Particle system based visual effects editor

Final report

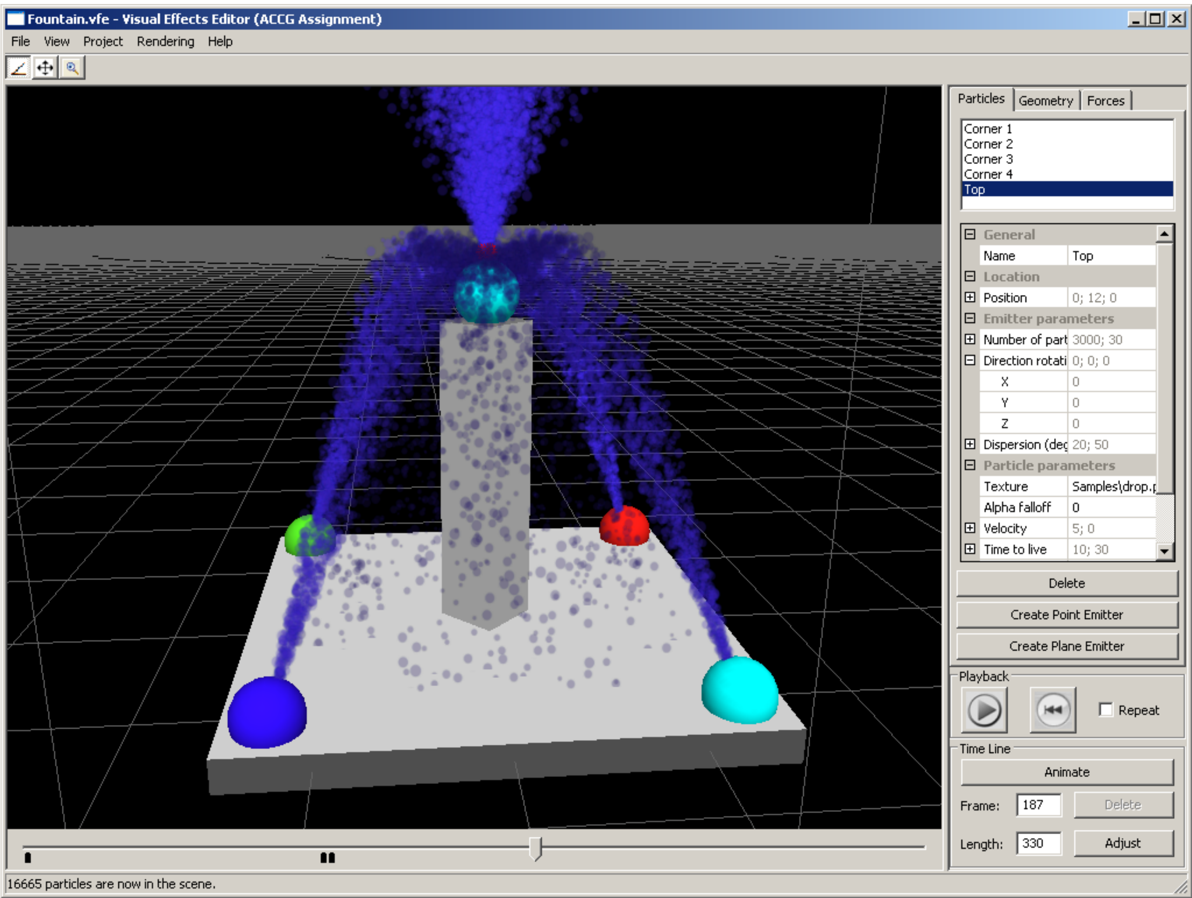
Additional component computer graphics course at Technische Universiteit Eindhoven

2008

1. Introduction

In this work we want to present our visual effects editor, which we implemented as an assignment for Additional component computer graphics course. Program manual is also provided as a part of this report in paper form and for user it is accessible by pressing F1 in application. Source code documentation is available on supplied CD in Documentation folder. Sample render outputs are available on supplied CD in Samples folder (sample source project files are in the Samples sub-folder of the Binary folder).

Our target was to create user friendly tool which could be used by artists to create impressive animations using particle systems. The animation uses key frames in which the parameters of particle emitters can be changed. This way the artist can achieve non regular behaviour of the particle systems. The parameter's values are interpolated between key frames by interpolation curve which can be edited by the artist.



We also wanted to give the artist other things, which could be useful for him. The first thing is placement of some basic geometry (spheres or boxes) which can help to understand dimensions and which improves orientation in 3D space. As the output is only 2D image and particles are 2D textures, the geometry can improve depth recognition. Second, the artist can create forces which will affect the particles. The force is only changing acceleration of the particles, but even using such a simple principle, the desired effects as wind or gravity are achievable.

The usability was one of the most important aspects of the editor. We designed user interface in a way that it should be understandable even without manual. It obeys few principles in all the controls. This fact improved unification and thus it is faster to learn the controls. Of course for more advanced actions as for example animating, the user manual is included. We have left some options mainly about rendering in the menu which are not much useful for user, because we selected the best option as default, but they are there to show that we have tried several ways to achieve better performance of the application.

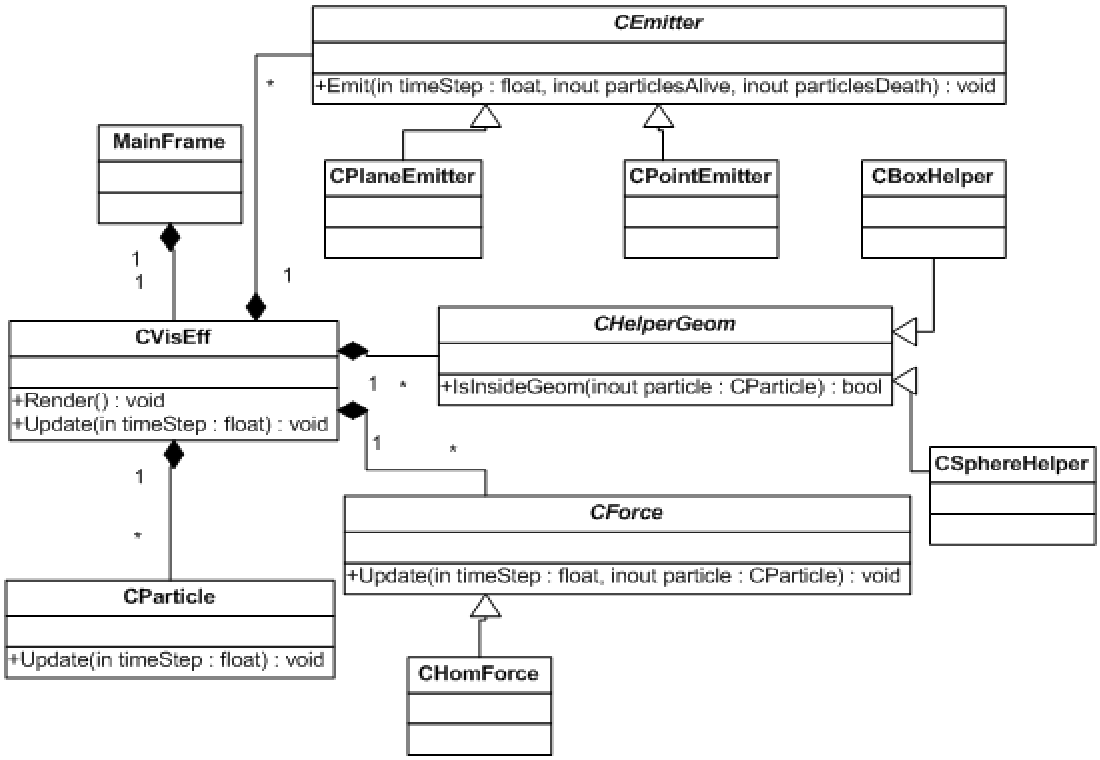
Application requirements were specified in the proposal, but we have made some changes in them, because they were not always smart enough.

The targeted platform is Windows XP operating system and it is useful to have graphic card with hardware T&L. The performance depends heavily on the complexity of the scene. The application is still usable on two year old notebook (Pentium M 1.73GHz, 1.5 GB RAM, ATI Radeon X700 with 64MB VRAM) with about 30 000 particles in scene.

2. Application design and implementation

At first we created graphical user interface with use of wxWidgets library and wxFormBuilder tool. We have implemented OpenGL view port there for interactive view of the scene. We decided that the whole GUI will be kept editable in wxFormBuilder, because our GUI design had not been finished yet. For editing of parameters we used wxPropertyGrid which is not supported in wxFormBuilder, so the handling of this had to be done in source code.

Then we made the decision that the whole user created project will be kept in one instance of class visual effect (CVisEff) which will be owned by the Main Frame of the application. This way we could keep the design of the CVisEff separated from GUI.



Very simplified class diagram to show the basic structure of the system

You can see, that the visual effect is owned by the GUI's MainFrame. The visual effect object is responsible for processing requests from user interface. It also takes care of rendering of all entities in scene (geometry, particles). But of course we separated functionality in other classes also.

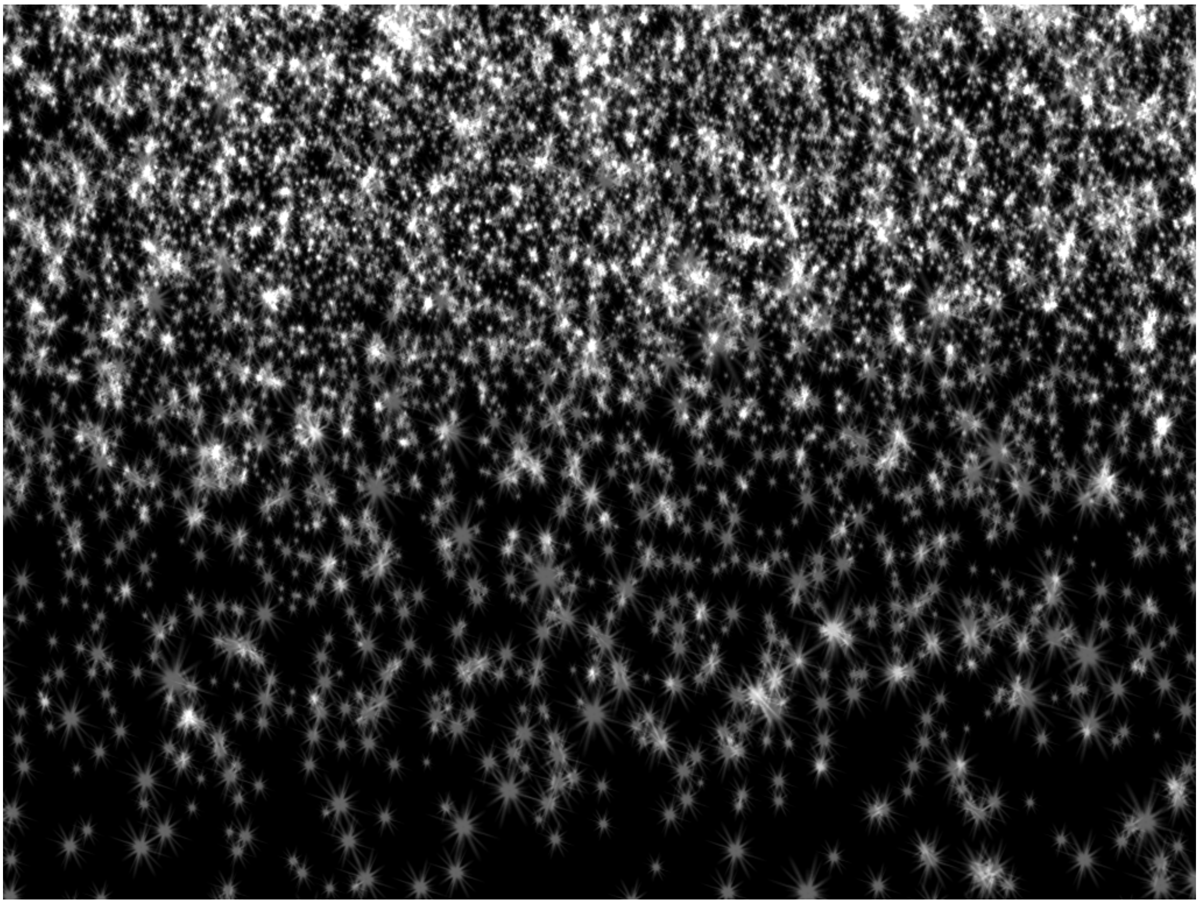
To show how the application works we will describe next, how the particles are managed and updated. This method is one of the most interesting. We will leave out animation part, because we will give it some space later.

3. Managing and updating the particles in the visual effect

The Update method of CvisEff is invoked by user interface. It is called when the user moves a slider to the right side or when the playback is turned on. The parameter of the Update method is timeStep which indicates how much time should pass, which is usually length of one frame (frame rate is 30 frames per second). When the user moves the slider to the left side, which means that the animation is going back in time, the animation rewinds to the first frame and then the Update method is called many times with the timeStep of frame length, until the animation is in the desired frame. This is of course computationally demanding, but it is not possible to do it other way, because the dead particles are thrown away and we would have to resurrect them which might be even more demanding. The CVisEff object holds two lists of particles: alive and dead particles. Alive particles list holds particles which are still alive and should be counted with. Dead particles list holds particles which died. This is good for performance and we will mention it later.

For every living particles few steps are done. First we decrease time to live of the particle, when it is lower than zero, the particle dies and it is moved to the list of dead particles and we do not count with it any more while updating or rendering. If the particle is still alive, we proceed with other computations with it. We try if it is inside a geometry (IsInsideGeom method is used) which has interaction setting set to Kill and if it does the particle is killed and moved to the list of dead particles. If it is still alive we continue with computation of influencing forces. For each force we test if the particle is inside geometry assigned to the force (IsInsideGeom method is used) and if it is, it is influenced by the force. The last step done with particle is to call its Update method which will update its state.

The particle has many parameters, but for Update method the most essential are position in space, velocity vector and acceleration vector. When the Update method of the particle is called the velocity is changed like this: *velocity += acceleration * timeStep* and then the position is changed like this: *position += velocity * timeStep*. By multiplication with timeStep we are scaling the vector according to elapsed time.



The forces are influencing only particle acceleration. The force has its direction and strength. When the particle is influenced, its acceleration is changed like this: *acceleration += direction * strength * timeStep*.

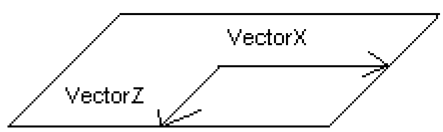
When all the particles were updated, we can proceed with emitting the new ones. For each emitter the Emit method is called, its parameters are timeStep, list of alive particles and list of dead particles. First, the emit method computes how many particles it should emit. The emitter remembers what "part of the particle" it did not emitted in previous frame when there was only the fraction of one. To this saved fraction the *timeStep * number of particles per second* value is added. Then we use the integral part as a number of particles to create. The non integral part of the number is saved for use in another frame. Then we continue with creation of particles. First, we check if there are any particles in the list of dead particles. If there are not any, we allocate thousand of new particles and put them into the list. Then we take the tail particle saved in the list.

We set new particle's parameters and move it to list of alive particles. Emitter remembers how the parameters of the particles were set by the user. These parameters are usually randomized somehow. Most of them are described as value and variation of the value. The value determines the central value of the parameter. The variation specifies in percentage deviation from the value – tells us how the parameter can change for every particle. For example the value is set to 300, if the variation is 0%, then the value is used. If the variation would be 10% then the value would be somewhere between 270 and 330 randomly. This pseudo random value is then set as a parameter to the particle.

Also some other pseudo random parameters are counted. For example the position of the particle on the limited plane (plane emitter) is counted like this:

*position = position of the emitter + VectorX * (random number in <-1,1>) + VectorZ * (random number in <-1,1>)*

Vectors VectorX and VectorZ look like on this sketch:



Vectors are orthogonal. Their length is size of the plane in the specific dimension. And the vectors are in the plane.

The direction of the acceleration and velocity is counted that we rotate the up vector (0,1,0) pseudo randomly in defined range.

There would be an undesired effect, which would occur when the emitter is moving fast in the space. It would create particles only in its actual position in that frame, but there would not be any particles in between the position in the current and the position in the previous frame. To overcome this, we always find out the previous position of the emitter and we put the particles randomly in between the previous and new position. In pseudo code it looks like this:

vector between emitter positions = previous emitter position – current emitter position

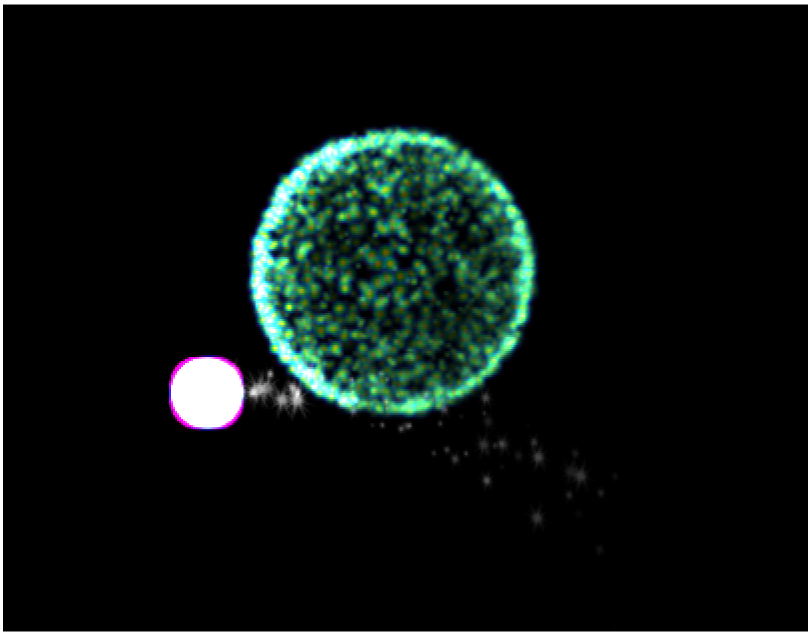
*particle position = actual emitter position + (vector between emitter positions * random number in <0,1>)*

When we emit all the particles we should have the Emit method ends, some new particles were added to the alive particles list and the Update method of the CVisEff ends too.

4. Rendering the particles of the visual effect

The Render method of CvisEff method is used to display the scene. The rendering is present in two forms in the system. The first rendering is used for displaying the intermediate results and previews while editing the particle system. It is done in real-time and so the results may be a bit different thanks to the non-constant time steps in the animation that may appear. The second form of rendering is the off-line rendering. It uses the same rendering sub-system but in different way. Time steps are constant and the results may have user defined resolution. These results are also frame by frame saved to the hard drive. To measure the performance of the rendering subsystem, there is a button in Render menu, Render batch test, which can execute the measurement of the performance. That is accomplished as rendering of the current frame 100 times. The time spent is then shown. So how does the rendering subsystem works?

Firstly we will explain how it works in interactive view. Later the differences between interactive and off-line rendering will be mentioned. At first rendering subsystem sets the transformation according to our camera setting. Then it sets the directional light vector. If the grid is turned on, it is rendered as line primitives. Then we render emitters' graphical representations. In other step the geometries are rendered. The ones which have some forces assigned to them are rendered as wireframe. Then the blending function is set according to project settings which include check box where it is possible to select, if we want normal or additive alpha. Then the RenderParticles method is invoked to continue with rendering of the alive particles.



First step of the RenderParticles method is to compute the destination of every particle from the view plane which is defined as a plane whose normal vector is equal to the look at vector of the camera and the camera position is in the plane. Then we sort the particles according the setting in Render menu and Sorting techniques sub-menu. One of the options is to sort with standard STL list.sort() method which is by our measurement the fastest one. The other implemented option was to use Shell sort, but it proved to be slower. The last option is that the particles will not be sorted. This is not useful when the transparency is used in textures or when the alpha falloff parameter of the emitter is set to something else than zero. Because it would lead to badly counted transparency.

The next and the last step is to render almost every alive particle. Just the particles with negative distance from the view plane, meaning that the particle is behind the view plane, are not rendered. We partly implemented four techniques to render them. Then we selected the fastest one and implemented whole functionality of the rendering (for example texturing support). There are many ways to render the particles. One of the main objectives of rendering is to rotate the particles so they face the view plane. This is called billboarding. The description of the techniques is always written for one particle, because the technique is then executed on all appropriate particles.

Our first partly implemented technique is very simple and slow. It creates new transformation matrix on the matrices stack of OpenGL and rotates and translates the space so the particle is in the right position and right orientation. Then the particle is rendered in its origin and the matrix is removed from the matrices stack. In pseudo code it works like this:

```
PushMatrix();
TransformateSpaceAccordingToCamera();
RenderQuad(size = sizeOfTheParticle, position = (0,0,0));
PopMatrix();
```

The other implemented technique proved to be the fastest one, so now it supports all the functionality including alpha falloff and textures. At first it computes the 4 coordinates of the quad placed in the origin, which is facing the camera. Then for every particle it uses these coordinates but moves them to the right position. In pseudo code it works like this:

```
rotatedQuad = rotateBasicQuadAccordingToCameraRotationMatrix;
Foreach particle
{
 quad = scaleBasicQuadTo(sizeOfTheParticle);
 quad.allCoordinates += positionOfTheParticle;
 Render(quad);
}
```

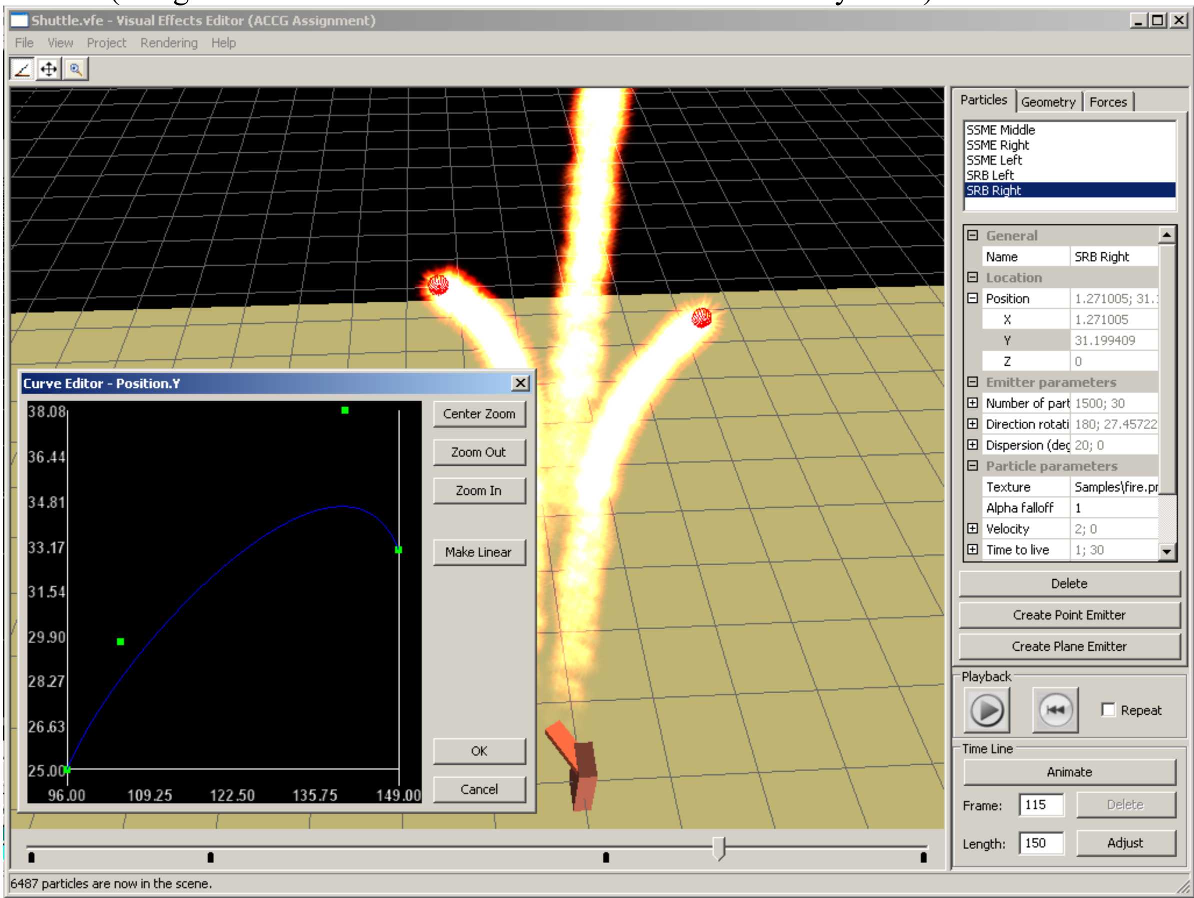
The "non billboarding" technique is not much of the technique because it does not do any billboarding. It was only used to evaluate how much time is spent with or without a billboarding. Because we had other ideas – for example to compute the billboarding inside the vertex shader - but while comparing our fastest method and the "non billboarding", we found out that there is very small difference in performance.

The last partly implemented technique is point sprites extension. We hoped that it will bring higher performance because with this extension only the position of the quad is sent to the card and the card should compute billboarding and position of all 4 points of the quads. So the bus should transfer only one point instead of 4 points. But this extension is poorly supported by the graphic card drivers and most importantly it was not any faster than the our fastest technique. So in the end our technique with one quad rotated to face the camera and move to appropriate positions was used as default.

Now we know how does the rendering of the visual effects works for the previewing so let's take a look on the differences in the off-line renderer. As stated before, off-line renderer uses normal rendering, but with some special features. The most important feature – rendering into the frame of any size that user enters in the renderer control window and saving such a frame into the file is achieved through the OpenGL p-buffers (pixel buffers) (theoretical background from [WYNN05]). This functionality is implemented by the graphics hardware vendors for longer time but we have even now experienced some problems with the combination of Windows Vista and Intel 950 GMA graphic card. Whenever there are some problems using this functionality for the rendering, user is warned. The process of the rendering itself works in the way that each single frame is rendered as described earlier (with the only difference that emitter representation, geometry with some force assigned and the grid are not rendered) and result of the rendering is saved to the file with user given prefix and the frame number. Than time is advanced exactly by the length of one frame and another frame is rendered. This way the whole visual effect is rendered so user gets exactly all the pictures of each frame.

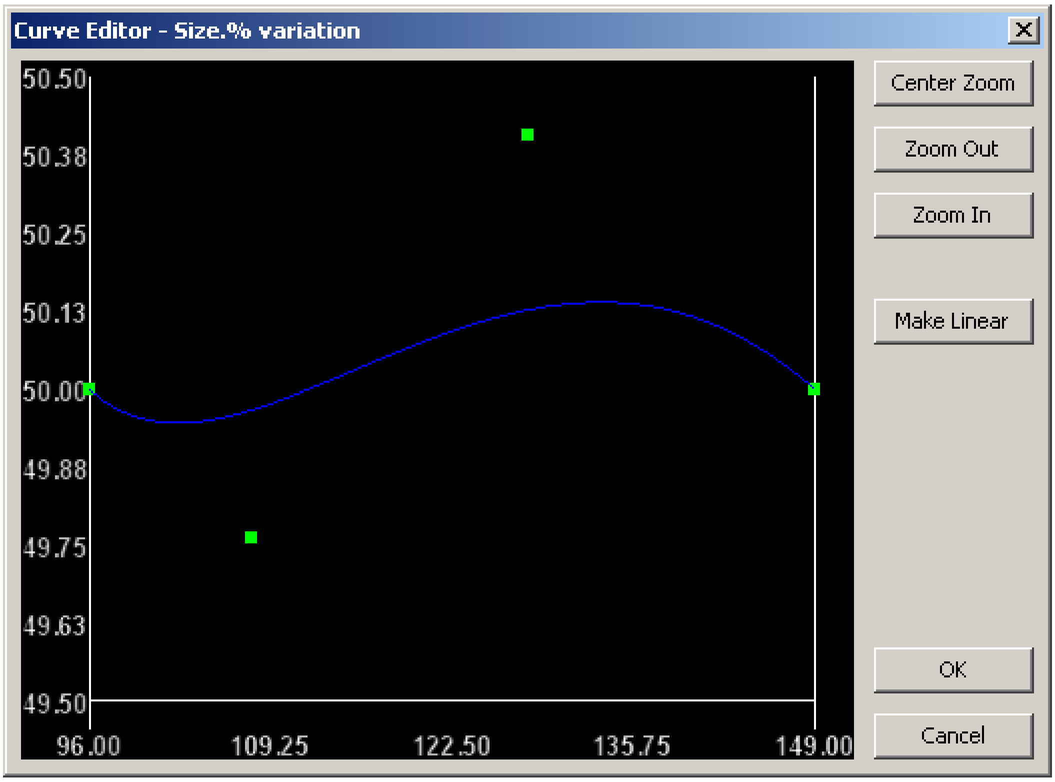
5. Animation subsystem of the application

Very important part of the application is the ability to animate all the relevant parameters of the particle emitters. User can animate not only the parameters of the emitters themselves (such as their position), but also the parameters of the emitted particles (such as their acceleration or it's variation). For this to be achieved we created a animation subsystem that automatically handles all the parameter changes in time and that is easily controllable by the user (using animation curves as usual in animation software systems).



As a basis for this system, we created an animated parameter abstraction. Because all the animated parameters we need to animate are either of floating-point type or can be simulated by floating-point type, we chose to create this animated parameter abstraction to be float. This animated parameter abstraction consists of one or more pieces of animation curves that touch each other in significant points called the key frames. Values of the animated parameters are set exactly at these points by the user. Each of these key frames is exactly located in the time. In between the key frames, animated parameter represents the value that is computed according to the shape of the animation curve belonging to that time interval.

The shape of this animation curve can also be altered by the user in embedded animation curve editor. As the animation curves, we chose two dimensional Bézier curves (theoretical background from [ZARA05]) because they give the user a good insight into how the value of the animated parameter (dependent variable) is mapped to the time (independent variable). Bézier curves are also easy to implement and they allow some operations to be done effectively (such as easy splitting the curve into two pieces that is needed when new key frame is inserted).



When user starts editing the curve between the two key frames (how is described in the manual) a nice interface appears and allows him to alter the shape as he needs. Bézier curve is described by four control points. Two corner points are the fixed values in the key frames that can not be changed in the editor, but rather in the property grid (again see the manual) but the middle two points can be moved around using mouse dragging.

Another important part of the animation system is the time line. The time line holds the information about where all the key frames are placed and manages the current state of the time in the visual effect.

We also have a simple abstraction for the accumulation of more animated parameters together (the animated parameter owner). It allows us to manipulate all the animated parameters at once, for example inserting key frames between the existing ones.

Now we have described all the parts of the animation subsystem, so let's take a closer look how it everything interacts together. During each update, the time line is advanced for some time and so new frame becomes the current one. Before any of the animated parameter is used, all of the parameters are updated (through the animated parameters owners) to the new values belonging to the new time. This means that they get the number of the current key frame (this means associated interpolation curve to address) and the number of the frame in between the two neighbouring key frames interval. They use these parameters to obtain proper animation curve and to get proper *y* value according to the *x* value represented by the in-between key frames frame number. Because Bézier curves are defined base on *t* parameter, but we needed to get *y* value based on *x* not on *t*, we used lookup table with precomputed *x* and *y* values. After this update, animated parameters generally start to behave that they have a different value and this value is used in the update of the visual effect as described earlier.

As another interesting part of the animation system, we implemented the editing. I do not mean only the editing of the interpolation curves as mentioned earlier. While inserting new key frames to the animation, there is a need to split the existing curve on some specific place (because all the key frames are common for all the animated parameters – we made this decision mostly because the characteristic of the visual effects we created our application for allows it – effect behave in some way and than suddenly changes and goes into another phase, so key frames for changes are needed for all the parameters). This way the user will be able to add some new key frame he didn't planned to use earlier and he will not loose the shape of animation curves he edited before. For this curve splitting, we used well known de Casteljau's algorithm.

6. Saving and loading of the scene

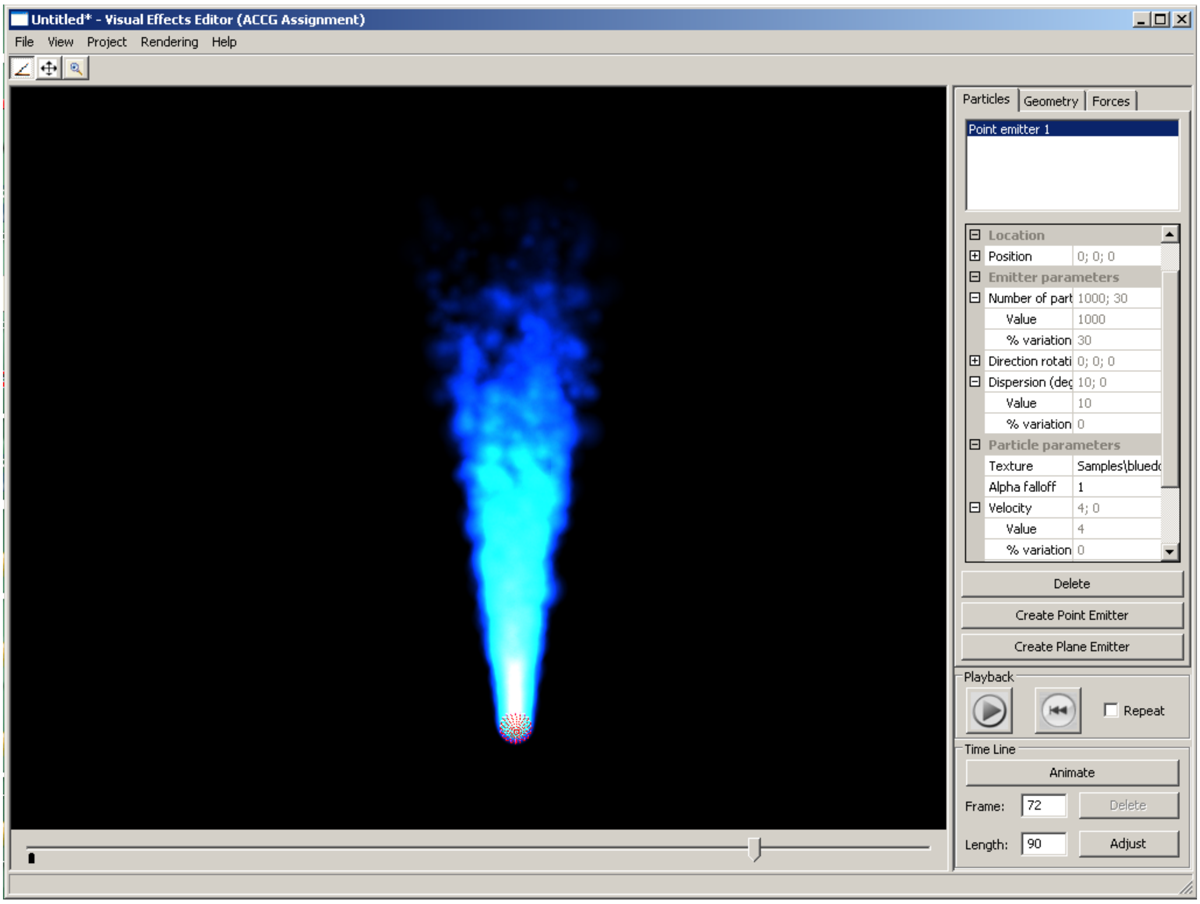
Because creating some visual effect can take a lot of time, we wanted to provide the user with possibility to save his unfinished work and to load it back again. For saving, we are using text file which contains information about all the elements of the visual effect. We created a simple framework that allows us to easily save and load all the entities we use inside the program including parameters of interpolation curves.

7. Conclusion and future work

In this assignment, we had a possibility to explore further into the topics of particle systems and animation curves. We also tried out how to cooperate in a small group of two people while creating a application that is not just a small sketch or draft, but a working system with user friendly interface usable by normal people (no computer specialists).

Compared to the proposal which we created at the beginning of our work, we had to left out some of the features we were expecting to implement. Finally, although the system is not implemented exactly according to the proposal, we were able to preserve it's usefulness even with the smaller range of features. It can be verified that the system is useful by looking at the samples and sample outputs or even by trying to use the system itself. With the supplied user manual it should not be a big problem.

While designing the application, we were also focused on writing it in the way that it is easily extendible in the future. Although some features were left out, their implementation may not be a problem thanks to the application design. The most valuable directions for the future work would be to implement selection of the entities and altering their position and rotation by mouse. This would shift usability to completely different level. Another directions might be the features described in the proposal such as bouncing of the particles from solid obstacles, importing geometry from some popular graphical format and animating parameters of geometry and forces, not only particle emitters. Another nice feature might be the possibility to edit the whole animation curve at once, not just the segments between the key frames.



We believe that our application is useful and great outputs can be achieved by skilled artist. Provided samples were created by us and we have absolutely no aesthetic sense.

8. Literature

1. Žára, J.; Beneš, B.; Sochor, J.; Felkel, P. (2005): *Moderní počítačová grafika (Modern Computer Graphics)*, ISBN 80-251-0454-0
2. Wynn, C. (2001): *Using P-Buffers for Off-Screen Rendering*, http://developer.nvidia.com/attach/6483