# OBJECTS VISUALIZATION IN DIGITAL TERRAINS USING ADAPTIVE VIEW-DEPENDENT TECHNIQUES

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Abstract: There are many applications involving featured terrains visualization. One of them is for gaming purposes. However, when dealing with real data, many of this applications fail to cope with such information. So, this work presents an efficient way to minimize or even remove this kind of problem. We propose a method based on image-based rendering and view-dependent visualization techniques. These methods were applied in terrain visualization with real vegetation data where distribution and type is determined from digital satellite images.

## 1 INTRODUCTION

There are many problems related to real-time visualization and simulation of featured terrains and some of these problems were already solved by a large number of computer graphics researchers. However, the problem of efficiently rendering featured terrains is still a challenge as recent demands for larger and more complex terrains are leading to an increase in the number of objects to be rendered. Depending on the current amount of objects to be rendered on each frame, the final results can be unsatisfactory because many applications are not well prepared to deal with such amounts of information.

Nowadays we can find many terrain visualization and simulation applications that require the display of objects with dense distribution. In many cases, the objects are vegetation data which include forests with many different elements as trees, bushes, grass and so on. Examples of works that have investigated the problem of visualization of vegetation data on terrains are (Lluch et al., 2004; Jakulin, 2000; Dietrich et al., 2005). In this work we also deal with the problem of rendering terrain with dense vegetation and part of the motivation is from the problem investigated in a previous work (Savelli and Beauclair, 2006).

In (Savelli and Beauclair, 2006), a satellite image was used extensively to help composing a certain visualization. First of all, the authors used the own satellite image as the terrain texture. Later, the authors have shown how to classify different kinds of vegetation using only information provided by the satellite image by applying a method based on the combination of wavelets representation and the split-and-merge algorithm for grouping similar information. The solution that was proposed was able to place a large number of elements on the considered terrain in a semi-automatic way.

The work presented here suggests a natural continuation based on the previous results where a simple, but efficient method, integrates a group of visualization techniques based on image-based rendering with level of detail representations (Akenine-Mller and Haines, 1998). The aim is to solve the problem of terrain rendering with a large amount of vegetation data. To be more specific, we propose a scheme that combines multi-resolution billboards representation with a mechanism for object rendering in which density may vary according to related camera position and viewing angle. In addition, a hierarchical structure is used in order to represent, in an efficient way, billboards collections placed on terrain.

The document structure is organized as following: in section 2 we discuss some important fundamentals and some relevant works associated to them; in section 3, we describe the proposed method giving a brief

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explanation on the first sub-section and a more detailed one on the following sub-sections; in section 4 results are presented from the implementation of the methods described in section 3. In section 5 we discuss probable future works. Finally, in section 6 we present a conclusion and some considerations.

# 2 MODELING TERRAIN AND OBJECTS

In general, interactive terrain visualization algorithms are rather complex. For this reason, in the last decade, the subject has received attention from many researches from all around the world. Hence, many strategies and solutions were developed since then.

In computer graphics, a terrain is basically a graphical object where a surface is used as the main geometrical support. Commonly, this surface is represented as a triangulated network where every single point has attributes and information provided from one or more texture maps. So, a given geographical region is modelled as a graphical three-dimension terrain composed by a triangulated network and a georeferenced texture. The final result is an empty terrain with no objects on it. All user can see is some elevation and geographical accidents like rivers and lagoons.

## 2.1 Terrain Level of Detail

In many cases, terrain data are represented by a huge amount of triangles and textures with very high resolution. In such conditions, simpler strategies are no longer capable to deal with all information for real time interaction. In order to avoid this problem, other sophisticated methods must be used. Such methods must take into consideration the properties of the scene as well as some intrinsic characteristics of visualization processes as existing spatial and temporal coherence in the environment.

Most actual methods agree that, in real time visualization algorithms, the more distant from the observer a given region is, the less refinement is necessary. This is a usual way to cut off unnecessary processing without harming the visualization quality.

The need for different levels of refinement have led developers to use a hierarchical structure where every element represents a small terrain fragment in a certain level of detail. Frequently, these structures determine a recursive terrain subdivision producing many regions that can be regular or irregular. In addition, it is necessary to define one or more schemes which are capable of determining the best representation, for each region, as a function of distance and observer position. In order to determine the level of detail used, these schemes evaluate the projection error between the chosen level and the most refined one (absolute error metric). Or optionally, between the chosen level and the refinement level immediately above in the same considered hierarchy (relative error metric).

Among all proposed works involving level of detail terrain visualization, two of the most significant are those from (Lindstrom and Pascucci, 2001; Lindstrom and Pascucci, 2002). The terrain visualization method implemented in this work follows the same principles and ideas described in both references (Poyart et al., 2002) and (Lindstrom and Pascucci, 2002).

## 2.2 Image-Base Object Modeling

Featured terrains are commonly useful for a very large application range such as simulations and games. The most difficult task consists in dealing with both terrain and object data because the latter can be very complex and numerous. A good example is a large terrain with very dense vegetation on it.

Likewise in the case of empty terrains, it is also possible to apply the same ideas and approaches of view-dependent level of detail to every single object spread all over the terrain surface. However, in some cases like, for example, forest visualization, the number of objects can be so huge that even variable level of detail geometric modelling may be insufficient to keep interaction in usable rates. In such cases, a reasonable alternative is to change completely or partially the representation from geometric models to image-based rendering structures.

Nowadays there are many image-based rendering visualization techniques including some simple ones like sprites and billboards and others much more sophisticated that in practice require implementation in Graphic Processing Units (GPUs), like depth sprites (Pharr and Fernando, 2005) and relief textures (Oliveira et al., 2000).

### 2.2.1 Sprites and Billboards

Sprites are graphical objects described, in most cases, by planar textured surfaces. The given texture is basically a snapshot from an object (real or synthetic) taken from a given point of view. In many cases, two textures are placed in a perpendicular way in order to produce a better approximation to 3D shapes as, for example, in the representation of trees.

A billboard is a graphical object similar to a sprite, however, differently from it, a billboard must rotate itself in order to always face the observer, producing the illusion of a three-dimensional effect in the visualization process (McReynolds and Blythe, 1998).

Supposing that we are only interested in image-base structures which require the less possible complexity, we tested both sprites and billboards strategies in a essay to figure out the most adequate one. Figure 1 shows a little group of trees using only sprites while Figure 2 shows only billboards trees.

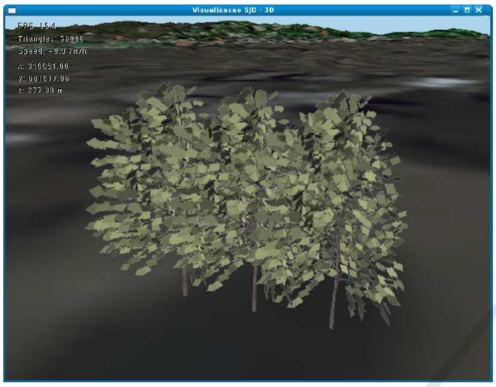


Figure 1: Trees represented as sprites.

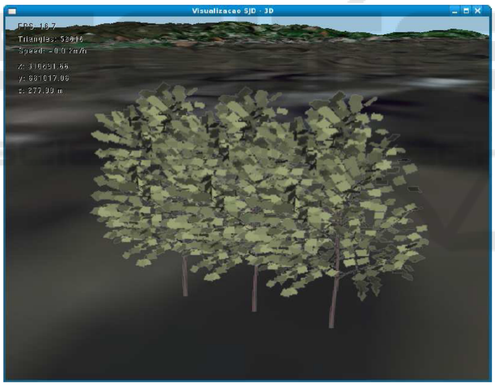


Figure 2: Trees represented as billboards.

In the beginning, we expected that sprite structures would require less computational effort than billboard structures. However, practical tests have shown exactly the opposite, frustrating our initial expectation. As we could observe, at each frame, drawing sprites is usually much more expensive than drawing the equivalent billboard. It became evident that graphical processing units can draw a textured polygon, evaluate a rotation matrix and finally, deal with all basic operations faster than drawing two static textured polygons. As we can see in Table 1 and graphically in Figure 3 when adding more and more trees to a given terrain, the frame-per-second taxes based on sprite structures reduced faster than when using billboard structures.

Table 1: Billboards vs sprites performances.

| Number of elements: | Frame-per-seconds: | |
|---|---|---|
| | Billboards: | Sprites: |
| 50 | 40.0 | 40.0 |
| 100 | 40.0 | 40.0 |
| 200 | 33.3 | 25.0 |
| 300 | 28.6 | 20.0 |
| 400 | 25.0 | 16.7 |

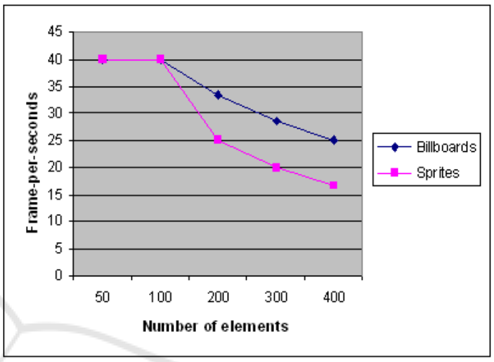


Figure 3: Billboards vs sprites graphic performances.

All values in Table 1 were obtained by running a very simple terrain visualization in a 1.6 GHz Intel 4 processor with 512 MB RAM memory and 256 MB GeForce FX5200 video graphic card.

As a consequence of the results, we decided to use a billboard-based strategy as the main representation structure in our method. However, sophisticated techniques like depth sprites and relief textures can be also used for more realistic results.

It is important to say that another strategy that was considered is the representation of vegetation elements by models generated by procedural strategies as, for example, L-Systems, using geometry shaders. Although such strategy seems promising, the use of geometry shaders has not produced competitive results yet, when large number of objects must be rendered. The cause for such poor performance is due to limitations in the buffer elements in current architectures. In the near future, it is expected that this limitations will vanish as it is becoming evident with the new generation of graphics hardware.

## 3 THE PROPOSED METHOD

All proposed techniques in this section are simple but efficient and belong to the group of image-based and view-dependent visualization problems. They are based in two main fundamental ideas: first, the use of different image resolutions to represent three-dimensional objects. Second, a technique which enables the variation of the density of the vegetation distribution, depending on the distance to observer.

### 3.1 Overview

In a previous work, using methods and practices cited in (Savelli and Beauclair, 2006), we distribute some vegetation types all over the terrain by computing their positions from satellite images. Here, for every vegetation element, we built a set of textures from five viewing angles in different digital resolutions. They include front, back, left, right and top views. In run-time and given a point of view, it is possible to create, dynamically, a radial partition of the terrain into three different regions in which we associate different levels of density for the vegetation distribution. The idea is to use less elements if the distance to the observer is sufficiently large., use a medium density for the intermediary regions and finally, draw all elements individually in regions close to the observer.

Once decided which density to use, we select one of the five viewing angle billboards according to the camera orientation. Next, we must choose the appropriated resolution level according to distance between camera and billboard. So, on the following subsections, we describe in details every necessary step to compose the final visualization.

### 3.2 Billboards Construction

An important key to get an acceptable object representation is to pick up a good texture to it. In the Internet, there are many images that could be used as tree textures, however, we opted to generate textures from three-dimension polygonal models. The reason to do so is simple and it is based on the idea that, once you have the model, the creation of all discussed viewing angles become more controllable and flexible increasing the chances to match our expectations in the process of texture creation.

In this work, we capture texture images of objects to create billboards. For that task, a software component was integrated to our visualization application in order to read and render three-dimensioned models described in .obj format in a separated frame buffer. This technique is also called frame buffer objects.

We also know that billboards are used with much more efficiency when objects have axial symmetry. When such symmetry is not present, billboards use tend to be limited. A classical technique called impostors (Schaufler, 1995) consists in generating dynamic billboards just for small scene parts where approximation error is significant. In this work, we do not use impostors and instead, we propose set of billboards having a single texture for every orthogonal projection located in the top semi-hemisphere as shown in Figure 4.

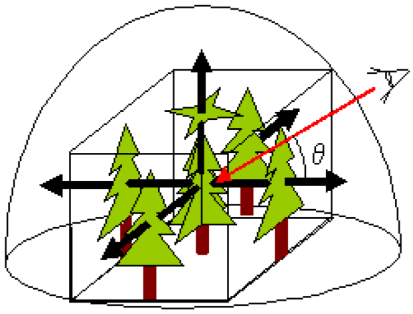


Figure 4: Billboards set and its orthogonal projections.

In our implementation, we get five textures where each one represents a different viewing angle of an object. In case, those five orthogonal textures are: front, back, left, right and top. In the visualization process, we select the billboard that has the minimum difference between the creation angle and the viewing one. Even with rotation transforms being applied to billboards, a special care is required in order to guarantee continuity when textures must be swapped. This could be solved by using 3D-warping techniques (McMillan, 1997) as we know all depth maps involved in such operation.

### 3.3 Elements Density Determination as a Function of Distance

It is known that, the more distant to observer an element is, the less vegetation details can be noticed. We have simulated this notion by discarding some very distant vegetation elements, saving CPU processing in rendering time.

In Figure 5 we can identify three distinct vegetation groups with different distances between them and the observer. The first group is the closest group to the observer, located in the bottom of the figure. The second group is around the middle of the figure, in an intermediary distance to observer. Finally, group three can be found on the extreme top part of figure being the most distant from all the analyzed ones. Looking at each individual group is is possible to notice how densities may vary according to distance.

In order to get the presented effect, we adopted the common level-of-detail technique. This technique is very useful to simplify three-dimensional model networks as described in (Chamberlain et al., 1996;

Figure 5: Billboards with adaptive density.

Funkhouser and Squin, 1993). In our case, level-of-detail was adapted to cut off some very far away billboards. The point is to do this in a smooth way without harming the visualization. For that, we divided the not culled terrain part into three different regions with distances $d_1$, $d_2$ and $d_3$ to the observer according to Figure 6. We decided, by experiments, that for a good visualization effect we must display 100% of elements in the first group. In the second one, only 80% are shown. Finally, in the last group, we have to cut off 50% of elements. After distance $d_3$, no elements are displayed.

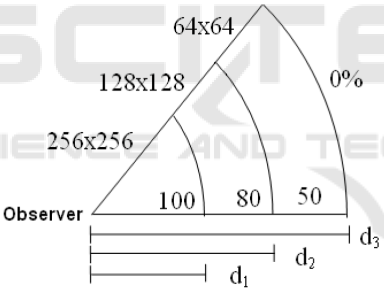


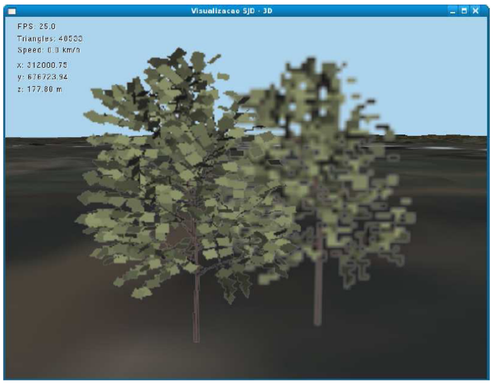
Figure 6: Mult-texture billboard distribution as function of distance.

## 3.4 Multi-Resolution Billboard

In order to increase even more the frame rates, we also include a multi-resolution representation for every created billboard. In Figure 7, there are two billboards with different resolutions. The left one has a 256x256 pixels texture while the right tree has only a 64x64 pixels texture.

The main idea consists in cutting off unnecessary processing changing texture resolution dynamically and at running time. To get the most efficiency, we must attach higher quality textures in billboards near observer and lower quality textures in billboards far enough from observer.

In our case of study, we work with three distinct resolution textures as described in (Jakulin, 2000). Resolutions are 64x64, 128x128 and 256x256 pixels. Figure 6 shows how we select texture resolution as a function of distance $d_1$, $d_2$ and $d_3$.



FPS: 25.0
Triangles: 40533
Speed: 0.0 km/h
x: 312000.75
y: 676723.94
z: 177.80 m

Figure 7: Mult-texture billboard distribution as function of distance.

## 3.5 Objects Grouping

The multi-resolution billboard method and the variable density distribution mechanism yielded nice results, however, the final visualization did not reflect precisely the real distribution as presented in satellite images. To avoid this sort of problem, other techniques must be used, such as level of detail and adaptive grouping.

Here, we consider that, if some vegetation element is sufficiently distant from the observer, the angular variations to make its billboard face the viewer would be so small that a set of elements should be represented as a unique group displayed in a single billboard. Thus, depending on the distance and angle visualization we can display now a set of objects as being a single billboard placed onto the terrain, instead of having only individual billboards. For this, we propose then a new method based on collection of imagens in which an hierarchical structure is used to deal with different types of objects grouping.

The objects grouping method applied in this work uses a special data structure based on a quadtree where each node can store a group of images taken from different points of view. The final quadtree has not only individual objects but also groups of objects. By construction, leaf nodes contain only individual objects while internal nodes contain representations of object groups. The set of nodes which have the same parental node can be represented, in a specific point of view, by a single image where all nodes appear together forming a unique group. Consequently, the collection of graphical objects is represented by an adaptive hierarchical structure.

### 3.5.1 Quadtree Structure

To build the quadtree structure, an hierarchical partitioning of the entire terrain domain must be done, where each cell (or node) represents a group of objects in a given level.

The subdivision method is done as following: we start with the root node containing the whole domain of the terrain. If that node contains more than one object, then it must be divided into four equal parts. Otherwise, the subdivision for that node is done. For each leaf-nodes we associate references to a set of predefined textures containing all views such as front, back, left, right and top. This must be done for every vegetation type used in the visualization. In Figure 8, we show a very small example where two kinds of vegetation elements are placed on the terrain. Note that, from bottom to top, internal nodes' textures are built based on their child-nodes. So, groups can be formed by individual objects, by other groups of objects or even by a synthetic polygonal objects, in the case they are available. The process is finished when a predefined quadtree level is reached where a single billboard will be hold too many objects. At this point, the visualization will be compromised and this strategy is no longer applicable.

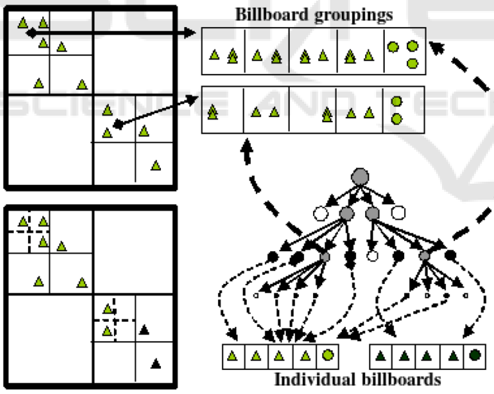


Figure 8: Object grouping representation using billboards.

Note that having only one element in the leaf-nodes is not the only possible solution. It is also possible to have leaf-nodes represent small groups of objects. In cases where terrains have a very dense vegetation, we could set an arbitrary amount of elements as being the minimum displayed group. Those group distributions would be based on the local average distribution that can be computed using basic statistical methods.

### 3.5.2 Selecting Representation Level

In order to have the quadtree structure working on a visualization process, a strategy is required for selecting the best representation level to use in a specific terrain region from the hierarchical billboard collection structure.

This selection must be based on the projection error which depends on factors like distance and angle of visualization. A reasonable error metric can be evaluated as proposed by (Schaufler, 1995) in his work about dynamic impostors.

Given a point of view, we must evaluate the projection error metric for each node starting from the root to the leaf-nodes. If the billboard (with single or multiple objects) has an error metric less than a given threshold, then we use that billboard to represent the whole objects in that region. Otherwise, we descend a level and repeat the same procedure until we reach a node in which the error is acceptable. In the worst case, all individual elements will be rendered and displayed, giving us the worst frame per second rate. However, in practice, this situation will only occur in regions close to observer. In the other ones, a single billboard will appear showing a group of elements and saving lots of time in rendering many objects.

An important comparison must be done about the proposed idea and the impostors technique. Unlike the impostors technique, here it is not necessary to recompute the three-dimensional objects' representation every time they are considered invalid. The main idea here is to use the representations with the largest groups of objects as possible according to the considered threshold. When this is not possible, the algorithm must descend the quadtree nodes, searching the first acceptable level of representation.

In order to illustrate how our structure can be used in the selection of different level of detail, we prepared a very simple prototype using only groups of one, two or three billboards for a small and constant bunch of three trees. The results from that prototype are shown in Figure 9. When the observer is far away from the given bunch of trees, only one billboard with three-trees texture is used. For this example, that is what we call the lowest level of representation. As the observer comes closer to that bunch, the method switches into two billboards now using two-trees and single-tree textures. Then, the selection process continues until all trees in the example are represented in different billboards using single-tree textures only. In that situation, the highest level is now reached.

As seen previously, by grouping objects using the proposed structure, we can render a larger amount of

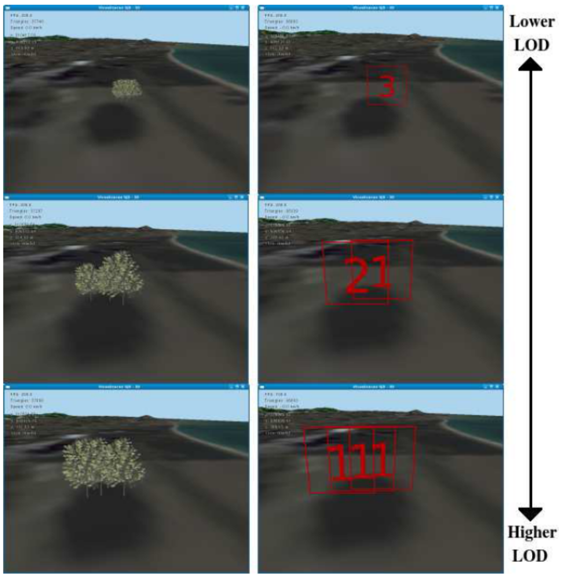


Figure 9: Simple example of representation level using quadtree.

objects with a less number of physical billboards. As a consequence, when using such strategy, we expect to render larger scenes in a more efficient way. To confirm this statement, we compared the FPS rate in both strategies (with and without objects grouping). For test purposes, we used a simple list of objects as data structure instead of a quadtree when no objects grouping are used in the visualization process. This simple structure appears to be useful in our tests and the performance results can be observed in Table 2.

Table 2: With and without objects grouping.

| Objects | List | | Quadtree | |
|---|---|---|---|---|
| | billboards | FPS | billboards | FPS |
| 100 | 100 | 85,9 | 60 | 90,3 |
| 200 | 200 | 69,3 | 125 | 75,9 |
| 300 | 300 | 58,5 | 166 | 67,6 |
| 400 | 400 | 50,7 | 219 | 60,9 |
| 500 | 500 | 45,0 | 266 | 55,7 |
| 600 | 600 | 39,9 | 327 | 49,4 |
| 700 | 700 | 36,2 | 394 | 45,0 |
| 800 | 800 | 33,0 | 479 | 40,0 |
| 900 | 900 | 30,3 | 531 | 36,9 |
| 1000 | 1000 | 27,9 | 641 | 33,0 |

## 4 RESULTS

Every technique presented so far, yields a slight improve in the processing performance. However, the greatest enhancement arises when all techniques are combined and applied simultaneously.

Final results can be observed with a reasonable degree of realism and interactive rates. Figures 10 and 11, at the end of this document, show the final visualization application in two different regions of a given terrain. Note that the frames per second (FPS) rate appear in the top left image corner. With no techniques seen in this paper, the frames per second rates would be around 0.02 for the same terrain and number of objects.

An important point is that it is not always possible to have the perfect equivalence between both strategies. We support the idea that, if the visualization of the environment involves mainly groups that are rather distant to the observer, then the designed approach becomes a very good approximation and viable solution.

## 5 FUTURE WORKS

As future works, we propose a bunch of improvements that solve some of the problems that appeared in the presented techniques.

In the current implementation, when a billboard is beyond a maximum distance, the application stops repainting it on every frame and the object disappears from the terrain. An alternative approach to avoid this abrupt change consists in using a technique called fading where imminent billboards would be removed in a gradual way. Another improvement would consider new techniques to minimize transitions between billboard views. In that case, a three-dimension warping strategy seems promising. Another interesting point is to take into consideration non-photo-realistic rendering techniques which can improve information perception in the visualization process.

## 6 CONCLUSIONS

We presented in this work some techniques based on three-dimension object representation by images and view-dependent visualization. Those techniques helped to handle very large terrains with densely distributed vegetation data . This work is also based on real data extracted from satellite images.

All presented techniques here are simple but efficient and have shown us how important is to consider view-dependent strategies in featured terrains, even with all the advanced hardware resources available nowadays.

We realized that such work is important not only considering the direct results but also understanding its uses in different contexts. Considering the fact that we have vegetation information provided from digital satellites images, this tool could be very useful for helping environment governmental offices and departments to monitor and control devastation in some critic regions. Considering military purposes, we could use this tool as a simulator attending part of new officials training process.

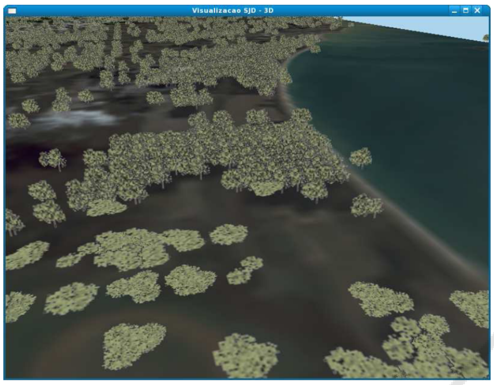


Figure 10: Final composition with 7357 objects using 1824 physical billboards.

Figure 11: Final composition with 10211 objects using 2479 physical billboards.

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