- Abstract (work in progess)-

Developments in Computer Graphics
at the crossroads of 2D and 3D techniques

to the German thesis

„Entwicklungen der Computergrafik im Spannungsfeld zwei- und dreidimensionaler Techniken"

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Summary:

In my thesis I outlined the developments of several computer graphic technologies and put them into context to their classic, non-digital forebears. I started with the photorealistic painting style commonly known as "**Trompe l´oeil**", went from there on to the development of photography, early special effects and, of course, the art of **matte painting**. This first part of the thesis I concluded with a review of **projected set extensions** (back- and front projection) and the introvision-technique I used to turn to the computer graphics.

After outlining basic functionality and problems I described texture mapping techniques and finally reached the pinnacle of the thesis with a review on **camera projection mapping** techniques, the pros and cons, actual productions using it (Episode I, AntZ IMAX) and the implementation in standard software packages.

From the projected textures used for photorealistic images I then went on to related techniques like "texture baking" and Disney´s "Deep Canvas" projecting strokes to render non-photorealistic imagery. I further described several approaches and types of **non-photorealistic graphic**s (both 2D and 3D techniques) and then reviewed the "Paint Particles" from the movie "What Dreams May Come".

The final part of the thesis filled the blanks in between and described several technologies neither 2D nor 3D. These were the "**Paint FX**" from Alias/Wavefront´s "Maya" Software, **voxel graphics** (volumetric pixels derived from 2D slices) and the broad field of **extended file formats** like RLA, RPF, Quicktime (including VR objects and panoramas) and the recent developments of light-reconstruction from RGB-normal-maps like they are used in the game "Doom 3".

1. Classic Techniques: Trompe l´oeil

The basic idea of the earliest paintings was to imitate reality. The first documented success of a realistic image is reported by Plinius the elder, who described a still-life by Zeuxis that depicted a bowl of wine that intriguingly, that even birds fell for it and tried to eat them.

The Trompe l´oeil (meaning "the art of fooling the eye") was often used to extend architecture with elaborate painted ornaments, views from painted windows or other gadgets otherwise impossible to implement. An early example is the home of Giulia Felice from the ruins of Pompeji.

After the collaps of the east-roman empire and the rise of Christianity (that at first prohibited any depiction) it was only until the renaissance the Trompe l´oeil was used again. It was often used on the outsides of altairs and castles. The pinnacle of realistic images were the still-lifes from the 17th century, primarily in the Netherlands. Later, in the 20th century, the surrealists used the Trompe l´oeil to assemble several realistic elements in an irreal fashion or to let the images escape the frame´s boundaries. Photorealism was the logical next step, that imitated the properties of photographs, and was primarily pursued by north American artists.

2. Optical Tricks for stage and shows

Outside the fine arts people also tried to fool the eye. In freak-shows, circuses and the theatre many techniques were employed, and some of these made it to the early movies.

One of these is the "forced perspective", where something is modelled with built-in perspective distortion to achieve a greater depth of field than there is room for. Of course, it best works from a central perspective, and lateral movement is almost guaranteed to destroy the illusion. It was often used, for example in "Metropolis", where the city was built in several layers with different scales, or the musical "Singin´ in the rain", where in a dream sequence a pink airfield with markings is in reality a twisted set of stairs.

Another technique was the pantasmagorium, a glass plate mounted in a 45° angle in front of a stage, so another actor could be mirrored onto the stage as a ghostly figure. That approach was, in a way, later employed both in the Schuefftan-technique (used to combine models with real sets) and the front-projection (where the camera filmed through the glass plate reflecting the projected image).

3. Photography and Film

The development of the camera started with the camera obscura by Ibm Al-Haithan in 1083. Daguerre managed to preserve a camera obscura´s image chemically in 1837 and the development concluded in the Lumiere´s first camera and projector 1895.

It´s important to note, that, asides from the camera obscuras use for painters, photography and moving pictures were nothing but oddities and spectacles these days, and a long way from the art form they are today. So, in order to provide something even more spectacular, people experimented with stereoscopic imagery ever since the photograph became available. After all the principles were known since Eukid. Yet, the photography offered the first efficient way to create stereoscopic images. To separately show the images to each eye they used viewing-cabinets in the beginning, later red/green-goggles and nowadays shutter-glasses (IMAX 3D).

Among the earliest effects artists Georges Méliès is the most prominent, as he experimented since 1896 with multiple exposures, varying speeds, miniature effects, forced perspective and large mechanical puppets. He even used mattes to selectively expose certain parts of an image, thus performing the very first compositings.

This technique later evolved to multi-pass motion-control shoots and ILM´s optical printer, where several images and their mattes could be assembled with minimum loss of quality (in

"Return of the Jedi" there were up to 80 elements per scene). The first digital compositing was performed in Spielberg´s 1987 Drama "The Empire of the Sun", where photographs of bombers were combined to flying squadrons.

4. Matte Paintings and Projected Extensions

Matte Paintings are static, painted extensions to a filmed frame. While skilled artists could create spectacular views (for example the Statue of Liberty in "Planet of the Apes") none could give the camera any mobility.

To overcome some of a matte painting´s limitations projected extensions were often used. Prominently featured in car-chases was the rear-projection, with the images projected from the back of a screen, the actors acting in front. To improve the integration of image and set the front-projection process was used in "2001" in 1968. The projected image had to be lighted away by 1000 additional lights, but you cannot tell where the set ends and the projection starts.

An improvement to the front-projection was the Introvision-process first used in Peter Hyams "Outland", where images of a model space station were projected on a roughly approximated set acting as a screen. Thus Sean Connery could effectively wander through the model station with full optical interaction like reflections on the helmet. This process is the basis of the camera projection mapping described later.

5. Computer Graphics

Most people are certainly familiar with the basic workings of a rendering pipeling. In the context of this abstract I´d only like to mention the elementary process of triangulation and texture mapping.

In order for the computer to calculate the intersection of a camera ray with a surface, this surface has to be processed into triangles to ensure a finite solution to the intersection. This, however is problematic when texturing organic objects.

Texture mapping is a technique much alike to maps of the earth. In order to depict the surface of the spherical planet a coordinate system was introduced, so any place on the map can relate o a place on the planet. The usual maps project the spherical earth´s surface on a cylinder, so the areas around the poles look stretched. Texture mapping introduces the U and V dimensions to the geometrys X, Y and Z dimension in order to move about the surface of an object. These UV-Coordinates are then used to calculate wich part of the object is colored by wich part of a file texture. Usual texture projections are spherical, cylindrical or planar. Usually, these work fine. However, there is still the issue of triangulation. When quadratic polygons are not unwrapped rectangulary there are certain to be distortions along the diagonal being created in triangulation.

This problem is one of the main issues of camera projection mapping. This technique was first used in 1991 in "Hook" to add some three dimensionality to a matte painting and later expanded by Paul Debevec in his "Fiat Lux" movie. He used multiple projections, another problem in commercial software packages, and blended between them as the camera moved.

Advantages of perspective-projected textures are that photographed footage adds incredible richness to a rendering and the full optical interaction, for example when using the maps as photon maps to illuminate characters. In actual productions it was used for example to create the Pod-Race track in "Episode 1" or to make the matte-painted backgrounds in "AntZ" more 3D for the "IMAX" version of the movie.

6. Related Techniques and NPR

Other programs employ similar techniques: Deep Paint 3D enables the user to retouch rendered views and then projects these back on the objects UV-coordinates. "Baking" of textures and rendered light-distributions also projects the results onto the object´s own texture coordinates.

Disney´s "Deep Canvas" on the other hand projects strokes on geometry, that are then rendered into beautiful non-photorealistic images while still being full 3D.

Non-photorealistic renderings can be divided into 3D and 2D approaches. 3D techniques process geometry to render something NPR, like cell shading evaluating the object normal´s angle to the camera ray, or use textured NURBS-stripes to create NURBS-"furballs" that then look like painted strokes. 2D techniques include filter-effects like in Photoshop or dithering algorithms, but current research projects even emploay artificial intelligence to analyze images and define areas of interest, so the computer can then almost artistically modulate the level of abstraction (via a filter effect) within the image.

"What Dreams May Come", the 1998 movie with Robin Williams used a technique called Paint Particles to create a painted world. From the filmed images the sets were reconstructed in 3D as particle clouds. The particles were rendered as sprites showing a singlebrush dot. When connected to animated geometry like trees and flowers and being colored by the source image, the worlds looked like live oil colors and even permitted the use of fluid simulations.

7. Other related techniques

There are several other techniques neither 3D nor 2D or NPR that are used every day.

For example Maya´s "Paint FX" are NURBS curves interpreted by 2D-rendering algorithms during 3D-renderings. This prevents them from being included in Raytracing and other features, but is an efficient way to create plains of grass, trees or other complex non-hero objects.

Voxel Graphics (volumetric pixels) visualize series of 2D images (for example the slices created by Cts) as 3D clouds that can be further processed into surfaces. In that case the slices usually have to be 2D-processed to identify the different organs. Another way to use voxel technology in standard software is to represent them via particles, an approach used by Lightwave 3D.

Then, of course, there are many multi-dimensional data formats available in computer graphics. Movies are images arrayed along a timeline, alpha or Z-depth channels offer additional information in a 2D image. The latest is the RPF (rich pixel format) from discreet, that can pack more information in a single file than one could possibly use. 3DSMAX can render motion-blur information and other render-information all into one indexed file to offer maximum comfort in compositing. Quicktime is more than a movie-format, as it´s a full-blown multimedia architecture. It enables users to create movies with VR-panoramas and objects interactively linked within the file and even allows to implement realtime 3D objects to be placed in such a multimedia file.

The latest in multi-dimensional image-based files are the "normal-maps" used by Paul Debevec to relight 2D images with 3D-light. This will also be employed in the upcoming "Doom 3" by id-Software, where each wall texture will also have normal information encoded into a RGB-image to allow dynamic lighting effects on a pure 2D basis.