TAMPERE UNIVERSITY
OF APPLIED SCIENCES

Methods of Creating Stylised Characters for Games Using Physically Based Rendering

Teemu Norvasto

Bachelor's thesis
May 2018
Degree Programme in Media and Arts

ABSTRACT

Tampereen Ammattikorkeakoulu
Tampere University of Applied Sciences
Degree Programme in Media and Arts

NORVASTO, TEEMU:
Methods of Creating Stylised Characters for Games using Physically Based Rendering

Bachelor's thesis 50 pages
May 2018

When this thesis was started, the author had been working in the game industry for a couple of years as a concept artist and 3D artist. He had acquired some experience working in different student projects and in different game companies.

The goal of this thesis was to observe and research methods that are used in modern games for crating stylised characters and what kind of knowledge and skills are required from the artist to achieve the best possible results. The thesis also observes what is considered stylised in the context of game graphics by observing modern games that showcase graphics that can be considered stylised. In addition, current visual trends in games are discussed.

The data for this thesis were collected from various sources including internet articles, books, videos online and observations. It also includes practical work created by the author specifically to analyse the results of this thesis as well as professional work the author has created for the game Stardust Galaxy Warriors. The first part of the thesis goes through definitions of visual styles in games and what physically based rendering means from the artists' point of view. The latter part collects the results of the practical part of the thesis and analyses the results

It was found that stylisation can be loosely divided into two main categories of exaggerated stylisation and simplified stylisation. Both of these categories contain many variations and the term remains relatively subjective.

Stylised graphics are very popular in modern games for many reasons, and it is quite beneficial for aspiring artists to think about what is involved in creating stylised graphics for games and to learn the tools required to make them.

Key words: 3D, game, art, character.

CONTENTS

ABBREVIATIONS AND TERMS

3D game	Refers to game that primarily uses 3D graphics for visual output.
Albedo map	A base colour input map
F0	Fresnel Reflectance at 0 Degrees
Mech	A term used in science fiction for a large, pilotable robot.
Mesh	Collection of vertices, edges and faces that defines the shape of an object in 3D computer graphics
PBR	Physically Based Rendering, a method of shading in modern game engines
Real-time	Graphics that are rendered in real-time i.e. all game graphics
RPG	Role Playing Game
SGW	Stardust Galaxy Warriors
Shader	A type of computer program used for shading
Stylised	Refers to any non-realistic representation of characters and environments in a game.
Texture map	An image applied (mapped) to the surface of a shape or polygon.

1 INTRODUCTION

The purpose of this thesis is to take an in depth look into stylised graphics in modern video games and to go through working methods and tools artists need to be aware of and have mastery of in order to produce stylised characters in a production environment of a game that utilizes physically based rendering in its shading.

The thesis will focus on the creation of characters and the tools the artist needs to know in order to work with modern shaders in games. The thesis draws from texts and books on traditional character design principles and how to apply those to game characters. Additional information is also gathered from internet articles, magazines, videos and blogs created by professionals working in the field. The emphasis will be on the advantages and disadvantages PBR offers in terms of time and visual quality.

The thesis will also look and analyse examples of modern games that feature a stylised art direction and discuss the advantages and disadvantages of it in comparison to realistic styles.

The last part features the author's own professional work in the games he has worked on at Dreamloop Games as well as personal work created for this thesis and an analysis of how well the work succeeded and what the author learned in the creation of these characters.

The objective of this thesis is to give information to aspiring 3D artists who would like to work in game development as well as the author's peers who are looking to deepen their knowledge of PBR and the creation of characters in games. The thesis aims to contain information about tools used in game development in a way that should be directly actionable to new and experienced artists.

2 VISUAL STYLES IN GAMES

2.1 Stylised graphics in modern games

This chapter of the thesis will attempt to define stylisation in game graphics and go through differences in visual styles in modern games, comparing visually stylised titles to realistic ones and assessing the advantages and disadvantages of them from both visual and technical standpoints.

It is of course impossible to create perfect realism in video games and the end result will always have to be some form of stylisation or interpretation of realism. The difference is that stylisation consciously strives to move away from realism to create something fantastical and enjoyable to look at, while realistically depicted games attempt to create the illusion of realism for the player to immerse themselves in.

In discussions the term stylised usually refers to any game that represents its world and characters in any coherent visual output that is distinguishable from realism. In most cases and especially in older games the differences are quite clear but as modern games and technology becomes more and more advanced the differences became more varied and subtle, and the line between realistic and stylised is not that clear. As game development tools have improved and the technical and artistic boundaries of game graphics are pushed we are seeing more and more innovative approaches to game graphics from realistic to very abstract

2.1.1 Exaggerated and minimalist stylisation

Kim Aava divides stylised graphics into two categories in her lvl80 article, Realistic vs. Stylised: Technique Overview. The categories are over exaggerated stylisation and minimalist stylisation. (Aava, lvl80, 2017) This is a fairly good categorization because it covers the most typical stylisations games, it doesn’t necessarily cover games that are more abstract or surreal but even many of them can still be place into one of these categories and for the sake of this thesis the categories are suitable.

Over exaggerated stylisation mostly plays with shapes and silhouettes and focuses on larger details and shapes and exaggerating and enlarging prominent details while ignoring microsurface details that are common and necessary in realistic graphics. (Aava, lvl80, 2017)

PICTURE 1. (Artstation, Eric McKenney, 2018)

This weapon prop (PICTURE 1.) by Eric McKenney is a good example of exaggerated stylisation. The primary focus in the modelling phase is on large shapes and an interesting silhouette and also exaggerating the shapes like making the barrel of the gun disproportionately thick. The modelling is then enhanced by bold colour choices. Its function as a weapon is made clear to us by the handles, a barrel and an indication of munitions and the dripping goo from the barrel. The gun doesn’t have much micro detail added in the texturing phase except for some dents, scratches and dirt which have been enlarged to exaggerate them and make them more visible. The screw heads on the weapon are also larger than they would be in real life. All of this creates a weapon that clearly has a unique function and sells the idea of how it might work in action and keeps it light hearted and humoristic. Stylisation doesn’t of course mean that it is automatically light hearted or whimsical, stylisation can be utilized to emphasize any kind of feeling or mood.

Minimalist stylisation is the other type of stylisation that can be seen quite often in games on PC and consoles as well as on mobile. It plays on simplicity with few details in both colour and shape and strips out most detail in an attempt to convey function in

as simple way as possible. (Aava, lvl80, 2017) This look of stylisation was popularized by the game Journey and is a prime example of it

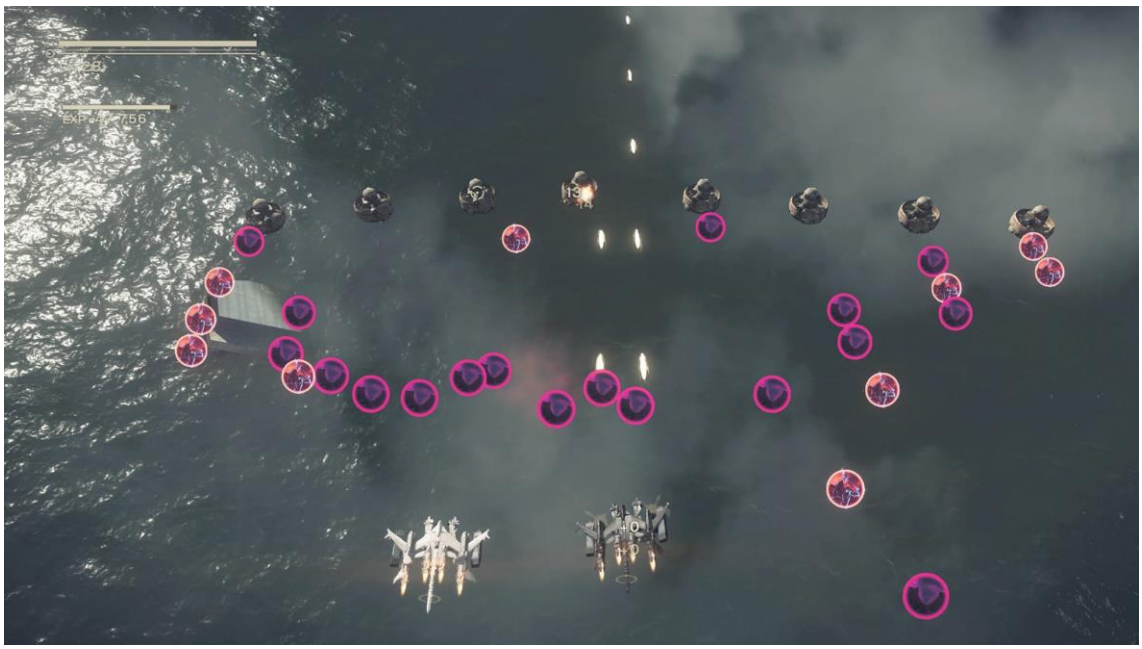
PICTURE 2. (Journey, Thatgamecompany, 2012)

Journey (PICTURE 2.) creates a unique visual experience in which the visual identity of characters and environments are created with simple shapes and mostly flat colours. Minimalist stylisation enables fast content creation since most of the assets are very simple and thus fast to produce. The style plays on simple shapes in a symbolist way which creates a very clear indication to the player for example whether a creature is hostile or if an environment is friendly or dangerous. (PICTURE 3.)

PICTURE 3. (Journey, Thatgamecompany, 2012)

Interestingly even though as computers and gaming consoles have become more and more powerful and capable of running graphically very complex games and have made visually almost photorealistic games a possibility, visually non-realistic games are still well represented in games that are popular for example in Metacritic score. (Metacritic, 2018) There are many potential reasons for this, players crave aesthetic experiences beyond just the realm of realism and in terms of gameplay and user experience stylised graphics offer more variety over realism because the game mechanics are not as strictly bound in the laws of nature to attempt to uphold the immersion and sense of realism. Of course attributing a games success purely due to aesthetics is not very accurate because there are many things that affect a games success, chief among them gameplay, but also brand, intellectual property, marketing, business model, timing of release, platform availability, and technical execution of the game, but what it shows is that there is an interest and a large target group that enjoys games which among other things feature a non-realistic visual style.

Stylised graphics often sacrifice realism for visual clarity to visualize interaction through symbolism or colour coding or utilizing more primitive shapes. If we look at this example from Nier: Automata (PICTURE 4.) we can see that even though it features realistic looking elements such as the water and the clouds the enemy bullets have been stylised to a degree that almost makes them look like symbols, all the bullets are perfect circles with a clear outline to make them very distinguishable from the environment and the difference in the colour and value of the bullets tells the player what type of bullets they are, in this case the light bullets can be removed by shooting them and the darker bullets can be removed by hitting them with a melee attack. This kind of simplification would not be possible for very realistic games which often strive for immersion and storytelling through realistic environments and characters.



PICTURE 4. (NieR: Automata, Platinum Games, 2017)

In the example below (PICTURE 5.) from Legend of Zelda, Breath of the wild, we can see that the hostility of the creatures are indicated by more saturated and contrasting colours and an angular shape language of the character design to separate them from the environment and inform the player on how to interact with them.

PICTURE 5. (Legend of Zelda, Breath of the wild, Nintendo, 2017)

2.1.2 Restrictions for game graphics

Despite the improving technology and increasing computational power of PCs, consoles and mobile devices, game developers still need to take into account technological limitations and a part of a game artists job is to be aware of things in their work that affects the performance of the game such as polygon count, amount of materials, texture sizes, the amount of bones in rigs and so on. Technical restrictions are defined by the target hardware and the developers have to adjust their work accordingly. One of the reasons to go for a more stylised visual output in a game project is the added performance value. Stylised graphics do not usually require as complex models, rigs, textures, lighting, shaders and post-processing effects to achieve the needed results and this means that the target hardware can be set significantly lower or the added performance can be utilized elsewhere.

For many game developers a stylised approach also makes larger projects more viable because assets might require less work and adding more content is not as big of an undertaking as it would be in realistic games where making new assets can be very time consuming.

It is also commercially viable, for example if we look at Metacritic scores for games in the year 2017 across all platforms, the first game that can be considered realistic in terms of visual output is Divinity: Original Sin 2 on the 4th place, and the top three, The Legend of Zelda: Breath of the Wild, (Switch) Super Mario Odyssey and The Legend of Zelda: Breath of the Wild, (WIIU) are all stylised. There are many other stylised games in the top ten, for example Persona 5, Undertale and Mario Kart Deluxe. (Metacritic, 2018)

2.1.3 Case study: Overwatch

Overwatch is an interesting modern example of stylised graphics that is also relevant to this thesis because the game uses modern shading which is PBR or very close to it but also retains the style that Blizzard is known for but also brings it to a new level by adding more complex character models, advanced lighting and materials and moves the Blizzards traditional hand painted look to a bit more realistic direction without losing its charm. This gives an opportunity to examine and observe how this look has been achieved, what kinds of elements are important and what kind of execution the art assets in the game have gone through.

If we look at Overwatch and try to define it by the categorization Kim Aava made, Overwatch as well as Blizzards other games, fall into the category of exaggerated stylisation. This can be clearly seen from the example below. Most of the environment assets are made with large clear shapes and contrasting colour choices. The game requires quite a high level of detail in its art because of the fact that players can get very close to the assets. This has been solved by picking characteristic details in each asset and emphasizing them such as the bricks and cracks in the walls which have been enlarged to show what the buildings are made of from a distance as well as on close inspection without creating too much visual clutter and breaking the style of the game. It is important to keep the level of exaggeration consistent across all of the art in the game to maintain a cohesive and pleasing look.

PICTURE 6. (Overwatch, Blizzard entertainment, 2016)

Despite the exaggeration Overwatch still maintains a level of realism which is shown in how light behaves with different materials, such as stone, metal, glass and fabrics which are some the benefits of working with PBR. (PICTURE 6.)

The characters of Overwatch are also exaggerated to the same degree as the environments and other assets, however they require slightly more detail because of the first person view of the game especially hands and weapons since they cover quite a large portion of the screen as the game is played. If we take a look at the highpoly 3D model

of the Cyborg skin for Soldier: 76 by Hong Chan Lim (PICTURE 7.) we can see that it is quite close to realism in terms of material definition but the proportions of the character are exaggerated, it is also very clear visually, all the parts are distinguishable from a distance and colour choices provide strong contrasts. It has a lot less small details such as dirt scratches, seams etc. than a modern realistic game such as for example Hellblade: Senua's Sacrifice would have. (PICTURE 8.) The details are enlarged and exaggerated. This shows the consistency of exaggeration in Overwatch' characters are the same as in its environments. Focus is on large clear shapes and strong contrasts with exaggerated key details and a clear material indication.

PICTURE 7. (Artstation , Hong Chan Lim, 2018)

PICTURE 8. (Artstation Jeff Goslan, 2018)

2.2 Realistic Graphics in modern games

In the past few years more realistic and cinematic looking games have become a possibility due to more powerful gaming consoles and PCs becoming accessible to consumers. It is important to take a thorough look at realistic graphics and how they have developed because that is the area that is the most complex and heavy in terms of performance power required and because most of the stylised graphics, if they do not strive for something very abstract, are still based off of reality or depicts reality in a distorted way thus it is important to observe and be aware of the differences.

If we take a look at this example of the development of the Assassins Creed Franchise (PICTURE 9.) over a ten year period we can see a very clear development on realism. The first Assassins Creed game upon its release in 2007 was pushing the limits of the hardware of its time and was considered very cutting edge in terms of realistic graphics. We can see for example cast shadows, complex materials and different materials reflecting light in different ways. It is however a bit rough especially looking back from todays graphics. We can see things like the boots of the soldiers being a continuous part of the whole leg, the stones on the ground seem very flat and they don’t really have perceivable depth and height variance, the texture resolution of clothing is blurry, the faces of the characters seem a bit simple and the overall feeling remains somewhat flat. When we compare this to the screenshot from Assassins creed origins we get a much stronger

feeling of a real living world and many of the things previously mentioned have improved. The characters clothing is much more complex both in terms of geometry and texture resolution. When we look at the ground the textures are much more crisp and detailed, the ground has clear height definition between patterns as well as different heights of rocks and slabs, there is some vegetation that looks quite convincing and for example the palm leaves in the distance convey a very realistic image. The game has also much more realistic atmospheric perspective which creates a greater sense of scale and a feeling of realism. Many of these things seem very small but they all add up to a more realistic whole and many of them were not possible to do in the before because of the limitations of the consumer hardware at the time.

PICTURE 9. (Assassins Creed, Assassins Creed: Origins, Ubisoft, 2007, 2017)

If we take a look at another example from a shorter time frame we can still see quite a lot of development in realism. This comparison is from the Metro series which features a post-apocalyptic Moscow both above and underground. The difference in depicted realism is quite striking. (PICTURE 10.) In the 2010 picture the lighting is very monotonous and it doesn't have much depth, the foggy effect created by the gas mask is not very realistic and at a glance it is not even clear that the character is wearing a mask at all and all the different materials in the scene seem very similar to eachother, which would be even more apparent if the game was in motion. The 2013 image from Metro: Last light looks much more realistic and striking. The condensed drops of water in the gas mask adds a much more realistic feeling, there is variance in the materials on the ground, the gun, the clothing, the vegetation and the building in the background and the game now features volumetric lighting effects and rays of light. Many of these visuals that make the newer Metro: Last light so much more realistic and impressive were not possible to do in a commercial product at the time of Metro 2033 which shows how much hardware and optimization had developed even in the short time period from 2010 to 2013.

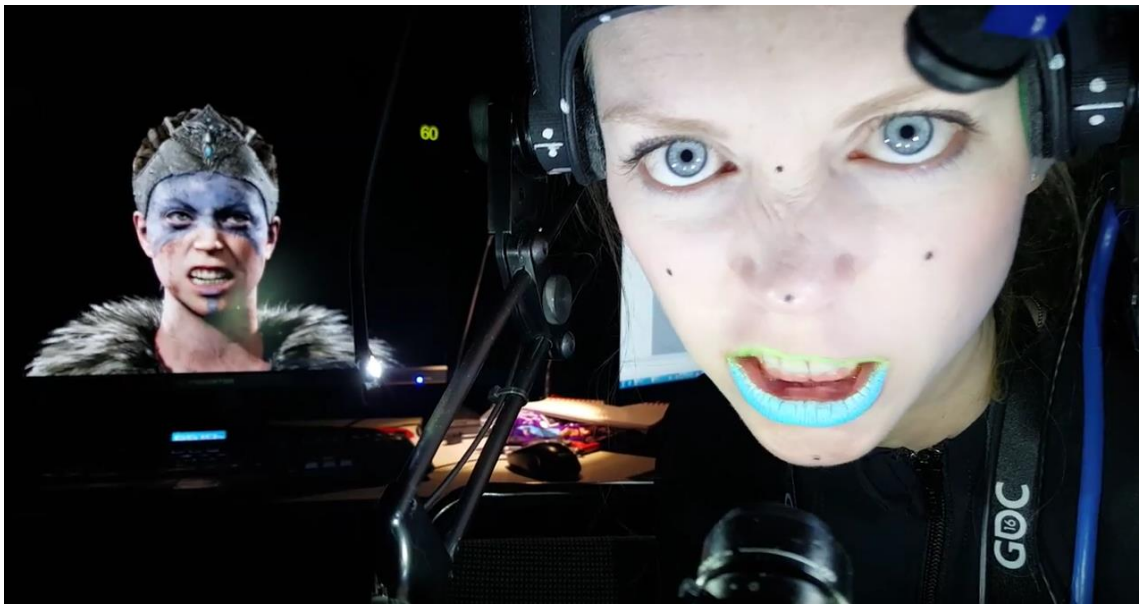
There is an interesting aspect to realism in games and films mentioned by Kim Aava in her lvl80 article referred to before. She mentions the term enhanced realism which is quite a good term to describe realistic games because if we look at games or even movies that are realistic we can still see a difference to real life because the light, colour and atmosphere are more vibrant than they actually would be, or vice versa some shots or areas might be more devoid of colour than what they would be. The imagery is being altered and enhanced to get the perfect shot or enhance the mood the creators want to convey to the viewer or the player, in a way this enhances or exaggerates realism thus in a way even realism in games can be considered a form of stylisation.

PICTURE 10. (Metro 2033, Metro: Last Light, 4A Games, 2010, 2013)

2.2.1 Case Study: Hellblade: Senuas Sacrifice

Hellblade is a great example of a highly realistic modern game developed by a relatively small studio Ninja Theory and they have pushed and developed existing technology especially in character realism in terms of believability in performance and in facial animation. Hellblade: Senuas Sacrifice tells the story of a young woman traumatized by events that happened in her life that causes her to suffer from mental illnesses such as schizophrenia. The game was developed in cooperation with psychologists such as Paul fletcher, a neuroscientist and an expert on psychosis from the University of Cambridge and patients suffering from mental illnesses to create an authentic take on what it feels to suffer from these symptoms. (Wikipedia, 2018) The game is very dependent on realism and high immersion in both visuals and audio.

Hellblade is a good example to take a look at because character realism and believability has been a big challenge in games. Game characters in realistic games tend to suffer from an uncanny effect because the complexity of human expression is so difficult to capture and because we as humans spot things that are even slightly off which breaks the immersion and makes the character look unrealistic or out of place. Ninja Theory developed a method with the developers at Epic to capture their lead actress in real time into their game engine via the use of a facial motion capture rig. (PICTURE 11.)



PICTURE 11. (Hellblade.com, 2017)

This method allowed them effectively to direct an actor and capture the scenes in real time in their game engine allowing for a faster and more efficient iteration process and a more realistic result in animation and character performance. In the images below (PICTURE 12, PICTURE 13) we can see the very realistic end result they achieved with the main character. Using PBR and techniques like high definition image scanning they achieved very realistic results on her skin. (Youtube, Hellblade development diary 16) Light reflections are very realistic and the eyes and expressions have life in them. The dirt, blood, bruises and war paint blend well together and her eyes look very real. A still image is a bit deceiving however since the bigger challenge is to keep it all cohesive when the model is moving and getting all the subtle changes in expressions and the movement of the eyes correct.

PICTURE 12. (Hellblade: Senua’s Sacrifice, Ninja Theory, 2017)

Hellblade is also a good indication of the development of tools and technology in the game industry which allows for smaller teams like Ninja Theory, roughly 20 people, to achieve very good results in terms of visual quality and scale of a project.

PICTURE 13. (Hellblade: Senua’s Sacrifice, Ninja Theory, 2017)

3 PHYSICALLY BASED RENDERING

3.1 What is physically based rendering

According to Wes McDermott, a technical artist at Allegorithmic, in his Comprehensive PBR Guide, physically based rendering is a method of shading used by many modern game engines that allows greater flexibility for artists and a more accurate representation of real world materials in different lighting scenarios. (McDermott, 3) PBR, while having specific ways of working, is not a strict standard but can be thought of more as a methodology, (McDermott, 2) because PBR allows for a lot of customization in its use and application of different maps with different shaders. In addition PBR also helps with visual consistency between many different artists work because the shading follows the principals of physics and it takes out the guesswork for artists while texturing 3d assets. The same kind of metal for example will use the same values in its roughness and metalness across all assets thus creating a unified look under different kinds of lighting.

There are two primary workflows when working with PBR which are called the metal/roughness and specular/glossiness workflows. Both of these workflows result in a similar look and one is not inherently better than the other, both can be used to create an equally good end results they merely use different kinds of texture maps to achieve the same look. (McDermott, 2)

3.1.1 Allegorithmic and Substance software

Allegorithmic is a French software development company that has created the Substance software (Substance Painter and Substance Designer) which have become standard tools for many game development companies that use PBR in their games. The software are used for material authoring and asset texturing. The practical part of this thesis is done with Allegorithmic software and the company the author works at also uses them.

Substance painter is a software that is mainly used for texturing unique assets whereas Substance designer is a node based software made for material authoring and to create procedural materials for game environments and assets.

3.1.2 Comparison of texturing workflows

Game asset texturing pipelines vary between different companies and projects and their needs. The texture requirements are dictated by the shaders of the game and the use of the particular asset in the game. Traditionally before PBR 3D games have used a diffuse/specular workflow. This workflow utilizes a diffuse map, a specular map and a normal map to create a look that is relatively realistic. The problem with this is that it is incapable of reflecting light as realistically as PBR and previously the hardware limitations of consumers machines were such that PBR was not a realistic choice for games. The diffuse/specular workflow creates a kind of a workaround for realistic results. This means that the diffuse map has light information in itself as well as colour information to create an illusion of different materials together with the specular and normal map.(McDermott, 3) The issue with this method is that it does not create a realistic representation in different lighting scenarios.

Now as computer processing power has increased it has made more complex and physically accurate rendering methods a reality and many games have adopted PBR as their primary shading method.

3.1.3 Stylisation and PBR

As PBR is very strong in depicting realistic material, why then use PBR methods for stylisation? There are many advantages over the previous standard of using diffuse, normal and specular maps. Realistic materials can be a part of the stylisation of a project, for example Pixar utilizes materials in their works that portray realistic features like fur, scales, skin and so on, and the exaggeration often comes from elsewhere such as the shapes featured in the characters, proportions and choices of colour. (PICTURE 14.)

PICTURE 14. (Monsters University, 2013)

Another advantage is the accurate behaviour in different lighting and the added control that PBR allows. Most stylised 3D games utilize lighting just as realistic games do and the fact that PBR accurately depicts materials in different lighting scenarios allows artists to create content that they know will be correctly represented in the game engine no matter what the lighting is. This also allows the use of more interesting and versatile lighting setups.

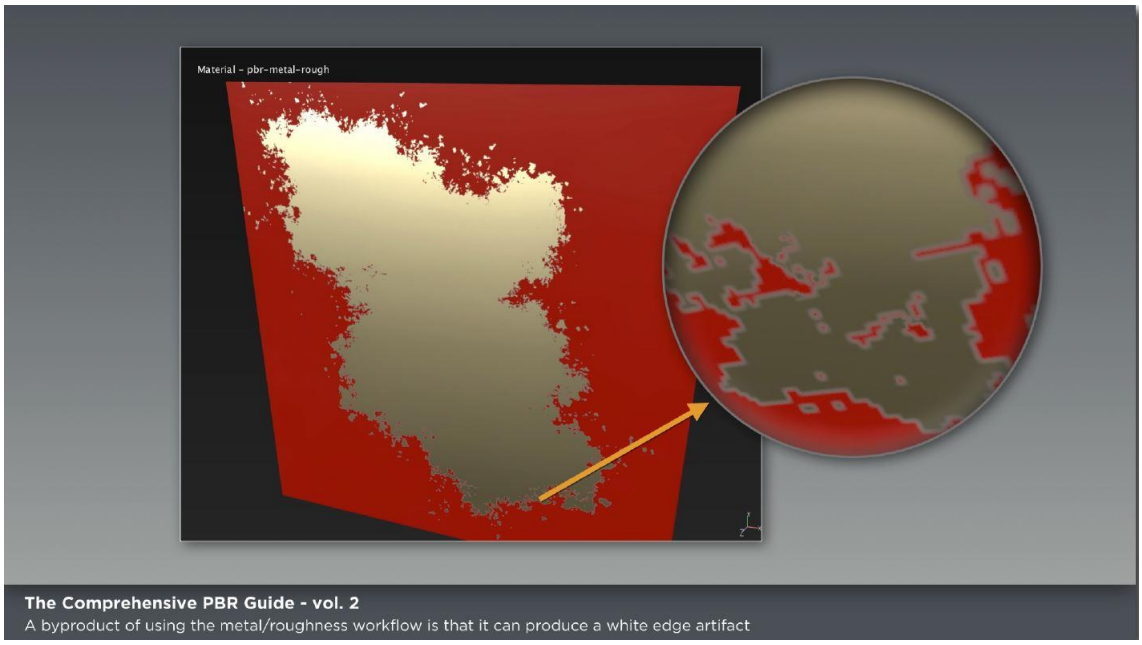
Lastly because PBR uses clear guidelines and specific values for specific materials thus it is much easier for artists to create visually consistent work without having to do much iteration and comparison to make sure everything looks correct as a whole.

3.2 PBR maps in detail

PBR uses two main workflows, the roughness/metallic workflow and the specular/glossiness workflow. These two workflows both produce similar end results and neither is inherently better than the other. which workflow is used is dependent on the projects game engine and shader implementation.

Roughness/metallic workflow uses an albedo, a metallic and a roughness map for material indication and the advantages of this workflow are that it is easier to create textures with it because it is less prone to errors caused by providing wrong dielectric F0, or the reflectance at 0 degrees, data in the metallic map and this means that you cannot break

the law of conservation of energy in the shader, (a surface cannot reflect more light back than it has received.) it also uses less memory because it uses only one RGB map (Albedo). The downside to this is that you have no control over your F0 for dielectrics. In addition to this the roughness/metallic workflow is prone to visual artifacts if the UV does not provide enough texture resolution to an area of the mesh and there is a fast transition from a non-metallic to a metallic surface. This can create white edges in the transition area as show in the picture below. (PICTURE 15.) This is an issue with the specular/glossiness workflow as well but it is not as visible because the effect is reversed and it produces a black fringe instead of white. (McDermott, 12)



PICTURE 15. (The Comprehensive PBR Guide vol. 2, McDermott, 2018)

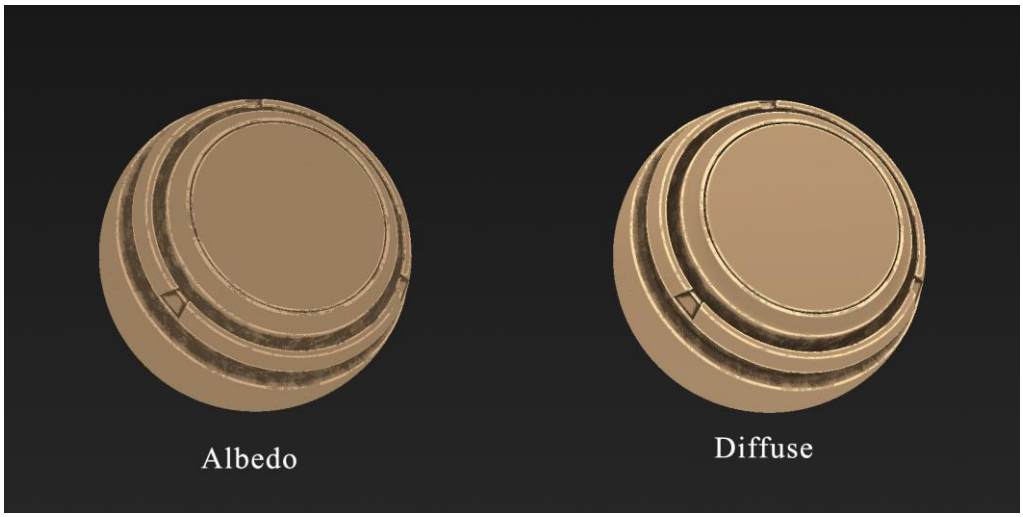
The specular/glossiness workflow uses a diffuse map, a specular map and a glossiness map. The difference to roughness/metallic is that the specular map allows for full control over the F0 of dielectrics which means that it is possible to provide wrong values and break the law of conservation of energy. It is also slightly more memory intensive because it uses an additional RGB map (Specular). It is however less prone to the before mentioned visual artefacts caused by poor texel density.

This thesis will focus on the roughness/metallic workflow as it is most relevant to the author's work and the company he works at. The texture maps used in this workflow are base colour, roughness, metallic and normal maps. Other maps that are sometimes used depending on the shader are ambient occlusion, height and emissive. The next parts will

go through each of these maps and their uses in more detail to get a better understanding on how these maps work together and what things artists need to be aware of when creating texture maps for PBR.

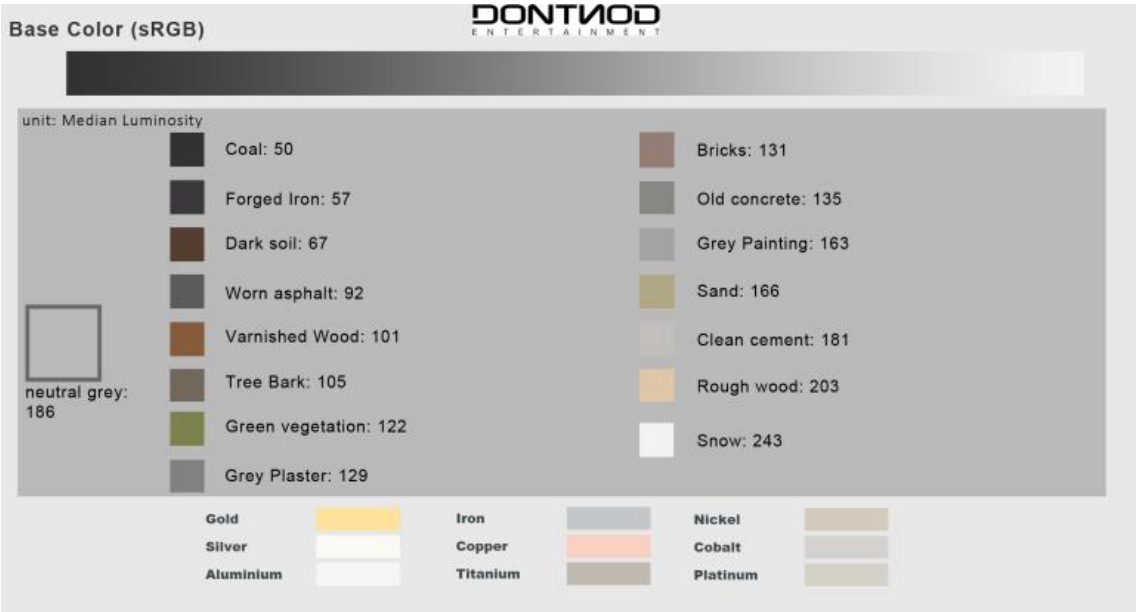
3.2.1 Base colour map

The base colour map, as the name indicates, holds colour information of the models texture. It represents the albedo for non-metal materials and the reflectance values for metals. Base colour maps should be thought of as quite flat in tonality in comparison to the traditional diffuse maps. (McDermott, 6) Diffuse maps have light information contained in them; this means that the value range of diffuse maps can and should be much wider than in base colour maps. (PICTURE 16.)



PICTURE 16. (Teemu Norvasto, 2018)

The base colour map is a 3 channel 8-bit RGB Map. In base colour maps one should not have too bright or too dark values, dark values should not go under 30 – 50 sRGB and bright colours should not go over 240 sRGB. There are many guidelines for the correct values of different materials in different game engines which help with consistency and accurate results. (PICTURE 17.)



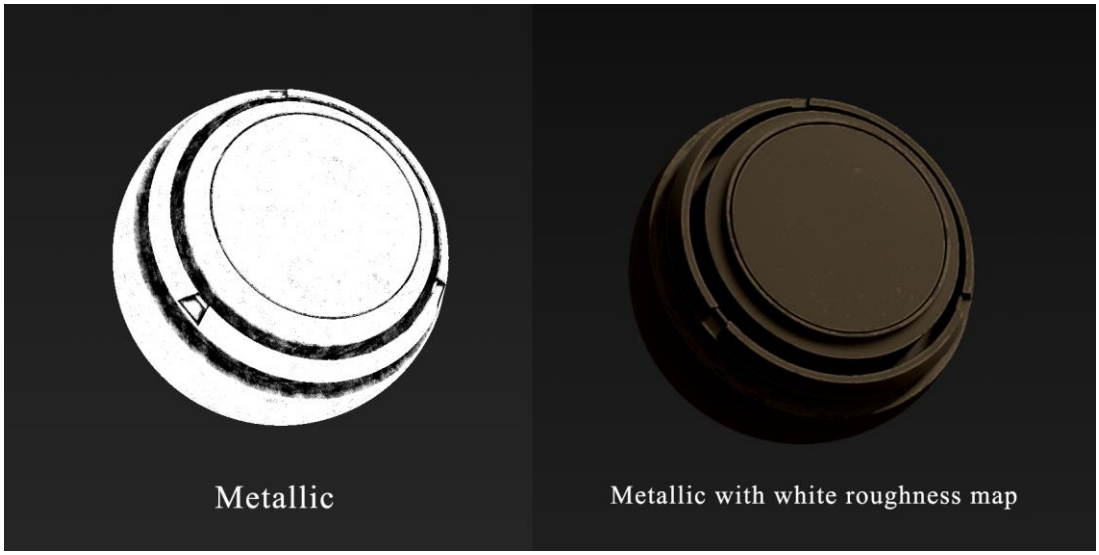
PICTURE 17. (Random thoughts about graphics in game, Sébastien Lagarde, 2014)

The creation of base colour maps is a pretty straightforward process as it is usually only a matter of selecting colours that are safe to work with in PBR and are appropriate for the material that the artist is planning to have. The base colour maps are often merely flat colours unless the material in question has some wear or damage that might require a different colour or if the material is layered in some way e.g. painted metal where the paint has peeled off from parts of the metal or a metal that has oil stains or parts that are rusting.

3.2.2 Metallic map

The metallic map is a single channel, 8-bit grayscale texture map that works like a mask for the shader to tell which parts of the base colour map are metallic and which are non-metallic. In a metallic map a value of 0.0 (Black - 0 sRGB) represents a non-metallic material and a value of 1.0 (White – 255 sRGB) represents raw metal. The metallic map is usually quite high in contrast because it functions as a mask that divides materials in metals and non-metals. It is however important to be aware of such thing as weathering or different coatings in metals that may affect the look of the metal. (PICTURE 18.) In this case we can see the dark parts of the metallic map hiding the underlying metal because there is dirt covering it, and the lighter parts indicate the clean metallic surface. This needs to be represented in the base colour map as well as the metallic map. The metalness of an object is a combination of the base colour value and the metallic map. (McDermott, 5 – 9) In the image you can also see the imager rendered in pbr with the

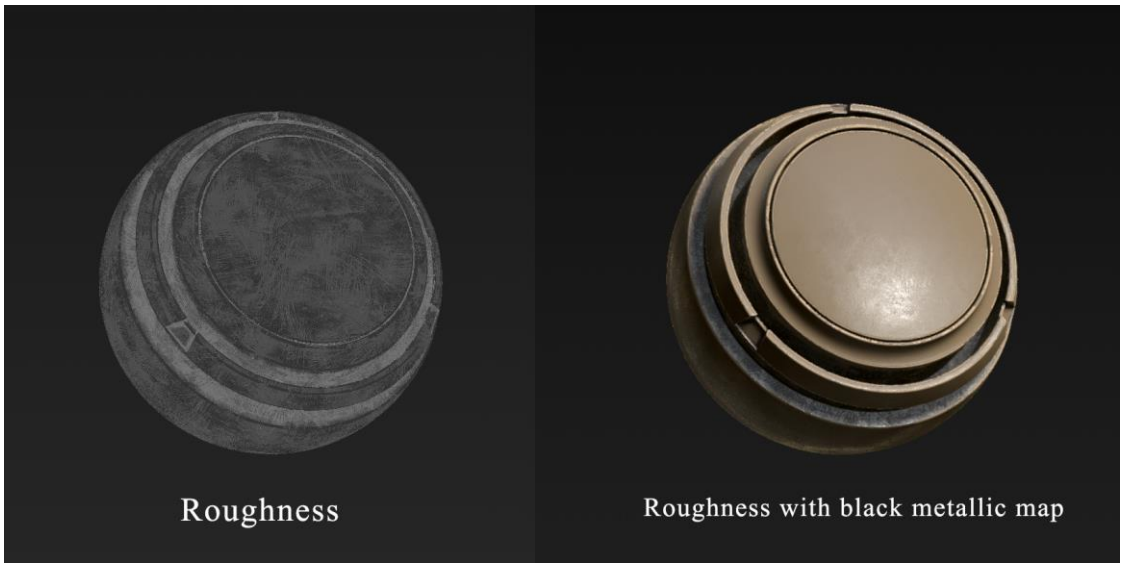
metallic map, but with a flat white roughness map. This is to show later how they work in concert to create a realistic result.



PICTURE 18. (Teemu Norvasto, 2018)

3.2.3 Roughness map

The roughness map is a single channlel 8-bit grayscale texture map that represents surface irregularities that cause light diffusion in the material. In practice this tells the shader how rough or smooth the object should look like. In a roughness map a value of 0.0 (Black - 0 sRGB) represents a smooth surface and a value of 1.0 (White – 255 sRGB) represents a rough surface. (McDermott, 10) Here we can see what the object looks like rendered with only roughness information and a black metallic map. (PICTURE 19.)

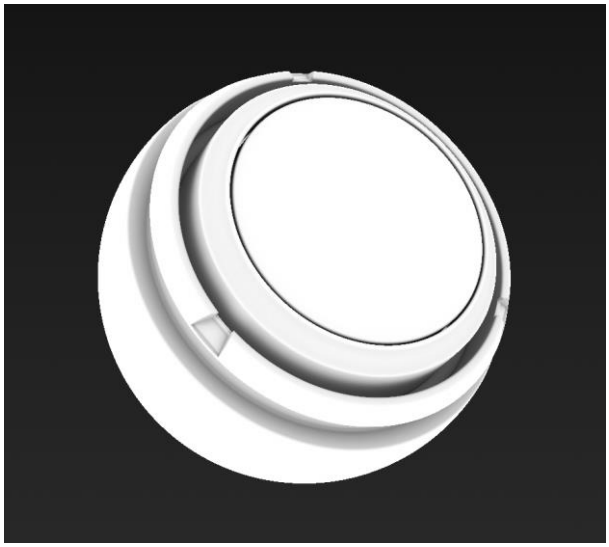


PICTURE 19. (Teemu Norvasto, 2018)

The roughness map is the map where you can be most creative. It allows the artist to indicate dirt stains, finger prints and other subtle things that can make an object come to life and tell a story.

3.2.4 Ambient occlusion map

Ambient occlusion as the name states occludes ambient lighting from parts of the mesh. Ambient occlusion is a grayscale texture map where a value of 0.0 (Black - 0 sRGB) represents full occlusion of ambient lighting and a value of 1.0 (White – 255 sRGB) represents no occlusion of ambient lighting.(McDermott, 20)



PICTURE 20. (Teemu Norvasto, 2018)

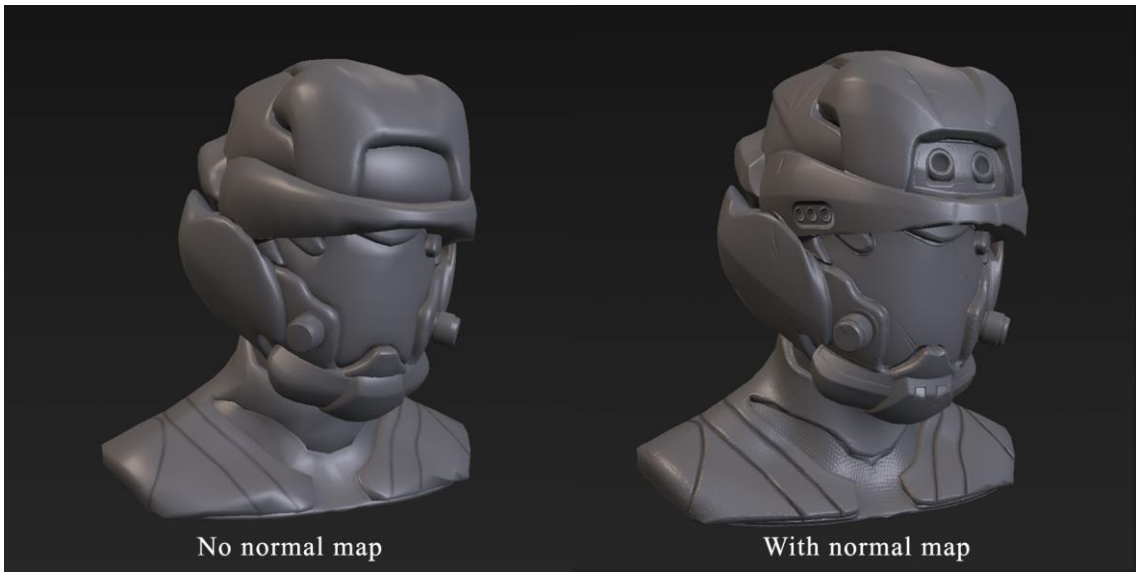
In traditional texturing workflows ambient occlusion information is often baked into a diffuse texture map to give depth and a more natural look, because unlike PBR workflows, the diffuse/specular workflow does not support a separate ambient occlusion channel.

Ambient occlusion maps are usually created by baking from a mesh or in substance softwares they can be converted from a normal map or a bitmap. Ambient occlusion usually does not require any work done by hand since the relevant information is usually in the mesh itself. If however you create things like holes or deep cuts or folds you will have to take the ambient occlusion of those things in to account while creating the textures, otherwise the results will be inconsistent with the rest of the texture and look wrong. (PICTURE 20.) The ambient occlusion map is also necessary when using pro-

cedural effects in Substance Painters for weathering and dirt as the ambient occlusion is used to guide the effect in which areas of the texture the effects should appear.

3.2.5 Normal map

Normal map is a 3 channel, 8-bit RGB texture map that is used to create surface detail (PICTURE 21) and its use is the same in PBR workflows as it is in traditional texturing workflows. (McDermott, 21) It creates adjustments to the surface normals before light calculations and allows for the use of finer detail from higher polygon meshes in a game environment that would otherwise be too heavy to use in a game. (Krishnamurphy & Levoy, 8)



PICTURE 21. (Teemu Norvasto, 2018)

Normal maps are usually created by baking from a higher polygon count mesh that has too much detail to be realistically usable in a game because of performance issues this creates the illusion of a more higher detail mesh than it actually is. Normal data can also be altered by hand without the use of a higher polygon mesh to add small details such as scratches, dents, cut lines etc. This can be beneficial for time saving reasons because it may be quite time consuming to create all the detail into a high polygon mesh.

3.2.6 Height Map

A height map can be used for parallax occlusion mapping which adds more apparent depth and realism (McDermott, 19) It is a single channel 8-bit grayscale map where a value of 0.0 (black – 0 sRGB) represents no increase in height to the surface area and a value of 1.0 (White – 255 sRGB) represents the maximum amount of increase in height as determined by the shader. (PICTURE 22.)

PICTURE 22. (Racoon Artworks, Martin Geupel, 2018)

Similar to a normal maps and ambient occlusion maps, height maps can be created by baking from a higher detail mesh. Height maps can also be painted by hand for example in Substance Painter or created procedurally in Substance Designer.

Finally when combined together all the maps form a realistic end result if used correctly (PICTURE 23.)

PICTURE 23. (Teemu Norvasto, 2018)

4 CASE STUDY

4.1 Author's Work in Dreamloop Games

This part of the thesis features work the author has done professionally for Dreamloop Games' titles Stardust Galaxy Warriors. It will go through the design part of the assets and analyse the choices made regarding the styles of the game as well as the execution of the assets and what choices were made and what tools were used during the making of the assets. Lastly there will be an analysis on how successful the whole process was, what has been learned and what changes should be made regarding future work.

4.1.1 Stardust Galaxy Warriors

The game was created on the Unity 3D engine and was initially released on steam on November 10th 2015 and later on PlayStation 4 and Xbox 1 under the name Stardust Galaxy Warriors: Stellar Climax with a new playable character which was added free to all previous owners of the game on PC.

Stardust Galaxy warriors is a side scrolling mecha shooter game that takes a lot of inspiration from old arcade games, cooperative shooter games and Japanese mecha animes and adds a modern touch to the formula with a four player cooperative mode, light RPG elements and customizable difficulty modifiers. (PICTURE 24.) The game is still in development with a new patch and DLC announced for summer 2018. The author worked and is currently working on the game as a lead concept artist and 3D artist and was responsible for the design of the playable character as well as enemies and environments. He also created a large amount of 3d models and textures for the game.

PICTURE 24. (Stardust Galaxy Warriors, 2016)

4.1.2 Design and style

Stardust Galaxy warriors' style went through quite a lot of iteration throughout its creation. The initial idea however has remained the same. The main goal was to bring a colourful slightly exaggerated take on Japanese military mecha animes' styles with a splash of humour in a Science fiction setting.

The design of the mechas evolved quite a bit during the early parts of development, the team created a few different iterations before arriving to the final designs, In the early phases of development the style was much more simplistic and featured much less details because in the initial scope of the project the mechas were only meant to be seen as very small on the screen and it was unnecessary to put too many details in to avoid visual clutter and make them read better to the players. (find an image of the first concepts)

As the development went on further the size of the player characters on screen varied as we were trying to find the perfect size for them, because if they were too small we could not distinguish them well and we wanted them to have more personality and meaningful variance and if they were too large it would make the four player cooperative mode impossible because they wouldn't be able to fit on the screen. As the gameplay got more fleshed out the team had already done two iterations of the first characters that had

made it into the game engine. At that point the final versions of the designs for all the four player characters were made (PICTURE 25.)

PICTURE 25. (Teemu Norvasto, 2016)

Each of the characters had an animal reference that was meant to reflect the mechas play style and feeling, Red Tiger would be aggressive and strong in close combat and the Blue Falcon would strike fast from a distance and so on, We didn't however want to anthropomorphise them too much so the outward appearance would remain very faithful to their Japanese mecha origins.

The Gundam series and figurines were a big influence on the designs of the mechs and the style of the game. (PICTURE 26.)

PICTURE 26. (Pinterest, 2018)

The challenge was to choose the amount of detail and where it would be relevant to add detail without compromising the readability of it in the game.

4.1.3 Creation

The main characters as well as other 3D assets in the game were modelled using either Autodesk 3DS Max or Maya, textured in either substance designer or substance painter and animated in Maya. As this part is the most relevant to thesis it will cover the creation of the assets in more detail and especially the texturing as that is the phase where PBR is relevant.

We will take one of the textures of the Silver Wolf who is one of the playable characters in the game, as an example. It is enough to go through the creation process on one of the characters because the creative and technical process is similar in all of them.

The 3D Models for the player characters were created by Szabolcs Sarosi in Maya based off of my initial designs. During the modelling process we tried to pay attention on creating a strong silhouette with an emphasis on the side profile as that was the angle the player would be viewing the model most of the time during gameplay. We kept the fo-

cal points on the extremities of the model such as the legs, hands and shoulders because most of the movement would be visible there during gameplay.

Texturing of the models was done in Substance Painter, the first important part in my experience has been thinking about how to divide materials and value and colour contrast, which parts are metal and which are not. The characters in SGW tend to be split into two colours with an accenting colour from the lights in the mechs eyes, engines and other places which help focus the viewer's eye on important areas of the mech. The first thing I do is give the whole mech a material and a colour that I think will cover the largest amount of the model. (PICTURE 27.)

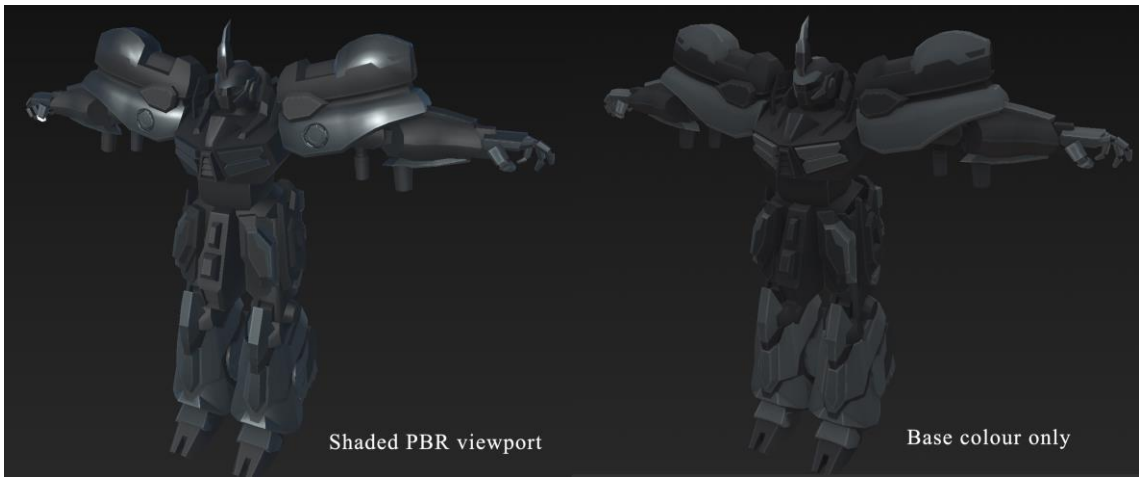
PICTURE 27. (Teemu Norvasto, 2018)

This is not the final material or colour, but just a place to get started. At this point there is usually a lot of room for iteration and experimentation so a good approach is to create another material that works well with the first one, mask out some areas of the model that should be of a different material and then start experimenting and tweaking the them. (PICTURE 28.) This is one of the strengths of Substance Painter. It is very easy to change existing materials in a non-destructive way when using fill layers and masks because you can always go back and change the colour or the value of any other channel in the material. Substance painter even allows the increase or decrease of resolution of the texture without any loss of quality. Already at this point the different materials are starting to show definition and the form of the model starts to read better and look more

interesting. Parts of the shoulders reflect light in different manner and start to look like metal and other parts are more matte, painted metal or some sort of rough surfaced plastic for example.

PICTURE 28. (Teemu Norvasto, 2018)

In the image below you can see the difference between only the base colour map and the fully shaded PBR Viewport. Already at this stage the effect the materials create is quite visible. (PICTURE 29.)



PICTURE 29. (Teemu Norvasto, 2018)

Once satisfied with the primary materials and how they are divided on the model I go in to add detail and add the accent colours. This is a challenging phase because it is very

easy to give the model too much detail. As stated earlier when going for an exaggerated stylised look it is important to think about the key details in the model and enlarge and exaggerate them, because if you start adding too much small detail it can start looking too realistic or just confusing. It is very important to keep a level of simplification so that everything reads properly but still looks interesting and detailed enough. In this phase I place details that are common in the references that I've collected such as panel loops, vents, air intakes and so on but trying to make them larger and keeping a tight control on not adding too much. (PICTURE 30.) This is quite challenging because the main influences such as the Japanese mecha anime Gundam relies quite heavily on small details to show scale and add believability and function to the machines.

PICTURE 30. (Teemu Norvasto, 2018)

At this point the model is starting to have all the essential elements placed and it is quite clear what the feeling of the whole texture is. It is still however quite sterile and lifeless in terms of variation in the texture, as if the machine was brand new. In the next phase I start adding more information to the roughness map to give a sense of wear and damage to the model to tie the whole texture together and give it a more consistent look. I also add stencils and texts, such as call signs and serial marks, signs for dangerous areas and other stamps to try to indicate the scale of the machine and give it a feeling that it is manufactured for military purposes instead of it being just a generic machine or a mechanical suit. I believe these are important details in this type of subject matter to give it believability and scale. (PICTURE 31.)

PICTURE 31. (Teemu Norvasto, 2018)

In the final phase I decided to give this texture a worn out and damaged finish so I added a strong wear on top of everything to create a more multi-layered effect on the texture, focusing on sharp and pronounced edges and corners. I increased the size of the damage to make it more visible from a distance and to maintain a sense of exaggeration (PICTURE 32.) Before finally exporting the textures I also added some sharpen filters to layers like the wear and roughness to make them pop a bit more.

PICTURE 32. (Teemu Norvasto, 2018)

4.1.4 Results

The feedback SGW has received for its visuals has been generally very good, this particular colour variation of Silver Wolf has not yet been released in the game so it is difficult to gauge what the response from users will be, but I hope it will be well received. We have done the usual critique and peer reviews inside our own team and we feel that this and the other unlockable colour variations will be well received. (PICTURE 33)

During the making of these colour variations I streamlined and improved my process in substance painter by being more organized and efficient with my layers and folders. This meant that I could easily come back to the project after a break of doing something else, which was necessary because during the making of these assets I had to go back and forth between different tasks which made it essential that I could continue the project easily and effectively after a period of time. As a result I now have an even clearer workflow from start to finish on all of my future texturing projects.

Another important lesson that I learned was to be selective and consistent with details. It is very easy to go overboard with the amount and variety of details like panel loops, vents, handles, lights and so on you can add in a mech like this. I feel it is important to pick a set of shapes and details and work creatively with them, this helps maintain cohesion and consistency and helps to avoid random and unnecessary detail. It also helps to keep a sense of the whole because the end result can end up being cluttered after adding all the detail layers such as texts, warning signs, dirt, damages and so on.

In future projects I think the most important things are still the fundamental design of the character as you can only do so many things in texturing. The design of the character is quite old and as an artist I feel it is always a bit of a mental challenge to go back to your old work because you strive to constantly improve and as you see your own work from a while back you can think of ways to improve it and you most likely won’t have a chance to go back and redo things so you have to work with what you have and that can be a bit frustrating.

From a technical point of view I think the biggest challenge was that because of the way the model is unwrapped it doesn’t allow any asymmetrical detail in its shoulders, arms or legs. This means that textures are mirrored on the other side of the model and for

example wear, damages and dirt is symmetrical which can make it look unnatural and strange. The advantage of this is an increase in texture space. However in my opinion because these characters are the main characters of the game the performance gained from this method is not necessarily worth restricting the end result in such a way.

PICTURE 33. (Teemu Norvasto, 2018)

5 Author's personal work done for the thesis

This part of the thesis covers the work the author has done specifically for the thesis to explore and experiment with methods that he has found useful in the texturing of 3D assets and the ideas of creating stylised 3D characters covered in this thesis. (PICTURE 34)

PICTURE 34. (Teemu Norvasto, 2017)

5.1.1 Design

The idea behind this piece was to create a quirky looking robot that would work in a desert environment as a scout that would get sent out to locate people who had become lost or stranded in the and needed rescue. The idea and the challenge were to create a machine that had character. This meant that I had to play with proportion and the structure of the robot and it ended up becoming almost like a soda can with legs and rocket engines.

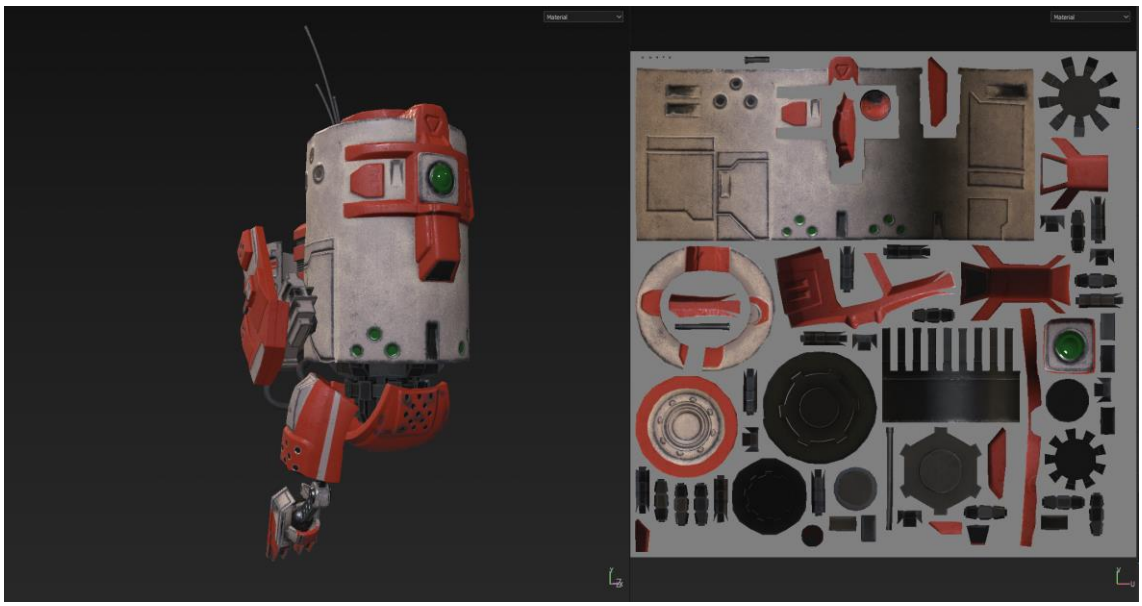
The robot started from a small sketch and I went on to refine that in 3D. I wanted to test how well I could design details and flesh out ideas in 3D. Initial design work for proportion and structure was done in 3DS Max and the final detailing and modelling of the highpoly model was done in ZBrush, retopology and unwrapping was done in 3DCoat.

The design of the robot falls into the category of exaggerated stylisation mentioned earlier in the thesis as discussed by Kim Aava in her lvl80 Article, Realistic vs. Stylised: Technique overview. The exaggeration can be seen in the elongated body and small legs that the robot has that gives a feeling of a slightly clumsy and awkwardly walking robot, the lens on its front is also made quite large to resemble an eye and to give and impression of a face which makes the robot look a bit more sympathetic and friendly. I decided to present the work on a small podium with a bit of ground material on it to give the robot some context and indicate the environment that it could be in. the reddish fog also gives an indication of a desert or a sandstorm.

5.1.2 Creation of textures

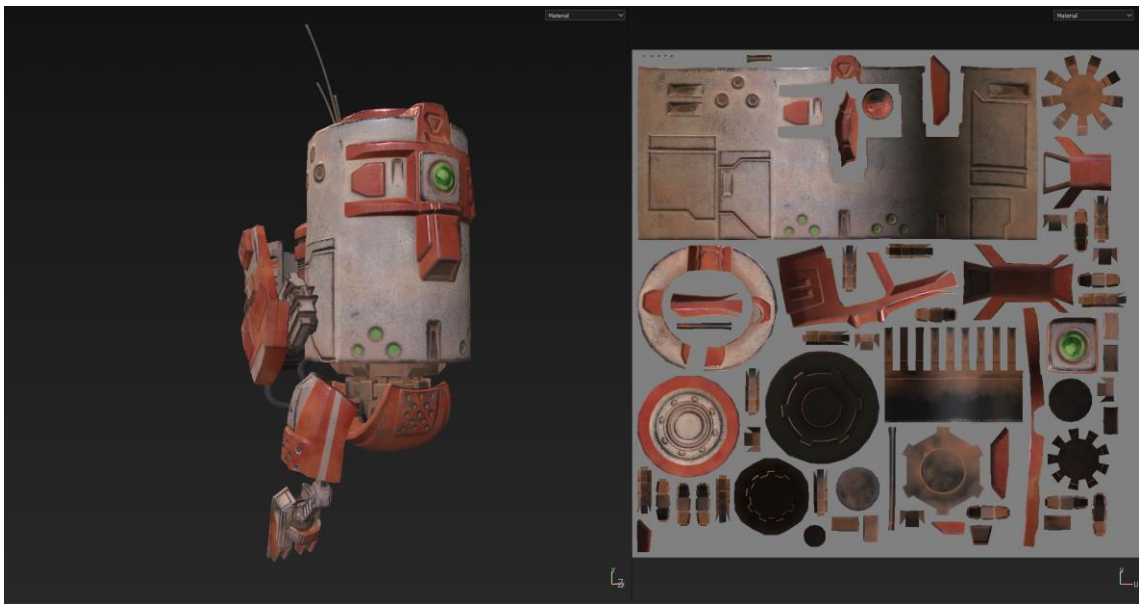
As this was a 3D project not done for a specific game but to explore techniques and create a piece of real-time 3D art I did not set myself very strict technical limitations regarding the amount of geometry, materials and texture resolution I however kept it within the limits of a potential game asset for a detailed important character for a modern game.

The process started similarly to the process used in the creation of the colour variation of Silver Wolf from SGW shown earlier by dividing the model in to materials and masking the areas that they cover such as the beige and red painted metal, the steel parts under the armour plates, legs, engines, exhaust pipes, the waist, glass lenses and rubber wiring. I chose a complementary colour scheme for the primary paint colour and the lights to make the details pop nicely and a more desaturated colour for the main body. (PICTURE 35.)



PICTURE 35. (Teemu Norvasto, 2017)

After separating the materials and picking out colours for them I started adding more detail and story to the texture. As this piece was meant to show a robot working in a desert environment I had the chance to add more environmental effects showing in the texture unlike in the texture for the Silver Wolf which goes through many different environments during the game thus I could only add very neutral wear and tear to the texture. In the case of the robot I added a lot of dirt and sand accumulating in crevasses and gaps in the model to make it look like it has been spending quite a bit of time in the desert. I also exposed some of the metal underneath the painted areas especially in sharp corners and edges and stained the engines and exhausts with soot. I made sure to make the legs and the lower part of the model more dirty and damaged to show the dirt and damages accumulated from walking on the ground. (PICTURE 36.)



PICTURE 36. (Teemu Norvasto, 2017)

Finally I added emissive lights to the lenses of the model which helps it feel like a powered up machine and then placed serial numbers, unit numbers and other stencilling to the body and the rubber hoses in the back of the robot. This helps to give some more storytelling and makes the robot feel like it is a part of a larger unit of similar robots and that it is utilized by some sort of official organization like a military unit or a rescue operation. (PICTURE 37.)

PICTURE 37. (Teemu Norvasto, 2017)

Finally an important thing in any piece of work is of course presentation. Personally when presenting real-time 3D work I use Marmoset Toolbag 3 because it is very fast

and efficient software to showcase your work. It also allows the uploading of interactive 3D viewers of your work to sites like Artstation or Sketchfab straight from the software.

In the case of this robot I created a small podium for it to show some ground of the area that it could potentially be in and created a lighting scheme that I felt was appropriate for a desert roaming robot without covering detail of the actual work. I feel it helps sell the piece much better when there is some hint of context for the work. (PICTURE 38.)

PICTURE 38. (Teemu Norvasto, 2017)

5.1.3 Results

This project was quite a big one and quite a challenge for me and I learned many things during the making of it. Not only about texturing and PBR but also about how to approach a more detailed and ambitious 3D project such as this and many things about problem solving during the modeling and retopology phases. In general I feel that my skills in 3D game art improved a lot on all areas of the production.

Regarding the results of the project, I am quite happy with how it looks. My goal was to create a slightly exaggerated quirky rescue robot and I think I got quite close to what I was striving for. I learned many things during the process and similarly to the retexture of silver wolf, the importance of being organized was an important lesson here. As the model and design gets more complex it becomes very difficult to maintain control over

the whole process and not get overwhelmed. I also noticed that as my folder structures and file names weren't very well thought out initially I started to lose a lot of time trying to find the correct files during retopology and painting especially because I had use many software for this project. This means that you have working files in the native formats of the software and you have the exported 3D files of parts of those working files when you want to move them to another software. This is a tricky part and one can get very confused and frustrated if not careful in naming and organizing things correctly. This is even more essential when switching on to something else for a while and coming back later, or if some other person is going to take over your work in the next phase as it can be very difficult to get working on it properly without wasting a lot of time trying to remember how everything was made and organized or the person working on it next might not be able to work on it at all without having to clarify and confirm many things first.

In this project many new ways of working were tested and learned. Previously my work had not included high poly models for baking normal maps most of the time as most of them had been small assets and environment pieces which didn't require it. In addition to this many new methods of approaching PBR texturing in Substance Painter in a much more non-destructive manner were learned. The project is not as heavy performance wise as many others before were and fill layers and masks were used to a greater effect in creating weathering and damage effects on the texture which resulted in producing the final result faster than before and allowed fast testing and changing of colors and materials. Understanding of stylisation played a large part in the decision making during the modeling and texturing process which helped approach the project in a more confident and decisive manner.

In the future for similar projects it would be beneficial to push the exaggeration of the 3D model more. Because this project was also about improving in 3D modeling both technically and artistically, but lacking confidence at the time, the design choices remained a bit lackluster. Learning in this field never ends of course so the lessons learned here will certainly show in the quality of my work in the future.

CONCLUSIONS

What I found during the making of this thesis is that there is not a lot of research that has been made about the different ways of visual expression in games. There is a lot of discussion online and among artists and the term stylised is used often and it is usually associated with a certain type of visual look which can be described as cartoony or playful or exaggerated and was in many ways coined by the aesthetic created by the company Blizzard and their games.

My conclusion is that even though the term stylised usually brings a certain aesthetic to mind the visual stylisation of games is far from absolute and there is an immense amount of variation in non-realistic graphics from completely abstract and surreal to realism or relatively close to it. A common factor in stylisation tends to be the varying amount of simplification. There is no clear wrong or right in this as is the case in most creative media; however for appealing results a key factor is a strong art direction and maintaining the visual rule set of what to simplify, what to exaggerate and to what degree you do these things.

Non-realistic games are also immensely popular at the moment and have been for a long time. The success of games like Overwatch, Dota 2, League of Legends, The Legend of Zelda: Breath of the Wild, and Fortnite are a testament of great game design but also of a stylised aesthetic.

It is difficult to say what makes a stylised aesthetic popular. Perhaps there is a timeless quality to it. A stylised aesthetically pleasing look can stand the test of time better than realistic games due to the rapidly developing technology which makes realistic games look outdated much faster than stylised ones.

A simplified aesthetic also caters well to games due to the fact that it can make interactions and visual indicators easier and clearer to read and understand. A game can be a hectic experience of movement, light, fast actions and rapid interactions and a clear and concise visual communication created by a simplified and stylised aesthetic can make the experience better for the player.

I learned many lessons both technical and visual during the making of the practical parts of this thesis. Stylisation is a very tricky subject and there is a lot of decision making involved in picking the right shapes, what to simplify and what to exaggerate which can be extremely difficult to get right. Good knowledge of shape design and the relations of shapes are highly important to reach good results; however it is difficult to know what is right and what is wrong due to the subjective nature of style. I find it is important to establish a rule set for your style and be very consistent with it. It helps greatly with decision making if you have some sort of a guideline to fall back to when you arrive at an impasse in your work and when you are not sure what to do. This art direction allows you to stay focused on the things that are most important in your project and helps you to arrive at an end result that looks great.

Modern tools and shading methods such as PBR and the substance softwares bring many helpful working methods to the artist and they are excellent in not only allowing you to create more impressive visuals than ever before, but they also allow for teams of many artists to maintain a more modular, non-destructive and consistent way of working which saves a lot of resources and allows for more iteration and projects of a larger scope.

The technical lessons learned from this thesis will allow me to create new work in a much more efficient manner and gives me confidence and knowledge to tackle more complex projects in the future. The main point of learning in my opinion still remains on the visual side. Decision making and finding the most attractive designs and shapes and just the right amounts of detail is still the greatest challenge and the most vital area of learning.

Hopefully this thesis has been useful to the reader and has successfully clarified and informed of stylisation in modern video games and given information on how to achieve good results with modern production tools regarding PBR and texturing. My personal skill and eye continues to develop further all the time and learning never stops as new technology is developed and the field of gaming keeps advancing and changing.

REFERENCES

Aava Kim, LVL80, Realistic vs. Stylized: Technique overview, Website, read on 17.12.2017, https://80.lv/articles/realistic-vs-stylized-technique-overview/

De Meo Francesco, Wccftech, The Legend Of Zelda Breath Of The Wild New Colorful Screenshots Focus On Bokoblins, website, Read on 3.3.2018, https://wccftech.com/legend-zelda-breath-of-the-wild-new-colorful-screenshots-focus-bokoblins/

Goslan Jeff, Artstation, 'Valravn' from Hellblade: Senua's Sacrifice, Website, Read on 17.3.2018, https://www.artstation.com/artwork/XQELL

Hellblade, Development Diary 21: Making a Virtual Human, Website, Read on 18.3.2018 http://www.hellblade.com/development-diary-21-making-a-virtual-human/

Imgur, Assassins Creed: Origins, Website, Read on 18.3.2018, https://i.imgur.com/9cmgJNt.png

Krishnamurthy Venkat, Levoy Marc, Fitting Smooth Surfaces to Dense Polygon Meshes, Computer Science Department, Stanford University, 1996

Lagarde Sébastien, Random Thoughts about Graphics in game, DONTNOD Physically based rendering chart for Unreal Engine 4, Blog, Read on, 11.2.2018 https://seblagarde.wordpress.com/2014/04/14/dontnod-physically-based-rendering-chart-for-unreal-engine-4/

Lawardorn, Damien, OnlySP, A Mind at War with Itself: Hellblade and the Lived Experience of Mental Illness, Website, Read on 9.5.2018, http://onlysp.com/hellblade-op-ed/

Lim Hong Chan, Artstation, Overwatch Soldier: 76 Cyborg high poly, Website, Read on 3.3.2018, https://www.artstation.com/artwork/kRqyA

Little John, Push Start Play, Game Review: Nier: Automata, website, Read on 17.3.2018 http://www.push-start.co.uk/game-review/game-review-nier-automata/

McDermott Wes, The Comprehensive PBR Guide by Allegorithmic - vol. 2, Read on 2.12.2017, www.allegorithmic.com/system/files/software/download/build/PBR_volume_02_rev05.pdf ,9.

Mckenney Eric, Artstation, Stylized Sci-Fi Goo Gun, Website, Read on. 3.3.2018, https://www.artstation.com/artwork/e9XGZ

Metacritic, Best games of 2017, website, Visited 17.3.2018 http://www.metacritic.com/browse/games/score/metascore/year/all/filtered?year_selected=2017,

MHM Podcast Network, New character posters for Monsters University, website, Read on, 11.3.2018, https://www.moviehousememories.com/new-character-posters-for-monsters-university/

Moby Games, Assassin's Creed, Website, Read on 18.3.2018, http://www.mobygames.com/game/assassins-creed

Rush Cole, Hollywoodchicago, Video Game Review: 'Journey' Achieves Perfection Again on PlayStation 4, Website, Read on, 3.3.2018, http://www.hollywoodchicago.com/news/25749/video-game-review-journey-achieves-perfection-again-on-playstation-4

Video game interfaces, Overwatch, Website, Read on 21.1.2018, http://videogameinterfaces.com/ui/blizzard/overwatch

Wikipedia, Hellblade: Senua's Sacrifice, Website, Read, 19.5.2018 https://en.wikipedia.org/wiki/Hellblade:_Senua%27s_Sacrifice

Wikipedia, Shader, Website, Read, 12.5.2018 https://en.wikipedia.org/wiki/Shader

Wikipedia, Texture mapping, Website, Read, 12.5.2018 https://en.wikipedia.org/wiki/Texture_mapping,

Wintory Austin, Gamer Girl Reviews, Journey, Blog, Read on 17.3.2018, https://jefisher3.wordpress.com/tag/austin-wintory/

Youtube, Hellblade, Development Diary 16: The face of Senua, Video, Watched on 19.5.2018, https://www.youtube.com/watch?v=mcB0hlkliV4