Using 3D Computer Animation Tools to Render Complex Simulations

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Abstract

A multi-disciplinary team of researchers and students created several simulations and visualizations of the terrorist attack on the Pentagon building that occurred on September 11, 2001. The process took advantage of both animation and finite element analysis (FEA) simulation techniques for visualization. The imagery produced portrays the collision event on the exterior and interior of the Pentagon. This paper details the difficulties and successes of implementing a process to animate and realistically render the approach, impact, and explosion of the plane, based on an expert analysis of the crash and FEA data. One of the purposes of this project was to develop a data pipeline from FEA simulations to 3D animation and rendering programs that can be extended to other simulations thus bridging the gap between two non-coherent systems creating scientifically accurate simulations.

Introduction

Shortly after the attack on the United States Pentagon on September 11, 2001 a team of inspectors and analysts were called in to assess the damage to the structure and report on how it reacted to the impact of a Boeing 757. Dr. Mete Sozen, a structural engineer at Purdue University, was one of the inspection team members. After the inspection, he and his assistant Dr. Sami Kilic began simulating the event using Lawrence Livermore Labs LS-Dyna3D. The simulation was initially performed on the columns because it is believed that their design ultimately kept the building from being damaged more than it was.

In order to simulate the shape of a plane crashing into the columns, a model appropriately meshed for the finite element analysis (FEA) software had to be produced. Sozen and Kilic discussed the problem of producing a model with faculty from the newly created Envision Center for Data Perceptualization. Chris Hoffmann, a professor of Computer Science at Purdue agreed to head up the meshing of the models and help run the simulations. Dr. Hoffmann created the plane at several resolutions so the simulation could be run for efficiency and accuracy.

A secondary goal of the collaboration between Sozen, Kilic, and the Envision Center was to be able to output the simulation in a meaningful way that would allow it to be visually realistic and engaging. Other participating faculty and graduate students of the Envision Center were brought into the project in order to take on this second task as the simulations were being executed. Dr. Voicu Popescu, of Computer Science and the Center, worked with Hoffmann to begin developing a process for translating the FEA data into a 3D animation application to render it in a realistic manner. Discreet's 3ds max was chosen because it was familiar to Popescu and availability at Purdue through the Department of Computer Graphics Technology. Scott Meador, of Computer Graphics Technology, was brought into the project as an expert in 3ds max and one who has had computer animation production experience. The last two collaborators assigned to the project were graduate students Amit Chourasia from Computer Graphics Technology, and Hendry Lim from Computer Science.

The animation and rendering group decided to break their role into two tasks. The first task was to figure out how to get the FEA data into 3ds max for rendering and the second was to animate the parts of the event that would not be simulated, specifically the plane's approach and impact with the Pentagon exterior. The simulations being done by Kilic and Hoffman were focused on the interior structure of the building. This paper focuses on these two animation aspects of the project. Some details of the crash are left out because of a lack of authorization to publish, but the overall process is detailed.

Creating the Exterior Animation

The Pentagon

The modeling process required various structural and architectural drawings of the Pentagon. Unfortunately, only structural drawings were made available to the team. AutoDesk's AutoCAD was used to model the building with precise measurements of the structural grid. The architectural features were added using photographs as reference for approximating the geometry.

Only one wedge of the Pentagon was affected by the crash, so it was modeled in detail with walls, columns, slabs, etc. The other parts were modeled as basic shapes matching the overall dimensions of the building for optimization and to save computational overhead. The completed model was imported into 3ds max via the DWG file format where textures were applied and surrounding details such as roads and terrain were added. Technical drawings of the roads and terrain were not supplied so the modeling was done in 3ds max based on high resolution aerial photographs.

The Airplane

Along with the structural drawings, a model of the Boeing 757 was acquired by Sozen and Kilic. The model was made up of polygons and optimized for computer animation. It was measured in 3ds max to check its accuracy against official drawings of the plane. The plane's wings and connecting sections were separated and imported into IronCad to measure its volume against the official data. It was determined by Sozen, Kilic, and the inspection team that the fuel in the wings had the greatest impact on the destruction of the building than any other part of the airplane. The simplified model of the plane was sent to Hoffman and Kilic for meshing and finite element analysis, while the detailed plane was textured to look like the one that crashed into the Pentagon.

Materials and Lighting

The inspection team and news media created several images of the Pentagon after the crash. These images were available to the team and were used for texturing the Pentagon building, lighting the scene, and determining the size and visual aspects of the explosion for the exterior animation. Using 3ds max's sunlight system, the sun, or key lighting in the scene was based on the accurate orientation and height of the sun at the time of day of the crash. For the explosion, the security camera images that were released to the public were used as a reference. This camera position was simulated in 3ds max as well to check for visual accuracy. Unfortunately, the airplane was difficult to discern in the security camera photographs, so the details of the security station and the Pentagon building had to be used to match the point of view and then show what the plane would have looked like with better photography and timing.

Animation

Animating the plane was accomplished based on both the findings of the inspection team and from eye-witness reports of the event. The angle that the plane struck the west wall of the building was determined by the inspection team. Sozen and his team also determined the speed that the plane was traveling at impact as well. Two witnesses of the crash had recalled that the plane flew at a very low altitude well in front of the building so it impacted nearly parallel to the ground. The plane rotated slightly to the right and hit a generator near the building possibly destroying an engine. The left engine also allegedly struck some objects before the plane impacted the wall. Its fuselage most likely struck the wall between the first and second floor slabs and was able to penetrate the first floor of the building.

To animate the plane a spline was drawn at the proper angle to the exterior wall and was drawn to a length of exactly one mile in 3D space. Based on the determined speed of the plane, keyframes were created of the plane following the path over time. This led to a very short animation, so the time was then proportionally rescaled to slow it down. For the explosion, the simple "fire effect" built in to 3ds max was used along with a particle system for the thick black smoke of the burning fuel.

Plane approaching the Pentagon building

Explosion at impact with the Pentagon building

Working with FEA

The original goal of this project was to use finite element analysis techniques to simulate the event with a high degree of accuracy. FEA was performed using Lawrence Livermore Labs LS Dyna3D on various elements involved in the crash beginning with the Pentagon's columns, and the airplane's wings and fuselage. Their displacements, distortions, and disintegration due to the collision were computed and recorded at various time intervals. This data was then used to recreate the geometry and animation in 3ds max for rendering.

FEA simulation issues and data

FEA required the elements to be subdivided into small segments. For instance, one of the cylindrical columns consisted of 15,000 radially arranged wedges. The simulation was performed on several different computers including high end PCs, a 32 processor SGI Origin 2000, and an IBM Regatta supercomputer at Purdue and at Indiana University. The simulation took a significant amount of time. Hoffmann and Kilic eventually stopped the simulations because the data sizes had exceeded the available processing power. The official project web site details the process of producing the FEA data at different stages.[1]

FEA yielded the displacement, deformation and distribution of various sub elements with different time steps. The simulation was performed by equivalent force distribution with which the plane might have struck the building.

The data was a simple ASCII file consisting of positional and connectivity information about the sub-elements at different time steps. The FEA post processor tool was capable of rendering some of the simulations as animated GIF sequences, which was very crude compared pre-rendered animation imagery. The post processor could also export VRML files that could be played back as animations.

Importing the FEA data into 3ds max

The data consisted of the position, orientation and size of each sub-element at different time intervals along with the connectivity information with other elements. (e.g.: there were about 90,000 nodes which made up around 15,000 wedges in a single column). The complete test simulation had about 1,000,000 nodes.

This data was read via a Max Script written by Chourasia and created the geometry and deformations through keyframed vertex animation. At present, deformation to the columns has been successfully imported into 3ds max and column explosions are near completion. There have been significant problems in importing the data because of the inefficiencies inherent in scripting languages of 3ds max and other 3D animation applications. A full-fledged 3ds max plugin using C++ is being developed by Hoffmann, Popescu and students from the Computer Science department to overcome limited scripting abilities of max.

In addition to the simulation, adding special effects to form dust and fire are underway to make the simulation look more realistic.

Materials for deforming geometry

Once the geometry is in 3ds max it is textured with realistic bitmaps and procedural maps. By using blend maps and materials in max, the material can be animated to change its look as the geometry is deformed and broken. The columns of the Pentagon were made from several layers of materials that are revealed as they are destroyed. The blended multi-layered materials allow the animators to show this change not only through the geometric deformations, but through the surface material changing as well.

Data Pipeline

The animation team's initial goal was to get the data from the FEA simulation into 3ds max. Two options were exhausted during the main production time. The first was to export the animation to the VRML format using LS Dyna3D's post processor. The VRML models were of a high quality, but the post processor was only capable of creating one file per instance of time and 3ds max was not able to import multiple VRML files to create animation. Also, because of the flexibility allowed to coders in the VRML specification, the importing capabilities of 3ds max are very limited and most 3D animation applications will only allow exporting of VRML files.

The second option taken on by the team was to use Max Script to parse the FEA data and create geometry and animation in 3ds max. It took several iterations of the script to deal with issues of processing the data and dealing with memory overhead. Technically the script worked, but it was highly inefficient and slow. The FEA data represents objects with internal structures that would not be seen in a rendered animation, so it had to be removed. This removal added to the complexity of the import script and is still is an aspect of the import problem that has not totally been solved.

It was determined by Hoffmann and Popescu that a plugin importer would be the best solution, but it was not started until the main project had completed. This plugin has yet to be implemented, but is still being developed.

Conclusions

The FEA processing challenge

Though work on the Pentagon project itself has been temporarily halted due to lack of computing resources, the researchers have been communicating with computing hardware manufacturers to see if the simulations can be expanded. During the main production of the project supercomputers were being used to get useful results, but the possibility of distributing the solution to many computers could hold the key to scaling the simulations.

Working with more robust 3D applications

It has been found through experience in subsequent visualization projects that 3ds max does not handle highly complex geometry as efficiently as other applications such as Alias|Wavefront's Maya, or Side Effects Houdini. Though 3ds max has a faster renderer, and is generally easier to use, it may not be appropriate for animating large data sets.

Too much data

Accurate simulations require maximum subdivision of elements for precise results. This process leads to a mammoth data set that is difficult to handle using the limited power of scripting languages for importing and creating geometry and animation. A post processing/pre-import of data would be of great help, which could reduce redundancy and data bloating ensuring efficient portability to various tools.

Performing case studies with similar data using different software tools can lead to identification of a robust and reliant tool. This would streamline development with consistency for future work.

Future Work

Simulation Team Goals

The Pentagon was the prototype project to create a pipeline for simulating disasters, and natural phenomena on architectural structures. It is the hope of the team that its current bottlenecks are overcome to the development of software tools or a pipeline for simulating various events. This could help engineers and designers build structures that could withstand events that are nearly impossible to simulate in another manner.

Animation for Visualization

With enough data and references, events can be reproduced in order to understand them better. Forensic animation specialists do this for recreating events for litigation. If the pipeline can be finished then simulation teams will be able to visualize events before they happen and then visualize them in a way that is easier to understand. It is also the goal of the team to use 3D animation applications to do some of the simulations instead of relying solely on the process of modeling, meshing, FEA, then importing into animation software. Since the Pentagon project, Meador and Sozen have re-teamed with graduate and undergraduate students to visualize a viaduct in Turkey that was damaged in a massive earthquake. The viaduct was modeled in Alias|Wavefront's Maya. The models were then animated both by hand keyframing based on data surveyed from the site, and also simulated through the Maya rigid body dynamics system to compare the outcomes. The dynamics system was not up to the task of a simulation of that scale, but it showed the structural engineers what 3D animation applications could do and how valuable they are for creating meaningful imagery to visualize projects.

Bibliography

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Biographies

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Scott Meador is an Assist. Professor in the Department of Computer Graphics Technology teaching several courses in 3D animation including Lighting and Rendering, and Production. He is also an Application Engineer with the new Envision Center for Data Perceptualization at Purdue. His research activities are in the areas of visualization, animation, video, compositing, and motion capture. Mr. Meador is a Discreet Certified Instructor as well.

AMIT CHOURASIA
Amit Chourasia is a graduate student in the School of Technology specializing in applied computer graphics. Amit specializes in computer graphics application development and visualization. His undergraduate degree is in architecture from IIT Kharagpur, India. His Master's Thesis is in 3D information visualization and he plans to graduate from Purdue in May of 2003.