Computer science
Case study: CGI

For use in May 2016 and November 2016

Instructions to candidates

- Case study booklet required for higher level paper 3.

Introduction

Animation has played an important role in entertainment for over 50 years, from its beginnings in television cartoons (aimed originally at children) through to sophisticated visual effects found in many of the latest films and computer games.

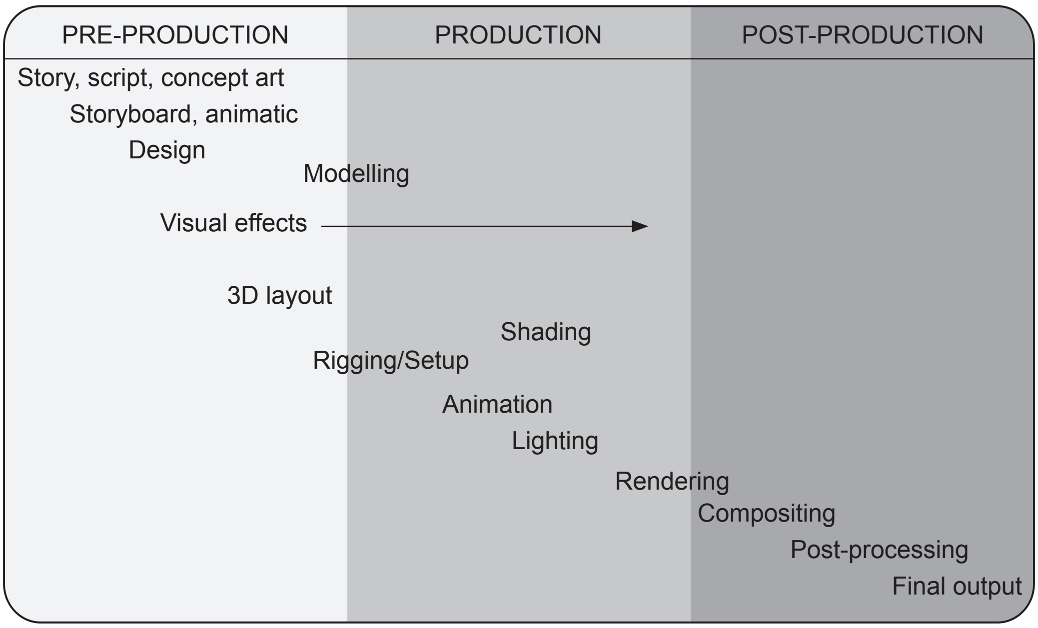
Before the involvement of computers, animation was a long-drawn-out affair carried out by teams of designers painstakingly drawing a series of frames, each of which showed the 2D scene a fraction of a second after the previous one. These frames would then be copied onto transparent cels. The cels were photographed as a continuous film. If the frame rate was high enough, the motion would appear realistic to the human eye.

Towards the end of the last century, computers were increasingly used in animation: an example being the production of the frames in between the hand-drawn keyframes. But it was not until 1995 that the first full length feature film to be completely generated through computer graphics techniques was produced, *Toy Story* from *Pixar Studios*.

Modern day animation falls into the field of computer-generated imagery (CGI), which brings massive processing power into the realm of film making. This allows anthropomorphic creatures and fantasy worlds to be seamlessly incorporated into films with a degree of photorealism that would not have been previously possible.

Advanced 3D modelling software now uses primitives to produce the initial wire-frame models. Each model is rigged with an array of information about the properties of its important features. Increased processing power has led to the extensive use of complex algorithms for interpolating between each of these properties as part of the tweening process. Rendering techniques allow lighting and shading to be applied to each frame.

Animation production pipeline



The desire to make animation as realistic as possible has led to motion capture (Mo-cap), a technique which allows actors to transmit their movements and, to a certain extent, their personalities and expressions onto imaginary characters, for example *Gollum* in the *Lord of the Rings* franchise.

The animation production pipeline, as shown in the diagram on the previous page, represents the various stages involved in modern day productions. This case study explores a small part of this pipeline through the eyes and words of the specialist technology company *Pacific FX*, a small firm that has entered the CGI market and which is engaged in projects involving work in films, commercials and computer games. Their focus is on providing the computer animation for these projects.

Pacific FX

Xiao-Ling is the head of one of the design teams at *Pacific FX* and discussed two of the current projects in which they are engaged. She explained that the steady increase in available and affordable processing power has allowed computer graphics and animation to reach levels that blur the distinction between fact and fiction, and allows small companies like *Pacific FX* to enter the market.

"We are currently working on two projects: a computer game designed to be played on ordinary home computers and a short animated commercial. The fact that one needs to be rendered in real-time whilst the other can be completely prepared offline leads to the possibility of using different techniques."

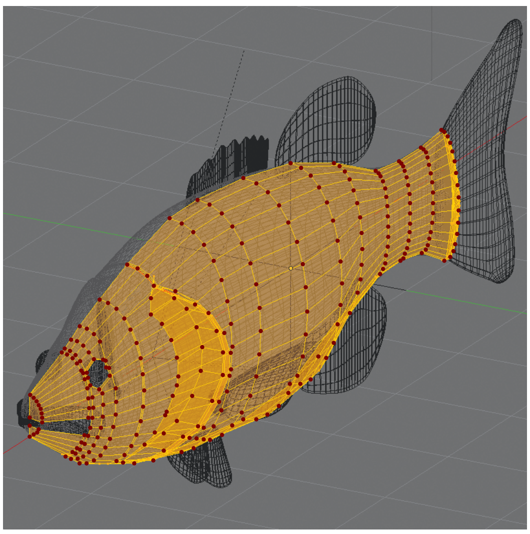
She went on to explain how the main principles of animation are similar to the pre-computer era.

"We still produce keyframes at significant points in the action, as was previously the case. But these keyframes are no longer hand-drawn. We either use modelling software directly to create the characters and objects or we create them as physical models and then use 3D scanners to import them into the software. In each case, wire-frame models are created out of many polygons (the smaller and more numerous the polygons, the more detail there will be) ready for the application of texture and colour."

She explained how the in between frames that used to be passed to the assistant designers to be hand-drawn are now created by computer algorithms that interpolate between the keyframes.

"The process of creating the frames is similar to the previous methods where keyframes are created and then the software carries out the tweening process. These keyframes are not necessarily created at regular intervals but must be carefully chosen. The algorithms basically interpolate between the attributes of each object to produce, usually, 24 frames per second. This, at its simplest, can be a straightforward translation in the x-direction (for example, rolling a sphere). However, in reality the process is far more complicated as each scene will have many objects, with each object being rigged with possibly hundreds of control points (avars). Each of these control points will have different attributes and each attribute may have its own algorithm for dealing with the tweening process (for example, a person turning their face and changing expression). The amount of processing required quickly adds up.

Wire-frame model of a fish



"For movement, built-in libraries based on inverse kinematics will be used. The process of morphing one face into another has some similarities to the tweening process, although the construction of the in between frames does differ."

She used the model of a fish (see wire-frame diagram) to illustrate the use of polygons and the positions of avars (shown as red circles). These avars are the significant points on each object that can be controlled by the animators through properties assigned to them which are then processed by the tweening algorithms.

The animated commercial project

Xiao-Ling discussed how they have experimented with the stop motion technique using plasticine models (as used in *Coraline* and the *Wallace and Gromit* films), but had preferred the greater degree of freedom offered by the use of wire-frame modelling.

The fact that this project can be produced offline has the benefit that rendering speed is not important, which led *Pacific FX* to investigate the possibilities of using Mo-cap. This involved attaching as many discs to their actors as there were avars on the wire-frame models. An array of cameras would then record all of the data associated with the movements of these discs. This data would later be input into the modelling program. Xiao-Ling added that both passive and active systems exist.

“Care has to be taken, however, as to how much realism is presented. Successful animation occurs when the audience empathizes with the characters and in this respect animators need to be aware of the *uncanny valley* effect.”

In spite of the availability of affordable processing, Xiao-Ling stressed that there were still limits to what a small company could realistically do. She referred to a *DreamWorks* film, *How to Train Your Dragon 2*.

“This film required the use of 10 000 simultaneous computing cores, and 75 million computing hours, to render all the images. It also requires 250 TB of active disk space to store the film. The major companies invest heavily in processing power that can involve both render farms and the use of the cloud. For companies such as ours, there always has to be a trade-off between realism and available processing power.”*

The computer game project

The real-time nature of this game affected the design decisions of Xiao-Ling’s team.

The background scenes can be created using standard matte designs but it is also possible to render landscapes using quite simple fractal algorithms, as Xiao-Ling said:

“Using the *Diamond Square* algorithm starting with simple rectangles, a surprising degree of complexity and realism can be produced, and by varying the ‘error’ an infinite variety of designs can be created.”

In the rendering process of each scene, the use of light and shade contribute significantly to the quality of the display. There are various algorithms that can be used, all of which attempt to solve the basic rendering equation. Here Xiao-Ling considered two different methods: ray-tracing and scanline rendering.

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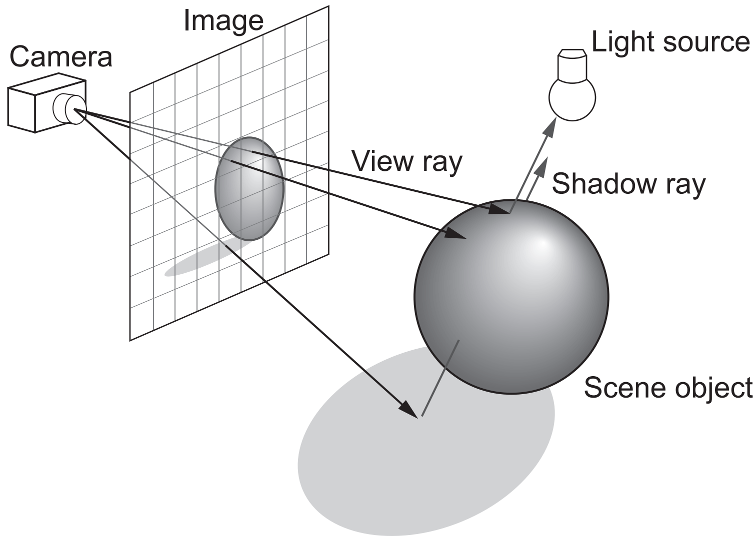
* www.telegraph.co.uk/technology/…/How-technology-is-driving-the…

Ray-tracing involves exploring the path of light rays between the eye of the viewer (the "camera" in the diagram) and the light source, taking into account the different effects that the virtual objects have on the passage of light. Although the basic algorithm is quite simple to understand, as the number of objects in each frame increases so do the changes of direction that the light rays can take. As the intensity and colour of light at each pixel needs to be computed for each frame, the computational cost can be high. It is fundamentally a recursive process that needs to be limited.

Ray-tracing



[Source: adapted from Henrik, http://en.wikipedia.org]

An alternative is scanline rendering which simplifies the issue of "hidden surface determination". The algorithm progressively scans each horizontal line of pixels. If objects are encountered, the one closest to the camera is then given a colour attribute which is dependent upon various factors.

Xiao-Ling added that because scanline rendering is an *embarrassingly parallel* algorithm it is particularly suited to be processed by GPUs.

Ethical considerations

Pacific FX has employed some computer science graduates who are currently undergoing training. Xiao-Ling explained that as part of this training course they look in detail at various ethical considerations that a responsible company should take into account when developing their CGI projects.

Future developments

Xiao-Ling concluded by taking a brief look into the future:

"One of the continual fascinations of this industry is that each year brings something different as new techniques are developed or present techniques are made possible by computer systems even more powerful than what we already have. It is certain that the games industry will be able to deliver real-time rendering which will put computer games at the same level of realism as animated films."

Challenges faced

Xiao-Ling and *Pacific FX's* challenges for the immediate future are:

- to investigate both scanline rendering and ray-tracing algorithms for use in the computer game project;
- to investigate the techniques of motion capture as a viable option for their commercial project;
- to investigate the demands made by the various processes and algorithms available;
- to prepare the ethics module for the training course;
- to be prepared to incorporate new techniques as they arise.

Additional terminology to the guide

2D/3D computer graphics
Animation production pipeline
Anthropomorphism
Avars
Cel
Computer-generated imagery (CGI)
Diamond Square algorithm
Embarrassingly parallel
Fractal landscapes
GPU
Hidden surface determination
Inverse kinematics
Keyframes
Matte (process)
Morphing
Motion capture (Mo-cap)
Photorealism
Primitives
Ray-tracing
Render farms
Rendering
Rendering equation
Scanline rendering
Stop motion (animation)
Tweening
Uncanny valley

Some companies, products, or individuals named in this case study are fictitious and any similarities with actual entities are purely coincidental.