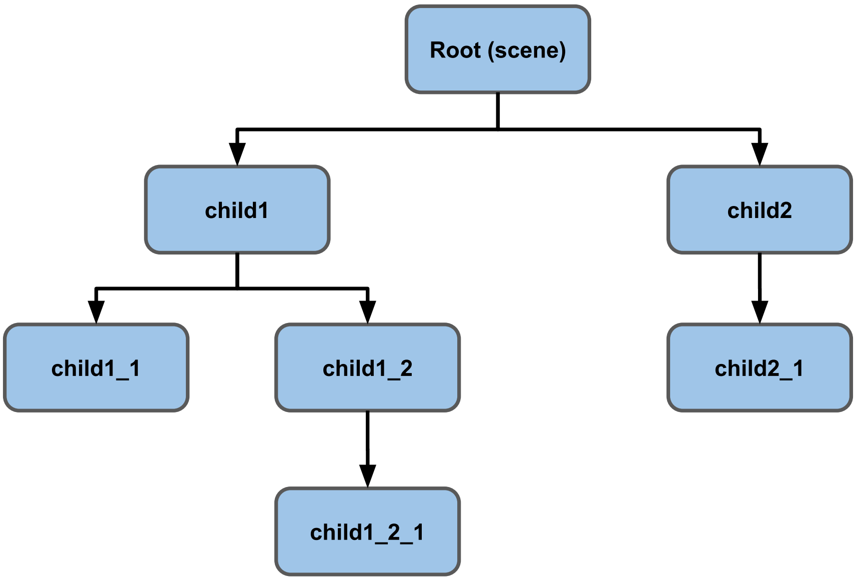
Three.js Scene Graph

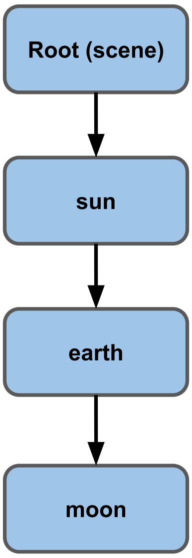
This article is part of a series of articles about three.js. The first article is three.js fundamentals. If you haven't read that yet you might want to consider starting there.

Three.js's core is arguably its scene graph. A scene graph in a 3D engine is a hierarchy of nodes in a graph where each node represents a local space.

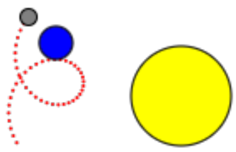


That's kind of abstract so let's try to give some examples.

One example might be solar system, sun, earth, moon.



The Earth orbits the Sun. The Moon orbits the Earth. The Moon moves in a circle around the Earth. From the Moon's point of view it's rotating in the "local space" of the Earth. Even though its motion relative to the Sun is some crazy spirograph like curve from the Moon's point of view it just has to concern itself with rotating around the Earth's local space.



To think of it another way, you living on the Earth do not have to think about the Earth's rotation on its axis nor its rotation around the Sun. You just walk or drive or swim or run as though the Earth is not moving or rotating at all. You walk, drive, swim, run, and live in the Earth's "local space" even though relative to the sun you are spinning around the earth at around 1000 miles per hour and around the sun at around 67,000 miles per hour. Your position in the solar system is similar to that of the moon above but you don't have to concern yourself. You just worry about your position relative to the earth in its "local space".

Let's take it one step at a time. Imagine we want to make a diagram of the sun, earth, and moon. We'll start with the sun by just making a sphere and putting it at the origin. Note: We're using sun, earth, moon as a demonstration of how to use a scene graph. Of course the real sun, earth, and moon use physics but for our purposes we'll fake it with a scene graph.

```
// an array of objects whose rotation to update
const objects = [];

// use just one sphere for everything
const radius = 1;
const widthSegments = 6;
const heightSegments = 6;
const sphereGeometry = new THREE.SphereBufferGeometry(
    radius, widthSegments, heightSegments);

const sunMaterial = new THREE.MeshPhongMaterial({emissive: 0xFFFF00});
const sunMesh = new THREE.Mesh(sphereGeometry, sunMaterial);
sunMesh.scale.set(5, 5, 5);  // make the sun large
scene.add(sunMesh);
objects.push(sunMesh);
```

We're using a really low-polygon sphere. Only 6 subdivisions around its equator. This is so it's easy to see the rotation.

We're going to reuse the same sphere for everything so we'll set a scale for the sun mesh of 5x.

We also set the phong material's `emissive` property to yellow. A phong material's emissive property is basically the color that will be drawn with no light hitting the surface. Light is added to that color.

Let's also put a single point light in the center of the scene. We'll go into more details about point lights later but for now the simple version is a point light represents light that eminates from a single point.

```
{
  const color = 0xFFFFFF;
  const intensity = 3;
  const light = new THREE.PointLight(color, intensity);
  scene.add(light);
}
```

To make it easy to see we're going to put the camera directly above the origin looking down. The easist way to do that is to use the `lookAt` function. The `lookAt` function will orient the camera from its position to "look at" the position we pass to `lookAt`. Before we do that though we need to tell the camera which way the top of the camera is facing or rather which way is "up" for the camera. For most situations positive Y being up is good enough but since we are looking straight down we need to tell the camera that positive Z is up.

```
const camera = new THREE.PerspectiveCamera(fov, aspect, near, far);
camera.position.set(0, 50, 0);
camera.up.set(0, 0, 1);
camera.lookAt(0, 0, 0);
```

In the render loop, adapted from previous examples, we're rotating all objects in our `objects` array with this code.

```
objects.forEach((obj) => {
  obj.rotation.y = time;
});
```

Since we added the `sunMesh` to the `objects` array it will rotate.

JS HTML CSS Codepen JSFiddle Result Run

```
import * as THREE from 'https://threejsfund

function main() {
  const canvas = document.querySelector('#c
  const renderer = new THREE.WebGLRenderer(

  const fov = 40;
  const aspect = 2;  // the canvas default
  const near = 0.1;
  const far = 1000;
  const camera = new THREE.PerspectiveCamer
  camera.position.set(0, 50, 0);
  camera.up.set(0, 0, 1);
  camera.lookAt(0, 0, 0);

  const scene = new THREE.Scene();

  {
    const color = 0xFFFFFF;
    const intensity = 3;
    const light = new THREE.PointLight(colo
    scene.add(light);
  }

  // an array of objects who's rotation to
  const objects = [];
```

[click here to open in a separate window]

Now let's add in the earth.

```
const earthMaterial = new THREE.MeshPhongMaterial({color: 0x2233FF, emissive: 0x112244});
const earthMesh = new THREE.Mesh(sphereGeometry, earthMaterial);
earthMesh.position.x = 10;
scene.add(earthMesh);
objects.push(earthMesh);
```

We make a material that is blue but we gave it a small amount of *emissive* blue so that it will show up against our black background.

We use the same `sphereGeometry` with our new blue `earthMaterial` to make an `earthMesh`. We position that 10 units to the left of the sun and add it to the scene. Since we added it to our `objects` array it will rotate too.

JS HTML CSS Codepen JSFiddle Result Run

```
import * as THREE from 'https://threejsfun

function main() {
  const canvas = document.querySelector('#c
  const renderer = new THREE.WebGLRenderer(

  const fov = 40;
  const aspect = 2;  // the canvas default
  const near = 0.1;
  const far = 1000;
  const camera = new THREE.PerspectiveCame
  camera.position.set(0, 50, 0);
  camera.up.set(0, 0, 1);
  camera.lookAt(0, 0, 0);

  const scene = new THREE.Scene();

  {
    const color = 0xFFFFFF;
    const intensity = 3;
    const light = new THREE.PointLight(colo
    scene.add(light);
  }

  const objects = [];
```

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You can see both the sun and the earth are rotating but the earth is not going around the sun. Let's make the earth a child of the sun

```
~~scene.add(earthMesh);~~
sunMesh.add(earthMesh);
```

and...

JS HTML CSS Codepen JSFiddle Result Run

```
import * as THREE from 'https://threejsfun

function main() {
  const canvas = document.querySelector('#c
  const renderer = new THREE.WebGLRenderer(

  const fov = 40;
  const aspect = 2;  // the canvas default
  const near = 0.1;
  const far = 1000;
  const camera = new THREE.PerspectiveCame
  camera.position.set(0, 150, 0);
  camera.up.set(0, 0, 1);
  camera.lookAt(0, 0, 0);

  const scene = new THREE.Scene();

  {
    const color = 0xFFFFFF;
    const intensity = 3;
    const light = new THREE.PointLight(colo
    scene.add(light);
  }

  const objects = [];
```

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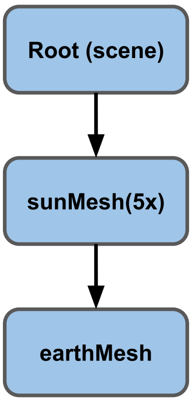
What happened? Why is the earth the same size as the sun and why is it so far away? I actually had to move the camera from 50 units above to 150 units above to see the earth.

We made the `earthMesh` a child of the `sunMesh`. The `sunMesh` has its scale set to 5x with `sunMesh.scale.set(5, 5, 5)`. That means the `sunMesh`s local space is 5 times as big. Anything put in that space will be multiplied by 5. That means the earth is now 5x larger and it's distance from the sun (`earthMesh.position.x = 10`) is also 5x as well.

Our scene graph currently looks like this



To fix it let's add an empty scene graph node. We'll parent both the sun and the earth to that node.

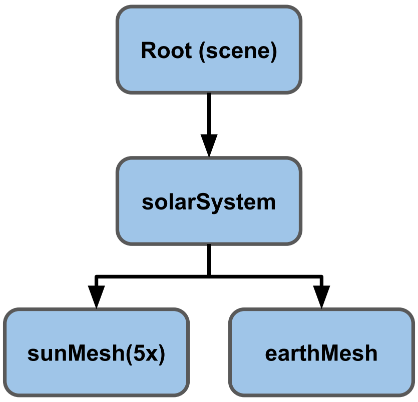
```
const solarSystem = new THREE.Object3D();
scene.add(solarSystem);
objects.push(solarSystem);

const sunMaterial = new THREE.MeshPhongMaterial({emissive: 0xFFFF00});
const sunMesh = new THREE.Mesh(sphereGeometry, sunMaterial);
sunMesh.scale.set(5, 5, 5);
scene.add(sunMesh);
solarSystem.add(sunMesh);
objects.push(sunMesh);

const earthMaterial = new THREE.MeshPhongMaterial({color: 0x2233FF, emissive: 0x112244});
const earthMesh = new THREE.Mesh(sphereGeometry, earthMaterial);
earthMesh.position.x = 10;
sunMesh.add(earthMesh);
solarSystem.add(earthMesh);
objects.push(earthMesh);
```

Here we made an `Object3D`. Like a `Mesh` it is also a node in the scene graph but unlike a `Mesh` it has no material or geometry. It just represents a local space.

Our new scene graph looks like this



Both the `sunMesh` and the `earthMesh` are children of the `solarSystem`. All 3 are being rotated and now because the `earthMesh` is not a child of the `sunMesh` it is no longer scaled by 5x.

JS HTML CSS Codepen JSFiddle Result Run

```
import * as THREE from 'https://threejsfunc

function main() {
  const canvas = document.querySelector('#c
  const renderer = new THREE.WebGLRenderer(

  const fov = 40;
  const aspect = 2;  // the canvas default
  const near = 0.1;
  const far = 1000;
  const camera = new THREE.PerspectiveCame
  camera.position.set(0, 50, 0);
  camera.up.set(0, 0, 1);
  camera.lookAt(0, 0, 0);

  const scene = new THREE.Scene();

  {
    const color = 0xFFFFFF;
    const intensity = 3;
    const light = new THREE.PointLight(colo
    scene.add(light);
  }

  const objects = [];
```

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Much better. The earth is smaller than the sun and it's rotating around the sun and rotating itself.

Continuing that same pattern let's add a moon.

```
const earthOrbit = new THREE.Object3D();
```

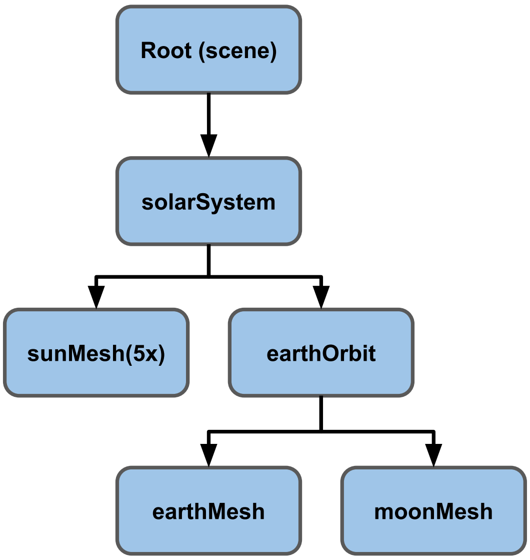
```
earthOrbit.position.x = 10;
solarSystem.add(earthOrbit);
objects.push(earthOrbit);

const earthMaterial = new THREE.MeshPhongMaterial({color: 0x2233FF, emissive: 0x112244});
const earthMesh = new THREE.Mesh(sphereGeometry, earthMaterial);
solarSystem.add(earthMesh);
earthOrbit.add(earthMesh);
objects.push(earthMesh);

const moonOrbit = new THREE.Object3D();
moonOrbit.position.x = 2;
earthOrbit.add(moonOrbit);

const moonMaterial = new THREE.MeshPhongMaterial({color: 0x888888, emissive: 0x222222});
const moonMesh = new THREE.Mesh(sphereGeometry, moonMaterial);
moonMesh.scale.set(.5, .5, .5);
moonOrbit.add(moonMesh);
objects.push(moonMesh);
```

Again we added another invisible scene graph node, an `Object3D` called `earthOrbit` and added both the `earthMesh` and the `moonMesh` to it. The new scene graph looks like this.



and here's that

JS HTML CSS Codepen JSFiddle Result Run

```
import * as THREE from 'https://threejsfun

function main() {
  const canvas = document.querySelector('#c
  const renderer = new THREE.WebGLRenderer(

  const fov = 40;
  const aspect = 2;  // the canvas default
  const near = 0.1;
  const far = 1000;
  const camera = new THREE.PerspectiveCamer
  camera.position.set(0, 50, 0);
  camera.up.set(0, 0, 1);
  camera.lookAt(0, 0, 0);

  const scene = new THREE.Scene();

  {
    const color = 0xFFFFFF;
    const intensity = 3;
    const light = new THREE.PointLight(colo
    scene.add(light);
  }

  const objects = [];
```

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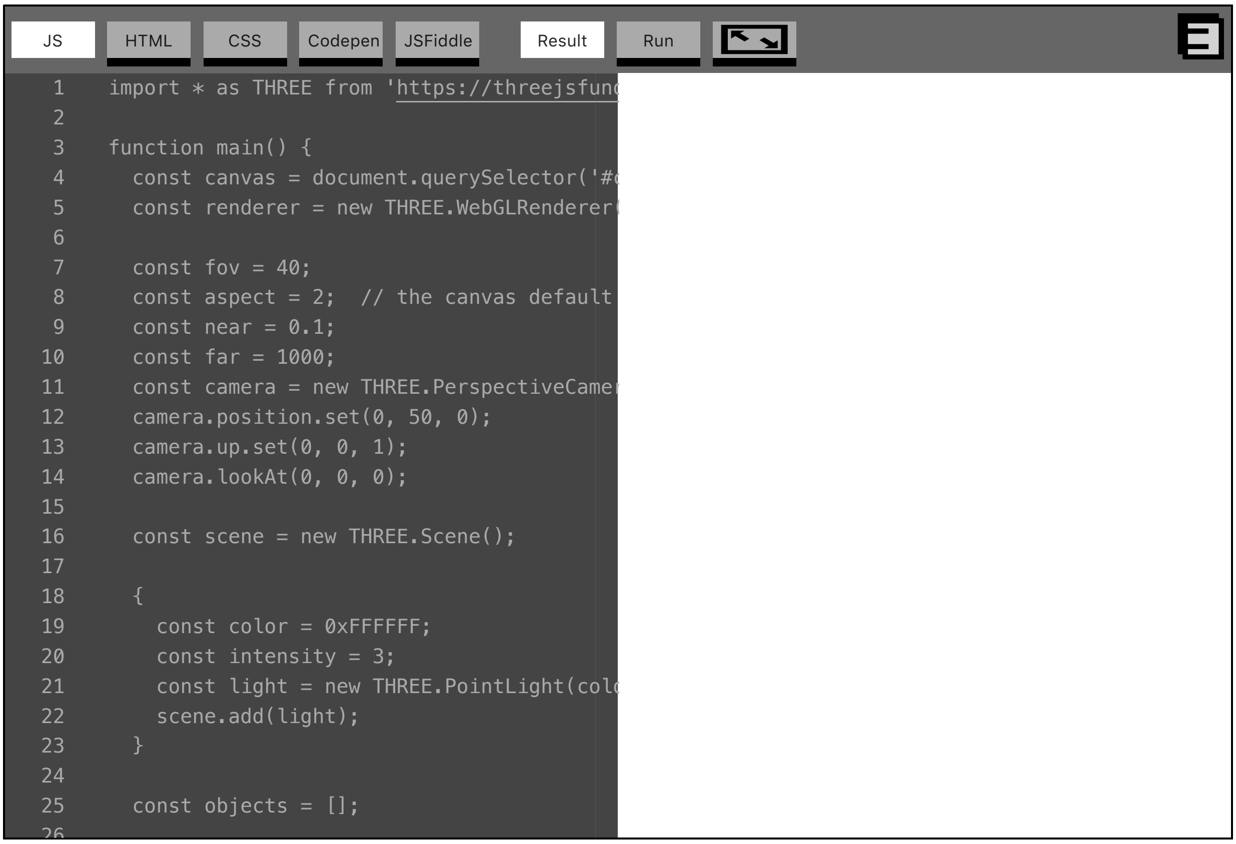
You can see the moon follows the spirograph pattern shown at the top of this article but we didn't have to manually compute it. We just setup our scene graph to do it for us.

It is often useful to draw something to visualize the nodes in the scene graph. Three.js has some helpful ummmm, helpers to ummm, ... help with this.

One is called an `AxesHelper`. It draws 3 lines representing the local X, Y, and Z axes. Let's add one to every node we created.

```
// add an AxesHelper to each node
objects.forEach((node) => {
  const axes = new THREE.AxesHelper();
  axes.material.depthTest = false;
  axes.renderOrder = 1;
  node.add(axes);
});
```

On our case we want the axes to appear even though they are inside the spheres. To do this we set their material's `depthTest` to false which means they will not check to see if they are drawing behind something else. We also set their `renderOrder` to 1 (the default is 0) so that they get drawn after all the spheres. Otherwise a sphere might draw over them and cover them up.




```js
import * as THREE from 'https://threejsfun

function main() {
  const canvas = document.querySelector('#c
  const renderer = new THREE.WebGLRenderer(

  const fov = 40;
  const aspect = 2;  // the canvas default
  const near = 0.1;
  const far = 1000;
  const camera = new THREE.PerspectiveCame
  camera.position.set(0, 50, 0);
  camera.up.set(0, 0, 1);
  camera.lookAt(0, 0, 0);

  const scene = new THREE.Scene();

  {
    const color = 0xFFFFFF;
    const intensity = 3;
    const light = new THREE.PointLight(colo
    scene.add(light);
  }

  const objects = [];
```

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We can see the x (red) and z (blue) axes. Since we are looking straight down and each of our objects is only rotating around its y axis we don't see much of the y (green) axes.

It might be hard to see some of them as there are 2 pairs of overlapping axes. Both the `sunMesh` and the `solarSystem` are at the same position. Similarly the `earthMesh` and `earthOrbit` are at the same position. Let's add some simple controls to allow us to turn them on/off for each node. While we're at it let's also add another helper called the `GridHelper`. It makes a 2D grid on the X,Z plane. By default the grid is 10x10 units.

We're also going to use [dat.GUI] which is a UI library that is very popular with three.js projects. dat.GUI takes an object and a property name on that object and based on the type of the property automatically makes a UI to manipulate that property.

We want to make both a `GridHelper` and an `AxesHelper` for each node. We need a label for each node so we'll get rid of the old loop and switch to calling some function to add the helpers for each node

```js
// add an AxesHelper to each node
objects.forEach((node) => {
  const axes = new THREE.AxesHelper();
  axes.material.depthTest = false;
  axes.renderOrder = 1;
  node.add(axes);
});
```

```
function makeAxisGrid(node, label, units) {
  const helper = new AxisGridHelper(node, units);
  gui.add(helper, 'visible').name(label);
}

makeAxisGrid(solarSystem, 'solarSystem', 25);
makeAxisGrid(sunMesh, 'sunMesh');
makeAxisGrid(earthOrbit, 'earthOrbit');
makeAxisGrid(earthMesh, 'earthMesh');
makeAxisGrid(moonMesh, 'moonMesh');
```

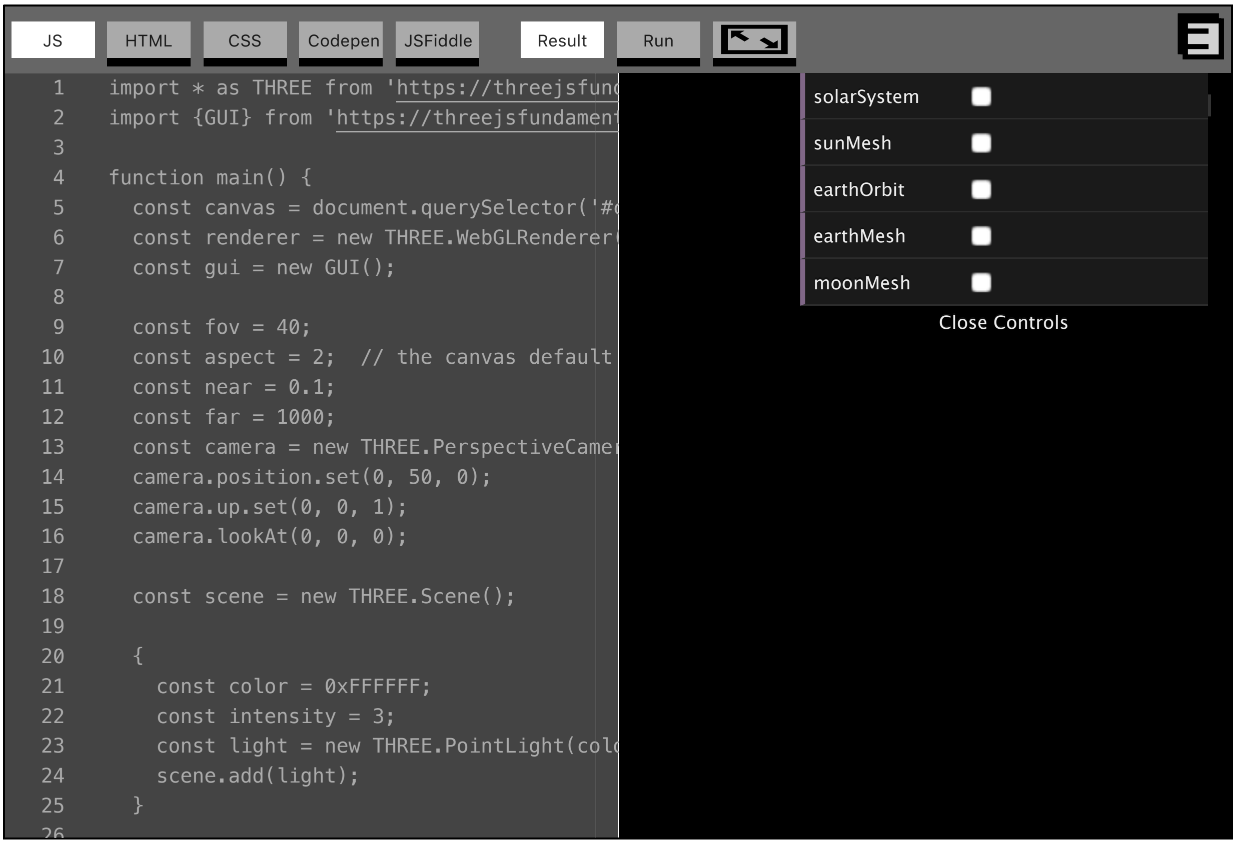
`makeAxisGrid` makes an `AxisGridHelper` which is a class we'll create to make dat.GUI happy. Like it says above dat.GUI will automagically make a UI that manipulates the named property of some object. It will create a different UI depending on the type of property. We want it to create a checkbox so we need to specify a `bool` property. But, we want both the axes and the grid to appear/disappear based on a single property so we'll make a class that has a getter and setter for a property. That way we can let dat.GUI think it's manipulating a single property but internally we can set the visible property of both the `AxesHelper` and `GridHelper` for a node.

```
// Turns both axes and grid visible on/off
// dat.GUI requires a property that returns a bool
// to decide to make a checkbox so we make a setter
// and getter for `visible` which we can tell dat.GUI
// to look at.
class AxisGridHelper {
  constructor(node, units = 10) {
    const axes = new THREE.AxesHelper();
    axes.material.depthTest = false;
    axes.renderOrder = 2;  // after the grid
    node.add(axes);

    const grid = new THREE.GridHelper(units, units);
    grid.material.depthTest = false;
    grid.renderOrder = 1;
    node.add(grid);

    this.grid = grid;
    this.axes = axes;
    this.visible = false;
  }
  get visible() {
    return this._visible;
  }
  set visible(v) {
    this._visible = v;
    this.grid.visible = v;
    this.axes.visible = v;
  }
}
```

One thing to notice is we set the `renderOrder` of the `AxesHelper` to 2 and for the `GridHelper` to 1 so that the axes get drawn after the grid. Otherwise the grid might overwrite the axes.



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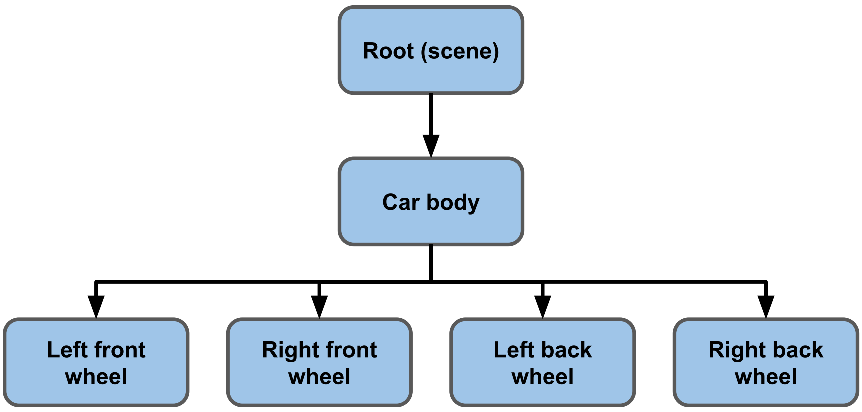
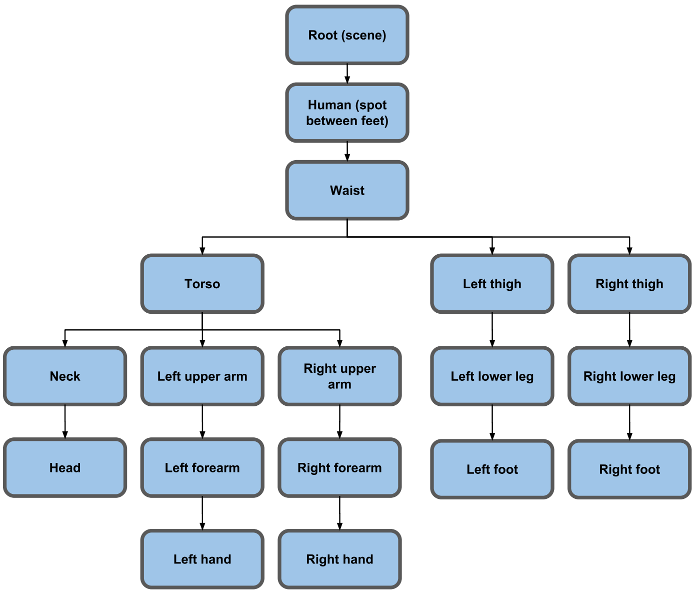
Turn on the `solarSystem` and you'll see how the earth is exactly 10 units out from the center just like we set above. You can see how the earth is in the *local space* of the `solarSystem`. Similary if you turn on the `earthOrbit` you'll see how the moon is exactly 2 units from the center of the *local space* of the `earthOrbit`.

A few more examples of scene graphs. An automobile in a simple game world might have a scene graph like this



If you move the car's body all the wheels will move with it. If you wanted the body to bounce separate from the wheels you might parent the body and the wheels to a "frame" node that represents the car's frame.

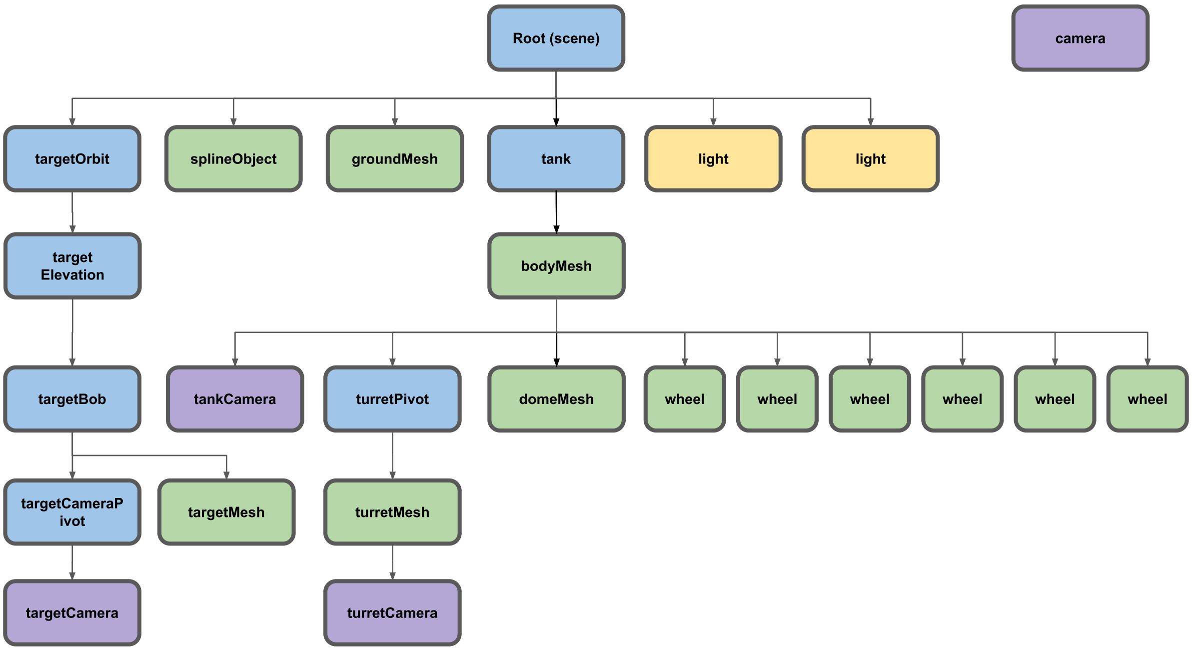
Another example is a human in a game world.



You can see the scene graph gets pretty complex for a human. In fact that scene graph above is simplified. For example you might extend it to cover every finger (at least another 28 nodes) and every toe (yet another 28 nodes) plus ones for the face and jaw, the eyes and maybe more.

Let's make one semi-complex scene graph. We'll make a tank. The tank will have 6 wheels and a turret. The tank will follow a path. There will be a sphere that moves around and the tank will target the sphere.

Here's the scene graph. The meshes are colored in green, the `Object3D`s in blue, the lights in gold, and the cameras in purple. One camera has not been added to the scene graph.



Look in the code to see the setup of all of these nodes.

For the target, the thing the tank is aiming at, there is a `targetOrbit` ([`Object3D`]) which just rotates similar to the `earthOrbit` above. A `targetElevation` ([`Object3D`]) which is a child of the `targetOrbit` provides an offset from the `targetOrbit` and a base elevation. Childed to that is another [`Object3D`] called `targetBob` which just bobs up and down relative to the `targetElevation`. Finally there's the `targetMesh` which is just a cube we rotate and change it's colors

```
// move target
targetOrbit.rotation.y = time * .27;
targetBob.position.y = Math.sin(time * 2) * 4;
targetMesh.rotation.x = time * 7;
targetMesh.rotation.y = time * 13;
targetMaterial.emissive.setHSL(time * 10 % 1, 1, .25);
targetMaterial.color.setHSL(time * 10 % 1, 1, .25);
```

For the tank there's an [`Object3D`] called `tank` which is used to move everything below it around. The code uses a [`SplineCurve`] which it can ask for positions along that curve. 0.0 is the start of the curve. 1.0 is the end of the curve. It asks for the current position where it puts the tank. It then asks for a position slightly further down the curve and uses that to point the tank in that direction using [`Object3D.lookAt`].

```
const tankPosition = new THREE.Vector2();
const tankTarget = new THREE.Vector2();

...

// move tank
const tankTime = time * .05;
```

```
curve.getPointAt(tankTime % 1, tankPosition);
curve.getPointAt((tankTime + 0.01) % 1, tankTarget);
tank.position.set(tankPosition.x, 0, tankPosition.y);
tank.lookAt(tankTarget.x, 0, tankTarget.y);
```

The turret on top of the tank is moved automatically by being a child of the tank. To point it at the target we just ask for the target's world position and then again use `Object3D.lookAt`

```
const targetPosition = new THREE.Vector3();

...

// face turret at target
targetMesh.getWorldPosition(targetPosition);
turretPivot.lookAt(targetPosition);
```

There's a `turretCamera` which is a child of the `turretMesh` so it will move up and down and rotate with the turret. We make that aim at the target.

```
// make the turretCamera look at target
turretCamera.lookAt(targetPosition);
```

There is also a `targetCameraPivot` which is a child of `targetBob` so it floats around with the target. We aim that back at the tank. It's purpose is to allow the `targetCamera` to be offset from the target itself. If we instead made the camera a child of `targetBob` and just aimed the camera itself it would be inside the target.

```
// make the targetCameraPivot look at the tank
tank.getWorldPosition(targetPosition);
targetCameraPivot.lookAt(targetPosition);
```

Finally we rotate all the wheels

```
wheelMeshes.forEach((obj) => {
  obj.rotation.x = time * 3;
});
```

For the cameras we setup an array of all 4 cameras at init time with descriptions.

```
const cameras = [
  { cam: camera, desc: 'detached camera', },
  { cam: turretCamera, desc: 'on turret looking at target', },
  { cam: targetCamera, desc: 'near target looking at tank', },
  { cam: tankCamera, desc: 'above back of tank', },
];

const infoElem = document.querySelector('#info');
```

and cycle through our cameras at render time.

```
const camera = cameras[time * .25 % cameras.length | 0];
infoElem.textContent = camera.desc;
```

JS HTML CSS Codepen JSFiddle Result Run

```
import * as THREE from 'https://threejsfund

function main() {
  const canvas = document.querySelector('#c
  const renderer = new THREE.WebGLRenderer(
  renderer.setClearColor(0xAAAAAA);
  renderer.shadowMap.enabled = true;

  function makeCamera(fov = 40) {
    const aspect = 2;  // the canvas defau
    const zNear = 0.1;
    const zFar = 1000;
    return new THREE.PerspectiveCamera(fov,
  }
  const camera = makeCamera();
  camera.position.set(8, 4, 10).multiplySca
  camera.lookAt(0, 0, 0);

  const scene = new THREE.Scene();

  {
    const light = new THREE.DirectionalLigh
    light.position.set(0, 20, 0);
    scene.add(light);
    light.castShadow = true;
    light.shadow.mapSize.width = 2048;
```

[click here to open in a separate window](#)

I hope this gives some idea of how scene graphs work and how you might use them. Making `Object3D` nodes and parenting things to them is an important step to using a 3D engine like three.js well. Often it might seem like some complex math is necessary to make something move and rotate the way you want. For example without a scene graph computing the motion of the moon or where to put the wheels of the car relative to its body would be very complicated but using a scene graph it becomes much easier.

[Next up we'll go over materials](#).