Qt 3D Basics

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Introducing Qt Quick

A set of technologies including:

- Declarative markup language: QML
- Language runtime integrated with Qt
- Qt Creator IDE support for the QML language
- Graphical design tool
- C++ API for integration with Qt applications

- Intuitive user interfaces
- Design-oriented
- Rapid prototyping and production
- Easy deployment

Qt 3D Basics

Feature Set

- It is not about 3D!
- Multi-purpose, not just a game engine
- Soft real-time simulation engine
- Designed to be scalable
- Extensible and flexible

Simulation Engine

- The core is not inherently about 3D
- It can deal with several domains at once
  - AI, logic, audio, etc.
  - And of course it contains a 3D renderer too!
- All you need for a complex system simulation
  - Mechanical systems
  - Physics
  - ... and also games

Scalability

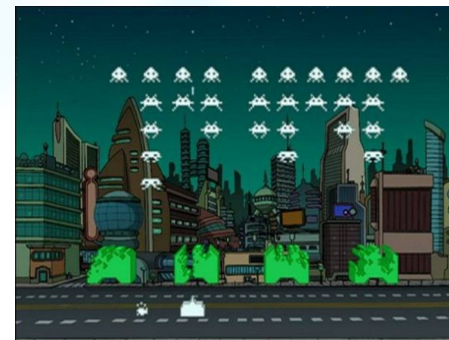
- Frontend / backend split
  - Frontend is lightweight and on the main thread
  - Backend executed in a secondary thread
    - Where the actual simulation runs
- Non-blocking frontend / backend communication
- Backend maximizes throughput via a thread pool

- Domains can be added via independent aspects
  - ... only if there's not something fitting your needs already
- Provide both C++ and QML APIs
- Integrates well with the rest of Qt
  - Pulling your simulation data from a database anyone?
- Entity Component System is used to combine behavior in your own objects
  - No deep inheritance hierarchy

Entity Component System?

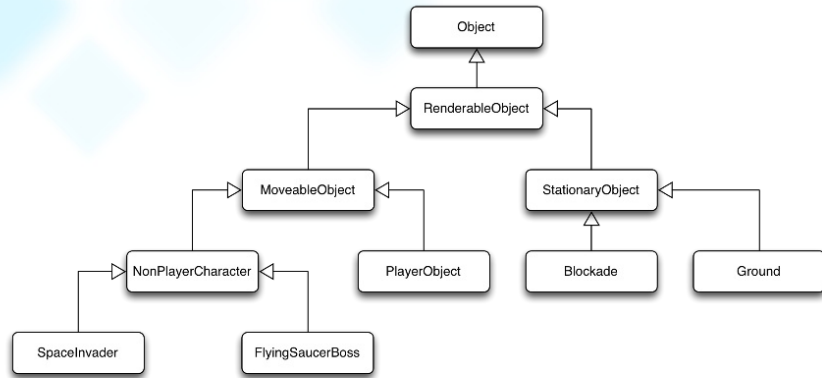
- ECS is an architectural pattern
  - Popular in game engines
  - Favors composition over inheritance
- An entity is a general purpose object
- An entity gets its behavior by combining data
- Data comes from typed components

- Let's analyse a familiar example: Space Invaders



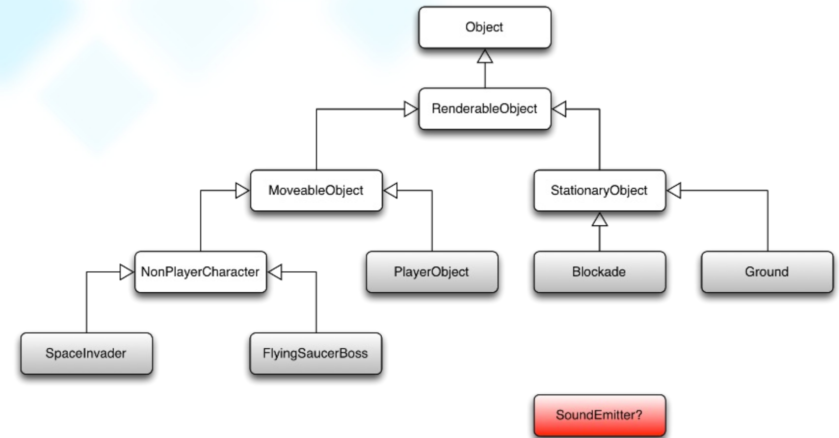
Composition vs Inheritance cont'd

- Typical inheritance hierarchy



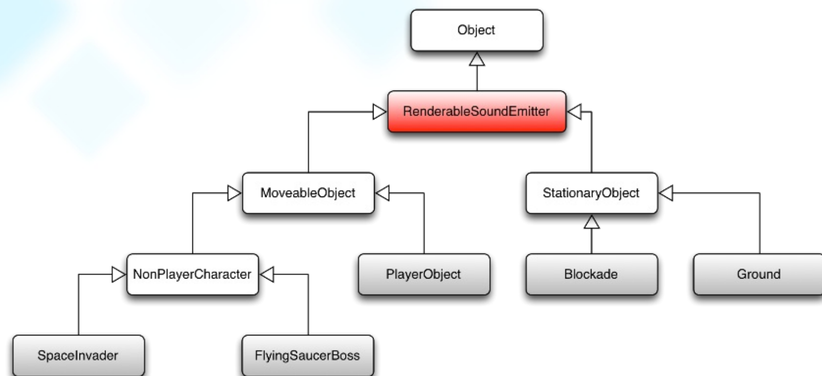
Composition vs Inheritance cont'd

- All fine until customer requires new feature:



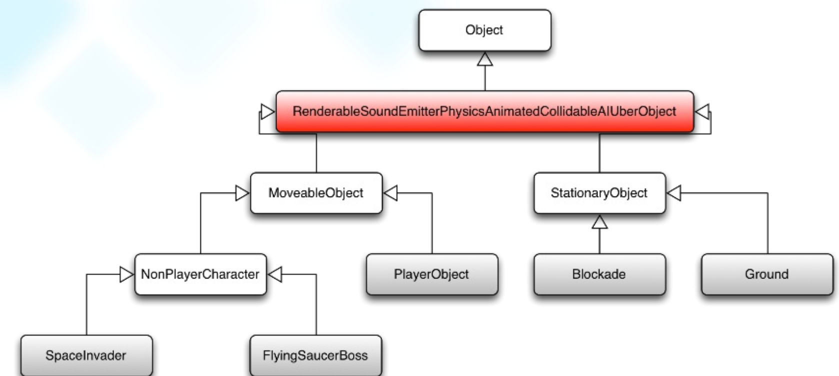
Composition vs Inheritance cont'd

- Typical solution: Add feature to base class



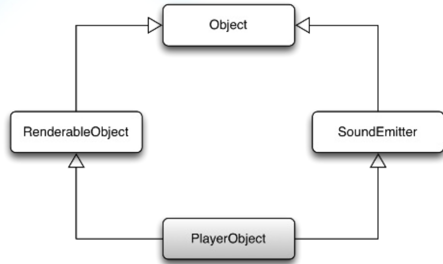
Composition vs Inheritance cont'd

- Doesn't scale:



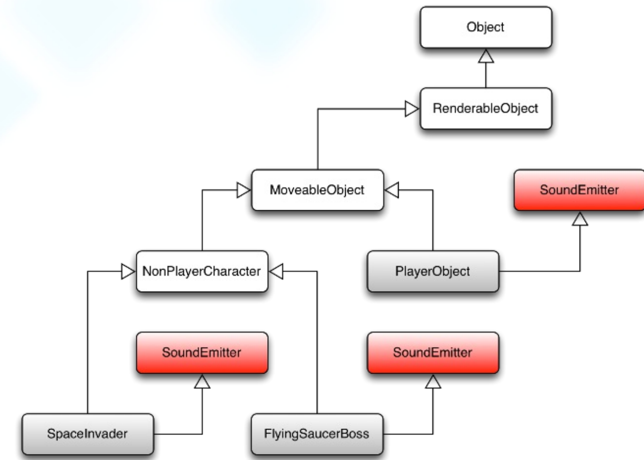
Composition vs Inheritance cont'd

- What about multiple inheritance?



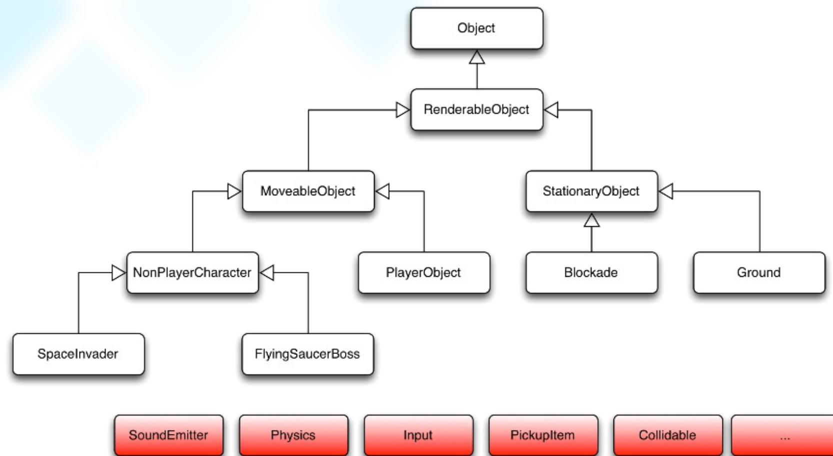
Composition vs Inheritance cont'd

- What about mix-in multiple inheritance?



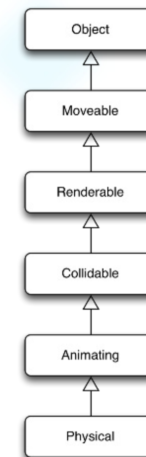
Composition vs Inheritance cont'd

- Does it scale?



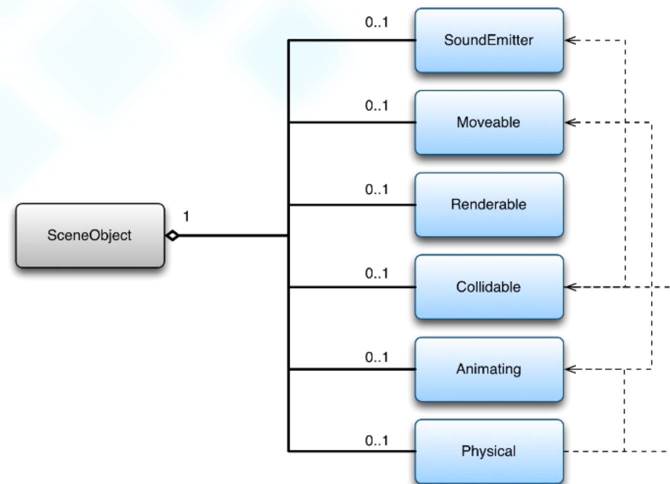
Composition vs Inheritance cont'd

- Is inheritance flexible enough?



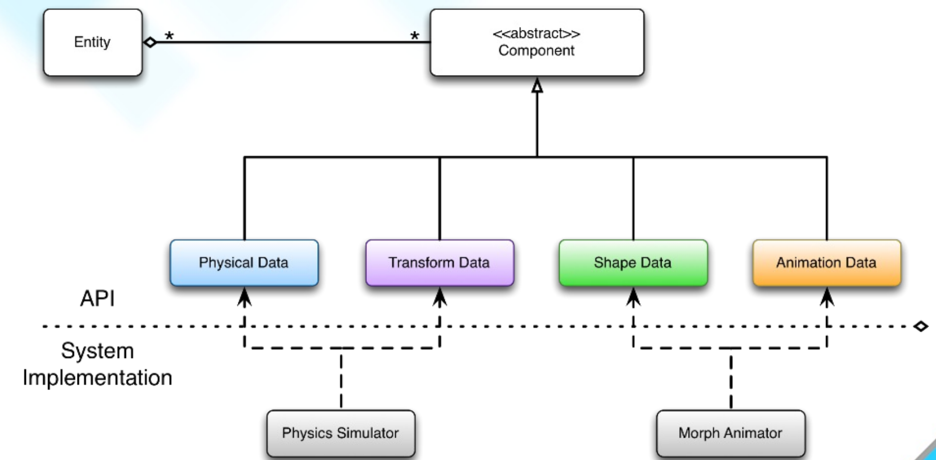
Composition vs Inheritance cont'd

- Is traditional fixed composition the panacea?



Entity Component System

- The Entity/Component data split gives flexibility to manage the API
- The System separation moves the behavior away from data avoiding dependencies between Components



Entity Component System Wrap-up

- Inheritance:
  - Relationships baked in at design time
  - Complex inheritance hierarchies: deep, wide, multiple inheritance
  - Features tend to migrate to base class
- Fixed Composition
  - Relationships still baked in at design time
  - Fixed maximum feature scope
  - Lots of functional domain details in the scene object
  - If functional domain objects contain both data and behavior they will have lots of inter-dependencies
- Entity Component System
  - Allows changes at runtime
  - Avoids inheritance limitations
  - Has additional costs:
    - More QObjects
    - Different to most OOP developer's experience
  - We don't have to bake in assumptions to Qt 3D that we can't later change when adding features.

Qt 3D Basics

Hello Donut

Hello Donut (QML)

- Good practice having root `Entity` to represent the scene
- One `Entity` per "object" in the scene
- Objects given behavior by attaching component subclasses
- For an `Entity` to be drawn it needs:
  - A mesh geometry describing its shape
  - A material describing its surface appearance

Demo qt3d/ex-hellodonut-qml

C++ API vs QML API

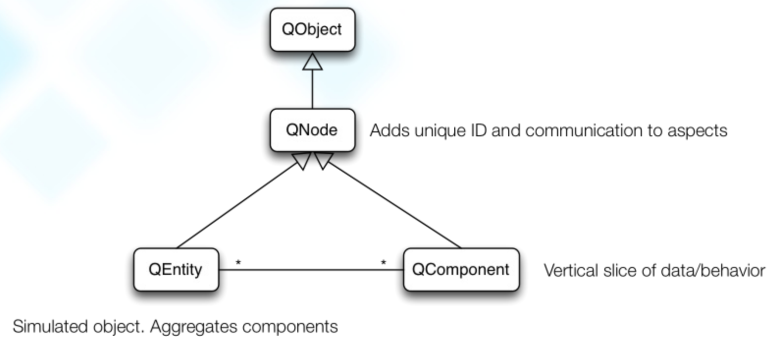
- QML API is a mirror of the C++ API
- C++ class names like the rest of Qt
- QML element names just don't have the Q in front
  - `Qt3DCore::QNode` vs `Node`
  - `Qt3DCore::QEntity` vs `Entity`
  - ...

Qt 3D Basics

Qt 3D ECS Explained

Everything is a QNode

- `Qt3DCore::QNode` is the base type for everything
  - It inherits from `QObject` and all its features
  - Internally implements the frontend/backend communication
- `Qt3DCore::QEntity`
  - It inherits from `Qt3DCore::QNode`
  - It just aggregates `Qt3DCore::QComponents`
- `Qt3DCore::QComponent`
  - It inherits from `Qt3DCore::QNode`
  - Actual data is provided by its subclasses
    - `Qt3DCore::QTransform`
    - `Qt3DRender::QMesh`
    - `Qt3DRender::QMaterial`
    - ...



You Still Need a System

- The simulation is executed by `Qt3DCore::QAspectEngine`
- `Qt3DCore::QAbstractAspect` subclass instances are registered on the engine
  - Behavior comes from the aspects processing component data
  - Aspects control the domains manipulated by your simulation
- Qt 3D provides
  - `Qt3DRender::QRenderAspect`
  - `Qt3DInput::QInputAspect`
  - `Qt3DLogic::QLogicAspect`
- Note that aspects have no API of their own
  - It is all provided by `Qt3DCore::QComponent` subclasses

The Scene Graph

The Scene Graph

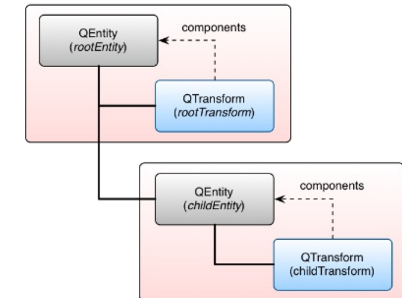
- The scene graph provides the spatial representation of the simulation
  - `Qt3DCore::QEntity`: what takes part in the simulation
  - `Qt3DCore::QTransform`: where it is, what scale it is, what orientation it has
- Hierarchical transforms are controlled by the parent/child relationship
  - Similar to `QWidget`, `QQuickItem`, etc.
- If the scene is rendered, we need a point of view on it
  - This is provided by `Qt3DRender::QCamera`

Qt3DCore::QTransform

- Inherits from `Qt3DCore::QComponent`
- Represents an affine transformation
- Three ways of using it:
  - Through properties: scale3D, rotation, translation
  - Through helper functions: `rotateAround()`
  - Through the matrix property
- Transformations are applied:
  - to objects in Scale/Rotation/Translation order
  - to coordinate systems in Translation/Rotation/Scale order
- Transformations are multiplied along the parent/child relationship

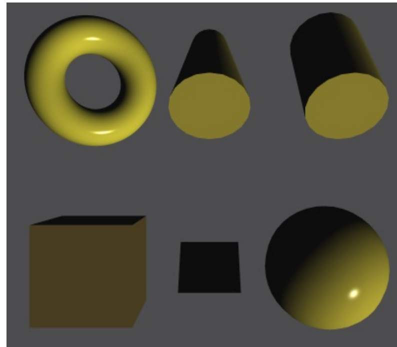
Transforms cont'd

```
1  import Qt3D.Core 2.0
2
3  Entity {
4      components: [
5          Transform {
6              scale3D: Qt.vector3d(1, 2, 1.5)
7              translation: Qt.vector3d(0, 0, -1)
8          }
9      ]
10
11     Entity {
12         components: [
13             Transform { translation: Qt.vector3d(0, 1, 0) }
14         ]
15     }
16 }
```



Geometries

- `Qt3DRender::QRenderAspect` draws `Qt3DCore::QEntitys` with a shape
- `Qt3DRender::QGeometryRenderer's` geometry property specifies the shape
- Qt 3D provides convenience subclasses of `Qt3DRender::QGeometryRenderer`:
  - `Qt3DExtras::QSphereMesh`
  - `Qt3DExtras::QCuboidMesh`
  - `Qt3DExtras::QPlaneMesh`
  - `Qt3DExtras::QTorusMesh`
  - `Qt3DExtras::QConeMesh`
  - `Qt3DExtras::QCylinderMesh`



Qt Demo examples/qt3d/basicshapes-cpp

Making your Own Geometries

- Using `Qt3DRender::QBuffer` we can create our own vertices
- `GeometryRenderer` controls how buffers are combined and parsed
- Useful to make you own geometries programmatically:
  - From a function
  - From data sets
  - From user interaction

Demo qt3d/ex-surface-function

Materials

- If a Qt3DCore::QEntity only has a shape it will appear black
- The Qt3DRender::QMaterial component provides a surface appearance
- Qt 3D provides convenience subclasses of Qt3DRender::QMaterial:
  - Qt3DExtras::QPhongMaterial
  - Qt3DExtras::QPhongAlphaMaterial
  - Qt3DExtras::QDiffuseMapMaterial
  - Qt3DExtras::QDiffuseSpecularMapMaterial
  - Qt3DExtras::QGoochMaterial
  - ...

Demo qt3d/sol-textured-scene

Lights

- Even with shapes and materials we would see nothing
- We need some lights
  - ... luckily Qt 3D sets a default one for us if none is provided
- In general we want some control of the scene lighting
- Qt 3D provides the following light types:
  - DirectionalLight
  - PointLight
  - SpotLight

Lab qt3d/ex-lights-qml

Custom Material example

```
1  import Qt3D.Render 2.0
2  ...
3
4  Material {
5      parameters: Parameter { name: "colorTint"; value: "yellow" }
6      effect: Effect {
7          techniques: [
8              Technique {
9                  filterKeys: FilterKey { name: "renderingStyle"; value: "forward" }
10
11                 graphicsApiFilter {
12                     api: GraphicsApiFilter.OpenGL
13                     majorVersion: 3
14                     minorVersion: 2
15                     profile: GraphicsApiFilter.CoreProfile
16                 }
17
18                 renderPasses: RenderPass {
19                     shaderProgram: ShaderProgram {
20                         vertexShaderCode: loadSource("qrc:/customshader.vert")
21                         fragmentShaderCode: loadSource("qrc:/customshader.frag")
22                     }
23                 }
24             }
25         ]
26     }
27 }
```

Demo qt3d/ex-glsl

Texture Composition and Filtering

- Possible to sample several textures in a single material
- Also easy to reuse stock lighting model
- Then you can blend as you see fit in the shader

Demo qt3d/sol-earth

Interacting with the scene

- High level picking provided by `Qt3DRender::QObjectPicker` component
  - Implicitly associated with mouse device
  - Uses ray-cast based picking
- `Qt3DRender::QObjectPicker` emits signals for you to handle:
  - `pressed(pick), released(pick), clicked(pick)`
  - `moved(pick)` - only when dragEnabled is true
  - `entered(), exited()` - only when hoverEnabled is true
- The containsMouse property provides a more declarative alternative to `entered(), exited()`
- The pick parameter of the signals is a `Qt3DRender::QPickEvent`
  - position in screen space
  - localIntersection in model space
  - worldIntersection in world space

Demo qt3d/ex-object-picker

Demo qt3d/ex-object-picker-qml

- To handle input we first need to generate input events
- Subclasses of `Qt3DInput::QAbstractPhysicalDevice` represent input devices
  - `Qt3DInput::QKeyboardDevice`
  - `Qt3DInput::QMouseDevice`
  - Others can be added later
- On it's own a device doesn't do much
  - Input handlers expose signals emitted in response to events

- Physical devices provide only discrete events
- Hard to use them to control a value over time
- Logical device provides a way to:
  - Have an analog view on a physical device
  - Aggregate several physical devices in a unified device
- Combined with input handler

Demo qt3d/ex-mouse-handler-qml

Putting it All Together: Moving Boxes

- Focus managed using tab
- Focused box appears bigger
- The arrows move the box on the plane
- Page up/down rotate the box on its Y axis
- Boxes light up when on mouse hover
- Clicking on a box gives it the focus
- Boxes can be moved around with the mouse

Demo qt3d/sol-moving-boxes-qml-step3

Integrating with QtQuick using Scene3D

- Provided by the `QtQuick.Scene3D` module
- Takes an `Entity` as child which will be your whole scene
- Loaded aspects are controlled with the aspects property
- Hover events are only accepted if the hoverEnabled property is true

Demo qt3d/ex-controls-overlay

- In 5.9, `Scene2D`, fully interactive Qt Quick UI mapped onto 3D geometry

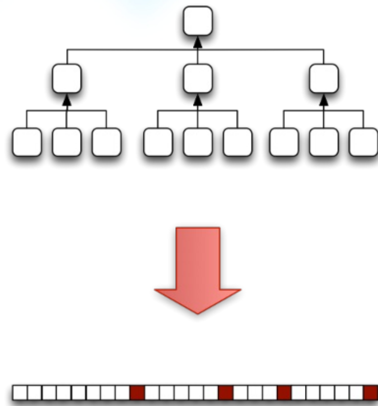
The Qt 3D Frame Graph

What is the Frame Graph For?

- With what we have seen so far, we can:
  - Draw geometry loaded from disk or generated dynamically
  - Use custom materials with shaders to change surface appearance
  - Make use of textures to increase surface details
- What about shadows?
- What about transparency?
- What about post processing effects?
- All these and others require control over *how* we render the Scene Graph
- The Frame Graph describes the rendering algorithm

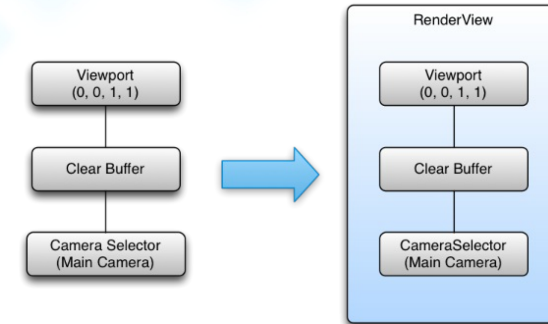
Structure and Behavior

- The nodes of the Frame Graph form a tree
- The entities of the Scene Graph form a tree
- The Frame Graph and Scene Graph are linearized into render commands



The Simplest Frame Graph

- It is important to structure your Frame Graph properly for performance reasons
- Might lead to deep and narrow trees
  - Simplest case being a one pass forward renderer



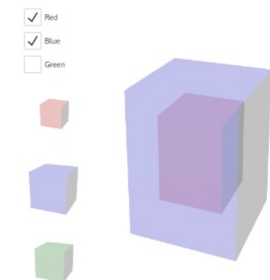
Several Points of View on a Scene

- `Camera` describes a point of view on a scene
- `Viewport` allows to split the render surface in several areas
  - They can be nested for further splitting
- `CameraSelector` allows to select a camera to render in a `Viewport`
- `ClearBuffers` decribes which buffers are cleared during the rendering
  - Generally necessary to get anything on screen
  - Also an easy way to control background color
- To avoid a branch to trigger a rendering give it a `NoDraw` element as leaf

Demo qt3d/ex-viewports

Showing Different Scenes in Viewports

- Our `Viewport`s all display the same scene...
- But they can display different subsets of the scene using layers
- Attach each entity to a `Layer`
- Have each `Viewport` display a subset of the entities using `LayerFilter`



Demo qt3d/ex-viewports-and-layers

- Rendering to a texture, support for framebuffers
- Multiple passes
- Post-Processing Effects

Demo qt3d/ex-gaussian-blur

Demo qt3d/ex-multiple-effects

Beyond the Tip of the Iceberg

- Texture mipmaps
- Cube Maps
- Portability of your code accross several OpenGL versions
- Complete control over the rendering algorithm
- Loading complete objects or scenes from files (3ds, collada, qml...)
- Post-processing effects (single or multi-pass)
- Instanced rendering
- etc.

Demo qt3d/sol-asteroids

Demo qt3d/ex-instanced-geometry

The Future of Qt 3D

What does the future hold for Qt 3D?

- Qt 3D Core
  - Efficiency improvemments
  - Backend threadpool and job handling improvements - jobs spawning jobs
- Qt 3D Render
  - Use Qt Quick or QPainter to render into a texture
  - Embed Qt Quick into Qt 3D including input handling (5.9)
  - Level of Detail (LOD) support for meshes (5.9)
  - Billboards - camera facing entities
  - Text support - 2D and 3D (5.9)
  - Additional materials such as Physics Based Rendering (PBR) materials
  - Particle systems
- Qt 3D Input
  - Axis inputs that apply cumulative axis values as position, velocity or acceleration
  - Additional input device support
    - 3D mouse controllers, game controllers
  - Enumerated inputs such as 8-way buttons, hat switches or dials

What does the future hold for Qt 3D?

- New aspects:
  - Collision Detection Aspect
    - Allows to detect when entities collide or enter/exit volumes in space
  - Animation Aspect
    - Keyframe animation (5.9 TP)
    - Skeletal animation
    - Morph target animation
    - Removes animation workload from main thread
  - Physics Aspect
    - Rigid body and soft body physics simulation
  - AI Aspect, 3D Positional Audio Aspect ...
- Tooling:
  - Design time tooling - scene editor
  - Qt 3D Studio
  - Build time tooling - asset conditioners for meshes, textures etc.

What does the future hold for Qt 3D?

- Qt 3D and the rest of Qt:
  - DataVis, Mapping are likely to be based on Qt 3D
  - Work on unifying rendering toolset
    - Single renderer, Vulkan, D12, Metal backends