I Apologize in Advance
for What You Might Hear in the Background 😊

Blender Shortcuts You Will Use a Lot

<table>
<thead>
<tr>
<th>Shortcut</th>
<th>What it Does</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMB</td>
<td>Select something</td>
</tr>
<tr>
<td>Shift-LMB</td>
<td>Add something else to the selection</td>
</tr>
<tr>
<td>MMB</td>
<td>Rotate the scene</td>
</tr>
<tr>
<td>Shift-MMB</td>
<td>Pan the scene</td>
</tr>
<tr>
<td>Scroll Wheel</td>
<td>Zoom in and out</td>
</tr>
<tr>
<td>Tab</td>
<td>Toggle between Object Mode and Edit Mode</td>
</tr>
<tr>
<td>Shift-tab</td>
<td>Bring up Mode pie menu</td>
</tr>
<tr>
<td>` (back quote)</td>
<td>Bring up View pie menu</td>
</tr>
<tr>
<td>a</td>
<td>Select all</td>
</tr>
<tr>
<td>Click in empty space</td>
<td>Unselect all</td>
</tr>
<tr>
<td>Alt-a</td>
<td>Unselect all</td>
</tr>
<tr>
<td>Escape</td>
<td>Get you out of almost anything (including stopping a render or an animation)</td>
</tr>
<tr>
<td>b, c</td>
<td>Box or circle select</td>
</tr>
<tr>
<td>Shift-d</td>
<td>Duplicate</td>
</tr>
<tr>
<td>e</td>
<td>Extrude (in edit mode)</td>
</tr>
<tr>
<td>F3</td>
<td>Search</td>
</tr>
<tr>
<td>F9</td>
<td>Grab (translate) an object</td>
</tr>
</tbody>
</table>

Blender Shortcuts You Will Use a Lot

<table>
<thead>
<tr>
<th>Shortcut</th>
<th>What it Does</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift-g</td>
<td>Group</td>
</tr>
<tr>
<td>t</td>
<td>Insert a keyframe</td>
</tr>
<tr>
<td>Control-j</td>
<td>Join 2 or more objects</td>
</tr>
<tr>
<td>n</td>
<td>Send object to a collection (layer)</td>
</tr>
<tr>
<td>Shift-n</td>
<td>Toggle the Sidebar menu</td>
</tr>
<tr>
<td>Shift-m</td>
<td>Recalculate normals</td>
</tr>
<tr>
<td>p</td>
<td>Toggle quad viewing</td>
</tr>
<tr>
<td>Control-p</td>
<td>Establish a parent-child relationship (last object selected will be the parent)</td>
</tr>
<tr>
<td>Alt-p</td>
<td>Delete a parent-child relationship</td>
</tr>
<tr>
<td>Control-Alt-q</td>
<td>Toggle object tools menu</td>
</tr>
<tr>
<td>f</td>
<td>Rotate an object</td>
</tr>
<tr>
<td>x</td>
<td>Scale an object</td>
</tr>
<tr>
<td>Shift-x</td>
<td>Pie menu for using the 3D Cursor</td>
</tr>
<tr>
<td>Spacebar</td>
<td>Start / Pause an animation</td>
</tr>
<tr>
<td>1</td>
<td>Toggle the Object Tools menu</td>
</tr>
<tr>
<td>2</td>
<td>Toggle whatever is selected</td>
</tr>
<tr>
<td>3</td>
<td>Bring up a display inside pie menu</td>
</tr>
<tr>
<td>Control-z</td>
<td>Undos</td>
</tr>
<tr>
<td>Alt-z</td>
<td>Toggle smudge mode</td>
</tr>
<tr>
<td>Control-Shift-z</td>
<td>Redo</td>
</tr>
<tr>
<td>F12</td>
<td>Render a scene image</td>
</tr>
<tr>
<td>F11</td>
<td>Return to the interactive scene</td>
</tr>
</tbody>
</table>
What is Blender?
Blender is a free program that lets you do professional-looking 3D modeling, rendering, and animation. This, not this.

Note: The version number changes often. These notes have been written against Blender version 2.9.3.

You can get Blender for yourself by going to: http://www.blender.org

Next Gen – a Blender-Animated Movie
See the trailer at: https://www.netflix.com/title/80988892

Why Do We Have These Notes?
Blender has thousands of buttons you can press. It is difficult to understand them all. These notes are here to show you what certain combinations of buttons do in order to learn them, and to remind you later when you’ve forgotten.

In these notes, what do these icons mean?
They tell you that if you go to our notes web site: http://cs.oregonstate.edu/~mjb/blender
you will find Blender input files (*.blend), texture map files (*.bmp), and animation movie files (*.mp4).

You can read a .blend file right into Blender (File → Open) so that you can experiment with these examples without having to first create them yourself.

You can play an .mp4 movie file right from your browser so that you can see how these examples look without having to run Blender at all.
A warning about me and the Notes

What Blender does

What I know

What the notes cover

What We Will Cover in these Notes

1. Navigating the screen layout
2. Viewing in 3D
3. Moving things around in 3D
4. Modeling, I
5. Appearance, I
6. Modeling, II
7. Rendering
8. Particle Systems
9. Physics Animation
10. Appearance, II
11. Vertex Sculpting
12. Vertex Painting
13. Keyframe Animation
14. 3D Printing
15. References

1. Navigating the Screen Layout

Full Screen Layout
**The Object Tools Menu**

- Select
- Cursor
- Transform
- Move
- Rotate
- Scale
- Annotate
- Measure

Toggled on and off with the 't' key.

**The Add Menu**

- Create geometry
- Create lights
- Create other cool stuff

This is the Add tab – you will spend a lot of time here!

**The Add→Mesh Menu**

You will especially spend a lot of time here!

**The Sidebar Panels**

Toggled on and off with the 'n' key.

**Computer Graphics**
The Blender Interface Widgets

If Blender shows you something that looks like this …

... you are expected to click a button to put yourself in a particular mode

If Blender shows you something that looks like this …

... you are expected to click in the box to bring up something else, like this

If Blender shows you something that looks like this …

... you are expected to turn features on and off by clicking in all or none of the checkboxes

If Blender shows you something that looks like this …

... you are expected to make a choice of just one of these options

If Blender shows you something that looks like this …

... you are expected to either left-click in the box and (keeping the left button down) drag the mouse left-right like a slider, or single-click in the box and type in a new value

If Blender shows you something that looks like this …

... you are expected to click in the box and then select from the resulting list
The Blender Interface Widgets

If Blender shows you an “Apply” button ...

... it means that you can click this button to get rid of your original model and replace it with a model that has the edits you have just made

If Blender shows you this icon (with or without the word “Open” ...

... it means that you can click this button to open a file

The Blender Interface Widgets

If Blender shows you something that looks like this ...

... you are expected to click in the box and select from a list of other objects in the scene

If Blender shows you something that looks like this ...

... the red color is telling you that you haven’t yet entered enough information in this panel

The File Menu

Start a new Blender scene (thus closing the scene you currently have open)

Open a previously-created Blender scene (thus closing the scene you currently have open)

Save the current scene in a file

Bring elements from another Blender file into this scene

Bring an image or object in from somewhere else

Send an image or object to somewhere else
The Difference Between New, Open, Link, and Append

**New** closes the scene you currently have, then initiates a new Blender scene.

**Open** closes the scene you currently have, then reads in a previously-stored Blender scene.

**Append** leaves the scene you currently have open, and adds elements of a previously-created scene into it.

**Link** is like Append, but every time you open the scene again, it will look at the file you are Linking from to see if changes have been made, and if so, will bring those into the scene instead of the first ones.

---

The Edit Menu

Control-Z or Edit→Undo are two of your best friends!

You can also select Undo History and go back in time to several commands ago.

---

The Render Menu

---

The Help Menu
2. Viewing in 3D

- Right-handed coordinate system
- X = Red
- Y = Green
- Z = Blue
- Middle mouse button (MMB) – orbit (rotate)
- Shift MMB – pan
- Scroll wheel – zoom
- View → Left, Right, …
- View → Toggle Quad View
- View → View Persp/Ortho

3D Coordinate Systems

Blender uses this convention

The Coordinate and Viewing System

The View Menu

The View Menu gives you access to lots of ways to change how you are viewing the scene
In orthographic, lines that are parallel in 3D remain parallel on the screen. Objects appear to be the same size as they get farther away.

In perspective, lines that are parallel in the 3D depth direction appear to converge on the screen. Objects appear to get smaller as they get farther away.

"Vanishing Point"

Use perspective when you want a more realistic view (which is most of the time).

Use orthographic to see if things separated in depth are the same size.

Or hit Control-Alt-q
Setting the initial Rendering Mode

On the vertical strip of icons on the right, click this one:

And then be sure the Render Engine is set to **Eevee**.

---

Setting the initial Display Mode

Use **Viewport Shading** to start. It gives good generic lighting.

Later, when we cover Rendering, we will use Rendered lighting, but not now.

---

3. Moving Things Around in 3D

We will get into this in more detail later, but just so that you have something on the screen, here is the Add Menu

These are all the different geometry things you can add into the scene. We will cover many of them, but not all.

This group is the **meshes**.

This group is the **curves**.
The Add → Mesh Menu

The UV Sphere, Torus, and Monkey are my favorites

Summary of the Mesh Objects

Coordinate System Conventions

• Right-handed coordinates
• Right-handed rotation rule
• Angles are in degrees

Right-handed Rotation Rule
Selecting an Object to Work On

LMB-click on the object you want to select. It will then be highlighted with an orange outline.

Selecting Multiple Objects to Work On: Two Ways to Do This

1. Hold down the Shift key while RMB-clicking

2. LMB a rectangular region around objects

Moving Things By Clicking and Dragging

Translate ("grab")

Rotate

Scale

Use Global or Local Coordinate System

Global and Local Coordinates

Global Coordinates align with the screen

Local Coordinates align with the object
Saying How to Move Things by Using the Keyboard

- LMB click to select an object
- Grab ‘g’
- Rotate ‘r’
- Scale ‘s’
- Grab using global axis: ‘g’ → ‘x’, etc.
- Grab using local axis: ‘g’ → ‘x’ → ‘x’
- Pick all but a particular axis: ‘g’ → ‘X’, ‘g’ → ‘X’ → ‘X’, etc.
- Grab a specific distance: ‘g’ → ‘x’ → 12.25 <return>
- Rotate a specific angle: ‘r’ → ‘x’ → 45 <return>
- Scale a specific factor: ‘s’ → ‘x’
- Scale a specific factor: ‘s’ → ‘x’ → 2.0 <return>

This is important — you will use this a lot!

Applying the Transformation

When you transform an object, Blender doesn’t change the object’s coordinates. It keeps the object’s original coordinates plus a record of the transformation. So, for example, if you scale an object by 2.0, Blender remembers it like this:

You Can Also Use the Sidebar Panel

Hit the ‘n’ key to toggle this panel

Applying the Transformation

If you want to actually alter the object’s coordinates, choose Object → Apply

You can pick a specific transformation to apply, but most of the time it is easiest to select All Transforms
Applying the Transformation

Once you apply the transformation, the Object Properties Box looks like this:

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>X: 2.000</td>
<td>X: 1.000</td>
</tr>
<tr>
<td>Y: 2.000</td>
<td>Y: 1.000</td>
</tr>
<tr>
<td>Z: 2.000</td>
<td>Z: 1.000</td>
</tr>
<tr>
<td>X: 5.31 m</td>
<td>X: 5.31 m</td>
</tr>
<tr>
<td>Y: 3.2 m</td>
<td>Y: 3.2 m</td>
</tr>
<tr>
<td>Z: 3.82 m</td>
<td>Z: 3.82 m</td>
</tr>
</tbody>
</table>

The Outliner

In the upper-right portion of the screen is the Outliner. Like the name implies, it shows an outline of your scene.

It is sometimes nice to have a summary of the scene so you can remind yourself of what all is in it.

Also, if your scene is cluttered, you can select an object by clicking on its name in the outliner as opposed to selecting it in the scene.

Double-clicking on a name will allow you to rename that object to something more sensible than, say, “sphere.”

Also, you can use the outliner to hide certain objects. Just click on the eye icon to hide/unhide.

Hint: If you hide something, don’t forget that you have hidden it. It is pretty freaky to be certain that you once created something, but now can’t find it anywhere in the scene.

4. Modeling, I

The Add Menu

These are all the different geometry things you can add into the scene. We will cover many of them, but not all.

This group is the meshes.

This group is the curves.
The Add→Mesh Menu

The UV Sphere, Torus, and Monkey are my favorites

When you Add a Mesh, a Small Menu Appears in the LL Corner

Try clicking on it.

The small menu lets you modify how the last thing you did works. In this case, the most important thing it is doing is letting you change the polygon resolution of the sphere. But, this menu only exists until you do something else. After that, the ability to change these values is gone.

Summary of the Mesh Objects

Personally, I like changing these two values to \textbf{64} and \textbf{32}, respectively.
Making the Mesh Objects Look Nicer

Blender is able to play a graphics trick to make your curved geometry look better. Select the object (LMB) then click the RMB and select **Shade Smooth**.

This doesn’t actually change any geometry – it’s just a really good computer graphics display trick. There are other ways to truly create smoother geometry.

How to Find Out How Detailed a Mesh Object Is

In the overlay menu, turn on **Statistics**

The number of Vertices, Edges, Faces, and Triangles show on the left side of the screen.

Duplicating an Object from the Tools Menu

Select the object (LMB) then click the RMB and select **Duplicate Objects**. This leaves the new object right on top of the old object and leaves you in Grab mode. Just move the mouse to separate the two objects.

Mirroring an Object

Oftentimes you want to create an object that is identical to itself, but is symmetric about an axis. This type of operation is called **mirroring**.

Create an object, in this case, Suzanne the Monkey.

Let’s say that we want to mirror this object left-right (y). Select the monkey, right click, then select **Mirror**, and then select **Y Global**.
Select and edit:

- A vertex
- An edge
- A face

Using the Tab key is so common, that “tab” has become a verb in the Blender community. As we like to say, “Just tab over into edit mode.”

Editing a Vertex

Be sure you are in vertex-editing mode

Left click on a vertex
Hit ‘g’ (grab) and move the mouse
You can also hit ‘x’, ‘y’, or ‘z’ to restrict motion

Editing a Vertex with Proportional Editing

Be sure you have Proportional Editing enabled

LMB click on a vertex
Hit ‘g’ (grab) and move the mouse
You can also hit ‘x’, ‘y’, or ‘z’ to restrict motion
The mouse Scroll Wheel changes the size of the Circle of Influence
You can also LMB select an edge or a face for editing or proportional editing.

Subdividing and Smoothing Really Show the Difference Between Localized and Proportional Editing
**An Unexpected Use for Proportional Editing**

Create a Plane, then go to Edit Mode, then box select all the edges, then click on Edge → Subdivide and subdivide it several times.

Enable Proportional Editing, then go one widget to the right and change the kind of Proportional Editing from Smooth to Random.

Go to Edit Mode, select a vertex, and lift it along with those around it.

Original

With Subdivision Surfaces
5. Appearance, I

The Button Properties Menues

- Tells you that we are in the Button Properties Menu
- Render Properties
- Output Properties
- View Layer Properties
- Scene Properties
- World Properties
- Collection Properties
- Object Properties
- Modifier Properties
- Particle Properties
- Physics Properties
- Object Constraint Properties
- Object Data Properties
- Material Properties (colors)
- Texture Properties

Clicking one of these brings up a much more detailed menu of options.

Using the Material Properties Menu

Click on this … to get this

Then, click on New

Using the Material Properties Menu

To make our lives simpler for now, click here to turn off Use Nodes mode
Using the Material Properties Menu

Use Nodes mode has been turned off

Clicking in here brings up a color wheel

The Color Wheel

Click in here to change the Hue and Saturation

Hue is the angle around the wheel
Saturation is the radius

These are the possible ways the color will be defined

Value is a color’s brightness

If you know the color definition numbers you want, you can type or slider them here

The Color Wheel in Action

Controlling Shininess

Turn Use Nodes off

Most matte

Most glossy

The Color Wheel in Action
**Computer Graphics**

**Color Scales**

- Red-Green-Blue
- Hue-Saturation-Value
- Hexadecimal

**RGB Additive Color Scale**

Blender’s RGB scale lets you give the red, green, and blue components in the range 0. – 1.

Blender’s hexadecimal scale lets you give the red, green, and blue components in the range 00 00 00 – FF FF FF.

**Hue-Saturation-Value (HSV) Color Scale**

Blender’s HSV scale lets you give the hue, saturation, and value components in the range 0. – 1.

**Subtractive Colors (CMYK)**

Blender’s CMYK scale lets you give the cyan, magenta, yellow, and black components in the range 0% – 100%.
Subtractive Color (CMYK)

R = Red
G = Green
B = Blue
W = White
C = Cyan
M = Magenta
Y = Yellow
K = Black

You See Lots of Color Printing Tests Like This!

Color Printing

- Uses subtractive colors
- Uses 3 (CMY) or 4 (CMYK) passes
- CMYK printers have a better-looking black

So Far We Have Been Using Viewport Shading

We have gotten pretty good views of our objects without having to position light sources, cameras, etc.
We Could Switch to Rendered Shading

But, that would require us to position light sources, cameras, etc. We're not ready for that yet.

But, here comes MatCap, a More Creative Use of Viewport Shading

Click on Viewport Shading and then click on the down-facing arrow. Studio Lighting is what you have been using. Instead, select MatCap, which stands for "Material Capture". Then, click on the sphere.

Up Pops a Lot of Material Options!

Try them, especially the shiny ones!

6. Modeling, II
Adding 3D Text

To change the text string, tab into Edit mode. The white rectangle acts as a text cursor. Backspace over “Text” and type your new text. The return key will let you enter multiple lines.

Changing the Style of 3D Text

So far, not very 3D, huh? Tab back to Object Mode, click on your text, then click on this Font button.

Extrude: give the letters height
Depth: bevel the top and bottom
Resolution: round the bevel

Changing the Look of 3D Text

From here on, your 3D text acts like any other 3D object. It can be grabbed (translated), rotated, and scaled.

It can be colored, too.

Edit Mode Subdivision

The Edit Mode subdivision feature adds more vertices, but doesn’t do any sort of smoothing (like the Subdivision Surface Modifier does). So, when you are done, you will have more vertices to sculpt with, but, in Object Mode, your object will look exactly the same as it did before.

1. Object Mode
2. Tab into Edit Mode
3. Get Ready to Edit Faces
**Edit Mode Subdivision**

4. Right-click Subdivide

5. You now have more vertices

6. Tab back into Object Mode

---

**A Multi-Vertex Picking Hint**

First, make this model:

1. Object Mode → Add → Mesh → Cylinder
2. Tab to Edit Mode → RMB → Subdivide

Now, **LMB-sweep** over these vertices. (I call them the "equator" or the "belt").

But, if you do that, you will only end up selecting the front vertices, that is, the ones you can see.

The trick is to go into **X-ray Mode**, by clicking here.

This will now let you select all the points in the belt.

---

**A Multi-Vertex Picking Hint**

Why do that? Well, if you have those vertices selected and you hit the s key (for scale) and move the mouse, then you can get this:
A Multi-Face Picking Hint

To create this model:
1. Add → Cube
2. Tab to Edit Mode → RMB → Subdivide → Subdivide

Suppose you want to select an entire row of faces in order to "fatten the belt". You could select all the faces individually (LMB → Shift-LMB). But, here's a better trick:
1. Click on one face in the row
2. Alt-LMB on another face down the row

A Face Picking Hint

Similarly, if you put yourself into face-picking mode:

And click on the top face of the cylinder (don't need the belt and don't need to be in X-ray Mode for this):

Intentionally Joining Two Objects

Let's say that you have two objects and want to join them together so that you can act on them as one object.
Intentionally Joining Two Objects

Easy! LMB on one, then Shift-LMB on the other, then hit Control-'j' ("join") on the keyboard. The orange "selection outline" now goes around both objects and the outliner shows just one object.

Separating Objects By Loose Parts

Select the Joined object. Tab over to Edit Mode. Then hit the ‘p’ key ("Partition"). You will then have three options on how to partition the joined object. If you select By Loose Parts, then the Joined object will be partitioned based on the original primitives that made it up.

Inset Faces (aka, Offset Curves)

Often you want to create a “face-within-a-face”. In Blender, this is called an Inset Face. (CAD systems often call this sort of thing an Offset Curve.)

In Edit Mode, select the top face. Then, either RMB → Inset Faces, or click on this icon on the left side:

Inset Faces (aka, Offset Curves)

With the LMB, push the little handle down until the Inset Face is the size you want.

At this point, you can select the inner face and hit g and z (grab in the z direction) to do this, or this.

Try rotating or scaling the inner face.

You can also create a new inset face inside the inset face you just created.
Select X-ray mode and select all vertices. Tab into Edit Mode.

Start with a cube. Tab into Edit Mode.

Grab one of the +’s and pull. You can even keep doing it.

I like XYZ mode so that you can extrude in any direction. When you get back to Object Mode, you will find that all of these are part of the same object.

Pick the number of duplicates to make. Pick the axis/axes about which to spin.

Pick the axis/axes about which to spin. Grab one of the blue +’s and rotate.

Start with a cube translated along the x axis (gx). Tab into Edit Mode. Click on the Spin Tool.

Be sure all of the object’s vertices are selected. Grab one of the blue +’s and rotate.
Computer Graphics

Vertex Groups

Using a group of vertices together is very useful. It is used for editing (like we are doing here), but also to pin certain vertices for cloth animation, to grow hair for hair simulation, and to rig objects for animation.

For that reason, Blender allows you to select the group and give them a name for later. This is called a Vertex Group.

1. Select the vertices in Edit Mode (Shift-LMB)

2. Select the Object Data Properties button

3. Click the + to add this as a new Vertex Group

4. Double-click on whatever the default name is ("Group" in this case) and type in a descriptive name for this Vertex Group

5. Click Assign

From now on, this group of vertices can be selected just by selecting the name from the list of Vertex Groups and clicking Select.

Extruding Faces – three ways

Extrude Individual Faces (cracks in between skyscrapers)

Extruding Faces Along Normals (push each face perpendicular to the surface)

Extrude Faces (push each face along the group average perpendicular to the surface)

Face Select Mode

Extrude Faces Along Normals

Extrude Faces

Shrink/Fatten and Push/Pull

Find this edit icon in the column on the left side of the screen. Click it with the LMB and leave the button down for a couple of seconds.

Shrink/Fatten and Push/Pull are very much like extruding faces. Here are the differences:

**Extruding** lifts the selected faces along their normals. It leaves behind a "cliff" that connects them to the surrounding faces.

**Shrink/Fatten** lifts the selected faces along their normals, but leaves behind a "ramp" connecting those faces to the surrounding ones.

**Push/Pull** essentially scales the selected faces around their centroid.

Shrink/Fatten and Push/Pull are very much like extruding faces. Here are the differences:

**Extruding** lifts the selected faces along their normals. It leaves behind a "cliff" that connects them to the surrounding faces.

**Shrink/Fatten** lifts the selected faces along their normals, but leaves behind a "ramp" connecting those faces to the surrounding ones.

**Push/Pull** essentially scales the selected faces around their centroid.

For example, suppose we start with this object and these selected faces:

Every one of the edit-icons that has a little arrow in the lower-right corner expands in this same way. Check ’em out!
Extrude, Shrink/Fatten, and Push/Pull

<table>
<thead>
<tr>
<th>Extrude</th>
<th>Shrink/Fatten</th>
<th>Push/Pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Button Properties Menus, Again

- Tells you that we are in the Button Properties Menu
- Render Properties
- Output Properties
- View Properties
- Scene Properties
- World Properties
- Object Properties
- Modifier Properties
- Particle Properties
- Physics Properties
- Object Constraint Properties
- Object Data Properties
- Material Properties (colors)
- Texture Properties

Clicking one of these brings up a much more detailed menu of options.

The Modifiers Menu

Modifiers don't actually change the object's permanent geometry – just the object's appearance on the screen. The geometry gets permanently changed only if you click the Apply button.

Blender Modifiers

Modifiers don't actually change the object’s permanent geometry – just the object’s appearance on the screen.

You Create an Original Object

You Apply a Blender Modifier

You See a Modified Object on the Screen
The Modifiers Menu

Modifiers don't actually change the object's permanent geometry – just the object's appearance on the screen.

Example: Here a cube has been beveled (one of the Modifiers). In Edit Mode you can see both the beveled cube and the original cube. You can edit the vertices and the new shape will get beveled as you edit.

My Favorite Modifier -- Subdivision Surface

This modifier increases the number of polygons in your object. At the same time, it smooths your object out. Be careful! It very quickly increases your polygon count.

Deleting and Moving Modifiers

Oftentimes you have a list of several Modifiers that are used with a single object. The Modifiers take effect in the order that they are in the list. To change this, you can:
• Delete a Modifier
• Move a Modifier elsewhere in the list and thus change how it modifies the object

Making Your Modifier Effect Permanent

Despite the name, Modifiers do not actually modify the object's underlying coordinates. They create an "alternate representation" that you can see. Most of the time, this is good. It lets you edit the underlying coordinates and have the Modifier then use them. If you want the Modifier to change the object's underlying coordinates permanently, bring up this sub-menu and click on Apply.
**Bevel Modifier**

Beveling causes edges to be rounded instead of sharp.

- **How much to bevel**
  - No beveling
  - Segments = 1
  - Segments = 2
  - Segments = 3

Smooth shading makes bevels look much better!

**Booleans (also known as Constructive Solid Geometry)**

Think of them as Venn diagrams in 3D!

- Two Overlapping Solids
- Union
- Intersection
- Difference

**Remember Venn Diagrams (Boolean Operators)?**

- Union
- Intersection
- Difference

**Boolean Modifier**

“Block minus Cylinder”

1. Select the cube
2. Click on **Modifiers**
3. Select the Modifier called **Boolean**
4. Specify the **Difference** Operator
5. Specify the **Cylinder** as what to the difference with
6. Click **Apply**
Boolean Modifier

Select the cylinder, hit it g (grab) and slide the cylinder away

The Resolution of the Second Object Determines the Resolution of the Resulting Surface

First object Second object Resulting surface

The Mirror Modifier

Let’s say that you want to create a mirror image of the monkey, but by using a Modifier, the mirror monkey will be linked to the original monkey so that any edits you do to the original will automatically end up in the mirror object.

But, that mirrored object will reflect about the object origin, this little dot right here. Which means that you will end up with something like this, which is probably not what you wanted.

So, the first thing we need to do is to move the object away from the little dot. You do this by Tabbing into Edit Mode and grabbing all the vertices and sliding them (gy).

In Edit Mode, the dot doesn’t move when you do this:

Now, Tab back to Object Mode, add the Mirror Modifier, and select Y.
The Mirror Modifier

So, now if you sculpt the original object, the mirrored object will get the same edits.

This is often good for creating a full object by only creating one half of it (e.g., a car) and mirroring it.

Array Modifier

The Array Modifier is used to duplicate an object according to a particular pattern. Suppose we want to turn a block into a staircase. We start with the block and add an Array modifier.

- **Apply** button (if we want to make this permanent)
- **The duplication count**
- How much to offset each duplication. It can be Constant, that is, based on a number of units. Or it can be Relative, that is, based on a number of size-of-this-object

Array Modifier to Make Stairs

Move each block in Y and Z to make the next stair step

- How many total steps to make

Screw Modifier

Before

- **Angle**: 40°
- **Screw**: 10 m
- **Threads**: 1

After
### Wireframe Modifier

**Turns each polygon into thick lines outlining each polygon**

- Thickness: 0.02 m
- Offset: 0.0000
- Boundary
- Replace Original
- **Thickness**
  - Even
  - Relative
- Crease Edges
- Material Offset: 0
- Vertex Group

But, these lines have thickness, keeping this as a Mesh.

---

### Modifier Order Matters!

**Subdivision Surface, then Wireframe**

- Wireframe, then Subdivision Surface

**Modifier Order Matters!**

---

### The Lattice Modifier

**Add a UV Sphere**

- In *Edit Mode*, select a group of sphere vertices and assign them as a **Vertex Group**

**Hints:**
1. Select the vertices in **Orthographic** and **X-ray** display modes
2. Double-click on the default name of the Vertex Group to give it a better name
Click the Lattice button and (perhaps) add more lattice detail.

Add a Lattice to the scene.

Add a Lattice Modifier to the sphere. Tell it the name of the lattice and the name of the Vertex Group to use.

In Edit Mode, grab vertices and slide them:

Turn on both X-ray Mode and Wireframe Mode.

Add a UV Sphere and a Cone. Either scale the sphere up or scale the cone down so the cone is inside the sphere.
The Shrinkwrap Modifier

1. Click on the sphere and select the Shrinkwrap Modifier.
2. Select the cone as the Target.
3. Adjust the Offset value. Positive values make most sense, but negative values are fun too!

The Build Modifier

1. I suspect this is more applicable to engineering-ish objects, but it fun no matter what. Let’s use our old friend Suzanne the monkey.
2. Go to Modifiers → Select Modifier → Build
3. You get the following Modifier box. All the values are good defaults:
4. At this point, Suzanne has disappeared. What!? To bring her back, grab the blue animation time slider and slowly move it to the right.
The Displace Modifier

This Modifier pushes vertices out perpendicular to the surface. I would describe it as “puffing out the object”.

Go to Modifers → Select Modifier → Displace
You get the following Modifier box. If your object suddenly looks weird, don’t worry! Set this value to 0:

Now, slowly increase to Strength to be greater than 0. What happens? Is it possible to set it to a value less than 0? What happens?

Texture Pattern Displacements

Click on the Texture Property button
Select which texture you want for the displacement pattern. I like Voronoi because of the cells

Remember the texture “name” (Texture.002) – you will need it later.
**Texture Pattern Displacements**

Click here and select the texture name from before. Select Normal (in computer graphics, normal means "perpendicular to the surface"). Experiment with different values of Strength.

**Aren’t you glad you didn’t have to sculpt this yourself? 😊**

**Metaball Objects**

Metaball Objects are another way to 3D model:

The cool thing is that, if you move (g) them close enough, they will "glom" into a single object.
Metaball Objects

There is a special Metaball properties menu to control their characteristics:

But, Metaball Objects are not meshes, so you cannot do a lot of the cool editing that you can with meshes. But, you can turn such an object into a mesh by selecting Object → Convert To → Mesh from Curve/Meta/Surf/Text.

After tabbing into Edit Mode

Importing Objects from Other Places

Collada = export format from game modeling systems
Stl = 3D printer format
3ds = format from Autodesk 3D Studio
Obj = Probably world’s most common export format There are a ton of .obj models for free on the Internet! Google the phrase: free obj files

File = dino.obj
You can get this file from the web page: http://cs.oregonstate.edu/~mjb/blender
As-is, flat shaded

Subdivision surfaced + Smooth shaded
Importing Objects from Other Places

Abusively edited

Exporting Objects to Other Places

Blender has a number of file formats it knows how to export to. If you are looking for a nice, general one to experiment with, try the .obj format.

Just be sure to use the RMB menu to select Shade Smooth first

Select File → Export → Wavefront (.obj)

Exporting to an OBJ File

This is the Blender file-output selection dialog box:

Obj-specific settings (see next slide)

OBJ-Specific File Settings

In the export dialog, be sure to click on

- Write Normals
- Include UVs
- Triangulate Faces
7. Rendering

We have been using this one. This one gave you good generic lighting so you could model without worrying about light sources. Now switch to this one. This one will give you a pretty-good preview of what happens when you actually render the scene. But, we now have to deal with Rendering specifics.

Rendering

“Rendering” is Blender’s process for creating really high-quality images. Click on Render → Render Image or hit the F12 key (you might have to hit the fn key at the same time). The rendering operation can often take some time, depending on how complex your scene is.

On-screen Rendering Mode

We have been using this one. This one gave you good generic lighting so you could model without worrying about light sources. Now switch to this one. This one will give you a pretty-good preview of what happens when you actually render the scene. But, we now have to deal with Rendering specifics.

Rendering Properties

Clicking on the Rendering Properties button will allow you to set various rendering parameters. The one you care about the most is Sampling resolution.

You want at least some Anti-Aliasing, which is done by making more than one sample per pixel. 64 and 16 are good values.

The rest of these are interesting, but not needed right now.
Output Properties

Clicking on the Output Properties button will allow you to set various rendering parameters. The one you care about the most is pixel resolution.

These are OK values, but you can improve your rendering speed by making them smaller. Don't make them smaller by changing the 1920x1080, make them smaller by changing the 100%.

Notice that the image aspect ratio being used here is 16:9 (=1920:1080). This is the most common aspect ratio today for TVs and computer monitors.

The rest of these are interesting, but not needed right now.

What is Anti-aliasing?

Anti-aliasing is a good-news bad-news joke.
Good news: the scene looks much smoother
Bad news: the scene takes longer to generate
Good news: you probably want to do it anyway

Anti-aliasing is Implemented by Oversampling within Each Pixel

Lighting

Let's say that you are in Solid Shading Mode and your scene situation looks like this

You now change to Render Mode and get this:

Blech! Why is the bottom part of my scene so dark?
The answer is that **Solid Shading Mode** doesn’t require your scene to be lit but **Render Mode** does.

By default, your scene has a single light in it. It looks like this. If you can’t find it, try zooming out. If you still can’t find it, select it in the **Outliner**.

This is like any other object.

A light is like any other object. It can be LMB clicked on (or selected in the **Outliner**). It can be grabbed (g) and moved around. Moving it around will change how the lighting looks.

But, to make this work better, you probably want to add more lights.
There are four types of Lights that you can Add:

1. A Point Lamp shines light in all directions. The light is local to the scene. This is usually the best type of light to start out with.

2. A Sun Lamp appears to come from a single direction and its rays are parallel. This acts as if the light is very far away.

3. A Spot Lamp is like a Point Lamp, but only shines in one particular direction.

4. An Area Lamp is light coming from a finite surface, like most lights really are.

Lighting – try this:
1. Add another Point Light
2. Position the Light (‘g’).
3. The Point Light has no obvious local coordinate system, so it just uses the global coordinate system.
4. As you move the Light, you will see the lighting of the scene change.
5. You will probably have to rotate the scene (MMB) to get the light position where you think it should be. Or, you can also toggle the Quad View mode (Control-Alt-q).
Lighting – Properties

This preview shows how the Light spreads out
What color to make the Light
How bright to make the Light shine.
Be sure this is clicked on in order to get this light to cast shadows

Lighting – Principles

In modeling, rendering, and animation, there are two major roles that lights play:
1. Key
2. Fill

Let's say we want to put a spotlight on the Monkey (and who doesn't?). We add a Spot Light. We position it over the Monkey and angle it down, like this. This is our "Key Light". It does what we most want to do.

We render and get this.

The Key Light is working really well, but the rest of the scene is too dark. We now need to use one or more Fill Lights.

Lighting – What does it Mean to Have a Colored Light?

E_R = L_R * M_R
E_G = L_G * M_G
E_B = L_B * M_B

Lighting – Principles

We add a Point Light and position it over the scene. Because we are in Render Mode, we can interactively see when we have it positioned well.

The scene looks much better. But, there are still two problems.
1. The rest of the scene is now bright enough that our "star" is no longer highlighted.
2. The Fill Light is casting another shadow which is distracting.

Computer Graphics
Lighting – Principles

So, we make two adjustments to our Fill Light:

- We lower its brightness.
- We un-click here to force it to not cast shadows.

Rendering

The view that is rendered is not the same orientation that you see on the screen. It is from the Camera position, which needs to be set separately.

The Camera

The camera is just like any other object in the scene.
1. It can be selected with a LMB click.
2. It has its own local coordinate system attached to it.

Note the local coordinate system for the camera:
- X is to the right of where the eye is looking
- Y is the up-vector
- Z is opposite of where the eye is looking

This is useful to know. For example, to dolly the camera in or out, select it and then move it in its local coordinates:

'g' → 'z' → 'z'
Aligning The Camera to Your Current Screen View

But, if you like your current screen view and want to move the camera there, just do this:

View → Align View → Align Active Camera to View

Setting a Background Color

Click on the World Properties button

Click on Color and dial in the background color

This only takes effect when rendering!

So, you must either be in Render Preview mode, or you must have done a Render

Screen Space Ambient Occlusion

Ambient Occlusion is a great computer graphics trick in which crevices are artificially darkened, heightening the sense of 3D-ness. You must be using the Eevee renderer to make this happen.
Bloom

Bloom is a rendering technique that emphasizes lighting “flares”. You must be using the Eevee renderer to make this happen.

Screen Space Reflections

Screen Space Reflections are a quick way to generate the appearance of internal reflections in your object. You must be using the Eevee renderer to make this happen.

Superimposed Wireframes

I don’t know why I find this so pleasing to look at. I just do.

Triggering a Rendering

What you see on your screen

What you see on the separate render window
What You See in the Separate Render Window

Saving a Rendered Image to a File

Different image file types
(PNG is good if you don't have any preference)
Saving a Rendered Image to a File

If this is called **Compression**, then smaller numbers will give you a larger image file with greater image quality.

If this is called **Quality**, then larger numbers will give you a larger image file with greater image quality.

![Image Format and Quality Settings]

**File Format** options include PNG, JPEG, and RGB.

**Color Depth** options are 8 or 16 bits.

**Compression** and **Quality** settings can be adjusted.

---

8. Particle Systems

**Importing an Image into PowerPoint**

Add this line to your HTML file:

```html
<img src="ball.png">
```
Particles don’t have to actually be particles.

Particles Bouncing Off Other Objects

Select the object to emit the particles from, then click this property button. Click the + sign to start a new particle system. Set the particles' initial velocities. See the next slide.
Particles – Expand Render and Viewport Display

- What material definition to color the particles with
- What particles to draw (this is fun to change!)
- If you like physics, change this to velocity
- Start with a small size, like this, but then experiment

Particles Bouncing Off Other Objects

1. Draw a plane to bounce particles from
2. Click the Physics Property Button
3. Click on the Collision option
4. Turn on the animation

Particles Bouncing Off Other Objects

- Physics properties of the surface being bounced off of
- Bouncing particles

Click here to start the particle animation
Hit the ESC key when you want it to stop
9. Physics Animation
Quick Physics Cheats

- Quick Fur
- Quick Explode
- Quick Smoke
- Quick Liquid

There are Eight Types of Physics Simulations

- Enable physics for:
  - Force Field
  - Collision
  - Cloth
  - Dynamic Point
  - Soft Body
  - Fluid
  - Rigid Body
  - Rigid Body Constraint

Let Blender Know You Want to do Rigid Body Physics

- Click on the Scene Properties Button
- Set Gravity (this value indicates gravity points downward and has a value of \(-9.81 \text{ meters/second}^2\))
- Be sure this is turned on

Rigid Body Collision Example

Set this up using what you know about modeling.
Slightly rotate the left-most domino to the right so that it will tip and start the sequence.

- dominos.blend
- dominos.mp4
Tell the Physics which Objects will be Involved

For each object that will be pulled by gravity (the dominos and the ball), select the object, click on the Physics Property Button, click on Rigid Body, and set the Type to Active.

Tell the Physics which Objects will be Involved

For each object that will not be pulled by gravity but will still be involved in the collisions (the floor), select it and set the Type to Passive.

Turn the Animation On

Hit the Escape key to stop the animation.

Setting Gravity

In order to do physics animations, Blender needs to have an idea of what Gravity is. The acceleration due to gravity near the surface of the earth is 9.81 meters/sec^2 (pointing down), which also equals 32.2 feet/sec^2.

You can set this by clicking on the Scene Properties Button and then scrolling down to the Gravity dialog area.

This is the default, but you can set Gravity to anything you want, including turning it off completely, or making it point upwards, or making it point sideways.
Gravity on Other Worlds

The acceleration due to gravity is not the same on all worlds. It depends on the mass of the body and its radius.

For fun, try setting gravity to what other bodies have in our solar system:

<table>
<thead>
<tr>
<th>Body</th>
<th>Gravity Acceleration (m/sec²)</th>
<th>g’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>3.70</td>
<td>0.38</td>
</tr>
<tr>
<td>Venus</td>
<td>8.87</td>
<td>0.90</td>
</tr>
<tr>
<td>Earth</td>
<td>9.81</td>
<td>1.00</td>
</tr>
<tr>
<td>Moon</td>
<td>1.62</td>
<td>0.17</td>
</tr>
<tr>
<td>Mars</td>
<td>3.71</td>
<td>0.38</td>
</tr>
<tr>
<td>Jupiter</td>
<td>24.79</td>
<td>2.53</td>
</tr>
<tr>
<td>Saturn</td>
<td>10.44</td>
<td>1.06</td>
</tr>
<tr>
<td>Uranus</td>
<td>8.69</td>
<td>0.89</td>
</tr>
<tr>
<td>Neptune</td>
<td>11.15</td>
<td>1.14</td>
</tr>
</tbody>
</table>

https://www.universetoday.com/35965/gravity-on-other-planets/

Gravity on Other Bodies

Or, invent your own planet! Pick a different “m/sec²”.

Another Cool Thing: Modeling Cloth

Scale the grid by 3 (s3) and move it in z (gz)

There is a difference in what different Mesh types will do. This needs to be a Grid – not a Plane!
Modeling Cloth -- Enable Collision with the Cube

You don't need to set any other parameters (unless you want to)

Select the cube.  Then go to the Physics Property Button.  Then click on Collision.

Modeling Cloth – Subdivide the Grid into More Pieces

If you select the grid and tab over to Edit Mode, you will see that it is already subdivided somewhat.  To act as a cloth, we'd like it subdivided some more.

Back in Object Mode, select the grid, then select Modifiers.  Then click Add Modifier and select Subdivision Surface.  Change the Viewport parameter from 1 to 2.  Click the Apply button.

Modeling Cloth – Tell the Grid that it is Really a Piece of Cloth

You can get away without changing any of these parameters, but, at some point, you will want to experiment with different values of Stiffness and Damping.

Select the grid.  Then go to the Physics Property Button.  Then click on Cloth.

Modeling Cloth – Run the Animation

Select the grid, RMB, then select Shade Smooth.  Then start the animation.
Baking the Cloth Animation

Why does the animation run so slowly? That is because it is computing the simulation while it is animating.

Instead, tell it to precompute the animation. You do this by selecting the Bake button (and waiting and waiting).

Now try animating.

Cloth Animation with Color, Texture, and Lighting

cloth.mp4

Cloth Animation: Pinning Vertices

One of the many fun parts of cloth animation is pinning some of the vertices. There are lots of reasons to do this, such as to pin the edge of a flag to its flagpole, or to pin a cloth to a clothesline.

To do this, Tab into Edit Mode, Shift-LMB the vertices to be pinned, and create a Vertex Group from them. (This was described in more detail in the Modeling section of these notes).

In the Cloth section of the grid’s Physics menu, select the name of the Vertex Group to be pinned.

When you re-animate, those vertices will be stationary.
Rendering an Animation

Render Animation kicks off the rendering of all your animation frames in order.

View Animation brings up a separate window and plays back your animation.

Hint: if this is just a test render, and you have lots of time-consuming visual effects going on, you might cut down the resolution and/or the number of rendered frames to speed things up.

Procedural Texturing

1. Leave Use Nodes turned on.
2. Select Principled BDSF (probably already selected)
3. Here, where you would normally select a color, click on this little circle
4. From that pop-up menu, select Voronoi Texture (or one of the others)
4. From that pop-up menu, select **Voronoi Texture** (or one of the others)

5. Change the **Scale** to change the size of the Voronoi cells

6. Try changing the **Randomness** as well!

7. As before, changing **Metallic** and **Roughness** affects the shininess.

---

**Image Texturing**

Start with a **UV Sphere** being shown in **Render Preview** mode

---

**Blender has these Built-in Procedural Textures**

---

**Image Texturing**

Says that you want to read a texture image from a file

Click here to open an image.
Image Texturing

**worldtex.bmp** is a good texture to try!

Let's Say That We Want to Render This Scene

- **Cube** and **Monkey** are opaque
- **Sphere** is both reflective and refractive
- **Plane** has a checkerboard texture on it
- **Scene** has lighting and shadows
- **Sphere** is both reflective and refractive
Making the Sphere Reflective and Refractive

Combine refraction and reflection effects together with the Mix Shader
How much to mix each shader
First shader is Glass to get the refraction
Transmission color
Index of Refraction
Second shader is Glossy to get the reflection
No inherent color in the reflection

Putting a Checkboard Pattern on the Plane

1. Leave Use Nodes turned on.
2. Select Principled BDSF (probably already selected)
3. Here, where you would normally select a color, click on this little circle
4. From that pop-up menu, select Checker Texture (or one of the others)
5. Here you can select the two colors making up the checkerboard
6. Change the scale to change the size of the checkerboard squares

Onscreen and Rendered Results with Eevee

Onscreen
Rendered

Onscreen and Rendered Results with Cycles

On-screen
Rendered
It starts at the eye:

The pixel is painted the color of the nearest object that is hit.

It's also straightforward to see if this point lies in a shadow:

Fire another ray towards each light source. If the ray hits anything, then the point does not receive that light.

It's also straightforward to handle reflection:

Fire another ray that represents the bounce from the reflection. Paint the pixel the color that this ray sees.
The Physics of Reflection

Law of Reflection:

\[ \theta_r = \theta_i \]

Angle of reflection = Angle of incidence

The Physics of Refraction

Snell’s Law of Refraction:

\[ \frac{\sin \theta_B}{\sin \theta_A} = \frac{\eta_A}{\eta_B} \]

<table>
<thead>
<tr>
<th>Material</th>
<th>Index of Refraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1.00000</td>
</tr>
<tr>
<td>Air</td>
<td>1.00029</td>
</tr>
<tr>
<td>Ice</td>
<td>1.309</td>
</tr>
<tr>
<td>Water</td>
<td>1.333</td>
</tr>
<tr>
<td>Plexiglass</td>
<td>1.49</td>
</tr>
<tr>
<td>Glass</td>
<td>1.60</td>
</tr>
<tr>
<td>Diamond</td>
<td>2.42</td>
</tr>
</tbody>
</table>

http://en.wikipedia.org/wiki/Refractive_index

What Actually is Ray-Tracing?

It’s also straightforward to handle refraction

Fire another ray that represents the bend from the refraction. Paint the pixel the color that this ray sees.

11. Vertex Sculpting
Vertex Sculpting

Vertex Sculpting is, well, sculpting vertices. But, in order to do this well, we need a lot of vertices. Start with a UV sphere mesh object.

Tab over to Edit Mode. RMB → Subdivide → Subdivide

When you get back to Object Mode, the sphere won't look any different than before because you just subdivided the polygons, not smoothed them. If you had wanted smoothing, you could have used the Subdivision Surface Modifier.

Now go to Sculpt Mode.

Lots of new options will appear at the top:

- Brush Radius (I like 25)
- Brush Strength (height)
- Add Material (+) or Subtract Material (-)
- Brush Characteristics
  - Stroking Characteristics
  - Surface Falloff from the Center of the Brush (I like Smoother)
  - Symmetry Control (I recommend you click all of these off for now.)

Sculpting usually looks better if you quick get over into Object Mode, RMB → Shade Smooth
Vertex Sculpting with Dynamic Topology (“Dyntopo”)

This cool – you are really going to like this!

- Set the Sculpt Mode to Draw
- Set Radius to 20
- Set Brush Strength to 1.0
- Add Material (+)
- Surface Falloff from the Center of the Brush to Smoother
- No Symmetry
- Click Dyntopo on (if you get a message, just click OK)

And, have at it!

How does Dyntopo Mode make such a smooth sculpt?
Let’s look at this in Sculpt Mode and then in Edit Mode:

That’s why it is called Dynamic Topology!

12. Vertex Painting
Vertex Sculpting is, well, sculpting vertices. But, in order to do this well, we need a lot of vertices.

Start with a UV sphere mesh object.

Tab over to **Edit Mode**.

RMB → Subdivide → Subdivide

When you get back to Object Mode, the sphere won’t look any different than before because you just subdivided the polygons, not smoothed them. If you had wanted smoothing, you could have used the **Subdivision Surface Modifier**.

Now go to **Vertex Paint Mode**.

Note: the brush size does not scale with zooming in or out. It stays the same size.

The “paintbrush” only drops “paint” when a vertex is inside the circle brush. This means that the paint does not smear along a nice line but looks splotchy like this.
How Do We Make it Less Splotchy?

Two approaches:
1. Make the object look smaller. That way more vertices will end up inside the brush circle.
2. Use Subdivide or Subdivision Surfaces to add more vertices.

The Effect of the Fac Parameter

Multiply
Fac = 0.00

Multiply
Fac = 0.50

Multiply
Fac = 1.00

Have a Nice Day!
13. Keyframe Animation

Keyframe animation is a technique that goes all the way back to the beginning of hand drawn animation (e.g., Walt Disney). Senior animators would specify key positions for the animated characters and then more junior animators would fill in the frames in between. This became known as keyframing and in-betweening.

Blender allows you to create the keyframes and get the computer to do the in-betweening. Here, we will keyframe-animate the monkey as she slaloms around a group of colored cubes:

Keyframe Example

Select the Animation workspace from the list at the top. This creates a screen layout that looks like this:

Camera View Window – what you will see if you Render
3D Viewport Window – what you are used to
Timeline Window – keeps track of what frame number we are on
Rendering
Compositing
Scripting
Slide the timeline indicator to what frame number you want to set, move the monkey where you want her, and RMB-select Insert Keyframe (or hit the 'i' key). From the pop-up menu, select LocRotScale, indicating that you want to record location, rotation, and scale factor.

Do it again: slide the timeline indicator to what frame number you want to set, move the monkey where you want her, and RMB-select Insert Keyframe (or hit the 'i' key). From the pop-up menu, select LocRotScale, indicating that you want to record location, rotation, and scale factor.

After a while, your timeline will look like this:

Then, click here and change the type of display to the Graph Editor:
Graph Editor

Your Graph Editor window should now look about like this.
Note that Blender has filled in the in-between values for you. (This is the “In-Betweening”.)

The Graph Editor Window

Click on the triangle. This gives you access to the curves. Clicking on the eye toggles whether or not you can see a curve. Clicking on the name of the curve makes that the current curve. You can then edit it.

The Graph Editor Window

Shortcuts when the cursor is in the Graph Window:

<table>
<thead>
<tr>
<th>Shortcut</th>
<th>What it does</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMB</td>
<td>Select a keyframe dot</td>
</tr>
<tr>
<td>Scroll wheel</td>
<td>Zoom in and out of the Graph</td>
</tr>
<tr>
<td>MMB</td>
<td>Pan the Graph</td>
</tr>
<tr>
<td>Shift-scroll wheel</td>
<td>Pan in Value (vertical)</td>
</tr>
<tr>
<td>Shift-MMB</td>
<td>Pan in Value (vertical) and Time (horizontal)</td>
</tr>
<tr>
<td>Control-MMB</td>
<td>Scale in Value (vertical) and Time (horizontal)</td>
</tr>
</tbody>
</table>
Hit the ‘n’ key. Like in the 3D View, a Number Panel pops up.

Click on the **Modifier** tab.
Then click on **Add Modifier**.

Select **Add Modifier**.
From the list of Modifiers, select **Noise**.

Use this menu to change the noise parameters **scale** and **strength**.
Notice what this does to the curve.
Now play the animation.

To avoid a collision, the money jumps up and the cube squishes.
Cameras and Lamps are just like any other object. As you have seen, they can be positioned. They can also be keyframe-animated. Like other objects, just select them and hit the ‘i’ key to insert a keyframe.

Rendering an Animation

This kicks off the rendering of all your animation frames in order.

Rendering an Animation to a File

Before kicking off the animation rendering, you need to specify the file name to put the animation into C:\tmp\mjb.avi and the type of file that it is to be.

Rendering an Animation to a File

Here are the animation file types that Blender supports.

<table>
<thead>
<tr>
<th>Movie File Type</th>
<th>File Size</th>
<th>Displayed?</th>
<th>Import into PowerPoint?</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVI JPEG</td>
<td>Didn’t work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVI Raw</td>
<td>148 MB</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: this scene is simple and compresses well. The mileage you get may vary.
Importing an Animation into YouTube

YouTube accepts videos in AVI and MPEG formats

Importing an Animation into PowerPoint

<table>
<thead>
<tr>
<th>Movie File Type</th>
<th>File Size</th>
<th>Displayed?</th>
<th>Import into PowerPoint?</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVI JPEG</td>
<td>Didn't work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVI Raw</td>
<td>148 MB</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Animation Tricks

1. In this example, we added the first keyframe, then the last keyframe, then three keyframes in the middle. Sometimes it is easiest to work that way. Other times it is easier to add them in sequential order.
2. Sometimes it is easier if you initially add a bunch of duplications of the object in various positions to get a feel for the motion, edit those positions as you see fit, and then use them as keyframe positions.
3. Extending from each keyframe dot is a line. That line can be twisted to change the slope of the curve at that keyframe. Select the dots at the end of that line and move them.
4. The Camera position and the Lamps can be animated too. For each, define an Empty object, force the Camera or Lamp to follow it (it’s one of the Constraints), then animate the Empty. Be sure to give the Empty a descriptive name – all Empties look alike.

John Lasseter’s Principles of Animation

1. **Squash and Stretch** – Defining the rigidity and mass of an object by distorting its shape during an action.
2. **Timing** – Spacing actions to define the weight and size of objects and the personality of characters.
3. **Anticipation** – The preparation for an action.
4. **Staging** – Presenting an idea so that it is unmistakably clear.
5. **Follow Through and Overlapping Action** – The termination of an action and establishing its relationship to the next action.
6. **Straight Ahead Action and Pose-To-Pose Action** – The two contrasting approaches to the creation of movement.
7. **Slow In and Out** – The spacing of the inbetween frames to achieve subtlety of timing and movement.
8. **Arcs** – The visual path of action for natural movement.
9. **Exaggeration** – Accentuating the essence of an idea via the design and the action.
10. **Secondary Action** – The action of an object resulting from another action,
11. **Appeal** – Creating a design or an action that the audience enjoys watching.

14. 3D Printing

The Process

"3D Printing" is defined by some sort of "additive" process. The current frenzy in 3D Printing consists mostly of systems that deposit layers of molten plastic:

The 3D Printing Geometry File

3D Printers are fed a file called an "STL File", which lists all the triangles in the object. Blender (as well as all CAD systems) can produce this type of file for you.

Object Rules for 3D Printing

1. The object must be a mesh and consist only of triangles.
2. Modifiers → Add Modifier → Triangulate

1. Alt-c to turn a Meta object or 3D Text into a mesh

solid
  facet normal 0.00 0.00 -1.00
  outer loop
  vertex -2.000000 -2.000000 0.250000
  vertex -1.980000 -1.980000 0.250000
  vertex -1.980000 -2.000000 0.250000
  endloop
  endfacet

  facet normal 0.00 0.00 -1.00
  outer loop
  vertex -2.000000 -2.000000 0.250000
  vertex -2.000000 -1.980000 0.250000
  vertex -1.980000 -1.980000 0.250000
  endloop
  endfacet

endsolid
Object Rules for 3D Printing

2. The object must be a legal solid. It must have a definite inside and a definite outside. It can’t have any missing face pieces.

The Simplified Euler’s Formula* for Legal Solids

*sometimes called the Euler-Poincaré formula

\[ F - E + V = 2 \]

For a cube, \(6 - 12 + 8 = 2\)

The full formula is:

\[ F - E + V - L = 2(B - G) \]

Watch Out for Overhangs!

Some 3D printers handle this by leaving unused material in place to support the overhangs.

Some 3D printers handle this by using software to add “support structures” to the overhangs.

Some 3D printers handle this better than others… 😊

http://twistedsifter.com/2013/08/when-3d-printing-goes-wrong/
Object Rules for 3D Printing

3. You can’t make an object by simply overlapping two objects in 3D. If you want both shapes together, do a Boolean union on them so that they become one complete object.

Overlapped in 3D

Boolean union

What Happens if You Do Overlap Objects?

Here’s what one of the 3D Printers in the OSU Library did:

Overlapped in 3D

Boolean union

Not bad – it could have been lots worse …

Object Rules for 3D Printing

4. Each edge in the mesh must bound 2 and only 2 triangles (this is known as the Vertex-to-Vertex Rule)

Installing the 3D Printing Add-on

Select Edit → Preferences
Select Add-ons → Mesh: 3D Print Toolbox

Installing the 3D Printing Add-on

Hit the 'n' key to see the sidebar menu. The 3D Print Toolbox will be a tab like this.

The 3D Printing Toolbox Add-on

Selecting your object and then clicking on Check All will give you this nice list of problems Blender thinks you will have if you try to 3D Print this object.

Selecting Clean Up will try to fix the problems.

Tab over to Edit Mode. Click in an empty area to unselect everything. Then click in all the places that show problems. Blender will light up the object in the places that provoked that problem, giving you a chance to fix them.
Output for 3D Printing

To export an STL file for 3D Printing:
1. Click here and select a folder for the file
2. Click here to write the file

.stl is the most common 3D printing file format

“STL” stands for Stereolithography.
The word “stereolithography” comes from the Greek words for “3D” and “writing”.

Want to see 3D Printing in Action?
Oregon State University’s library has 3D Printers for use by OSU students.
To see them via webcam, go to: http://webcam.oregonstate.edu/3dprinter
Click here to see the live, streaming view.

15. References

Blender References

http://cs.oregonstate.edu/~mjb/blender
http://blender.org
http://www.blender.org/education-help/
http://www.blenderguru.com/


Camp Blender

http://cs.oregonstate.edu/~mjb/blender

Mike Bailey
mjb@cs.oregonstate.edu

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.