UNIVERSIDADE CATÓLICA PORTUGUESA

# DRAWING FROM MOTION CAPTURE:
# DEVELOPING VISUAL LANGUAGES OF ANIMATION

Thesis presented to the Universidade Católica Portuguesa
for the degree of Doctor of Philosophy of the Science and
Technology of the Arts program

Ricardo Sá Carneiro Megre

School of Arts
February, 2021

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# Abstract

The work presented in this thesis aims to explore novel approaches of combining motion capture with drawing and 3D animation. As the art form of animation matures, possibilities of hybrid techniques become more feasible, and crosses between traditional and digital media provide new opportunities for artistic expression.

3D computer animation is used for its keyframing and rendering advancements, that result in complex pipelines where different areas of technical and artistic specialists contribute to the end result. Motion capture is mostly used for realistic animation, more often than not for live-action filmmaking, as a visual effect. Realistic animated films depend on retargeting techniques, designed to preserve actors performances with a high degree of accuracy.

In this thesis, we investigate alternative production methods that do not depend on retargeting, and provide animators with greater options for experimentation and expressivity. As motion capture data is a great source for naturalistic movements, we aim to combine it with interactive methods such as digital sculpting and 3D drawing.

As drawing is predominately used in preproduction, in both the case of realistic animation and visual effects, we embed it instead to alternative production methods, where artists can benefit from improvisation and expression, while emerging in a three-dimensional environment. Additionally, we apply these alternative methods for the visual development of animation, where they become relevant for the creation of specific visual languages that can be used to articulate concrete ideas for storytelling in animation.

Keywords:
Motion Capture; Drawing; 3D Animation; Hand-drawn Animation; Computer Graphics; Storytelling;

# Index

# Introduction

With the advances of computer technology, the art form of animation has evolved from traditional media, using techniques such as drawing, painting and sculpting to tell stories to digital media, using 3D animation and motion capture techniques, resulting in detailed and sophisticated visuals and motions.

While 3D keyframe animation has become the standard medium used in the West for the production of animation, motion capture has fallen into a more specific niche, that of photo-realism. The role of drawing, in both cases, became mostly restricted to the pre-production phase, for the design of concept art, for characters, props and backgrounds, and for the development of storyboards [1].

Motion capture (mocap) became the established practice to produce visual effects for live-action films, used to give life to digital characters, such as Gollum in the Lord of the Rings trilogy (Jackson, 2001-2003), or Hulk and Thanos in Marvel's Avengers (Whedon, 2012-2015; Russo & Russo, 2018-2019), giving filmmakers the advantage of physically based motion. With mocap, natural forces such as gravity dictate the visual language of the characters' movement, and more importantly, actors can be used as the base foundation for the performance of the digital characters. In this sense animators are only needed at the end of the process to polish and tweak the recorded data.

The introduction of computer graphics (CG) changed the animation industry with innovative films such as Toy Story (Lasseter, 1995), A Bug's Life (Lasseter, 1998) and Monsters, Inc. (Docter, 2001), created by Pixar Animation Studios. The success of these 3D animated films was the result of more than a decade of development, from when the group was originally formed, to the company's inception in 1986, to the premiere of the first feature-length 3D animated film, Toy Story in 1995.

The triumph of the new medium paved the way for the creation of new 3D animated films such as, Antz (Darnell & Johnson, 1998) and Shrek (Adamson & Jenson, 2001) from DreamWorks, and Ice Age (Wedge, 2002) from Blue Sky Studios. Eventually, even Disney Animation Studios mostly abandoned the production of hand-drawn animated feature films, replacing them with the production of 3D animations, such as Chicken Little (Dindal, 2005), Bolt (Williams & Howard, 2008) and Tangled (Greno & Howard, 2010).

Figure 1 - Mocap recording with actor Luís Megre - photo by Bernardo Rangel

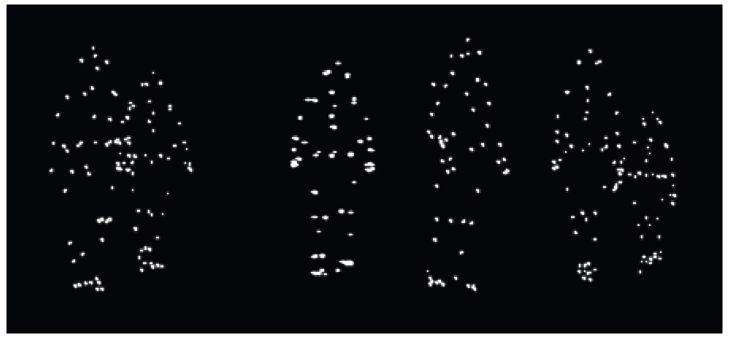


Figure 2 - Captured motions overlayed in 3D space (2018)

In 3D animated films, motion capture is more rarely used. Examples such as Final Fantasy: the Spirits Within (Sakaguchi, 2001), The Polar Express (Zemeckis, 2004) and the Adventures of Tintin (Spielberg, 2011) among others, innovated by their realistic approach, while basing the computer animation on mocap recordings. The photo-realistic results often produced an uncanny response in the audience and such films were considered to fall into the Uncanny Valley, a theory coined by Masahiro Mori (1970) used to describe a similar effect produced by realistic robots. More recently, the series Love, Death and Robots (Miller & Fincher, 2019) features some episodes where mocap is extensively used to produce realistic movement for ultra-realistic characters [2] [3].

On the other hand, the boundaries between 2D and 3D animation have been recently blurred in films that combine both mediums to develop the film's visual language, in examples such as Disney's short-films Paperman (Kahrs, 2012) and Feast (Osborne, 2014), Pixar's Day and Night (Newton, 2010) and Blue Umbrella (Unseld, 2013), and in feature-films such as The Peanuts Movie (Martino, 2015), Spider-Man: Into the Spider-Verse (Persichetti, Ramsey & Rothman, 2018) and Klaus (Pablos, 2019) [4]. These approaches give a new dimension to hand-drawn animation, combining it with computer generated elements. They also breed new life into 3D animation, embedding it with more natural elements from traditional media.

The goal of our research is to explore and develop alternative production methods to the standard 3D and mocap workflows, combining and integrating mocap with traditional hand-drawn and 3D animation. We hope that, by incorporating and blending drawing with performance and technology, we will be able to establish alternative approaches that benefit the visual development and character animation in narrative films.



## Hypotheses

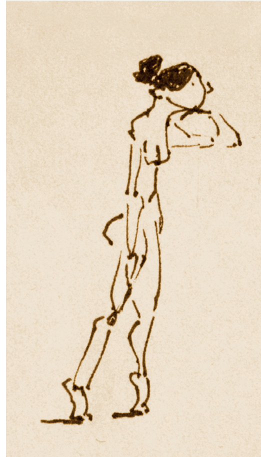


Figure 3 - Untitled sketch (2020)

How can the visual languages of animation be developed by emerging computer technologies?

Is it possible to avoid falling into the Uncanny Valley when creating animation based on motion capture, where realistic motion supports the creative process?

As standard mocap use is targeted for realistic characters, what use is there for a more stylized approach?

Can mocap be used for animation without depending on the standard retargeting pipeline, where characters are directly driven from captured data?

If so, how can alternative methods be employed, in an attempt to incorporate traditional and digital media through experimentation, for this effect?

How can drawing and movement be integrated with technology?

In particular, how can drawing from mocap be used, when creating 3D computer animation?

How do the visual development and animation processes benefit from this approach?

What are the advantages and disadvantages of these methods?

As technology drastically changes the possibilities within the art form of animation, we aim to discover and develop new methods and processes by which the digital medium can be redefined.

When creating animation, its visual language can be characterized with a particular vocabulary, especially in comparison to live-action filmmaking. From this visual development concepts emerge that can help animators navigate the multitude of opportunities for artistic creation.

As motion capture is a technique closer to live-action filmmaking, we explore alternative approaches that benefit the production of animated films, integrating traditional media in the animation filmmaking process of the 21st century, permeated by computers and digital information systems.

In this thesis, we aim to explore the boundaries of animation as an art form, formalizing procedures that converge drawing, animation and motion capture, culminating in theories and practices that will be materialized in an animated film.

Although apparently simple, drawing from motion capture can be implemented in a variety of different ways, from a simple two-dimensional approach to sophisticated uses of 3D tools, making some approaches extremely complex. This is due to existing technologies that are either aimed for keyframe animation, supporting the CG animator, or for automation in mocap where digital processes are intended to preserve actors' performances. On the other hand, hand-drawn animation

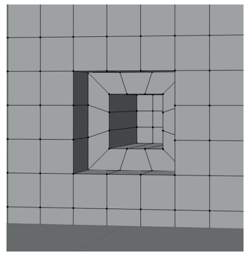


Figure 4 - Wireframe of 3D polygonal model

requires skilled draftsmanship, that combines expertise in drawing, movement and performance.

Additionally, the 3D pipeline is highly specialized and artists occupy a particular niche in standardized productions. Due to this fact, CG technology has evolved to serve extremely specific needs, with many tools becoming obsolete in the process. Implementing drawing with these processes in 3D software, means knowing how to use different tools and how to custom-build methods, from the more established ones to those that are now in the category of legacy [5]. These methods must be led and guided by an artistic vision, that aims to produce a particular result, or reaction.

## Research Motivations

Our research is based on two key points, the first relates to our personal artistic practice, the second to the experience of teaching animation to university students. Regarding our artistic practice, our inquiry is motivated both by previous work and by the desire to expand it into new experiments and discoveries. Regarding teaching experience, our research is related to more than a decade of teaching at university level, at bachelor's and master's courses, from the topics of 2D and 3D animation, to animation project development and multimedia courses. In such way, this thesis is written with animation students in mind, progressing from introductory subjects to more advanced ones.

Both aspects are intertwined, where artistic examples are often used as teaching materials, and particular courses and students' projects foment new research and new exploration. These methods and examples are explored in detail throughout the chapters of the second section of the thesis, expanding on the first section, that reviews the historical evolution of the art form of animation.

The possibility of practice-based research offers the opportunity to look back and document work that was completed until the end of 2015, and to produce new images and animations from that point on that reflect on specific topics and questions. It also presents the challenge of aiming to new grounds and registering and cataloguing the steps taken into these unknown territories.

Additionally, we intend to contribute to the development of an artistic practice that combines 2D, 3D and mocap methods. As this new field is still underdeveloped, we hope to advance new ideas and establish practices that can help and inspire fellow artists and students, that may also wish to explore this new discipline.



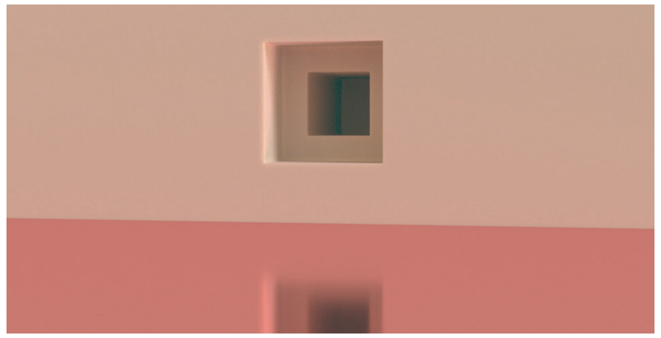


Figure 5 - 3D Wall (2017)

The art form of animation can be extremely rich, visually. Despite being relatively recent, with the first advances made at the end of the ninetieth century and with the introduction of the computer late in the 20th century, as it matures it offers new opportunities of expansion to other artistic fields, including painting, illustration, comics, installation, architecture, among many others. Drawing in particular, assumes a new force in this evolution, as 3D and 2D methods often evolve inspired by one another.

As different methodologies can be highly technical and often mastered by specialists, we aim to articulate the different mediums in alternative methods that can be used for the production of computer animated films featuring characters, in a more general and straight-forward manner.

In 3D modeling, different tools are needed to progress from general forms to details. Computer programs such as Autodesk Maya, feature many versions of these tools that have been evolving for the last decades. The introduction of digital sculpting revolutionized computer graphics, bringing greater interactivity and expressivity to the creative process. The software ZBrush, from Pixologic, singlehandedly brought this change to digital artists, allowing for artistic problems to be solved before technical ones, and not at the same time.

The introduction of such software, transformed digital media to become closer to already established traditional media.

Drawing, on one hand, can be used as a single tool to produce general forms as well as details. On the other, it can also be used to describe light and shadow, and it can be used in a more expressive way, not being restricted to closed forms and shapes, as 3D often is. Drawing can add expressiveness and intent.

For Maya users, custom-built tools are usually created in studios by developers and technicians that address the creative needs of the team of digital artists. For independent filmmakers plug-ins can be found online, although they

Figure 6 - Mocap recordings with Sandra Ribeiro and Miguel Gomes

usually address more general limitations of the software and are targeted for very specific applications.

Newer 3D software such as Blender, excels by integrating high-end tools, previously developed in other software, without paying the price of big legacy. This is visible from the digital sculpting tools, to the more recently 3D drawing tools using grease pencil.

Our approach is inspired in finding alternative workflows for the retargeting techniques used in mocap, and in possibilities resulting from the recent application of drawing in 3D for animation.

As the 3D pipeline is built for different areas of specialists, it requires a long series of processes from conception to final results, including modeling, surfacing, layout, rigging, animation, lighting and rendering.

For mocap, the process of editing and changing the original motion by animators can be difficult and often create undesired results. As the starting point from the retargeted data can produce uncanny movement out of the box, animators can spend a good deal of time adjusting the performance. The final character animation is the result of the combination of the captured performance, the animation and the original character design They are not created at the same time, they are put together later on.

Also, with 3D keyframe animation, a model of a character has to be build first, in order for animators to articulate characters into poses that are interpolated by the computer. In opposition to mocap, here the animators fully control the performance through a control rig. Despite this, the design of the character pre-dates this process and can only be modified within certain constraints.

By combining mocap and drawing, we hope to produce more immediate results, as only a selected part of the pipeline's workflow is used to approximate the visual language of the drawings.

## Goals and Limits of Research

To document the main techniques used in CG industry by using previous artwork from 2005 to 2015, and new examples produced in the context of the thesis, up to the present;

To articulate referenced authors in coherent arguments that inspire the artistic research;

To combine the documentation with practice-based research, producing images and animations that illustrates the emerging concepts;



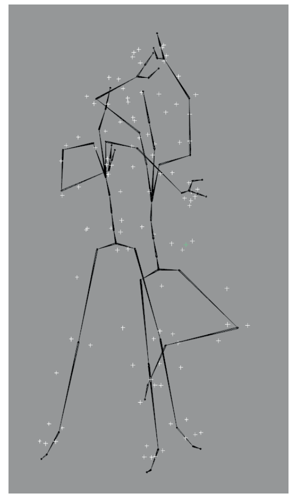


Figure 7 - Mocap recordings with Sandra Ribeiro and Miguel Gomes

To develop alternative methods for creating animation, using drawing, 3D and mocap;

To create an application of the knowledge acquired through artistic research;

To publish results, contributing to academic community;

To illustrate the procedures with tutorials, aimed for students to use in classes;

And finally, to create the visual development for the animation of a short film, giving form to theory with practice, contributing for artistic research.

This research focuses on applying mocap for animation, and not as a visual effect for live-action films, nor games or publicity. It excludes these areas as we are interested in the application of the methods referred to storytelling in animation.

We do not aim to produce a novel technique, that can be streamlined and used by others, but rather to combine existing methods to produce visual development for a particular type of animation [6].

The goal of the research is not to produce photo-realistic results and test them related to the Uncanny Valley theory, although these concepts are included in the research as they inform the paths taken.

Our research does not aim to use motion-capture as a real-time technique.

Only general biped human capture was used in our research, excluding facial or animal capture.

Every chapter is accompanied by a QR code that provides additional content, as well as moving examples of animations, expanding the thesis to an online format.

## Contents

### 1. The Art Form of Animation

The first section of the thesis addresses animation as an art form in general, through main developments from its inception to modern times, and key figures that moved the art form forward, both technologically and artistically. It is organized in three different chapters: Animation in the 21st Century, Traditional Media, and Digital Media.

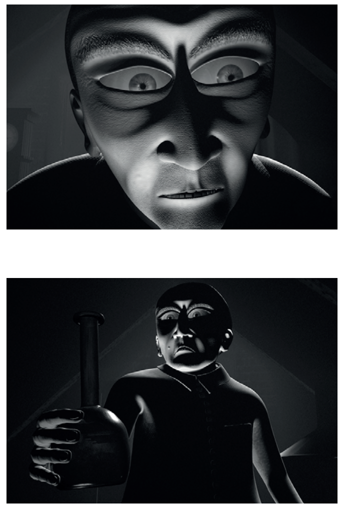


Figure 8 - Croped frames from Hourglass (Megre, 2008).

### 1.1. The 21st Century

The first chapter focuses on the definition of animation through the perspective of renowned animators and authors, the role of animation in contemporary culture, its adulthood, tent-pole films and adult themed independent animation. The role of technology is also addressed, concerning realism, the use of motion capture and the Uncanny Valley theory.

### 1.2. Traditional Media

The second chapter provides an historical background, from the creation of the first optical toys, to the development of cinema, cartoons and animated films. The artistic and technical developments of the 20th century are expanded through examples of key pioneers, from inventors, to artists and filmmakers. The invention of optical toys is addressed and the role of drawing is contrasted with the industrialized method of producing live-action films. Also, the filmmaking pioneers in stop-motion and hand-drawn animation are named, together with their achievements. Finally, the tensions between live-action and animation are explored, through the topic of animated realities. Here, the connection between rotoscoping, the Uncanny Valley, and animation principles is established, and the issues of standardization, hyper-realism, orthodox and experimental animation, as well as the role of believability versus realism.

### 1.3. Digital Media

The third chapter moves on to the beginning of digital drawing and computer animation, from the early experiments using machines, to the first computer animated films and the birth of 3D animation. The advancement of computer graphics, technology and artistic development is reviewed, specifically in the group that evolved from NYIT, to Lucasfilm, eventually forming Pixar Animation Studios. Stylization and realism are further looked upon, in their relationship to the Uncanny Valley. Fundamental examples are analyzed and crossed referenced by their visual languages, such as stylization, abstraction, photorealism and psychorealism, as well as mixed media and experimentation, and frontiers of the art form, the illusion of life and the suspension of disbelief.

## 2. CG Animation

The second section focuses on Computer Graphics, more specifically on 3D animation. It covers the main techniques from the production pipeline that are relevant for our research. All the examples in this section are produced by the authors, with few exceptions that are clearly identified. The examples presented in the figures relate the authors' artistic progression since 2005, paired with significant technological advancements, that are relevant to our research.



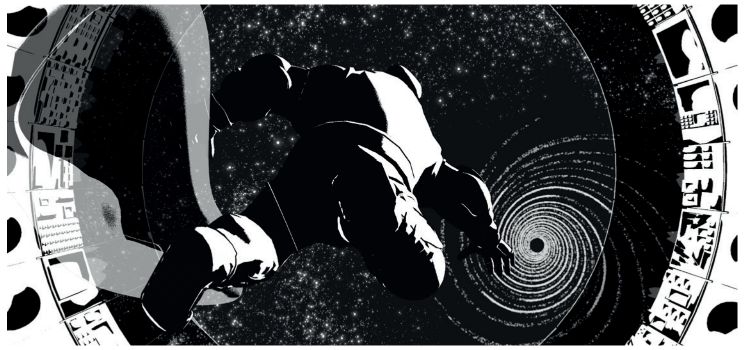


Figure 9 - 7200 Light-Years (Megre, 2007).

### 2.1. The 3D Pipeline

The fourth chapter addresses main processes of production in 3D animated films. The workflow of production development and specific software is addressed, from 3D modeling, surfacing and layout, to rigging, animation, simulation and rendering. Computer programs such as Maya, RenderMan, Arnold and ZBrush among others, are introduced.

### 2.2. 3D Modeling

This chapter examines the main types of geometry, namely Polygons, NURBS and Subdivisions, within the software Autodesk Maya. Beginning with surfaces, primitives and curves, as well as transformations in 3D, general features are explained. Following, NURBS components are described, from patches to CVs and isoparms, accompanied by examples, such as the Utah Teapot. NURBS operations are covered, namely lofts, revolves, extrudes and trimmed surfaces. Regarding Polygons, components are looked into, such as vertices, edges, faces and UVs, followed by character modeling techniques. For subdivisions, smooth surfaces are analyzed, in features such as proxies and smooth mesh preview, and their implications in topology, creation aspects and tessellation.

### 2.3. Digital Sculpting

The application of subdivisions to digital sculpting is covered, and its significance to multi-resolution when creating characters using base meshes. Levels of detail are further explained and a general overview over sculpting tools is given. Topology and deformation are related to retopology techniques, where substitute

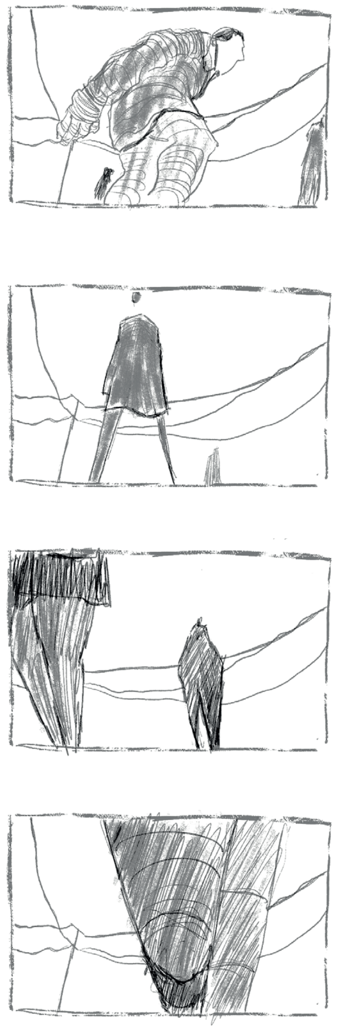


Figure 10 - Storybords for short-film, Out-of-Balance (in development)

meshes are used for remeshing surfaces for animation. Dynamic topology with Dynamesh and Sculptris Pro are demonstrated as well, featuring their advantages for interactivity and sculpting from life.

### 2.4. 3D Animation

This chapter features computer animation techniques and the application of the principles of animation to the development of visual languages. Firstly, character animation and storytelling are covered, concerning the creation of the illusion of life. Secondly, animation techniques such as frames per second, animating on "twos" and the fundamental principles are addressed in detail. Thirdly, the previous ideas are further expanded upon within computer animation, through keyframing, interpolation, Blend Shapes and control rigs using joints, forward and inverse kinematics. Lastly, visual languages of animation are looked into, addressing the possibility of using 3D software to produce animation with digital 2D hand-drawings, acting principles, the suspension of disbelief and the plasmatic quality of the art form.

### 2.5. Rendering

The last chapter of this section covers rendering in detail, from main concepts of composition, light and color, to the early advancements and modern tools. Storytelling and film languages are related through cinematography elements, such as frame, format, shot size, color, and lighting, as well as key differences from 2D to 3D and live-action. Rendering and composting are addressed, highlighting the possibilities of different workflows. Early technological advancements are analyzed, in particular bits and pixels, the frame buffer and the development of 2D systems to 3D scanline rendering, UV mapping, types of textures, diffuse and specular material reflections, types of lights and ambient occlusion. In regard to modern tools, ray tracing and photorealism is covered through different render engines, namely RenderMan, Mental Ray and Arnold. Global illumination concepts are analyzed, such as physical lighting, soft shadows, indirect illumination, image-based lighting, high dynamic range, among others. Finally, Path-tracing and current technology is described, and features such as light-paths, sub-surface scattering, volume rendering and 3D lines.

## 3. Drawing from Mocap

The last section covers motion capture technology and its relationship with animation and live action. The examples used here were mostly produced



as practice-based research, with some exceptions prior to 2015 that used to contextualize standard workflows. Alternative practices are experimented with, resulting in the visual development for the animation of a short-film, that originated from the overall research.

### 3.1 Capturing the figure

This chapter focuses on capturing human movement, its origins through photography and chronophotography, and the application of the scientific method for measurements, and the reduction of the representation as a means of digital thinking. Motion capture standard practices are demonstrated, presenting the main techniques such as reconstruction, solving, retargeting and keyframing. Relations to live-action and rotoscoping are established, as well as parallels with Disney animators and the need for animation principles. Alternative methods are explored, focusing initially on digital sculpting, where a workflow using digital armatures and control rigs allows for greater expression and improvisation when designing the animation from motion capture. Lastly, alternative methods are explored using 3D drawing applying the previous developments to the interpretation of actor's movements. In these examples, connections between animation and performance are addressed, using drawing as an expressive tool to interpret motion capture data in Maya and Blender.

### 3.2 Moving Bodies

The final chapter of the thesis relates theory and practice into visual development and animation, for a short-film that is beginning to be produced. Drawing is established as the main vehicle for creating moving bodies for animation, through the initial examples of digital hand-drawn animation. Following these examples, a period of experimentation is used to develop a particular workflow for drawing in 3D. The workflow combines mocap data as reference, armatures and control rigs for animation, and digital sculpting for the production of the final forms. The final results are used to inform the design of the characters for the film, establishing new relations with the film's aesthetics and with the role of the drawn line. The designs are further developed with storyboards, where mocap is extensively used for camera placement, composition, and as reference for key poses. The visual development is finally concluded with its intersection with animation tests, where specific ideas are conveyed as a result of studying mocap data. Additionally, 3D drawing is used to support the shading and lighting processes, through the creation of specific surfaces as 3D canvas, and compositing where all the different elements are combined in the end.

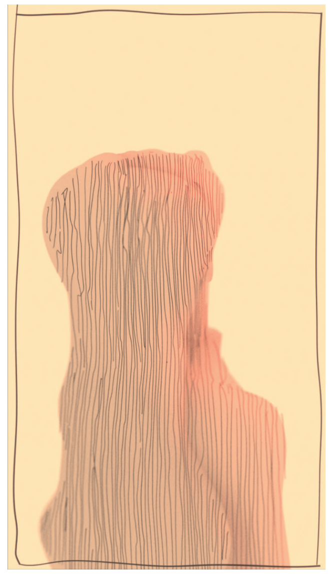


Figure 11 - Visual development and animation for Out-of-Balance (in-development)

## End Notes

[1] Exceptions such as Hotel Transylvania 2 (Tartakovsky, 2015) use 2D drawings to inform the 3D animation process, as displayed in Sony's YouTube video (Sony Pictures Animation, 2016): https://youtu.be/wGDCh1rtFFU (last accessed 22/02/2021).

[2] Technical process for episode 13 from season 1, Lucky 13 (Chen, 2019), reviewed by Mike Seymour (Seymour, 2019) at: https://www.fxguide.com/fxfeatured/the-remarkable-lucky-13/ (last accessed 22/02/2021).

[3] VFX Supervisor Chris Waegner talks about overcoming the Uncanny Valley on Sony Pictures Imageworks website, available at: https://www.imageworks.com/our-craft/feature-animation/movies/love-death-robots-lucky-13

[4] Hand-drawn animated films such as Beauty and Beast (Trousdale & Wise, 1991) and Tarzan (Lima & Buck, 1999) have used mixed computer techniques before, although they were used to create specific elements, not as a significant part of the visual vocabulary of the animation.

[5] Term used to describe outdated tools in computer programs.

[6] Tools such as "Sketch-Based Skeleton-Driven 2D Animation and Motion Capture" (Pan & Zhang, 2011) among others, already exist for the purpose of streamlining 2D and mocap methods.

# 1. The Art Form of Animation

## 1.1. 21st Century

Animation is often described as the illusion of life. As modern technology reshapes this art form, its boundaries also become more undefined. Although, were these frontiers ever clear and defined? If one thinks of animation as a sequence of drawings, then it differs from live-action film that is created by a sequence of photographs. Despite this definition, that can be applied to hand-drawn 2D animation, other forms of animation can also be created using photographs, as is the case of stop-motion, where puppets are articulated and photographed one frame at a time [1].

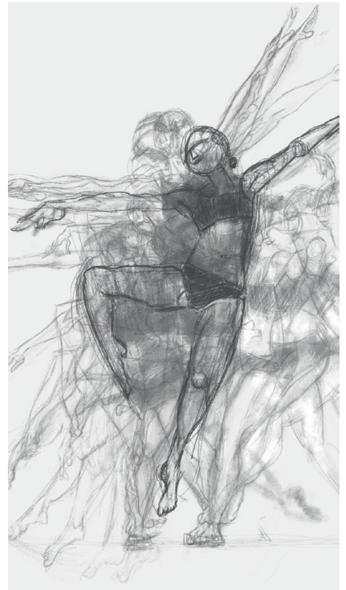


Figure 1 - Girl Jumping (2020), digital 2D animation

Pixilation, a particular stop-motion technique, uses actors to create the illusion of movement, photographed frame by frame. Drawings themselves, when animating using sand, oil paint on glass, or other traditional media, also depend on photography to capture the illusion of life onto film, in order to project it onto a screen. With today's digital media, computer animation often uses photo-realistic techniques for its development and final aesthetics. And the same technology is also used to blend realistic animated characters with live-action as a visual effect (VFX), or to re-age actors, making them younger or older, or even more surprisingly, create performances for actors that have already passed away [2].

Distinguished Disney animators and authors, Frank Thomas and Ollie Johnston, allude to the fact that early cave paintings, created by the Cro-Magnon man, showed beautiful representations suggesting movement combined with inner-life. For thousands of years since then, artists tried to capture movement in sculpture and paintings. Animation was born as an art form that allows movement to be represented, to "capture that illusive spark of life" (Thomas & Johnston, 1981:13).

Thomas and Johnston describe that artists can create movement by a series of sequential drawings that are projected at a constant rate onto a

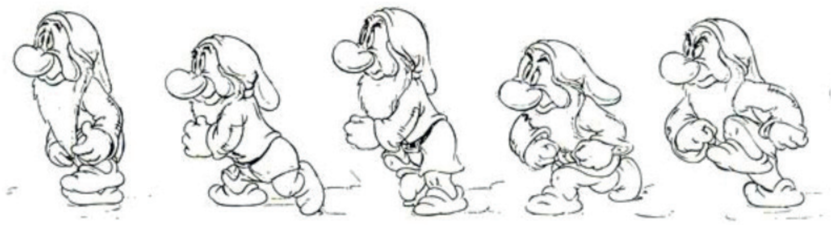
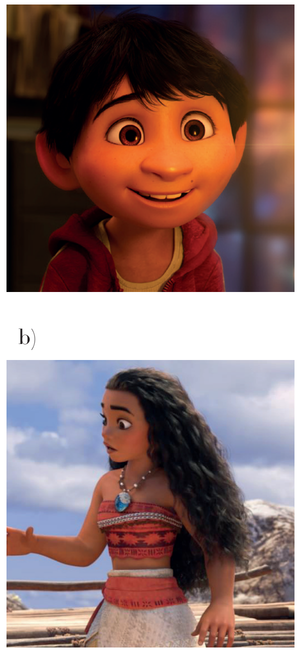


Figure 2 - Bill Tytla Grumpy animation - Snow White and the Seven Dwarfs (Hand, 1937)

a)



b)

Figure 3 - a) Coco (Unkrich, 2017);
b) Moana (Musker & Clements, 2016)

screen, although the movement itself, could represent the actual figure, by capturing its motion in detail, or a caricature of it, making the audience feel the emotions of the characters. As artists in this new art form, the disciplines of acting and theatre are added to draftsmanship and design. Quoting the distinguished Disney animator, Bill Tytla, the authors write that, when asked by a group of young animators on how to produce prime quality animation, Tytla mentions that as the possibilities are infinite, the problems cannot be reduced to a single one, nor the characters, nor the timing, "it's a sum of all factors named" (Thomas & Johnston, 1981:15). Tytla adds,

> *"To me it's just as much a mystery as ever before - sometimes I get it - sometimes I don't. I wish I knew, then I'd do it more often." (Thomas & Johnston, 1981:15).*

The authors explain that, regardless the process of animation being extremely difficult, the rewards of the medium contemplate the opportunity for the artist's self-expression. As animation can evoke emotions and convey specific feelings, the opportunity of the medium relies on its ability to communicate with any type of audience, despite any language barriers (Thomas & Johnston, 1981).

Researcher and author Paul Wells, defines animation as one of the most notorious facets of the world's popular culture. Due to its distinctive language, animation can be used to "create the art of the impossible". Our culture's visual landscape is defined by movies produced by Disney, Pixar, DreamWorks and Studio Ghibli, as well as TV series such as The Simpsons (Groening *et al.*, 1989-present) and South Park (Parker *et al.*, 1997-present). As these companies permeate society with consumable products, independent animation thrives in festivals despite economic hard times, and live-action blockbusters use animation as invisible VFX, in some regard, even extinguishing the definition of live-action itself (Wells, 2006:7).

Wells focuses on animation as a cross and inter-disciplinary art and craft, comprehending drawing, performance, sculpture, computer science, amongst many





others, where its unique vocabulary serves different approaches, whether traditional or digital techniques are used. The tools can produce a wide range of styles, from cartoons to abstraction, making animation the most experimental art form of mainstream culture (Wells, 2006).

> *"Animation continually offers new possibilities narratively, aesthetically and technically, encouraging new animators, artists and practitioners to explore new kinds of storytelling, to create new graphic and illustrative styles, and to use both traditional and new tools in the execution of their work." (Wells, 2006:7).*

## Adulthood

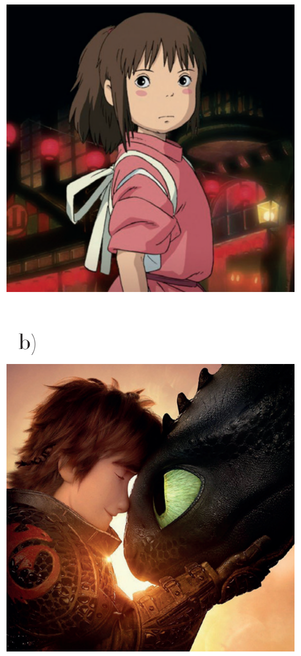
Acting for animation teacher and author Ed Hooks, argues that animation is moving from its adolescence phase into adulthood. Hooks defines the 1930's as the infancy of animation, when it was referred to as cartoons, opening for live-action feature films. More recently, animation has seen tremendous change, evolving technologically with computer graphics revolutionizing its possibilities.

On the other hand, the art form has also slowed down in artistic growth, with complex assembly line depending on specialists, schools often graduate "animation technicians" instead of artists, and Hollywood animated films are generally targeted at children, depending on merchandizing for profits. Today, animation is becoming more international as it matures, it moves away from Hollywood and merchandize oriented films (Hooks, 2017:2).

Hooks characterizes big budget animated features, created by the mainstream studios, as tent-pole movies, franchises that support a wide game of branded items, from toys to theme parks and ocean liner cruises. Despite their popularity, Hooks considers that films such as Frozen (Buck & Lee, 2013), lack in artistic value with poor screenplays and underdeveloped characters (Hooks, 2017).

Hooks adds, Pixar's Toy Story (Lasseter, 1995) directed by John Lasseter, the world's first CG feature animated film, was a game changer, showing the artistic possibilities within CG animation. DreamWorks tried to follow Pixar's success with Antz (Darnell & Johnson, 1998), and in 2004, Disney moved away from hand-drawn animation and into CG, firing 250 people and closing the Florida unit [3]. With CG films, studios stopped depending exclusively on artistic talent that could draw and paint, instead, new animators only need to know how to operate computer software.

a)



b)

Figure 4 - a) Spirited Away (Miyazaki, 2001); b) How to Train Your Dragon: The Hidden World (DeBlois, 2019)

Figure 5 - Chico and Rita (Trueba *et al.*, 2010)

a)

b)

After Pixar was bought by Disney in 2006 for 7 billion dollars, Hooks believes it became a cog in Disney's marketing machine, producing Cars (Lasseter, 2006), Cars 2 (Lasseter, 2011) and Cars 3 (Fee, 2017), one of most successful Disney franchises movies despite lacking artistic value. In some ways, the technology developed for producing CG films "(…) has been harnessed to serve commerce" (Hooks, 2017:50).

Ed Hooks adds that today, as animation enters its adulthood, there are new opportunities for creating animated films. As internet streaming companies such as Netflix, Amazon or HBO now compete with major studios, and with support from crowdfunding initiatives like Kickstarter, Indigogo, Ulule, Patreon and Pozible, artists and filmmakers have new ways to create, finance and distribute their movies. As an example, Anomalisa (Johnson & Kaufman, 2015) a stop-motion animation feature film for adults, was able to raise almost half-million dollars on Kickstarter, enough for starting the production of the film, even before larger investors joined in. Films such as Chico and Rita (Trueba *et al.*, 2010), as well as Ernest & Celestine (Renner *et al.*, 2012), were pitched at Cartoon Movie, a pitching and co-producing event in France, where they received significant investments. These are new opportunities for today's filmmakers that did not exist fifty years ago (Hooks, 2017).

Hooks points out the real need for adult-themed animation, just as Anomalisa proved, by being nominated for an Academy Award for best animated feature. Equally to Chico & Rita, Waltz with Bashir (Folman, 2008), is a good example of adult-themed animation, despite both movies not being tent-poles (Hooks, 2017).

During the 1980's and 1990's, the introduction of computer generated imagery (CGI) in filmmaking, both in animation and visual effects for live-action, brought tremendous benefits to the field, developing the existing methods and

Figure 6 - a) Waltz with Bashir (Folman, 2008);
b) Anomalisa (Johnson & Kaufman, 2015)





contributing to the evolution of its aesthetics.

At the beginning of the 21st century, a few 3D animated feature films were innovating the state of the art by creating for the first time fully realistic characters, instead of creating stylized ones. Films such as Final Fantasy: The Spirits Within (Sakaguchi, 2001), and Beowulf (Zemeckis, 2007), attempted to introduce realism in CG animation, using photorealistic rendering [4], and driving the characters performances with motion capture [5].

The characters in Beowulf, followed the advancements made in Final Fantasy, where highly detailed characters were driven not by keyframe animation alone, but also with mocap and simulation [6]. (Alexander *et al.*, 2009).

CG films created by Pixar, DreamWorks or Disney, rely on keyframe animation, to create the performances for the characters. With this technique, animators use the computer to manipulate and pose the characters, and the animation software helps to create additional poses, after being given the key poses. With motion capture, actors control the performance of the digital characters, by dressing in a suit with reflective markers, indicating anatomical landmarks to the system. The computer then maps the information onto the virtual characters, providing unprecedented amount of precision. The mapping can be a straight translation, where a specific motion from the actor controls a correspondent motion in the character, or the mapping can be indirect, as "human hand and finger patterns controlling a character's skin color or emotional state." (Sturman, 1999:1).

Although more realistic films were using breakthrough advances in technology, they were not appreciated by most critics due to a strange sense in the character's depiction that made the movies uncomfortable to watch [7]. The phenomenon was instantly related with the Uncanny Valley hypothesis, coined by Masahiro Mori to describe a similar effect in robotics during the 1970's.

> *"In climbing toward the goal of making robots appear human, our affinity for them increases until we come to a valley, which I call the Uncanny Valley." (Mori, 1970:33)..*

Part of the blame went to the mocap technology, as filmmakers pursued the most realistic approach possible, opening wide a long discussion about the Uncanny Valley in 3D animation, and igniting strong opinions in the business about the best methods to avoid this paradigm.

The term Uncanny Valley was introduced in 1970 by the robotics

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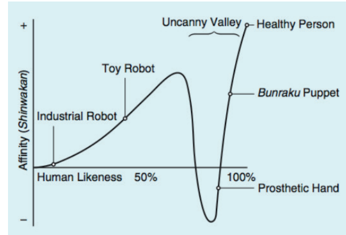


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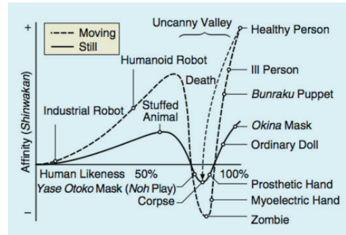


Figure 7 - Uncanny Valley
a) relationship between affinity and human likeness;
b) comparison between still and motion

a)

b)

Figure 8 - a) Beowulf (Zemeckis, 2007); b) Final Fantasy: The Spirits Within (Sakaguchi, 2001)

professor Masahiro Mori, to describe the sudden phenomena that occurred when robots were built to closely resemble humans. As the robots look more and more like realistic humans, the affinity suddenly decreases, contradicting common sense. The effect is even amplified when the robots are switched on, intensifying the sense of eeriness as they move (Mori, 1970).

With the development of computer graphics and its technology, the term Uncanny Valley started to be used referring to realistic characters that were created in films such as, Final Fantasy, Beowulf, The Polar Express (Zemeckis, 2004), and The Adventures of Tintin (Spielberg, 2011). These films' realistic human characters contrasted with the ones from Shrek (Adamson & Jensen, 2001) and The Incredibles (Bird, 2004), in which the filmmakers used similar technology, but opted to stylize the characters, both in their form as well as in their movement.

Lucia Modesto, a character technical director co-supervisor on Shrek, and Andy Jones, an animation director on Final Fantasy, comment on the uncanny and eerie feelings that the characters presented, in an interview by Lawrence Weschler for Wired Magazine. Modesto notes that, when her team was developing Princess Fiona, the character was starting to look too real and distinctly displeasing. As this started to happen, Modesto and her team had to restrain the amount of realism, in order to make the character more appealing. Jones refers that the eeriness effect appeared, as his team pushed for greater realism. Although the goal was not to produce 100% realistic humans, as they advanced into realism it felt they were controlling a puppet that resembled a corpse (Weschler, 2002).

The final results were very different, and while the more stylized feature animations were acclaimed by the critics and box office, the realistic ones did not perform as well and were claimed to fall into the Uncanny Valley.

Animated CG films are not alone in this problematic, as some digital characters created as a visual effect for live-action also failed to convince audiences. VFX and computer 3D animation share most of the same CG methods and techniques to produce the final images the audience sees on screen. Nevertheless, the two fields are fundamentally different in their purpose, conceptually speaking. In films that use VFX, computer graphics are used with the purpose of adding elements to the film, creating something that does not exist in real life, or that is difficult to achieve in some other fashion.

Thus, the goal of making realistic CG humans through VFX, is usually to create a digital double that can be used for dangerous stunt actions, or





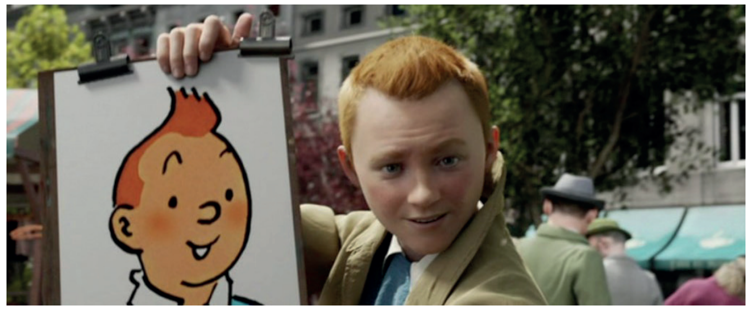

Figure 9 - The Adventures of Tintin (Spielberg, 2011)

even to age or resuscitate an actor. This is the case of the character Grand Moff Tarkin, which was brought to life for Rogue One (Edwards, 2016) after the actor Peter Cushing passed away. There is also the famous example of the actor Paul Walker who died during the filming of Furious 7 (Wan, 2015), and had his scenes completed in post-production using computer technology.

Nevertheless, in 3D animated films CG is the medium itself, separating it from traditional 2D animation. Here, the purpose of creating characters is to give them life through animation, and not to use them as digital replicas of already existing humans. This is a fundamental and different approach to creating digital human characters, to the one used in realistic VFX. In fact, one could say that this is an important distinction to make, when referring to the Uncanny Valley problematic.

Animated characters are designed, they are not human replicas. This being the case, why bother making Tintin a realistic character, if originally, he was created as a cartoon for comic books? Or, inversely, create CG versions of Angelina Jolie and Antony Hopkins for a 3D animated film, as in the case of Beowulf? Could it be that, part of the problem, is that animation is using techniques to create realistic characters without a specific purpose behind it, besides making it look realistic?

In the article "Final Fantasy or the Incredibles", published in the Animation Studies Online Journal, M. Butler and L. Joschko argue that, "the value of entertainment resides in the effective communication of ideas and in the personality of characters more so than in the technical mastery of reaching ultra-realistic characters" (Butler & Joschko, 2009:59).

At the Siggraph 99 conference, a panel called "Visual Effects: Incredible Effects vs Credible Science", featured scientists, artists and filmmakers such as, Syd Mead, Rob Minkoff and Stuart Sumida, among others, discussing the balance of science, art and storytelling. Moderated by illustrator and art director, George

a)

b)

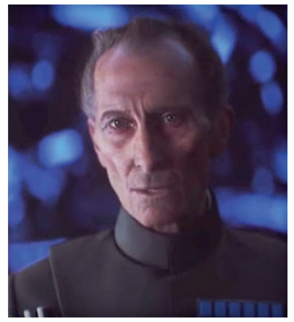

Figure 10 - Grand Moff Tarkin character:
a) Actor Peter Cushing in Star Wars: Episode IV - A New Hope (Lucas, 1977);
b) CG replica in Rogue One (Edwards, 2016)

Figure 11 - a) Stuart Little (Minkoff, 1999); b) Mr. Peabody & Sherman (Minkoff, 2014)

Suhayda, the panel reflected on the problematic of realism in filmmaking (Suhayda *et al.*, 1999).

Futurist and designer Syd Mead, responsible for iconic imagery in Blade Runner (Scott, 1982), Tron (Lisberger, 1982), Aliens (Cameron, 1986), Elysium (Blomkamp, 2013) and Blade Runner 2049 (Villeneuve, 2017), defines human perception as nebulous and formless as the illusions created in films. Different from scientific truth, a moving target based on human's best guesses supported by observation, populist reality is perception dependent, based on human senses, emotions and culture (Suhayda *et al.*, 1999). Mead adds:

> *"The "reality" that we assume as our base reference is actually quite unstable and has been proven to actually contradict direct observation. Add enough Prozac, and lemon drops may start to taste blue." (Suhayda et al, 1999:145).*

Mead expresses that, in entertainment, the goal is not to have the two realities competing with one another, but instead, in matching the film's effects reality to the audience idea of reality. This has always been a challenge in entertainment, the gap between believability and pretense (Suhayda *et al.*, 1999:145).

Rob Minkoff, co-director of The Lion King (Allers & Minkoff, 1994), and director of Stuart Little (Minkoff, 1999) and Mr. Peabody & Sherman (Minkoff, 2014), argues that science supports story, and sometimes can even suggest it. As an example, Minkoff explains the amount of research that goes into the creation of believability in a character such as Stuart Little, as both the director and the crew spend a great deal of time in education in topics such as anatomy, movement, fur and cloth. Minkoff believes this instruction should start with the director, so the crew knows the director understands and respects their work, as a simplistic approach will not have good results in creating CG films (Suhayda *et al.*, 1999).

Bill Westenhofer, a VFX supervisor for Spawn (Dippé, 1997), Life of Pi (Lee, 2012) and Wonder Woman (Jenkins, 2017), argues that it is the human capacity of extrapolating what is known into the unknown that gives artists and filmmakers the artistic license they often need. For story purposes, reality has to be balanced with imagery, in order to express a visual and emotional impact. Westenhofer believes that education is key forming experts in the extrapolation procedure, as simple observation is not sufficient to correctly judge and evaluate what is not working in the filmmaking process (Suhayda *et al.*, 1999). Describing





Figure 12 - Life of Pi (Lee, 2012)

reality, Westenhofer comments:

> *"Reality: An interesting subject in a profession that portrays the unreal, surreal, or too real to have been simply filmed in a camera." (Suhayda et al., 1999:146).*

Jay Redd,  VFX supervisor on Monster House (Kenan, 2006), Men in Black 3 (Sonnenfeld, 2012), and Alice Through the Looking Glass (Bobin, 2016), focuses on the collaborative nature of feature films, bringing together artists and technicians, that continually define what reality is, and is not. As advancements in technology encourage and assist storytelling, the capability of creating convincing and believable worlds becomes greater and greater (Suhayda *et al.*, 1999).

Dr. Stuart Sumida, a biology professor and researcher of human and animal anatomy, and consultant on animated films such as The Lion King, Tarzan (Lima & Buck, 1999), Ratatouille (Bird, 2007), Kung Fu Panda (Osborn & Stevenson, 2008) and How to Train Your Dragon (DeBlois & Sanders, 2010) amongst many others, marks out that fidelity to reality and the entertaining aspect of filmmaking do not contradict each other, as reality is often stranger than fiction. Dr. Sumida explains that there is a gigantic gap between funding available for the sciences, computing and research, and resources for entertainment based on technology with "far less primary data than is popularly thought" (Suhayda *et al.*, 1999:145). As a key aspect of filmmaking is collaboration, progress is only possible if studios acknowledge scientists as part of their available options, not only as consultants but being more entangled with the processes of story and character development. On the other hand, universities and museums must recognize the entertainment industry as "professionally valid as the old 'publish-or-perish' mentality" (Suhayda *et al.*, 1999:145).

## End Notes

[1] - Frame rates are explained in more detail in chapter 2.4. 3D Animation (page 103).

[2] - Technical process of re-aging actors in Irishman (Scorsese, 2019) on FX Guide Website (Seymoure, 2019): https://www.fxguide.com/fxfeatured/de-aging-the-irishman/ (last accessed 22/02/2021).

[3] - Disney Officially Closes Florida Animation Studio, (Desowitz, 2004): https://www.awn.com/news/disney-officially-closes-florida-animation-studio (last accessed 22/02/2021).

[4] - Photo-realistic rendering explained in detail in chapter 3.5. Rendering (page 135).

[5] - Motion capture explained in more detail in chapter 3.1. Capturing the Figure (page 148).

[6] - Simulation and dynamics addressed in chapter 2.1. The 3D Pipeline (page 63), keyframing techniques covered in detail in chapter 2.4. 3D Animation (page 110).

[7] - The best and worst of the Uncanny Valley (Oneto, 2019): https://www.ign.com/articles/2019/02/14/the-best-and-worst-of-the-uncanny-valley-and-cg-movie-characters (last accessed 22/02/2021).

# 1.2. Traditional Media

*"I remember once saying to Emery Hawkins (a wonderful, unsung animator), "I'm afraid my brains are in my hand." Emery said, "Where else would they be? It's a language of drawing. It's not a language of tongue."" (Williams, 2001:10).*

Director of animation and author, Richard Williams, famous for his work on Who Framed Roger Rabbit (Zemeckis, 1988), refers to animation as drawing in time. Williams notes that, drawings made over 35,000 years ago on the walls of caves, sometimes displayed animals with four pairs of legs, conveying motion, as did some sequences of drawings made in dozens of columns of Egyptian temples, or Greek figures that decorated pots, depicting different phases of motion (Williams, 2001).

Still, creating drawings that "walk and talk and think" means animators must pay special attention to the characters' performance. Quoting one of Disney's "Nine Old Men" [1], Milt Kahl, the author expresses that, is not the drawings or the articulation of movement that are essential, but the performance. "You'll get all tangled up if you think of it in a technical way!" (Williams, 2001:12).

Despite human's ancient fascination with motion, it was only in the nineteenth century that the first drawings really started to come to life. The development of optical toys, concurrently to the early advancements in photography, marked the first attempts of creating the illusion of life. While photography meant the possibility of capturing life, optical toys were designed to create the illusion of life itself.

Animation author Giannalberto Bendazzi, explains that optical toys were developed to explore the limits of human vision, and its reaction to movement. In 1824 the British physician Peter Mark Roget introduced the term persistence of vision, that explained how images were preserved in the human eye, before being replaced by new ones. When the sequence of images is created at high enough rate, it gives the impression to the viewer of seeing movement instead of still images. This discovery fueled the exploration of optical toys and other experiments over the following fifty years (Bendazzi, 2016).

One of these first experiments was the Thaumatrope, invented in 1825 by Dr John Ayrton. The device consists of a simple disc, attached to two strings, displaying

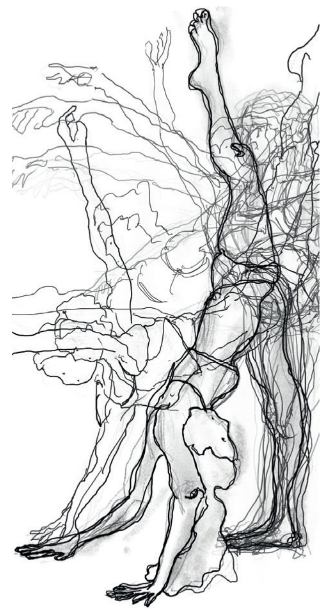

Figure 1 - Girl Falling (2020), digital 2D animation

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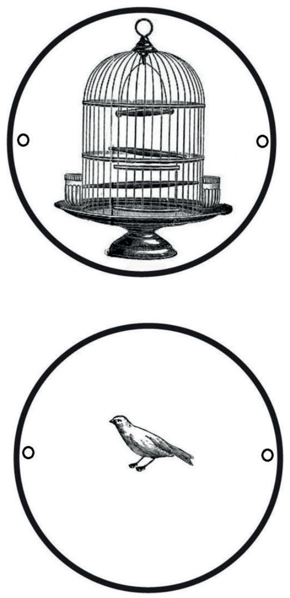

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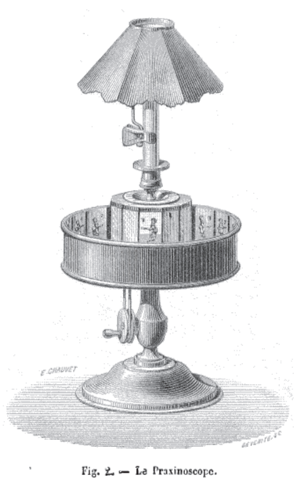



Figure 2 - a) Zoetrope,
b) Praxinoscope

two different images, one on the front and one on the back. When rotated by the twisting strings, the disc's images appear to be juxtaposed, due to persistence of vision. A bird, drawn on one side, appears to be inside a bird-cage, as the strings unfold and make the disc spin (Lord & Sibley, 2004).

Despite demonstrating the principle of persistence of vision, the Thaumatrope does not create the illusion of movement. The Phenakistiscope, invented by Joseph Plateau in 1832, allowed for a greater number of drawings to be used. This optical toy consists of two discs, that are fixed onto a handle in order to spin. The first disc has a number of slits, that are opened in between the sequential drawings are made around the perimeter of the second disc. To observe the figures coming to life, the disc is turned into a mirror, and the viewer looks through the thin slots that are opened in-between the drawings. The disc is spun and the sequence of drawings appear to move. As the device has added complexity, the illusion is far greater than with the Thaumatrope.

Finally, these ideas were put together into a single object, the Zoetrope. Created by British mathematician George Horner in 1833, consisting on a rotating drum with slits, rather than a disc. On the interior, strips of paper with the sequences of drawings can be placed. This construction allows for interchangeable stripes, providing a great number of motions for just one device, and different viewers can observe the illusion simultaneously.

At the end of the nineteenth century, the pioneer and inventor Charles-Émile Reynaud created the first animated public performance with his Théâtre Optique in Paris. Reynaud's device was constructed using rotating drums and glass plates, and the images were projected for large audiences. This was an evolution of his previous invention, the Praxinoscope, similar to the Zoetrope, but the slits were replaced by mirrored plates placed on the center of the drum, reflecting the sequences of drawings on the strips. The show had three different short cartoons, A Good Beer (Reynaud, 1892), The Clown and His Dogs (Reynaud, 1892) and Poor Pete (Reynaud, 1892) and were followed by synchronous sounds. Reynaud's Théâtre Optique is especially relevant by virtue of predating the concept of cinema, only presented by the brothers Lumière in 1895, with their invention, the Cinematograph (Pikkov, 2010).

As cinema expanded, the industrialized motion picture became more famous than the hand-crafted animated film. Audiences were rather drawn into photographic, live-action movies, and talented artists such as Reynaud could not compete. Even when he saved time by working from photographs, he would use them as references and transform them into drawings. This craftsmanship left him behind the constant innovation in live-action (Bendazzi 2016).

At the time, highly skilled artistic craftsmanship may had proven not to be





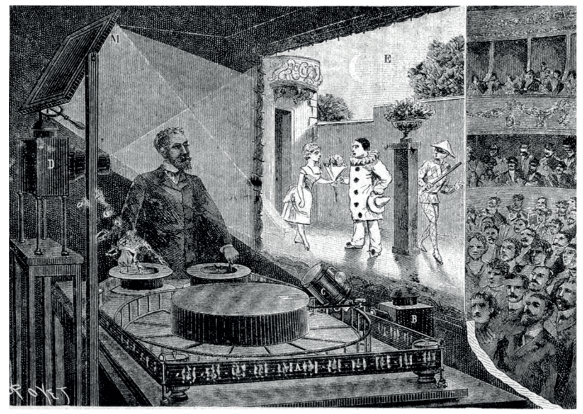


Figure 3 - Théâtre optique by Charles-Émile Reynaud

the best strategy to compete with industrialized methods of producing live-action film. Despite this, Reynaud became a remarkable reference, for the great possibilities that this new art form presented. Although he is mostly recognized by his inventions, and audiences may never appreciate the amount of work needed to make his drawings come to life on a screen, his animations featured a special characteristic that exhibit his true genius. Reynaud understood that designing the movement was as important as designing the shapes. As he deconstructed the photographs into drawings, he developed a specific language that could not be created by standard live-action film.

> *"While the drawing itself is nothing more than an example of good graphics, the movement is impressive even to the present-day viewer. (…) Reynaud's drawing becomes beautiful when it moves, because the inventor of animation sensed that drawings had to be functional to their dynamics. (…) What counted was human intervention; craftsmanship, to Reynaud, was the mother of art." (Bendazzi, 2016:126).*

Animator Peter Lord and author Brian Sibley acknowledge the differences between animation and live-action filmmaking, while in live-action nothing is hidden in-between frames, in animation the space between on image and another, is filled with multiple creative decisions. If the decisions end up constructing a well-made film, they will be invisible to the audience. As every single frame is created from scratch, the animators become over loaded by a time-consuming series of actions. Despite this, animation is a highly creative endeavor, demanding from the creators a clear vision, tremendous patience and "a sustained belief in the film that is being made" (Lord & Sibley, 2004:18).

a)

b)

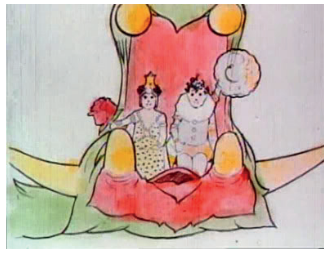


Figure 4 - a) Humorous Phases of Funny Faces (Blackton, 1906); b) Little Nemo (McCay, 1911)

If some of those creative actions are done poorly, with underdeveloped characters or animation, or even due to budget constraints, the audience will perceive it. As the illusion of life is broken, the complex process of creating every frame has to address the overall and long-term end result. Animation is also highly constrained by the medium used, often requiring advanced techniques to be implemented.

## The Pioneers

A series of artistic and technical advancements in the early 20th century, helped to shape animation into what it is today. Developments in stop-motion animation and hand-drawn animation were made by diverse filmmakers, that advanced their mediums by the creation of new stories, characters and techniques. Filmmakers such as Méliès, Blackton, Cohl, McCay, Barre, Bray, Sullivan and Mesmer, Fleischer and Disney were pioneers in realizing their vision. Hand-drawn animation became the most popular expression of the art-form, due to its link to storytelling and illustration, the heritage of cartoonists, caricaturists and graphic designers in advertising (Lord & Sibley, 2004).

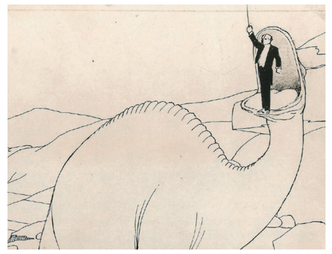
Georges Méliès created Voyage to the Moon (Méliès, 1902), using camera tricks by photographing a scene, stopping the film, altering the scene, and photographing it again. This became the standard technique used by filmmakers, called stop-motion. Méliès mixed the animated footage with live-action, blurring the limits of the two different mediums. Two years later, Stuart Blackton created Humorous Phases of Funny Faces (Blackton, 1906), combining drawing with stop-motion techniques, using chalk on a blackboard, showing the characters being drawn by the artist's hand first, and gaining their own life afterwards. Blackton became the first animator to fully record an animation onto film. Although Reynaud already created animation for audiences, he was using his optical theatre device, instead.

Emile Cohl's Fantasmagorie (Cohl, 1908) introduced morphing techniques to create transformations between characters and objects, sometimes crossing the line between narrative animation and abstraction, revealing the magic beneath the illusion. This experimentation was also carried on by cartoonist Winsor McCay, author of comic Little Nemo in Slumberland (McCay, 1905-1927). McCay made an adaptation of Little Nemo (McCay, 1911) featuring animated characters and morphing techniques. The characters displayed unusual three dimensionality, and the transformations revealed the possibilities within the animated pictures,





a)



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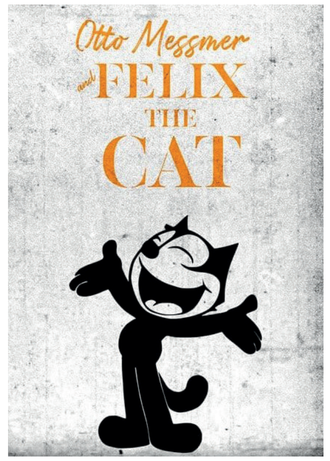



Figure 5 - a) Gertie The Dinosaur (McCay; 1914); b) Felix the Cat (Mesmer, 1919-1921)

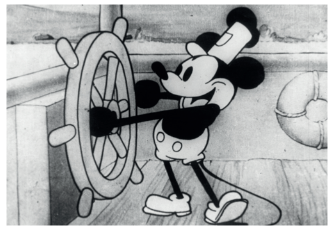
displaying McCay's natural craftsmanship. McCay's beautiful drawings in motion, proved that the art form is as closely tight to artistic ability as it is to technological improvements. In McCay's film, characters would squash, stretch and be created through horizontal slices. The connection between the surreal nature of the stories and the possibilities of animation's rich vocabulary revealed McCay's pure genius.

Winsor McCay continued innovating with Gertie The Dinosaur (McCay, 1914). The film was shown to audiences as the author would perform a "live" interaction with Gertie's character, giving instructions as for example, to bow to the audience, expanding the connection between film and theatre. Four years later, McCay produced his most technical and ambitious film, The Sinking of Lusitania (McCay, 1918) an animated documentary that expressed McCay's other side, more satirical and political, where his images engaged with sociological problems and reflected the artist's values.

The Animated Grouch Chaser (Barré, 1915) by Raoul Barré, displayed technical developments such as registration paper with punch holes, keeping the drawings aligned without wobbling. In addition, Barré separated the characters from the background, cutting the animated character's paper, avoiding the time consuming process of drawing the background for each frame. John R. Bray improved on this method by adding backgrounds drawn on celluloid and placing them on top of the animated drawings. Later, Earl Hurd pioneered the use of animating characters on celluloid sheets, placed over painted backgrounds, in the series Bobby Bump (Hurd, 1915-1925). This technique became the standard method of producing 2D hand-drawn animation, until the later development of computer animation (Lord & Sibley, 2004).

Felix the Cat (Sullivan & Mesmer, 1919-1921) was the first animation superstar, internationally acclaimed, created by Pat Sullivan and Otto Mesmer. Although Sullivan owned the character, Mesmer was the main animator and actual creator, developing the character for Paramount's news reel Screen Magazine in 1919 (Bendazzi 2016). The first twenty-five short animations were shown to audiences in theatres, from 1919 to 1921, and featured anthropomorphized animal characters, as well as objects, using morphing techniques to serve the narrative, assuming different shapes and functions as needed. Felix the cat explored the limits of rational thought, transforming the irrational into common reality. This was an important distinction from live-action film. With Felix, animation opened the possibilities of what animation could be, within its own form, but also in the outside world, as the merchandize for the character showed the way for many toys and products that would later come to follow [2].

a)



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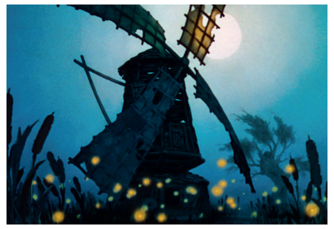


Figure 6 - a) Steamboat Willie (Iwerks, 1928);
b) The Old Mill (Jackson, 1937)

Walt Disney made enormous contributions to advance the art form, both artistic and technological, with the introduction of sound, complex camera movements and by creating the first animated feature film. The first animation with sound, Steamboat Willie (Iwerks, 1928), featured one of today's most famous icons of animation Mickey Mouse, that made his first appearances in Plane Crazy (Iwerks, 1928) and The Gallopin' Gaucho (Iwerks, 1928) [3].

The following year marked the beginning of the production of the series Silly Symphonies (Disney *et al.* 1929-1939). Along that period, the studio grew and went through a lot of experimentation, resulting in inventions such as the Multiplane Camera, developed by Bill Garity and firstly used in the Silly Symphony, The Old Mill (Jackson, 1937). The Multiplane Camera was used in Snow White and the Seven Dwarfs (Hand, 1937), the world's first animated feature film, and later in films such as Pinocchio (Sharpsteen, 1940), Bambi (Hand, 1942), and up to The Little Mermaid (Clements & Musker, 1989), bringing audiences deeper into the flat 2D drawings and paintings, by displaying and moving different parts of the composition at different rates. As the foreground, middle ground and background are created in separate layers, moving the camera and the different planes creates parallax effects and results in a more realistic animation [4].

## Animated Realities

*"The early development of the cartoon form was characterized by an overtly signified tension between animation and its relationship to live-action. Clearly, these early efforts foreground the art of animation as an artist-led activity with a distinctive language - the Fleischer brothers enabled Koko the Clown to emerge 'Out of the Inkwell' into the real world (…), while Disney's early work reversed the process, and showed 'Alice' in an animated environment…" (Wells, 1998:38).*

Animation and live-action were often combined, resulting in different visual languages, as was the case of Alice's Wonderland (Disney, 1923), where Alice enters the world of cartoons, the actress being filmed using live-action and integrated with animated drawings, or the rotoscoped Koko the Clown, featuring an animated character traced out of live-action film [5].

Rotoscoping was developed and patented by Max Fleischer in 1917, consisting of a method of tracing live-action footage, that was projected onto a





glass surface. Max tested the method with his young brother Dave, who wore a clown suit with distinctive marks to help the tracing process. Out of the Inkwell (Fleischer, 1918-1929) relied massively on live-action, although Koko's actions eventually depended less on Dave's rotoscoping (Barrier, 1999).

The method of copying human motion can also be seen in Disney films such as Snow White and the Seven Dwarfs. In order to achieve credible movement for the human characters, animators used traced over live-action footage of actors, that were filmed acting out the scenes. The method of rotoscoping is still used today, and can be considered a precursor to motion capture, "where the motion is "captured" painstakingly by hand" (Sturman, 1999:1).

Animator and author Iwao Takamoto, an artist in Disney's films during the 1950's, describes how the human characters on Cinderella (Jackson *et al.*, 1959) were created using rotoscoping, mainly for the Cinderella character. Takamoto distinguishes Disney's approach to rotoscoping from other studios, that did not rely on simply tracing over photostats, as the results were always unrealistic and rough. Referring to Frank Thomas and Ollie Johnston's alternative approach, Takamoto explains the artists would extensively study the recorded footage, and only then created the animation from scratch (Takamoto & Mallory, 2009).

Thomas and Johnston mention that the live-action studies amazed the animators, as the motion of the recorded human figure exhibited much more detail than any of the artists could have guessed. The principles created at the studio, such as "squash and stretch", developed only as theories for animating characters, were displayed as living examples in the photostats. However, when the animators would directly trace over the live-action images, copied a particular human action, or even just stayed to close to the references, they would get strange results (Thomas & Johnston, 1981).

*"The moves appeared real enough, but the figure lost the illusion of life. (…) The actor's movements had to be reinterpreted in the world of our designs and shapes and forms." (Thomas & Johnston, 1981:323)*

These issues of traditional animation and rotoscoping, overlap with the problems of realism and the Uncanny Valley, in 3D animation and motion capture. Although live-action provides rich and complex examples of how humans move and act, copying it seems to subtract from it as well. When the rotoscoped results are too close to the source, the suspension of disbelief is broken and the magic does not hold up anymore [6]. Walt Disney's animators employed the animation

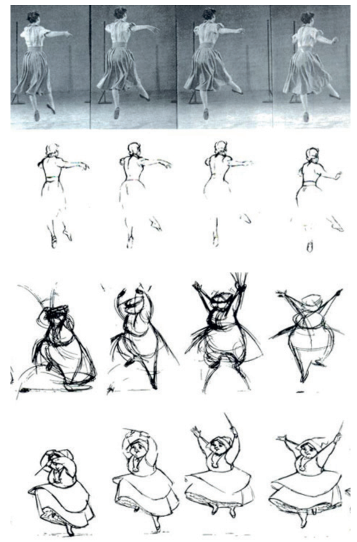
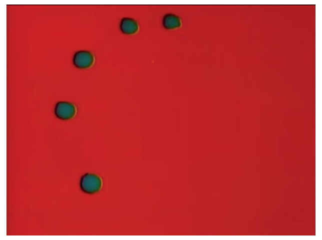


Figure 7 - Cinderlla (Jackson, 1959), live-action as reference

a)



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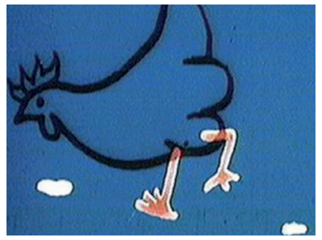


Figure 8 - a) Dots (McLaren, 1940);
b) HenHop (McLaren, 1942)

principles on top of what they would learn from live-action, developing the famous Disney style.

Author Paul Wells argues that Disney's highly industrialized cel animation, with its hyper-realistic style that Wells characterizes as orthodox animation, is in opposition to an experimental approach, that offers an alternative to narrative, using abstraction through primordial elements such as lines and shapes. Experimental animation usually has a strong relationship to music, as if its translation to a visual medium would result in colors and shapes that move at different rhythms (Wells, 1998).

Films such as Composition in Blue (Fischinger, 1935) and Symphonie Diagonale (Eggeling, 1925), use geometric forms and colors to evoke particular feelings, resisting to the rational constructs inherit to narrative and figurative animated films. The power that abstraction represents in animation, can be demonstrated by a wide variety of possibilities that exist within the art form.

Norman McLaren goes beyond experimenting with lines and forms, and explores with sound as well, creating synthetic sounds by drawing directly on film inside the sound track, hand animating sound itself. In films such as Dots (McLaren, 1940), Hen Hop (McLaren, 1942) and Dollar Dance (McLaren, 1943), the filmmaker plays with abstraction and figurative drawings that are drawn directly on to film stock.

While in Dots, McLaren creates both the animation and sound, forming abstract shapes and synthetic sounds, in Hen Hop he animates a chicken dancing to a pre-recorded soundtrack. Here, the representational figure of the chicken is created from, and transformed into abstract shapes, that evolve to form an egg. Love on the Wing (McLaren, 1938) also mixes constructed forms and abstraction, through the use of multi-plane photographs on the background, where surrealist painted forms and volumes are displayed, and animated lines on the foreground, that are constantly transformed into moving figures and symbols through metamorphose.

Abstraction creates a particular visual language, that provides specific articulation of ideas. In this sense, Paul Wells suggests that orthodox animation is closer to prose than experimental animation, that instead is closer to poetry due to its suggestive capacity (Wells, 1998:46)

On the other hand, Disney and Japanese Anime, constructed by an orthodox approach, depends on standardization and mass-production cel-animation, resulting in a hyper-realism that favors narrative and figurative continuity. Wells adds that, despite realism being a subjective concept and open to interpretation, the nature of the constructed animated film has the capacity of resisting this notion. In this sense,





Figure 9 - Bambi (1942)

films such as Bambi are confined to a narrow visual vocabulary due to the proximity of its design, context and action, that depict characters and backgrounds according to "the conventional physical laws of the 'real' world" (Wells 1998:25).

As live-action necessarily represents the natural world, animation can instead address the metaphysical reality, presenting meaning instead of form. The meaning is created by a unique vocabulary, that does not exist in live-action filmmaking. When combining both approaches, orthodox and experimental animation, Wells defines this new type of animation as development animation, "representing the aesthetic and philosophic tension between the two apparent extremes (Wells 1998:35).

Stop-motion animated films as The Hand (Trnka, 1965), or Dimensions of Dialogue (Švankmajer, 1982), are good examples of animated films that redefine the art form, by combining different aspects of figurative and abstract concepts in a subversive discourse. The Hand, created by stop-motion animator Jiří Trnka, reflects on the role of the artist, as artistic freedom and authoritarianism are in conflict, through manipulation and thought control. Here, the main character struggles with his artistic creation being constantly interrupted by a hand, that instructs the protagonist to create a sculpted hand (in its own image), instead of the main character's original intention.

In Jan Švankmajer's Dimensions of Dialogue, surrealistic characters made of everyday objects, such as food and utensils, eat each other and transform themselves into new characters. In the second chapter of the film, two beloved characters made of clay, create an amorphous life-form that eventually becomes their demise. In the third chapter, two clay heads exchange real objects through their mouths, and the constant mismatching eventually results in the wrecking of the characters.

Author Cathryn Vasseleu highlights Švankmajer's tactile experience, providing imaginative stimulus and allowing the filmmaker to animate through

Figure 10 - The Hand (Trnka, 1965)

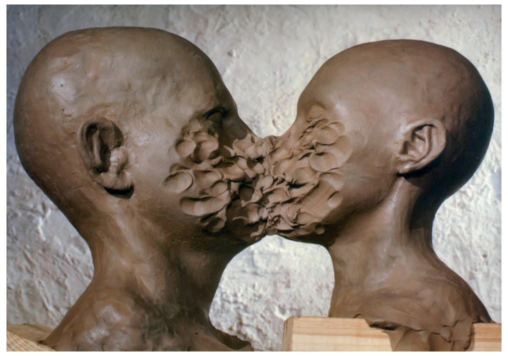
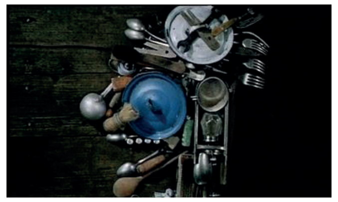


Figure 11 - Dimensions of Dialogue (Švankmajer, 1982): Passionate Discourse

a)



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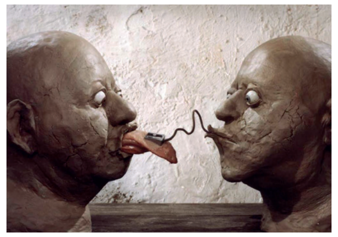


Figure 12 - Dimensions of Dialogue (Švankmajer, 1982): a) Eternal Conversation; b) Exhaustive Discussion

touch. Švankmajer's tactile creativity can be seen throughout his films, such as Arcimboldo Elements Game (Švankmajer, 1990), among others, using hand gestures to conjure specific feelings in the audience, connecting the senses of touch and vision according to his surrealist principles. Vasseleu contrasts 'Švankmajer's touch' in opposition to 'Disney's touch', where the first aims to establish uncanny relationships through the dialogue between his objects, often animating old toys, puppets and dolls that have decayed, and the second intends to create the illusion of life through drawings that are illusively realistic (Vasseleu 2009).

Despite Disney's commercial animation favoring a figurative and narrative approach, inspired by European illustrators and children's tales, and advanced by an orthodox hyper-realistic style, not all the studio's films fall into that category, nor the same style.

Fantasia (Armstrong, *et al.* 1940), Disney's third feature film, animated to the sound of classical music performed by the Philadelphia Orchestra, emphasizes abstraction and experimentation. The film, composed of eight short animations, experiments throughout with different types of visual representation. The segments Toccata and Fugue, as well The Pastoral Symphony are exclusively expressed by abstract lines and shapes, created to relate and represent the sounds produced by the instruments.

Although the level of experimentation does not achieve the same freedom and results as McLaren's films, there is still a great deal of departure from Disney's previous films. Other segments, despite being more figurative, also exhibit some level of unconstrained animation, even if in the form of visual effects, as sparkles and shining elements, as is the case of The Nutcracker Suite, The Sorcerer's Apprentice and Rite of Spring.

Another Disney example that moves away from the orthodox canon is the animated feature, Who Framed Roger Rabbit (Zemeckis, 1988), directed by Robert Zemeckis, that constantly challenges the audience's notion of what is real. Being a live-action and animated film at the same time, a balance had to be created in both worlds for the film to be convincing. This balance had to be particularly fine-tuned as the film is filled with adult themes, using metaphors to address issues of sexuality, alcoholism and segregation.

The feature opens up with a false set up, bringing the viewer inside a fully cartoon world, that turns out to be only the inside of a film set, in the 'real world'. The main character, Roger Rabbit, tries his best to take care of Baby Herman in the middle of flying kitchen knives and other incidents, created as gags. The scene cuts, as result of Roger forgetting his lines. Immediately, the audience is presented with Baby Herman coming out of character, revealing his true personality and rude behavior, as he tries to look under the skirts of a human character, as he passes by her. Although initially presented as an innocent baby, Herman, during the film, smokes cigars and inappropriately touches another human female character, challenging the notions of what a cartoon character is supposed to be, and can or not do.

Another audacious character, Jessica Rabbit, is designed with a very different approach from other Disney princesses, with qualities that are not necessarily family friendly. As she is photographed playing patty-cake by the private detective Eddie Valiant, played by Bob Hoskins, it is implied that, despite being an apparently naive action, it would the equivalent of cartoon's sexual relationships. As Jessica explains to Valiant in a scene, she is not bad, she is just drawn this way.

Eddie Valiant, the main human character, displays a problem with alcoholism, and the villain, Judge Doom, played by Christopher Lloyd, kills toons by melting them in a chemical he calls 'The Dip', that in fact is essentially oil, paint thinner and film dissolver [7].

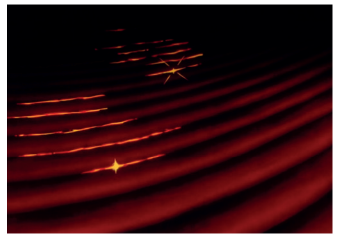
One of the main themes, that most definitely escapes younger audiences, is segregation. Toontown, the town where all the toons live, is separated from the real world, reflecting the condition of animation regarding live-action film, often seen as a lesser art-form, or even just a medium only targeted for children. Cartoons are often portrayed as second class citizens, as Mr. Maroon explains to Valiant while feeding Dumbo's character, that he received him and half the cast from Fantasia, as a loan from Disney, because they work for peanuts.

Technically, the film uses animation and both optical and practical effects to construct convincing interactions between the animated and live-action world. As Roger Rabbit breaks real plates on his head, or exits the scene through a



a)

b)



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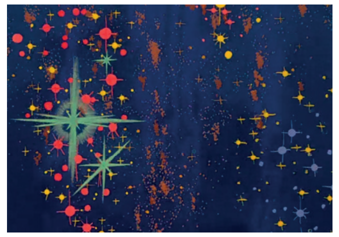

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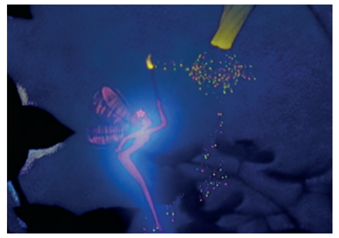


Figure 13 - Fantasia (Armstrong, *et al.* 1940) a), b), c) Toccata and Fungue in D Minor; d) The Nutcracker Suite

window living a cut out silhouette on real blinders, effects had to be created to deliver those interactions. Mechanical rigs were built to move a real cigar that would eventually appear in Baby Herman's hand. Guns and other props would be manipulated by puppeteers on set, constantly blurring the lines of what is real or fake. On the other hand, when Jessica sends a flying cartoony kiss to Eddie Valiant, he reacts creating the sense that that drawing does exist and move through space, in reality.

Interviewed for the documentary, Behind the Ears: The True Story of Roger Rabbit (Bernstein, 2003), the movie's director Robert Zemeckis, explains that the aim was to have characters that combine the Disney technique, Warner Brother's style characters, and Tex Avery humor (Bernstein, 2003). Describing the most important aspects of the film, Zemeckis adds:

> *"I think always what the trick is to doing something that's really technically heavy, is to not lose sight of trying to always have a way for the audience to identify with the movie on an emotional level. Even though it's a cartoon rabbit, the audience is emotionally invested in Roger…" (Bernstein, 2003:35"00).*

Besides live-action and animation, effects had to be added by ILM, where shadows and highlights would be composited over the animated characters. VFX supervisor, Ken Ralston, describes that there were some thoughts of using early computer 3D technology to make the characters three-dimensional, but they opted by not using them in order to pay homage to the great cartoons. They had to find an in-between area to make the characters flat but also convey the feeling that they are part of the world they wander (Bernstein, 2003).

Director of animation, Richard Williams, awarded a Special Achievement Award from the Academy for Animation Direction and the Creation of Cartoon Characters for his work on the film, points out that Jessica Rabbit could not be real. If she was, she could not stand without falling, as a consequence of her proportions. Their goal with the animation, was to do what is impossible to do with a camera, trying to have an element of impossibility in everything, but still it trying to make it believable (Bernstein, 2003).

In an interview by Jeremy Clarke, Richard Williams expresses that initially he feared the combination of animation and live-action would be too

Figure 14 - Who Framed Roger Rabbit (Zemeckis, 1988)





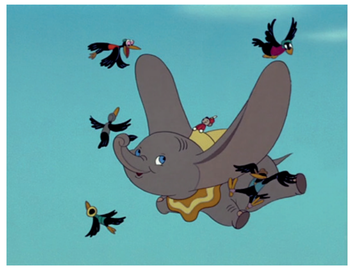
artificial. The problem was not only that live-action could make the animation look fake, but the opposite too, that the cartoons could make live-action look false. At the first meeting with the director, Robert Zemeckis, and the executive producer, Steven Spielberg, Williams reveals they agreed that the crucial point would be making interactions constantly between the two universes. Consequently, the team created a proof of concept, even before casting the actors, to demonstrate their approach would work (Clarke, 1988).

In another example, Williams refers he had to fight for a scene that was going to be cut out of the movie due to budget and schedule. In the beginning of the film, a scene sets up Roger's character, as a well-meaning disaster type of personality. In spite of the scene having already rough sketches, only when the full animation was created, more than one year after its original inception, did the Rabbit come to life. Williams explains that the essence of the character is created during the animation process, and that this process transcends the original ideas in the sketches (Clarke, 1988).

When asked by Clarke about the Disney style, Richard Williams replies that there is not an intentional style, but rather a combination of styles of the artists that work at the studio. Recalling a conversation Williams had with Frank Thomas, he points out that Walt Disney himself was not satisfied with the fact that, despite having numerous artists designing the films, the animation would always have the same look, to what Thomas reacted saying, it was his own natural way of drawing. Williams expands on the issues related of style within the Disney studio, pointing out that Dumbo (Sharpsteen, 1941) was developed to utilize old school animators, with a more vaudevillian approach, and Bambi (Hand, 1942) was produced using a new wave of animators, that pushed for greater realism (Clarke, 1988) [8].

Nevertheless, Williams says, Disney's films capture the audience's attention by creating strong stories and characters, with developed personalities, and making the viewers forget that they are just drawings. Animators such as Frank Thomas, Ollie Johnson and Milt Kahl were never after realism, but believability instead (Clarke, 1988).

a)



b)

Figure 15 - a) Dumbo (Sharpsteen, 1941);
b) Pinocchio (Sharpsteen, 1940)

## End Notes

[1] - Disney's "Nine Old Men" addressed in chapter 2.4. 3D Animation (page 101).

[2] - 100 years of Felix the Cat (Bonfield 2019): https://www.nfsa.gov.au/latest/100-years-felix-cat (last accessed 13/10/2020)

[3] - The origins of Mickey Mouse (Smith, n.d.): https://www.loc.gov/static/programs/national-film-preservation-board/documents/steamboat_willie.pdf (last accessed 13/10/2020)

[4] - The multiplane educator guide (Walt Disney Family Museum, n.a.) website: https://www.waltdisney.org/sites/default/files/2018-08/WDFMMultiplaneEducatorGuide.pdf (last accessed 13/10/2020)

[5] - Out of the Inkwell (Fleischer 1918-1929), at the Public Domain Review (n.d.): https://publicdomainreview.org/collection/out-of-the-inkwell-the-tantalizing--fly-1919 (last accessed 13/10/2020)

[6] - Suspension of disbelief by Coleridge (1817) and Hooks (2011) further explained at the end of next chapter, 1.3. Digital Media (page 57).

[7] - The "Dip" from Who Framed Roger Rabbit (Zemeckis, 1988) explained in Disney's Fandom website: https://disney.fandom.com/wiki/Dip (last accessed 13/10/2020)

[8] - Animation principles explained in detail in chapter 2.4. 3D Animation (page 104).

## 2.2. Digital Media

*"Two types of pioneers created the art of computer graphics. One group was the scientist-engineers who longed to be artists. The other group was the artists who yearned to create works that went beyond the traditional medium of paint and pencils. Their muse led them to become inventors in order to realize their vision." (Sito, 2013).*

One of the early examples of a system created to draw on the computer is Ivan Sutherland's Sketchpad. This pioneer system, developed in 1963 as a novel digital drawing tool, used a light pen in combination with push buttons controls, to draw directly on a computer display. The system, a combination of hardware and software, offered the possibility of drawing digitally and modify the strokes, creating for example perfect circles, lines and arcs, or even to move parts of the drawings, giving the possibility to create movement. Sutherland, indicates that Sketchpad's utility was not restricted to engineering drawings, as the capability of adding motion to the drawings opened up the possibility of creating cartoons (Sutherland, 2003).

Sutherland would become a central figure in the development of computer graphics, as computer scientist and professor at the University of Utah, where many of his students helped to create and develop the medium as we know it today.

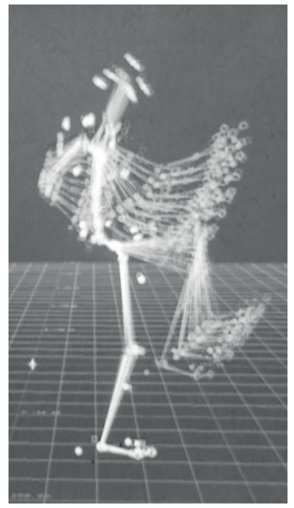


Figure 1 - Motion Capture data from recording session (2018)

Amidst the first instances of animation created using machines are filmed such as, Five Abstract Film Exercises (Whitney & Whitney, 1943-1944), Oscillons (Laposky, 1954) and Abstronic (Bute, 1954). While both Bute and Laposky created their films using modified oscilloscopes to paint with light, the Whitney brothers invented their own machines, tailored for their creations. These films displayed abstract visuals, produced by the interaction of human - machine, and marked a rupture with traditional media, advancing into a new field of experimentation.

James Whitney's Lapis (Whitney, 1966), a landmark in computer-

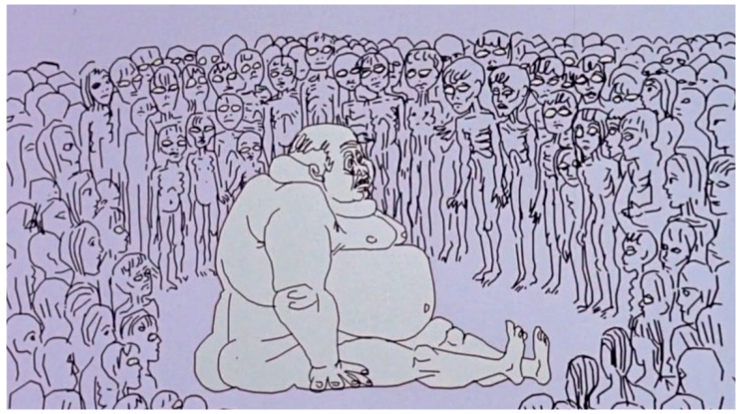


Figure 2 - Hunger (Foldès, 1974)

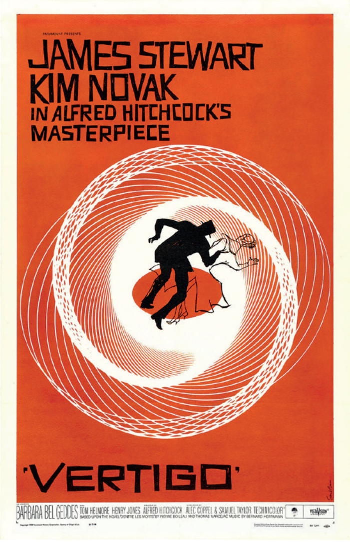



Figure 3 -Vertigo (Hitchcock, 1958)

aided animation, presents beautiful abstract animation of moving geometry, expanding and collapsing into the word "lapis". His brother John Whitney created the Analog Cam Machine used to generate the effects for the opening credits of Vertigo (Hitchcock, 1958). Using reassembled parts bought from the army, the mechanism consisted of mechanical cams, gears and servo motors, controlling the motion of the artwork that would be exposed to a camera (Sito, 2013).

Years later, while working at IBM, John Whitney created Arabesque (Whitney, 1975) considered to be his masterpiece. Similar to Lapis, in the abstraction of digital forms, his piece also features moving lines, but was composed entirely using a computer.

The short films Hummingbird (Csuri, 1967), Frog (Csuri, 1967) and Metadata (Foldès, 1970), innovated by being produced using exclusively the computer. The films combination of drawings with morphing techniques, using abstracted and figurative shapes, demonstrated the potential use for digital animation. Hunger (Foldès, 1974), took these concepts further and developed a narrative, becoming a turning point in the history of digital animation.

The story, portraying gluttony and hunger, introduces a main character that collapses into over-indulgence, exposing the contrast between a world of consumerism with one of poverty. Animator and historian Tom Sito, refers that the value of the short film was recognized by being the first computer animation to be nominated for an Academy Award, and that Foldès became a symbol of excellency for the medium, inspiring a new generation of animators to come (Sito, 2013).





## 3D Animation

Many of the fundamental techniques of 3D computer graphics were developed at the University of Utah, during the decades of the 1970's and 1980's. Early examples of digitized 3D objects created there, are a Volkswagen Beetle, built by some of Sutherland's students, a human hand and face, by Ed Catmull and Fred Parke respectively, and the famous Utah teapot by Martin Newell.

The film Halftone Animation (Catmull & Parke, 1972), a combination of Catmull's "Animated Hand" and Parke's "Animated Faces", displayed 3D moving objects that were smooth shaded, instead of displaying faceted geometry. The groundbreaking film created such an impression, that was years later used as an effect in the feature film Futureworld (Heffron, 1976). Besides using Catmull and Parke's work, the film also featured a computer generated sequence created by Gary Demos and John Whitney Jr, revealing the actor Peter Fonda's digitized face, into a 3D model.

As computer graphics developed, the digital revolution was led by artists and filmmakers, as well by scientists and engineers in different universities, and the advancements were often presented at ACM SIGGRAPH conference. The conference, that had its first edition in 1973, became a standard destination for the many CG professionals that aimed to have their work presented there. SIGGRAPH grew from a gathering of around six hundred attendees, in its inception, to tens of thousands of participants at current time [1]. Two of the attendees, Ed Catmull and Alvy Ray Smith, the co-founders of Pixar (later in 1986), started working together at New York Institute of Technology (NYIT) a decade earlier. There, they would advance the state-of-the-art of computer graphics, and form the initial group of people that would join the Lucasfilm Computer Division, that would later become Pixar.

Filmmaker George Lucas, creator of the Star Wars franchise, founded Lucasfilm in 1971. From Lucasfilm was born the company responsible for the development of the effects of Star Wars: Episode IV - A New Hope (Lucas, 1977), Industrial Light and Magic (ILM). In 1979, the Lucasfilm Computer Graphics Division was established at ILM, led by Ed Catmull.

In the early days at NYIT, under the wing of Alex Schure, the original four members, Catmull, Blanchard, Smith and DiFranscesco, were joined by Jim Blinn, Ralph Guggenheim, Jim Clark, among others. At Lucasfilm, the group grew and attracted leading pioneers. In 1980, Loren Carpenter presented his short film Vol Libre (Carpenter, 1980) at SIGGRAPH. The innovative fly through camera, framing CG mountains constructed using fractal algorithms, granted Carpenter a

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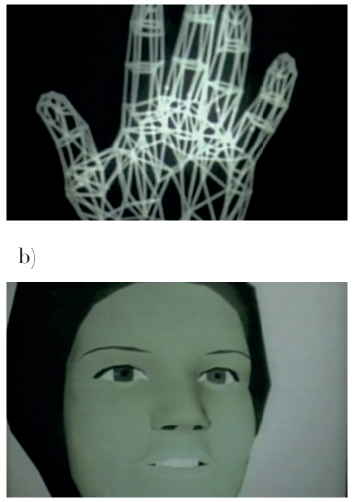

Figure 4 -Halftone Animation (Catmull & Parkee, 1972)
a) Animated Hand;
b) Animated Faces

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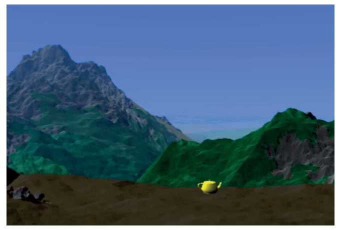

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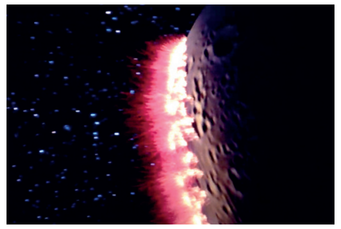

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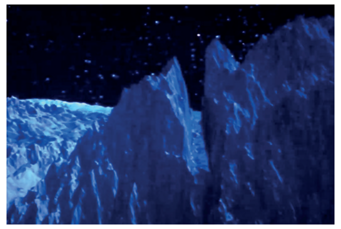

Figure 5 - a) Vol Libre (Carpenter, 1980);
b), c) Genesis Effect - Star Trek II: The Wrath of Khan (Meyer, 1982)

spot at Lucasfilm CG division [2].

Author David Price mentions that, despite George Lucas having conceivably the world's top talent, regarding computer graphics, Lucas concern was not to make computer animation. The special effects group at ILM was not particularly interested in computer graphics, and Star Wars: Episode V - The Empire Strikes Back (Kershner, 1980) had even less use of computer graphics than the first film, from the same franchise. This frustrated Catmull and Smith, and in the following year they saw their breakthrough to get due recognition, when they had the chance to develop a sequence for Star Trek II: The Wrath of Khan (Meyer, 1982) (Price, 2008).

Alvy Ray Smith created storyboards for the scene, Carpenter animated fractal mountains and the camera motion. Tom Duff, Tom Porter and Rob Cook developed a computer program for generating textures, offering support to ILM artists painting the surface of the planet, and Bill Reeves implemented a particle system to simulate fire. The sequence was a 'sixty-second commercial' with the goal to impress George Lucas, becoming the most visual dramatic CG scene created up to that time (Price, 2008:41).

Tron (Lisberger, 1982) was released the same year, eventually becoming a hallmark of CGI, even though it received mixed reviews from audiences and critics [3]. As the film became a reference for future CG artists, many traditional animators were inspired to experiment with the computer, one of them being John Lasseter, the next big hire for the Computer Division at Lucasfilm.

Lasseter was hired as the only animator, as the rest of the team had a technical background. Although CG was starting to challenge the established rules of filmmaking, slowly becoming a fundamental tool for creating effects for live-action, Catmull, Smith and the rest of the group, were rather pursuing how to use technology to create computer animation as an art form.

With Lasseter on board, the group created their first computer animation, The Adventures of André and Wally B. (Smith, 1984). The film, directed by Alvy Ray Smith, was a breakthrough on many levels, using animation principles and 3D bending shapes, resulting in character action never achieved before. On a more technical level, the film introduced motion blur, a novel computer technique, that softens the motion of objects. Lasseter animated the film using Motion Doctor (MD), the software developed by Tom Duff and Eben Ostby. The rendering done by Rob Cook and Loren Carpenter built the foundations for the development of Pixar's famous render engine, RenderMan [4].

John Lasseter, in an interview with Alan Yentob, featured in the BBC





documentary, Imagine - From Pencils to Pixels (Yentob, 2003), recalls a particular reaction from a member of the audience, at the film's premiere. The reaction he received after the screening, was that the film was very funny, followed by the question, with what software was that achieved? After trying to explain, without success, that the software was not responsible for the film's appeal, Lasseter realized that computer animated films were being created by the same people who were writing the software, without the understanding of the artistic background developed throughout the previous decades (Yentob, 2003). Lasseter adds:

> *"Here is an art form that is growing out of a science (…) without any knowledge of the history of animation. What makes a pencil line become a character, what makes a drawing become emotion?" (Yentob, 2003:15'00).*

Although Lucas public reaction to the film was polite, privately he expressed the film was unpleasant to watch, author David Price indicates. As the characters and story were basic, Lucas felt that the Computer Division ought not to be making movies. Alvy Ray Smith reasoned that George Lucas could not make the leap from the film's crudeness to what it could be, and to what the team could actually achieve. The Computer Division was bought by Apple's co-founder Steve Jobs in 1986, and Ed Catmull and Alvy Ray Smith became the co-founders of Pixar (Price, 2008).

As they had difficulties selling the company's main product, the Pixar Image Computer, slowly they realized the true potential that existed in the software developed for their films. Pixar wanted to create tools for artists, as their software was akin to Stradivarius instruments. The computer program RenderMan, was developed alongside the short films, becoming a must-have software, in any professional production studio. Still, their main goal was to make films, and the path to developing a feature film, besides doing short animations, included doing commercials. That would bring Pixar exposure and credibility. Eventually, their aim would be to try to develop a thirty to sixty-minutes television special (Price, 2008).

Pixar's next short film, Luxo Jr (Lasseter, 1986), was reduced to the most fundamental possible form. The main character, a Luxo lamp, eventually became the studio's mascot. As time and money were a constraint, the background created was minimalist. The focus went to the two characters on screen and their interactions with a ball.

In an interview for the documentary The Pixar Story (Iwerks, 2007),

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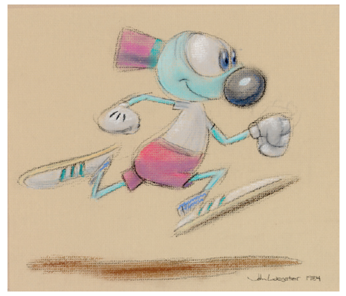

Figure 6 -The Adventures of Andre and Wally B. (Smith, 1984)
a) Final frame of the film;
b) Lasseter's study for the film

a)

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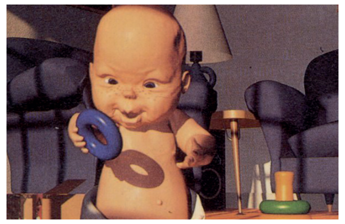

Figure 7 - a) Luxo Jr (Lasseter, 1986)
b), c) Tin Toy (Lasseter, 1988)

Lasseter brings up that Catmull's original idea, was to create a small film that revealed the team's identity. Lasseter though of doing something simple and geometric, as he stared a Luxo lamp on his desk. By moving it with his hands, he was able to pull personality out of it, giving the impression that the once inanimate object was alive.

The simple environment and lack of camera movements were counterbalanced by well-developed characters. The animation principles were developed in a visually captivating performance, where the character's personalities were clear and interesting. Despite its short duration, the film showed more artistic innovation, and less technological development. The mood and cinematography displayed a new level of detail and realism, and audiences were convinced there was life in the two simple objects, the two Luxo lamps. Ed Catmull refers that the film was a turning point for everyone, it was a "pure little story", and once that was accomplished, it became a new goal for the team (Iwerks, 2007:26"25).

Pixar's following shorts, Red's Dream (Lasseter, 1987), Tin Toy (Lasseter, 1988) and Knick Knack (Lasseter, 1989), displayed an increase in complexity, with more detail in the construction of the sets and characters, as well in the amount of animation for each film. For these projects, the RenderMan rendering engine, responsible for the final images, was further developed becoming more capable of producing realistic scenes, where light and shadow, reflections and refractions, texture mapping, amongst other effects, were advanced through algorithms, that allowed for rendering more complex scenes faster [5].

Red's Dream opens to a rainy sequence, where the mood is created by the street lights. A unicycle at a store, called Red, dreams about performing at the circus alongside with a clown. Although the appealing look of the film, the clown, a more organic character, shows an uncanny stiffness, especially at the level of facial expressions.

This strange effect would be repeated in Tin Toy. Here, a toy with a life of its own interacts with a human baby, that antagonizes the toys in the living room. The more realistic baby, contrasts with the stylized toys, as the baby's face demonstrates a strange roughness quality, only made worse by movement. The uncanniness, resulting from the crude application of the technology, in combination with the character's design and animation, showed that development was still needed before more naturalistic and nuanced characters could be animated with the computer. Nevertheless, Tin Toy received an Academy Award for best short film, the first time given to a computer animated film.

For Knick Knack, Pixar returned to a more stylized approach, and working





Figure 8 -Toy Story (Lasseter, 1995)

again with characters that resemble toys. These films would inspire the concept behind Toy Story (Lasseter, 1995). In 1990, Pixar expanded their artistic team by hiring Andrew Stanton and Pete Docter. Together with Lasseter and Joe Ranft, they would write the original story for the studio's first feature film, Toy Story.

The film's initial sequence introduces Andy, a boy playing with his toys, including Woody, the movie's main character. The shots are composed from the toys' perspective, showing predominantly Andy's hands only, avoiding any close up shots of the human character's face. However, one of the toys, Mr. Potato Head, is left in a baby's cradle. The baby Molly, starts chewing on the toy, analogously to Tin Toy. In this moment, as an exception to the previous shots, the baby's face is shown and fully animated. Following the cradle shot, Andy picks up Woody from the floor and the audience is presented with Andy's face for the first time, also in a brief moment. Contrary to Tin Toy, the moments featuring humans are carefully selected and crafted. Human characters throughout the film are primarily depicted from the toy's ground point of view, only so often showing facial expressions. Their faces, still somewhat crude, display a certain appeal that is clearly balanced by the amount of exposure throughout the film.

On the other hand, when Woody and the rest of the toys come to life, their expressivity is rich and their stylization provides a wider range for believability. As the toys are designed with different proportions and characteristics, and each toy is animated with certain constraints, it creates individual vocabularies that showcase different set of possibilities and styles of animation. This demonstrates that the director John Lasseter and the creative team behind the film, understood the design aspects are not only relevant for the static figures of the characters, but also for the function of their movement.

The film took over four years to produce and changed the art form of

a)

b)

c)

Figure 9 - a) Geri's Game (Pinkava, 1997);
b) Shrek (Adamson & Sanders, 2001);
c) The Incredibles (Bird, 2004)

animation, validating computer graphics and making Pixar a world known brand. The feature film, A Bugs Life (Lasseter, 1998), accompanied by the short film Geri's Game (Pinkava, 1997) continued to improve the existing technology, as well as artistic development. While A Bugs Life, directed by John Lasseter and co-directed by Andrew Stanton, presented stylized ants and insects on a wide variety of organic sets, Geri's Game, directed by Jan Pinkava, featured a human character with naturalistic looking skin and wrinkles, despite the stylization. For both films, Pixar developed novel 3D modeling techniques called subdivisions, providing new ways to construct 3D models, showing a large improvement over the previous NURBS techniques [6]. This advancement, provided better tools for animators to improve their artistic skills with.

Approaching the end of the 20th century, Antz (Darnell & Johnson, 1998), marked the beginning of DreamWorks Animation, a joint venture of Steven Spielberg, Jeffrey Katzenberg and David Geffen. The studio became famous for characters such as Shrek (Adamson & Jenson, 2001), the cast from Madagascar (Darnell & McGrath, 2005), Kung Fu Panda (Osborne & Stevenson, 2008) and How to Train Your Dragon (DeBlois & Sanders, 2010). Pixar followed with Toy Story 2 (Lasseter, 1999), Monsters Inc. (Docter, 2001) Finding Nemo (Stanton, 2003) and The Incredibles (Bird, 2004).

As 3D animation evolved to be the new standard, Disney Animation slowly started to incorporate computer techniques into their film productions, starting with the Computer Animation Production System (CAPS), a digital ink and paint program, developed by Pixar for Disney. The Rescuers Down Under (Butoy & Gabriel, 1990) was the first hand-drawn film to be fully painted with digital tools, using CAPS. 3D backgrounds were later used in combination with CAPS for Beauty and the Beast (Trousdale & Wise, 1991), Aladdin (Clements & Musker, 1992) and Tarzan (Lima & Buck, 1999), amongst others, replacing Disney's out of date Multiplane Camera. Slowly, Disney started to leave hand-drawn animation behind, in exchange for the more modern computer generated animation, with Chicken Little (Dindal, 2005), Meet The Robinsons (Anderson, 2007) and Bolt (Williams & Howard, 2008), and later with Tangled (Greno & Howard, 2010) and Frozen (Buck & Lee, 2013).





## Realism and the Uncanny Valley

The beginning of the 20th century also brought about the widespread use of Mocap techniques. Films such as Final Fantasy: The Spirits Within (Sakaguchi, 2001), The Polar Express (Zemeckis, 2004), Beowulf (Zemeckis, 2007), and The Adventures of Tintin (Spielberg, 2011) stand out by their realistic approach and motion capture techniques, instead of CG keyframing and stylization.

This approach contrasts with films such as Shrek and The Incredibles, where animators give life to the characters using keyframing techniques, by digitally manipulating 3D models as if they were puppets inside the computer. Through the process of keyframing, the animators define the key poses and the computer helps to calculate additional in-between poses, inside animation software. The animators create the performance through the computer, while with motion capture, the performance is originally created by actors in mocap suits.

In the Newsweek article "Why is Tom Hanks less than human", Steve Levy quotes Aaron Warner who was a producer on Shrek, "We don't do any motion capture.", "Our animators are actors in and of themselves." (Levy, 2004).

In the same sense, Pixar's Ratatouille (Bird, 2007), directed by Brad Bird from The Incredibles and co-directed by Jan Pinkava from Geri's Game, presents a small gag at the end credits, assuring one-hundred percent quality, genuine animation, as "no motion capture or any other performance shortcuts were used in the production of this film" (Bird, 2007).

Steve Levy explains motion capture, that drives movies such as Beowulf, Final Fantasy and The Adventures of Tintin. These examples do not use CG animators to drive the performance of the characters; instead, they use actors and stunt performers. Referring to Beowulf's director, and The Incredibles supervising technical director, Levy adds that:

> *"[Robert] Zemeckis and "Pixar's Rick Sayre, agree that performance is key to vivifying a CG-generated human. But when Zemeckis talks about performance, he means something that Tom Hanks does with 165 sensors glued to his face. (...) Sayre defines performance as the way a CG character is scripted, framed, moved and lit." (Levy, 2004).*

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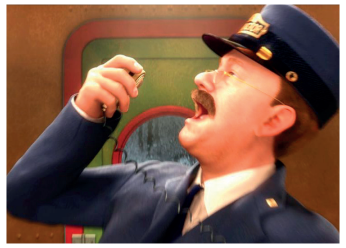
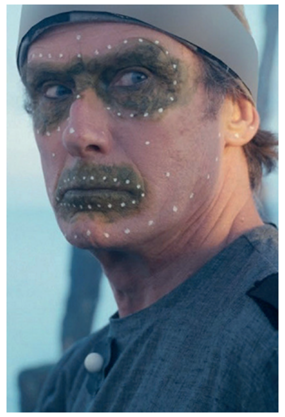


Figure 10 -The Polar Express (Zeemeckis, 2004)
a) Actor Tom Hanks in a Mocap suit
b) The Conductor character

a)



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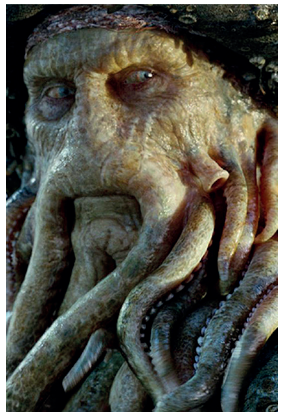

Figure 11 -Pirates of the Caribbean: At World's End (Verbinski, 2007)
a) Actor Bill Nighy in Mocap Suit
b) Davy Jones charater

The VFX author, journalist and psychologist Peter Plantec, wrote the AnimationWorld Magazine,'s (AWN) article "Crossing the Uncanny Valley". Here, he looked at the approach Industrial Light and Magic (ILM) used to create the photorealistic character Davy Jones, for Pirates of the Caribbean: At World's End (Verbinski, 2007) based on the performance of the actor Bill Nighy. Plantec writes:

> *"Pure technology is not capable of capturing near the level of performance needed to cross the Uncanny Valley. So, ILM wisely used keyframe tweaks based on the actual video of Nighy's eyes. It was absolutely necessary and, for me, it worked superbly. I believe that it was the marriage of superb on-set MoCap, married to brilliant hand animation that catapulted Davy into the realm of the believable." (Plantec, 2007).*

The director Brad Bird, in an interview with Adam Jacques for The Independent, explains that there is a bias when crediting mocap performances, featuring only the actors and discarding the role of the animators. Bird gives as a major example of this Andy Serkis, who despite being a great actor, is often singly credited for the performance of digital characters, such as Golum from The Lord of the Rings trilogy (Jackson, 2001-2003). Bird adds that, to his knowledge, there were shots in the films that did not utilize any of Serkis's mocap, and were done exclusively by the animators. (Jacques, 2015).

It is clear that animators and actors can work together to produce the final result of character's performance, although the role of the animator can be less valued and understood. Technical progress is often the reason, prioritized in detriment of story or artistic development, producing uncanny results that can be difficult for an audience to watch. Mocap is indeed a technological achievement, even though the method of copying human motion dates back to Disney films such as Snow White and the Seven Dwarfs (Hand, 1937) and even earlier, as the method of rotoscoping was patented as early as 1917 by Max Fleischer, creator of Betty Boop character.

Together with copying, come aesthetic issues that concern both technical implement, as well as artistic choices, regarding designing and animating characters. In this sense, the Uncanny Valley problematic goes back beyond robotics, to the foundations of filmmaking. Disney's animators applied animation principles such as squash and stretch, anticipation and exaggeration, to avoid the strangeness that emerges from copying reality.

Ollie Johnston, interviewed by Paul Wells in 1999, explains that the





process of rotoscoping from film resulted in unpleasant results and stiff movements, as film presented the animators with too much information. The principles were used to emphasize what was relevant for the animator, and nothing more. Johnston expands this with the notion that, as animation lives outside the of limits of live action, it does not only exist to serve as a translation from live-action footage. The animator creates the performance of the character in relation to the scene, considering weight, movement, rhythm, and the environment, creating the specific concepts behind the action (Wells, 2006).

John Lasseter, reflecting about the implementation of the animation principles developed by Disney animators to 3D animation, early when the technology was still in its infancy, argues that computer tools, either hardware or software, are not enough to produce rich entertainment for audiences. Animation principles developed at Disney Animation Studios, are tools as well, important when defining characters' actions and making them feel believable to an audience. The principles themselves, are "tools which are just as important as the computers we work with." (Lasseter, 1987:43).

> *"Perhaps staying out of the Uncanny Valley entirely should not be the ultimate goal of all animators, but rather using it sparingly and cleverly, as another element of the rich language of animation." (Kunz, 2015:85).*

Going inside the Uncanny Valley, author and researcher Sahra Kunz suggests that the valley could also be a place of experimentation, where filmmaking could strive. As many filmmakers make an effort to cross, or stay out of the valley, some also try to use the uncanny as a useful tool for creating their films, as is the case of Chris Landreth (Kunz, 2015).

Groundbreaking filmmaker, Chris Landreth, director of 3D short films such as, the end (Landreth, 1995), Bingo (Landreth, 1998), Ryan (Landreth, 2004), The Spine (Landreth, 2009) and Subconscious Password (Landreth, 2013), often uses the intrinsic language of computer graphics, with all its perks, from glitches and generative qualities, to the eeriness and digital components, to advance the stories for his films.

He started out making films as an in-house artist for Alias, the original developer for the software Maya, an industry standard of 3D animation. Landreth started to create his short films, using and often 'abusing' the

Figure 12 -a) Bingo (Landreth, 1998);
b) The Spine (Landreth, 2009);
c) Subconscious Password (Landreth, 2013)

Figure 13 -Ryan (Landreth, 1998)

computer program as it was being developed [7]. What this means is that the filmmaker would, more often than not, subvert the tools that were developed for certain methods and practices, and embed the story and filming process with this approach. For, the end and Bingo, unconventional software tools were appropriated for the design of the characters. Processes for simulating dynamics were instead used to build the characters' features. This constitutes a rich vocabulary that provides an opportunity to express the character's inner personality, thoughts and emotions. By mixing figurative notions with experimentation, a language is created that can articulate a particular discourse, in this case about politics, identity, and the fragility of human's social constructs.

Ryan, an animated documentary about Ryan Larkin, once famous traditional animator, is created with Landreth's 'Psychorealism' style, a term the author uses to refer to surrealistic CG imagery that characterizes physiological aspects of the characters. Awarded an Academy Award for Best Animated Short Film in 2005, it not only celebrates subjectivity, but also examines the filmmaking process, as the materialization of the artist's ideas into film, can oftentimes drain the body of its creator, resulting in breakdown, anxiety and depression.

Mentioning his film Subconscious Password, Chris Landreth explains to the author Dan Sarto for AWN, the challenge of going into the Uncanny Valley as a deliberate choice. As pixilation animation is combined with CG, the film's visual depiction of characters and backgrounds strives not to be realistic, although it uses eeriness as a visual quality to challenge both the notions of the reality of the characters, as well as the conventions of 3D animation. Landreth continues, as the Uncanny Valley is often acquainted with feelings of repudiation, it can be hard to see it as a useful and valuable tool. But the uncanny feeling of resembling reality, here is used to describe how the internal processes of the characters work (Sarto, 2013). The filmmaker adds,





*"They're not real people in our heads. They're cool simulations of them. It was a challenge to keep to that as far as the look of the film, without going into the conventions of what CG normally tries to do there." (Sarto, 2013).*

Landreth adds that, as big box office films depend on big budgets and they cannot afford the same aesthetic experiments as low budget films, where low stakes open new sets of possibilities. Still, he believes that films such as Inside Out (Docter, 2015) [8] represent tremendous risk, as they portray characters inside a person's head, a distant concept from the usual blockbusters (Sarto, 2013).

Short films, in comparison to feature-length films, present a notable format for experimentation, as reduced budgets provide the opportunity of failing without heavy consequences. Pixar's feature length films are generally opened with a short film in theaters. Pixar's tradition of shorts, since its inception, is now expanded to a new format for streaming, called Sparkshorts, where Pixar's artists can develop their own projects, exploring storytelling, new techniques and new production workflows [9].

The short films released at the beginning of the 21st century for theatrical release, such as For the Birds (Eggleston, 2000), Boundin' (Luckey, 2003), One Man Band (Andrews & Jimenez, 2005) and Presto (Sweetland, 2008), advanced the technical and artistic maturity of the studio. As technology was improved upon, its relationship with narrative and craftsmanship was put to the test, exploring the boundaries of the digital medium. More recent short films diverge from the early examples, by presenting photo-realistic images, nuanced narratives, and complex characters.

With Partly Cloudy (Sohn, 2009), new possibilities of what can be achieved is unfolded. The story features cloud-like characters that can adjust their shape and refine it to be just anything. The cloud characters transform small portions of cloud into new-born babies and animals, that are then carried by storks, but a dark cloud is only capable of producing menacing and dangerous animals, proving to be a challenge for a particular stork. The concepts presented on the film, provide subtext that expands the storyline into different layers of meaning. What is apparently a naive story, touches on subjects of discrimination and social relations. This is taken as an opportunity to reflect on human psychology, as complex feelings and emotions that can be expressed by the conflict of different situations, created here by the transformation of clouds into various types of characters, matched by complex and detailed computer imagery.

Day and Night (2010, Newton), combines 2D and 3D animation into a

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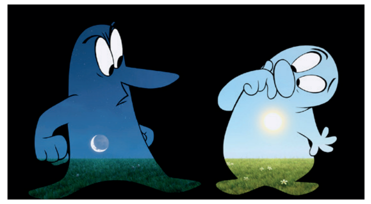


Figure 14 -a) Partly Cloudy (Sohn, 2009);
b) Day and Night (Neewton, 2010)

Figure 15 -The Blue Umbrella (Unseld, 2013)

visually dazzling film, about two opposite characters, Day and Night, that dread each other, as they are in contradiction of one another. This somewhat abstract concept, is achieved by hand-drawn 2D characters, displaying 3D backgrounds inside their silhouettes, changing accordingly to their state of mind. With this short movie, Pixar reshapes the boundaries of the art form, not only by combining different types of animation, but also by demonstrating that certain ideas need a special vocabulary to be constructed with.

At the time the film was created, Disney had stopped producing hand-drawn animation and 3D animation became the new "kid on the block". Day and Night challenged the industry's establishments, by fully articulating the two mediums into one. As the two characters in film discover what it is truly unique about the other, a message caught on radio inside one of the characters speaks about the fear of the unknown, an actual quote from Dr. Wayne Dyer [10]. The quote refers to prejudice towards new ideas that often are rejected because of fear, and overturned for more familiar ones. Instead, Dyer points out, for him, "the most beautiful things in all the universe, are the most mysterious." (2010, Newton).

The short-films Blue Umbrella (Unseld, 2013) and Piper (Barillaro, 2016), display stunning photo-realistic images, sometimes almost undistinguishable from live-action. Advances in rendering technology, using global illumination techniques and ray tracing algorithms, generate increasingly greater realism. Nevertheless, the characters in The Blue Umbrella are highly stylized in form and motion. The two main characters, the umbrellas, are a combination of realistic animated umbrellas with very simplified 2D eyes and mouths. Despite the realistic representation of humans and backgrounds, the city's objects are designed to take advantage of abstraction as well. Screws, knobs and handles are represented as facial features, demonstrating that the expression of emotion can occur in everyday common objects, if the animation is carefully hand-crafted.

Piper, features a hungry sandpiper hatchling, learning survival strategies to feed himself at the sea shore. The short film presents very unique characters in their design and movement, despite the hyper-real, detailed and nuanced look, constructed by every feather and grain of sand. Still, Pixar's artists and technicians deliver an outstanding film, as a testimony of the full capacity of computer animation. With such a variety of possibilities, from stylization to abstraction, combined with photo-realism and nuanced storytelling, featuring sometimes abstract concepts and metaphors, it seems there are endless possibilities within the art form. But there are limits to what can be done, before the illusion breaks and audiences stop believing the magic.





Figure 16 - Piper (Barillaro, 2016)

Author Ed Hooks explains that, in theatre, the audience knows the character portrayed by an actor is not real, thus, the audience understands that what happens on stage is pretend, and the audience pretends not to know it (Hooks, 2011).

The term, willing suspension of disbelief, was introduced by poet and philosopher Samuel Taylor Coleridge, when describing his original ideas for the poems he conceived for the book Lyrical Ballads, written together with William Wordsworth. Here, Coleridge explains that in order to represent in his poems, characters that had supernatural or romanticized characteristics, the reader would have to willingly suspend his disbelief in the moment, to find a human interest and affinity with these "shadows of imagination". This transaction, the author called "poetic faith" (Coleridge, 1817:5). Hooks expands on this notion:

> *"The audience suspends its disbelief in the unreality of the character in order to empathize. It is the responsibility of the storyteller to define the parameters within which the audience must spend its disbelief." (Hooks, 2011:65).*

Giving as an example, Walt Disney's Pinocchio (Sharpsteen, 1940), Hooks points out that Jiminy Cricket opens the film singing and talking directly to the audience. Once this is established early in the beginning of the movie, that a cricket can speak and sing, believing that a wooden puppet can come to life will be also credible for the audience. On the other hand, Up (Docter, 2009) only establishes that dogs can talk half-way in the film, resulting in a bad story structure, Hooks asserts. If dogs would happen to talk in an animated film, then it should be established as soon as possible, otherwise, the audiences may not be able to suspend their disbelief (Hooks, 2011).

Regarding realistic digital human characters, the author believes that the pathway to cross the Uncanny Valley is not dependent on mastering human physiology, and the connection of anatomical features to the character's thoughts. As humans can behave inconsistently, and often display contradictory actions, it is essential for artists to capture those behaviors. Hooks adds that, although technology may bring us close to mastering the interactions between muscles and thinking, we still are very far away from capturing the unknown factor, the mystery of human behavior. So, in order to depict characters believably, artists should not overindulge in technology, as "human behavior is best depicted in poetry rather than science." (Hooks, 2011:67).

## End Notes

[1] SIGGRAPH's history in their website (ACM SIGGRAPH, n.d.): https://www.siggraph.org/about/history/ (last accessed 1/11/2020)

[2] - More information on Loren Carpenter in chapter 2.5. Rendering (page 133).

[3] Tron 35th anniversary (King, 2017) on Variety's website: https://variety.com/2017/film/news/tron-jeff-bridges-cgi-1982-disney-anniversary-1202486941/ (last accessed 1/11/2020)

[4] More info on RenderMan can be found in chapter 2.1. The 3D Pipeline (page 64) and in chapter 2.5. Rendering (pages 134-141).

[5] More info on early rendering techniques in chapter 2.5. Rendering (pages 129).

[6] Modeling techniques explained in more detail in chapter 2.2. 3D Modeling (page 71) and in chapter 2.3. Digital Sculpting (page 89).

[7] More references can be found on Landreth's website: http://www.chrislandreth.com/about-chris (last accessed 1/11/2020)

[8] The film Inside Out (Docter, 2015) was still in development at the time of the interview.

[9] Available on Disney Plus: https://www.disneyplus.com/pt-pt/home (last accessed 1/11/2020)

[10] Dr. Wayne Dyer is an author in the field of self-development and motivational speaker.

# 2. Computer Graphics Animation

## 2.1. The 3D Pipeline

This section of the thesis reviews the state of the art of the main technologies and methods used in the industry, that are useful for the progress of our investigation. Referencing key contributors and innovations is as important as the possibilities they unfold. In this sense, most of the examples used in the following chapters, will be of artwork produced by us since 2005 to present date. This provides a scope of progression, both of the technology and of the artistic practice, essential to contextualize the research based project, in the last section of the thesis. As this progression increases the possibility for detail and realism, being paired with specific tools and computer techniques will continuously address animated languages and aesthetics.

A 3D animation production is divided into a sequence of tasks, usually referred to as the pipeline. In animation studios, the tasks are distributed by different departments, where a diversity of skills and methods are shared between artists and technicians. Before a film enters production, ideas are developed at a pre-production phase, where script and storyboards [1] are created, as well as concept art [2] for characters and backgrounds. Here, the art and story departments collaborate in defining the film's narrative and visual look. The pre-production of a project is essential for its budget to be approved and green-lit for production.

Figure 1 shows a comparison of panels from the storyboards to the final frames, for 7200 Light-Years (Megre, 2007). This experimental film, produced as the author's master's degree project, explores the possibility of falling into a black hole. The main character Moss, an astronaut exploring deep space, enters the event horizon of a collapsed star located 7200 light-years from Earth, to discover what is hidden at the singularity.

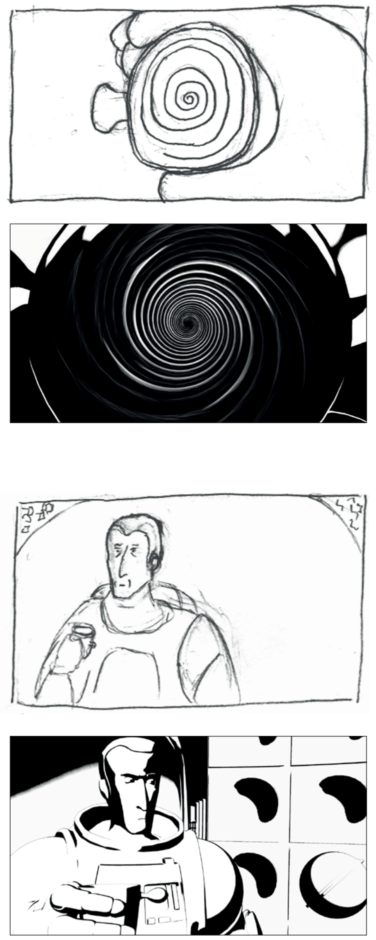
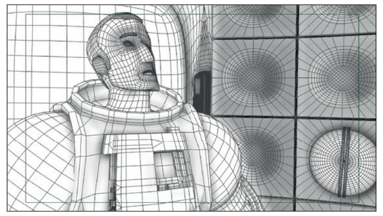
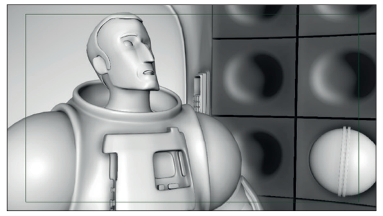


Figure 1 - 7200 Light-Years (Megre, 2007), from storyboards to final frames

a)



b)



c)

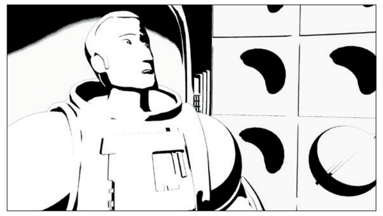


Figure 2 - a) wireframes of the models, b) shaded 3D models, c) rendering and final look applyied

## Production Development

For a standard production development, a film pipeline consists of the following processes: 3D modeling, surfacing, layout, rigging, animation, simulation/effects, lighting and rendering.

To create 3D models of characters, props and backgrounds, different techniques are used by artists, from modifying geometry in 3D space, to sculpting with digital clay. Models can be created by scanning objects or actors into the computer, used as a base for modeling, or by applying procedural techniques, generating models using algorithms.

Coloring and shading the 3D models, combines 3D painting techniques with mapping images onto surfaces and setting up different material attributes. While the same models can have different materials, such as glass or metal, it is still possible to paint scratches or textures on top. In the specific case of this film, only the eye pupils were painted as dots. The two tone effect was produced by shading and rendering the 3D models, and filtering the images in post-production (figures 2 and 3).

The layout development combines the different assets [3] into the first versions of the shots, creating computer files with virtual cameras [4], temporary 3D models and animations, that represent the next step after the storyboards. These files will eventually be updated with completed animated characters, until then, they serve to block the camera's movements [5], setting up different camera lens, and expressing the original storyboarded ideas, into three-dimensions.

The rigging process applies digital joints and deformers to the models, allowing for characters to be manipulated like digital puppets. Props, environments and cameras can be rigged as well to perform specific actions. Then in animation, keyframing techniques [6] are used to change attributes, allowing for motion and expression to be created.

Animators using the computer can create extremely detailed and nuanced performances, combining the high level of control granted by a character's rig, with their own creative ideas for the action. Although the storyboards and the script may suggest the action, ultimately, the animators are responsible for what will be performed by the characters. As they go beyond the original ideas developed in pre-production, animators create the illusion of life by fleshing out characteristics, personality and style of movement, essential to captivate audiences.





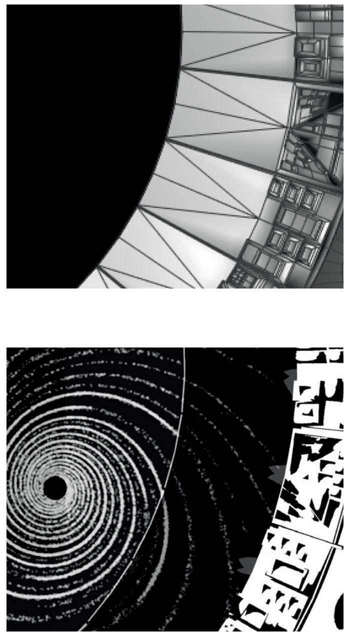


Figure 3 - Crop frame illustrating the 3D model, of the interior control panels, rendered with Maya software, filtered and composited in After Effects

Not everything that moves in the film is solely animated. Clothing, hair, or natural processes like wind going through vegetation, are mostly simulated by the effects and simulation departments. Here, computer simulation is used to calculate complex procedures, allowing technical directors to produce all sorts of effects, for characters and backgrounds. Some workflows, as character's simulations, *e.g.* hair/fur grooming or clothing simulation, may be necessarily co-developed by different departments. Artists may model the shape of a character's hair, but its motion is simulated by technical directors; characters cloths can be simulated on top of its animated performance. The spiral in figure 3, as the other spirals in the film, display the use of simulated particles, affected by vortex fields [7].

Finally, the lighting and rendering stage sets up color and mood through light placement, wrapping up the production. In rendering, the 3D space is converted into flat 2D images, that will be delivered to editorial. This is done in parallel to lighting, as the two are part of the same process. Still, rendering algorithms can be tweaked to control aspects such as noise or resolution of the final images.

While some tasks have to be completed in order for others to start, there is also overlapping when possible, depending on particular workflows. Some characters can take a long time to be completed, for example in Rango (Verbinski, 2011), the main character took around eight months to be built [8]. It is essential that, during this time, the layout department can use a temporary version of the character to set up cameras for different shots, the rigging department may also use temporary models to explore the technical needs for animation. And when a preliminary version of the rig is ready, animators can start to do some tests, to explore the character's personality. The workflow can be modified from project to project, to accommodate specific needs.

In post-production, sequences of images are composited in layers, resulting in the final frames [9]. Colors are polished, and sound is added to the film's cut. In live-action film, editing is necessarily at the end of production, as film needs to be shot prior to cutting. However, in animation the film evolves directly from storyboarding to editing, creating a temporary version of the film, called animatic, or film reel. The animatic is constantly changed, as final animations and renders move "down the pipeline". If dialog exists, voice actors must be recorded before the animation is created. This is usually a fundamental step in creating the key beats of the film's edit.

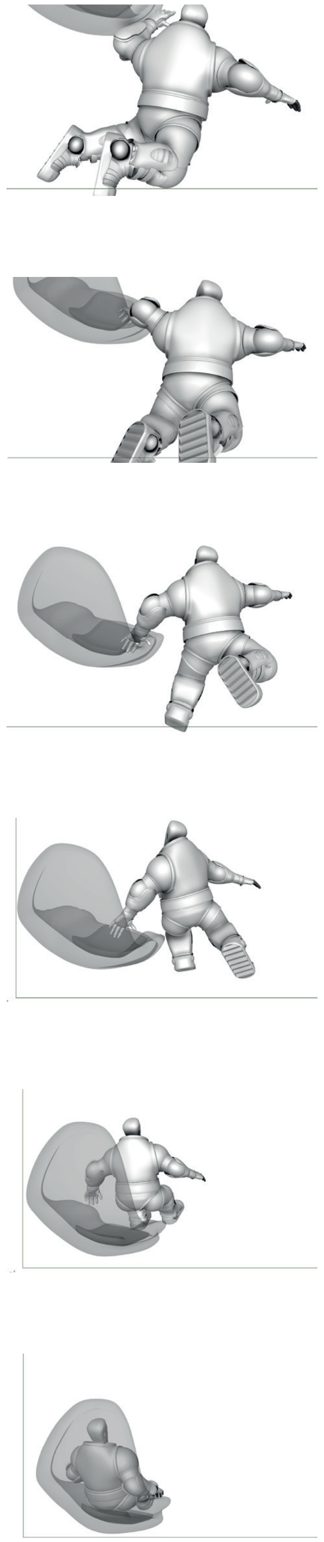


Figure 4 - key poses for the action, interpolation provides in-between frames

## Computer Programs

Regarding software, two main options exist within studios: the proprietary programs, developed in-house, and commercial or open source tools, available both for companies and the general public. It is standard practice for companies to add custom-built tools into commercial software, with specific procedures that evolve along different productions.

Pixar for example, uses their proprietary software Presto for animation, while Disney uses Maya, a commercial software produced by Autodesk. Scott Kervasage, the effects supervisor on Wreck-it Ralph (Moore, 2012), interviewed by Ian Fails for FX Guide, explains that for the film the team used motion capture for the movements of the camera, requiring specific software, in this case Maya (Failes, 2012). In another example, the VFX supervisor Steve Golberg for Frozen 2 (Buck & Lee, 2019), in an article by Alex Dudok de Wit for Cartoon Brew, explains how a specific tool was developed for Maya, providing the possibility to interact with the wind using curves in space, allowing the team to shape and edit its motion in real time (de Wit. 2019).

For rendering, Disney developed an in-house render engine called Hyperion, used since the production of Big Hero 6 (Hall & Williams, 2014). Pixar owns RenderMan, also internally developed, but contrary to Hyperion it is distributed commercially. RenderMan is one of the most established render engines. Created in the 1980's [10], it has been used in major blockbusters, from the original Jurassic Park (Spielberg, 1993) and Toy Story (Lasseter, 1995), to the latest Toy Story 4 (Cooley, 2019) or Star Wars: Episode IX - The Rise of Skywalker (Abrams, 2019) [11].

The most commonly 3D commercial softwares used in the entertainment industry for films, games and advertising are Maya and 3ds Max (both from Autodesk), Side FX Houdini, Foundry Modo, Maxon Cinema 4D, NewTec LightWave and Blender [12].

While Maya is famous for its scripting capabilities, allowing to write custom tools that are used and developed across different projects, Blender is a free and open source alternative, that has been increasingly adopted in productions in the recent years, as its tools have matured.

Regarding digital sculpting, the industry standards are Pixologic ZBrush and Autodesk Mudbox, that also include 3D painting capabilities. Blender and other commercial programs, such as Modo from Foundry, have internal sculpting tools as well. ChronoSculpt, developed by NewTec, stands out by providing tools





Figure 5 - 7200 Light-Years (Megre, 2007): Final frame with composited elements

to sculpt over time, enabling the sculpting of animations and simulations, altering shapes and forms.

By being a pioneer in the development of the field of digital sculpting, ZBrush is one of the most versatile options. With powerful and innovative tools, it is a game changing software, bringing traditional concept artists and sculptors into digital 3D applications.

Surfacing is traditionally done with a combination of 3D and 2D applications, as for example, Maya and Adobe Photoshop. For an artist to see the final result of an object's surface, texturing, shading and lighting/rendering must be used in conjunction, and require different computer hardware applications.

The evolving technologies of CPUs and GPUs specify what tools allow for real-time production, providing interactive results, or offline rendering, where artists must wait for the computer to return the colored pixels. Heavy-cost computing tools, that require slower renders, can produce more realistic results. For real-time interactivity, algorithms often use approximations, good enough for keeping artists productive. With these constraints, the lights and materials are created in a program such as Maya and textures developed inside programs like Photoshop. The textures are then imported to the materials in the 3D application, via their attributes.

More recently, specialized surfacing software has been developed, such as Mari or Substance Painter, that allow for 3D texture painting and procedural surfacing, an alternative to generic packages. Before this development, surfacing was a mixed media that depended on 2D and 3D techniques. With the recent surfacing approach, all the processes can be done in 3D, and afterwards materials are exported to the main software for rendering. As an advantage,

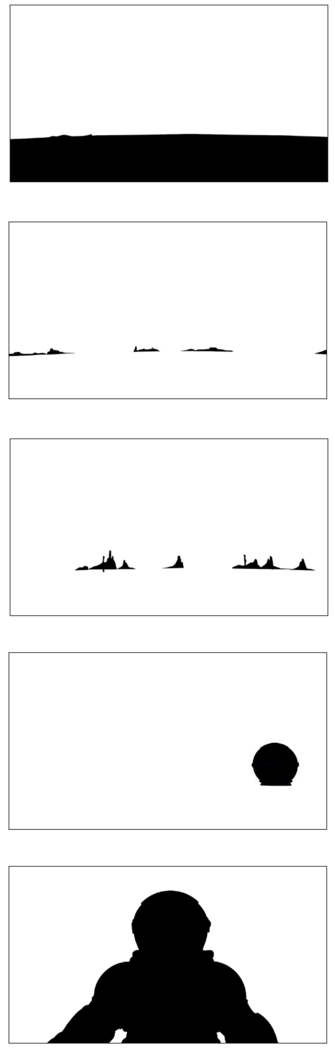
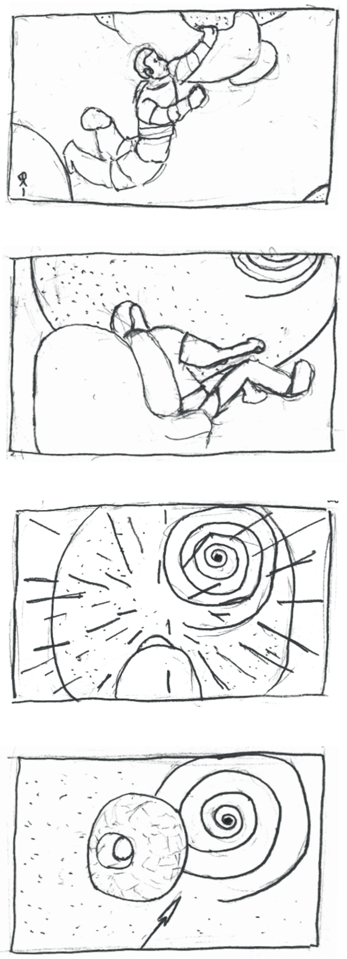


Figure 6 - Seperated elements in layeres for compositing



specific 3D painting brushes can be incorporated together with procedural textures [13] with real-time feedback on the material. This gives artists an intuitive and less technical approach, allowing for greater experimentation and iteration. Because these types of software exist for this purpose alone, they are capable of producing a high degree of detail in textures, even more than digital sculpting tools [14].

For rendering, Renderman, Arnold and V-ray are predominantly used as CPU renders, and more recently have GPU capabilities expanded into them. GPU renders are also widely used, *e.g.* Redshift, Octane Render and Maxwell, as graphics cards become more powerful and capable of raytracing [15], a feature previously exclusive to CPU renderers.

Figure 6 illustrates the post-production process. After animation is finished, elements are rendered separately, conserving the light and shading but including respective alpha channels [16], providing individual layers or nodes for compositing, when adding post-processing, such as color grading or image filtering. Regarding post-production software used in the animation, VFX or commercials industries, the main options are After-Effects, Nuke or Flame.

For our research, the computer programs we will be using are Maya, for creating 3D models, rigs and animation, Renderman and Arnold, as plug-ins inside Maya, for surfacing and rendering. Finally, for digital sculpting and painting, ZBrush and Photoshop will be used.

Additionally, Blender will also be used for 3D drawing, providing built-in capabilities to be compared to Maya's. For post-production, Nuke will be used, due to its benefits of being node-based, contrary to After Effects, which is layer-based [17].

Animator and author Tom Sito, points out that the first generations of CG artists had multiple occupations within film's productions, and "refused to be pigeonholed into a narrow job classification." (Sito, 2013:268).

As the industry evolved, many specializations were created. Inside studios, the departments evolved with different fields of expertise, from modeling, rigging and texturing, to sculpting, lighting, rendering and compositing, among others. The industry also grew worldwide. Artist's jobs, that used to be considered unique, today depend more on technical aspects and can be cheaply outsourced overseas (Sito, 2013). Sito adds,

Figure 7 - 7200 Light-Years (2007); storyboards





*"The digital revolution is over, but the evolution of digital media will go on. The modern software programs described here will one day seem as quaint as a candle-tick telephone. It's taken only a lifetime to go from Ivan Sutherland's Sketchpad, with a glowing white line on a four-inch-square computer monitor, to the digital blockbuster movies of today. Who knows what we will see in another lifetime?" (Sito, 2013:269).*

The technological developments in CG animation, from the early days to contemporary achievements, were made in pursuit of improving the art form, with the goal of proving that this new medium was a viable way to tell stories.

As computer animation outgrew traditional techniques, many predicted that CG would be the end of other forms of animation, such as 2D hand-drawn animation. With the digital evolution, even Disney Animation Studios, one of the world's greatest references for 2D animation, switched to 3D computer animation, stopping entirely to produce hand-drawn motion pictures.

The truth is that, despite being the new game in town, CG also created a hunger for traditional animation in audiences, and this desire to bring back 2D is currently playing a role in the evolution of CG.

Drawing and 2D techniques are being mixed with 3D, in short-films such as Pixar's Day and Night (Newton, 2010), Disney's Paperman (Kahrs, 2012) or more recently in feature-films such as Spider-Man: Into the Spider-Verse (Persichetti, *et al.* 2018) or Klaus (Pablos, 2019).

The role of drawing, once restricted to the pre-production stage, to design the look of a film, is slowly becoming more visible in the final product, occupying a new space in the production development, and requiring new tools to be created. As the art form continues to evolve, the function of drawing will surely be a fundamental aspect in its definition.

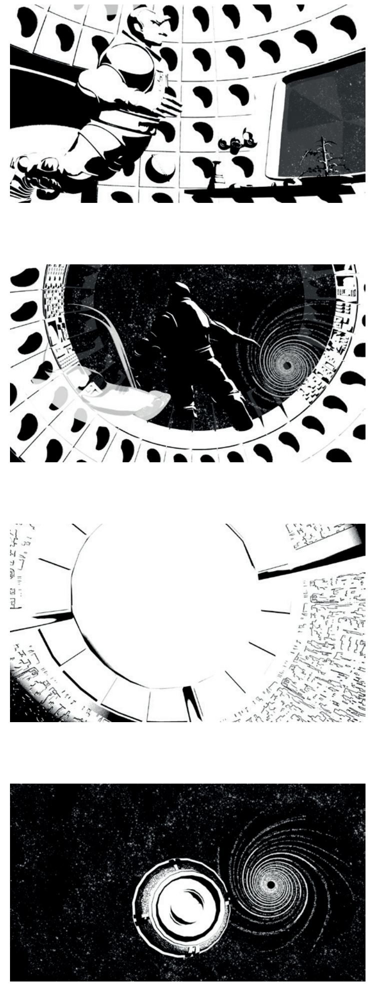


Figure 8 - 7200 Light-Years (Megre, 2007); final frames

## End Notes

[1] - Panels of sequences of drawings that illustrate the story.

[2] - Art produced during the pre-production of films, consisting of drawings, paintings and illustrations.

[3] - 3D models to be used during production. They can be developed and published at different stages, containing geometry only, or also textures, control rigs and animations.

[4] - Cameras that provide the view into the 3D virtual space of computer programs.

[5] - General poses of cameras and characters, providing information about composition and duration of a scene.

[6] - CG technique that calculates the transitions between starting and ending positions. Topic covered in depth in chapter 2.4. 3D Animation (page 110).

[7] - Computer techniques that relate emissions of particles with different fields, that control their behavior through attributes.

[8] - Development of characters for Rango (Verbinski, 2011) covered in chapter 2.3. Digital Sculpting (page 93).

[9] - Compositing programs overlay 2D images in order to produce the final result, displayed in figure 6 of this chapter.

[10] - History of RenderMan (Failes, 2018) on the magazine of the Visual Effects Society: https://www.vfxvoice.com/renderman-at-30-a-visual-history/ (last accessed 1/11/2020).

[11] - List of films available on RederMan's (n.d.) website: https://renderman.pixar.com/movies (last accessed 1/11/2020).

[12] - List of modeling software (Jarratt, 2021) on Creative Bloq website: https://www.creativebloq.com/features/best-3d-modelling-software (last accessed 1/11/2020).

[13] - Textures created using algorithms, such as noise and ramp textures.

[14] - Detailing characters with textures in Mari (FlippedNormals, 2018): https://youtu.be/u7DwaYsb9JY (last accessed 1/11/2020).

[15] - Rendering technique that requires simulating paths of light. Topic covered in more depth in chapter 2.5. Rendering (page 135).



[16] - Transparency channel in digital images, covered in chapter 2.5. Rendering (page 130).

[17] - Layers are vertically stacked, nodes are distributed along a flat 2D space, resulting in different workflows.

## 2.2. 3D Modeling

Figure 1 - Utah Teapot displayed in Maya's viewport [1]

In this chapter, we provide an analysis of a selection of modeling techniques, which we consider relevant for the existing problematics in our research, not a description of all the tools and modeling techniques available.

The modeling types of geometry used in Maya are NURBS [2], Polygons and Subdivisions. The 3D models can be constructed from a variety of primitives, for instance planes, cubes, cylinders, spheres, or by combining curves, *e.g. bezier* curves. Objects can be transformed using three different types of modifiers, translation, rotation and scale. Also, their components can be transformed in the same manner. In general terms, components can be thought of as points, lines and planes. Depending on the nature of the different types of geometry, components will have different names and characteristics. The transformations can occur in a three axis system, X, Y and Z. In Maya, the X axis defines left and right, the Y axis defines up and down, and the Z axis front and back.

Traditionally, the starting point for creating these models comes from drawings, photographs or even clay sculptures, that are digitized and used as a construction base for the digital models.

NURBS main attribute is that they allow for curved surfaces to be easily created, either through primitives or curves, using smooth patches to define shapes. Polygons, instead, are incapable of creating curved geometry, as they consist of flat surfaces. In order to display smooth surfaces, a great amount of polygonal faces are

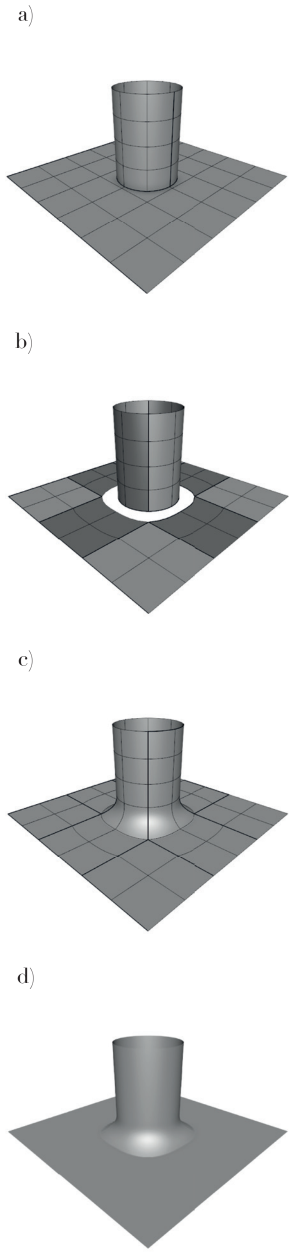



Figure 2 - NURBS cylinder and plane joined by patch modeling technique.

required, so they are small enough to represent curvature. Historically, this meant heavy processing for computers.

Subdivisions combine both ideas and offer the possibility of displaying curved and flat surfaces at different levels of resolution. By subdividing a geometry into greater detail, but maintaining the overall manipulation through a control mesh, subdivisions allow control over the coarser and finer detail of this surface. Subdivisions also have a special application with digital sculpting programs, where form is created with a more organic approach, inspired by real processes such as sculpting in clay.

> *"Patches and fine polygonal meshes represent two ends of a spectrum. Patches efficiently describe large smooth sections of a surface but cannot model fine detail very well. Polygonal meshes are good at describing very fine detail accurately using dense meshes, but do not provide coarser manipulation semantics. Subdivision connects and unifies these two extremes." (Zorin, 1999:2)*

## NURBS

NURBS stands for non-uniform rational b-splines and, until the introduction of subdivisions surfaces, they were the animation industry standard for creating smooth 3D models. They are constructed of parametric patches, that consist in rectangular surfaces of rows and columns, providing useful attributes like smooth curvature and easy texture mapping [3].

One of the most relevant early examples of curved surfaces is the "Utah Teapot", using *bezier* curves, visible in figure 1. Created by Martin Newell in 1975 and later modified by Jim Blinn to the vertically scaled down version, it remains one of the most popular CG objects in history [4]. At that time, Newell was looking for real life references to create more complicated pictures for his research. In conversation with his wife, Sandra Newell, Martin explained he was looking for an object that would be recognizable, but not too complicated, and Sandra suggested the set they were using for having tea at the moment [5]. Using the teapot as a starting point, considering its recognizable smooth shape that contrasted with some sharp angles, Newell sketched its shape on paper and used it as a guide to calculate the coordinates of the 3D model. The original data of the model consisted of twenty-eight surface patches, plus four patches that created





the bottom of the teapot. Using *bezier* curves, the profiles of the lid, the rim and body were revolved, creating three-dimensional forms. The spout and handle were created from cylindrical tubes (Crow, 1987).

The teapot was used by Newell and Blinn as base model for presenting their advancements in texture mapping and reflections. Improving techniques that extended Catmull's subdivision algorithm, they demonstrated that digital images could be generated, displaying greater realism combining simulated reflections with generated pattern and textures (Blinn & Newell, 1976).

The surfaces of NURBS objects are calculated by points called control vertices (CVs), and lines called isoparms. Isoparms are the boundaries of surface patches that define the 3D model. If more detail needs to be added to a particular patch, new isoparms need to be added across the entire model, as patches must be kept rectangular. This is a fundamental characteristic of the process when working with this type of geometry. Because this process can become difficult to manage when creating more complex objects, NURBS trimming attributes allows to cut and join different patches without constantly rebuilding them.

In figure 2, the image a) shows two primitives, a cylinder and a plane, that will be attached and stitched together. In images b) and c), the plane is segmented into nine different patches, by selecting and detaching intersecting isoparms, and deleting the middle patch. The cylinder is divided into four parts, and the new twelve patches are rebuild, matching the parametrization. Each part of the cylinder is re-attached to a matching patch belonging to the plane. Finally, in image d), all the patches are stitched together, for deformation to be possible when animating.

Smoothness can be created with a small number of control points that are resolution independent, meaning that the camera can move closer to the models and they will retain their curvature. Because patches are rectangular, applying texture maps is a straightforward process. Texture maps have X and Y coordinates, that can be matched by the U and V parameters of the 3D surface.

Figure 3 shows that, as an alternative to patch modeling, trimmed surfaces can be used. Here, projecting and intersecting curves on surfaces define new regions, *e.g.* holes can be created without matching parametrization. Fillets can then be used to create transitions, adding detail to patches independently of the topology. The trimming method is very flexible, but if the models are deformed the seams can become visible, and the computation needed to create these relations can become quite heavy, requiring adding more resolution and resulting in heavy tessellation. Also, once a detailed model is constructed by many surfaces, texture

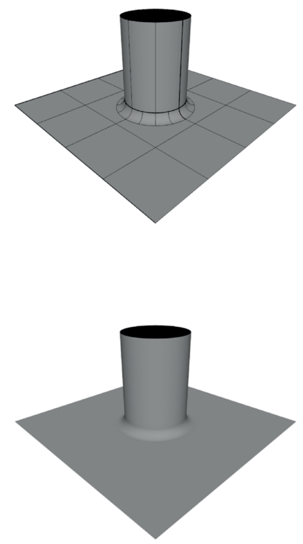


Figure 3 - NURBS cylinder and plane joined by the "Circular Fillet" tool.

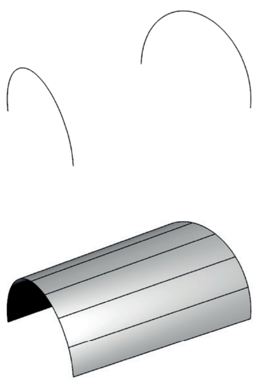


Figure 4 - Creating a surface for a roof tile, drawing two cubic curves that form the NURBS geometry through a "Loft" operation

mapping can become increasingly difficult, as UVs [6] cannot be edited separately from the mesh (Meade & Arima, 2007).

Seams are one of the largest issues, originating in the quad layout nature of the patches. To create more complex structures, individual patches are stitched together, which is often a time consuming process. Avoiding seams is crucial in animation, as they break the continuity of the model. Patch modeling solves the seams issue by creating continuous tessellation, matching the parameterization of different patches and stitching them together, so when control vertices move, they do it together. Despite this, the modeling process means constant rebuilding the U and V parameters of surfaces. As this matching is done manually, it results in the process being labor intensive.

NURBS were the main option for creating the characters and sets in Pixar until 1997, when they were replaced by subdivisions, that solved the concerns with seams and deformations, providing more freedom creating characters. (DeRose *et al.*, 1998).

> *"With NURBS, or B-splines, models are created with patches and as a model is animated, the patches often tear apart at the seams. Subdivision surfaces solve that problem and a second problem as well: With NURBS, adding detail in one place in a model often produces additional detail elsewhere. That doesn't happen with subdivision surfaces. This meant the animators could work in a facile way with surfaces that had complexity only in the areas useful for facial animation."* (Robertson, 1998:3)

In Computer Aided Design (CAD) applications, NURBS are the standard approach to constructing geometry, as they provide both precision and flexibility when working with solid models. Inside Maya, the possibility of using curves to form objects is one of the most relevant aspects for our research, as drawing tools can be introduced into the 3D workflow, connecting gesture directly to geometry. Using a drawing tablet connected to the computer to draw curves, allows for the design of shape and form, bringing artistic skills directly to the 3D environment. When two curves are connected, the number of CVs has to be considered, as well as the curving angle, so artifacts will not appear.

Figure 4 displays a roof tile generated by using the "Loft" tool to create a surface from the two curves. The patch can be edited by changing the surface's CVs, or the CV points from the original curves, that are still connected to the





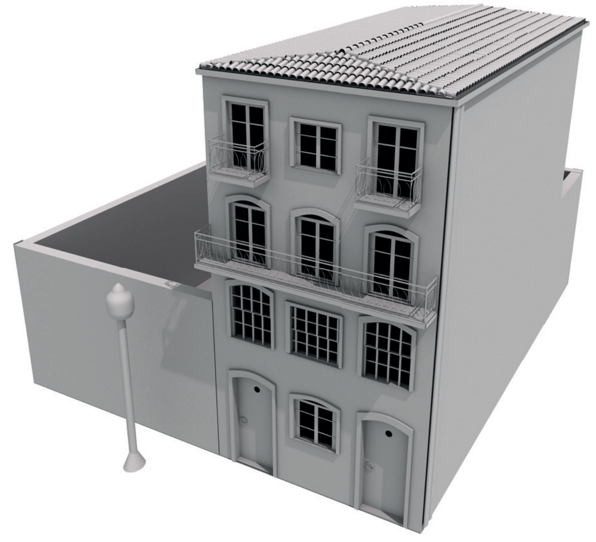


Figure 5 - Model of a house created using NURBS surfaces (2005)

surface after the operation.

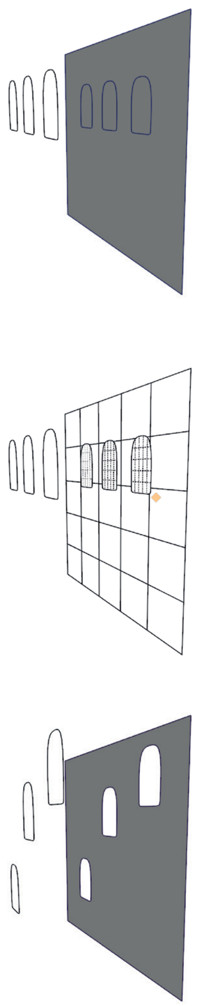
In figure 6, a single profile curve is revolved around a center vertical axis, generating the 3D model. NURBS can be equally used in the construction of flat surfaces, as trimming tools provide the option of cutting projected curves, without parametrizing patches, as is visible in figure 7.

With trimming operations, shapes can be extracted from surfaces, that result from the projection of curves on patches from a perpendicular view. Curves can create shapes when projected, making the design of forms closer to hand-drawing. This is a preferable approach to creating 3D models, instead of the approach of changing geometry attributes, such as position, rotation or scale.

Trimming allows for the opening of the windows to be drawn with curves, and to be cut off from the patch afterwards. In figure 7, curves are projected on a plane and shapes are cut-out. The cut-out projection tool is still active after the operation, providing interactive feedback when moving the position and shape of the original curves, updating the projection.

In Figure 5, the surfaces are created using both primitives and CV curves, as the latest are connected to form NURBS patches. For surfaces such as the walls, NURBS planes are used and curves are projected onto this surface to create the windows. For the roof tiles, "3 Cubic" CV curves are used for the bottom and top profiles, and connected using the "Loft" parameter to create the organic form. For the balconies, curves are also used to generate geometry. Here, a closed curve, *e.g.* a circle, can be transformed along another curve using the "Extrude" operation,

Figure 6 - Creating a surface for a lamp, creating a profile curve and using the "Revolve" tool



thus creating a pipe-like form. It is also possible to use a profile curve and revolve it around a center axis. This was the case for the lamp.

Going back to the Utah teapot, when interviewed by Matthew Piper for the Salt Lake Tribune in 2016, Newell recalls the reason he shared his teapot computer data with other researchers, was so they had a starting point when comparing researching results. But surprisingly, what happened was "the 1970's version of something going viral" (Piper, 2016). The model of the teapot became famous and is used until today in classes and rendering competitions all over the globe. Pixar's Renderman team distributes a limited edition of the "walking teapot" collectible at ACM SIGGRAPH conference every year.

The most relevant aspect about the 3D model of the teapot, is not so much its technical development, but the way it became such an icon of CG culture.

The rich iconography that is represented by its shape, distinguishes it from other 3D models created at the time. This status of icon grew as CG became a commercial medium, and embodied the convergence of two different cultures, the arts and sciences (Lehmann, 2012).

This is an important factor when balancing technical and creative aspects, working with CG animation. Tools such as NURBS may be developed for specific purposes, and using them may help creators achieve desired results. But ultimately, pictures are being created. And so is the potential of artistic expression, where the symbolism carried by the images will surpass the technical achievements. The technical advancements will be even more significant, once they are transformed into iconic pictures, that hold value in our culture.

## Polygons

Polygons, that are created of flat surfaces, are an alternative to NURBS. Composed of faces, edges and vertices, polygons do not display curved surfaces but offer much flexibility, providing the creation of arbitrary topology. They are the most commonly used geometry type [7] and can be constructed of triangles, quads (four sides) or n-gons (more than four sides). Faces can be easily modified by adding edges to them, or faces can be extruded, originating new geometry. Vertices can be merged and separated, or even added one-by-one when retopologizing a model [8].

Polygons fall short, comparatively to NURBS, in their capability of mapping textures onto the surface. UV coordinates in polygons are not unfolded

Figure 7 - Curves projected on plane. Trimming operation. Changing position cut out forms interactively.





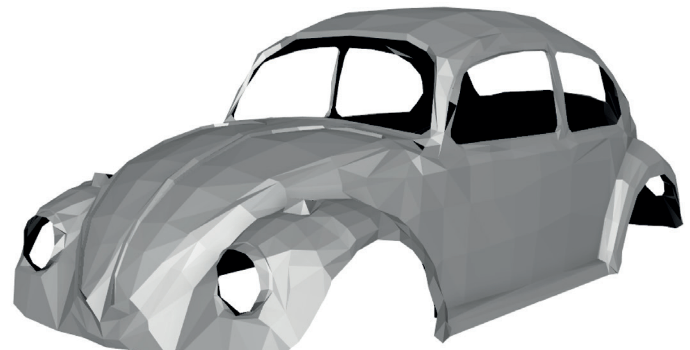


Figure 8 - Sutherland's Volkswagen Beetle, displayed in Maya's viewport [9]

in 2D space during the modeling process, thus have to be mapped after the model is constructed. Smoothness can be achieved by adding more polygons to a surface, however the geometry becomes more difficult to control. To work around this limitation, polygons can be converted to subdivisions, making them suitable for organic modeling.

Conversion between geometry types is possible, both NURBS and Polygons can be converted into Subdivisions. NURBS can also be converted into polygons, but not the other way around. Subdividing polygons may result in artifacts if the number of sides is not considered. For this reason n-gons and triangles are often avoided, quads being predominantly used.

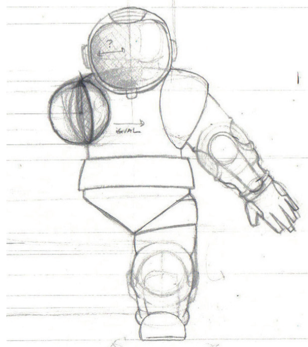
The 3D model of the Volkswagen Beatle is a famous benchmark in the early use of polygons. It was created in 1972, when Ivan Sutherland challenged his students at the University of Utah, to choose an iconic object to model, that would produce a realistic render [10]. Between these students were Jim Clark, Bus Tuong Phong and Robert McDermott, that borrowed Sutherland's wife's car, and painted X, Y, Z coordinates on the vehicle. The coordinates were entered manually into the computer, resulting in the final 3D model. But the process was not straightforward, as the measurements introduced some errors, making the different parts difficult to connect.

Dennis Ting, the computer department staffer who was able to assemble the final version of the model weeks after they started, concluded that the cost of human and computer time, exceeded the street value of the Volkswagen itself [11].

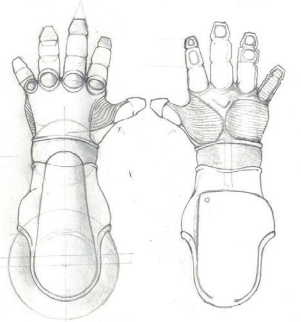
In the same year, at the University of Utah, Ed Catmull and Fred Parke created the film Halftone Animation (Catmull & Parke, 1972), that featured the

a)

b)



c)



d)

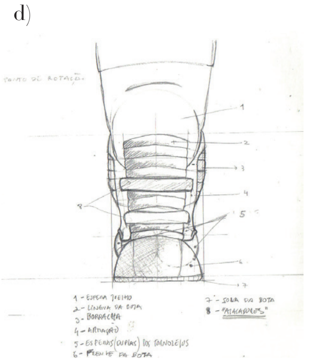


Figure 9 - 7200 Light-Years (Megre, 2007) - Concept sketches, a) Ricardo Megre b), c), d) Vitor Martins

sequences, "A Computer Animated Hand" and "Computer Animated Faces". Catmull created a model of his left hand using plaster, then drew coordinates on the model and digitized them. These coordinates were displayed on the computer as polygons, and animated by a 3D animation software written by Catmull (Price, 2008).

*"Just getting a look at his imagery was a task in itself. Because the display hardware never showed the entire image on screen at any one moment - it took thirty-seconds or so to cycle through the image - Catmull could see a frame of his work only by taking a long-exposure Polaroid of the screen and looking at the snapshot. Once he was satisfied, he then shot the footage using thirty-five-millimeter movie camera that the department had rigged to take pictures from a CRT screen." (Price, 2008:14).*

Catmull and and Parke's CG animation was later used in the film Futureworld (Heffron, 1976), becoming an important milestone in computer graphics history, and the beginning of wide spread usage of CG animation in sci-fi movies, in Hollywood.

Technology has come a long way since the 1970's, and it has being made significantly more accessible since the decades of 2000's, as computers became more capable of handling higher number of polygons and software became more developed.

For the construction of the main character in 7200 Light-Years (Megre, 2007), model sheets were drawn first, developing early exploratory sketches. This work was done in collaboration with Vitor Martins, who helped finding solutions for the design of the suit.

Figure 10 shows the evolution of the character's model. In images a), b) and c), using the designs from the model sheets, vertices were added on a side view, connected by edges as more points were added. The edges creating the profile were extruded, forming new faces. After the profile was defined, an eye ball was created using a NURBS sphere, representing the volume the eye socket would cover. Around the eye ball, a new set of faces forming a loop was created, forming the shape around the socket. The same procedure was used for the surrounding area of the mouth. The rest of the face was constructed afterwards, by connecting new polygons to the already existing ones.





This approach is based on a method by Jae-jin Choi for making a standard face. Although his process is very similar, Choi uses the character sheet only at the end, where the 3D model is adjusted to fit the image plane, where the sketch is mapped onto a texture (Choi, 2004).

Starting from the profile allows to ground the model on the original design and to work with symmetry. By adding additional edges, form is constructed at the same time that topology is defined. Using rings of polygons, called edge-loops, around the eyes and mouth, good deformation can be created when expressions are animated on the character.

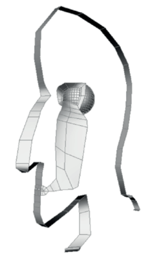
In figure 10, the images d) and e) show the original polygonal model, and the subdivided one, with additional geometry for hair and eyebrows. In image d), the polygon's properties are adjusted to display softer edges, providing continuous and smooth surface on the model. Afterwards, the mesh itself is subdivided, making the appearance of the silhouette smooth as well. Subdivisions make smoothing existing polygons possible, but make the modeling process of adding and editing polygons more difficult later.

This process of adapting topology to fit the character's design can be quite hard. As different designs require different topologies, they might require spending a long time moving vertices in space, and changing the flow of topology. This is more of a logical problem solving, like solving a puzzle, than a creative one, where one is trying to find a character in three-dimensional form. For this reason, iterating the design of the model in the computer is not a viable choice, when using 3D modeling. It is much easier to draw different sketches and explore possibilities outside the 3D software, and upon committing to a specific design, develop the model for animation.

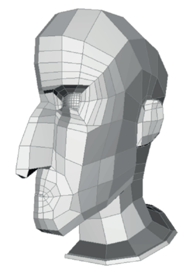
The suit was created by cutting and modifying planes, spheres and cylinders (figure 11). Round forms such as the knees, elbows and the helmet used polygonal sphere primitives as a starting point. Pieces such as the oxygen tanks, fingers or limbs used modified cylinders, where more edges were added and moved to define form and volume. The panels on the front of the suit started with planes, and selected faces were extruded inward, and scaled down forming the buttons and screens. The same process was also used for the belt, adding the three semi-round shapes. After all the detail was constructed, the surfaces were subdivided, resulting in a smooth 3D model that could be animated.

a)

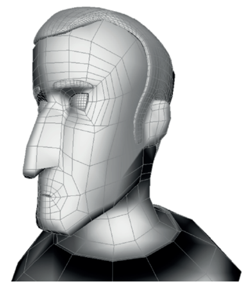
b)



c)



d)



e)

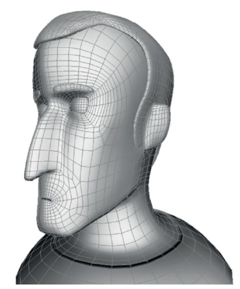


Figure 10 - Moss character polygonal model construction - 7200 Light-Years (2007)

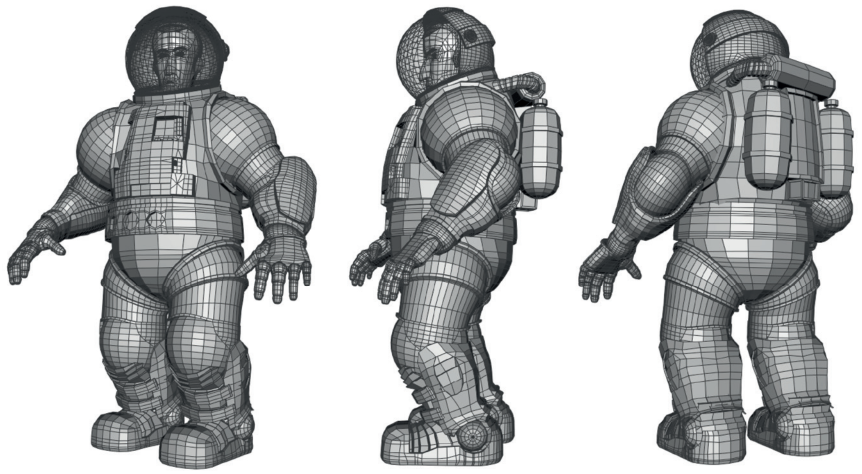


Figure 11 - Moss character full model using polygons

## Subdivisions

*"Twenty years ago the publication of the papers by Catmull and Clark and Doo and Sabin marked the beginning of subdivision for surface modeling. This year, another milestone occurred when subdivision hit the big screen in Pixar's short "Geri's Game", for which Pixar received an Academy award for "Best Animated Short Film"." (Zorin et al., 1999:11)*

Subdivisions can be used to model curved surfaces, similar to NURBS, but achieve smoothness by successive levels of refinement, according to particular subdivision rules. (Zorin *et al.*, 1999) In 1974, Ed Catmull made advancements in computer graphics by presenting a method of using subdivided patches, called sub-patches, to produce curved surfaces. In his PhD dissertation, Catmull demonstrated that along with being able to represent curved surfaces, his method also provided the possibility of mapping textures onto the surface (Catmull, 1974). He was able to produce several images using his method. In these images, spiral tubes, bottles and glasses showed smooth curved silhouettes, as well as patches and cylinders with textures mapped onto them.

Later in 1978, Ed Catmull and James Clark presented a subdivision method based on Catmull's patch subdivisions, that was able to recursively generate surfaces on arbitrary topologies, instead of the existing methods that relied on topological rectangles (Catmull & Clark, 1978).





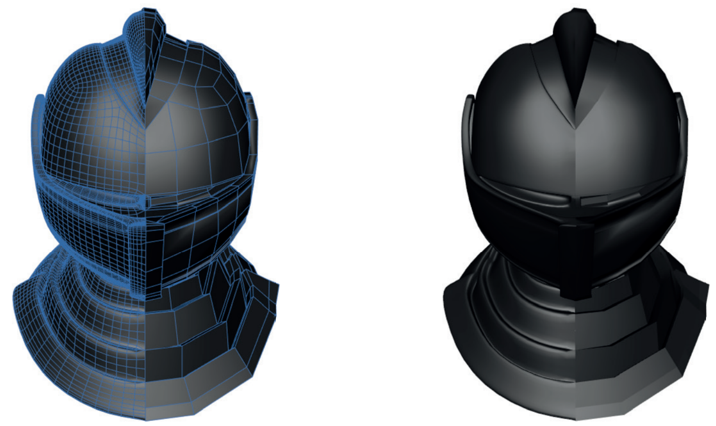


Figure 12 - Character from short-film Armor (Megre, 2007), displaying subdivision proxy modeling

Subdivision modeling is distinct from other geometry types, as it generates smooth geometry on arbitrary topology, *e.g.* surfaces with holes, which are refined using levels of detail (LOD). Changing the amount of detail is dependent on the level of subdivision. With this method, the original model becomes a control mesh, when edited, changes recursively the different LODs. The Catmull-Clark scheme produces cubic surfaces, being the minimum degree required by many other types of software, making this scheme favored comparatively to others. (McDonnell, 2000)

Catmull-Clark algorithm is a popular subdivisions scheme, used by studios like Pixar and available in most 3D applications, that allow for different levels of detail, as in each of them the surface progressively doubles the number of faces but also shrinks away from the its control mesh. In the example shown in figure 13, the original mesh is subdivided, losing the its volume but keeping its surface tessellation, making it easy to edit vertices or to change topology. In a) and b) it is possible to see the original cube being subdivided into two levels, functioning as control mesh for the subdivided mesh. In c) the control mesh is hidden and two extra levels of detail are added.

Regarding sharp edges, topological choices have to be implemented, such as inserting edge loops, in order to preserve sharpness in the model. As an alternative to this process, where too many edge loops may add unnecessary geometry to a model, subdivisions provide a creasing process to add sharpness to specific components.

In figure 14, images a) and b) display a polygonal plane being used as starting point, its vertices at the center are moved, forming an octagonal shape.

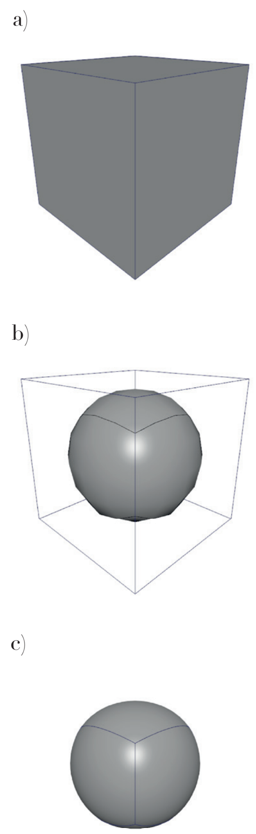



Figure 13 - Polygon cube subdvived four levels into a sphere

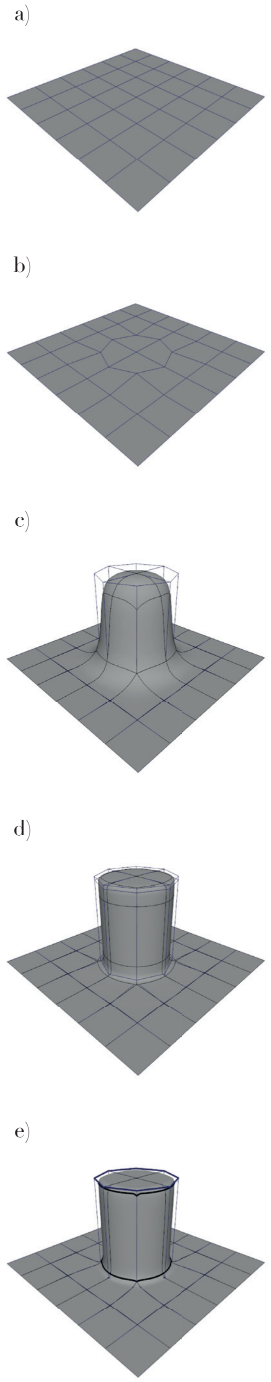



Figure 14 - Cylinder made from a plane using subdivisions, with sharp edges created by edge loops and crease sets

In image c), the faces contained in the shape are extruded forming new geometry. The images c) and d) display both the control mesh and the subdivided model, here two edge-loops are added next to the existing ones (on the top and at the bottom of the cylinder), causing the subdivided model to have sharp edges at the transitions. When edge-loops are added, they force the refinement to be sharper, as vertices are close together. In image e) a different method is implemented. Instead of adding more geometry to increase sharpness, a crease modifier is added, allowing to sharpen the existing edges by a chosen value, without adding any extra geometry.

Despite the technological advancements made in subdivisions in the 1970s, Pixar Animation Studios was still using NURBS to build their characters until the production of the short film Geri's Game (Pinkava, 1997), that opened for A Bug's Life (Lasseter, 1998) in theatres. In Geri's Game, Pixar was able to implement subdivisions for the first time. Using the algorithm to model the main character Geri, Pixar created its most advanced human at the time.

Modeling with subdivisions made it possible to add sharp edges within the character's smooth surface, describing sharp creases in the characters hands, such as finger nails, and maintaining smoothness when deformed in by animators. This was done without creating any seams, one of the larger restrictions imposed when using NURBS (DeRose *et al.*, 1998).

In the example shown in figure 12, subdivisions were used to create the 3D model, featuring arbitrary topology, smooth surfaces and sharp edges. Subdivisions can be implemented in a variety of ways, here, smooth proxy option was used. One of the options of the smooth proxy modifier, is to provide a symmetrical mirrored mesh, displaying half of the surface subdivided and granting real-time control over the design.

Contrary to the previous example displayed in figures 10 and 11, where subdivisions were used only at the end of the modeling process, changing the actual tessellation of the surface, here the model is subdivided through its construction phase, maintaining the current tessellation as a control mesh, offering more flexibility for experimentation. This is an important point, as digital processes aim to be comparable to physical ones, such as drawing or sculpting. Interactivity is an essential requirement for testing out new ideas, and explore creative options.

Despite the advantages, the process of using smoothed proxies is not flawless, or particularly easy to use. Editing half the mesh without seeing the whole smoothed model, can be in part counterintuitive and can represent an impediment





to interaction. Smooth proxy also features the possibility of displaying both the original polygonal surface and the smoothed surface juxtaposed, but displaying both meshes can cause visual interference and difficulty in distinguishing forms. The smooth proxy process can sometimes break, if a topological problem occurs that ceases the proxy mesh to work correctly. In this case, the smoothed proxy has to be deleted and a new one created, hindering the creative progress. Another drawback using smooth proxy, is that only control meshes can be modified. The smooth mesh cannot be edited, only displayed dependently of the low resolution model.

In 2008, Maya was released with the new implementation of subdivisions, called smooth mesh preview [12]. The advantage of this application, is that polygons can be displayed as smoothed surfaces interactively, without the need of using proxy models. In this way, polygons can be subdivided instantly using hotkeys on the keyboard, allowing to see the end result instantly. The display can be set back to the original polygons, or to the control mesh mode, where both surfaces are displayed overlaid.

The smooth mesh preview process, is only displaying the subdivided control mesh using the graphics card, keeping the topology of the model without actually smoothing it. If the model is exported to a different software, the subdivisions will not be present, unless the tessellation is changed as well.

Figure 15 shows the 3D model of Ezra using subdivisions, the main character in the short-film Hourglass (Megre, 2008). The amount of geometry is fairly small, and still, it is able to produce smooth surfaces. Comparatively to the Moss character which was constructed with polygons and had subdivisions applied to display a smooth result at the end, Ezra was created displaying the final smooth look from the beginning. Creating facial expressions was a much more interactive experience, having the possibility to work with subdivisions.

The default subdivisions algorithm to smooth a polygon model until 2014 version was Maya Catmull-Clarck. Since the 2015 version, Pixar's OpenSubdiv algorithm has been introduced, offering adaptive subdivisions that take into consideration the model's distance from the camera, topology and frame rates [13].

Pixar's OpenSubdiv, an open source implementation of subdivisions, optimizes the use of the control mesh for the final volume of detail, and keeps the previous slow subdivision process, at fast and interactive framerates, designed to take advantage of parallel GPU and CPU architectures. This is an alternative to

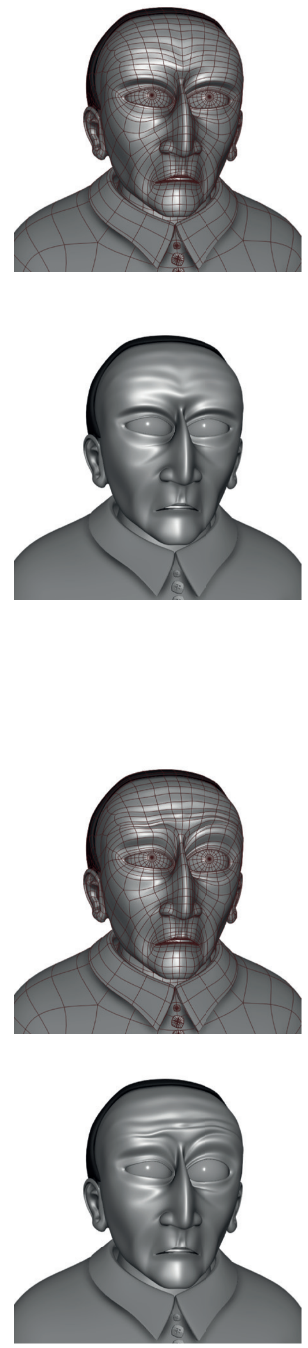


Figure 15 - Ezra character model construction and facial expressions using subdivisions smooth mesh preview- Hourglass (Megre, 2008)

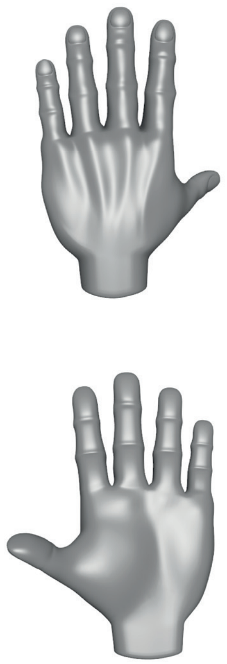


Figure 16 - Ezra's hands modeled with subdivisions smooth mesh preview

Catmull-Clarck scheme where, for example, sculpted details created in a different software, could only be seen through displacement maps, at render time. Instead, OpendSubdiv provides real-time feedback of subdivisions, even using displacement maps [14].

Progression of technology is crucial for artists to have the possibility of expressing their ideas. When technology is underdeveloped, it can hinder the creative process. The evolution of the tools can provide a means to achieve greater realism, as it becomes possible to create more complex objects with the computer. As NURBS offers the opportunity to represent curved surfaces, objects that were smooth in reality, such as the teapot, present themselves as contestants to be depicted digitally. Thus, these achievements carry with themselves the symbolism of human progress and evolution.

Today, there are alternative methods and technologies to choose from, as patch modeling with NURBS can be difficult. When using polygons and subdivisions, artists can perform the same tasks much quicker. Techniques are developed to improve on existing limitations, offering new solutions. Despite this, combining existing technologies with different and alternative methods supports experimentation, and this can give birth to new artistic ideas.

Technological limitation can be a creative impediment, as NURBS were a constraint in deforming 3D models, in the early days of CG animation. But artistic expression is not dependable on just the tools, as the tools themselves can be subverted or used for different purposes, if they inspire or foster creativity. The technical skills that artists develop, working with specific methods, should accommodate for the necessities of the projects and help in them with the creative process. Surely, it is easy to understand that technology allows for certain imagery to be created, but tools are nothing without the handling of the artists, that carry the vision of what is to be created. It is a matter of how one chooses to use them. They can be used beyond the purpose they were made, as long as they work for the creative process, and not against it.

In the example of the 3D house, displayed in figure 5, NURBS were used to build all the geometry, although there are not many curved surfaces.  In this case, trimmed surfaces offered the possibility for the opening of windows and doors, without creating specifying topology for that. This interactive method nurtured experimentation, which is fundamental in artistic practice.

Alex Nijmeh, head of workflow at Walt Disney Animation Studios, and Christopher Nichols, the author of the CG Garage podcast, recall in conversation





Figure 17 - Frame from HourGlass (Megre, 2008)

working with Eric Hanson a veteran CG artist, that worked on the 3D models of cityscapes for The Fifth Element (Besson, 1997). Nijmeh comments that, as Hanson introduced Maya in their studio, he started teaching everyone how to use NURBS. Nichols replied that, although NURBS were not necessarily the future, Hanson was still using them exclusively. (Nichols, 2020). Nijmeh adds,

*"He was holding onto it and we were all working in polys and getting into a subD world. He's like, "NURBS dude. That's going to get you there." But we did a lot. He built an entire city out of NURBS." (Nichols, 2020).*

In a previous interview for the CG Garage podcast in 2015, Chris Nichols speaks directly with Eric Hanson about his preference of using NURBS for modeling. Hanson points out that it was his particular capability of producing highly detailed models with NURBS that got him noticed by the company Digital Domain, where we went to create cityscapes for The Fifth Element. As geometry types can be converted onto each other and NURBS commands can output their result in polygons, Nichols and Hanson note that the tools are just a vehicle to a goal (Nichols, 2015).

The motivation for the groups of artists working with digital tools, is to be able to create something that has never been seen before, something new. And that is the link that bonds artists working in the CG industry, to break new ground and develop something that did not exist until they created it. (Nichols, 2015).

## End Notes

[1] Utah Teapot model in Wavefront format (Obj), downloaded from Utah teapot page on Wikipedia: “https://en.wikipedia.org/wiki/Utah_teapot#OBJ_Conversion” (last accessed 15/04/2020).

[2] NURBS stand for Non-uniform rational B-splines.

[3] RenderMan online documentation, regarding NURBS geometry: https://rmanwiki.pixar.com/display/REN/NURBS (last accessed 15/04/2020).

[4] Utah Teapot webpage, at the University of Utah - Computer Graphics website: “https://graphics.cs.utah.edu/history/utah_teapot.php” (last accessed 15/04/2020).

[5] Martin Newell tells the story of the Teapot, at honoring event to Ivan Sutherland. “VR@50: Reception Honoring Ivan Sutherland”, at ACMSIGGRAPH (2018) YouTube channel: https://youtu.be/VktqJ5I9aKY?t=3739 (last accessed 15/04/2020).

[6] UVs and texture mapping explained in more detail in chapter 2.5. Rendering (page 130).

[7] More information on geometry type of polygons can be found on RenderMan’s online documentation: https://rmanwiki.pixar.com/display/REN/Polygons (last accessed 15/04/2020).

[8] - Retopology techniques addressed in chapter 2.3. Digital Sculpting (page 92).

[9] Volswagen Beetle model in Wavefront format (Obj), downloaded from Wikipedia:
https://en.wikipedia.org/wiki/Sutherland%27s_Volkswagen (last accessed 15/04/2020).

[10] [11] Robert McDermott recollects his graduate first graduate year, as Sutherland student, on the University of Utah’s website: https://www.cs.utah.edu/docs/misc/Uteapot03.pdf (last accessed 15/04/2020).

[12] Subdivisions with smooth mesh preview among other features in Maya 2008, reviewed by Galpern (2008) on Animation World Network website: https://www.awn.com/vfxworld/maya-2008-review-workflow-key (last accessed 15/04/2020).

[13] More information on Subdivion Surfaces using OpenSubdiv can be found on RenderMan’s website: https://graphics.pixar.com/opensubdiv/docs/subdivision_surfaces.html (last accessed 15/04/2020).

[14] Displacement maps covered in chapter 2.5. Rendering (page 138).

# 2.3. Digital Sculpting

Before digital sculpting started to be used in 3D animated productions, digital modeling was more of a technical field than a creative one. This did not meant that modeling was not a creative endeavor. But it was mostly used as a tool to create digital versions of real existing *maquette*s and clay sculptures.

From an historic perspective, objects were digitized to create virtual models, from the Utah teapot to Catmull's hand. Not surprisingly, many animated characters were also created physically first, before being built on the computer. For some of the characters in Toy Story (Lasseter, 1994), physical clay sculptures were created and digitized using a magnetic field digitizing table (Villemin *et al.*, 2015).

At Pixar, digital modelers used the digitized data, together with drawings and illustrations, to translate the designs to virtual models, using software such as Maya or their proprietary program Marionette (Henne *et al.*, 1996).

For one of Pixar's first films, Luxo Jr. (Lasseter, 1986), the 3D models for characters were constructed using Bill Reeves's software called Model Editor (ME). John Lasseter and the group creating the film did not have an interactive software where they could design 3D models. Instead, they had to measure a real lamp and use a programming modeling language to enter the data into the computer (Price, 2008).

> *"Lasseter would type lines of code using a text-editing program to define the way the object was put together, save them in a computer file, and then watch ME draw a wire-frame version of the object. If it didn't look right, he would have to go back, try to fix the file, and repeat the cycle." (Price, 2008:68).*

A decade later, even with the introduction of interactive software and with the implementation of subdivisions, 3D modeling was still mostly a technical tool. Jan Pinkava, the director of Geri's Game, worked on development of the main character with traditional media, with the collaboration of the sculptor Jerome Ranft who created Geri's *maquette* in clay, based on Pinkava's drawings.

Figure 1 - Untitled bust (2019) - digitally sculpted in Zbrush, rendered in Maya using RenderMan

Figure 2 - Drummer (2018): Concept art and base mesh for character

The sculpture was later digitized and used as the base for the digital character (Failes, 2017).

3D modeling, either using polygons, NURBS or subdivisions, was not the most organic process for creating characters, even when the technology advanced significantly. From entering code on the computer to create Pixar's mascot, in the original Luxo Jr., to the advances made possible with subdivisions in Geri's Game and A Bug's Life (Lasseter, 1998), most of the creative process when building characters was still being made outside the digital medium. That would change with the introduction of digital sculpting.

## Sculpting with Subdivisions

In 1999, a company called Pixologic presented a demo for its software ZBrush, at SIGGRAPH '99 conference [1], releasing the commercial version to the public in 2000. Initially, the program was developed mainly as a 3D painting software, although it was improved with sculpting capabilities, implementing subdivision surfaces in 2004. This implementation allows to sculpt while storing subdivision history, using levels of detail (LOD) [2]. This frees up digital artists to move back and forth between LODs and work on a 3D model organically, by sculpting objects with millions of polygons [3].

Using a drawing tablet, artists can use the multi-resolution subdivisions, combined with digital sculpting tools to sculpt directly on the computer. These tools aim to mimic the feel of real sculpting tools, surpassing other modeling techniques, that can be rather technical and difficult to work with.

Sculpting organic forms directly inside the computer, represents an important breakthrough for digital artists. Using different LODs to interact with the resolution of the model, benefits the creative side and manages computer resources. Comparatively, in real life a sculpture can be refined from general forms to details, but it is not possible to go back to different levels and change them. For example, to change the size of a finished arm, the detail is lost when adding or subtracting more clay. In ZBrush, a specific coarser LOD can be modified in scale, and the detail is preserved in the finer levels.

Other aspects, such as automatic symmetry, or undos, are large advantages the digital medium carries in contrast to traditional clay sculpting. This supports experimentation, analogously to the previous 3D modeling approaches, making the digital art form progress into uncharted territories.

Describing his creative process, CG artist Marco Menco starts a model by





creating a base mesh. This mesh is then imported into ZBrush, where Menco starts to experiment using the software as a sketch pad. This process frees up the artist to experiment different designs (Digital Art Masters: Volume 2, 2007).

In figure 2, a similar process is represented. Simple polygonal cubes were used to block the overall form of the character, based on a previous sketch that was imported to Maya as an image plane. With a box modeling approach, the cubes were used to describe the general forms, namely the head, torso and limbs. Starting with simple polygonal shapes, the main proportions were characterized, defining hight, width and length, and the rotation of the blocks indicated the balance of the figure. When subdividing later on, detail could be added with sculpting tools.

After the boxes were transformed to represent the main shapes, such as the torso, arms, hands, head, legs and feet, they were merged forming larger structures. In this case, the head and arms, were attached to the torso, the legs and feet were kept separately. Within the connections, new polygons were created to ensure the transitions. The smooth preview in Maya, allowed to anticipate how much geometry needed to be added, and where the creases needed to exist, *e.g.* the fingertips should keep sharp edges, to create boxy/cylindrical forms for the fingers. Displayed as subdivisions, the forms presented the final volume the mesh would have once more levels were added in ZBrush.

When importing the model to ZBrush, multi-resolution was used to subdivide the model. The LOD was used to sketch the features, at the higher subdivision, and the blocking of the main planes could be created at a coarser level. In figure 3, the character was subdivided and sculpted, firstly the main features were sketched with sharp clay tools, as the "Dam_Standard", providing the freedom to find the character in three-dimensions, through trial and error. Once the character was established, digital clay was added and subtracted using brushes like the "Clay" tool, "Clay Tubes" or "Clay Buildup" to create general forms for the eyes, ears, mouth and nose. These brushes have some texture to them, giving a sensorial feel to the model and help defining it (more clearly visible in figure 1).

Finally, detail was added by polishing the model's roughness, using "Trim Dynamic" and "Smooth" tools, averaging the vertices, establishing smaller planes and smoothing the surface. The Dam_Standard was used at this time to carve finer elements, like the wrinkles under the eyes or the eye-brows.

When the final sculpt of the head was finished it was imported back into Maya. The highest LOD had half-million polygons, comparatively to the original 40 polygonal faces (visible in figure 2). Animating this many polygons is

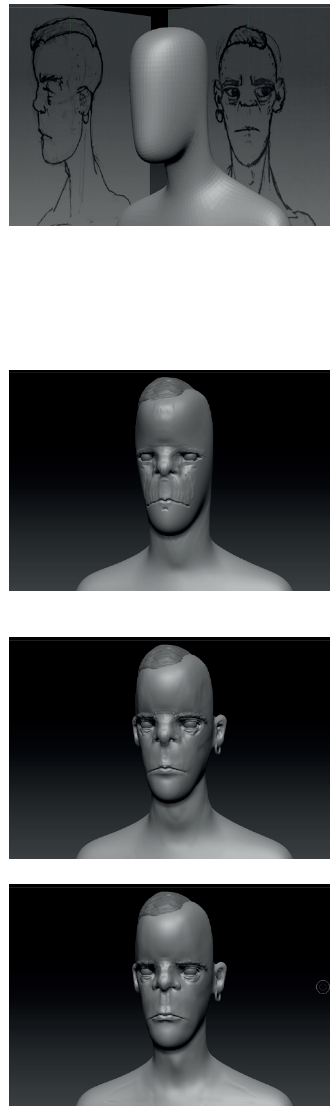


Figure 3 - Drumma (2019): Character sculpting process using subdivisions

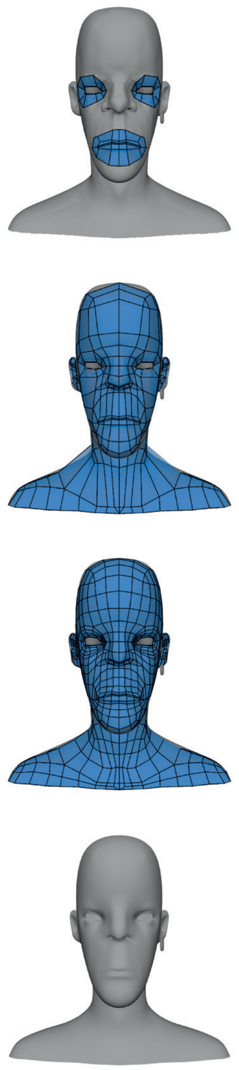


Figure 4 - Character re-topology process, creating a new topology for animation

impractical, as the mesh is difficult for the computer to calculate, and too dense for artists and technical directors to manipulate, rig and animate. To overcome this, the details can be mapped through textures, *e.g.* normal, bump and displacement maps, that display the sculpted elements [4]. Still, correct topology needs to be created for animation.

## Topology

In order to create models for animation, mapping the details through textures is not enough. A good construction of topology is also necessary, and it is essential for correct deformation. Character artist Daniel Peteuil defines topology as a "clean edge flow that will describe both form and movement" (Anatomy for 3D Artists: The Essential Guide for CG Professionals, 2015). In the chapter of "Retopologizing", Peteuil specifies that the quality and realism of the characters in motion depend on the pattern of polygons. When created in a static pose, the models can have more of an arbitrary topology, that if subdivided, will still capture correct anatomical detail. But if that mesh is deformed without proper topology, it will not look convincing and will not be able to display correct articulation.

As follows, when creating animation, later on the pipeline, not all the base meshes will deform the same way. For the Drummer character, the bending of the torso, arms or legs, will require different topology from the head, that needs to support facial expressions. In this sense, the torso, arms, hands and legs, mostly kept the topology of the boxes after being sculpted, but the head had to be re-topologized.

This sculpting method prioritizes building the structure from large forms to details in a fast way, but without too much consideration for animation requirements. The goal is to define a character quickly and with room for experimentation. This approach is contrary to the previous ones presented in the 3D Modeling chapter, where topology is prioritized when using polygons and subdivisions (through smooth mesh display), using the edge-loop procedure.

Because this character was constructed for animation, re-topology techniques for its head needed to be applied, after the digital sculpture was finished. Although it may seem a complicated way to go about it, this frees up digital artists to worry about aesthetic issues, like designing shapes, form and structure first, and later define the technical aspects of the character, like the flow of the topology.

Displayed in figure 4, is the construction of a substitute mesh for the characters head. This new low resolution model has a better performance for animation, and the sculpted details were projected onto its surface and displayed using texture maps. Here the sculpted mesh was set to "live" mode in Maya, functioning as an attractive





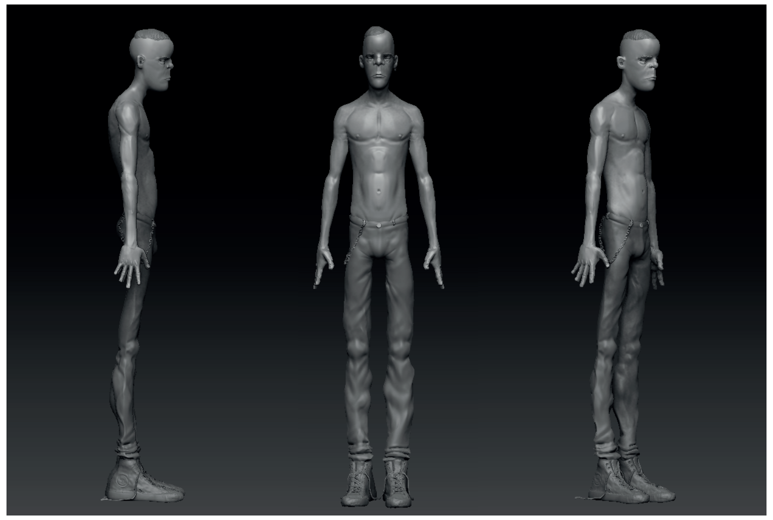


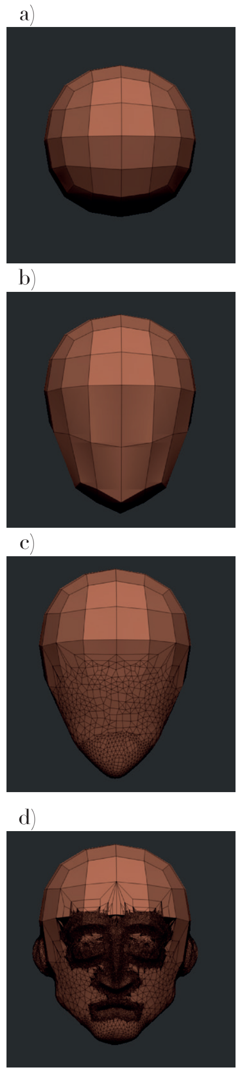
Figure 5 - Final sculpted model, featuring subdivisions, manual and auto re-topology

magnet, permitting new vertices to be added to the surface, with the "Quad Draw" tool. As the points were connected to form new faces, a new mesh covered the digital sculpture's surface. The flow of the edge loops around the eyes and mouth was designed to deform as the muscles of the face would [5].

Following the morphology of the muscles facilitates the creation of expressions, opening and closing the eyes and the mouth. The new mesh now had around 14000 polygons, in contrast to the half-million of the sculpted version. On the other hand, the new model has lost the detail drawn by the high resolution mesh. To recover it, the new topology is sent back to ZBrush, subdivided, and the details transferred between the two models with a projection. Thus, the final model will keep both the sculpted information (displayed through textures) and correct topology to deform well.

Besides manual re-topology, automatic algorithms exist in ZBrush, such as "ZRemesher" that provide new topology with a certain pre-determined resolution. Additionally, guides can be drawn on the model, guiding the flow of the mesh. Depending on the intention, this method presents good enough results for characters that do not feature a lot of expression, or for parts of the body where deformation is straight forward. But for greater control, defining the topology manually will produce the best results.

Digital artists working on Rango (Verbinski, 2011) took a novel approach in creating the characters for the film. Using ZBrush, 3D artists at Industrial Light and Magic (ILM) were able to produce quick digital sculpts based on the artwork developed by the production designer Crash McCreery. The team was able to produce each character's digital *maquette* in just three days, bringing the creative process




into the computer. After approval, the models were used to develop 3D assets for animation, adding to the characters correct topology, rigs, fur, hair, paint, wardrobe and facial libraries. (Pixologic, 2011).

This approach represents a paradigm shift, as producing 3D models in the computer becomes feasible, due to the fast and organic interaction with the software. Interviewed in 2011, the production model supervisor Geoff Campbell talks about the quick process of producing ZBrush *maquette*s at the beginning of digital modeling, without adding more time to the production timeline:

> *"Mia Lee was the first to throw together a maquette with textures that she did it in three days, yet with such accuracy that production in LA thought it was a finished model ready for shots. Everyone did an amazing job keeping to the three-day schedule and knocking out exquisite maquettes. It would have been a tremendous challenge had we not had ZBrush because you needed to work sculpturally without concerning yourself with topology, and the tool set in ZBrush was perfect for this work." (Pixologic, 2011).*

Campbell explains that, by adding the digital *maquette* at the beginning of the modeling process, planned schedule was actually reduced by weeks. As the client was able to see and approve the model beforehand, 3D artists and technical directors could then finish the model. The main characters, Rango and Beans, were particular cases as they required more time for development. Still, for those characters, Campbell went numerous times to Los Angeles to sit with the client, and there he would produce quick ZBrush sculptures based on their drawings (Pixologic, 2011).

Rango went on to receive the Oscar for Best Animated Feature Film in 2012, and the creator of ZBrush, Ofer Alon was awarded a Scientific and Technical Achievement Academy Award, for the design and implementation of ZBrush, for multi-resolution sculpting of digital models.

## Dynamic Topology

ZBrush features such as "Dynamesh" and "Sculptris Pro", provide dynamic topology (dynamic tessellation) making it possible to turn a simple primitive, like a cube or a sphere, into a complex model, turning geometry into "infinite" clay.

In the example shown in figure 6, a simple sphere was used initially, and new geometry was added by pushing faces and activating dynamic topology. In this case

Figure 6 - Dynamic topology using "Sculptis Pro" in ZBrush





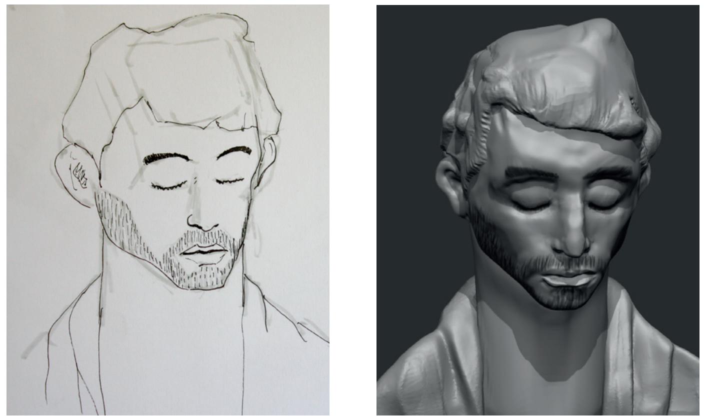


Figure 7 - Untitled bust (2020); Drawing from live model and digital sculpt.

the option "Sculptris Pro" in ZBrush was activated, transforming the sculpting tools into dynamic tools. Instead of just sculpting existing polygons, the tools can now add more geometry providing new surfaces where needed, interactively and in real-time.

In figure 6, the images a) and b) show a sphere being stretched, using the "Move brush", without the dynamic option turned on. From this point on, the model could be subdivided, using multi-resolution, and detail could be added into the finer levels of detail. The issue with that approach is that the distribution of the polygonal faces is not even, once the geometry is stretched as it moves away from the initial sphere. Consequently, the subdivision method creates uneven surfaces that will not be able to represent details uniformly. The images c) and d) display new geometry that was created when "Sculptris Pro" was turned on. Here, the previous stretched polygons were turned into new topology, and detail could be added where needed, without any consideration for manually controlling the topology.

For the purpose of demonstration, the wireframe of the model was displayed, although it was not present through the sculpting process, making this process invisible. This method, despite being a fast approach to creating shape and form, without creating base meshes first, is not compatible with subdivisions. It is possible to replace the creation of base meshes with this method, but re-topology methods still need to be implemented, if the model is designed for animation.

In Figure 6, it is possible to observe the density of the mesh, created by this method. To simplify the topology, a new dynamic method called "Dynamesh", is applied - visible in figure 8 b). This method re-topologizes the mesh, using only quads, and provides a simple and uniform topology that can now be subdivided. "Dynamesh" is the predecessor of "Sculptris Pro", discarding the requirement for base meshes, facilitating the early stages of sculpting. Although a useful tool, "Dynamesh" does not work in real time, the algorithm converts existing geometry into a new

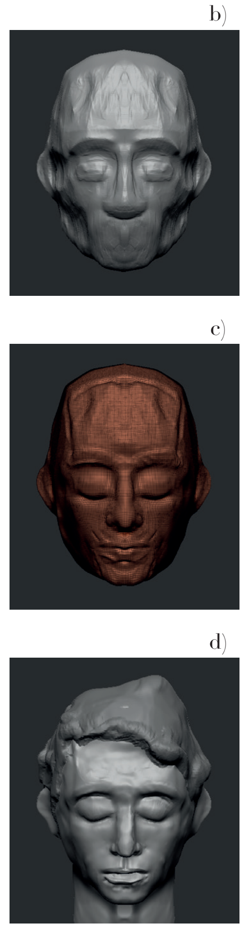



Figure 8
Dynamic topology using "Dynamesh" in ZBrush

Figure 9 - Study of a skull (2017) - Digital sculpting in ZBrush, rendered in Maya using RenderMan

uniformly distributed topology, with an assigned resolution.

Before software like ZBrush or Mudbox existed, modeling a human figure was a very mechanical process, vertices had to be moved individually, in a slow and tedious manner. There are ways of accelerating the workflow, using tools to modify groups of vertices instead, moving and adjusting the volume of the figure. However, the process does not resemble natural sculpting techniques at all. The renowned digital sculptor and author Ryan Kingsley, previously Chief Creative Officer for ZBrush, distinguishes the modeling processes from digital sculpting, with the following analogy: when traditionally creating a physical sculpture, artists do not produce the sculpture and the mold simultaneously. 3D modeling's largest creative constraint, is that the topology of the surface has to be produced together with its form. That is a time consuming and an unproductive way to create art (Kingsley, 2004).

Kingsley points out that technology and artistic ability are the two core concerns when creating realistic characters. If around 2005 technology was the main issue, around 2011 artistic ability is the largest concern, for character creation (Kingsley, 2011). Kingsley adds:

> *"The demand for realism increases with technological advances. Today, it is your ability to sculpt a face, but in two years' time realism may depend on understanding what happens to palpebral ligament when your character is frightened." (Kingsley, 2011:1).*

Today, there are many applications that provide tools for digital sculpting, as a growing search for this medium exists, from artists that want digital clay, such as traditional sculptors like Rick Baker, a multi Academy Award winner. Films such as The Lord of the Rings trilogy (Jackson, 2001-2003) and King Kong (Jackson, 2005), use digital sculpting extensively in their art departments, helping to close the gap between concept and production (Plantec, 2005).





Geoff Campbell interviewed by Bill Desowitz, regarding ILM's implementation of ZBrush in their pipeline, expresses that the program triggered a "renaissance in Sculpture", giving more freedom to 3D artists and surpassing the productivity when using traditional clay *maquette*s (Desowitz, 2005).

Digital sculpting frees up artists from technical considerations and opens up space in the creative process for greater freedom of expression. Because the process is more interactive, it establishes the opportunity to either do more iterations on a model, or to do anatomy studies, or even investigate the limits of the art form, without the constraints that come from constantly thinking about topology. Figure 9 shows a study of a skull, created from photographic references. Here, dynamic topology is used to sketch the main features, adjust proportions and sculpt details. Being in a digital medium, one can easily create copies of the model, and rotate them, displaying it from different angles.

Using digital sculpting to sculpt from life models, is another possibility. Untitled Bust (2020) in figure 7, displays a model built from a drawing done during a live model session. Female Study (2018) in figure 10, was created directly from a life model, in a long pose session. Here, digital sculpting was used during the session, creating the model directly in the computer.

The session was part of a traditional sculpting class, "Modeling and Molding", taught by Prof. Rui Ferro, at the Faculty of Fine Arts, University of Porto. Although the class features traditional sculpting in clay, guests were brought in to experiment with the digital medium as well. ZBrush was used with dynamic topology, to quickly lay down proportions, angles of the body and to start to sculpt the main features. Additional work and rendering were done later after the session. The result highlights the potential of expression from modern digital tools, and how far technology has evolved, providing interactivity for artistic practice.

The future of the medium may feature smaller devices, such as digital tablets, as different sculpting applications exist today. For instance, Forger and Sculptura 3D, are programs for digital sculpting that free up the medium from computers, and support mobility. Other options, as Wacom tablets, provide a full operating system supporting more robust sculpting software, and still benefit the portability. Sculpting from life, is just one of the possibilities that digital artists may take advantage of, comparatively to artists a decade before. New expressive and artistic styles may carry contemporary artistic values and ideas, as digital sculpting symbolizes a change and evolution of the digital medium. Most certainly, the advancements and future of the art form will feature more artistic innovation, than technological advancements.

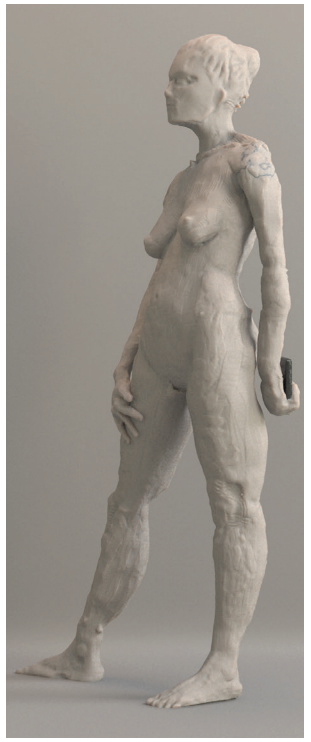


Figure 10 - Female figure (2018) - digital study from live model - Digital sculpting in ZBrush, rendered in Maya using RenderMan

## End Notes

[1] Review of ZBrush from reprinted issue of Design Graphics Magazine on Pixlogic's website: http://pixologic.com/news/archives/pdf/designgraphics2000.pdf (last accessed 12/05/2020).

[2] - Subdivisions and LODs reviewed in Computer Arts issue, published on Pixologic's website:
http://pixologic.com/news/archives/pdf/computerartsmag2004.pdf (last accessed 12/05/2020).

[3] - More information can be found on ZBrush online user guide: http://docs.pixologic.com/user-guide/3d-modeling/modeling-basics/subdivision-levels/#controls (last accessed 12/05/2020).

[4] - This process will be covered in more depth, in chapter 2.5. Rendering (page 138).

[5] - Flow of topology and retopology techniques by Southern (2019) on Creative Bloq: https://www.creativebloq.com/how-to/3-essential-zbrush-retopology-techniques (last accessed 12/05/2020).

# 2.4. 3D Animation

*"On display in Luxo Jr. was a further insight, Lasseter's stroke of genius: that inanimate objects as characters held the potential for dramatic value. If the animator understood and applied the animation principles of Disney's Nine Old Men, objects would engross audiences with their emotions; they could appear, indeed, more human than humans." (Price, 2008:92).*

In the first half of the 20th century, before computers came along, Disney's artists played a central role in defining the art form of animation, as we know it today. As animation developed during the 20th century in different parts of the world, a diversity of existing styles and techniques emerged, from Stop-motion to Pixilation, from traditional media such as clay, sand, or paint, to hand-drawn cell animation. Despite the multiplicity of the field, animation produced in Disney Animation Studios became one of the more influential styles for the development of computer animation.

As it developed, CG eventually transformed Disney Studios, firstly with the acquisition of Pixar in 2006, and later with the production of 3D animated films, such as Chicken Little (Dindal, 2005), Bolt (Williams & Howard, 2008) and (Greno & Howard, Tangled 2010).

Among the early Disney animators were the "Nine Old Men": Les Clark, Marc Davis, Ollie Johnston, Milt Kahl, Ward Kimball, Eric Larson, John Lounsberry, Wolfgang Reitherman and Frank Thomas. This group of animators helped to define the possibilities within the visual languages of animation. They developed novel techniques together with outstanding performances, for characters in Snow White and the Seven Dwarfs (Hand, 1937), Pinocchio (Sharpsteen & Luske, 1940), Dumbo (Sharpsteen, 1941), Bambi (Hand, 1942), Cinderella (Jackson *et al.*, 1950) and many others. After retiring, two of these men, Frank Thomas and Ollie Johnston, wrote the influential book The Illusion of Life (Thomas & Johnston, 1981), where many of the ideas behind the creation of Disney's films are present.

One of Disney's largest achievements, was to evolve animation from short

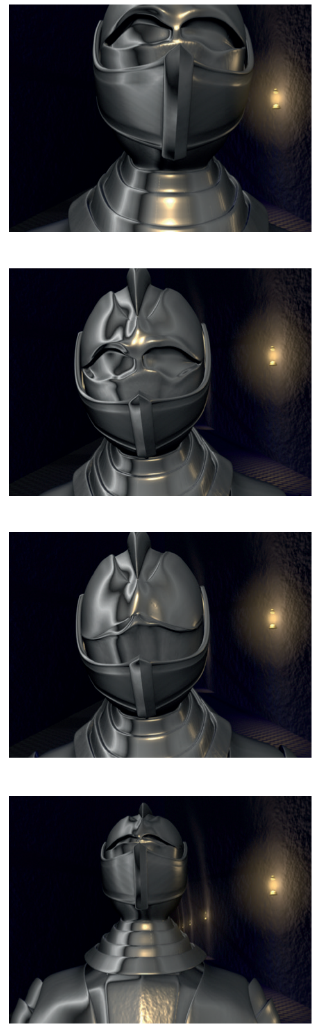


Figure 1 - Frames from Armor (Megre, 2007) - character's reaction as he steps on a sharp nail

cartoons into the feature-length format. In the early 20th century, animation was referred to as cartoons, where comic strip-like drawings were brought to life on the big-screen, usually before the main event, a live-action film. Disney changed this notion by making the first feature-length animated film.

Although this was an important distinction in how the art form was perceived, what really made a difference was how the characters were animated. Disney's films were about character animation and how audiences believed in these characters. Tracing the evolution of the studio means tracing the evolution of the animated characters, not only the studio or the animators that were part of it (Thomas & Johnston, 1981).

Thomas and Johnston explain that, in order to develop a character, Disney animators had to develop an interesting personality as well. And the way they went about it, so the audience could empathize with their creations, was through adversity. Feeling the emotions of the characters is what holds the attention of the audience, and caring about what happens to these characters is what makes the illusion true (Thomas & Johnston, 1981).

Figure 1 and 2 show excerpts of Armor (Megre, 2007), a short film where the main character repeatedly fails in his efforts to display strength. The film plays with having the character fall short on his attempts to present power and vigor, exposing his true personality. The misfortune the Armor goes through, helps both in the delivery of his emotions and the character's arc through the story.

The film also plays on the concept of giving life to characters, and the possibilities within animation, in opposition to live-action. An empty armor has no life in reality, thus through animation, specific concepts and ideas can be thought of. Figure 2 display's the Armor's head falling to the floor. As the character has to pick himself up and put himself back together, the action grants additional meaning to the story. In this sense, animation as an art form, promotes specific possibilities of discourse and subtext.

Animation, breathing life into characters, can be both a conceptual and practical exercise. On one hand, animators can conceptualize characters, with specific personalities and emotions that are displayed through adversities; on the other, developing a craft is needed to express the ideas through drawings, and these drawings must be connected through time, flowing from one to another. The skills required to do that, go beyond the capability of just producing illustrations.

The discipline of animation, integrates the aspects of storytelling, with the craft of designing characters for the medium of film. Artist John Hench, a painter and background artist at Disney studio, refers to this historic development as a

Figure 2 - Frames from Armor (Megre, 2007)



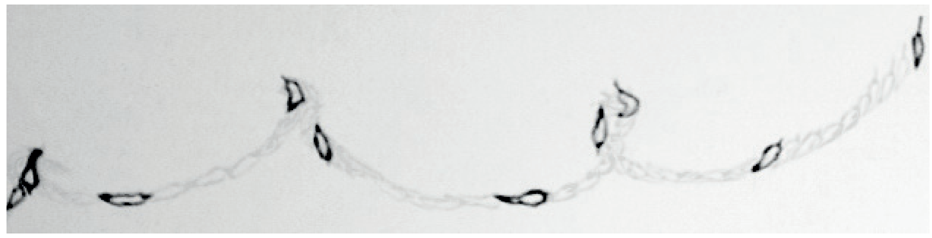


Figure 3 - Leaves (2004) - Hand-drawn 2D animation

new "(…) kind of language, and a very precise one" (Thomas & Johnston, 1981:23).

In figure 3, the key drawings of an animated leaf, are overlapped with the in-between drawings, that together form its movement. This is the process of hand drawn animation.

At Disney Studios, the animator would create the main action by drawing key-poses, and an assistant would draw the in-between poses. As this was a long process, shooting tests were often created to give the artists feedback on their work. Using rough and loose drawings to provide the energy and intent of the scene, animators would have these drawings transferred to film and projected, so they could have a sense of the sequence. This sequence would later be extended in the number of drawings, and animation would be cleaned up and polished, to be traced and inked afterwards. Animation was far from being an interactive process.

One-second of traditional 2D animation can be created by a sequence of twelve different drawings, resulting in a twelve frames-per-second (12 FPS) frame rate. It differs from live-action where twenty-four photographs make one-second of film, at the frame rate of 24 FPS.

Because film projectors usually work with 24 FPS projection rate, animation is usually produced "on twos", where each drawing is duplicated to achieve 24 FPS. If an animation is produced using the full twenty-four drawings at 24FPS, it is referred to as animating "on ones".

Animating "on twos" impacts the fluidity of motion comparatively to live action, but compensates by reducing the amount of work for the animators. Still, traditional animators often work in collaboration with assistants to produce the sequence of drawings. Today, with digital tools, a mixed approach can be used. Portions of an animated sequence can be produced "on twos", where other portions can be animated "on ones", as in the case of Spider-man: Into the Spider-Verse (Persichetti, *et al.*, 2019). Here, animators only use a higher frame rate to describe particular motions, if more detail is needed [1].

## The Fundamental Principles of Animation

At Disney Studios, the animators would take direction from Walt Disney himself, who would provide direction for the films, feedback on the animations, and would even act out the characters. For Mickey Mouse, Walt would act out the part and the animators would stand around him drawing the performance and expressions (Eisenstein, 1986). Walt was the central figure of the studio, responsible for the creative decisions, from the general direction of the story, to particular details on the performance of the characters.

Nevertheless, the animators still had to develop the language of the medium, to accommodate all the factors in relation to how the lines flow from one drawing to another. One key aspect, fundamental in this relation of the drawings, is weight. Artists in the studio developed concepts that helped conveying weight and expression to their characters. They would often refer to the same expressions to trigger each other when animating, while pushing to improve the scenes. As new concepts regarding the mechanics of animation emerged, they started to be repeated, as they produced predictable quality in the results. Eventually, these methods were perfected and taught to new artists when joining the team. Eventually, they became the so called 12 principles of animation. (Thomas & Johnston, 1981) The fundamental principles are:

1. SQUASH AND STRETCH - shape and form during movement.
2. ANTICIPATION - precedes an action.
3. STAGING - composition of the actions of characters and cameras.
4. STRAIGHT AHEAD AND POSE-TO-POSE - two methods of animating.
5. FOLLOW THROUGH AND OVERLAPPING ACTION - conclusion of an action and variance in time.
6. SLOW IN AND SLOW OUT - acceleration and deceleration.
7. ARCS - curved paths to describe shape or movement through time.
8. SECONDARY ACTION - complementary action to a primary one.
9. TIMING - number of drawings for the duration of a specific motion, rhythm.
10. EXAGGERATION - pushing an action further, stylization.
11. SOLID DRAWING - drawing volumes.
12. APPEAL - design of shapes and movement, characterization.

When relating sequences of drawings, the animated principle of Squash and Stretch showed the importance of weight in motion. This principle became essential when describing organic forms, underlying the foundations for character animation.

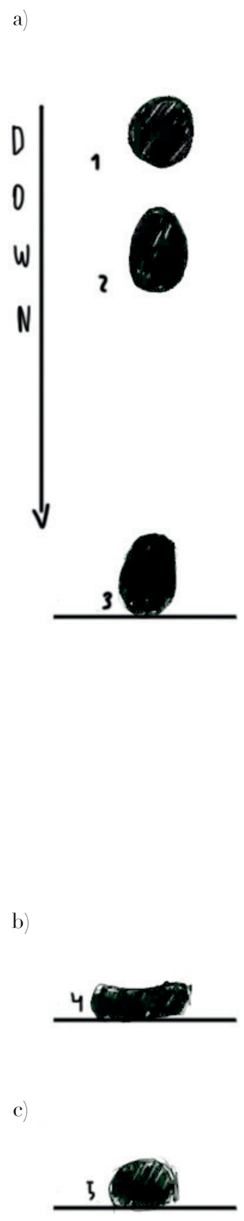



Figure 4 - Bouncing ball - part A - downward motion





Disney's artists established this principle by producing only two drawings to describe an action, and moving back and forth between these key drawings, they could enhance certain aspects of the drawings, benefiting the action. Often, this principle is thought of as a way to characterize the action, providing characters with a certain elasticity, making them appear more cartoonish. But the principle was so innovative, because it addressed the weight aspect, as well as establishing key drawings for animation. Thomas and Johnston describe that what used to be a smile, became a relationship between lips and cheeks, and legs squashed and stretched in volume when bending, showing volume to be preserved (Thomas & Johnston, 1981).

> *"By far the most important discovery was what we call Squash and Stretch. When a fixed shape is moved about on the paper from one drawing to the next, there is a marked rigidity that is emphasized by the movement. In real life, this occurs only with the most rigid shapes, such as chairs and dishes and pans. Anything composed of living flesh, no matter how bony, will show considerable movement within its shape in progressing through an action.".*
> *(Thomas & Johnston, 1981:47)*

Besides teaching these principles to new artists, a standard test was given to them, a bouncing ball. Here, the some of the principles are developed giving life to a simple ball. Figure 4 and 5 display the 10 drawings that are used to construct a simple bouncing ball, animated "on twos", drawn to form a loop that can be repeated overtime.

By designing the ball's shape using squash and stretch, weight is addressed through a dynamic change in its form. This flexibility helps giving a sense of movement. The fast timing of the action is the result of only twenty frames (less than a second), by having ten drawings animated "on twos".

Slow in and Slow out is achieved by placing the in-between drawings unevenly distributed through the composition, *e.g.* drawing number two is close to number one, than to number three. This gives the sense of acceleration as the ball falls, and deceleration as it returns to the original position.

Animation director and author Richard Williams, in his acclaimed book Animator's Survival Kit (Williams, 2001), combines the two principles, timing, and slow in and slow out in one expression: Timing and Spacing (Williams, 2001). Williams, famous for his work on Who Framed Roger Rabbit (Zemeckis, 1988), uses this concept to describe the time and rhythm of the action. By doing this, he addresses not only the speed of the actions with timing, but also the marking of key drawings,

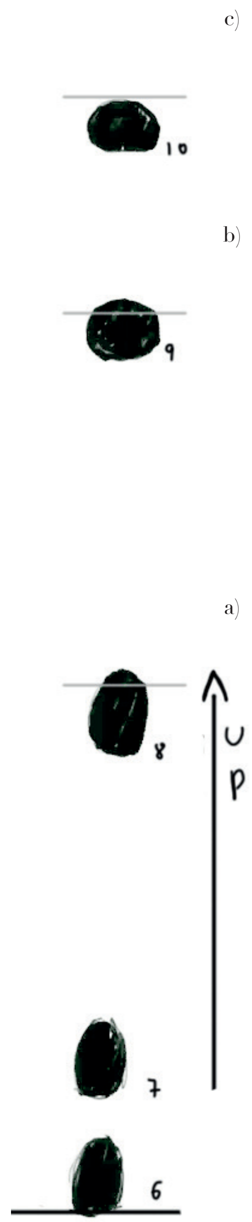



Figure 5 - Bouncing ball - part B - upward motion

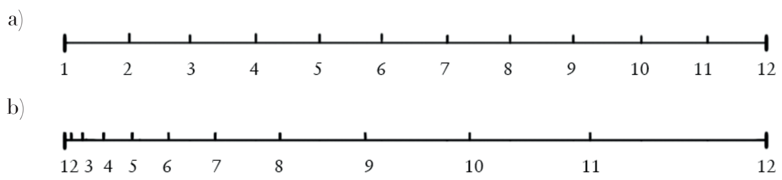



Figure 6 - Timing charts, uniform motion and acceleration

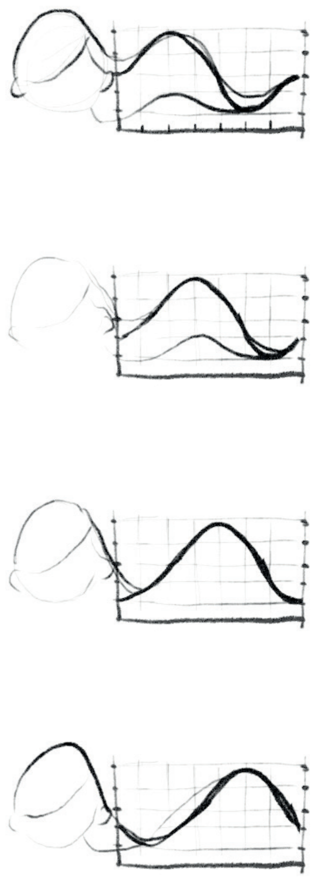


Figure 7 - Animation sketch for Wavy Hair (2020)

or beats of the action. He uses spacing to describe the motion of the in-between frames, that could be speeding up and slowing down, or moving uniformly at a constant speed.

Regarding bouncing balls, Williams suggests placing a contact pose before squashing the ball. Williams refers he learned this insight from Ken Harris, a master animator at Warner Bros who was a mentor to him. When analyzing the bouncing ball from the classic book “How to Animate Cartoons” (Blair, 1980), Harris told Williams to instead add a contact drawing before the ball touches the ground, in order to give it more life (Williams, 2001). The method can be applied to all sorts of actions, from characters walking or jumping, when their feet touch the ground, to any other example where a shape is pressed onto another.

The bouncing ball is an important exercise, because the theory it produces can be extrapolated to characters, human or animal, or even inanimate objects. The rhythm of the action, or the feeling, is the fundamental goal to be achieved. This will represent the inner life of a character, and playing with it provides expression when representing emotion and personality.

Despite its simplicity, a bouncing ball can also be deceiving, it is a sophisticated system that combines several basic principles. These principles can be isolated and further applied independently when animating.

Arcs are a key principle when describing a shape’s motion through time. Natural movement is rarely described using straight lines. From a walk, to a simple head turning, the shape of the motion can be thought of using curved arcs. Figure 3 shows path of motion the leaf follows, displayed by the juxtaposed drawings that become invisible when in motion. In figures 7 and 9, the motion of the hair is abstracted into a moving wave, using arcs as well.

Follow through and overlapping action, describe how different segments of a character or an object, can have different key drawings at different timings. In both figure 7 and 9, these principles are applied to the wavy form of the hair, displacing it through time. The original wave is not static, moving in time instead. The peaks and valleys of the shape move horizontally in the picture plane, one





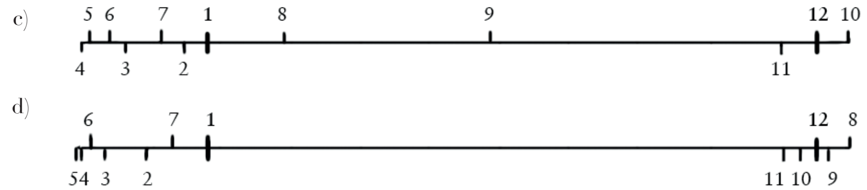



Figure 8 - Timing charts, uniform motion and acceleration (top)

frame at a time. The left part of the hair peaks in the first picture, but falls into a valley on the last.

When planning an action, timing charts can be used to determine the timing and spacing of animation, as well as other principles that address specific problems of a scene. Considering two different charts with identical time, *e.g.* one-second at 12 FPS, the spacing can differ producing completely different results. Figure 6 demonstrates a uniform spacing in image a), in opposition to a Slow out in image b). For the Slow out, each space between different positions is larger than the previous, growing as it progresses. Despite objects traveling through these paths departing and arriving at the same time, the a) moves at a constant rate and b) slowly picks up speed and suddenly stops at a halt.

Figure 8 shows that, by using the same path but shortening the beginning and end positions, room for Anticipation and Follow through can be created. In image c) the animation goes from the first position to the forth backwards, creating an Anticipation. Then, in a Slow out, passes the end position with a Follow through motion, finally falling back to the final destination. Although the timing is kept, the action is changed, making the motion more dynamic by applying these principles.

Motion can still be taken to an extreme before breaking its definition and legibility. Additionally, the fundamental principle of Exaggeration, is applied to generate a stronger action in image d). Even though the principle of Exaggeration is more of a subjective principle than a practical one, it is very useful to improve a scene and explore stylistic and formulaic approaches, stimulating creativity. In image d) the drawings between the two key positions, the beginning and end, are eliminated, and transferred to the Anticipation and Follow-through segments, ensuring the timing of the action. The result is a powerful motion, that can be used for energetic moves and gestures, even though no original drawings connect the key positions. In part, the illusion can be also thought of as a trick. There are no drawings connecting to different positions, just the expectation and the rebound of a specific movement. These stylistic choices can be used across different scenes,

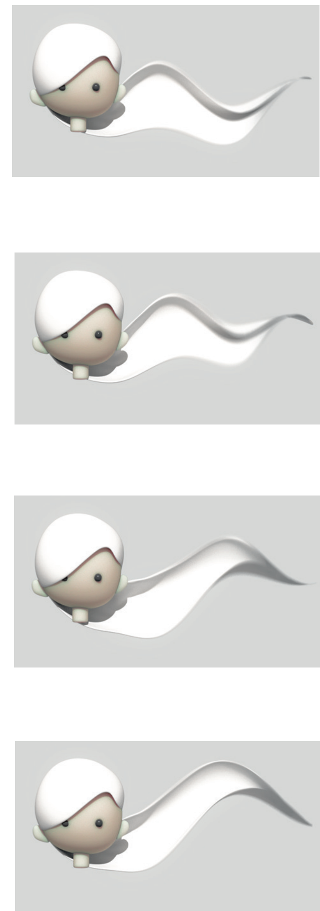


Figure 9 - 3D Animation sketch for Wavy Hair (2020)

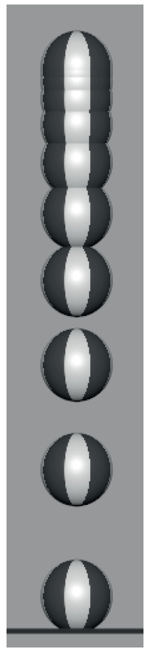


Figure 10 - 3D bouncing ball

to form a cohesive language that enhances the expression of particular storytelling.

Co-founder of Aardman Studios and animation director Peter Lord, describes how Exaggeration is used in the stop-motion films produced at the studio. Films such as Wallace and Gromit: The Wrong Trousers (Park, 1993), Chicken Run (Lord & Park, 2000) and Shaun the Sheep Movie (Burton & Starzak, 2015), are not realistic at all, they are rather exaggerated. Lord explains that Aardman's projects feature exaggerated movement, even if it might appear naturalistic. The scene is firstly performed by the animators themselves as reference, and then simplified and exaggerated, adding caricature and stylization to the puppets when animated. This simplification and exaggeration is crucial to create believability, instead of copying from reality. When done properly, it gives the audience the sense that the character's performance is, "uncannily natural". (Lord & Sibley, 1998:134)

Exaggeration at first glance, may appear to mean creating something "over the top", too cartoony or quirky, but in fact serves the purpose of creating style and believability in animation. Lord adds that, when defining action, 'poses' and 'holds' are used to describe movement and pauses, and when creating 'holds' for the characters, the puppets should not stay completely still (Lord & Sibley, 1998).

Depending on the style and medium of animation, it is also possible to create a 'hold' using only a single drawing, that is extended over time. Many 2D hand-drawn animations feature this approach, either to save production costs, or part of the design of the animation. In The Red Turtle (de Wit, 2016), the director uses this type of exaggeration to create simplicity and restrained movements, producing very subtle results. Again, the choices of style, combined with particular choices in storytelling, should create a consistency in the animated language.

Similar to Follow Through and Overlapping Action, Secondary Action can be used to describe simultaneous animation in different objects, or different layers of the same character. As an example, a character can be walking and waving to someone, the two concepts are not connected necessarily, but together create a more complex action. In figure 2, the Armor's head is rotating slightly on the ground, but the expression in the eyes is animated to show his frustration. Having a Secondary Animation, that does not attract the viewers attention as much as the primary, can augment a scene by supplementing it with subtext. Nuanced performances depend immensely on animating both the character's main action, as well as the character's thoughts. Secondary Action is close to Exaggeration, as both can be used more on a personal level, as the animator is trying to convey certain aspects when staging the performance.

The principle of Staging, concerns the composition of the scene's space and





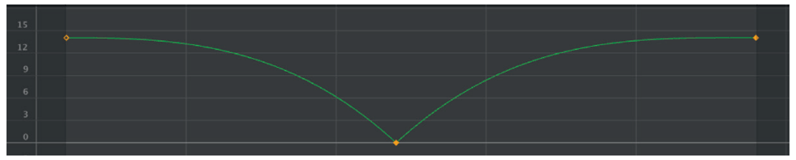


Figure 11 -3D bouncing ball - Graph Editor

action, similar to film and theatre. It is the most broad principle, being developed as early as in the process of storyboarding and later in layout, relating the performance of the characters with camera. Pose-to-pose and Straight ahead action, refer to the animator's approach to creating the action. The animator can plan it by designing the key poses, then adding specific in-between drawings connecting the existing ones. This is the pose-to-pose method. As an alternative, the animator can make the first drawing, and move forward frame by frame. This method presents more spontaneity, ideal for more fluid action. A combination of the two processes is possible, benefiting from planning the action and accentuating specific movements with improvisation.

The two principles Solid drawing and Appeal, define the visual aspects of the drawings. Drawing can assume a flat look if the shapes are not considered together with form. Designing characters moving through space must acknowledge the third dimension, as objects should be represented as solids. It is important for characters to appear three-dimensional, but also for characters to move in space and keep visual consistency through time.

Appeal can be associated with the design of a character's shape, which is one aspect of it. But more importantly, it has to do with a character's personality, defining a protagonist or a villain, through their design and action. It is crucial that a heroic character looks like one, and moves like one as well.

## Computer Animation

The short film Hunger (Folds, 1973), directed by the pioneer Peter Folds, is one of the early examples of the computer animation. The film was created using a two and a half dimensions system, developed by Nestor Burtnyk and Marceli Wein, providing tools to manipulate the drawings digitally. The film represents a turning point in history, because of its technological achievements, as well as being the first time an animated story was told using the computer, resulting in the first CG nomination for an Academy Award, (Parent, 2002).

Advances in keyframing, a technique that creates in-between frames for two

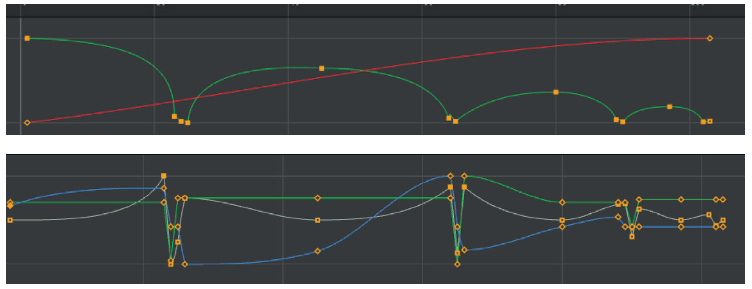


Figure 12 - 3D bouncing ball forward motion and Squash and Stretch

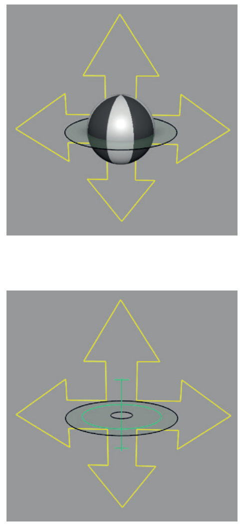


Figure 13 - 3D contol rig for ball

given key drawings, showed the potential for computer animation, comparatively to the traditional medium. Burtnyk and Wein development keyframing techniques that allowed artists to draw key drawings and use a computer program to interpolate them, generating in-betweens (Burtnyk, Wein 1971). This progress represents a major breakthrough for the obvious reasons, as it makes the job of animators easier, once less drawings are necessary to produce the final result. As importantly, animation becomes interactive, fundamentally transforming the creative process.

Without the help of computer software, animators must produce the key drawings, and the result of in-betweening can only be seen only after a long process. If artists need to change aspects of the design in key drawings, the in-betweens must be redrawn as well. With keyframing techniques, animators can preview and playback the animation as it is being produced, and use the interactive process to experiment with the results given by interpolation.

Figure 10 and 11 display how Timing and Spacing translate into Maya's graph editor. The three yellow dots represent the three keyframes for the ball, two identical at the top, and one on the bottom, creating a loop. The two symmetrical green curves represent the downward and upward motion. If they were to be set as straight lines, the ball would move without any acceleration or deceleration. Having the curves form a "V" shape, results in Slow out and Slow in, respectively.

For the creation of a simple bouncing ball using 3D animation, a control rig is built first. Here, all the commands necessary to perform the actions are created, and displayed in an interactive and accessible manner to animators. In figure 13, image a) presents the ball together with its deformation rig. The main arrow is the controller for the translation, rotation and scale of the ball. The disc around the ball, is the squash and stretch control. It deforms the ball preserving volume, and it can be placed and rotated in 3D space. This feature enables the ball to squash when hitting the floor, or a wall, or to stretch vertically, horizontally and diagonally, as displayed in





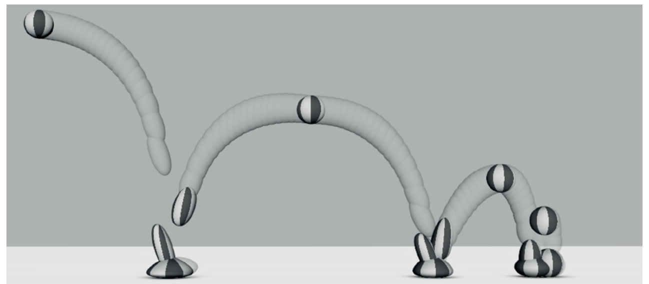


Figure 14 - Bouncing ball - 3D keyframees and in-betweens

figure 14.

The controllers are the only way to interact with the ball. The 3D model is never manipulated directly, in order to preserve its attributes. The controllers themselves are connected to the ball attributes and to other hidden deformers. In figure 13, image b) is possible to see the squash and stretch deformer, highlighted in green, that is hidden from selection when the control rig is published.

The animation controls are created using NURBS curves, as these curves are by default hidden when rendering. Thus, they present a good solution for controlling objects, as they are displayed only during the animation process.

The graph displayed in figure 12 a), shows the upward and downward movement, depicted by the green curve, and the forward motion by the red curve. The red curve has only two keyframes, compared to the thirteen keys on the green curve. This allows to control the forward motion by just adjusting the shape of the curve, making the design of the animation interactive and straightforward when experimenting with different results.

On the other hand, the graph displayed on figure 12 b), illustrates the keyframes and in-betweens for the squash and stretch controller. The grey curve shows the squashing and stretching effect, the green line the position of deformation inside the ball (more to its center, top or bottom) and the blue line the rotation of the deformation, for the diagonal stretching.

At this point, the interpolation process can become complex, despite the simplicity of the animation, with a simple rig. For full characters, the complexity of process escalates immensely. While there are gains in having interaction, the intricacies of interpolation can also represent a detriment, while designing animation.

Half Tone Animation (Catmull & Parke, 1972), used keyframing techniques to create both the hand's movement for Catmull's animated hand and Parke's animated face. In the paper where the methods developed for the film are documented, Catmull

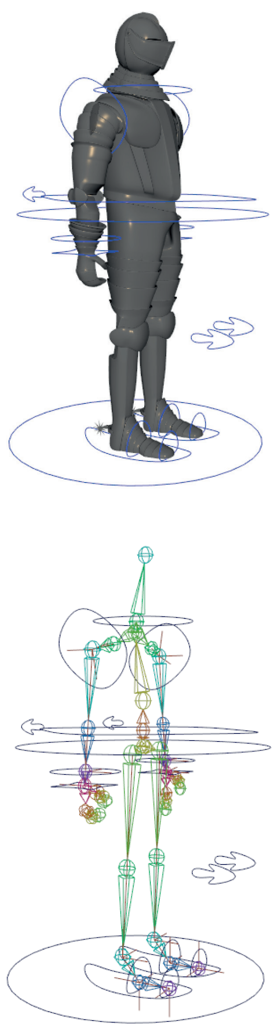


Figure 15 - Character rig fo Armor (Megre, 2007)

describes the process of creating the motion of the hand, using interpolation to create Slow ins and Slow outs. The types of motion the system permitted only covered very generic ones, and a great amount of research was still needed. (Catmull, 1972)

To create more complex motion in computer animation, skeleton techniques were developed to overcome the limitations of previous methods. Those methods were only able to connect points in different frames using straight lines, or to create transitions for the whole picture, without applying different weights in different spaces (Burtnyk & Wein, 1976).

In 1978, while director of the Computer Graphics Lab of the New York Institute of Technology (NYIT), Catmull was aware of the challenges ahead for the development of 3D-computer character animation.

> *"While there has been some success and a great deal of optimism, the promise of higher output and quality using a computer has not been realized. The transition from simple drawings optimized for use on the computer to the complicated and detailed drawings of quality conventional animation has been much harder than expected. The principle difficulty is that the animators drawings are really two dimensional projections of three dimensional characters as visualized in the animators head, hence information is lost, ie. one leg obscures another." (Catmull, 1978:348)*

Catmull points out that the potential computer animation promised to some at the time, was to make high quality animation affordable. As the Disney Studios hand-drawn animation was so expensive, that the studio at the time could not afford to produce new films with the quality of Pinocchio (Sharpsteen & Luske, 1940) or Fantasia (Armstrong *et al.*, 1949). The computer could be used to make the process faster and cheaper, however, the possibility of wholly cost-effective CG character animation was still to be proved. The degree of difficult of difficulty of CG development, was comparable to artificial intelligence development (Catmull, 1978).

As drawings are abstract 2D images that aim to represent a three dimensional reality, information is lost in translation. Using a computer system to produce images that connect these representations, can become an extremely difficult challenge, with many solutions for different problems, from interpolation to data management, where hundreds of thousands of drawings need to be organized in different shots and divided into different scenes.





The main obstacle in producing high quality computer animation systems, is in addressing all the different possibilities that emerge from various types of motion, from humans and animals, to cloth, hair and natural phenomena as fire and water. When drawing shapes in 2D animation, the drawn line represents the limits of the surfaces, and in-between drawings address the same problems as the key drawings do, representing a convincing two-dimensional projection of a 3D world. Artists behind the creation of traditional 2D animation, develop a discipline through practice to be able to create these abstractions. Interpolation helps to solve some problems, despite being a general technique, that can be used alone or in combination with others.

Many solutions can be found in modern 3D software, joint based methods to articulate figures, dynamics simulations for the deformation of cloth and hair, particles and fluids to simulate leaves on a tree reacting to wind, or being under the rain. For characters, specific sets of tools became the standard, providing animators controls to pose the models, without them having to have too much consideration for the inner construction process.

The Armor character in figure 15 has a joint based rig, providing both forward kinematics (FK) and inverse kinematics (IK). The joints are bound to the geometry, being responsible for the motion of the surface's vertices. On the other hand, the joints are connected to the controls via their attributes. In figure 15 a), the character is presented with the control rig, in its published version, in b), the control rig is presented together with the joint system (in color).

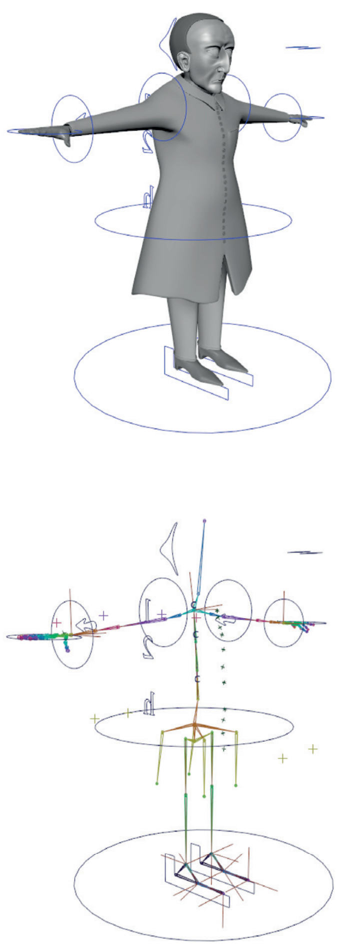
FK motion consists on articulating simple skeleton structures, where joints are part of a hierarchy, that is moved from top to bottom in the chain of command, *e.g.* rotating the shoulder, then rotating the elbow, and finally the wrist.

The IK system connects the hierarchy of joints, enabling to move the whole hierarchy from its end point. For instance, a hand can be moved in space (using translation) while picking up an object, and the elbow and shoulder joints assume rotations accordingly. IKs are fundamental in moving characters while walking or running, where the feet have to be attached to the floor in specific poses, while the torso and limbs are moving.

Joint based systems can be combined with Blend Shapes, where for example, expressions for the face can be created. Through a layer system, a surface can be modified, having this change recorded into a new layer, and accessed when animating the character. Displayed in figure 16, expressions such as surprise, pain and relieve were created, as well as blinking of the eyes.

Figure 16 - Character's expressions through Blend Shapes

For characters to be rigged, the models are created in a "T" pose, separating



the arms from the torso. This makes the skinning process easier, when associating the surface's vertices to the joints, through a weighting process. Alternatively, "A" poses are also used, where the arms are rotated away from the torso in a 45º angle, instead of the 90º in the previous case.

Ezra's character, from the short film Hourglass (Megre, 2008), is exemplified in figure 17 a), in a "T" pose. The rig, despite being apparently simpler in visual terms, than the one created for the Armor character, has many more attributes, although most are hidden in the published version. The character features more joints and attributes for controlling the hands, and the feet controls allow for complex motion, *e.g.* being able to pose the character on the tip of the toes.

The FK and IK systems for arms and legs provide a switch to easily change from one system to another, while animating. The lab coat has extra joints to be manipulated, and the buttons have "rivet" controls, in order to change the positions to the coat, avoiding intersections.

For the expressions, a great amount of Blend Shapes were created, providing the character with nuanced expressions, visible when up close. This, combined with the rig and subtle lighting and mood, creates a specific visual vocabulary. The final results of the 3D animation can be seen in figure 18.

One of the groups making advancements in the decade of the 1980's, was LucasFilm Computer Graphics Department, that would later become Pixar. In 1983, the co-founders Alvy Ray Smith and Ed Catmull, decided to make a CG short film with the goal of publishing the results of their advancements, as well as having a film to demonstrate them. John Lasseter was hired as a consultant on it, although he ended up re-designing the characters and becoming the film's single animator.

The Adventures of André and Wally-B (Smith, 1984) became the first film produced by this group, followed by the numerous short films as Pixar Animation Studios, up to the production of the world's first 3D animated feature film, Toy Story (Lasseter, 1994).

Alvy Ray Smith, the film's director, explains that having the goal of producing a 3D animation featuring articulated characters, the team took the most advantage of having a real animator aboard for the first time. As Lasseter re-designed the characters with new illustrations, the 3D models required new primitives to be created on the computer. The main character, André, required special shapes to describe its torso, eyelids and mouth, with correct deformations. For the torso, Catmull designed a teardrop-like shape, providing the necessary

Figure 17 - Ezra in "T" pose with control rig





bending for the character's articulation. For the eye-lids and mouth, David Salesin helped by Catmull and Carpenter, created a new primitive called "bound", a curve type object bounded to the surface of a sphere, essential to describe these forms. The new teardrop primitive was also used for the second character Wally, where the shape of the feet were designed to move as water balloons (Smith, 1984).

Besides the suggestions John Lasseter had for the models, he had also ideas for improving the system he was using for animating the characters, called Motion Doctor (MD), designed by Duff.

> *"Animation controls were added to the model as John needed them - another form of extensibility which proved to be very important. The final form of the André model had 547 animation controls, and the final form of the Wally model, by Bill Reeves, had about 252 controls. One of the successes of the animation program was a presentation of this large number of controls to John in such a logical way that he was unaware of the complexity." (Smith 1984:4).*

The Adventures of André and Wally-B was presented at SIGGRAPH 94. The film's breakthrough use of motion blur and bending shapes, squashing and stretching was something the audience had never seen. Notwithstanding all the technical achievements, the team made sure the imagery carried the look of Lasseter's art. In the face of all the challenges computer animation represented, from interpolation, deformable primitives, management systems, part of the solution was designing the tools to allow the expression of artists to come through. Despite general technical advancements being transversal to 3D animated productions, a certain degree of customization and construction of new tools is also essential for each project.

Sonoko Konishi, a technical director at Pixar, recalls that for the production of Toy Story, the film's main character Woody, was built with a control rig of 596 controls. Sixteen years later, for the production of Toy Story 3 (Unkrich, 2010), Woody's rig had been developed up to 2245 controls (Villemin *et al.*, 2015).

> *"As our technology progresses and animators skills become more and more refined we keep adding more and more tools for them to control and shape the characters. But we cant forget what was achieved with those early rigs." (Villemin et al., 2015:7).*

Figure 18 - Final frames from HourGlass (Megre, 2008)

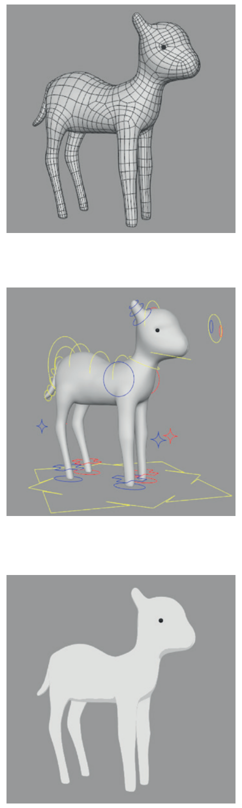


Figure 19 - Lamb's 3D model, contol rig and final color

Technical progression goes hand in hand with artistic creativity. Technological development is a creative endeavor as well. If not properly conceptualized it can fail, as artistic creation often does. Artistic skills evolve over time, and this maturation, is what informs the direction of the development of new tools.

## Visual Languages of Animation

3D animation is not restricted to a specific vocabulary, it is not constrained by the Pixar's or Disney's approach, nor by photorealism when integrated with live-action, as a visual effect. The fact that 3D animation is produced using the computer, provides a wide range of possibilities in creating relations between the visual aspects and the motion of the characters. This relation can be a delicate one, especially when supporting a narrative.

Figure 19 illustrates "Churro" a little lamb, created for the theatre play The Big War of "Patoá" (Figueira *et al.*, 2019), that combines the performance of the actor Rodrigo Santos with animated backgrounds. The play, created by Jorge Louraço Figueira, Pedro Alves and Ricardo Megre, tells the story of a grandfather that, as a result of being worried about his grandson moving to study in a new city, Porto, writes him a dictionary with the city's jargon (Patois). As the play is created for adults and children, the design of the performance and animation, are directed towards both ends of the age spectrum.

The pipeline for the creation of the lamb's model, started by creating a digital sculpt using ZBrush's dynamic surfacing tools and automatic re-topology. Adjustments to the new topology were done in Maya, where the character was later rigged, colored and animated. The character's shading is done only with two tones, as the result of the two-dimensional look of the play's visual development. This aspect is balanced with very simple and stylized animation.

As 3D animation allows for a high range of possibilities, animation principles may have to be considered differently when designing the visual vocabulary for a particular film aesthetic.

In 1987, one year after the production of Pixar's first official short-film, Luxo Jr. (Lasseter, 1986), the film's director published an article relating Disney's animation principles to 3D animation. Here, the author shows how the traditional principles were applied throughout the production of the two previous short films; The Adventures of Andre and Wally B. and Luxo Jr. Lasseter indicates that, as 3D computer animation





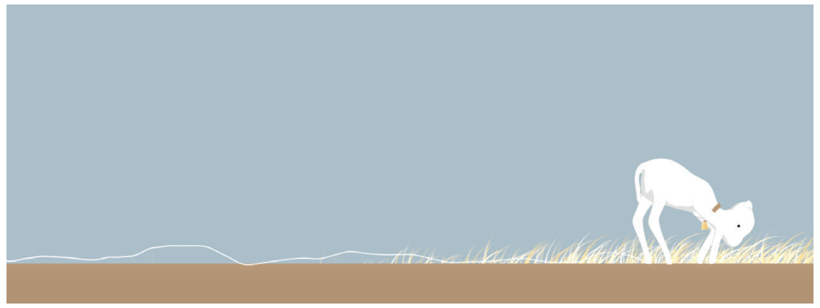


Figure 20 - Final frame from The Big War of "Patoá" (Figueira et al, 2019)

progressed, a large amount of the research focused on processes and techniques of image rendering, instead of animation, as was the case in 2D animation. On the other hand, the systems created for 3D computer animation, were developed by private corporations for internal purposes, not allowing traditional animators to use them. As soon as commercial 3D animation methods emerged, insufficient techniques had been designed surrounding animation itself (Lasseter, 1987).

*"Much of this bad animation will be due to unfamiliarity with the fundamental principles that have been used for hand drawn character animation for over 50 years. Understanding these principles of traditional animation is essential to producing good computer animation. Such an understanding should also be important to the designers of the systems used by these animators." (Lasseter, 1987:35).*

Despite the difference, between the two techniques, where 2D animation consists in sequences of hand-made drawings and 3D animation creates three-dimensional models in which the movement is produced by keyframing, Lasseter points out that most principles will translate from one to the other. The meaning of most principles remain the same, regardless of the medium used to animate. Still, principles such as Squash and Stretch, Slow in and Slow out, Arcs, Appeal, Straight Ahead Action and Pose to Pose, might see a modification to their application dependent on the medium (Lasseter, 1987).

When applying the principle of Squash and Stretch, the author understood its importance as a means to create weight and to design key poses, despite its use to define the rigidity of an object or shape. As an example, a bouncing ball is compared to Luxo Jr. hopping, where the character extends and compresses without deforming, due to the built-in hinges. Secondly, the author applies the principle

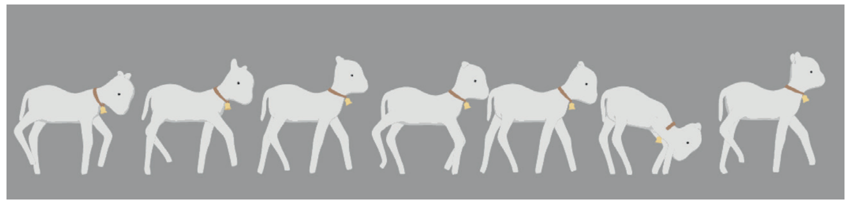


Figure 21 - Lamb's key poses

to the "strobing" problem, which is the result of rapid movements that create the impression of several objects emerging separately, instead of a continuous action of a single object. Regarding the cases in which motion blur cannot be applied, Squash and Stretch allows the deformation of the object throughout the animation, resulting in a continuous form and therefore dealing with the "strobing" issue (Lasseter, 1987).

This is an issue, especially when animating "on twos", as in the example shown in figure 21. The less frames exist for the animation, the higher the risk of breaking the continuity of motion with fast movements that create the "strobing" effect.

Straight Ahead and Pose-to-Pose action have a specific set of issues, when applied to 3D animation. In the Pose-to-Pose method, a character may have key positions of elements in their hierarchy in different timings. The Lamb's rig in figure 19 shows different controls for different parts of the body, allowing for separate keyframes to transform the members of the hierarchy independently.

Figure 21 displays the character in motion, looking for grass to eat, until it is interrupted by the sound of other lambs calling. The animation follows the fundamental principles, as well as key principles from Richard Williams for locomotion. Here, key poses such as contact, down, passing and up positions can be seen [2]. The in-betweens are calculated through interpolation, and controlled by the graph's editor curves. The extreme positions for the head, ears and tail, differ in timing from the legs and torso, providing Follow-Through and Overlapping Action, as the character moves.

As it walks, he also looks for grass to eat. This Secondary Action helps to create the illusion for the character. As soon as it finds the grass, its rhythm accelerates briefly. Using keyframes, the process of repeating actions, and changing their speed is straight-forward. Had the animation been produced with traditional hand-drawn animation, conceptualizing all these different, but subtle changes, would have been much more difficult.

For the principle of Appeal, Lasseter notices an aesthetic problem originating in symmetry, which is easily produced by the computer. Despite being commonly used, it can have unwanted aesthetic results in which the animated characters might





lose appeal by appearing too symmetrical, and thus becoming artificial. Lasseter also goes in-depth in some principles and concerns that were more relevant at the time. At the end he concludes that although 3D animation generated by computer has as a base a new series of "hardware" and "software" tools which animators can work with, the principles of animation are also tools and are as important as the computers on which the animations are produced (Lasseter, 1987).

The animation principles are general guidelines developed to create believability in characters, both in their physicality and personality. Although this is true, there are no particular rules on how they should be applied.

Sonoko Konishi and Michael Venturni, technical director and animator at Pixar, published an article in 2007 demonstrating how the principle of appeal was developed in Ratatouille (Bird, 2007). As rats can be unappealing for a significant number of people, Pixar's different departments developed the character's visual aspect through articulation (Konishi & Venturni, 2007).

The rats were designed by constructing simple silhouettes, instead of complex ones, and by lowering their center of gravity. For the face, the team designed softness to the mouth, eyes and cheeks, creating an appealing smile, adding many controls for the teeth, in order to articulate the figures, producing pleasing shapes. As all of these implementations were done by articulating the 3D model, the choices made were conscious ones, not built-in rules. (Konishi & Venturni, 2007).

Animation historian Giannalberto Bendazzi, considering Disney's animation principles, expresses they can be interpreted on an individual level. They are subjective, not strict rules, but guides to navigate the art form (Bendazzi, 2016).

> *"As always, the secrets, once stated, became rules - iron for the mediocre who followed them blindly, gold for the intelligent who knew how to interpret and often subvert them." (Bendazzi 2016 :480).*

Creating believability and appealing characters is at the core of animation. The computer is merely a medium for the art form to be expressed, and the selection of tools should be made accordingly to particular aesthetic choices.

For The Great War of "Patoá", a combination of animation techniques were used, some using interpolation, some using hand-drawn animation, despite being used a 3D software, like Maya. In Figure 22, a string of the lamb's wool is transformed into the word "Anho", one of the many words used in Porto's jargon for lamb, without any use of interpolation. In the play, as lines are continuously transformed into words, it is essential that the rest of the 3D elements' visual vocabulary, as the lamb, or the

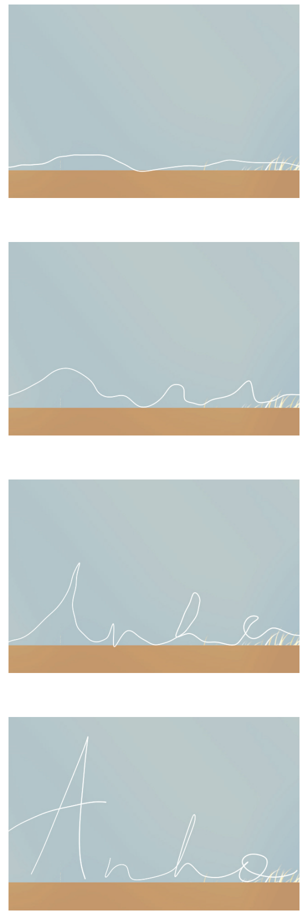


Figure 22 - 3D drawing and animation of the lamb's wool

images of the city, are in harmony with the hand-drawn digital lines.

The implementation of animation principles has the goal of telling stories visually, through animated characters. For the author and actor Ed Hooks, moving illustrations is not enough to achieve the illusion of life. Renowned for his book Acting for Animators (2011), and masterclasses, Hooks emphasizes the importance of acting principles applied to animation, when giving life to characters. The author defines acting as "behaving believably in pretend circumstances - for a theatrical purpose." (Hooks 2011:19).

> *"With regular reality, 100 percent of everything is shown. Theatrical reality, by contrast, has form and is condensed in time and space. With theatrical reality, you only show the parts that tell a particular story. Further, an essential ingredient of theatrical reality is conflict. (…) Your character should play an action in pursuit of an objective while overcoming an obstacle." (Hooks 2011:18).*

Hooks describes how empathy emerges through conflict, as characters' actions are described when pursuing goals while overcoming obstacles. When defining the action of a character, emotion cannot be acted out on its own. A goal must be set first. Once the goal is clear, an obstacle or conflict, should be placed before it, making the action actable. The obstacle can have a positive or negative connotation. The empathy the audience feels for the character, is essential for its members to willingly suspend their disbelief. (Hooks 2011)

Many other aspects can contribute to the suspension of disbelief, from composition to shot continuity. Specific to animation, the previously referred strobing effect, can break the continuity of the action. With computer animation, motion blur can be used to address this issue, although other options may produce the same result, as stretching the in-between shapes.

Lasseter provided this option at a time where motion blur was expensive to calculate. Both options inject a specific style to the animation. Still, they can be used together to develop a specific language for the film, or mixed to achieve different results. A modern example of this can be seen in Spider-Man: Into the Spider-Verse, where no motion blur was used in the production of the film [3]. Instead, the directors used smudges to stretch out duplicated shapes from the 3D models, as if they were blurred by the hand of the artists, inspired by the comics. Interviewed by Amidi for Cartoon Brew, co-director Persichetti expresses:

Figure 23 - Moss deformation - 7200 Light-Years (Megre, 2007)





> *"We get to make a Spider-Man movie animated so we can look at the source material — the comics — and pull from that, and we can find a visual language that feels like it's derivative of a comic book." (Amidi, 2018).*

Film director and theorist Sergei Eisenstein, describes animation's unique quality as plasmaticness, distinguishing drawings, that despite their definite forms, are yet without stable forms. This primordial protoplasm, grants animation a living plasticity, a morphing quality, that lets it assume any form freely (Eisenstein, 1986).

Author Paul Wells, expands on a particular attribute of animation. The audience may rejoice with a successful realization, as the animators' free expression of their work, their conceptualized fantasy, materializes into the film itself. The viewers may feel a particular satisfaction from the achievement of a symbolic world defined "in a language which only operates on its own terms." (Wells, 1998:228).

Nuclear to animation, is the possibility of any construct, analogous to life itself. As follows, the art form can assume any individual form of expression, both artistic or technological.

Its constitutional plasmaticness can be cherished or disregarded by technology, it is up to the artists to draw a line and create a language that benefits the storytelling and engages the audience at the same time. Having no hard rules for how to conceive computer animation, both hand-drawn animation or complex rigged characters can be created by a 3D software. As 3D can be very nuanced and detailed, there is a tendency in the animation industry for exploring realism. But realism and animation are in opposition, in some sense.

The visual languages of animation, engage in a specific way with our suspension of disbelief. When mixing live action with animation, generating photorealistic images, animation attributes can be lost and the message the audience receives can be a mixed one. Having conflicting visual languages can cause aesthetic dissonance, or lack of harmony, often producing uncanny results where the visual appeal is not there anymore. It is the possibility of not being real, that can make animation so interesting. Characters can be deformed and manipulated in specific ways, communicating with the spectator, even if on a merely subliminal level.

Figure 24 - Moss deformation - 7200 Light-Years (Megre, 2007)

## End Notes

[1] Animating “on ones” and “on twos” in Spider-man: Into the Spider-Verse (Persichetti, et al., 2019) addressed by the film’s FX Supervisor Pav Grochola on SideFX website:
https://www.sidefx.com/community/spider-man-into-the-spider-verse/ (last accessed 2/09/2020).

[2] Richard Williams goes in detail on the subject of walking cycles with different variations throughout his book Animator’s Survival Kit (Williams, 2001).

[3] The film’s visual effects supeervisor Danny Dimian explains the team’s novel use of motion blur and topics related to stylization and technical processes to Ian Failes (2018), on Cartoon Brew’s website: https://www.cartoonbrew.com/feature-film/if-its-not-broke-break-it-sony-imageworks-renegade-approach-to-spider-man-into-the-spider-verse-167321.html (last accessed 2/09/2020).

# 2.5. Rendering

When rendering, artists combine lighting, color and composition to create mood for the animation. Rendering can simply mean applying light and dark tones to characters and scenes, or coloring the tones to evoke a specific theme and emotion. With more advanced algorithms and render engines, a more nuanced cinematography can be achieved, combining complex textures and materials, with soft shadows and rich half-tones and highlights. Atmosphere and camera, play a fundamental role in relating these concepts to one another.

In the pipeline, rendering is not confined to the coloring phase after the characters are animated, as would happen in traditional cell animation. Rendering technology can be used to develop the look of the characters and backgrounds, applying textures and surface materials, even before the characters are animated. The 3D render is a dynamic process, as layout artists can introduce camera and lighting schemes, texture artists define the aspect of surfaces, lighting artists the directional and quality of light.

Disney's films such as Snow White and the Seven Dwarfs (Hand, 1937) or Bambi (Hand, 1942), despite their rich environments, applied flat colors to characters to save production costs. Creating shadows on moving characters, would gave implied animating the shadows as well, increasing the film's budgets tremendously.

The Fleischer brothers produced one of the earliest examples of shaded animation, in the Superman cartoons (Fleischer, 1941-1942) [1]. Film director and author, Richard Fleischer, describes the look of the cartoon series as very realistic, combining the shaded characters with rich and dramatic compositions. As it took a significant increase in production time, compared to other short cartoons, due to the skill and effort necessary, the budget for each episode was double that of average cartoons (Fleischer, 2005).

Lighting in animation stands apart from live-action. Although they share similar vocabulary when creating cinematography, animation's visual design is not restrained by physics, presenting a wider range of styles. Rendering light and color in 3D animation also differs from traditional 2D, as

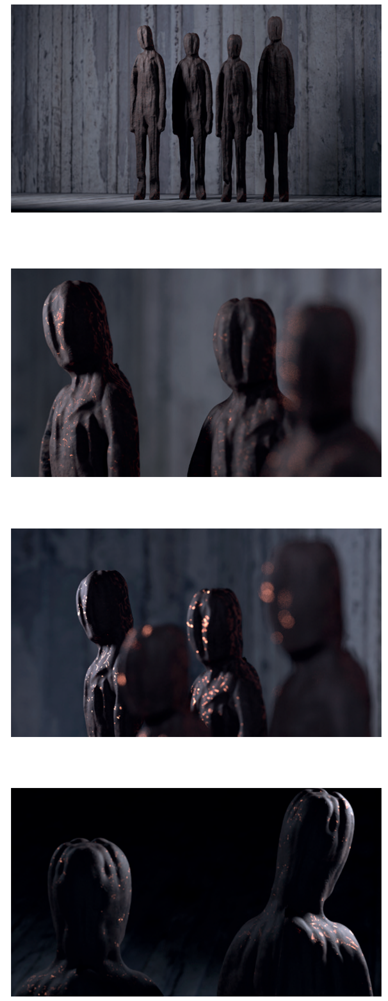


Figure 1 - Untitled Figures (2015), digital sculptures rendered with RenderMan.

Figure 2 - The Great War of Patoá (Figueira et al., 2019), animated light on the cityscape.

computer generated processes provide interactivity in the lighting development, and different production methods, resulting in distinctive visuals.

Render engines, such as Renderman or Arnold, not only provide photorealistic tools, as they also offer a range of non-physical possibilities, closer to 2D animation. 3D artists can benefit from the best of both worlds, the look of the film can be closer to live-action cinematography, or to cell animation, with a more painterly or illustrated feel.

Figure 2, a cropped area from the full shot in figure 3, shows the animated sun-light painting the buildings and the bridge of the cityscape, illustrating the passage of time. Despite its two-dimensional look, the scene is created with 3D models. The light is slowly animated, creating the possibility of motion, as well as experimentation with different color schemes.

Lighting and rendering were developed inside Maya using Maya Hardware, a scanline render engine. The material, a two-tone ramp shader, was used for the houses and rooftops, sharing a bluish tone with the background. The second orange tone, is activated by a directional light, simulating the sun-light. Different layers were created (on the right page, figure 4) and combined together in post-production, inside the compositing software, Nuke.

Independently of the application, the function of value, color and composition in animation, serve the purpose of supporting storytelling. Production designer and author, Hans Bacher mentions the layout stage as a visually crucial moment in a film, when the camera shots are designed to represent the rough sketches as “the storyboard is being translated into film language” (Bacher 2008:60).

> *“The color in our films corresponded with specific events in the story, and just as there is an “emotion/action curve” there should be a “color mood curve”. (…) For example, a love scene will need different colors than a suspense scene. At the end of the film, the color is especially important to build up the climax. (…) And just as music is a substantial ingredient used to establish the mood of the story, the proper colors and color combinations are just as important.”*
>
> *(Bacher, 2008:139-140).*

Format and composition are the first aspects to consider, before putting values on screen. The standard 35 mm film, has a 3:4 format, almost squared. With anamorphic lenses, the same 35 mm can be extended into widescreen, with a 1:1,85 aspect ratio, or even into cinemascope, with a 1:2 format. With larger film, as 70 mm, it is possible to achieve super-widescreen, usually called Panavision format, with





Figure 3 - The Great War of Patoá (Figueira et al., 2019) - 3D models by Filipe Sobral, rendering by Ricardo Megre.

1:2,35 proportions. Different formats dictate different rules for creating compositions (Bacher, 2008:98).

When staging the action, the rhythm of the composition is dependent on the camera placement, movement, and focal length, that defines the angle of view. The general composition units vary between the long shot (or wide shot), medium shot and close-up. As they overlap sections of space, they can be used together to create spatial and time consistency. There are no rules on how to use these composition units, and even the naming of the shots varies (Katz, 1991).

Author Steve D. Katz expands on the naming convention for the basic framing, using the height of the human figure. A full shot is used for the full figure, a medium full shot framing from the head to the knees. For medium shots, medium is used for the waist up, and medium close for a shot from the navel up. Close shot is used for the chest up, wide close-up for the shoulders up, full close-up for the pit of the neck up, medium close-up for the face, and extreme close-up for details inside the face (Katz, 1991).

The shot size can vary from extreme wide, framing landscapes with characters, often used for opening scenes, wide shots for full characters in action or dialogue, medium and close-up to emphasize the body language, face and expressions, as well as for detailed emotions and micro-expressions.

The size of the shot can be determined by the proximity of the camera to the subject, or by the focal length, where the camera lens is used to zoom in on the characters. A shot created using a wide angle lens, around 20mm, will distort space but fit more information into the picture plane. A standard 50mm lens will often be used for medium and close-up shots. Photo-lens, 150mm and higher, will compress the space, reducing the depth, and can be used for dramatic purposes, framing characters in close-up and extreme-close shots [2].

Figure 4 -Rendered layers for the final compositing.

Figure 5 - Final composited night scene using the same 3D scene with alternative lighting and shading.

When zooming in on a character, depth of field decreases and more of the scene becomes out-of-focus. This effect contributes to creating flat space, where the three-dimensional space loses its depth, accentuating the two dimensions of the screen surface. In opposition, deep space emphasizes the perspective of the scene, contributing to the illusion of a three-dimensional space on a flat screen (Block, 2008).

In the art book, The Ballad of Rango (Cohen, 2011), author David S. Cohen interviews the director and film's supervisors, providing insight to the creative process of the production of Rango (Verbinski, 2011). Regarding lighting and cinematography, Cohen reveals that the approach from the VFX artists, was philosophically different from the director of photography, Roger Deakins. The VFX supervisor John Knoll (co-creator of Photoshop), explained that the first tests for the desert, featured a good and realistic balance between the brightness of the sun, the sky, and the reflex of the sun from the sand, creating a convincing hot environment. However, Deakins felt the composition was too flat, and pushed for adding more blacks and bounce cards, to better define the forms of the scene (Cohen, 2011).

Interviewed, Deakins expresses that cinematography is not determined by the hardware, but by the cinematographer's approach in representing the characters, where "personality is more important than the technology." (Cohen, 2011:129). Deakins adds:

> *"The digital-animated way of making movies has been kind of crashing, like moving plates, into the live-action way. Traditional animators are using live-action techniques, and the live-action filmmakers are taking techniques from animation to broaden their palette." (Cohen, 2011:129).*

Figure 6 - Renders from the night scene.





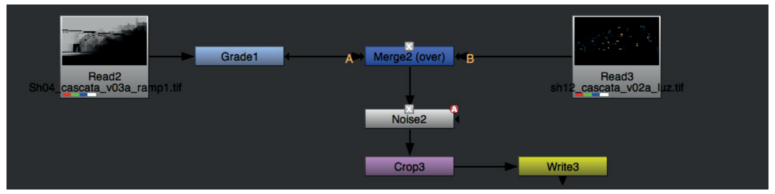



Figure 7 - Renders combined for the night scene in compositing, using node based system, Nuke.

The different mediums play important roles in influencing one another, and in refining themselves. In CG animation, the ideas in which the final look is presented are not bound by a specific software.

On one hand, images can be produced entirely within a 3D software, like Maya, using a simple scanline render engine such as Maya's Hardware, or an advanced path-tracer, such as Pixar's RenderMan. On the other hand, the images can be sent as different layers, and composited in a 2D software. As rendering can become a slow process, where images can take from minutes to hours to render, dependently on their complexity, manipulating different components of an image in compositing can offer interactivity back to artists.

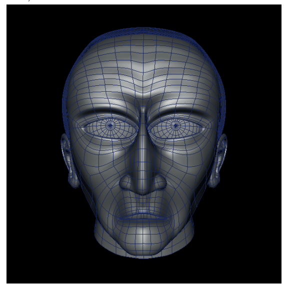
Figure 4 and figure 6 display the different rendered images that, composited together result in figure 3 and figure 5. The same 3D scene, with two different lighting schemes, produce different results, such as the sunrise with the animated sunlight, and the nightfall mood, where the city's lights are turned on in the mist. Figure 7, presents the compositing nodes, in Nuke. The images are combined and a noise effect is added for the fog. A "grade node" changes the color of the black and white render into a purple tone, the crop node transforms the image into a 16:9 aspect ratio (or 1:17 format), and the write node creates the final sequence that is later imported into editing.

## Early Advancements

Author Michael Rubin points out that, one of the most straightforward uses of computer graphics, is to use the computer to color pixels. On one hand, image resolution corresponds to the number of pixels, and the higher resolution the greater number of pixels. On the other hand, better color fidelity corresponds to more bits for each pixel. While a 1-bit image equals black and white, a 8-bit equals to 256 colors. 24-bit corresponds to 16 million colors, the color resolution used for television, as for film, a 36-bit equals almost seven billion colors. The frame buffer, the predecessor of

Figure 8 - HourGlass (Megre, 2008), Ezra's character visual development, with textures and lighting

a)



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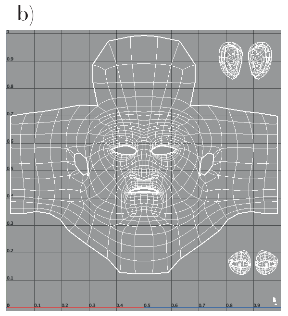


Figure 9 - a) Ezra's 3D model; b) unwrapped UV map.

the graphics card, was used to store the image into memory.

Dick Shoup, a researcher at Xerox Palo Alto Research Center (PARC), in 1972 developed both a paint program and hardware to manage the images, a frame buffer he called the picture memory. Shoup would draw using a stylus on a digital tablet, and present the images on a TV screen (Rubin, 2006).

> *"The history of Paint, Superpaint, AVA, Aurora, Paintbox and Photoshop is the birth of 2D compositing as we know it today. Nuke, Shake, Flame, Henry and Harry were all built on the building blocks of research that certainly can be traced back to Paint. Today any computer can provide digital painting but it all started in the 1970s, and its story is the story of all the 2D packages that would follow." (Seymour, 2012).*

Pixar's co-founder Alvy Ray Smith was inspired by the 8 bit program, SuperPaint, developed by Dick Shoup at Xerox PARC. From that point on, Smith knew what he wanted to do for the rest of his life. (Rubin, 2006). At PARC, together with David DiFrancesco, Smith worked with one of the first frame buffers, experimenting on creating images. In 1975, they joined Malcolm Blanchard and Ed Catmull at NYIT [3]. There, Smith developed the Big Paint program and later in 1976, developed Paint 3, the first 24 bit RGB system, featuring HSV color control (Rubin, 2006).

The HSV system allows for controlling color in an intuitive manner, where hue, saturation and value can be adjusted independently, and automatically the color is translated into RGB (red, green and blue). At the NYIT lab, the six frame buffers that made Paint3 possible, also increased the bit-depth, allowing the researchers to develop anti-aliasing techniques, where the stair step-edges in images, called "jaggies", were made softer. In 1977, Smith and Catmull invented the alpha channel,





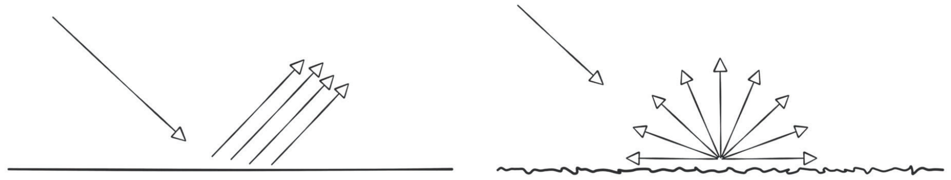


Figure 10 - specular (left) and diffuse (right) light reflection

adding transparency to images, making it possible to composite 3D elements in post-production, or to juxtapose CG with live action (Seymour, 2012).

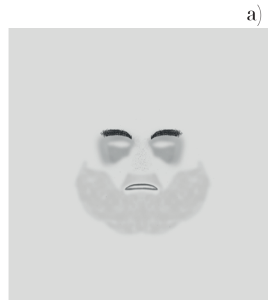
Around 1984, at Lucasfilm, John and Thomas Knoll implemented a paint system with some of Smith's ideas, in the first version of Photoshop (Seymour, 2012). Tom Porter, Alvy Ray Smith and Dick Shoup went to receive a technical Academy Award for Paint Systems in 1998, and the Knoll brothers together with Mark Hamburg, received an Academy Award for Photoshop in 2019.

Besides having the utility of compositing images that originate in a 3D software, 2D programs are also used to paint textures to be applied on 3D models. The painted textures are connected to the 3D surface's material, the shader, and influence its response to light. The shader's main attributes used to plug-in textures, are the diffuse, specular and bump channels. The diffuse attribute is responsible for the overall color, the specular controls the amount of highlights and the bump regulates the surface smoothness or irregularity.

In order to connect the textures, 3D models must be unwrapped first, into two-dimensional U and V coordinates, in a process called UV mapping. Visible in figure 9, the 3D model was unwrapped into a UV map. Firstly, UV maps are projected from 3D to 2D. This can be done using different methods that best fit the object's form, namely planar, cylindrical or spherical mapping. In this case, a planar projection was applied from the front view (Z axis), providing low distortion to the features of the face. The model was then cut, from the hair line to the back of the neck, and unwrapped. For the unwrapping, the unfold tool was used to uncover the hidden polygonal surfaces that were facing the back (in this case, the back of the head).

UV maps can be opened in any 2D software, *e.g.* Photoshop, and textures can be painted, as the color for the skin, as well as the other textures, allowing manual control for the interaction of the light with the surfaces. On the right, in figure 11, three textures are displayed. The first color map, is shown here only in grayscale colors due the black and white nature of the project. The second map, a specular map, controls the specular highlights of the forehead, nose, cheeks, lips and chin.

a)



b)

c)

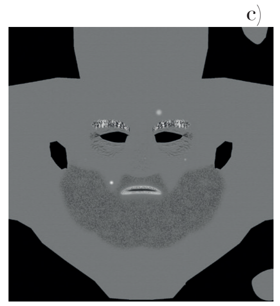
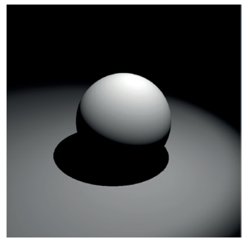


Figure 11 - Texture maps: a) Diffuse (color), b) specular, c) bump.

Figure 12 - Scanline rendering in combination with ray tracing for shading the glass material

a)



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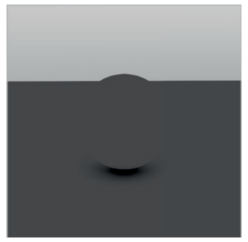
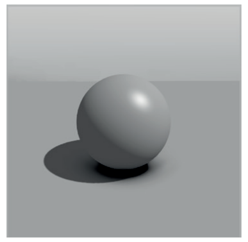


c)



Where the white value is painted, the highlights will be stronger, where the black value is painted, no highlights will be visible. The third, a bump map, can be used to change roughness of the surface. White values can be used to create bumps, and black to create dimples. Fifty per cent grey will leave the surface smooth and unchanged.

In 1976, Jim Blinn did an internship at NYIT and worked closely with Catmull and Smith. In 1980, Blinn was back at the University of Utah and expanded on Catmull's concept of texture mapping, developing bump mapping (Blinn, 1978), adding more realism to skin, through adding irregularities to the polygonal surface (Sito, 2013).

Comparatively to modeling and animation, rendering is more complicated, requiring slow computer calculations to produce the final images, often resulting in a time consuming process. To add detail to an image, more polygons need to be drawn, as this takes place, more rendering time is needed. In the 1970's, rendering was still in its "early childhood" (Rubin, 2006:116).

Figure 13 displays a sphere being rendered in Maya with simple scanline algorithms. In image a) the sphere was lit by a spot light. The light had a decay rate set to quadratic, to mimic the way real light loses energy as in moves away from its source. This created a natural gradient, from light to dark, visible on the surface of the sphere. The material of the sphere, a simple Lambert shader, was used to represent the diffuse light reflected. The shadows were produced by depth map shadows, that have to be filtered to hide the its "jaggies". The spotlight has many attributes, for instance, the cone angle, penumbra angle, and drop-off, that contribute to producing the soft round circular shape, similar to stage lights.

Image b), displays the same sphere, that was lit by an ambient light, producing flat shading, together with ambient occlusion algorithm to create soft contact shadows. This algorithm approximates the attenuation of light due to

Figure 13 - Lighting schemes using scanline rendering with Maya Hardware





proximity of objects, ideal to create fast soft shadows to mimic, for example, an overcast sky [4].

In image c), a directional light was added to the previous scheme, simulating the sun's rays as parallel lines, creating parallel shadows in different objects. The directional light, in combination with ambient light and ambient occlusion, can be used for exterior scenes. A Phong material was used for the sphere in this image, providing a combination of diffuse and specular reflection, visible in the highlight.

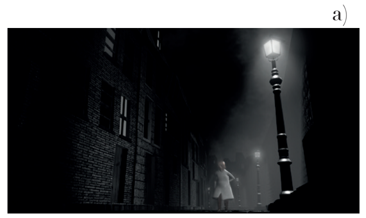
The advantage of the methods presented in figure 13, is that today they can be rendered in real-time, providing greater interactivity. The images displayed for HourGlass (Megre, 2008) in figure 12 and 14, were rendered with Maya Software, using mostly spot lights and directional lights. At the time, these scanline techniques were not capable of real-time rendering on a regular computer. Still, the render times were much inferior to renders using additionally ray tracing, as the example shown in figure 12, where glass reflection and refraction was calculated by this algorithm, producing physically corrected results, impossible to achieve with regular scanline rendering.

Additional attributes as fog, can be created using spot lights, as displayed in figure 14 a) and b). Spot lights are also a great tool to create light pools, as those seen in image a). Here, the buildings were lit by hidden spot lights, faking the light emitted from the lamps. In image d), the outside light enters through the window using a spot light, painting the window's shape on the floor. However, Scanline rendering does not produce indirect lighting, where reflected light bounces from surfaces and colors other objects. This was accomplished by faking the indirect light, using multiple spot lights with lower intensity, as seen in image a) and c).

Vol Libre (Carpenter, 1980), a short film created by Loren Carpenter, is the first example of CG use of fractals. Carpenter used these generating algorithms to create detailed mountains, featuring high number of polygons, with render times of twenty to forty minutes per frame. The same software was used to produce the effects for a planet in the Genesis Sequence of the film, Star Trek 2, The Wrath of Khan (Meyer, 1982) [5].

The film was shown at a screening in SIGGRAPH 1980, as Carpenter had hopes of getting the attention of Ed Catmull and Alvy Ray Smith, whom he knew would attend the computer animation festival. Indeed, Catmull and Smith were at the screening, and immediately hired Carpenter (Seymore, 2013).

a)



b)

c)

d)

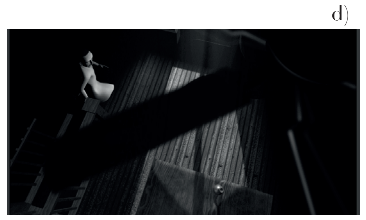


Figure 14 - HourGlass (Megre, 2008), lighting using spot and directional lights, for direct and indirect illumination

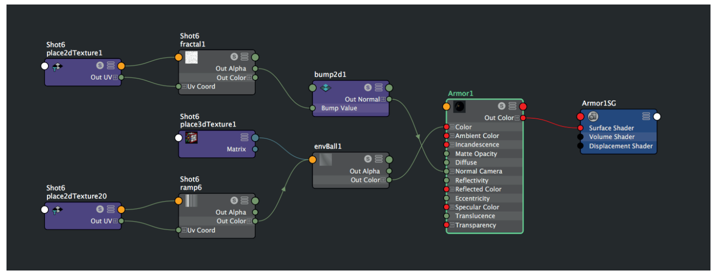
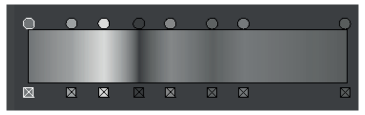


Figure 15 - Shader tree for the surface material of the Armor character 3D model



Pixar's development of the short 3D animations, The Adventures of Andre & Wally B. (Smith, 1984), Luxo Jr. (Lasseter, 1986) and Red's Dream (Lasseter, 1987), as well the VFX produced for the feature film, Young Sherlock Holmes (Levinson, 1985), contributed to the creation of RenderMan. Rob Cook, Loren Carpenter and Ed Catmull developed the Reyes algorithm, a scanline render developed for "fast high-quality rendering of complex images" (Cook, *et al.* 1987:95).

The team's goal was to produce complex images that were visually rich, supporting a variety of primitives, such as 3D models, particles and fractals, with complex shaders, and render high quality antialiased pictures at high speeds. The render architecture was designed to be flexible, in order to incorporate new tools, although the researchers were not pursuing ray tracing at the time. (Cook, *et al.* 1987).

Ray tracing techniques had been developed by the same researchers in 1984, with distributed ray tracing solutions for motion blur, depth of field, penumbras, translucency, shadows, fuzzy reflections and refractions (Cook, et al 1984). In their famous "Pool Balls" rendered picture [6], the researchers demonstrated the use of motion blur, that also was present in The Adventures of André & Wally B. Despite this, the team felt Reyes would benefit from a scanline rendering algorithm, as many lighting effects could be approximated with texture maps, and the renderer architecture would prioritize complex geometry and large models. As an example, a single frame from Luxo Jr. took half-an-hour to render at a 724x434 resolution (Cook, *et al.* 1987).

Primary author of RenderMan, Rob Cook, introduced the concept of shader trees, used for creating more complex materials, using a flexible tree structure. (Cook, 1984) Figure 15 displays the shader tree for the material visible in figure 16. Instead of using raytracing for the metal reflections, a ramp (figure 16 a) is connected to an environment ball, giving the appearance of ray traced reflections.

Figure 16 - a) Ramp used to simulate reflections; b) Scanline render featuring "fake" metal shader for Armor (Megre, 2007)





Loren Carpenter, one of the creators behind RenderMan, interviewed by Mike Seymour for FX Guide, discusses the development of the render engine. Carpenter explains that initially, while at Lucasfilm, RenderMan was not thought of as a product. Carpenter wanted to create a render engine at high standard film quality. The goal was to create a renderer that could produce images to be intercut with live-action, unnoticeably. This involved capturing rich detail as a real camera would, and this notion was out of reach at the time. The most advanced renderers could only handle a handful of polygons and mimic plastic materials (Seymore, 2013).

## Modern Tools

VFX Supervisor and author, Boaz Livny, describes that when rendering, images are captured from a synthetic environment, as if they were photographed in the real world. This approach to rendering is defined as photorealism (Livny, 2008).

> *"(…) photorealism - the process of taking images so the environment appears natural and consistent with the content, including the lighting, shading, and photographic characteristics (depth of field, field of view, lens distortion, and so on). The environment, however, needn't be confined to the realism of a car commercial; it can be crazy characters in imaginary worlds." (Livny 2008:xv)*

Modern renderers include features such as ray tracing, global illumination, physical lights, soft shadows, indirect illumination, sub-surface scattering, among others. The images in figure 17, showcase ray traced reflections for the shaders of the black liquid and the knives, physical lights with soft ray traced shadows, and global illumination using image-based lighting (IBL), with the Mental Ray render. Most of these features were not practical to be used during the decades of the 1980's and 1990's, but advancements in computing made these options increasingly feasible. One of the big advantages modern renderers have, compared to old ones, is in their capability of creating global illumination.

In films such as Toy Story (Lasseter, 1994), indirect lighting and color

Figure 17 - Black & White Festival Promo (Borges & Megre, 2011), created by Loopa, using ray tracing techniques with mental ray render

Figure 18 - City Cubes (2017), rendered with RenderMan, using Image based lighting (IBL) with a high dynamic range (HDR) panoramic image

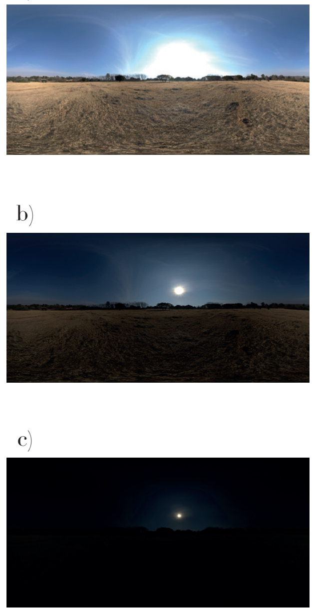



Figure 19 - HDR exposure samples, used for the dome light

bleeding effects were solely created by artists, that manually placed additional lights to give the impression of bounced light scattered through space. RenderMan principal developer, Per Christensen, describes the advancements of global illumination for the creation of more realistic images, including effects such as soft darkening under an object and color bleeding between different surfaces, as subtle but essential to create realistic images (Batali, *et al.* 2003).

Global illumination achieves such effects through the use of ambient occlusion, image-based lighting using high-dynamic range images (HDR), and indirect illumination (color bleeding). It is possible to fake these effects by having artists placing bounce lights manually, but it demands a lot of trial and error before achieving the desired results. Global illumination techniques can be used to help this process, and although they are slower to render than scanline, the algorithms have become more efficient and computers faster. (Batali, *et al.* 2003)

Software like RenderMan and Arnold calculate light paths between lights and the camera. One of the applications is to link 16 bit or 32 bit HDR panoramic images to a dome light, that lights the 3D scene. This process, referred to as image based lighting (IBL), visible in figure 18, is a fundamental component of creating photo-realistic images. In this example, the entire 3D scene is lit by a single IBL dome light.

HDR images are created using photography, combining a number of different exposures into a single image. In figure 19, three samples of the same 32 bit HDR, demonstrate the quality of these specific images. In the highest exposure (image a)), the sun is overexposed and the detail on the ground is visible. In the lowest exposure, in image c), the sun is now more defined, but the rest of the image is underexposed. The final HDR used for the lighting, carries this information through the shaders, that can be adjusted for specific exposures, reacting to light with physical correct attributes.





Figure 20 - Chess Kights (2019), rendered with Arnold, using BRDF shaders

For the production of the feature film Monsters University (Scanlon, 2013), and the short film The Blue Umbrella (Unseld, 2013), Pixar switched its lighting pipeline to a physically based system, using ray tracing. Ray tracing was used occasionally, for instance in Cars (Lasseter, 2006), although integrated with other scanline techniques. As the rendering workflow became more and more complex for lighting artists to manage, where shots could feature thousands of lights and shaders to tweak, Pixar implemented a new system that could handle the complexity, freeing artists to focus on creative decisions. (McAuley, *et al.* 2013)

Authors Hery and Villemin refer that, to solve the Render equation, where the light emitted in the scene is described by the different materials, the RenderMan team implemented different integrators. To solve the equation, Monte Carlo raytracing is usually used, although render times can become unfeasible. Therefore, different integrators were used to optimize the process of relating physical lights to materials, featuring a bidirectional reflectance distribution function (BRDF) model (McAuley, *et al.* 2013).

With this new implementation, the cinematographer for Monsters University, Jean-Claude Kalache, reported that the lighting artists doubled their productivity, as well it more than doubled the shot lighting efficiency, freeing up Pixar's crew for more artistic exploration. Chris Bernardi, the shading lead on the same feature film, described that combining HDR lighting with BRDFs, made it easier to create a broader diversity of materials, mostly by just tweaking the specular roughness control. (McAuley, *et al.* 2013)

BRDFs are an essential part of creating realistic images, defining the objects' surfaces based on physical behavior of light, as visible in figure 20. Besides the surface's shading, the detail in modeling is an integral part of the complexity needed to produce such images. Sculpted detail in high resolution models become unfeasible when animating, or if a scene requires a high number of models that have been

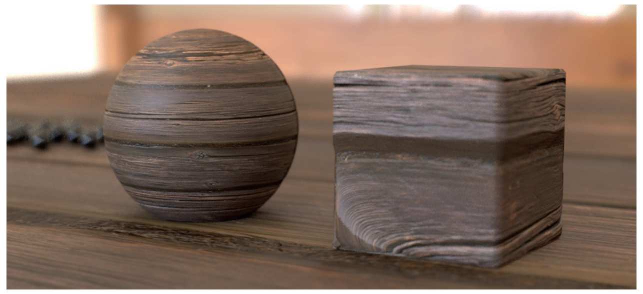
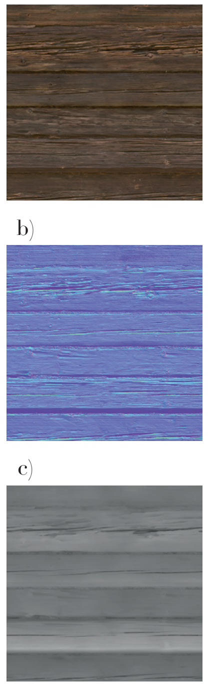


Figure 21 - BRDF materials, with color, normal and displacement maps, using a HDR for lighting, rendered with Arnold

a)
b)
c)



subdivided into millions of polygons. Besides bump maps, normal and displacement maps can be used to represent detail in low resolution 3D models.

Rob Cook introduced displacement maps as an extension of bump maps. While bump maps are constrained to the geometry's interior surface and only affect its appearance in reaction to light, displacement maps can change the silhouette of a model, moving the location of vertices and perturbing the surface's normals. As they perform their calculations before the shading calculations, they can almost be regarded as a type of modeling. (Cook, 1984)

In 1998, authors Cohen, Olano and Manocha made advancements in the development of normal maps, creating an algorithm for appearance-preserving simplification, where surface details can be stored onto a map and displayed in a model with a small number of triangles (Cohen, *et al.* 1998). Compared to bump maps, that can only simulate details on the Y axis (up and down), normal maps can create details on all three axes, due to their RGB nature. In figure 22 the three textures are visible, that combined, create the final result in figure 21. Image a) displays the color texture map, used on the material's diffuse channel, b) the normal map, used for the detail inside the surface, c) the displacement map, used to displace both the inside and outside of the models' silhouette.

Researcher Henrik Wann Jensen, points out that synthesizing realistic images of complex models can only be handled by Monte Carlo ray tracing, as shown by advancements in the algorithms and computer power. Monte Carlo ray tracing can be applied through different methods, from path tracing and bidirectional path tracing, to Metropolis light transport, irradiance caching or photon mapping. Within its advantages, Monte Carlo raytracing supports procedural geometry, geometry instances, BRDFs, specular reflections and complex scenes. The main disadvantage is that it produces noisy images. If addressed by adding more samples, the renders become quite slow. Alternatively, the rendering process can be optimized to sample

Figure 22 - Wood textures: color, normal and displacement maps





the 3D scene with more efficiency (Jensen, et al, 2003).

Path tracing is a recursive method that uses rays, traced from the point of view of a camera, in order to find out the pixels' colors. The direct illumination is calculated from tracing rays between lights and objects' surfaces. Indirect light is calculated from a new ray, spawned from the intersection point used for the direct illumination (Christensen & Jarosz 2016). The short film Bunny (Wedge, 1998), produced by Blue Sky Studios, the creators of Ice Age (Wedge, 2002), is a landmark on the use of path tracing. The film's innovative use of this technique, provided diffuse illumination, depth of field and motion blur, rendered at film quality (Christensen & Jarosz, 2016).

Despite the ground-breaking advancement, the path tracing algorithm had already been developed more than a decade before. James T. Kajiya introduced the rendering equation to describe the transport of light, scattering off of different surfaces, suited to computer graphics. To solve the equation, Kajiya used Monte Carlo algorithms (Kajiya, 1986).

While the method was introduced simultaneously to the development of RenderMan REYES algorithm, path tracing was considered to be impractical to be implemented, due to producing images with too much noise, in particular with cases where motion blur and depth of field was used, as well as requiring the entire scene's geometry to fit in memory (Christensen, *et al.* 2018).

Sony's animated feature Monster House (Kenan, 2006) was the first feature film to use Arnold. The creator, Marcos Fajardo, was inspired by the rendering techniques used in Bunny, and developed a rendering path tracer that would set a new standard of rendering in the industry. Animated features such as Cloudy With a Chance of Meatballs (Lord & Mille, 2009) and Spider-Man: Into the Spider-Verse (Persichetti, *et al.* 2018) were rendered with Arnold. The software was also extensively used to render VFX for films such as Star Trek Into Darkness (Abrams, 2013), Guardians of the Galaxy (Gunn, 2014), Star Wars: Episode VII - The Force Awakens (Abrams, 2015) and Blade Runner 2049 (Villeneuve, 2017).

In 2014, RenderMan 19 was released, completely rewritten, featuring integrators that relied on path tracing and bi-directional path tracing, using the new RIS render system, instead of REYES. Finding Dory (Stanton & MacLane, 2016) became the first Pixar feature film to be fully rendered with RIS. Besides rendering Pixar's films, the new system is also used in animated features and heavy VFX features, *e.g.* The Lego Movie (Miller & Lord,2014), Interstellar (Nolan, 2014), Kubo and the Two Strings (Knight, 2016), Avengers: Endgame (Russo & Russo, 2019) and The Irishman (Scorsese, 2019).

Also in 2014, Walt Disney Animation Studios released Big Hero 6 (Hall &

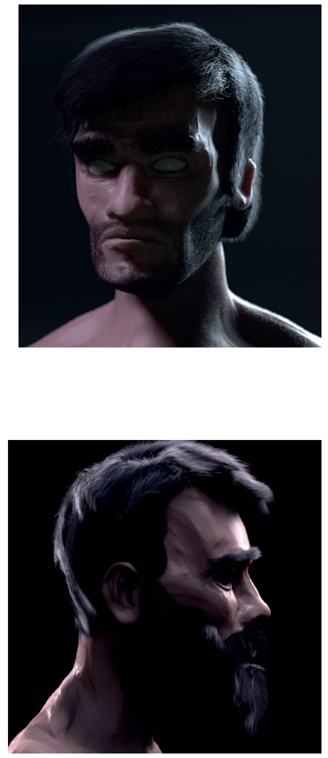


Figure 23 - Untitled Characters (2016), sculted in ZBrush and renderer with RenderMan in Maya

Williams, 2014) rendered with their new physically-based path tracer, Hyperion. Disney's proprietary renderer has been used for all its feature films since then, from Zootopia (Howard & Moore, 2016) and Moana (Musker & Clements, 2016) to Ralph Breaks the Internet (Moore & Johnston, 2018) and Frozen II (Buck & Lee 2019).

New render engines can handle complex translucent materials, with sub-surface scattering (SSS), essential to create naturalistic skin, wax or marble. Figure 23 displays characters rendered with RenderMan RIS, using SSS for the skin, with the PxrSurface material, and PxrMarschnerHair for hair, developed for Monsters University. Figure 25 displays subtle volumetric effects, where geometry was converted into fog using PxrVolume.

Photorealism does not mean necessarily reality itself, as the visual style can be expanded into imaginary representations. As path tracers are also compatible with geometry instancing, enabling an object to be duplicated numerous times without creating unfeasible slow render times, photorealistic techniques can be combined with instancing, for detailed and experimental results, as displayed in figures 24 and 25.

Within modern films, rendering artists have become a part of the film's pre-production as well, creating rough concept images using 3D software. Production designer Ben Procter, interviewed by Christopher Nichols for CG Garage podcast, discusses the co-existence of digital and traditional media in the art department. Procter explains the different processes for the production of the Avatar sequels, while working with a traditional painter Alastair Maher, who is both a traditional paint supervisor and a look development texture artists, using digital tools. As Maher "speaks" both visual languages, Procter asks for specific things, such as "more breakup in the SpecMap", when critiquing some work of his crew. As Procter explains what he needs, in terms of digital tools in the specular map, Maher can translate to traditional techniques, such as trying to apply a glaze with a sponge (Nichols, 2020).

The visual languages used in animation and VFX films, are formed both by the aesthetic vocabulary and technical jargon, depending on the medium used. Animation, as an evolving art form, grows with experimentation. Despite the advancements in photo-realistic rendering, films such as Paperman (Kahrs, 2012) move the boundaries from experimenting cross-overs between 2D and 3D.

The film's producer Kristina Reed, interviewed by Jim Macquarrie for Wired, explains that the expressiveness conveyed by artists in their drawings, in the lines themselves, can be lost in the CG world. As computer generated

Figure 24 - Untitled Figure (2017), created in Blender, rendered with Cycles path tracer



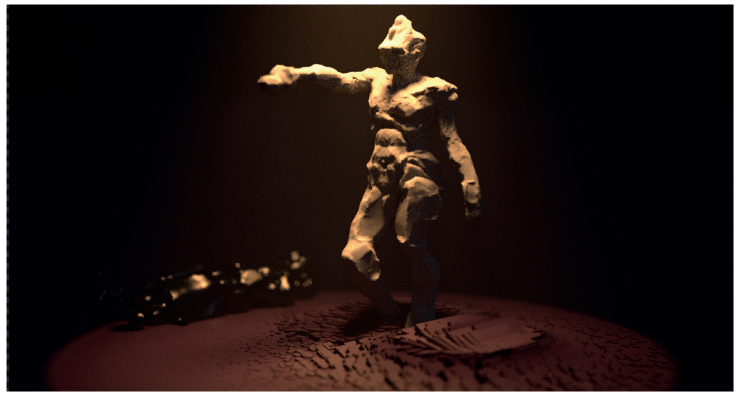


Figure 25 - Untitled Figure (2018), rendered with RenderMan

animation requires a complex process, from modeling to rigging, the final result is very separate from the actual art. Additionally, Reed wanted to address the issue of having two independent crews, the hand-drawn talent was separated from the CG talent. Disney's proprietary system, Meander, was used to merge the artists' line work with the cg renders, moving towards a new visual frontier, away from the hyper-real CG look, a trend in most 3D animated films (Macquarrie, 2012).

Paperman's director John Kars, interviewed by Christina Radish for Collider, recalls when working on Tangled (Greno & Howard, 2010) with animation director Glen Kean, contemplating the idea of having Kean's drawings moving together with the 3D computer animation. As visual storytelling in animation relies even more on showing the action very clearly, and having "to distill it down to its essence", Kars pursued the idea of retaining the expressive drawn line and combining it with the subtle and rich motion of CG (Radish, 2012).

Innovation in animation does not automatically correspond to photo-realism. Path-tracers can be used to render hand-drawn lines, as the example shown in figure 26. In this example, digital drawing is used to generate triangles, using 3D tools such as MASH in Maya, and rendering with Arnold's Curve Collector, a shader for controlling the visual aspect of NURBS curves.

Pixar's co-founder and president of Walt Disney Animation Studio, Ed Catmull, interviewed in 2001 by Steve Kennedy and Deanna Haunsperger, discusses the role of technology in Pixar's filmmaking. When asked about Pixar's success, Catmull replies that the studio's secret is to avoiding to get too much absorbed by the technology, so it does not become more important than the story. Regarding making realistic animated films, Catmull adds that above all, they are artistic creations, and the goal is not to achieve realism, the goal is artistic creation (Kennedy, Haunsperger, 2001).

Figure 26 - Generative face (2020), 3D drawing rendered with Arnold in Maya

## End Notes

[1] More information about the history of shading and lighting in animation can be found on Foundry's website: https://www.foundry.com/insights/film-tv/lighting-in-animation (last accessed 17/8/2020).

[2] Comparison between different types of lenses by Wieczorek (2019) on Medium: https://medium.com/ice-cream-geometry/what-is-a-normal-lens-35mm--50mm-43mm-compared-to-the-human-eye-cf7e43cc3366

[3] Where Catmull would later develop Tween in 1977.

[4] Ambient occlusion further explained on Unreal Engine's website: https://docs.unrealengine.com/en-US/RenderingAndGraphics/PostProcessEffects/AmbientOcclusion/index.html (last accessed 17/8/2020).

[5] Information found on Carpenter's Vimeo channel: https://vimeo.com/5810737 (last accessed 17/8/2020).

[6] More information and modern interpretations of the original image can be found on FXGuide's website: https://www.fxguide.com/fxfeatured/1984_-_pool_balls_25_years_later/
(last accessed 17/8/2020).

# 3. Drawing from Mocap

## 3.1. Capturing the Figure

*"Motion is the most apparent of the characteristics of life; it manifests itself in all the functions; it is even the essence of several of them." (Marey, 1874:27).*

In this chapter we demonstrate novel multidisciplinary methods for computer animation, using mocap as reference, and combining techniques from both traditional 2D animation, 3D animation and digital sculpting. Firstly, the concepts developed are introduced, followed by examples of the standard use of motion capture technology. Lastly, alternative methods are demonstrated, focusing on sculpting and drawing in three-dimensions. The case studies present alternative methods, and were specifically developed as part of the artistic research of the thesis. The results demonstrate the methods and visuals that are created from alternative practices.

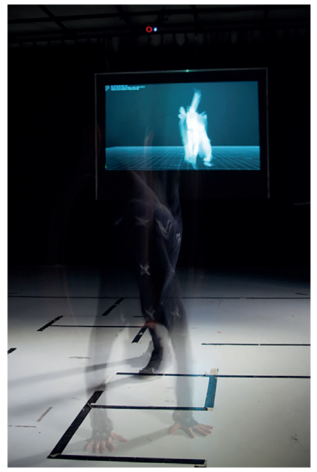


Figure 1- Mocap session; Performance - Luís Megre, photography - Bernardo Rangel

Capturing the motion of humans and animals began in the 19th century with the work of two pioneers, that were essential in redefining our visual culture, the first being Eadweard Muybridge, and the second Étienne-Jules Marey.

Artist, anatomy teacher and author Sarah Simblet, acknowledges how important Muybridges's photographies were in transforming our perception and ideas of how humans and animals actually move. Not only his sequence of photographed images break up moving bodies in different moments in time, but they also expose the inner figure, changing through those particular motions. The author adds that, Muybridge's classic work in the 19th century has influenced the following generations of artists, who since then have produced works of art reflecting the beauty of the captured figures in motion, from the hypnotizing vigor of athletes, to the dynamic and fleeting effect these bodies display through time (Simblet, 2001).

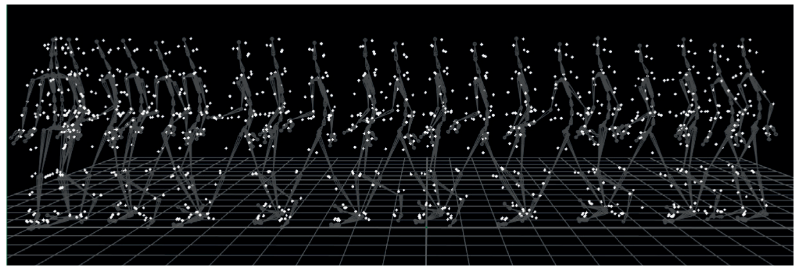


Figure 2- Mocap session; walking motion captured (selected frames)

Étienne-Jules Marey, in his book Animal Mechanism: A Treatise on Terrestrial and Aerial Locomotion (1874), describes how it is only possible to know matter by its properties, one being inseparable from the other. The word property being a construction of human language, Marey clarifies how for example, weight, heat and color express the way particular attributes of bodies in Nature, manifest themselves to human senses. A phenomenon occurs when matter changes its state, Marey adds, "(…) and by a new application of language we call the unknown cause which has produced this phenomenon, Force." (Marey, 1874:5)

Contrary to Eadweard Muybridge, who was first and foremost a photographer, Étienne-Jules Marey was a scientist. Marey's advancements in physiology predated his invention of chronophotography, and even Muybridges's first image of a horse trotting at full speed in 1872, or Muybridge's published ideas on animal locomotion in 1877. Although Muybridge proved that the horse's feet were entirely off of the ground in 1872, his work with animal locomotion expanded on Marey's previous work, through the medium of photography (Animal Locomotion: The Muybridge Work at the University of Pennsylvania, 1888).

Marey's approach differed from Muybridge's as well. Instead of using photography to depict the captured motion in a sequence of images, Marey used chronophotography and exposed multiple movements in the same photograph [1]. The chronophotographic gun, innovated by Marey, consisted of a revolving cylinder allowing for images to be captured at twelve FPS [2], a major influence on the development of the motion picture camera [3].

Professor and author Marta Braun, argues the reason Muybridge had success and recognition, while the public knowledge of Marey's work has remained confined, is in part because Marey's innovations are seen as a small part of the history of the development of photography, or because his images are only valued by their artistic quality. When Marta Braun started her research, she believed that Marey's name was connected with Muybridge's, as both were pioneers in photographing motion, with extensive influence in painting of the nineteenth and 20th century. However, when Braun started to research Marey's negatives and documents, she became gradually convinced that the formed idea of Marey's work was far from complete (Braun, 1992).

Although Muybridge and Marey's photographic work of locomotion was accomplished roughly at a similar time in Philadelphia, Muybridge was an artist conditioned by his visual heritage. Even if Muybridge used grids against which the figures were captured, his photographs have been misread. Rather than being scientific illustrations of movement, they are fictions. On the other hand, Marey's photographs could not be fully understood without the insight of his scientific aims, as well of his achievements in physiology before that time (Braun 1992:xvi).

Braun states that Marey's goal was to make the world visible through measurement. His graphing machines were instruments that had already proved to function in physics and mechanics, so he adapted his graphic method and instruments to trace the relation between time and space, measuring complex motion beyond what was possible to describe by language alone. With the introduction of a chonograph, Marey also introduced new models capable of analyzing the results from his instruments, that he called his schémas. His graphic method not only contributed to making physiology an exact science, it has allowed him to "(…) make visible the language of life itself." (Braun, 1992:22).

*"Like Leonardo da Vinci before him, Marey desired above all to make the world visible; only thus, he believed, could it be measured, and only through measurement could it be truly known. Marey's world was the world of motion in all its forms; its conquest was his greatest achievement." (Braun 1992:xvii).*

Stephen Mamber, a researcher and professor in Cinema and Media Studies recognizes Marta Braun as a large motive for the recognition of Étienne-Jules Marey's work. According to Braun, the previous view of Marey labeled him as 'pre-cinema', capturing complex motion with his chronophotographic gun, such as the movement of the wings of flying birds. With the exposition brought by Braun, Mamber argues that Marey's work shifted categories, and instead of anticipating cinema, Marey's alternative ideas of movement rather fit the notions of digital media. Ideas that, despite being repressed at the time by the type of cinema developed by the Lumiére brothers, still prevail to the present day (Mamber, 2006).

Mamber describes Marey as an "artist-scientist of space time", whose significant contribution was to produce tools that could capture the complex natural world in a particular way, that could be visualized, analyzed, and described in discrete

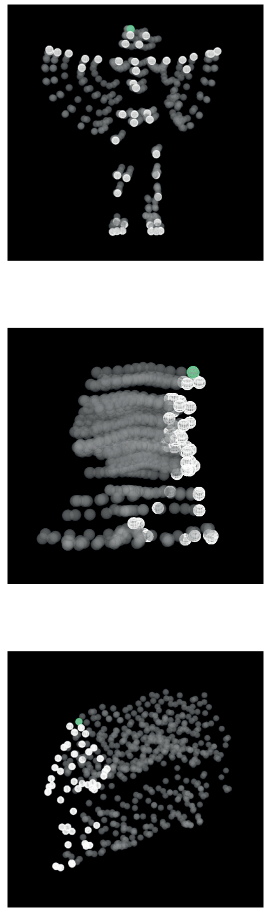


Figure 3 - Mocap points displayed in Maya with "ghosted" frames

Figure 4- Motion displayed inside the mocap volume, surronded by optical cameeras

intervals. Marey's interest in representing change, encompassed the depiction of movement, although it was not restricted to it. His approximation to digital thinking is clear in his goal of graphing sets of parameters, not only by registering captured data into x, y and z space axis, but also through time. The motion in time and space, represented through numerical calculus, allowed for the information to be transformed, rearranged and travelled through (Mamber, 2006).

Marey's use of photography, the author adds, was done particularly as a graphing technique. His chronophotographs did not intend to record the visible world, instead to reveal the hidden reality of nature. Through mapping the captured information into points and trajectories, which are measurable components, the observation of movements could be done without the interference of the physical volume of the body (Mamber, 2006).

> *"It is as if the idea of movement must be abstracted for the particulars which photography would make overly distracting. A process of visual reduction was needed to arrive at an essence." (Mamber, 2006:87).*

Not only was Marey aware of the potential and limitations of photography, as he also knew that the reconstruction of movement is not identical to just capturing it. Mamber points out that Marey recognized photography's main strength, was its ability to represent with enormous accuracy, although Marey considered it to be just one method of graphic representation among others. Marey considered the single perspective produced by the camera as a large limitation, and expanded his experimentation to the stereoscopic, using multiple cameras (Mamber, 2006).

## Motion Capture

The aspects of abstraction, reconstruction and stereoscopic photography are the foundations of contemporary motion capture technology (mocap). With mocap, sensors are placed on actor's bodies, and recorded by an array of cameras that capture the moving data into a computer, where the information is reconstructed into 3D space [4].

Today, live action is used through mocap technology to create digital animation, as a visual effect for films, such as The BFG (Spielberg, 2016), and Beauty and the Beast (Condon, 2017), or for realistic animated films, such as





particular episodes of Love Death and Robots (Miller & Fincher, 2019), created for Netflix.

Author Maureen Furniss describes mocap as a method that allows for real time animation to be created, through the use of sensors that display the movement of objects when recorded. However, Furniss adds that as a technique, mocap can be considered an evolution of rotoscoping, placing it closer to live-action, rather than to animation (Furniss, 2014).

She explains that despite mocap having been developed in the 1970s for military use, it has only more recently has become cost-effective and time-efficient, and started to be used at the end of 1990s for the production of animated television series, aimed at younger audiences (Furniss, 2014).

Using sensors on actors' bodies, motion is captured into computer data, and digital characters can be moved without the necessary intervention of animators. Despite the similarities, the key difference from the previous rotoscope technique, is that mocap can even move characters in real time.

Star Wars: Episode I - The Phantom Menace (Lucas, 1999), featured the first animated character using mocap, Jar Jar Binks [5]. Before that, the director Brad Silberling had intentions of using mocap techniques for Casper (Silberling, 1995), states the author Paula Parisi, in an article for Wired Magazine. Although there was the expectation that the extensive use of the technology would save production time, Silberling eventually changed his mind. Parisi, referring an interview with the film's digital-character supervisor Dennis Muren, explains that, after experimenting with the technology, they realized that a better performance could be achieved using animators, rather than using an actor in a mocap suit (Parisi, 1995).

Although computers and mocap systems have evolved significantly since then, and largely used in films such as Beowulf (Zemeckis, 2007), Avatar (Cameron, 2009) or the trilogy of The Planet of the Apes (Wyatt, 2011, Reeves, 2014-2017), blending the definitions of live action and animation, the methods are still very technical and often difficult to work with.

Standard mocap methodology for creating animation consists in retargeting (transferring) the recorded data from actors and performers to existing digital characters, providing them with movement. The motion is then polished and tweaked by animators, until the final result is achieved. The captured motion is mapped through controls and sliders in 3D software, in order to be retargeted to an existing 3D character (figure 5). The results can be edited and polished, however, while having a starting base for the performance can be truly helpful, mocap data can also be very hard to manipulate. The process of retargeting the data from the actor to a character

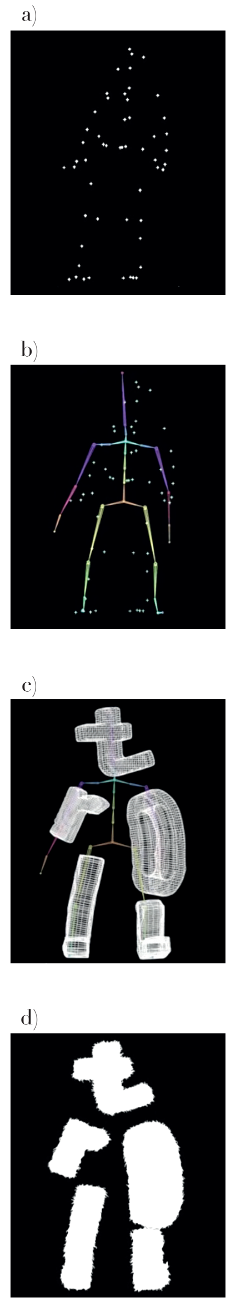



Figure 5- Troll (Borges & Megre, 2014), retargeting process

Figure 6 - Troll (Borge & Megre, 2014), frame from final film.


Figure 7- animated logo, Loopa; This is Pacifica

forces the animators to be concerned with matching the two together, rather than focusing on creating the actual performance.

In 3D animation, on the other hand, motion is created one key pose at a time. The animators articulate characters using keyframes, that are interpolated by the computer resulting in the in-betweens. Achieving good results, when using mocap and 3D animation, depends on balancing both methods.

In figure 5, it is possible to see the retargeting process for Troll (Borges & Megre, 2014). The project was created as joined collaboration of the design studio This is Pacifica, and animation studio Loopa, using the motion capture studio at the School of Arts of the Portuguese Catholic University, in Porto. The challenge was to animate a logo using motion capture, where the combination of naturalistic movement and abstract typography could produce the illusion of life. Here, animation is thought in terms of shapes as well as motion. Not being constrained by a regular physical human form, but rather creating more abstract visuals that can represent motion, inspired the creative process.

Figure 5 a) displays the original captured data, reconstructed from the 2D information recorded by the cameras that are placed around the stage, into digital points in 3D space. The mocap studio, features a Vicon system that uses optical cameras in combination with the software Blade, to record and process the data. The reconstructed points may have errors or missing data, resulting from occlusion [6], when the markers on the mocap suit become invisible to the system, *e.g.* when the actor rolls on the floor, occluding markers from the camera with his own body.

The markers were labeled with specific names, making them recognizable to the system. Then, a solving skeleton was attached to the markers in Blade, that helped to establish the position of the points, even when occluded, by estimating their positions relative to each other. Finally, the solving skeleton was retargeted to a





skeleton in Maya, visible in figure 5, b). The skeleton controlled the 3D geometry of the character, visible in figure 5 c) and d). The animation was then created on top, using a control rig, through animation layers in Maya. This becomes a highly technical process, as the mocap data is recorded onto every single frame, and interpolation often requires deleting data and reconstructing the movement by placing new keyframes by "hand".

With this standard workflow, the same final motion was used to drive both a more realistic version of the character, that was integrated with live-action footage, visible in figure 6, or the final flat logo silhouette, visible in figure 7, resulting in different visual languages.

Besides the original drawing of the typography, drawing was not used during the process of 3D animation and rendering. The only exception to this, were the drawings created to study the original motion of the actor Valdemar Santos in the forest (figure 8). As the mocap data was recorded in the studio, where the floor is flat, it was necessary to study the original performance in the forest. As the performances done in both places were not exactly similar, studies needed to be made in order to produce the desired results.

*"No one knows for sure why a pencil tracing of a live action figure should look so stiff and unnatural on the screen, unless there simply is no reality in a copy." (Thomas & Johnston 1981:323).*

Disney animators were conscious of both of the potential and limitation of rotoscoping live action footage. References were shot on camera and studied in detail, informing and inspiring their creative spirits while coming up with new ideas for their animations (Thomas & Johnston, 1981).

In a similar way, when using mocap, specific choices have to be taken into consideration to conceptually benefit the film, as using the data as reference for animation. Using dancers, musicians and actors in a technological space, one can record up to a millimeter in detail of the movement of a performance. As the captured data is saved within a three-dimensional virtual space, it can be played repeatedly, giving animators access to the expertise that specific performers have to offer. This opens up a channel for research and studying captured motion, providing new insights to the animators.

On one hand, studying the data captured from a mocap session can inform the creative decisions animators make, and be reflected onto different levels of their designs, from abstraction to greater realism. On the other hand,

Figure 8- Studies of the performance of actor Valdemar Santos

direct retargeting may produce uncanny results, as the Uncanny Valley term is used to describe an aesthetic experience, that characterizes visual dissonance and lack of appeal. As creating animation is a pursuit of believability, it is not a necessity to try to achieve realism, thus falling into the Uncanny Valley is avoidable.

As animation is a construction, from the choice of frames per second, key poses, figurative or more abstract, mocap should be used as reference, for poses, motion and weight. Also, it is possible to combine this information with other references, from photography and video, to drawing and illustration, and other types of art.

Author and animator Tom Sito refers that, although mocap technology considerably speeds up the painstaking process of animation, it is important to acknowledge that it is not a painstaking process for the animators, whom actually enjoy doing it (Sito, 2013).

Replacing the techniques of traditional 2D animation and computer generated 3D animation by mocap, may lead to what Sito calls the "uncanny hybrid". In this paradigm shift, artists are often hindered and discarded, and the technology gets repeatedly disproved and discredited by poor results. (Sito, 2013:199).

## Alternative Methods - Digital Sculpting

In the following method, we develop a process to create animation based on mocap data, without being restricted by standard practices that depend on retargeting mocap data onto existing rigged 3D models, allowing for visual expression and improvisation, while taking advantage of naturalistic motion and interaction with a three dimensional environment.

Achieving realistic animation is surely not dependent on technical processes, or specific mediums. A good example of this is The Red Turtle (deWit, 2016) directed by Michaël  Dudok deWit, where, despite the simple 2D stylized designs of the characters, their movement is natural and often realistic. And this is achieved without rotoscoping any live action footage (Amidi, 2017).

So, what methods can be used that take advantage of the best of both worlds? In which way can mocap be combined with animation? And what type of animation? Through experimentation, combining different techniques and approaches, while referencing real life, we are able to create bridges represented

Figure 9- Mise-en-scène (Borges & Megre, 2015) Experimental short-film using motion capture





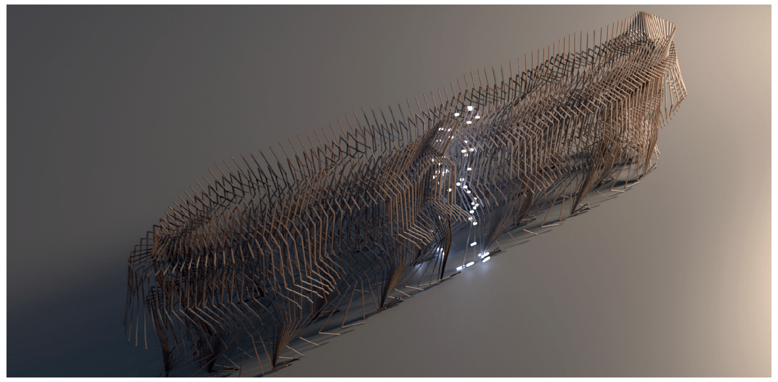
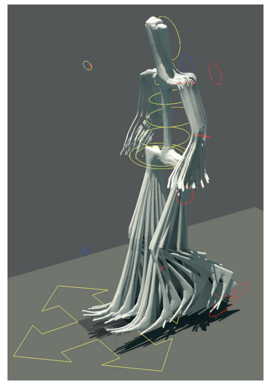


Figure 10 - Visualising motion through spheres and a simplified armature

by new visual imagery, that hopefully can inspire and contribute to the development of this artistic practice.

Our approach starts with building a structure connecting the original sensor markers onto a simplified figure, an armature. The markers themselves, are also isolated into small polygonal spheres, providing information on the positive and negative spaces.



Visualizing the data fosters the study of the figure in motion, from the timing of each action, to the spacing of each position, in a 3D virtual environment where lights and cameras are easily added to the scene. In this case, a simple walk was recorded at 120 FPS, converted into 12 FPS so the number of poses could be legible. Here, the motion can be edited or cut, timings can be adjusted and multiple clips from different takes can be put together. At this point, no retargeting techniques have been used. This means that the data recorded is not being applied to a 3D model of a different character, with different proportions.

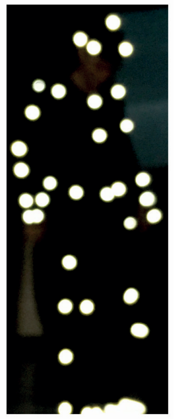
In a first iteration, polygonal cubes are controlled by locators that carry the data from the original sensors. By creating cubes, we work directly with geometry that will be sculpted, contrary to locators [7]. For this effect, faces of the cubes are connected, providing the structure for the armature represented in figure 10. Other types of structures are also possible within this process.

The main departure from standard practice, is that 3D geometry is used to build the points and the armature. Because of this, the polygonal geometry can be exported into a digital sculpting application, in this case ZBrush, and form can be constructed, as in the process displayed in figures 12 and 14. There, the armature is inflated, subdivided into smaller polygons for greater resolution and sculpted. The spheres representing the markers, provide information for the limits of the volume of the original actor.

A large limitation of this approach, is that it is very difficult to overlay

Figure 11- Armatures with control rig

a)



b)

c)

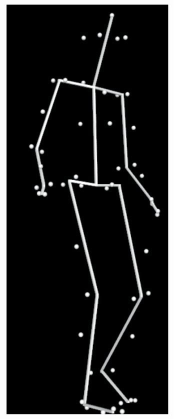


Figure 12 - a) Actor Luís Megre with markers; b) Digital locators and retargeting skeleton; c) Armature and markers made by polygons;

different poses, as they are spread out in 3D space. This becomes a problem when trying to sculpt similar poses in different times, or when creating interpolation of poses for in-betweens.

In a second iteration, a new armature is created and driven by a control rig, instead of the original locators, visible in figure 11. This rig consists of digital joints and deformers that can control and manipulate a 3D character. The rigging system is now driven by the locators, but it is possible to freeze its movement in space, for example in X and Z axis (left and right, back and forth) and allow only for the rotation of the limbs. This facilitates the overlapping of poses, speeding up the process of creating sculptures that relate to each other.

The rig is built featuring automation, and it can be easily reassembled for different characters with different proportions. The construction of the rig was recorded into actions, and transferred into a script that can be loaded into Maya at any given time. This offers the opportunity of quickly rigging characters, and also to open the code in a new document and edit it, or add new functionalities to the system [8]. The rigging system was built using multiple joint hierarchies. There is a joint hierarchy that controls the geometry skinned to it, and a second and third joint systems that control the previous joints. The second one is a FK (forward kinematics) system, providing only rotations to be used, particularly useful for organic motions, *e.g.* anticipation and follow through. The third system was built on IKs (inverse kinematics), and allows for the torso and head to be moved, while keeping the feet and hands locked onto the floor or walls. As the systems independently feed into the skinned joints, they provide stability to the animation system, without many of the glitches that often occur when a single system is used, resulting in internal conflicts of motion.

A third feature in the construction of the system is worth mentioning. The standard approach to rigging, is to use parent relationships for the joints, and constraint relationships for the connection of the joints and IKs to the controls. In our approach, mostly parenting was used instead. This means that the joints are almost always parented to the controllers, and not to each other. In terms of hierarchies, it can become hard to read and navigate through the system to troubleshoot problems, or add new features. Despite this, the use of constraints is heavier to calculate and slows down the performance of the playback, often resulting into lack of interactivity with the animation, as it has to be exported to video to be seen at its actual frame rate.

Our approach offers greater interactivity and allows for higher resolution models to be rigged, without slowing down the preview of the action. This is a crucial point, if one is to create heavy geometry as the result of sculpted models. Although





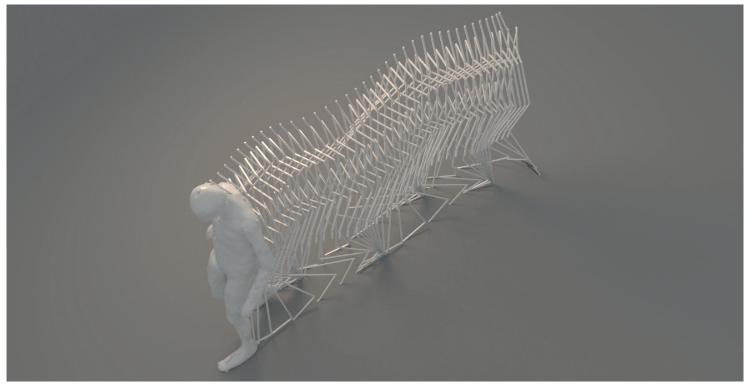


Figure 13 - Walking man (2020) Digital sculpting from mocap data

it is possible to export the details of the sculptures from ZBrush using texture maps, as normals and displacements, this approach provides the opportunity to more easily test the deformation of the sculpted detail when animating.

At the end of the sculpting phase, all the different key poses were displayed at their correct time. As the motion in space is unlocked, the sculpted forms are moved across the space (figure 13). An advantage of this method is that, the control rig created is built the same way as it would be for creating standard 3D animation. So eventually, all the key poses could be easily manipulated, and in-betweens would be automatically updated. This concept is further developed in the next chapter.

Having digital sculptures driven by a control rig, differs from the method usually used in a 3D animation, where a T-Pose model is articulated, by presenting the opportunity of creating form at specific poses, that might vary significantly from one another. Additionally, one can still control the display of the digital sculptures and the armature, that can be turned visible at their given time, or at a different one. This allows to illustrate motion and contributes to the final visual design of the animation, displayed in figure 13.

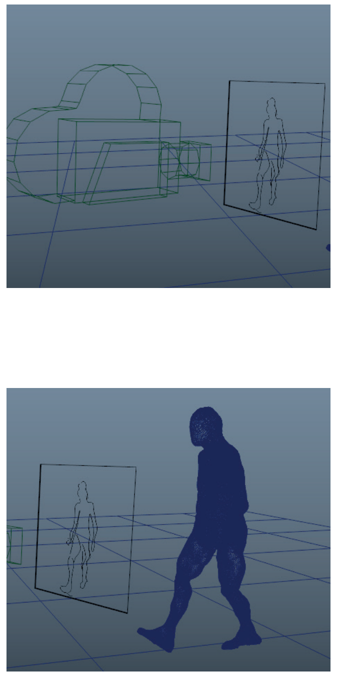
## Alternative methods - 3D drawing

While mocap is bound by physics and naturalistic movements, animation can be exaggerated, weight and force can be conveyed, rather than imposed. Both differ aesthetically but neither the approaches of mocap nor 3D animation, take full advantage of 2D animation methods, where drawings dictate shape, form and motion at the same time. In those cases, the characters can be designed for the movement they perform in particular shots. This also opens up possibilities for more experimental approaches, where abstraction can more easily exist.

a)

b)

Figure 14 - a) Armature inflated and subdivided; b) Final form sculpted



Our approach using 3D drawing, combines the different disciplines and allows form to be created for each key pose, using digital sculpting tools for development and motion capture as reference. Then, poses can be interpolated so the method is still interactive allowing for experimentation [9]. Using drawing from the mocap data as the starting point, allows for greater understanding of the poses by studying the human figure in motion. This creates new opportunities for designing the animation, regarding shapes, forms and movement. A balance between the original performance and the final animated performance plays into both the aesthetics and techniques used.

Authors Kitagawa and Windsor refer that, while mocap is a fast way of generating human motion in the computer, it does not replace 3D animation, nor is it always the best approach for a project (Kitagawa & Windsor, 2008). On the other hand, why use animation at all and not just mocap? Artist and researcher Brigitta Hosea defines animation as an artificial construct that could not be created in real-time (Hosea, 2012).

*"Although the animated character lacks physical presence, its very immateriality raises fascinating questions about the site of performance in animation, of notions of the animator as a performer and that, in the eyes of the viewer, an artificially constructed animated character is giving a performance." (Hosea, 2012:33).*

Hosea highlights the complex notions that surround performance in animation, and its relation with the audience. On one hand, it is clear that the animators are who create the performance, by combining their own ideas, feelings and emotions, with the movement of their characters. On the other hand, the constructed character never actually comes to life, lacking the physical presence that the author refers to (Hosea, 2012).

This concept of immateriality, is the essential place of action for the animator. If, through the performance, that immateriality is not filled with something that the audience believes in, then the illusion is lost. This is why animation is not created in real-time, the animator needs to construct the performance, that will transform the character's immateriality into something apparently real.

Although the method of creating digital sculptures from mocap data is a step forward in defining the performance visually, the method lacks spontaneity in building the figure and designing shapes can be challenging. Adding digital

Figure 15 - Drawing in Maya through a camera's perspective





drawing to the process allows for gestural design, giving the animator more space to interpret the original performance, and more flexibility designing shapes and motion simultaneously.

Animation teacher and author, Sahra Kunz, indicates that by being able to use drawing as a tool, the animator can express and define ideas in terms of character and composition (Kunz, 2013). The author adds,

*"Besides looking at drawing as a tool, one must also look at it as a graphic style or language. This means that apart from being used to develop ideas, drawing can be a personal form of expression, visible in the final format of the film." (Kunz 2013:51).*

Drawing is often used in 2D animation as a means of delivering both composition and performance of characters, similar to 3D animation or stop-motion. Despite this, the way drawing is applied to animation, can invoke additional content and expressivity, as Kunz points out. This forms a particular vocabulary, or language, that itself is used to communicate the story. In this sense, using drawing for animation can benefit specific ideas and communicate stories in a unique way.

So, how can drawing be combined with the previous method? One option is to use Maya's Pencil tool, that draws creating NURBS curves, to draw directly inside the computer program. Despite this being a possibility, Maya has limited options for drawing in three-dimensional space. To draw from any angle on the figure, requires for the drawing to happen on a two-dimensional space existing between the camera and the 3D model.

In an alternative method, the mocap data is sent to the 3D application Blender, that recently has being improving a drawing tool called Grease Pencil [10]. This allows to draw directly in a 3D space, although it also has limitations that will be addressed in the next chapter. Despite the constraints, in Blender one takes advantages of being able to manipulate digital lines, using their vector characteristics, applying modifiers, using different camera perspectives to define the volume, and most importantly, converting them to 3D geometry.

Once the lines are drawn, they can be moved in space to better represent the figure's volumes. Lines can also be connected to create planes, facilitating the design of shapes, or can be converted to 3D geometry by being applied thickness.

By combining the armature with the 3D lines and using them on a sculpting application, the process can be further developed. The armature provides the interior structure of the figure, the points from the sensors suggest the limits of the volume,

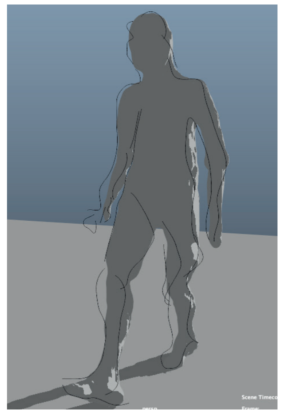
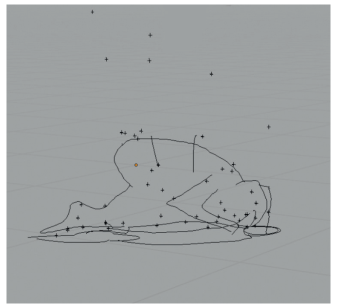


Figure 16 - 3D lines and digial sculpture combined



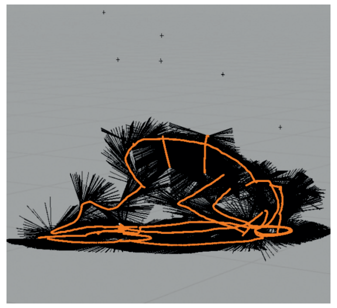


Figure 17 - 3D drawing in Blender, using Mocap as reference

the lines from drawings define shape and intent, characterizing the performance from the animator's point of view, adding new poses with relative ease if necessary.

Author Nancy Beiman points out that not all scenes are possible to act out, in order to create references for animation (Beiman, 2010). In this sense, being able to use digital sculpting and drawing from mocap data shows to be a great improvement, if one wishes to build up visually on the performance. This could be to exaggerate something that it is there, or to add something that is not, as weight, forces, or anything the mind wishes to imagine. Mocap offers detailed three-dimensional references, a great resource for studying the human figure in motion.

For expressive animation, where the drawing actively defines the character's performance, mocap can provide useful references to be studied and applied to concepts related to particular storytelling. The methods introduced are further developed in the next chapter, where they are exposed to a wider range of motions and problematics, allowing us to detect possible improvements and advantages, as well as limitations over alternative techniques.

Animation director Richard Williams offers a good perspective on the topic, even if it is not related to mocap per se. Artistic tools are just tools, in order to be properly used, nature and reality have to be studied first. If not, creating something new will most definitely fall short (Williams, 2001).

> *"Good drawing is not copying the surface. It has to do with understanding and expression. We don't want to learn to draw just to end up being imprisoned in showing off our knowledge of joints and muscles. We want to get the kind of reality that a camera can't get. (...) But don't confuse a drawing with a map! We're animating masses, not lines. So we have to understand how mass works in reality. In order to depart from reality, our work has to be based on reality." (Williams, 2001:34).*

Author Paul Wells, referring to Chris Landreth's short-film Ryan (Landreth, 2004), expresses that the more artistic and maverick types of projects are the ones that move the art form forward. These types of projects, due to their ability to experiment and produce alternative results, are the ones that move away from the mainstream system (Wells, 2006).

Referring to Jan Svankmajer's stop-motion work, that features a more experimental and conceptual approach, Wells expresses Svankmajer's films not





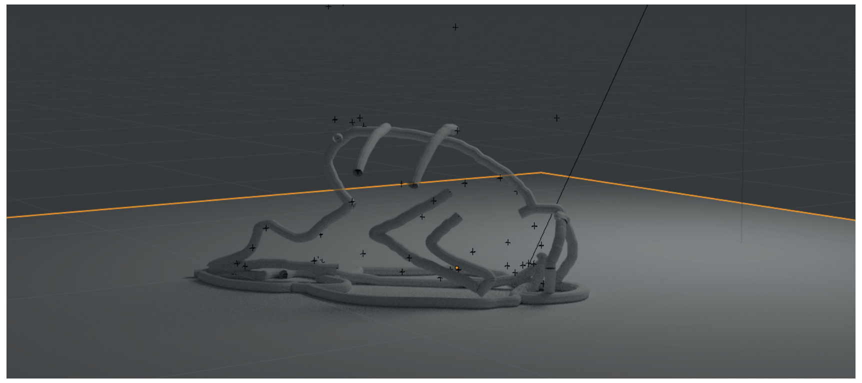


Figure 18 - Lines converted into geometry in Blender

only result in novel visual developments, but more importantly, in the possibility of alternative narratives (Wells, 2006).

The goal with our case-studies, produced as practice-based research, is to conclude how experimenting with different computer techniques can be useful for the construction of particular visual languages, and how these constructions can be at the core of the creation of alternative narratives as well.

> *"An information space, a database, a toolkit, a storage device, a set of interfaces - are we talking about Marey's nineteenth century or our own early twenty-first century? (...) Motion-capture is Marey brought to the digital, and one waits expectantly for uses of these methods for purposes other than to produce cheap animation by capturing the motion." (Mamber, 2004:89).*

As author Steven Mamber refers, the work of Étienne-Jules Marey not only represents movement through a diversity of methods that resemble digital techniques, such as mapping and graphing techniques, but represents as well an alternative approach to capturing the figure in motion. Movement relates to energy as part of something larger, in a similar sense as visual elements in live-action film, *e.g.* shot size, relate to style. In such manner, mapping range and duration of motion serves the large purpose of understanding animals and humans (Mamber, 2004).

Mamber adds that capturing bodies in motion, in Marey's perspective, means reconstructing and rediscovering the original movement, and as it is reconstituted, the knowledge necessary to understanding it is constructed as well. In the same way that animation necessitates the study of motion to be created, "modeling the world means acquiring, measuring and re-presenting it." (Mamber 2004:89).

## End Notes

[1] Images and additional information of Marey's chronophotography at The MET website: https://www.metmuseum.org/art/collection/search/265094 (last accessed 01/02/2021).

[2] Details about chronophotography is article by Allison Meier (2015) on Hyperallergic's website: https://hyperallergic.com/197464/the-scientist-who-shot-his--photos-with-a-gun-and-inspired-futurism/ (last accessed 01/02/2021).

[3] Relation between chronophotography and motion pictures on the National Museem of American History's website: https://americanhistory.si.edu/muybridge/htm/htm_sec1/sec1p3.htm (last accessed 01/02/2021).

[4] Article about different mocap systems by Seymoure (2008) on FXGuide website: https://www.fxguide.com/fxfeatured/demystifying_motion_capture_technique/?highlight=motion%20capture (last accessed 01/02/2021).

[5] Article about the development of Jar Jar Binks by Ian Failes (2019) on Befores & Afters online magazine: https://beforesandafters.com/2019/05/24/jar-jar-binks--was-nearly-a-practical-suit-and-a-cg-head/

[6] Not to be confusion with occlusion in rendering.

[7] Although locators provide with three-dimensional positions in space, they are not geometry. Thus, they need to be connected in order to be manipulated with modeling tools.

[8] Although the system is not yet ready for being made available to other Maya users, the goal is to make the rig an open source tool in the future, for artists and technicians to use and modify freely.

[9] This particular issue is developed in the next chapter 3.2. Moving Bodies (page 168).

[10] More information about the grease pencil on Blender's website: https://www.blender.org/features/grease-pencil/ (last accessed 01/02/2021).

# 3.2. Moving Bodies

*“This is the story of the blocked human form where the bending, twisting or turning of volume gives the sensation of movement held together by rhythm.” (Bridgman, 1924/1971:vii).*

In this chapter, we address how drawing in 3D can be used as an alternative to existing mocap workflows, in the production of 3D animation. Firstly, drawing concepts are approached and related to hand-drawn animation. Secondly, through experimentation, animation and drawing principles are explored using motion capture as reference, from which the animation workflow is developed. Lastly, the workflow is extended for the creation of the visual development and animation of a short-film, Out-of-Balance (Megre, in development). The short-film was conceived as result of the ideas presented in this chapter and the previous one.

The particular aspect of studying bodies in motion, is the main inspiration for the development of the ideas presented here. The moving body, both physically and emotionally, can inspire the creation of stories that are influenced, or suggested by actors’ performances. This is the motivation for our main research project, where drawing methods are developed in 3D, using captured motion as reference. From this motivation, mocap sessions were recorded, drawing studies from live models, from photographs, and from imagination were done as well. From the research, the idea for a short-film was born, resulting from the recordings of a particular mocap session, as drawings began to be made from it.

Artist George B. Bridgman, painter, teacher and author on the topics of artistic anatomy and figure drawing, defines blocks as the fundamental construction elements when drawing the human figure. From the possibilities within the relationships of these structures, Bridgman creates the sense of motion and rhythm, when drawing the figure. He expresses that this approach has the goal of stimulating the study and research of the hidden framework of the human body, as well as the intention of inspiring students and readers to

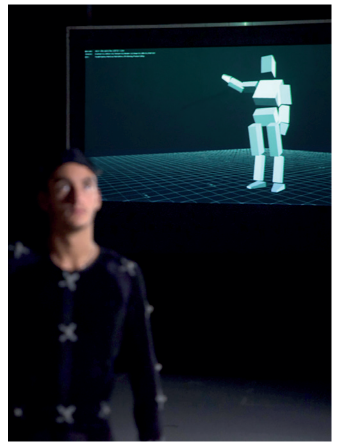


Figure 1 - Mocap session displaying the figure as blocks; Performance - Luís Megre, photography - Bernardo Rangel

Figure 2 - Untitled Figure (2020); Drawing from live model session

"carry on to independent and better ideas." (Bridgman, 1924/1971:vii).

Bridgman specifies that the first step in producing a drawing from life, is to have a precise mental conception of what it is to be drawn. A model can be studied from different angles, action or inaction can be considered while forming a mental image, and marks can be drawn onto paper, while considering the proportions of the figure and the balance of the composition (Bridgman, 1924/1971).

For the actual representation of the drawing, the author considers rhythm as being the main goal. As poetry and music only exist by virtue of rhythm, in drawing and painting, elements such as outlines, light, shadow and color, are also established by rhythm. And in order to express it, artists must consider the balance of the blocks and volumes, the relationship between passive and active sides of the body in action, and the dynamic correlation in symmetry (Bridgman, 1924/1971).

Bridgman describes how, in figure drawing, the eye of the artist follows either a line, a plane or a mass. Despite the construction of the drawing being made from lines, the mental image that is created should conceptualize masses first, planes secondly, and lines only at the end. In such manner, the author suggests one should think about masses and construct them in lines. As the masses interlock and relate to one another, wedging occurs. The blocks used to conceive the main masses of the body, may be bent, twisted or turned in space, representing the balance of the figure when in action or rest. As the spine is the main structure that connects the three fundamental blocks, head, chest and pelvis, its limitation of articulation dictates to a large degree, the range of motion of the entire body. The muscles support this range of motion and can be represented by lines of contour and by wedges that describe how they interlock (Bridgman, 1920/1973).

Figure 2 displays a study from a life model, using pen and ink. With a light brush, markings and general proportions were firstly laid out, indicating major





shapes and forms, as well as the rhythmic gesture that relates the bending, twisting and turning of volumes, creating squashing and stretching on active and passive sides of the body. With a darker finer pen, contour lines were drawn to accentuate the outline and the wedging that occurs from overlapping volumes. Finally, by mixing both brushes, darker outlines were drawn to accentuate shadow areas and details at the intersection of different surfaces, or to represent the turning of forms.

## Hand-Drawn Animation

Artist and figure drawing teacher, John H. Vanderpoel, articulates that in order to successfully depict the human body, either in drawing or in other artistic medium, artists must have a "lean sense of construction" (Vanderpoel, 1935/1958:11).

As the construction of the figure can be so complex, due to its diverse beauty, character and action, knowledge of its intricacy is not enough for a noteworthy representation, Vanderpoel expresses. An exhaustive understanding is necessary, in combination with the practicing of simple execution, to apply the knowledge to an artistic end. The result application of the structure's knowledge, awareness of action and character, depends upon a thorough period of academic study. The author points out that, if one wishes to successfully render the figure, light and shadow, color, values, tones and composition can be studied independently, and in depth (Vanderpoel, 1935/1958).

> *"Great skill in draftsmanship is highly desirable, but the student should be warned not to give it his sole attention for too long a period. He should test his skill and knowledge by memory drawing and by applying them to composition." (Vanderpoel, 1935/1958 :135).*

Although the pursuit of great skill is necessary, Vanderpoel adds it can also lead to the danger of artists being fascinated with insignificant detail. The first priority when drawing, either from life, memory or imagination, is to represent and accentuate both the action of the figure, and the main shapes and forms that describe it, while keeping a clear mental image of the composition (Vanderpoel, 1935/1958).

When studying artistic anatomy for the creation of compositions, either when drawing images from imagination or memory, or when drawing animation, it is necessary to consider both the construction of the figure and the meaning of action. If not, the composition can be lost in details that do not bring additional

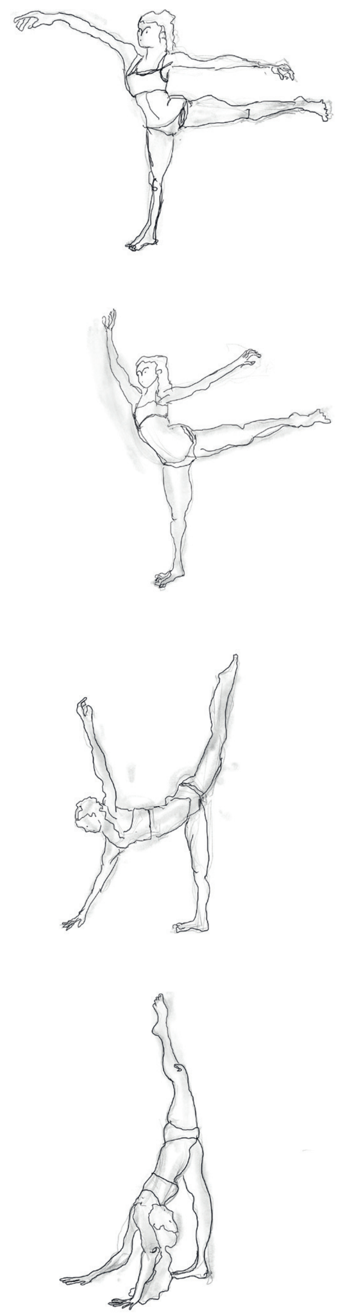


Figure 3 - Girl Falling (2020), digital 2D animation

Figure 4 - Girl Jumping (2020), digital 2D animation

meaning or significance. In hand-drawn animation, as the moving line represents the moving body, its expressivity can encompass the meaning of motion as well. In this sense, with 2D animation, the rhythm of the moving line can be designed for the composition, in addition to the construction, controlling the overall expression.

Figure 3 displays Girl Falling, a short 2D animated sequence, created with Procreate on an iPad, using the Bodies in Motion website as reference [1]. On this website, hundreds of motions and 3D scans of athletes and performers are archived and available for study and research. As the sequences of high-resolution photographs are recorded between fourteen and sixteen images per second, the human anatomy is displayed in action with high detail.

For the creation of this sequence, the Principle of Animation, Straight Ahead was used, where drawings were simply created one after the other. In each drawing, lines were firstly drawn with a soft and light brush, providing the proportions of the figure, as well as placement and composition within the canvas. With a finer soft brush, outlines and details such as the features of the face, center lines and fingers were drawn. Lastly, the construction lines were mostly erased, becoming barely visible, and the final drawing was created, using a dark brush. Using the onion-skin option [2], additional drawings were turned visible, and the feature was used as a guide to place new construction lines, as well as the final drawing for each pose. With the Straight-Ahead approach, the animation was created in a more improvisational style, where lines follow structures more loosely.

In figure 4, Girl Jumping, illustrates a Pose-to-pose approach, instead. This method provides more opportunities to relate Animation Principles to the main poses of the action, such as Squash and Stretch, Timing, Slow in and Slow out. Using another example from the Bodies in Motion website, a study of the key poses was done first of all. Akin to the previous case, a large soft brush was used for the study of the key poses, helping to compose a mental image of the animation and to structure





the proportions of the figure.

The concepts displayed in the key poses, namely Timing and Spacing, Squash and Stretch, Anticipation, Follow-Through and Overlapping Action, were transferred to the creation of a bouncing ball, represented in figure 5 a). Here, the ideas were further developed. Once the action was clear enough, those ideas were applied back to the animation of the figure, and in-between poses were designed. This methodology helps maintaining the overall structure of the masses of the body, as they are deformed through motion.

A loosened treatment was kept when drawing, resembling the one used in Girl Falling. These loose drawings were further developed as a concept, reflecting on the notions of development animation (combining both orthodox and experimental approaches) and the plasmatic quality of animation, covered in previous chapters. These ideas were elaborated to create a dissipation at the end of the sequence, playing with concepts of abstraction and believability.

As the drawings were cleaned and polished, throughout multiple sessions, onion-skin was extensively used in order to approximate the look of the drawings, and to develop the overall expression of the animation.

Artist and author Ron Lemen, known for his instructional articles and videos on artistic anatomy, highlights the importance of practicing, in an article published in How to Draw and Paint Anatomy, a publication featuring various art instructors by the editor, Clair Howlett. Lemen tackles some fundamental issues in figure drawing, such as drawing center lines being as important as to bringing "the manager along to the big game", or similar to Bridgman, drawing blocks and shapes with edges and corners first, in order to represent organic forms (Howlett, 2012:26). Lemen also focuses on the significance of practice figure drawing regularly, as it provides artists with the ability to "perform with clarity" (Howlett, 2012:21).

In the same publication, Marshall Vandruff, artist and teacher on topics of art and storytelling, expands on the notion of visualizing the drawing, in order to create figures from imagination, as well as observation:

> *"Whether you draw, paint, sculpt, model or animate, basic knowledge of anatomy and form will enable you to get your ideas into images. When you create any animal you see in your mind's eye, that's mastery." (Howlett, 2012:59).*

Vandruff adds that, the secret to mastering human and animal anatomy for

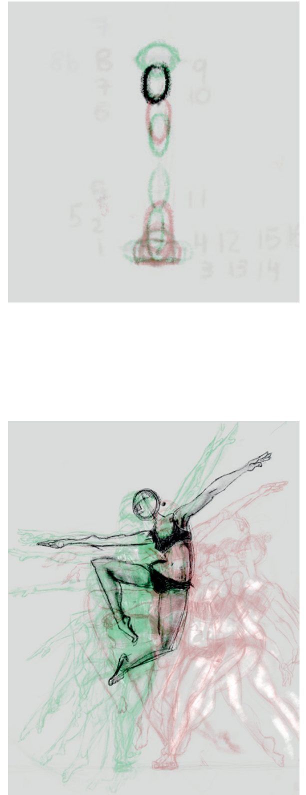
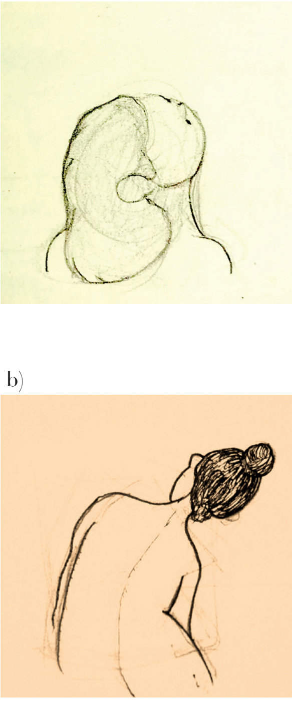


Figure 5 - Onion skin display in color the previous and following drawings from the current one




inventing figures, is firstly to be able to represent simple forms through drawing, such as spheres, cylinders, and blocks, and then combine them into more complex structures, resulting in three-dimensional figures in a three-dimensional world [3].

On one hand, drawings can be produced as the final expression, where the ideas conveyed in the drawings relate to the action and intent of the scene, as well as the visual style and vocabulary, essential in the creation of the language in which the rules of the particular animation will operate. On the other hand, drawings can also be used as mediation, relating the hidden structures of shapes, forms and actions, to the final drawings that express character's feelings and emotions.

The repetition of exercises and the practice of figure drawing in various forms, is essential in developing both the expressivity of the drawing, that can relate line, values and color, to composition and storytelling, and the more general medium of drawing, where it can be used to construct particular concepts and ideas, and apply them to any other medium.

## Experimentation

Motion-capture in the computer animation industry is mostly used through retargeting methods. Despite this, the original data that is actually recorded, before being transferred to digital characters, only consists of points in space. Retargeting workflows feature their own sets of problems and constraints, that can be addressed through software processes, using algorithms to transfer information between actors and characters, by joint systems and complex rigs.

Alternatively, the recorded points can be simply used as references, in a similar manner as markings are used when drawing. The points are not confined to retargeting methods, instead they can be used to plan the animation by helping to create a mental concept, as one studies the rhythm of the moving figures.

For our research, besides the drawings from life models and 2D animations from photographic references, additional drawings were created from imagination, and motion capture sessions were recorded as well. These specific drawings and mocap recordings, both experiment with animation principles and drawing concepts. The results were later used to develop the story for an animated short-film, Out-of-Balance (in development).

Through drawing, studies were done inspired by principles such as squash and stretch, anticipation and follow through, balance, twisting and turning of the

Figure 6 - Sketches from imagination (2020), using animation and figure drawing principles





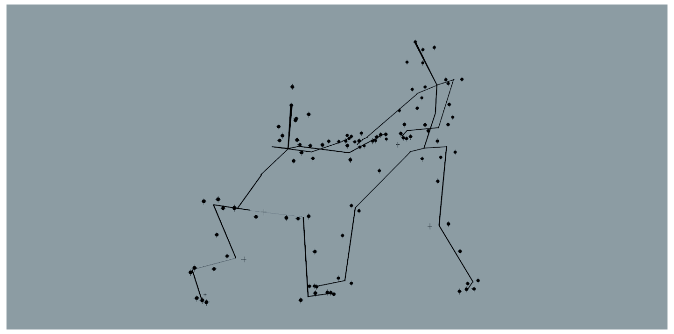


Figure 7 - Actors Sandra Ribeiro and Miguel Gomes, performing balancing movements. Mocap data represented by markers and armatures

figure were done. In figure 6, sketches done from imagination reflect on force and rhythm, through the principle of squash and stretch, where one side of the figure compresses as the other extends.

Regarding motion capture, a session was recorded at the School of Arts of the Catholic University in Porto, with the actors Sandra Ribeiro and Miguel Gomes, with the stage direction of Teresa Lima. For this particular session, experimentation with principles of animation and drawing were used, as a motivation for the actions of the actors. The animation and drawing concepts were the starting point of different motions, being interpreted and further developed by the actors, as displayed in figures 7 and 8. From those actions, improvisation and dramatic exercises were created, and emotion became visible through conflict.

The initial movements of the actors consisted of squashing and stretching, and twisting and turning exercises. These simple exercises were aimed to display the range of motion of the actors. Through drawing, construction and rhythm could be studied.

Secondly, the actors performed balancing exercises and together started to create a performance, based on pushing and pulling one another. Here, the previous principles could be seen in action, through more complex sets of movements. These motions, either to keep each other balanced, or to purposely throw the other out of balance, were the base of developing the story for the animated short-film. The conflict that emerged from these motions, where both actors had goals and obstacles, was the starting point of the creation of two main characters, Alice and Lewis.

Additionally, walking cycles and hide and seek exercises were recorded, and together with the previous actions were used as studies, references and inspiration, to create the narrative.

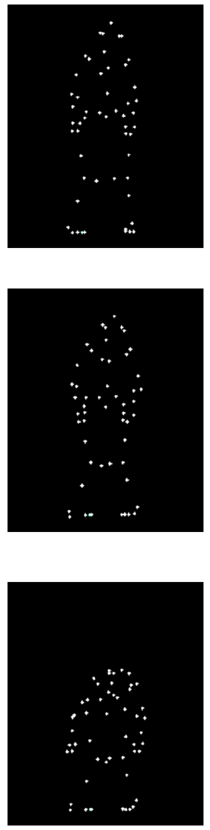


Figure 8 - Actress Sandra Ribeiro, performing squash and stretch movements

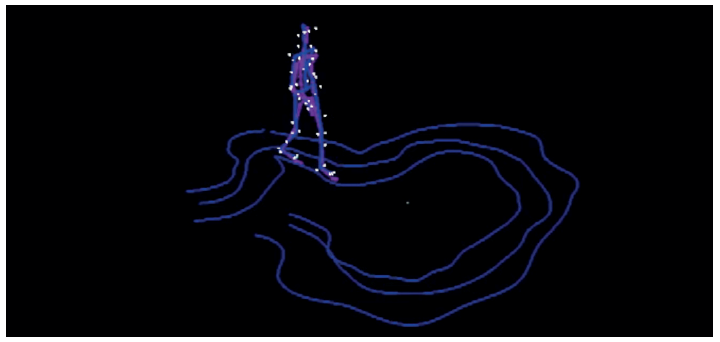


Figure 9 - Studying motion capture using drawing as mediation

Figure 10 - Studying motion capture using drawing as mediation

Mike Wellins, an artist, filmmaker and author of the book, Storytelling Through Animation (2005), points to the fact that both in live-action and animated films, half the development is scientific, either using cameras or computers, and the other half is artistic, where ideas are materialized in performance, composition and visual development. The technical aspects of computer animation can be laborious and complex, despite this, CG tools provide the possibility of profound inquiring and studying, which is not possible in the same manner with traditional media. The author adds that, as a consequence, innovation in animation is only possible with constant experimentation. Through experimentation, stories can emerge from compelling designs, produced with any visual medium (Wellins, 2005).

Wellins articulates that trial and error are essential to produce something yet unknown, as visual explorations are fundamental for the development of appealing visual stories. The essence of experimenting implies that there are no predetermined results, and that filmmakers can only learn through fortunate or unfortunate outcomes. This is a crucial point in discovering new techniques and to articulate and structure new ideas, as "(…) experimentation is the life blood of filmmaking and animation" (Wellins, 2005:74).

Wellins defines the expression 'mastering the critical eye', as a means to describe the critical brain, as it refers to awareness of important details, as well as the ability to relate those details with the overall picture. This can be in terms of performance and character animation, in its relationship with story, as well as in the overall framework of production. For successful filmmaking, a critical eye is necessary, one that is highly aware of visual elements such as timing, pacing, and consistency of style, besides being able to focus and direct the eyes and emotions of the audience (Wellins, 2005:74).

In this way, drawing can be used as a tool to explore, study and understand rhythms, paths and lines of action, that are recorded with motion capture. Working





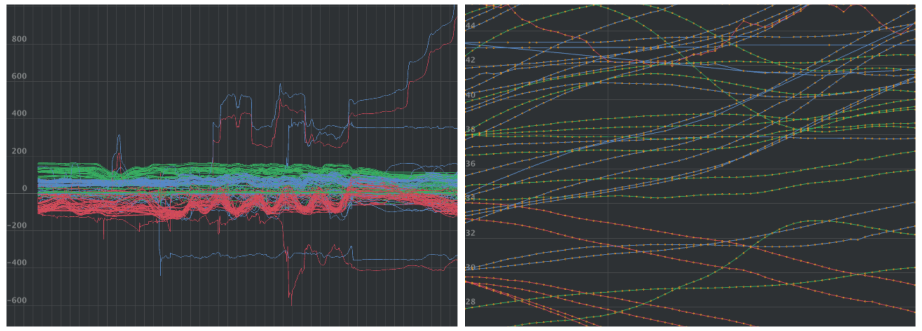


Figure 11 - Graph Editor with motion capture data

in a 3D environment, the space occupied by the performance can be studied as well, as can be seen in the examples of figures 9 and 10.

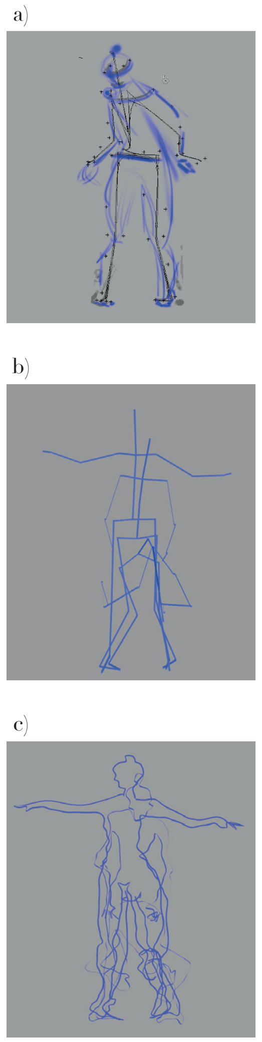
In figure 9, actress Sandra Ribeiro is trying to go around the actor Miguel Gomes, who is made invisible for this example, for the purpose of analyzing the movements of Sandra alone. Even with just one performer, the captured results can be dense and difficult to process intellectually. As the actress moves from one side to the other, lines were drawn using Maya, to display the different paths taken. Thus, drawing was not used as an expressive tool, but just as mediation between the performance and the 3D environment.

Additional experiments were also done using an iPad and Procreate. This approach is constrained by locked position of the camera, as the mocap data has to be converted into 2D images and imported as a sequence of images inside Procreate, as the example shown in figure 10. In this example, the rhythm and lines of action were studied through drawing.

For drawing to be used as an expressive tool, besides being used to study and analyze movement, an experimental method was developed that expands on the ideas from the last chapter, as well as on the ideas presented at the beginning of this one. The main goal of this experimentation was to integrate technology with movement and drawing, as well as to discover which methods within the 3D pipeline were absolutely necessary for this effect, and which ones could be discarded.

Firstly in the workflow, specific actions were selected from the recorded data and the file was cleaned, by deleting additional information that would not contribute to the final animation. As figure 11 displays, the recorded data from mocap markers onto the 3D locators inside the software is highly dense, as keyframes are created automatically for every frame, at 120 fps.

Secondly, 2D drawings were drawn overlaying key poses, indicating which




frames would be used for constructing the animation, as shown in figure 12. On one hand, the drawings done on top of motion capture data helped to interpret the actor's movements, on the other they could be used to diverge from the original reference, adding or changing information according to the ideas developed in the story. Afterwards, the drawings were cleaned up using the Pencil Curve tool, that placed new lines in 3D space. These new lines prepared the placing of the animation, as they could be modified in three-dimensions, using translation, rotation and scaling tools.

After experimenting with the Grease Pencil tool in the 3D software Blender, the Maya drawing tools were chosen instead. In figure 12, image a) demonstrates Maya's own Grease Pencil being used to sketch on top of mocap markers and the of the armature, image b) shows a selection of armatures that represent key poses to be used for animation, and in image c), final drawings are created using the Pencil Curve tool, resulting in 3D outlines.

As Blender's Grease Pencil has more features than Maya's drawing tools, such as softness and opacity, a combination of tools had to be used in Maya, namely Maya's own Grease Pencil and the Pencil Curve tool. Maya's Grease Pencil does not support 3D lines contrary to Blender's, although it features softness, opacity, and onion skins. Maya's Pencil Curve tool provides the means to draw in 3D space, although the line thickness has to be controlled using costume-built attributes.

Despite Blender's Grease Pencil taking better advantage of the 3D space and more successfully bridging the gap between 2D and 3D, the rigging tools and armatures were already developed at this point using Maya, making the workflow with Maya's drawing tools easier. Additionally, the process of exporting the lines from Blender's Grease Pencil to geometry in Maya was not as straightforward as the automated process that was eventually developed in Maya. In this approach, the Pencil Curve tool was used to create the lines, and a NURBS Circle was used to perform an Extrude operation, resulting in thickness and converting the result to Polygonal surfaces, displayed in figure 12c. As the number of CVs can be easily controlled, the 3D lines result in low-resolution geometry, that can be smoothed using Maya's Subdivisions. The 3D lines can also be exported to ZBrush, together with the armatures, and used to develop the 3D models for the characters.

Blender's 3D drawing tools use a set of parameters that help to guide the drawings, invisible 2D planes that occupy the 3D space, as frontal, side and top planes. A key difference from Maya is that the user does not have to use an orthographic view [4], the drawing can be created in space as the user rotates around it [5], although the tool settings have to be manually changed for the lines to occupy different 2D planes. Lines can also be placed in 3D space without the help of these guides, although the

Figure 12 - Maya's Grease pencil and Pencil tool





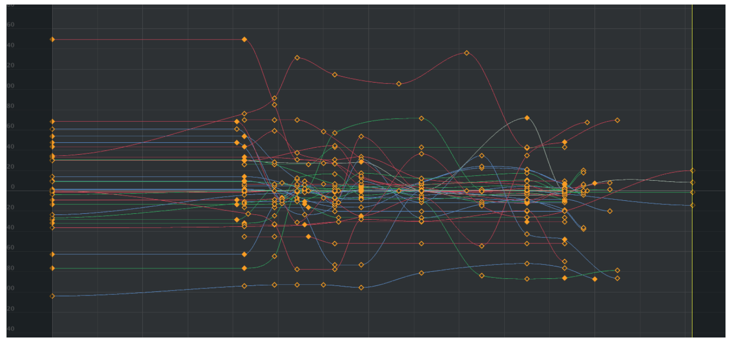


Figure 13 - Graph editor with animation

results are often not accurate as the software fails to understand the direction of the lines in depth. As an alternative, a similar method was constructed in Maya, using NURBS geometry as three-dimensional canvases for drawing, that will be covered more in depth in the following sub-chapter, Visual Development and Animation.

The armature can be generated from the mocap data, determining the main structure, proportions and motion of the character, although it can also be controlled by a rigging system. If the armature is to be driven by the mocap data, it requires retargeting to be used. Alternatively, if the mocap data is used to create just the initial proportions of the armature and control rig, then the rig can be used instead to articulate and animate the armature freely, without the constraints of retargeting.

This alternative application gives full control to the animator, that can pose the armature according to the 3D drawings. As the mocap data can be still displayed and interacted with, the rig allows to control and puppeteer the armature in 3D, and animation can be created using interpolation methods to experiment with different solutions of in-between frames, while referencing the original mocap data (figure 14).

As the rigged armature was not driven by motion capture, but by keyframing, timing and spacing could be changed easily, and new opportunities could be found to interpret the original action, in order to better fit the storytelling.

In figure 13, the final keyframes are displayed, together with the interpolated curves. The animated curves are significantly less dense than the original mocap data, as they were built one key pose at a time, based on the key drawings. Finally, the original line drawings were re-timed to represent the changes made during the animation process and exported into ZBrush to create

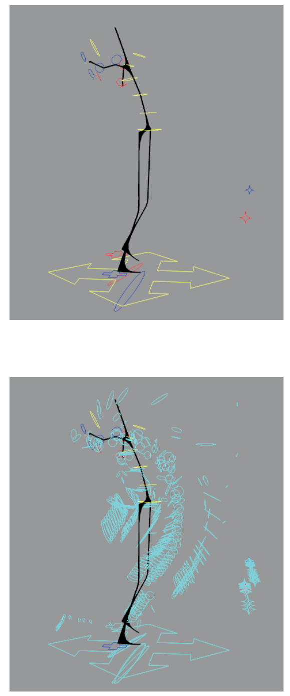


Figure 14 - Keyframe animation - rigged armature and 3D drawings

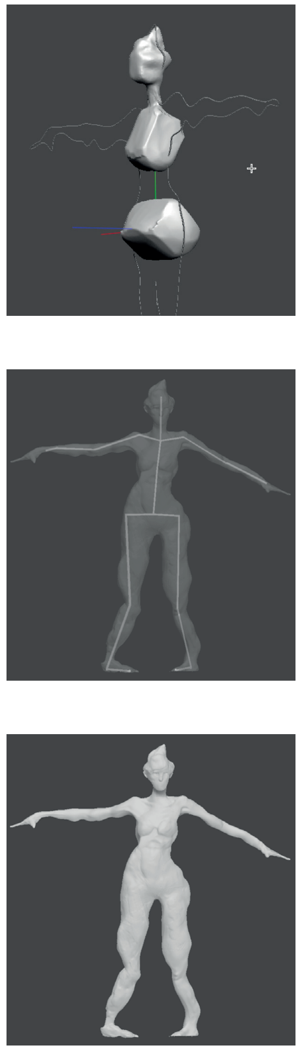


Figure 15 - Digital sculpting of early version of Alice in ZBrush

the volumes for the key poses.

Figure 15 displays the sculpted model for an early version of the main character, Alice. The outlines and armature were exported to ZBrush and used as guides to develop the form. Along with the surfaces from Maya, blocks were built to describe the primary masses of the figure, the head, ribcage and pelvis, and how they relate to each other. The secondary forms were constructed following the pose and gesture of the 3D lines.

If this method was to be used to sculpt all the key-poses of the animation, each key pose as well as all the in-between poses would have to be sculpted from scratch. It would be possible to interpolate the key sculpts, although this process would have to be done linearly. Not only was the animation made with the armature featured non-linear interpolation, in order to create Slow ins and Slow outs, but it also the animation was done using joints, that provide rotations for polygonal vertices in turn of an axis. Interpolating key sculpts would simply result in translation of those vertices, which is not the same type of motion.

Ultimately, this method would become identical to Straight Ahead animation, as each pose would have to be created independently. Digital artist Alexander Lee, uses a similar method to produce stop-motion animation using Maya and ZBrush, although Lee has developed a costume script to exchange 3D models between the different software and does not use drawings as starting point, but rather an existing 3D model [6].

Instead, the "T" pose sculpture is sent back to Maya, and skinned to the control rig, to be deformed with the already existing animation. This is close to Pose-to-pose animation. Only key poses would be sculpted and interpolation methods would be used to produce the in-between results.

This approach is very similar to the standard keyframe animation, as a model is animated using a rig, and corrective shapes are introduced to correct the deformation of the model. The main difference is that our method starts with 3D key drawings, and the animation is made using just an armature, abstracting the character's movements. As the key sculpts are developed to fit into the 3D drawings, often times this means deforming the geometry beyond the capabilities of the control rig.

For this effect, Maya features the Pose Editor tool, that enables animated poses to be adjusted through Blend Shapes. The Pose Editor main limitation is that Maya is not equipped with capable sculpting tools, in comparison to ZBrush. Alternatively to using the Pose editor, the interpolated results are sent back to ZBrush as independent models, one for each key pose. Here, the key posed models are sculpted to fit into the 3D drawings that were previously created.





The process of creating corrective shapes using ZBrush was one of the largest challenges in our research, as little information could be found on this matter. ZBrush did not support character animation, as an alternative, independent models for the key poses had to be imported instead.

Different models could be combined into the same tool in ZBrush, using sub-tools, although they could not be used to produce corrective shapes. It was possible to start with a model and use 3D Layers [7] to produce new versions, similar to Maya's Blend Shapes. There were in fact protocols in ZBrush to export different 3D Layers directly to Maya's Blend Shapes. The problem with this technique was that it was meant to be used as an exporting tool, but not as an importing tool.

Despite this, it appeared not to exist a well-documented method of importing several poses into different layers of a single 3D model, and export them back into the animated rigged model.

After extensive research, and trying different methods for exchanging corrective shapes, video tutorials by CG artists and instructors, Joseph Drust from Pixologic ZBrush [8] and Morten Jaeger from Flipped Normals [9] were used as a starting point for a new procedure.

Both references illustrate methods of replacing different posed models in ZBrush, while maintaining sculpted details from the previous versions, in the cases where the model's topology is identical. Jaeger additionally demonstrates how to record the model swapping into a 3D layer. This allowed for a T-pose model to be imported, and key poses added as 3D layers, where adjustments such as corrective shapes could be made.

Even though the importing aspect was solved, a second problem needed to be addressed to complete the workflow. The "T" Pose model in Maya was bound to the animation rig. Thus, the new poses were being produced by the deforming joints. As corrective shapes would be imported from ZBrush, intended to work as the new key poses through Blend Shapes, the T-Pose model would be transformed twice, resulting in incorrect deformation. To fix this aspect, different experiments were done to understand the correct exchanging method.

The final workflow consisted of importing the undeformed "T" pose model to ZBrush, and interpolated key poses to 3D layers, displayed in figure 16 a) and b), respectively. This allowed to switch between the different poses. The breakthrough implied creating an additional empty layer, where the sculpting for the corrective shape was recorded (figure 18 c)). When the layers of the key poses were turned off, the corrective shapes were applied to stand-in "T" poses instead, visible in figure 16 d).

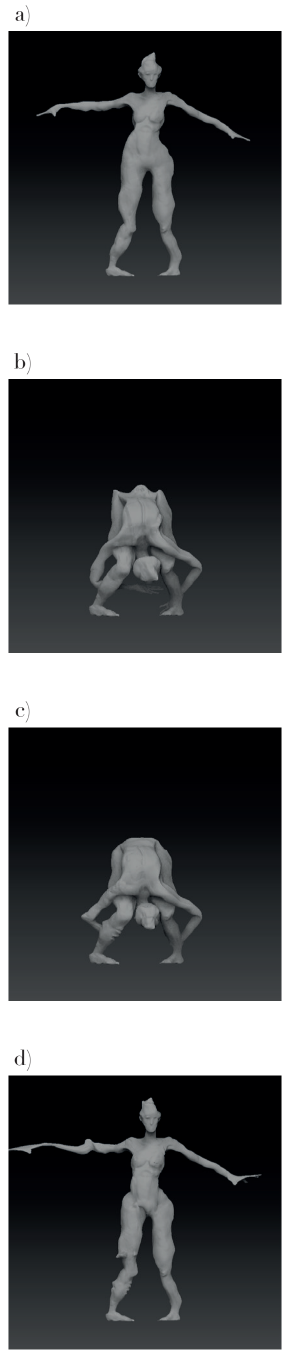



Figure 16 - Corrective shapes and stand-in T-pose

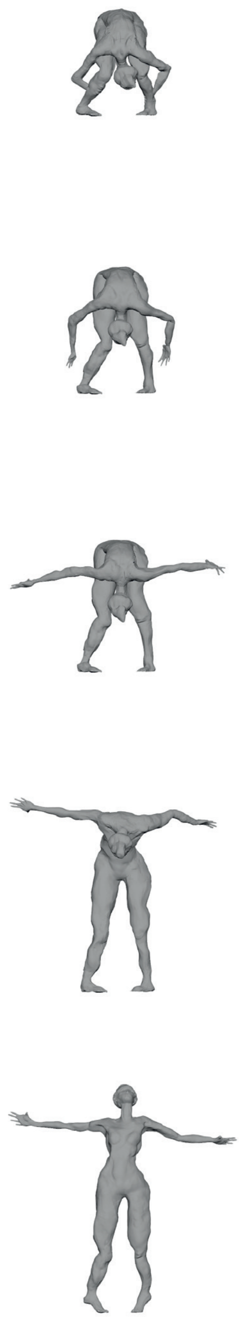


Figure 17 - Final key poses, using interpolation and corrective shapes via stand-in T-poses

Although the "T" pose appeared to be deforming incorrectly, it performed as expected when it was applied to the animated model in Maya. In the same way, all the corrective key poses were exported from ZBrush as strangely deformed stand-in "T" poses, following particular naming conventions, in order to be correctly plugged into the character model, via Blend Shapes. Finally, the Blend Shapes were keyframed, following the timing and spacing of animation of the rig.

As the animation and sculpting processes were concluded, lights and materials were added to the character's scene, different types of surfaces experimented with, creating distinctive looks. Figure 18 displays the various renders, from a more two-dimensional approach to a more three-dimensional. Outlines and shadows were created, using Arnold render to produce the outlines, with a Toon shader, and Renderman to produce the shadows, using a PxrSurface shader, visible in image a). The two different rendered images were then composited with Nuke, where the result from the PxrSurface was posterized, reducing it to only back and white values and merged with the outlines. In b) a clay-like material was developed using RenderMan, where lighting options were further explored, in their relationship to the surface, using the PxrSurface Shader and physical lights. In image c), color and value adjustments were developed in Nuke, setting up the mood for the story and performance of the character.

The results demonstrate the developed workflow, combining drawing, motion capture and 3D animation. As drawing dictated the integration of technology with movement, a particular pipeline had to be developed. For drawings to function as an expressive tool, mocap was simply used as reference, providing information about camera angles, proportions of the figure, composition, as well as timing and spacing of the action.

In order to avoid retargeting from mocap, a rigged armature was used to articulate the inner-figure of the character, displayed together with 3D drawings, as shapes and motion were designed together. Using 3D keyframe animation to pose and articulate the armature, benefited from the mocap data, that displayed motion through time and virtual space. Despite appearing extremely simple, this concept was key in relating drawings with 3D animation. As the rig was not confined by the retargeted data, the poses could be easily adjusted to follow or diverge from the original performance.

This flexibility was restrained by the necessity to produce the volume of the figure at the end of animation, contrary to the standard 3D animation pipeline, where models are created at the beginning. Although this was not an issue in the beginning, when producing the "T" pose model that would follow the





animated rig, it became one as corrective shapes were produced. As a solution, a precise workflow was introduced, using 3D layers in ZBrush and stand-in "T" poses that held the information for the corrective shapes. As the animation was already constructed, it was important that these corrective shapes could follow the interpolation created by the rig. If not, then all individual frames would have to be sculpted, one at a time.

The outcome displayed expressive forms in motion, as drawings established the visual language for the 3D animation. Mocap was used as reference, and interpolation was used to experiment with different rhythms of the action. The volume was constructed at the end, in a similar way to how shading is drawn in 2D animation, allowing for additional movement inside the volume itself. While the rig was driving the figure, the inner forms were additionally animated, as volumes needed to be preserved, using animation principles.

Although the pipeline for the film was established at this point, the final look needed to be further developed. The 2D visual results, with CG outlines and shadows (figure 18 a)), lacked the original expressiveness of the 3D lines, created for the key poses. The more 3D visual results (figure 18 b) and c)) were somewhat odd when moving, as the contour of the figure and inner volume did not always work together harmoniously.

Hand-drawn animation is expressive in such way, that it holds together visually even when a lack of consistency exists in the representation of the figure. As 3D models were generated from the lines, connected to produce the animation, and rendered with physically based render engines, the original expression appeared to be lost in the process, and produced less appealing results.

> *"Avoid all elaborate or unnecessary tones and do not make four tones or values where only three are needed. It is important to keep in mind the big, simple masses and to keep your shading simple, for shading does not make a drawing." (Bridgman, 1924/1971:73).*

Bridgman indicates that shading the figure is meant to help the drawn outline to produce the effect of solidity, width and depth. As the body is thought of general masses, unnecessary tones should be avoided, as they can withdraw from the impression of those greater forms, (Bridgman, 1924/1971).

Gottfried Bammes, an artist, anatomy teacher and author, conveys that in order to broaden his understanding of the exact nature of human body, he had


Figure 18 - Experimeenting with visuals using differeent rendering techniques

Figure 19 - New exploratory drawings with traditional media for Out-of-Balance

to pursue the extreme limits of simplification. Furthermore, by immersing in this combination of accurate knowledge with simplification exercises, one engages with the "essential and consistent preliminary work that is required to become artistically creative." (Bammes, 2011:X).

Bammes adds that, oftentimes particular details are rejected when depicting the figure, in fear of losing artistic unity. If this were to be justified, then exaggerating details could not have an artistic expression. The author clarifies that the role of artistic anatomy, is to correctly distill the nature of specific aspects of the body, so artists can "present an individual object in its most simplified form and assign its value within the body as a whole." (Bammes, 2011:11).

These were the ideas that were used moving forward, when creating the visual development and test animations for the short-film, Out-of-Balance.

## Visual Development and Animation

*"At its simplest, stories have a conflict at their basis whether overt, where one character conquers another, or the sublime, where a character whose conflict is with life in general. (…) Without it, a film or a play or an animation is just a series of incidents and events." (Wellins, 2005:24)*

Wellins alludes to the fact that storytelling has been with humanity for tens of thousands of years, that stories can be told in numerous forms, from songs and plays to books and films. At their core, stories feature a character in conflict, either with other characters or with the circumstances in life. Visual storytelling, the author adds, has the goal of moving beyond simple events, into "an interesting and compelling form that creates some type of emotional connection." (Wellins, 2005:25).

He adds that, the role of the director, even in the face of all possible challenges that may appear, is to use any tools and production materials to create "(…) the visual language to tell the story in the best way." (Wellins, 2005:94)

The script for Out-of-Balance was developed together with Pedro Alves, author and film teacher, and acting teacher Teresa Lima, stage director in the mocap recordings. Based on the performance of the actors Sandra Ribeiro and Miguel Gomes, the script evolved to tell the story of the characters Alice and Lewis.

Alice, the main character, becomes lost in a crowded space. As she tries





Figure 20 - Digital drawings done on iPad using Procreate

to find her way, she loses balance and falls down on the floor, helpless. Lewis, the secondary character that is passing by, tries to help Alice back on her feet. But the two become intertwined, in a dance where they try to balance one another.

The story was created as a reciprocal process between written ideas, captured movements, drawings and experiments done on the computer. As drawings became captured action, the actor's performance inspired the characters development. As the method for using drawing from mocap was established from experimentation, the design of the film started to be produced.

The story is meant to have a level of abstract representation, where the characters becoming interconnected with one another is paired by the visual development, as the story is told visually through animation. Because the results from experimentation did not use the drawn line in the intended expressive way, new visual experiments had to be realized. Figure 19 displays additional drawings, done in traditional media, developing the mocap ideas addressed in the previous experimentation process into new visual concepts. Figure 20 illustrates new designs for Alice, created with digital media, exploring the silhouette through a combination of line and shape.

In the documentary Inside Pixar (2020), an episode directed by Erica Milsom features Deanna Marsigliese, character art director at Pixar, addressing "the art of the pivot". Masigliese explains that when particular designs do not get solved as expected, in respect to the creative process, that artists must be able to pivot and approach problems in a new way. When development is stuck, the result from a blank page or from the challenge of trying something different, finding inspiration can be challenging (Milsom, 2020).

Masigliese refers that artists can find inspiration from taking a break, or changing to other mediums, in order to jumpstart the creative process again. As Masigliese uses different materials to pivot to new ideas, she invites these particular materials to be a part of the art that is being made. In this way, part of the control over the creative process is being given away, facilitating new inspiration to be found (Milsom, 2020).

As Masigliese has a background in animation, she often times starts the designing process for a character by asking the following question: how would the character move? By imagining the action that characterizes the design, she reverse-engineers the process and creates the final visuals for the characters. Despite this, starting a new project is always a new and different challenge, Masigliese adds:

> *"Every time you shift onto a new project, it's a whole new education. Every film is a classroom and you're just learning, learning, learning. A new design language, new character designs, a new style of animation. It's starting all over again." (Milsom, 2020:04"00m).*

The designs of the characters for Out-of-Balance, were set to explore the relations between details and whole figures, as expression of the story through its constructing elements. The creation of the concept for film was done on two fronts simultaneously, in the story and the in designs.

As the story was being developed, drawings and sketches were produced, and experimentation with drawing from the mocap data was done as well, resulting in the examples displayed previously. Once the method of drawing in 3D was established, solutions for the design of the film were worked on. The goal was not simply to create characters and backgrounds, instead, the intention was to find visual solutions that could be used to tell the story in the best way, while overcoming the visual limitations of the previous approach, produced during experimentation.

The fundamental idea that guided the project, was to draw from motion capture. On one hand, drawing would be used in a more literal sense, functioning as a tool to produce the animation from the mocap recordings. On the other hand, drawing meant retrieving the story from the actors' performance, that featured a tension where both try to keep each-other balanced. The drawn lines were thought of as the key visual element to bind them together, using a more expressive vocabulary, with the intention of supporting the story with subtext, created by different designs.

Figure 21 - First versions of drawings done using constraining lines for cross-hatching





Figure 21 demonstrates the first results, where characters were built from constraining lines, the key visual element for the articulation of the elements of the story. Furthermore, additional sessions had been recorded in the mocap studio of simple walking cycles. These recordings motivated the creation of additional characters, that would function as a moving crowd, building the space where Alice becomes lost.

Artist and author Sarah Simblet points out that, through the centuries, artists have undertaken on the intricate study of the human anatomy for a variety of reasons, as it can instruct on the topics of movement, articulation, gesture and pose, improving and evolving the way artists work. By looking through the outer layers, in order to describe the underlying components, artists invent what Simblet calls the "invisible body". This invention, not only can be used to give insight to the human machine that is created through the miracle of life, but also to give insight to "(…) the mysterious workings of the imagination itself." (Simblet, 2001:197).

Simblet continues, as the relationships between the exterior and interior body are drawn by artists, understanding of the structures can be created, as well as a specific visual language is developed. This grants artists the capacity to relate their speculation with observation and knowledge. In this sense, imagination is used to map and represent the invisible (Simblet, 2001).

> *"This is the freedom that Leonardo found in anatomy: His drawings are domains of imaginative speculation - a forum of ideas where art and science meet. The body remains essentially the same. Our knowledge, expressive language, and portrayal of it continually shifts and evolves to invent new routs of vision." (Simblet, 2001:197).*

Character designer and animator Tom Bancroft, author of the book Creating Characters with Personality (Bancroft, 2006), argues that creating characters for animation can be as difficult as creating realistic paintings. The fundamental issue is for artists to develop the knowledge of when to stop "working" a drawing, which can often be "(…) harder to do than to continue adding details." (Bancroft, 2006:27).

The main elements for designing characters are shape, size and variance, and by combining these elements, more complex shapes can be created. To create complex characters, these elements must be articulated, and by identifying the origins of the shapes that contribute to the design, artists can more easily re-create the character's drawings. Although simplification is used to create the designs,

Figure 22 - First versions of drawings done using constraining lines for cross-hatching

Figure 23 - Final version of Alice

*e.g.* juxtaposing curves facing straight lines, artistic anatomy is still essential for improving designs, as they will fall short if they are anatomically "off" (Bancroft, 2006).

In the introduction of Bancroft's book, former Disney animator and director Glen Keane, designer of iconic characters such as Ariel, for The Little Mermaid (Clements & Musker, 1989), the Beast for Beauty and the Beast (Condon, 1991) and Rapunzel for Tangled (Greno & Howard, 2010), describes the struggle present in every character creation. Keane explains that there are no solutions for an easy path, as for every design he creates hundreds of exploratory drawings, while working to achieve a magical moment where he recognizes the character he was looking for, staring back at him (Bancroft, 2006). Keane adds:

> *"This kind of search is personal and intense, so much so that great characters we create seem truly to live and breathe in our imagination. One of the great rewards of our craft is knowing that the close attachment we feel to our characters will be shared by the thousands who will believe in them as well." (Bancroft 2006:intro)*

Recalling the process of trying to find the design for the Beast, Keane expresses that any of the countless drawings he created, or any of other artists versions as well, could be the character he was looking for. Although, none of the versions truly represented the living character from the story. Only after several months, while trying to explain to an animator through drawings how the character would look like, the character suddenly appeared, as if he always existed and suddenly was visible on the paper (Bancroft, 2006).





Figures 23 and 24 display the final design of the characters Alice and Lewis. The characters were drawn with the intent of preserving the illustrative and expressive quality of the line, that is used in the film to represent their circumstances, conflicts, and inner feelings, in combination with their particular personality. Alice, in a way, is out of the box, as she becomes lost and does not fit with the crowd. Lewis, emerges from the crowd, represented by moving lines, with the goal to help Alice. The lines also express their inner body, and their design evolves throughout the story. Simple shapes were used to be able to recreate the designs from various angles and perspectives. This simplification, finding visual solutions for the characters, was done throughout an extensive period of discovery, through many different versions of designs.

Glenn Keane, interviewed by Mike Wellins explains in detail the different stages of developing characters for animation. When asked by Wellins what does inform him the most when creating his characters, he compares the process to meeting someone for the first time. There is a first impression that can be created from a particular way someone speaks, or dresses. Despite this, creating animation requires going deeper than the superficial aspects, Keane says. Those deeper levels are created by shared experiences, where personal aspects of the artists relate to characteristics of their created fictional beings. As a consequence, an uncomfortable feeling of exposure is necessary, if artists truly want to create a character on a deeper level, as something raw and real needs to be expressed to develop the story from the character's perspective (Wellins, 2005).

Keane asserts that this is the guiding compass when discovering the characters, whether in the design process or during storyboarding. As he feels the characters already exist before, artists are just revealing them, getting incrementally closer to correct description. Wellins adds:

> *"So for you, it's really about feeling and discovering a connection through this kind of reaching and finding your way. Kind of like the sculptor who felt like he was freeing something that was trapped in the marble." (Wellins, 2005:16).*

Keane also deeply expresses the struggle and fear that result from the element of pressure during production, in combination with not being really certain of oneself, even after developing his skills over thirty years.

On one hand, the buildup of skills is an essential requirement, being passionate is not nearly enough, Keane states. Studying the great masters, such as Michelangelo, Rembrandt, Monet or Degas, dissecting cartoons and how an idea is

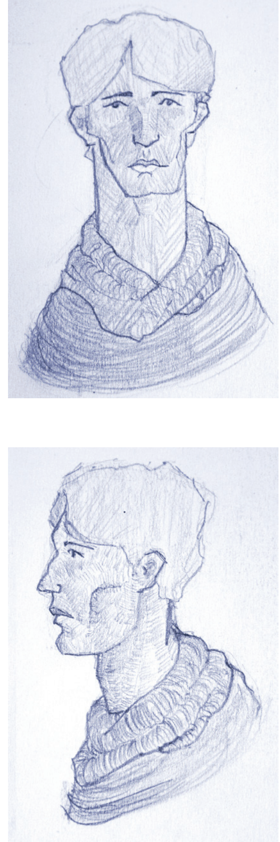


Figure 24 - Final vesion of Lewis

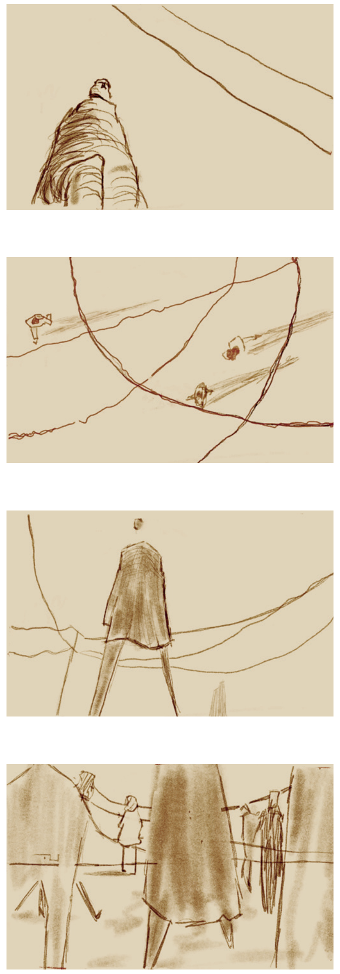


Figure 25 - Storyboards of opening shots for Out-of-Balance

presented in a clear way, using the animation principles and good composition, as well as learning from previous mistakes, are fundamental steps in acquiring the necessary skillset. On the other hand, there are no guarantees that those skills will result in anything significant. In order to do that, artists must ask the question, "(…) what are you going to say with it?" And how does that add value to making the character apparently real? (Wellins, 2005:16).

Dan Scanlon, director of Pixar's Monsters University (Scanlon, 2013) and Onward (Scanlon, 2020), talks about the process of developing a film, in the documentary series Inside Pixar. In season one, episode five, directed by Tony Kaplan, Dan Scanlon compares coming up with an idea for a film to falling in love, as there is not much one can do to make sure that it happens. Scanlon explains that part of the dramatic process of storytelling, is that filmmakers must look for experiences that were hard and transform those struggles into ideas for the film. (Kaplan 2020)

> *"To come up with an idea that has some honesty and is emotional, you have to be really vulnerable. As a filmmaker, you have to be open to thinking about things that are uncomfortable, or things you're scared of, you don't want think about because they're sure and they're real." (Kaplan 2020: 04"12)*

The author Joseph Campbell, professor of literature and well known for his work on mythology, defines a hero as someone "(…) who has been able to battle past his personal and local historical limitations (…)" (Campbell, 1949:14).

Campbell establishes the standard path of the myth of the hero's journey, composed by the concepts of separation, initiation and return. In this adventure, the hero leaves common reality and enters the supernatural world, where he wins over the forces that he encounters there and comes back to the regular world, reborn. This structure, that is at the center of the monomyth, is transversal to myths in general, from Prometheus to Moses and to the Buddha (Campbell, 1949).

Filmmaker Darious Britt refers that, although the Hero with a Thousand Faces (Campbell, 1949) covers concepts that apply to general mythology, it was not developed for film and screenwriting specifically. In his YouTube video, Britt expresses that he uses the three act structure as a road map to structure the stories for his films, has it helps with the creative challenges and to move the story forward, avoiding repetition (D4Darious, 2014).





Syd Field, author of Screenplay: The Foundations of Screenwriting (Field, 1979), expresses that the elements of a story, either characters or places, are part of a dramatic structure with a beginning, middle and end. A screenplay differs from other storytelling mediums as it is meant to tell a story through images, as a visual medium (Field, 1979).

Field establishes a linear structure as the model for writing screenplays, with three acts and two plot points, that divide the three acts. In act I, the story is setup, main characters introduced, as well the premise for the plot. At the end of the act, a plot point (or incident) occurs that changes the direction of the story towards the resolution in act three. In the second act, the main character follows the central goal established in act I, through a series of conflicts. Field defines act II as the act of confrontation, as the protagonist will mostly have to overcome obstacles while pursuing the main goal. This is crucial when defining the story through the character's perspective, " (…) because the basis of all drama is conflict" (Field, 1979:9).

The third act, the resolution, establishes if the protagonists is able to achieve the desired goal, or not. A strong conclusion is necessary to make the story clear and intelligible. The author adds that the linear three act structure can be found in any screenplay, as it provides "(…) a linear arrangement of related incidents, episodes, or events leading to a dramatic resolution" (Field, 1979:10).

When defining the main character, Field proposes dividing the characterization into interior and exterior aspects. The interior aspects are the character's biography, from birth until the beginning of the film, constructing the character's personality. The exterior elements, are defined throughout the film, as the character reveals these aspects through action. Because the story is developed in a visual medium, the character has to be defined visually, through conflicts. The conflicts define the character's goals, and the character essence is defined through action (Field, 1979).

Figure 25 and 26 display images from the storyboard, where the compositions were created to include the characters in motion within spaces composed of posts with electric wires. The constructed space around the moving figures sets up the language for the film, using lines to represent the elements and to provide ideas of connection, energy, order and chaos. Alice becomes gradually lost in this crowded space, eventually losing her balance and falling down. Lewis materializes from the crowd, represented at this point by moving lines. As he helps Alice off the ground, both become entangled with one another through the lines that define them. The incident changes the direction of the story for the following

Figure 26 - Storyboards for losing the balance sequence

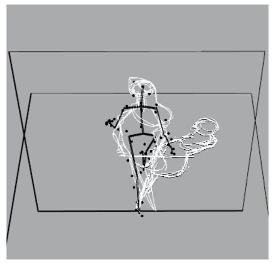


Figure 27 - 3D drawings on top of mocap and armature, using NURBS planes as canvases

acts, up to the resolution in act III.

The recorded mocap data was used for the construction of the storyboard, informing on camera angles and performance of the characters. The ideas developed during this process did not necessarily match the actor's original performance, instead, many of the movements were deconstructed into key poses, re-timed and changed during storyboarding, to better serve the story. Still, having mocap as a base reference helped significantly in order to find moments that could support the creation of the narrative, while offering the possibility to interact within the 3D space, choosing the best visual references for those ideas.

Figures 27 and 28 illustrate the process of visual development for an introductory shot, using 3D drawing to construct the scene, on top of the mocap data and storyboard drawings. On a first approach, sketches were created using the Pencil tool, to draw on NURBS planes, in Maya. This provided a 2D canvas that could be transformed and rotated in 3D space. Its placement informed the orientation and perspective of the drawing, in regard to the camera angle.

In Maya, lines can be drawn on NURBS surfaces, set to "live" mode [10], so this method was added to the previous workflow developed during experimentation. This new step in our pipeline, also created the possibility to form new patches from the previous lines, drawn on the NURBS surfaces, and used to form new 3D canvases for drawing inside outlines. For this, the sketched drawings were cleaned up with new lines, that were selected and used to form a new surface patch, using a Loft operation, *e.g.* vertical lines from the post. This new surface, was used as a 3D canvas, where cross-contour lines were drawn, as shown in the final result, in figure 28.

For Alice, two different planes were used, a bottom one where the sketch was facing the camera, overlaying an armature from Sandra Ribeiro's movements. A new vertical plane was also created for a new drawing, establishing the main proportions and design of the character, using both the armature and previous drawing as marks for its construction. The lines were eventually converted into geometry, and exported into ZBrush, together with the armature and mocap markers, where the main volumes were defined.

A supplementary process was added at this point in ZBrush, where correct topology was created by a method of painting guiding lines on surfaces, together with the ZRemesher algorithm, based on a video tutorial from Danny Mac [11]. Back in Maya, this helped to convert the guiding lines that resulted into edges of the polygonal surfaces, into NURBS curves. These curves were subsequently used to form new patches, used as a new 3D canvas, for drawing the constraining lines around the character. When the drawing was complete, the NURBS canvas was hidden and the lines became juxtaposed to the polygonal model, created in ZBrush.



Figure 28 - Visual development and animation, combining 3D drawing with path-tracing rendering

Finally, the lines were rendered with a Curve Collector tool, using Arnold render engine, providing attributes for thickness, color and shading. The surfaces were rendered with Arnold's Standard shader, a directional light for the sun's angle, and a sky dome light for the sky. Additional geometry was constructed, consisting of simple primitives, to cast shadows on the floor, helping to visually develop the composition, and staging the character's action using negative space.

Ed Hooks establishes the seven major acting principles, used to define the action of the characters, that can be applied for theatre, live-action or animated film. These principles help to create scenes, represented in a series of different shots, as the characters progress through the story.

In the first principle, a relationship is established between thoughts, emotions and action. Hooks defines an emotion as, "an automatic value response", that is directly related to the values one holds. As values are directly tightened to thoughts, action naturally emerges from thinking, triggered by emotions (Hooks, 2011:12).

The second and third principles, already briefly covered in the chapter "3D Animation", address empathy and theatrical reality, respectively.

With empathy, Hooks relates a character's emotion to the audience, conveying that if the audience does not connect emotionally to the character's feelings, the illusion of life is lost. As human survival is based on social behavior, empathy is the key for establishing relations that can help individuals strive. Although, Hooks adds, one must be careful not to mistake empathy with sympathy The later means just feeling sorry for someone, and does not necessarily go along with the former.

With theatrical reality, Hooks answers the question, of how to specifically connect the character's emotions to the audience. Because "acting is behaving believably in pretend circumstances - for a theatrical purpose", emotion by itself

Figure 29 - Key poses for balancing sequence

does not hold any theatrical value. This being the case, characters must act, as a result of emotions, in order for the audience to empathize (Hooks, 2011:20). As theatrical reality is compressed in space and time, particular moments can be selected to show the most relevant actions of the character, that are highlighted by overcoming conflict while pursuing established goals (Hooks, 2011).

The following four acting principles, relate the previous concepts, creating stronger ideas for developing scenes: action and reaction, changing actions, beginning in the middle, and negotiation.

As life itself is dynamic and complex, performance should include reactions as well, *e.g.* listening to someone talking, considering that it will relate to the character's values, and trigger another action by its turn. Changing actions, can also be the result of achieving a goal and pursuing a  new one, or not being able to overcome an obstacle, and new possible actions have to be presented to the character, either in pursuit of the same goal, or of a new one. (Hooks, 2011).

Because theatrical reality is edited and constructed, performance must contemplate the previous action and the following as well. Thus, it is necessary to create the backstory for the scene, *e.g.* the character is in a hurry, as it will determine how the scene begins, as it will be in the middle of a previous one. Negotiation considers that scenes depend on the character's being successful or not, when trying to overcome the conflict. This concept establishes that, in order for one character to win, another must lose. This progresses the character through the story (Hooks, 2011).

Walt Stanchfield, animator, writer and drawing teacher at Disney Animation Studios from the 1950's to the 1970's, points out the importance of the artist's expression in animation. For the book Gesture Drawing for Animation (Stanchfield, 2007), editor Leo Brody collected the handout notes from Stanchfield classes and arranged them in an unpublished book, made available on his website [12]. In his notes, Stanchfield emphasizes the importance of reading and observing, as they will sharpen the artist's mind, besides the already referred pre-requisites, from animation principles, to acting, clarity and empathy, among many others. (Stanchfield, 2007)

He adds that, the style that serves the purpose best for animation, is loose and expressive, while referring to drawings from Bill Tytla, Milt Kahl, Frank Thomas and Ollie Johnston. In order for a drawing to be successful, its construction must be beautifully put, although it is not that which the audience should notice, but emotion instead (Stanchfield, 2007).

The artists should go for the truth, using gesture and construction elements





of the drawing to depict those specific emotions, so its expression supports the story coming alive (Stanchfield, 2007).

*"Draw ideas, not things; action, not poses; gestures, not anatomical structures." (Stanchfield, 2007:1)*

Animation filmmaker Michäel Dudok de Wit, director of short-films such as Father and Daughter (de Wit, 2000) awarded an Oscar for best animated-short film, and the feature-film The Red Turtle (de Wit, 2016), co-produced by Studio Ghibli and Wild Bunch, shares his thoughts about the future of hand-drawn animation, while answering questions from the animation students of the School of Arts of the Catholic University of Porto.

In the YouTube video published on the CITAR research center channel, de Wit expresses that 2D hand-drawn animation will continue to be a big part of the future of the animation industry, despite the fact that some believed 3D computer animation was going to replace it. de Wit adds that, although CG animation is very polished and professional, and suits the division of tasks in big productions very well, "hand-drawn animation will always be loved." (Escola das Artes - UCP, 2020:07"45)

The filmmaker adds that, the reason drawings have such a significance in our culture, is because we have been developing this art-form since pre-historical times. As he recalls his experience of visiting a cave on the south of France, de Wit describes how the beautiful drawings of stylized animals resemble so much the artwork produced today, that he had the impression he was looking at drawings created by his colleagues. Because line drawing is human, and it is not perfect, personal imperfections are revealed by the lines, and it is the main reason why we love drawings so much. Experienced artists transform these imperfections into character, into charm. (Escola das Artes - UCP, 2020)

He also believes that hand-drawn animation has yet to reach its peak, and that hybrid animation where CG is combined with drawing, is full of potential, for practical and artistic reasons. Referring to the use of 3D in The Red Turtle, he explains that, despite the film being made using 2D, the turtles were almost impossible to animate by hand, as they had very rigid shapes that slowly turned in perspective, with the patters on the carapaces as an additional layer of complexity. Because it was not an enjoyable process of animating, 3D techniques were integrated with 2D. Ideally, the audience is not distracted by the hybrid animation, and just enjoys the storytelling (Escola das Artes - UCP, 2020).

Referring to his process of development, the filmmaker adds that,

Figure 30 - Key poses for supporting sequence

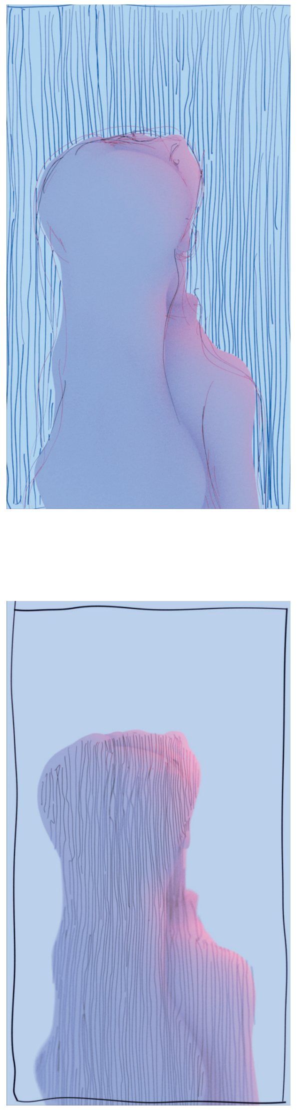


Figure 31 - Visual development and animation, using 3D lines to describe positive and negative spaces

although it varies for each project, usually there is a period where the ideas for a story are developed in his mind, for periods of weeks, months, and even years [13]. Once a particular set of ideas turn into the beginning of the story for a film, drawings are created, along with color tests of the final look, written synopsis and research. The pre-production and storyboarding processes are essential to mature ideas before the film is financed and enters production, allowing for a variety of ideas to be experimented with without weighting heavily on the film's budget and production time (Escola das Artes - UCP, 2020).

Usually, his animations are developed without any use of dialogue, as it creates opportunities for a more poetic discourse, when creating the visual languages of the film. The filmmaker also makes sparse use of close-ups, as he argues that they are just tools, and not all the tools need to be used for the production of a film. As his characters are always part of their surrounding environment, their emotions are developed through animation using the movement of their bodies (Escola das Artes - UCP, 2020).

Finally, as inspiration for his style, among many examples de Wit points out

Asian illustration, as its discovery was a pivoting point in his artistic path. Giving as example Chinese and Japanese brush drawings, created by Buddhist monks and priests, he highlights the freshness and rawness of the drawings, that combines spontaneity and simplicity, with maturity. As it may appear a paradox, it actually reflects a very refined type of art. These drawings also reflect high sensitivity for negative space, or empty space. The filmmaker reveals that the power of empty space, is that it provides the right amount of visual information to the composition, necessary to tell the story (Escola das Artes - UCP, 2020).

Pete Docter, director of Monsters, Inc. (Docter, 2001), Up (Docter, 2009), Inside Out (Docter, 2015) and Soul (Docter, 2020), in conversation with Richard Crouse for Toronto International Film Festival (TIFF), discusses the topic of artistry and technology in animation. In this YouTube video on the TIFF channel, Crouse refers that the animation from characters of Inside Out, resembles the type of animation created by Tex Avery, famous animator and Director at Warner Bros. where he created characters such as Daffy Duck (1937), Elmer Fudd (1940) and Buggs Bunny (1940) (TIFF Originals, 2015).

Docter refers that such movies are a part of his roots, and that in the early days of Toy Story, those types of movements with deformations were hard to do using 3D, and especially difficult to sustain during a whole feature-film. Finally, with Inside Out, technology had been developed that could deliver great stretches





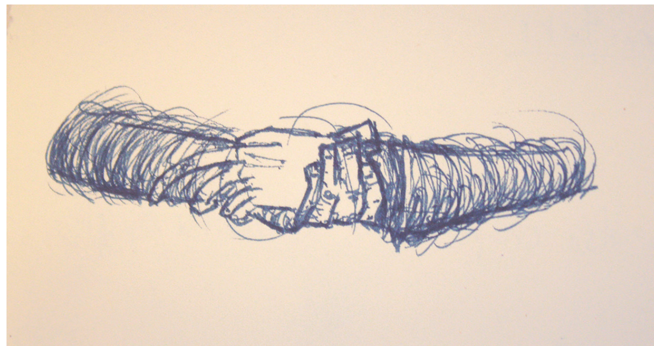


Figure 32 - Drawing for entangled sequence

and distortions. However, in the wrong hands, those techniques can also be "off-putting and odd", Docter adds. The filmmaker explains that, Inside Out, more than any other film up to that time, was successful as a consequence of "great artistry in the animation" (TIFF Originals, 2015:58"00).

Figures 31 and 32 display a progression on the visual development. In figure 31, lines were used to convey the positive and negatives spaces of the composition, describing Alice's inner and outer worlds. The lines were drawn vertically, although they were drawn of 3D surfaces. This expands on the possibilities that two-dimensional mediums offer, as the camera can be moved through and around the lines, lights and camera depth of field can be added as well. Additionally, deformers were added to the lines, creating movement with a wave effect.

In figure 32 Alice and Lewis were represented with lines that form the final shapes as they move closer to each other. The lines are drawn to express the movement and intent of the scene, as the two characters move towards one another, gestural lines enter the composition and eventually wrap around the final forms.

Pixar's character art director Deanna Marsigliese, in the documentary series Inside Pixar, expresses that "(…) inspiration is queen of all things" (Milsom, 2020:01"30).

Marsigliese adds that, in any creative project, there is a level of trust artists need to have with themselves, as well as with the universe itself, and with the "creative gods", as she feels the artistic process means challenging fate in a way, giving up some of the control and welcoming something else to be a part of the creative development (Milsom, 2020:09"20).

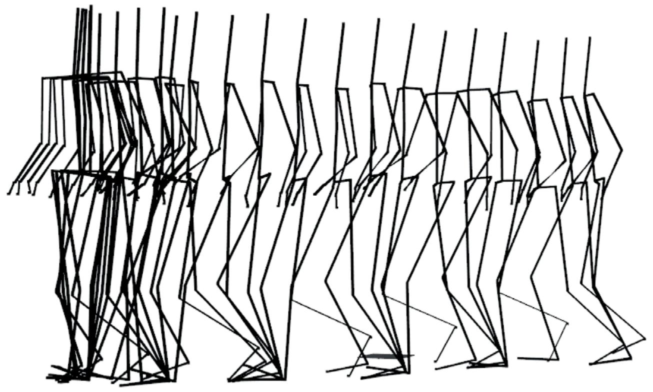


Figure 33 - Selection of poses from the mocap of Sandra Ribeiro

*"Another thing I've learned, though, is that when it comes, it really does feel like something happening though you. It's this totally magical, amazing thing, and I love that everyone can be creative. It's not specific to just a professional artist. Everyone can tap into this. It's really some kind of magic." (Milsom 2020:09"20)*

Figures 33 and 34 display a sequence where walking cycles from Sandra Ribeiro were interpreted, producing the final animated sequence. The actions from mocap display her agitated movements, as Alice is becoming increasingly nervous from being lost. The drawings were done to exaggerate the action, as the naturalistic poses from the armatures did not represent the meaning of the scene as clearly as intended.

In figure 34, the most of the previous workflows were fully used, to construct form as the animation progresses. Lines were drawn for key poses and animated using deformers and interpolation techniques for in-between poses. The shapes and volumes were animated using a combination of Straight-ahead, where dynamic topology was used to add more geometry as needed, and a control rig with FK joints to articulate the character. Corrective shapes were created at the end of the process, through a stand-in process identical to the one using during experimentation.

Mike Wellins, regarding hybrid animation, points out that combining different styles and techniques is not something new in animation, what is actually new is to combine traditional techniques with the latest technology (Wellins,

Figure 34 - Visual developement and animation of Alice getting lost

2005).

With concerns of finding the right balance between all the elements in the process to produce the final film, Wellins expresses in his interview with Glen Keane, that even if one has mastered the draftsmanship, it is still a tough process, and it does not get easier along the way. Keane compares the creative process to entering a dark room while trying to find the light switch, while tumbling and feeling the way through. Once the switch is found and the lights are turned on, the path seems easy, although it only becomes clear once one looks back on it (Wellins, 2005).

Keane adds that walking that path takes a lot of faith, in order to keep moving forward. As artists become lost in the complexities of creating a story, while surrounded by an overwhelming amount of artistic problems, it is necessary to trust that eventually, gifts are going to come along the process that help solve one problem at a time. These gifts can be a creative spark, the right person for a particular challenge, or the right reference from one of the old masters (Wellins, 2005).

Keane conveys that ideally, one aspires to be like Joe Grant, an artist and writer at Disney, that at age of 96 would come every day and create new drawings, always fresh with new ideas. Keane makes the parallel to Grant's energy, to a story of an art teacher that teaches figure drawing to adults. As he explains to his daughter where he goes all day, "Well honey, I go teach people how to draw", he receives the reaction "You mean they forget?". Ideally, Keane concludes, artists aspire to be like Joe Grant, where one never forgets to think like a child, and still draws just for the enjoyment and gratification that it gives (Wellins, 2005:20).

## End Notes

[1] Original references can be found on Bodies in Motion website: https://www.bodiesinmotion.photo (last accessed 01/02/2021).

[2] CG technique that displays allows users to display and edit multiple frames at once.

[3] Referring to 2D drawing and not to 3D software.

[4] Orthographic views do not represent depth.

[5] Maya only provides this option when drawing on the floor plane.

[6] Examples of Lee's work can be seen on his YouTube channel: https://www.youtube.com/user/AlexanderLee1 (last accessed 01/02/2021).

[7] - Information about ZBrush3D layers on Pixologic's website: http://docs.pixologic.com/user-guide/3d-modeling/sculpting/3d-layers/ (last accessed 01/02/2021).

[8] - Transforming posed models back into "T" pose, on Pixologic ZBrush (2017) website: https://youtu.be/l-Gs6iPqCm4 (last accessed 01/02/2021).

[9] - Transferring details between 3D meshes on FlippedNormals (2014) YouTube channel: https://youtu.be/kKeZrqldv90 (last accessed 01/02/2021).

[10] - Process addressed for the creation of retopology in chapter 2.3. Digital Sculpting (page 92).

[11] - Process of creating new topology from Polygroups on Danny Mac 3D (2018) YouTube channel: https://youtu.be/9kSaJ1b4QZU (last accessed 01/02/2021).

[12] - Information published by Amid Amidi (2007) on Cartoon Brew's website: https://www.cartoonbrew.com/books/walt-stanchfields-gesture-drawing-for-animation-2743.html (last accessed 01/02/2021).

[13] - The Red Turtle (de Wit, 2016) took 9 years to complete.

# Conclusion

Animation was born as an art form that allows to represent movement as a form of self-expression, as Thomas and Johnston conveyed. Even before the development of the Fundamental Principles of Animation at the Disney Animation Studios, artists such as Reynaud understood that designing the movement was as important as designing the figures. As Reynaud and McCay showed through their natural craftsmanship, success in animation depends as much on technological improvements as on artistic ability.

Although animation is capable of articulating ideas through its unique vocabulary, its tension with live-action filmmaking is also a significant factor when defining the boundaries of the art form, as Wells and Bendazzi point out.

On one hand, a more formulaic approach resulted in Disney realism, in contrast to experimental animation. On the other, rotoscoping led to eerie results that could be avoided by those same formulas, principles that helped artists to understand the nature of motion.

With the evolution of technology, similar problems appeared. Hand-drawn animation was replaced by 3D animation, as a result of standardization, and mocap films led to uncanny results, what Sito calls the "uncanny hybrid". As animation enters its adulthood, Hooks points out that new opportunities for independent animation appear, the result of streaming companies and animation festivals, that provide a larger space for adult themed animation.

Through the transition from adolescence to adulthood, CG techniques were perfected with robust software, photo-realism, digital sculpting, and more recently 3D drawing. In the early days, technology mostly determined the visual language of the new medium. As Lasseter points out, the art form was growing out of the sciences without the knowledge of the history and principles of animation. More recently, hybrid films such as Paperman (Kars, 2012) and Spider-Man: Into the Spider-Verse (Persichetti *et al.*, 2018), showed that CG can be combined with different techniques, such as drawing, for the visual development of animation. As Kars and de Wit refer, the drawn line can be used in an expressive way, while benefiting the film with the nuanced movements produced by CG.

Figure 1 - Study for Out-of-Balance

Figure 2 - Study for Out-of-Balance

Stylization and abstraction, in combination with realism and figurative storytelling, can now be combined to create believable characters. As expressed by Sito, only a life-time away from today's CG blockbusters, Sketchpad was invented by Sutherland. In the same way, the future evolution of the art form depends on today's breakthroughs and innovations.

CG Technology has improved significantly from its inception, when the cost of creating a digital car could be as expensive as the actual car. As digital sculpting introduced a new emphasis on digital artistic creation, we were motivated to experiment with CG techniques to find alternative methods of producing animation, when using motion capture.

Digital sculpting from life inspired us to experiment with mocap data, using alternative production methods, while attempting to expand the possibilities within the rich visual languages of animation, from the visual composition to the rhythm of movement.

In these alternative methods, we discovered how to use mocap to study motion with high detailed precision, similar to the methods used by Marey at the end of the 19th century. Without being limited by retargeting methods, more room for experimentation and expression was found to exist, that benefited from improvisation and spontaneity, when using digital sculpting.

While mocap can significantly speed up the animation process, even up to real-time, animation also means creating the performance from scratch, as was done by Disney animators. As Johnston refers, animation is meant to live outside the limits of live action, as the animator is responsible for the performance of the characters in relation to the scene, creating the concepts behind the action.

Mocap's most distinctive quality, we discovered, is in its capability to abstract motion, making the invisible forces visible through measurement. Marey's chronophotography predates digital mocap innovation by a visual process of reduction that leads to an essence, as Mamber refers.

Our technical methodology was produced hand in hand with the artistic development, through the use of armatures to create animation, in combination with digital sculpting.

We found digital drawing to be the next logical step, as it can create shape, form and motion at the same time, and could be combined with the previous approach. Not only can 3D drawing be used to develop ideas faster and more spontaneously, being a more immediate medium, as it also results in a personal form of expression that can be visible in the final film, as Kunz points out.

While applying the concepts of hand-drawn animation to mocap and 3D drawing, the results unfolded into the inception of a short-film, Out-of-Balance. Through an important period of experimentation, as Wellins refers, the workflow to draw directly in 3D from mocap data was established, as well its articulation with the digital sculpting tools.

From this experimentation, we discovered that despite the enormous possibilities computers provided, CG could also be a limiting tool. With 3D tools, the whole model had to be constructed in order to be able to represent details. The two could not be separated. Furthermore, by using drawing as a vehicle for the construction of the 3D models, meant that the drawn lines should be the main visual expression, as the results lacked its original expressivity.

Drawing provides the necessary vocabulary to depict only what is fundamental, and can create direct relations between general forms and details, crucial to characterize the moving body and to develop characters that function within stories. The motive of constructing 3D models became only to support drawings, by additional elements such as color and shading.

In the same way as mocap was used only as reference for animation, where drawings for key poses and armatures for interpolation were used, 3D models began to be used as 3D canvases, to support the construction of the 3D drawing, that could follow or diverge from its closed form.

With this in mind, the visual development for the animation began to be produced, using different media, both traditional and digital, to explore alternatives to the previous results. The pursuit creating new visuals, resulted from pivoting and continuing to approach the process in new ways, as expressed by Marsigliese.

Animation can also mean abstraction, where the plasmatic quality referred by Eisenstein comes through in its most apparent way. Wells's development animation, inspired the vocabulary created to describe the inner and outer worlds of our characters, Alice and Lewis. Tools such as 3D drawing, provided the expressiveness to articulate those ideas, representing the invisible body, that Simblet refers, somewhat parallel to the notions of immaterial performance, by Beiman.

As a result, drawing was used from mocap: for the development of the story, using animation and drawing principles to establish main concepts; for storyboards, facilitating the choice of key poses, camera angles and shot sizes; for the visual development of the characters, as mocap data informed 3D lines through main proportions, and consequently used to guide the construction of 3D forms using digital sculpting; for animation, where mocap data was used to discover and understand rhythms, action, and animation principles in general.

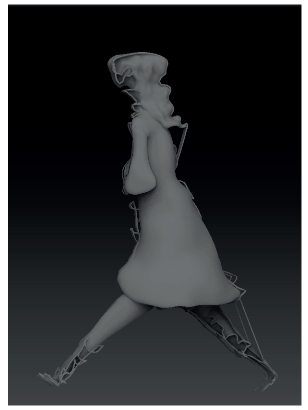


Figure 3 - 3D model to be used together with 3D drawing

Figure 4 - Study for animation, combining mocap with drawings from imagination

Figure 5 - Study for animation, combining mocap with drawings from imagination

Finally, 3D drawing was also used to contribute to shading and rendering, where outlines and cross contour lines were used to establish the shapes and volumes, with hatching techniques representing the surfaces created from the volumes.

Mocap could be used in a more straight-forward way, applied to 2D directly, without the 3D steps. Nevertheless, by using 3D techniques one can benefit from the CG tools to develop a richer language, mainly as a consequence of interactivity and polished processes, that can depict with great detail and accuracy.

As drawing is a tool of the mind, it can more directly represent ideas. The combination of different media creates the opportunity to visually develop stories in a unique way, that neither medium can produce individually on its own.

Although we did not find any significant technological limitations, work arounds had to be developed, as Maya's tools were not as mature as Blender's, nor the integration of drawing with 3D is a well-established practice, today.

Drawing can be used as an expressive tool for the visual development and animation of films, creating the vocabulary needed to tell particular stories through animated characters. This creates the possibility of access the unknown aspect of creativity through the immediacy of drawing, that is so important in storytelling, and continue to follow the chosen path with the use of the computer, to alter or extend on the designs, to study new possibilities, and return to drawing with new insight.

The results from the alternative methods and from experimentation were presented and published in two international conferences, during the production of the thesis. The additional results will continue to be published, as the short-film continues to be developed. Images, animations and tutorials were created, documenting the many different processes, that can be found online, as support material, though the use of the QR codes available in each chapter.

Visual development and animations have been produced for an independent short-film, that will be used to search for funding, for its production. Some of the methods developed were already used as teaching materials, namely 3D drawing, showing the potential for self-expression in students' projects, opening new possibilities for education.

As Keane, Wellins and Scanlon refer, storytelling is a personal endeavor, as the inner journey of discovering ideas requires sincerity. The tools need to be developed as the process evolves, supporting the creative process. Mocap and 3D drawing are powerful tools, that not only can speed up animation process, but more importantly, guide the creative process. Due to their visual languages, compositions can be defined with lesser elements than 3D standard production.

Independently of its use, it is crucial to consider what is going to be expressed in the compositions. That requires a long process of searching through personal ideas and emotions, that can be used to develop characters and stories.

Drawing from mocap can be used to help to guide the constructions of the movements and rhythms of the animated scene. More importantly, the ideas for characters and story can be drawn from the actor's recordings, expanding the creative process by inviting collaboration.

Empathy is an essential part of the illusion of life, fundamental in creating the connection between the artists' work and their audiences. It is as important for the discovery of artists' inner ideas and emotions that can lead to characters and stories.

Through the recording of moving bodies, empathy can lead to the discovery of new creative possibilities that reflect artists' values and consequently connect audiences. Creating suspension of disbelief, as Coleridge and Hooks express, is creating poetic truth. And as Hooks advises, artists should not depend solely on technology, as Art describes the human spirit, better than any other tool.

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