3D+TIME FILE FORMATS

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Abstract

This report presents an overview of 3D+time data content and file formats for preservation purposes. It enumerate the various data representations for this type of data as well as the past and current 144 file formats used for storing such data. This overview serves as a foundation for understanding the information loss introduced by 3D+time file format conversions with many of the software packages designed for viewing and converting 3D+time data files. The ultimate goal of this work is to understand the scalability issues of dealing with algorithms, storage and preservation requirements for data as we increase the dimensionality in general (e.g., moving from 2D images to video, 2D images to 3D geometry, and 3D geometry to 3D+time).

Contents

1 Introduction

3D+time data is becoming an increasingly important paradigm of stored information. Over the past decade we have seen a boom of 3D digital animations in television (programming and advertising), movies, and video games. These 3D digital animations consist of 3D digital objects that articulate and/or change position over time. The content is created by animating and converting 3D models into animations, by producing stereoscopic 3D or 2D-to-3D converted movies[1], or by developing 3D games and managing multi-media content repositories. With the increasing amounts of digital animations (3D+time with attributes), there is a need to understand file formats with the content corresponding to 3D activity.

While initially most of this 3D animate data was artificial, having had been created by a human animator, this trend is rapidly changing. Due to progress in embedded processing, increasing bandwidths, much cheaper hardware, and the emergence of a population that has grown accustomed to such content, we are seeing the development of commercial camera equipment capable of capturing 3D digital reconstructions directly from a live scene in real time. This is true not only at macroscopic scale but also at microscopic scale of interest to medical applications. As our concern is the preservation of digital data we focus on the representations used to store this 3D+time data and the formats by which they are saved to in a file. Unlike our earlier report on 3D file formats [2] where we were looking back on a domain which had accumulated a huge number of formats over the time, we find ourselves here in a situation of still looking forward at what formats will become the industry standard and hence of interest to the archivists. Although we have observed that many of the 3D graphics file formats support some form of animation, 3D+time data representation and storage is still somewhat at its beginning when it comes to defining the methodologies for expanding existing n dimensional to (n+1) dimensional formats. In this technical report we will enumerate the growing source of 3D+time content, the various representations for storing such data, past file formats for motion capture and graphics animations, and new formats for real world 3D+time data.

2 3D+time Data Representations

Similar to 3D data, 3D+time data can be represented in several ways. In this section we provide an overview of the various representations for 3D+time content.

[1] Discussion Blog “2D to 3D converted movies...is that better than Shooting in”, URL: http://realvision.ae/forum/viewtopic.php?f=3&t=29

2.1 3D Points in Time

In the simplest extension from 2D video to 3D animations we extend 2D frame pixels of the form *(x,y)* to 3D points of the form *(x,y,z)*. Unlike 2D video frames which are usually densely stored with data for every point in an image frame given, the 3D analog of a volume tends to result in huge amounts of data. Typically, 3D point data is sparsely stored with points sampled from various points of interest on the surface of scene objects. Collections of points visible at each time *t* can be stored together and displayed at appropriate times to produce an animation.

This simple and straight forward representation of 3D+time data can be converted to by most other types of 3D+time representations by sampling. However, this representation though sparsely storing 3D+time information still tends to result in large file sizes as a large number of points can accumulate over time fairly quickly. In addition, viewing data stored in this way suffers from aliasing when users zoom in on objects in the scene. Since the data is a cloud of points, even if the individual points are indistinguishable from a distance, by zooming in a user will be able to see those points and worse yet the gaps in between them. Aliasing can be reduced by further sampling (i.e. storing more points). However, this will have added cost in terms of file size. Another common method of reducing aliasing is to render points as splats [1, 4]. Rather than drawing a point a small flattened sphere is rendered in its place. Unlike a zero dimensional point, these 2D splats have area. Therefore as a user zooms in, while likely to still notice discontinuities between splats, should no longer see gaps between them. It is important to note also that splats require some additional information from the scene, specifically the area covered by each splat along with each splats normal (i.e. orientation). Though requiring far fewer parameters than super sampling the data, this additional data is not always readily available.

Motion capture data is often stored as lists of points in time, where each body markers location is represented by a 3D point. Volumetric data is often stored in this way as well. Analogous to 2D images with pixels, volumes are dense 3D point representations where the points are referred to as voxels.

2.2 3D Scene Graphs with Transformations

3D animations have been around for some time now, most notably within the video game industry and more recently within the TV and movie industries. Data within these industries, being designed by humans, is far more structured than simple clouds of points. This structure allows for increased efficiency with regards to file storage size.

A typical means of storing this animated data is in the form of a scene graph. A scene graph is an acyclic directed graph with 3D data at its leaf nodes and functions, transformations, and parameters for functions making up its internal nodes. The 3D data can be represented by any static surface or solid representation such clouds of points, meshes, B-Rep solids, etc… [3]. Internal nodes can represent rigid transformations (e.g. rotations and translations) and light sources that will be applied to all child nodes. With just these nodes the scene graph is still static. To animate a part or all of the geometry we include interpolator nodes and timers. Interpolator nodes are functions parameterized by a number of key points and a moment in time (obtained from a parent timer node). These nodes use the given values to identify and return points in between its associated key points. These intermediate points can then be used by other nodes such as transformations to determine a translation or an angle of rotation.

A skeleton rigged model can be animated in this manner by using bone positions, where bones are merely groups of related geometry, and making them the key points for interpolators. As a parent timer increments its value, intermediate bone positions will be generated. When the intermediate bone positions are applied to the

underlying geometry then they will provide the perception of animation. While such a scene graph is now dynamic in the sense that groups of geometry can move in time, with just these nodes it is still static with regards to the geometry present in the scene. Consider a scene consisting of cars crossing through an intersection. The cars will come and go over time (i.e. the geometry involved in the animation is changing). To accommodate these types of scenes, scene graphs allow for various node modifying operations such as: insert, update, and delete. To have an object enter the scene an insert operation is required to add the corresponding geometry and transformations to the graph. When the object leaves the scene a delete operation is used to remove its corresponding nodes.

With these operations a scene graph can be used to represent fairly arbitrary 3D+time animations including clouds of points in time. To store an animated cloud of points the graph will have to be updated at each time instance so as to insert a node containing the list of points visible at that time while at the same time deleting all nodes from the previous time instance. However, scene graphs usually utilize other geometric representations, for example polygonal meshes. These representations, which sparsely represent an objects surface, allow for much smaller file sizes than could be achieved by storing 3D clouds of points.

2.3 Simulcast of 2D Views

3D data can be thought of as a large number of 2D views. By rotating, translating, and zooming a user can obtain an infinite number of views of a 3D scene. In light of this one might represent 3D+time data as a number of contemporary 2D video streams, each taken from a different view point. This approach is one of several being considered for the next generation TV broadcasts that will include 3D data. By using multiple regular 2D video cameras one can effectively transmit 3D+time data by broadcasting each view simultaneously. On the user side the needed view can be obtained by searching for the closest broadcasted view to the users view or by attempting to interpolate between these views if need be. To obtain the 3D position of points in a scene only two views are really required. Using stereo correspondences between points the two views can be used along with the cameras orientation and position in order to triangulate the depth and overall position of each point. While stereo reconstruction is a well-studied area in the field of computer vision [5], it does suffer with regards to quality in areas with little texture, highly repetitive texture, or where occlusion exists in one view. Methods of dealing with these situations are still a topic of active research. Another important point to make is that while computer algorithms for stereo tend to suffer from these degenerate situations, humans themselves are much better (or much more forgiving). In other words rather than reconstructing the depth from the two images it is becoming a very common practice to simply display the two views and let the human watcher interpret the images as 3D much like they would the two images coming from their two eyes. The key here is to insure that each image is delivered separately to the two eyes. Methods for doing this are Anaglyph glass (with a different color over each eye), polarized glasses (with orthogonal orientations over each eye), synchronized shutters (which open and close in time with alternating left and right images on a display), and auto-stereoscopic displays (which can use lenticular lenses to make a different image visible depending on the viewing angle).

2.4 2D + Depth

Rather than dealing with the bandwidth limitations associated with transmitting an arbitrary number of views another option is to perform stereo reconstruction on the camera side and transmit the reconstructed depth information from one of these views as another channel of data. When depth data is quantized into a discrete range of values it can be treated as a simple gray scale image. These 2D depth maps can be stored as another color channel so that, using the RGB colors space as an example, we can send the red, green, blue layers as usual and include one additional layer consisting of this depth data.

This representation is favorable for 3D TV as it allows the current 2D formats to be reused by simply including another channel of data. On the receivers side new views can be created as needed from this data simply by knowing the cameras position, recovering 3D points, applying a desired rigid transformation, and projecting the points back into the image plane. In this way an arbitrary number of views can be obtained from only one additional channel of data (i.e. one monochrome image). It should be noted that the farther one gets away from the original view used to reconstruct the depth, the more artifacts will be present. Thus, while a 2D + Z representation improves bandwidth efficiency, there is a significant cost in terms of quality at views different from the broadcasted view.

2.5 Multi View Coding

Multi-view coding attempts to address the quality problems with 2D + Z data at novel views while maintaining as much of the bandwidth efficiency as possible. Like in the case of the simulcast representation multiple views are transmitted. This time however each view is 2D + Z data. By including each view's depth information, nearby views can still be interpolated. Before interpolation however we must choose one or more of the transmitted views as our basis, ideally picking views that are closer so as to reduce resulting artifacts. By still using view interpolation we can transmit fewer views than would be required for the same level of quality using a simulcast scheme.

2.6 Information Loss When Converting Representations

The various 3D+time data representations can be converted to one another. However, similar to the 3D data representations, some conversions are more difficult to do than others. In addition, when converted between various 3D+time representations one must consider various computational and storage requirements that may arise, as well as the information loss due to conversions. We briefly outline some of these considerations.

Conversions of 3D points in time representations: 3D points in time are probably the lowest level representation one could use for 3D+time data. As mentioned before we can store 3D+time information within a scene graph. Nonetheless, using scene graphs does not take advantage of the sparse nature of a 3D point cloud since we are basically storing the points per frame inside of a graph structure. In this case, we really gain nothing in terms of reducing space requirements and in fact we are likely increasing it a bit. We add to the overall complexity of files by keeping 3D points from the entire surface of objects in the scene instead of converting multiple views needed to a simulcast representation. We can also easily include depth information from these views to convert to a 2D+depth or multi-view coding representation. Each of these conversions however leads to information loss as the original data had information from potentially any view and now we restrict the data to some small finite number of views. On the other hand, these view restrictions will save significantly on the amount of data sent. In addition, since these methods often simply add an additional channel to traditional video formats, many of their compression methods would still apply leading to huge savings in file size.

Conversions of scene graph representations: Converting from scene graphs to the other representations has many of the same tradeoffs as those mentioned when converting 3D point clouds to other representations. Since we have a full 3D model at each time instance we can easily sample points from its surface at each frame to create a 3D point cloud representation. This will throw away the benefits of a sparse representation and likely dramatically increase the files size. The only real benefit in doing this would be that the file with 3D points over time would be far less complex. Like 3D clouds of points we can convert scene graphs to simulcast, 2D+depth, and multi view coding representations by rendering the scene from multiple views and including depth. Each conversion again would introduce some information loss. Whether or not savings will

be seen in terms of file storage is not a certainty. Though these view-based representations have the advantage of long used compression techniques, scene graphs are fairly sparsely represented to begin with. In fact the result of the conversion may be a larger file.

Conversions of simulcast of 2D view representation: Converting from the multi-view 2D representation to 3D point clouds is much more costly and difficult. Furthermore, converting these to a 3D structure such as the scene graph is non-trivial. From the two 2D images in a simulcast representation we can use stereo correlation (or the triangulation of left and right eye views with an object surface) to recover depth information, effectively converting two 2D images to a 2D+depth image representation. Nevertheless, algorithms for stereo correlation are usually far worse in determining depth accurately than human beings. This is true especially when dealing with areas of the image that lack distinctive texture. Thus, with regards to the perception of depth it might actually be better to send the two views and let the humans watching it reconstruct the depth than sending this reconstructed depth information and presenting it to the human at poorer perceptual quality.

Conversions of 2D+depth representations: Converted from 2D+depth to a multi-view coding is impossible as we have only one view. Converting this 2D+depth information to a 3D cloud of points can be done fairly easily by knowing location and orientation of the camera used to take the images with respect to the world coordinate system. However, this 3D cloud of points will not be of the whole scene but of the scene as seen from the view captured in the original view or views. When this 3D cloud of points is viewed from a viewing angle deviating from the original view then artifacts such as holes will be seen. In addition, since we will lose access to the compression methods used in video representations the resulting file will likely be larger. As mentioned previously a 3D point cloud representation can then be converted to a scene graph representation although there is no gain in doing so. If we began from a multi-view coding representation and converted to a 3D point cloud then we would create a scene much closer to the original. The more views we obtained the better the reconstructed scene. In practice, we will likely have only a small handful of views and thus we would always observe some artifacts in the reconstructed 3D cloud of points.

2.7 Information Loss When Converting File Formats

The information loss when converting data representations is a part of the information loss when converting file formats. Many of the file formats are proprietary and therefore evaluating information loss requires data-driven approaches. The data-driven evaluation approaches have been prototyped using the NCSA Polyglot system at http://isda.ncsa.uiuc.edu/NARA/conversion.html.

3 Vendors Developing Software and Hardware Products Generating 3D+time Data

This section provides an incomplete summary of vendors that have developed products generating 3D+time data. Over the past decade we have seen this market really begin to take off with the investment in specialized chipsets, onboard computation, and a growing market demand for such products (movies and gaming especially). The 3D+time data generated are often in the form of 2D+depth, 3D point clouds, and volumetric data. There are also systems that produce polygonal meshes directly as well.

The hardware and software products generating 3D+time data refer to camera-based, motion capture based or volumetric based acquisition of 3D information over time as documented in Table 1. Besides the 3D+time content creation directly from physical scenes by sensing, there are also many vendors in the movie and

gaming domains that create 3D+time content by simulations. We have provided a list of major vendors (producers and consumers of 3D+time content) in Appendix 8 and Appendix 9.

Table 1: An overview of vendors developing and/or selling products generating 3D+time data.

Vendor	Type	Details	URL
Ariel Dynamics	Camera based	Video-based 3D motion analysis from multiple cameras	http://www.arielnet.com/start/apas/default.html
PhaseSpace Corp.	Camera based and Motion capture	Marker based tracking technology	http://www.phasespace.com/rnd.html
XSENS	Motion capture	MEMS inertia sensors	http://www.xsens.com
InterSense	Motion capture	MEMS accelerometer, angular rate gyro, and magnetometer sensor data	http://www.intersense.com
ViALUX GmbH	Camera based	zSnapper - Combines multiple scanners enabling full-360° shape data in one shot	http://www.vialux.de/HTML/en_ddscan.htm
3DV Systems *purchased by Microsoft in '09*	Camera based	zCam – near-infrared based stereo camera	http://www.3dvsystems.com
GestureTek	Camera based		http://www.gesturetek.com
Hewlett Packard	Camera based	Coliseum system – Multi-camera 3D reconstruction of head	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.58.5548&rep=rep1&type=pdf
Microsoft	Camera based	RoundTable (formerly RingCam) – Five cameras covering 360 degrees combined with audio	http://www.humanproductivitylab.com
Eyetoy Kinetic	Camera based	Real time stereo system for gaming	http://www.eyetoykinetic.com
Organic Motion	Camera based	Markerless motion capture system	http://www.organicmotion.com
TYZX Inc.	Camera based	3D stereo camera based on stereo vision and embedded processing	http://www.tyzx.com/products/DeepSeaG2.html

Videre Design	Camera based	3D stereo camera based on stereo vision and embedded processing	http://www.videredesign.com
Point Grey Inc.	Camera based	Bumblebee - 3D stereo camera with libraries for fast stereo vision on a PC	http://www.ptgrey.com/products
Canesta	Camera based	Time-of-flight range camera	http://www.canesta.com
4DViewsSolutions	Camera based	Silhouette-based 3D reconstruction method that builds a collection of polygons describing the filmed subject	http://www.4dviews.com
Teliris	Camera based	Tele-presence with multiple 2D cameras	http://teliris.com/telepresence-solutions.html
AT&T	Camera based	Tele-presence with multiple 2D cameras	http://www.business.att.com
Polycom	Camera based	Tele-presence with multiple 2D cameras	http://www.polycom.com
Microsoft Research	Camera based	Tele-presence with multiple 2D cameras	http://research.microsoft.com
CISCO	Camera based	Tele-presence with multiple 2D cameras	http://www.cisco.com
HP	Camera based	Halo system - Tele-presence with multiple 2D cameras	http://www.telepresenceoptions.com/2010/06/hp_signs_up_with_vidyo_wainhou
2D3	Camera based	Enhancement of 2D to create 3D perception	http://www.2d3.com/product
Vicon	Camera based	Boujou	http://www.vicon.com
GE	Volumetric	4D Ultrasound, high definition magnetic resonance (HDMR) systems	http://www.gehealthcare.com
HP /Philips	Volumetric	HP Sonos 5500 - Ultrasound System with a 3D transducer	http://www.ambassadormedical.com

4 3D+time Formats

In this section we attempt to outline a number of file formats that support 3D+time data. We divided the 3D+time formats into the original 3D file formats extended by vendors to provide animation support in Section 4.1 and those file formats that have been dedicated to containing 3D+time data in Section 4.2.

4.1 3D Formats with Animation Support

In our previous report we attempted to enumerate many of the available 3D formats. Many of these formats support some sort of animation, making them in effect 3D+time formats. In this section we attempt to identify specifically which of these formats are capable of storing animations (i.e. 3D+time data).

Table 2: A list of 3D file formats indicating which do and do not support animation. With each format we included a reference URL along with a snippet from the text that indicates whether or not the format supports animation.

Extension	Name	Animation Support	Source	Sentence from source
3dm	*Rhino*	*Yes*	http://www.rhino3d.com/4/display.htm	simple animation
3dmf	*Quickdraw 3D*	*No*	http://www.3dartist.com/3dao/s/18/qd3d.htm	A key issue is the absence of support for animation in the 3DMF file format, and in the QuickDraw architecture in general.
3ds	*3D Studio*	*Yes*	http://docs.autodesk.com/3DSMAX/13/ENU/Autodesk%203ds%20Max%202011%20Help/index.html?url=./files/WS1a9193826455f5ff-3a29af00119afd28e95-101.htm,topicNumber=d0e427543	With 3ds Max, you can create 3D computer animation for a variety of applications.
		Yes	http://www.3dmagix.com	Announcing: The Revolutionary 3D Software That Has Helped 6,100 People In 67 Countries Create Cutting-Edge Animations From The Comfort Of Their Own Home...
ac	*AC3D*	*Yes*	http://scenery.x-plane.com/tutorials.php?doc=ac3d_animation.php	Creating Animated Objects with AC3D
ai	*Adobe Illustrator*	*Yes*	http://livedocs.adobe.com/en_US/Illustrator/13.0/hel	There are many ways to create Flash animations in Illustrator.

			p.html?content=WS714a382cdf7d304e7e07d0100196cbc5f-6356.html	
arc	*I-DEAS*	*Yes*	http://www.ijme.us/issues/fall2001/software.html	The result produced from the internal solver of I-DEAS predicts the motion output of all parts.
ase	*ASCII Scene Export*	*Yes*	http://wiki.beyondunreal.com/Legacy:ASE_File_Format	*TM_ANIMATION Block containing information about the transformation of the animation.
asm	*Pro/Engineer, Solid Edge, SolidWorks*	*Yes*	http://www.engr.uvic.ca/~mech410/proe_tutorials_files/DAOConcepts.pdf	Design Animation is a tool for creating animation sequences using Pro/ENGINEER parts, assemblies, and mechanisms previously created in Mechanism Design.
		Yes	http://www.plm.automation.siemens.com/en_us/about_us/newsroom/press/press_release.cfm?Component=34179&ComponentTemplate=822	a leading global provider of product lifecycle management (PLM) software and services, today announced enhancements to motion simulation and animation within Solid Edge®.
atr	*Lightscape Material*	*Yes*	http://www.squidoo.com/Lightscape-3#module80919271	Animation: Professional keyframing control for camera animation.
bdl	*OneSpace Designer*	*Yes*	http://www.kxcad.com/cad-onespace-What-s-new-in-OneSpace-Designer-Modeling-2006.html	Animation: Now you can trace an animation to help visualize the path of each animated object.
blend	*Blender*	*Yes*	http://www.blender.org/features-gallery/features/	Armature (skeleton) deformation with forward/inverse kinematics with pole target support
blk	*Lightscape Blocks*	*Yes*	http://www.squidoo.com/Lightscape-3#module80919271	Animation: Professional keyframing control for camera animation.
br4	*Bryce*	*Yes*	http://www.cadtutor.net/dd/bryce/anim/anim.html	Animation between these keyframes is calculated by the application, in this case by Bryce.
bvh	*Motion*	*Yes*	http://www.siggraph.org/education/materials/HyperG	Motion capture for computer character animation involves the

	Capture		raph/animation/character_animation/motion_capture/history1.htm	mapping of human motion onto the motion of a computer character.
c4d	*Cinema 4D*	*Yes*	http://www.maxon.net/en/products.html	CINEMA 4D Visualize provides everything you need to produce fantastic images and animations quickly, easily and to any level of realism.
cab	*TrueSpace*	*Yes*	http://www.caligari.com/Gallery/press_animations.html	the focus for trueSpace6 has always been on animation.
cadds	*CADDS*	*No*	http://www.ptc.com/products/cadds5	
catdrawing, catshape	*CATIA V5*	*No*	http://www.3ds.com/products/catia/portfolio/catia-v5/catia-v5r20/	
catpart, catproduct	*CATIA V5*	*No*	http://www.3ds.com/products/catia/portfolio/catia-v5/catia-v5r20/	
cgr	*CATIA Drawing*	*No*	http://www.3ds.com/products/catia/portfolio/catia-v5/catia-v5r20/	
chr	*3Ds Max Characters*	*Yes*	http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=13581855	Increase your animation output per artist. Autodesk® MotionBuilder® real-time 3D character animation software can make film and game animation pipelines more efficient.
dae	*AutoDesk Collada*	*Yes*	http://www.collada.org/mediawiki/index.php/ColladaMax	added export of animation layers, as COLLADA animation clips.
ddf	*Data Descriptive File*	*No*	http://reference.wolfram.com/mathematica/ref/format/SDTS.html	
dem	*Digital Elevation Models*	*No*	http://en.wikipedia.org/wiki/Digital_elevation_model	
df	*LightScape Parameter*	*Yes*	http://www.squidoo.com/Lightscape-	Animation: Professional keyframing control for camera

			3#module80919271	animation.
dlv	*CATIA V4*	*No*	http://en.wikipedia.org/wiki/CATIA	
drf	*VIZ Reader*	*Yes*	http://www.autodesk.com/us/interactiveoverviews/viz_demo/viz_english.html	Containing a wide range of animation tools, Autodesk VIZ is ideal for creating walkthroughs, mechanical demonstrations and much more.
dwf	*AutoDesk Composer Design Web Format*	*Yes*	http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=4086277	Even team members who don't have or are unfamiliar with complex CAD software can fully visualize digital prototypes created in Autodesk® Inventor® software and AutoCAD® software based applications—including detailed manufacturing design data, such as bill of materials information and animated assembly instructions.
dwg	*Legacy AutoCAD Drawing*	*No*	http://docs.autodesk.com/MAXDES/13/ENU/Autodesk%203ds%20Max%20Design%202011%20Help/index.html?url=./files/WSf742dab04106313339aef003112a1ce9423-7f5d.htm,topicNumber=d0e423843	
dws	*AutoCAD Standards*	*No*	http://docs.autodesk.com/ACD/2010/ENU/AutoCAD%202010%20User%20Documentation/index.html?url=WS1a9193826455f5ffa23ce210c4a30acaf-781a.htm,topicNumber=d0e20767	
dwt	*AutoCAD Drawing Template*	*No*	http://docs.autodesk.com/ACD/2010/ENU/AutoCAD%202010%20User%20Documentation/index.html?url=WS1a9193826455f5ffa23ce210c4a30acaf-78f3.htm,topicNumber=d0	

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dxf	*AutoCAD Drawing Exchange Format*	*No*	http://docs.autodesk.com/MAXDES/13/ENU/Autodesk%203ds%20Max%20Design%202011%20Help/index.html?url=./files/WSf742dab04106313339aef003112a1ce9423-7f5d.htm,topicNumber=d0e423843	
eim	*Electric Image*	*Yes*	http://www.eias3d.com/products/eias-overview/	The Electric Image Animation System (EIAS) is an eminent 3D animation and rendering package.
eps	*Encapsulated Postscript*	*No*	http://desktoppub.about.com/gi/o.htm?zi=1/XJ&zTi=1&sdn=desktoppub&cdn=compute&tm=62&f=00&tt=14&bt=0&bts=0&zu=http%3A//www.designer-info.com/Draw/understanding_eps.htm	
exp	*CATIA V4*	*No*	http://en.wikipedia.org/wiki/CATIA	
fac	*Electric Image*	*Yes*	http://www.eias3d.com/products/eias-overview/	The Electric Image Animation System (EIAS) is an eminent 3D animation and rendering package.
fbx	*AutoDesk Kaydara FBX*	*Yes*	http://usa.autodesk.com/adsk/servlet/item?linkID=10235884&id=6904543&siteID=123112	FBX can be used as an interchange format between 3D modeling/animation/rendering packages, 3D scanners (hardware), 3D content providers, motion capture systems, camera tracking systems, and other applications.
fbl	*CADfix Log File*	*No*	http://www.transcendata.com/products/cadfix/	
fig	*xfig*	*No*	http://epb.lbl.gov/xfig/	
flt	*Flight Studio OpenFlight*	*Yes*	http://usa.autodesk.com/adsk/servlet/item?linkID=14271594&id=5600405&site	it will also offer them all of the award-winning content creation tools in Discreet's 3ds max 6

			ID=123112	animation software,
fmz	*FormZ Project File*	*Yes*	http://www.formz.com/products/formz/formzFeatures.php	form•Z, the 3D form synthesizer, is above all a 3D modeling program, even though it also includes drafting, rendering and animation
gmax	*AutoDesk Game Creator*	*Yes*	http://images.autodesk.com/adsk/files/gmax_whitepaper.pdf	gmax is a free downloadable 3d content creation and animation platform for consumers
gts	*GNU Triangulated Surface*	*No*	http://gts.sourceforge.net/	animation platform for consumers.
hp, hgl, hpl, hpgl	*HP-GL*	*No*	http://local.wasp.uwa.edu.au/~pbourke/dataformats/hpgl/	
hrc	*SoftImage*	*Yes*	http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=13571168	Autodesk® Softimage® software is a high-performance 3D character animation and visual effects application.
htr	*Motion Analysis HTR file*	*Yes*	http://www.cs.wisc.edu/graphics/Courses/cs-838-1999/Jeff/HTR.html	The Motion Analysis HTR (Hierarchical Translation-Rotation) format was developed as the native skeleton format for the Motion Analysis skeleton generating software.
ipt, iam	*AutoDesk Inventor*	*Yes*	http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=13718190#channels_Simulation	Use motion simulation software—not intuition—to enhance your design decisions.
		Yes	http://images.autodesk.com/adsk/files/inventor_2011_technical_whats_new_us.pdf	Inventor 2011 features enhancements to simulation visualization, including the ability to record animations of displacement and stress results over time.
ifc	*Industry Foundation Classes*	*No*	http://www.buildingsmart.com/bim	

ige, igs, iges	*Initial 2D/3D Graphics Exchange Specification*	*No*	http://homepages.cae.wisc.edu/~me232/info/dxf_iges_step.pdf	
ini	*POV-Ray animation script*	*Yes*	http://www.povray.org/documentation/view/3.6.0/790/	The animation script possibly also uses an INI file with the same basename as the scene file.
iob	*3D Object TDDDB Format*	*Yes*	http://www.imaginefa.com	Bend, Twist, Taper, Shear, Scale, Move, all manipulations are Animatable.
ipt, iam	*AutoDesk Inventor*	*Yes*	http://images.autodesk.com/adsk/files/inventor_2011_technical_whats_new_us.pdf	Inventor 2011 features enhancements to simulation visualization, including the ability to record animations of displacement and stress results over time.
iv	*Open Inventor*	*Yes*	http://oss.sgi.com/projects/inventor/	provides animation objects called Engines
jt	*JT*	*No*	http://en.wikipedia.org/wiki/JT_%28visualization_format%29	
k3d	*K-3D Native*	*Yes*	http://www.k-3d.org/	K-3D is free-as-in-freedom 3D modeling and animation software. It combines flexible plugins with a visualization pipeline architecture, making K-3D a versatile and powerful tool for artists.
kmz	*Google Earth Model*	*Yes*	http://code.google.com/apis/kml/documentation/kmlreference.html#gxtrack	In Google Earth, the time slider allows the user to move the view through time, which animates the position of the object.
lay	*LightScape Layers*	*Yes*	http://www.squidoo.com/Lightscape-3#module80919271	Animation: Professional keyframing control for camera animation.
lp	*LightScape Presentation*	*Yes*	http://www.squidoo.com/Lightscape-3#module80919271	Animation: Professional keyframing control for camera animation.
ls	*LightScape*	*Yes*	http://www.squidoo.com/Lightscape-	Animation: Professional keyframing control for camera

			3#module80919271	animation.
lw	*LightWave 3D*	*Yes*	http://www.newtek.com/lightwave/#	LightWave is a complete modeling, rendering and animation system
lwo	*LightWave 3D 5.0 Object*	*Yes*	http://www.newtek.com/lightwave/#	LightWave is a complete modeling, rendering and animation system
lws	*LightWave 3D Scene*	*Yes*	http://www.newtek.com/lightwave/#	LightWave is a complete modeling, rendering and animation system
lxo	*Luxology Modo*	*Yes*	http://www.luxology.com/modo/	And now, modo is a true end-to-end solution that includes true 3D sculpting tools, animation and network rendering!
m3g	*JSR-184*	*Yes*	http://en.wikipedia.org/wiki/Mobile_3D_Graphics_API	The M3G standard also specifies a file format for 3D model data, including animation data.
ma	*Maya Scene ASCII*	*Yes*	http://caad.arch.ethz.ch/info/maya/manual/FileFormats/FileFormats.fm.html	Maya scene files define the geometry, lighting, animation, rendering, and other properties of a scene.
max	*3Ds Max*	*Yes*	http://www.file-extensions.org/max-file-extension	The max file extension is associated with 3D Studio MAX, a modeling, animation and rendering package developed by Autodesk, Inc.. The max file format is native format of 3D Studio Max.
mb	*Maya Scene binary*	*Yes*	http://www.file-extensions.org/max-file-extension	The max file extension is associated with 3D Studio MAX, a modeling, animation and rendering package developed by Autodesk, Inc.. The max file format is native format of 3D Studio Max.
map	*Quake 3*	*Yes*	http://www.misofruit.co.kr/seojewoo/programming/opengl/Quake3Format.htm	These objects can be movable such as doors, platforms, etc
md2	*Quake 2 Player Model*	*Yes*	http://www.brighthub.com/hubfolio/matthew-casperson/articles/50141.a	MD2 models are easy to find there is a good selection of well modelled, textured and animated

			spx	models available.
md3	*Quake 3*	*Yes*	http://www.misfitcode.com/misfitmodel3d/olh_quakemd3.html#animations	MD3 animations specify vertex positions for each vertex for each frame of each animation. This can be tedious. When creating a model from scratch it is usually easier to save the model in MM3D format and create skeletal animations. Then when you are ready to export to MD3, convert the skeletal animations to frame animations using the Animation Sets Window and save as an MD3.
mdd	*Vertex Key Frame Animation*	*Yes*	http://www.luxology.com/modo/features/animation/	modo can also read .MDD files to render animations created in other 3D applications.
mel	*Maya Embedded Language Script*	*Yes*	http://en.wikipedia.org/wiki/Maya_Embedded_Language	Animation tools
mf1	*I-DEAS*	*Yes*	http://www.ijme.us/issues/fall2001/software.html	The result produced from the internal solver of I-DEAS predicts the motion output of all parts.
model	*CATIA V4*	*No*	http://en.wikipedia.org/wiki/CATIA	
mon		*No*	http://mirex.mypage.sk/index.php?selected=1	? - MON :GM (Geometry, Materials)
mot	*LightWave 3D Motion*	*Yes*	http://www.newtek.com/lightwave/	LightWave is a complete modeling, rendering and animation system.
mp	*Maya Scene PLE*	*Yes*	http://www.techmixer.com/free-autodesk-maya-personal-learning-edition-download/	Free Autodesk Maya is available download now for personal learning purpose. As we know, Autodesk Maya license is a very expensive ($ 4,995) 3D modeling and animation software. However, you can download the free Autodesk Maya Personal Learning Edition (PLE) is a special version of Autodesk® Maya® software,

				which provides free access to Maya for non-commercial use.
ms3d	*MilkShape 3D*	*Yes*	http://chumbalum.swissquake.ch/ms3d/help/htmlfiles/Keyframer.html	Animation is produced by storing several keyframes to the keyframer then playing them back using the controls on the keyframer.
mtx	*OpenFX Model*	*Yes*	http://www.openfx.org/about-plugins.html	Animation Physical Effects
ndo	*Nendo*	*No*	http://www.izware.com/nendo/index.htm	
neu	*Pro/Engineer*	*Yes*	http://www.eng-tips.com/faqs.cfm?fid=975	Animations in Pro/ENGINEER are a great way to communicate movement, assembly instructions, etc.
obj	*Wavefront*	*No*	http://en.wikipedia.org/wiki/Obj	The OBJ file format is a simple data-format that represents 3D geometry alone
obp	*Bryce*	*Yes*	http://www.daz3d.com/i/software/bryce/new?%23animation=&_m=d	add life to your environments by animating your favorite DAZ figures, animals and accessories inside DAZ|Studio and then importing the animations into your Bryce scene.
off	*DEC Object file*	*No*	http://www.fileformat.info/format/off/egff.htm	
p21		*No*	http://en.wikipedia.org/wiki/ISO_10303-21	
par, psm, pwd	*Solid Edge*	*Yes*	http://www.plm.automation.siemens.com/en_us/about_us/newsroom/press/press_release.cfm?Component=34179&ComponentTemplate=822	a leading global provider of product lifecycle management (PLM) software and services, today announced enhancements to motion simulation and animation within Solid Edge®.
pdb	*PDB Reader v3*	*No*	http://www.chromecow.com/downloads/lscript/pdb-reader-v285	It contains the XYZ spatial coordinates of the atoms in a molecule, but nothing else.
pd, pd	*CADDS*	*No*	http://www.ptc.com/products/cadds5	

pdf	*Portable Document Format*	*Yes*	http://www.adobe.com/designcenter/tutorials/flashpdf	PDF is the complete solution for delivering interactive content, including movies and sounds.
pkg	*I-DEAS, OneSpace Designer*	*Yes*	http://www.kxcad.com/cad-onespace-What-s-new-in-OneSpace-Designer-Modeling-2006.html	Now you can trace an animation to help visualize the path of each animated object.
plt	*HP-GL*	*No*	http://local.wasp.uwa.edu.au/~pbourke/dataformats/hpgl/	
ply	*Stanford PLY*	*Yes*	http://graphics.stanford.edu/data/3Dscanrep/	The models in this archive are fairly widely used in the graphics, visualization, and vision communities. Things people have done with these models include simplification, multi-resolution representation, curved surface fitting, compression, texture mapping, modeling, deformation, animation, physically-based simulation, texture synthesis, and rendering.
pov	*POV-Ray Rendering Instructions*	*Yes*	http://www.povray.org/resources/links/3D_Animation_Utilities/	
pp2	*Poser*	*Yes*	http://artzone.daz3d.com/wiki/doku.php/pub/tutorials/poser/poser-misc42	Props can also contain morphs. In my case the paper plane has 2 morphs to bend the left and the right wing.
prc, prd	*PRC Adobe 3D Reviewer*	*No*	http://help.adobe.com/en_US/Acrobat/9.0/3D/WSABFA8AF8-44F3-4161-8BCC-8A1A72FE873C.html	
prw	*Adobe 3D Reviewer*	*Yes*	http://help.adobe.com/en_US/Acrobat/9.0/3D/WS58a04a822e3e50102bd615109794195ff-7c13.w.html	Add animations.
prj	*3Ds Studio Mesh*	*Yes*	http://docs.autodesk.com/MAXDES/13/ENU/Autod	If you choose to merge the objects with the current scene, you'll be

			esk%203ds%20Max%20Design%202011%20Help/index.html?url=./files/WS1a9193826455f5ffba679e112a6a19004176.htm,topicNumber=d0e423095	asked whether you want to reset the length of the animation in the scene to the length of the imported file (if the imported file contains animation).
prt	*I-DEAS, NX (Unigraphics), Pro/Engineer*	*Yes*	http://www.plm.automation.siemens.com/en_us/products/nx/simulation/mechanical_simulation/index.shtml	New capabilities such as co-simulation of motion and controls, test correlation, and finite element analysis of assemblies allow engineers to better understand system effects early in the development process.
ps	*Post Script*	*Yes*	http://www.math.fsu.edu/~bellenot/LogAnim	Reading a big postscipt in ghostview can animate a log.
pwc	*Pulse*	*No*	http://www.pulsemicro.com/pulse-products-2009-tajimadgml-usa.htm	
pz3	*Poser*	*Yes*	http://poser.smithmicro.com/poser.html	Complete 3D and figure animation
raw	*Raw Faces*	*No*	http://stackoverflow.com/questions/282449/whats-the-best-3d-model-format-for-loading-and-displaying-inanimate-textured-obj	Takes less than 10 lines of code to parse and display, but doesn't contain color, textures, shaders, animation or anything else.
rib	*Renderman*	*Yes*	https://renderman.pixar.com/products/whats_renderman/standard.html	Pixar's RenderMan has been specifically engineered to meet the demanding challenges of rendering 3D animation and visual effects.
rif	*Radiance*	*Yes*	http://radsite.lbl.gov/radiance/framew.html	Because the rendering of high resolution images is often a time-consuming affair, a crude, interactive render ing program is provided. This program permits a scene to be rendered at low resolution from any perspective, providing a convenient means for studying a proposed design and selecting viewpoints for high-resolution batch rendering or

				animation.
rvt, rte, rfa	*Rent (Revit?)*	*No*	http://books.google.com/books?id=nMRYv3038Y8C&pg=PA70&lpg=PA70&dq=rvt,+rte,+rfa+revit&source=bl&ots=z1O-hEzxdA&sig=-cWc0MvwuW0lRzQPzs23oy90gC0&hl=en&ei=xkqaTMfNG57enQev79TvDg&sa=X&oi=book_result&ct=result&resnum=10&ved=0CEQQ6AEwCQ#v=onepage&q=rvt%2C%20rte%2C%20rfa%20revit&f=false	p. 70 for file format confirmation
rwx	*Renderware*	*No*	http://en.wikipedia.org/wiki/RenderWare	
s3d	*Strata 3D*	*No*	http://www.strata.com/solutions/interactive_content/	
sab, sat	*ACIS*	*No*	http://www.spatial.com/products/3d-acis-modeling	
scn	*TrueSpace*	*Yes*	http://www.caligari.com/products/trueSpace/ts75/Brochure/solutions_animation.asp	trueSpace7.6 is now free so you can make animations as fantastic as these for free!
sda, sdp, sds, sdw, ses	*OneSpace Designer*	*No*	http://www.ptc.com/products/cocreate	
sdac, sdpc, sdsc, sdwc	*OneSpace Designer*	*No*	http://www.ptc.com/products/cocreate	
session	*CATIA V4*	*No*	http://en.wikipedia.org/wiki/CATIA	
shp	*3D Studio Shape*	*No*	http://docs.autodesk.com/3DSMAX/13/ENU/Autodesk%203ds%20Max%202011%20Help/index.html?url=./files/WSf742dab04106313339aef003112a1ce9423-7f61.htm,topicNumber=d0	

			e422008	
skp	*Google SketchUp*	*Yes*	http://sketchup.google.com/intl/en/product/features.html	Scenes: Save views and create animations
slc, sl, slo	*Renderman*	*Yes*	https://renderman.pixar.com/products/tools/rps.html	Use RenderMan to create any look you need. From simulating traditional 2D animation to creating complex yet subtle environmental effects, RenderMan will deliver.
sldasm, sldlfp, sldprt	*SolidWorks*	*Yes*	http://www.solidworks.com/sw/products/SolidWorks%20Simulation.htm	Check for colliding parts and output numerical and graphic data of the results, as well as animations of your tests.
slp	*Pro Engineering*	*Yes*	http://www.okino.com/conv/imp_slp.htm	Once the SLP file has been imported it can be automatically exploded into separate objects, and each object can have its vertices welded together. The resulting optimized polygon mesh can then be rendered with no changes necessary using such programs as Okino's NuGraf; Autodesk 3ds Max, Autodesk Maya, etc. For an example of this conversion process click here to see a rendering of a Pro/E model rendered within Okino's NuGraf software.
stl	*Stereo Lithography*	*No*	http://en.wikipedia.org/wiki/STL_%28file_format%29	STL files describe only the surface geometry of a three dimensional object without any representation of color, texture or other common CAD model attributes.
stp, step	*Standard for the Exchange for Product Data*	*No*	http://en.wikipedia.org/wiki/ISO_10303	
svg	*Scalable Vector Graphics*	*Yes*	http://en.wikipedia.org/wiki/Scalable_Vector_Graphics	Scalable Vector Graphics (SVG) is a family of specifications of an XML-based file format for describing two-dimensional vector

				graphics, both static and dynamic (i.e. interactive or animated).
trc	*Motion Analysis TRC file*	*Yes*	http://www.kxcad.net/autodesk/3ds_max/Autodesk_3ds_Max_9_Reference/importing_trc_files.html	It contains a header section and a motion section.
u3d	*Universal 3D*	*Yes*	http://www.ecma-international.org/publications/standards/Ecma-363.htm	and bones-based animation
unv	*I-DEAS*	*Yes*	http://www.ijme.us/issues/fall2001/software.html	In addition, the graphs for geometric properties, which include displacement, velocity, and acceleration, can be viewed once the mechanism is solved.
vrml	*Virtual Reality Modeling Language*	*Yes*	http://support.microsoft.com/kb/151840	VRML is a modeling language for specifying interactive animation.
vue	*AutoDesk 3D Studio Animation*	*Yes*	http://usa.autodesk.com/adsk/servlet/pc/index?id=13567410&siteID=123112	Autodesk® 3ds Max® and Autodesk® 3ds Max® Design software provide powerful, integrated 3D modeling, animation, rendering, and compositing that enable artists and designers to more quickly ramp up for production.
vw	*LightScape View*	*Yes*	http://www.squidoo.com/Lightscape-3#module80919271	Animation: Professional keyframing control for camera animation.
w3d	*Shockwave 3D Scene*	*Yes*	http://www.adobe.com/support/director/work_3d/models_use_in_sw/models_use_in_sw09.html	By default, the Shockwave 3D exporter captures the animation of all objects in the scene in every frame.
wings	*Wings 3D*	*No*	http://www.wings3d.com/	There is no support in Wings for doing animations.
wire	*Alias Wire*	*Yes*	http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=14437427#channels_Design%20Visual	Show design functionality without building a working prototype. Make object properties such as position and color change over

			ization	time, displaying them in real time or as rendered images.
wrl, wrz	*VRML 1.0, VRML 2.0, VRML 97*	*Yes*	http://en.wikipedia.org/wiki/VRML	Animations, sounds, lighting, and other aspects of the virtual world can interact with the user or may be triggered by external events such as timers.
x3d, x3dv	*Extensible 3D (VRML 3.0, uses XML, 2004)*	*Yes*	http://www.web3d.org/x3d/content/README.X3D-Edit.html	Web3D Specifications for Extensible 3D (X3D) Graphics, Humanoid Animation (H-Anim) and the Virtual Reality Modeling Language (VRML 97) are now included.
x	*Direct X*	*Yes*	http://www.gamedev.net/reference/articles/article2079.asp	For animation, the main "object" of the hierarchy is an animation set.
x_b, x_t, xmt, xmt txt	*Parasolid*	*No*	http://www.plm.automation.siemens.com/en_us/Images/parasolid%20fs%20W%203_tcm1023-7381.pdf	
xas, xpr	*Pro/Engineer*	*Yes*	http://www.ptc.com/products/proengineer	Complete virtual simulation capabilities enable you to improve product performance and exceed product quality goals
xim		*No*	http://www.ida-step.net/components/editors	
xml	*Land XML, VIS Material XML Import*	*No*	http://www.landxml.org/schema/LandXML-1.2/LandXML-1.2.xsd	
xsi	*Soft Image XSI*	*Yes*	http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=13571168	Autodesk® Softimage® software is a high-performance 3D character animation and visual effects application.
xv0, xv3	*Lattice XVL*	*Yes*	http://www.lattice3d.com/products/products_player_3d_software.html	If animations are embedded in the file, XVl Player delivers full controls to view that data, plus assembly tree information.

4.2 Dedicated 3D+time Formats

In this section we outline formats dedicated to containing 3D+time data in Table 3.

Table 3: File formats developed specifically for 3D+time content.

	Extension	Name	Information
1	bvh	BioVision Hierarchical Data	A standard ASCII representation for humanoid movement. The file header describes joints in terms of their positions and initial offsets. The file data describes offsets per joint per frame with 1 frame per line.
2	c3d		Developed by the National Institute for Health for the purpose of biomechanics research. The header of this binary format contains information such as frame rate and number of points. The file data contains 3D point coordinates stored sequentially per frame.
3	hdr, img	Analyze	Used for 4D MRI data. The format is based on the 3D volumetric Analyze 7.5 file. The Analyze 7.5 format contains a separate header and image file. The header file, *.hdr, contains metadata in the form of size, scale, and descriptions of data. The data file, *.img, contains 2D slices stacked over depth. The 4D Analyze format, Analyze AVW, uses a concatenation of these 3D volumetric files to represent 4D data.
4	mp4	MPEG-4	MPEG-4 Part 16, the Animate Framework eXtension (AFX) add support for 3D animation streams (ISO/IEC 14496-16, 2000). Uses VRML 2.0 to incorporate scene graphs, interaction in terms of viewpoints/navigation/clicking, and animation via key frames or JavaScript programming.

5 Summary

This report summarized creation, representation and storage of 3D+time digital content. As illustrated in our technical report by documenting 140 + 4 file formats, there is an abundance of file formats for 3D+time content and therefore there is a need for file format conversions. The abundance of 3D+time file formats is due to the common practice of vendors to extend the file formats designed for 3D content to accommodate also 3D+time content. As documented in our technical report summarizing 3D file formats [2], the use of a wide spectrum of 3D file formats propagates to the application domains handling 3D+time content. These new application domains include 3D TV, gaming, special effects and animations. They stimulate the growth of the number of methods to create 3D+time content by sensing or by simulations, and lead to an increasing number of files containing 3D+time content.

Based on the material presented in this report, questions arise about preservation of 3D+time content. These questions include issues related to 3D+time content representation, preservation storage file format, and information losses due to file format conversions that would be inevitable. In addition, one would like to understand the scalability issues as we increase spatial dimensionality and include temporal dimensionality of digital information about physical or virtual worlds (i.e., moving from 2D images to video, 2D images to 3D geometry, and 3D geometry to 3D+time). These issues remain open research topics and addressing them might leverage all information gathered in this report.

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7 Appendix A. Datasets

This section presents several collections of 3D+time data are available for download over the Internet.

URL	Formats
http://www.MyMultiMediaWorld.com	*.mp4

8 Appendix B. Production Studios and Companies Creating Animations and 3D Effects

This list of companies is obtained from http://www.okino.com/conv/users.htm. According to the web site, the list was assembled based on information from the Fortune magazine, the U.S. Pentagon's current top 100 list, and the "Industry Week" magazine.

Adaptive Media, Aldis Animation, Amaze, Animal Logic, Animation Science, Applied 3D Science, Argonaut, Arkitek Studios, Aardman Animations, BBC tv, Blur Studios, BrainCell Pictures, Broadsword Interactive, CBC Canada, Caribiner, CG2, Cirring Interactive, Cinemagic, Cinesite, Crambambouli, Creatures, Criterion, Crush Interactive, Dawn Interactive, Deutsche tv, Digital Anvil, Digital Artworks, Digital Forays, DNA, Dream Team, Disney Interactive, Digital Animations, DreamWorks Interactive, Encore Video, Enthed Animation, Entertainment Design Workshop, Evermore Entertainment, Flying Spot, FOX Studios, Framestore, Frantic Films, Fun Key Studios, GestureTek, Gigawatt Studios, Granda tv, Grollier, Head Games, Hiero Graphics, HumanCode, ICON, ILM, Infobyte, Imagine Interactive, In-Media, Interactive Media, Lionhearth, Looped Picture, Marathon, MindInMotion, Mirashade, National Geographic tv, NBC, NFB Canada, Pacific Title, Paradigm Productions, Pixel Liberation Front, P.I.X.A.R, Praxis Films, Quantum 3D, Rainmaker Entertainment, Red Lemon Studios, Riot, Sony Interactive, Tangerine Films, Tokyo Broadcasting, TOSC, Toybox, Vantage Point Imaging, VFX Interactive, Viewpoint Digital, Visual Approach, Walt Disney, Warner Brothers, Weta Digital, Westwood Studios, WildTangent.

9 Appendix C. Companies Focusing on 3D Game Development

This list of companies is obtained from http://www.okino.com/conv/users.htm. According to the web site, the list was assembled based on information from the Fortune magazine, the U.S. Pentagon's current top 100 list and the "Industry Week" magazine.

8th Wonder, Accolade, Acclaim, Atari, Avalanche, Beyond Games, Bitmap Brothers, Blizzard North, Blue Sky, Broderbund, Cavedog, Climax, Crystal Dynamics, Dill Pixels, Dragonlore, EA, Ensemble Studios, Epic,

Fasa, Funcom, GT Interactive, High Voltage Software, id Software, Immersia, Intelligent Games, Interplay, Ion Storm, Kaon, Kodiak Games, Leaping Lizard, LucasArts, Mak, Microforum, MegaMedia, Microprose, Mythic, Namco, Nintendo, Nocturnale, NuFx, Origin, Piranha Bytes, Rainbo Studios, Raven, Ronin Games, Reflections, Rockstar, Saffire, Secret, Sega, Software, Sierra On-Line, SingleTrac, Spacetime Arts, SPGS, Sports Simulation, Stage 22, StormFront Studios, Ubisoft, Universal Interactive, Virgin Interactive, Virtual World Entertainment (MechWarrior 3), Williams/Bally/Midway, Z-Axis, Zombie VR Studios.

10 References

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