3D modeling using Autodesk Maya

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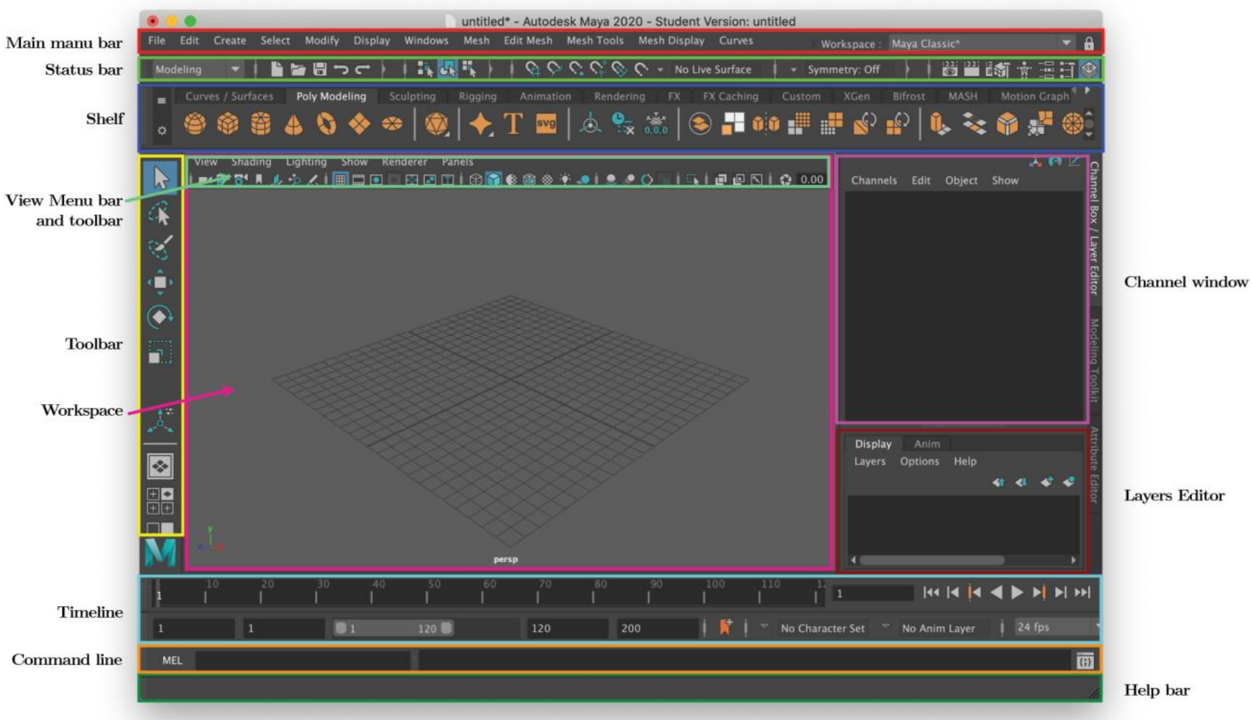
Lection 01

Maya - Introduction

Overview

1. User interface
2. Projects and files
3. Scene views
4. Objects and components
5. Primitives
6. Basic transformations and pivots

User interface



Default screen structure (see the figure above):

- Menu bar (bright red), contains menus through which we access tools and / or perform desired actions in modeling, rendering, animation, ... The first 6 menus do not change, the rest depend on the selected mode of operation, which is selected in the status bar;
- Status bar (bright green), contains a set of shortcuts to commands and tools for object and component selection. In addition, you can select the mode of operation in the status bar and thus adjust the composition of menus and shelves;
- Shelf (dark blue), provides quick and easy access to frequently used tools. The user can adjust the shelves to their own needs;
- Toolbar (yellow), contains the basic tools and the last tool used. In addition, we can customize the look of the workspace in the toolbox;
- Workspace (pink), is the central part of the user interface, which is intended primarily for viewing the scene. It can also display the various editors we use in our workflow;
- Channels Window (bright violet), provides access to object and node attributes. Attributes can be set in this window and linked to animation key frames;
- Layers Pane (dark violet), layers allow objects to be grouped together, which can then be considered separately from the other layers. Individual layers can be hidden or even rendered separately;
- Timeline (bright blue), allows you to move through the time dimension of the scene. On it we can define key frames or interactively watch an animated scene. You can use the command buttons to step through time, start playback, or set animation properties;
- Command line (orange), you can run MEL or Python commands directly from the command line;
- Help bar (dark green), shows quick help with working with the user interface, the state of execution of actions, errors and other information.

Projects and files

Projects

In Maya, the work is project-based. It makes the most sense to create a separate project for each integrated case in which both the program settings files and all the necessary files for work will be stored. Create a new project in Maya by choosing *File* -> *Project* -> *New*. You must specify the project name and the directory in which you want to save all project files (eg *Documents \ Maya*). For individual file locations, it is best to select the *Use Defaults* option. When you have entered the project settings, press *Accept*. This determines where your files will be stored (scenes in the scenes subfolder, images in the images subfolder, etc.). It is recommended that folder names do not contain spaces or special characters.

If you are working on several projects, you can switch between them by selecting:
File -> *Project* -> *Set*.

If you have not defined a project, your files will be stored in the folder *documents_folder* \ *maya* \ *projects* \ *default*, where *documents_folder* is the system folder in which the documents of each system user are located.

File typer in Maya

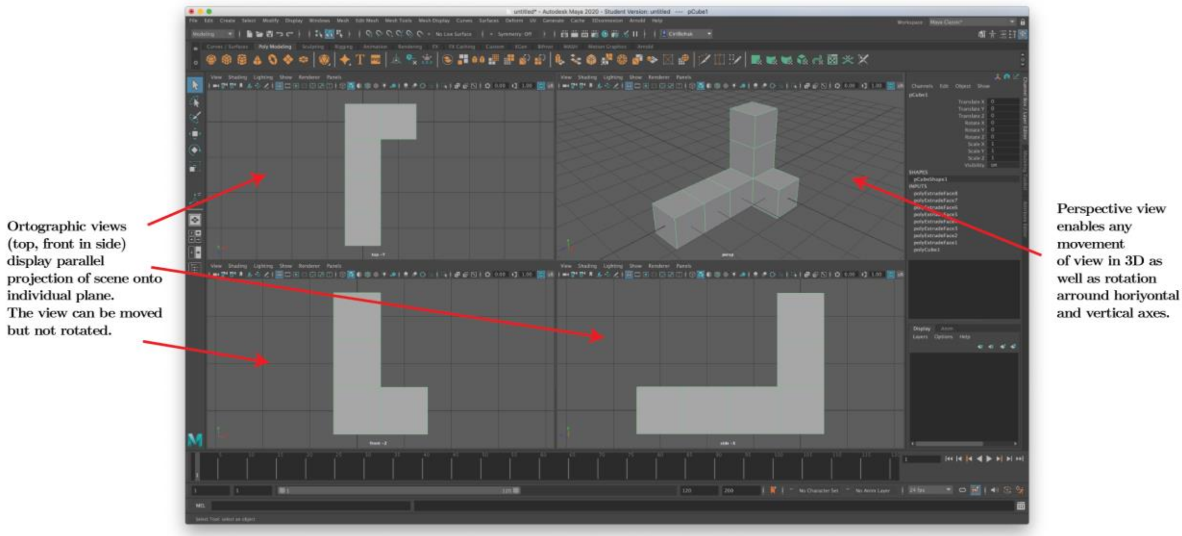
Maya has some of its own file formats to store information about scenes, images, scripts. In addition to these, it also supports a wide range of other formats that can be used to share data with other applications.

- Maya binary (.mb) the files contain a scene description in binary form. The description includes objects, textures, animations, and some other details;
- Maya IFF (.iff) files are used to store rendered (bitmap) images. In addition to information about the colors of individual pixels, the file can also store information about depth, mask, or anything else;
- Skripte MEL (.mel) are text files in which the commands of the Maya MEL language are written, with which we can supplement the functionalities offered by the user interface, and so e.g. we generatively generate certain objects, algorithmically define the execution of animations, etc. The same can be achieved with Python (.py) scripts.

Scene views

When modeling a scene, we mostly work in 3D space. Cameras with orthographic and perspective view offer us various possibilities of insight into the scene.

Default scene views:



Changing the view (camera)

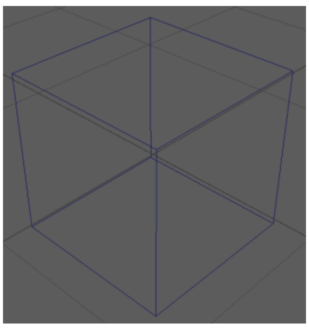
The scene view can be adapted to the needs by changing the position and direction of the camera, which determines the selected view.

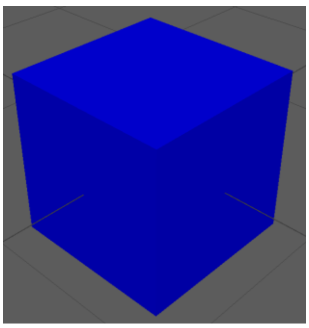
- Rotation - by pressing the [ALT] key and pressing the left mouse button [LMB], you can rotate the camera around the vertical and horizontal axes.
- Move (vertical and horizontal) – you can move the camera left / right and up / down by pressing the [ALT] button and pressing the middle mouse button [MMB].
- Zooming – by pressing the [ALT] key and pressing the right mouse button [RMB], the camera can be moved towards or away from the center of the scene. The same can be achieved by using the mouse wheel [MW].

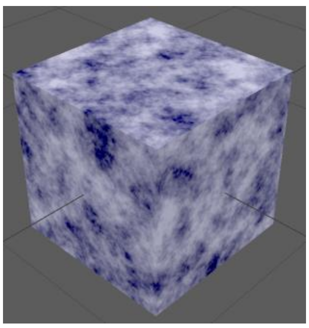
Object display

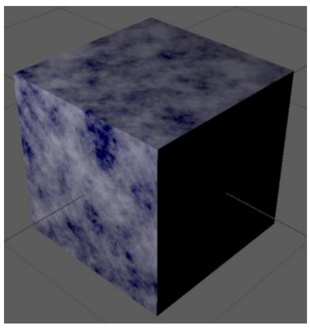
Individual objects can be displayed in the scene with varying accuracy. Use the [1], [2] and [3] keys to switch between different ways of displaying models, from the roughest to the most accurate (smoothed).

We can also change the way the object is displayed / shaded. Use [4] - [7] keys to toggle between:


4 – Wireframe


5 – Color view


6 – Texture view


7 – Lighting view

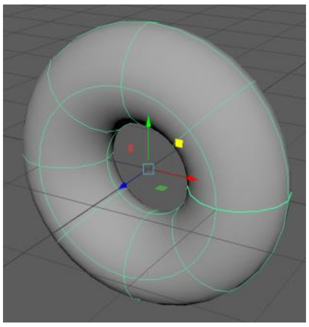
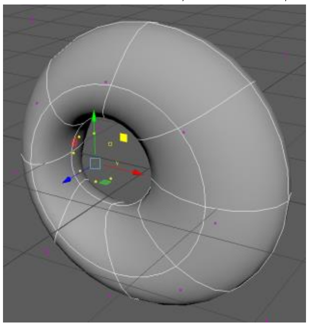
Objects and components

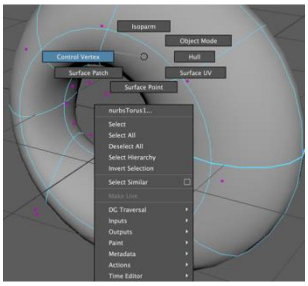
The scene is made up of objects. Objects include: curves, surfaces, cameras, lights, deformations,...

Objects consist of components such as checkpoints, polygons, gripping points and the like. Objects present in the scene can be viewed in the Outliner window (*Window* -> *Outliner* or select it in the toolbar).

Manipulation mode

In Maya, you can interact with objects in two ways: in *object mode* or in *component mode*:

- Object mode - where we work with objects as a whole:
  
- Component mode - where the individual components of the object are also visible. Depending on the type of geometry, the object can consist of various components (control points, nodes / edges / surfaces, etc.). The figure shows the work with control points:
  

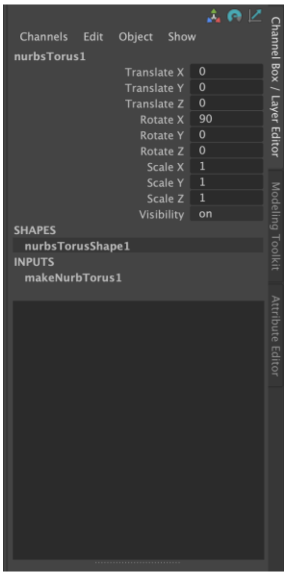


Switch between modes by pressing the [F8] key, selecting one of the buttons in the status bar (where the first icon  represents *working with objects* and the second *working with components*), from the menu accessible by clicking with [LMB] on the object and selecting the appropriate components as shown in the figure to the right.

Attributes and nodes

Attributes

All properties of objects and components are stored as attributes. When we model, animate, or otherwise manipulate objects, we directly or indirectly change attributes. Attributes can be viewed or changed directly in the channel window or in the attribute editor ([CTRL + A] key).



Channel window

Attribute editor

Nodes

Nodes are the basic building blocks in Maya operation. Nodes are groups of related attributes that may be interconnected and / or interdependent. For example, the attributes that determine the transformation of an object are grouped in a transformation node. The basic types of nodes are:

- Transform nodes – determine the position, orientation and magnification of objects;
- Shape nodes – determine the position of individual components of the object;
- Input nodes – determine how objects are constructed;
- Shading nodes – determine the properties of materials for individual objects.

Dependency graph

It represents a collection of nodes that are interconnected. The dependency graph allows us to identify and connect individual nodes. This graph can be viewed in the Hypergraph window (*Window -> Hypergraph*).

Primitives

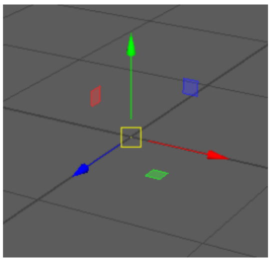
Primitives are prefabricated objects of commonly used shapes. Maya offers a range of basic objects that can be used as a basis for further shaping. These primitives are, for example: sphere, cube, cylinder, cone, plane, torus, circle, square (sqare),... Primitives can be of the NURBS type, polygonal or volumetric. More or less than those listed are available for each type of primitive. Primitives can be created via menus: for NURBS primitives: *Create-> NURBS Primitives->*..., for polygon primitives: *Create-> Polygon Primitives->*..., and for volumetric primitives: *Create-> Volume Primitives->*...

Before making a basic object, by selecting the square next the menu option, we can also determine its basic parameters, such as: size, accuracy, number of components, etc.

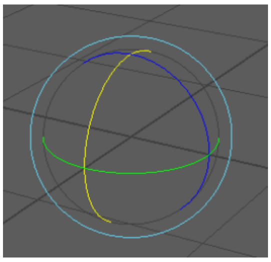
Basic transformations and pivots

Basic transformations include changing the position, orientation and size of an object / component in space. Basic transformations can be performed by directly changing the attributes (in the *Channel Window* or the *Attribute Editor*) or by using transformation tools. These tools are:

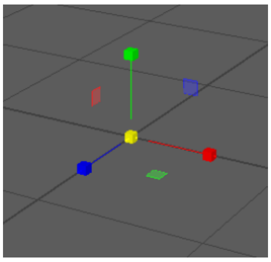
- **M**ove tool – shortcut is [W]

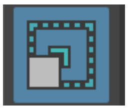


- **R**otate tool – shortcut is [E]



- **S**cale tool – shortcut is [R]





Pivots

Pivots are points in space that represent a reference point for performing transformations (e.g. a point around which an object rotates). The pickup can be edited by pressing the [Insert] key (or [d] on MacOS) when one of the basic transformation tools is selected. Once we have arranged the grip, we return to normal operation by pressing the same key again.

Lekcija 02

Maya – Modeling with NURBS

Overview

7. NURBS curves
8. NURBS surfaces
9. Grouping objects
10. Wirking with components
11. Use of Revolve
12. Use of Loft

Example 1: Rocket

As the first example of working with Maya, we will make a simple rocket.

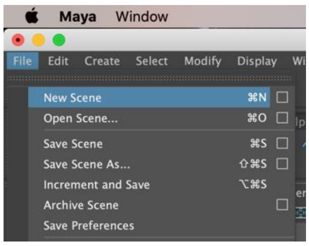


Figure 1: Creating new scene.

First we create a new scene: *File-> New Scene* or the shortcut [Ctrl + N] (on MacOS [Cmd + N]).

A new window will appear, in the middle of which the spatial grid is displayed. The current view is *perspective* and allows us to view the scene and the objects in it from all sides. You can change the view by pressing the [Space] key, which shows us 4 views (front, side, top and perspective), return to the desired view by moving the mouse over it and pressing the space bar again.

Rocket body

We will first create the rocket body. The goal is to create a cylindrical body with a tip at the top and an opening at the bottom.

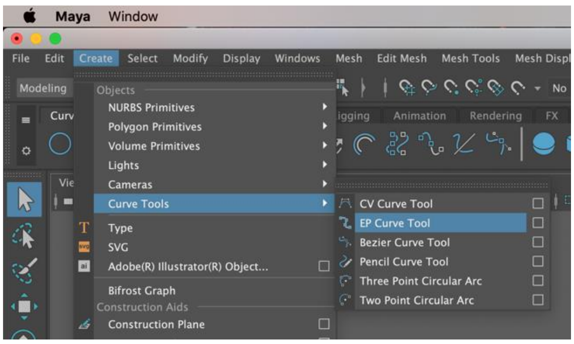
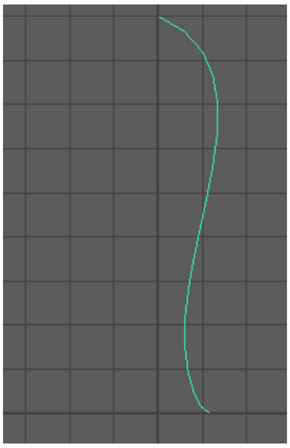


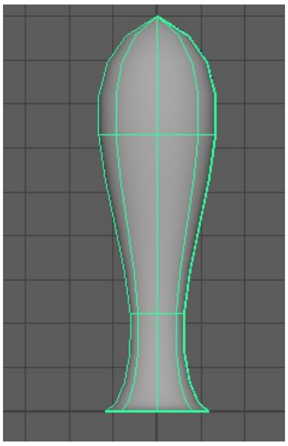
Figure 2: Create->Curve Tools->EP Curve Tool

We switch to the side view where we will create the silhouette of our rocket using curves. In the status bar, switch to Modeling mode and then select *Create-> Curve Tools-> EP Curve Tool* from the menu.

With this tool, we can add points in the side view, and Maya will draw a fitting curve through them. We will create only one edge of the rocket body as seen from the side.

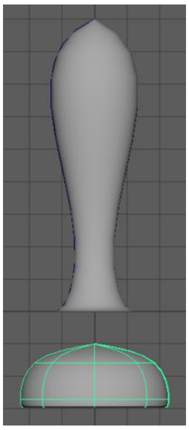


Insert a few points so that you get a curve similar to the one in the picture. If necessary, switch to component editing mode [F8] and move each point to get the desired look.



With such a curve, we can now create a revolved body by rotating the curve around the y-axis and thus forming the hull of our rocket. We do this by using the Revolve tool. Select the curve (let it be green), then select *Surfaces-> Revolve* via the menus. The result is a grid of curves, as shown in the figure to the right. If we switch back to perspective view we see that we have really created a 3D object.

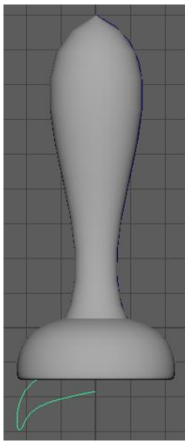
If we now highlight an object, its properties are displayed in the Channel Window, including the name in our case *revolvedSurfaceShape1*. Maya assigns a name to each newly created object. We can also change this name ourselves, which helps us later when we have a lot of items in the scene and we want to quickly find the one we want in the list. Let's rename our object *rocketBody*.



Rocket engine

In the next step, we will create the exhaust of the rocket engine. Similar to the construction of the body, we will use the revolve function here as well. The procedure is the same, and the goal is to get a rocket shape similar to the one in the picture on the right. We also change the name of this object to *rocketExhaust*.

We can now combine the body and exhaust of the rocket. Select the exhaust, press the [W] key to activate move tool and move it so that it connects to the rocket frame. The easiest way to move the exhaust is in the side view, as this is the best way to see when it is in the correct position.



We can use the Channel Window to move objects more precisely, but if the accuracy of the grid is sufficient, we can turn on the use of the grid (snap to grid) with the button  in the status bar. This allows us to place points only on the grid.

We can see that after the shift, the curve we used to make the exhaust is still visible, which is also shown in the picture on the right. In fact, there is also a curve in the scene that we used to make the body. We can delete both curves without any worries, as we no longer need them. This is done by selecting both curves (several objects can be marked at the same time by holding down the [Shift] key and clicking on all the desired objects) and deleting them using the [Delete] key.

If we make a mistake in our work or want to go back to the previous step, we can easily use the undo function. It is accessible via the *Edit-> Undo* menu or using the shortcut [Ctrl + Z] (on MacOS [Cmd + Z]) or just [Z]. You can also redo the canceled action with *Edit-> Redo* or. Use the [Ctrl + Shift + Z] shortcut or just [Shift + Z] to use the [Cmd] key instead of [Ctrl] on MacOS.

Connecting objects into groups

We will now connect the two components of the rocket into a group (we will group them). This means that both objects will be connected so that we can move them together, we can assign certain properties to them at once, and so on.

First, mark both objects by clicking and holding [LMB] to the left above the rocket frame and dragging the lower part of the rocket exhaust to the right, or by clicking [LMB] on one object first, pressing and holding the [Shift] key, and then clicking with [LMB] to another subject.

Now select *Edit-> Group* from the menu or press the [Ctrl + G] keys. We notice that the whole structure now turns green, which tells us that the object is highlighted, and a new name appears in the channel window, namely *group1*. We will also change this name to something more friendly, namely the rocketBase.

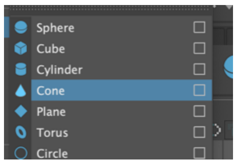
If we now click somewhere outside the rocket and then click [LMB] again somewhere on the rocket, we would expect the *rocketBase* group to be selected, but this will not happen. If we click on *rocketExhaust* or *rocketBody*, only the component we clicked on will be selected, which is contrary to what we talked about in the groups. It is important to be aware that by linking an object into a group, individual objects from this group do not lose the opportunity to select them individually and assign them only their specific properties.

Maya applies the principle of hierarchy, the group *rocketBase* is the parent of the objects *rocketExhaust* and *rocketFrame*, which are descendants of the group *rocketBase*. The objects of the *rocketExhaust* and *rocketBody* are siblings.

When we have one of the siblings, we can access the parent by pressing the [Up] arrow, on the contrary, we can access the sons with the [Down] arrow. The siblings are accessed with the [Left] arrow or the [Right] arrow.

Creating flaps

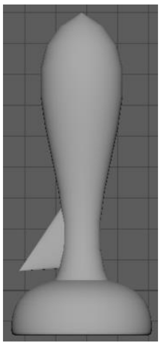
The rocket flaps will be made with the help of flattened cones, which will be further reshaped.



First, we move the current model of the rocket from the coordinate starting point so that we can create one instance of the flap in it. From the menu, select *Create-> NURBS Primitives-> Cone* □ (click on the box when selecting). This allows us to define the basic properties of the cone. Define the properties:

- Axis: Y
- Radius: 1.5
- Height: 3

we press Apply. This created a cone with the desired properties in the coordinate origin. We rename it rocketFlap1.



This, of course, is not yet a flap, as it should be slightly twisted, smaller and flattened. Rotate it 120º around the x-axis in the Channel Window. Then flatten it by scaling it in the same direction to 1/5 of the original value by entering the value 0.2 in the Channel Window under the *ScaleX* attribute. The flaps are slightly reduced in the y and z directions to a value of 0.75.

The wing is moved into the rocket so that the cone shell partially extends from the rocket and the bottom is completely hidden as shown in the figure.

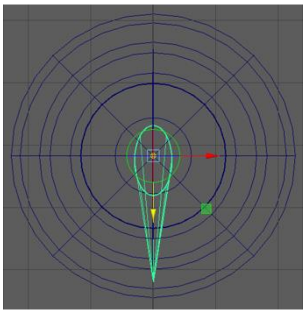
We want to make 5 more flaps and distribute them evenly around the rocket's hull. We will do this by using the duplicate tool, which allows us to multiply the desired object as many times as we like. With additional settings, we can achieve a special behavior of the duplication function, which allows you to place duplicates in the desired places.

Pivots

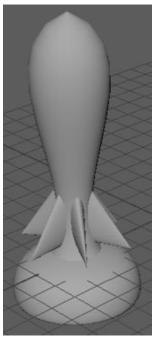
Before we start duplicating objects, let's look at where the pivots of individual objects are located. As already mentioned, pivot points are reference points around which transformations operate.

Duplicating flaps

In order to make the flaps as elegant as possible with as little extra work as possible, we will multiply one flap we already have 5 times and rotate it 60º za around the center of the rocket each time.



By default, the pivot of an individual object is at its center. In the case of a cone, this is in the center of the base area. So if we want to multiply the cone around the center of the rocket, we have to move its grip to the center of the rocket. This is done by moving to the view from above, pressing the [d] key to manipulate the grip and moving it as close as possible to the center of the rocket. For help, you can switch to grid drawing mode by pressing the [4] key.



Make sure that the flap is still selected and select *Edit-> Duplicate Special* □ from the menu. In the second column of the *Rotate* row, enter the value 60 (the second column represents the rotation around the y axis). Enter a value of 5 in the *Number of Copies* field and press the *Apply* button. As a result, we get 5 new flaps in the appropriate places.

For the end, all we have to do is mark all the objects together, make a new rocket group and save the scene by selecting from the *File-> Save* menu.

Example 2: Boat

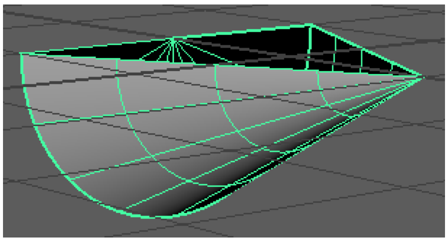
In the second case, we will upgrade the knowledge of the first case with other very useful functions and create a simple boat.

Framework

As with a rocket, in the case of a boat, you could first create a framework using a revolve tool. When setting the tool, you would set the curve to rotate only 180º. Instead, we will learn how to edit components.

For the axis, we will use half of the cone, which is created by selecting *Create-> NURBS Primitives-> Cone* □ from the menu. We determine the following properties:

- axis: z
- end sweep angle: 180 (s tem bomo dobili samo polovico stožca)
- radius: 1
- height: 2
- number of sections: 8
- number of spans: 4
- caps: bottom
- select also *Extra transform on Caps*



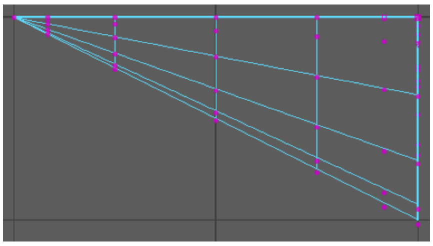
Then click *Create*. In the coordinate starting point, a cone will appear as shown in the picture on the right.

If we look at the cone more closely, we see that it consists of several sections, in the horizontal direction of eight, and in the vertical direction of four, which corresponds to the settings of the creation tool.

These settings have not been important to us so far, but they are very important in modeling, as each intersection of the two green lines in the image means one point that can be moved manually and thus change the entire object. We will see how this is used below.

First, we will rework our cone a bit more. In the Channel Window, we will transform it by entering 0.5 in the *Scale X* window, 0.75 in the *Scale Y* window and 1.5 in *Scale Z*. With this, we shrunk our boat, reduced its depth and lengthened it.

Now, however, we will manually change the cone to make it more like the hull of a boat. First, change the view to Side View.

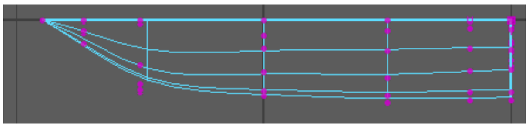


If shading is on, switch it off with the [4] key. Highlight an object and use the [F8] key to switch to *Component Selection Mode*. We now have a picture on the screen similar to the one in the picture on the right.

To zoom in on an object so that it is completely in our view, it is achieved by highlighting it and then pressing the [F] or [A] key.

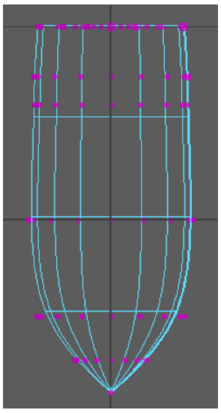
First we notice the purple dots. These points are control vertices (CV) and allow us to model an object accurately.

We will design the object by selecting points from right to left and moving them so that in the end we get something similar to the one shown in the picture on the right.



When moving the control points, care must be taken to always select the points with the mouse by pressing and holding [LMB] to the left-above of the selected point and dragging to the right-bottom position, relative to the point. We will call this a marquee choice in the future. We have to choose points in this way because we have to take into account that we are looking at the object from the side, which means that there are parallel points on the opposite (invisible) side, which we also select and move in this way to ensure symmetry.

We will now change the view to the top and widen our boat a bit, giving it its final shape. As with editing from the page, here we select the points and move them so that we get an image similar to the image on the right.



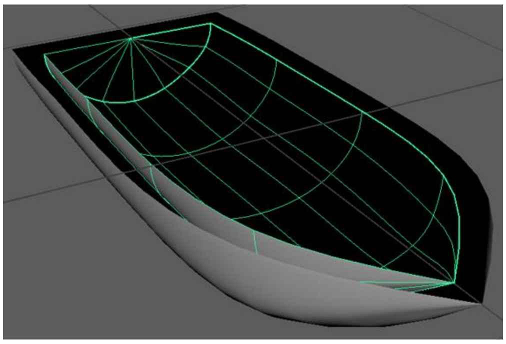
When finished, turn off component editing with the [F8] key.

If we look at the boat in perspective, we see that the product is already quite realistic, but we must add to the object the thickness of the material with which it is made.

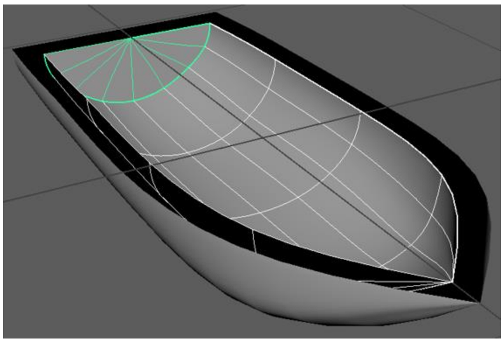
We will first duplicate the already made frame, reduce it and fill the holes between the two objects, which will give us the feeling that the object is made of real material, such as iron or wood, and not of a very thin one, such as e.g. paper.

Highlight our framework and select *Edit-> Duplicate Special* iz from the menu. If you remember the first example - rockets, you know that we have already used the duplicate function and that we have set some special properties for it. Maya has this property of remembering these settings until we change them.

Therefore, within the Duplicate Special window, select *Edit-> Reset Settings* from the menu and then *Duplicate*. By doing so, we will be an object that is the same as our framework and that lies in the same place as our framework. The newly created object is also already automatically selected, so there is no need to select it again.



We will now slightly reduce the new object by entering in the channel window: *scale X* - 0.8, *scale Y* - 0.8, *scale Z* - 0.9. After the duplication and reduction is complete, we get a picture similar to the picture on the right.

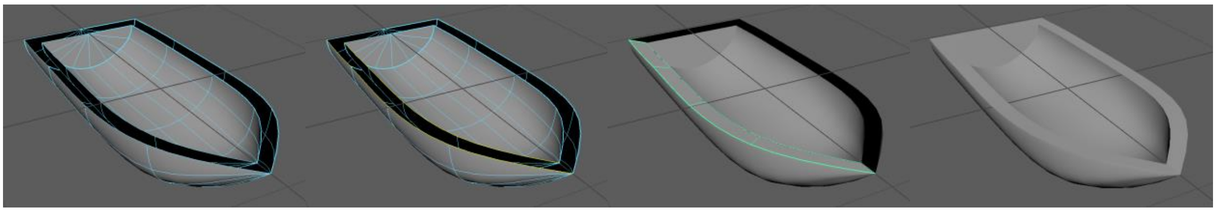


We can observe that one side of the surfaces is dark and the other is gray. We need to know that Maya distinguishes between the inside and outside of surfaces. Therefore, the inner boat needs to be *turned*. To achieve this, highlight it and select *Surfaces-> Reverse Directions* from the menu. The result is the correctly oriented surfaces shown on the right.

Loft

Now all we have to do is connect the inside and outside of the boat. We will do this using the Loft function. To connect surfaces with the loft tool, we need to mark the edge curves of each surface. This is achieved by clicking on [RMB] on each shell and selecting *isoparm*. The mesh of both shells will thus turn blue. In this mode, you can select the edge curves you want to connect by clicking and the [Shift] key. When selected, they turn yellow. Then select *Surfaces-> Loft* from the menu. A new surface is created that connects the marked curves. If the surface is dark it is turned upside down and we have to turn it in the same way as we described above. Repeat this process for all missing surfaces.

The image below shows the sequence of steps and then the final product.



Lection 03

Maya - Modeling with polygons

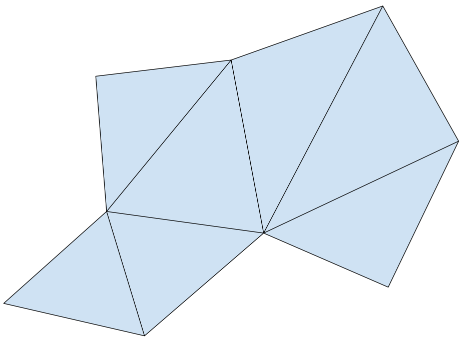
Povzetek

1. Polygons
2. Edges
3. Vertices
4. Extrude
5. Create polygon
6. Mesh smooth

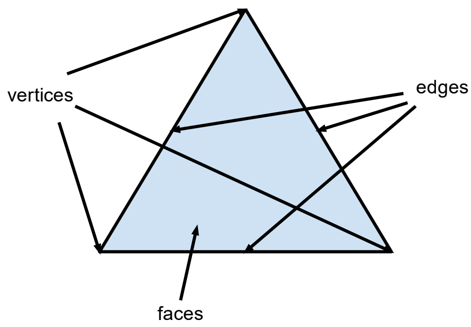
Unlike modeling with curves and surfaces, modeling with mesh geometry was developed for completely different purposes, as mesh geometry has limited accuracy in depicting curved surfaces. Of course, by adding details, we can increase the accuracy as we wish, but this is not the basic purpose of the technique. The basic components of a grid geometry are: vertices, edges, and faces, which are usually composed of polygons.

What are polygons?

Polygons are 2D primitives with three or more vertices. In fact, all polygons with more than three vertices are transformed into triangles before drawing, and only then are they drawn. The reason for this lies mainly in the design of graphis pipelines and due to the need for a uniform definition of objects.



Polygon geometry is still the predominant way of presenting 3D objects and is most prevalent mainly due to its use in 3D interactive computer graphics (e.g. in computer games). As a result, many different tools and accessories are available by designing such 3D geometry. In the following, we will look at how such geometry can be formed at the lower level - by moving individual vertices.



Each triangle consists of the basic building blocks: (1) vertices, (2) edges, and (3) faces, which is also shown in the figure to the right.

As we have already learned, Maya offers us a set of basic primitives for a starting point in 3D modeling (cube, cylinder, cone, ...). Most of these building blocks can also be defined by polygons. When modeling using polygons, we take the nearest primitive as a starting point, which is then formed into the final desired shape.

Why Polygons?

As mentioned in the previous chapter, the main reason for their use is their high prevalence and consequent adaptation of both software and hardware. Last but not least, graphics cards are highly optimized just for drawing 3D geometry represented by polygons.

A very positive feature is the compactness of the presentation. More complex 3D geometry can be designed from polygons by using a larger number of polygons in places where we want more detail, but where there is no such need, we can use a smaller number of polygons.

They are also very convenient due to the fact that it is very easy to "glue" textures to polygons - images that represent a more detailed structure of objects and also determine their color and appearance. Over the years, many techniques have also developed that allow us to add additional virtual details to otherwise roughly defined 3D models (e.g., using bumps, offsets, normal mapping). There are still many advantages, but we will get to know only a small selection of them during the workshop.

Creating polygon models

To create polygon geometry, we need to start with one of the primitives available to us. The simplest is the primitive of the plane, represented by four vertices, 4 edges, and one surface. To create new polygons, we need to change such an initial geometry in edit mode, which is presented in the next section.

As a starting primitive, it makes the most sense to choose the primitive that best represents the shape and properties of the desired final product. To make a face, we can start with a cube or a sphere (both are a good starting point), for elongated objects it is usually best to choose a cylinder or an elongated square, etc.

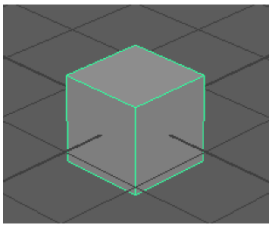
Example 1: Space ship

We will learn the basics of modeling through modeling a simple space ship where we will take a cube as a basis. The cube basically consists of 6 faces, 12 edges and 8 nodes.

Polygons

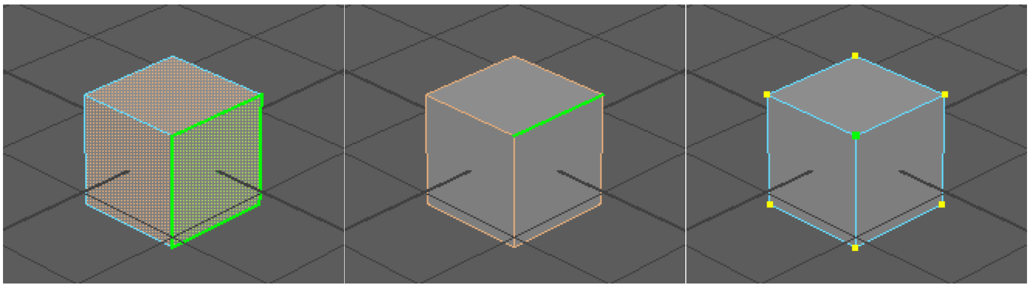
While the rocket in the first lesson consisted of a multitude of curves and surfaces, we will use polygons made up of triangles to model the spaceship. The reason for this lies in the suitability of such a geometry for real-time rendering, as the hardware is strongly adapted to the processing of the geometry thus defined.

Modeling



To begin, we will create a new polygon cube *Create -> Polygon Primitives -> Cube*. If we have not changed the basic properties of the tool, a cube with an edge of 1 unit will appear in the center of the scene as shown in the image on the right.

As we said in the introduction to the chapter, the cube has different components, which are visible in the pictures below:

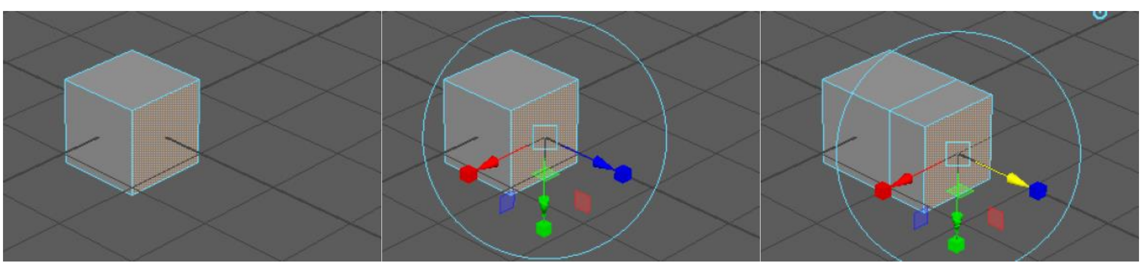


Faces Edges Vertices

The basic form of network geometry can be transformed by arranging the components. But before we get into that, let's show how we can model with grid geometry with some of the tools Maya offers.

Extrue

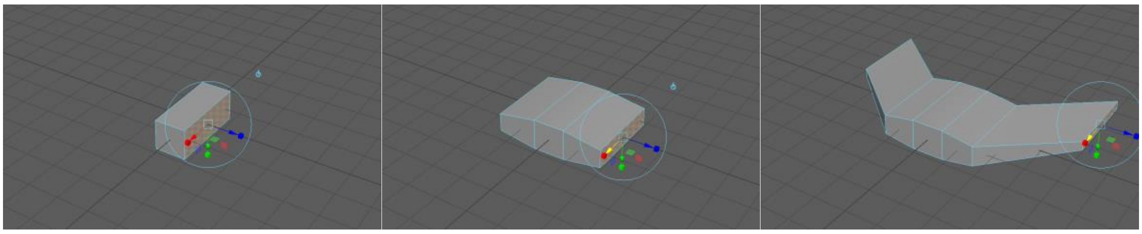
The most common tool used in polygon modeling is extrude. With this tool, a marked polygon or several polygons can be extracted from the model in the direction of its normal and thus create new faces in geometry. The Extraction Example tool is shown in the figure below.



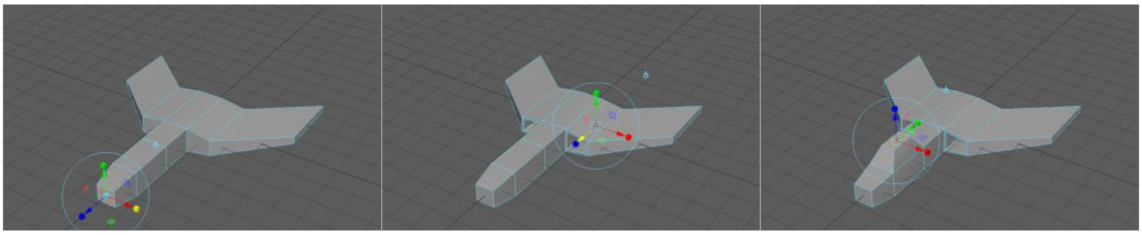
We use both in component mode, which shows faces (right-click on an object and select face). Highlight one or more faces, then choose *Edit Mesh -> Extrude* from the menu (or use the shortcut [Ctrl + E] on a Mac [Cmd + E]). A special manipulator appears that allows us to pull out the face and move it relative to the original. It is most often pulled out in the direction of the blue minipulator. The face can also be enlarged / reduced at the same time. With this tool, we will continue to build the entire spaceship.

Creation of space ship

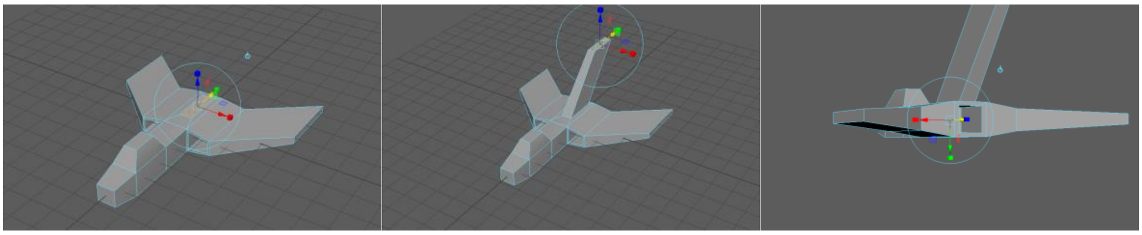
First, we change the cube into a square by scaling along one dimension. Then mark the edge faces of the square and pull them out and shrink slightly in the vertical direction. Then we pull out both new cheeks again, which we also shrink, and in addition we move back. You can use the shortcut [G] to reuse the same tool.



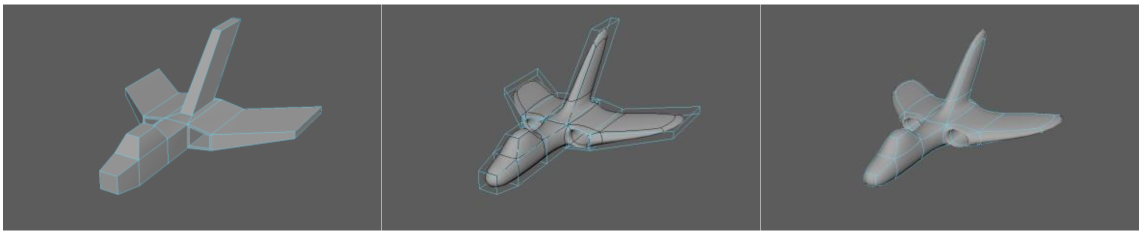
Then do the extension of the central front cheek three times and reduce the back slightly in the devh directions. Mark the lychees with the nose pulled out, trigger the pull-out and reduce them slightly. With the next pull of both faces, we deepen them into the interior of the ship. This added openings for air intake during flight in the atmosphere. We also pull out the cockpit.



We also add the tail wing, which is pulled out of the rear upper part of the torso, where the first pull-out first reduces the face, and the second pull-out pulls out the tail wing, which narrows at the top and moves back. In the last step, we add the drive opening of the main engine, which is made in the same way as the air intake openings.



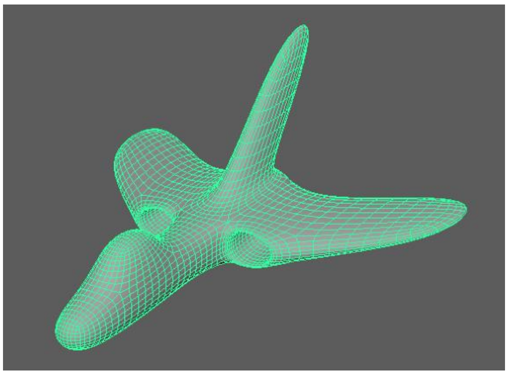
Our spaceship is extremely *angular*. To get a slightly more realistic look, it needs to be smoothed. To see a preview of the smoothed model, we can use the already known functionality of Maya, where we can switch between three levels of detailed display of the model with the keys [1], [2] and [3] as shown in the pictures below. Such an alien ship already looks more realistic, and we can make it in minutes.



In doing so, we must be aware that we did not actually smooth the grid geometry, which we must also perform before the desired final rendering.

Smooting

Mesh Smooth is a process of more detailed division of the mesh geometry, which divides the individual face of our network into several faces, placing the intermediate nodes in such positions that the shape of the model is smoothed. In Maya, linear and exponential smoothing is available, and we can set a number of parameters for each. If you select *Mesh -> Smooth* ☐ v from the menu, you can choose between smoothing settings. By default, Maya smoothes with the exponential method with 3-fold cheek splitting. The final look for our spaceship is shown in the image to the right.



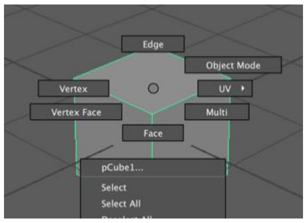
Example 2: Squid

Polygon modeling is also often used in modeling organic things, as the user has control over how the shapes will adapt to other things, where they will be more and where less detailed, and what similarities we will add.

Manipulation of individual components

As we have already shown in the case of curves and surfaces, even in the case of using a polygon grid, only individual components of geometry can be edited. Thus, scrolling, rotation, and scaling tools can be used to manipulate an individual or set of selected components in a single display mode.

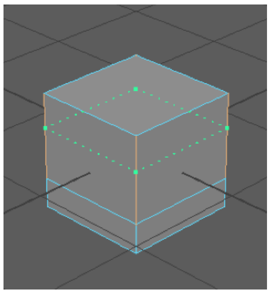
Component display selection



When you right-click on an object, a menu will appear with options to display the various components of the object. We are currently interested in: Vertex, Edge, Face, Vertex Face and Multi (all three types of components).

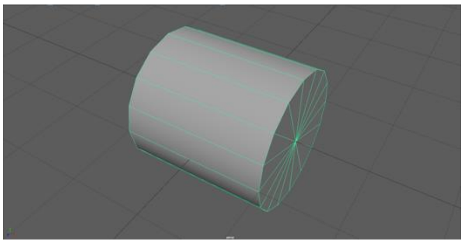
In this way, we can use selection tools to select those components of our object that we actually want to edit.

Adding Edge Loop



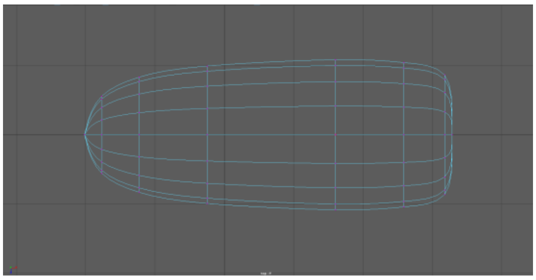
A very welcome modeling tool is also the *Insert Edge Loop tool*. The tool is available in the *Mesh Tools-> Insert Edge Loop* menu. This tool allows us to add a new loop of edges connected in one direction around the entire object (if possible) at the desired location on the existing edge, as shown in the example of the cube in the figure to the right.

Creating squitd

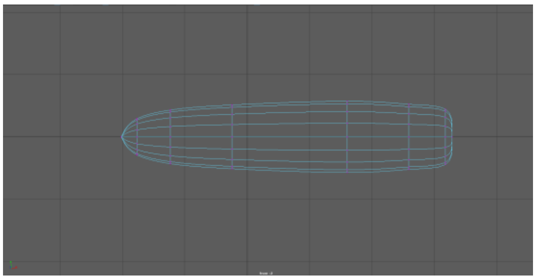


We start making squid with a simple cone. In the menu, select *Create -> Polygon Primitives -> Cylinder* ☐ where we change the number of axis divisions (Axis divisions) to 16 and change the axis along which we will create a cone to X and click the Create button.

Switch to the detailed display mode with the [3] key. By adding new edge loops and evenly enlarging / reducing the entire edge loops in the top and side view, we finish the desired shape.

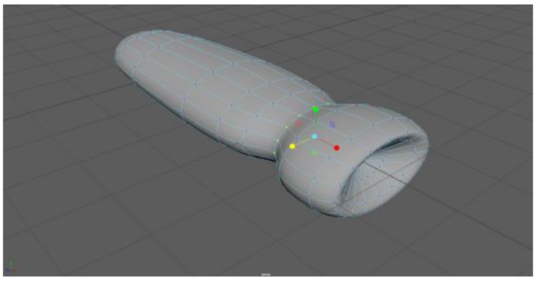


Top view

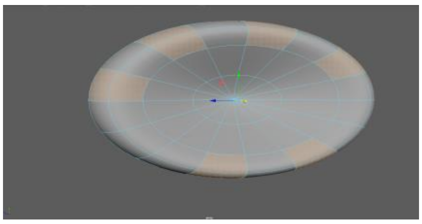


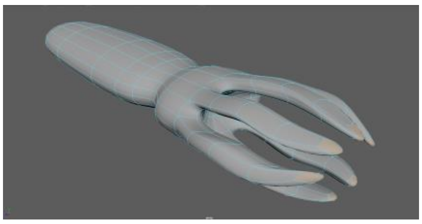
Side view

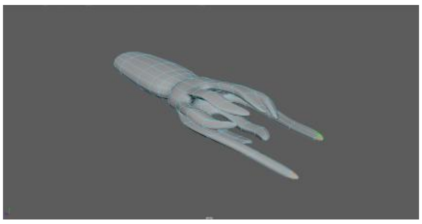
Add a few more loop loops and move the appropriate knots to form the squid head as well.



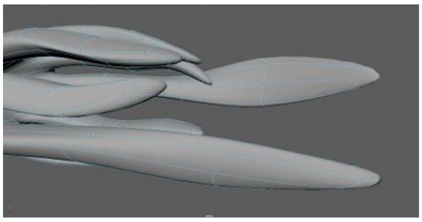
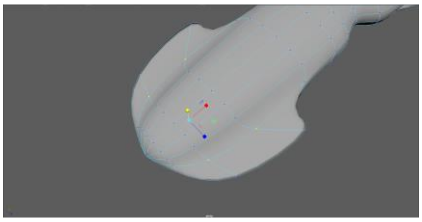
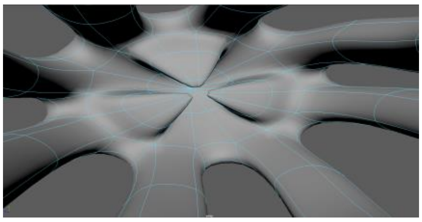
We continue to make tentacles. Squids have 8 tentacles, of which 6 shorter and 2 longer. We will use a pull-out tool several times to make the tentacles. First, we select 6 faces for pulling out shorter tentacles, where we then reach the approximately desired result by pulling out, scaling and rotating. Repeat the process to make two longer tentacles.



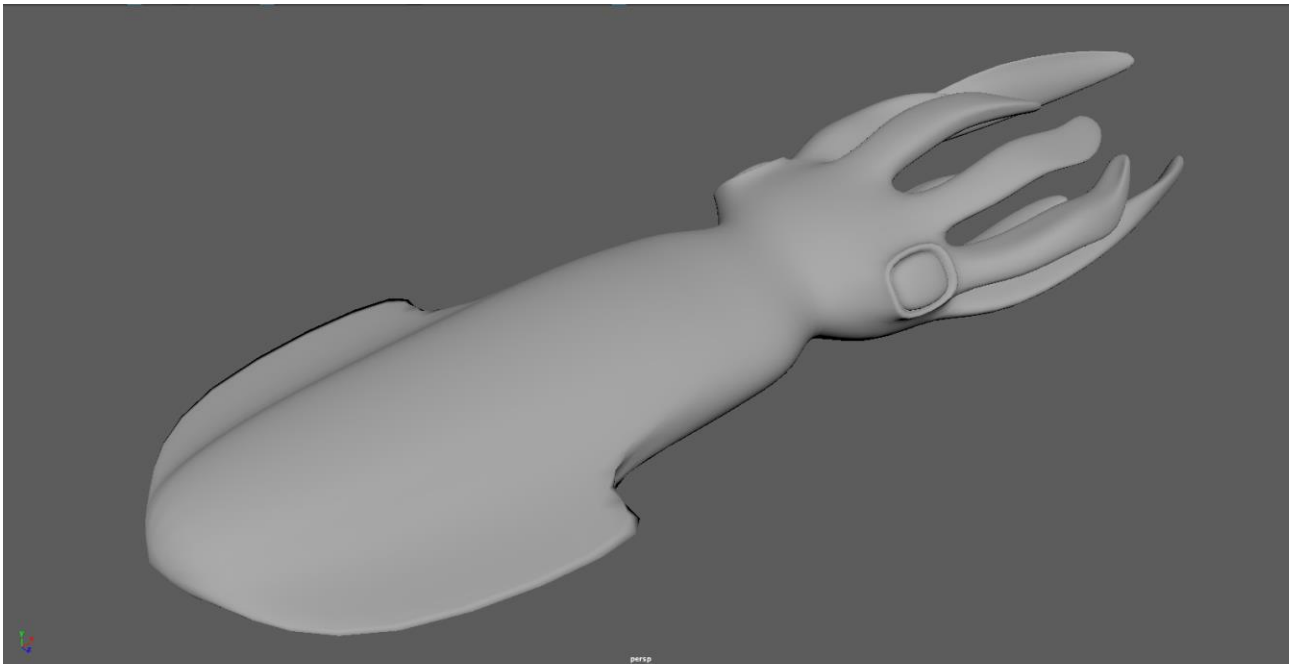




Let's work on longer tentacles a bit more to get a characteristically widened part at the end. By arranging the vertices at the front, we add the fins. With the extraction, add the characteristic jaws.

What's left is to add eyes. There is still a lot of room to add details.



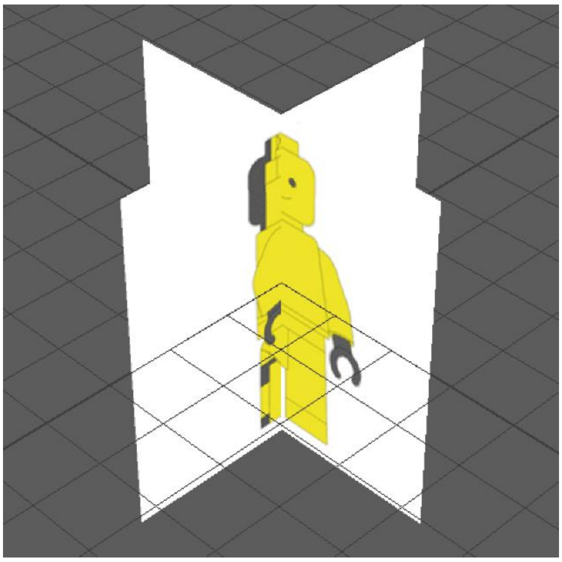
Example 3: LEGO figure

When making 3D models, we always use references. References can be photographs, pictures, sketches or even objects that we want to model. We can often help ourselves with images captured from specific views (e.g., from the front, from the side, from above, etc.). Such images can also be inserted into the scene itself as an aid to use.

Using reference images in a scene

Maya offers a very simple import of reference images into the scene itself, tied to a concrete view. We achieve this most elegantly if we have precisely aligned images from different views of the same dimensions and resolution.

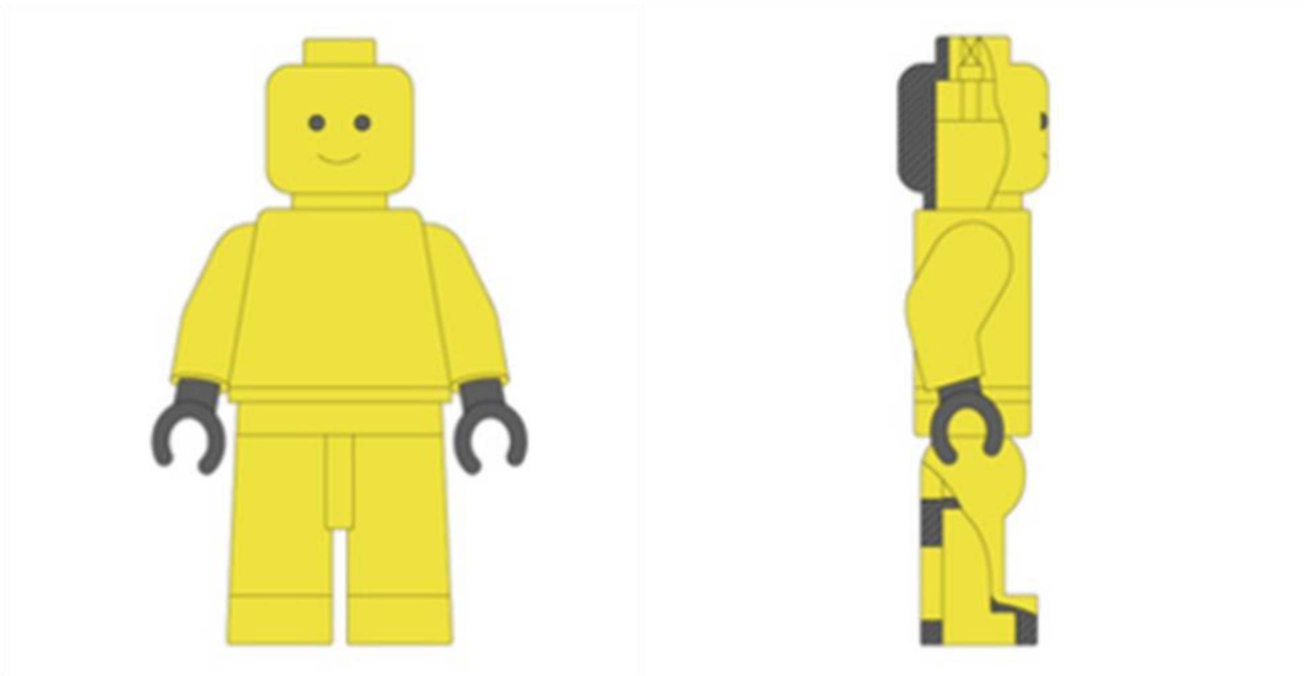
In the view where we want to add a reference image, click on the button in the viewport toolbar. A window for selecting a file opens, where we find the appropriate file with the image, select it and confirm the selection. In our scene, a surface appears aligned with the selected view, showing the selected image. In case we want to use several reference images in different views, we repeat the process for each view.



If the reference images are not aligned or the same size, this can also be achieved in Maya by moving, enlarging / reducing the areas with the reference images. The figure on the right shows the use of two reference images (for side and front view).

LEGO figure

Based on the presented techniques, make a LEGO little man as shown in the pictures below.



Lection 04

Maya – Advanced mesh modeling

Overview

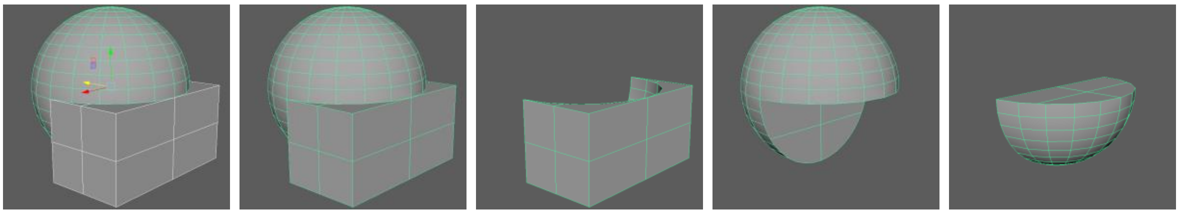
13. Grouping geometry
14. Editing geometry
15. Deformers
16. Live geometry

Real-world objects often consist of simpler basic forms, or at least parts of objects take on more basic forms. Thus, we can also help ourselves in modeling by combining simpler shapes in the production of more complex shapes. Therefore we can use different tools to combine geometry.

Tools for merging the geometry

Bool operations

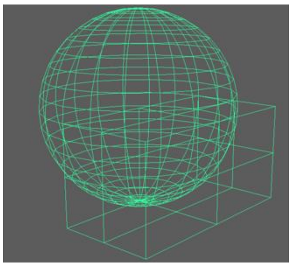
You have probably already learned about Boolean operations in the basics of logic (union, intersection, difference) and as such they also appear in 3D modeling. In Maya, they are available in the *Mesh->Booleans* menu, where we find: *union*, *difference*, and *intersection*. In this way, two (or more shapes) can be combined as shown in the figure below:



Original objects | Union | Box without spehere | Sphere without box | Intersection

With the difference opperator the result depends on which object we are subtracting from other objects (which depends on the order of selecting them). In doing so, we can observe that the density of the geometry grid summarizes the density of individual objects, which can occasionally cause headaches. Especially when we want to breathe a very specific shape of objects.

Combining mesh geometry



We can also combine mesh geometry without interfering with the composition itself. You can do this by using the combine tool. The tool is accessible from the *Mesh* -> *Combine* menu. As a result, we get one geometry that combines the grid representations of all the merged objects as shown in the figure to the right for the example above. In this way, we can then combine (or not) individual mesh primitives and connect them to each other.

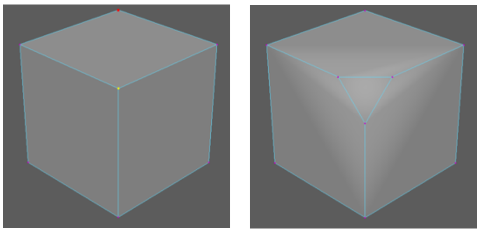
Separating the geometry

If we have unconnected parts of the mesh in one geometry, it occasionally makes sense to separate or dismantle it into individual separate objects. This can be achieved by using the separate tool available in the *Mesh* -> *Separate* menu. The same can be achieved with the tool for detaching the part of geometry available in the menu *Edit Mesh* -> *Detach*. This tool separates the selected part of the geometry from the rest but does not separate it into another object.

Editing geometry

In the previous part, we learned about some basic tools for editing geometry, and here we will present some more tools that often come in handy.

Chamfer



Chamfer is a tool that cuts off a corner and replaces it with new corners moved along the connected edges. The operation is shown in the figure on the right.

Merging vertices

In Maya, we also have some tools for combining corners. The most commonly used:

- merge, available in the *Edit Mesh* -> *Merge* menu, which combines selected vertices that are closer to the prescribed threshold. The threshold is set in the tool settings.
- merge to center, available in the *Edit Mesh* -> *Merge to Center* menu, which merges the selected nodes into their center of gravity.
- collapse, available in the *Edit Mesh* -> *Collapse* menu, which collapses the marked edges or faces in the vertex.

Deformers

With deformers, we can transform 3D geometry in accordance with mathematically undefined deformations. The deformers are available in the *Deform* -> *Nonlinear* menu and are: *bend*, *flare*, *sine*, *squash*, *twist* and *wave*.

Deformers are merely modifications over objects and therefore do not change their functioning mesh geometry irreversibly. For this reason, it is also important that if we want to preserve their function, we pay attention to how we transform the geometry.

Deliting geometry history

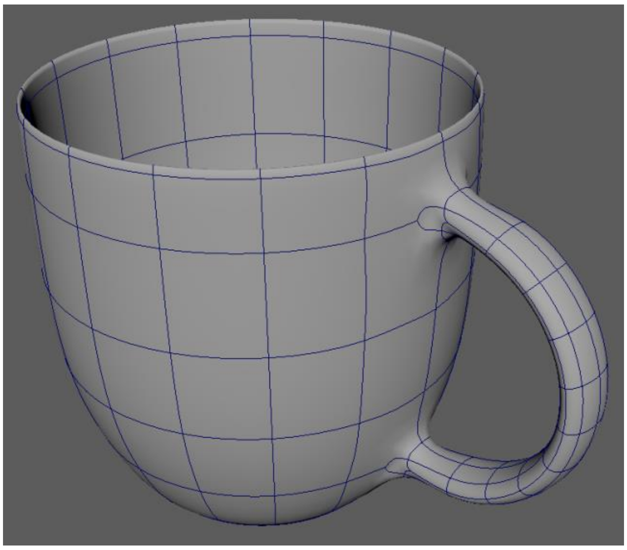
If we are finally convinced that we no longer want to edit geometry properties based on initial attributes and / or deformers, it makes sense to erase the history of objects. This bakes the shape of the geometry and makes it independent of the initial paratmeters (e.g. number of sections in the cylinder, etc.).

To do this, select the object and then select *Edit* -> *Delete by Type* -> *History* from the menu.

Example 1: Teacup

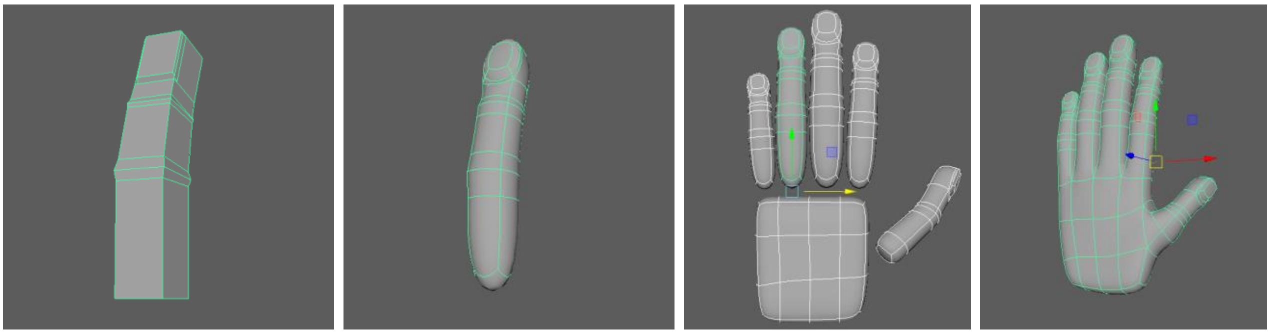
With the tools presented above, we can very easily create a cup from two cylinders as shown in the picture below:

- one cylinder is used to make the main part, where by adding edge loops we increase the desired shape accuracy and by moving and scaling the corners we achieve the desired shape of the main part;
- the second cylinder is used to make the handle.
- Bend the cylinder, wipe its caps and bring it closer to the main part.
- The cylinder is combined with the combine function.
- With the chamfer function, add the required number of corners to connect the nets at both ends of the handles in the appropriate places.
- With the merge to center function, we combine the corresponding pairs of nodes and thus connect both parts of the geometry.



Example 2: Hand

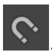
With the same tools, we can also model more organic models, such as the arm. We mostly used the tools *extrude*, *insert edge loop*, *combine*, *merge to center*. We start with the box then make one finger, multiply it. Adjust each finger and attach all fingers to the palm. The process is shown in the figure below.



Example 3: Goose

We often use modeling to help us with approximate models, which represent the approximate shape of our final model. We can also create such an auxiliary framework by rendering basic primitives.

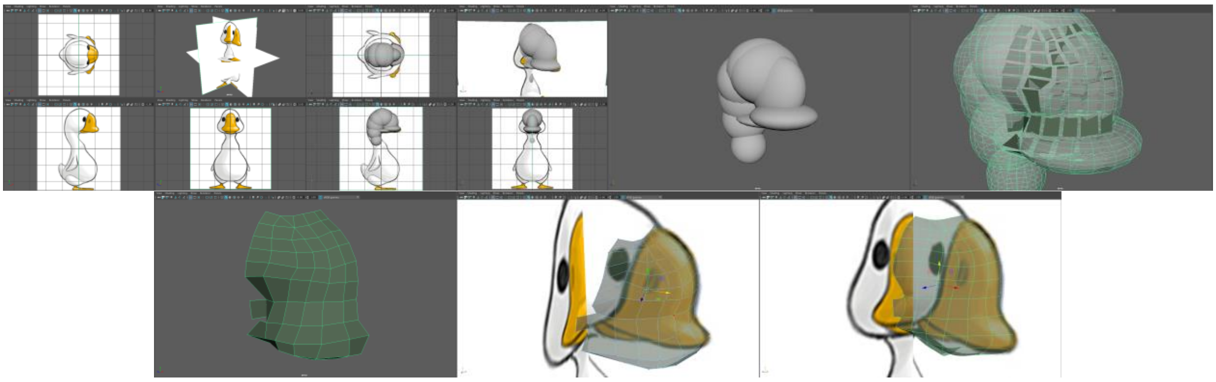
In our case, we depicted the basic shape of the goose head with a few spheres to which we adjusted the size and stretched / shrunk them along each axis to fit the auxiliary sketches. The smaller the objects we use, the more accurate the framework can be established.

We further combined these spheres into one geometry using the combine tool. Then we erased the history of the newly created object and used it for a *live geometry* .

In this mode, the mouse automatically sticks to the *live object* when creating a new geometry, so we can create new faces on its surface. We create new faces with the *Mesh Tools -> Create Polygon* tool. It is best to create quads and triangles. We must be careful to create them counterclockwise, otherwise the faces are turned inside out.

We create faces next to each other. Once we have created the desired amount, we combine them with the combine tool, erase their history, and then connect them in the appropriate corners using the *merge* and *merge to center* tools.

The final shape is obtained by adapting this grid in detail to the sketches and, if necessary, adding / subtracting new nodes.



Lection 05

Maya – Rendering

Overview

17. Materials
18. Textures
19. Lights
20. Camera
21. Rendering
22. Post-processing

The process of calculating an image showing our 3D scene is called rendering. In order to be able to calculate such an image, we have to assign materials to individual objects in our scene, place lights in the scene that will illuminate the objects, prepare a camera that will define the view of the scene, determine any special effects and finally trigger the rendering.

Materials

The appearance of objects in a scene depends most on what material the object is made of. In Maya, we have a collection of pre-prepared materials that we can use and adapt to our needs. Materials differ from each other in the way light is reflected. The most basic among them are:

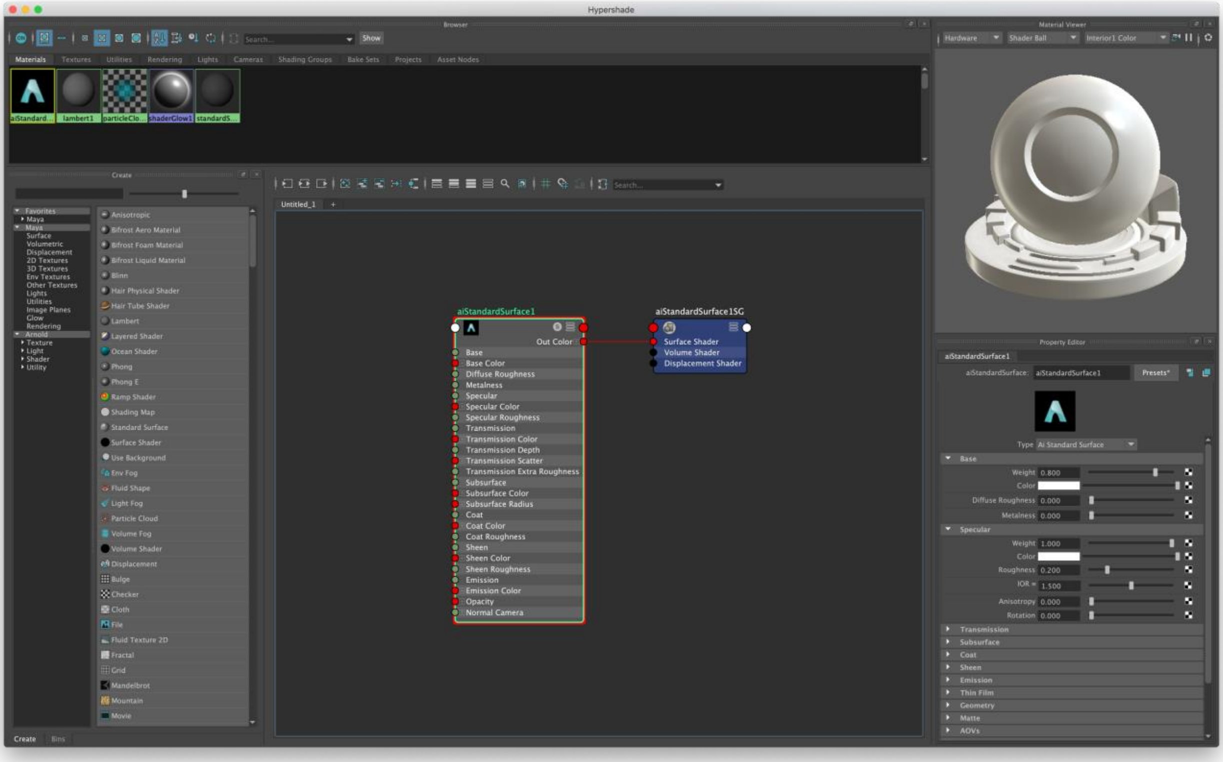
- *Lambert material*, used for matte surfaces (unpolished surfaces, chalk, etc.),
- *Blinn material*, suitable for metal surfaces, and
- *Phong material,* which is suitable for glass and polished plastic surfaces.

In addition to the basic materials, there are many other materials available in Maya (with the Arnold renderer).

Adding material to the scene

We add material into the scene using the Hypershade window, which is opened in the menu by selecting *Windows* -> *Rendering Editors* -> *Hypershade*. Hypershade is a space where we work with materials and textures, lights, cameras and other elements that affect imaging. The appearance of the window is shown in the figure below and includes: list of materials and auxiliary structures (bottom left), list of already created materials (above), Properties of selected material /

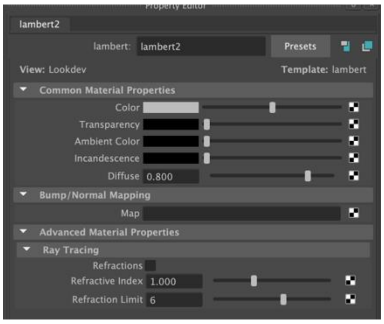
auxiliary structure (right), and work surface for connecting materials and auxiliary structures (middle).



We create new material by selecting the base from the left list. This creates a new material in the scene, which we will be able to assign to the objects, and at the same time this material and its composition are displayed in the central window. We adapt the material to the object in the scene by dragging it from the list above in the Hypershade window with the middle mouse button.

Adjusting material

The material can be processed by changing the appropriate properties (color, transparency, etc.) in the right part of the Hypershade Attribure window. The number of material properties depends on the type of material selected and can vary from a few simple parameters (in the case of Lambert type material) to a multitude of different parameters (in the case of materials included with the Arnold renderer), properties of Maya's material *Lambert*, and on the right Arnold's material *aiStandardSurface*. Arnold's material contains many preset settings that can be accessed via the *Presets* button.



The most important common attributes that determine the properties of materials are:

- *Color* – determines the base color of the material. Left-clicking on the color field opens a color selection window. With the slider, you can change the brightness of the selected color.
- *Transparency* – determines the transparency of the material. Use the slider to change the intensity of transparency. By changing the color field, you can change the default white transparency (the material is transparent to all colors) to color transparency (the material is transparent to the selected color).
- *Ambient Color* – determines the ambient color, which is present even without external lighting.
- *Incandescence* – determines the color and intensity of the light emitted by the material (it does not illuminate other objects).
- *Diffuse* – determines how strongly the material scatters light.
- *Specular Color* – determines the color of the mirrored reflection.
- *Reflectivity* – determines the reflectivity of the material.
- *Reflected color* – determines the color of the reflection.

Assigning material to the object

If we want an object to have the properties of a material when it is rendered, we must assign it the desired material. To do this, click on the desired material in the Hypershade panel with the middle mouse button and drag it to the object. Alternatively, select an item (or items), then right-click in the hypershade panel to open the context menu and select the Assign Material to Selection option. The third option is to click on the object in the scene with [RMB] and select *Assign Existing Material* from the menu, then select the desired material.

Textures

Textures add patterns to homogeneous base materials. Patterns can be based on color or some other attribute of the material (transparency ...).

The process of making a simple texture is as follows:

1. Add and adjust the material in the scene you want to add a texture to.
2. In the left part of the Hypershade panel inside the Create section (in the Textures folder) with the middle mouse button click on the desired texture and drag it to the material on which you will paste the texture (the material is visible on the desktop in the right part of the Hypershade panel). When we drop the texture on the material, we have to determine which attribute of the material (color, transparency ...) will be associated with the texture.
3. In the attribute editor, we process the texture according to our requirements.

Lights

Much like it is in the real world, the lights in Maya are needed to illuminate the scene. Maya knows some basic types of lights that we can use in our work. The basic types of lights are:

- *Ambient Light* – radiates in two ways: some light radiates evenly in all directions from the position of the light in the room, and some light radiates in all directions from all directions.
- *Directional Light* – strains evenly in one direction only, so that the rays are parallel to each other, as in the case of a very distant source of light (for example, sunlight).
- *Point Light* – strain evenly in all directions from the position of the light in the room (for example, candle light).
- *Spot Light* – strain evenly in limited directions (cone) from the position of the light in the room (for example, the headlight light).

Adding lights into the scene

The light is added to the scene with the help of Hypershade (similar to the materials included in the scene). By including a light in the scene, it is placed in the default place (center) in the room (and oriented in the default direction). The light must then be moved to the desired location and, in the case of a directional light, oriented in the desired direction. For this we use already known tools for movement and orientation or a light manipulator.

Adjusting lights

After we add a light to the scene, we adjust it according to our needs. We process the light by changing the corresponding attributes that define it (similar to the material) using the attribute editor.

The most important common attributes that determine the properties of a light are:

- *Color* – defines light color.

- *Intensity* – defines light intensity (it can also be negative => removing the light).

Rendering

Creating an image is the final stage in rendering. Based on the layout of the model, materials, textures, lights, cameras and special effects in the scene, an image or several images of the scene are created (calculated). Before we start creating the image, we can change the default settings of the parameters when creating the image (resolution, quality, ...). The image creation parameters are viewed and set in the *Windows -> Render Settings* window. It is used to review and set the parameters that determine the production (calculation) of the image. The window contains a large number of parameters, such as image name, image format, resolution, image quality and others, which can be changed and thus affect the calculation of the image.

Some important parameters when calculating the image:

- *Image File Output -> Camera* – specifies the active camera for the image.
- *Resolution -> Width* – defines image width.
- *Resolution -> Height* – defines image height.
- *Raytracing Quality -> Raytracing* – include ray tracing calculation mode.

You can create an image and view it in the window *Windows -> Render View.*

Render View

We use it to create and view created images. The image will be created according to the current rendering settings. The rendering process is started by clicking on . We can create only a part of the image by first selecting the part we are interested in with the mouse in the Render View window, and then clicking on to start the image creation process. Outside the part we marked, the previous image remains unchanged (useful for comparison).

The default camera when making an image is the one that corresponds to the perspective view of the scene.

Lection 06

Maya – Animation

Overview

23. Keyframes
24. Animation curves
25. Animation with deformers
26. Animation with constraints

Animation is a process in which we manipulate / transform / move objects and thus achieve the feeling that they are moving. Animation dates back to the 19th century and has been constantly evolving since then. 3D animation has its beginnings in the 1940s, and since the 1970s it has regularly appeared as an important part of the film industry. Since then, however, animation has appeared in a variety of environments for a variety of purposes.

Basics

Keyframes

Animation using keyframes is done by placing / transforming the object into the desired position at the desired time points. During such positions, the animation frameworks can then create the animation themselves, which can then be further corrected using animation curves.

The keyframe determines (fixes) the values of the selected attributes at some point in time. Attribute values at keyless intervals are calculated automatically. Place the key frame in the properties window on the right side of the screen or in the *Animate* -> *Set Key* menu (red bars are drawn on the timeline at the bottom of the screen for each set key point). The keyboard shortcut is the [S] key.

You can set animation keyframes for almost any object attribute (not just position, rotation, and resizing). If you right-click on the name of a parameter (e.g., color material), you can select *Set key* in the menu to set the key frame for this parameter.

Timeline

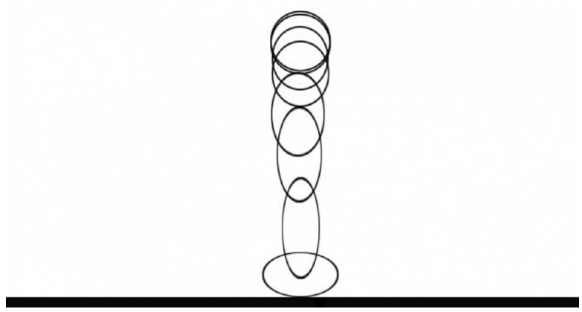
At the bottom of Maya's window is a timeline that shows the length of the animation (in thumbnails) and where you are in the animations. By entering the value in the input window on the left and right under the time bar, you can extend or shorten the length of the animation.

You can move to a specific animation thumbnail by clicking on the ribbon; if you press the bar with the left mouse button, all the animated parameters will be recalculated and set to the correct values, but if you press the bar with the middle button, the animated parameters will not get new values.

Animation Curves

Based on the set key frames, Maya calculates the animation curves for the animated attributes. These curves can be corrected in the *Graph Editor* (*Window* -> *Animation Editors* -> *Graph Editor*). Keyframes and tangents are selected with the left mouse button and moved with the middle mouse button.

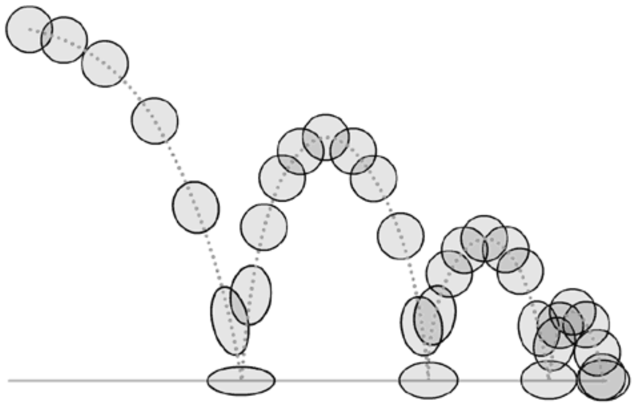
Example 1: Bouncing ball



We will learn the basics of animation on the example of a bouncing ball. We will first animate the ball in place as shown in the sketch on the right. To achieve such an animation, it is necessary to use only basic transformation tools (displacement and scaling).

We start right at the top, where we place the first key frame, then move on the timeline to where we want the ball to touch the ground. Perform the necessary transformations (move the ball to the base and partially flatten it). We add a key box. Let’s repeat the same for the lower bounce. In addition to flattening on impact, we can also add the stretch of the ball when accelerating.

In the second exercise, we add a shift along the horizontal axis, as indicated by the sketch to the right.



When setting key frames, of course, we can fix them later and thus change the entire animation or just the part we are not happy with. We can also use a curve editor to correct certain properties of the animation, where we can set the properties of individual changes over time very precisely.

Example 2: Swimming fish

We will learn more advanced animation techniques with Maya on the example of a swimming fish. Our goal should be to create an animation in which a simple fish moves through the water with movements. It should be followed by a camera.

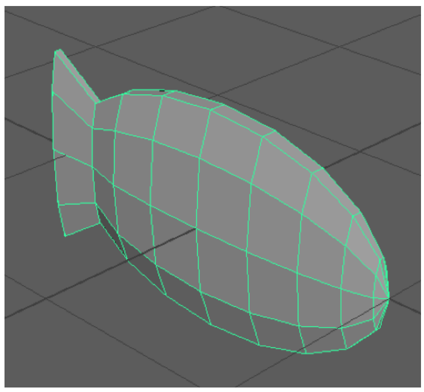
Modeling fish

Before we get acquainted with more advanced animation concepts, let's build a 3D model of a simple fish, which will serve as a basis for working with deformers and constraints.

We will use a ball as a fish, the shape of which we will change. We will change the ball into a fish by directly transforming the control points, which are the basis of the ball (this method differs from changing the shape of the body by using deformers, which transform the body control points only indirectly).

A fish in a horizontal position will be much easier to shape if the sphere has a polar axis in a horizontal position. Since the default orientation of this axis is vertical, we need to change the appropriate parameter to construct the sphere. Place the ball on the scene with

menu selection *Create* -> *Polygon Primitives* -> *Sphere* ☐. The orientation of the polar axis of the sphere is changed by changing the *Axis* parameter. We set its value to X. We also make the design a little easier by increasing the number of control points. This is achieved by increasing the number of height and rotational distributions of the sphere. In our case, we increase them to "axis division = 10" and "height division = 10".



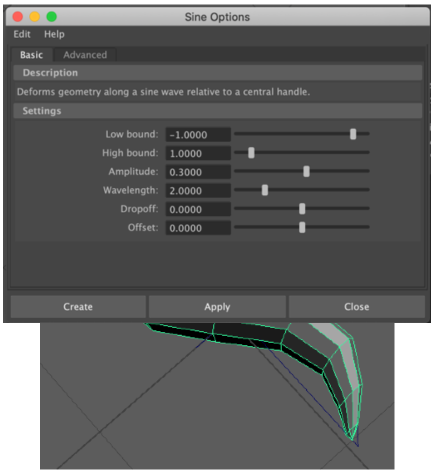
The sphere is transformed into a fish by direct transformation of the vertices as shown in the figure to the right.

Animation of swimming movements with deformer

Realistic animation of the swimming movements of the fish with the direct transformation of the control points of the fish body would be very difficult to achieve. For this purpose, we prefer to use one of the deformers, which enable easy and complete changing of the shape of any objects.

With deformers we can change the shape of any object, the structure of which is defined by control points. These are NURBS curves, NURBS plots, polygon plots and lattices. Maya contains several types of deformers. Some of them are, for example:

- Lattice: allows free deformations based on the deformation network on the object;
- Cluster: allows the transformation of control points with different impact;
- Nonlinear deformers: allow bending, twisting, wave, ... objects;



Use of sinus deformer

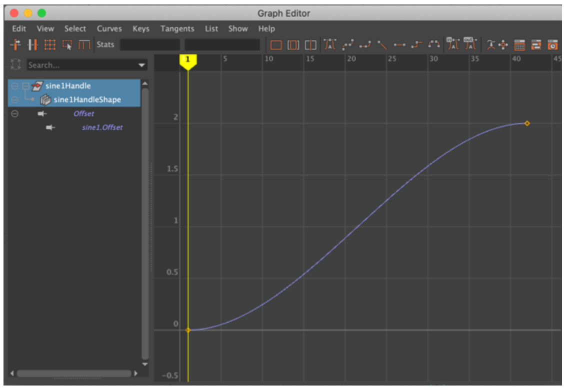
First we mark the object we want to deform (in our case it is a fish). Then we create a nonlinear sinusoidal deformer with the menu selection *Deform* -> *Create Nonlinear* -> *Sine*. By selecting the input node *sine1* in the *Channel Box* window, we can interactively access the parameters of our deformer. Since the parameter that determines the amplitude of the sine curve is equal to 0, we set it to one of 0 different values (for example, "Amplitude = 0.3").

Deformer animation

The next step is to animate the deformer. This ensures that the curvature of the fish due to the influence of the sinus deformer will change over time. The parameter of the sinusoidal deformer, which in our case needs to be changed over time, is the Offset parameter. As a result, the impact of the deformer and therefore the shape of the fish will change.

In the time window, we place ourselves on the thumbnail 0 (most likely we are already there). In the *Attribute Editor* window, set the value of the *Offset* = 0 and set a keyframe for this parameter. Then, in the time window, place one of the later frames (for example, frame 39), change the value of the parameter *Offset* = -2, and set the key frame for this parameter again. It makes sense that the absolute value of the *Offset* parameter in the second case is equal to the *Wavelength* parameter, as this way the curvature of the fish returns to the initial position.

At this point, our animation involves one full swing of the fish (frames 0 to 39) and the rest of the fish is motionless. The movement in the rest of the animation is created by periodically repeating the already defined animation of the *Offset* parameter. This can be achieved with the graph editor, which is opened with the menu selection *Window* -> *Animation Editors* -> *Graph Editor*. This shows us the animation curves for the parameters we animated. In our case, we see a curve that determines the value of the *Offset* parameter as a function of the frame number (i.e., as a function of time).



Periodic repetition is achieved by selecting the desired curve and select *Curves* -> *Post Infinity* -> *Cycle* via the menu. This will repeat the change of the selected parameter in the animation indefinitely.

Animation along the curve

One of the last steps to realizing our idea is to animate the movement of a whole fish along a path here and there. We do this by creating a curve that represents the desired path and attaching the fish to that curve. The fish will then move along the curve from its beginning to its end during our animation. In this type of animation, we do not need to deal with the direct setting of key points.

First, we create a curve that represents the path. This is done with the curve tool obtained with the Create EP Curve Tool menu selection. Subsequently, the curve can be further corrected by transforming the control points.

The fish then needs to be pinned to the path curve. In fact, a sinus deformer also needs to be attached along with the fish in order to maintain the impact and periodically bend the fish. Therefore, it is best to group the fish and the deformer first (highlight the fish and the deformer and select *Edit* -> *Group* in the menu). Now attach the created group to the curve by first selecting the group then the curve and selecting *Animate* -> *Paths* -> *Attach to Path* in the menu. If we start the animation now, we notice that the whole fish moves along a defined path of movement and at the same time bends in accordance with the sinusoidal deformer. However, it is necessary to correct the orientation of the fish so that it is always directed with the head in the direction of the current movement. This can be done by changing the parameters *Follow = on*, *Front Axis = Z*, *Up Axis = Y* and *Inverse Front = On* with the attribute editor of the *motionPath1* node.

Camera tracking with restrictions

Even tracking the camera of a moving fish can be greatly simplified. For this purpose, we can use constraints to ensure that the attributes of one object (for example, position) influence the attributes of another (for example, orientation) - position, orientation ... we limit with another object.

Maya knows many kinds of limitations. These include, for example:

- Point Constraint, which limits the position of one object by the position of one or more others;
- Aim Constraint, which limits the orientation of the object so that it is always directed towards others;
- Orient Constraint, which limits the orientation of one object by the orientation of one or more others.

We will follow the moving fish with a new camera, which we create with the menu selection *Create* -> *Cameras* -> *Camera*. This camera will not be static, but will follow the movement of the fish along its path with the direction of the body. We will apply the orientation limit.

Orientation restriction is achieved by selecting a group with a fish and a deformer, and then a camera (the last object that will be restricted must be selected). Once we have such selected items, we create a constraint with the *Constrain* -> *Aim* menu selection. Finally, the orientation of the camera needs to be corrected. To do this, correct the *Aim Vector* parameter to (0,0, -1) in the node that represents the camera constraint (probably called *camera1_ aimConstraint1*) with the attribute editor.

Lection 07

Maya – Importing objects into Maya

Maya supports a wide range of 3D formats that can be imported. The largest set of formats is available to us on Windows, elsewhere the set of formats is quite limited.

You can use the IGES or STL format to download from the SolidWorks environment. Details for exporting IGES format models from the SolidWorks environment can be found in the original script for the RPO I object.

If you do not need to open the exported models in Maya then turn off the Export 3D Curve features option when exporting to IGES format.

3D models in the Maya era are represented either by mesh geometry or by surfaces. Working with them is the same as we have already met.