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Breathing life into your applications: Animation with Qt 3D

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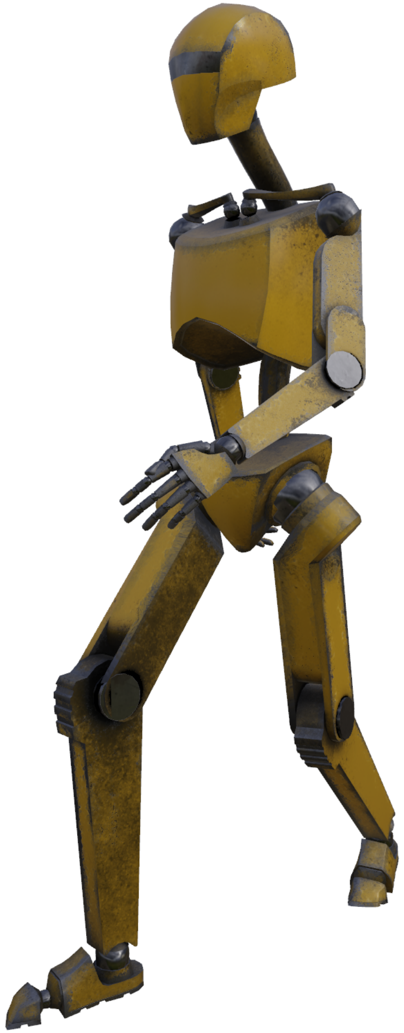
KDAB



Contents

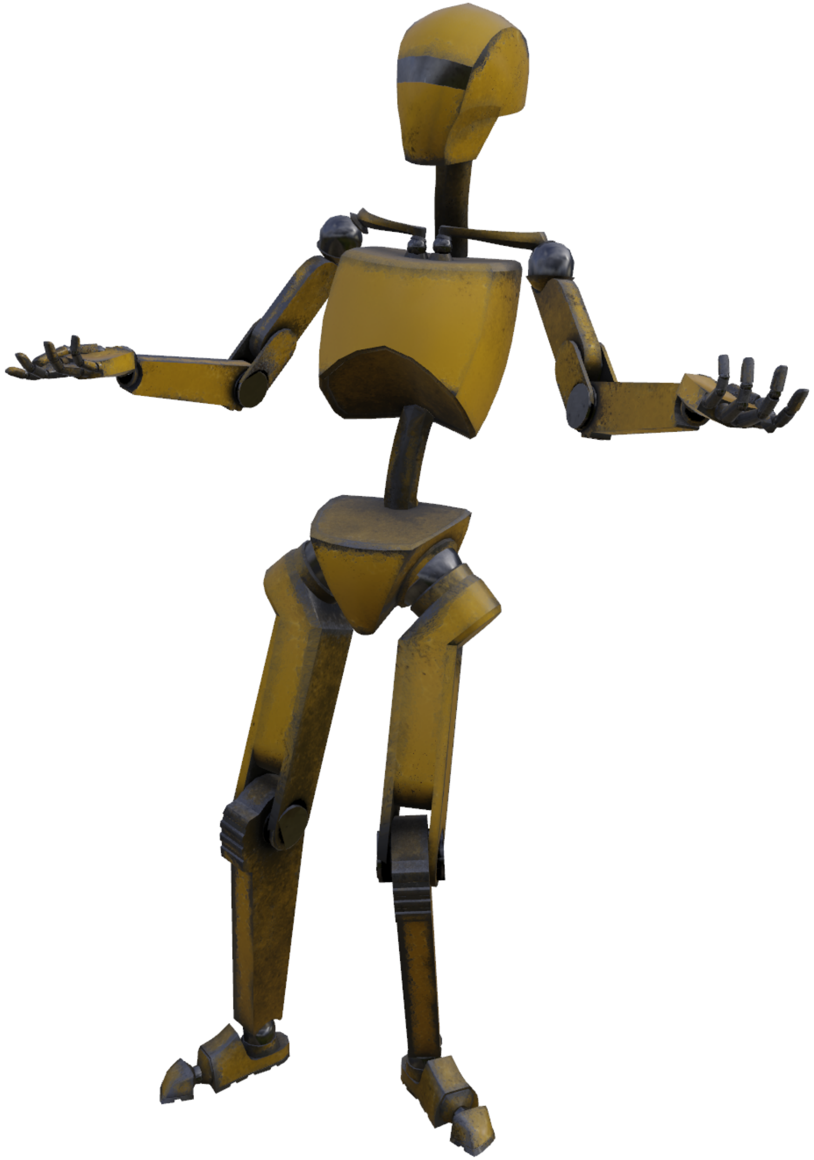
- Overview of Animations in Qt 3D
- Simple Animations
- Skeletal Animations
- Blended Animations
- For the future

Credit to **Johann Woelper** and
Timo Buske for producing the assets

Overview of Animations in Qt 3D

Why are we doing this?

- Qt is not only for developers
- Content creators too
- Developers not great at complex content
- Artists not great at software development
- Let each do what they are good at!



Why are we doing this?

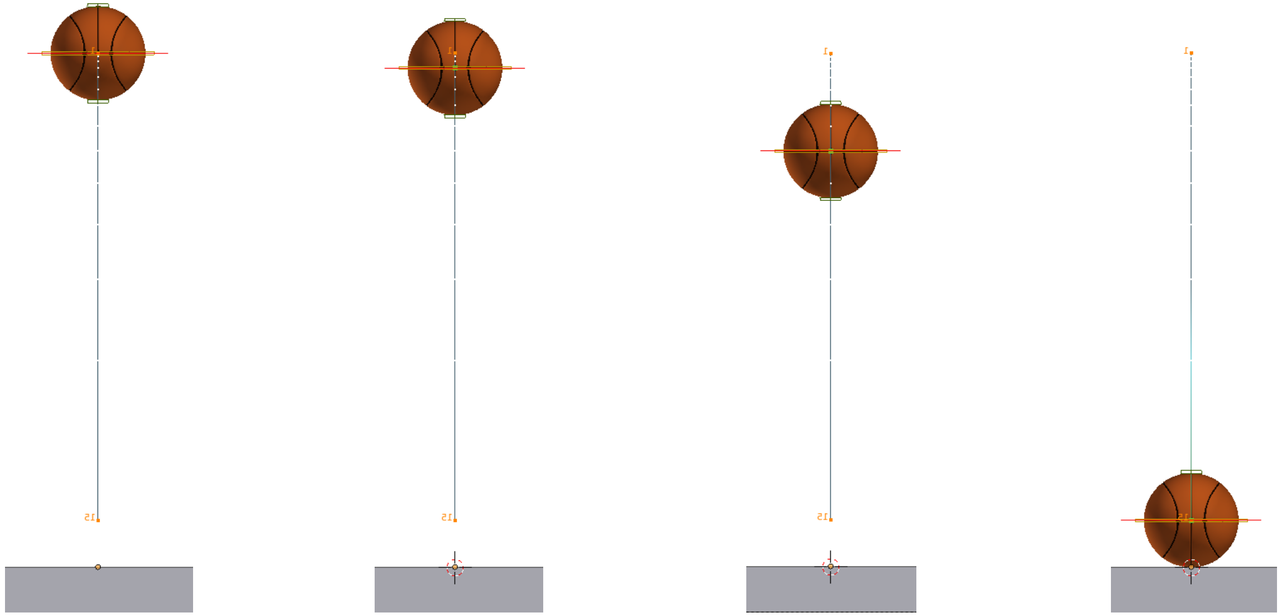
- Scalability
- Complex animations consume lots of data
- Qt 3D scales well to many cores
- Non-blocking on main thread
- Frontend objects can opt-in to property updates

What is Animation?

- Sequence of still frames
- Rapid display fools our primitive monkey brains
- Traditional animators draw every frame

Key Framed Animations

- Computers are good at maths
- Animators set positions at key points in time (frames)
- Get the computer to interpolate

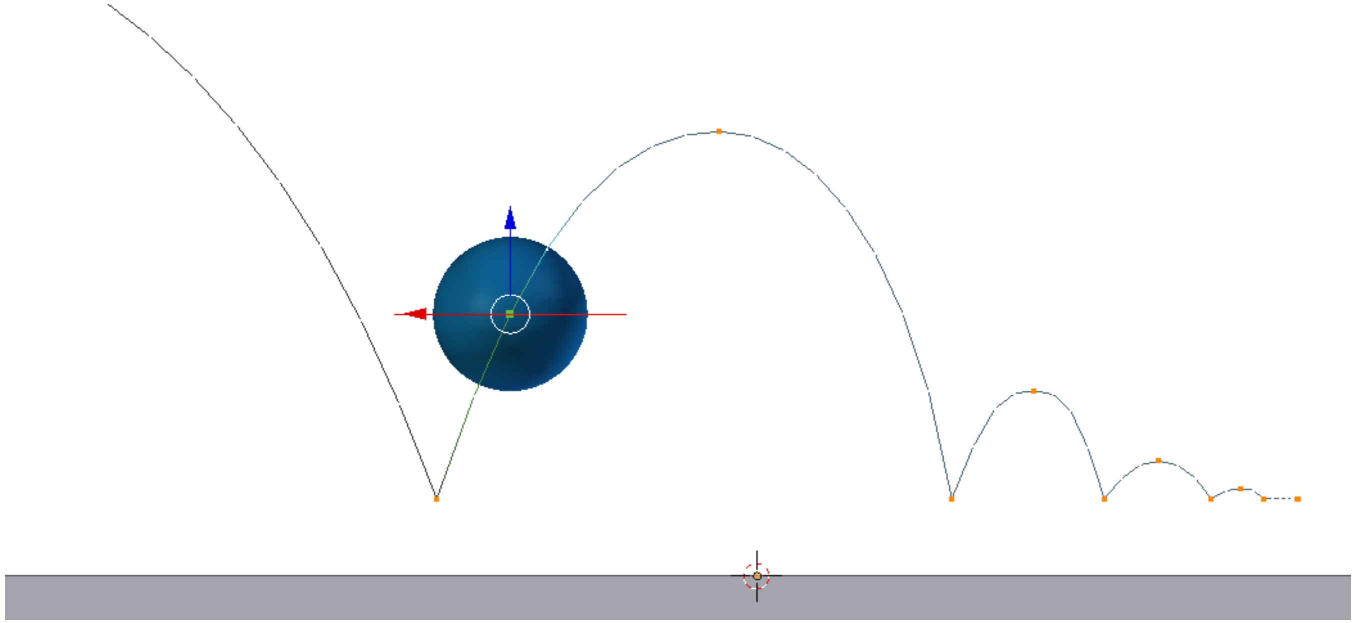


Offline vs Real-time

- Offline rendering (TV & Movies)
  - Time of each frame known exactly
  - Exactly scripted
- Real-time rendering (Applications/Games)
  - Variations in timing
  - Interactive

Offline vs Real-time

- Offline rendering
  - Artists can set exact positions at every frame
  - Animations for one specific use

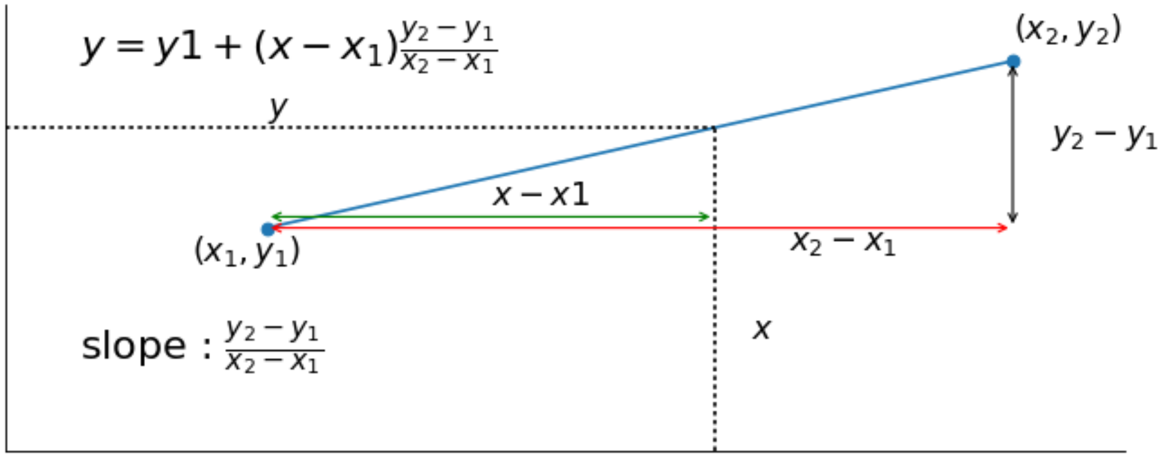


Offline vs Real-time

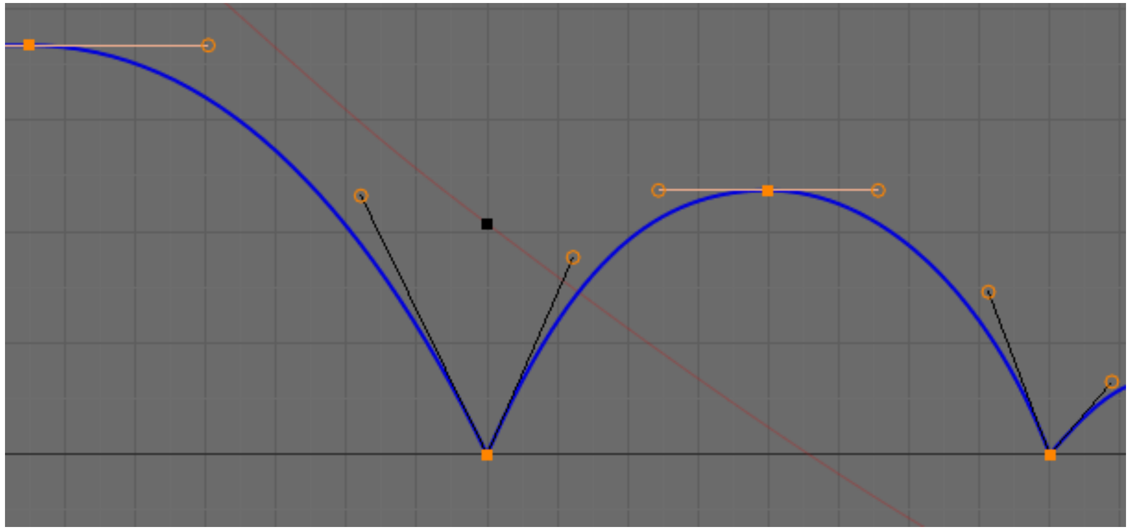
- Real-time rendering
  - Need to calculate position at any time
  - Animations need to be reusable
  - Ideally animations should be able to be composed

Interpolation

- Linear Interpolation (LERP)
  - Simpler mathematics
  - More data
- Higher Order
  - More complicated mathematics
  - Less data



$y = y1 + (x - x_1)\frac{y_2 - y_1}{x_2 - x_1}$
(x_2, y_2)
y
$y_2 - y_1$
$x - x1$
(x_1, y_1)
$x_2 - x_1$
slope : $\frac{y_2 - y_1}{x_2 - x_1}$
x



Workflow

- Artists author using higher order
- Asset conditioning
  - Process to run-time format
  - Export curves or re-sample curves for lerping
- Consumption

Authoring Example

- Simple bouncing ball

Animation Tips

- Artists can use familiar tools
- Using data rather than forcing programmer art:
- Squash and stretch
- Anticipation
- Variation
- Fine control (rebound, inertia etc.)

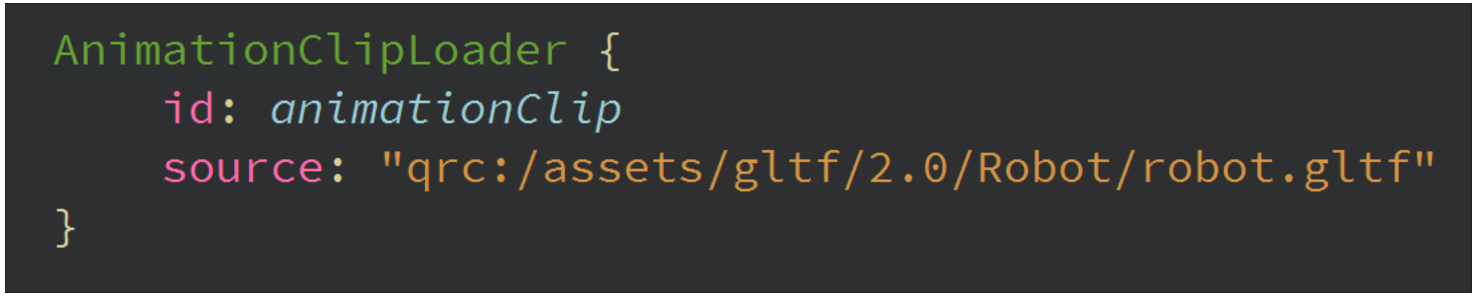
Simple Animations

Animations at Runtime

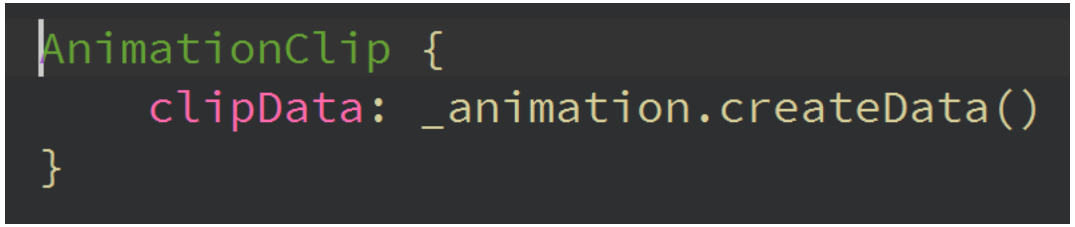
- 3 concepts:
  - Animation data
  - Animation playback
  - Target for the animation
- Qt Quick animations conflate all 3
- Qt 3D separates them for reuse, flexibility and efficiency

Animation Data

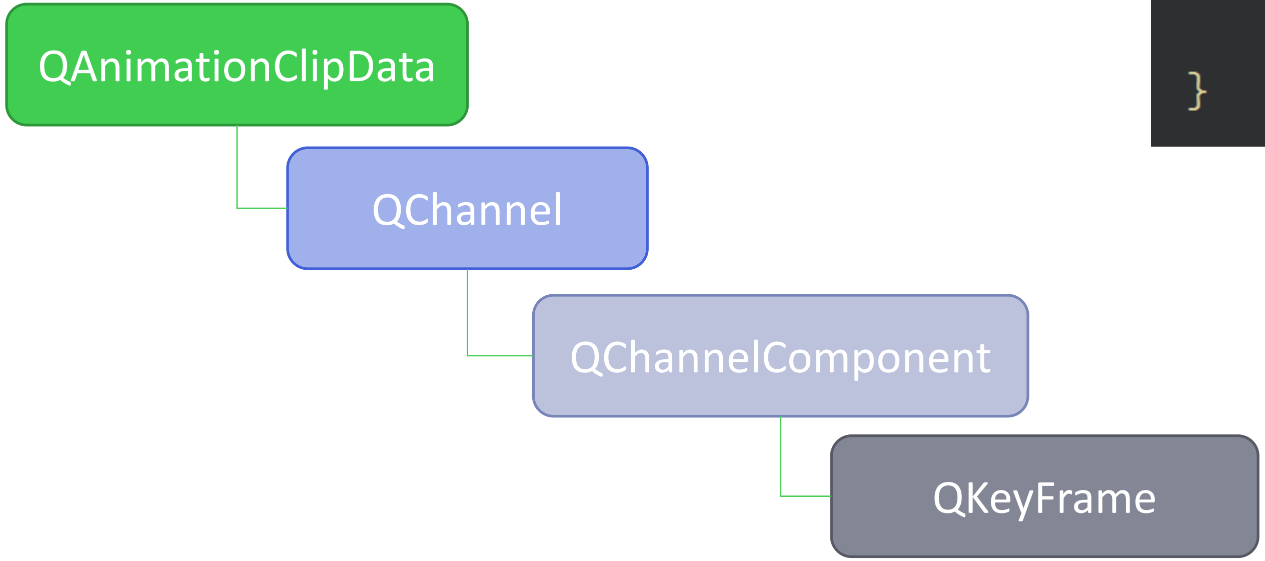
- Data from artist:
  - `AnimationClipLoader`
- Data from application:
  - `AnimationClip`



```
AnimationClipLoader {
    id: animationClip
    source: "qrc:/assets/gltf/2.0/Robot/robot.gltf"
}
```

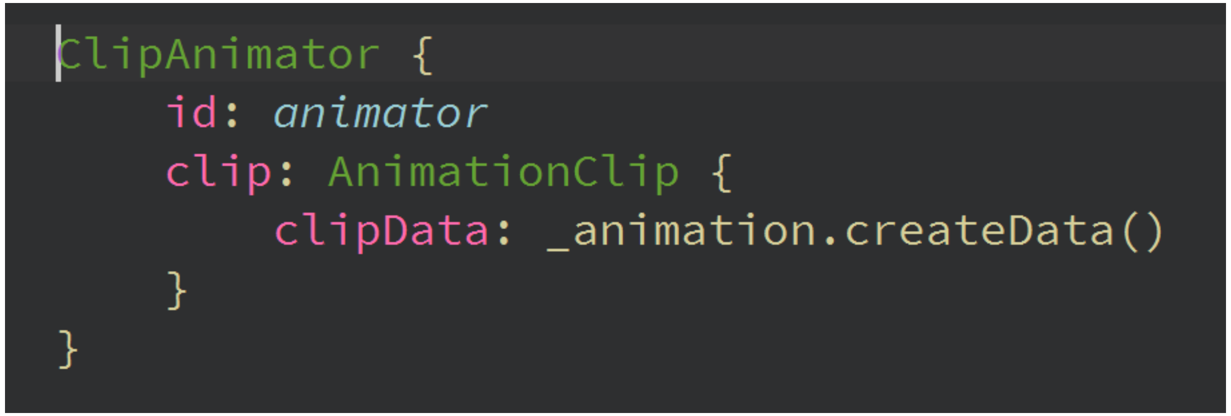


```
AnimationClip {
    clipData: _animation.createData()
}
```



Animation Playback

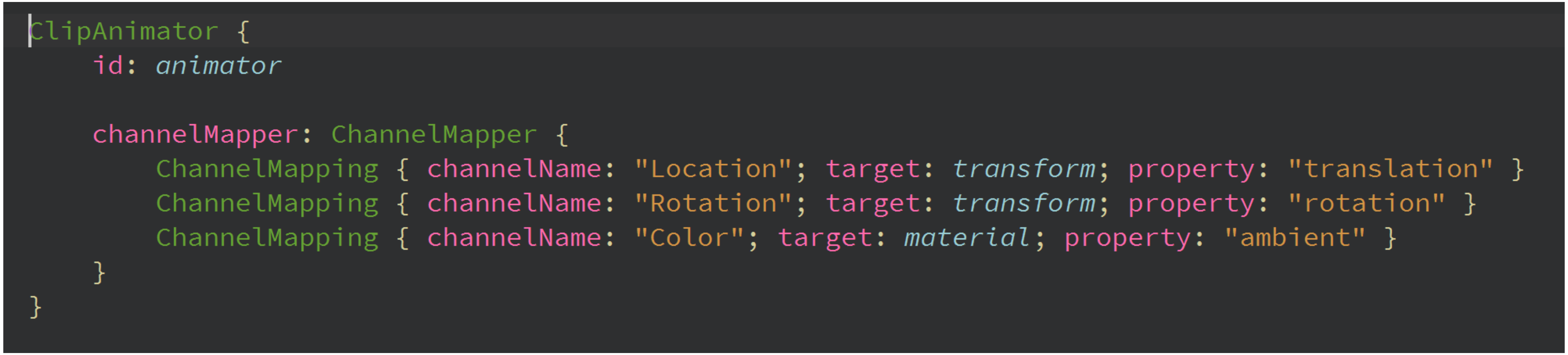
- Simple playback achieved with ClipAnimator
- More advanced options available (see later)



```
ClipAnimator {
    id: animator
    clip: AnimationClip {
        clipData: _animation.createData()
    }
}
```

Animation Targets

- Animations are reusable
- Map animation data to multiple properties of multiple objects
- ChannelMapper and ChannelMapping

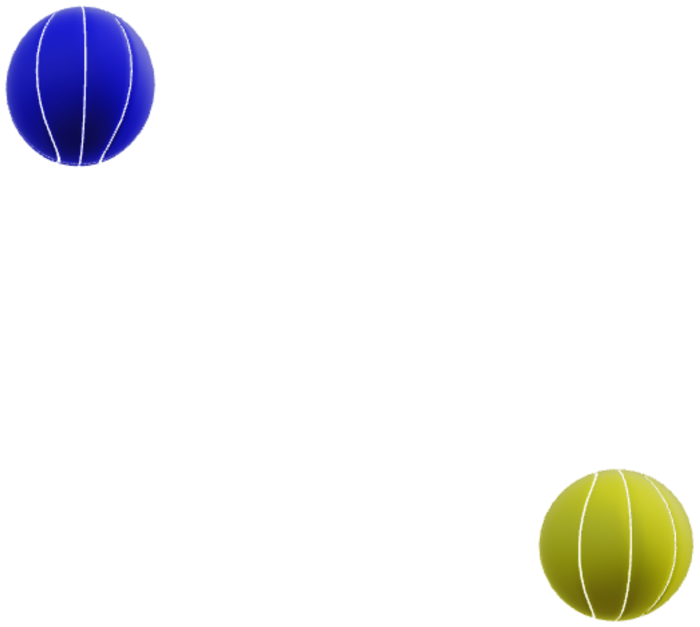


```
ClipAnimator {
    id: animator

    channelMapper: ChannelMapper {
        ChannelMapping { channelName: "Location"; target: transform; property: "translation" }
        ChannelMapping { channelName: "Rotation"; target: transform; property: "rotation" }
        ChannelMapping { channelName: "Color"; target: material; property: "ambient" }
    }
}
```

Playback Example

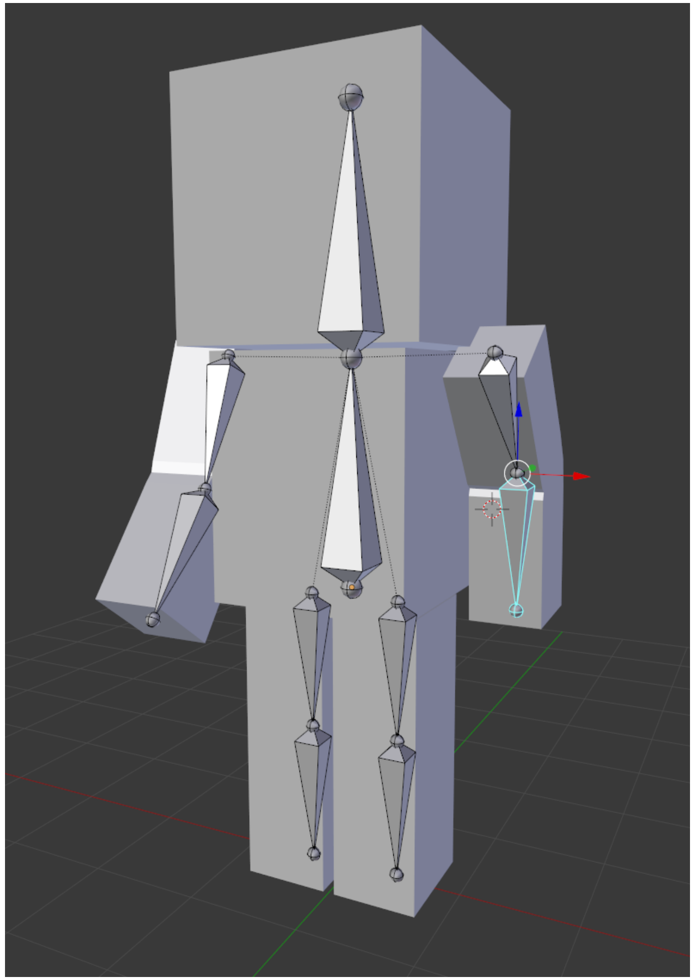
- Simple bouncing ball



Skeletal Animations

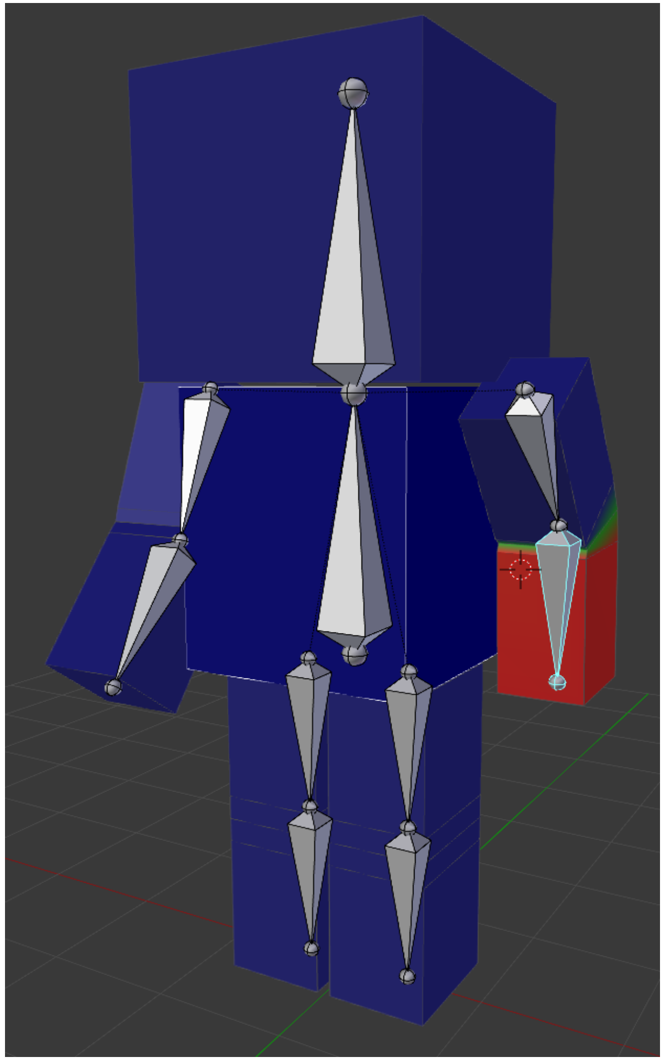
What is Skeletal Animation?

- So far we’ve dealt with rigid body transforms
  - Acts on whole mesh
  - Limitations on how “alive” we can make objects feel
- Skeletons (Armatures) allow to deform a mesh
  - Living creatures deform
  - Handy to be able to animate parts of a mesh
  - Does not need to be “squishy” like us meatbags
- Before we animate…
- We need to know how to render skinned meshes



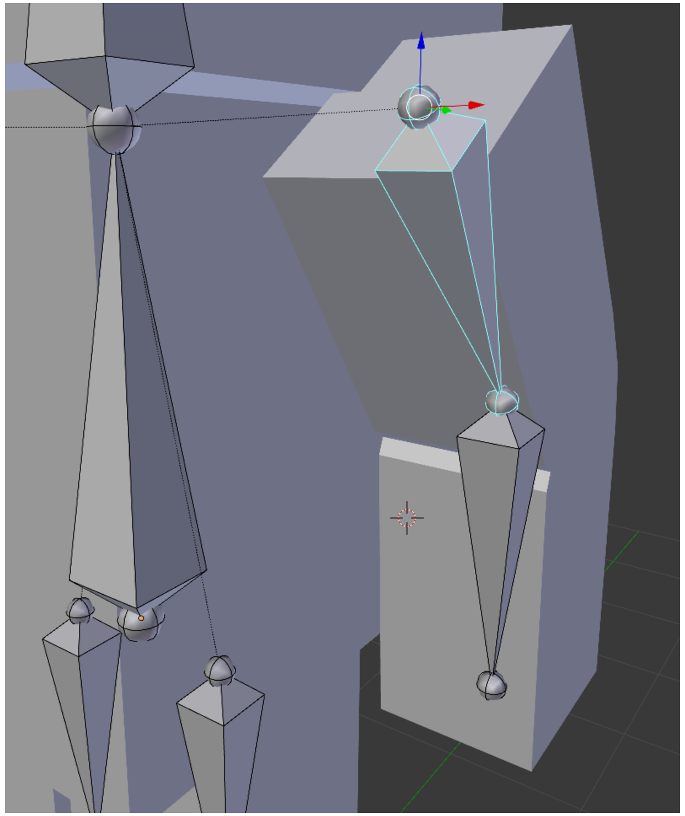
Creating Skinned Meshes

- Artist:
  - Creates mesh
  - Creates a skeleton
  - Binds vertices of mesh to one or more bones
  - Bone indices and weights stored as per-vertex attributes of the mesh
  - Usually limited to 4 bones influencing each vertex
  - Creates animations for bones (key framed poses)
  - Export

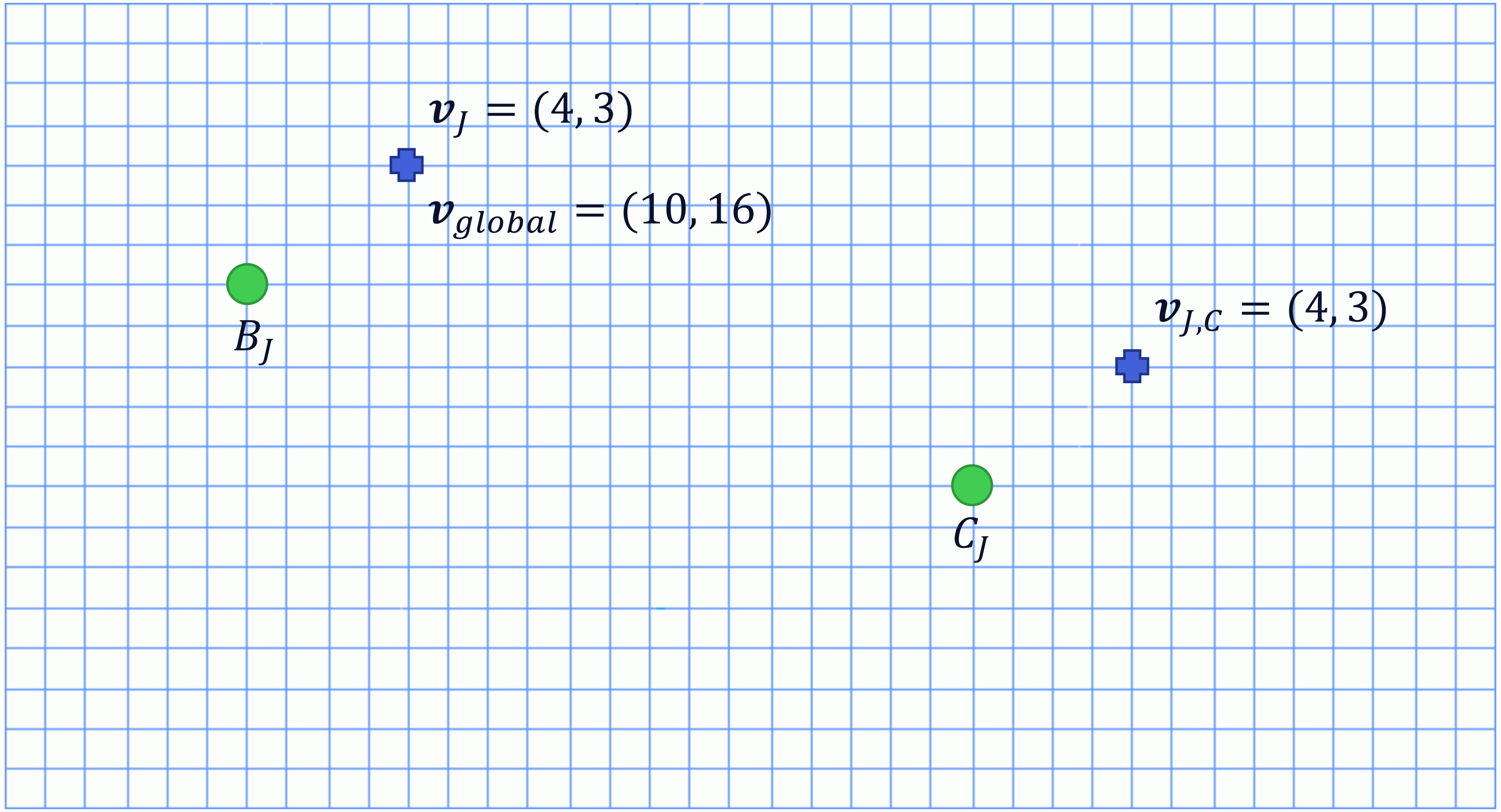


Joint vs Bone

- Literature refers to **Joints** and **Bones**
- The terms are interchangeable
- DCC tools often show bones graphically
- Joint is technically more correct
- Not physical bones
- Skeleton is just a hierarchy of nested coordinate systems
  - Usual parent child inheritance of transforms
  - Just applied within a single Entity



Drawing a Skinned Mesh
Single vertex single joint



$\boldsymbol{v}_J = (4, 3)$
$\boldsymbol{v}_{global} = (10, 16)$
B_J
$\boldsymbol{v}_{J,C} = (4, 3)$
C_J

$$\boldsymbol{v}_{J,C} = C_J B_J^{-1} \boldsymbol{v}_J$$

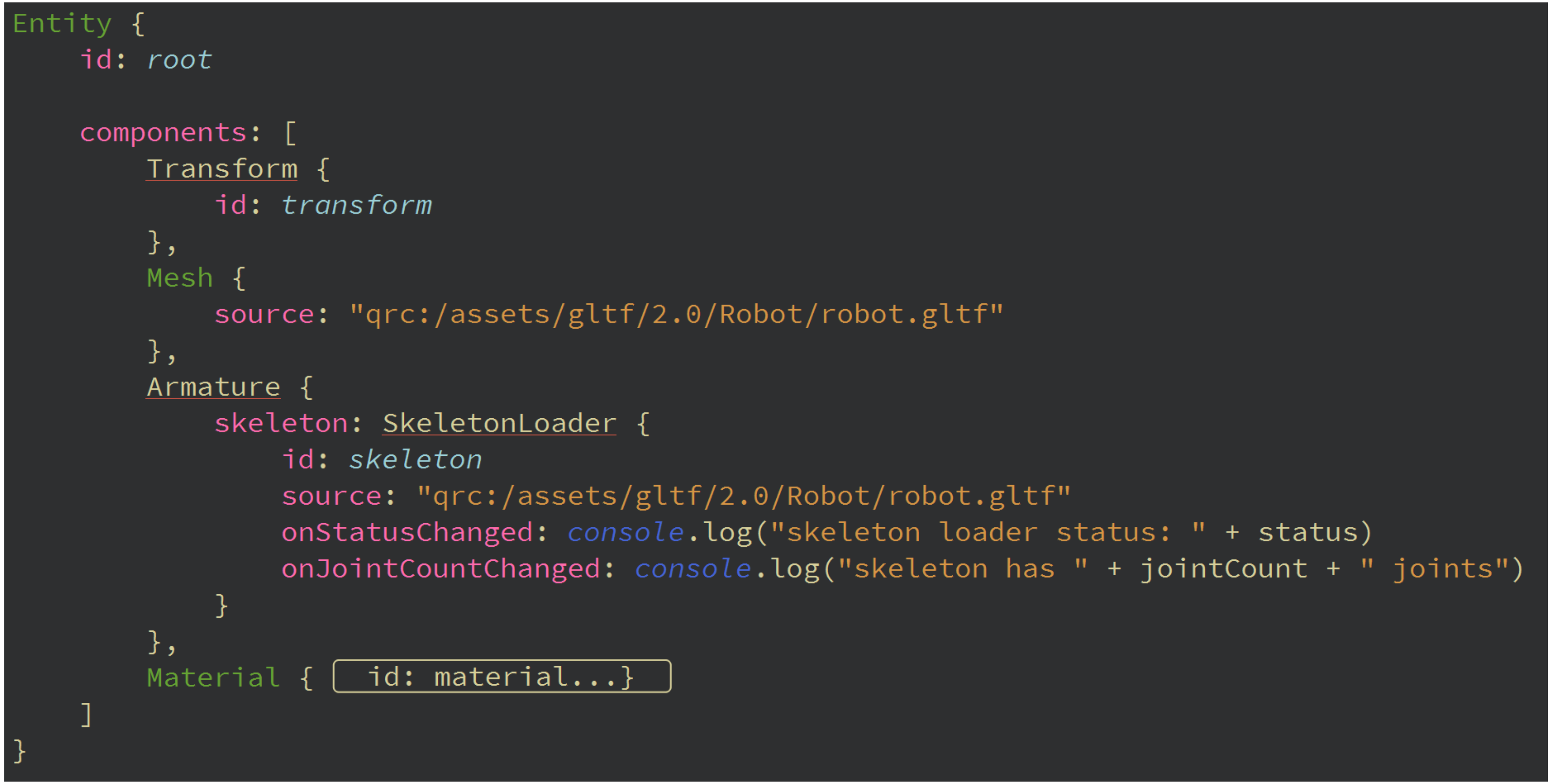
Drawing a Skinned Mesh

- Realistic Case: **Many vertices, weighted joints**
- Exactly the same maths!
- We store the joint poses as local transforms
- To calculate joint global pose we need to compose it with parent, grandparent…
- Inverse bind matrix never changes
- Best performance by linearising the joint hierarchy
- Calculate skinning matrix for each joint in the array
- Pass to shader program as uniform array or UBO
- Vertex shader applies weighted skinning matrices to vertices

Skinned Meshes in Qt 3D

- Entity should aggregate:
  - GeometryRenderer component referencing…
    - Geometry containing joint indices and joint weights
    - Use Mesh for loading from file
  - Armature component referencing…
    - Skeleton of joints
    - Use SkeletonLoader for loading from file
    - Can optionally create frontend hierarchy of Joints

Skinned Mesh Example



```
Entity {
    id: root

    components: [
        Transform {
            id: transform
        },
        Mesh {
            source: "qrc:/assets/gltf/2.0/Robot/robot.gltf"
        },
        Armature {
            skeleton: SkeletonLoader {
                id: skeleton
                source: "qrc:/assets/gltf/2.0/Robot/robot.gltf"
                onStatusChanged: console.log("skeleton loader status: " + status)
                onJointCountChanged: console.log("skeleton has " + jointCount + " joints")
            }
        },
        Material {  id: material...}
    ]
}
```

Animating a Skinned Mesh

- We already have everything we need!
- Animation data contains local transforms of joints
- Map animation data to skeleton with SkeletonMapping
- Animator updates skeleton pose and sends to render aspect
    - Simple or with a blend tree
- Renderer calculates new skinning matrix palette and…
- Draws skinned mesh as usual

Skeletal Animation Example

- Humanoid

Playback Speed

- Nice to be able to control animation playback speed
- Default uses global simulation time (wall time)
- Can set a Clock on one or more ClipAnimators
- Control speed with Clock's playbackRate property
- All associated animators affected
- Useful for some effects
  - E.g. Allows to slow down animation of 3D objects whilst keeping 2D UI fluid

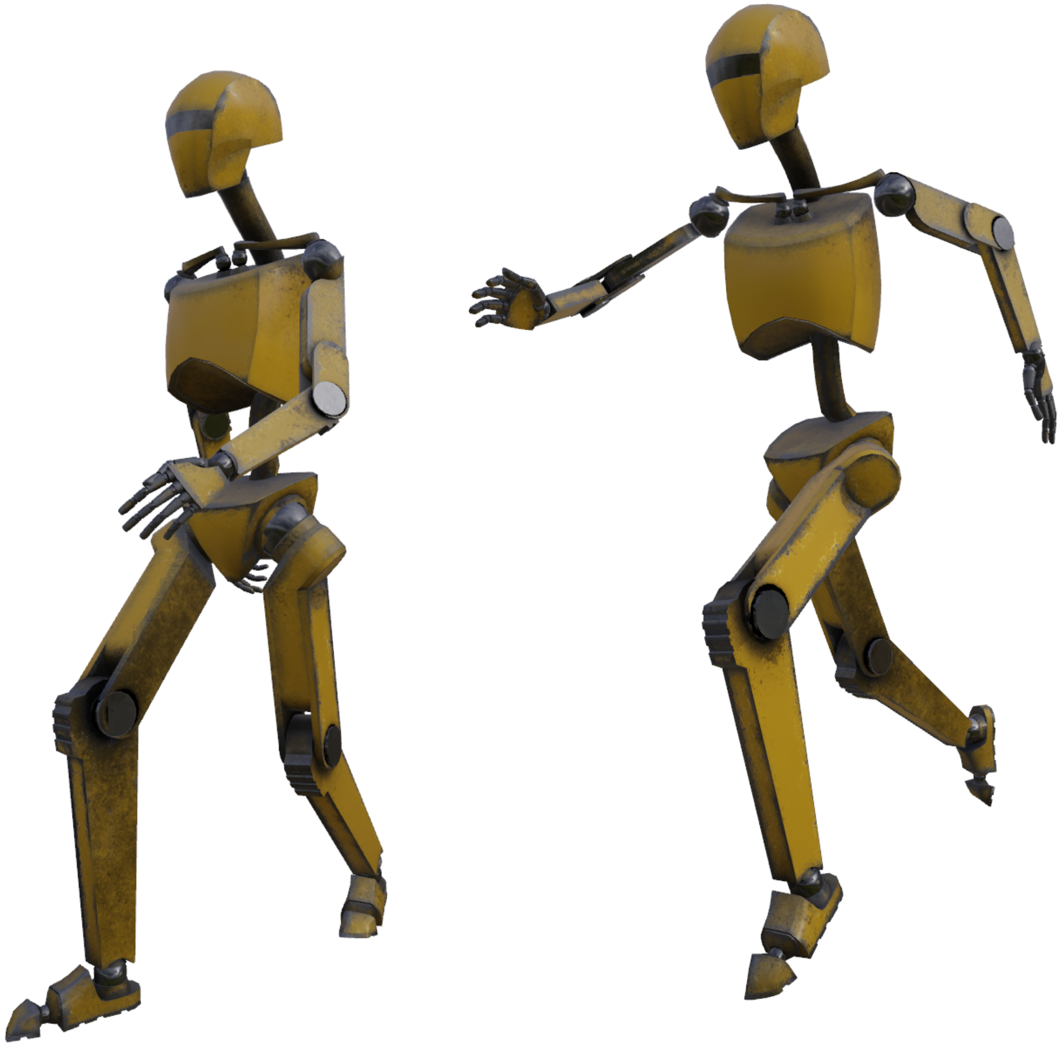
Blended Animations

Why Blend?

- Avoid combinatorial explosion
- Smooth transitions
- Run-time control

Uses of Animation Blending

- Smoothly mix walk cycle and run cycle
- Animate head in different ways whilst walking
- Blend from healthy to injured
- Transition from idle to walking
- Blend from backward/forward motion to strafing



How to Blend Animations

- Simple case: Walking vs Running
- Walk animation cycle: 3 seconds
- Run animation cycle: 2 seconds
- Blend factor controlled by user input (Axis)
- Or any other program data

How to Blend Animations

- Work in normalised time (phase on range [0,1]) for each contributing clip
- Requires feet to hit ground at same phase in both clips

How to Blend Animations

- From global time, calculate phase, ∅
- Evaluate channels from walk clip at $\emptyset, A(\emptyset)$
- Evaluate channels from run clip at $\emptyset, B(\emptyset)$
- LERP to get resulting channel values $C = (1 - \beta)A + \beta B$
- Complicated to deal with missing data

Other Types of Blend

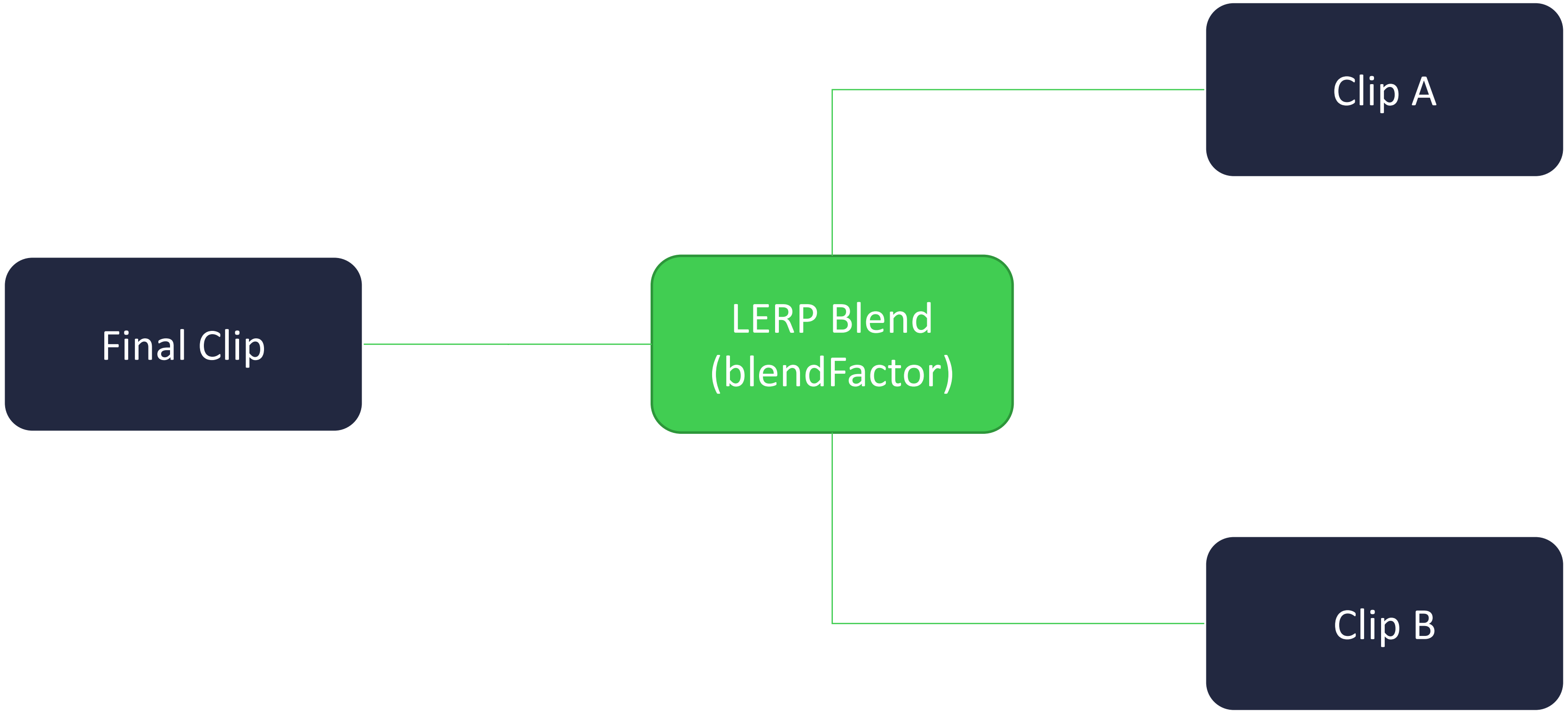
- LERP is common
- Other possible types:
  - Additive
  - Generalised 1D LERP
  - Bilinear 2D LERP
  - Barycentric LERP
  - Generalised Barycentric LERP

Combining Blends

- No reason to limit to a single blend?
- Combine in an arbitrary **blend tree**
- An Abstract Syntax Tree (AST) for animations
- “Constants” are animation clips
- Arguments are blend parameters
  - Bound to user inputs or
  - Application data

Animation Blending Example

- Simple LERP Blend Tree



For the Future

Future Animation Work

- Morph target animation: Absolute and relative targets
- Orchestrated clip animator: State machine controlled set of blend trees with transitions
- Channel masking and blending operations
- Root motion extraction
- More optimisations
- Tooling: Graphical blend tree designer

Summary

- Qt 3D offers high performance animations
- Opt-in to property changes
- Artists create data
- Developers integrate data into application
- First class support for skeletal animations
- Playback rate support
- Animation blending

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Thank you for listening!
Any questions?

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