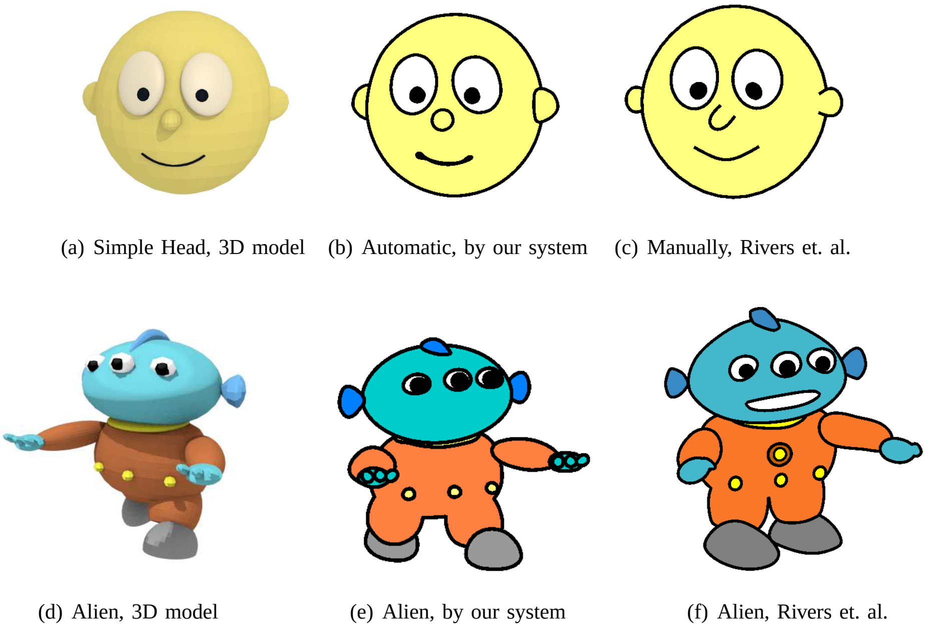

(a) Simple Head, 3D model
(b) Automatic, by our system
(c) Manually, Rivers et. al.
(d) Alien, 3D model
(e) Alien, by our system
(f) Alien, Rivers et. al.

Fig. 7. Some 3D models, example 2.5D cartoon models built using our system (with colours manually adjusted), and manually created 2.5D models by Rivers et. al. [10], shown for comparison.

views makes a 2.5D cartoon model inefficient to render. So converting complex 3D models to 2.5D may not be practically useful in such cases. Therefore, we assume the input models of our system are in the first place suitable for Rivers' structure.

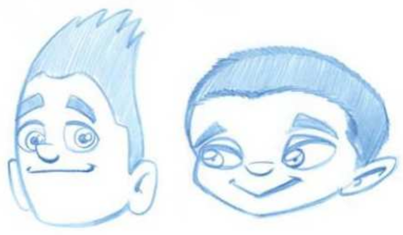


Fig. 8. In some cases, whether the nose stroke is open or closed depends on what style the artist wants to present [8].

Our system is a general system, which means that the system does not consider the a cigar and the fingers holding it as different kinds of objects. In some cases there are different ways that an artist might use to present a 3D shape, for example as in Figure.8. In other cases, when a shape obviously should be left open, such as fingers on palm, our system does not automatically keep that stroke open. This is left to the users for now. Improvements to help the system learn different kinds of objects is a possible direction of research.

Once a sketch has been built by the system, it could be very easy to add new features on the sketch, as shown in Fig. 9.

VII. Conclusion and Future Work

In this paper, we have presented a novel approach for automatic 2.5D modelling. Our system is able to produce 2.5D models from real-world objects through 3D meshes with minimum human monitoring. It is helpful to artists who want to preserve stylistic 2D elements provided by the 2.5D cartoon model and reduce manual labour. To the best of our knowledge, there is no existing work on automatic 2.5D cartoon modelling, and our approach is the first solution to this problem.

Though able to create fully functional models, our system should be considered as a sketching system, that saves artists from basic labour intensive work and lets them focus on the more creative parts, such as colour and style.

In future, we plan to implement more practical software and

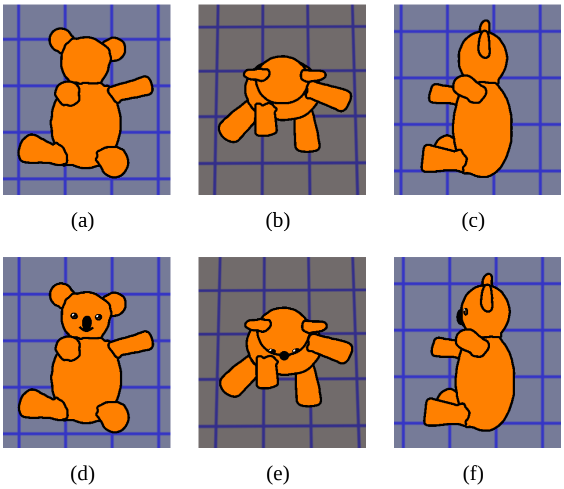
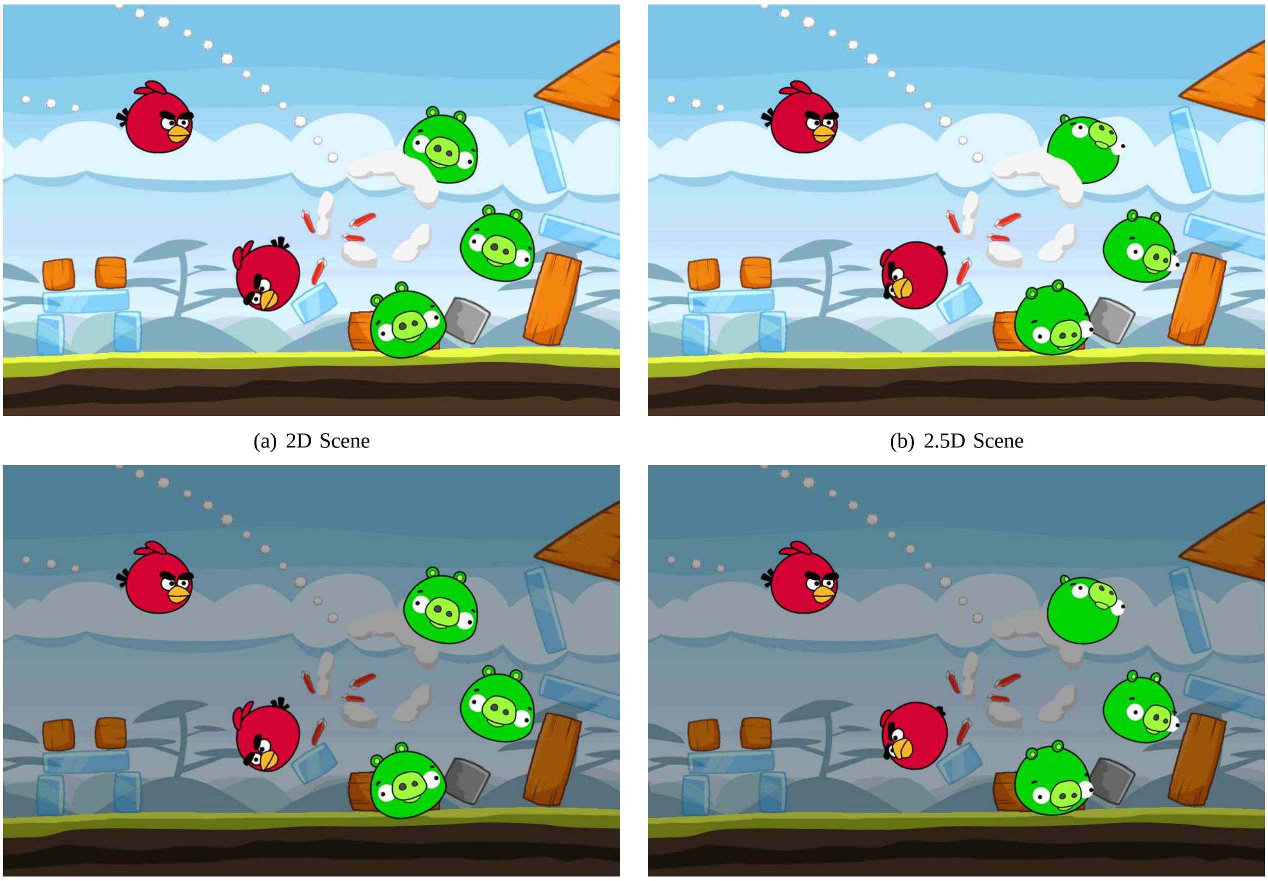


Fig. 9. Top: A bear model created by our system. Bottom: With only a few manual changes to the automatically built bear, a koala model is created.



(a) 2D Scene

(b) 2.5D Scene

(c) 2D elements highlighted

(d) 2.5D elements highlighted

Fig. 10. 2D and 2.5D scene of Angry Birds, with comparison of pure 2D and 2.5D elements in scene. 2.5D cartoon birds built using our system.

improve the billboard reconstruction algorithm to gain better results.

Acknowledgements

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