Current Trends In Low-Cost 3D Character Animation Systems

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Abstract

It is often believed that very expensive and complex hardware and software systems are required to produce 3D character animation (3DCA). This paper discusses current trends in low-cost off-the-shelf systems that produce broadcast-quality 3DCA videos in a production process cycle, and proposes an entry-level system that comprises a suite of PC-based hardware and software components to achieve effective production of 3DCA. In order to better understand and appreciate the requirements of 3DCA, a description of the production cycle and character animation principles is presented.

1. Introduction

Nowadays, almost every television show or movie you see contains elements of computer-generated graphics and visual special effects. In an effort to create virtual worlds in a three-dimensional space, 3D animation is widely used. These consisted from simple spinning logos to complex architectural walkthroughs. However, when trying to mimic reality, especially of organic beings, like animals or humans, a specialised form of animation known as character animation is utilised. Traditionally applied when producing cartoons [1], these ideas and techniques were incorporated into 3D technology to provide us with 3D character animation (3DCA).

A big challenge today in producing 3DCA is that technical-savvy computer persons may quickly learn complex 3DCA software packages but know little of traditional character animation principles, while the artistically inclined folk grapple with computer jargon and technology. Worst, 3DCA software packages may be designed by those not familiar with 3DCA techniques and requirements. Finally, for those among us who would love to explore this exciting genre will rapidly discover that the greatest deterrent is the high cost of purchasing 3DCA systems.

What is needed are low-cost 3DCA systems that are easy-to-use and designed with the character animator in mind.

To begin with, this paper shall discuss the 4P's of 3DCA, which are Purpose, Production, Principles and Practice. In Purpose, we explore the objective of 3DCA and discover areas of application that are currently popular in utilising this technology. For Production, the three main processes of the cycle are elaborated, namely Pre-production, Production and Post-production. A cross-reference to the multi-disciplinary skills and knowledge requirements for 3DCA will be revealed at this point.

From the demands and requirements set out from the Production cycle, we review the Principles of character animation as developed by Disney [1]. At this stage, we take a look at how to put 3DCA into Practice. Each of these processes in the Production cycle is examined with respect to the software and hardware typically used by professionals world-wide. Emphasis is on the use of low-cost off-the-shelf components rather than specialised, propriety tools created by production studios or third-party developers. Importance is placed on the workflow aspect of 3DCA as it affects the interoperability of components as well as collaboration of team members.

These findings will ascertain the base technical feature set needed by low-cost 3DCA systems to fulfil the needs of a principle-driven methodology for effective yet creative 3DCA production. A comparison table then summarises the differences between low-cost and high-end 3DCA software packages. Finally, a proposal for an entry-level 3DCA system is made, which consists of a schematic diagram of the various components networked together. A breakdown of estimated costing for the individual components is incorporated, and where appropriate, the proposal shall contain alternative solutions or options so that various requirements can be met.

Although this paper seems to weigh towards technology, its emphasis is on content, and that it is the artist not the tool that will bring about the illusion of life.

This paper assumes that the reader is aware of the basics of 3D animation, such as the 3D coordinate system, primitive modelling techniques (lathing, extrusion, unibody construction), simple skeletal building techniques

(bone to mesh assignment), and straightforward animation techniques (path, keyframe). If the reader is unaccustomed to such terminology, it is recommended that a short course or book reading on Basic 3D Animation be taken [20, 21, 22]. Although popular issues like rendering (raytracing, radiosity) and special effects (particle simulation, volumetrics, rigid body dynamics, to name a few) are touched upon, these topics are not talked about in detail because the focus of this paper is 3D character animation, which really is a branch of 3D animation.

2. Purpose of 3D Character Animation

One of the basic purposes of animation, whether 2D, 3D, traditional or computer-generated, is storytelling. Essentially, it is a form of communication, a means of expressing ideas visually, where the content may be factual or fiction. Animation itself is the creation of the illusion of motion. By displaying sequential images one after another in rapid succession items drawn or recorded on the images can appear to move.

Character animation can be defined as animation in which objects or characters are animated to give the illusion of personality, life, and character. This is distinguished from other types of animation such as basic flying logos or visualisation since the objects are meant to appear alive and act on their accord rather than simply move.

Needless to say, 3DCA is currently popular in the realm of entertainment, such as in movies like "Toy Story" and "Dinosaur", as well as in computer games. However, you will find 3DCA applied also in the communication industry like television broadcast for use in virtual news casting [11] and commercials, the education sector for use in computer-assisted learning, for example using agent/avatar technology [12], to act as a digital tutor. In architecture, engineering and manufacturing, visualisation, simulation and digital prototyping, respectively, are usually supplemented with 3DCA to produce a virtual environment that can showcase the products.

3. The Production Cycle

There are generally three parts in the production process: pre-production, production and post-production [2,3].

In the pre-production stage, we have the following activities:

- *Story design* – where the concept and theme of the story is designed [6]. This would involve scriptwriting and storyboarding [7], which are textual and graphical representations of the screenplay, respectively. Character design and art direction plays a vital part in the overall plan.

- *Voice recording* – where dialogue is acted out and recorded. These sessions are normally videotaped so it can later be used during the animation stage as reference.

- *Music score* – these are created with the theme in mind, and may include sound effects as well. The sound files can also be used as reference during the animation stage.

- *Story reel* – this is a video of the storyboard images combined with audio and timed appropriately to act as a prototype of the whole story.

During the production stage [4,5], we have the following activities that may occur in parallel:

- *Modelling* – there are many ways to model objects, from using polygons to patches, and it depends on whether they are more organic or mechanical. For 3DCA, key requirements are:
    - Efficient, low-density mesh
    - Natural curved lines and smooth joins
    - Point-level realtime sculpting
    - Rotoscope assisted modelling
    - Unibody construction
    - Nested group editing
    - Seamless bone integration
    - Orthogonal and perspective views
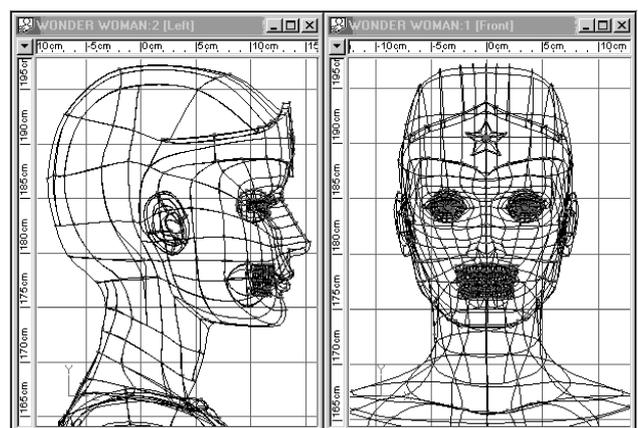   - Import/export of various file formats

Figure 1: Modelling a face using patches

- *Texturing* – the models are given surface properties and "skin" which give them their look. Key requirements for 3DCA are:

- Custom layerable and animatable 3D procedural textures, images and object attributes
- Supports multiple image-map types and shader modifiers
- Intuitive placement and editing of image-maps
- Realtime preview and editing of surface textures and image maps

- *Rigging* – to animate a model, a skeletal system comprising a set of bones and constraints (relationships) are integrated into the model. Key requirements for 3DCA are:
  - Switchable forward kinematics (FK) & inverse kinematics (IK) based bone linkages
  - Reusable bone and constraint hierarchy
  - Support for multiple realtime attribute-level constraint (relationship) types to provide control bone structure
  - Weighted blending of control points for natural deformation of mesh and muscle
  - Kinematic rotational stiffness and lockable bones
  - Quaternion interpolation for bone rotation
  - Constraints can be blended and animated

- *Staging* – this is the layout of the models and props in their environment. Using the story reel as a guide, cameras and lights are placed accordingly and a rough animation is created. For 3DCA, key requirements are:
  - Customisable viewport for object placement and scene editing
  - Intuitive user interface and uniform object manipulator
  - Fully editable timeline window
  - Supports various camera attributes (eg. depth of field) and light types

- *Animating* – is where motion is applied to the models and through timing and acting [8], their character and personality is used to tell the story. In 3DCA, important requirements are:
  - Keyframe, timeline and channel graph motion editing with realtime display feedback
  - Skeletal and muscle control features, onion skinning
  - Support for scrubbable audio, lip-synch automation and phoneme creation
  - Stride length to prevent feet slippage
  - Swappable lightweight proxy models
  - Pose motion: slider-controlled ranged actions

- Provides for action reuse, overloading, blending and non-linear animation
- Rigid and soft-body dynamics, esp. cloth simulation. Other special effects such as particles, hair, fluids, esp. with collision detection become useful at this stage if they cannot be integrated in the post-production phase.
- Object flocking or crowd simulation
- Supports motion capture and motion tracking

- *Rendering* – is the CPU-intensive process of generating the image of a scene complete with lighting and texture details. Although features like global illumination and caustics are hot topics, for 3DCA, the following are key requirements during the rendering stage:
  - Realtime previews can be saved as output
  - Level of detail of realtime previews can be adjusted, including options to selectively display objects in boxed, wireframe, or shaded mode
  - Realtime preview of shadows, motion blur and particle effects
  - Bound progressive rendering for partial viewport renders
  - Alpha and shadow buffers rendering for compositing
  - Network-capable (multi-threaded and distributed) photorealistic and stylistic (toon) renderer

Figure 2: Final quality render

Although the post-production stage is classified as the final part, due to the non-linearity of the digital medium,

many of its activities are done throughout the production cycle. For example, the story reel is continuously edited and refined with completed segments until the finished product is delivered. In post-production, we perform:

-   *Editing* – where the rearrangement of shots and scenes are done, and transitions are added. Quite often, visual effects are applied in the post-production stage, and these include lighting and camera effects. For better control, shots are rendered separately and are then composited together, using multiplane style layering techniques. Next, vocal recordings, sound effects and music are layered in and synchronised together with the video. Key requirements for 3DCA are the abilities to do:
    -   Compositing using alpha channels
    -   Importing of still images into video clips, and a variety of multimedia formats
    -   Multi-channel non-linear digital editing
    -   Audio mixer

-   *Output* – once the video is finalised, an output format is required to match the desired playback medium. In fact, this has to be decided at the pre-production stage because the differences in analogue and digital formats will affect the various production processes. Popular output destinations are:
    -   Video – for TV broadcast
    -   CD – for interactive CD or DVD-based apps
    -   Film – for cinema
    -   Web – for streaming over the Internet

It is interesting to take note of the multi-disciplinary skills that may be required throughout the production cycle. Below is a table summarising the skills needed during the production stage:

Phase	Type	Skill	Ref
Modelling	Organic	Artistic	[4]
	Mechanical	Technical	[5]
Texturing	Procedural	Programming	[5]
	Image-mapping	Painting	[5]
Rigging	Skeletal hierarchy	Anatomy	[4,9]
Staging	Layout	Cinematography	[10]
Animating	Character	Acting	[4,8,9]
Rendering	Photorealistic	Technical	[5]
	Stylistic	Artistic	[5]

Table 1 : Skills required during Production

Below is an indication of the business potential of 3D in the global market by Machover Associates (Jan 2000):

	US$-bil	
	In 2000	*In 2005*
CAD/CAM	7.6	15.9
Art/Animation	5.2	11.0
Multimedia *	7.5	16.7
Real Time Simulation	1.2	2.2
Scientific Visualisation	1.5	3.9
Graphic Arts	4.3	12.6
Virtual Reality	1.4	3.6
Other	2.6	5.4
Total	31.3	71.3

Table 2: Forecast market for commercial/industrial 3D computer graphics applications, by type, worldwide.
* Includes desktop video.

4. The Principles of Character Animation

I would like to review these principles as developed by Disney [1] while taking note of important features that need to be present in 3DCA package to make it happen. I've divided these principles into basic and advanced sections.

-   Basic

    -   *Squash & Stretch*
        -   This is a way of deforming an object such that it shows how rigid the object is. For example if a rubber ball bounces and hits the ground it will tend to flatten when it hits. This is the squash principle. As it starts to bounce up it will stretch in the direction it is going. One important note about squash and stretch is that no matter how an object deforms it should still appear to retain its volume. 3DCA packages should provide:
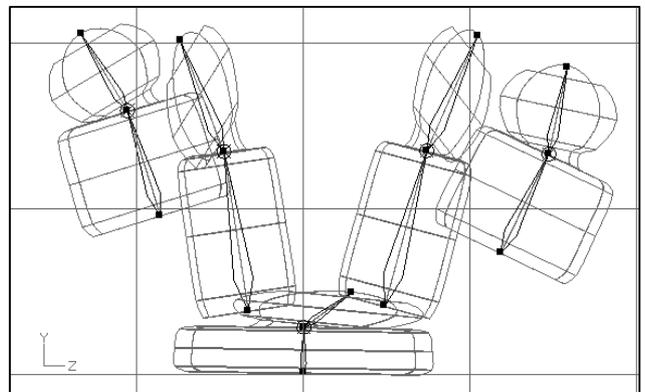   -   Bone scaling, mesh deformation

Figure 3: Squash and Stretch using bone scaling

Anticipation

- Action in animation usually occurs in three sections. The setup for the motion, the actual action and then follow-through of the action. The first part is known as anticipation. In some cases anticipation is needed physically. For example before you can throw a ball you must first swing your arm backwards. The backward motion is the anticipation, the throw itself is the motion. In addition anticipation is used to lead the viewers eye to prepare them for the action that follows. 3DCA packages should provide:
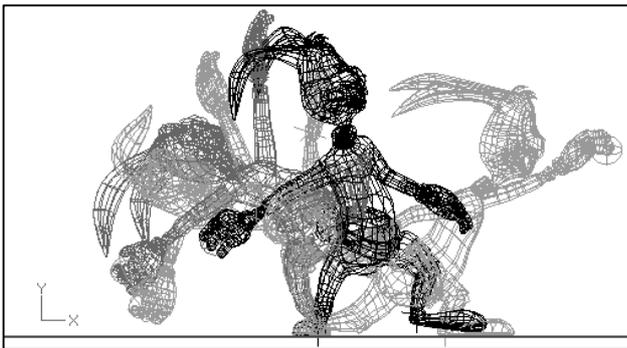 - Onion skinning

Figure 4: Onion skinning for Anticipation and Arcs

- *Slow In & Slow Out*
  - This term deals with the acceleration and deceleration of an object between keyframes. Objects rarely start or stop suddenly, so by making an object slow down as it approaches (slow-in) or slowly speed up as it leaves (slow-out) you can smooth out action. 3DCA packages should provide:
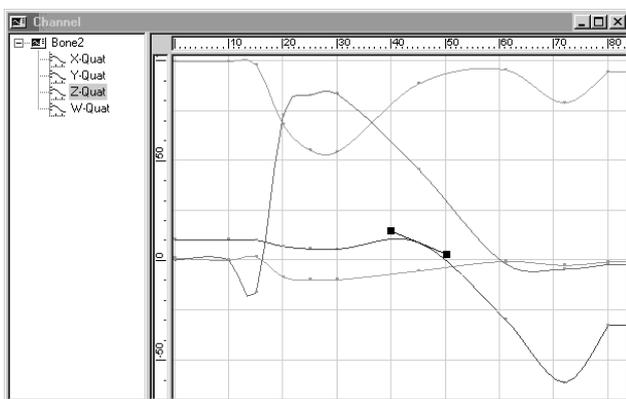   - Keyframe editing, channel graph editing, curve bias control

Figure 5: Channel graph editing with curve bias control

- *Staging*
  - Staging is presenting an action or item so that it is easily understood. Facets normally looked at are Line of Action, Silhouettes, Symmetry, and Balance. 3DCA packages should provide:
    - Constraints to do auto-balancing, black on white silhouette display mode

- *Pose-to-pose / Straight Ahead Action*
  - There are two basic methods to creating animation. Setting up key poses and then generating in-between images creates pose-to-pose animation. This is the basic computer "keyframe" approach to animation. It is excellent for tweaking timing and planning out the animation ahead of time. Straight ahead animation is one where the animator sets up objects one frame at a time in sequence, until the end of the action is reached. This approach tends to yield a more creative and spontaneous look but can be difficult to time correctly and tweak. 3DCA packages should provide:
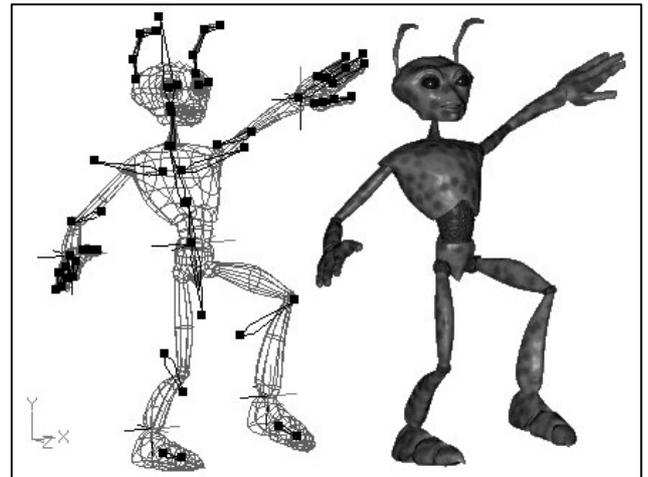   - Keyframe editing, channel graph editing, non-linear animation

Figure 6: Staging for clear presentation

- *Arcs*
  - In the real world almost all action moves in an arc. When creating animation one should try to have motion follow curved paths rather than linear ones. 3DCA packages should provide:
    - Spline-based motion paths, Object-path onion skinning, IK/FK switching with quarternion bone rotation

- Advanced

    - *Follow Through and Overlapping Action*
        - Follow through is the movement at the end of a motion. In most cases objects don't stop suddenly, but tend to travel a little farther past their end point. When objects with loose parts or appendages move, these parts tend to move with a different timing than the main section. The difference in timing of these loose parts is known as overlapping action. 3DCA packages should provide:
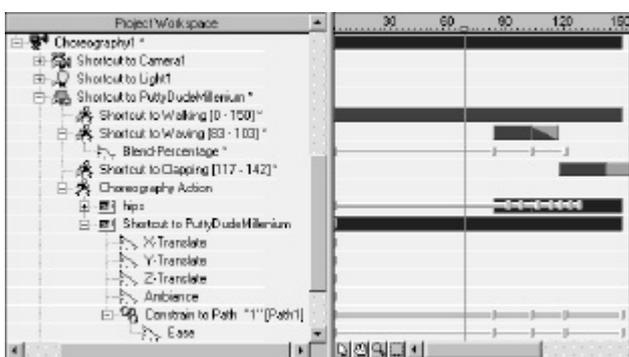   - Relationships with lag, Softbody dynamics

Figure 7: Keyframe editing and non-linear animation

- *Secondary Action*
    - Secondary Action is an action that occurs because of another action. It creates interest and realism in the animation. In addition secondary action should be staged such that it can be noticed but still not overpower the main action. 3DCA packages should provide:
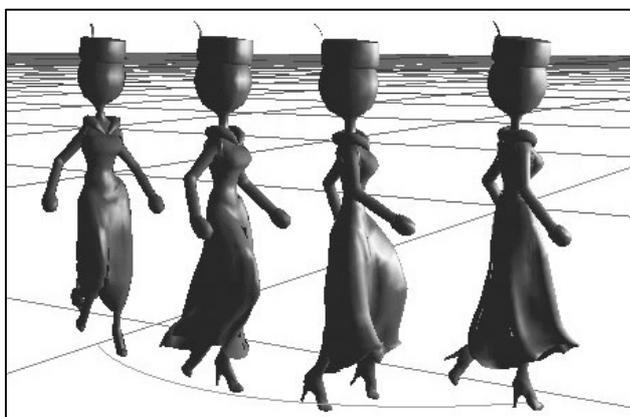   - Action objects, Cloth simulation, Pose motion

Figure 8: Cloth simulation for secondary action

- *Timing*
    - Timing is the speed of an action. Timing is critical in animation because it determines how characters are perceived. Timing can also affect the sense of an object's weight. When animating in synchronisation with sound, for example during lip-synch, matching the timing is important. 3DCA packages should provide:
        - Timeline editing, Realtime display interaction, Rotoscoping, Audio-scrubbing, Motion-capture support

- *Exaggeration*
    - The idea behind exaggeration is to accent the action. However it should be balanced and not used arbitrarily. One should figure out the reason for an action and how to exaggerate the needed sections. The result will be that the animation will seem more lifelike and entertaining.

- *Appeal*
    - Appeal means anything that a person likes to see. This can be quality of charm, design, simplicity, communication or magnetism. Appeal can be gained by correctly utilising other principles such as exaggeration in design, avoiding twins, using overlapping action, and others. One should strive to avoid weak or awkward design, shapes and motion.

- *Personality*
    - This word isn't actually a principle of animation, but refers to the correct application of the other principles. Personality determines the success of animation. The idea is that the animated creature really becomes alive and enters the true character of the role. One character would not perform an action the same way in two different emotional states. No two characters would act the same. It is also important to make the personality of a character distinct, but at the same time be familiar to the audience.

The last three principles (exaggeration, appeal, and personality) rely more on the animator's skill and have little relation to any software function. As such, they can't really be automated.

5. 3D Character Animation in Practice

In order to put 3DCA into practice, you will need both hardware and software.

- Hardware
    - The most important components are the CPU (central processor), RAM (system memory), and GPU (graphics processor / video card). You can never have enough CPU power, so start with the best you can afford. Single or dual-processor configurations of Intel Pentium III or AMD Athlons running at minimum 1.0 GHz should be considered. A minimum of 256MB of RAM is essential, the more being the merrier. For the GPU, it must support OPENGL v1.2 and DirectX v8.0 to perform realtime display interactions. If you are going to do video editing, then a fast and large harddisk is necessary, preferably utilising Ultra-SCSI. If you intend to use live-action video as reference footage or to integrate it with your 3D work, then you'll need a good video-capture card. It is best to use a card that can accept digital Firewire input, and use a digital video camera for shooting in the DV format. A good monitor of 19" minimum is recommended for viewing. A pressure-sensitive tablet is useful for texture creation and image editing. You'll need an image scanner to scan in (or digicam to photograph) your storyboard drawings to make your story reel. A CD-Writer is helpful for making backups and producing CD-based applications, and a colour inkjet printer can be used to print sample renderings. Don't forget the sound system (card, speakers, and microphone) if you're interested in voice dubbing and adding music.

- Software
    - During pre-production, in the preparation of the story reel, you'll need a video-editing program. A sound editor, together with a music and effects CD library can be used for adding audio into the story reel. There are in fact software to assist you in the creation of storyboards and scriptwriting, but the tried and tested pencil and paper are often more effective.
    - During production, you'll of course need your 3DCA package, and an image editor for producing surface textures for your objects. A CD library of pre-made 3D models, materials and actions can speed up your work.
    - For post-production, a video compositing and effects program is needed to combine the different layers of imagery. The video editor and sound mixer is used to generate final output. A critical decision should have been made earlier as to what format the output should be. You may need extra software like encoders, convertors, authoring programs, and plug-ins to produce the desired effect.
        - Video – PAL or NTSC? Tape or VCD?
        - CD – AVI, Quicktime, MPEG? Screen resolution? Filesize? DVD?
        - Film – Render size and time? Aspect ratio?
        - Web – Streaming, Flash, Shockwave3D? Download time vs. quality? Interactive?

- Network
    - One of the most time-consuming processes is rendering out the final images. A single frame can take several hours to render if it is complex, and you'll need about 30 frames just to make up 1 second of video time. A good way to conquer this problem is to divide the workload among several computers that are connected on a LAN. The 3DCA package must support distributed rendering. A master software is run on the controlling computer, while a slave software is run on each network node. The master instructs the slaves which frame to render and is scheduled to operate automatically. Rendered files are output into a shared folder on the controlling computer. This collection of networked computers is typically known as a render farm.
    - The render slave need only have a powerful CPU, lots of RAM, and a network card. You may not even need a harddisk as some operating systems and network cards support remote execution booting. This saves you from the headache of harddisk crashes and maintenance.
    - The more render slaves you have, the greater your processing power. However, licensing costs are usually on a per node basis. Unlimited node licenses are also available. (For the "Comparison of 3DCA Packages" in the next section, to give a fair and equal price comparison, the unlimited node network license was used.)
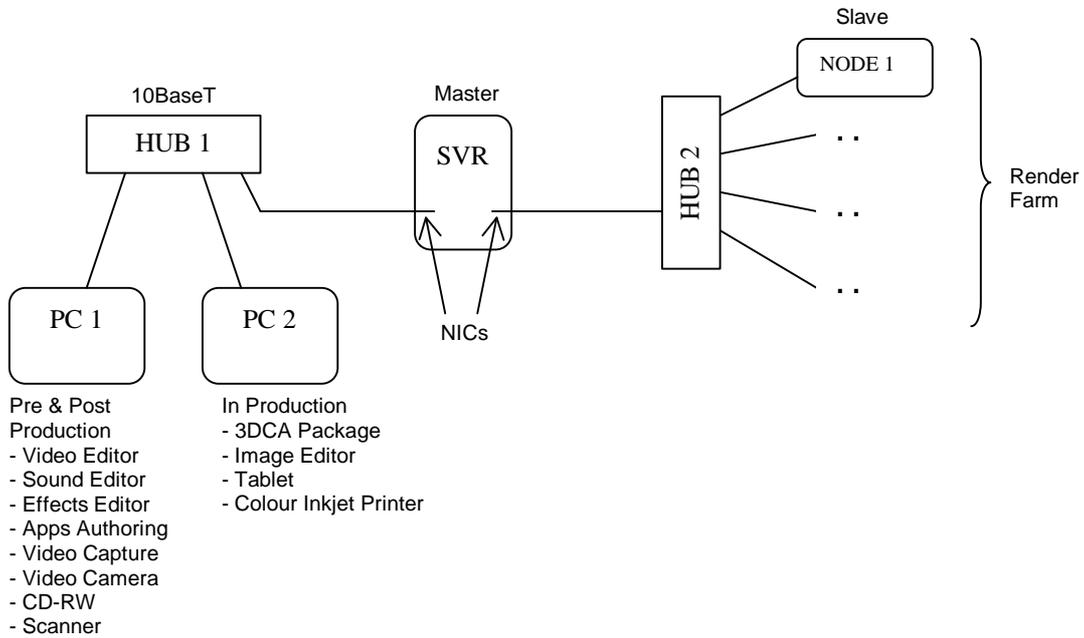
6. Comparison of 3D Character Animation Packages

Features	Software			
	Animation Master	Realsoft3D	Lightwave	Maya
Category (E=Entry-level, M=Mid-range, H=High-end)	E	E	M	H
Version	9.0	4.1	6.5	4.0
Platform (W = MsWindows, M=MacOS, U=Unix, L=Linux)	WM	W	WM	WMU
Price US$ (single seat, network version – unlimited nodes)	700	700	2495	16000
Modelling				
- Efficient, low-density mesh	✓	✓	✓	✓
- Natural curved lines and smooth joins	✓	✓	✓	✓
- Point-level realtime sculpting	✓	✓	✓	✓
- Rotoscope assisted modelling	✓	✗	✓	✓
- Unibody construction	✓	✓	✓	✓
- Nested group editing	✓	✓	✓	✓
- Seamless bone integration	✓	✓	✓	✓
- Orthogonal and perspective views	✓	✓	✓	✓
- Import/export of various file formats	✓	✓	✓	✓
Rigging				
- Switchable forward kinematics (FK) & inverse kinematics (IK) based bone linkages	✓	✓	✓	✓
- Reusable bone and constraint hierarchy	✓	✓	✓	✓
- Support for multiple realtime attribute-level constraint (relationship) types to provide control bone structure, like auto-balancing	✓	✓	✓	✓
- Weighted blending of control points for natural deformation of mesh and muscle	✓	✓	✓	✓
- Kinematic rotational stiffness and lockable bones	✓	✓	✓	✓
- Quaternion interpolation for bone rotation	✓		✓	✓
- Constraints can be blended and animated	✓	✓	✓	✓
- Relationships with target lagging	✓	✓	✓	✓
- Scripting or Expressions (programming language)	✗	✓	✓	✓
Animating				
- Keyframe, timeline and channel graph motion editing with realtime display feedback	✓	✓	✓	✓
- Skeletal and muscle control features, onion skinning, bone scaling, Curve bias control	✓	✓	✓	✓
- Support for scrubbable audio, lip-synch automation and phoneme creation	✓	✗	✓	✓
- Stride length to prevent feet slippage	✓	✓	✓	✓
- Spline-based motion paths	✓	✓	✓	✓
- Swappable lightweight proxy models	✓	✗	✓	✓
- Video rotoscoping	✓	✗	✓	✓
- Able to animate materials, decals, lights, cameras and other attributes	✓	✓	✓	✓
- Pose motion: slider-controlled ranged actions	✓	✗	✓	✓
- Provides for action reuse, action objects, overloading, blending and non-linear animation	✓	✓	✓	✓
- Rigid and soft-body dynamics, esp. cloth simulation. Other special effects such as particles, hair, fluids, esp. with collision detection become useful at this stage if they cannot be integrated in the post-production phase.	✓	✓	✓	✓
- Object flocking or crowd simulation	✓	✓	✓	✓
- Supports motion capture and motion tracking	✓	✗	✓	✓

Websites :

1. Animation Master – http://www.hash.com
2. Realsoft3D – http://www.realsoft3d.com
3. Lightwave – http://www.lightwave6.com
4. Maya – http://www.aliaswavefront.com/en/WhatWeDo/maya/index.shtml

See [13] for more websites.

7. Proposal for an Entry-Level 3D Character Animation System

PC1
- Intel Pentium III 1.0 GHz / AMD Athlon 1.2 GHz
- 384MB RAM
- 1 x 30GB EIDE, 1 x 10 GB Ultra-SCSI
- nVidia GeForce3 64MB, 19" monitor
  - all above - $1900
- Creative Sound Blaster Live 5.1 - $99
- Creative DT2220 Surround Speakers - $129
- 1 x 10BaseT NIC - $50
- Matrox RT2500 - $999
- Sony Handycam DCR-PC110e - $1999
- 4x4x8x CD-RW - $99
- HP Scanjet 5300c - $199
- MS-Windows 2000 Pro SP2 - $300
- Adobe Premiere v6.0 - $550
- Adobe After-Effects v5.0 - $649
- Macromedia Director v8.5 - $1199
- Sonic Foundry Acid Pro v3.0, Vegas Audio v2.0 - $700

PC2
- Intel Pentium III 1.0 GHz / AMD Athlon 1.2 GHz
- 384MB RAM
- 1 x 30GB EIDE
- nVidia GeForce3 64MB, 19" monitor
  - all above - $1900
- Creative Sound Blaster Live 5.1 - $99
- Creative DT2220 Surround Speakers - $129
- 1 x 10BaseT NIC - $50
- Wacom Intuos 6x8 Tablet - $299
- HP Deskjet 990c - $399
- MS-Windows 2000 Pro SP2 - $300
- Hash Animation Master 2001 v9.0 - $700
- Adobe Photoshop v6.0 - $600

SVR
- Intel Pentium III 1.0 GHz / AMD Athlon 1.2 GHz
- 128MB RAM
- 3 x 30GB EIDE RAID-5
- SVGA, 15" monitor
- 2 x 100BaseT NIC
  - all above - $2000
- MS-Windows 2000 Server SP2 (10 users) - $1199
- (Runs the AM2001 Render Master)

NODE
- Intel Pentium III 1.0 GHz / AMD Athlon 1.2 GHz
- 256MB RAM
- SVGA, no monitor
- 1 x 10BaseT NIC with remote exec. boot chip
  - all above - $700
- (Runs the AM2001 Render Slave)

HUB
- 16-port 10BaseT - $150

ESTIMATED PRICES:

- PC1 – US$8890
- PC2 – US$4476
- SVR – US$3199
- NODE – US$700
- HUB – US$150

EST. PRICE (10 NETWORK NODES): US$23,865

8. Conclusion

With the power available in personal computers today at increasingly competitive prices, producing 3D character animations for broadcast, film, games and the multimedia industry is becoming an affordable pursuit. What used to cost hundreds of thousands of dollars, and usually required complex and proprietary systems that needed arcane technical know-how, can be obtained for a fraction of the cost using only off-the-shelf packages which are easy to use.

The recommendations made in the previous section for an entry-level 3DCA system are actually much higher than necessary. In fact, a complete system can be configured to operate from a single high-end PC. Although a few notable short films has been created by a single person on a single computer, it is highly recommended to streamline the workload and processes so that it is more flexible in tackling concurrent tasks and more extensible to cater for growing demands.

An alternative to a dedicated render farm is to utilise existing computers on your network. If you work in a company that has hundreds of PCs connected on a LAN, these machines are usually idle in the night, weekends or during holidays. You can make use of these computers as rendering slaves. Some 3DCA packages support Internet-based rendering, so you can even render across the World Wide Web.

In conclusion, this paper has shown that it is possible to acquire a low-cost 3D character animation system that can produce broadcast-quality output in a production environment.

9. Acknowledgements

Screenshots were made using Hash Animation Master software and 3D models come from their website at http://www.hash.com.

10. References

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