

Blender

Instructor: Aaron F. Ross

Blender is an all-purpose 3D graphics package that excels in many production contexts. It can be applied to any graphics discipline, including but not limited to animation, visual effects, motion graphics, games, design visualization, and simulations. This course covers the basic techniques of modeling, materials, animation, lighting, and rendering. Learn the capabilities and best practices of Blender, efficient workflows, and choosing appropriate tools for desired results.

Topics covered include:

- General concepts of 3D production
- Project setup and asset management
- User interface
- Object creation and transforms
- Add-on extensions
- Parametric modeling with Modifiers
- Polygon modeling
- Subdivision surface modeling
- Sculpting
- Spline modeling
- Text and graphics
- Materials and mapping
- Physically-based rendering
- UV projection and layout
- Practical, studio, and environment lighting
- Camera operation
- Creating and editing animation keyframes
- Fine-tuning animation with the Graph Editor
- Coordinate systems and object origins
- Scene management with the Outliner
- Hierarchies and Constraints
- Production rendering and basic compositing
- Rendering an animation sequence

1. Introductions
 - a. Instructor background and experience
 - b. Learner backgrounds, career / production goals, and desired learning outcomes
2. Presentation: 3D graphic production concepts
 - a. Modeling: construction of objects
 - i. Form and structure
 - ii. Vector-based
 - iii. UV coordinates
 - b. Materials
 - i. Superficial surface properties, e.g. color, roughness, transparency
 - ii. Maps: vary material property across a surface
 - c. Lighting
 - i. Photometric lighting: real-world light intensities
 - ii. Global illumination: light interaction with multiple surfaces
 - iii. Lighting paradigms
 - (1) Practical / available / diegetic
 - (2) Studio / stage / non-diegetic
 - (3) Environment / ambient
 - d. Layout and camera
 - i. Merge and place assets in a primary scene
 - ii. Placeholders may stand in while assets are being made
 - iii. Environment construction determined by camera angles
 - iv. Trickery such as forced perspective and matte paintings

- e. Animation
 - i. Rigging: setup of animation controls
 - ii. Keyframing: automatic transitions between manual poses
 - iii. Motion capture / performance capture
 - iv. Dynamics: physical simulations
 - v. Visual effects: non-character animation
- f. Rendering
 - i. Project 3D scene to 2D image
 - ii. Real-time: viewports, games, simulations
 - iii. Non-real-time (offline): motion pictures, animation
- 3. Asset management
 - a. Asset types and folders
 - b. Embed dependent assets in the scene file: **Pack Resources**
- 4. Interface basics
 - a. **Edit > Preferences > Interface > Resolution Scale**
 - b. **Edit > Preferences > Save & Load > Save Versions = 0**
Disable automatic saving `.blend1` files
 - c. **Workspace tabs**
 - d. Menus
 - e. **Areas**
 - i. **Properties**
 - ii. **Outliner**
- 5. Viewports
 - a. Navigation
 - i. **Orbit: middle mouse drag**

- ii. **Pan** (truck/pedestal): **SHIFT + middle mouse drag**
- iii. **Zoom / Dolly**: **CTRL + SHIFT + middle mouse drag**
- iv. **Edit > Preferences > Navigation**
 - (1) **Orbit & Pan > Orbit Around Selection**
 - (2) **Zoom > Zoom to Mouse Position**
- b. **Maximize View**: **CTRL + SPACEBAR**
- c. **Toolbar**: selection and transform tools
Shortcut: **T**
- d. **Sidebar**
Shortcut: **N**
- e. Orthographic viewports and **Quad View** (shortcut: **CTRL + ALT + Q**)
- f. **Gizmos**
 - i. Disable distracting heads up tools: **Navigate**
- g. **Overlays**
- h. **Shading** modes
 - i. **Wireframe**
Shortcut: **SHIFT + Z**
 - ii. **Solid** aka shaded
 - (1) Renderer: **Workbench**
 - iii. **Material Preview**
 - (1) Renderer: **EEVEE**
 - iv. **Rendered**
 - (1) Production renderer: **Properties > Render tab > Render Engine**
 - (2) Default is the EEVEE real-time renderer
- 6. **Units and Grid**
 - a. **Properties > Scene tab > Units**

- i. **Unit System**
 - ii. **Unit Scale**
 - b. Perspective grid spacing: **Viewport Overlays > Scale**
- 7. **Snapping**
 - a. **Snap Target**
 - i. **Increment vs. Grid**
 - b. **Affect: Move, Rotate, Scale**
- 8. **Blender Add-on extensions**
 - a. **Edit > Preferences > Add-ons**
 - i. These are all free
 - ii. Also available at extensions.blender.org
 - b. blender-addons.org
 - c. gumroad.com
 - d. blendermarket.com
 - e. github.com
 - i. **WonderMesh** parametric primitives
Non-destructive, reversible mesh property
https://github.com/WiresoulStudio/Wonder_Mesh
- 9. **Parametric modeling with Modifiers**
 - a. Non-destructive, reversible
 - b. Modifiers are calculated from top to bottom
 - c. **Deformer Origin**
 - i. Default center of deformer operation is the Object Origin aka object pivot
 - ii. **Add > Empty** aka dummy, locator, point helper
 - d. Bake a single Modifier: **individual Modifier toolbar > pulldown list > Apply**

- e. Bake all: **Viewport menu > Object > Apply > Visual Geometry to Mesh**
Shortcut: **CTRL + A**

10. Polygon mesh basics

- a. **Edit Mode**
Shortcut: **TAB**
- b. Component types: **Vertex, Edge, Face**
Shortcuts: **1, 2, 3** on alphabetic keypad
- c. Level of detail vs. fidelity
- d. Smoothing: shading effect of soft edges, gradient applied across faces
 - i. **Object > Shade Smooth** or **Shade Flat**
 - ii. **Object > Shade Auto Smooth**
 - (1) Same as **Add Modifier > Normal > Smooth By Angle**
 - iii. **Edge > Mark Sharp** or **Clear Sharp**
 - (1) Confusingly does the same thing, and overrides any existing smoothing

11. Mesh Edit Mode

- a. Default Blender scheme of colors and highlighting is problematic
- b. Overlays
 - i. Disable **Faces** and **Center**
- c. Viewport Shading (Workbench)
 - i. **Wire Color = Object** or **Random**
 - (1) **Properties > Object > Viewport Display > Color**
 - ii. **Color = Object** or **Single**
 - (1) **Single** reveals an unlabeled color swatch directly below. It looks like a gray blank nothingness, but it's actually a color swatch.
- d. **Extrude**
 - i. **Extrude Along Normals**

ii. **Inset**

Shortcut: move cursor OFF the selection, then press I.
Move mouse to adjust, then click to execute.

e. **Select > More / Less**

f. **Dissolve**

Shortcut: **CTRL + DELETE**

g. **Bevel Modifier**

12. Additional mesh modeling tools

a. **Loop Cut**

- i. Click an edge to bisect a face loop
- ii. Adjust Last Operation pop-up > **Loop Cut and Slide**
- iii. Slide Offset: **Factor** slider
- iv. **Number of Cuts**

b. Disable Adjust Last Operation pop-up during low-level modeling

- i. **View > Adjust Last Operation**
- ii. Shortcut to display floating pop-up only when needed: **F9**

c. **Proportional Editing** aka “soft selection”

Shortcut: **O**

- i. **Size** = radius
Shortcut: **mouse wheel**
Only works while a transformation is already in progress!
- ii. But before you do that ... choose **Falloff** type
Pie menu shortcut: **SHIFT + O**

d. Symmetry

i. **Tool Options > Mirror > X**

(1) Destructive, does not work correctly with Proportional Editing

ii. **Mirror Modifier**

(1) For sanity, first delete one side of the model (polygons in negative X)

(2) Clean up display, allow selection of mirrored components: **Show On Cage**

(3) Protect the seam from gaps and overlaps: **Clipping**

13. Subdivision Surface modeling

- a. Polygon count: **Gizmos > Statistics**
- b. Iterations / level of detail
 - i. **Levels Viewport vs. Render**
 - ii. Levels Viewport shortcut: **CTRL + numeral** on alphabetic keypad
Subdivision Modifier will be added if it doesn't already exist
Values above 3 are probably excessive and risk overloading CPU and RAM
 - iii. Show all edges: disable **Optimal Display**
- c. Topology
 - i. Try to use only *quadrilateral* polygons
 - ii. Try to avoid *poles* where more than four edges meet at a single vertex
 - iii. Conform *edge flow* to the contours of the shape
- d. Increase curvature without increasing poly count: **Edge Crease**
 - i. Shortcut: **SHIFT + E**
 - ii. **Sidebar > Item tab > Mean Crease** (average value of selected edges)
 - iii. Display: **Overlays > Creases**
- e. Bake / collapse subdivisions
 - i. Destructive / non-reversible
 - ii. **Save As** to a new filename before performing a destructive operation
E.g. `my_fabulous_model_baked.blend`
 - iii. **Object > Apply > Visual Geometry to Mesh**
 - iv. **Save** file again

14. Sculpt Mode

- a. **Brush Asset toolbar: Draw, Grab, Inflate, etc.**
 - i. **Display Settings tab > Names**
 - ii. Tiny scrollbar on the Brush Asset toolbar
Shortcut: **mouse wheel**
- b. **Properties > Tool tab > Brush Settings**
 - i. Brush Settings also found in **Sidebar (N) > Tool tab**
 - ii. **Radius Unit = Scene**
 - iii. **Radius** shortcut: press **F**, move mouse without dragging, click to exit or **[]** (square brackets)
 - iv. **Strength** shortcut: press **SHIFT + F**, move mouse without dragging, click to exit
 - v. **Smooth** shortcut: **SHIFT + drag**
 - vi. **Direction (Add / Subtract)** shortcut: **CTRL + drag**

15. Spline Curve modeling

- a. **Edit > Preferences > Get Extensions > search > Extra Curve Objects**
- b. Poly, Bezier, and NURBS
 - i. Poly curves are always linear segments
 - ii. **Edit Mode > Curve > Set Spline Type**
- c. Control vertices
 - i. **Edit Mode > Control Points > Set Handle Type**
Shortcut: **V**
 - (1) **Automatic**: smooth curve through point
 - (2) **Vector**: linear segment
 - (3) **Aligned**: linked handles
 - (4) **Free**: unlinked handles

- d. **Curve Pen tool**
 - i. **Create Point**: click in viewport
 - ii. **Extrude Point** (extend existing curve): click an endpoint, then click in view
 - iii. **Close Spline (Cyclic)**: click first endpoint, then click second endpoint
 - iv. **Insert Point**: **CTRL + click** on curve
 - v. **Delete Point**: **CTRL + click** on point
 - vi. **Lock Handle Angle** (adjust length only): click handle, then **left ALT + drag**
 - vii. **Link Handles**: click handle, then **right CTRL + drag**
- e. **Properties > Data tab > Geometry**
 - i. **Extrude and Offset**
 - ii. Polygon strands: **Bevel = Round**
 - iii. Thickness: **Depth**
 - iv. Level of detail around circumference of implicit circular path: **Resolution**
Number of sub-segments in each 90 degree arc of the implicit circle
- f. **Properties > Data tab > Shape**
 - i. **2D vs. 3D**
 - ii. Level of detail along length of spline: **Resolution Preview U**
Number of interpolated sub-segments within each segment
- g. Sweep along path: **Geometry > Bevel = Object**
 - i. Use eyedropper to select profile curve in viewport
 - ii. LOD controlled separately for path and profile curve: **Resolution Preview U**
 - iii. To interpolate sub-segments within a linear segment, it must be a Bezier spline with Free handles
 - (1) If necessary, add more CVs: **Segments > Subdivide**
 - iv. Clean up geometry
 - (1) Position profile curve relative to its Origin

- (a) **Edit Mode > Select > All**, then Move/Translate
- (b) or **Object Mode > Sidebar (N) > Tool tab > Options > Transform > Affect Only > Origins**

(2) Offset path curve to restore to the original shape

- (a) **Object Mode > Properties > Data > Geometry > Offset**
- (b) or **Edit Mode > Select > All**, then **Curve > Transform > Push/Pull**

16. Text

a. Viewport Edit Mode

- i. Text characters are edited directly in viewport
- ii. Typeface variant (Bold, Italic, etc.): viewport **Text** menu

b. Properties > Data tab (Text)

- i. Browse for font: **Font rollout > Regular > folder icon**
- ii. Classic chamfered 3D text:
 - (1) **Paragraph > Alignment > Horizontal = Center**
 - (2) **Geometry > Extrude = 0.1 m**
 - (3) **Geometry > Bevel = Profile**
 - (4) **Geometry > Bevel > Depth = 0.01 m**
 - (5) **Geometry > Bevel > Resolution = 0**
 - (6) **Add Modifier > Normals > Smooth by Angle**

17. Viewport Shading

- a. Solid/Wireframe: **Workbench**
- b. Rendered: **Cycles**
- c. Material Preview: **EEVEE**
 - i. **Scene Lights and Scene World**

18. Shader Editor

- a. Main window > **Shading tab**
 - i. Change **World** environment
 - (1) **Add > Texture > Sky Texture**
 - (2) Connect **Color** to Background node
 - (3) Background **Strength = 0.15**
- b. Object color vs. material
 - i. **Properties > Object > Viewport Display > Color**
- c. Create material
- d. Building shader trees
 - i. **Shader Editor Menu > Add nodes**
 - ii. **Right-click > Add**
 - iii. Drag out from an input port
- e. Properties of selected node: Sidebar
Shortcut: **N**

19. Physically-based materials

- a. **Principled BSDF** shader
 - i. Physically-based rendering “principles”
Bidirectional Scattering Distribution Function
 - ii. **Base Color**
 - iii. **Roughness**
 - iv. **Metallic**
 - v. **IOR** (Index of Refraction)
- b. Layers of the Principled BSDF shader are available as separate nodes
 - i. e.g. Metallic BSDF, Diffuse BSDF, etc.

- ii. Optimize rendering by using only the needed properties
- iii. Build your own custom shader

20. Mapping basics

- a. Mappable properties: color, relief, floating point
- b. File maps
 - i. 2D images stored in linked external files
 - ii. **Image Texture** nodes
 - iii. Asset management

21. UV Projection

- a. UV coordinates in the shading network
 - i. **Texture Coordinates** node UV output → **Mapping** node Vector input → Mapping node Vector output → **Image Texture** Vector input
- b. UV coordinates stored in object vertices
- c. Project UVs from Camera
 - i. Create **Image Texture** node and connect to **Base Color** or **Emission Color**
 - (1) The other, unconnected property should be set to black
 - ii. Click **New**, enter a **Name**, set **Generated Type** to **Color Grid**
 - iii. **Viewport menu > Add > Camera**
 - (1) Rename: **Camera UV Projection** or similar
 - (2) Position and rotate in preparation for projection
 - (3) **Properties > Data (Camera) > Type = Orthographic**
 - iv. **Add Modifier > Edit > UV Project**
 - (1) Assign Camera: click **Object** eyedropper, choose Camera in scene
 - (2) Adjust Modifier **Scale**
 - (3) Position Camera

22. Procedural maps

- a. 2D or 3D patterns generated within the application
- b. Don't require UV coordinates
- c. **Noise Texture** node

23. UV Layout

- a. Boundaries of UV space
- b. Tiling
- c. Unwrapping

24. Rendering in Cycles

- a. Enable GPU in **Edit > Preferences > System > Cycles Render Devices**
 - i. Choose **Optix** if possible
- b. **Properties > Scene > Scene**
 - i. **Render Engine = Cycles**
 - ii. **Device = GPU Compute**
- c. **Sampling > Viewport > Max Samples = 128**
- d. **Sampling > Render > Max Samples = 512**
- e. **Sampling > Denoise > Use GPU = enabled**
or **Denoiser = Optix**
- f. **Viewport > Shading Mode = Rendered**
 - i. GPU needs to precompile, be prepared for a long wait the first time
 - ii. **Pause** button at upper right
- g. **Properties > Scene > Color Management**
 - i. **Exposure**
 - ii. **View Transform = Standard**
 - (1) Linear response, no contrast curve applied

h. **Properties > Output**

- i. **Format > Resolution = 1280 x 720**
- ii. **Frame Range > End = 1**
- iii. To automatically save the file, we need to render an animation sequence of only one frame

iv. **Output**

- (1) Browse to **/renderoutput** folder and enter a filename
Add a trailing underscore to separate filename from frame number
- (2) **Color = RGB**
 - (a) **RGBA** would create a PNG with embedded transparency
Background would be knocked out and could never be recovered
- (3) **Compression = 0**
- (4) **Image Sequence > Overwrite = disabled**

i. **Main Menu > Render > Render Animation**

- i. **Render > Render Image (F12)** would not save any file
We would need to manually save each rendered image

25. Camera basics

a. Toggle view between **Camera** and **User Perspective**

- i. **Navigation** overlay > **Camera** icon
Shortcut: **numpad 0**

b. **Lock Camera to View**

- i. First person camera navigation within viewport
- ii. Also known as **Enable view navigation within the camera view**
- iii. **Camera view > Navigation** overlay > **Lock** icon
- iv. **Sidebar (N) > View tab > View Lock > Camera to View**
 - (1) Disabled: 2D zoom
 - (2) Enabled: 3D dolly

- c. Field of view: **Focal Length**
 - i. Sidebar property is only for User Perspective views
 - ii. Camera object > **Properties** > **Data tab (Camera)** > **Lens** > **Focal Length**
- d. Film gate mask: **Properties** > **Data tab (Camera)** > **Viewport Display** > **Passepartout** (type of picture frame, image inside cutout matte)
- e. Aspect ratio: **Properties** > **Output** > **Format** > **Resolution**

26. Lighting basics

- a. **Point, Sun, Spot, Area**
- b. Size matters! Softness of light and shadow is controlled by size of light source
- c. **Point**
 - i. **Power**
 - ii. Size of light sphere: **Radius**
- d. **Use Nodes** = enabled
- e. Assign **Color** to **Blackbody**
 - i. 4800 degrees Kelvin
 - ii. Doesn't currently work in EEVEE

27. Practical and available lighting

- a. **Area**
 - i. **Shape**
 - ii. **Beam Shape** > **Spread**
 - (1) Focused / collimated beam
 - iii. Office ceiling light fixtures
 - (1) **Shape = Rectangle**
 - (2) **Size X = 0.54 m**
 - (3) **Size Y = 1.15 m**

(4) **Position XYZ** = -2.575 1.05 3.98

(5) **Power** = 60 W

iv. Instancing: multiple objects share the same data-block

(1) Change one object, all instances update

(2) One object in multiple places at the same time

(3) **Viewport menu > Object > Duplicate Linked**

b. Light shapes are not visible to the camera

i. Perplexing limitation

ii. Sub-optimal workaround: mesh object with shader Emission

(1) Very inefficient and slow to render

(2) No Spread property

iii. Better workaround: combine Area light with self-illuminated mesh object

(1) **Light Path** node > **Is Camera Ray** output → **Mix Shader** node **Fac** input

(2) **Principled BSDF** node → **Mix Shader** node top Shader input

(3) **Emission Shader** node → **Mix Shader** node bottom Shader input

c. **Sun**

i. Also known as *distant*, *directional*, or *direct* light

ii. Better control with standard pan / tilt rotations

(1) **Sidebar (N) > Transform tab > Rotation = YXZ Euler**

(2) **Rotation X = locked**

(3) **Transform Orientation = Gimbal**

(4) **Z** is pan, **Y** is tilt

iii. Size of sun disc: **Angle**

28. Studio lighting

a. **Spot**

- i. Cone Angle: **Spot Size**
- ii. Size of light disc: **Radius**
- iii. Center falloff: **Blend**

b. Fill: Point or Area lights

- i. **Properties > Data (Light) > Cast Shadow** = disabled
- ii. **Properties > Object > Shading > Shadow Linking > New**
 - (1) Drag object(s) from Outliner into the new Collection
 - (2) If checkbox is off, then the listed object will not cast a shadow from the selected light

29. Environment lighting

- a. **World Output** node **Surface** input
- b. Flat color: **Background** node
- c. Color temperature: **Blackbody** node
- d. **Properties > Render > Color Management > White Balance**
- e. HDRI: **Environment Texture** node
- f. **Sky Texture** node

30. Animation basics

- a. **Properties > Output > Format > Frame rate**
- b. **Frame Range** is the playback range
Independent of **Timeline** range
- c. **Timeline > Playback pulldown > Sync**

31. Insert Keyframe

- a. For clarity, display transforms first: **Sidebar (N) > Item tab**

- b. Choose which channels / tracks to animate
 - i. By default, all transform channels will be keyed
 - ii. **Timeline > Keying pulldown > Active Keying Set**
 - (1) Only works with interactive manipulation, not numeric entry
- c. **Object > Animation > Insert Keyframe**
Shortcut: **I**
 - i. Keyframes are inserted at current time, for current Active Keying Set, regardless of whether or not any channel value has updated
 - ii. Even if only one axis is updated, all three axes are keyed
 - iii. Insert Keyframe Menu shortcut: **K**
- d. If a channel is updated without inserting a key, then when the current time changes, the existing channel values are loaded
 - i. If you forget to insert a key and then scrub timeline, you lose those changes
 - ii. Undo won't save you
- e. Channels can be manually keyed, ignoring Active Keying Set
 - i. Numeric entry field of any transform or property
 - (1) Green: at least one keyframe, at some time other than current
 - (2) Orange: keyframe at the current time
 - ii. Key all axes: **right-click > Insert Keyframes**
 - iii. Key individual axes: **right-click > Insert Single Keyframe**
 - iv. Key object properties: click dot to right of field, or hover mouse and press **I**

32. Timeline

- a. Transport shortcuts
 - i. Play/Pause: **SPACE**
 - ii. Jump to First Frame: **SHIFT + LEFTARROW**
 - iii. Jump to Last Frame: **SHIFT + RIGHTARROW**

- iv. Jump to Previous/Next Keyframe: **DOWNARROW** / **UPARROW**
- b. Newly created keys are selected automatically, highlighted in orange
- c. Drag to move keys
- d. **Summary** track displays all keys for selected objects
 - i. Open up Summary to access individual channels
- e. A bar between keyframes indicates a static value in that time range

33. Auto Keyframe

- a. Enable with dot icon to the left of transport controls
- b. Interactive manipulation
 - i. Creates key(s) at current time
 - ii. If no Active Keying Set is enabled, only the updated axes are keyed
 - iii. If an Active Keying Set is enabled, all axes are keyed
- c. Numeric entry
 - i. Only the updated axes are keyed
 - ii. If no keys exist on a channel, numeric entry does not create keys
 - iii. If keys do exist on a channel, numeric entry creates keys

34. Dope Sheet

- a. Very similar to Timeline
- b. **Filters**
Buttons on Dope Sheet header
 - i. Only Show Selected
- c. **Channels**
 - i. Not all rows are actual channels, e.g. top-level **Object** rows and **Action** rows
 - ii. **Action** rows are containers for Object properties, e.g. Transforms
 - iii. Individual transform axis rows are actual channels that can hold keyframes

- (1) Object Transform rows are containers for individual transform channels
- (2) If an Object Transform row is collapsed, then Channel menu commands operate on all subordinate (hidden) channels

iv. Delete static channels: **Clean Channels**

35. Graph Editor

- a. Function curves
 - i. Transform or property value is the vertical axis
 - ii. Rate of change indicated by slope
- b. Selected keyframe values: **Sidebar (N) > F-Curve tab**
- c. Shortcuts
 - i. Pan: **middle mouse drag**
 - ii. Zoom: **CTRL + middle mouse drag**
 - iii. **Constrain to Time** (preserve value): start moving a key or handle, then press **X**
 - iv. **Constrain to Value** (preserve time): start moving a key or handle, then press **Y**
- d. **Interpolation modes**
 - i. **Linear**
 - ii. **Constant** also known as *step* or *hold* keys
 - iii. **Bezier Handle Type**
 - (1) **Automatic**
 - (2) **Automatic Clamped**: prevent overshooting
 - (3) **Aligned**: lock angles (move together)
 - (4) **Free**: unlock angles (move separately)
 - (5) **Vector**: linear (handles point to neighboring keyframes)
 - iv. No way to lock incoming and outgoing handle lengths together

- (1) Select a single keyframe
- (2) **Graph Editor menu > Key > Snap > Equalize Handles**
- (3) Scale the key

36. Outliner

- a. Default mode: **View Layer**
 - i. Display layers and scene hierarchy combined in one window; unorthodox
 - ii. On rare occasions you may need to use **Scenes** or **Blender File** mode
- b. **Filters > Selectable**
- c. **Collections**
 - i. All objects must be members of at least one Collection
 - ii. If an object is Removed or Unlinked from all Collections, it is “orphan data” with “zero users” and gets automatically deleted when the scene is saved
 - iii. Objects can be members of more than one Collection at a time
 - iv. Collection membership is not inherited from parent
 - v. **Right-click > Select Hierarchy**
 - vi. Drag and drop
 - vii. **Move to Collection**
 - (1) Shortcut: **M**
 - viii. **Link to Collection** (instance object in multiple Collections)
Shortcut: **SHIFT + M**
 - ix. **Remove from Collection**
Shortcut: **CTRL + ALT + G**

37. Coordinate systems

- a. **Transformation Orientation** pulldown
 - i. Temporary frame of reference for transforms
 - ii. Not a property of the object, but the behavior of the Gizmo

- b. **Global:** relative to world/scene
- c. **Local:** relative to object **Origin**
- d. **View:** screen space
- e. **Parent:** relative to object parent
 - i. All transforms are *actually* calculated relative to the object parent
 - ii. Parent orientation sets the temporary frame of reference to the *true* coordinate space of object transforms
 - iii. If the object has no parent, then the global world/scene is the parent
- f. **Gimbal:** low-level visualization for rotations
 - i. Gizmo displays the interaction of rotation axes relative to one another
 - ii. Avoids problems such as rotations getting stuck or animating out of control
- g. **Normal:** relative to average orientation of selected faces
- h. **Custom**
 - i. Select an object or component
 - ii. Transformation Orientation pulldown > click **plus sign** icon

38. Transform Pivot Point

- a. Determines the temporary location of the Object Gizmo
- b. Temporary center for rotation and scale operations
- c. Rotate and scale around average position of object Origins: **Median Point**
- d. Rotate and scale each object separately: **Individual Origins**

39. Origins

- a. Also known as *pivot point* or *anchor point* in other programs, but in Blender the Pivot Point is the location of the Object Gizmo
- b. Origin is the center of object transforms; values displayed are those of the selected object's Origin
- c. Origin position and orientation are critical for animated rotations

- d. Must be finalized before creating keyframes
- e. **Sidebar (N) > Tool tab > Options > Transform > Affect Only > Origins**

40. Hierarchies

- a. Chain of linked objects; articulated structure such as skeleton
- b. Children inherit transforms from their parents
- c. An object may have many children, but only one parent
- d. Any object can be linked: geometry, lights, cameras, etc.
- e. Scaling in hierarchies can cause problems. Keep all object Scale values at 1.0
- f. **Object > Apply > Scale**
Shortcut: **CTRL + A**
- g. **Empty** object: a visible but non-rendering transform node for building hierarchies and rigs
 - i. Also known in other programs as *dummy, locator, helper, point*

41. Parenting / linking

- a. Blender is unconventional and problematic without specific intervention
 - i. In reality, transforms are calculated relative to object parent
 - ii. Problem: Blender obscures this by displaying values with an offset
 - iii. Child object transforms are displayed in Global coordinates, but this is not how child transforms work!
- b. To make Blender display child transforms correctly:
 - i. Select desired child(ren), **SHIFT**+select desired parent (makes it Active)
 - ii. **Object > Parent > Make Parent without Inverse (Keep Transform)**
 - iii. Shortcut: **CTRL + P**
Then in popup menu: **Object (Keep Transform Without Inverse)**
- c. To unparent (break link):
 - i. Select child

- ii. **Object > Parent > Clear and Keep Transformation**
- iii. Shortcut: **ALT + P**
Then in popup menu: **Clear and Keep Transformation**

42. Constraints

- a. **Properties > Constraints tab**
- b. A constraint applied to an object (“owner”) will override its transforms
 - i. Combine effects using Empty objects / Parents and/or Constraints
- c. A Constraint also requires a target
- d. “Look at” constraint: **Track To**

43. Drivers

- a. Connect transforms and/or properties to one another
 - i. Optionally use scripted math expressions
- b. Simple workflow
 - i. Right-click a property or transform, choose **Copy As New Driver**
 - ii. Right-click some other property or transform, choose **Paste Driver**
- c. Wheel on the ground: $Z \text{ position} = \text{radius}$
- d. Wheel turning: $Z \text{ rotation} = -Y \text{ position} / \text{radius}$

44. Geometry Nodes

- a. Start with a mesh object
- b. **Geometry Nodes tab > Geometry Node Editor > click New**
 - i. Geometry Nodes Modifier added
- c. **Pin** the Editor to keep graph visible regardless of current object selection
- d. Drag objects from Outliner into Editor
- e. **Add nodes shortcut: SHIFT + A**
- f. I/O ports with long strips instead of dots accept multiple inputs