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SFML Game Development

Learn how to use SFML 2.0 to develop your own feature-packed game

Foreword by Laurent Gomila, Author of SFML

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Jan Haller

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Foreword

I'm really honored to write the first words of this book, the very first one about SFML. When I started to write this library, in 2006, I couldn't imagine that it would become so much popular. Around 100,000 visitors per month, 100 new forum posts everyday... this is huge! And this is just the beginning; with the release of SFML 2.0, the library makes an important step forward. While SFML 1 is a constantly evolving (understand "unstable") API, SFML 2.0 is meant to be a robust, stable, and mature foundation for the future. And hopefully a solid base for more and more great games.

Increasing popularity also means more effort from the authors to provide complete
.

othing more
than an improved API documentation. Users often ask me where they can find a
y,
job to fill
book that
covers the basics of game programming, as well as everything that SFML has to
appreciate
about this book is that it is written with the same philosophy that is behind SFML: good design, simplicity, and modern code.

I hope you will enjoy reading this book as much as I did and find what you're looking for; whether you're a beginner who wants to learn game programming with SFML, or a more experienced programmer who wants to improve his design and
ve questions
glad to
answer you.

Laurent Gomila

Author of SFML

Software Engineer, Tegesoft, France

About the Authors

Artur Moreira is a game development enthusiast who ultimately aims to start a
g
games and game-related software for over 4 years. Most of the effort in that time was put in creating an open source game-making library with lots of flexibility and portability. The library is called *Nephilim* and is known for supporting all major
s-
rototypes
and games for educational and commercial purposes.

Aside from the programming, he also puts some focus in creative areas such as 3D modeling, digital painting, and music composing.

I would like to thank, first of all, my girlfriend for her patience and unconditional support every single time the writing was taking all of my time and energy. Also, I can't be thankful enough for the support of my parents and sisters, along with all the closest relatives, whose support is ever-present and always helpful. On the technical side, I would like to directly thank Jan Haller and Henrik Vogelius Hansson, the co-authors of the book, for their remarkable collaboration, skill, and teamwork. It's been always a pleasure to work with them.

Henrik Vogelius Hansson has always been in love with both games and
the indie
scene with Defrost Games and their game *Project Temporality*. The next company that
such as
Crusader Kings 2.

community and has even provided a binding for Ruby called *rbSFML*.

I would like to thank my co-authors, Jan and Artur, for the amazing cooperation and great times. I am also very happy and would like to thank my family that encouraged me to pursue this line of work. Also special thanks to my grandmother.

Jan Haller
Technology. In his free time, he occasionally develops games in C++. He is also interested in the creation of graphics and 3D models.

many of his
aracter
has to firious
nity,
getting a lot of insights into the development of SFML 2. He has also written a C++ library called *Thor*, which extends SFML by ready-to-use features such as particle systems or animations.

I would like to thank Laurent Gomila for the passion and huge efforts he invested into the Simple and Fast Multimedia Library. It has always been interesting to discuss with him about the library and its development process. I would also like to thank my co-authors, Artur Moreira and Henrik Vogelius Hansson, who have been a very nice team to work with.

About the Reviewers

Brandon DeRosier is a free software supporter, software engineer, and a hobbyist
game developer living in the Greater Boston area. Driven by an early interest
of his
alongside
these games. Over time, he developed his skills as a programmer—as well as an
ly, he is
directing these skills and interests towards game design.

As a member of the Free Software Foundation, he understands that the
concealing of source code is unethical and regressive; dedicated to the digital
ent and
distribution of free software.

Brandon is currently pursuing a Bachelor of Science degree in Computer
n helping
others learn. Occasionally, he gives lectures in classes and clubs, with hopes of
ch as
SFML and LWJGL.

I'd like to thank my partner, Yamilah Atallah, for brainstorming
game ideas with me, coming up with meaningful concepts and
wonderful designs, and changing my life in so many positive ways;
with this support, my interest in game development has grown.

Karol Gasiński is a programmer, entrepreneur, and traveler living in Poland, Europe. He works as a Graphic Software Engineer at an Intel Research &
ards. As a
and
OpenGL ES Specifications—the industry standard for high-performance graphics.

-level
ears. In
the past, he has worked on mobile versions of games such as *Medieval Total War*, *Pro Evolution Soccer*, and *Silent Hill*. Currently he is the founder and chairman of
astest
growing industry event in the country.

Karol gives lectures on most Polish conferences and events for game developers including WGK, GameDay, SWPC, the DigitalFrontier course, IGK, and others. You can also meet him on GDC Europe and GDC San Francisco, where each year he gathers inspiration for his new games.

Eyal Kalderon is a self-taught computer programmer and high school student.
yal
developed his early skills in Visual Basic and made a switch to C# early on. Eyal has made himself at home for several years now programming with C and C++ and using shell scripts to automate every task he finds boring. After trying SDL, Eyal switched to SFML in 2010, enjoyed it, and has been following its progress closely ever since.

nd
professional publications, Eyal chose to erect 'nullpwd' (`nullpwd.wordpress.com`)
midating
front for various software topics, such as programming, penetration systems, and the current happenings of the open source community.

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for immediate access.

Table of Contents

Preface

Welcome to the pages of *SFML Game Development*!

Whether you are just grabbing our book in a store, previewing it in your e-book reader, or you have already bought it—you have taken your first step in becoming a game developer by picking up this book.

ent
fields such as software development, graphical design, music composition, and
yet
developers never cease to be creative and to come up with innovations. This book conveys the process of game development in a way that covers state-of-the-art techniques, leaving you ready to implement your own ideas.

itious
newcomer to the field of making games. Although the book requires no previous
iques
that will help you grow as a game developer.

Throughout the book, we develop a 2D game with SFML. We focus on a top-scrolling aircraft shooter, where the player acts as a pilot and is confronted with various challenges. We begin with the bare bones of each element and continuously add functionality as we progress in the book. In every chapter, new features are introduced, and the code is updated accordingly. Therefore, you will not only see the concepts in theory, but also will have a direct implementation at hand, which you can investigate and extend the way you like.

s of this
book. May it be a good experience in all its extent! Please enjoy!

What this book covers

Chapter 1, *Making a Game Tick*, introduces the SFML library and shows you basic concepts such as the game loop and rendering.

Chapter 2, *Keeping Track of Your Textures – Resource Management*, covers the loading and management of external resources such as images, fonts, and sounds.

Chapter 3, *Forge of the Gods – Shaping Our World*, builds up the framework of the game world and addresses the concept of scene graphs and game entities.

Chapter 4, *Command and Control – Input Handling*, shows how to react to user input from the keyboard, mouse, and joystick.

Chapter 5, *Diverting the Game Flow – State Stack*, covers switching between application states such as different menus, or between menus and the game itself.

Chapter 6, *Waiting and Maintenance Area – Menus*, introduces a simple graphical user interface in the menus.

Chapter 7, *Warfare Unleashed – Implementing Gameplay*, approaches actual gameplay mechanisms. Enemies, bullets, missiles, power-ups and collision detection are implemented.

Chapter 8, *Every Pixel Counts – Adding Visual Effects*, enhances the graphical
rs.

Chapter 9, *Cranking Up the Bass – Music and Sound Effects*, explains a way to integrate audio into the game.

Chapter 10, *Company Atop The Clouds – Co-op Multiplayer*, covers networking basics and a multiplayer implementation over the network.

What you need for this book

nd
install it. You can get SFML at `www.sfml-dev.org`; the first chapter gives a brief installation guide.

In case you decide to recompile SFML yourself, you will also require the cross-platform build tool CMake, which can be downloaded from `www.cmake.org`.

Who this book is for

SFML Game Development is aimed at audiences of all ages who already know how to
reader already
has some experience in programming and knows the language well.

The ideal reader for such a book would be a person who is experienced in C++ and
rious
nts to read
learn more
about SFML in a bigger practical example, we strongly encourage to read on!

Conventions

In this book, you will find a number of styles of text that distinguish between
and an
explanation of their meaning.

Code words in text are shown as follows: "To manage all these screens and transitions, we create the `StateStack` class."

A block of code is set as follows:

```
namespace GUI
{
    class Component : public sf::Drawable,
                      public sf::Transformable
   {
        public:
          typedef std::shared_ptr<Component> Ptr;

                              Component();
```

, the
relevant lines or items are set in bold:

```
: mChildren()
, mSelectedChild(-1)
{
}

void Container::pack(std::shared_ptr<GUI::Component> component)
{
```

New terms and **important words** are shown in bold. Words that you see on the is: "It shows a
background with a little information about the game, besides its title and then blinks a big old **Press any key to continue** message".

Warnings or important notes appear in a box like this.

Tips and tricks appear like this.

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1
Making a Game Tick

Through the words in this book, we will attempt to convey the best knowledge we possibly can. We aim to teach techniques that we learned along the years, techniques that we would like to have been told about in our early days of game development. We now write this book to save your time, by showing you directly the solution to common problems, and why things work the way they do.

opment,
we will especially focus on the **Simple and Fast Multimedia Library** (**SFML**). Every part of this book will be about developing a game and leveraging the advantages
we use the C++
programming language, we will try our best to use the language in a modern way,
es, in a
en, however,
it is a good thing if we grow with it and adapt to the possibilities it has to offer in the present day.

This chapter introduces the SFML library and shows you its capabilities by creating a small application. We are going to address the basic concepts relevant to game development, namely; rendering, game loops, and code organization. Furthermore, the first part of our game code developed, will serve as a basis for the coming chapters.

Introducing SFML

Before we start developing a game, we would like to tell you a little bit about the library we will use throughout the book. SFML is an object-oriented C++
ing a
simple, user-friendly **application programming interface** (**API**), and allowing for both high performances and fast development.

ou and the
hardware. It is split into five modules:

- **System**: This is a core module upon which all other modules are built. It provides two-dimensional and three-dimensional vector classes, clocks, threads, and Unicode strings, among other things.
- **Window**: The Window module makes it possible to create application windows, and to collect user input, such as mouse movement or key presses.
- **Graphics**: This module provides all functionalities that are related to two-dimensional rendering, such as images, texts, shapes, and colors.
- **Audio**: SFML also offers a module to work with sound. When you want to
he
module you have to look for.
- **Network**: Another medium SFML covers is the network, a more and more important part of our interconnected world. This module allows you to send
h as
HTTP or FTP.

SFML. We will
ingle class.
We recommend having a look at the SFML documentation, which is available at `www.sfml-dev.org/documentation.php`. The documentation explains every class
ping a
game using SFML.

SFML is open source, which means that you have access to its complete source code. Usually, the implementations aren't relevant to the user, but if you are interested in how something was solved, don't hesitate to skim through SFML's code.

You can use
SFML in both open and closed source projects, both free and commercial.

Downloading and installation

aries, or
recompile them yourself. The first option is simpler, but you have to wait for major
latest development
sources, you can download the current Git revision. The configuration software CMake is used to prepare the sources for compilation with a compiler of your choice. For example, CMake creates Visual Studio solutions or g++ Makefiles. The
h can be
found at `www.sfml-dev.org/tutorials.php`.

As mentioned, SFML is split into five modules. There are five headers to include a complete module (and its dependencies). To include the whole Audio module, you can write:

```
#include <SFML/Audio.hpp>
```

On the other hand, if you need a specific header file, you can find it in the directory of the corresponding module:

```
#include <SFML/Audio/Sound.hpp>
```

Each module is compiled to a separate library, which makes it possible to use only
t can be
rding to the
scheme `sfml-module[-s][-d]`. The `-s` postfix is required if you link statically; the `-d` postfix specifies debug mode. For example, to link the Graphics module statically in release mode, you have to specify the library `sfml-graphics-s` in your linker options. Depending on your compiler, a file extension (such as `.lib`) might be necessary. Keep in mind that some modules depend on others; therefore, you have
hich

An important point to note is that if you link SFML statically, you have to define the macro `SFML_STATIC` in your projects, so that the linker knows what functions to resolve.

In case you do not know how linking a library works for a specific compiler, please refer to the online tutorials. They explain how to install everything correctly, and are always up-to-date.

A minimal example

a minimal
oks like, its
general flow of execution, and some basic functionality.

```
#include <SFML/Graphics.hpp>

int main()
{
    sf::RenderWindow window(sf::VideoMode(640, 480), "SFML 
Application");
    sf::CircleShape shape;
    shape.setRadius(40.f);
    shape.setPosition(100.f, 100.f);
```

```
        shape.setFillColor(sf::Color::Cyan);
        while (window.isOpen())
        {
        sf::Event event;
        while (window.pollEvent(event))
        {
            if (event.type == sf::Event::Closed)
                window.close();
        }
        window.clear();
        window.draw(shape);
        window.display();
        }
    }
```

All this application does is to open a window onto which we can render, with a width of 640 pixels and a height of 480 pixels. Its title says `"SFML Application"`. Then, a cyan geometric circle is created, and while the window is open, it is drawn
hecks for user
input that may have arrived from the underlying window. In our case, we only handle the `sf::Event::Closed` event, which arrives every time the application
press an
application-terminating shortcut, such as *Alt* + *F4*.

t fear.
This book contains all you need to know about this and much more.

A few notes on C++

after
nguage
ters, and
(strings,
streams, and the STL). If you feel unsure, we recommend reading a good C++ book, before or in parallel to this book, since SFML and our code sometimes uses advanced techniques. Game development is a difficult topic on its own; it is very frustrating if you additionally have to fight C++. Even if it takes some time to reasonably learn
u days of
tedious debugging.

C++11
se a new
C++11 technique, we will briefly explain it.

An issue that is widely underestimated, especially by beginners, is the importance of clean code. Before making a game, it is always a good idea to have a rough imagination of the game features and their implementation. It may help to draw sketches on a paper, in order to visualize contexts better. Also during development, it is crucial to keep an eye on the code design, and to refactor messy code where necessary.

Some key aspects of good code are as follows:

- **Modularity**: In this the functionalities are separated, and dependencies

  n of
  s
  by widely avoiding global variables, distributing functionality to different
  de
  base to different headers and implementation files, and try to include only what is really necessary.
- **Abstraction**: In this, the functionality is encapsulated into classes and functions. Code duplication is avoided. The usage of low-level operations, such as manual memory management (`new`/`delete`) is minimized,

  RAII. In short, keep most of your code on a high abstraction level, such that it is expressive and achieves a lot of actions within a few lines. When you need
  l looks
  clean.
- **Code style**: One thing, be consistent. It does not matter what naming convention you use, or if you have a space between `if` and the opening
  keep the
  done
  after several weeks. Use comments where appropriate.

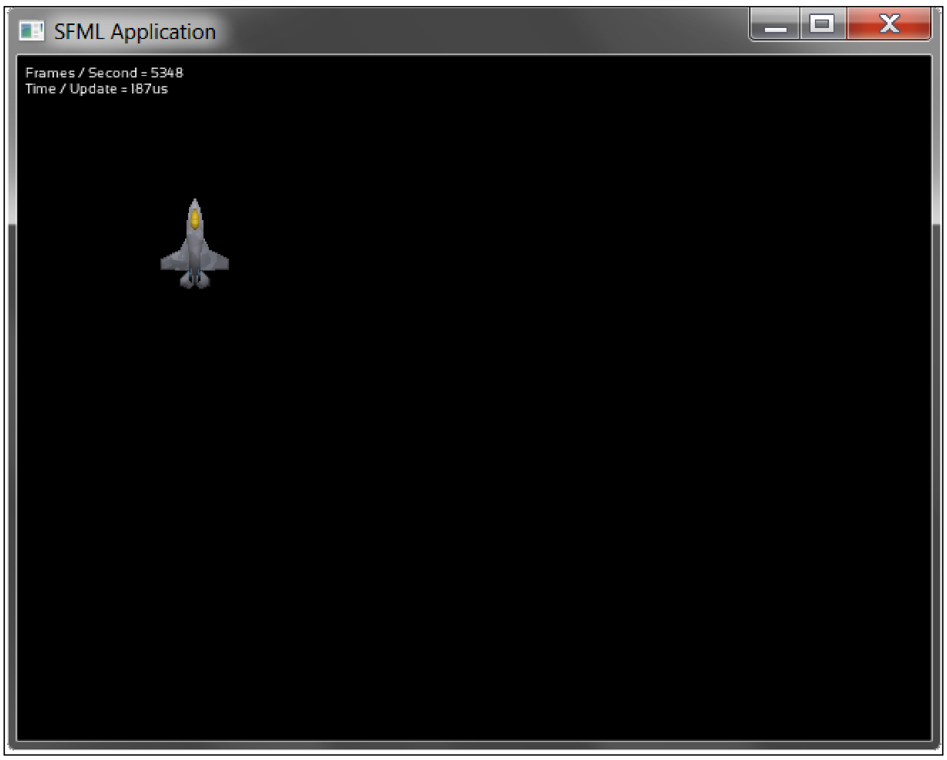
tructured
total mess
gging, or
abstract; you
will automatically gain experience while developing projects.

lable for
download on the Packt Publishing website.

Developing the first game

Now that we got the boring parts finished, we can finally start making a game. So where do we start? What do we do first? First, you should have an idea of what kind
the purpose
ntrols an
aircraft viewed from the top, and has to find its way through a level full of enemies.

the end of
this chapter.



lifies a
oing
the player,
and having a way for the player to manipulate the game.

The Game class

In this chapter, we implement the basis for your game that will get you going. The root for us is a class called `Game`; instead of doing our logic in the `main()` function as we did in the minimal example, we move everything into the `Game` class instead.
de, as we can
extract separate functionality into their own functions, and use them within the `Game`
 the code:
develop
there, these three parts would grow quite a lot, and we would end up with a gigantic wall of code, which would be nearly impossible to navigate. The `Game` class helps us out here.

Here is the general design of the class and its intended usage:

```
class Game
{
    public:
                            Game();
        void                run();

    private:
        void                processEvents();
        void                update();
        void                render();

    private:
        sf::RenderWindow mWindow;
        sf::CircleShape  mPlayer;
};

int main()
{
    Game game;
    game.run();
}
```

As you can clearly see, we replaced all the code in the `main()` function from the minimal example with just a `Game` object and a call to its `run()` function. The idea here is that we have hidden the loop we had previously in the `run()` function. It doesn't happen very often that we have to fiddle with it anyway. Now, we can move the actual code that updates the game to the `update()` function, and the code that renders it to the `render()` function. The method `processEvents()` is responsible for player input. So if we want to get something actually done, we implement it in one of the three private functions.

Downloading the example code

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Let's have a look at the code now:

```
Game::Game()
: mWindow(sf::VideoMode(640, 480), "SFML Application")
, mPlayer()
{
    mPlayer.setRadius(40.f);
    mPlayer.setPosition(100.f, 100.f);
    mPlayer.setFillColor(sf::Color::Cyan);
}
void Game::run()
{
    while (mWindow.isOpen())
    {
        processEvents();
        update();
        render();
    }
}
```

The function `processEvents()` handles user input. It polls the application window for any input events, and will close the window if a `Closed` event occurs (the user clicks on the window's **X** button).

```
void Game::processEvents()
{
    sf::Event event;
    while (mWindow.pollEvent(event))
    {
        if (event.type == sf::Event::Closed)
            mWindow.close();
    }
}
```

The method `update()` updates the game logic, that is, everything that happens in the fill it as
we add functionality to the game.

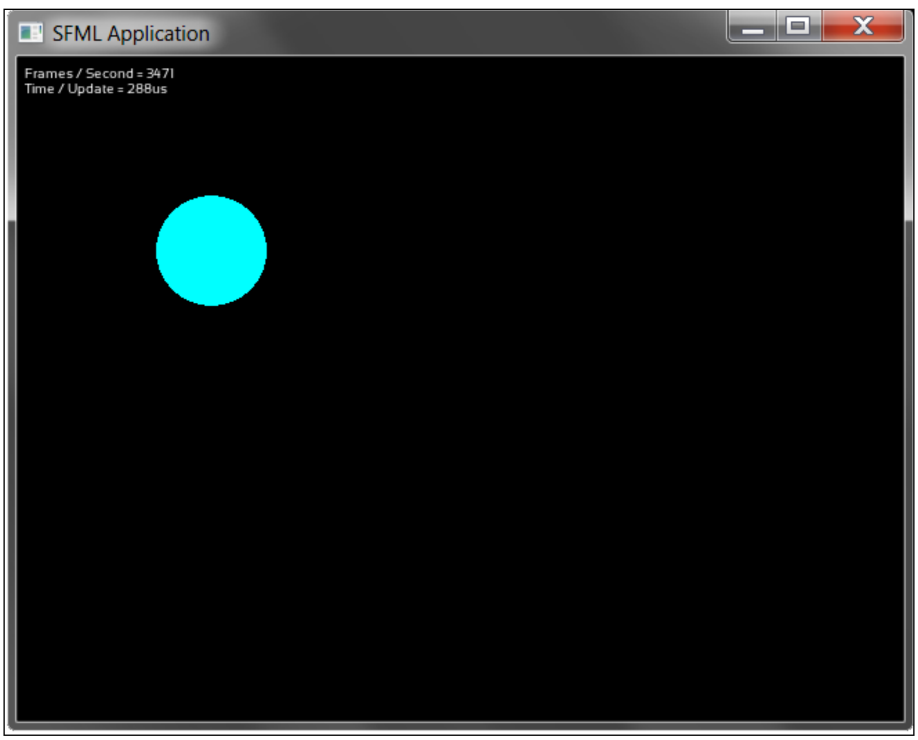
```
void Game::update()
{
}
```

The `render()` method renders our game to the screen. It consists of three parts.
utput of the
f the current
frame by calling the `sf::RenderWindow::draw()` method. After we have drawn everything, we need to actually display it on the screen. The `render()` method looks as follows:

```
void Game::render()
{
    mWindow.clear();
    mWindow.draw(mPlayer);
    mWindow.display();
}
```

cyan circle,
we are going to have a deeper look at the rendering step.

ll looks like it
ler part.



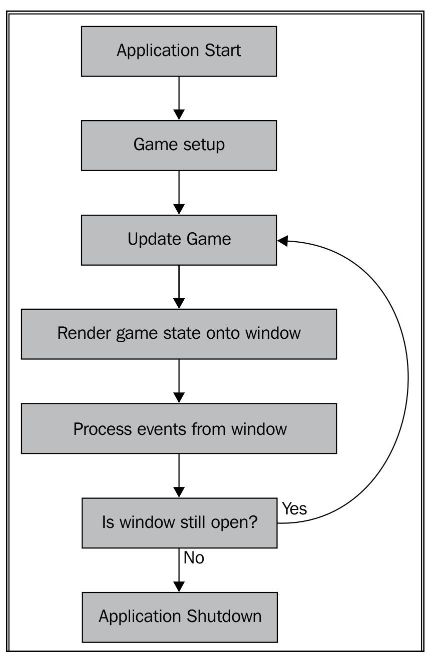
FML minimal
ing fancy
yet, but we are well on our way.

Game loops and frames

Now talking a little more in-depth about the loop we have placed in the `run()` function. This loop is most often called the **main loop** or the **game loop** because it
o iterate, the
to terminate its
execution as soon as the window ceases to exist.

events
from the window, then we update the game, and finally we render the results on the screen. An iteration of the game loop is most often called a **frame** or a **tick**. You might have heard of the term **frames per second** (**FPS**). This is a measurement of how many loop iterations the game can do during a second. Sometimes, the concept
o encompass the
input processing and logic updates as well.

We can explain this visually with a flow chart to further help you see clearly the logic of our loop.



y thing left
out is the event processing. That functionality could have its own flow chart. But it
self if the user
requests it.

is done
nless we
explicitly tell it to. So, if we don't tell it to draw the circle, it won't draw it. If the state
r a new
know that
the graphics have changed.

ppen over
.

Input over several frames

First we have to be able to detect that the user is pressing down a key on his
we will
settle with input detection by responding to *events*.

What are events? The word itself implies something that is happening with our
interacts
. For our
s to a
uniform structure that we can use with ease: `sf::Event`. Once the window internally detects that some kind of input has happened, it will store an `sf::Event` object containing information about that input. We will then poll all those events as fast as we can, in order to respond to them.

SFML supports a wide variety of events, but there are two event types that interest us here: `sf::Event::KeyPressed` and `sf::Event::KeyReleased`. They represent a key being pressed and released respectively.

indow for
events, and have a case differentiation on the event type.

```
void Game::processEvents()
{
    sf::Event event;
    while (mWindow.pollEvent(event))
    {
        switch (event.type)
        {
```

For each time the `while` loop iterates, it means a new event that was registered by
e will only
check for some types of events, which are of our interest right now.

```
                case sf::Event::KeyPressed:
                    handlePlayerInput(event.key.code, true);
                    break;
                case sf::Event::KeyReleased:
                    handlePlayerInput(event.key.code, false);
                    break;
                case sf::Event::Closed:
                    mWindow.close();
                    break;
            }
        }
    }
```

In the `handlePlayerInput()` function, we check which key on the keyboard has been pressed or released. To store this information, we use four Boolean member variables: `mIsMovingUp`, `mIsMovingDown`, `mIsMovingLeft`, and `mIsMovingRight`. We set the corresponding variable depending on the key being pressed or released.

```
void Game::handlePlayerInput(sf::Keyboard::Key key,
bool isPressed)
{
    if (key == sf::Keyboard::W)
        mIsMovingUp = isPressed;
    else if (key == sf::Keyboard::S)
        mIsMovingDown = isPressed;
    else if (key == sf::Keyboard::A)
        mIsMovingLeft = isPressed;
    else if (key == sf::Keyboard::D)
        mIsMovingRight = isPressed;
}
```

In `Game::handlePlayerInput()` we receive the enumerator describing the key that was pressed or released. The flag describing whether a press or release occurred is passed as the second argument. So we check what key the user is manipulating, and change our state depending on that.

when we
main loop
ew position
depending on this input. This method gives us a great advantage. So finally we can write something in our `update()` function, namely, the movement of our player.
ne the
movement accordingly. By using `+=` (instead of `=`) and `if` (instead of `else if`), we
ft are pressed
at the same time—the `movement` stays zero. The `update()` function is shown in the following code snippet:

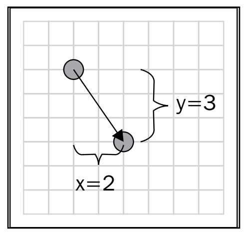
```
void Game::update()
{
    sf::Vector2f movement(0.f, 0.f);
    if (mIsMovingUp)
        movement.y -= 1.f;
    if (mIsMovingDown)
        movement.y += 1.f;
    if (mIsMovingLeft)
        movement.x -= 1.f;
    if (mIsMovingRight)
        movement.x += 1.f;

    mPlayer.move(movement);
}
```

We introduce two new things here: a vector and the `move()` function on the circle shape. The `move()` function does what its name says, it moves the shape by the amount we provide it.

Vector algebra

of rules and
definitions, which go beyond the scope of our book. However, SFML's `sf::Vector2`
To be as
simple as we could possibly be, we know that a coordinate in a two-dimensional Cartesian system would need two components: `x` and `y`. Because in graphics all coordinates are expressed with the decimal `float` data type, `sf::Vector2` is instantiated as `sf::Vector2<float>`, which conveniently has a typedef named `sf::Vector2f`. Such an object is made to contain two member variables, `x` and `y`. This makes our life simpler, because now we don't need to pass two variables to functions, as we can fit both in a single `sf::Vector2f` object. `sf::Vector2f` also defines common vector operations, such as additions and subtractions with other vectors, or multiplications and divisions with scalars (single values), effectively shortening our code.

d to define
positions, but they also are a perfect fit to define orientations. So, a vector is great to
, or even to
little more to
uch as the
directions,
as it makes no sense in positions. We consider a vector normalized if it has length
me direction as
before normalization. The following figure visualizes the vector (2, 3). This vector represents a translation of 2 units to the right and 3 units down.



Please do not confuse `sf::Vector2f` with `std::vector`. While their names are similar, the fily
allocated array from the standard C++ library.

In our case, our vector called `movement` expresses a movement from the origin of
on. It might be
a bit tricky getting into the whole way of thinking in different spaces if you don't like math.

Vector algebra is very interesting, and definitely something very useful if you know it. So we recommend you study it. Mathematics is your friend as soon as you stop fighting it; it really makes a lot of things easier for you in programming. It is almost safe to claim that this subsection of math is the single most important topic when we need to implement gameplay mechanics. A wide range of problems that you will face in almost any kind of game are already solved and well-studied before, so you're better off learning this subject than reinventing the wheel every time. To avoid leaving you hanging, here's an example: Let's say you have point A and point B, which represent two characters in an action game. When the enemy at point A wants to shoot our player at point B, it needs to know the direction in which to shoot the projectile. Why waste your brains thinking on how to solve this problem if this field of math defines this operation as one of its most basic rules? All you need is to find the direction vector C, which is obtained by calculating B minus A. The difference between two positions gives us the direction between the two. Yes, that easy!

Frame-independent movement

circle, but
it won't move uniformly. It will probably be very fast, because currently we have
unning
the `update()` le
of hundreds of times each second, if not more. If we move the shape by one pixel
aking our
little player fly all over the screen. You cannot just change the `movement` value to something lower, as it will only fix the problem for your computer. If you move to a slower or faster computer, the speed will change again.

So how do we solve this? Well, let's look at the problem we are facing. We are having
e
s a simple
formula you should remember from your old school days. It's the formula that goes: *distance* = *speed* * *time*. Now why is this relevant for us? Because with this formula
ways travels
t computer
to make this
work.

```
void Game::update(sf::Time deltaTime)
{
    sf::Vector2f movement(0.f, 0.f);
    if (mIsMovingUp)
        movement.y -= PlayerSpeed;
    if (mIsMovingDown)
        movement.y += PlayerSpeed;
    if (mIsMovingLeft)
        movement.x -= PlayerSpeed;
    if (mIsMovingRight)
        movement.x += PlayerSpeed;

    mPlayer.move(movement * deltaTime.asSeconds());
}
```

The major difference we have made here is that we now receive a time value every
ry frame,
d since
the last frame **delta time** (or **time step**), and often abbreviate it as `dt` in the code. But
s for it.

In SFML, there is a class that measures the time from when it was started. What out the
class `sf::Clock`. It has a function called `restart()`, which lets the clock return ng it ideal
for our current situation. SFML uses the class `sf::Time` for all time formats; it is a convenient data type that can be converted from and to seconds, milliseconds, and microseconds. Here's the modified `Game::run()` member function:

```
void Game::run()
{
    sf::Clock clock;
    while (mWindow.isOpen())
    {
        sf::Time deltaTime = clock.restart();
        processEvents();
        update(deltaTime);
        render();
  }
}
```

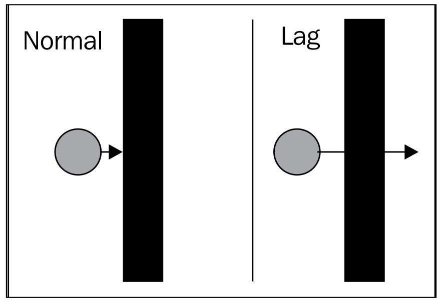
There is no big difference; we create a `clock`, and in every frame we query it for its current elapsed time, restart the `clock`, and then pass this time to the update function.

Fixed time steps

The solution we have come up with so far is sufficient for many cases. But it is not here delta
impossible
d you can't
guarantee that the delta time remains the same.

ime. This
r moves
lide with.
This is why physics engines expect the delta time to be fixed.

The following is a figure describing the problem we are referring to:



What we will do now is use a technique called fixed time steps. We write code that guarantees that in any circumstances, we always give the same delta time to the update function, no matter what happens. If you find that sounding difficult, there is no big difference from what we already have. We just have to do some book-keeping in our code for how much time has passed since we last called the `update()` function.

```
void Game::run()
{
    sf::Clock clock;
    sf::Time timeSinceLastUpdate = sf::Time::Zero;
    while (mWindow.isOpen())
    {
        processEvents();
        timeSinceLastUpdate += clock.restart();
        while (timeSinceLastUpdate > TimePerFrame)
        {
            timeSinceLastUpdate -= TimePerFrame;
            processEvents();
            update(TimePerFrame);
        }
        render();
    }
}
```

elapsed in
a variable `timeSinceLastUpdate`. When we are over the required amount for one frame, we subtract the desired length of this frame (namely `TimePerFrame`), and
. This
the same
logic
frame rate will be set to 60 frames per second by having the `TimePerFrame` constant equal to `sf::seconds(1.f / 60.f)`.

Eventually, we have two `while` loops. The outer one is the game loop as we know it, and calls the `render()` method. The inner one collects user input, and computes
s slow, it may
happen that `processEvents()` and `update()` are called multiple times before one `render()`ate is
ing can
lead to `render()` being called multiple times without a logic update in between.
screen,
o smoothen
the game flow.

led explanations
at `http://gafferongames.com/game-physics/fix-your-timestep`.

Other techniques related to frame rates

e handling
and frame updates. One of them is `sf::sleep()`, a function that interrupts the work on
exact timing
purposes. The method `sf::RenderWindow::setFramerateLimit()` tries to achieve the specified frame rate by calling `sf::sleep()` internally. It is a nice function for testing purposes, but it also lacks precision.

Another important technique is **vertical synchronization**, also known as **V-Sync**. Enabled V-Sync adapts the rate of graphical updates (calls of `sf::RenderWindow::display()`) to the refresh rate of the monitor, usually around 60Hz. This can avoid graphical artifacts such as screen tearing, where a part of your window shows the old frame, and another the new one. You can enable or disable V-Sync using the method `sf::RenderWindow::setVerticalSyncEnabled()`.

Displaying sprites on the screen

ring a boring
single color circle to the screen, let's actually render an image. To do this, SFML provides a couple of tools to make your life easy. First we have the `sf::Texture`
is the
`sf::Sprite`
and how to
put one on the screen.

A simple example of their relationship is as follows:

```
sf::Texture texture;
if (!texture.loadFromFile("path/to/file.png"))
{
  // Handle loading error
}
sf::Sprite sprite(texture);
sprite.setPosition(100.f, 100.f);
window.clear();
window.draw(sprite);
window.display();
```

Here, we load a `texture` from the hard drive, and check if loading has succeeded.
00, 100), relative
to the upper-left window corner.

File paths and working directories

About file paths, it would be useful to make some things clear. First, the slashes that separate directories in a path in order to locate a file will be most often forward slashes (/), especially in Unix-like operating systems. In Windows, you will occasionally see back slashes (\) used instead, but probably not everywhere. Do not let this confuse you, the only true cross-platform way to specify a file path is using forward slashes, so make sure they are always your choice, even in Windows.

n the

ger,
the working directory is exactly where the executable is located; however, this is not
ory, and it
nside the
rectories is
for loading fi
s you make
them absolute by starting them with a slash in Unix-like operating systems, or with a drive letter in Windows.

Real-time rendering

In a game simulation, it is highly likely that there will be changes to what's drawn
most cases
the screen
for that given frame.

Many programs use a render-on-demand approach. They will only redraw a new
rmance
y the nature
e
opted
entirely the concept of **real-time rendering**, which ignores frame requests as they
le. If while
playing your favorite game you eventually noticed a usual FPS count of 30 or 60, this
s, more frames
o the end
processor
power for other tasks, such as logic processing. In short, nowadays, the whole scene
t frame.

To explain the notion of real-time rendering a bit further, we would like to mention the concept of **double buffering** that comes inherently attached to it. Double buffering is a technique that was created to negate graphical glitches derived from
used,
programmers needed to have additional concerns when drawing to the screen, to ensure that only what belongs to a frame is drawn in it, and that there are no remains of pixels from previous frames.

Double buffering defines two virtual screens to draw graphics to. The front buffer
. The front
er is the one
s fully
drawn in the back buffer, we use the SFML's `sf::RenderWindow::display()` function to put the contents of the back buffer on the screen. The back buffer becomes the front buffer, while the front buffer that was set will now be the back
the
previous frame unharmed, as well as a working buffer that we can safely change at
and then
fering.

Adapting the code

In our code, we replace `sf::CircleShape` with `sf::Sprite`, which only requires minor modifications. We load an image file called `Eagle.png`. The relative path to it is `Media/Textures`. Don't worry if you don't have the file; you can download it together with the whole source code.

```
// Game.hpp
class Game
{
    public:
                    Game();
        ...
    private:
        sf::Texture mTexture;
        sf::Sprite  mPlayer;
        ...
};

// Game.cpp
Game::Game()
: ...
, mTexture()
, mPlayer()
{
    if (!mTexture.loadFromFile("Media/Textures/Eagle.png"))
    {
        // Handle loading error
    }
    mPlayer.setTexture(mTexture);
    mPlayer.setPosition(100.f, 100.f);
}
```

No code changes have to be done to get our `render()` function to work with sprites instead of shapes. SFML is nice in that way. Everything that can be drawn to a window has to inherit from the abstract class `sf::Drawable`. As long as it is possible, e, because if
 be identical
or similar functions in other classes.

in the
beginning of the chapter. You are also very well on the way to making your game.

as Snake or Pac-Man with ease.

Summary

ost basic
ways have
present in order to save yourself from losing time in such issues, and instead, focus on making a great game.

In this chapter we:

- Learned what SFML is, and what functionality it provides
- Listened to input, and moved the player over several frames
- Rendered an image to the screen
- Learned about game loops and delta times, and saw the strengths and weaknesses of different approaches to handle time steps.

hat to the
tionality

recommend you try yourself; the only things you need are `sf::Text` and `sf::Font`
asses in
SFML's API documentation at `www.sfml-dev.org`.

This concludes our introduction chapter. From now on we are going to investigate different aspects of SFML and game development in a more detailed manner. In the next chapter, we start with resource handling, which explains the backgrounds behind textures, fonts, and other resources.

2

Keeping Track of Your Textures – Resource Management

play a sprite
that uses the texture. During the process of game development, you encounter such
it images,
fonts, or sounds. This chapter intends to give you a broader understanding of the
following points:

- What is the motivation behind external resources
- Which classes for resource handling and manipulation does the Simple and Fast Multimedia Library (SFML) provide
- What might a typical use case in a game look like
- How do we cope with the constantly recurring need to manage resources in a simple way

Defining resources

In game development, the term **resource** denotes an external component, which the
is **asset**.

Mostly, resources are heavyweight multimedia items, such as images, music themes, or fonts. "Heavyweight" refers to the fact that those objects occupy a lot of memory,
fects the
s on them to
a minimum.

Non-multimedia items such as scripts that describe the in-game world, menu content, or artificial intelligence are also considered resources. Configuration files containing user settings such as the screen resolution and the music volume are good examples of resources as well. However, when we mention resources in the book, we mostly refer to multimedia resources.

Resources are usually loaded from a file on the hard disk. Although being the most
he RAM or
the network.

Resources in SFML

SFML offers classes to deal with a wide variety of resources. Often, the resource
tead, there
is an intermediate front-end class, which refers to the resource. In contrast to the resource class which holds all the data, the front-end class is lightweight and can be copied without severe performance impacts.

All resource classes contain member functions to load from different places. Depending on the exact resource type, there may be slight deviations. A typical method to load a resource from a file has the following signature:

```
bool loadFromFile(const std::string& filename);
```

The function parameter contains the path to the file, where the resource is stored, and the return value is a `bool`, which is `true` if loading was successful, and `false`
o possible errors,
such as invalid file paths.

SFML resources also provide methods to load resources from media other than the hard disk. The function `loadFromMemory()` loads a resource from RAM, which
utable.
The member function `loadFromStream()` loads the resource using a custom `sf::InputStream` instance. This allows the user to exactly specify the loading process. Important use cases of user-defined streams are encrypted and/or compressed file archives.

SFML's resource classes are explained in more detail in the following sections. For this game, we will focus on loading from files.

Textures

The class `sf::Texture` represents a graphical image. The image is stored as an array of pixels in the graphics card's video memory, that is, it does not reside in the RAM.
s red, green,
ny common
.

Textures can be drawn on the screen with the `sf::Sprite` class. A sprite is a lightweight object that refers to a texture or a rectangular part of it. It stores attributes such as the position, rotation, scale, or color to affect the way the texture
ture and have
different attributes, while the texture itself is not affected. The separation between
ty to deal
with graphics using `sf::Sprite`, while the heavyweight `sf::Texture` need not be modified.

Images

The `sf::Image` class is a container for pixel values. It behaves similarly to `sf::Texture`; however it stores its pixels on the RAM instead of the video memory, which makes it possible to manipulate single pixels. `sf::Image` is able to load the same image formats as `sf::Texture`. It is also capable of saving the stored image back to a file. It is interesting to know that `sf::Texture` loads the data using an intermediate `sf::Image`, more exactly, the `sf::Texture::loadFromX()` functions are just a shortcut for combined `sf::Image::loadFromX()` and `sf::Texture::loadFromImage()` calls.

When we want to display a `sf::Image` on the screen, we first have to convert it into a `sf::Texture`, and create a `sf::Sprite` referring to it. It is also possible to
ons where not
graphics card
is wasted. In cases where we do not need to access the single pixels of an image after loading, we are better off when we directly use `sf::Texture`.

An important use case for `sf::Image` is the situation where big textures are required. `sf::Texture` can only store textures on the graphics card that do not exceed a hardware-dependent size. This limit can be retrieved with `sf::Texture::getMaximumSize()`. If you try to load bigger textures into `sf::Texture`, loading will fail. However, you sometimes still need to draw big can do is
to load the pixels into `sf::Image`, which does not use the graphics card's memory to store them. Afterwards, you can create multiple `sf::Texture` objects, of which each whole image
can be drawn by using multiple `sf::Sprite` objects, where each sprite references one texture.

Fonts

The `sf::Font` class is SFML's resource type that stores a character font and provides is the visual
n the user
ponding glyph
is sought in the font file. Therefore, `sf::Font` does not load the complete font data into memory. As a consequence, the font source (file, memory location, or stream) y font
formats, most notably, **true type fonts** (**TTF**) and **open type fonts** (**OTF**).

To display text on the screen, we use the class `sf::Text`. Analogous to sprites, texts are lightweight objects that refer to fonts. In a game, there are usually only a few ave many
`sf::Text` instances that refer to a small amount of `sf::Font` objects.

Shaders

A shader is a program that operates directly on the graphics card. Shaders are used clude a bloom
shader that amplifies bright parts of the scene, a toon shader that makes objects look like in a cartoon, or a blur effect which simulates flickering hot air. Since SFML builds upon OpenGL, its shader instances use the **OpenGL Shading Language** (**GLSL**), a programming language similar to C. SFML supports vertex shaders rs (which
manipulate pixels of the scene).

`sf::Shader` can be created from a `std::string` containing the GLSL code of a his case it can
be loaded from two strings. It is also possible to initialize a `sf::Shader` instance by passing the filename of a GLSL source file to its constructor.

Sound buffers

The `sf::SoundBuffer` class is used to store a sound effect. It holds an array of 16 bit audio samples, where each sample specifies the amplitude of the audio waveform at a given time. A sound buffer allows access and modification of the samples, but it cannot play audio. Supported file formats are WAV, OGG, AIFF, and many more. The MP3 format is not supported because of its restrictive license.

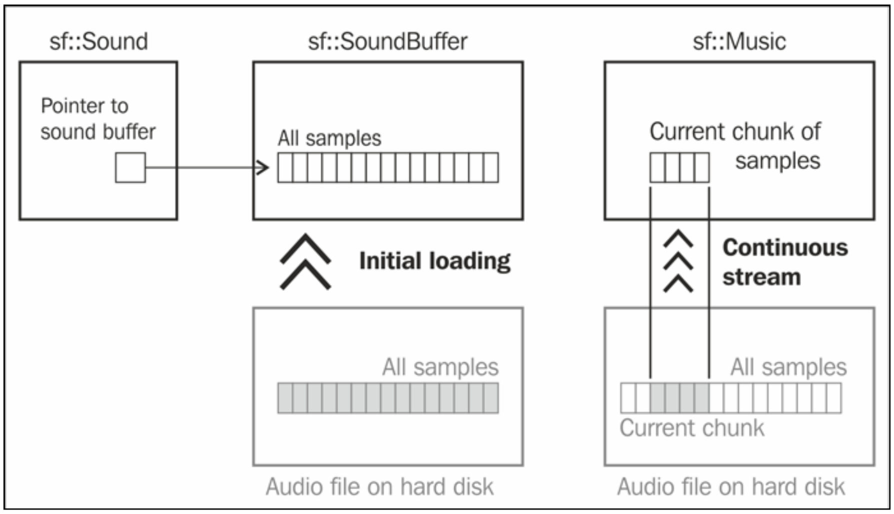
`sf::Sound`
to a texture containing the pixels, a sound refers to a sound buffer containing the audio samples. Analogous to textures, sound buffers must remain alive while they are used by sounds. `sf::Sound` objects can be played, paused, and stopped and have configurable attributes such as volume or pitch. Note that a `sf::Sound` play the sound
effect immediately.

Music

`sf::Music` is the class to play music. While `sf::SoundBuffer` is appropriate for short sound effects (explosions, button clicks, and so on.), `sf::Music` is designed to handle music themes. Themes are usually much longer and thus require more memory than sound effects. As a result, `sf::Music` does not load all data at once.
chunks of
r example,
a file or memory location) must remain valid while the music is in use. That is also why `sf::Music` methods are called `openFromX()` instead of `loadFromX()`, where "X" denotes a source media such as "File". The supported audio formats are the same as for `sf::SoundBuffer`.

For music themes, there is no separation between heavyweight resource and lightweight front-end. `sf::Music` manages all at once: in addition to the loading functionality, it offers many of the `sf::Sound` methods to play, pause, or stop a theme or to configure other parameters. Its objects must also remain alive while the music plays.

The difference between sound buffers and music is shown in the following diagram.
data from
n the right, a
music object streams from the hard disk, that is, it continuously loads small chunks. It can be played on its own.



A typical use case

not know
yet how to apply this knowledge to our game. While the approach you have seen in *Chapter 1*, *Making a Game Tick*, may work for simple examples, it does not scale well to a bigger project. As our game grows, we have to reflect about how the resources are going to be used. This is explained in the next sections.

Graphics

ld and
different objects in it. We need to think about how we get from an image on the hard disk to its visualization on the screen.

- Game entities such as the player's airplane, enemies, or the landscape are represented with sprites and possibly texts. They do not own the heavy
hem.

- As a consequence, the resources (textures and fonts) need to be accessible by long as
  any front-end object refers to them, so we have to find an appropriate scope to declare the resources.
- A sprite in the airplane must somehow get a reference to the texture stored r
  parameter to the airplane class.

Audio

Another important resource is audio, which can be divided into sound effects and n the
final application, when all we start with is a bunch of audio files in a directory:

- Sound effects are not tied to a specific game entity such as an airplane; they e that
  explodes and creates an explosion sound. When we destroy the plane object, do
  not store `sf::Sound` instances in the game entities, but in an object which remains alive throughout a mission. The same applies to the underlying `sf::SoundBuffer` objects which are used by `sf::Sound`.
- For music themes, the semantics are similar. It may even occur that the same theme is played across multiple missions. Ideally, the `sf::Music` objects exist in a scope that outlives a single mission.
- Although the game entities do not own sound effects, they are supposed s
  playing new sound effects.

Acquiring, releasing, and accessing resources

Once we have decided which resources are required by the application, the next step decide how
the resources are stored in the application, as well as who is responsible of loading and releasing them.

- We want to load the resource in advance, for example, at the time the game starts or the player begins a new mission. In contrast to loading on demand (as soon as a resource is needed), this approach has the advantage that possible loading times occur in the beginning and not during a game. Therefore, the game itself remains fluent and is not interrupted because of resources.

- When resources are likely to not be needed anymore, we can release them and free the memory. This is usually the case at the end of a mission or
  rly
  the
  next
  explosion may follow a few seconds later.
- There must be a possibility to get a reference to a certain resource after it has been loaded—using a resource identifier. This identifier (ID) could be the file path as a `std::string`. This has some disadvantages: all classes that use a resource must hardcode the path, so if it changes, a lot of code needs to be
  case
  es
  an ID. Since an enum has a predefined set of possible states, we get some compile-time safety, and we can handle the paths in a central place.

In conclusion, we have the heavy resource classes which shall be loaded when appropriate, but before the game. Throughout their lifetime, front-end classes such as sprites or sounds may reference them, so we must keep the resources alive. When they are not needed anymore, we can release them.

An automated approach

that relieves
C++
idiom **Resource Acquisition Is Initialization** (**RAII**) comes in handy.

> RAII describes the principle that resources are acquired in a class' constructor and released in its destructor. Since both constructor and
>
> out of scope, there is no need to track resources manually. RAII is mostly used for automatic memory management (as in smart pointers), but it
>
> manual allocation and deallocation (such as `new/delete` pairs) is that deallocation is guaranteed to take place, even when there are multiple
> y
> with manual memory management, every possible path would have to be protected with a `delete` operator. As a result, the code becomes quickly unreadable and error-prone.

onstruction
(loading) and destruction (release) of SFML resource objects.

Let's begin with a class that holds `sf::Texture` objects and loads them from files. We call it `TextureHolder`. Once we have implemented the semantics for textures, we can generalize the implementation to work with other resource types.

Finding an appropriate container

First, we must find the right data structure to store the textures. We ought to choose an STL container that does not perform unnecessary copies. `std::vector` is the
the dynamic
ll references
ke to access
the textures by an enum, so the associative container `std::map` looks like the perfect choice. The key type is our enumeration, the value type is the `sf::Texture`.

> The C++11 standard introduces **strongly typed enumerations**, also known as enum class. Unlike traditional enums, they do not offer implicit conversion to integers, and their enumerators reside in the scope of the enum type itself. Since C++11 is still being implemented
>
> book, we focus on C++11 features that have already been implemented for a few years. Unfortunately, strongly typed enums do not fall into this category, that's why we do not use them in the book. If they are supported by your compiler, we still recommend using them.

We call our enum as `ID`, and let it contain three texture identifiers `Landscape`, `Airplane`, and `Missile`. We nest it into a namespace `Textures`. The namespace gives us a scope for the enumerators. Instead of writing just `Airplane`, we have `Textures::Airplane` which clearly describes the intention and avoids possible name collisions in the global scope:

```
namespace Textures
{
    enum ID { Landscape, Airplane, Missile };
}
```

We do not store the `sf::Texture` directly, but we wrap it into a `std::unique_ptr`.

> **Unique pointers** are class templates that act like pointers. They automatically call the `delete` operator in their destructor, thus they provide means of RAII for pointers. They support C++11 move semantics, which allow to transfer ownership between objects without copying. A `std::unique_ptr<T>` instance is the sole owner of the `T` object it points to, hence the name "unique".

Unique pointers give us a lot of flexibility; we can basically pass around heavyweight t are non-
copyable, such as, `sf::Shader`. Our class then looks as shown in the following code:

```
class TextureHolder
{
    private:
        std::map<Textures::ID,
                 std::unique_ptr<sf::Texture>> mTextureMap;
};
```

The compiler-generated default constructor is fine, our map is initially empty. Same for the destructor, `std::map` and `std::unique_ptr` take care of the proper deallocation, so we do not need to define our own destructor.

Loading from files

s to take a
parameter for the filename and one for the identifier. The identifier is used as a key to store the resource in the map:

```
void load(Textures::ID id, const std::string& filename);
```

In the function definition, we first create a `sf::Texture` object and store it in the unique pointer. Then, we load the texture from the given filename. After loading, we can insert the texture to the map `mTextureMap`. Here, we use `std::move()` to take ownership from the variable `texture` and transfer it as an argument to `std::make_pair()`, which constructs a key-value pair for the map:

```
void TextureHolder::load(Textures::ID id, const std::string& filename)
{
    std::unique_ptr<sf::Texture> texture(new sf::Texture());
    texture->loadFromFile(filename);

    mTextureMap.insert(std::make_pair(id, std::move(texture)));
}
```

Accessing the textures

So far, we have seen how to load resources. Now we finally want to use them. We write a method `get()` that returns a reference to a texture. The method has one parameter, namely the identifier for the resource. The method signature looks as follows:

```
sf::Texture& get(Textures::ID id);
```

kup

in the map to find the corresponding texture entry for the passed key. The method `std::map::find()` returns an iterator to the found element, or `end()` if nothing is found. Since the iterator points to a `std::pair<const Textures::ID, std::unique_ptr<sf::Texture>>`, we have to access its second member to get the unique pointer, and dereference it to get the texture:

```
sf::Texture& TextureHolder::get(Textures::ID id)
{
    auto found = mTextureMap.find(id);
    return *found->second;
}
```

> **Type inference** is a language feature that has been introduced with C++11, which allows the compiler to find out the type of expressions. The `decltype` keyword returns the type of an expression, while the `auto` keyword deduces the correct type at initialization. Type inference
>
> ree
>
> lines are semantically equivalent:
>
> ```
> int         a = 7;
> decltype(7) a = 7;   // decltype(7) is int
> auto        a = 7;   // auto is deduced as int
> ```

In order to be able to invoke `get()` also, if we only have a pointer or reference to a `const TextureHolder` at hand, we need to provide a const-qualified overload. This new member function returns a reference to a `const sf::Texture`, therefore the caller cannot change the texture. The signature is slightly different:

```
const sf::Texture& get(Textures::ID id) const;
```

now
looks as follows:

```
class TextureHolder
{
    public:
        void                    load(Textures::ID id,
                                     const std::string& filename);
        sf::Texture&            get(Textures::ID id);
        const sf::Texture&      get(Textures::ID id) const;
    private:
        std::map<Textures::ID,
                  std::unique_ptr<sf::Texture>> mTextureMap;
};
```

Now the `get()` method is easy to use and can directly be invoked when a texture is requested:

```
TextureHolder textures;
textures.load(Textures::Airplane, "Media/Textures/Airplane.png");

sf::Sprite playerPlane;
playerPlane.setTexture(textures.get(Textures::Airplane));
```

Error handling

, there
may be errors which we have to recognize and handle meaningfully. The first
ified file
might not exist, or the file might have an invalid image format, or be too big for the video memory of the graphics card. To handle such errors, the method `sf::Texture::loadFromFile()` returns a Boolean value that is true in case of success, and false in case of failure.

case, we
have to consider that the texture is later needed by sprites that are rendered on the
back. One
hite), so the
player of
our game to fiddle around with rectangles; he should either have a proper airplane
ller of
our `load()` method that something did not work. A possibility to implement these notifications is shown in the next sections.

Boolean return values

We could follow SFML's philosophy and return a Boolean value denoting success or failure. This approach has some disadvantages. We cannot use the return type for
every time
he calls `load()`. This is easily overlooked, and if it is not, it leads to messy usage
y stated our
objective consists of performing as much work as possible in the `TextureHolder`, to relieve the user from writing boilerplate code.

Throwing exceptions

We choose
the standard exception type `std::runtime_error`. To its constructor, we pass an
he filename:

```
if (!texture->loadFromFile(filename))
    throw std::runtime_error("TextureHolder::load - Failed to load "
    + filename);
```

Exceptions have the big advantage that user code can be kept clean of error handling. Clients can now have the following code:

```
TextureHolder textures;
textures.load(Textures::Landscape, "Media/Textures/Desert.png");
textures.load(Textures::Airplane, "Media/Textures/Airplane.png");
textures.load(Textures::Missile, "Media/Textures/Missile.png");
```

ion will be
thrown until a `try-catch` block catches it and reacts meaningfully. It is possible that the exception passes several functions before it is eventually handled.

be aware of
will refuse
member
function `std::map::insert()` returns a pair with an iterator to the inserted element and a Boolean value which is true if inserting was successful. We store this returned pair and check its second member (the Boolean value). Instead of writing `std::pair<std::map<Textures::ID, std::unique_ptr<sf::Texture>>::iterator, bool>`, we can use C++11 type inference:

```
auto inserted = mTextureMap.insert(std::make_pair(id,
std::move(resource)));
```

Now, `inserted` is our pair containing an iterator and a Boolean value, `inserted.second`lse, we
ituation?

We could throw a `std::runtime_error` exception again. However, in contrast to a loading failure, double insertion is not a runtime error. The attempt to insert the same ID twice in the map is a logic error, meaning, there is a mistake in the application logic—in other words, a bug. A well-formed program would not attempt to load the same resource twice. In comparison, runtime errors occur in correctly written programs too, for example, if the user renames or moves the resource files. For logic errors, the standard library provides the exception class `std::logic_error`.

This raises already the next question: how do you handle such exceptions? It is not that once you have thrown an exception, you can forget about it and the world is in
u and not
ase of a loading
failure, we can tell the player that the files were not found, and prevent him from
d to tell
the player that the programmer accidentally called `load()` twice? Certainly not. This bug must not occur in the final application. There is no way to recover from
en, and we risk
upsetting even more if we ignore the error. What if the two `load()` calls are passed the same ID, but different filenames? We do not know with which resource the ID is associated. If we later want to access a resource by its ID, we might get the wrong resource, and thus display a wrong image on the screen. In this manner, errors can
e being
noticed. In case of a logic error, we would like the program to interrupt immediately.

Assertions

Clearly, a mechanism apart from exceptions is appropriate, which shows us directly
into play.
The macro `assert` evaluates its expression; if it is false in debug mode, a breakpoint is triggered, halting the program execution and directly pointing to the source of the error. In release mode, assertions are optimized away, so we do not waste any performance to check for errors that cannot occur. The `assert` expression is completely removed in release mode, so make sure you only use it for error checks, and not to implement actual functionality with possible side effects.

We have to insert a single line, we expect that the Boolean member of the pair returned by `std::map::insert()` is true:

```
assert(inserted.second);
```

That is already it. The whole method looks now as follows:

```
void TextureHolder::load(Textures::ID id, const std::string& filename)
{
    std::unique_ptr<sf::Texture> texture(new sf::Texture());
    if (!texture->loadFromFile(filename))
        throw std::runtime_error("TextureHolder::load -
        Failed to load "     + filename);

    auto inserted = mTextureMap.insert(std::make_pair(id,
    std::move(texture)));
    assert(inserted.second);
}
```

In our method `get()`, there are things that may go wrong too. The requested texture to load the
textures before we access them. Consequently, we verify whether the texture has been found, again using `assert`:

```
sf::Texture& TextureHolder::get(Textures::ID id)
{
    auto found = mTextureMap.find(id);
    assert(found != mTextureMap.end());

    return *found->second;
}
```

Generalizing the approach

o handle
other resources such as fonts and sound buffers too. As the implementation looks
`FontHolder`
and `SoundBufferHolder` with exactly the same functionality. Instead, we write a class template, which we instantiate for different resource classes.

We call our template `ResourceHolder` and equip it with two template parameters:

- **Resource**: The type of resource, for example, `sf::Texture`. We design the
  ce
  class which conforms to the required interface (providing `loadFromFile()` methods), nothing keeps you from using it together with `ResourceHolder`.
- **Identifier**: The ID type for resource access, for example, `Textures::ID`.
  ions.
  Any type that supports an `operator<` can be used as identifier, for example, `std::string`.

The transition from `TextureHolder` to `ResourceHolder<Resource, Identifier>` is straightforward. We replace the used types with the generic template parameters: `sf::Texture` becomes `Resource`, and `Textures::ID` becomes `Identifier`. Furthermore, we rename some variables to reflect the fact that we are talking about resources in general, not only textures. We also adapt the member functions accordingly.

> One thing we have to note when using templates is that the complete implementation needs to be in the header. We cannot use `.cpp` files for the method definitions anymore, but we would still like to separate interface and implementation. That is why we use a file `ResourceHolder.hpp` for the class definition, and a file `ResourceHolder.inl` for the method definitions. At the end of the `.hpp` file, we include the `.inl` file containing the implementation. `.inl` is a common file extension for inline template implementations.

The generalized class definition has the following interface:

```
template <typename Resource, typename Identifier>
class ResourceHolder
{
    public:
        void              load(Identifier id,
                               const std::string& filename);

        Resource&         get(Identifier id);
        const Resource&   get(Identifier id) const;

    private:
        std::map<Identifier,
                 std::unique_ptr<Resource>> mResourceMap;
};
```

The `load()` method can be written in the following way. Like before, we attempt to load the resource from a file, and then we insert the unique pointer into the map and make sure the insertion was successful:

```
template <typename Resource, typename Identifier>
void ResourceHolder<Resource, Identifier>::load(Identifier id,
const std::string& filename)
{
    std::unique_ptr<Resource> resource(new Resource());
    if (!resource->loadFromFile(filename))
        throw std::runtime_error("ResourceHolder::load - Failed to
        load " + filename);
```

```
auto inserted = mResourceMap.insert(
std::make_pair(id, std::move(resource)));
    assert(inserted.second);
}
```

The two overloaded `get()` member functions are generalized using the same principle, that is why they are not listed here. You can refer to the online code base for a complete implementation.

Compatibility with sf::Music

As initially mentioned, the class `sf::Music` has semantics that are very different from other resource types. This begins already with its `openFromFile()` method that is not compatible to the `loadFromFile()` call in our implementation. Because of its ts—each
contains the
whole music data at once.

Instead of forcing `sf::Music` into a concept it does not fit, we decide to not store it inside `ResourceHolder` instances. This does not imply that there will be no
depth
during *Chapter 9*, *Cranking Up the Bass – Music and Sound Effects*.

A special case – sf::Shader

There is one resource type we have yet to cover: shaders. Since a SFML shader
f `sf::Shader`
deviates slightly from the other resource classes in SFML. `sf::Shader` provides two methods to load from a file:

```
bool loadFromFile(const std::string& filename, sf::Shader::Type type);
bool loadFromFile(const std::string& vertexShaderFilename,
const std::string& fragmentShaderFilename);
```

The fipecified
fragment
shader.

This interface is an issue for our generic implementation, because `ResourceHolder::load()` contains the following expression:

```
resource->loadFromFile(filename)
```

Which assumes that `loadFromFile()` is invoked with one argument. For `sf::Shader`, we have to specify two instead.

The solution is simple: we write an overloaded `ResourceHolder::load()`
the second
argument to `sf::Shader::loadFromFile()`. This parameter can have the type `sf::Shader::Type` or `const std::string&`. In order to cope with both types, we add a function template parameter. Our new `load()` function has the following declaration:

```
template <typename Parameter>
void load(Identifier id, const std::string& filename,
const Parameter& secondParam);
```

The function definition is listed in the following code. Do not confuse yourself by the two template parameter lists; the first one is required for the class template `ResourceHolder` and the second one for the function template `ResourceHolder::load()`. In the function body, only the `loadFromFile()` call is different from before.

```
template <typename Resource, typename Identifier>
template <typename Parameter>
void ResourceHolder<Resource, Identifier>::load(Identifier id,
const std::string& filename, const Parameter& secondParam)
{
    std::unique_ptr<Resource> resource(new Resource());
    if (!resource->loadFromFile(filename, secondParam))
        throw ...;

    ... // insertion like before
}
```

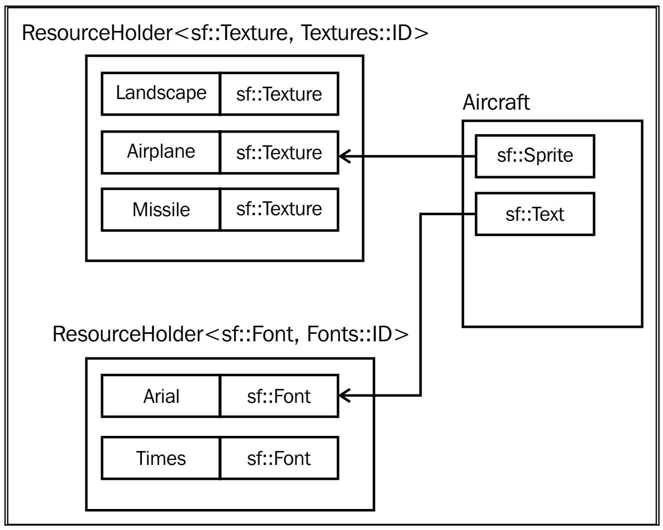
A nice side effect of this additional overload is that it enables other argument combinations for `loadFromFile()` too. The method of `sf::Texture` actually looks as shown in the following line of code:

```
bool loadFromFile(const std::string& filename,
const IntRect& area = IntRect())
```

rectangular
area of the image. Usually, we do not specify it and load the whole file, but thanks to our second `load()` overload, we have now the possibility to use this parameter.

inserts
resources into the map, in order to reduce code duplication.

Using the new `ResourceHolder` class template, we can visualize a possible in-game
ders, one for
textures and one for fonts. Each one contains a map of enumerators to resources. The
player's `Aircraft`
a text that points to a font.



Summary

agement.
By now, we know the ideas behind resources and the facilities SFML provides to
d in a
with passing
ssible error
sources as well as techniques to handle them appropriately.

In the next chapter, we are going to develop the game world with a variety of objects in it. Most of these objects require different resources, which is a good opportunity to show our resource holder in a real-world example.

3

Forge of the Gods – Shaping Our World

g of
external resources. To sum up, we have investigated mechanisms to ensure that textures, fonts, or sounds are ready to be used as soon as we need them. This chapter attempts to bring knowledge around a few key topics:

- Entity systems in concept and practice
- The viewable area of our world and scrolling
- Tree-based scene graphs, rendering and updating of many entities
- Composition of all elements to shape the world

When writing a game, we invariably find the need to conceptualize our vision of the
ant to have
a clear idea of the scope of our vision. The world in our mind doesn't even have to scale remotely to what we consider our real world; it is a product of our own
whole world
e universe
along with all the stars and planets.

The point is, it does not matter how our vision of the world looks, how small or big it
want to represent
e will apply
these concepts directly to our own sample vision of a game, while leaving a solid
pts.

Entities

An **entity**
e the player's
strength. Entities interact with each other: enemy airplanes can fire missiles, the
it the
pickup to
s are nearly
unlimited, and they may occur between almost any pair of entity types.

entity
hierarchy. We have a base class called `Entity`, which contains the data and functionality that all different kinds of entities have in common. We have multiple classes that derive from `Entity`, and that implement specific functionality. These derived classes could represent airplanes, projectiles (such as missiles), or pickups. One commonality between different entities is that they can move in our world with a certain velocity.

We implement the velocity attribute in the base class `Entity`, so each concrete entity has it. The velocity is represented using a two-dimensional vector. In addition to the member variable, we provide the `get` and `set` functions to access the velocity from outside the class. The `setVelocity()` method is overloaded to take either a vector or two separate floats. The header `Entity.hpp` contains the following class definition:

```
class Entity
{
    public:
        void                setVelocity(sf::Vector2f velocity);
        void                setVelocity(float vx, float vy);
        sf::Vector2f        getVelocity() const;

    private:
        sf::Vector2f        mVelocity;
};
```

After initialization, we want the velocity to be zero. Since the class `sf::Vector2f`
, we need not
define our own constructor; the compiler-generated one works fine.

The function definitions in the file `Entity.cpp` are not terribly surprising:

```
void Entity::setVelocity(sf::Vector2f velocity)
{
    mVelocity = velocity;
}

void Entity::setVelocity(float vx, float vy)
{
    mVelocity.x = vx;
    mVelocity.y = vy;
}

sf::Vector2f Entity::getVelocity() const
{
    return mVelocity;
}
```

Aircraft

Using the example of the aircraft, we need to define a concrete entity class. We derive it from `Entity`. Since we have different airplanes in our game, it would be nice to call it
`Type` and make it a member of the `Aircraft` class. Therefore, we can now refer to it as `Aircraft::Type`, which is quite expressive when we see it in the code. Up to now, we have two distinct airplanes, we call them `Eagle` and `Raptor`. Each type of aircraft corresponds to an enumerator in our enum.

rrent type as
ng code:

```
class Aircraft : public Entity
{
    public:
        enum Type
        {
            Eagle,
            Raptor,
        };

    public:
        explicit        Aircraft(Type type);

    private:
        Type            mType;
};
```

The constructor's definition is straightforward; we let it initialize our `mType` member variable:

```
Aircraft::Aircraft(Type type): mType(type)
{
}
```

Now this is the fundament for our `Aircraft` class. During this book, we will continuously extend it and add new functionality.

Alternative entity designs

el game
software, all of
which have its own advantages and drawbacks.

slightly
different entity types. Imagine a complex game with different kinds of vehicles, such as tanks, ships, submarines, airplanes, and more. Every entity type has different capabilities, such as flying, transporting people, carrying weapons, and diving. It may be tempting to create corresponding base classes `TransportEntity`, `ArmedEntity`, `DivingEntity` that all derive from `Entity`. A submarine could then inherit `ArmedEntity` and `DivingEntity`; an armed freighter could inherit `TransportEntity` and `ArmedEntity`. On one hand, this design leads hand to the so-called diamond of death, where the base class `Entity` is indirectly inherited multiple times, requiring virtual inheritance. On the other hand, the hierarchy
nt entities, it
is moved to base classes. This makes classes towards the root of the hierarchy a lot
ch inherit a
erly large,
hence slower to process and more difficult to maintain.

In such a case, **component-based design** would be an alternative, meaning that
f base classes.
xpect, this
on each
other than theory would like them to, and they need an efficient and flexible way to
nly an
e first game
y hierarchies do
not show, so we chose this approach for the sake of simplicity.

ponent-based
game design, we recommend reading the article series on the following website:

http://stefan.boxbox.org/game-development-design.

Rendering the scene

At one point, we have to reflect about how the game is rendered on the screen.
How do we draw all the entities, the scenery, and interface elements (such as a health
h which we
iterate. For each element, we call a possible `Entity::draw()` function to draw the
ts that
appear behind others (such as the scenery background) are drawn first.

Relative coordinates

t difficult
of airplanes,
could set the
e of "plane
t of the leader"
ll (300, 100) a
relative position, expressing where plane A is located with respect to the leader.

but also to
so want the
planes to be headed towards the same direction as the leader. In other words, we
want their rotation to be the same. If the followers' relative rotation is zero, all planes
will face the same direction, namely the leader's one.

The advantage of relative coordinates consists of avoiding the need for manual
ve to
ery follower,
e the position
of the leader changes, which is cumbersome and error-prone (one can easily forget to
pproach: we

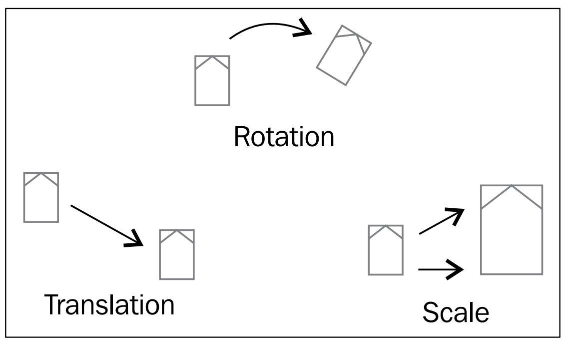
following the
tually, we
build up a hierarchy of objects with relative transforms.

SFML and transforms

in our
which we
can build our own abstractions.

A geometrical **transform** specifies the way an object is represented on the screen. In mathematical terms, a transform maps a coordinate system onto another. **Translation** affects the position of an object, **rotation** affects its orientation, and **scale**
rations, we will
focus on them, because they are the ones mostly used.

SFML provides an API to work with position, rotation, and scale in the class `sf::Transformable`. The class stores the three transforms separately and provides useful accessor functions such as `setPosition()`, `move()`, `rotate()`, `getScale()`, and many more. It can be used as a base class, such that the derived class
the three
transforms you will encounter again and again:



`sf::Transformable` also contains the methods `setOrigin()` and `getOrigin()`, which give access to the coordinate system's origin. The origin is the reference point for the three transforms—it determines, which point in the object is looked at to set/get the position, or around which point the object rotates, or which point the object uses as the center for scaling. The origin is specified in local coordinates (relative to the object). By default, it has the value (0, 0) and resides in the object's upper-left corner. Calling `setOrigin()` with the half object size places the origin to the object's center.

SFML provides another useful base class for graphical entities: the class
`sf::Drawable`
the following signature:

```
virtual void Drawable::draw(sf::RenderTarget& target,
                            sf::RenderStates states) const = 0
```

The first parameter specifies, where the drawable object is drawn to. Mostly, this will be a `sf::RenderWindow`. The second parameter contains additional information for the rendering process, such as blend mode, transform, the used texture, or shader. SFML's high-level classes `Sprite`, `Text`, and `Shape` are all derived from `Transformable` and `Drawable`.

Scene graphs

In order to manage transform hierarchies in a user-friendly way, we develop a **scene graph**—a tree data structure consisting of multiple nodes, called **scene nodes**. Each scene node can store an object that is drawn on the screen, most often this is an entity.

e
osition,
rotation, and scale relative to their parent.

A scene graph contains a root scene node, which exists only once in a world. It
ent node.

Scene nodes

We represent the nodes in the scene graph with a class called `SceneNode`. Before we
graph
destruction.
its children are
rn down.

To store the children, we make use of the STL container `std::vector`. We cannot use `std::vector<SceneNode>`, since element types must be complete types (which they are only at the end of the `SceneNode` class definition, but not at the time of declaring the container as a member variable) and since our class is polymorphic (there will be derived classes overriding virtual functions of `SceneNode`). We could use `std::vector<SceneNode*>`, but then we would have to manage memory ourselves, so we take `std::vector<std::unique_ptr<SceneNode>>` instead. Since we are going to use the type `std::unique_ptr<SceneNode>` really often, we create a typedef for it, as a member inside the `SceneNode` class.

tored, so our
class looks as follows:

```
class SceneNode
{
    public:
        typedef std::unique_ptr<SceneNode> Ptr;

    public:
                                SceneNode();

    private:
        std::vector<Ptr>    mChildren;
        SceneNode*          mParent;
};
```

The constructor initializes the parent pointer to `nullptr` and leaves the container empty.

> `nullptr` is a keyword introduced with C++11 and represents the value of a null pointer. The formerly used `NULL` is a macro for the integer value `0`, which implies many problems. A function overloaded for `int` and `char*`, that is passed `NULL` as argument, would unexpectedly choose the `int` overload.
>
> For null pointer literals, `nullptr` should always be preferred over `0` or `NULL`. It is also convertible to the standard library smart pointers `std::unique_ptr` and `std::shared_ptr`.

Node insertion and removal

Now we write an interface to insert or remove child nodes into or from a scene node. We do this by adding the following two functions:

```
void        attachChild(Ptr child);
Ptr         detachChild(const SceneNode& node);
```

The first method takes a `unique_ptr<SceneNode>` by value, taking ownership of the scene node. The second method searches for an occurrence of the specified
n wrapped in a
`unique_ptr`. If the return value is ignored, the node will be destroyed.

arent
by moving
its contents in the following code snippet:

```
void SceneNode::attachChild(Ptr child)
{
    child->mParent = this;
    mChildren.push_back(std::move(child));
}
```

The second method is slightly more complex. First, we search for the specified node in the container with the help of a lambda expression.

> Lambda expressions are a C++11 language feature. They allow the definition of local functions inside other functions, and the direct usage in surrounding code.
>
> A **lambda expression** creates an anonymous function object, similar to a named functor class with overloaded `operator()`. Its declaration consists of the following parts:
>
> - The capture list specifies to which variables in the surrounding scope the lambda expression has access. `[]` captures no variables, `[&]` captures all variables by reference, `[=]` by value, `[&node]` and `[node]` capture only the listed variables by reference or value, respectively. The capture list is comparable to the arguments passed to a functor's constructor.
> - The parameter list contains the parameters passed to the function. These correspond to the parameters of the functor's `operator()`.
> - The return type has the syntax `-> type`. If the function body consists of a single return statement, the return type can be omitted.
> - The function body is enclosed in `{}` and contains the actual statements.

true if
the element's pointer `p.get()` is equal to the address of the wanted node. The STL algorithm `std::find_if()` returns an iterator to the found element, which we check for validity using `assert`.

```
SceneNode::Ptr SceneNode::detachChild(const SceneNode& node)
{
    auto found = std::find_if(mChildren.begin(), mChildren.end(),
    [&] (Ptr& p) -> bool { return p.get() == &node; });

    assert(found != mChildren.end());
```

ntainer
into the variable `result`. We set the node's parent pointer to `nullptr`, erase the empty element from the container, and return the smart pointer containing the detached node.

```
        Ptr result = std::move(*found);
        result->mParent = nullptr;
        mChildren.erase(found);
        return result;
    }
```

n
concentrate on the actual rendering.

Making scene nodes drawable

Our `SceneNode` class shall be rendered on the screen, thus we derive it from `sf::Drawable`. It shall store its current position, rotation, and scale as well as
, we derive
also from `sf::Transformable`, which gives us all that for free. In addition, we derive privately from `sf::NonCopyable` to state that our scene nodes cannot be copied (copy constructor and copy assignment operator are disabled).

We override the pure virtual `draw()` function of `sf::Drawable` to render the whole scene node. We also provide a new virtual function `drawCurrent()` which only
by classes
deriving from `SceneNode`.

```
class SceneNode : public sf::Transformable, public sf::Drawable,
                  private sf::NonCopyable
{
    public:
        typedef std::unique_ptr<SceneNode> Ptr;

    public:
                            SceneNode();

        void                attachChild(Ptr child);
        Ptr                 detachChild(const SceneNode& node);

    private:
        virtual void        draw(sf::RenderTarget& target,
                                sf::RenderStates states) const;
```

```
        virtual void      drawCurrent(sf::RenderTarget& target,
                              sf::RenderStates states) const;

    private:
        std::vector<Ptr>  mChildren;
        SceneNode*        mParent;
};
```

The `draw()` function allows our class to be used as shown in the following code snippet:

```
sf::RenderWindow window(...);
SceneNode::Ptr node(...);
window.draw(*node); // note: no node->draw(window) here!
```

The `window` class internally calls our `draw()` function. No other classes need access
 feature, you
can declare `draw()` with the `final` keyword, to prevent the function from being overridden in classes derived from `SceneNode`.

s:

- The current node's transform that determines position, rotation, and scale relative to the parent node. It is retrieved via base class method `sf::Transformable::getTransform()`.
- The parameter `states`, which is passed by value and has a member variable `transform` of type `sf::Transform`. This variable holds the information where to render the parent scene node.

loaded
multiplication operators. Our expression with `operator*=` combines the parent's
he absolute
transform of the current node, which stores where in the world our scene node is placed.

```
void SceneNode::draw(sf::RenderTarget& target,
                     sf::RenderStates states) const
{
    states.transform *= getTransform();
```

Now, `states.transform` contains the absolute world transform. We can draw the derived object with it by calling `drawCurrent()`. Both parameters are forwarded.

By the way, the `sf::Sprite` class handles transforms very similarly: it also combines
ectively copy
SFML's behavior in `SceneNode`.

container of
smart pointers, and recursively invoke `draw()` on each element, again forwarding both parameters.

```
    drawCurrent(target, states);

    for (auto itr = mChildren.begin();
              itr != mChildren.end(); ++itr)
    {
        (*itr)->draw(target, states);
    }
}
```

In the code, we have factored out the last part into a function `drawChildren()`.

> In C++11, iteration through sequences can be achieved with the **range-based for** statement. It has the following syntax, which can be read as "for each `variable` in `sequence`":
>
> ```
> for (Type variable : sequence)
> ```

If all current compilers supported range-based for, we could use the following code to iterate over all child nodes:

```
for (const Ptr& child : mChildren)
{
    child->draw(target, states);
}
```

Fortunately, C++ is a very powerful language. It allows us to emulate the range-based for loop with a few limitations, using a self-written macro `FOREACH`. We chose the
feature is widely supported. Our loop then looks as follows:

```
FOREACH(const Ptr& child, mChildren)
{
    child->draw(target, states);
}
```

terator loop.

Drawing entities

but nothing
is actually rendered yet. In order to do so, the virtual method `drawCurrent()` must be overridden in derived classes. One of these derived classes is `Entity`; it inherits `SceneNode`, so that entities can be placed in the scene and rendered by SFML.

a
`sf::Sprite` object. This sprite becomes a member of the `Aircraft` class.

```
class Aircraft : public Entity // inherits indirectly SceneNode
{
    public:
        explicit        Aircraft(Type type);
        virtual void    drawCurrent(sf::RenderTarget& target,
                                    sf::RenderStates states) const;

    private:
        Type            mType;
        sf::Sprite      mSprite;
};
```

In `drawCurrent()`, we only draw the sprite. We call `sf::RenderTarget::draw()`, and pass `const sf::Drawable&` (our sprite) as first argument and the render states as second argument.

```
void Aircraft::drawCurrent(sf::RenderTarget& target,
                           sf::RenderStates states) const
{
    target.draw(mSprite, states);
}
```

ring for
at all the
actual work is performed in our scene node and SFML.

Connecting entities with resources

you know,
sprites need a texture to refer to, but where to get it from?

In *Chapter 2*, *Keeping Track of Your Textures – Resource Management*, we have developed the class template `ResourceHolder<Resource, Identifier>` which is able to store SFML resource objects such as textures. Now the time for its first
h
ure, the
resource type will be `sf::Texture`.

Next, we ought to find a type for the resource identifier. For aircraft textures, we could use the enum `Aircraft::Type`. However, there might be other objects than Therefore, we
create a new enumeration `Textures::ID` with identifiers for the textures. So far, we only have two texture IDs, one for each of our aircraft types.

```
namespace Textures
{
    enum ID
    {
        Eagle,
        Raptor,
    };
}
```

Having defined the identifier type, we are ready to instantiate our resource holder for textures. Because it is used in several places, we create a type definition for it:

```
typedef ResourceHolder<sf::Texture, Textures::ID> TextureHolder;
```

We will now go back to our `Aircraft` class. In its constructor, we want to initialize the sprite with the correct texture. We could add a constructor parameter `const sf::Texture&`
This has the advantage that the knowledge about the used texture stays local to our plane—the creator of the plane need not know what texture it uses. Also, if the plane issile), we
s it.

Our constructor has now this declaration:

```
Aircraft(Type type, const TextureHolder& textures);
```

The `TextureHolder` class, which is an instantiation of the `ResourceHolder` class template, provides a function `const sf::Texture& get(Textures::ID id) const` which we can invoke with an identifier to get a texture back.

We do not have the identifier yet, but we have the plane type, stored in the constructor parameter type. We can map the aircraft type to the corresponding texture ID, for example, with a `switch` statement:

```
Textures::ID toTextureID(Aircraft::Type type)
{
    switch (type)
    {
        case Aircraft::Eagle:
            return Textures::Eagle;
```

```
        case Aircraft::Raptor:
            return Textures::Raptor;
    }
}
```

We define this global function at the beginning of the `Aircraft.cpp` file, so it does not appear in the `Aircraft` interface. In our constructor, we then initialize our sprite with the texture:

```
Aircraft::Aircraft(Type type, const TextureHolder& textures):
mType(type), mSprite(textures.get(toTextureID(type)))

{

}
```

Instead of the `sf::Sprite` constructor which takes `const sf::Texture&`, it would also have been possible to call the method `sf::Sprite::setTexture()`.

Aligning the origin

When we call
`setPosition()`, we therefore always set the position of the sprite's upper-left
wever more
te's origin
to its center.

For the center, we need the half size of the sprite. With `getLocalBounds()`, we get the local bounding rectangle (local means not taking any `sf::Sprite` transforms into account—as opposed to `getGlobalBounds()`). The rectangle is of type `sf::FloatRect`, which stores four float variables called `left`, `top`, `width`, and `height`. SFML also provides `sf::IntRect`, which stores four int varibles. Our local bounding rectangle's `left` and `top` coordinates are zero, while its `width` and `height` correspond to the sprite's texture size.

```
sf::FloatRect bounds = mSprite.getLocalBounds();
mSprite.setOrigin(bounds.width / 2.f, bounds.height / 2.f);
```

After all this work, our aircraft is finally drawable! When it is added to a scene graph, and somebody draws it, our plane will appear on the screen.

Scene layers

n a certain
e sky) must
be drawn after them. For example, we might first draw a desert background, then an oasis and some buildings, above which we draw the planes, and eventually some health bars located in front of them. This is rather cumbersome to handle
e the
order manually.

's current
a **layer**. Inside
r the different
layers in the right order. We represent a layer with an empty scene node, directly
t is only
supposed to render its children. Since the scene graph is traversed node by node, we
of layer two.
e corresponding
rs, without
the need to manually sort objects.

entities
tor
`LayerCount`layers.

```
enum Layer
{
    Background,
    Air,
    LayerCount
};
```

Updating the scene

In each frame, we update our world with all the entities inside. During an update,
ther,
collisions are checked, and missiles are launched. Updating changes the state of
ed as a
snapshot of a part of the world at a given time point.

s. To
achieve this, we implement a public `update()` member function in the `SceneNode` class. Analogous to the way we have proceeded for the `draw()` function, we split up `update()`odes.
We thus write two private methods `updateCurrent()` and `updateChildren()`, of which the former is virtual.

All update functions take the frame time `dt` as a parameter of type `sf::Time` (the SFML class for time spans). This is the frame time we computed for the `Game` class in *Chapter 1*, *Making a Game Tick*. In our game, we work with fixed time steps, so `dt`
 scene nodes
and make entity behavior dependent on it. This leaves us the flexibility to change the
ime.

We add the following methods to our `SceneNode` class:

```
public:
    void            update(sf::Time dt);

private:
    virtual void    updateCurrent(sf::Time dt);
    void            updateChildren(sf::Time dt);
```

The implementation is the same as for rendering. The definition of `updateCurrent()` remains empty, by default we do nothing for a scene node.

```
void SceneNode::update(sf::Time dt)
{
    updateCurrent(dt);
    updateChildren(dt);
}

void SceneNode::updateCurrent(sf::Time)
{
}

void SceneNode::updateChildren(sf::Time dt)
{
    FOREACH(Ptr& child, mChildren)
        child->update(dt);
}
```

In derived classes, we can now implement specific update functionality, such as movement of each entity. In the `Entity` class, we override the virtual `updateCurrent()` method, in order to apply the current velocity. The class definition of `Entity` is expanded by the following lines of code:

```
private:
    virtual void        updateCurrent(sf::Time dt);
```

We offset the position by the velocity depending on the time step. A longer time step leads to a bigger offset, meaning that our entity is moved further over longer time.

```
void Entity::updateCurrent(sf::Time dt)
{
    move(mVelocity * dt.asSeconds());
}
```

Here, `move()` is a function of the indirect base class `sf::Transformable`. The expression `move(offset)` is a shortcut for `setPosition(getPosition() + offset)`.

Since `Aircraft` inherits `Entity`, the update functionality for it is also inherited. We thus do not need to re-define `updateCurrent()` in the `Aircraft` class, unless we want to execute further actions specifically for aircraft.

One step back – absolute transforms

Relative coordinates are nice and useful, but there are cases where we still want
to find out
d to know
dinate system.

To compute the absolute transforms, we can step upwards in the class hierarchy, and
o the reason
why we introduced the parent pointer in the `SceneNode` class. In addition to the function `getPosition()`, which is inherited from `sf::Transformable` and returns the relative position, we add a new method `getWorldPosition()` to `SceneNode`, which returns the absolute position. First, we add a function `getWorldTransform()` that takes into account all the parent transforms. It multiplies all the `sf::Transform`
looks as
follows. The position can be computed by transforming the origin `sf::Vector2f()` using the absolute transform.

```
sf::Transform SceneNode::getWorldTransform() const
{
    sf::Transform transform = sf::Transform::Identity;
```

```
    for (const SceneNode* node = this;
       node != nullptr; node = node->mParent)
    transform = node->getTransform() * transform;

  return transform;
}

sf::Vector2f SceneNode::getWorldPosition() const
{
    return getWorldTransform() * sf::Vector2f();
}
```

The constant `sf::Transform::Identity` represents the identity transform, which
essary in this
code, but it clarifies the way how transforms are applied from the beginning.

The view

A **view**see. You
every game
programmer needs to understand views in depth, simply because every graphical game will require that knowledge to be applied directly. Sometimes it is called view, camera, or differently. Be it a two-dimensional or three-dimensional simulation, this concept will always be present.

ctangle that
ime.

rm many
d, a spy
of two views
pplications.

It is not hard to grasp the power of the view; you may begin by knowing SFML, which provides us this utility in the conveniently named class `sf::View`. This class acts as a viewing lens, which ensures that anything you attempt to draw to the screen that is outside the view's rectangle will remain unseen.

Besides the viewing rectangle, another parameter that defines the `sf::View` class is
le to the
actual application window.

Viewport

rectangle, in
unit-length coordinates, that defines what region of the application's window is going to be used. So, a viewport rectangle starting at (0, 0) and ending in (1, 1) means
. This is the
most common use of viewports.

Another special use case for this concept is to provide split-screen multiplayer support. In order to do that, one would only need to have two `sf::View` objects,
ch view would
be confit
rectangles defi0,
top=0.5, width=1, height=0.5).

This would immediately mean that we would have two distinct "eyes" looking at the
hese eyes
may be looking at any region of the world without any conflicts. After having those two views configured, having a split-screen support would be as simple as activating the first view, rendering the world, then activating the second, and rendering it again. But always beware that rendering the world twice will effectively consume twice as much rendering power.

View optimizations

Requesting an object to draw itself to the screen, also known as a **draw call**, is one
y game that
ring
performance by reducing draw calls as much as we can.

One way to do this is to use **culling**, which is a term that encompasses a wide range
o do, and
the benefits will almost always be worth the extra work. For example, checking if every object is within the viewing rectangle and only draw them if they are, is a very simple form of efficient culling.

are iterating
in the
performance. Because of this, game developers usually implement some kind of spatial subdivision. A spatial subdivision system can be done in many ways, but
all objects
up of objects
altogether, avoiding expensive iterations and tests on those objects.

One of the most popular ways to subdivide space is to use a **quad tree**. A quad tree
 they subdivide
at least
allows us to
stop iterating through every object and only perform tests down the tree if each cell
m from O(n) to
so much more
efficient to find objects within the scene.

An alternative is a **circle tree**, which is similar to the quad tree, but instead each cell is a circle. This allows a different distribution of the objects and cheaper to compute
. For each
scene you may want to pick the most appropriate algorithm that will give you the most efficiency.

Resolution and aspect ratio

plicitly.
Now, it is very important to know how the viewing rectangle interacts with the
specifiwhat
effects can we achieve by exploiting these notions to the limit. The **resolution** is the number of pixels a monitor or application window displays in each dimension. It is usually specified as width times height, for example, 1024 x 768. The **aspect ratio** is the ratio of the width to the height, for example, 1024:768 = 4:3.

The simplest possible use case of views is to have a window with a fixed size, and
t ratio
if the
e a case of
shrinking or stretching of our world.

and a view
reen, and
when we verify, we see a perfect circle. However, as soon as we increase the view's rectangle height, without growing its width, as a result of trying to map more pixels
tically. It
maintains the same width as before, but the height is smaller, turning the circle into
her that our
.

It is very difficult to the programmer to predict view sizes that will fit perfectly to
s as well as
very wide ones, and sometimes there is no perfect solution to this issue. However,
there are tricks that can help handling this situation, to provide a better gaming
aves a
o the
his kind
of techniques is outside the scope of the book, but it is likely that after understanding
to implement
them by intuition.

enting
graphical glitches. It can be used to apply effects to the world, by animating the
ays.

View scrolling

Now that we covered the most important parameters of `sf::View`, we will talk about how we use it in the context of the chapter's sample game.

After knowing how to define the viewport, and mapping to it an arbitrary region of the world with `sf::View::setRect()` with correct aspect ratio, we now want to move the view around, to create movement along the game world.

Since our game's action occurs in a vertical corridor, with no horizontal movement apart from moving the plane inside the fixed width window we see, we don't need to consider the x axis.

also scroll
axis (up), so
layer's aircraft
by the exact same distance, so it won't get left behind, but remains in action.

This incremental and automatic scrolling operation of the view is simply done in the update code, by doing:

```
mWorldView.move(0.f, mScrollSpeed * dt.asSeconds());
```

onds, so
we ensure that the speed of *n* pixels per second is guaranteed, independent of the simulation frame rate.

Zoom and rotation

The `sf::View` utility gives us another two precious features: zooming and rotating our view.

We can use the `sf::View::zoom(float factor)` function to easily approach or move away from the center of the view. The `factor` parameter means that the current view's rectangle will be multiplied by it. It is really that simple. A factor of
will grow the
view's rectangle, which makes objects appear smaller and gives us the impression to
a factor
when we zoom
in a real camera.

About rotation, `sf::View` allows us to turn our view orientation to another angle
results of this
entation, and
then imagine the whole content rotating relative to the center of the view.

This is a concept that is better understood by experimenting until the desired effect is reached. You can use `sf::View::rotate(float degrees)` to add a rotation angle to the current one, or `sf::View::setRotation(float degrees)` to set the rotation of the view to an absolute value.

Landscape rendering

els
and with
in a very
ides out of
the box.

SpriteNode

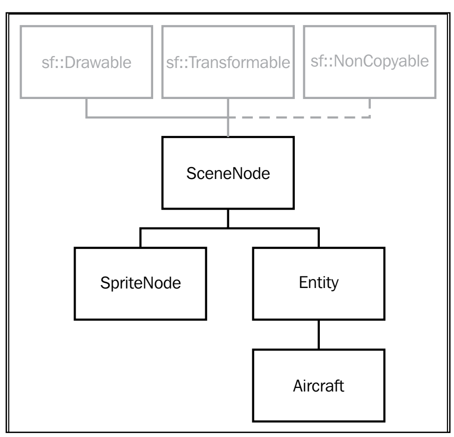
eated a
new `SceneNode` type, the `SpriteNode`, which acts as a simple `sf::Sprite` that can be plugged into our tree structure. Conveniently, this is all we need to make our landscape. We only have to create `SpriteNode` and attach it to our background layer of the scene graph.

all
snippet of the `SpriteNode` declaration:

```
class SpriteNode : public SceneNode
{
    public:
        explicit       SpriteNode(const sf::Texture& texture);
                       SpriteNode(const sf::Texture& texture,
                                  const sf::IntRect& rect);

    private:
        virtual void   drawCurrent(sf::RenderTarget& target,
                                   sf::RenderStates states) const;

    private:
        sf::Sprite     mSprite;
};
```

The `sf::Sprite` class is constructed and prepared at startup and not touched again
at the relative
ation, and
scale of `SpriteNode`, and these transforms are inherently applied to the `sf::Sprite`
object as well.

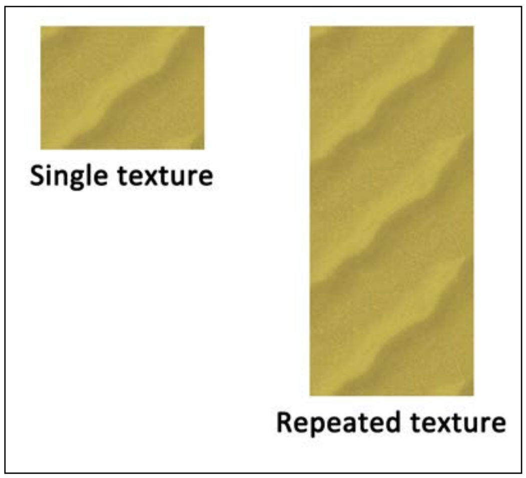
e graph for
the moment. The following diagram should give you an impression of the current
 black ones
are ours.



Landscape texture

g
multiple images to represent it along the whole level, we used a tileable texture.

A tileable texture is no more than an image that can be put together continuously, without letting the player notice that we actually have one single image repeating the image
is not noticeable. The image's beginning fits perfectly into its ending, creating an illusion of infinity, with just one texture. As you can see in the following figure, multiple desert images can be put together without creating a hard seam, giving the illusion that it's only one image.



enough to fill
one screen. Using the following technique, we made it look infinite, repeating itself along the whole level.

Texture repeating

The key to our tiling effect is exactly the texture repeating feature that SFML provides us. Every `sf::Texture` comes along with the option to enable repeating along both axis with the `sf::Texture::setRepeated(bool)` function.

When repeating is enabled for a texture, it means that it will be theoretically infinite, tiling itself continuously as much as required. When a `sf::Sprite` object links to a texture in this mode, it will behave normally until the sprite requests a texture rectangle that is larger than the texture's real dimensions. In that moment, the sprite will display the texture along its whole size.

h as
a floor's tile. Using this texture with a `sf::Sprite` object would normally
with
`sf::Sprite::setTextureRect()`. However, as soon as the texture activates its repeating mode, `sf::Sprite` would now render a nice tiled floor, without any extra effort!

Composing our world

how to
render and update objects in the world, and we have seen how views and scrolling
time to
assemble them to shape a model of our fictional world.

Completely unforeseen, we create a new class called `World`. On one side, our `World` class must contain all the data related to rendering:

- A reference to the render window
- The world's current view
- A texture holder with all the textures needed inside the world
- The scene graph
- Some pointers to access the scene graph's layer nodes

On the other hand, we store some logical data:

- The bounding rectangle of the world, storing its dimensions
- The position where the player's plane appears in the beginning
- The speed with which the world is scrolled
- A pointer to the player's aircraft

aw the
d up the
scene. Since we only have one world and we don't want it to be copied, the class derives privately from `sf::NonCopyable`.

```
class World : private sf::NonCopyable
{
    public:
        explicit        World(sf::RenderWindow& window);
        void            update(sf::Time dt);
        void            draw();
```

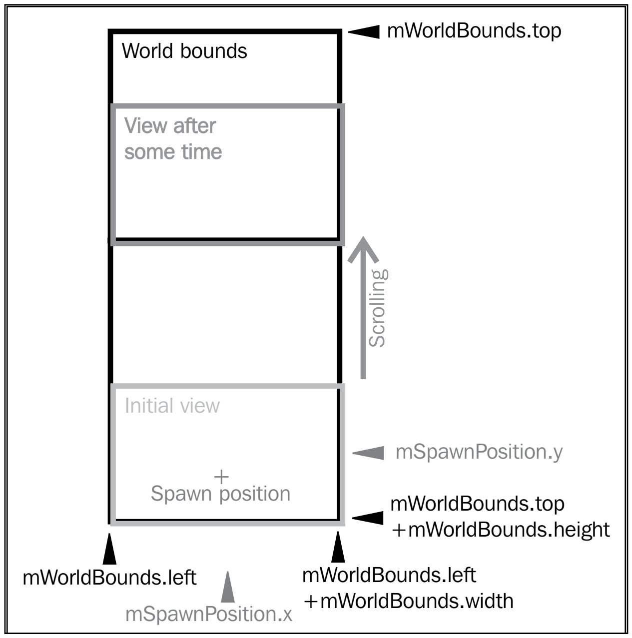
```
    private:
        void            loadTextures();
        void            buildScene();

    private:
        enum Layer
        {
            Background,
            Air,
            LayerCount
        };

    private:
        sf::RenderWindow&                   mWindow;
        sf::View                            mWorldView;
        TextureHolder                       mTextures;
        SceneNode                           mSceneGraph;
        std::array<SceneNode*, LayerCount>  mSceneLayers;

        sf::FloatRect                       mWorldBounds;
        sf::Vector2f                        mSpawnPosition;
        float                               mScrollSpeed;
        Aircraft*                           mPlayerAircraft;
};
```

For the scene layers, we use an array of pointers with the size `LayerCount`.

> `std::array` is a C++11 class template for fixed-size static arrays. It
>
> advantages. It provides value semantics, which allow copies, assignments, and passing or returning objects from functions. There is no implicit conversion to pointers, and index access is checked in debug mode. Additionally, an STL-conforming interface with useful methods such as `size()`, `begin()`, or `end()` is provided. Because of the additional safety and features, `std::array` should always be preferred over C arrays.

World initialization

In the constructor, we build up the world. The following figure can help to imagine the dimensions of our world:



The constructor initializes the important attributes. The `mWorldBounds` rectangle Its width equals the
window's width, and for its height we take an arbitrary value, here `2000`. This is rather small value, but it shows already after a short time that the desert texture ceases to repeat any longer, leaving behind a black background.

The `mSpawnPosition` vector is initialized depending on the world bounds and the window. According to the previous figure, the vector's x coordinate is assigned the middle of the screen, and its y coordinate is the same as the bottom of the world minus a half screen height.

```
: mWindow(window)
, mWorldView(window.getDefaultView())
, mWorldBounds(
    0.f,                                 // left X position
    0.f,                                 // top Y position
    mWorldView.getSize().x,              // width
    2000.f)                              // height
, mSpawnPosition(
    mWorldView.getSize().x / 2.f,                    // X
    mWorldBounds.height - mWorldView.getSize()
, mPlayerAircraft(nullptr)                           // Y
{
    loadTextures();
    buildScene();

    mWorldView.setCenter(mSpawnPosition);
}
```

For the scroll speed, we choose a negative value, since we scroll upwards and the y
ointer literal.
harge of
further initialization. Finally, we move the view to the correct start position. As you see in the figure, its center initially matches the player's spawn position.

Loading the textures

Now, let's have a look at texture loading. Thanks to our `ResourceHolder` class, this part could not be simpler:

```
void World::loadTextures()
{
    mTextures.load(Textures::Eagle,  "Media/Textures/Eagle.png");
    mTextures.load(Textures::Raptor, "Media/Textures/Raptor.png");
    mTextures.load(Textures::Desert, "Media/Textures/Desert.png");
}
```

We do not handle exceptions here, since the `World` class cannot react to them. Without the textures, we are not able to construct our world meaningfully, thus it is reasonable that we let possible exceptions abort the constructor.

xception
handler into the `main()` function, giving the user a meaningful error description:

```
int main()
{
    try
    {
        Game game;
        game.run();
    }
    catch (std::exception& e)
    {
        std::cout << "\nEXCEPTION: " << e.what() << std::endl;
    }
}
```

Building the scene

the
`World::buildScene()` method. First, we initialize the different scene layers.
element.
`std::unique_ptr::get()` returns a raw pointer to the stored object, we do not transfer ownership to the array. Finally, we attach the new node to the scene graph's root node as shown in the following code:

```
for (std::size_t i = 0; i < LayerCount; ++i)
{
    SceneNode::Ptr layer(new SceneNode());
    mSceneLayers[i] = layer.get();

    mSceneGraph.attachChild(std::move(layer));
}
```

After the background texture for the desert is loaded, we configure it to repeat
conversion
from the world bounds (which have the type `sf::FloatRect` and thus store float coordinates).

```
sf::Texture& texture = mTextures.get(Textures::Desert);
sf::IntRect textureRect(mWorldBounds);
texture.setRepeated(true);
```

Then, we create our `SpriteNode` class that links to the desert texture. We pass to its constructor the texture rectangle. This grants that our sprite is as big as the whole
 the whole
level in -y direction.

```
std::unique_ptr<SpriteNode> backgroundSprite(
    new SpriteNode(texture, textureRect));
backgroundSprite->setPosition(
    mWorldBounds.left,
    mWorldBounds.top);
mSceneLayers[Background]
    ->attachChild(std::move(backgroundSprite));
```

 create the
player's airplane. We set the world's pointer `mPlayerAircraft` to the newly created
and velocity.
The forward velocity equals the scroll speed. We also introduce a sideward velocity with value `40`, to show a more interesting movement pattern. At last, we attach the plane to the `Air` scene layer.

```
std::unique_ptr<Aircraft> leader(
    new Aircraft(Aircraft::Eagle, mTextures));
mPlayerAircraft = leader.get();
mPlayerAircraft->setPosition(mSpawnPosition);
mPlayerAircraft->setVelocity(40.f, mScrollSpeed);
mSceneLayers[Air]->attachChild(std::move(leader));
```

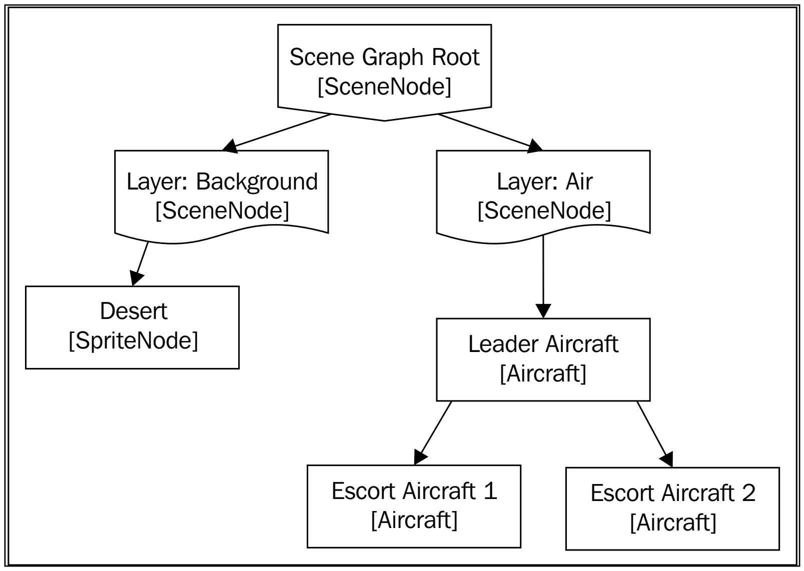
r airplanes,
scort to the
leader's scene node. The specified position is thus interpreted relative to the leader. In the following example, the first escort plane is located `80` units to the left and `50` units behind the leader:

```
std::unique_ptr<Aircraft> leftEscort(
    new Aircraft(Aircraft::Raptor, mTextures));
leftEscort->setPosition(-80.f, 50.f);
mPlayerAircraft->attachChild(std::move(leftEscort));
```

For the second escort, the code is almost the same, except that the relative x position is now positive, meaning that this plane is located to the right.

```
std::unique_ptr<Aircraft> rightEscort(
    new Aircraft(Aircraft::Raptor, mTextures));
rightEscort->setPosition(80.f, 50.f);
mPlayerAircraft->attachChild(std::move(rightEscort));
```

That was it, now our scene is ready! Now, our scene graph looks as shown in the following diagram. Below the description of each node, you see the most derived class type.



Update and draw

The `update()` and `draw()` methods bring the encapsulated scene graph functionality to the API of the `World` class.

scene graph:

```
void World::draw()
{
    mWindow.setView(mWorldView);
    mWindow.draw(mSceneGraph);
}
```

the view is
scrolled according to the passed time. Next, we check if the player's aircraft reaches a certain distance (`150`) from the world's borders, and flip its x velocity in this case.
, and the
which
actually applies the velocities.

```
void World::update(sf::Time dt)
{
    mWorldView.move(0.f, mScrollSpeed * dt.asSeconds());

    sf::Vector2f position = mPlayerAircraft->getPosition();
    sf::Vector2f velocity = mPlayerAircraft->getVelocity();

    if (position.x <= mWorldBounds.left + 150
    || position.x >= mWorldBounds.left + mWorldBounds.width - 150)
    {
        velocity.x = -velocity.x;
        mPlayerAircraft->setVelocity(velocity);
    }

    mSceneGraph.update(dt);
}
```

Integrating the Game class

By now we already know how the `Game` class works, what a game loop is for, and how to take advantage of it. For this chapter, we take the previously used `Game` class, and plug into it our newcomer `World` class.

Because we obeyed a few principles, this integration is very easy and it's just a matter of having a `World` object inside the `Game` class, and then letting it update and draw itself in the appropriate times.

The run() method

Our application's `main()` function has a simple job. It allocates a `Game` object, and lets it run itself through the `run()` method. When the `run()` method exits, the program releases its resources and closes.

Therefore, it is within the `run()` method that the magic happens! It is responsible for
dating
the world, and ordering the rendering of the game.

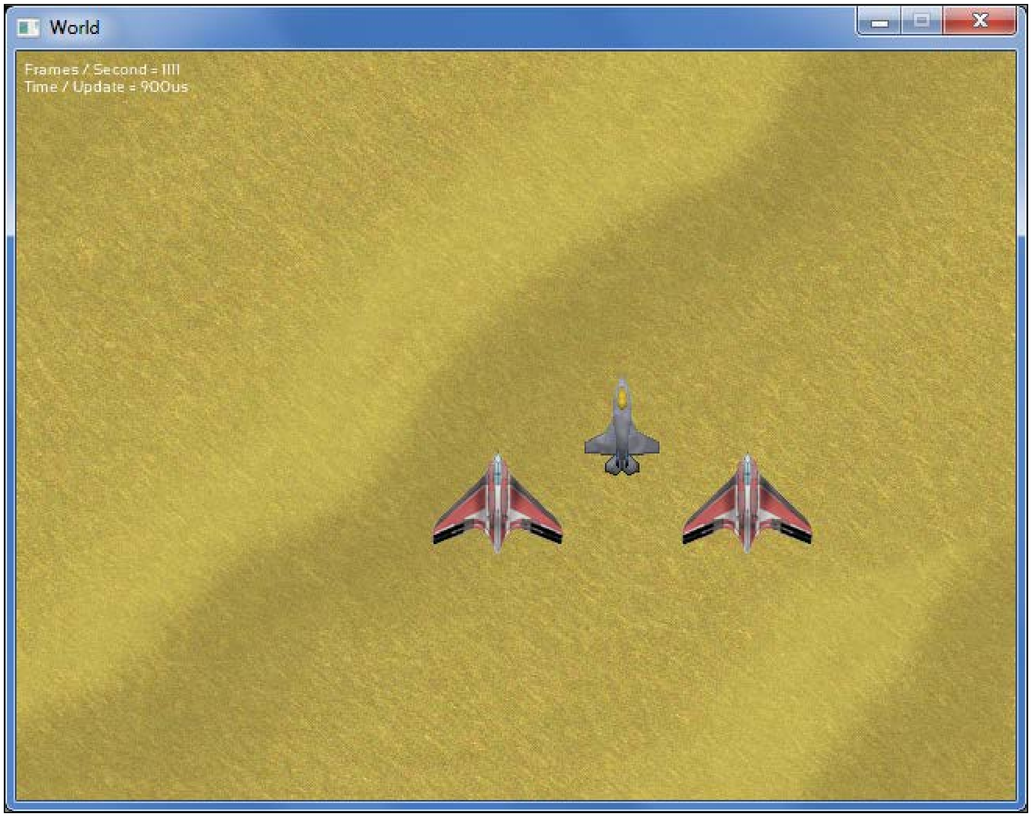
In the next chapter, events and input will be covered in depth. For now, it is
run()
method:

```
mWindow.clear();
mWorld.draw();

mWindow.setView(mWindow.getDefaultView());
mWindow.draw(mStatisticsText);
mWindow.display();
```

This code closely resembles the high-level drawing of a frame for any game. The function call `mWindow.clear()` ensures that our frame buffer, the canvas where the
the world
draw itself, where it defines its own view and orders the scene graph to render
he screen for
same so the
text always appears fixed on the screen.

On the `mWindow.display()` call, we tell SFML we are done drawing the frame and it proceeds to upload it to our screen right away.

s and
cture in
y out our
ins many
as cameras,
nderstand
ion.
r may
not have known, for example, practical use cases of C++11 features. So far, our result looks as shown in the following screenshot:



Summary

This chapter has moved away from the typical minimal examples, and has given mind that
we have chosen one of many design options—not every game needs a scene graph, sometimes a list of entities is enough.

In the next chapter you can expect information about handling both input
rn about
command systems to deliver input to game entities as well as dynamic key binding mechanisms, which allow you to configure the set of controls of a game in runtime.

4

Command and Control – Input Handling

game
n this chapter,
ld.

In this chapter we aim to learn:

- SFML events and their purpose as input
- SFML real-time input and its difference from events
- A command-based communication system to deliver events in our world
- How to dynamically bind keys at runtime

ve not
really delved into what they are or what they are meant to be used for. That is the
fiinput than just
simply events.

Polling events

Generally speaking, **events** are objects that are triggered when something
underlying
that is
easier to use and cross-platform. SFML goes with a polling design to have you
to the
ng SFML
event type, and puts it into a queue of waiting events. In your actual application code, you extract events from this queue using the `sf::Window::pollEvent()` function (note that `sf::Window` is the base class of `sf::RenderWindow`, without the rendering functionality). The `pollEvent()` function signature is a bit interesting:

```
bool sf::Window::pollEvent(sf::Event& event);
```

with
`pollEvent()`
actual event and a value affirming that we got it from the list. If the second value is false, we will not receive anything.

SFML uses a common approach to a polling system, which allows us to retrieve one event instance at a time by continuously calling `pollEvent()` until the
poll. In the
meanwhile, for every positive return value, we know that our `sf::Event` variable has been filled with important event information.

is
following fashion:

```
sf::Event event;
while (window.pollEvent(event))
{
    // Handle the event
}
```

y. There is a
`waitEvent()` function as well, that waits until it receives an event, but that is pretty redundant for our case, so we will not dig into that.

The event structure we have used so much already is built up of an enum and a union of different event structures. As a short reminder, a union is similar to `struct`, with the main difference that all the member variables occupy the same memory location. Therefore, only one member can be actively used at a time. Applied to `sf::Event`, the very nature of union grants that an event will never be two things at the same time. Depending on the value of the `sf::Event::type` member variable, a different union member is filled with useful data. When we receive an event, we first check the type of it, and depending on it we access the specific data. We have to be careful to access the correct union members, otherwise we risk undefined behavior.

We can group the different events to four different categories: **window**, **joystick**, **keyboard**, and **mouse**. We will try to cover each and every one of the events, but it will be near to impossible to go into too much detail, otherwise this chapter would be
in case
anything is unclear on the events.

Window events

at concern
windows directly. I have listed them as follows, with their intended purposes and the conditions under which they are generated:

- `sf::Event::Closed`: This event occurs when the users somehow request that they want the window closed. Mostly, this amounts to pressing the **[X]** button in the window, or a shortcut such as *Alt* + *F4* on Windows. This event
lenty
and your application should always handle this event.
- `sf::Event::Resized`: This event is triggered when the window is resized. Most often this is when the user drags on the edges of the window to manually resize it. The data type associated with this is `sf::Event::SizeEvent` and can be accessed through the member `event.size`. Of course, resizing the window is only possible if you have enabled it to be resized.
- `sf::Event::LostFocus` and `sf::Event::GainedFocus`: These events come from the window when it gains or loses focus. Focus here means that this
the
vents.

  clicks outside the window or switches to another application.

Joystick events

Now we have to cover the joystick-based events. These events are fired whenever
has a data
structure associated with it. A common member they all have is the ID number for
k generated
ing joystick
events that can be generated:

- Joysticks have buttons, for button-related events we have the event types `sf::Event::JoystickButtonPressed` and `sf::Event::JoystickButtonReleased`. These are triggered when a
ated
with this is `sf::Event::JoystickButtonEvent` with the member `event.joystickButton`. You should keep in mind that the buttons can be of a variable amount.
- The `sf::Event::JoystickMoved` event is generated when the analog stick or digital cross moves; it has the structure `sf::Event::JoystickMoveEvent` for its data. It is accessible through the member `event.joystickMove`. A thing
in an
axis as well. It is not guaranteed that the joysticks support all axes.
- Last we have the event of when a joystick is connected or disconnected, allowing you to handle hot-plugging joysticks. The event types are `sf::Event::JoystickConnected` and `sf::Event::JoystickDisconnected`. The data type is `sf::Event::JoystickConnectEvent` and is accessible through the member `event.joystickConnect`.

Keyboard events

Now the defining feature of a PC, the keyboard. The keyboard generates events as the primary input device available to computers:

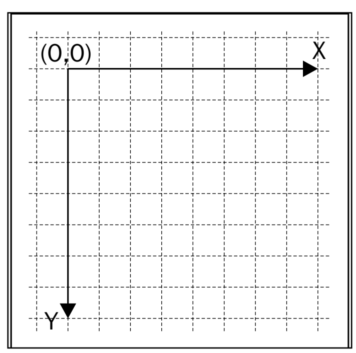
- For the event when the user presses down a key, we have the event type `sf::Event::KeyPressed`. The data structure for this event is `sf::Event::KeyEvent`, which is accessed through `event.key`. It holds all the data of the current state of the keyboard associated with that key press. The member variable `event.key.code` contains the actual key, while other members such as `event.key.control` are Booleans that state whether a modifier is pressed. If you hold a key for a while, multiple `KeyPressed` events will be triggered. This key repetition option can be deactivated using `sf::Window::setKeyRepeatEnabled()`.

- The event `sf::Event::KeyReleased` is the counterpart to `KeyPressed`; it is triggered when you release a key. To retrieve information about the key release, you can also access the structure `sf::Event::KeyEvent` via `event.key`—just like when a key was pressed.
- Last, we have a little special event that SFML creates for your convenience. It is called `sf::Event::TextEntered` and is designed for receiving formatted
  s task,
  so this event helps out a lot. The data structure is `sf::Event::TextEvent` and it is accessible through `event.text`.

Mouse events

ated when
the state of the cursor, the mouse buttons or the mouse wheel changes:

- First we have the `sf::Event::MouseEntered` and `sf::Event::MouseLeft` events. These are triggered when the mouse cursor enters or leaves the window.
- Next we consider when the cursor moves inside the window. The type for this is `sf::Event::MouseMoved` and its associated structure is `sf::MouseMoveEvent`. You can access the data from the `event.mouseMove` member. The coordinates in the data structure are measured in window
  om
  your window's current view. Please notice how the Y coordinate increases as
  d
  then grows up to the size of the window:



- Then, we have the buttons of the mouse. For them we have the `sf::Event::MouseButtonPressed` and `sf::Event::MouseButtonReleased` types. They come associated with the `sf::Event::MouseButtonEvent` structure and its data can be accessed through the `event.mouseButton` member.
- Last is the mouse wheel on the mouse. When its state changes, it generates an event of type `sf::Event::MouseWheelMoved`. Attached with this is the data structure `sf::Event::MouseWheelEvent` that you can access via the member `event.mouseWheel`.

> Always remember, the mouse wheel doesn't have a global state. This means that we will be notified that the mouse wheel is being moved by some unit, but this information doesn't constitute an actual rotation value, just an offset corresponding to the movement we performed with the physical mouse.

Getting the input state in real time

s is that
they report once when the state changes, but you cannot continuously ask them how the state of the input devices look right now.

xamples
easier, has
implemented classes that let you access these states in **real time** whenever you want
ote this
alternative method of handling user input.

The three classes `sf::Joystick`, `sf::Keyboard`, and `sf::Mouse` can provide almost
minor
is shown;
we recommend visiting the SFML documentation for more details on them. The
be instantiated.
e:

- `sf::Joystick`: This class provides same tools that are similar to the
ey
can state if a joystick is connected or disconnected or get the current input
s and
if the joystick supports a specific axis.

- `sf::Keyboard`: This is a really small class. It has one function `isKeyPressed()`, you can ask if a key is pressed and it returns either `true` or `false`. Nothing fancy.
- `sf::Mouse`: This class is a bit tricky. It behaves normally with the buttons, the function `isButtonPressed()` tells you if a button is being pressed or not.
  olled
  the event from a window so you always knew what window you wanted

  ask `sf::Mouse::getPosition()` for the mouse position, you will get the
  will
  is as
  you first expected.

remember
when we had that circle that we moved by pressing keys on the keyboard? We polled events from the window and pushed them to `Game::handlePlayerInput()` and then we did the movement in `Game::update()`:

```
void Game::handlePlayerInput(sf::Keyboard::Key key,
bool isPressed)
{
    if (key == sf::Keyboard::W)
        mIsMovingUp = isPressed;
        else if (key == sf::Keyboard::S)
      mIsMovingDown = isPressed;
      else if (key == sf::Keyboard::A)
      mIsMovingLeft = isPressed;
      else if (key == sf::Keyboard::D)
      mIsMovingRight = isPressed;
}

void Game::update()
{
    sf::Vector2f movement(0.f, 0.f);
    if (mIsMovingUp)
        movement.y -= 1.f;
    if (mIsMovingDown)
        movement.y += 1.f;
    if (mIsMovingLeft)
        movement.x -= 1.f;
    if (mIsMovingRight)
        movement.x += 1.f;

    mPlayer.move(movement);
}
```

een pressed
e this
by asking `sf::Keyboard` if a button has been pressed down, instead of checking a couple of Boolean values. The exact same functionality but using real-time input instead will be significantly smaller. We do not even need the `handlePlayerInput()` function anymore because everything will be handled in `update()` instead:

```
void Game::update(sf::Time elapsedTime)
{
    sf::Vector2f movement(0.f, 0.f);
    if (sf::Keyboard::isKeyPressed(sf::Keyboard::W))
        movement.y -= PlayerSpeed;
    if (sf::Keyboard::isKeyPressed(sf::Keyboard::S))
        movement.y += PlayerSpeed;
    if (sf::Keyboard::isKeyPressed(sf::Keyboard::A))
        movement.x -= PlayerSpeed;
    if (sf::Keyboard::isKeyPressed(sf::Keyboard::D))
        movement.x += PlayerSpeed;

    mPlayer.move(movement * elapsedTime.asSeconds());
}
```

ate keys
are being pressed. This removes our need of book keeping the events, making our life much easier and our code much simpler to read and follow.

golden
hammer. Events are still very much needed and have their own purposes as we will explore now.

Events and real-time input – when to use which

a state has
hen you use
the real-time functions. Here is an example:

```
if (sf::Mouse::isButtonPressed(sf::Mouse::Left))
    // WHILE the left mouse button is being pressed, do something
if (event.type == sf::Event::MouseButtonPressed)
    // WHEN the left mouse button has been pressed, do something
```

In the first `if` statement we do something during the time that the mouse is being pressed down, while in the second version we only do something once after we have pressed the button down.

Delta movement from the mouse

f the
cursor. For the game we are making here in this book, it won't be needed but it's such a common functionality that we should still go through what it is.

The delta movement is the difference of the cursor position between two frames; that is, it is the distance that the cursor has traveled:

```
sf::Vector2i mousePosition = sf::Mouse::getPosition(mWindow);
sf::Vector2i delta = mLastMousePosition - mousePosition;
mLastMousePosition = mousePosition;
```

A little book keeping is needed here but nothing major. The delta vector contains the data we need for anything relative. Now we are not making a first person shooter,
tation of the
camera. There are uses in 2D as well of course! Delta mouse movement can be used for dragging the view of a map and lots more.

In some cases this naive method can become a problem eventually. What if you are
tside the
nd the
good, if we go
back to a first person shooter example, it would make the game totally unplayable. But thanks to SFML this problem is easy to solve.

In the `sf::Mouse` class we have a `setPosition()` function pair. It works exactly the same as the `sf::Mouse::getPosition()` functions, but it sets the mouse position on
n that sets it
in the screen coordinates or you can set it relative to your window:

```
sf::Vector2i windowCenter(mWindow.getSize() / 2u);
sf::Vector2i mousePosition = sf::Mouse::getPosition(mWindow);
sf::Vector2i delta = windowCenter - mousePosition;
sf::Mouse::setPosition(windowCenter, mWindow);
```

e have
m the center
e half size of
the window.

Playing nice with your application neighborhood

Now what we learned in the last part is indeed handy, but it has got its problem. What if the user tabs out and tries to interact with the other applications that are running in the background? We would be constantly forcing the mouse back to the center of our window, making it impossible to do anything else than playing our game.

ncluding
e it
n the user
doesn't want to interact with us anymore and behave properly.

This is where events come in again. If you remember, we had the event types `sf::Event::GainedFocus` and `sf::Event::LostFocus` that notify the application as soon as the window gains or loses focus:

```
void Game::processEvents()
{
    sf::Event event;
    while(mWindow.pollEvent(event))
    {
        if (event.type == sf::Event::GainedFocus)
            mIsPaused = false;
        else if (event.type == sf::Event::LostFocus)
            mIsPaused = true;
    }
}

void Game::run()
{
    while (mWindow.isOpen())
    {
        if (!mIsPaused)
            update();

        render();
        processEvents();
    }
}
```

e a Boolean
or not. Then,
e with
called if the
vents, and
time.

A command-based communication system

our
game, we might handle them as follows (the aircraft methods are fictional to show the principle):

```
// One-time events
sf::Event event;
while (window.pollEvent(event))
{
    if (event.type == sf::Event::KeyPressed
     && event.key.code == sf::Keyboard::X)
        mPlayerAircraft->launchMissile();
}

// Real-time input
if (sf::Keyboard::isKeyPressed(sf::Keyboard::Left))
    mPlayerAircraft->moveLeft();
else if (sf::Keyboard::isKeyPressed(sf::Keyboard::Right))
    mPlayerAircraft->moveRight();
```

There are several problems with this approach. On one side, we have hardcoded keys, so a user cannot choose WASD instead of arrow keys for movement. On the
code grows
as we implement more features, and makes the originally simple code complicated.

For example, imagine that we want to keep the airplane inside the screen bounds. So we could only move the airplanes to the left if it is currently inside the screen, which can be verified using an `if` condition. In case of the missiles, we want to check whether enough ammunition is available before firing, leading to another `if` statement. Maybe, we want to limit the fire interval, so that the player must wait at least one second between two launched missiles. For this, we need a timer and further logic, and we already have plenty of game-logic code mixed with the input-handling code. Sure, we could outsource the code into functions, but there is still a problem.

Sometimes, we do not know whom to affect when the user input occurs. Imagine a guided missile which is steered by the player. The missile itself may be stored somewhere in the depths of the world's scene graph, we do not have access to it at
sed from the
scene graph via the `World` to the `Game` class. The same thoughts apply to many other entities in the game, eventually we would duplicate the information about the world at the place where input is handled.

This is of course not what we want. Instead, we aim to separate input handling and game logics. A possible approach to achieve this goal is discussed in the following sections.

Introducing commands

ts.
A command is able to alter the object and to issue orders such as moving an entity, firing a weapon, and triggering an explosion.

We design a structure `Command` that contains a function object, which can be called on any game object represented by a scene node:

```
struct Command
{
    std::function<void(SceneNode&, sf::Time)>    action;
};
```

> `std::function` is a C++11 class template to implements callback mechanisms. It treats functions as objects and makes it possible to copy functions or to store them in containers. The `std::function` class is compatible with function pointers, member function pointers, functors, and lambda expressions. The template parameter represents the signature of the function being stored.

The following example shows `std::function` in action. First, we assign a function pointer to it, then we assign a lambda expression:

```
int add(int a, int b) { return a + b };
std::function<int(int, int)> adder1 = &add;
std::function<int(int, int)> adder2
    = [] (int a, int b) { return a + b; };
```

The `std::function` object can be called using its overloaded `operator()`:

```
int sum = adder1(3, 5);         // same as add(3, 5)
```

> Using the standard function template `std::bind()`, the function arguments can be bound to the given values. The `std::bind()` function returns a new function object that can be stored inside `std::function`.

In the earlier example, we can fix the second argument to `1` and thus have a new function that takes only one argument. The placeholder `_1` expresses that the first
t `1`:

```
std::function<int(int)> increaser = std::bind(&add, _1, 1);
int increased = increaser(5);     // same as add(5, 1)
```

For more detailed information, consult a standard library documentation such as `www.cppreference.com`. Coming back to our game, the `Command` structure's member variable `action` contains the function that implements the order issued to an object. The first parameter is a reference to a scene node, which is affected by the command.
ample, we
can instantiate a command as follows:

```
void moveLeft(SceneNode& node, sf::Time dt)
{
    node.move(-30.f * dt.asSeconds(), 0.f);
}

Command c;
c.action = &moveLeft;
```

n as follows:

```
c.action = [] (SceneNode& node, sf::Time dt)
{
    node.move(-30.f * dt.asSeconds(), 0.f);
};
```

In short, we can now define any operation on a scene node inside a `Command` object. The advantage of a command over a direct function call is abstraction: We do not
the action
that is performed on it. The message passing system is responsible to deliver the commands to the correct recipients.

Receiver categories

different
ich are likely
to receive similar commands. For example, the player's aircraft is an own category,
d so on.

We define an enum to refer to the different categories. Each category except `None` is initialized with an integer that has one bit set to `1`, and the rest are set to `0`:

```
namespace Category
{
    enum Type
    {
        None            = 0,
        Scene           = 1 << 0,
        PlayerAircraft  = 1 << 1,
        AlliedAircraft  = 1 << 2,
        EnemyAircraft   = 1 << 3,
    };
}
```

`OR` operator.
a
combined category as follows:

```
unsigned int anyAircraft = Category::PlayerAircraft
                         | Category::AlliedAircraft
                         | Category::EnemyAircraft;
```

The `SceneNode` class gets a new virtual method that returns the category of the game object. In the base class, we return `Category::Scene` by default:

```
unsigned int SceneNode::getCategory() const
{
    return Category::Scene;
}
```

In a derived class, we can override `getCategory()` to return a specific category. For example, we can say that an aircraft belongs to the player if it is of type `Eagle`, and that it is an enemy otherwise:

```
unsigned int Aircraft::getCategory() const
{
    switch (mType)
    {
        case Eagle:
            return Category::PlayerAircraft;

        default:
            return Category::EnemyAircraft;
    }
}
```

Of course, this is just a simple demonstration of how categories work. You can implement a much more complex logic to determine a game object's category. An
to combine
categories. This is the reason why the return type of `getCategory()` is `unsigned int` and not `Category::Type`.

In our game, categories are stored as `unsigned int` variables. This implies a small issue that you should be aware of: Integer flags are not type-safe. Meaningless
he
`Category`
enum types:

```
Command command;
command.category = Aircraft::Eagle; // only Eagles receive command
```

Accidentally, the enums `Category::Type` and `Aircraft::Type` were mistaken,
achieved by
overloading bitwise operators for the enum, a dedicated class template `Flags<Enum>` could store flag combinations.

Getting back to commands, we give our `Command` class another member variable that stores the recipients of the command in a category:

```
struct Command
{                                                 Command();

    std::function<void(SceneNode&, sf::Time)>     action;
    unsigned int                                  category;
};
```

The default constructor initializes the category to `Category::None`. By assigning a
If we want a
tegory can be
set accordingly:

```
Command command;
command.action = ...;
command.category = Category::AlliedAircraft
                 | Category::EnemyAircraft;
```

Command execution

We have discussed how to construct commands with a function and a receiver
receivers.

In our world, commands are passed to the scene graph, inside which they are distributed to all scene nodes with the corresponding game objects. Each scene node is responsible for forwarding a command to its children.

We write a non-virtual method `SceneNode::onCommand()` which is called every time a command is passed to the scene graph. First, we check if the current scene node is a receiver of the command, that is, if it is listed in the command's receiver category. The check is performed using the bitwise `AND` operator. If a bit is set in both the command's and the current node's category, then we know that the node receives the command. In this case, we can execute the command by invoking the `action` member of type `std::function` on the current node, and with the current frame time. The second part of `onCommand()` forwards the command to all the child nodes:

```
void SceneNode::onCommand(const Command& command, sf::Time dt)
{
    if (command.category & getCategory())
        command.action(*this, dt);

    FOREACH(Ptr& child, mChildren)
        child->onCommand(command, dt);
}
```

Command queues

Now that the interface to distribute a command inside the scene graph is ready,
r this
purpose, we write a new class `CommandQueue`. This class is a very thin wrapper around a queue of commands. A queue is a **FIFO** (**first in, first out**) data structure that ensures that elements, which are inserted first, are also removed first. Only the
container
adapter `std::queue`, which implements a queue interface on top of a full-featured STL container such as `std::deque`.

Our class looks similar to the following:

```
class CommandQueue
{
    public:
        void        push(const Command& command);
        Command     pop();
        bool        isEmpty() const;

    private:
        std::queue<Command> mQueue;
};
```

e underlying
`std::queue`. Their definitions are straightforward, and hence they are omitted here.

The `World` class holds an instance of `CommandQueue`. In the `World::update()`
forwarded
to the scene graph:

```
void World::update(sf::Time dt)
{
    ...

    // Forward commands to the scene graph
    while (!mCommandQueue.isEmpty())
        mSceneGraph.onCommand(mCommandQueue.pop(), dt);

    // Regular update step
    mSceneGraph.update(dt);
}
```

As explained earlier, `SceneNode::onCommand()` distributes a command across all scene nodes. We also provide a getter function to access the command queue from outside the world:

```
CommandQueue& World::getCommandQueue()
{
    return mCommandQueue;
}
```

Handling player input

e commands
now, player
input has been handled in the `Game` class. But it deserves an own class, we call it `Player`.

The `Player` class contains two methods to react to the SFML events and real-time input, respectively:

```
class Player
{
    public:
        void     handleEvent(const sf::Event& event,
                             CommandQueue& commands);
        void     handleRealtimeInput(CommandQueue& commands);
};
```

These methods are invoked from the `Game` class, inside the `processInput()` member function. Only the `sf::Event::Closed` event is still handled inside `Game`, all other events are delegated to the `Player` class:

```
void Game::processInput()
{
    CommandQueue& commands = mWorld.getCommandQueue();

    sf::Event event;
    while (mWindow.pollEvent(event))
    {
        mPlayer.handleEvent(event, commands);

        if (event.type == sf::Event::Closed)
            mWindow.close();
    }

    mPlayer.handleRealtimeInput(commands);
}
```

Now let's see how input is handled inside the `Player` class. We treat the example of the arrow keys and real-time input with `sf::Keyboard`. What we want to do is nd, we need
r to the following:

```
struct AircraftMover
{
    AircraftMover(float vx, float vy)
    : velocity(vx, vy)
    {
    }

    void operator() (SceneNode& node, sf::Time) const
    {
        Aircraft& aircraft = static_cast<Aircraft&>(node);
        aircraft.accelerate(velocity);
    }

    sf::Vector2f velocity;
};
```

When the functor is invoked, `operator()` is called, which adds `(vx, vy)` to the current aircraft velocity. `aircraft.accelerate(velocity)` is a utility function that acts equivalently to `aircraft.setVelocity(aircraft.getVelocity() + velocity)`. In other words, the variable `velocity` is added to the aircraft's current velocity. The downcast is required because the command stores a function which is invoked on `SceneNode&`, but we need `Aircraft&`. It is safe as long as we guarantee with the receiver category that only correct types receive the command. We can now construct a command as follows:

```
Command moveLeft;
moveLeft.category = Category::PlayerAircraft;
moveLeft.action = AircraftMover(-playerSpeed, 0.f);
```

Since we often work on entities that are classes derived from `SceneNode`, the constant need for downcasts is annoying. It would be much more user friendly if we could directly create a function with the signature `void(Aircraft& aircraft, sf::Time dt)` instead. This is possible, if we provide a small adapter `derivedAction()` that takes a function on a derived class such as `Aircraft` and converts it to a function on the `SceneNode` base class. We create a lambda expression, inside which we invoke the original function `fn` on the derived class, passing a downcast argument to it. An e, which
is extremely helpful to avoid bugs. The lambda expression uses a `[=]` capture list, meaning that variables referenced from its body (such as the variable `fn`) are copied from the surrounding scope:

```
template <typename GameObject, typename Function>
std::function<void(SceneNode&, sf::Time)>
    derivedAction(Function fn)
{
    return [=] (SceneNode& node, sf::Time dt)
    {
        // Check if cast is safe
        assert(dynamic_cast<GameObject*>(&node) != nullptr);

        // Downcast node and invoke function on it
        fn(static_cast<GameObject&>(node), dt);
    };
}
```

Given this adapter, we can change our `AircraftMover` to take `Aircraft&` instead of `SceneNode&`:

```
struct AircraftMover
{
    ...

    void operator() (Aircraft& aircraft, sf::Time) const
    {
        aircraft.accelerate(velocity);
    }
};
```

A command would then be constructed as follows:

```
Command moveLeft;
moveLeft.category = Category::PlayerAircraft;
moveLeft.action
    = derivedAction<Aircraft>(AircraftMover(-playerSpeed, 0));
```

it should
be worth the advantage that after writing it once, we can create actions in a much cleaner way, without the need to downcast again and again.

Let's get back to the interesting part. Let's finally define `Player::handleRealtimeInput()`, which creates a command every frame an arrow key is held down:

```
void Player::handleRealtimeInput(CommandQueue& commands)
{
    const float playerSpeed = 30.f;

    if (sf::Keyboard::isKeyPressed(sf::Keyboard::Up))
    {
        Command moveLeft;
        moveLeft.category = Category::PlayerAircraft;
        moveLeft.action = derivedAction<Aircraft>(
            AircraftMover(-playerSpeed, 0.f));
        commands.push(moveLeft);
    }
}
```

we write a
lambda expression that outputs the position of the player's aircraft every time the user presses the *P* key:

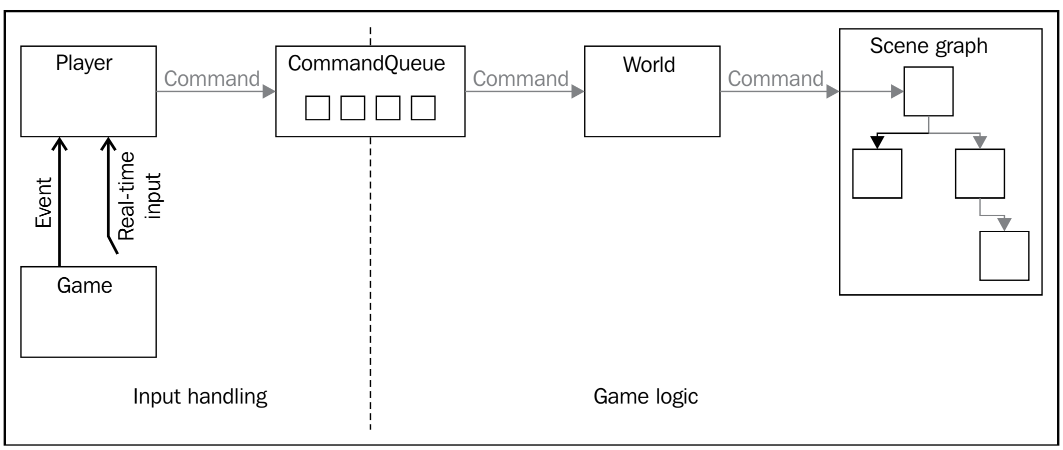
```
void Player::handleEvent(const sf::Event& event,
                         CommandQueue& commands)
{
    if (event.type == sf::Event::KeyPressed
     && event.key.code == sf::Keyboard::P)
    {
        Command output;
        output.category = Category::PlayerAircraft;
        output.action = [] (SceneNode& s, sf::Time)
        {
            std::cout << s.getPosition().x << ","
                      << s.getPosition().y << "\n";
        };
        commands.push(output);
    }
}
```

Simple, isn't it? Once you have understood the concepts of functions and lambda
u don't have
to use lambda expressions, you can still stick to functors such as `AircraftMover`. But in some situations, lambdas allow you to express semantics far more compactly.

Now that was it, our command system is complete!

Commands in a nutshell

We have discussed many components in our command-based system; easy for
bout
ndling and
a game logic side. SFML events are polled in `Game` and forwarded to `Player`, which transforms the events to commands and feeds `CommandQueue` with them. The same process is followed for the real-time input, `Player` checks the current input state and pushes corresponding commands to the queue. The `CommandQueue` class stores a queue of commands and acts as the bridge between input handling and game logic. On the game logic side, the `World` class pops commands from the `CommandQueue` class and sends them to the root of the scene graph, inside which the commands are distributed depending on their receiver categories. Eventually, the functions stored in each command are applied to the correct game objects.
The following diagram gives an overview of the command system and the way it is integrated into our game architecture:



Implementing the game logic

You certainly remember the basic example of the aircraft floating from left to right and back from *Chapter 3*, *Forge of the Gods – Shaping Our World*. As we now use player
e; for
example we want to ensure that the player's plane remains inside the view, now that it can move freely.

All this is done in the function `World::update()`. In the following paragraphs, we advance through it step by step, explaining each piece of code. We begin with scrolling the view and setting the player's velocity to zero. Note that we really use
to the moving
view. The scrolling speed is addressed later in this function:

```
void World::update(sf::Time dt)
{
    mWorldView.move(0.f, mScrollSpeed * dt.asSeconds());
    mPlayerAircraft->setVelocity(0.f, 0.f);
```

Next, all commands from the queue are forwarded to the scene graph. This makes
lane's
velocity will be changed:

```
    while (!mCommandQueue.isEmpty())
        mSceneGraph.onCommand(mCommandQueue.pop(), dt);
```

Now, the basic velocity has been set. If right and top arrow keys are both held down, the plane will fly diagonally to the upper-right corner, but the velocity will be faster
t diagonal
d the scroll
have
checked for diagonal movements if the velocity had not been zero:

```
    sf::Vector2f velocity = mPlayerAircraft->getVelocity();

    if (velocity.x != 0.f && velocity.y != 0.f)
        mPlayerAircraft->setVelocity(velocity / std::sqrt(2.f));

    mPlayerAircraft->accelerate(0.f, mScrollSpeed);
```

In the next step, the regular update step of the scene is performed:

```
    mSceneGraph.update(dt);
```

he visible area
then we keep
all X and Y coordinates inside the boundaries, given some distance to the screen's border. Last, we call `Aircraft::setPosition()` to apply the corrected position:

```
    sf::FloatRect viewBounds(
        mWorldView.getCenter() - mWorldView.getSize() / 2.f,
        mWorldView.getSize());
    const float borderDistance = 40.f;

    sf::Vector2f position = mPlayerAircraft->getPosition();
    position.x = std::max(position.x,
        viewBounds.left + borderDistance);
    position.x = std::min(position.x,
        viewBounds.left + viewBounds.width - borderDistance);
    position.y = std::max(position.y,
        viewBounds.top + borderDistance);
    position.y = std::min(position.y,
        viewBounds.top + viewBounds.height - borderDistance);
    mPlayerAircraft->setPosition(position);
}
```

A general-purpose communication mechanism

What you have seen in the previous sections are commands—how they are used for input. Note that during the design process of our message-passing system, we have paid attention to encapsulate input handling and to make the other components generic and reusable. Only the `Player` class is directly coupled to the input; the classes `Command` and `CommandQueue` can deal with any functions that affect scene nodes for a given amount of time.

e our
command system for other sources of control, like the network or artificial

notify entities about happenings in the world. All we need to do is to set up the corresponding command, push it to the queue, and it will be automatically delivered to the related scene nodes.

Customizing key bindings

A big part with input management in a game is allowing the user to customize how he interacts with it, like the keys. Most of the time, you can find the most popular key
s be people
that want to do stuff their way.

We have to provide tools in order to dynamically bind the keys to specific actions. With the command queue introduced in the previous sections, this becomes a much easier task to accomplish.

With the command queue, we already define specific actions for a specific key. The difference is that right now, we have it hardcoded as follows:

```
if (sf::Keyboard::isKeyPressed(sf::Keyboard::Left))
    commands.push(moveLeft);
if (sf::Keyboard::isKeyPressed(sf::Keyboard::Right))
    commands.push(moveRight);
```

The problem with this code is that it is very inflexible. We have to change a lot in
arate sets
of data that we want to link together. We have the actual action that we want to perform, such as moving left or right. Then, we have the input key, the key that is to trigger the action.

Now the keys in `sf::Keyboard` are just part of an enum. So on top of this, we create an enum in our `Player` class that represents the different kinds of actions we associate with the pressed keys:

```
class Player
{
    public:
        enum Action
        {
            MoveLeft,
            MoveRight,
            ...
        };

        void                assignKey(Action action,
                                      sf::Keyboard::Key key);
        sf::Keyboard::Key   getAssignedKey(Action action) const;
        ...
```

```
    private:
        static bool        isRealtimeAction(Action action);

    private:
        std::map<sf::Keyboard::Key, Action> mKeyBinding;
        std::map<Action, Command>           mActionBinding;
};
```

Here, we have divided the input into two abstractions. We have the key binding to a specific action, and we have the binding of an action to a specific command. This is all we need to remove any hardcoded segments of input.

Next step is actually using this to translate an input to a command, which will essentially be our key bindings. We do this best by iterating through our key
sed. If it is,
we tell the command queue to insert our command we provide it with. The function `Player::isRealtimeAction()` returns if the specified action is triggered by the real-time input (as opposed to events).

```
void Player::handleRealtimeInput(CommandQueue& commands)
{
    FOREACH(auto pair, mKeyBinding)
    {
        if (sf::Keyboard::isKeyPressed(pair.first)
        && isRealtimeAction(pair.second))
            commands.push(mActionBinding[pair.second]);
    }
}
```

rwise
nothing will happen.

The two functions `assignKey()` and `getAssignedKey()` set and get the key mapped to a specific action. Their implementations perform map operations as expected, the only notable thing is that `assignKey()` checks that no two keys map to the same action.

The command stored under an action in `mActionBinding` knows exactly what it is supposed to do, so you don't have to provide any extra code to handle the key
ready done this
nds in the
map together instead of unique variables.

you expect
and prepare everything to work:

```
Player::Player()
{
    mKeyBinding[sf::Keyboard::Left] = MoveLeft;
    mKeyBinding[sf::Keyboard::Right] = MoveRight;

    mActionBinding[MoveLeft].action =
    [] (SceneNode& node, sf::Time dt)
    {
        node.move(-playerSpeed * dt.asSeconds(), 0.f);
    };

    mActionBinding[MoveRight].action =
    [] (SceneNode& node, sf::Time dt)
    {
        node.move(playerSpeed * dt.asSeconds(), 0.f);
    };

    FOREACH(auto& pair, mActionBinding)
        pair.second.category = Category::PlayerAircraft;
}
```

We assign the actions to the keys and achieve our initial key binding. After that we create the commands and implement the lambda function to be executed. The last
ayer aircraft.
It should all look familiar.

bility to make
bindings or
a way to parse the data from a `config` file. We will actually create a settings screen later in the book in the GUI chapter. This would have been a way too big topic to cover in this chapter as well.

Why a player is not an entity

Well, the `Player` class can very much be considered as an entity, but in our case it is
n the world of the
cene graph.

ntly, we
thing in
the player entity.

nd gives a
nice separation of the external input signals from the player and the game logic. We
ing a giant
blob inside the hierarchy of entities.

Summary

e input
est concept you
heavier action.
a lot of
attention on how to capture input and handle every detail about it. This is essential for every game, after all, who would like to play a game that plays itself?

is now
words, the
game's
mechanics and systems, but that instead allow a coherent flow between multiple
hers that
n handling
this kind of management that you see in games so often.

5
Diverting the Game Flow – State Stack

ficient
program structure for a game, modern game loops, and data structures to contain a
making it an
interactive simulation. With the combination of all those pieces of knowledge, we can
more than
that. A full blown product doesn't just open and let you play without an explanation,
hapter, the
ability to make the game richer by adding different states and screens to it.

ows:

- The state and the stack
- Navigating between states
- Moving our game into a state
- The title screen as the entry point of the game
- Our old friend, the main menu
- Implementing an overlay pause screen
- A simple example of a concurrent loading state

Defining a state

While it is a bit difficult to define correctly what a state actually is, and because that
pass our
own idea of what states are and how they should behave.

an object
onality
and information.

; however,
's try to
will
often see most games showing introduction videos, from the trailer of the game to company brand logos. We can look at each of these screens as states. In fact, having a `VideoState`
fit this model perfectly!

d minor
would
look closely at
any game, we can more or less define what belongs to each state, and that is the exact
you can
separate your game into multiple states, but practicing always makes you achieve cleaner and more efficient designs!

Using such a system is of extreme importance. The combination of all these screens working together as one final product always makes a game feel more professional and rich in features.

e whole
lel, rendering
to the same screen, to achieve a variety of effects such as the very common pause screen, which still shows the game in background without motion.

To manage states efficiently and in an easy way, we create the stack!

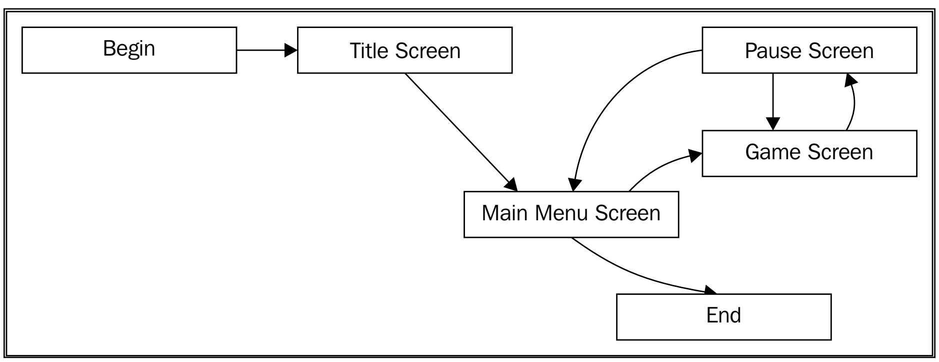
The state stack

One way to visualize the flow of the game screens would be to picture a finite state
However,
e active state
into a stack.

> **Finite State Machine (FSM)**: While this is a well known concept across the world of computation, we will shortly describe the state machine as a collection of states that ensures that only one state is active at any given time. The transition of the current state into a new one is always triggered by a condition or a timer. So, for any state of the FSM, there will be a determined set of triggers that will activate new states when appropriate.

Now, turning the active state into a stack essentially means that the current state
, when
at a time,
and while this is true, we effectively have a finite state machine as it is known by the computer science community. In other situations, however, such as the infamous
on top of
states, representing the active state all together.

As you can see in the following figure, a usual game flow can be represented like this:



To manage all these screens and transitions, we create the `StateStack` class:

```
class StateStack : private sf::NonCopyable
{
    public:
        enum Action
        {
            Push,
            Pop,
            Clear,
        };

    public:
        explicit            StateStack(State::Context context);

        template <typename T>
        void                registerState(States::ID stateID);

        void                update(sf::Time dt);
        void                draw();
        void                handleEvent(const sf::Event& event);

        void                pushState(States::ID stateID);
        void                popState();
        void                clearStates();

        bool                isEmpty() const;

    private:
        State::Ptr          createState(States::ID stateID);
        void                applyPendingChanges();

    private:
        struct PendingChange
        {
            ...
            Action              action;
            States::ID          stateID;
        };

    private:
        std::vector<State::Ptr>             mStack;
        std::vector<PendingChange>          mPendingList;
        State::Context                      mContext;
        std::map<States::ID,
            std::function<State::Ptr()>>    mFactories;
};
```

We also create the so called `State` class:

```
class State
{
    public:
        typedef std::unique_ptr<State> Ptr;
        struct Context { ... };

    public:
                        State(StateStack& stack, Context context);
        virtual         ~State();

        virtual void    draw() = 0;
        virtual bool    update(sf::Time dt) = 0;
        virtual bool    handleEvent(const sf::Event& event) = 0;

    protected:
        void            requestStackPush(States::ID stateID);
        void            requestStackPop();
        void            requestStateClear();

        Context         getContext() const;

    private:
        StateStack*     mStack;
        Context         mContext;
};
```

Adding states to StateStack

All states in the game have a unique identifier declared in an enum `States`, located in the `StateIdentifiers.hpp` file. For example, ID `States::Game` refers to the `GameState` class.

not create all
, therefore
we avoid loading resources of never-used states. Instead, we have factory functions that create a new state on-demand, represented by `std::function`. The member variable `StateStack::mFactories` maps state IDs to those factory functions.

A member function `StateStack::registerState()` inserts such mappings. The template parameter `T` is the derived state class we want to register. A lambda derived class `T` by
into a unique
pointer and returned as a base class pointer. The lambda expression is assigned to the corresponding state ID in the map:

```
template <typename T>
void StateStack::registerState(States::ID stateID)
{
    mFactories[stateID] = [this] ()
    {
        return State::Ptr(new T(*this, mContext));
    };
}
```

This approach has the advantage that the `StateStack` class need not know the concrete state classes, we thus keep dependencies low. For state classes that take
argument
adic templates,
a single function template will handle all these cases.

The `createState()` method takes an ID of a state, and returns a smart pointer to a newly created object of the corresponding state class. It does so by looking up the ID in the map and invoking the stored `std::function` factory, which returns the `std::unique_ptr` to the `State` base class:

```
State::Ptr StateStack::createState(States::ID stateID)
{
  auto found = mFactories.find(stateID);
  assert(found != mFactories.end());

  return found->second();
}
```

Handling updates, input, and drawing

Until this point, we taught the concept of the stack and the states it holds. Now it is time to feed our `StateStack` and consequently our active `State` objects with events, update, and drawing orders.

Input

k will deliver
that event to the active states:

```
void StateStack::handleEvent(const sf::Event& event)
{
    for (auto itr = mStack.rbegin(); itr != mStack.rend(); ++itr)
    {
        if (!(*itr)->handleEvent(event))
            return;
    }

    applyPendingChanges();
}
```

In this `for`he
any of the
states returns false in its `handleEvent()` method, the loop is immediately ended. This gives the control to the states that may not want to let input flow to other states than itself!

Update

he
f desired.

Draw

Drawing is straightforward; the `StateStack` class will order every active state to render itself.

The first state to be drawn is the lowest and oldest on the stack, and only then come the others, in order. This grants that the states are transparent, and you will be able
from the
lower states, you can use `sf::RectangleShape` to draw a colored rectangle over the
this chapter.

Delayed pop/push operations

As you can see in the source, the `StateStack` class provides the `pushState()` and `popState()` functions to let us add and remove states from the active stack.

is not possible
to alter the active state stack because it would generate a conflict when adding/removing objects to a container that is being iterated.

Because of this, those functions don't immediately push or pop states into the stack, but rather register these actions in a pending action list, so they can be processed later, when it's safe.

Then, inside your own state logic code, you call `requestStackPush()` and `requestStackPop()`, allowing the states to alter the stack from within their own code, without risking the safety of the program, thanks to the delayed processing of push and pop operations.

A special kind of pop operation is also provided, allowing a state to call `requestStackClear()`, which will completely empty the active stack.

These delayed processing operations are done in the following function:

```
void StateStack::applyPendingChanges()
{
    FOREACH(PendingChange change, mPendingList)
    {
        switch (change.action)
        {
            case Push:
                mStack.push_back(createState(change.stateID));
                break;

            case Pop:
                mStack.pop_back();
                break;

            case Clear:
                mStack.clear();
                break;
        }
    }

    mPendingList.clear();
}
```

The state context

to the screen,
among other common things. Due to this fact, and to avoid unnecessary memory wasting by loading the same texture or font to memory in multiple places, we introduced the `State::Context` structure. It works as a holder of shared objects between all states of our game.

Essentially, every state will now have access to the `getContext()` method, which
esource
structure:

```
struct Context
{
                         Context(sf::RenderWindow& window,
                                 TextureHolder& textures,
                                 FontHolder& fonts,
                                 Player& player);

    sf::RenderWindow*    window;
    TextureHolder*       textures;
    FontHolder*          fonts;
    Player*              player;
};
```

emory by
e access to the
sizing our
objects relatively to the view's dimensions.

Integrating the stack in the Application class

Since we have now more states than the game itself, we create a new class `Application` that controls input, logic updates, and rendering. Having a ready `StateStack` implementation waiting to be used, it is time to promote it into the `Application` class. We will plug our new state architecture into our `Application` class and then start using it!

First, we add the `mStateStack` member variable to `Application`. We register all the states in an own method:

```
void Application::registerStates()
{
    mStateStack.registerState<TitleState>(States::Title);
    mStateStack.registerState<MenuState>(States::Menu);
    mStateStack.registerState<GameState>(States::Game);
    mStateStack.registerState<PauseState>(States::Pause);
}
```

n of our
state architecture:

- Feeding it with events in the `Application::processInput()` function:

```
while (mWindow.pollEvent(event))
{
    mStateStack.handleEvent(event);
}
```

- Updating with the elapsed time:

```
void Application::update(sf::Time dt)
{
    mStateStack.update(dt);
}
```

- Rendering of the stack, in the middle of the frame draw:

```
mStateStack.draw();
```

- Closing the game when no more states are left:

```
if (mStateStack.isEmpty())
    mWindow.close();
```

constructor
we make the machine start with the title screen!

```
mStateStack.pushState(States::Title);
```

Navigating between states

e screen
starts up the program, but how to make the title screen call another state to its place when someone hits a key?

That is exactly what the `StateStack` class's delayed push and pop mechanism is for. Inside a state `handleEvent()` and `update()`, you are given three methods to control the execution and transitions of states: `requestStackPush()`, `requestStackPop()`, and `requestStackClear()`.

d, or to show
do throughout
this chapter.

Creating the game state

tack into our
sample game. It is fully functional but yet empty, so, it is finally time to create our first state, the game state.

For this, we create a class named `GameState` and we proceed to relocate the code that could be found in the `Game` class related to the actual aircraft gameplay to its new home:

```
class GameState : public State
{
    public:
                                GameState(StateStack& stack,
                                          Context context);

        virtual void            draw();
        virtual bool            update(sf::Time dt);
        virtual bool            handleEvent(const sf::Event& event);

    private:
        World                   mWorld;
        Player&                 mPlayer;
};
```

The title screen

Because a good place to start is always the beginning, we are about to create the title screen; that initial screen you sometimes see in games. Before you enter the main menu of the game, it asks you to press any key.

We decided to go with the name `TitleState`, and define it as follows:

```
class TitleState : public State
{
    public:
                            TitleState(StateStack& stack,
                                       Context context);

        virtual void        draw();
        virtual bool        update(sf::Time dt);
        virtual bool        handleEvent(const sf::Event& event);

    private:
        sf::Sprite          mBackgroundSprite;
        sf::Text            mText;

        bool                mShowText;
        sf::Time            mTextEffectTime;
};
```

e used to
ides its title
and then blinks a big old **Press any key to continue** message.

a new state:

```
bool TitleState::handleEvent(const sf::Event& event)
{
    if (event.type == sf::Event::KeyPressed)
    {
        requestStackPop();
        requestStackPush(States::Menu);
    }

    return true;
}
```

king
effect on the `sf::Text` object is achieved through this little trick:

```
bool TitleState::update(sf::Time dt)
{
    mTextEffectTime += dt;

    if (mTextEffectTime >= sf::seconds(0.5f))
    {
        mShowText = !mShowText;
        mTextEffectTime = sf::Time::Zero;
    }

    return true;
}
```

The magic happening here is simple. The variable `mShowText` determines the visibility of the `sf::Text` object, so we toggle it every half second, achieving the blinking effect.

Every time the state updates, we have a time counter `mTextEffectTime` that
r than half a
second, we just toggle the `mShowText` variable and restart the counter.

Main menu

Okay, our title screen just finished, the user pressed a key and it is time to launch another screen, the famous main menu!

This is probably the most common state you will find in virtually every game, it is
h the game.
our game,
watch videos and artwork, or simply exit the game.

esents two
ing the
return key or alternate between the options with the up and down arrow keys.

the topic in
the next chapter, therefore you can expect interesting improvements to it when we introduce the user interfaces in more depth!

nt the option
selection, and here is how we did it:

```
enum OptionNames
{
    Play,
    Exit,
};

std::vector<sf::Text>    mOptions;
std::size_t              mOptionIndex;
```

First we declare the containers of our options in the `MenuState` class, as well as the enumerator of the available options.

Then, we setup and push to the `mOptions` array the `sf::Text` objects, in the constructor, as follows:

```
sf::Text playOption;
playOption.setFont(font);
playOption.setString("Play");
centerOrigin(playOption);
playOption.setPosition(context.window->getView().getSize() / 2.f);
mOptions.push_back(playOption);
```

The `mOptionIndex` integer variable is present so that we can track which is the currently selected option between all those in the `mOptions` array; it will have a value between `0` and `n-1`, `n` being the number of options in the menu, which is two in our example.

Finally, we define the most important function that helps controlling this menu:

```
void MenuState::updateOptionText()
{
    if (mOptions.empty())
        return;

    // White all texts
    FOREACH(sf::Text& text, mOptions)
        text.setColor(sf::Color::White);

    // Red the selected text
    mOptions[mOptionIndex].setColor(sf::Color::Red);
}
```

This function is called once after constructing `mOptions` and again every time the `mOptionIndex`
in red, and the remaining is in white.

About what makes the `mOptionIndex` value actually change, it is merely simple handling of key presses in the `handleEvent()` function:

```
if (event.key.code == sf::Keyboard::Up)
{
    if (mOptionIndex > 0)
        mOptionIndex--;
    else
        mOptionIndex = mOptions.size() - 1;

    updateOptionText();
}

else if (event.key.code == sf::Keyboard::Down)
{
    if (mOptionIndex < mOptions.size() - 1)
        mOptionIndex++;
    else
        mOptionIndex = 0;

    updateOptionText();
}
```

it is time
:

```
if (event.key.code == sf::Keyboard::Return)
{
    if (mOptionIndex == Play)
    {
        requestStackPop();
        requestStackPush(States::Game);
    }
    else if (mOptionIndex == Exit)
    {
        requestStackPop();
    }
}
```

However, the
Exitshing
anything else in its place.

In consequence, after the MenuState class is popped, the state stack is left empty. This is exactly the condition that is checked in the Application class in order to exit
.

Of course, if there would be another state present in the stack at this moment, it would not really be empty, and the game could not close. A good way to prevent this would be to request a clearing of the whole stack, instead of just popping the menu state. However, by doing it this way we can detect possible programming errors faster by not concealing the presence of a state that shouldn't be there in the first place.

Pausing the game

After having a cute menu that allows the game to start playing, we find ourselves locked again inside GameState. Indeed, we can play, but what about when we get tired of it or just want to take a break? That's when the pause screen comes into the scene!

We make use of the PauseState class not only as a way to rest and go have a coffee, but also as a gateway for going back to the main menu.

although it
it is a state
that is not meant to work by itself, but rather on the top of the state stack, living simultaneously with GameState, at least.

Because of this, we apply directly the concepts we implemented in the StateStack mechanism. The screen of PauseState is transparent and we can see the game in the background:

```
void PauseState::draw()
{
    sf::RenderWindow& window = *getContext().window;
    window.setView(window.getDefaultView());

    sf::RectangleShape backgroundShape;
    backgroundShape.setFillColor(sf::Color(0, 0, 0, 150));
    backgroundShape.setSize(sf::Vector2f(window.getSize()));

    window.draw(backgroundShape);
    window.draw(mPausedText);
    window.draw(mInstructionText);
}
```

ready
drawn. The `backgroundShape` rectangle fits the whole screen as a way to darken
o see the
game we could simply set the fill color of `backgroundShape` with full alpha (255).

On the event handling topic, we simply define `PauseState` to pop it again and return to game if *Escape* is pressed again. Besides that, we also return to the main menu when *Backspace* is pressed:

```
if (event.key.code == sf::Keyboard::BackSpace)
{
    requestStateClear();
    requestStackPush(States::Menu);
}
```

So, why call `requestStateClear()` instead of `requestStatePop()`? Easy! The `PauseState` class has no idea how many states are lying underneath it in the stack.

Even though usually there will be only `GameState` living under it, this may not be a truth quite easily. `GameState` might have pushed other game play states on its top, like tutorial states or information displayers.

nly then a
push of the main menu.

The last thing that is very important to notice about `PauseState` is the `return false;` statement in the end of `handleEvent()` and `update()` functions.

If you were paying close attention earlier this chapter, it will be obvious to you what
ions works as a
smooth trick to automatically pause our `GameState`. Because `PauseState` is the top
all those are
inherently paused by absence of input or discrete time updates.

For convenience, we could have a pause method in the `GameState` class but we don't even need it thanks to the state system!

The loading screen – sample

e have
decided to provide a possible implementation of such a state. You can find its source
f through the
following paragraphs into understanding it.

forms a
task in the background, using a parallel thread of execution. Using threads and
ML does
provide `sf::Thread`, a cross-platform implementation for launching and managing
iefly
introduce the use of `sf::Thread` and apply it directly into our loading screen.

But why do we need to use threads? Simply because a loading screen will most often be passing a number of resources from the hard drive into memory and this will be a lengthy process, and even worse, a blocking process.

We need to ensure that our state remains fluid in its execution, that all calls are finished as fast as they can, and the game has a solid frame rate. Having our loading screen stuck in a method loading a huge list of resources would defeat this purpose,
n't display
appen in a
parallel thread, while the loading state keeps running without interruption!

In order to implement such a state we create two classes, `LoadingState` and `ParallelTask`. `LoadingState` is responsible for displaying information of what is being loaded and a progress bar so the user has some perception of how much time is left to begin playing. The `ParallelTask` class will manage the actual loading operation and give some feedback to the `LoadingState` class.

er's sample
application, you can find their sources in `LoadingState.hpp`, `LoadingState.cpp`, `ParallelTask.hpp`, and `ParallelTask.cpp` in the source directory of the chapter.

Progress bar

To better understand the implementation of `LoadingState` which is not that different from the other screens, lets take a look at its members:

```
sf::Text            mLoadingText;
sf::RectangleShape  mProgressBarBackground;
sf::RectangleShape  mProgressBar;
ParallelTask        mLoadingTask;
```

We have `sf::Text` to display our `Loading Resources` string, two `sf::RectangleShape` objects for the progress bar background and fill, and a `ParallelTask` object.

First things first, constructing the objects happens as follows:

```
mLoadingText.setFont(font);
mLoadingText.setString("Loading Resources");
centerOrigin(mLoadingText);
mLoadingText.setPosition(window.getSize().x / 2u, window.getSize().y /
2u + 50);

mProgressBarBackground.setFillColor(sf::Color::White);
mProgressBarBackground.setSize(sf::Vector2f(window.getSize().x - 20,
10));
mProgressBarBackground.setPosition(10, mLoadingText.getPosition().y +
40);

mProgressBar.setFillColor(sf::Color(100,100,100));
mProgressBar.setSize(sf::Vector2f(200, 10));
mProgressBar.setPosition(10, mLoadingText.getPosition().y + 40);

setCompletion(0.f);

mLoadingTask.execute();
```

The `mLoadingText` function is configured with position, font, and string. Then, the ize that fits the h side.

Both `mProgressBar` and `mProgressBarBackground` are at the exact same position, so that `mProgressBar` can grow inside the background correctly. The progress bar is set with a grey color, so it can be seen over its background.

To fith a width of 100 pixels and then launch the parallel task.

The `setCompletion()` method is nothing more than the following:

```
void LoadingState::setCompletion(float percent)
{
    if (percent > 1.f)
        percent = 1.f; // clamp

    mProgressBar.setSize(sf::Vector2f(
        mProgressBarBackground.getSize().x * percent,
        mProgressBar.getSize().y));
}
```

It merely resets the width of the progress bar fill color to a percent of the background width, as you can see.

k is already
executing in the background; now it is important to go fetch data from the task to update the state:

```
bool LoadingState::update(sf::Time)
{
    // Update the progress bar from the remote task or finish it
    if (mLoadingTask.isFinished())
    {
        requestStackPop();
        requestStackPush(States::Game);
    }
    else
    {
        setCompletion(mLoadingTask.getCompletion());
    }
    return true;
}
```

This method's body is just as simple as it looks, if the parallel task has finished
y has the
ill only
update the progress bar.

ParallelTask

So far we have been able to see that a `ParallelTask` object runs in the background and allows querying some information about the task's progress.

To remain as simple as possible explaining the concept of a task executed in a parallel thread, we decided to implement the sample class as a dummy operation
or a timer to
expire and finalize the task.

But, before explaining our implementation, let's approach a couple of
concepts rapidly.

Thread

ion. You know
the mandatory `main()` function, right? That is the entry point of every application,
in one. You
can visualize it as a sequential stream of commands that flows until the `main()`
function is over and exits the program.

We can conclude from this that one thread is one function call. The same way `main()`
on, we spawn a
new thread by "calling" its function, the only difference between that and a normal
call is that the program doesn't wait until that function ends, but rather continues
execution while another stream of commands starts running in parallel.

This is the essence of multi-threading and there isn't a lot to add to it. To do this branching in execution, SFML provides `sf::Thread`. This class implies that you have to link a `sf::Thread` object to a function on its constructor, such as `sf::Thread(&myFunc)` for a global function or `sf::Thread(&MyClass::myFunc, myClassObject)` for a member function of a class.

When you call `sf::Thread::launch()`, all it does is to call the linked function in a separate thread.

Destroying
the `sf::Thread` object while its thread is still running results in an abrupt
termination of the thread.

Seems easy, right? Well, there are some more things to have in consideration. Using
ve in mind
when working with them.

Concurrency

When two threads are running in parallel, everything will go smoothly if they don't
or more
mmunicate
between them.

It probably goes without saying that if the processor is reading and writing to the same memory address at the same time, we are going to have a nice crash or an undefict.

But then, how to guarantee that multiple threads operate on shared data at turns,
be taken
!

Here, we introduce you to `sf::Mutex and sf::Lock`. These are incredible tools to protect shared data when working with multi-threading. We won't be explaining in depth how they work internally, but rather try to apply it directly and understand it by example, by looking at the `ParallelTask` class implementation.

Task implementation

The code for this implementation is as follows:

```
class ParallelTask
{
    public:
                            ParallelTask();
        void                execute();
        bool                isFinished();
        float               getCompletion();

    private:
        void                runTask();

    private:
        sf::Thread          mThread;
        bool                mFinished;
        sf::Clock           mElapsedTime;
        sf::Mutex           mMutex;
};
```

By taking a look at the `ParallelTask` declaration, you can see that the API used by `LoadingState` exposed. Besides that, you can see the `runTask()` function, which is the actual thread function that is launched in parallel execution.

Then, in its members, we can see the expected `sf::Thread`, the `sf::Clock` to count t or not. The
`sf::Mutex` object is meant to protect both the `mClock` and `mFinished` variables from concurrent access, as you will see in the following sample:

```
bool ParallelTask::isFinished()
{
    sf::Lock lock(mMutex);
    return mFinished;
}
```

The fiu noticed,
isFinished() is called by LoadingState::update(), which is the main thread while mFinished can be changed by the task thread as well, immediately when it finishes. This could randomly cause a simultaneous read and write by two threads, which would result in bad luck for us as programmers. We say randomly because there is nothing controlling the synchronization of the two threads, the simultaneous access can either happen or not.

By locking the sf::Mutex object before touching sensitive data, we ensure that if
e other thread
ll wait in
line to access shared data one at a time.

Because sf::Lock is a RAII compliant class, as soon as it goes out of scope and is destructed, the sf::Mutex object automatically unlocks.

To finalize, here is the actual thread function of our task:

```
void ParallelTask::runTask()
{
    // Dummy task - stall 10 seconds
    bool ended = false;
    while (!ended)
    {
        sf::Lock lock(mMutex); // Protect the clock
        if (mElapsedTime.getElapsedTime().asSeconds() >= 10.f)
            ended = true;
    }

    { // mFinished may be accessed from multiple threads, protect
        sf::Lock lock(mMutex);
        mFinished = true;
    }
}
```

shared
as soon as

All this function does is it remains in a while loop until the clock has ticked for ten seconds and then lets the thread finish after setting mFinished to true.

Summary

Here we conclude the fifth chapter of the book. Through its pages, we tried to pass on a lot of useful information about state managing and game flow. We talked
. Also, we
using our
`StateStack` system to our advantage. Navigation between states was also covered and we even talked about functionality we don't use in the game, but that will certainly come handy in the future! Better to know and not need it, than to need it and not know about it!

ame, but
will be
asp these
concepts the best you can!

We will
discuss how to implement a basic version of a widget hierarchy containing buttons and labels.

6
Waiting and Maintenance Area – Menus

Most games have menus and it's something the player expects when opening up a
onds to the
t have
t's a prime
s what we
will do in this chapter:

- Design a user interface components hierarchy
- Implement the base component class
- Implement containers, labels, and buttons
- Create a proper title screen
- Create a settings screen

f creating
a **graphical user interface** (**GUI**). GUI design is a huge topic that deserves its own
book, but we will do a crash course together.

button and
navigate
by the keyboard. The difference lies in complexity of the methods: one does not
e hierarchy.

The GUI hierarchy, the Java way

kits such as
 not exactly
reproduced, rather is used as a source of inspiration. In the end, what we aim to achieve is a working menu state based on this design, but without pumping the state full of boilerplate GUI code.

We create a namespace `GUI` in order to make the distinction clear to other parts of our game, since a lot of the names such as "component" are generic, and can be
re hierarchy
rests on. We call it `Component` and in our case it is quite small. It defines the interface that we will be using regularly besides setting up the objects. The class defines a couple of virtual functions, one of which is the `handleEvent()` function. We let the `Component` class inherit from `sf::Drawable` for the same reason as the scene nodes. To have an interface for drawing to an SFML window:

```
namespace GUI
{
class Component : public sf::Drawable
                , public sf::Transformable
                , private sf::NonCopyable
{
    public:
        typedef std::shared_ptr<Component> Ptr;
    public:
                            Component();
        virtual             ~Component();
        virtual bool        isSelectable() const = 0;
        bool                isSelected() const;
        virtual void        select();
        virtual void        deselect();
        virtual bool        isActive() const;
        virtual void        activate();
        virtual void        deactivate();
        virtual void        handleEvent(const sf::Event& event) = 0;
    private:
        bool                mIsSelected;
        bool                mIsActive;
};
}
```

You might be wondering about the pure virtual `isSelectable()` function and
oment,
you can just assume that `isSelectable()` returns false, and that the virtual ones
is the
`Component::handleEvent()` function because this is where the magic happens.
The typedef of a shared pointer of `Component` to the name `Component::Ptr` is for convenience purposes. You don't need it, but it makes code more readable, by simplifying the name we use.

> The class template `std::shared_ptr` is a C++11 smart pointer. In contrast to `std::unique_ptr`, multiple pointers share an object.
>
> `shared_ptr` points to it. If an object is not referenced anymore, it will be destroyed.
>
> While unique pointers result in zero performance and memory overhead, shared pointers are rather expensive because of reference counting semantics and thread safety. Therefore, they should be used with care— shared ownership is rarely required.
>
> The function template `std::make_shared()` allows construction of shared pointer objects. Instead of the first statement with the `new`
>
> (object and reference counter are stored together).
>
> ```
> std::shared_ptr<T> s(new T(a, b));
> auto s = std::make_shared<T>(a, b);
> ```

have been
so diligent in using before, is because it is more flexible. We want to give you a
hand,
`std::shared_ptr` allows users of GUI components to hold a `std::weak_ptr` which
becomes invalid as soon as the `Component` is destroyed. But more importantly, a
(maybe
e same
attributes, they can share it.

s
different for every class inheriting from `Component`. Further classes we define
are `GUI::Container`, `GUI::Button`, and `GUI::Label`. These are the most basic
with more
components later.

bviously
using a
It is also
r to highlight
it. This is to know when you try to activate a button, which button should it activate.
So let's look at the implementation of the `Container` class. We start with the public
interface which consists of the following functions:

```
Container::Container()
: mChildren()
, mSelectedChild(-1)
{
}
```

```
void Container::pack(Component::Ptr component)
{
    mChildren.push_back(component);
    if (!hasSelection() && component->isSelectable())
        select(mChildren.size() - 1);
}
bool Container::isSelectable() const
{
    return false;
}
```

can pack a
we have a
currently selected child. If not, we check if the incoming child is selectable, and if it is, we select it. Lastly, a container is not a selectable component.

Now to the exciting part:

```
void Container::handleEvent(const sf::Event& event)
{
    if (hasSelection() && mChildren[mSelectedChild]->isActive())
    {
        mChildren[mSelectedChild]->handleEvent(event);
    }
    else if (event.type == sf::Event::KeyReleased)
    {
        if (event.key.code == sf::Keyboard::W
         || event.key.code == sf::Keyboard::Up)
        {
            selectPrevious();
        }
        else if (event.key.code == sf::Keyboard::S
              || event.key.code == sf::Keyboard::Down)
        {
            selectNext();
        }
        else if (event.key.code == sf::Keyboard::Return
              || event.key.code == sf::Keyboard::Space)
        {
            if (hasSelection())
                mChildren[mSelectedChild]->activate();
        }
    }
}
```

urrent state
of the container and what input we get from the events, the action that is performed is different. Let's go through the function.

`hasSelection()`, and whether the component is active. All the helper function does is; check if the `mSelectedChild` variable is a valid index, zero, or more. If
ld receive
y to have a
ot used,
but it would be extremely useful when you implement an input box, or any kind of component that needs to capture input.

vide ways for
onent. In
f having a
large function with a lot of logic in it.

```
void Container::select(std::size_t index)
{
    if (mChildren[index]->isSelectable())
    {
        if (hasSelection())
            mChildren[mSelectedChild]->deselect();
        mChildren[index]->select();
        mSelectedChild = index;
    }
}

void Container::selectNext()
{
    if (!hasSelection())
        return;
    // Search next component that is selectable
    int next = mSelectedChild;
    do
        next = (next + 1) % mChildren.size();
    while (!mChildren[next]->isSelectable());
    // Select that component
    select(next);
}
void Container::selectPrevious()
{
    if (!hasSelection())
        return;
```

```
        // Search previous component that is selectable
        int prev = mSelectedChild;
        do
            prev = (prev + mChildren.size() - 1) % mChildren.size();
        while (!mChildren[prev]->isSelectable());
        // Select that component
        select(prev);
    }
```

complex. The
fie sure only
one component is marked as selected. The `selectPrevious()` and `selectNext()` functions only implement the stepping to find the next selectable component and the looping of the menu selection.

The `Container` acts as the root for the GUI we want to show. You create a GUI object at the top in your state, and then you pack other components into it. Here is a demonstration using labels:

```
auto demoLabel = std::make_shared<GUI::Label>(
    "This is a demonstration!", *getContext().fonts);
mGUIContainer.pack(demoLabel);

// Later in code...
mWindow.draw(mGUIContainer);
while(mWindow.pollEvent(event))

mGUIContainer.handleEvent(event);
```

You see in the states code how this simplifies a lot of problems, and makes the code a lot cleaner and nicer to read. `Label` is a very small class, as all it does is simply show some text on the screen.

```
Label::Label(const std::string& text, const FontHolder& fonts)
: mText(text, fonts.get(Fonts::Label), 16)
{
}

bool Label::isSelectable() const
{
    return false;
}
void Label::draw(sf::RenderTarget& target, sf::RenderStates states)
const
{
```

```
        states.transform *= getTransform();
        target.draw(mText, states);
    }
    void Label::setText(const std::string& text)
    {
        mText.setString(text);
    }
```

The only thing to note is that labels are not selectable. They are just a bunch of text, so there is no reason to be able to select them.

Let's get to the interesting part that we want in the GUI buttons. Fortunately,
, buttons
or rendering
and execution on activation.

text that a
button renders. But most often, we want a button to execute something when it is
th callbacks
using the handy `std::function` class. When the button is activated by the GUI container, we execute the callback.

so we also
support the poll method where you ask the button if it is held down. In our system, we call it toggle, that is, the button remains in a pressed state until explicitly told to change. Normally, the button deactivates itself after the callback has been fired. If the button can be toggled on the other hand, it will not deactivate; this must be explicitly done by the user.

In the context of a button, the terms "activate" and "deactivate" refer to the two states
hese are
ivate but
em in a list box.

```
    Button::Button(const FontHolder& fonts, const TextureHolder& textures)
    // ...
    {
        mSprite.setTexture(mNormalTexture);
        mText.setPosition(sf::Vector2f(mNormalTexture.getSize() / 2u));
    }

    bool Button::isSelectable() const
    {
        return true;
    }
```

```
void Button::select()
{
    Component::select();
    mSprite.setTexture(mSelectedTexture);
}

void Button::deselect()
{
    Component::deselect();
    mSprite.setTexture(mNormalTexture);
}

void Button::activate()
{
    Component::activate();
    if (mIsToggle)
        mSprite.setTexture(mPressedTexture);
    if (mCallback)
        mCallback();
    if (!mIsToggle)
        deactivate();
}

void Button::deactivate()
{
    Component::deactivate();
    if (mIsToggle)
    {
        if (isSelected())
            mSprite.setTexture(mSelectedTexture);
        else
            mSprite.setTexture(mNormalTexture);
    }
}
```

We only have to book-keep the current texture of the sprite and its activation/
classes.
And the callback makes it very easy to hook in your own code to be run.

Updating the menu

So, let's see our code in actual use. Do you remember MenuState from the previous chapter? There we implemented some menu logic, so you could choose enu state
shrinks drastically.

```
MenuState::MenuState(StateStack& stack, Context context)
: State(stack, context)
, mGUIContainer()
{
    ...
    auto playButton = std::make_shared<GUI::Button>(
        *context.fonts, *context.textures);
    playButton->setPosition(100, 250);
    playButton->setText("Play");
    playButton->setCallback([this] ()
    {
        requestStackPop();
        requestStackPush(States::Game);
    });
    mGUIContainer.pack(playButton);
}
```

The constructor initializes the buttons and packs them into the Container. As you can see, the lambda expression we give to the Button is the place where we actually describe the action we want the button to do. The rest of the functions are changed to use the GUI container to render and handle events.

```
void MenuState::draw()
{
    sf::RenderWindow& window = *getContext().window;
    window.setView(window.getDefaultView());
    window.draw(mBackgroundSprite);
    window.draw(mGUIContainer);
}
bool MenuState::update(sf::Time)
{
    return true;
}
bool MenuState::handleEvent(const sf::Event& event)
{
    mGUIContainer.handleEvent(event);
    return false;
}
```

This gives us much cleaner code than what we had in the previous chapter. Now
 a menu in
r to this
code, so we won't go through that as well.

The promised key bindings

We implement a new state; the `SettingsState` which you access through a button on the menu. What is the purpose for the `SettingsState` in our example? Currentlywe have the key bindings inside there. Everything we need has already been implemented with the GUI, so we only have to define the actual state.

The constructor of the `SettingsState` class one is pretty big so we snip it.

```
SettingsState::SettingsState(StateStack& stack, Context context)
: State(stack, context)
, mGUIContainer()
{
    mBackgroundSprite.setTexture(
        context.textures->get(Textures::TitleScreen));
    mBindingButtons[Player::MoveLeft] =
        std::make_shared<GUI::Button>(...);
    mBindingLabels[Player::MoveLeft] =
        std::make_shared<GUI::Label>(...);
    ... // More buttons and labels
    updateLabels();
    auto backButton = std::make_shared<GUI::Button>(...);
    backButton->setPosition(100, 375);
    backButton->setText("Back");
    backButton->setCallback([this] ()
    {
        requestStackPop();
    });
    mGUIContainer.pack(mBindingButtons[Player::MoveLeft]);
    mGUIContainer.pack(mBindingLabels[Player::MoveLeft]);
    ...
    mGUIContainer.pack(backButton);
}
```

We have put all the binding buttons and the associated labels in a static array, and duplicate a
e marked
the button as one that toggles. We also have an `updateLabels()` function call. It's a helper function to make sure the labels are writing out the correct name for the key.

```
void SettingsState::updateLabels()
{
    Player& player = *getContext().player;
    for (std::size_t i = 0; i < Player::ActionCount; ++i)
    {
        sf::Keyboard::Key key =
           player.getAssignedKey(static_cast<Player::Action>(i));
        mBindingLabels[i]->setText(toString(key));
    }
}
```

d update them.
Now moving on to the `handleEvent()` function, where we actually do something with the buttons.

```
bool SettingsState::handleEvent(const sf::Event& event)
{
    bool isKeyBinding = false;
    for (std::size_t action = 0; action < Player::ActionCount;
++action)
    {
        if (mBindingButtons[action]->isActive())
        {
            isKeyBinding = true;
            if (event.type == sf::Event::KeyReleased)
            {
                getContext().player->assignKey
(static_cast<Player::Action>(action), event.key.code);
                mBindingButtons[action]->deactivate();
            }
            break;
        }
    }

    if (isKeyBinding)
        updateLabels();
    else
        mGUIContainer.handleEvent(event);
    return false;
}
```

So how do we do this? If a button is pressed, then it will be activated, and since it's a button that toggles, it will stay active until we tell it to deactivate. So we loop through the array of buttons and check if anyone of them is active. If they are, then we are currently binding a key. When we get a key released event, then we change that binding on the player to the new key with the specified action before we deactivate the button again. After the loop, we update the labels, such that they have the correct name for everything. If no button is active, then we are not currently trying to bind a key, and should pass the event to the GUI container instead.

screenshot:

Summary

can
a
functional user interface.

Implementing a nice and simple composite GUI library, along with handling its
so, we have
e menu
and the settings state richer than ever.

Now it is time to keep going into the next chapter, where we will handle gameplay mechanics. This means adding a fun factor to the game we are making, by adding enemies, projectiles, and other gameplay rules, which define a game's quality more
best
graphically accurate game if it weren't fun?

7

Warfare Unleashed – Implementing Gameplay

In *Chapter 5*, *Diverting the Game Flow – State Stack* and *Chapter 6*, *Waiting and Maintenance Area – Menus*, you have seen how to handle menus and states, now it is time to return to the actual game. Up till now, we have built a world that can ms through
updates, drawing, and commands. However, this is not particularly interesting as long as the world is empty.

ore part of
s. We are
going to cover the following topics:

- Enemy aircraft controlled by a simple artificial intelligence
- Projectiles such as a machine gun or missiles
- Pickups that improve the player's equipment
- Collision detection and response between entities in the scene graph
- The world's update cycle and automatic removal of entities

Equipping the entities

You have heard about entities for the first time in *Chapter 3*, *Forge of the Gods – Shaping Our World*, where we built the `World` class and the scene graph. As a quick reminder, the `SceneNode` base class was inherited by the `Entity` class. Entities are the central part of this chapter. It's all about the interaction between entities of
 is reasonable to
think about crucial properties our entities need to have.

Introducing hitpoints

Since, we are preparing our airplanes for the battlefield, we need to provide them with new specific attributes. To our class definition of `Entity`, we add a new member variable that memorizes the current hitpoints. **Hitpoints** (**HP**) are a measure for the hull integrity of an entity; the entity is destroyed as soon as the hitpoints reach or fall below zero.

ow the
modification of the hitpoints. We do not provide direct write access, however,
he plane is
repaired). Also, a `destroy()` function instantly destroys the entity.

```
class Entity : public SceneNode
{
    public:
        explicit    Entity(int hitpoints);
        void        repair(int points);
        void        damage(int points);
        void        destroy();

        int         getHitpoints() const;
        bool        isDestroyed() const;

        ...
    private:
        int         mHitpoints;
        ...
};
```

The implementation is as expected: `repair()` adds the specified hitpoints, `damage()` subtracts them, and `destroy()` sets them to zero.

Storing entity attributes in data tables

In our game, there are already two different airplanes with different attributes. For
. With an
ints, used
texture, or fire rate may vary strongly among them. We need to think of a way to

What we clearly want to avoid are case differentiations in every `Aircraft` method, since this makes the local logic code less readable, and spreads the attributes across different functions. Instead of `if/else` cascades or `switch` statements, we can store the attributes in a central table, and just access the table every time we need an attribute.

Let's define the type of such a table entry in the case of an airplane. We choose the simplest way, and have a structure `AircraftData` with all members public. This type is defined in the file `DataTables.hpp`.

```
struct AircraftData
{
    int             hitpoints;
    float           speed;
    Textures::ID    texture;
};
```

While `AircraftData` is a single table entry, the whole table is represented as a sequence of entries, namely `std::vector<AircraftData>`.

Next, we write a function that initializes the table for different aircraft types. We begin to define a vector of the correct size (`Aircraft::TypeCount` is the last enumerator of the enum `Aircraft::Type`, it contains the number of different aircraft use them
as indices in our STL container. We thus initialize all the attributes for different airplanes, and eventually return the filled table.

```
std::vector<AircraftData> initializeAircraftData()
{
    std::vector<AircraftData> data(Aircraft::TypeCount);

    data[Aircraft::Eagle].hitpoints = 100;
    data[Aircraft::Eagle].speed = 200.f;
    data[Aircraft::Eagle].texture = Textures::Eagle;

    data[Aircraft::Raptor].hitpoints = 20;
    data[Aircraft::Raptor].speed = 80.f;
    data[Aircraft::Raptor].texture = Textures::Raptor;
    ...

    return data;
}
```

The global function `initializeAircraftData()` is declared in `DataTables.hpp` and defined in `DataTables.cpp`. It is used inside `Aircraft.cpp`, to initialize a global constant `Table`. This constant is declared locally in the `.cpp` file, so only the `Aircraft` internals can access it. In order to avoid name collisions in other files, we use an anonymous namespace.

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

Inside the `Aircraft` methods, we can access a constant attribute of the own plane type using the member variable `mType` as index. For example, `Table[mType].hitpoints` denotes the maximal hitpoints of the current aircraft.

Data tables are only the first step of storing gameplay constants. For more flexibility, and to avoid recompiling the application, you can also store these constants externally, for example, in a simple text file or using a specific file format. The application initially loads these files, parses the values, and fills the data tables accordingly.

> Nowadays, it is very common to load gameplay information from external resources. There are text-based formats such as YAML or XML, as well as, many application-specific text and binary formats. There are also well-known C++ libraries such as Boost.Serialize (`www.boost.org`) that help with loading and saving data structures from C++.
>
> One possibility that has recently gained popularity consists of using script languages, most notably Lua (`www.lua.org`), in addition to C++. This has the advantage that not only constant data, but dynamic functionality can be outsourced and loaded during runtime.

Displaying text

hitpoints or
d to be shown
next to the entity, it stands to reason to attach it to the corresponding scene node. We therefore, create a `TextNode` class which inherits `SceneNode` as shown in the following code:

```
class TextNode : public SceneNode
{
    public:
        explicit            TextNode(const FontHolder& fonts,
                            const std::string& text);
        void                setString(const std::string& text);

    private:
        virtual void        drawCurrent(sf::RenderTarget& target,
                            sf::RenderStates states) const;

    private:
        sf::Text            mText;
};
```

The implementation of the functions is not complicated. The SFML class `sf::Text` provides most of what we need. In the `TextNode` constructor, we retrieve the font from the resource holder and assign it to the text.

```
TextNode::TextNode(const FontHolder& fonts, const std::string& text)
{
    mText.setFont(fonts.get(Fonts::Main));
    mText.setCharacterSize(20);
    setString(text);
}
```

ender target,
as you know it from sprites.

```
void TextNode::drawCurrent(sf::RenderTarget& target, sf::RenderStates
states) const
{
    target.draw(mText, states);
}
```

s a new string
to the text node, and automatically adapts to its size. `centerOrigin()` is a utility
lifies positioning
a lot.

```
void TextNode::setString(const std::string& text)
{
    mText.setString(text);
    centerOrigin(mText);
}
```

In the `Aircraft`.
We keep a pointer `mHealthDisplay` as a member variable and let it point to the attached node.

```
std::unique_ptr<TextNode> healthDisplay(new TextNode(fonts, ""));
mHealthDisplay = healthDisplay.get();
attachChild(std::move(healthDisplay));
```

In the method `Aircraft::update()`, we check for the current hitpoints, and convert them to a string, using our custom `toString()` function. The text node's string and relative position are set. Additionally, we set the text node's rotation to the negative
n order to have
the text always upright, independent of the aircraft's orientation.

```
mHealthDisplay->setString(toString(getHitpoints()) + " HP");
mHealthDisplay->setPosition(0.f, 50.f);
mHealthDisplay->setRotation(-getRotation());
```

Creating enemies

Enemies are other instances of the `Aircraft` class. They appear at the top of the screen and move downwards, until they fly past the bottom of the screen. Most he new
aircraft functionality.

Movement patterns

By default, enemies fly downwards in a straight line. But it would be nice if different enemies moved differently, giving the feeling of a very basic **artificial intelligence** (**AI**). Thus, we introduce specific movement patterns. Such a pattern can be described as a sequence of directions to which the enemy airplane heads. A direction consists of an angle and a distance.

```
struct Direction
{
                            Direction(float angle, float distance);
    float                   angle;
    float                   distance;
};
```

Our data table for aircraft gets a new entry for the sequence of directions as shown in following code:

```
struct AircraftData
{
    int                      hitpoints;
    float                    speed;
    Textures::ID             texture;
    std::vector<Direction>  directions;
};
```

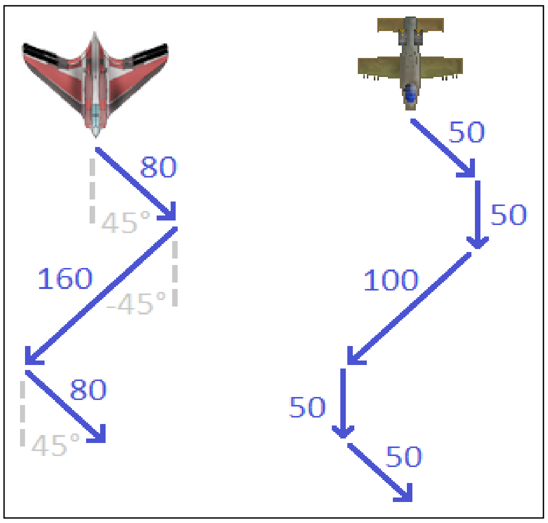
Let's implement a zigzag movement pattern for the Raptor plane. First, it steers for `80` units in `45` degrees direction. Then, the angle changes to `-45` degrees, and the plane traverses `160` units back. Last, it moves again `80` units in `+45` degrees direction, until it arrives at its original x position.

```
data[Aircraft::Raptor].directions.push_back(Direction( 45, 80));
data[Aircraft::Raptor].directions.push_back(Direction(-45, 160));
data[Aircraft::Raptor].directions.push_back(Direction( 45, 80));
```

For the Avenger plane, we use a slightly more complex pattern: it is essentially a zigzag, but between the two diagonal movements, the plane moves straight for `50` units.

```
data[Aircraft::Avenger].directions.push_back(Direction(+45,  50));
data[Aircraft::Avenger].directions.push_back(Direction(  0,  50));
data[Aircraft::Avenger].directions.push_back(Direction(-45, 100));
data[Aircraft::Avenger].directions.push_back(Direction(  0,  50));
data[Aircraft::Avenger].directions.push_back(Direction(+45,  50));
```

The following figure shows the sequence of directions for both planes; the Raptor plane is located on the left, Avenger on the right:



This way of defining movement is very simple, yet it enables a lot of possibilities. You can let the planes fly in any direction (also sideward or backwards); you can even approximate curves when using small intervals.

patterns.
To the `Aircraft` class, we add two member variables: `mTravelledDistance`, which denotes the distance already travelled for each direction, and `mDirectionIndex`, to know which direction the plane is currently taking.

erence to `const`
named `directions`. We only proceed if there are movement patterns for the current type (otherwise the plane flies straight down).

```
void Aircraft::updateMovementPattern(sf::Time dt)
{
    const std::vector<Direction>& directions
    = Table[mType].directions;
    if (!directions.empty())
    {
```

plane (that
so, the index is
advanced to the next direction. The modulo operator allows a cycle; after finishing the last direction, the plane begins again with the first one.

```
            float distanceToTravel
            = directions[mDirectionIndex].distance;
            if (mTravelledDistance > distanceToTravel)
            {
                mDirectionIndex
                = (mDirectionIndex + 1) % directions.size();
                mTravelledDistance = 0.f;
            }
```

Now, we have to get a velocity vector out of the angle. First, we turn the angle by 90 degrees (by default, 0 degrees points to the right), but since our planes fly downwards, we work in a rotated coordinate system, such that we can use a minus to toggle between left/right. We also have to convert degrees to radians, using our function `toRadian()`.

The velocity's x component is computed using the cosine of the angle multiplied
used.
Eventually, the travelled distance is updated:

```
            float radians
            = toRadian(directions[mDirectionIndex].angle + 90.f);
            float vx = getMaxSpeed() * std::cos(radians);
            float vy = getMaxSpeed() * std::sin(radians);
            setVelocity(vx, vy);
            mTravelledDistance += getMaxSpeed() * dt.asSeconds();
        }
    }
```

> Note that if the distance to travel is no multiple of the aircraft speed, the plane will fly further than intended. This error is usually small, because there are many logic frames per second, and hardly noticeable, since each enemy will only be in the view for a short time.

Spawning enemies

ed them
as soon as they come closer to the player. By doing so, we do not need to process enemies that are relevant in the distant future; the scene graph can concentrate on updating and drawing active enemies.

We create a structure nested inside the `World` class that represents a spawn point for an enemy.

```
struct SpawnPoint
{
    SpawnPoint(Aircraft::Type type, float x, float y);

    Aircraft::Type type;
    float          x;
    float          y;
};
```

A member variable `World::mEnemySpawnPoints` of type `std::vector<SpawnPoint>` holds all future spawn points. As soon as an enemy position enters the battlefield, the corresponding enemy is created and inserted to the scene graph, and the spawn point is removed.

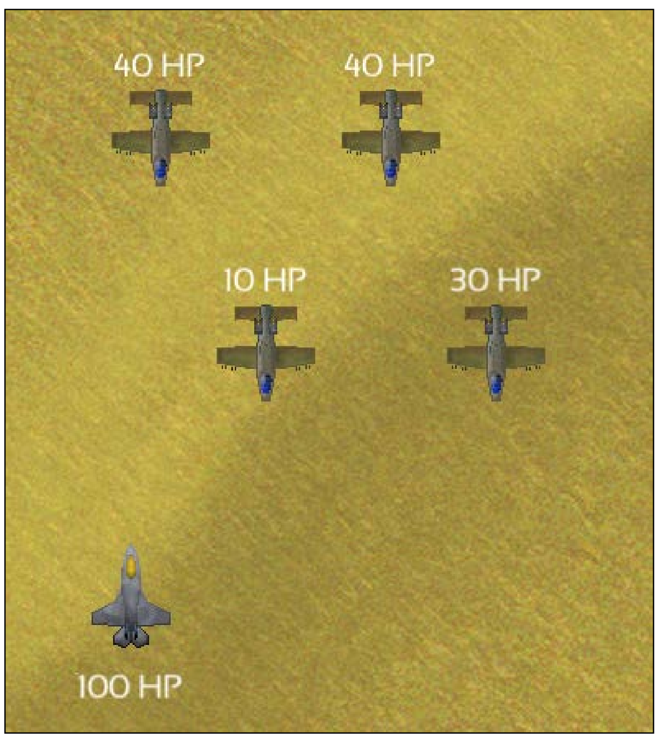
The `World` class member function `getBattlefieldBounds()`, returns `sf::FloatRect` to the battlefield area, similar to `getViewBounds()`. The battlefield area extends the view area by a small rectangle at the top, inside which new
s below the
battlefield's `top` member, the enemy will be created at its spawn point. Since enemies face downwards, they are rotated by 180 degrees.

```
void World::spawnEnemies()
{
    while (!mEnemySpawnPoints.empty()
        && mEnemySpawnPoints.back().y
         > getBattlefieldBounds().top)
    {
        SpawnPoint spawn = mEnemySpawnPoints.back();

        std::unique_ptr<Aircraft> enemy(
            new Aircraft(spawn.type, mTextures, mFonts));
        enemy->setPosition(spawn.x, spawn.y);
        enemy->setRotation(180.f);

        mSceneLayers[Air]->attachChild(std::move(enemy));

        mEnemySpawnPoints.pop_back();
    }
}
```

Now, let's insert the spawn points. `addEnemy()` effectively calls `mEnemySpawnPoints.push_back()`, and interprets the passed coordinates relative to hem by their
y coordinates. By doing so, `spawnEnemies()` needs to check only the elements at the end of the sequence instead of iterating through it every time.

```
void World::addEnemies()
{
    addEnemy(Aircraft::Raptor,    0.f,  500.f);
    addEnemy(Aircraft::Avenger, -70.f, 1400.f);
    ...

    std::sort(mEnemySpawnPoints.begin(), mEnemySpawnPoints.end(),
    [] (SpawnPoint lhs, SpawnPoint rhs)
    {
        return lhs.y < rhs.y;
    });
}
```

, you see
how many hitpoints it has left.



Adding projectiles

tial for
our game. The code to interact with the World class is already defined, thanks to the actions in Player and to the existing Entity base class. All that's left is to define the projectiles themselves.

We start with the Projectile class. We have normal machine gun bullets and homing missiles represented by the same class. This class inherits from the Entity class and is quite small, since it doesn't have anything special that differentiates it
 later.

```
class Projectile : public Entity
{
    public:
        enum Type
        {
            AlliedBullet,
            EnemyBullet,
            Missile,
            TypeCount
        };

    public:
                                Projectile(Type type,
                                const TextureHolder& textures);

        void                    guideTowards(sf::Vector2f position);
        bool                    isGuided() const;

        virtual unsigned int        getCategory() const;
        virtual sf::FloatRect       getBoundingRect() const;
        float                       getMaxSpeed() const;
        int                         getDamage() const;


    private:
        virtual void            updateCurrent(sf::Time dt,
                                CommandQueue& commands);
        virtual void            drawCurrent(sf::RenderTarget& target,
                                sf::RenderStates states) const;
```

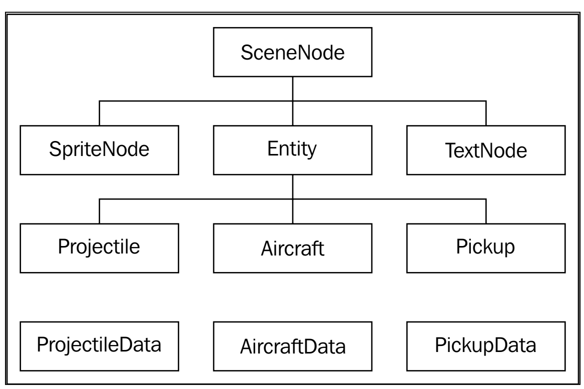
```
    private:
        Type                mType;
        sf::Sprite          mSprite;
        sf::Vector2f        mTargetDirection;
};
```

he one to
plementation.
You might notice, we use the same data tables that we used in the `Aircraft` class to store data.

```
Projectile::Projectile(Type type, const TextureHolder& textures)
: Entity(1)
, mType(type)
, mSprite(textures.get(Table[type].texture))
{
    centerOrigin(mSprite);
}
```

projectile.
vior of
missiles. The rest of the functions don't hold anything particularly interesting. Draw

To get an overview of the class hierarchy in the scene graph, here is an inheritance
are
of the
following diagram:



Firing bullets and missiles

So let's try and shoot some bullets in the game. We start with adding two new actions in the `Player` class: `Fire` and `LaunchMissile`. We define the default key bindings for these to be the Space bar and *M* keys.

```
Player::Player()
{
    // Set initial key bindings
    mKeyBinding[sf::Keyboard::Left] = MoveLeft;
    mKeyBinding[sf::Keyboard::Right] = MoveRight;
    mKeyBinding[sf::Keyboard::Up] = MoveUp;
    mKeyBinding[sf::Keyboard::Down] = MoveDown;
    mKeyBinding[sf::Keyboard::Space] = Fire;
    mKeyBinding[sf::Keyboard::M] = LaunchMissile;

    // ...
}

void Player::initializeActions()
{
    // ...
    mActionBinding[Fire].action = derivedAction<Aircraft>(
    std::bind(&Aircraft::fire, _1));
    mActionBinding[LaunchMissile].action =derivedAction<Aircraft>(
    std::bind(&Aircraft::launchMissile, _1));
}
```

fired
which calls the aircraft's `fire()` and `launchMissile()` functions. However, we cannot put the actual code that fires the bullet or missile in those two functions. The reason is, because if we could, we would have no concept of how much time has elapsed. We don't want to fire a projectile for every frame. We want there to be some cool down until the next time we fire a bullet, to accomplish that we need to use the delta time passed in the aircraft's `update()` function.

Instead, we mark what we want to fire by setting the Boolean flags `mIsFiring` or `mIsLaunchingMissile` to true in the `Aircraft::fire()` and the `Aircraft::launchMissile()` functions, respectively. Then we perform the actual logic in the `update()` function using commands. In order to make the code clearer to read, we have extracted it to its own function.

```
void Aircraft::checkProjectileLaunch(sf::Time dt, CommandQueue&
commands)
{
    if (mIsFiring && mFireCountdown <= sf::Time::Zero)
```

```
        {
            commands.push(mFireCommand);
            mFireCountdown += sf::seconds(1.f / (mFireRateLevel+1));
            mIsFiring = false;
        }
        else if (mFireCountdown > sf::Time::Zero)
        {
            mFireCountdown -= dt;
        }

        if (mIsLaunchingMissile)
        {
            commands.push(mMissileCommand);
            mIsLaunchingMissile = false;
        }
    }
```

the
last bullet was fired, we can fire another bullet. The actual creation of the bullet is done using a command which we will look at later. After we spawn the bullet, we reset the countdown. Here, we use `+=` instead of `=`; with a simple assignment, we
error as
iable
`mFireCountdown` in `Aircraft`. Like that, we can improve the aircraft's fire rate easily. So if the fire rate level is one, then we can fire a bullet every half a second, increase
ember to
o fire.
e bar.

he `Player`
class, we made the input an event-based (not real-time based) input.

```
bool Player::isRealtimeAction(Action action)
{
    switch (action)
    {
        case MoveLeft:
        case MoveRight:
        case MoveDown:
        case MoveUp:
        case Fire:
            return true;
```

```
        default:
            return false;
    }
}
```

Since the `switch` statement does not identify `LaunchMissile` as a real-time input, the user has to release the *M* key before he can shoot another missile. The user wants to save his missiles for the moment he needs them.

ot the
projectiles. We define them in the constructor in order to have access to the texture holder. This shows one of the strengths of lambda expressions in C++11.

```
Aircraft::Aircraft(Type type, const TextureHolder& textures)
{
    mFireCommand.category = Category::SceneAirLayer;
    mFireCommand.action =
    [this, &textures] (SceneNode& node, sf::Time)
    {
        createBullets(node, textures);
    };

    mMissileCommand.category = Category::SceneAirLayer;
    mMissileCommand.action =
    [this, &textures] (SceneNode& node, sf::Time)
    {
        createProjectile(node, Projectile::Missile, 0.f, 0.5f,
        textures);
    };
}
```

difficulty,
his makes the
`Aircraft` class and our code a lot simpler, since the reference does not need to exist in the `update()` function.

The commands are sent to the air layer in the scene graph. This is the node where we
han bullets, that's
why we call directly `Aircraft::createProjectile()`. So how do we create bullets then?

```
void Aircraft::createBullets(SceneNode& node, const TextureHolder&
textures) const
{
    Projectile::Type type = isAllied()
    ? Projectile::AlliedBullet : Projectile::EnemyBullet;
```

```
        switch (mSpreadLevel)
        {
            case 1:
                createProjectile(node, type, 0.0f, 0.5f, textures);
                break;

            case 2:
                createProjectile(node, type, -0.33f, 0.33f, textures);
                createProjectile(node, type, +0.33f, 0.33f, textures);
                break;

            case 3:
                createProjectile(node, type, -0.5f, 0.33f, textures);
                createProjectile(node, type,  0.0f, 0.5f, textures);
                createProjectile(node, type, +0.5f, 0.33f, textures);
                break;
        }
    }
```

For projectiles, we provide different levels of fire spread in order to make the game
s aircraft
becomes more powerful as he is playing. The function calls `createProjectile()` just as it was done for the missile.

raph?

```
    void Aircraft::createProjectile(SceneNode& node,
    Projectile::Type type, float xOffset, float yOffset,
    const TextureHolder& textures) const
    {
        std::unique_ptr<Projectile> projectile(
            new Projectile(type, textures));

        sf::Vector2f offset(
            xOffset * mSprite.getGlobalBounds().width,
            yOffset * mSprite.getGlobalBounds().height);
        sf::Vector2f velocity(0, projectile->getMaxSpeed());

        float sign = isAllied() ? -1.f : +1.f;
        projectile->setPosition(getWorldPosition() + offset * sign);
        projectile->setVelocity(velocity * sign);
        node.attachChild(std::move(projectile));
    }
```

equired by
enemy or the
ets to go
upwards like the player's bullets or the other way around.

Implementing gunfire for enemies is now a tiny step; instead of calling `fire()` when
wing code to
the beginning of the `checkProjectileLaunch()` function:

```
if (!isAllied())
    fire();
```

Now we have bullets that fly and split the sky.

Homing missiles

ssiles?
be capable of
seeking enemies autonomously.

Let's fi
missiles, the functions `guideTowards()` and `isGuided()`, as well as the variable `mTargetDirection` are important. Their implementation looks as follows:

```
bool Projectile::isGuided() const
{
    return mType == Missile;
}

void Projectile::guideTowards(sf::Vector2f position)
{
    assert(isGuided());
    mTargetDirection = unitVector(position - getWorldPosition());
}
```

The function `unitVector()` is a helper we have written. It divides a vector by its length, thus, always returns a vector of length one. The target direction is therefore a unit vector headed towards the target.

In the function `updateCurrent()`, we steer our missile. We change the current
vector to it. By
on, having the
effect that the missile flies along a curve towards the target.

`approachRate` is a constant that determines, to what extent the target direction contributes to the velocity. `newVelocity`, which is the weighted sum of the two vectors, is scaled to the maximum speed of the missile. It is assigned to the missile's velocity, and its angle is assigned to the missile's rotation. We use `+90` here, because the missile texture points upwards (instead of right).

```
void Projectile::updateCurrent(sf::Time dt,
CommandQueue& commands)
{
    if (isGuided())
    {
        const float approachRate = 200.f;

        sf::Vector2f newVelocity = unitVector(approachRate
        * dt.asSeconds() * mTargetDirection + getVelocity());

        newVelocity *= getMaxSpeed();
        float angle = std::atan2(newVelocity.y, newVelocity.x);

        setRotation(toDegree(angle) + 90.f);
        setVelocity(newVelocity);
    }

    Entity::updateCurrent(dt, commands);
}
```

> Note that there are many possibilities to guide a missile. **Steering behaviors** define a whole field of AI; they incorporate advanced mechanisms such as evasion, interception, and group behavior. Don't hesitate to search on the internet if you're interested.

Now, we have guided the missile to a certain position, but how to retrieve that position? We want our missile to pursuit the closest enemy. For this, we switch from `Projectile` to the `World` class, where we write a new function. First, we store all currently active (that is, already spawned and not yet destroyed) enemies in the member variable `mActiveEnemies`. With the command facility, this task is almost trivial:

```
void World::guideMissiles()
{
    Command enemyCollector;
    enemyCollector.category = Category::EnemyAircraft;
    enemyCollector.action = derivedAction<Aircraft>(
    [this] (Aircraft& enemy, sf::Time)
```

```
{
    if (!enemy.isDestroyed())
        mActiveEnemies.push_back(&enemy);
});
```

Next, we have to find the nearest enemy for each missile. We set up another command, now for projectiles, that iterates through the active enemies to find the closest one. Here, `distance()` is a helper function that returns the distance between the centers of two scene nodes.

```
Command missileGuider;
missileGuider.category = Category::AlliedProjectile;
missileGuider.action = derivedAction<Projectile>(
[this] (Projectile& missile, sf::Time)
{
    // Ignore unguided bullets
    if (!missile.isGuided())
        return;

    float minDistance = std::numeric_limits<float>::max();
    Aircraft* closestEnemy = nullptr;

    FOREACH(Aircraft* enemy, mActiveEnemies)
    {
        float enemyDistance = distance(missile, *enemy);

        if (enemyDistance < minDistance)
        {
            closestEnemy = enemy;
            minDistance = enemyDistance;
        }
    }
```

In case we found a closest enemy, we let the missile chase it.

```
    if (closestEnemy)
        missile.guideTowards(
        closestEnemy->getWorldPosition());
});
```

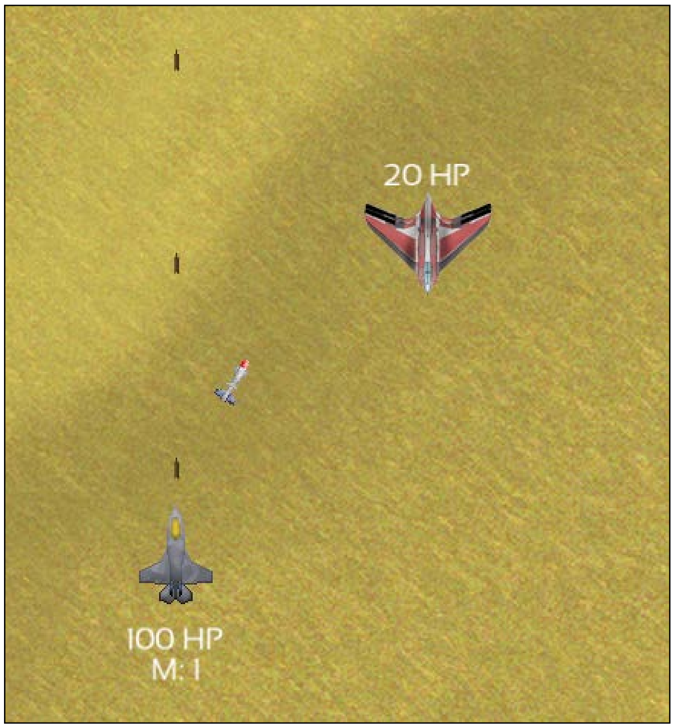
After defining the second command, we push both to our queue, and reset the
uted, they
wait in the queue until they are invoked on the scene graph in `World::update()`.

```
mCommandQueue.push(enemyCollector);
mCommandQueue.push(missileGuider);
```

```
        mActiveEnemies.clear();
    }
```

That's it, now we are able to fire and forget!

The result looks as follows:



Picking up some goodies

Now we have implemented enemies and projectiles. But even if the player shot
his success
changes anything. You want to give the player the feeling that he is progressing in
when they
are killed. So let's go ahead and implement that in our game.

need have
t we want
is only an entity that, when the player touches it, applies an effect to the player and disappears. Not much work with our current framework.

```
class Pickup : public Entity
{
    public:
        enum Type
        {
            HealthRefill,
            MissileRefill,
            FireSpread,
            FireRate,
            TypeCount
        };

    public:
                             Pickup(Type type,
                             const TextureHolder& textures);

        virtual unsigned int   getCategory() const;
        virtual sf::FloatRect  getBoundingRect() const;

        void                   apply(Aircraft& player) const;

    protected:
        virtual void       drawCurrent(sf::RenderTarget& target,
                           sf::RenderStates states) const;

    private:
        Type               mType;
        sf::Sprite         mSprite;
};
```

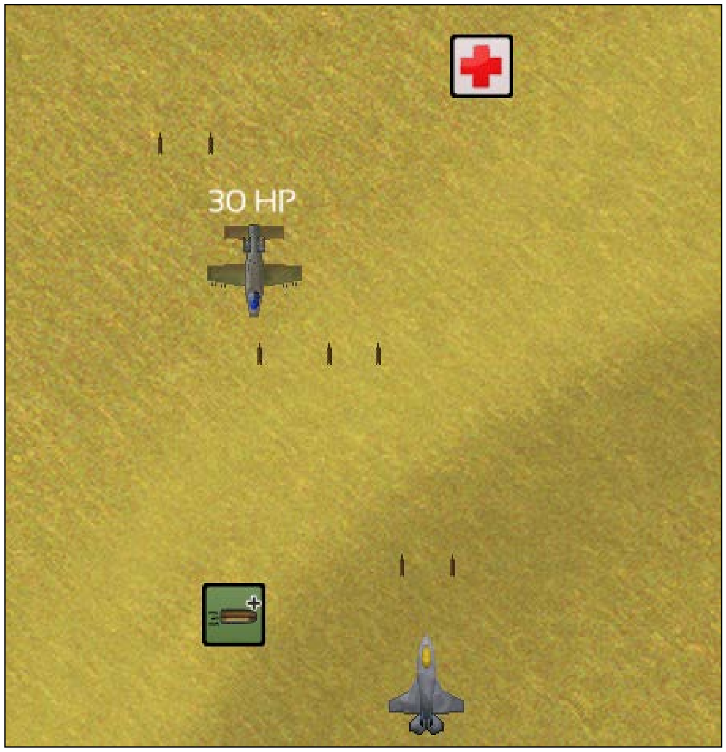
So, let's start looking at a few interesting parts. As usual, we have a data table,
d expect
it. Let's investigate the `apply()` function, and how the data table is created. In `apply()`, a function object stored in the table is invoked with `player` as argument. The `initializePickupData()` function initializes the function objects, using `std::bind()` that redirects to the `Aircraft` member functions.

```
void Pickup::apply(Aircraft& player) const
{
    Table[mType].action(player);
}
```

```
std::vector<PickupData> initializePickupData()
{
    std::vector<PickupData> data(Pickup::TypeCount);

    data[Pickup::HealthRefill].texture = Textures::HealthRefill;
    data[Pickup::HealthRefill].action
    = std::bind(&Aircraft::repair, _1, 25);

    data[Pickup::MissileRefill].texture = Textures::MissileRefill;
    data[Pickup::MissileRefill].action
    = std::bind(&Aircraft::collectMissiles, _1, 3);

    data[Pickup::FireSpread].texture = Textures::FireSpread;
    data[Pickup::FireSpread].action
    = std::bind(&Aircraft::increaseSpread, _1);

    data[Pickup::FireRate].texture = Textures::FireRate;
    data[Pickup::FireRate].action
    = std::bind(&Aircraft::increaseFireRate, _1);

    return data;
}
```

The pickups call already defined functions on the player aircraft that let us modify its state. These functions may repair it, refill it with missiles, or improve its firepower. It's nice when things just work out of the box.

That's how the scene looks when two pickups (health and fire rate) are floating in the once, which is
the result of a previously collected fire spread pickup.



Collision detection and response

ween them.

Most interactions occur in the form of a collision; two airplanes collide and explode, projectiles of the player's Gatling gun perforate an enemy, and a pickup is collected by the player, and so on.

First, we write a function that computes the **bounding rectangle** of an entity.
ity.
es
computations simpler. Here is an example implementation: `getWorldTransform()` multiplies the `sf::Transform` objects from the scene root to the leaf.
`sf::Transform::transformRect()` transforms a rectangle, and may enlarge
ed).
`sf::Sprite::getGlobalBounds()` returns the sprite's bounding rectangle relative to the aircraft.

```
sf::FloatRect Aircraft::getBoundingRect() const
{
    return getWorldTransform()
           .transformRect(mSprite.getGlobalBounds());
}
```

To get a better imagination of the bounding rectangle, take a look at `SceneNode.cpp` in the online code base. You can uncomment the call to `drawBoundingRect()` inside `SceneNode::draw()`.

etween two
es for an
, and good
enough for many purposes.

> There is a wide range of more elaborated collision detection algorithms. A popular algorithm is the **Separating Axis Theorem**, which checks for collisions between two convex polygons. You can read more about it at `www.metanetsoftware.com/technique/tutorialA.html`.

Our function is implemented using the SFML method `sf::FloatRect::intersects()` which checks for rectangle intersection.

```
bool collision(const SceneNode& lhs, const SceneNode& rhs)
{
    return lhs.getBoundingRect()
              .intersects(rhs.getBoundingRect());
}
```

> Note that we wrote the function for `SceneNode` and not `Entity`. This is because collision occurs inside the scene graph, so we avoid the downcasts. Scene nodes that do not have a physical representation have an empty bounding rectangle, which does not intersect with others.

Finding the collision pairs

Given the `collision()` function, we can determine in each frame, which pairs of entities collide. We store the pointers to the entities in `std::pair<SceneNode*, SceneNode*>`, for which we have created the `SceneNode::Pair` typedef. All collision pairs are stored in a `std::set` instance.

Basically, we need to compare every scene node with every other scene node to determine if a collision between the two occurs. To do this in a recursive way, we use two methods. The first one, `checkNodeCollision()`, evaluates a collision between `*this` with its children, and the function argument `node`.

The first three lines check if a collision occurs, and if the nodes are not identical (we do not want an entity to collide with itself). By calling `isDestroyed()`, we exclude entities that have already been destroyed, and that are no longer part of
set. The STL
algorithm `std::minmax()` takes two arguments and returns a pair with `first` being the smaller, and `second` being the greater of the two arguments (where smaller means lower address in this case). Thus, `std::minmax(a,b)` and `std::minmax(b,a)`
ether with
s A and B is
inserted only once (and not twice as A-B and B-A pairs).

```
void SceneNode::checkNodeCollision(SceneNode& node, std::set<Pair>&
collisionPairs)
{
    if (this != &node && collision(*this, node)
     && !isDestroyed() && !node.isDestroyed())
        collisionPairs.insert(std::minmax(this, &node));

    FOREACH(Ptr& child, mChildren)
        child->checkNodeCollision(node, collisionPairs);
}
```

The second part invokes the function recursively for all children of `*this`.

to
check the whole scene graph against all nodes. This is where our second function `checkSceneCollision()` comes into play. For the argument and all its children, a collision between the current node `*this` and the argument node `sceneGraph` is evaluated.

```
void SceneNode::checkSceneCollision(SceneNode& sceneGraph,
std::set<Pair>& collisionPairs)
{
    checkNodeCollision(sceneGraph, collisionPairs);

    FOREACH(Ptr& child, sceneGraph.mChildren)
        checkSceneCollision(*child, collisionPairs);
}
```

Reacting to collisions

What we have seen now is how collision detection works. The other part is collision response, where collisions result in gameplay actions.

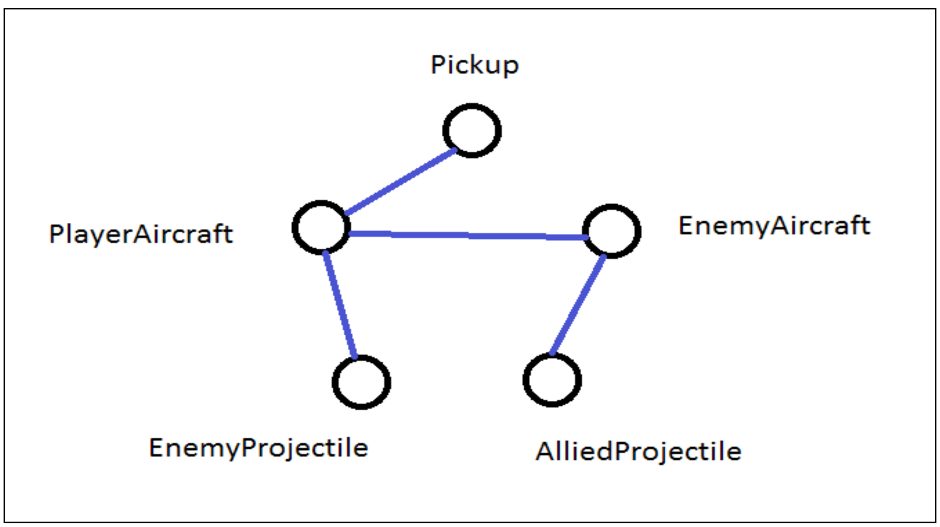
For every frame, we store all collided scene nodes in a set. Now we can iterate through this set of `SceneNode*` pairs, and dispatch on the categories of each collision partner. First, we write a helper function that returns true if a given pair matches two collision
between the player aircraft and a dropped pickup. We do not want the order of the parameters `type1` and `type2` to influence the result, that's why we check if the first node matches the first category and the second node the second category, as well as vice versa. In the vice versa case, we swap the node pointers so that their order is the same as the arguments' order. Because the first parameter `colliders` is passed by reference, the caller will then have a consistent ordering (`colliders.first` matches `type1` and `colliders.second` matches `type2`).

```
bool matchesCategories(SceneNode::Pair& colliders,
                       Category::Type type1, Category::Type type2)
{
    unsigned int category1 = colliders.first->getCategory();
    unsigned int category2 = colliders.second->getCategory();

    if (type1 & category1 && type2 & category2)
    {
        return true;
    }
    else if (type1 & category2 && type2 & category1)
    {
        std::swap(colliders.first, colliders.second);
        return true;
    }
    else
    {
        return false;
    }
}
```

ene graph
for collisions, and fill the set with collision pairs. Then, we iterate through the set and differentiate between the collisions categories.

```
void World::handleCollisions()
{
    std::set<SceneNode::Pair> collisionPairs;
    mSceneGraph.checkSceneCollision(mSceneGraph, collisionPairs);

    FOREACH(SceneNode::Pair pair, collisionPairs)
    {
        if (matchesCategories(pair,
            Category::PlayerAircraft, Category::EnemyAircraft))
        {
            ... // React to player-enemy collision
        }
    }
}
```

own in the
following diagram:



Correspondingly, we need four calls to `matchesCategories()` in order to react to all possible combinations. Note that the argument pair is passed by reference—possibly its members are swapped to match the category order. Therefore, we can be sure about the pointer's categories, and safely downcast from `SceneNode*` to the concrete entity.

We begin with the collision between the two airplanes. In this case, we always
's
current hitpoints.

```
if (matchesCategories(pair,
    Category::PlayerAircraft, Category::EnemyAircraft))
{
    auto& player = static_cast<Aircraft&>(*pair.first);
    auto& enemy = static_cast<Aircraft&>(*pair.second);

    player.damage(enemy.getHitpoints());
    enemy.destroy();
}
```

Next, we handle the case where the player's aircraft collects a pickup by touching it. We apply the effect to the player and destroy the pickup.

```
else if (matchesCategories(pair,
    Category::PlayerAircraft, Category::Pickup))
{
    auto& player = static_cast<Aircraft&>(*pair.first);
    auto& pickup = static_cast<Pickup&>(*pair.second);

    pickup.apply(player);
    pickup.destroy();
}
```

y consider
player projectiles that hit the enemy airplanes, and enemy projectiles that hit the
unify them.
raft.

```
else if (matchesCategories(pair,
    Category::EnemyAircraft, Category::AlliedProjectile)
  || matchesCategories(pair,
    Category::PlayerAircraft, Category::EnemyProjectile))
{
    auto& aircraft = static_cast<Aircraft&>(*pair.first);
    auto& projectile = static_cast<Projectile&>(*pair.second);

    aircraft.damage(projectile.getDamage());
    projectile.destroy();
}
```

s by adding
another `if` clause. Want to intercept enemy missiles? No problem; add a case for `Category::AlliedProjectile` and `Category::EnemyProjectile`. Allow friendly
fifor two
entities of category `Category::EnemyAircraft`.

An outlook on optimizations

Since we test all possible scene node combinations, the number of collision checks
odes. This can
several
ways to cope with this issue.

First, needless comparisons can be reduced. Recursion can be replaced with iteration;
graphs. This
would avoid checking each combination twice, and checking a scene node for collision with itself.

```
for (SceneNode::iterator left = mSceneGraph.begin();
     left != mSceneGraph.end(); ++left)
{
    for (SceneNode::iterator right = std::next(left);
         right != mSceneGraph.end(); ++right)
    {
        ... // Collision detection
    }
}
```

By storing pointers to entities that are interesting for collisions (instead of all scene nodes) in a separate container, we would reduce unnecessary checks too. We could even go further and directly store the entities with their full type. For example, we might have `std::vector<Aircraft*>` for the enemies and `std::vector<Projectile*>` for the allied bullets, so there would be no need for category dispatching.

Those approaches are a good start, but the time complexity is still quadratic. In a big
s for collisions,
since most of them are too far away. An optimization would base on locality. We
is, the world
could be divided into a grid of equally sized cells. Each entity is assigned to a cell.
hbor cells are
oing this
way further would lead to data structures such as quadtrees.

Concerning collision response, if there are many cases to consider, the dispatching
th partners
would serve as indices, and the table entries are function objects that implement the collision response for a concrete collider pair.

As nice as these optimizations sound, there is a price to pay—the implementation becomes more complicated. A decent amount of book keeping is required to keep
, it might
ties must be
inserted, and destroyed entities must be removed from the right cell.

In conclusion, such optimizations are not only nice to have, but a bare necessity when the world and the number of entities grow. However, the implied book-keeping overhead does not pay off for smaller scenarios, which is a reason why we kept things simple in our game.

An interacting world

we look at
functionality that is defined in the `World` class. You have already seen the collision in the last section.

Cleaning everything up

During the game, entities are destroyed in battle, and have to be removed from the
e through
from
their parents. To find out whether a node has been destroyed, we write the virtual function `SceneNode::isDestroyed()`. By default, it returns false. A derived entity
be the case
when the hitpoints are zero or less (that is, the entity is destroyed).

```
bool Entity::isDestroyed() const
{
    return mHitpoints <= 0;
}
```

In addition, we add a virtual function that checks if a scene node should be removed from the scene graph. By default, this is true as soon as the node is destroyed.

```
bool SceneNode::isMarkedForRemoval() const
{
    return isDestroyed();
}
```

However, this need not always be the case. Imagine an entity that has been destroyed, but still needs to reside for some time in the world, in order to drop a pickup, show an explosion animation, or similar. While `isDestroyed()` tells he world
anymore, `isMarkedForRemoval()` tells whether the scene node can be removed from the scene graph. The `Aircraft` class itself delays removal after destruction, to let enemies drop their pickups in the `update()` function. There, a special flag determines the return value.

```
bool Aircraft::isMarkedForRemoval() const
{
    return mIsMarkedForRemoval;
}
```

The removal is performed by the following method. In the first part, `std::remove_if()` beginning,
and the ones to remove at the end. The call to `erase()` actually destroys these `SceneNode::Ptr`
child nodes. `std::mem_fn()` creates a function object which returns true, if and only if, the member function passed as argument returns true.

```
void SceneNode::removeWrecks()
{
    auto wreckfieldBegin = std::remove_if(mChildren.begin(),
    mChildren.end(), std::mem_fn(&SceneNode::isMarkedForRemoval));
    mChildren.erase(wreckfieldBegin, mChildren.end());

    std::for_each(mChildren.begin(), mChildren.end(),
    std::mem_fn(&SceneNode::removeWrecks));
}
```

This function can now be called in `World::update()`, and we automatically get rid of all nodes that request their removal.

Out of view, out of the world

rojectiles
ss void.
Enemies that fly past the screen continue to fly, although the player will never see them again, which can be costly performance-wise.

our collision
he view.
Remember that `getBattlefieldBounds()` returns `sf::FloatRect`, which is slightly bigger than `getViewBounds()`. It also contains the area beyond the view, inside
of which
the bounding rectangle doesn't intersect with the battlefield's bounding rectangle (that is, they are outside).

```
void World::destroyEntitiesOutsideView()
{
    Command command;
    command.category = Category::Projectile
                     | Category::EnemyAircraft;
    command.action = derivedAction<Entity>(
    [this] (Entity& e, sf::Time)
    {
        if (!getBattlefieldBounds()
        .intersects(e.getBoundingRect()))
            e.destroy();
    });

    mCommandQueue.push(command);
}
```

The final update

A lot of new logic code has found its way into the `World` class; the different functions are invoked from `World::update()`, which currently looks as follows. The function names are self-explanatory.

```
void World::update(sf::Time dt)
{
    mWorldView.move(0.f, mScrollSpeed * dt.asSeconds());
    mPlayerAircraft->setVelocity(0.f, 0.f);

    destroyEntitiesOutsideView();
    guideMissiles();

    while (!mCommandQueue.isEmpty())
        mSceneGraph.onCommand(mCommandQueue.pop(), dt);
    adaptPlayerVelocity();
```

```
        handleCollisions();
        mSceneGraph.removeWrecks();
        spawnEnemies();

        mSceneGraph.update(dt, mCommandQueue);
        adaptPlayerPosition();
    }
```

Victory and defeat

er through
nd become a
pilot legend. Or you fall victim to the enemy fleet and die in a horrible plane crash.

Anyway, the player should be informed by the game about his fate. In most games, there are victory and defeat conditions. In our airplane game, a mission is complete if you cross the level's border at the end. A mission is failed if your plane is destroyed. To display this information, we have written `GameOverState` that displays an
, statistics,
ins
their
, you are
free to look at the original code base at any time.

Summary

This was probably the most difficult chapter up to now, as it combines all the game-
, entities,
ent that the
existing framework made a lot of new tasks simple to achieve.

r
es. We let
enemies spawn, follow certain movement patterns, fire in regular intervals, and drop pickups upon destruction. Collision detection and response was implemented, and we discussed performance considerations. Eventually, we managed the world's update cycle, and cleaned up destroyed entities.

Now that the game foundation has been built, we are ready to add more graphical content. In the next chapter, we are going to add a variety of visual effects to improve the appearance of our game.

8

Every Pixel Counts – Adding Visual Effects

nality.
We finally reached a point where our game is playable, where all the game mechanisms are implemented. With a bit of creativity, you should already be able
—a game
ics. Be
it cutting-edge 3D scenes in the newest real-time strategy game or the nostalgic atmosphere of a pixel-art indie title, graphics determine to a big extent how the player feels.

are going to
cover various techniques that are used in modern games to create graphical effects of different kinds. To mention a few:

- Texture atlases and how different objects can be stored in one texture
- Texture mapping and vertex arrays
- Particle systems to create effects such as fire or smoke
- Animations that show an object in motion
- Render textures as an alternative to render windows
- Shaders to give the whole scene a distinct look

a lot with
SFML, this one will introduce many new features of its Graphics module.

Defining texture atlases

A **texture atlas** describes the concept of a single texture that contains multiple objects. You may also encounter other terms, such as **sprite sheet**, or **tile set** in the
mage files,
time. Since
 texture
res for each
nd. Every
texture was stored in its own PNG file. The code design looked as follows:

- Textures were stored inside `TextureHolder`, our container storing `sf::Texture` objects.
- We had an enum `Textures::ID` to identify the different textures in a `TextureHolder`. By that, we could easily refer to different textures without knowing the actual `sf::Texture` object or the filename.
- The textures used in the scene were loaded in `World::loadTextures()`.
- They were bound to sprites in the specific entity classes such as `Aircraft`. For a given entity, data tables stored the texture ID it used.

The SFML sprite class `sf::Sprite` offers the possibility to set a **texture rectangle** (or texture rect for short), containing the pixel coordinates of a specific object inside
ted the
tiling background for our world in *Chapter 3, Forge of the Gods – Shaping Our World*. The rectangle is of type `sf::IntRect` and stores four integral values: the x and y coordinates of the left-upper pixel (members `left` and `top`) as well as the size (members `width` and `height`).

For example, the following texture rectangle `rect` begins at (`0`, `15`) and has a width of `30` and height of `20`. The size excludes the last pixel; the pixel with coordinates (`30`, `35`) is outside the rectangle.

```
sf::IntRect rect(0, 15, 30, 20);
```

Given a texture and a rectangle, you can initialize a sprite using the constructor, or you can set the attributes later with the corresponding methods.

```
sf::Texture texture = ...;
sf::IntRect rect = ...;
```

```
sf::Sprite sprite(texture, rect);

sf::Sprite sprite2;
sprite2.setTexture(texture);
sprite2.setTextureRect(rect);
```

If no rectangle is specified, the sprite will assume that the whole texture is used. This is what we have always done so far.

Adapting the game code

tead of
whole textures. First, we must remove many of our resource identifiers. All the aircraft, projectile and pickup textures will be merged to one texture, with an ID of `Entities`. The texture containing the three buttons is accessible via `Buttons`. Eventually, we only have the following identifiers:

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

In case you wonder, `Jungle` is the new background we will paint. It is much bigger and far more interesting than the desert we had before. `FinishLine` is a texture used to the scene
graph using `SpriteNode`. `Explosion` and `Particle` are going to be introduced soon.

With the new image files in our `Media` folder, the method `World::loadTextures()`
xture
ardcoded in
the initialization functions.

```
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;
}
```

The last part to extend is the entities that use the textures. Now, 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);
    ...
}
```

e Eagle
ith texture
atlases! Visually, there will be no difference to what we had before.

Low-level rendering

Besides the high-level convenience classes `sf::Sprite`, `sf::Text` and `sf::Shape`, SFML provides a low-level graphics API which is more complicated to use, but allows more flexibility. In the next section, we are going to look behind the scenes of rendering and discuss corresponding techniques as they are implemented in SFML.

OpenGL and graphics cards

The graphics card architecture consists of many components. Notable are the **graphics processing unit** (**GPU**), which performs computations on the graphics card, and the **video memory**, which stores data such as textures. In contrast to their counterparts CPU and RAM, graphics cards' components are highly optimized to process 2D and 3D graphics.

SFML is built on top of the **Open Graphics Library** (**OpenGL**). OpenGL is, like DirectX, a specification of an interface to the graphics card. Operating systems
ard
hus have
the benefit of more modern features.

The way SFML is designed is heavily influenced by the underlying OpenGL
s low-level
accesses away; therefore users can work with the library without even knowing
hniques,
in order to see the whole picture. For specific requirements, it is also possible to mix SFML and OpenGL.

Understanding render targets

A **render target** defines the place where 2D objects such as sprites, texts, or shapes are rendered. In SFML, this boils down to the abstract base class `sf::RenderTarget`. Apart from `clear()` and `draw()` methods, the class provides functionality to manipulate the current view.

A **render window** is a concrete implementation of a render target. Render windows
In
addition, they provide facilities for input handling and configurations such as V-Sync. The class `sf::RenderWindow`, which we have been using all the time, inherits `sf::RenderTarget` and `sf::Window`.

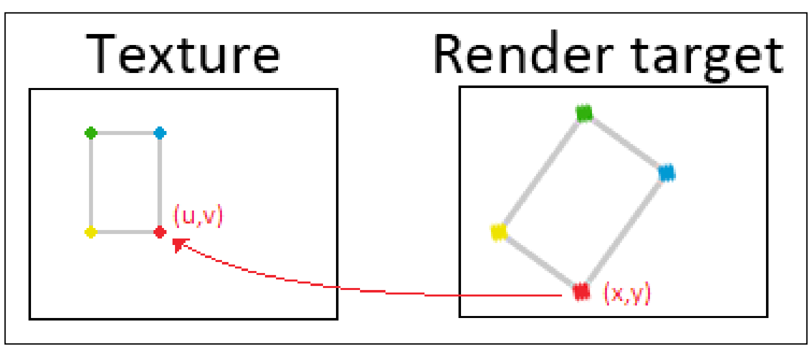
A **render texture** is another realization of the render target concept. Here, you do not to render a
or example,
saved to a file or edited as a whole. SFML provides the class `sf::RenderTexture` which derives from `sf::RenderTarget`. Notable is the method `getTexture()` which returns `const sf::Texture&` with the render texture's current contents. As with render windows, you must call `display()` before you can actually use that texture. This step is often forgotten.

Texture mapping

We have worked a lot with textures in the game, but not explained how they are actually displayed on the screen. **Texel** (**texture element**) is the term used for pixels in texture space. The case where every texel in the texture corresponds to a pixel on
ct and the
view affect the way how pixels are displayed on the screen.

Every graphical object on the screen consists of vertices. A **vertex** is a point that
defiic
primitives such as lines, triangles, rectangles, and so on. In most cases, we have rectangular objects (such as `sf::Sprite`) that have four vertices, namely the four corners of the rectangle. Polygons (modeled by `sf::Shape`) allow a different number of vertices.

n the render
ource texture, in
texels). Texture coordinates are sometimes also called UV coordinates, because the variables u and v are often used instead of x and y. The process of **texture mapping**
specifi
to know which pixels have to be drawn where. This mapping is clarified in the following figure:



This figure only shows an aligned rectangle in the texture, the proportions of which
reedom to
uld just
experiment yourself.

SFML provides the class `sf::Vertex` that represents a vertex of the geometric object. It has the following public member variables:

- `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

All geometric primitives except points consist of more than one vertex. A **vertex array** is a collection of vertices that are drawn together. A vertex array need not necessarily represent a single geometric object; it may also store the vertices of many objects.

In SFML, the class `sf::VertexArray` is used to model vertex arrays. It is a thin wrapper around `std::vector<sf::Vertex>` and derives from `sf::Drawable`. We
es using the
index operator.

The **primitive type** determines how the vertices are interpreted to form a geometric primitive. For example, the primitive type `sf::Triangles` interprets three subsequent vertices as one triangle, the next three vertices as another triangle, and so on. `sf::Quads` interprets four subsequent vertices as a quadrilateral. When we work with rectangles, we will be using the `sf::Quads` primitive type.

A small, incomplete example should give you a rough idea how vertices, vertex arrays and render targets interact:

```
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);
```

The main reason to use `sf::VertexArray` instead of high-level classes such as `sf::Sprite` is performance. The rendering performance primarily depends on the
w routine
r many
f vertex arrays.

Particle systems

Visual effects such as fire, rain, or smoke have one thing in common: they have a
a single
sprite. Even an animated sprite is too limited for many cases, because such effects should come with certain randomness. Fire may have sparks flying in arbitrary directions; smoke may be blown away by the wind.

This is why we need another model to visualize these sorts of effects: **particles**. A particle is a tiny object that makes up a part of the whole effect; you can imagine it as
n do they lead
to an emergent visual pattern such as fire.

A **particle system** is a component that manages the behavior of many particles to form the desired effect. **Emitters** continuously create new particles and add them to the system. **Affectors** affect existing particles with respect to motion, fade-out, scaling, and many other properties.

particle
system could contain `std::vector<sf::Sprite>`. The problem with this approach
ay easily
consist of many thousands of particles, thousands of draw calls on the GPU are not
rendered;
. Clearly,
we need a technique to reduce the amount of draw calls.

object with
vertex array. This
gives us a method to draw everything with only one draw call.

Particles and particle types

In our game, we want to create an effect for the burned propellant and the emitted smoke of homing missiles. Both can be handled in a similar way, the main difference ures. The final
gle particles
anymore, the trace of the missiles looks like a continuous stream.

We define l the
particle disappears. The `Particle::Type` data type is used to differ between smoke and propellant effects.

```
struct Particle
{
    enum Type
    {
        Propellant,
        Smoke,
        ParticleCount
    };

    sf::Vector2f     position;
    sf::Color        color;
    sf::Time         lifetime;
};
```

r attributes in a
know it, from
the entity data tables:

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

Particle nodes

ph. We will to
create a class `ParticleNode`, which can be inserted into the scene and which acts as a particle system. The class definition looks as follows:

```
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;
};
```

Many methods for drawing and updating are already known from other `SceneNode` definitions, thus not listed here. `getCategory()` returns `Category::ParticleSystem`, a separate category. `getParticleType()` returns the particle type (smoke or propellant) which is stored in `mType`.

A new addition is `addParticle()`, which looks up the data table and inserts a particle into the system:

```
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);
}
```

In the update method, we first remove all particles of which the lifetime has
cles are stored
at the beginning of the container. Therefore, it is enough to remove the front element of `mParticles` as long as its lifetime is smaller or equal to zero (this is also the reason why we employed `std::deque`). In the middle part of the function, we decrease the lifetime of each particle by the current frame time. Finally, every time the particle container is modified, we enable a flag to express that the render geometry must be recomputed:

```
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;
}
```

The rendering part is shown next. The `mVertexArray` member is declared `mutable`, since it is not a part of the object's logical state. This allows optimizations: we only rebuild the vertex array if something has changed, and directly before drawing (instead of after each update). This way, if the particle system is updated multiple times in a row before being drawn, we do not needlessly compute the vertices each time.

After checking whether we need to recompute the vertices, we set the `sf::RenderStates` texture to our particle texture and draw the vertex array:

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

    states.texture = &mTexture;
    target.draw(mVertexArray, states);
}
```

The rebuild of the vertex array is shown in the following code snippet. First, we save the texture's full and half sizes in variables, to determine the vertex positions more easily. For `size`, the constructor syntax is used rather than =, because a `sf::Vector2i` (vector of integers) is converted to `sf::Vector2f` (vector of floats). We clear the vertex array, removing all vertices in it, but keeping the memory allocated:

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

    mVertexArray.clear();
```

For each particle, we compute the ratio between the remaining and total lifetime—
5]. The alpha value
ly until they
are completely invisible:

```
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));
```

every corner
of our rectangle. The first two arguments denote the target coordinates; the next two denote the texture coordinates. The fifth argument is the vertex color. Since we need
s.

```
        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);
    }
```

`sf::Vertex` and
adds it to `sf::VertexArray`:

```
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

located, it
stands to reason that emitters should be attached to missiles. Once more, our scene graph comes in very handy: we can create a new scene node `EmitterNode` for emitters and attach it to the `Projectile` node of the missile.

`EmitterNode` is rather simple, its class definition is shown in the following code snippet:

```
class EmitterNode : public SceneNode
{
    public:
        explicit        EmitterNode(Particle::Type type);
        ...
```

```
    private:
        sf::Time        mAccumulatedTime;
        Particle::Type  mType;
        ParticleNode*   mParticleSystem;
};
```

The pointer `mParticleSystem` points to the `ParticleNode` into which the `EmitterNode` emits particles. Initially, it is `nullptr`. In the update function, we
rwise, we
need to find the system corresponding to the emitter. "Corresponding" means both use the same particle type, for example, `Particle::Smoke`. We send a command through the scene graph to find the right particle system. It sets the member variable `mParticleSystem` to the found `ParticleNode`:

```
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);
    }
}
```

it particles
osely as
mount of emitted
umulators,
as we did for the logic game loop in *Chapter 1*, *Making a Game Tick*. We emit particles as long as the emission interval still fits into the current frame. The remaining time is stored in `mAccumulatedTime` and is carried over to the next frame.

```
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());
    }
}
```

Why do we separate `EmitterNode` and `ParticleNode`? Emitters can be considered
ey are not
pdate and
itters
that emit into a single particle system. We only need one `ParticleNode` instance
can have
different transforms. An `EmitterNode` is attached to a missile, emitting particles that take the missile's transform into account. As soon as particles have been emitted, they are managed by the `ParticleNode`, which uses the global coordinate system. It is reasonable that particles, once created, are no longer influenced by the orientation of the object that created them.

Affectors

rticles during
o each particle
every frame—a meaningful abstraction might therefore be:

```
std::function<void(Particle&, sf::Time)>
```

ers. The
`ParticleNode`
its update. We have not implemented affectors in our code since we don't need their functionality at the moment, but you are free to extend the system however you like!

Embedding particles in the world

That was it for the definition of emitters and particle systems. We now add these nodes to the scene graph. First the emitter in the `Projectile` constructor; we set its
 the center):

```
if (isGuided()) // if this projectile is a missile
{
    std::unique_ptr<EmitterNode> smoke(
        new EmitterNode(Particle::Smoke));
    smoke->setPosition(0.f, getBoundingRect().height / 2.f);
    attachChild(std::move(smoke));
}
```

 graph's root.
 we split the
existing scene layer `Air` into two layers `LowerAir` and `UpperAir`. In the following, you see an excerpt of `World::buildScene()`:

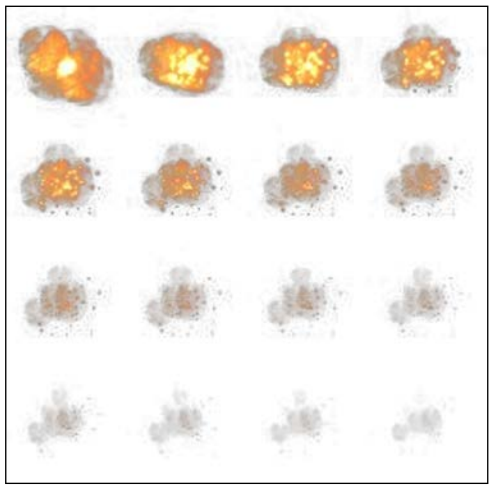
```
std::unique_ptr<ParticleNode> smokeNode(
    new ParticleNode(Particle::Smoke, mTextures));
mSceneLayers[LowerAir]->attachChild(std::move(smokeNode));
```

So far we have only considered the smoke effect, but the propellant fire works in exactly the sameway. By adding the fire particle system after the smoke, it is
ed by smoke.

Animated sprites

d
down.
expect a huge
explosion, don't you?

ledge will
be used to build our animation. An animation consists of several **frames**, and we
 similar to
ame loop
lly lasts for
many game loop iterations.



This is the sprite sheet we use for the animation. How does it work? As time elapses,
n is finished.

We do not define the animation class as a scene node but only as a drawable and a
, which
gives a little more flexibility when and where we can use it.

```
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;
};
```

ally a sprite.
We could do without a sprite if we so desired, but it defines a lot of functions that
, this vector
defines the size of one frame for us. We have the values concerning frames, how
time for
rame change.

is performed
in the `Animation::update()` function, so it grows quite big. Because of that the function is explained in the following sections.

```
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);
```

and we
lapse
before we progress to the next frame. If we are on the first frame, then our texture `rect` should start at the beginning of the animation sprite sheet:

```
    while (mElapsedTime >= timePerFrame && (mCurrentFrame <=
mNumFrames || mRepeat))
    {
```

So while time has elapsed since we last updated, and is enough to count as a new
eration:

```
        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);
}
```

In each iteration, we move the resulting texture rect quite easily. We move it a step to the right, all the way until we reach the end, if that occurs we move the rect down g for what

This is the core of the animation and covers everything we need. It's very much packed together in the update function, but it is all required.

et's start with
the `Aircraft` constructor.

```
mExplosion.setFrameSize(sf::Vector2i(256, 256));
mExplosion.setNumFrames(16);
mExplosion.setDuration(sf::seconds(1));

centerOrigin(mExplosion);
```

Here we set up our explosion. We define the size of one frame of the animation,
ter the
animation sprite's origin, so that it is easier to position.

or the
explosion. It's not much but we still have to do it:

```
if (isDestroyed() && mShowExplosion)
    target.draw(mExplosion, states);
else
    target.draw(mSprite, states);
```

We cannot simply check for `isDestroyed()`, because we have no way of distinguishing between airplanes that are shot down or that leave the screen. We only want the former to explode—hence the Boolean variable `mShowExplosion`.

won't progress. The `return` statement prevents destroyed aircraft from further logic processing:

```
if (isDestroyed())
{
    checkPickupDrop(commands);
    mExplosion.update(dt);
    return;
}
```

This would run perfectly, except that right now the aircraft would be removed
y stays
oon as it
en) or the
explosion is finished:

```
bool Aircraft::isMarkedForRemoval() const
{
    return isDestroyed()
        && (mExplosion.isFinished() || !mShowExplosion);
}
```

And now we finally have our properly exploding planes, which give much more immersion to the game.

The Eagle has rolled!

roll axis (from
the plane's
inclination will change. Here, we don't need a full-fledged animation. It is enough to check whether the X velocity is negative (flying left) or positive (flying right), and to set the texture rect accordingly.

hether it
ure rectangles
located to right of the original rect, with the same size.

```
void Aircraft::updateRollAnimation()
{
    if (Table[mType].hasRollAnimation)
```

```
    {
        sf::IntRect textureRect = Table[mType].textureRect;

        // Roll left: Texture rect offset once
        if (getVelocity().x < 0.f)
            textureRect.left += textureRect.width;

        // Roll right: Texture rect offset twice
        else if (getVelocity().x > 0.f)
            textureRect.left += 2 * textureRect.width;

        mSprite.setTextureRect(textureRect);
    }
}
```

Post effects and shaders

hem?
One of the techniques they use is something called **post rendering** or **post effects**. It's
ng that data,
ts is using
shaders, which we will delve into later.

The fien we
will actually create an effect called **bloom** using shaders.

Fullscreen post effects

Well, the effect has to be applied to the whole screen, otherwise it is pretty useless. That is why we define a specific `PostEffect` class in order to make this a bit easier.

```
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);
};
```

This is an abstract class with some helper functions. `apply()` is the virtual function we have to define our effect code in. The `isSupported()` function checks if the graphics card supports post effects. This is only an alias for `sf::Shader::isAvailable()`; unless your GPU is ancient, it should be supported. The last function is `applyShader()`, and it is just a simple helper used internally by the derived class, so you don't have to bother with making sure you render over the entire output.

Now you might notice that the input argument to the post effect is a render texture.
might
So we have
to render the game graphics to an immediate buffer.

So in our `World`

```
mSceneTexture.create(mTarget.getSize().x, mTarget.getSize().y);
```

ave to
change our rendering code in the world, but thanks to the `sf::RenderTarget`
see if post
effects work on this computer:

```
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);
    }
}
```

We will get to the bloom effect later. We still have the `PostEffect::applyShader()`
ader we will
explain shortly:

```
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);
}
```

uad covers
the entire target output. Here you see us define an instance of the sf::RenderStates class. The purpose of this class is to convey settings to the draw() call: the shader member sets the shader we want to use, while blendMode specifies the way how
ne, we choose
er target.

> You might notice that we are using `sf::TriangleStrip`, but still create a quad from it. Triangles are most often in favor as the primitive type quad has been declared obsolete in later versions of OpenGL. Luckily it is still backwards compatible, so you can use it in SFML if you want to get something up and running fast. For the difference between `sf::Triangle` and `sf::TriangleStrip` please look at the SFML documentation.

Shaders

s
themselves deserve their own book in order to be explained fully.

Previously the graphics pipeline has always been fixed. You put in vertices and you got out a fif
data and operations on the vertices.

details we
unfortunately cannot cover. A **shader** in this pipeline is a program that is executed
re. The
tions are
d for
other computations at the same time.

however,
SFML provides support for only vertex and fragment shaders. Since the API uses
for
writing the shaders is **GL Shading Language** (**GLSL**). We are afraid that this book won't be able to cover this language, but the resources on OpenGL's own webpage `www.opengl.org` are very helpful for this endeavor.

The bloom effect

.

The effect has been a bit exaggerated in this demonstration picture, but this is what we are going for. When really strong light enters our eyes, it bleeds out over other parts that are not actually lit by the light. This is a visual artifact that actually does not exist in reality.

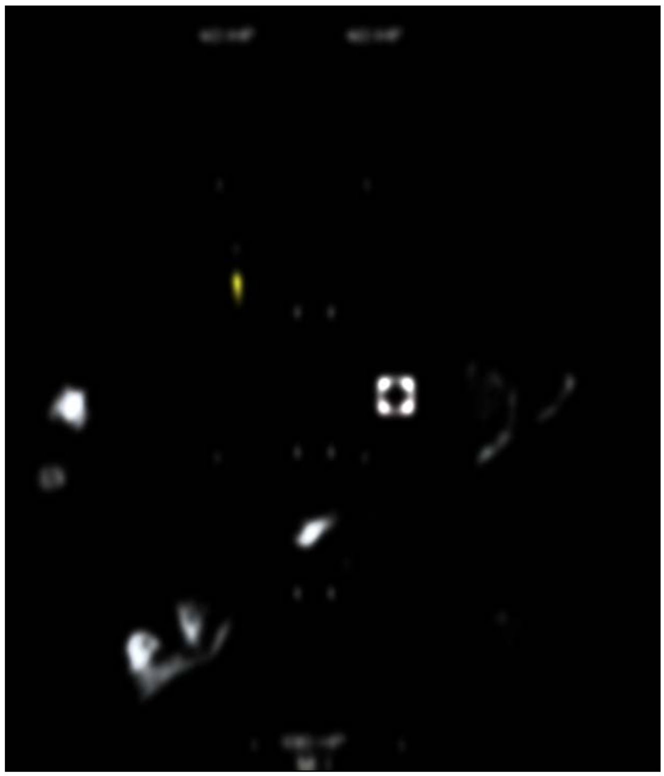
ct in
multiple shader passes. The output of a shader program can only be used as input in shader will
consist of multiple steps; each step is implemented in its own GLSL program.

Let us start by defining a source image that we have as input to our bloom effect.

The first shader is the brightness pass; we filter out what is bright and what is not bright in the image by a simple threshold. The resulting image is mostly black:

m effect.

If we simply added these colors to the scene colors, we wouldn't get the bloom effect.
ooth out
aussian
rter size of the
original texture.



blurred
textures together, and add those to the original scene that we received at the start.
le to miss.
Normally you would want this effect to be more subtle.

Even the fire exhaust particles on the missile get some love from the post effect. After some further tweaking, you have a game that can really stand out.

So let's firy that
oes one thing,
so it's easy to get a grasp about what is happening in those files if you read them.

We define a class called `BloomEffect` that inherits and implements the abstract `PostEffect` class. We override the virtual function `apply()`:

```
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);
    }
```

Here is the whole effect in its glory, well simplified. It goes through each step we talked about before. The only thing out of the ordinary here is the `prepareTextures()` function. This function sets up and creates the render textures been moved to
the constructor, but this way the effect will always adapt to the size of the input.

```
    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);
        }
    }
```

caling down
of the texture. So the texture itself has to be smaller as well. The rest of the functions perform the steps we explained before.

Here, you see the `sf::Shader` class in action. A reference to it is retrieved from a resource holder dedicated to shaders. The method `sf::Shader::setParameter()` passes values from C++ to the GLSL program. In the shader, you can access these values. `applyShader()` eventually performs the rendering and `display()` updates the render target.

```
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));
  }
}

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);
}
```

If you find shaders interesting we recommend you read up on them. There is a lot of
 to hand. Also
definitely have a look at the shaders we have written.

Here's an example of a good and popular tutorial on GLSL:

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

Summary

o longer
phical and
rendering techniques and how they fit in our game. After an in-depth look at the
a particle system
oom effect on
the whole scene.

Note that there exist already implementations for many of the techniques shown in
ve a look at
the **Thor**tends
SFML by providing fully configurable particle systems and animations. Other
lities, and
much more. The library is available at `www.bromeon.ch/libraries/thor`.

odule.
We will go through both streaming music and sound effects.

9

Cranking Up the Bass – Music and Sound Effects

mes.
years,
; yet audio
s in
particular often put a huge effort in making games unique in their art style, which includes audio, graphics, and story. If used appropriately, music themes and sounds can have a tremendous impact on the atmosphere conveyed by a game.

ding audio
into a game, taking the opportunity to have a closer look at SFML's Audio module. We are going to do the following:

- Play different music themes in the background
- Play sound effects that correspond to game events such as explosions
- Position sound effects in the 2D world to convey a feeling of spatial sound

Music themes

First, we want to play background music depending on the state we are currently in. lf. We'll
define a corresponding `enum`:

```
namespace Music
{
    enum ID
    {
        MenuTheme,
        MissionTheme,
    };
}
```

ng:

```
class MusicPlayer : private sf::NonCopyable
{
    public:
                            MusicPlayer();

        void                play(Music::ID theme);
        void                stop();

        void                setPaused(bool paused);
        void                setVolume(float volume);

    private:
        sf::Music                           mMusic;
        std::map<Music::ID, std::string>    mFilenames;
        float                               mVolume;
};
```

The method names should be self-explanatory. We have a single `sf::Music` instance that represents the currently-played music. The `mFilenames` variable maps music IDs to filenames and is initialized in the constructor. The volume takes a value between `0` and `100`; we'll initialize it to full volume. As SFML does not support the MP3 format, we'll use OGG for our files. If you are wondering how to convert between different formats, one possibility is the **Audacity** software (`http://audacity.sourceforge.net`).

```
MusicPlayer::MusicPlayer()
: mMusic()
, mFilenames()
, mVolume(100.f)
{
    mFilenames[Music::MenuTheme]     = "Media/Music/MenuTheme.ogg";
    mFilenames[Music::MissionTheme] = "Media/Music/MissionTheme.ogg";
}
```

Loading and playing

SFML uses the `sf::Music` class to deal with music themes. As already mentioned in *Chapter 2*, *Keeping Track of Your Textures – Resource Management*, this class behaves differently from other resource classes. Since music themes are usually long and may

`sf::Music`

streams them from the source media, usually the hard disk. This means that only

theme

progresses. As a result, the source media must be available for as long as the music is played. For files, this means that you should not unplug an external storage device with the music on it. You can also load resources from different sources such as the RAM; in the case of music, *you* are responsible for their constant availability.

In the `MusicPlayer::play()` method, the path of the desired music is looked up in the map. The theme is loaded and possible loading errors are checked. The streaming nature is also the reason why the method of `sf::Music` to open a theme from the hard disk is named `openFromFile()` and not `loadFromFile()`.

```
void MusicPlayer::play(Music::ID theme)
{
    std::string filename = mFilenames[theme];

    if (!mMusic.openFromFile(filename))
        throw std::runtime_error("Music " + filename + " could not be
loaded.");

    mMusic.setVolume(mVolume);
    mMusic.setLoop(true);
    mMusic.play();
}
```

At the end, you can see some new statements. The `setVolume()` method sets the music's volume to a value in the range `[0, 100]`, with `0` being mute and `100` being the maximum volume. The `setLoop()` method specifies whether the theme is played again as soon as its end is reached; background themes are usually looped. The `play()` method eventually starts the music. Since music and sound effects use their

, you

have to keep the `sf::Music` object alive as long as the music is being played.

Music themes can be stopped or paused; for this purpose, `sf::Music` provides the `stop()` and `pause()` methods. If a theme is paused, you can resume it from the time where it was paused. A stopped music, in contrast, is replayed from the beginning. If we call `openFromFile()`, the music will automatically be stopped. The `getStatus()` of the three
enumerators in the `sf::Music` scope: `Playing`, `Paused`, or `Stopped`.

```
void MusicPlayer::stop()
{
    mMusic.stop();
}

void MusicPlayer::setPaused(bool paused)
{
    if (paused)
        mMusic.pause();
    else
        mMusic.play();
}
```

Use case – In-game themes

w going
to invoke the `MusicPlayer` routines in the different states of our game. First, the `Application` class gets a `MusicPlayer` instance and the `State::Context` class gets a new pointer, named `music`, to the music player.

In the menu state's constructor, we play the menu theme:

```
MenuState::MenuState(StateStack& stack, Context context)
: State(stack, context)
, ...
{
    ...
    context.music->play(Music::MenuTheme);
}
```

theme:

```
GameState::GameState(StateStack& stack, Context context)
: State(stack, context)
, ...
{
    ...
    context.music->play(Music::MissionTheme);
}
```

If the application switches to one of these two states, the `MusicPlayer::play()`
ew theme
being played.

ell.
This can be handled in the `PauseState` constructor. We also define the `PauseState` destructor which resumes the music. As soon as the pause state is over, the music shall no longer pause.

```
PauseState::PauseState(StateStack& stack, Context context)
: State(stack, context)
, ...
{
    getContext().music->setPaused(true);
}

PauseState::~PauseState()
{
    getContext().music->setPaused(false);
}
```

operational. There are many ways to extend the current functionality: Playlists
lemented
by continuous adaption of the music volume. Some modern games play different
ave to pay
ass kicks in.

Sound effects

We have many gameplay events that can be represented by sounds: Fired machine guns, launched missiles, explosions, collection of pickups, and so on. Unlike music, sound effects are mostly very short. As a consequence, they can be loaded
files
without wasting too much memory. We are going to use the `sf::SoundBuffer` resource class to store the audio samples for our sound effects.

The following enumeration of sound effects is used in our game. We'll also create a `typedef` for the resource holder of `sf::SoundBuffer`.

```
namespace SoundEffect
{
    enum ID
    {
        AlliedGunfire,
        EnemyGunfire,
        Explosion1,
        Explosion2,
        LaunchMissile,
        CollectPickup,
        Button,
    };
}

typedef ResourceHolder<sf::SoundBuffer, SoundEffect::ID>
SoundBufferHolder;
```

We implement a class for the sound effects, one similar to the `MusicPlayer` class:

```
class SoundPlayer : private sf::NonCopyable
{
    public:
                        SoundPlayer();

        void            play(SoundEffect::ID effect);
        void            play(SoundEffect::ID effect,
                             sf::Vector2f position);

        void            removeStoppedSounds();
        void            setListenerPosition(sf::Vector2f position);
        sf::Vector2f    getListenerPosition() const;

    private:
        SoundBufferHolder       mSoundBuffers;
        std::list<sf::Sound>    mSounds;
};
```

The class contains a resource holder for the sound buffers and a list of currently active sound effects. Since more than one sound effect may be active at the same time, we need a container.

Loading, inserting, and playing

ing the
`SoundBufferHolder::load()` function, in a similar fashion to the textures and fonts we loaded in earlier chapters. The first argument we pass is a `SoundEffect::ID` enumerator, the second is the filename:

```
SoundPlayer::SoundPlayer()
: mSoundBuffers()
, mSounds()
{
    mSoundBuffers.load(SoundEffect::AlliedGunfire,
    "Media/Sound/AlliedGunfire.wav");
    mSoundBuffers.load(SoundEffect::EnemyGunfire,
    "Media/Sound/EnemyGunfire.wav");
    ...
}
```

How do we play a sound? First, we have to look up the correct sound buffer by calling `SoundBufferHolder::get()`. We add a new `sf::Sound` instance that uses the sound and
call `sf::Sound::play()` to play the sound:

```
void SoundPlayer::play(SoundEffect::ID effect)
{
    mSounds.push_back(sf::Sound(mSoundBuffers.get(effect)));
    mSounds.back().play();
}
```

Instead of the `sf::Sound` constructor, you can also use the `setBuffer()` method to initialize the sound buffer.

You might wonder why we took the `std::list` STL container. The problem with `std::vector` is that it may relocate existing sounds as we add new ones, thus invalidating them mid-play. Also, we cannot efficiently remove random elements from a `std::vector` container without changing the element order. It is also important that we first insert the sound and then play it. Otherwise, a copy would be inserted, and the local sound object would stop playing as soon as it left scope.

Removing sounds

As soon as a sound effect has finished playing, there is no point of keeping it in the list any longer. We therefore provide a `removeStoppedSounds()` method which removes all sounds that have stopped. As soon as `sf::Sound` finishes playing, it automatically switches to the `Stopped` state. The method is written in a simple way, thanks to the `std::list::remove_if()` method and lambda expressions:

```
void SoundPlayer::removeStoppedSounds()
{
    mSounds.remove_if([] (const sf::Sound& s)
    {
        return s.getStatus() == sf::Sound::Stopped;
    });
}
```

Use case – GUI sounds

Our `SoundPlayer` object is instantiated as a member of the `Application` class, similar to `MusicPlayer`. It is also added to the `State::Context` structure:

```
class State
{
    public:
        struct Context
        {
            ...
            MusicPlayer*        music;
            SoundPlayer*        sounds;
        };
};
```

t. We'll add a
member `SoundPlayer& mSounds` to the `Button` class. We'll then adapt its constructor to take an entire `Context` object and initialize the reference to the
sound player:

```
Button::Button(State::Context context)
: ...
, mSounds(*context.sounds)
{
    ...
}
```

In the `Button::activate()` method, which is called when a button is clicked, we'll play the corresponding sound:

```
void Button::activate()
{
    ...
    mSounds.play(SoundEffect::Button);
}
```

Several `Button` objects are instantiated in their corresponding state classes. As a short reminder, here is an excerpt of the constructor of such a state class. The context ionally, the
music theme is played in that constructor:

```
MenuState::MenuState(StateStack& stack, Context context)
: State(stack, context)
, ...
{
    auto playButton = std::make_shared<GUI::Button>(context);
    auto settingsButton = std::make_shared<GUI::Button>(context);
    auto exitButton = std::make_shared<GUI::Button>(context);
    ...

    context.music->play(Music::MenuTheme);
}
```

Now you'll hear a sound every time you activate a button.

Sounds in 3D space

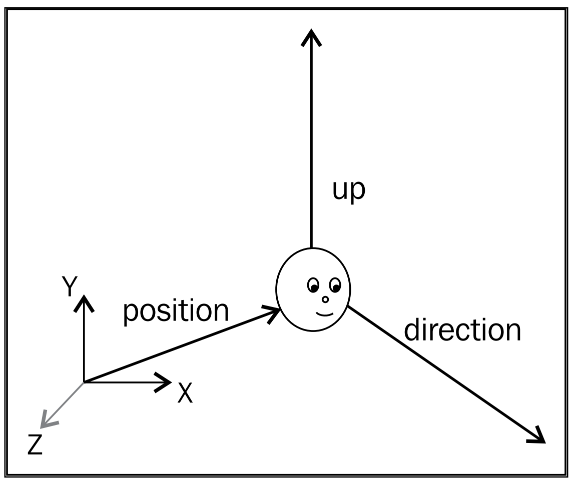
ve
world.
Like graphical objects, sounds can have a position.

The coordinate system for sounds is three-dimensional. SFML's sound API works with the `sf::Vector3f` type, a 3D vector with the members `x`, `y`, and `z`. SFML internally uses **Open Audio Library** (**OpenAL**), an interface for low-level audio epts we are
going to discuss here. **Spatializing** sounds means nothing more than to locate them in the 3D space, that is, to give them a spatial representation.

The listener

analogy is to
tion can be
described with the following three 3D vectors:

- **Position**: This vector describes where the listener is located in 3D space.
- **Up**e up
  vector is hardcoded to `(0, 1, 0)`, thus "up" lies always in the +Y direction.
- **Direction**: This vector expresses where the listener is "looking". It is a relative vector, not a position in space. SFML uses a default direction of `(0, 0, -1)`, meaning that the listener is headed towards the negative Z axis. It must be linearly independent from the up vector, so don't choose a direction with both X and Z axes set to zero. The direction vector need not have a unit length.



The orientation of the listener determines how sounds are perceived. If a sound is played on the right-hand side of the listener, the user will hear it in its right
rentiate
between front and rear sounds.

SFML provides the `sf::Listener` class which has the `setPosition()` and `setDirection()` methods to set the corresponding attributes. The `sf::Listener`
d.

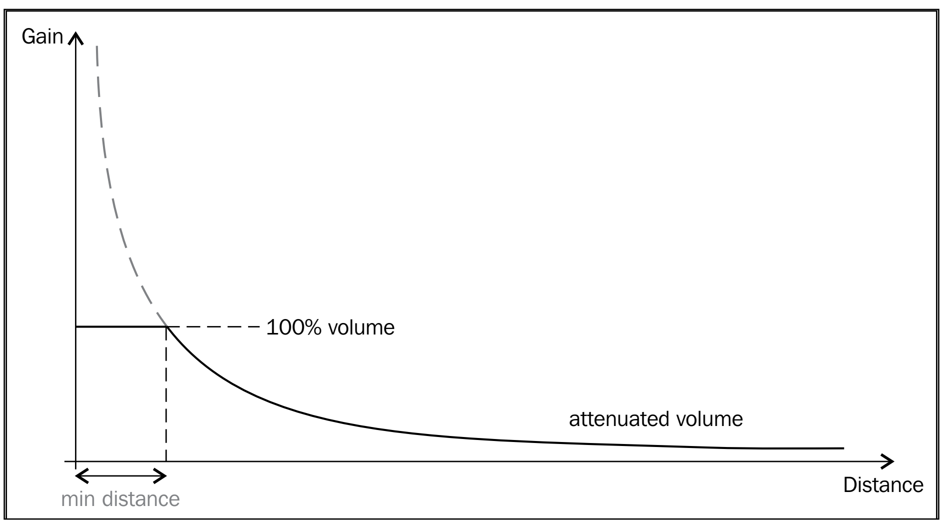
Attenuation factor and minimum distance

Close sounds are perceived louder than distant ones. The sound's volume is inversely proportional to its distance from the listener (we have a *1/distance* relationship, also known as the inverse distance model).

The **attenuation factor** determines how fast a sound is attenuated depending on the n distance or
the closer the sound has to get to be played at a given volume.

The minimum distance is the distance between the listener and the sound at which 100 percent volume is achieved. If the sound comes closer, the volume will not

The following figure should give you a better understanding of the perceived sound volume depending on its distance to the listener. There are two cases: Distances smaller than the minimum distance yield a constant volume of 100%, bigger



Attenuation factor and minimum distance are specific to each sound. SFML provides the `setAttenuation()` and `setMinDistance()` methods in the `sf::Sound` class. For sound spatialization, the `setPosition()` method is required to position a sound in space.

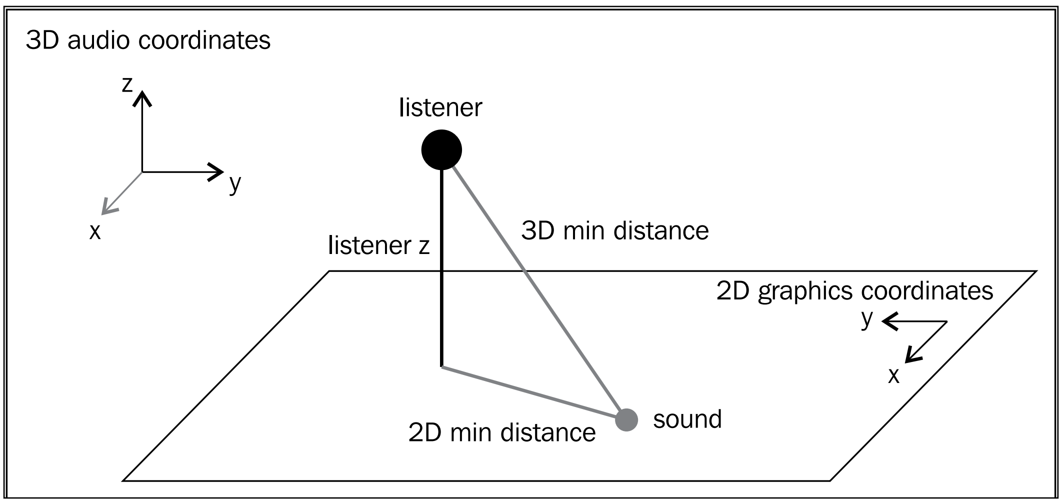
Positioning the listener

Our sounds are located in the plane of the monitor, thus their Z coordinate is always

s Z coordinate to
0, just like the sounds. This is wrong. When you do this, a sound moving from left to right will pass directly through the listener. As a result, you first hear the sound only in the left ear, and only afterwards in the right ear. Even if the sound is very close, you will not hear it in both ears.

n the
it. The
listener's Z coordinate therefore has a value greater than zero.

he
listener's place in the 2D world and the sound. Since the listener itself resides outside
 with the
Pythagorean theorem, as shown in the following figure:



Playing spatial sounds

ound
effects must have a single channel (mono). Stereo sounds are played at full volume, regardless of their position in space.

In SoundPlayer.cpp, we create an anonymous namespace for a few constants
 with
these values!

```
namespace
{
    const float ListenerZ = 300.f;
    const float Attenuation = 8.f;
    const float MinDistance2D = 200.f;
    const float MinDistance3D =
      std::sqrt(MinDistance2D*MinDistance2D + ListenerZ*ListenerZ);
}
```

cs
coordinate system. Both coordinate systems are completely unrelated; how to map one onto another depends on the use case. In the previous figure, you see how the axes of both coordinate systems are aligned.

We implement the remaining functions of the sound player, beginning with the listener's position. The X coordinate is the same in both graphics and audio system.
Y direction,
 take the
constant distance between the listener and the screen plane:

```
void SoundPlayer::setListenerPosition(sf::Vector2f position)
{
    sf::Listener::setPosition(position.x, -position.y, ListenerZ);
}
```

Next, we define the second overload of the play() function, which takes a 2D
gate Y, but
e sound.
Finally, the sound is played:

```
void SoundPlayer::play(SoundEffect::ID effect, sf::Vector2f position)
{
    mSounds.push_back(sf::Sound());
    sf::Sound& sound = mSounds.back();

    sound.setBuffer(mSoundBuffers.get(effect));
    sound.setPosition(position.x, -position.y, 0.f);
    sound.setAttenuation(Attenuation);
    sound.setMinDistance(MinDistance3D);

    sound.play();
}
```

Now, we must make sure that non-spatialized sounds (such as a button click) are
cted, which is
not always what we want. In our first `play()` overload, we make sure the sound
ume. The
`getListenerPosition()` function transforms the 3D listener position back to 2D graphics coordinates:

```
void SoundPlayer::play(SoundEffect::ID effect)
{
    play(effect, getListenerPosition());
}
```

Use case – In-game sound effects

nt to embed
can do
that, we need access to the sound player; we let `GameState` pass a `SoundPlayer` reference to our `World` class.

Inside the world, we would like to have a dedicated scene node for sounds, so that we can use our command system to play sounds. We'll add a `SoundNode` class, which is a simple adapter to the `SoundPlayer` class:

```
class SoundNode : public SceneNode
{
    public:
        explicit        SoundNode(SoundPlayer& player);
        void            playSound(SoundEffect::ID sound,
                                  sf::Vector2f position);

        virtual unsigned int    getCategory() const;

    private:
        SoundPlayer&            mSounds;
};
```

The function definitions are not particularly interesting. The `getCategory()` method returns a new `SoundEffect` category, while `playSound()` forwards its arguments to the `mSounds` sound player. The sound node is inserted into the scene graph in `World::buildScene()`.

Anyway, this allows us to define a `playLocalSound()` method for entities, which sends a command to the sound node. As all of our current sound effects are related to airplanes, we define `playLocalSound()` in the `Aircraft` class; but it would also be possible to have it in the `Entity` or `SceneNode` base classes:

```
void Aircraft::playLocalSound(CommandQueue& commands, SoundEffect::ID
effect)
{
    Command command;
    command.category = Category::SoundEffect;
    command.action = derivedAction<SoundNode>(
    std::bind(&SoundNode::playSound,
              _1, effect, getWorldPosition()));

    commands.push(command);
}
```

The `std::bind()` call might look more confusing than it actually is. It converts the `SoundNode::playSound()` function to a functor, using the following parameters:

- `_1`: This is the first parameter of `Command::action` (namely `SceneNode&`), which is interpreted as the `this` pointer of `SoundNode::playSound()`
- `effect`: This is the sound effect ID
- `getWorldPosition()`: This is the position where the sound is played

Now we've written this method once, so we don't have to fiddle with commands for
launching a missile and firing the machine gun. In the case of the machine gun, we only have to
add two `playLocalSound()` calls:

```
void Aircraft::checkProjectileLaunch(sf::Time dt, CommandQueue&
commands)
{
    ...
    if (mIsFiring && mFireCountdown <= sf::Time::Zero)
    {
        playLocalSound(commands, isAllied() ?
        SoundEffect::AlliedGunfire : SoundEffect::EnemyGunfire);
        ...
    }

    if (mIsLaunchingMissile)
    {
        playLocalSound(commands, SoundEffect::LaunchMissile);
        ...
    }
}
```

y, we
randomly choose one of two possible sound effects. For the pickup collection, which is performed in `World::handleCollisions()`, we proceed in a slightly different manner. Since we are in the `World` class and not a scene node, we invoke `playLocalSound()` on the player's aircraft:

```
else if (matchesCategories(pair, Category::PlayerAircraft,
Category::Pickup))
{
    auto& player = static_cast<Aircraft&>(*pair.first);
    auto& pickup = static_cast<Pickup&>(*pair.second);

    pickup.apply(player);
    pickup.destroy();
    player.playLocalSound(mCommandQueue, SoundEffect::CollectPickup);
}
```

Because we are in the `World` class, we could directly call `SoundPlayer::play()`; however, we still use `SoundNode` for symmetry reasons. If the implementation of `Aircraft::playLocalSound()` or `SoundNode::playSound()` changes, the modifications will still be applied to all spatial sound effects.

unds that
have finished playing. We'll set the listener to the player's aircraft position, so
ction which is
invoked in `World::update()`:

```
void World::updateSounds()
{
    mSounds.setListenerPosition(
        mPlayerAircraft->getWorldPosition());
    mSounds.removeStoppedSounds();
}
```

Summary

in 2D games.
We saw how the concepts are implemented using SFML classes and functions. In
n state.
We also created sound effects for various in-game events, and positioned them in the world in order to enable a spatial audition.

e; a
ve
actual
challenge is the fine-tuning and the combination of suitable sound effects and music themes in order to create a unique atmosphere.

The audio functionality completes the attempt to create a playable game that uses different sources of media. However, so far, only one player can play it. In the next chapter, we are going to improve the situation by adding multiplayer support.

10

Company Atop the Clouds – Co-op Multiplayer

After a long journey through to the book, with lots of lessons learned, we have
th growing
overlooked
as it can be very difficult to learn and implement. It is complicated enough for people
ly network
programmers are very experienced and good at it, so they can do it efficiently and provide a good multiplayer gameplay to the end users.

Obviously, even if we wanted to, we couldn't teach every single thing about
ver, we
, keeping
things as simple as possible. Based on the game we've built so far throughout
ork
gameplay over the Internet.

The following is what this chapter has to teach essentially:

- Network sockets
- Client-server architecture
- Creating a protocol for communication
- Applying the concepts to our game
- Short introduction on latency problems
- Tips and tricks on cheating prevention

Let's now immerse ourselves in this complicated topic with a short introduction.

Playing multiplayer games

We've seen multiplayer games since computer games emerged—decades ago.
es in a
co-operative mode with common goals and other times for a competitive experience. The point is that playing with someone else is usually lots of fun!

's
then, it
was very usual for games to have a local multiplayer mode. This allowed a big trend for split screen and other types of local multiplayer gameplay. **Local Area Network** (**LAN**
fight with
ssed and the
Internet became more powerful, the local multiplayer modes became less and less
day. Either
mode is not extinguished or anything close to that, but the game market seems to mark a tendency for online games.

For the purpose of this book, and to cover the networking field of programming,
ully-
me
developers use a lot these days which allows you to actually have local co-op on top of a networked architecture!

Interacting with sockets

o understand
how computers communicate with each other. This is the technological base that everyone should know before trying to do anything with networking.

without the
need to understand the deeper concepts, with the help of SFML's socket classes.

A **socket**en
two applications. These applications are *virtual*, in the sense, they only matter in the
e you can
use sockets to connect an application to itself, as we do in this chapter. These sockets are the base of all networked programs; therefore, they are extremely important. As sockets are a rather complicated concept, SFML provides classes to manage them.

There are the following two main ways of communicating between multiple machines:

TCP

Transmission Control Protocol (**TCP**) is a network convention for transferring
that is
connected to the Internet and therefore uses the **Internet Protocol** (**IP**), which TCP is
a networked
e peer can
"speak" TCP/IP, communication is possible.

osted in
Linux machines while others will be in Windows. Because they all use TCP/IP, it is not relevant what the operating system is, the website will be transferred to our browser and we will be able to visualize it just the same.

SFML provides two cross-platform classes for using TCP sockets: `sf::TcpSocket` and `sf::TcpListener`, which are exactly what we will use to achieve an online gameplay in this chapter. The `sf::TcpSocket` class initiates TCP connections, while the `sf::TcpListener` class listens on a certain port for an incoming connection.

m. When you
use it, many things are being managed by the OS, which takes some weight out of your back.

> The TCP protocol comes with the following features by default:
>
> - **Packet ordering**: It will ensure packet ordering so you can assume that your data will arrive to the destination in the same order you sent it.
> - **Packet restructuring**: It also provides packet restructuring facilities, completely built in. This means that if a packet is too big, it will be split into smaller ones to make the network transfer possible while still arriving at the destination in a seamless way.
> - **Reliability**: It is another strong aspect of this protocol. It will ensure every that packet gets to the destination, without
>
>   is assumed to have lost its connection. However, before a packet is assumed to be impossible to transfer, it is re-sent many times in an attempt to eventually deliver it successfully.

a
connection or a tunnel is made first. This means that before sending or receiving
n between
them. This is done when one of them enters a listening state on a specific port, using `sf::TcpListener`, and the other uses `sf::TcpSocket` to connect to that port. Once that connection is successfully established, data is free to roam!

> A **network port** is an integer number, normally ranging from 0 to 65535, which defines a "gateway" in your network where data and connections can pass through to your application's sockets. You are
>
> as you do the following:
>
> - Be careful not to pick reserved ports by your operating system.
> - Avoid picking ports that are commonly used by other programs, which will cause a conflict. For example, port 80 is used very often by web servers, remote desktop apps, and others. As a general rule, avoid using ports below 1024.
> - Make sure both the client and the server know the same port so communication can happen.

, this
protocol offers advantages such as, ordered arrival of data and reliable data sending.
The fi
matters because they will get there in the same order! The latter means that the data
ses, even
essential, but unfortunately, it adds an extra overhead to the network performance
, and C,
packet B keeps
getting lost before arriving at the remote peer. This means that A will get to the destination, but B and C won't until B is sent successfully.

That said, we can conclude that this protocol is very adequate for file transfers and
ss hungry for
mes, which
have higher speed requirements.

UDP

User Datagram Protocol (**UDP**) is another often used tool for network programming.
bytes
UDP has a
very different set of rules.

The first important thing about this protocol is to know that it is *connectionless*.
nd send it
somewhere and it either gets there or not, and you are not notified of it.

This may seem strange at first. You may think "Why would I want to send data that may not even get there?" and it is normal to be suspicious about the utility of such a network protocol at first, but you'll understand how powerful it can become if made right.

e is no
ement
a custom protocol on top of UDP that allows sending some data reliably, by sending data continuously until a confirmation of arrival is received, while other data is sent unreliably.

it a
; you have
in UDP, it's
important to keep packets small and efficient.

To use such sockets, SFML provides `sf::UdpSocket`. You just need to create an object of this type, bind to a port with the `sf::UdpSocket::bind()` function, and then either send data through it or check if anything was received using the `sf::UdpSocket::send()` and `sf::UdpSocket::receive()` functions respectively.

ion
and tutorials on `www.sfml-dev.org` should provide what you need in order to understand them in detail.

Socket selectors

Another facility that SFML provides is the `sf::SocketSelector` class. This one is
fe easier if you
choose to use it.

This class will act as an observer for your sockets. It will hold pointers

`sf::SocketSelector::wait()` and it will return when one or more of the sockets receive some data. Once this happens, you handle the data somehow and call the function again. This will ensure you always are notified of packets and handle them in a simple and centralized manner.

You can call `sf::SocketSelector::add()` for any type of socket and listener: `sf::TcpListener`, `sf::TcpSocket`, or `sf::UdpSocket`.

then call
`sf::SocketSelector::wait()`. When it returns, you know one of the sockets
that was
by using `sf::SocketSelector::isReady(socket)` and then act upon it.

Custom protocols

re used
than
those two, but very often build custom protocols on top of them.

the more
focused
on a specifi
sending fix
process of actually transferring that file over a lower-level protocol.

A **custom protocol** is merely a set of rules set in stone of how communication needs
CP or UDP
or even both; but it automatically absorbs all advantages and limitations of the
underlying protocol.

There are many custom protocols that are used widely. For example, HTTP and FTP
are two protocols that are used worldwide and are implemented on top of TCP/
n a web
page in your Internet browser, it was received through the TCP/IP network protocol,
more specifically with the rules of the HTTP protocol.

As if SFML's basic socket support weren't good enough, it also implements
`sf::Http` and `sf::Ftp`, which you can use to communicate with any machine that is
advantage,
for example, to directly transfer files to FTP servers, or to request web pages from
remote hosts using HTTP. We won't cover such classes, as they go out of the scope
of the book, but to bring up your curiosity, you could use `sf::Http` to send some
For example,
it online for
everyone to see!

ion
Creating the structure for multiplayer. It will be our own set of rules that are specific to
t see how it
.

Data transport

kings,
but we only talked about sending and receiving data in an abstract way. We referred
w is it done?

a collection
of raw bytes. Therefore, it must be sent in a way that can be read again by the remote
retty much
anything that is digital.

For this, we pack and unpack our data into a byte array when sending/receiving it! When we use the term **packet**, we refer to a collection of bytes, which contain one or more primitives (integers, floats, and others). This is very efficient from the
primitives;
they all go at once in the same byte array. However, we have a per-packet overhead, namely the packet headers that are required by the lower-level protocols (most notably IP and TCP/UDP).

lesome to
get right when done from scratch.

To add complexity to this task, you can't make assumptions on what byte ordering
an operating
k at it as
he number 3
he number 3

Luckily, SFML has also solved this! You can and should use the `sf::Packet` class to address this issue. It is very simple to work with and it will make your life easier in every way, as opposed to implementing it all from scratch. If properly understanding
d be the
other half into making a good networked application.

The following code shows how to pack some data and send it:

```
sf::Packet packet;
std::string myString = "Hello Sir!";
sf::Int32 myNumber = 20;
sf::Int8 myNumber2 = 3;
packet << myString << myNumber << myNumber2;
mySocket.send(packet);
```

This is as easy as it gets. You should notice the use of the operator `<<`. SFML
ny
items in a single line, all being packed correctly within `sf::Packet`.

k that
same data:

```
sf::Packet packet;
std::string myString;
sf::Int32 myNumber;
sf::Int8 myNumber2;
mySocket.receive(packet);
packet >> myString >> myNumber >> myNumber2;
```

Easy enough, isn't it? Now we know to use sockets, send and receive data; but how do we know what data are we reading? An application will most likely want to act
mes handy to
is for and
what to do with it.

Network architectures

s in the
architecture of the multiplayer mode.

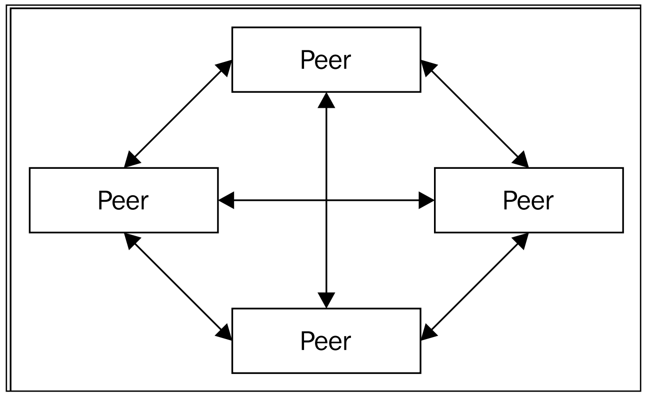
We call the playable game application a *client*, network-wise, and this part of the book concerns how clients communicate with each other and who they communicate with.

There are at least two major approaches to a networked simulation.

Peer-to-peer

This architecture was and still is used in online games; however, it fits a very specific set of purposes and is used less widely than its counterpart client-server architecture.

networking is the topic. What defines this architecture is essentially the fact that
it in the
following figure:



These inter-connections between all the clients, which somehow resemble a spider's
, they
eing each
other's movements, and other actions. When a client means to do something, such as when the jump key is pressed and the character should jump, it notifies every other client of this, so they can see it happen too.

However, while this approach can be efficient, as the network processing is done
tunately can't
be avoided.

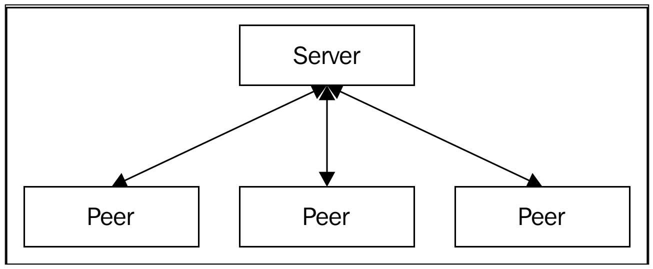
The major problem with the technique is that cheating cannot be prevented. A client
ayers can and
roy the
fun of the game to other players.

llowed
actions? That's where the other network architecture kicks in!

Client-server architecture

dard as far
s will
be particularly useful for nearly all networking tasks you will be doing and not exclusively games.

ontrol
 security.
The following figure shows how computers are laid in such architecture:



ed systems)
r any
circumstances, about other client's address or information. The server acts as a proxy,
ver is
does.

Authoritative servers

In reality, having one server manage all of the clients and be in charge of all their communications easily puts the server application under a heavy processing and networking load. It is hard to develop and maintain efficient and fast servers that can hold many clients at once. However, this cost is easily compensated by the advantages this architecture inherently gives us. The most notable feature is the authority of the server, entirely preventing the cheating and exploiting by the players.

How is this achieved, you may ask? It is easy to explain and a bit harder to get right while developing, but what happens, in essence, is that the server holds the
ated in the
server application is considered valid. This way, each client will only receive valid state information about the server and will always have correct and proper values in the simulation.

lients, and
tion. When
to know if that
 well to do
y modify
its client to do weird things that were not programmed that way initially, that we cannot prevent, but as long as the input that comes from that client is checked, the
client sees is
merely a local version and the server, which is still intact.

This is the basis for all cheat prevention in online servers. It works effectively and is an important area that must never be neglected. For the sake of simplicity, in our implementation, the server is not entirely authoritative, so cheating would be possible.

Creating the structure for multiplayer

You must be fed up with networking theory by now, and you actually want to see some code! Right, it is now time to start the concrete implementation of our game server.

and
created a new state MultiplayerGameState, which is very similar to GameState
at filass
defiate, and
indow, and
ifferent
players and socket connections:

```
class MultiplayerGameState : public State
{
    public:
                        MultiplayerGameState(StateStack& stack,
                            Context context, bool isHost);

        virtual void    draw();
        virtual bool    update(sf::Time dt);
        virtual bool    handleEvent(const sf::Event& event);
                        ...

    private:
        void            updateBroadcastMessage(
                            sf::Time elapsedTime);
        void            handlePacket(sf::Int32 packetType,
                            sf::Packet& packet);

    private:
        typedef std::unique_ptr<Player> PlayerPtr;

    private:
        World                       mWorld;
        sf::RenderWindow&           mWindow;
        TextureHolder&              mTextureHolder;
```

```
        std::map<int, PlayerPtr>    mPlayers;
        std::vector<sf::Int32>      mLocalPlayerIdentifiers;
        sf::TcpSocket               mSocket;
        bool                        mConnected;
        std::unique_ptr<GameServer> mGameServer;
        sf::Clock                   mTickClock;

        std::vector<std::string>    mBroadcasts;
        sf::Text                    mBroadcastText;
        sf::Time                    mBroadcastElapsedTime;
        ...
}
```

`Host`
and `Join`ted
a custom constructor for `MultiplayerGameState`, which takes a parameter clearly stating whether this state will be hosting or just joining. You can see those changes in `StateStack.cpp`. Because both modes are almost equal, it wouldn't even make sense
ost, it will launch
tructor!
By this logic, we can say that `MultiplayerGameState` is the client-side of our application and `GameServer` is the server-side.

Working with the Server

ing the
`GameServer` class to understand properly what is going on.

Server thread

To begin with, we decided to put the server in a separate thread. This is very useful in many ways. For once, server processing can be intensive and could hurt the frame rate on the client. On the other hand, if the server is running on a parallel thread, aside from improving its performance, it also allows it to perform blocking calls whenever necessary, and the game keeps running smoothly. Another plus in this approach is that our server does not communicate programmatically with the client, it communicates only via network; therefore, we don't even need to care about synchronization between the two. It is just like as if server is running on a different application!

As we have already introduced `sf::Thread` before in *Chapter 5*, *Diverting the Game Flow – State Stack*, we will skip that topic here. It is important to notice that `GameServer::executionThread()` is the thread function and that it starts running when `GameServer` gets constructed, and is stopped before it gets destructed.

Now, inside `GameServer::executionThread()` is where all the magic happens. First rule is that while `executionThread()` doesn't return a value, the parallel thread alization, the
server loop, and termination. Take a look at this pseudo-code:

```
void GameServer::executionThread()
{
      initialize();
      while(!timeToStop) loop();
      shutdown();
}
```

Not unlike the client-side of the game, we must do the appropriate things in the starts, we are
going to tell the `sf::TcpListener` socket to start accepting new connections. This is ing variables
 that much to
initialize at this point as the world is still empty without any ally or enemy aircraft, and the basic variables are initialized by the constructor.

he `while`
commended,
or by setting the `timeToStop` Boolean variable to `true`, effectively ending the `while` loop at the end of the next step.

Server loop

mers take
 way that is not
unusual to see across programs. The following is the simplified anatomy of each step in the loop:

```
handleIncomingPackets();
handleIncomingConnections();

while (stepTime >= stepInterval)
{
    updateLogic();
    stepTime -= stepInterval;
}
while (tickTime >= tickInterval)
{
    tick();
    tickTime -= tickInterval;
}

sf::sleep(sf::milliseconds(50));
```

The first two functions are going to respectively handle all incoming traffic from the connected peers and accept new connections, if there are any. Then, `updateLogic()` will be very similar to the client's `update()` functions; it will simply perform the
e. The next
function, `tick()`, is very similar to the previous update step, but usually executes fewer times and is used to send a snapshot of the server's state to the clients. In our case, we send updates to the clients 20 times per second. We may call this frequency the **tick rate**.

Just to be clear, the main reason `tick()` and `updateLogic()` functions are not
g time and
a
heavy load on the network with no benefits. Ideally, we want to send as little data
nds.
This way, `updateLogic()` runs a lot faster to always keep the data as refreshed as possible, while `tick()` only performs as few times as necessary to make sure the

Finally, the call to `sf::sleep()` is entirely optional; however, it is not a bad idea to tell the thread to sleep a bit and let the client's thread take the processor for itself for a little while. The bigger time you pass to `sf::sleep()`, the less time will be spent on server's tasks. It will be fine just until the server has too many tasks to perform and too little time to do them.

Before heading to the depths of these functions, let's rest a bit by looking at the data structures we will use, and how they are laid out.

Peers and aircraft

e-player
, but many
e peer in the
efore the server
e game
and which peers they belong to:

```
struct RemotePeer
{
                              RemotePeer();

    sf::TcpSocket             socket;
    sf::Time                  lastPacketTime;
    std::vector<sf::Int32>    aircraftIdentifiers;
    bool                      ready;
    bool                      timedOut;
};
```

The preceding code snippet shows the structure of `RemotePeer`, which is declared inside `GameServer`. The constructor merely initializes the peer's data to an invalid state, which by itself means the peer is instanced, but not yet pointing to an actual
e chapter that
we will use to communicate exclusively with a specific peer. The `lastPacketTime`
that peer.
This is used to deduct disconnections and timeouts by a simple rule: If the peer did not send any data after *n* seconds, kick it out because something is wrong, as there are packets that the client has to compromise to send regularly.

The `aircraftIdentifiers` variable is an interesting one. It holds a list of IDs of all the planes that belong to a specific peer. There is a good reason there is only an integer here: All the aircraft data is centralized in `GameServer`, and is easily referred to in there by using this integer ID, if needed.

The `ready`er
connection. It only becomes `true` after a successful connection and sending the world state to the newly connected socket.

The `timedOut` variable is just a flag that is set in the server logic to tell the `handleDisconnections()` function that this peer needs to be erased.

```
std::size_t                           mAircraftCount;
std::map<sf::Int32, AircraftInfo>     mAircraftInfo;
std::vector<PeerPtr>                  mPeers;
```

The preceding code snippet shows where all the peers are stored, as well as the mentioned aircraft data. `mAircraftCount` will always contain the total of
ied using
`mAircraftInfo`, through the `struct` declared as follows:

```
// Structure to store information about current aircraft state
struct AircraftInfo
{
    sf::Vector2f                position;
    sf::Int32                   hitpoints;
    sf::Int32                   missileAmmo;
    std::map<sf::Int32, bool>   realtimeActions;
};
```

he set of real-time

The size of `mPeers` is always the number of truly connected peers plus one. That
lid once a new
alid one is
created for the same purpose! This way, new peers are always added at the end and can be removed from the middle of `std::vector` without problems, as the "standby" peer is always guaranteed to be at the last position of the array. The number of truly connected peers can be queried with `mConnectedPlayers`. There is a chance you are still struggling to understand why this extra peer is kept in the vector. Well, it had to be somewhere since `sf::TcpListener::accept()` requires it, so it was just a
peer to the
vector anyway, so it is reasonable to construct it there in advance.

```
sf::Int32  mAircraftIdentifierCounter;
```

The aircraft identifier counter is an integer that starts at 1 and grows by one
matter
gned
new unique identifiers. Also, we would like to emphasize the difference between `mConnectedPlayers` and `mAircraftCount`. While the former refers to unique
t in the game.

Hot Seat

This makes
our system inherently apt to handle what the gaming community refers to as **Hot Seat**e the
sion.

For this reason, our sample allows this mode at any time. As soon as you press the *Return*aying
school game
t the game.

Accepting new clients

is
our `mListenerSocket`, which is of type `sf::TcpListener`. As long as the `mConnectedPlayers` value is below `mMaxConnectedPlayers`, that connection is
ing for new
connections, effectively rejecting them all.

The `sf::TcpListener::accept()` function is where the connection actually
nd the
server. It takes an already-instanced socket which is initialized in case of success.
Conveniently, we have that extra peer always allocated for this purpose! That's
ollowing is
what we do:

```
if (mListenerSocket.accept(mPeers.last()->socket) ==
    sf::TcpListener::Done)
```

ocking
and non-blocking. The main difference is that the first will hold the program from
onses,
and the latter will never block execution, keeping the fluidity of the program. It
is good to remember that we set our `mListenerSocket` as a non-blocking socket.
re threads.
The calls to `sf::TcpListener::accept()` that are constantly happening, return
server
sockets are set to non-blocking as well for the same reason.

So, what does it mean when `sf::TcpListener::accept()` returns a successful response? It means a new client is trying to join, whether it's the first or the nth, whether it's local or in another country, we treat it the same way. There are a few
e a new
aircraft to it:

```
// order the new client to spawn its own plane (player 1)
mAircraftInfo[mAircraftIdentifierCounter].position =
    sf::Vector2f(mBattleFieldRect.width / 2,
    mBattleFieldRect.top + mBattleFieldRect.height / 2);

sf::Packet packet;
mAircraftInfo[mAircraftIdentifierCounter].hitpoints = 100;
mAircraftInfo[mAircraftIdentifierCounter].missileAmmo = 2;

packet << static_cast<sf::Int32>(Server::SpawnSelf);
packet << mAircraftIdentifierCounter;
packet << mAircraftInfo[mAircraftIdentifierCounter].position.x;
packet << mAircraftInfo[mAircraftIdentifierCounter].position.y;

mPeers[mConnectedPlayers]
->aircraftIdentifiers.push_back(mAircraftIdentifierCounter);

broadcastMessage("New player!");
informWorldState(mPeers[mConnectedPlayers]->socket);
notifyPlayerSpawn(mAircraftIdentifierCounter++);
```

```
mPeers[mConnectedPlayers]->socket.send(packet);
mPeers[mConnectedPlayers]->ready = true;
mPeers[mConnectedPlayers]->lastPacketTime = now(); // prevent initial
timeouts
mAircraftCount++;
mConnectedPlayers++;
```

First, we use our identifier counter to get a new ID for the new aircraft, then, we bind at aircraft to
belong to the newly created peer, using the `aircraftIdentifiers` struct.

Now, there are the following four things that we send to the client:

- The order to spawn itself immediately
- The current state of the world with all the current aircraft
- How big the map is
- How much distance has been travelled already inside the map

are aware of a
new player. Finally, and not as a mandatory step, we use `broadcastMessage()` to send a message to all previously connected peers, informing them of the new player that just joined!

The first thing in the list is actually the last being sent for a reason: When the client spawns the aircraft, it expects the world to be configured already with the current state. This is where TCP sockets come in very useful, as they help us ensure the ordering of the packet arrival, making our game logic more consistent.

To finish, we just increment the proper peer and aircraft counters, that is, `mConnectedPlayers` and `mAircraftCount` respectively, and set the current activity.

After setting `mPeers.last()->ready` to `true`, we are ready to instance the new ailable slots for
peers in the server, otherwise, the `mListenerSocket` socket will go back to a sleeping to life later,
if users leave in the meanwhile.

Handling disconnections

quick
that is the case,
server along
with all its aircraft.

There are two main scenarios for disconnection; the first is when a user explicitly quits the game, intentionally leaving the simulation by sending a specific packet
k, and the
packets are not arriving anymore—the situation that we know as **timeout**.

its `mTimedOut`
flag to `true`, `handlingDisconnections()` is called, and does the following:

```
FOREACH(sf::Int32 identifier, (*itr)->aircraftIdentifiers)
{
    sendToAll(sf::Packet() << static_cast<sf::Int32>
   (Server::PlayerDisconnect) << identifier);
    mAircraftInfo.erase(identifier);
}

mConnectedPlayers--;
mAircraftCount -= (*itr)->aircraftIdentifiers.size();

itr = mPeers.erase(itr);

// Go back to a listening state if needed
if (mConnectedPlayers < mMaxConnectedPlayers)
{
    mPeers.push_back(PeerPtr(new RemotePeer()));
    setListening(true);
}

broadcastMessage("An ally has disconnected.");
```

As you can see, it iterates over every peer, and for those who are flagged to be
Then, the
proper counters are decremented again and `mAircraftInfo` is partially cleared so
effectively
released from the `mPeers` list. Finally, if it's necessary, we resurrect the listener
isconnected"

Incoming packets

omplex. We
em. We
npacking
`sf::Packet`. However, every packet must conform to some rules in order for both
e presence
of each packet.

All packets have a fixed identifier, sized as a `sf::Int32` for coherence. This identifier is what explicitly tells us what the packet contains and what it brings inside:

```
sf::Packet packet;
packet << static_cast<sf::Int32>(identifier);
```

The rest of the packet data depends on what the identifier actually is. All identifiers we defined are under `NetworkProtocol.hpp`. All packets that originate in the server are under the `Server`, and all the packets that come from the client are in the `Client` namespace. The following is a code snippet with those identifiers:

```
namespace Server
{
    enum PacketType
    {
        BroadcastMessage,
        SpawnSelf,
        ...
    };
}

namespace Client
{
    enum PacketType
    {
        PlayerEvent,
        PlayerRealtimeChange,
        ...
    };
}
```

By making sure that both clients and server use the same "network language" by
o the
specifi
protocol, which we call the network protocol, custom-made to fit our needs! As stated earlier in the chapter, defining such a protocol is, in many ways, similar to how other protocols were defined, such as HTTP and FTP.

Now let's understand how packets are handled in code:

```
bool detectedTimeout = false;

FOREACH(PeerPtr& peer, mPeers)
{
    if (peer->ready)
```

```
        {
            sf::Packet packet;
            while (peer->socket.receive(packet) == sf::Socket::Done)
            {
                // Interpret packet and react to it
                handleIncomingPacket(packet, detectedTimeout, *peer);

                peer->lastPacketTime = now();
                packet.clear();
            }

            if (now() >= peer->lastPacketTime + mClientTimeoutTime)
            {
                peer->timedOut = true;
                detectedTimeout = true;
            }
        }
    }

    if (detectedTimeout)
        handleDisconnections();
```

for each
ing
`sf::TcpSocket::receive()` function.

For each packet received, we call `handleIncomingPacket()` and reset the timestamp
acket, we test
this timestamp against a predefined timeout limit. If no packet was received for at least `mClientTimeoutTime`, then the Boolean `detectedTimeout` flag is set, allowing a call to `handleDisconnections()`, which will remove the peer that timed out, as it was marked for removal by setting `timedOut` to `true` on the peer.

Now, let's take a look at how we handle a packet from the client:

```
sf::Int32 packetType;
packet >> packetType;

switch (packetType)
{
    ...
}
```

As we mentioned, the packet identifier, which clearly states the packet type, depending on whether it was sent by the client or the server, is fixed to be always a `sf::Int32` value, so we begin by unpacking that header. Now, since that number matches directly with the members of the corresponding enumerator, we perform a switch on it. The preceding code snippet does not contain all cases that we handle, so we can better understand the flow of the server logic and later analyze each packet properly.

This is exactly what defines the interaction between peers and the rules of the
e,
when we get a packet from the client of type `Client::PlayerEvent`, we already know from the "specification" that we can find in the packet's data two `sf::Int32` variables: the aircraft identifier and the action identifier that matches directly the one in the `Player.hpp` file. This way, when we read such a packet, we can broadcast it
e same time.

Studying our protocol

ing what
each server packet exactly means.

Every packet in the `Server::PacketType` enum is formed by the bullet's title as its identifier. That assumed, we explain the following packed parameters:

- `BroadcastMessage`: This takes a `std::string` and is used to send a message to all clients, which they would show on the screen for some seconds.
- `SpawnSelf`: This takes a `sf::Int32` value for the aircraft identifier and two flwn its
  player one's aircraft.
- `InitialState`: This takes two float values, the world height and the initial scrolling in it, then a `sf::Int32` value with the count of aircraft in the world; then for each, it takes a `sf::Int32` identifier and two float values with the position of the airplane.
- `PlayerEvent`: This takes two `sf::Int32` variables: the aircraft identifier and the action identifier, as declared in `Player`. This is used to inform all peers that plane X has triggered an action.
- `PlayerRealtimeChange`: This is same as `PlayerEvent`, but for real-time actions. This means that we are changing an ongoing state to either `true` or `false`, so we add a Boolean value to the parameters.
- `PlayerConnect`: This is same as `SpawnSelf`, but indicates that an aircraft from a different client is entering the world.
- `PlayerDisconnect`: This takes one `sf::Int32` value with the aircraft identifier to be destroyed.

- `AcceptCoopPartner`: This is used to tell the client that it is free to spawn another local plane. It takes a `sf::Int32` value and two float values with the identifier of the aircraft to be spawned and its initial position.
- `SpawnEnemy`: This takes one `sf::Int32` value with the type of the aircraft as declared in `Aircraft` class and two float values indicating where the enemy should spawn.
- `SpawnPickup`: Similar to `SpawnEnemy`, but applies for the spawn of a pickup in the world. The first `sf::Int32` value to be packed is declared inside the `Pickup` class.
- `UpdateClientState`: This takes one float value with the current scrolling of the world in the server, and then a `sf::Int32` value with the aircraft count. For each aircraft, it packs one `sf::Int32` value with the identifier and two float values for position.
- `MissionSuccess`: This has no arguments. It is simply used to inform the client that the game is over.

Understanding the ticks and updates

In the pseudo-code, we referred to the `updateLogic()`, now let's take a look at what it actually does:

```
while (stepTime >= stepInterval)
{
    mBattleFieldRect.top += mBattleFieldScrollSpeed *
    stepInterval.asSeconds();
    stepTime -= stepInterval;
}
```

Comments are probably not needed, as fixed time steps were already explained in *Chapter 1, Making a Game Tick*. All that is being actually updated in here is the `mBattleFieldRect` variable, which scrolls upwards into the end of the level—an exact replica of what happens in the client with the world view.

we use

pseudo-code:

```
while (tickTime >= tickInterval)
{
    updateClientState();
    checkMissionEnd();
    spawnEnemies();
    spawnPickups;

    tickTime -= tickInterval;
}
```

The fistate,
which consists of the current scrolling of the world (`mBattleFieldRect.top + mBattleFieldRect.height`) and the positions of all aircraft.

About the aircraft positioning, it is important to notice that the server is not an authority over the movement of aircraft, but rather an agent in their synchronization. When you control your aircraft with the keys, the server will obey and register
al plane
ach client
is responsible for the positions of its own aircraft. The server will however dispatch each client's positions to all others!

Then, `checkMissionEnd()` corresponds to the code that will check if all aircraft are near enough to the end of the level for the `Server::MissionSuccess` packet to be
he menu. This
 the effective
end of the level and a given offset, provided in the `endLevel` constant.

After that, both `spawnEnemies()` and `spawnPickups()` functions will be responsible

locations, by using the `randomInt()` utility function.

Synchronization issues

ear
 way
for all clients. This is intended and accounted for. We sacrificed a bit on the final polish level of the networked simulation, so it could remain simple. We understand
t minds at
first. We could never learn everything about it in one book, let alone in one chapter. Therefore, we went with an approach as simple as possible in this chapter. We would
u can extend
them later into a fully-polished game than to have a way bigger codebase to look and get lost in.

Taking a peek in the other end – the client

We have looked in the server extensively and have hopefully clarified all systems
 a lot of
he other
me into a
fully-networked game.

Let's examine the `MultiplayerGameState` constructor first:

```
sf::IpAddress ip;
if (isHost)
{
    mGameServer.reset(new GameServer());
    ip = "127.0.0.1";
}
else
{
    ip = getAddressFromFile();
}

if (mSocket.connect(ip, ServerPort, sf::seconds(5.f)) ==
    sf::TcpSocket::Done)
    mConnected = true;
else
    mFailedConnectionClock.restart();

mSocket.setBlocking(false);
...
```

We need to deduce which IP to communicate with, in order to successfully join a game. If we are the host, we just connect to the loopback address `127.0.0.1`, otherwise, we need to connect to a pseudo-remote server. This means that in
ser is testing
 another
computer, we actually need a valid IP address. We get it from a file conveniently named `ip.txt`, which is created and saved in the same directory as the executable
ing this file is
the way to go if you want to pick an arbitrary IP to connect to.

The port used is `5000` and it is hardcoded both in the server and the client. If you try the application, make sure you don't have other games or programs conflicting with this port.

> The loopback address we referred previously is simply a widely adopted IPv4 address that points to the local host or the machine itself where it is being used.

After attempting to connect with a timeout of five seconds, we either set the client
r another 5
seconds, in the meantime showing the error message stating that connection was not possible.

Most things in `MultiplayerGameState` are a direct copy of how `GameState` used to work. Though there are some changes and additions we would like to mention. In the `update()` function, besides what was already there, we now check for incoming packets from the server:

```
sf::Packet packet;
if (mSocket.receive(packet) == sf::Socket::Done)
{
    sf::Int32 packetType;
    packet >> packetType;
    handlePacket(packetType, packet);
}
```

The `handlePacket()` function is very alike to the server's `handleIncomingPacket()` function.

messages
from the server on the screen and the text that blinks prompting a second player to join in by pressing the *Return* or *Enter* key:

```
updateBroadcastMessage(dt);

mPlayerInvitationTime += dt;
if (mPlayerInvitationTime > sf::seconds(1.f))
    mPlayerInvitationTime = sf::Time::Zero;
```

Finally, we tick the client in the same way and rate we tick in the server. Instead of sitions of its
local aircraft:

```
if (mTickClock.getElapsedTime() > sf::seconds(1.f / 20.f))
{
    sf::Packet positionUpdatePacket;
    positionUpdatePacket << static_cast<sf::Int32>(
                            Client::PositionUpdate);
    positionUpdatePacket << static_cast<sf::Int32>(
                            mLocalPlayerIdentifiers.size());

    FOREACH(sf::Int32 identifier, mLocalPlayerIdentifiers)
    {
        if (Aircraft* aircraft = mWorld.getAircraft(identifier))
            positionUpdatePacket << identifier
                                 << aircraft->getPosition().x
                                 << aircraft->getPosition().y;
    }

    mSocket.send(positionUpdatePacket);
    mTickClock.restart();
}
```

Client packets

Here's the protocol explanation for the client. The `Client::PacketType` enum contains the following enumerators:

- `PlayerEvent`: This takes two `sf::Int32` variables, an aircraft identifier, and the event to be triggered as defined in the `Player` class. It is used to request the server to trigger an event on the requested aircraft.
- `Quit`: This takes no parameters. It simply informs the server that the game state is closing, so it can remove its aircraft immediately.
- `PlayerRealtimeChange`: This is the same as `PlayerEvent`, but additionally r not.
- `RequestCoopPartner`: This takes no parameters. It is sent when the user presses the *Return* key to request the server a local partner. Its counterpart `AcceptCoopPartner` will contain all information to actually do the spawn of the friendly unit.
- `PositionUpdate`: This is what we saw in the client's tick code. It takes a `sf::Int32` variable with the number of local aircraft, and for each aircraft, it packs another `sf::Int32` variable for the identifier and two float values for the position.
- `GameEvent`: This packet informs the server of a specific happening in the client's game logic, such as enemy explosions.

Transmitting game actions via network nodes

Now, we will take a closer look at the `GameEvent` packet, which is sent when certain
es in a
er, a pick-
lows you
to extend it for any game action. First, we have a `GameActions` namespace which
re an action:

```
namespace GameActions
{
    enum Type { EnemyExplode };

    struct Action
    {
                            Action();
                            Action(Type type, sf::Vector2f position);

        Type                type;
        sf::Vector2f        position;
    };
}
```

In *Chapter 9, Cranking Up the Bass – Music and Sound Effects*, you saw that we used a dedicated scene node class named `SoundNode` to build an interface between command-based game events and another game component, in that case, the sound player. Here, we are repeating this approach: We create a `NetworkNode` class that lets objects in the scene directly send events over the network:

```
class NetworkNode : public SceneNode
{
    public:
                         NetworkNode();

        void             notifyGameAction(GameActions::Type type,
                         sf::Vector2f position);
        bool             pollGameAction(GameActions::Info& out);
        ...

    private:
        std::queue<GameActions::Action>    mPendingActions;
};
```

This class holds a queue of game actions that are going to be transmitted. The `notifyGameAction()` method inserts a new game action into the queue, while `pollGameAction()` checks if an action is pending. If so, it pops the action from
rom SFML's
`pollEvent()` function.

Now, how does this look in practice? In the `Aircraft::updateCurrent()` method,
 enemy. In this
case, we issue a command. The `Category::Network` category is the receiver category of `NetworkNode`:

```
Command command;
command.category = Category::Network;
command.action = derivedAction<NetworkNode>(
                 [position] (NetworkNode& node, sf::Time)
{
    node.notifyGameAction(GameActions::EnemyExplode, position);
});
```

The network node itself is placed in the `World` class. A `World::pollGameAction()`
of the game
where we only have access to the world, but not its scene and entities.

One example is the `MultiplayerGameState` class. In its `update()` function, we interpret the game action and build a packet based on it, which is then sent over the network. We fill the packet with the `Client::GameEvent` packet type, the game action type (which in our case is always `GameActions::EnemyExplode`) and the position coordinates.

```
GameActions::Action gameAction;
while (mWorld.pollGameAction(gameAction))
{
    sf::Packet packet;
    packet << static_cast<sf::Int32>(Client::GameEvent);
    packet << static_cast<sf::Int32>(gameAction.type);
    packet << gameAction.position.x;
    packet << gameAction.position.y;

    mSocket.send(packet);
}
```

On the server side, in `GameServer::handleIncomingPacket()`, this packet is
ill
be spawned with a certain probability. This in turn leads to a packet of type `Server::SpawnPickup`, which is distributed to all clients.

The new pause state

For this chapter, the pause state was slightly modified. The same `PauseState` class was now modified to accept an option in its constructor to either allow or deny underlying states from being updated. The "default" behavior didn't change, but if we pass this parameter as `true`, the underlying states keep updating. This was
use the
or go back to
the main menu!

Settings

You may now configure two sets of keys in the Settings screen! This was done by not using an application wide `Player` instance anymore, rather by using a proper `KeyBinding` structure, holding the keys that are later passed to `Player` instances at will.

The new Player class

The `Player`er
mode. Players are not hardcoded anymore in a state context scope, but rather, there is one player for each human-controlled aircraft in the world.

Every player is now identified by the same identifier that classifies one aircraft, so they can be paired up fast. Also, the constructor of `Player` now looks like the following:

```
Player(sf::TcpSocket* socket, sf::Int32 identifier,
       const KeyBinding* binding);
```

We pass on a socket instance or a `nullptr`, defining whether the `Player` class is
d, is valid for
sending data to the server, which we will do next!

The identifi
Finally, we also have `KeyBinding` being passed here. We will be passing it three different things: The defined keys for the player 1, player 2, and `nullptr` in case this
y the server!

As for event and input handling by the `Player` class, it now works a little differently too.

he ones with
otal control
over its planes along with immediate responsiveness and smoothness. At the same
movement.

Latency

Programming and maintaining efficient server software is already a very hard task; however, to add even more complexity to this duty, we must deal with latency too.
tips on how to
deal with these issues.

Roughly, **latency** is the delay a network packet takes to reach its destination. The bigger the latency, the more we get behind in the networked simulation, and in consequence, the gameplay gets worse.

work
heir
very
smooth for some players while completely unplayable for others; it will be a mess.
Unfortunately, it is not in the hands of the programmer to deal with the network's
latency at all. A programmer can at best prepare the software to behave a little better
a very hard
ies need
specialized and experienced network programmers to achieve a good simulation
asonable
limits. Latency becomes a more and more determining factor as the geographical
en different
on the way
data must
s (also called
round-trip time). Therefore, physics significantly limits the way how multiplayer
games can be played across large distances.

Latency versus bandwidth

, while
the latter denotes the capacity of the link. If you imagine a link as a pipe, the latency is related to its length, and thus to the time the water requires to flow through it. Bandwidth however is determined by the cross-section of the pipe; it specifies how much water can flow through it in a certain amount of time.

You cannot make a single bit arrive faster by increasing the bandwidth. What you can do however is to send many bits in parallel, so that a bigger chunk of data still needs less time to be transmitted. The bandwidth determines how much data you can send in a certain amount of time.

View scrolling compensation

at the
different
threads or even different machines, some discrepancies may occur occasionally.
the
synchronized
tion in every
e the view.

The trick is simple. When the view is scrolled, we multiply the scroll offset with a compensation factor:

```
mWorldView.move(0.f, mScrollSpeed * dt.asSeconds() *
                     mScrollSpeedCompensation);
```

nc, and vary
it, so the view scrolls faster or slower depending on how distanced it is from the
e get the
update:

```
    mWorld.setWorldScrollCompensation(currentViewPosition /
    currentWorldPosition);
```

This will keep the view synchronized while never losing smoothness, unless
in
normal circumstances.

Aircraft interpolation

trick for
chronization
so you could
face different algorithms and techniques and hopefully learn from them.

Remember, that each client commands its own planes and just informs the server
ack of where
to its peers so
they can synchronize with the true simulation data.

The planes would move quite accurately anyway with the real-time input information that comes from the server, but still some desynchronization could
aircraft in
after some ticks
the aircraft are completely synchronized:

```
if (aircraft && !isLocalPlane)
{
    sf::Vector2f interpolatedPosition = aircraft->getPosition() +
    (aircraftPosition - aircraft->getPosition()) * 0.1f;
    aircraft->setPosition(interpolatedPosition);
}
```

interpolate
n
(`aircraftPosition`). We have hardcoded an interpolation "amount" of `0.1f`, which
ositions.
This small value avoids having the aircraft "jump" from place to place, except when
ng too much.

Cheating prevention

s this
secure? Is a hacky player able to exploit the game to its benefit somehow?"

like to
explain you how to make every little thing cheat-proof. However, we don't want to give you the fish by bloating the code with lots of validations; but rather, explicitly writing about how you can learn how to fish.

of
il a clever
user starts doing packet-sniffing and sending things that are not really expected by our protocol.

case, and
how would we prevent it by looking at a few examples:

- In the client's tick, we let the client decide where its planes are going to be
  would
  be able to position its aircraft in any location, effectively warping from place to place as much as he wanted. We would fix this by not accepting the new positions in the server without some validations first. We would need to

  ht

  simply logging what happened to a file.
- Another great example of how we could exploit this game is to look at the `PlayerEvent` packet on the client-side. It carries an aircraft identifier and an action to perform. However, as the server doesn't check if the identifier sent
  ple's
  planes shoot bullets and missiles.

it can be
ry to break the
server state for an in-game profit.

rver,
many
afe online
of data
ember, as
long as the server's state is sane and controlled, there is no cheating, as hard as it may be to achieve this.

Summary

In this final chapter, you learned about basic networking concepts. We had a
rporated
h new
a
mechanism to communicate with other players on the same keyboard, the local area
aces,
ly in
another game.

the way and
we can only thank you for reading through our pages patiently. Finally, our aircraft
ains many
ource and
graphical
user interface. We implemented actual gameplay mechanisms, polished the appearance using a variety of visual effects, played sound and music, and eventually
ties to
further improve our game, there are virtually no limits!

e a lot
ideas to
ce of
le would
handle differently. Therefore, don't be afraid of experimenting and trying out your own ideas! Be it code design, art style, or the gameplay itself—be creative, this is the
reading
uck on
your journey!

Index

Symbols

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

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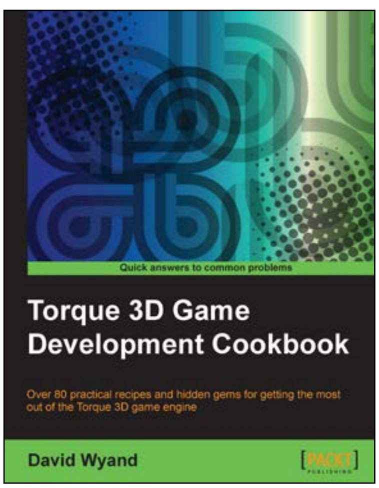

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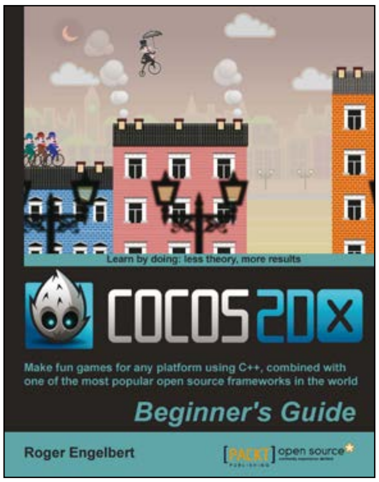

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