# Textures

## Baking and Normal Map Theory

An introduction to the concept of “baking” textures

Revision: 001

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# Baking|Contents

This lesson will cover the following:

1. What is baking, what is it used for and how does it work
2. A typical Baking Workflow
3. Working with smoothing groups
4. Baking process in Substance Painter
5. A common baking issue for new students

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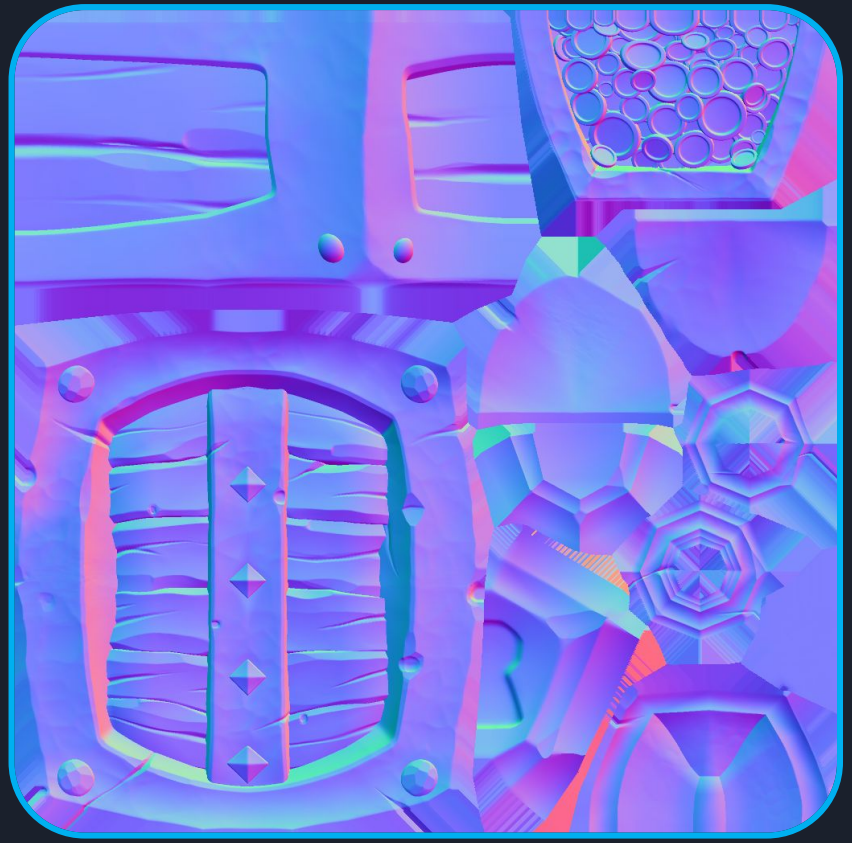
# Baking|What is Baking?

Baking is the process of transferring details from one model to another.

In Game Art more specifically it is usually the method of transferring details from a high detail model to a lower more “game ready” model for use in engine

- A baking tool is the software used to complete the baking process
- Baking uses ray projection methods to capture data from a high detail model and transfer that information to the corresponding UV space on the low detail

# Baking| What is the result?

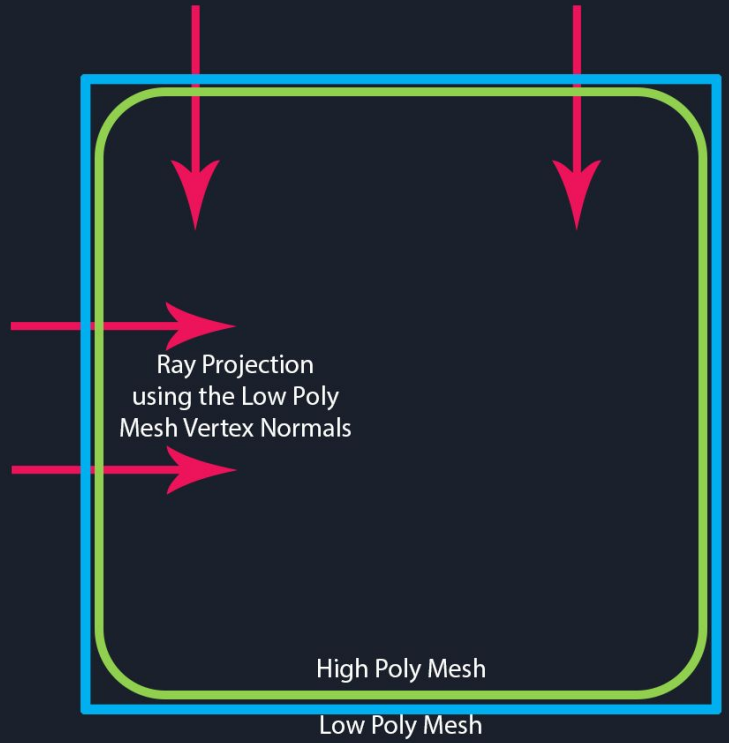


Baking generates several textures that can be used in the texturing process or by the engine to enhance the low poly model. One of the most important baked textures is the Tangent Space Normal Map or “Normal Map”

The normal map stores directions at each pixel, these are the “normals”. The RGB channels relate to the XYZ coordinates of the model and the orientation of the normals on those faces.

Each pixel of the normal map stores the surface slope of the high poly mesh source. This is interpreted by the engine to fake the lighting effect of surface detail like bumps or dents.

# Baking| How does it work?

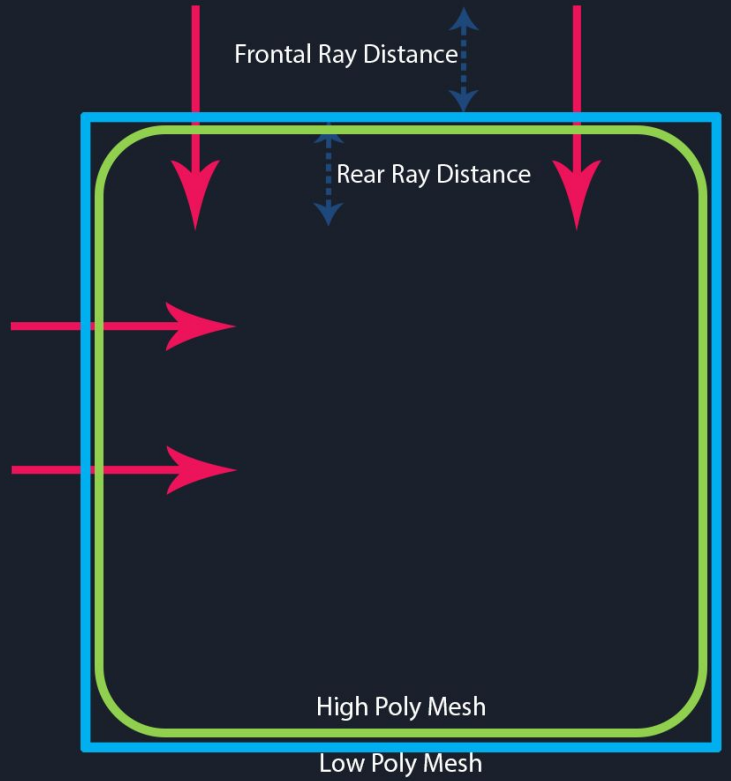



Baking relies on a method called ray projection.

This involves projecting a ray from a source mesh towards a target mesh. When a ray intersects the target mesh it records the surface detail and translates that into a texture map using the source models UV map.

This example shows a ray shooting outwards along the vertex normals of the low poly mesh (the source mesh), then the ray is cast back inwards. When a ray intersects the high poly (target mesh) the data is transferred to the UV's

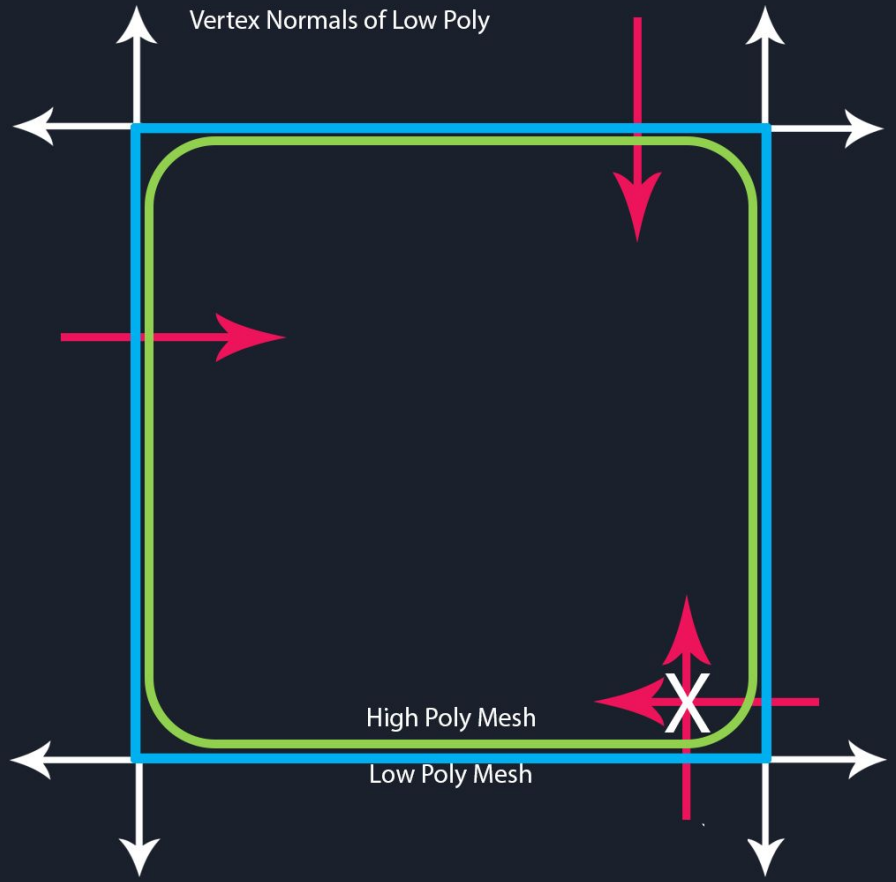
# Baking| Ray Distances




Many Baking tools allow customisation of “ray distances”. This affects the distance a ray travels outwards from the low poly mesh and then back inwards to the low poly mesh

Setting ray distances too low can result in the ray projection not capturing data for the bake. Ray distances being too high can result in rays intersecting, resulting in artifacts as rays translate incorrect information to the UV’s

# Baking| Vertex Normals



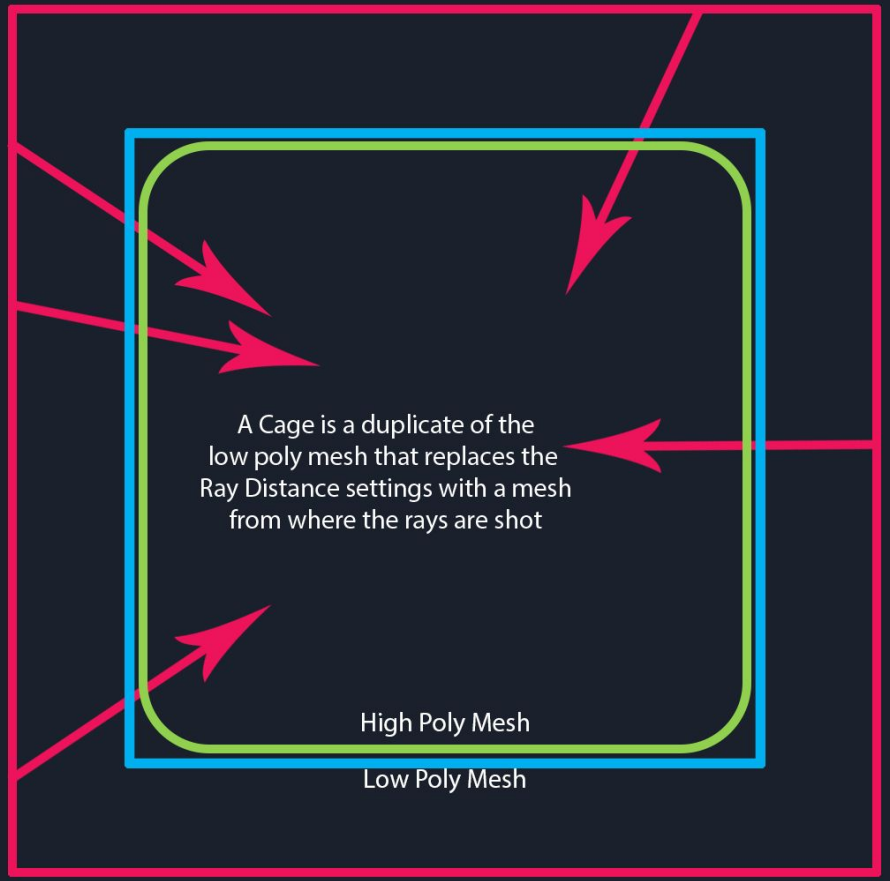

Projected rays utilise the vertex normals of their source (low poly or cage) to dictate their angle.

Changing the angle of the vertex normals by using Smoothing Groups or Hard and Soft Edges changes the angle of the ray projection. Some geometry may be captured more (or less) accurately depending on the direction of the vertex normals.

Hard edges and a distance-based raycast cause the rays to sometimes miss information and overlap as seen in this example **(3)**

This method of using the low poly mesh normals directly for your projection direction is known as **Explicit Mesh Projection**

# Baking| What is a Cage?



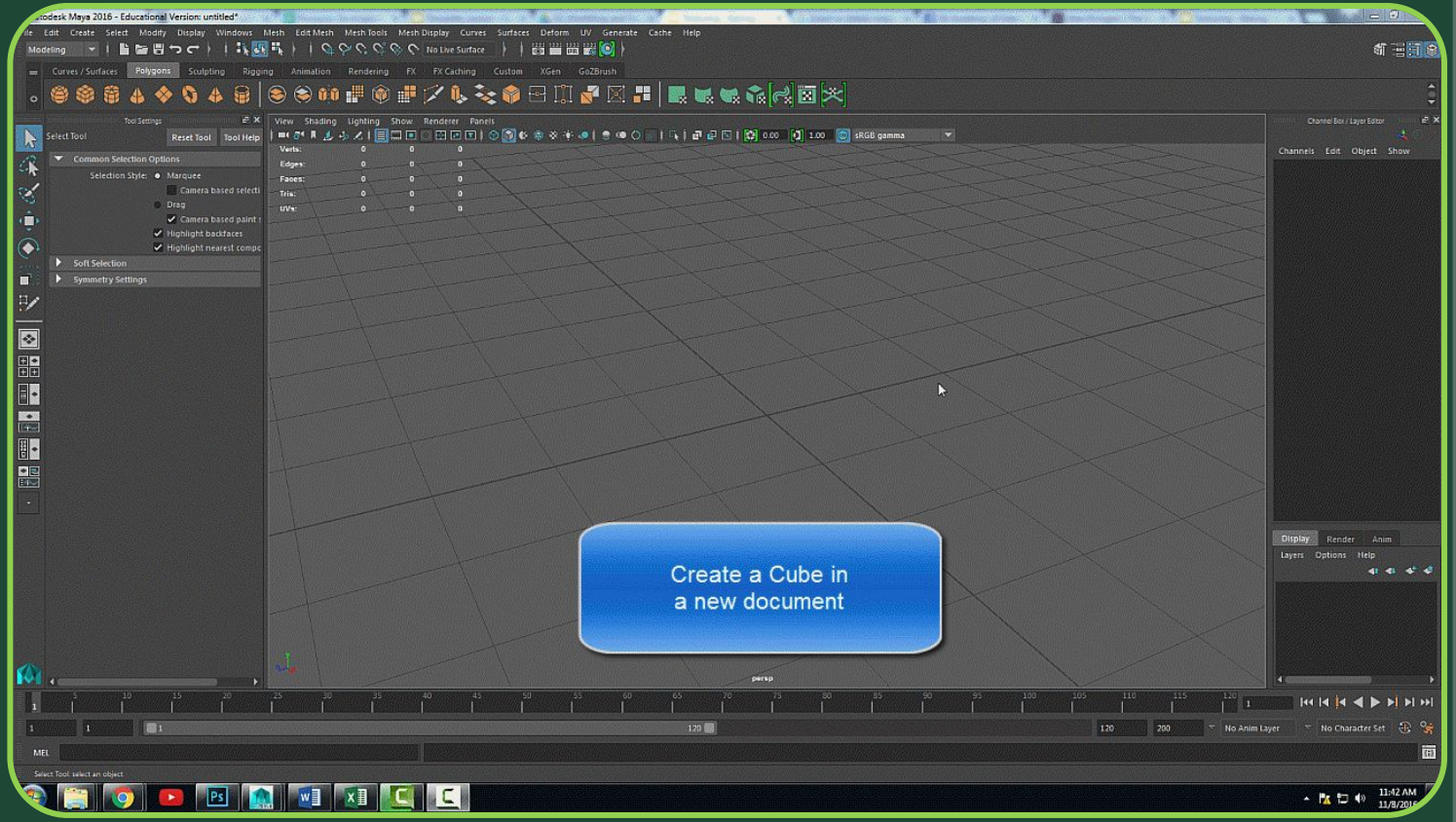

When we are looking for a clean bake, we **may** need to utilise a Cage.

A Cage is a mesh, usually an inflated duplicate of the low poly mesh, that an artist can use as part of the baking process. A Cage's vertex normals are averaged or *smoothed*, giving a more continuous and cleaner bake

Rays are projected inwards from the cage. Some software programs and bakers will allow you to control the distance and angle of the rays.

Cages can be created in 3D applications like Maya or within other bakers like Marmoset Toolbag.

# Baking| Experiment with Vertex Normals




1. In a new document create a cube
2. Using the display properties, display the cube's vertex normals
3. The green lines protruding from each vertice are the vertex normals for that vertex
4. By using what is often referred to as smoothing groups an artist can alter the vertex normals
5. Doing so also alters the way Maya or a similar product will attempt to render the shape
6. Try altering the vertex normals on some of the geometry from the Polygons shelf in Maya

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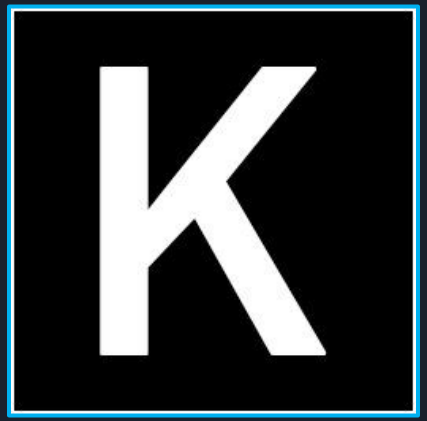
# Baking| Baking Software



There are many programs that can be used for baking. We will mainly use substance painter for baking. Below is a list of common software used for baking.

- Substance Painter - Commonly used baker ideal when using substance painter for texturing.
- Substance Designer - Has the ability to transfer textures from another model.
- Knald - Commonly used GPU based baker. Very quick to bake and able to tweak bake results real-time. Knald is not free.
- Marmoset Toolbag - Has great features, able to paint offset and skew direction of bake rays
- Xnormal - Older free baker that produces good results.

# Baking| Baking Workflows

Baking workflows vary between artists but a common workflow consists of

- Create a high poly model
- Re-topologise the high poly model to create a matching low poly model
- UV map the low poly model
- Triangulate and mirror the low poly model
- Offset mirrored UV's
- Set Smoothing Groups
- Clean up and optimise low poly and high poly model
- Create a cage
- Bake in tool
- Import and test

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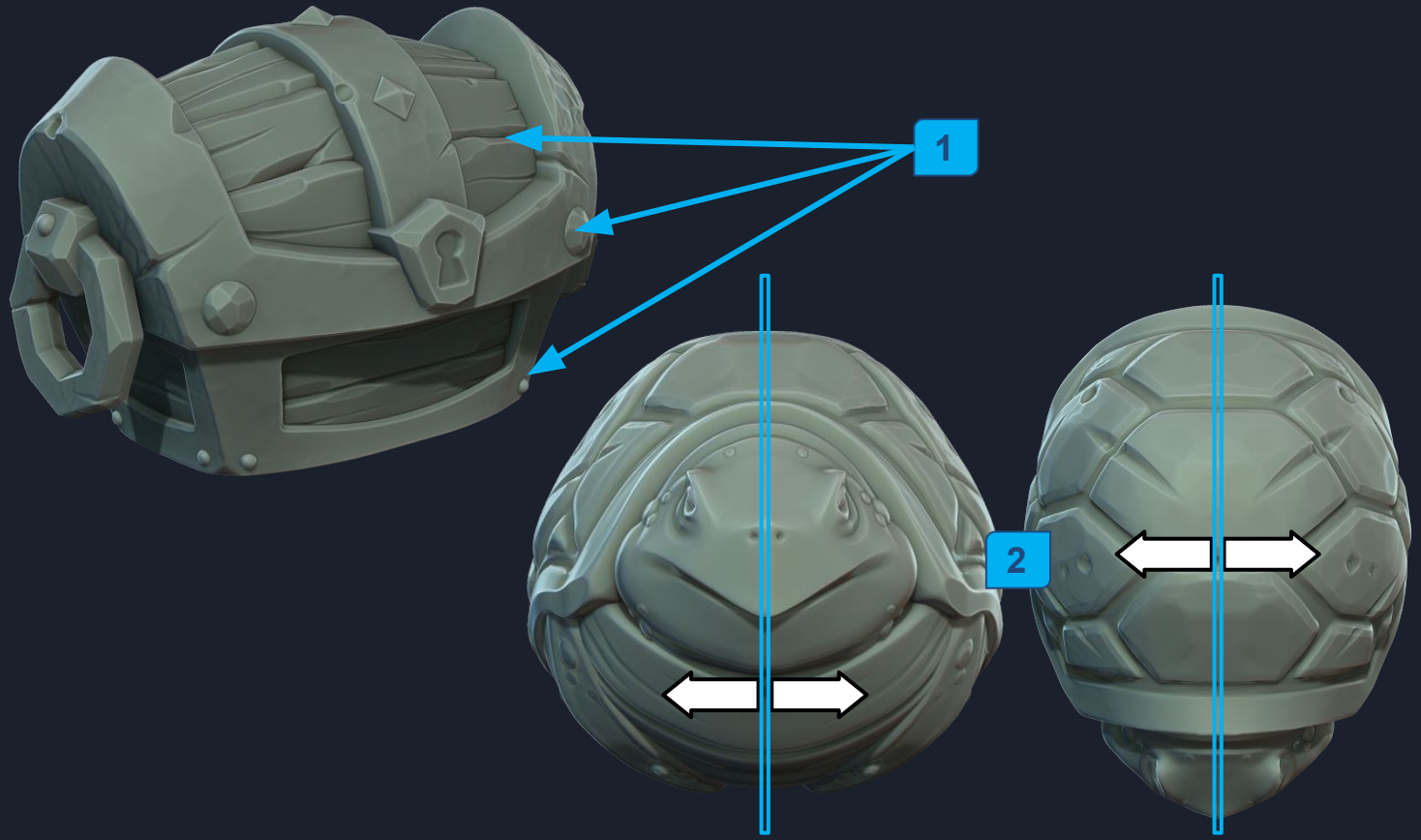
# Baking| High Poly

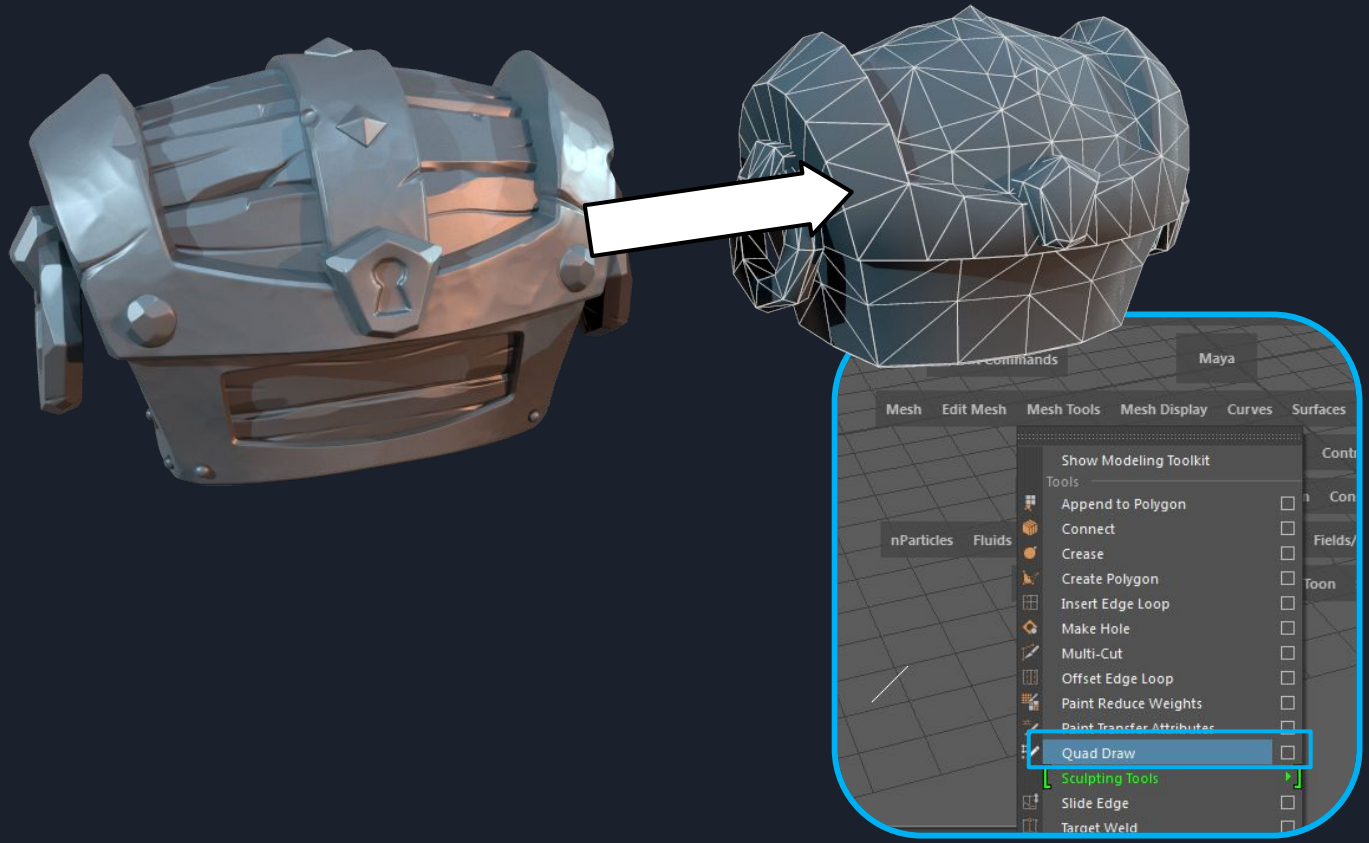



The first part of a baking workflow is creating your high poly model. A High poly model can be created in a sculpting program like Zbrush or within Maya itself. When creating a high poly model the artist should consider;

1. Efficient Geometry. With baking, surface detail from the high poly can be shown through a normal map and texturing without needing actual geometry. Small details like scratches, skin wrinkles, pores and rock noise etc

2. A high poly model can also utilise symmetry. This will allow the low poly model to also be symmetrical, optimising geometry, UV space and texture resolution

# Baking| Retopology




Once a high poly has been created the next task is to create a retopologised version of that model. This is a low poly model that will be used in engine and will have the high poly detail “baked” on it.

- If the high poly has symmetrical areas, create those areas on the low poly and duplicate them later in the workflow.
- Use more geometry to help the baking process on fine areas of detail. Spikes, teeth and sharp points are good examples of areas where more geometry should be used.
- Using Maya’s Quad Draw tool an artist can load the high poly into Maya and “paint” vertices directly onto it, creating a low poly that matches the high poly

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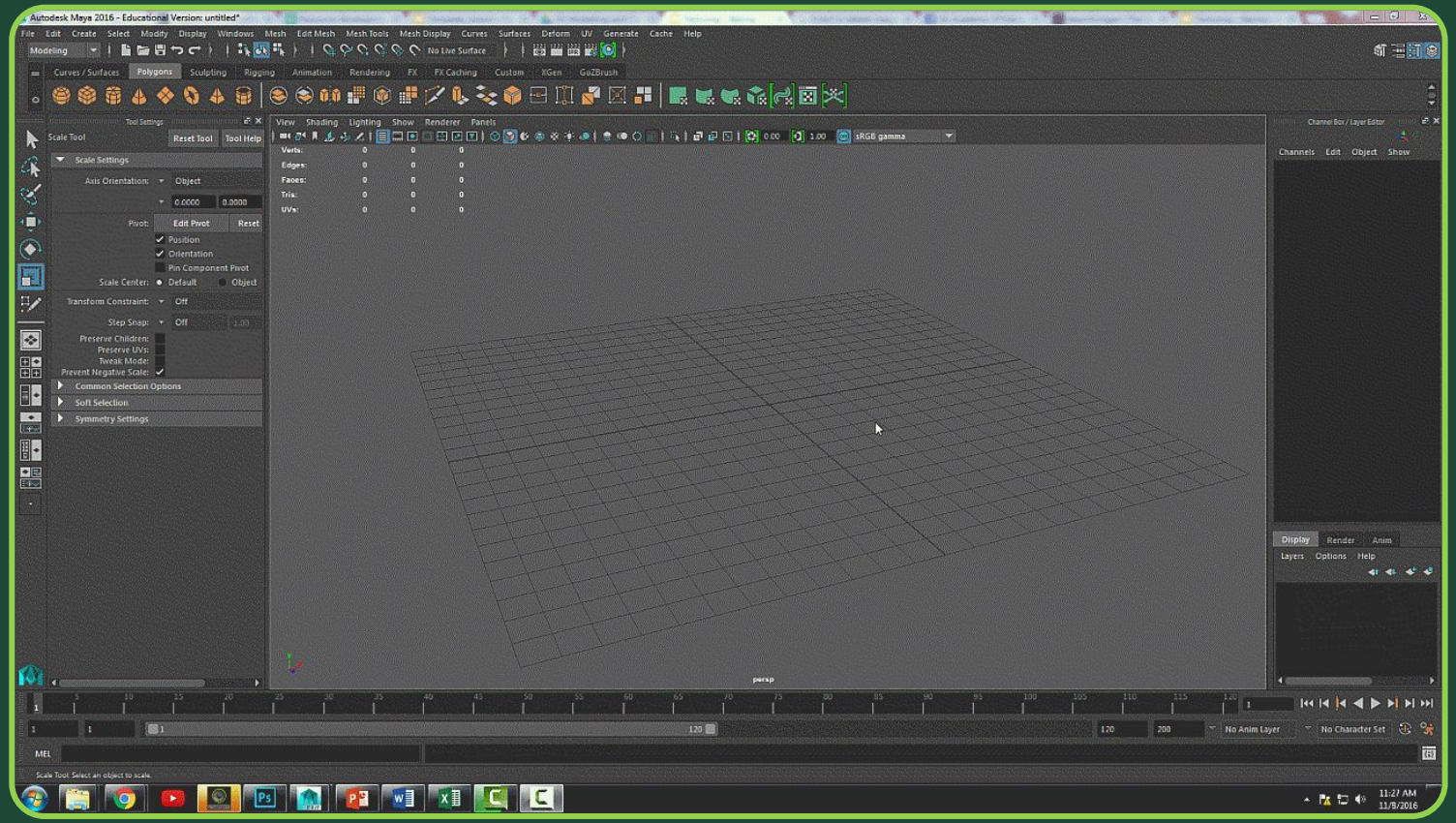
# Baking| Using Quad Draw




1. In Maya, create a new document and a new Sphere
2. Place the Sphere in a new layer. When geometry is live, it cannot be hidden or selected so a layer is very handy
3. Smooth the Sphere to add some geometry, simulating a “high poly”
4. Make the Sphere live. This is done by clicking the small magnet icon with the Sphere selected
5. With the Sphere live, it is used as a reference for Quad Draw
6. Using Quad Draw, click and create vertices on the Sphere
7. Shift click between vertices to create a face

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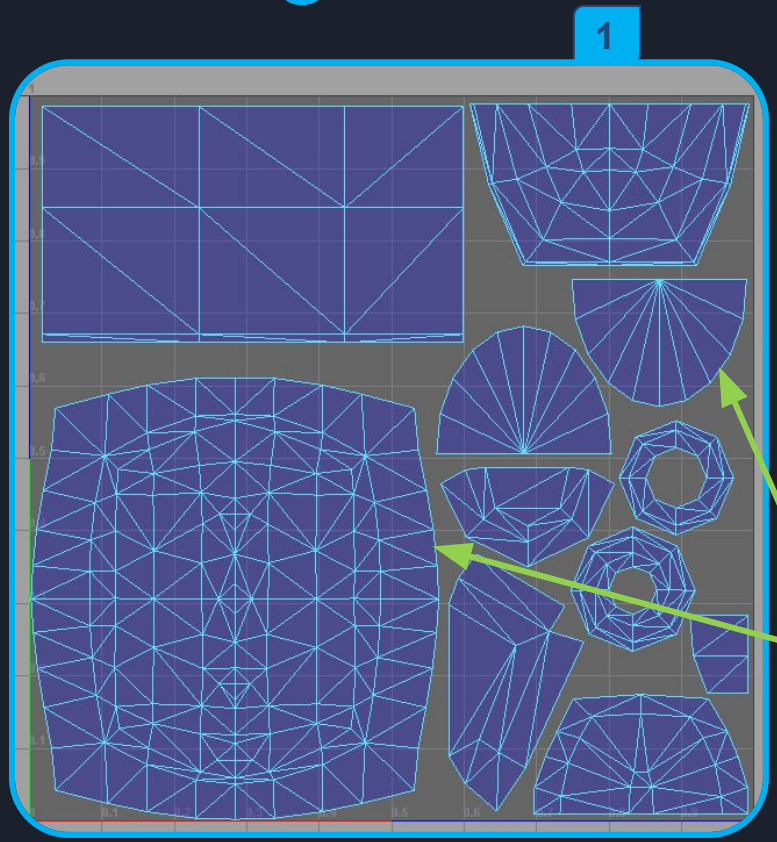
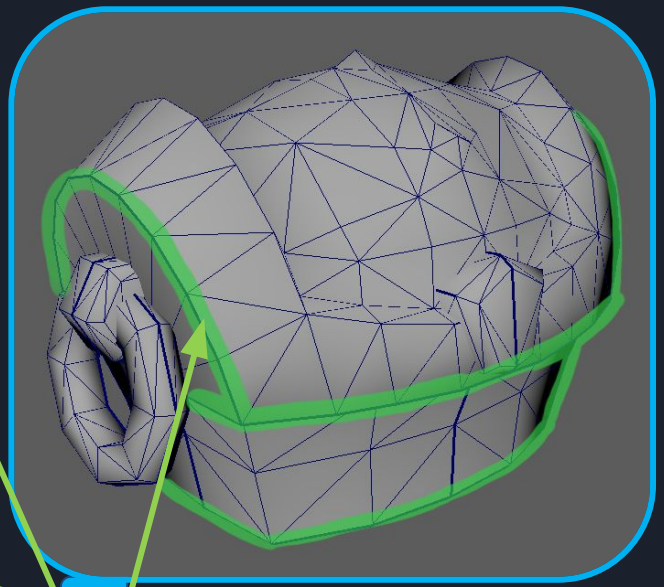
# Baking| UV



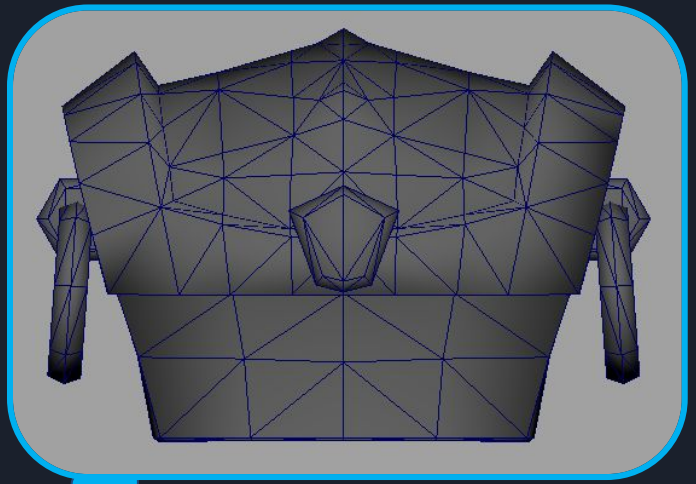




Planned hard edges in the smoothing groups are also UV borders.

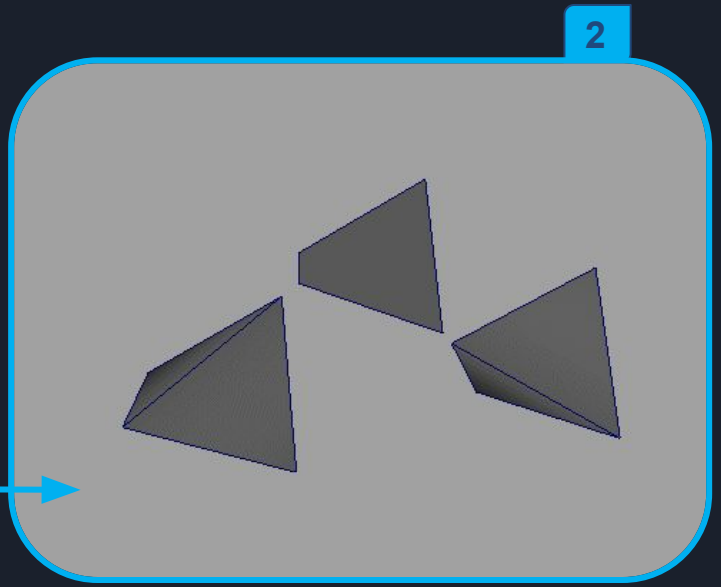
Your **low poly** needs to be UV unwrapped. During the baking process the baker will use the information it receives from the ray projection to translate the data it receives to the relevant piece of the low poly model. This is achieved by creating textures using the UV's of the low poly model

1. The 0-1 UV space is what a baking tool uses to generate its textures
2. Discussed later, but anywhere you plan to have a hard edge, you **NEED** to have a UV border to prevent shading artifacts.
3. Try to orientate your UV's horizontally and vertically. While UV islands may fit easier on odd angles, it increases aliasing artifacts on a bake. Don't be afraid to align UV's manually after an Unfold.

# Baking| Triangulate



1



2

Here you can see the result of triangulating this non-planar face with two different edge intersections. The result is vastly different topology. Allowing each piece of software to triangulate your low poly in the baking workflow could cause huge issues if this occurs on your model

Before you bake your low poly needs to be triangulated. This is important for several reasons

1. When using symmetry across a low poly model, you want your topology to also be mirrored. Not doing so results in shading and display errors as the surface normals are not mirrored, even though the engine is expecting them to be so.
2. Some baking tools and engines will automatically triangulate a low poly model for you if it has not already been done. While handy, this can result in two different applications triangulating the same surface differently, altering the way the baked maps are rendered

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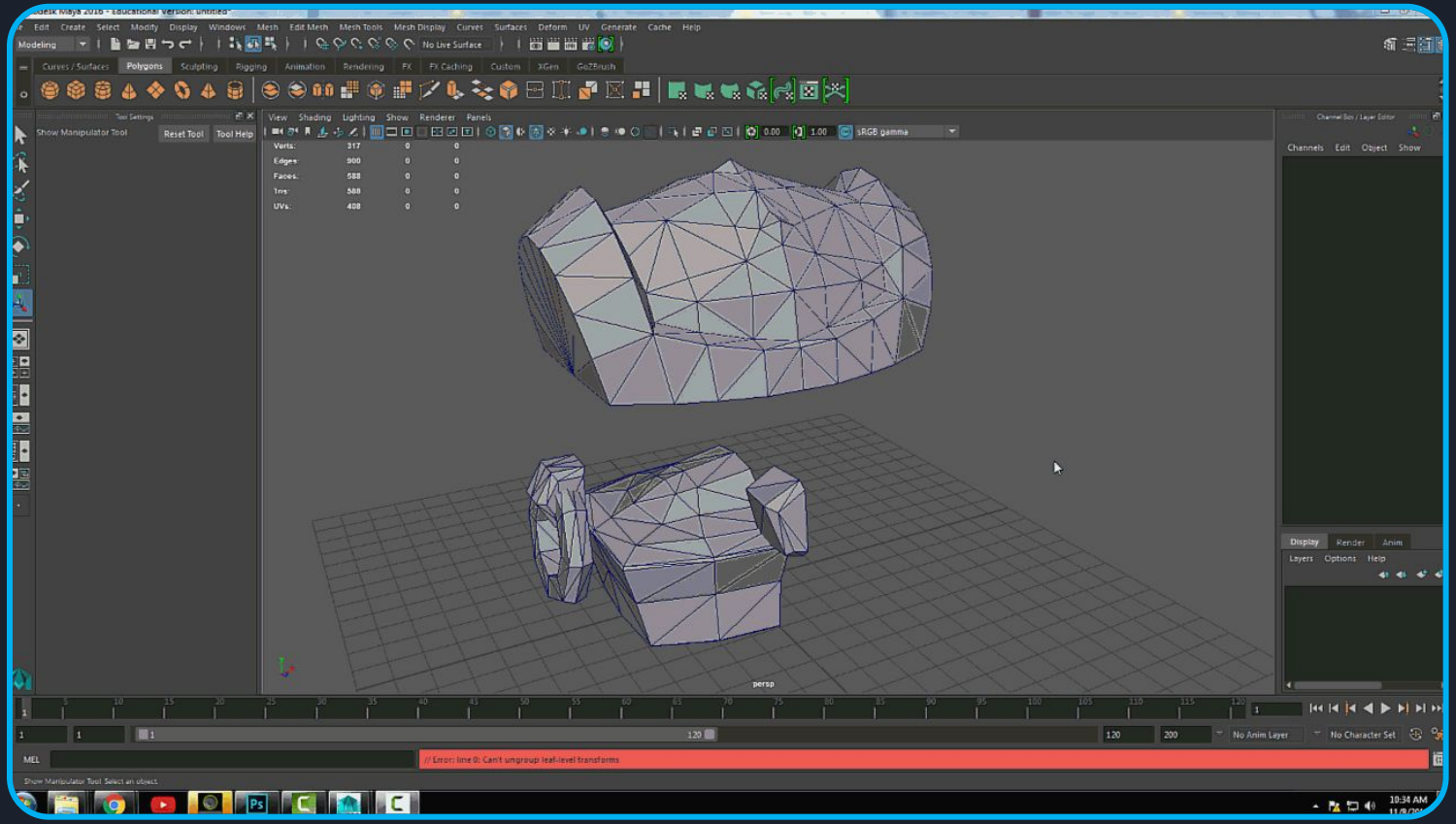
# Baking| Duplicate and Mirror



There are many ways to duplicate and mirror geometry in Maya. One example is shown on this slide

- When mirroring geometry it is possible the face normals can be reversed, resulting in the mesh being displayed inside out. If this occurs use **Mesh Display -> Normals -> Reverse** to revert this.
- After duplicating geometry you will need to combine and weld vertices together across the axis you mirrored.
- Make sure after duplicating and mirroring you check your transformations, history and groups and remove any no longer needed.

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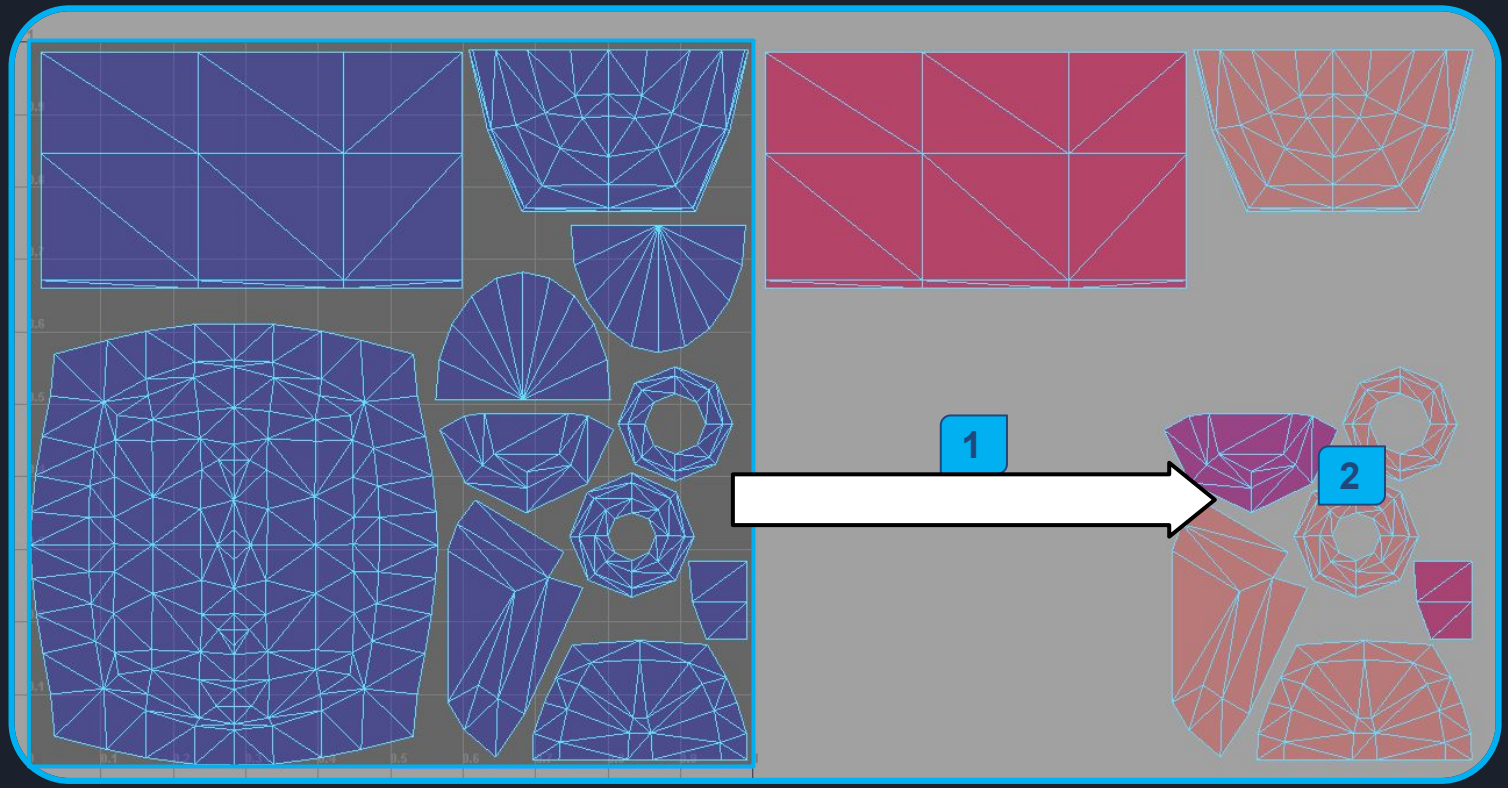
# Baking| Offset UV's

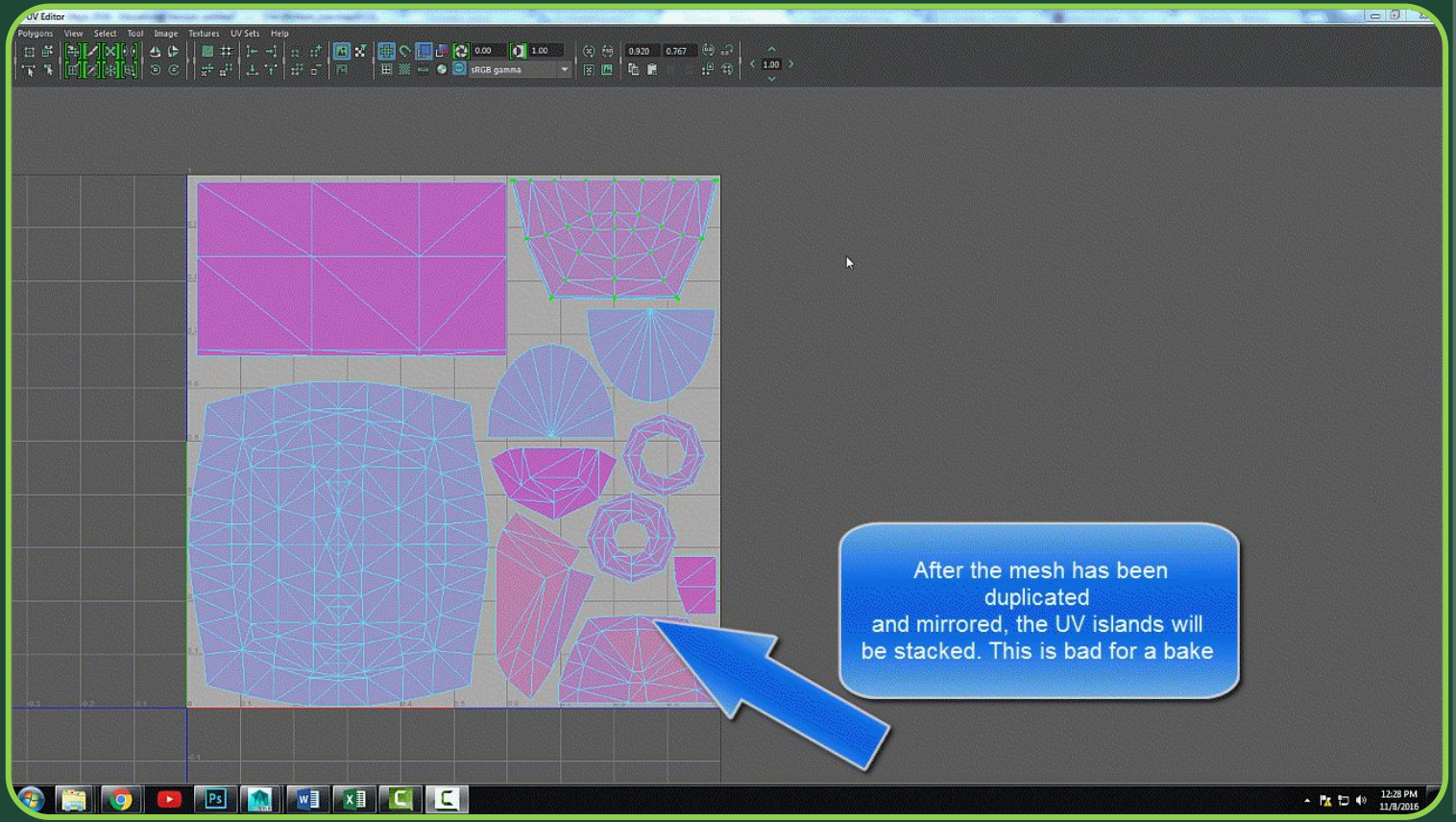



When mirroring parts of the low poly model to utilise the symmetry of a high poly sculpt, UV's of the mirrored pieces will become stacked. While this is great for the end result, it can cause several issues during the bake process;

1. To get around this, stacked shells are moved out of the 0-1 UV space for the duration of the bake.

2. The UV shells outside of the 0-1 UV space will not have any affect on the bake. Once the bake has been finished these UV shells can be move back inside the 0-1 UV space

# Baking| Offset UV's




1. Moving UV's out of the 0-1 space is good practice for clean bake results. While in some cases it could be possible a mesh will not have issues with stacked UV's it is bad practice to assume it will always be the case
2. For efficiency a Quick Selection Set could be made of all shifted UV's in order to quickly select them for moving them back later.
3. Naming conventions can help with isolating a working file for baking and your final deliverable version

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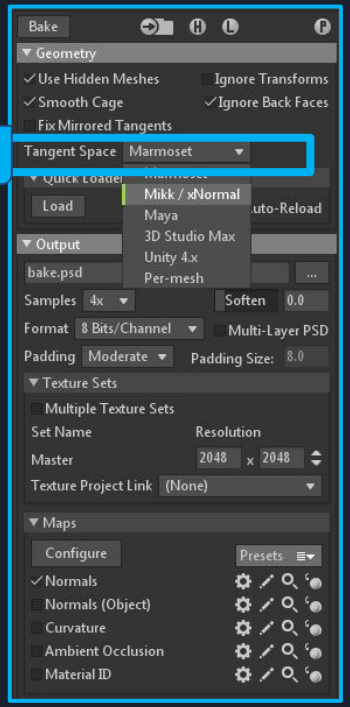
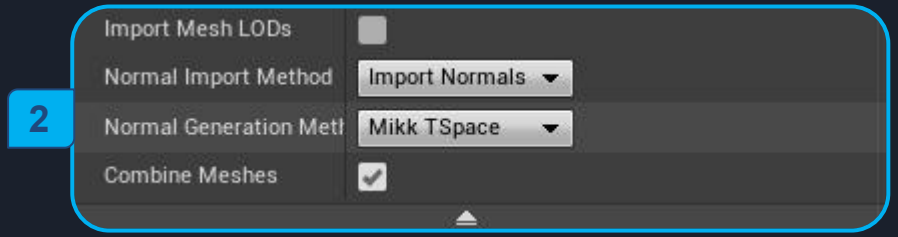
# Baking| Synced Baking Workflow

## Tangent Basis Calculators (keeping your workflow synced)





Keeping your workflow **synced** to your destination engine is extremely important. This ensures the way your baking application calculates tangent space is the same as your engine. Substance painter is alway set to MikkTSpace and cannot be changed. However in other bakers there may be an option to change it to MikkTSpace

1. For example Marmoset Toolbag require the user to change to Mikk / xNormal Tangent Space calculator. This is the same calculator Unreal and Unity use **(2)**. Maya uses a different Tangent Space Calculator.
2. Having your baking process synced to your destination engine you don't need to use as many hard edges to avoid smoothing errors. But learning and utilising them is still good practice.

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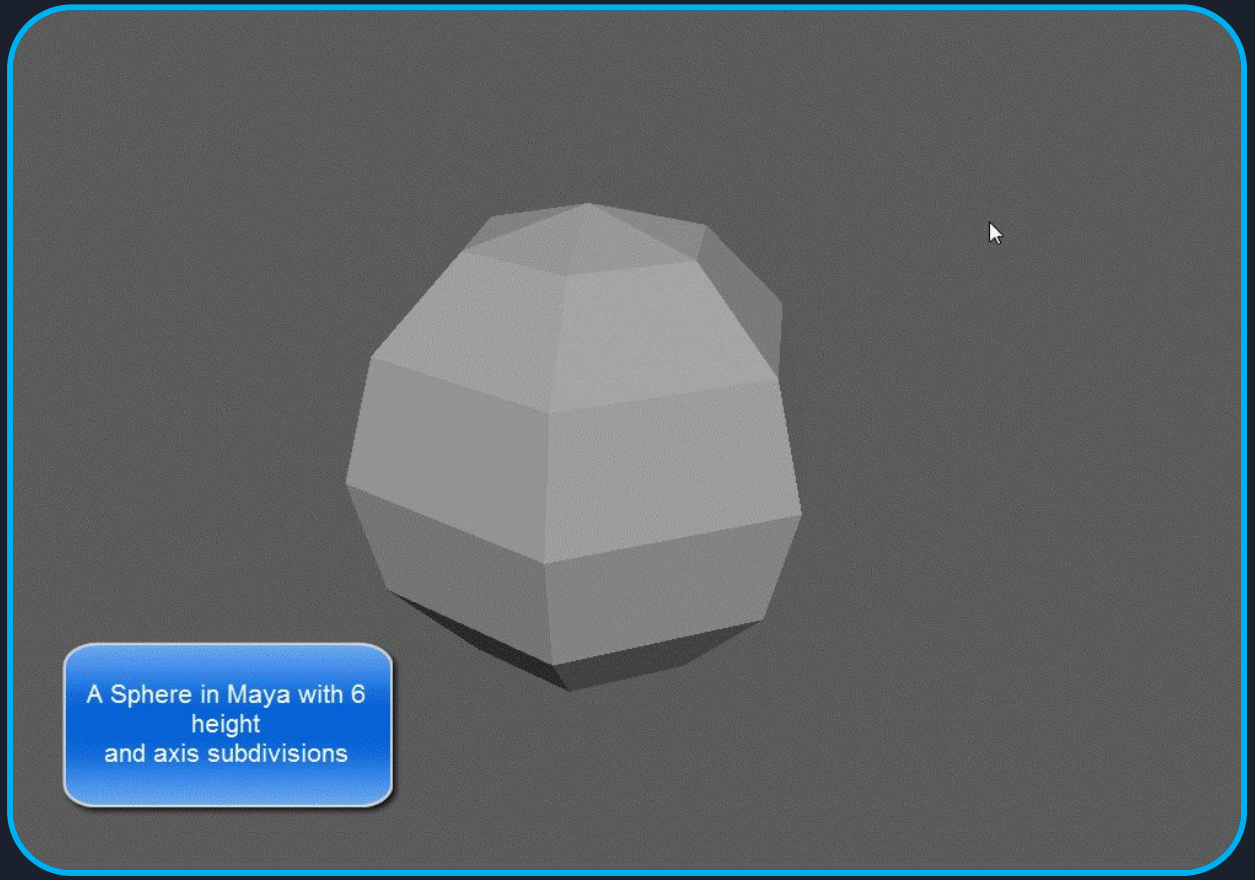
# Baking| Smoothing Groups in Maya



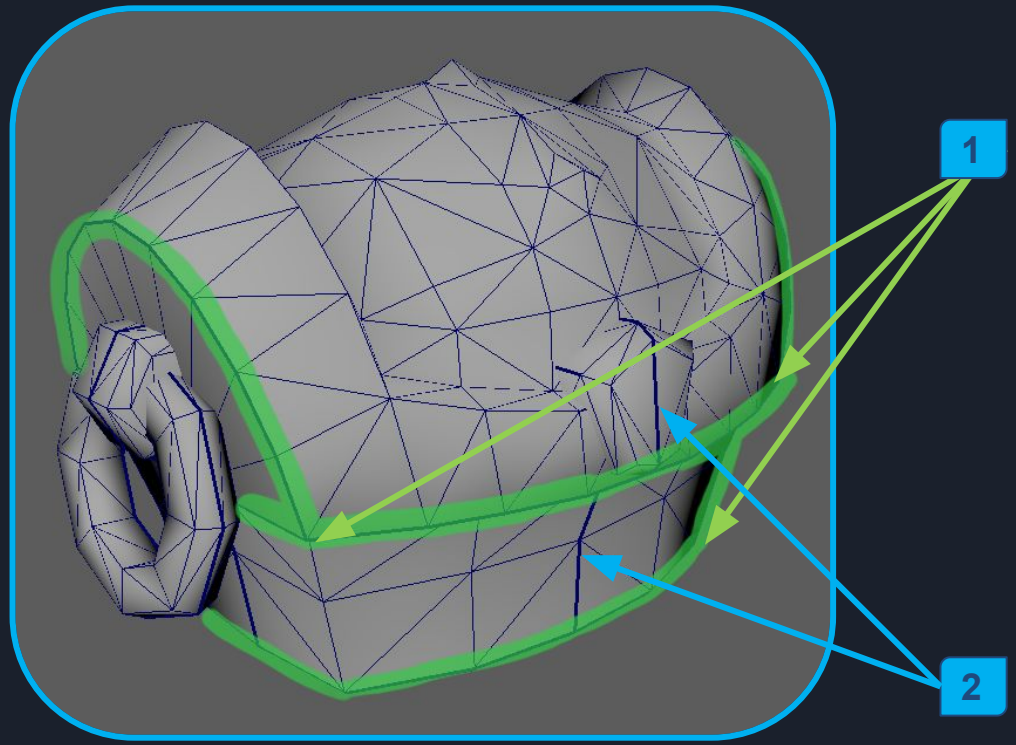

Maya uses Soft and Hard Edges to allow the user to edit vertex normals. This is commonly referred to as Smoothing Groups in Game Art.

The concept of Smoothing Groups or Soft and Hard edges is an important aspect of creating an efficient and clean model for a bake and use in a game engine.

Smoothing Groups create hard/soft edges between polygons, by splitting/combining vertex normals.

When neighboring polygons do not share the same Smoothing Group, this creates a hard edge between them.

# Baking| Smoothing Groups




Planned hard edges in the smoothing groups are also UV borders.

Hard Edges **MUST** be UV Border Edges

BUT

However, there are also multiple UV Borders that aren't hard edges as seen here.

UV Border Edges **DON'T HAVE** to be Hard Edges

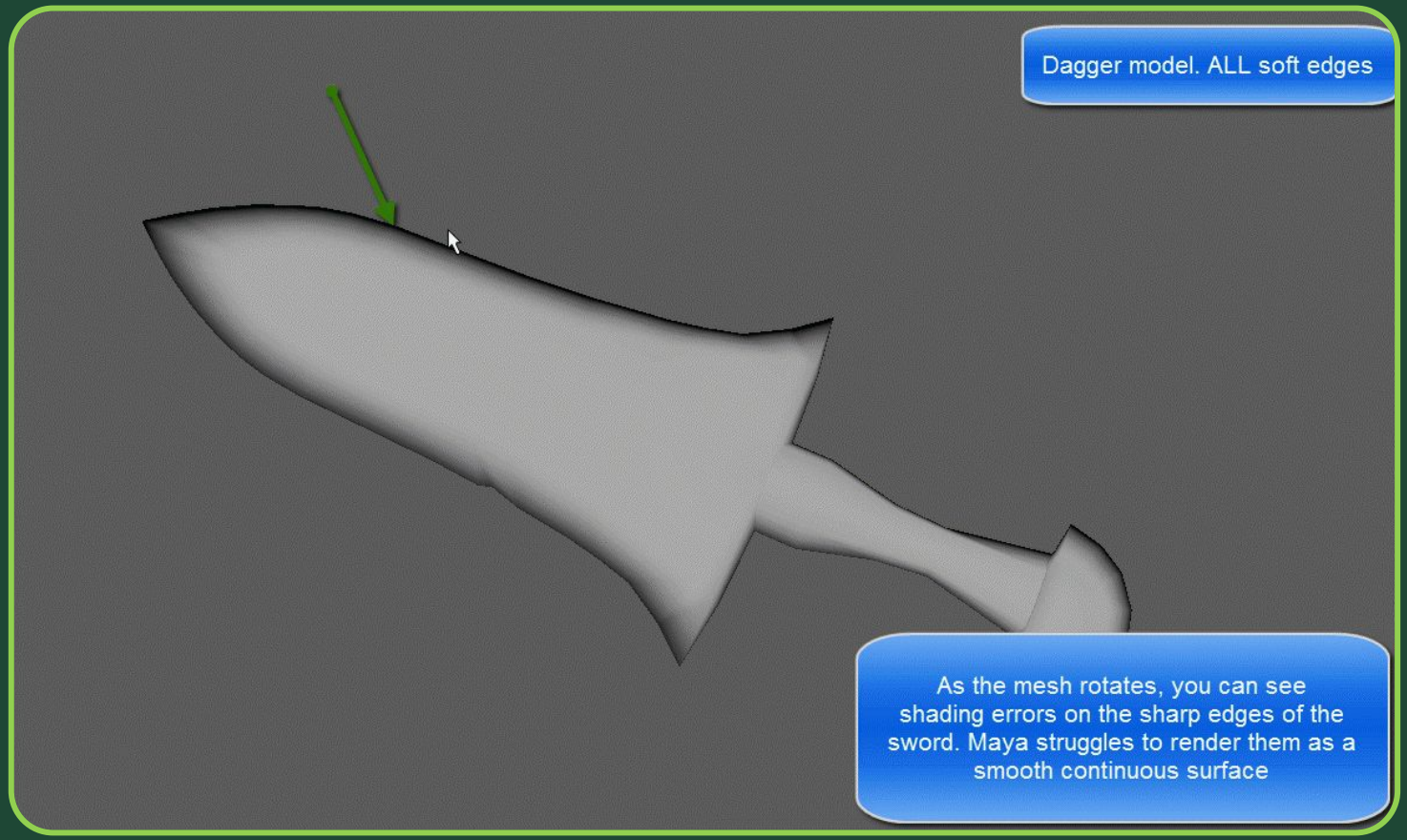
Sometimes a mesh should not just all be set to soft edges.

Sharp edges, those of roughly 90 degrees or less or "acute" can have shading issues when softened due to the engine trying to render the edge as a continuous smooth surface. This can cause baking issues if you're not using a synched workflow to your destination engine

If a mesh has an edge that needs to be hardened to fix shading issues, that edge also needs to be a UV Border Edge as discussed earlier

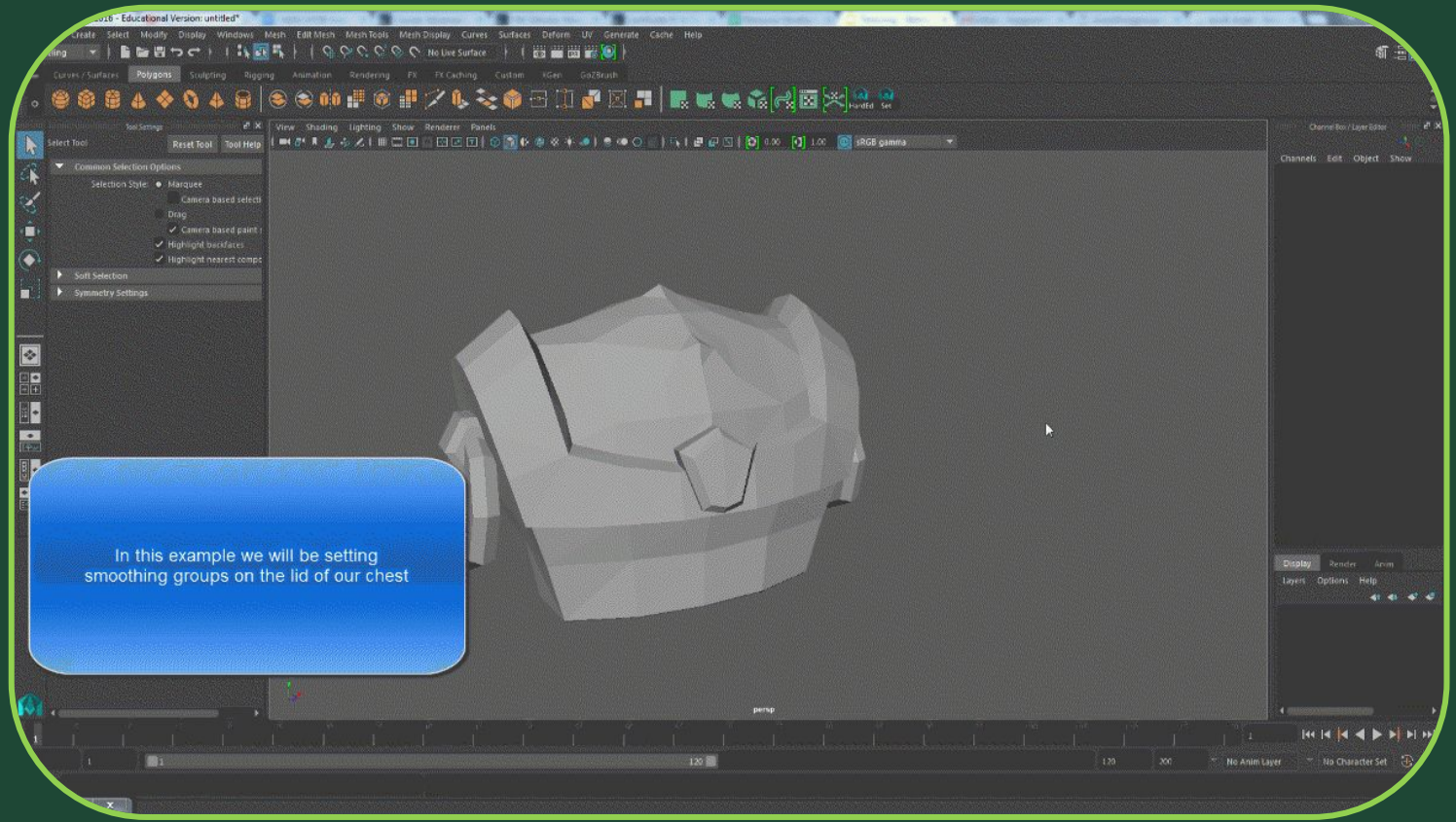
When exporting your model out of Maya you have an option to include these Smoothing Groups when exporting as an .FBX.

# Baking| Smoothing Groups Example




1. When modelling for game engines a good artist will consider all aspects of the workflow as they work. While this will come with practice, giving considerations to the low poly while sculpting the high poly will improve a workflow
2. While splitting UV islands to accommodate hard edges may seem daunting when it comes to texturing. Many Industry standard applications for texturing and baking allow painting in 3D, alleviating this issue

# Baking| Assigning Smoothing Groups




In order to get the highest quality bake, we need to assign smoothing groups to our mesh keeping in mind our UV islands and any hard edges we had planned.

- With the example of our Chest we will assign a smoothing group (Soft) to majority of the surface. It was sculpted in a way to avoid many sharp edges.
- Following that we will setting a Hard Edge to split the smoothing groups along the few sharp edges, the bottom of the lid and the sides. The edge here is very acute and will benefit from a Hard Edge considering we already have a UV Border Edge there as planned
- This process is repeated for all UV islands on the mesh.

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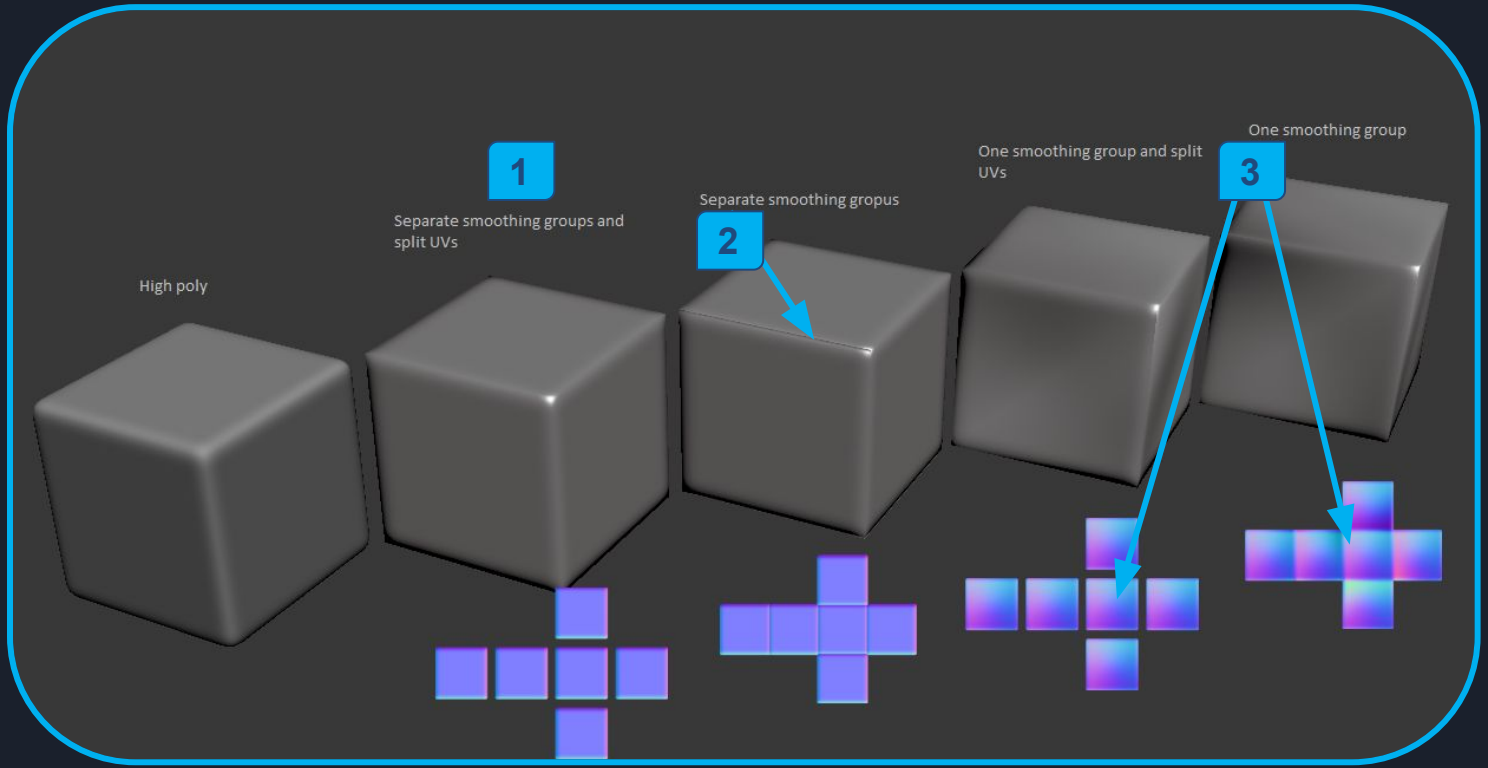
# Baking| Smoothing Groups and Bakes




While some artists may argue that setting smoothing groups before a bake is redundant if you're using a properly synced workflow and modeled in appropriate bevels in your low poly model. There are some benefits to developing the habit particularly when dealing with objects with lower poly count limits.

1. This example shows the perfect bake. Here all sides of the square are separate Smoothing Groups or Hard Edges and the UV islands are split.
2. Here you can see the result of Hard Edges but not splitting the UV edges. The black lines are due to incorrect interpolation of the normal map gradient.
3. These example show bad baking practice where drastic gradients have appeared on the normal map.

Having a clean normal map with no gradients will mean your normal is easier to compress, use on LOD meshes or use in other programs like Quixel, Substance etc.

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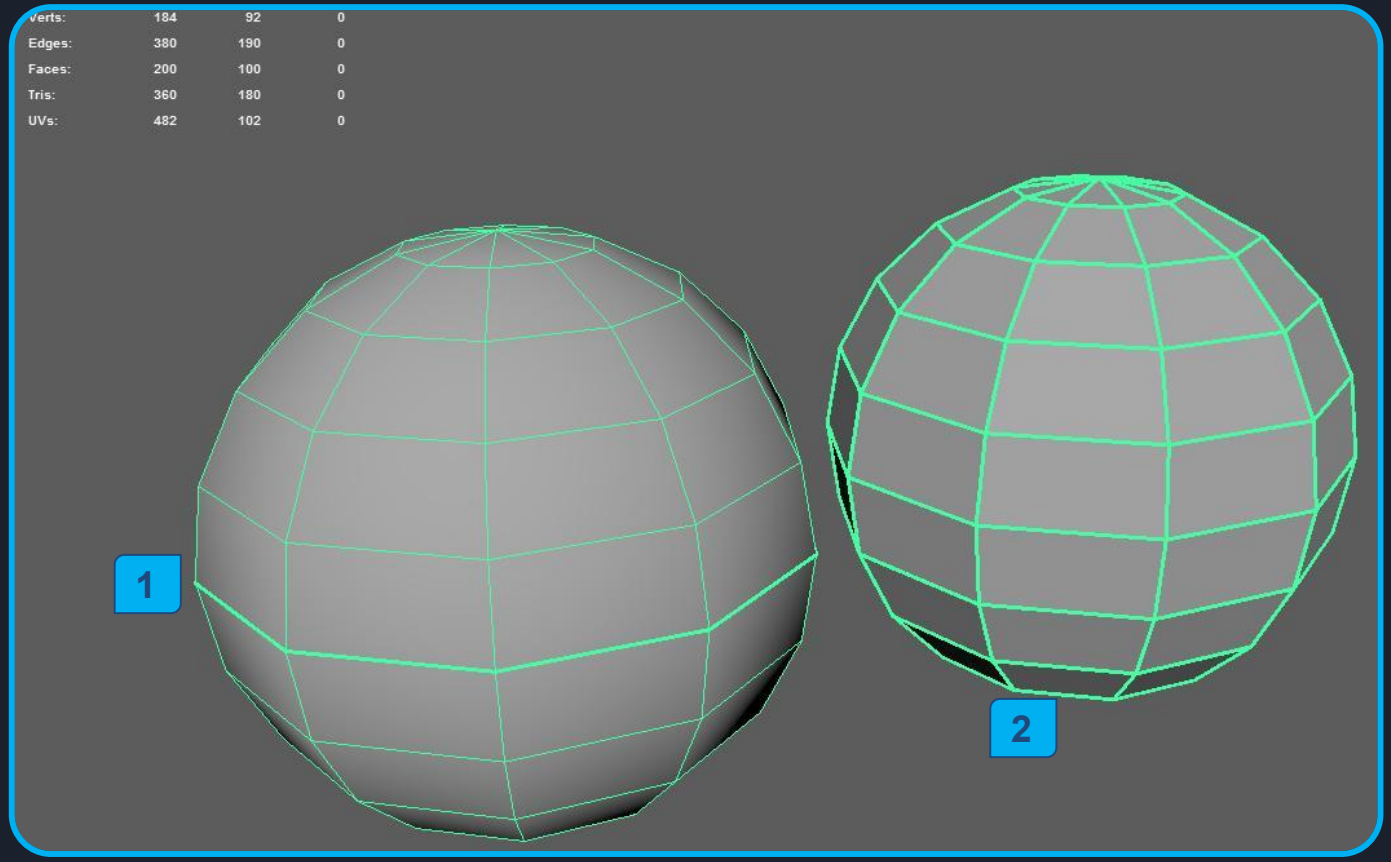
# Baking| Hard Edges and UV Border Edges




When creating a Hard Edge or a UV Border Edge you are splitting the Vertex Normals by doubling the vertices along that edge.

As an example let's look at two spheres within Maya.

1. One has a single UV Border around the diameter and has a single smoothing group.
2. The other has individual UV Borders for each face and has separate smoothing groups for each face too.

Here you can see both Spheres in Maya are being displayed as having 92 verts, with a combined total of 184.

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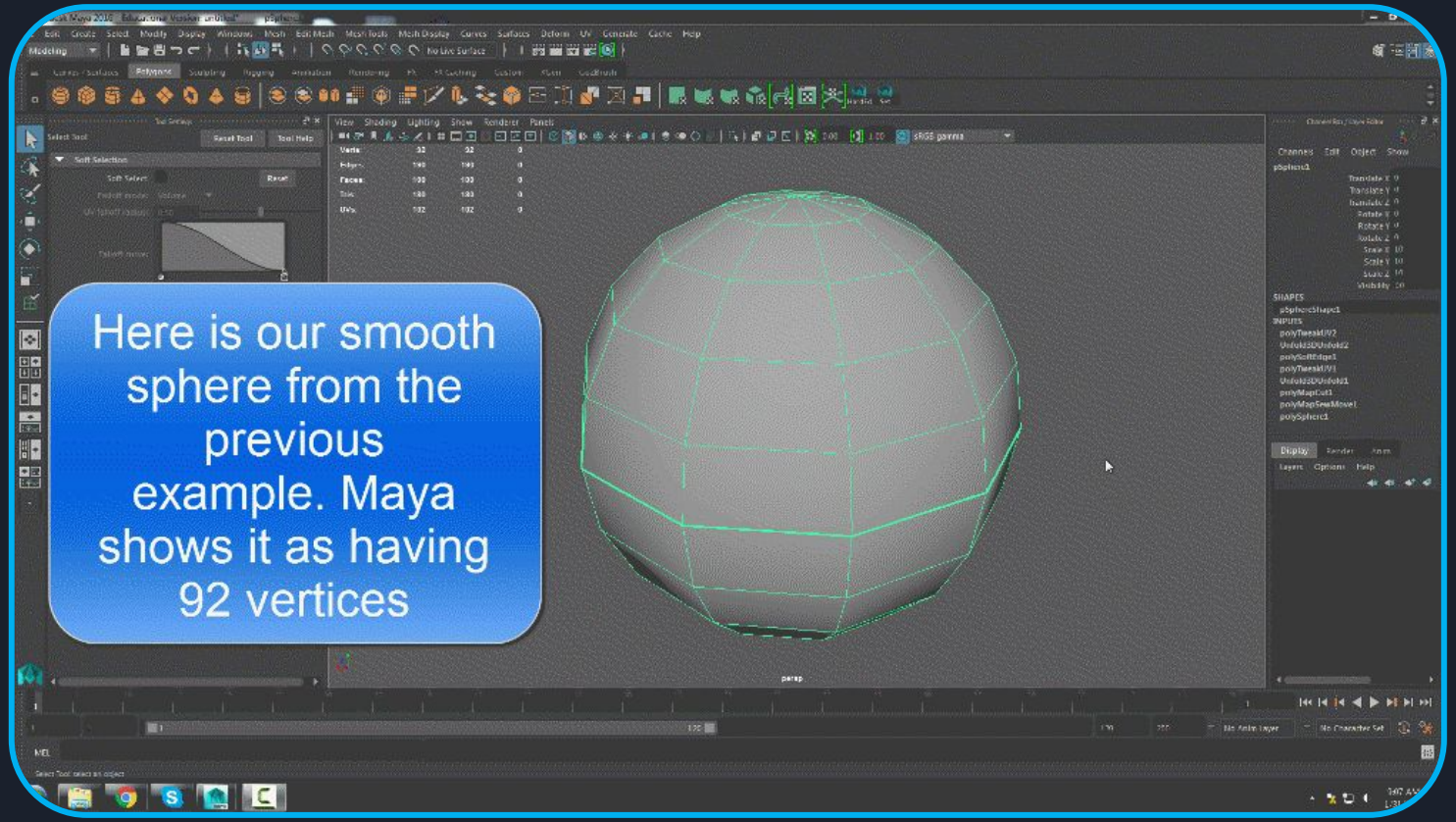
# Baking| Hard Edges and UV Border Edges




When using Smoothing Groups and UV Border Edges on a game model we must consider in engine performance.

When creating a Hard Edge or a UV Border Edge you are splitting the Vertex Normals by doubling the vertices along that edge.

Because Hard Edges split the vertex normals, it makes sense to create a UV Border there as they also split the vertex normal.

However, they **don't** stack.

3D modelling programs will calculate the total number of vertices differently than Game engines.

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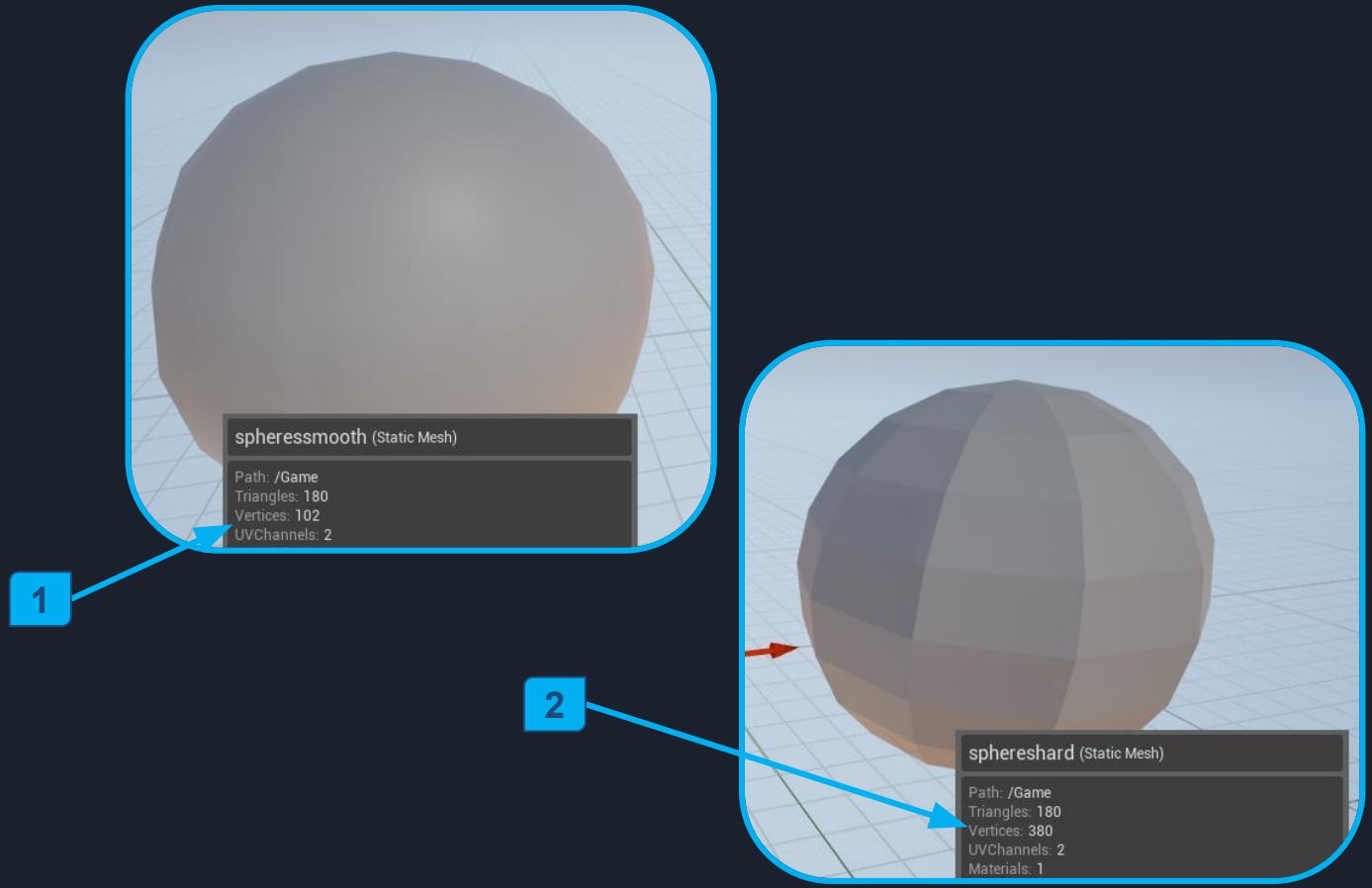
# Baking| Hard Edges and UV Border Edges




The best practice comes from planning your Hard Edges and UV Borders in advance.

Hard edge and UV Border Edges increases your in engine vertex count. This can affect performance in some cases more so than your poly or triangle count.

Here you can see the actual result in the UE4 engine.

1. The Smooth sphere's UV border edge around its diameter, creates an extra 10 vertices as they're split along that UV Border Edge.
2. The Hard Sphere on the other hand has a massive 380 vertices in the Game engine.

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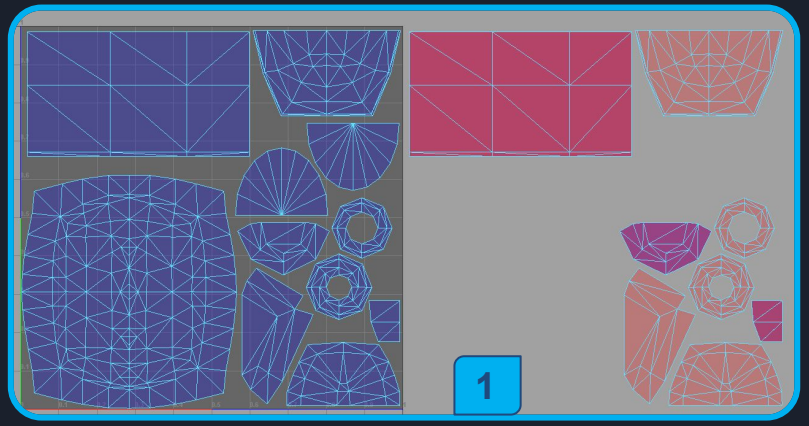
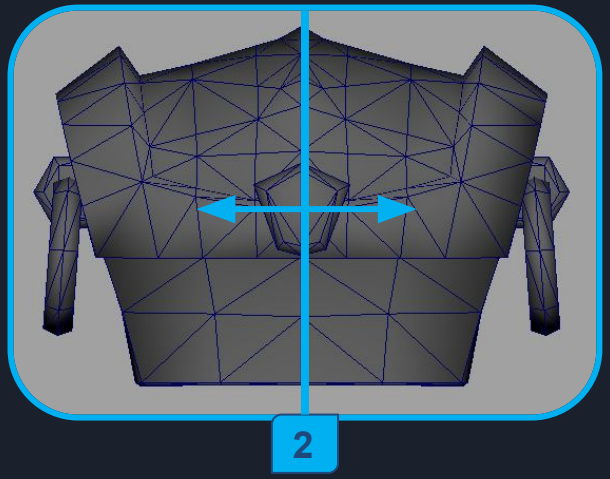
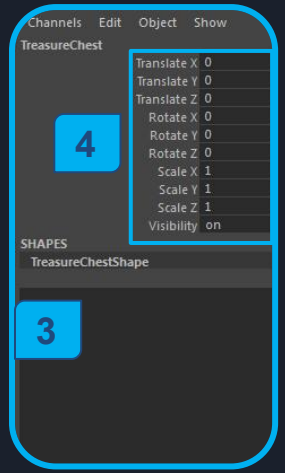
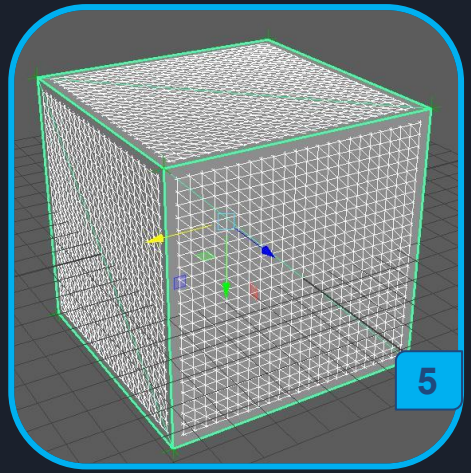
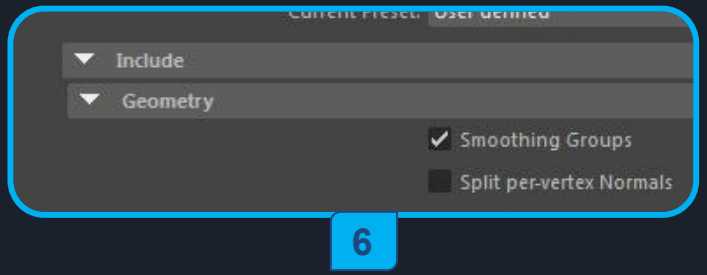
# Baking| Pre-Baking Checklist




Before you move to the baking application a quick checklist should be conducted to make sure all requirements are covered

1. The low poly model has been UV'd and the 0-1 UV space has no stacked UV shells
2. The low poly model is triangulated and any parts of the low poly using symmetry has symmetrical geometry too
3. All history is deleted on the low poly model
4. Transformations have been frozen on the low poly model
5. The high poly and low poly model are orientated directly on top of each other, preferably at the world origin (0,0,0)
6. The low poly model is exported with smoothing groups

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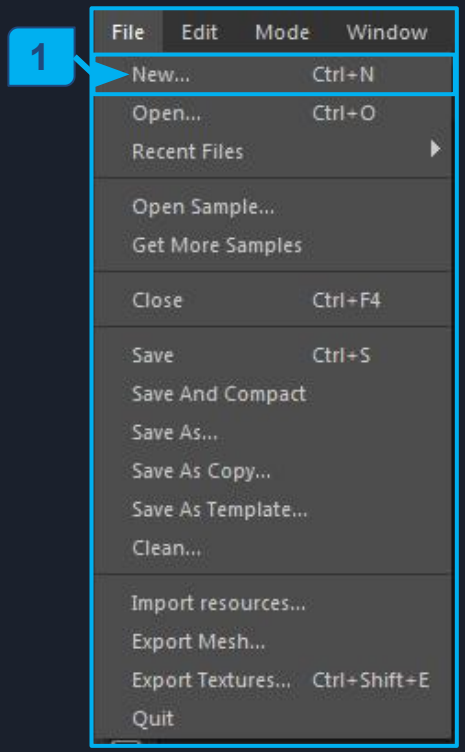
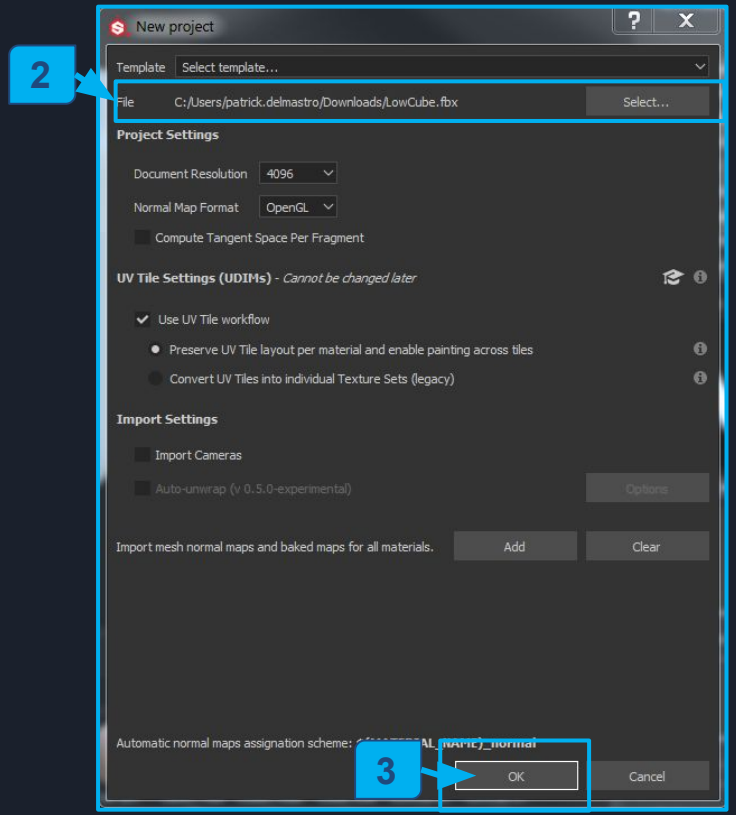
# Baking| Baking in Substance Painter

## Loading the low poly in a new project




Once our low poly and high poly are finalised we are ready to proceed with the bake. We will use substance painter to bake the textures.

1. Once substance painter is open, start a new project by going to file then new or ctrl + n
2. This will open a new project window. In the window click on the “select” button. This will open up the explorer window. Navigate and choose “LowCube.fbx”.
3. Then click the “OK” button.

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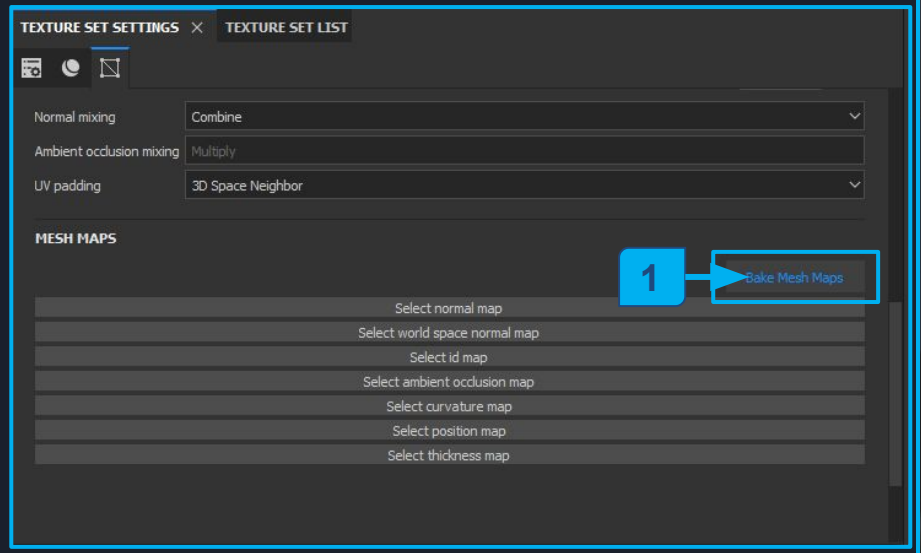
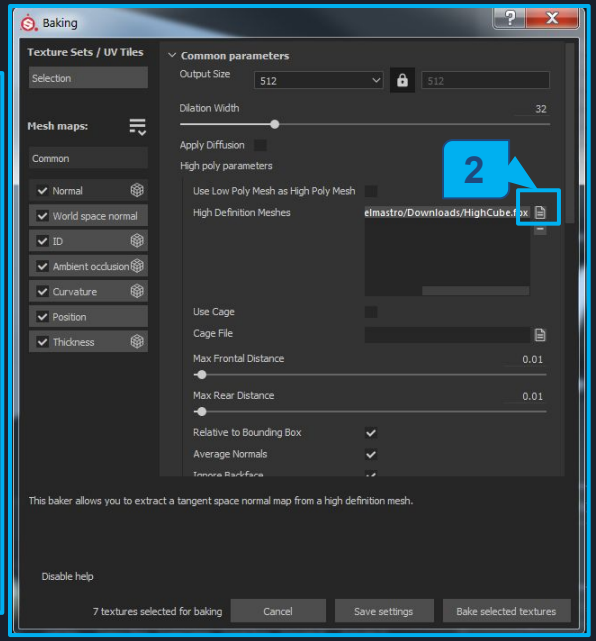
# Baking| Baking in Substance Painter

## Loading the high poly mesh.




Now that the low poly model has been added we need to add the high poly source model.

1. In the texture set settings tab click on the"bake mesh maps" button.
2. Click on the high definition mesh button. This will open up the explorer window. Navigate and select "HighCube.fbx".

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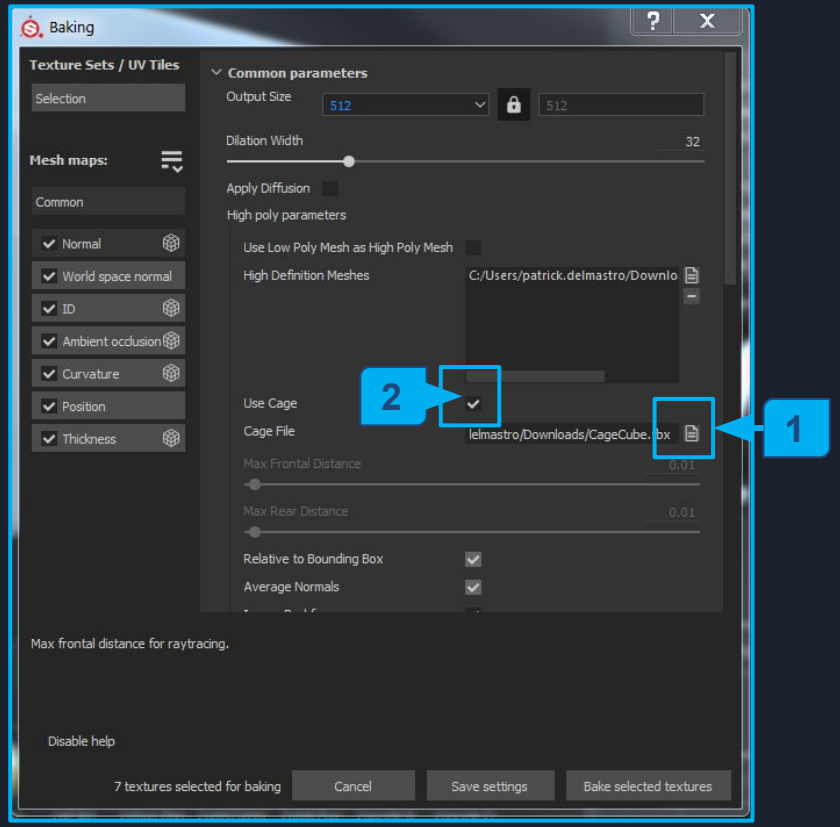
# Baking| Baking in Substance Painter

## Loading in the cage mesh




Using a "Cage" will replace the low poly as the source of the rays distance and direction. A cage give us more control over the baking process and can help us achieve a much cleaner and representative bake.

It is possible to bake without a cage. However for this example we are baking using hard edges and requires a cage to produce correct normal map results.

1. Click on the cage file button. This will open the explorer window. Select the "CageCube.fbx" file.
2. Next to use cage, click the checkbox to activate the cage.

Note: Baking using mesh name is used in substance painter which is for more complicated models with many elements. This will be covered in future lessons.

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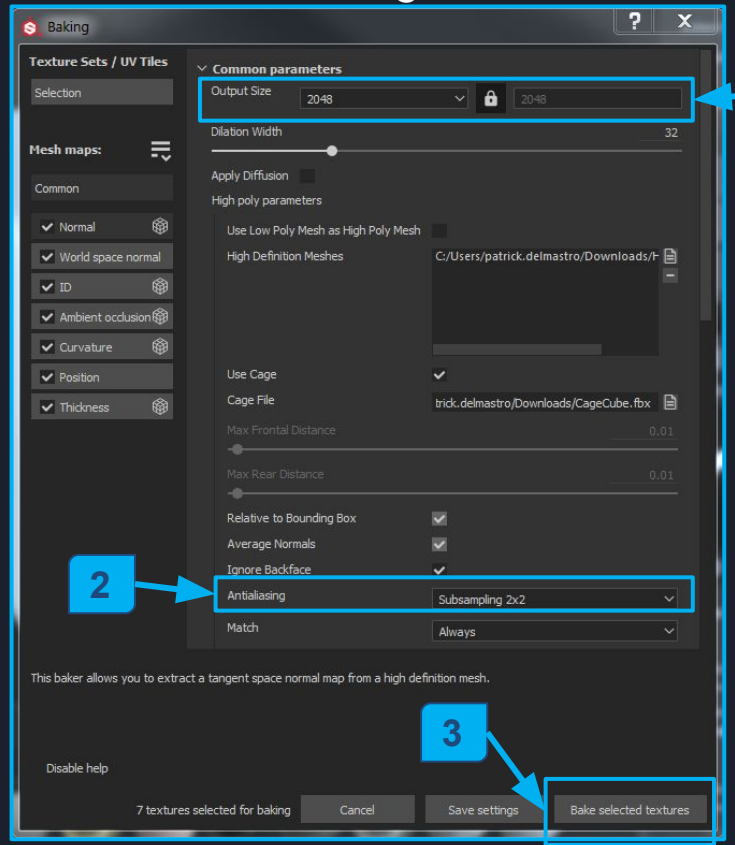
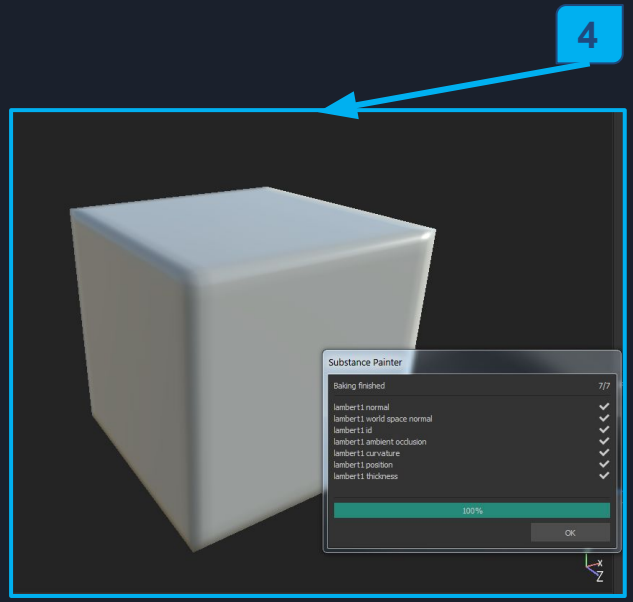
# Baking| Baking in Substance Painter

## Final bake settings




+ Shift to rotate the light in the viewport




It is recommend while in the testing process of baking to enable only the normal map texture using a low output size to save on bake time. Once we have achieve good test bake results we can confidently increase the output texture size and antialiasing subsampling method for high quality results.

1. Change the Output Size to 2048. This will bake the maps as a 2048 x 2048 texture. Larger output size will increase bake time.
2. Change the Antialiasing to Subsampling 2x2. Higher samples achieve better texture quality, however takes longer to render.
3. Click on the “Bake selected textures” button. This will start the baking the selected textures. Bakes can take a few minutes to complete.
4. A screenshot of the baked model completed. If some maps are not rendering without errors try disabling GPU raytracing in Edit -> settings -> General options.

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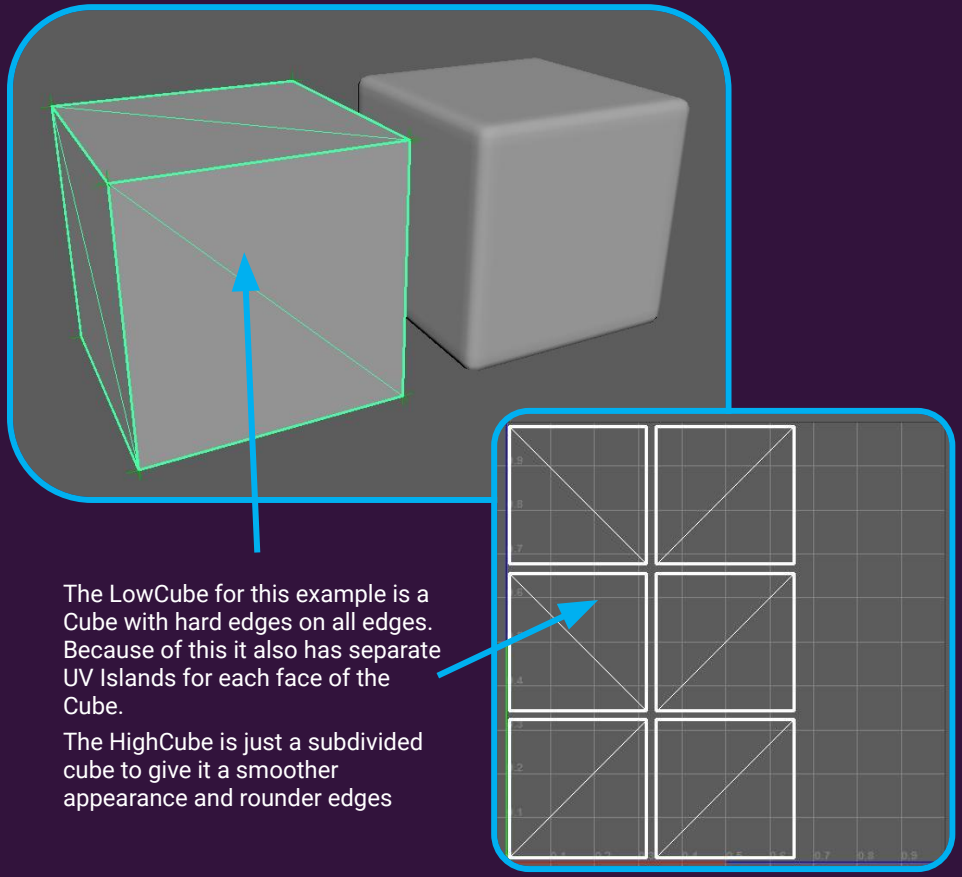
# Exercise| Let's try a Bake



The LowCube for this example is a Cube with hard edges on all edges. Because of this it also has separate UV Islands for each face of the Cube.

The HighCube is just a subdivided cube to give it a smoother appearance and rounder edges

Now that we've had an intro to the basic baking process in Substance Painter, let's try some bakes using the provided resources with this tutorial. The purpose of this exercise is to bake two different normal maps using the same high and low poly geometry.

For the first render. Render without the use cage check box ticked. Once the bake is complete take a screenshot of the result.

For the next bake, bake using the cage with use cage checkbox ticked. Take a screenshot and compare the results of the bake.

You have **15** Minutes

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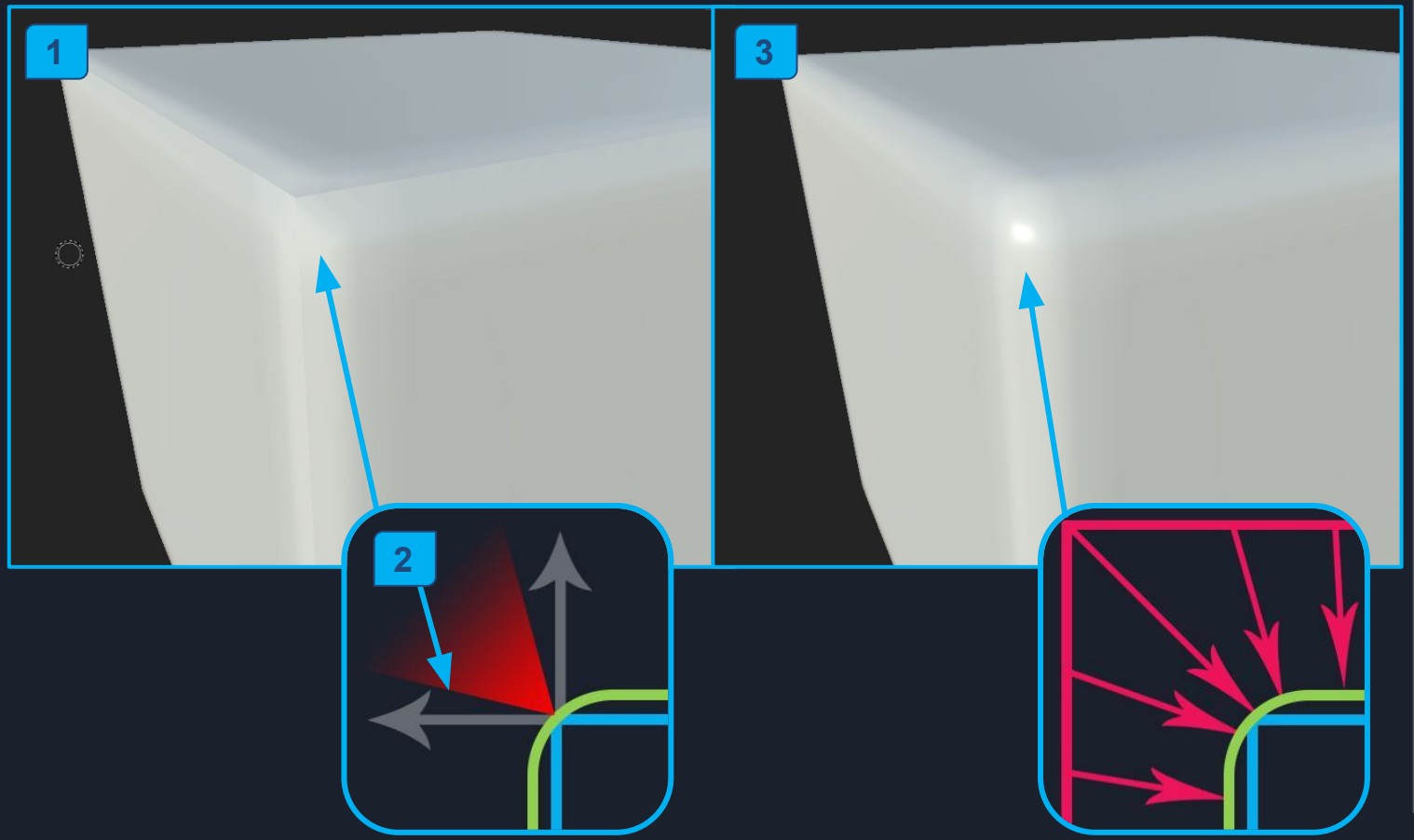
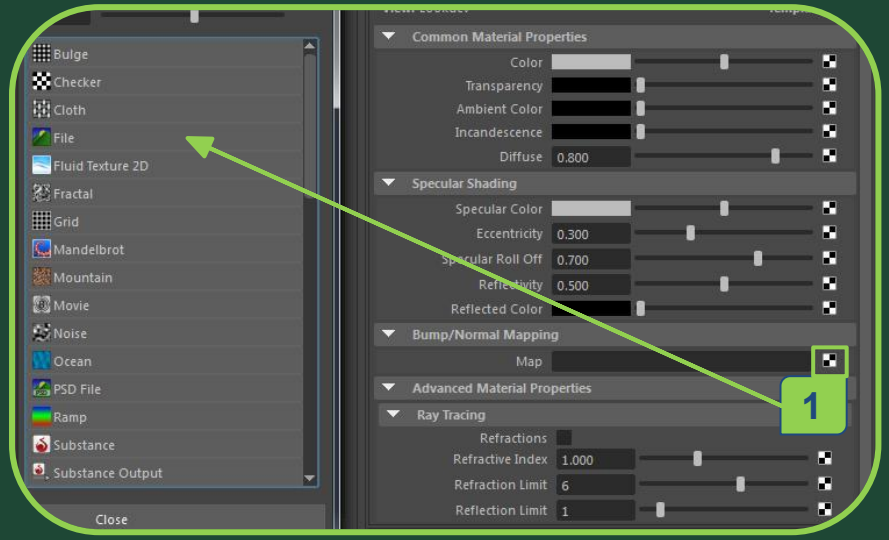
# Baking| Evaluating the Results




Here you can see the results in Substance Painter you should achieve from the bake.

1. This Cube shows the result of not using a Cage. The split vertex normals on the cube as a result of the hard edges has caused a visible seam in the rendering of the normal map.
2. Here you can see how the hard edge vertex normals create an area where the rays are not cast, leading to the visible seam error
3. This Cube shows the result of correctly using a Cage. Here the rays cast from the averaged vertex normals of the cage have captured the smooth corners of the cube. But, our hard edges of low poly help to reduce the smoothing errors of the normal map

# Baking| Viewing Normal Maps in Maya

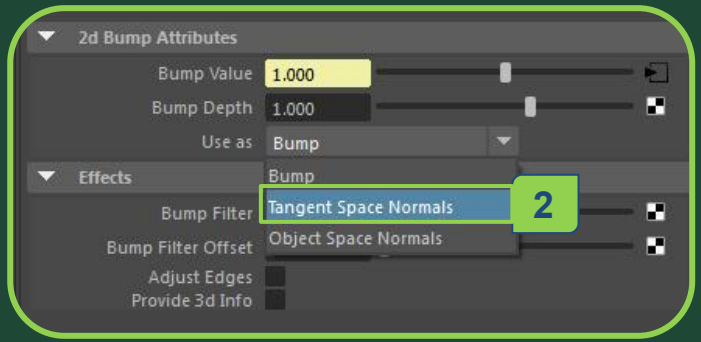


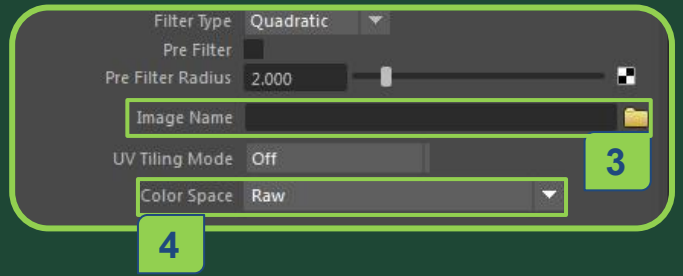

1. Within the Hypershade of a material, Click the checker box of the Normal Mapping field and select the **File** option.
2. Once clicked, we need to make sure we set the map we're loading to a **Tangent Space Normal Map** as that is what we baked.
3. Load the normal map using the file browser
4. Maya applies some color space filtering to textures when loaded. We don't want that for a normal map as it can affect the way the normal map is interpreted. Setting this to **Raw** will remove Maya's filtering.

While not ideal for game art, it is good to know how to load a normal map into Maya using the blinn material.

For the best testing we should be using a game engine like UE4 or Unity that uses the same Tangent Basis Calculator that our baker did. We could also use an application like Marmoset Toolbag.

In the future, it is advised to use such programs instead of Maya for testing normal maps

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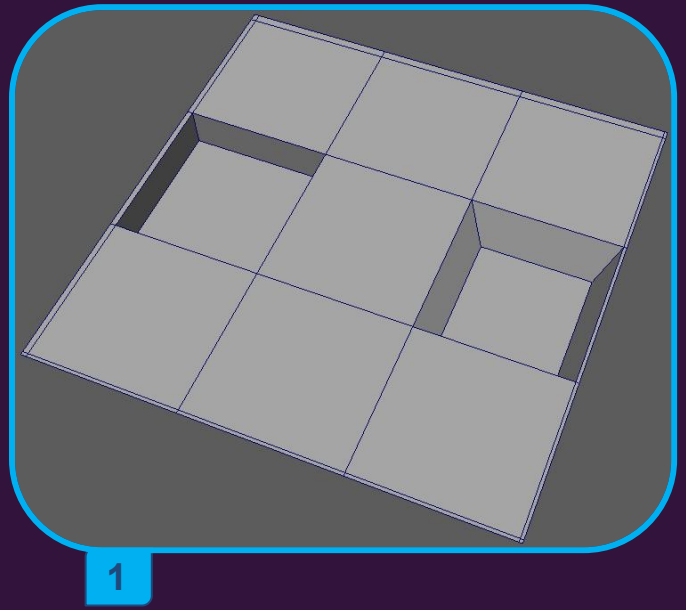
# Exercise| Another Quick Baking Tip

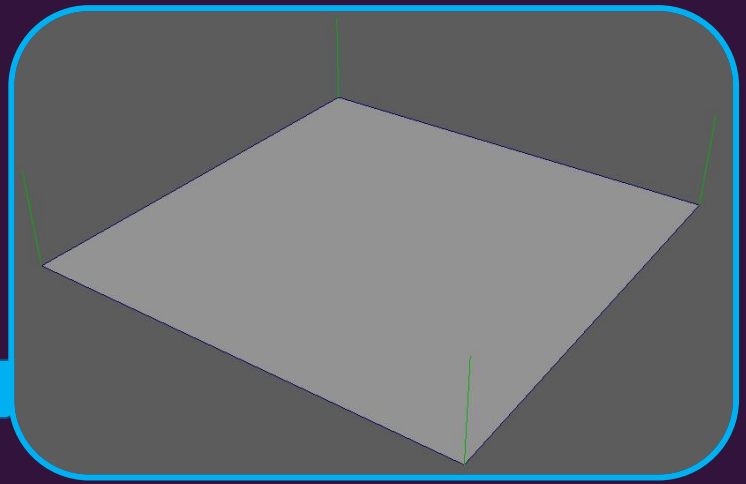


1

Think about baking this example geometry (1) to a flat plane.

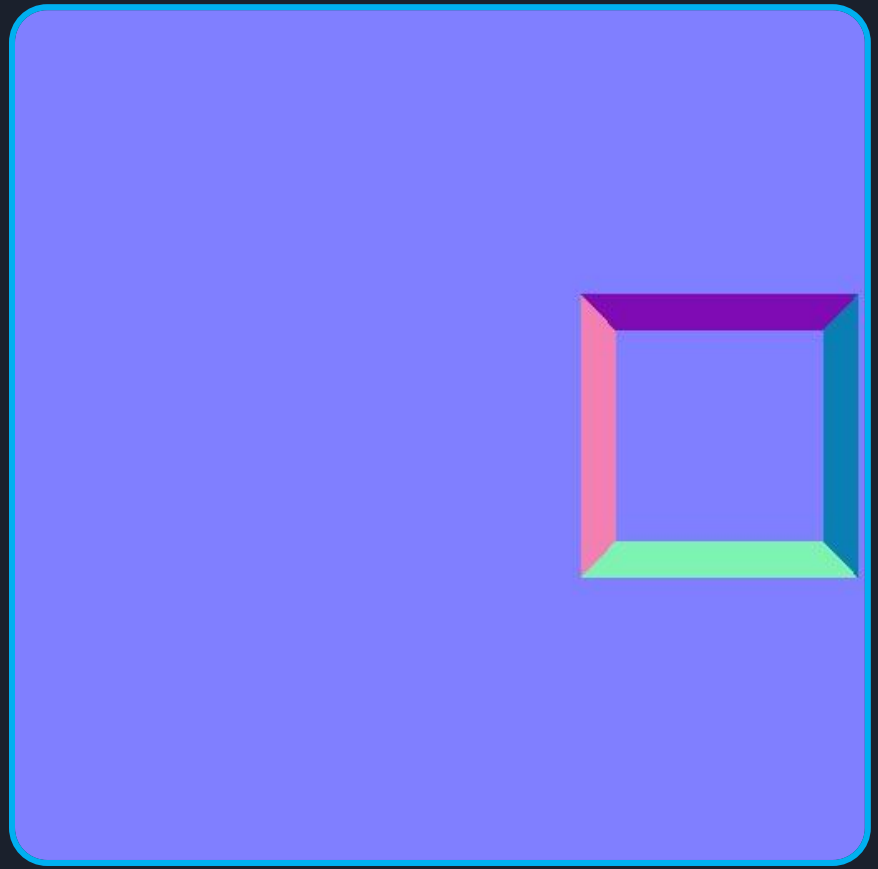
There are 2 extrusions. One straight down on the z-axis and one extruded and scaled to create a bevel.

If this is baked onto a flat plane (2) with the vertex normals as shown, what do you think the results would be on a normal map?



2

# Baking| The Result



This is the resulting normal map of the bake from the last slide.

But wait?!.....

Didn't we have two extrusions on that example? What went wrong?

# Baking| The Reason

The reason for the incorrect bake is the vertex normal angles being set in a way that the geometry of the high poly isn't accurately captured.

In the example shown, the rays don't actually capture any data on the left extrusion. Due to the extrusion and the rays being parallel, they won't appear on the normal map.

The bevelled example on the right however has some nice geometry that the rays intersect with. This results in a good baking translation to the normal map.

# Baking| Conclusion


This quick introduction to the concept of baking has covered some of the important basics of getting a clean bake for basic geometry

Resources such as the Polycount Wiki and relevant threads are invaluable resources in your understanding of baking textures.

New bakers and methodologies are always emerging in the field. Coming up with a baking workflow that works for you as an artist will take time and practice.

Future lessons will deal with baking textures in addition to a normal map, other baking programs and complex baking set ups

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