Week 11

Particle Systems

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Objectives

- Explore texture atlases, mapping and vertex arrays
- Implement particle systems to create effects
- Implement animation to show an object in motion
- Render textures and utilize shaders to create a distinct look

Texture Atlases

- A **texture atlas** is a single texture that contains multiple objects
  - Also known as a sprite sheet or tile set
  - Results in fewer image files thus reducing switching between textures
  - SFML sprite class `sf::Sprite` contains a texture rectangle containing pixel coordinates
  - Rectangle is of type `sf::IntRect`

Texture Atlases (cont'd.)

- Aircraft, projectile and pickup textures will be merged to one texture, with an ID of `Entities`
- Eventually, we only have the following identifiers:

```
namespace Textures
{
    enum ID
    {
        Entities,
        Jungle,
        TitleScreen,
        Buttons,
        Explosion,
        Particle,
        FinishLine,
    };
}
```

Texture Atlases (cont'd.)

- We modify our data tables to store a texture rectangle in addition to the texture ID as below:

```
struct AircraftData
{
    Textures::ID texture;
    sf::IntRect textureRect;
    ...
};

std::vector<AircraftData> initializeAircraftData()
{
    std::vector<AircraftData> data(Aircraft::TypeCount);
    data[Aircraft::Eagle].texture = Textures::Entities;
    data[Aircraft::Eagle].textureRect = sf::IntRect(0, 0, 48, 64);
    ...

    return data;
}
```

Texture Atlases (cont'd.)

- Then we initialize the sprite with both texture and texture rect:

```
namespace
{
    const std::vector<AircraftData> Table = initializeAircraftData();
}

Aircraft::Aircraft(Type type, const TextureHolder& textures,
    const FontHolder& fonts) : mSprite(
    textures.get(Table[type].texture), // sf::Texture
    Table[type].textureRect) // sf::IntRect
    , ...
{
    centerOrigin(mSprite);
    ...
}
```

Rendering in SFML

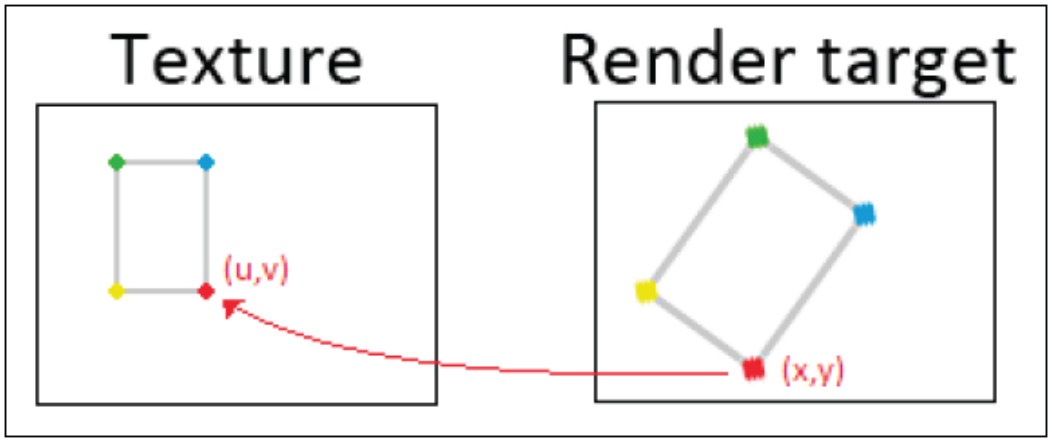
- SFML is built atop the Open Graphics Library (OpenGL)
- A render target is the place where 2D objects such as sprites, text or shapes are rendered
- SFML uses the abstract base class sf::RenderTarget
  - `clear()` and `draw()` methods
- A render window is a concrete implementation of a render target
  - The class is `sf::RenderWindow`

Rendering in SFML (cont'd.)

- A render texture is another realization of the render target concept
  - You do not draw objects to a window
  - Instead to a texture
  - Class is `sf::RenderTexture`

Texture Mapping

- A texel (texture element) is the term used for pixels in texture space
- A vertex is a point that defines the geometry of an object
  - Create lines, triangles, rectangles, etc.
- Texture mapping defines how target coordinates are mapped onto texture coordinates



Texture Mapping (cont'd.)

- SFML provides `sf:Vertex` that represents a vertex
  - `sf::Vector2f position` – the target coordinates (x,y)
  - `sf::Vector2f texCoords` – the texture coordinates (u,v)
  - `sf::Color color` – used to colorize the vertex

Vertex Arrays

- A vertex array is a collection of vertices that are drawn together
  - The class is `sf::VertexArray`
  - Below is a small, incomplete example of how everything interacts:

```
sf::Vertex v;
v.position = sf::Vector2f(x, y);
v.texCoords = sf::Vector2f(u, v);
v.color = sf::Color::Blue;

sf::VertexArray vertices;
vertices.setPrimitiveType(sf::Quads);
vertices.append(v);
...

sf::RenderTarget& target = ...;
target.draw(vertices);
```

Particle Systems

- A particle system manages the behavior of many particles to a desired effect
  - **Emitters** create new particles continuously
  - **Affectors** essentially animate or change particles

- We don`t model each particle to a sprite as each one would have to be drawn separately
- Instead, each particle is modeled as an object with four vertices and then inserted into a single vertex array
- Then, we have a method to draw them all with only one draw call

Particle Systems (cont'd.)

Particle Systems (cont'd.)

```
struct Particle
{
   enum Type
   {
      Propellant,
      Smoke,
      ParticleCount
   };
   sf::Vector2f position;
   sf::Color color;
   sf::Time lifetime;
};

struct ParticleData
{
   sf::Color color;
   sf::Time lifetime;
};
```

Particle Nodes

```
class ParticleNode : public SceneNode
{
public:
    ParticleNode( Particle::Type type, const TextureHolder& textures);
    void addParticle( sf::Vector2f position);
    Particle::Type getParticleType() const;
    virtual unsigned int getCategory() const;
    ...
private:
    std::deque<Particle> mParticles;
    const sf::Texture& mTexture;
    Particle::Type mType;
    mutable sf::VertexArray mVertexArray;
    mutable bool mNeedsVertexUpdate;
};
```

Particle Nodes (cont'd.)

```
void ParticleNode::addParticle(sf::Vector2f position)
{
    Particle particle;
    particle.position = position;
    particle.color = Table[mType].color;
    particle.lifetime = Table[mType].lifetime;
    mParticles.push_back(particle);
}

void ParticleNode::updateCurrent(sf::Time dt, CommandQueue&)
{
    while (!mParticles.empty() && mParticles.front().lifetime <= sf::Time::Zero)
        mParticles.pop_front();

    FOREACH(Particle& particle, mParticles)
        particle.lifetime -= dt;

    mNeedsVertexUpdate = true;
}
```

Particle Nodes (cont'd.)

```
void ParticleNode::drawCurrent(sf::RenderTarget& target,
   sf::RenderStates states) const
{
   if (mNeedsVertexUpdate)
   {
       computeVertices();
       mNeedsVertexUpdate = false;
   }
   states.texture = &mTexture;
   target.draw(mVertexArray, states);
}
```

Particle Nodes (cont'd.)

```
void ParticleNode::computeVertices() const
{
    sf::Vector2f size(mTexture.getSize());
    sf::Vector2f half = size / 2.f;

    mVertexArray.clear();

    FOREACH(const Particle& particle, mParticles)
    {
        sf::Vector2f pos = particle.position;
        sf::Color c = particle.color;
        float ratio = particle.lifetime.asSeconds()
                / Table[mType].lifetime.asSeconds();
        c.a = static_cast<sf::Uint8>(255 * std::max(ratio, 0.f));

        addVertex(pos.x - half.x, pos.y - half.y, 0.f, 0.f, c);
        addVertex(pos.x + half.x, pos.y - half.y, size.x, 0.f, c);
        addVertex(pos.x + half.x, pos.y + half.y, size.x, size.y, c);
        addVertex(pos.x - half.x, pos.y + half.y, 0.f, size.y, c);
    }
}
```

Particle Nodes (cont'd.)

```
void ParticleNode::addVertex(float worldX, float worldY,
   float texCoordX, float texCoordY, const sf::Color& color) const
{
   sf::Vertex vertex;
   vertex.position = sf::Vector2f(worldX, worldY);
   vertex.texCoords = sf::Vector2f(texCoordX, texCoordY);
   vertex.color = color;
   mVertexArray.append(vertex);
}
```

Emitter Nodes

```
class EmitterNode : public SceneNode
{
public:
   explicit EmitterNode(Particle::Type type);
   ...
private:
   sf::Time mAccumulatedTime;
   Particle::Type mType;
   ParticleNode* mParticleSystem;
};
```

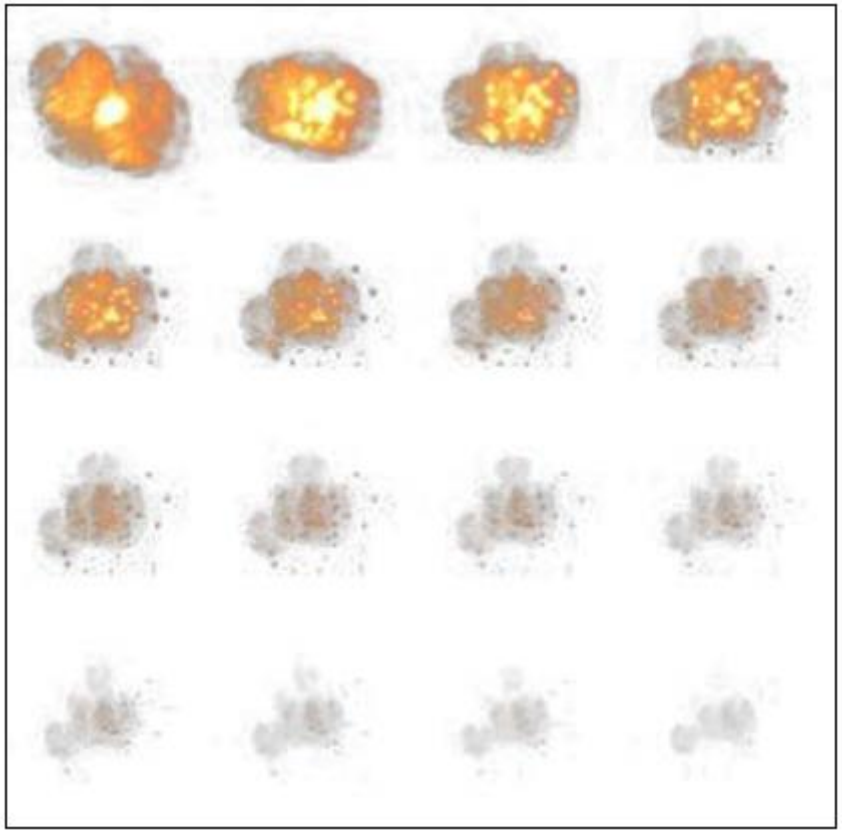
Emitter Nodes (cont'd.)

```
void EmitterNode::updateCurrent(sf::Time dt, CommandQueue& commands)
{
   if (mParticleSystem)
   {
       emitParticles(dt);
   }
   else
   {
       auto finder = [this] (ParticleNode& container, sf::Time)
       {
              if (container.getParticleType() == mType)
                     mParticleSystem = &container;
       };
       Command command;
       command.category = Category::ParticleSystem;
       command.action = derivedAction<ParticleNode>(finder);
       commands.push(command);
   }
}
```

Emitter Nodes (cont'd.)

```
void EmitterNode::emitParticles(sf::Time dt)
{
   const float emissionRate = 30.f;
   const sf::Time interval = sf::seconds(1.f) / emissionRate;
   mAccumulatedTime += dt;
   while (mAccumulatedTime > interval)
   {
       mAccumulatedTime -= interval;
       mParticleSystem->addParticle(getWorldPosition());
   }
}
```

Animated Sprites



Animated Sprites (cont'd.)

```
class Animation : public sf::Drawable, public sf::Transformable
{
public:
   ...
private:
   ...
   sf::Sprite mSprite;
   sf::Vector2i mFrameSize;
   std::size_t mNumFrames;
   std::size_t mCurrentFrame;
   sf::Time mDuration;
   sf::Time mElapsedTime;
   bool mRepeat;
};
```

Animated Sprites (cont'd.)

```
void Animation::update(sf::Time dt)
{
    sf::Time timePerFrame = mDuration / static_cast<float>(mNumFrames);
    mElapsedTime += dt;
    sf::Vector2i textureBounds(mSprite.getTexture()->getSize());
    sf::IntRect textureRect = mSprite.getTextureRect();

    if (mCurrentFrame == 0)
        textureRect = sf::IntRect(0, 0, mFrameSize.x, mFrameSize.y);
```

Animated Sprites (cont'd.)

```
    while (mElapsedTime >= timePerFrame && (mCurrentFrame <= mNumFrames || mRepeat))
    {
       textureRect.left += textureRect.width;
       if (textureRect.left + textureRect.width > textureBounds.x)
       {
         textureRect.left = 0;
         textureRect.top += textureRect.height;
       }
       mElapsedTime -= timePerFrame;
       if (mRepeat)
       {
         mCurrentFrame = (mCurrentFrame + 1) % mNumFrames;
         if (mCurrentFrame == 0)
                   textureRect = sf::IntRect(0, 0, mFrameSize.x, mFrameSize.y);
       }
       else
       {
         mCurrentFrame++;
       }
    }
    mSprite.setTextureRect(textureRect);
}
```

Post Effects

```
class PostEffect
{
public:
   virtual ~PostEffect();
   virtual void apply(const sf::RenderTexture& input,
       sf::RenderTarget& output) = 0;
   static bool isSupported();
protected:
   static void applyShader(const sf::Shader& shader,
       sf::RenderTarget& output);
};
```

Post Effects (cont'd.)

```
void World::draw()
{
   if (PostEffect::isSupported())
   {
      mSceneTexture.clear();
      mSceneTexture.setView(mWorldView);
      mSceneTexture.draw(mSceneGraph);
      mSceneTexture.display();
      mBloomEffect.apply(mSceneTexture, mTarget);
   }
   else
   {
      mTarget.setView(mWorldView);
      mTarget.draw(mSceneGraph);
   }
}
```

Post Effects (cont'd.)

```
void PostEffect::applyShader(const sf::Shader& shader, sf::RenderTarget& output)
{
    sf::Vector2f outputSize = static_cast<sf::Vector2f>(output. getSize());

    sf::VertexArray vertices(sf::TrianglesStrip, 4);
    vertices[0] = sf::Vertex(sf::Vector2f(0, 0), sf::Vector2f(0, 1));
    vertices[1] = sf::Vertex(sf::Vector2f(outputSize.x, 0), sf::Vector2f(1, 1));
    vertices[2] = sf::Vertex(sf::Vector2f(0, outputSize.y), sf::Vector2f(0, 0));
    vertices[3] = sf::Vertex(sf::Vector2f(outputSize), sf::Vector2f(1, 0));

    sf::RenderStates states;
    states.shader = &shader;
    states.blendMode = sf::BlendNone;
    output.draw(vertices, states);
}
```

Shaders

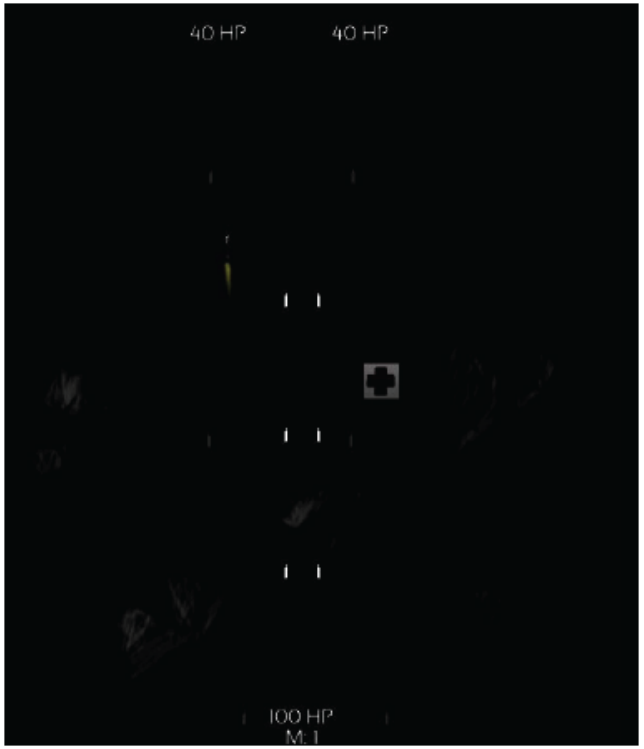
- A shader is a program that is executes on the data you provide
  - Vertices, textures and more
- Bloom:

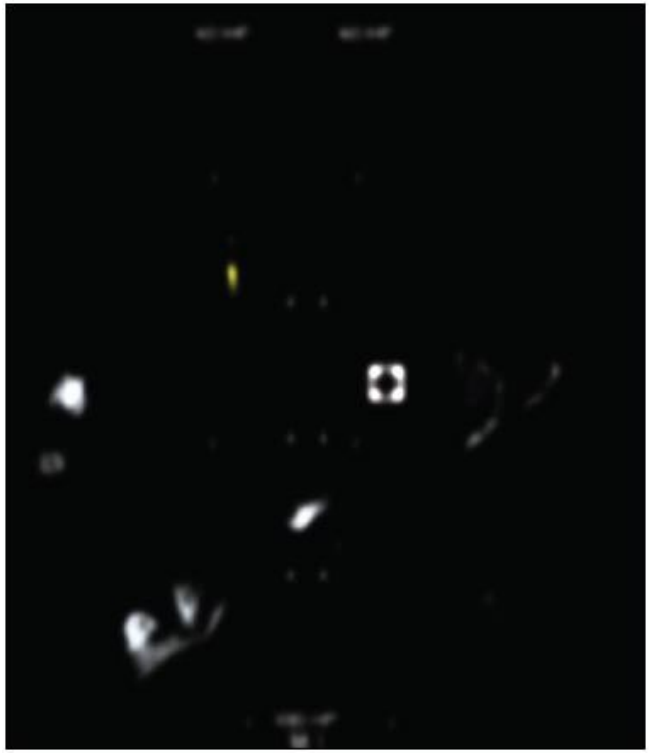
Bloom

- To achieve the bloom effect, we have multiple shader passes
- Source image:

Bloom (cont'd.)

- Brightness pass and Gaussian blur





Bloom (cont'd.)

- The following is an exaggerated demonstration:

Bloom (cont'd.)

```
void BloomEffect::apply(const sf::RenderTexture& input, sf::RenderTarget& output)
{
    prepareTextures(input.getSize());
    filterBright(input, mBrightnessTexture);

    downsample(mBrightnessTexture, mFirstPassTextures[0]);
    blurMultipass(mFirstPassTextures);

    downsample(mFirstPassTextures[0], mSecondPassTextures[0]);
    blurMultipass(mSecondPassTextures);

    add(mFirstPassTextures[0], mSecondPassTextures[0], mFirstPassTextures[1]);
    mFirstPassTextures[1].display();
    add(input, mFirstPassTextures[1], output);
}
```

Bloom (cont'd.)

```
void BloomEffect::prepareTextures(sf::Vector2u size)
{
   if (mBrightnessTexture.getSize() != size)
   {
      mBrightnessTexture.create(size.x, size.y);
      mBrightnessTexture.setSmooth(true);
      mFirstPassTextures[0].create(size.x / 2, size.y / 2);
      mFirstPassTextures[0].setSmooth(true);
      mFirstPassTextures[1].create(size.x / 2, size.y / 2);
      mFirstPassTextures[1].setSmooth(true);
      mSecondPassTextures[0].create(size.x / 4, size.y / 4);
      mSecondPassTextures[0].setSmooth(true);
      mSecondPassTextures[1].create(size.x / 4, size.y / 4);
      mSecondPassTextures[1].setSmooth(true);
   }
}
```

Bloom (cont'd.)

```
void BloomEffect::filterBright(const sf::RenderTexture& input, sf::RenderTexture& output)
{
    sf::Shader& brightness = mShaders.get(Shaders::BrightnessPass);

    brightness.setParameter("source", input.getTexture());
    applyShader(brightness, output);
    output.display();
}

void BloomEffect::blurMultipass(RenderTextureArray& renderTextures)
{
    sf::Vector2u textureSize = renderTextures[0].getSize();

    for (std::size_t count = 0; count < 2; ++count)
    {
         blur(renderTextures[0], renderTextures[1], sf::Vector2f(0.f, 1.f /
         textureSize.y));
         blur(renderTextures[1], renderTextures[0], sf::Vector2f(1.f /
         textureSize.x, 0.f));
    }
}
```

Bloom (cont'd.)

```
void BloomEffect::blur(const sf::RenderTexture& input, sf::RenderTexture& output, sf::Vector2f
    offsetFactor)
{
    sf::Shader& gaussianBlur = mShaders.get(Shaders::GaussianBlurPass);
    gaussianBlur.setParameter("source", input.getTexture());
    gaussianBlur.setParameter("offsetFactor", offsetFactor);
    applyShader(gaussianBlur, output);
    output.display();
}

void BloomEffect::downsample(const sf::RenderTexture& input, sf::RenderTexture& output)
{
    sf::Shader& downSampler = mShaders.get(Shaders::DownSamplePass);
    downSampler.setParameter("source", input.getTexture());
    downSampler.setParameter("sourceSize", sf::Vector2f(input.
    getSize()));
    applyShader(downSampler, output);
    output.display();
}

void BloomEffect::add(const sf::RenderTexture& source, const sf::RenderTexture& bloom,
    sf::RenderTarget& output)
{
    sf::Shader& adder = mShaders.get(Shaders::AddPass);
    adder.setParameter("source", source.getTexture());
    adder.setParameter("bloom", bloom.getTexture());
    applyShader(adder, output);
}
```

GLSL Tutorial

- http://www.lighthouse3d.com/tutorials/glsl-tutorial