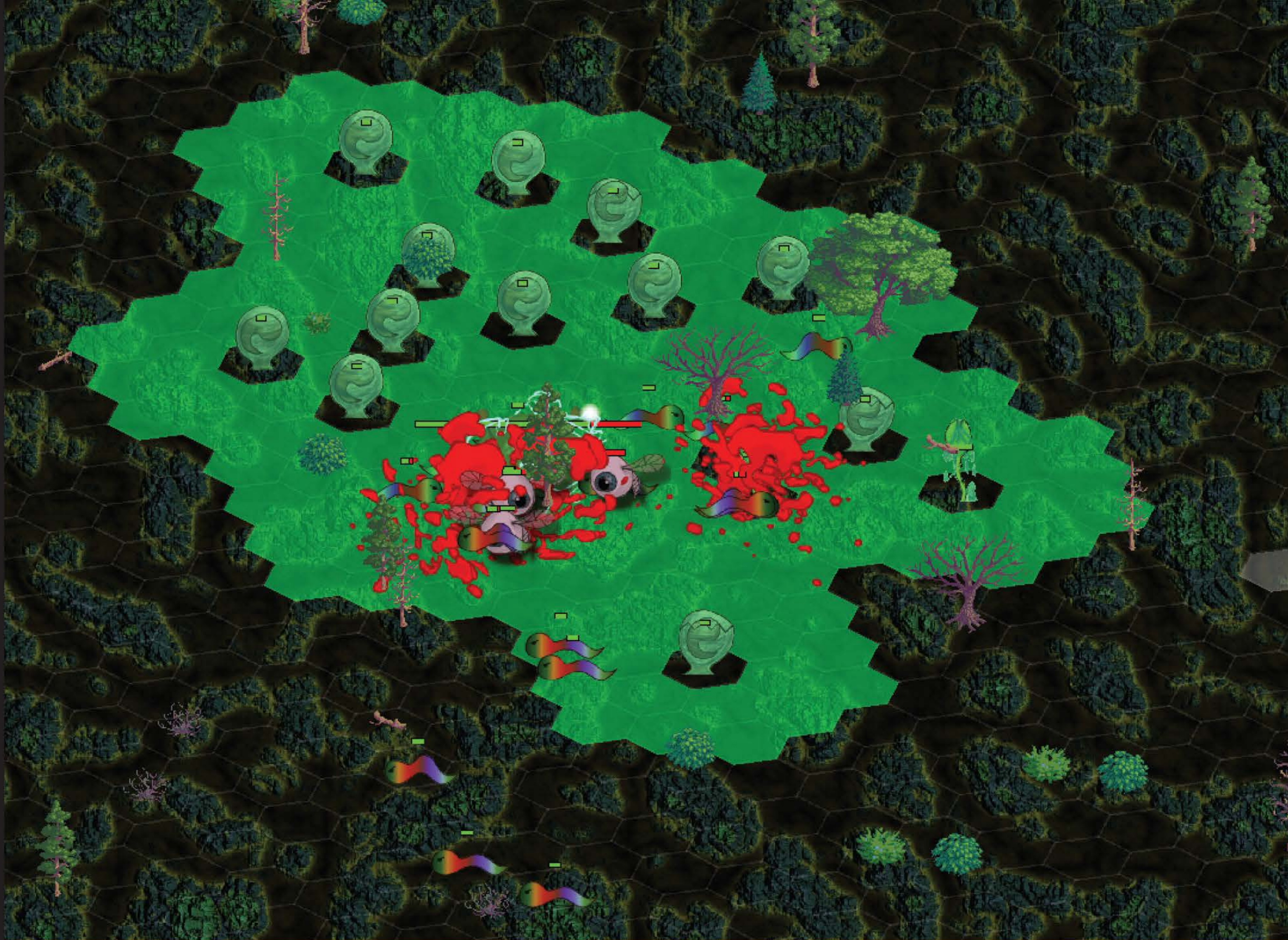

Community Experience Distilled

SFML Blueprints

Sharpen your game development skills and improve your C++ and SFML knowledge with five exciting projects

Maxime Barbier

[PACKT] PUBLISHING open source* community experience distilled

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BIRMINGHAM - MUMBAI

SFML Blueprints

First published: May 2015

Production reference: 1220515

Published by Packt Publishing Ltd.
Livery Place
35 Livery Street
Birmingham B3 2PB, UK.

ISBN 978-1-78439-847-7

www.packtpub.com

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Maxime Barbier has recently finished his studies and is now a software
s been
since
2010. Also, he really likes game programming.

of his work.
them are
used in this book. Game programming is his hobby, and he really likes the challenges involved in such a project. He also loves sharing his knowledge with other people,
activity in
the open source community.

Since 9 years, he has been working on different projects such as Anka Dreles, which is a pen and paper role-playing game, and is putting in effort to convert it into a computer game.

He also loves sailing and was a sailing teacher for several years while studying.
eling
around the world.

such as
SFML Game Development and *Getting Started with OUYA*, both by Packt Publishing.

I would like to thank my girlfriend for her patience and efforts on this book, and in particular, for all the asserts made especially for this book. I would also like to thank my family and friends for supporting me during this process. Finally, I would like to thank the team at Packt Publishing for giving me the opportunity to work on this project.

About the Reviewers

Nolwenn Bauvais is a French student of English literature, civilization, and translation. She took the opportunity to work with Maxime Barbier as a grammar reviewer for this book. She loves reading, and her final goal is to become an hotographer
cts.

> I would like to thank Maxime Barbier for giving me the opportunity to work in my field of study.

Jason Bunn is a game developer from Tennessee and is currently pursuing a masters degree in applied computer science. He has worked in the game duation.

Jason was a developer at On The Level Game Studios, where he helped create a couple of titles using the Unity3D engine. He has since begun tinkering with 2D games using SFML and SDL.

> Special thanks to my wife, Ashleigh, and our wonderful kids for being patient with me as I continue my life-long learning endeavors!

Tom Ivanyo is a game developer and computer science major. He started
 he has
miliar
with many useful APIs and libraries.

ith XNA.
lmost 2 years
before making the change to SFML. Currently, he is working with Doug Madden on
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Vittorio Romeo is a computer science student at the University of Messina
and a C++ enthusiast. Since childhood, he has been interested in computers,
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ee open
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at CppCon 2014.

Richa Sachdeva is an avid programmer. She believes in designing games that are high on educational content as well as entertainment and is contributing two cents towards creating and exploring different dimensions in the field of game programming. She is a physics graduate, who—somewhere along the course—found her true calling in computers and ever since has been amazed by this strange pixelated world. While not thinking about games or which movie to watch, she finds solace in writing.

Michael Shaw, growing up in the small city of Gympie, discovered an interest
, he
attended a Certificate IV course in Interactive Digital Media run by a passionate
in. He
nd the
riety of
2D and 3D game programming and design skills in both C++ and C#. The software
ranged from basic 2D frameworks to using Unity3D to develop major projects. He
ear, he
produced a project of his own design with a team of three other programmers and
two artists.

I would like to thank my fiancée, Natasha, for supporting me through the reviewing of this book.

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dentials for
immediate access.

Table of Contents

Preface

Throughout this book, I'll try to share my knowledge on how to make video games and share them with you. Five different projects will be covered, which include many techniques and ways to resolve quite commons problems involved in game development.

and
the SFML library (version 2.2).

rs and
give you all the keys in hand to build every kind of game you want in 2D, with the only limit of your imagination.

What this book covers

Chapter 1, *Preparing the Environment*, helps you install everything needed for this
g is fine.

Chapter 2, *General Game Architecture, User Inputs, and Resource Management*, explains general game architectures, managing user inputs and finally, how to keep track of external resources.

Chapter 3, *Making an Entire 2D Game*, helps you build Asteroid and Tetris clones, learning entity models and board management.

Chapter 4, *Playing with Physics*, provides a description of physical engines. It also covers the usage of Box2D paired with SFML, and turns our Tetris into a new game, Gravitris.

Chapter 5, *Playing with User Interfaces*, helps you create and use a game user interface. It introductes you to SFGUI and adding them to our Gravitris game.

Chapter 6, Boost Your Code Using Multithreading, introduces multithreading and adapts our game to use it.

Chapter 7, Building a Real-time Tower Defense Game from Scratch – Part 1, helps you
), and an
entity system. Finally, you will create all the game logic.

Chapter 8, Build a Real-time Tower Defense Game from Scratch – Part 2, Networking,
ustom
communication protocol, and modify our game to allow multiplayer matches over the network. Then, we finally add a save/load option to our game using Sqlite3 through an ORM.

What you need for this book

ssumed to
ts of the
s important
't have the
prerequisites, it can get frustrating. So, don't hesitate to read some books or tutorials on C++ before starting with this one.

Who this book is for

This book is for developers who know the basics of the SFML library and its
uired.

Conventions

In this book, you will find a number of styles of text that distinguish between different kinds of information. Here are some examples of these styles, and an explanation of their meaning.

Code words in text, folder names, filenames, file extensions, pathnames, dummy URLs, user input, and Twitter handles are shown as follows: "We also add the point calculation to this class with the `addLines()` function."

A block of code is set as follows:

```
AnimatedSprite::AnimatedSprite(Animation* animation,Status
status,const sf::Time& deltaTime,bool loop,int repeat) :
onFinished(defaultFunc),_delta(deltaTime),_loop(loop),
_repeat(repeat),_status(status)
```

```
{
setAnimation(animation);
}
```

,
the relevant lines or items are set in bold:

```
int main(intargc,char* argv[])
```

Any command-line input or output is written as follows:

```
sudo make install
```

New terms and **important words** are shown in bold. Words that you see on the
is: "We will
also use this class to display the **Game Over** message if it's needed".

> Warnings or important notes appear in a box like this.

> Tips and tricks appear like this.

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ortant for
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g so, you can
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1
Preparing the Environment

games
ill require
knowledge from the previous one.

In this first chapter, we will cover basics points needed for the future such as:

- Installing a compiler for C++11
- Installing CMake
- Installing SFML 2.2
- Building a minimal SFML project

Before getting started, let's talk about each technology and why we will use them.

C++11

The C++ programming language is a very powerful tool and has really great performance, but it is also really complex, even after years of practice. It allows us to program at both a low and high level. It's useful to make some optimizations on our program such as having the ability to directly manipulate memory. Building software utilizing C++ libraries allows us to work at a higher level and when performance is crucial, at a low level. Moreover, the C/C++ compilers are very efficient at optimizing code. The result is that, right now, C++ is the most powerful language in terms of speed, and thanks to the zero cost abstraction, you are not paying for what you don't use, or for the abstraction you are provided.

I'll try to use this language in a modern way, using the object-oriented approach. Sometimes, I'll bypass this approach to use the C way for optimizations. So do not be shocked to see some "old school code". Moreover, all the main compilers now support the standard language released in 2011, so we can use it everywhere without any trouble. This version adds some really useful features in the language that will be used in this book, such as the following:

- Keywords are one such important feature. The following are a few of them:
    - `auto`: This automatically detects the type of the new variable. It is really useful for the instantiation of iterators. The auto keyword already existed in the past, but has been deprecated for a long time, and its meaning has now changed.
    - `nullptr`: This is a new keyword introducing a strong type for the old NULL value. You can always use NULL, but it's preferable to use `nullptr`, which is any pointer type with 0 as the value.
    - `override` and `final`: These two keywords already exist in some languages such as Java. These are simple indications not only for the compiler but also for the programmer, but don't specify what they indicate. Don't hesitate to use them. You can take a look to the documentation of them here `http://en.cppreference.com/w/cpp/language/override` and `http://en.cppreference.com/w/cpp/language/final`.
- The range-based `for` loops is a new kind of loop in the language `foreach`. Moreover, you can use the new `auto` keyword to reduce your code drastically. The following syntax is very simple:

  `for(auto& var : table){...}.`

  In this example, `table` is a container (vector and list) and `var` is a reference to the stored variable. Using `&` allows us to modify the variable contained inside the table and avoids copies.
- C++11 introduces the smart pointers. There are multiple pointers
  he
  is to

  ensure

  en
  use
  of this pointer, more especially `shared_ptr`, will reduce the execution speed of your program, so use them carefully.

- The lambda expression or anonymous function is a new type introduced
  a
  e past,
  functor was used to achieve this kind of comportment. An example
  of functor and lambda is as follows:

  ```
  class Func(){ void operator()(){/* code here */}};
  auto f = [](){/* code here*/};
  ```

- If you already know the use of the variadics function with the ellipse operator (. . .), this notion should trouble you, as the usage of it is different. The variadics template is just the amelioration of template with any number of parameters using the ellipse operator. A good example for this is the tuple class. A tuple contains any number of values of any type known at compile time. Without the variadics template, it was not really possible to build this class, but now it is really easy. By the way, the tuple class was introduced in C++11. There are several other features, such as threads, pair, and so on.

SFML

SFML stands for **Simple and Fast Multimedia Library**. This is a framework written
e describes
to deliver high
ded into
five modules, which are compiled in a separated file:

- **System**: This is the main module, and is required by all others. It provides clocks, threads, and two or three dimensions with all their logics (mathematics operations).
- **Window**: This module allows the application to interact with the user by managing windows and the inputs from the mouse, keyboard, and joystick.
- **Graphics**: This module allows the user to use all the graphical basic elements such as textures, shapes, texts, colors, shaders, and more.
- **Audio**: This module allows the user to use some sound. Thanks to this, we will be able to play some themes, music, and sounds.
- **Network**: This module manages not only socket and type safe transfers but also HTTP and FTP protocols. It's also very useful to communicate between different programs.

Each module used by our programs will need to be linked to them at compile time. We don't need to link them all if it's not necessary. This book will cover each module, but not all the SFML classes. I recommend you take a look at the SFML documentation at `http://www.sfml-dev.org/documentation.php`, as it's very interesting and complete. Every module and class is well described in different sections.

Now that the main technologies have been presented, let's install all that we need to use them.

Installation of a C++11 compiler

As mentioned previously, we will use C++11, so we need a compiler for it.
prefer.

For Linux users

this
tall GCC/G++
nager. Under
ine:

```
sudo apt-get install gcc g++ clang -y
```

For Mac users

ompiler under
Mac OS X.

For Windows users

Mingw-gcc
isual Studio,
nstead use
another IDE such as Code::Blocks (see the following paragraph).

For all users

d configure
your system to use it (by adding it to the system path). If you have not been able to do this, another solution is to install an IDE like Code::Blocks, which has the
C++11,
and doesn't require any system configuration.

I will choose the IDE option with Code::Blocks for the rest of the book, because it does not depend on a specific operating system and everyone will be able to navigate. You can download it at `http://www.codeblocks.org/downloads/26`. The installation is really easy; you just have to follow the wizard.

Installing CMake

ating system
and in a compiler-independent manner. This configuration is really simple. We will
nd to build all the
future projects of this book. Using CMake gives us a cross-platform solution. We will
s 3.0.2.

For Linux users

packet
manager. For example, under Debian, use this command line:

```
sudo apt-get install cmake cmake-gui -y
```

For other operating systems

You can download the CMake binary for your system at `http://www.cmake.org/download/`
be used.

Installing SFML 2.2

d the
prebuilt version, which can be found at `http://sfml-dev.org/download/sfml/2.2/`, but ensure that the version you download is compatible with your compiler.

ferable to
the previous one to avoid any trouble.

Building SFML yourself

Compiling SFML is not as difficult as we might think, and is within the reach of everyone. First of all, we will need to install some dependencies.

Installing dependencies

e that
you have all the dependencies installed along with their development files.
Here is the list of dependencies:

- `pthread`
- `opengl`
- `xlib`
- `xrandr`
- `freetype`
- `glew`
- `jpeg`
- `sndfile`
- `openal`

Linux

ese libraries.
the
command line for Debian:

```
sudo apt-get install libglu1-mesa-dev freeglut3-dev mesa-common-dev
libxrandr-dev libfreetype6-dev libglew-dev libjpeg-dev libsndfile1-dev
libopenal-dev -y
```

Other operating systems

On Windows and Mac OS X, all the needed dependencies are provided directly with SFML, so you don't have to download or install anything. Compilation will work out of the box.

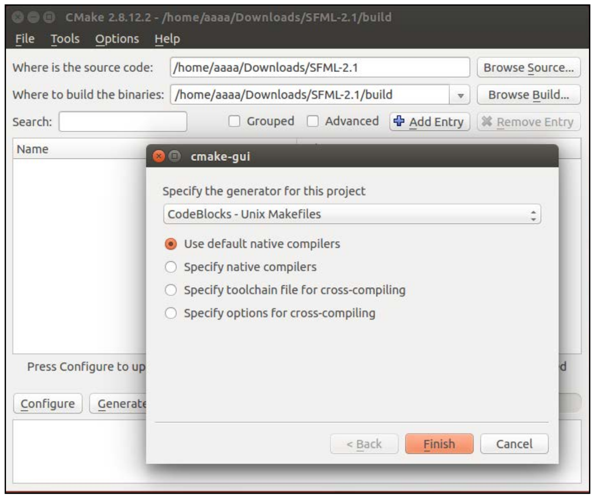
Compilation of SFML

need to use
CMake, by following these steps:

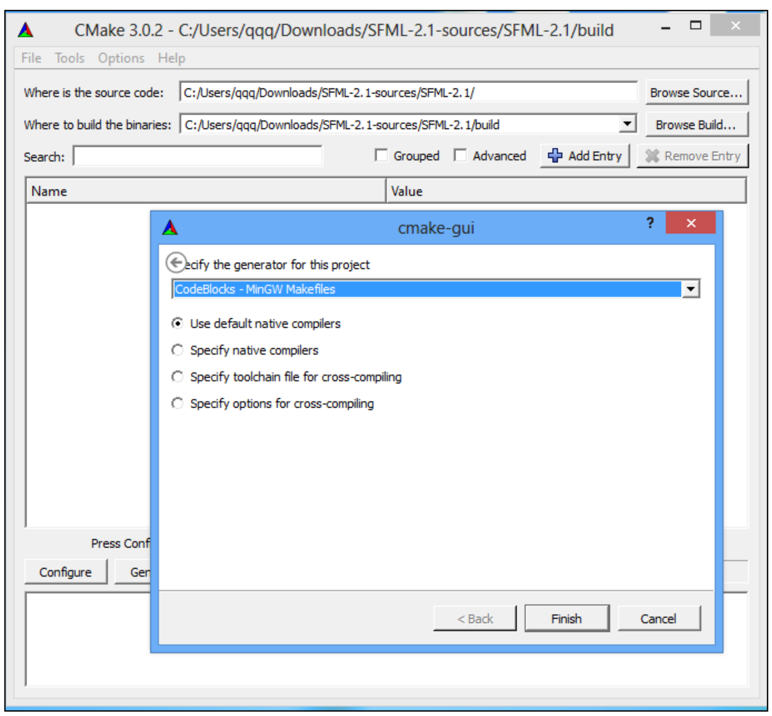
1. Download the source code at `http://sfml-dev.org/download/sfml/2.2/` and extract it.
2. Open CMake and specify the source code directory and the build directory. By convention, the build directory is called `build` and is at the root level of the source directory.

3. Press the **Configure** button, and select **Code::Blocks** with the right option for your system.

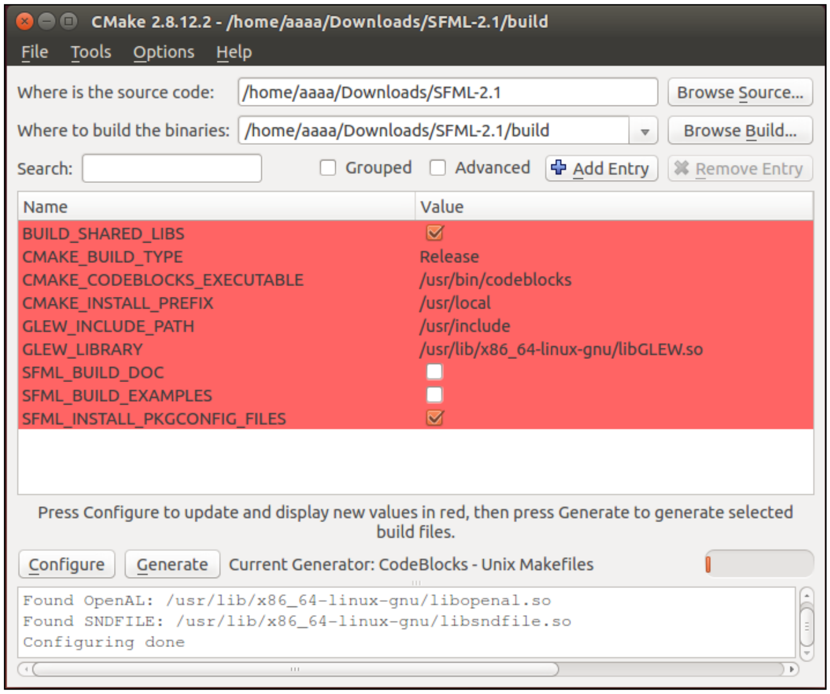
   Under Linux, choose **Unix Makefiles**. It should look like this:



   Under Windows, choose **MinGW Makefiles**. It should look like this:



4. And finally, press the **Generate** button. You'll have an output like this:



Now the Code::Blocks file is built, and can be found in your build directory. Open it with Code::Blocks and click on the **Build** button. All the binary files will be built and put in the `build/lib` directory. At this point, you have several files with an extension that depend on your system. They are as follows:

- `libsfml-system`
- `libsfml-window`
- `libsfml-graphics`
- `libsfml-audio`
- `libsfml-network`

Each file corresponds to a different SFML module that will be needed to run our future games.

Now it's time to configure our system to be able to find them. All that we need to do is add the `build/lib` directory to our system path.

Linux

To compile in Linux, first open a terminal and run the following command:

```
cd /your/path/to/SFML-2.2/build
```

The following command will install the binary files under `/usr/local/lib/` and the headers files in `/usr/local/include/SFML/`:

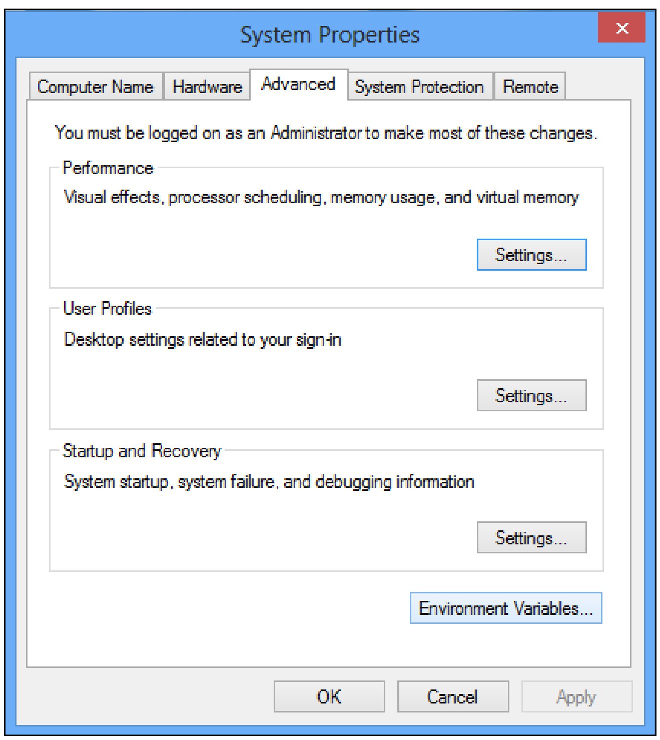
```
sudo make install
```

By default, `/usr/local/` is in your system path, so no more manipulations are required.

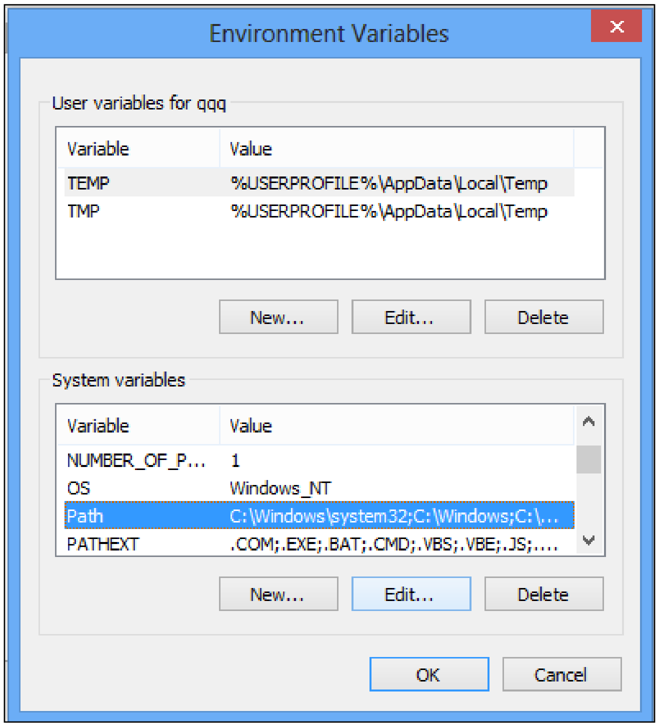
Windows

On Windows, you will need to add to your system path, the `/build/lib/` directory, as follows:

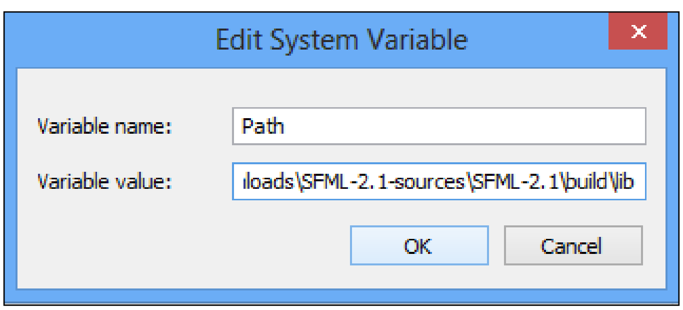
1. Go to the **Advanced** tab in **System Properties**, and click on the **Environment Variables** button:



2. Then, select **Path** in the **System variables** table and click on the **Edit...** button:



3. Now edit the **Variable value** input text, add `;C:\your\path\to\SFML-2.2\build\lib`, and then validate it by clicking on **OK** in all the open windows:

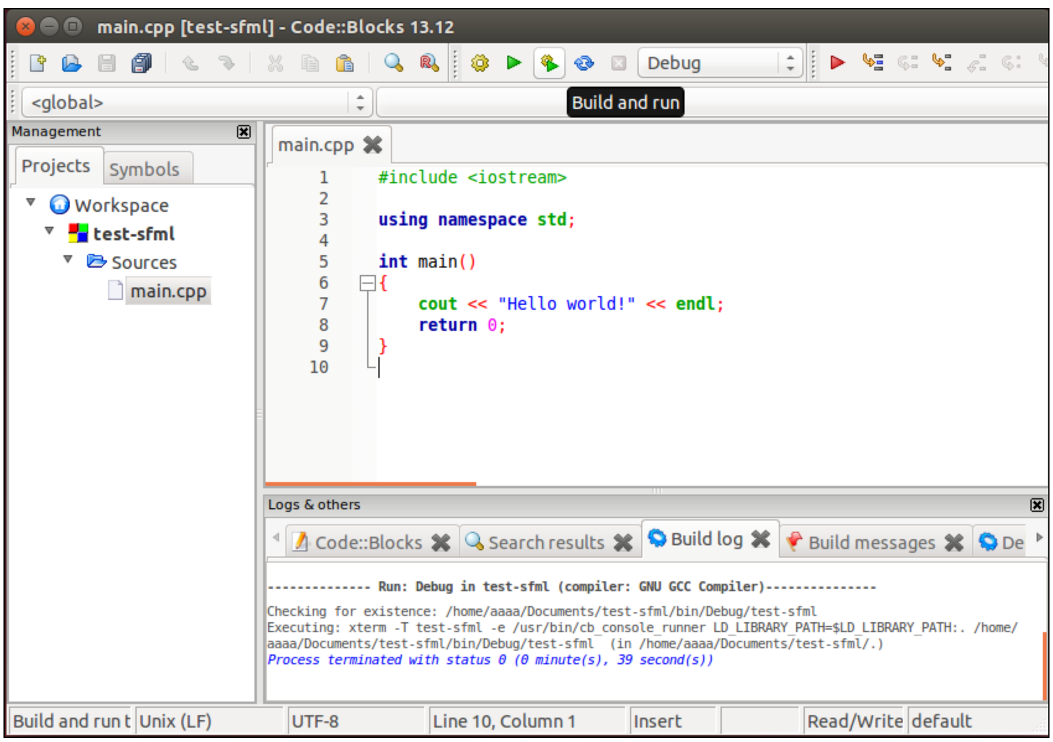


At this point, your system is configured to find the SFML `dll` modules.

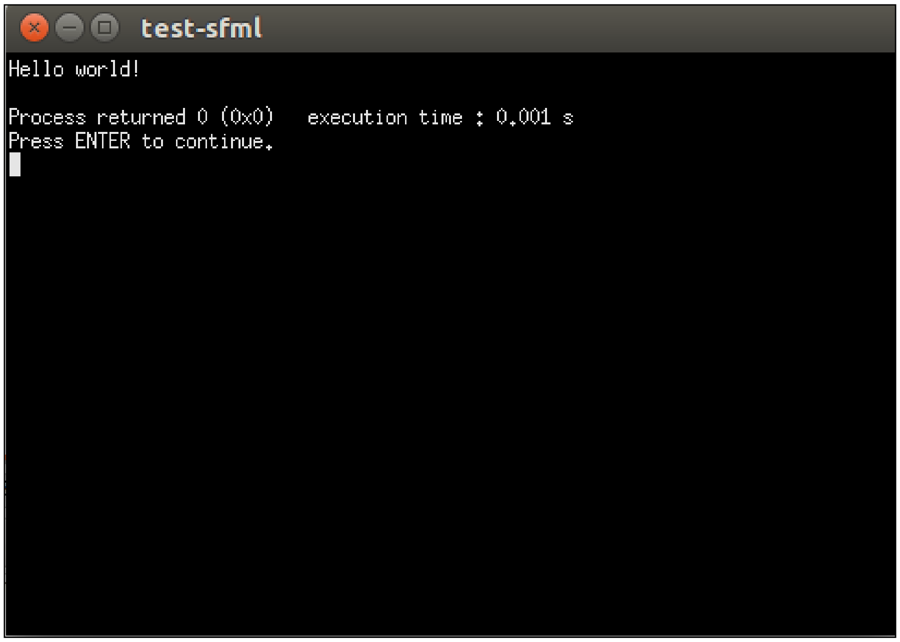
Code::Blocks and SFML

Now that your system is configured to find the SFML binary files, it's time for us to configure Code::Blocks and finally test whether everything is fine with your fresh installation. To do so, follow these steps:

1. Run Code::Blocks, go to **File** | **New** | **Project**, and then choose **Console Application**.
2. Click on **GO**.
3. Choose **C++** as the programming language, and follow the instructions until the project is created. A default `main.cpp` file is now created with a typical `Hello world` program. Try to build and run it to check whether your compiler is correctly detected.



as a `Hello world!` message, as follows:

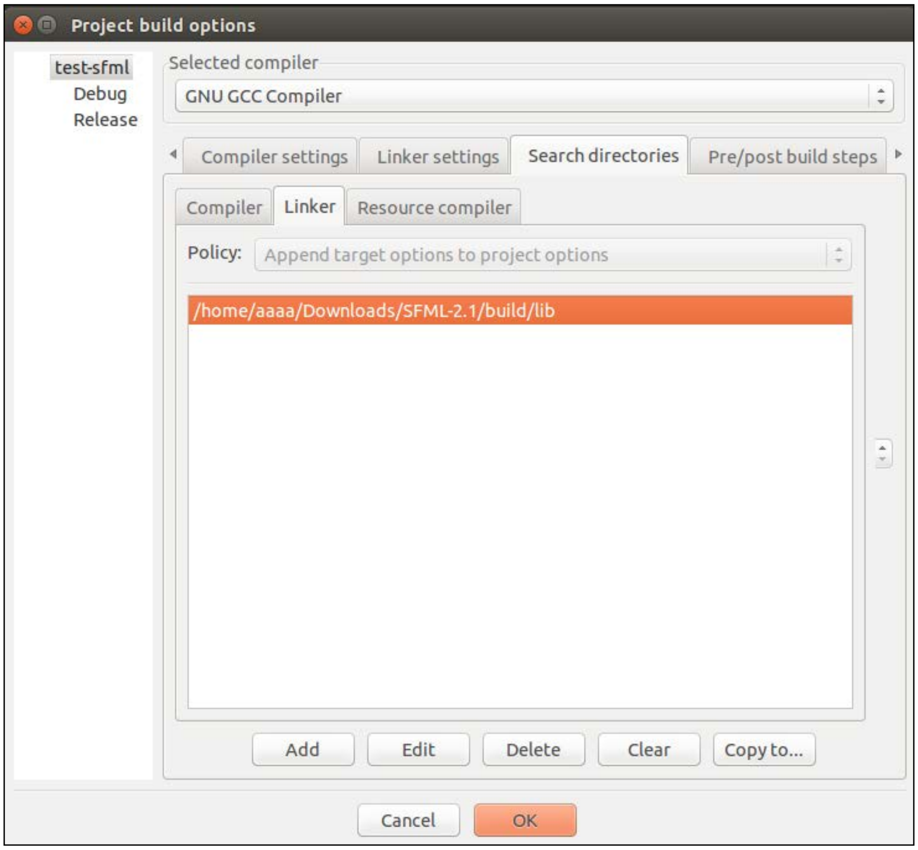


If you have this output, everything is fine. In any other case, make sure you have followed all the steps for the installations.

Now we will configure Code::Blocks to find the SFML library, and ask it to link with wing steps:

1. Go to **Project** | **Build options** and select your project at the root level (not debug or release).
2. Go to **Search directories**. Here we have to add the path where the compiler and the linker can find the SFML.
3. For the compiler, add your SFML folder.

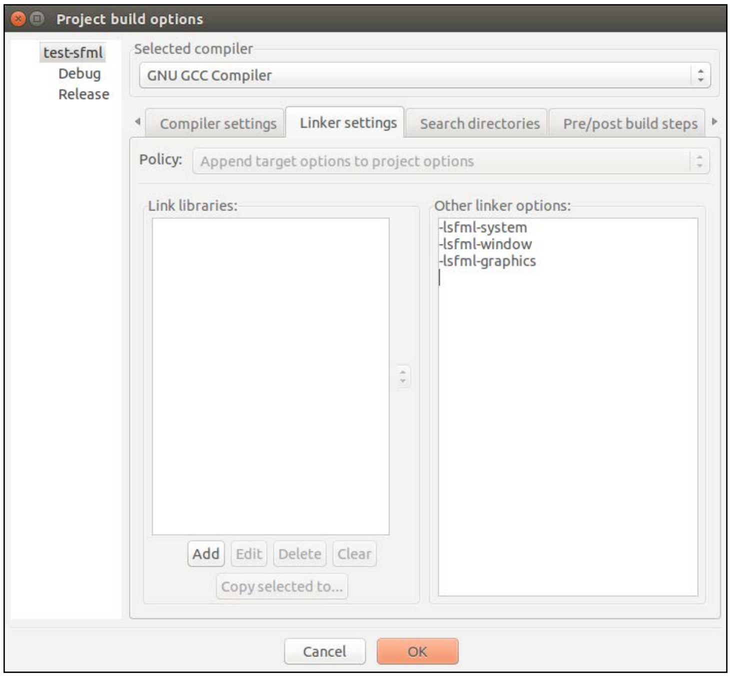
4. For the linker, add the `build/lib` folder, as follows:



Now we need to ask the linker which libraries our project needs. All our future SFML projects will need the System, Window, and Graphics modules, so we will add them:

1. Go to the **Linker settings** tab.
2. Add `-lsfml-system`, `-lsfml-window` and `-lsfml-graphics` in the **Other linker options** column.

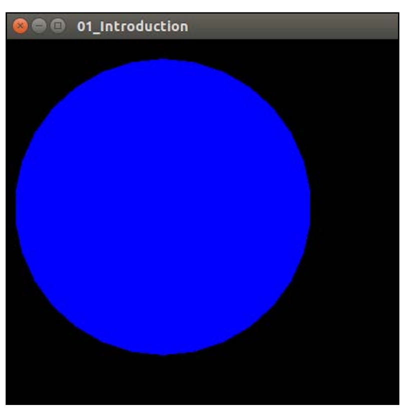
3. Now click on **OK**.



Good news, all the configurations are now finished. We will eventually need to add a library to the linker in the future (audio, network), but that's it.

A minimal example

plication
will show us the window as in the following screenshot:



The following code snippet brings about this window:

```
int main(int argc,char* argv[])
{
    sf::RenderWindow window(sf::VideoMode(400,
400),"01_Introduction");
    window.setFramerateLimit(60);

    //create a circle
    sf::CircleShape circle(150);
    circle.setFillColor(sf::Color::Blue);
    circle.setPosition(10, 20);

    //game loop
    while (window.isOpen())
    {
       //manage the events
        sf::Event event;
        while(window.pollEvent(event))
        {
            if ((event.type == sf::Event::Closed)
                or (event.type == sf::Event::KeyPressed and
event.key.code == sf::Keyboard::Escape))
                window.close(); //close the window
        }
        window.clear(); //clear the windows to black
        window.draw(circle); //draw the circle
        window.display(); //display the result on screen
    }
    return 0;
}
```

ight of
400 pixels and its title is `01_Introduction`. Then a blue circle with a radius of 150
ser events
ed (close the
button or click *Alt* + *F4*), or if the user has pressed the *Esc* button on his keyboard. In both case, we close the window, that will result to the program exit.

Summary

them.
ronments,
ML
projects in this book. Then we installed SFML 2.2, and followed on to build a very basic SFML application.

In the next chapter we will gain knowledge on how to structure a game, manage user inputs, and keep trace of our resources.

2

General Game Architecture, User Inputs, and Resource Management

Now that the boring part is over, let's start working with SFML. In this chapter, we are not yet going to build a complete game, but instead we'll learn some basic skills that are required to build a game. These are as follows:

- Understanding a basic game architecture
- Managing user inputs
- Keeping a track of external resources

do these

General structure of a game

Before starting to build randomly and without any specific planning, we need to
r action-
ter is to
game.
Through this part, we will study:

- The game class
- The frame rate
- The player class
- Event management

The game class

me,
which contains:

- Window creation
- Creation of graphic display
- Handle user inputs
- Deal with the user inputs
- Display game objects on the screen

ct-oriented
practices and define various states in different functions. Moreover, we will encapsulate the methods in a new class named `Game`, and we will minimize the `main` function. This `Game` class will be the starting point for all our future games:

```
class Game
{
    public:
        Game(const Game&) = delete;
        Game& operator=(const Game&) = delete;
        Game();
        void run();

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

        sf::RenderWindow _window;
        sf::CircleShape  _player;
};


int main(int argc,char* argv[])
{
    Game game;
    game.run();

    return 0;
}
```

> `= delete` is a C++11 feature that allows us to explicitly delete a special member function such as constructor, move constructor, copy constructor, copy-assignment operator, move copy-assignment operator, and destructor. It tells to the compiler to not
>
> noncopyable. Another solution would be to extend the class from `sf::NonCopyable`.
>
> `= default` is also possible to explicitly tell the compiler to build the default version of this member function. It could, for example, be used to define a custom constructor and a default constructor.

Now we have the basic `Game` class structured, in which the functions are separated function
because we will be present in the `Game::run()` function. Now, we simply have to call the `Game::run()` function.

We can now move all the codes from the main function into the functions—`processEvents()`, `update()`, or `render()`—depending on what we are trying to achieve:

- `processEvents()`: This will manage all events from the user
- `update()`: This will update the entire game
- `render()`: This will manage all the rendering of the game

ions.

Now, let's have a look at the implementation:

1. The constructor initializes the window and the player:

```
Game::Game() : _window(sf::VideoMode(800, 600),"02_Game_Archi"),
_player(150)
{
        _player.setFillColor(sf::Color::Blue);
        _player.setPosition(10, 20);
}
```

2. The `Game::run()` method hides the main `game` loop:

```
void Game::run()
{
    while (_window.isOpen())
    {
```

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

3. The `Game::processEvents()` method handles user inputs. It simply polls all the events received from the window since the last frame, such as a button in the window title bar or a keyboard key being pressed. In the following code, d's
   Esc key. In response, we close the window:

```
void Game::processEvents() {
  sf::Event event;
  while(_window.pollEvent(event)) {
    if ((event.type == sf::Event::Closed)
    or ((event.type == sf::Event::KeyPressed) and (event.key.code
== sf::Keyboard::Escape))) {
      _window.close();
    }
  }
}
```

4. The `update()` method updates our game logic. For the moment, we don't have any logic, but in the near future we will see how to modify the logic of our game:

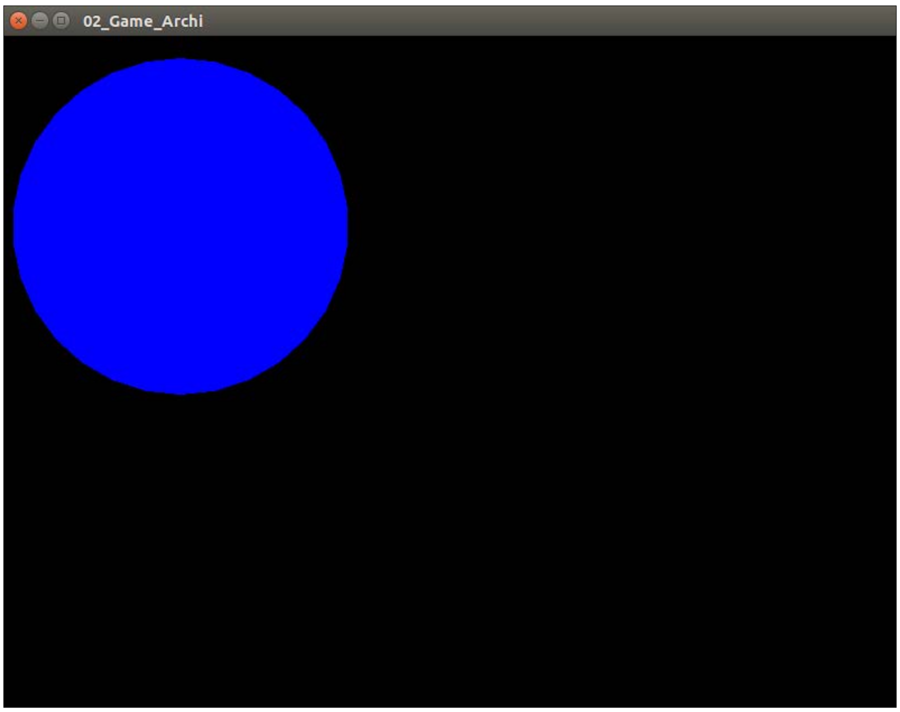
```
void Game::update(){}
```

5. The `Game::render()` method renders the game to the screen. First, we clear the window with a color, usually `sf::Color::Black`, which is the default, then we render our object for the frame, and finally, we display it on the screen:

```
void Game::render() {
  _window.clear();
  _window.draw(_player);
  _window.display();
}
```

> **Downloading the color images of this book**
> We also provide you with a PDF file that has color images of the screenshots/diagrams used in this book. The color images will help you better understand the changes in the output. You can download this file from `https://www.packtpub.com/sites/default/files/downloads/B03963_8477OS_Graphics.pdf`.

There is no change on the final render of the scene, compared to the minimal
there is more
cause the
functions have been reduced to the minimal, and it's easier for you to find what
you want:

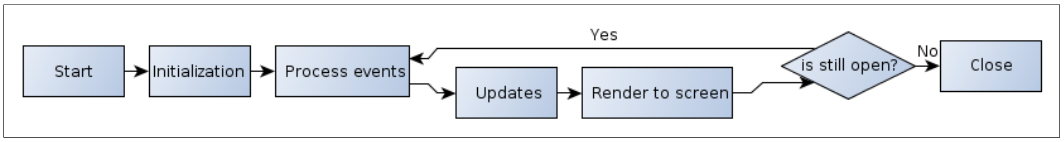


Game loops

Now that the `Game` class has been introduced, let's talk about the loop inside the
`Game::run()` function. This loop is called the `game` loop or `main` loop. It runs
of the loop.
Each iteration of this loop is called a frame. The term **frames per second** (**FPS**) is a
econd. I
will come back to this point later.

ents. Then we
update the games states. Finally, we render the game to the screen.

As you might have noticed, this sounds a lot like the `run` method of the `Game` class. To explain more visually, this loop is a flowchart representing the logic:



t
detail the `Game::processEvents()` method in depth here. For the moment, the game loop has been kept simple, so you can learn the basics first. Later, we will be getting back to each of the methods in the `Game::run()` method, such as the `Game::processEvents()` method, and adding more complexity.

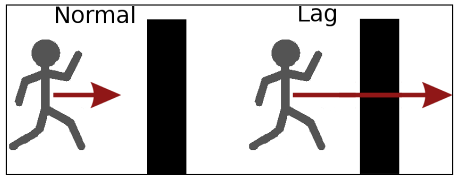
The frame rate

We are now coming back to the frames. As I have already said, a frame is a complete iteration of the `game` loop. The final result is the new `game` states that can be displayed on the screen.

Humans are unable to see unlimited number of images per second. There is some interpolation between each image that we perceive with our brain. The result is that we don't need to display a great amount of images each second. But the more images displayed, the greater will the quality of the final result be. For example, at the cinema, only 24 images are displayed per second.

In video games, most of the time, we try to make a loop as quick as we can. The number of images displayed reaches 30 to 60 per second. Below 30 FPS, there can
o avoid
problems.

One of the most common problems caused by the lag effect is the displacement of
ion. The speed
is often measured in pixels per second. Now imagine your game, for any reason, has
l effect
is that all your entities will teleport themselves. But this is not the main issue. The big issue is with the collisions. Take an example of an entity that was walking in the direction of a wall when the lag happens, the entity will literally cross over the wall. Here is a figure that represents the problem:

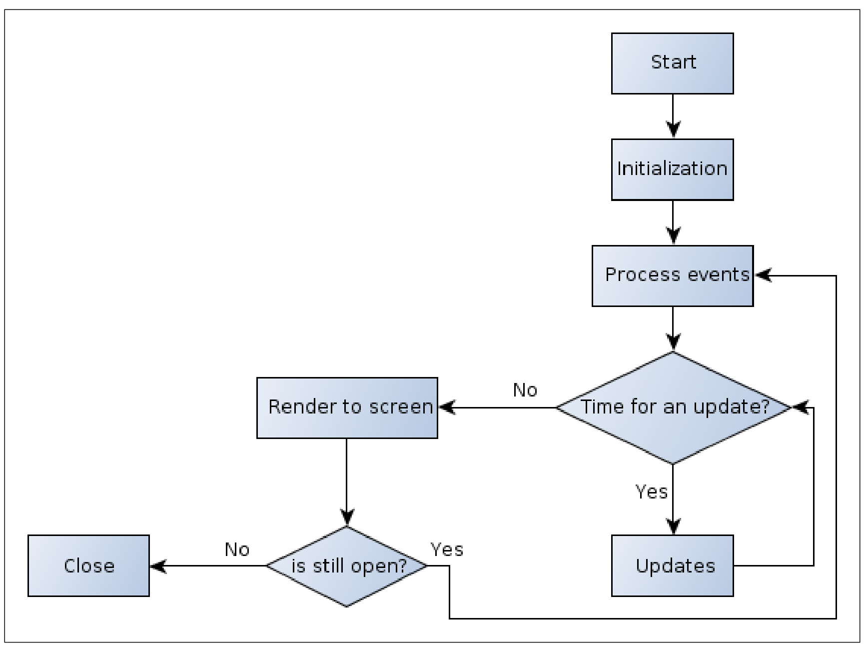


To fix this problem, there are three different approaches. The first is called variable time steps, second is fixed time steps, and third that mix them together.

Fixed time steps

The fixed time steps approach, as its name suggests, is an approach where each call to the `Game::update()` function is made with the same time interval. The units used, for example, for the movement are relative to the frame. Because each frame is separate from the others of the same time, we don't need more complexity. The only thing we need to pay attention to is to choose the basic values to be sure that there are no problems.

Here is the new flowchart of the `game` loop:



Now we will implement the new `Game` class in the following code snippet:

```
void Game::run(int frame_per_seconds)
{
    sf::Clock clock;
    sf::Time timeSinceLastUpdate = sf::Time::Zero;
    sf::Time TimePerFrame = sf::seconds(1.f/frame_per_seconds);

    while (_window.isOpen())
    {
        processEvents();
        bool repaint = false;

        timeSinceLastUpdate += clock.restart();
        while (timeSinceLastUpdate > TimePerFrame)
        {
            timeSinceLastUpdate -= TimePerFrame;
            repaint = true;
            update(TimePerFrame);
        }
        if(repaint)
            render();
    }
}
```

This code ensures that each call to the `Game::update()` function will always take
revious
call of the
`Game::update()` function, and then we only call it again, when the time exceeds the frame rate. The code could be improved by sleeping with `sf::sleep` the remainder of the free time in the loop. It's a bit more difficult (because needs to measure the time spent in the previous update+render), but won't waste CPU time.

A little change has been made on the `Game::update()` function by adding a parameter to it. Its new signature is now:

```
void update(sf::Time deltaTime);
```

`Game::update()`. Currently, there is no great interest in it, but later there will be.

Because the state of the game is changed only when `Game::update()` is called, the call to `Game::render()` is made when at least an update is made.

Variable time steps

The variable time steps approach is different from fixed time steps, as the name suggests. The main idea here is to execute the `game` loop as quickly as we can,
ere have to
se we cannot
the
`Game::update()` function, and multiply it with the base unit.

Our actual implementation of the `game` loop corresponds to the variable time steps
me since the
last loop:

```
void Game::run()
{
    sf::Clock clock;

    while (_window.isOpen())
    {
        processEvents();
        update(clock.restart());
        render();
    }
}
```

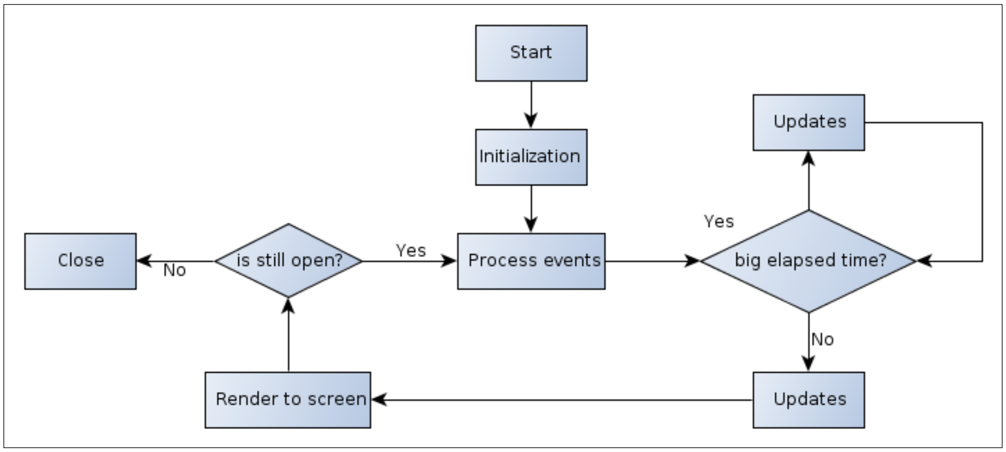
The only thing new here is `sf::Clock` and the parameter to the `Game::update()`
s too slow
(the time between two steps is important).

Minimum time steps

he idea is
to run the game as quickly as possible by ensuring the time parameter passed in the `Game::update()` method is not too high. The consequence is that we ensure to have a minimal frame rate, but no maximal. To sum up, we want two things:

- To allow the game to run as quickly as possible
- If, for any reason, the time between the two loops becomes higher than, let's
  ta time
  pass to the `Game::update()` function is not higher than 30 FPS.

Here is the flowchart representing this solution:



Now we will implement the new `run` function in the following code snippet:

```
void Game::run(int minimum_frame_per_seconds)) {
    sf::Clock clock;
   sf::Time timeSinceLastUpdate;
    sf::Time TimePerFrame = sf::seconds(1.f/minimum_frame_per_
seconds);

   while (_window.isOpen()) {
       processEvents();
      timeSinceLastUpdate = clock.restart();

      while (timeSinceLastUpdate > TimePerFrame) {
           timeSinceLastUpdate -= TimePerFrame;
           update(TimePerFrame);
      }
     update(timeSinceLastUpdate);
     render();
   }
}
```

On each frame, the `Game::update()` and `Game::render()` methods are called, but
nt, the
`Game::update()` method is called with the maximum value allowed, as many times as necessary.

ending on
, we will
use the minimum time steps approach.

l return to
this particular point in *Chapter 4*, *Playing with Physics*. But knowing that it will take
of these
loops can have a frame rate different from each other.

> There are other approaches to manage the frame rate of an application. One of the most common is the `sleep()` function, which interrupts the application during a specified time and gives the processor the opportunity
>
> kinds of applications that need exact timing. SFML provides us with a `sf::RenderWindow::setFramerateLimit()` function that tries to fix the frame rate of the running application by calling `sf::sleep()` internally. This is a good solution, but for testing only.
>
> Another solution is to use the vertical synchronization by calling `void sf::Window::setVerticalSyncEnabled(bool)`. It will limit the
> the
> time 60 Hz, but there is no guarantee). It helps in avoiding some visual
>
> across different computers). V-Sync can occasionally lock too low on some
> f.

Move our player

Now that we have a clean `game` loop, let's move our `Player` object. For now, let's
y that will
not depend on the frame rate. First, let's consider the player.

The player class

`Player`
the type of game. Here our goal is just to be able to move and rotate it. So the information required is as follows:

- Its shape, size, and color
- Its direction
- Its speed

Let's change the `Player` shape to a square using the SFML class `sf::RectangleShape`. The direction and the speed can be merged into a single
tion). SFML
provides a nice class for this: `sf::Vector2f`. We will also need to add speed and rotation and set the position of the player, but we will also update it and finally display it on the screen.

Finally, we obtain this class:

```
class Player : public sf::Drawable {
  public:
    Player(const Player&) = delete;
    Player& operator=(const Player&) = delete;
    Player();

    template<typename ... Args>
    void setPosition(Args&& ... args) {
      _shape.setPosition(std::forward<Args>(args)...);
    }

    void update(sf::Time deltaTime);
    bool isMoving;
    int rotation;

  private:
     virtual void draw(sf::RenderTarget& target, sf::RenderStates
states) const override;
     sf::RectangleShape  _shape;
     sf::Vector2f        _velocity;
}
```

nd it
from `sf::Drawable`. This class simply adds the `draw()` virtual method to the class
 keyword
of C++11: `override`.

> Using override, we are sure that we make an override and not an overload. This is a new keyword from C++11.

Moreover, as in the `Game` class, we make the player non-copyable by explicitly deleting the default implementation of methods.

Now, let's speak about the `Player::setPosition()` method. As you can see, its signature is really strange. Here, I use another C++11 feature: the `variadic` template. As you know, `sf::Transformable` has two versions of the `setPosition()` method. The first one takes two float numbers, and the second takes `sf::Vector2f` as the
ossibility
of C++. I simply forward the arguments to `sf::Transformable::setPosition()` without knowing them. By using this, we can use both of the `sf::Transformable::setPosition()` functions.

First, we declare the parameter type of the function as the following template:

```
template<typename Arg> void setPosition(Arg arg);
```

 the
ellipse operator. The result is as follows:

```
template<typename … Args> void setPosition(Args ... args);
```

Since we don't want to fix the type of parameter (constant, left-reference, or right-
or, in this
 kind of type
by simply adding `&&`. The final signature of the function now is as follows:

```
template<typename … Args> void setPosition(Args&& ... args);
```

Now, to perfectly forward the parameters to `sf::Transformable::setPosition()`,
nd call
`std::forward` on each of them:

```
_shape.setPosition(std::forward<Args>(args)...);
```

That's it! We can now use any of the `sf::Transformable::setPosition()` methods. This approach is really powerful to make some generic code, so try to understand it.

The `Player` class also has two public attributes: `isMoving` and `rotation`. These attributes will simply store the inputs' states.

Now take a look to the implementation of the functions:

```
Player::Player() : _shape(sf::Vector2f(32,32))
 {
     _shape.setFillColor(sf::Color::Blue);
     _shape.setOrigin(16,16);
 }
```

Here, we just change the `_shape` constructor to fit with the `sf::RectangeShape` constructor, and center the origin of the shape to its gravity center:

```
void Player::update(sf::Time deltaTime)
{
    float seconds = deltaTime.asSeconds();
    if(rotation != 0)
    {
        float angle = (rotation>0?1:-1)*180*seconds;
        _shape.rotate(angle);
    }
```

```
        if(isMoving)
        {
            float angle = _shape.getRotation() / 180 * M_PI - M_PI / 2;
            _velocity += sf::Vector2f(std::cos(angle),std::sin(angle)) *
    60.f * seconds;
        }
        _shape.move(seconds * _velocity);
    }
```

Here is the important part. This function updates our player in the following manner:

- First we rotate it if necessary.
- Then, if the player is moving, we simply get the angle of rotation of the shape
  eed
  e
  maximal speed.
- To finish, we just have to move it; this is incredibly easy. We simply need to call the `move` method on `shape` with `velocity` as the parameter.

Because each frame is not executed in the same time, we need to multiply all the
the last call. Here
I choose to use pixels per second as the unit, so we need to multiply the value with the number of seconds since the last call; `sf::Time` provides this ability:

```
    void Player::draw(sf::RenderTarget& target, sf::RenderStates states)
    const
    {
        target.draw(_shape,states);
    }
```

This function is not difficult and should not surprise you.

Now, we need to update the `Game::processEvents()` function to set the values of `isMoving` and `rotation`:

```
    void Game::processEvents()
    {
        sf::Event event;

        while(_window.pollEvent(event))
        {
            if (event.type == sf::Event::Closed)
                _window.close();
```

```
            else if (event.type == sf::Event::KeyPressed)
            {
                if (event.key.code == sf::Keyboard::Escape)
                    _window.close();
                else if(event.key.code == sf::Keyboard::Up)
                    _player.isMoving = true;
                else if (event.key.code == sf::Keyboard::Left)
                    _player.rotation = -1;
                else if (event.key.code == sf::Keyboard::Right)
                    _player.rotation = 1;
            }
            else if (event.type == sf::Event::KeyReleased)
            {
                if(event.key.code == sf::Keyboard::Up)
                    _player.isMoving = false;
                else if (event.key.code == sf::Keyboard::Left)
                    _player.rotation = 0;
                else if (event.key.code == sf::Keyboard::Right)
                    _player.rotation = 0;
            }
        }
    }
```

With this code, we set the value of `isMoving` to `true` when the up arrow key is pressed and to `false` when it is released. The same trick is used to set the rotation depending on the left and right arrows, but here we set the rotation direction, `1` for clockwise, `-1` for counterclockwise, and `0` to none. All the computations have already been made in `Player::update()`.

Managing user inputs

SFML
provides us with two different approaches. The first is by polling the events received from a `sf::Window` instance, and the other is by checking the state in real time of an entry.

First of all, what is an event?

Generally, an event is an object that is triggered when something changes/happens. them
in an OS-independent way. This is the `sf::Event` class. This class deals with a vast number of events, as follows:

- Windows contains four different kinds of events. They are as follows:
    - Close
    - Resize
    - Gain/lose focus
    - The mouse pointer goes in/out of the window
- There are three events for the mouse. They are as follows:
    - Move
    - Key press/release
    - Wheel press, release, or move
- The keyboard contains two events. They are as follows:
    - Keys press/release
    - Text entered
- The joystick is also managed with four events. They are as follows:
    - Connected/disconnected
    - Move
    - Press/release the key
    - Enter text

I suggest you take a look at the SFML documentation for this class at `http://www.sfml-dev.org/tutorials/2.2/window-events.php`. An important thing to have in mind is that `sf::Event` is nothing but a big union, so you have to pay attention to access the right attributes of an event depending on its type.

Polling events

These kinds of events are stored in a queue by a `sf::Window` instance.
To deal with them, we simply need to extract them one by one using the `sf::Window::pollEvent()` method. Its signature is as follows:

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

This signature is a bit interesting. The return value is set to `true` if an event has been extracted from the queue and `false` in other cases. When an event is extracted, the
s, the event
parameter is the event that we get when the function returns `true`. The typical use of this is as follows:

```
sf::Event event;
while(_window.pollEvent(event))
{
    // do something with the event
}
```

t, we use
the event polling to deal with the user inputs.

These event types are used for specific cases (such as closing the window, using the
yer because
 will also
be jerky.

Real-time events

SFML provides us with the possibility to check the state of an entity at any time.
e events, but
we simply check the position of the mouse, and whether a specific button or key is
ell adapted for
the player's actions such as movement, shooting, and so on.

As you have probably noticed, our actual use of event in the `Player` class
ng
the controls keys. To do this, we will add a `processEvents()` method in the `Player` class that will set the value of `isMoving` and `rotation`. We will also change our `Game::processEvents()` function to call the newly created `Player::processEvents()` method. Also, because `isMoving` and `rotation` will be set inside the `Player` class, we will move them as private attributes.

Here is the signature of the new method:

```
void processEvents();
```

As you can see, this is the exact same signature as `Game::processEvents()`. Its implementation is as follows:

```
void Player::processEvents()
{
    isMoving = sf::Keyboard::isKeyPressed(sf::Keyboard::Up);
```

```
        rotation = 0;
        rotation-= sf::Keyboard::isKeyPressed(sf::Keyboard::Left);
        rotation+= sf::Keyboard::isKeyPressed(sf::Keyboard::Right);
    }
```

First, we set the `isMoving` value, depending on the up arrow state. To do this, we use the `sf::Keyboard::isKeyPressed()` function. Because this function is a static one,

```
static bool sf::Keyboard::isKeyPressed(sf::Keyboard::Key);
```

This function returns `true` if the key is pressed, and `false` if not. Really simple, isn't it?

Now, let's talk about the rotation. The rotation depends on two different inputs. So, we need to think "What will happen if the user presses both at the same time?". It to consider it.
Here, I use a really simple solution:

- First, I reset the value of `rotation`
- Then, I add `rotation` depending on the input state for both the keys

By doing this, if no key is pressed, `rotation` stays to its initial value, that is, `0`. If one of the inputs is pressed, then `rotation` takes the value of `1` or `-1`, and if both are pressed, the two inputs will cancel each other out, so everything is fine and we get the result we expected.

Now, let's focus on the `Player::update()` method. This one is not really different. The only line we have to change is the following:

```
float angle = (rotation>0?1:-1)*180*seconds;
```

Because we now set `rotation` inside the `Player` class, we are sure that its value is ve it. The
new line is reduced to the following:

```
float angle = rotation*180*seconds;
```

Now, let's take a look at the updated `Game::processEvents()` method:

```
void Game::processEvents()
{
    sf::Event event;
    while(_window.pollEvent(event))
    {
        if (event.type == sf::Event::Closed)//Close window
            _window.close();
```

```
            else if (event.type == sf::Event::KeyPressed) //keyboard input
            {
                if (event.key.code == sf::Keyboard::Escape)
                    _window.close();
            }
        }
        _player.processEvents();
    }
```

d to the
player. The only thing to do is to call the `Player::processEvents()` method instead of managing the player controls.

Handling user inputs

Now that the events are known better, it could be interesting to be able to bind
llow us
to dynamically add functionalities. In a game, you sometimes have the possibility to upgrade some weapons, or to use new ones; one option is to make sure that the
ayer when he is
ode and increase
the readability of the latter.

To do this, we need a system that allows us to add functionalities to an entity, and that can be triggered by an event. This event can be in real time or generated by polling a `sf::Window` instance.

Using the Action class

We will create a new class containing an `sf::Event` instance that needs to be
al `sf::Event`
instance is executed. The comparison operators are a good way to do this, but it
th, as we
don't pool them. So we will also need `Action::test()` to check if a real-time event is satisfied. We will also need to know whether the event has to be triggered by pressing or releasing the input, or both.

The code for the `Action` class is as follows:

```
class Action
{
    public:
```

```
        enum Type
        {
            RealTime=1,
            Pressed=1<<1,
            Released=1<<2
        };

        Action(const sf::Keyboard::Key& key,int type=Type::RealTime|T
ype::Pressed);
        Action(const sf::Mouse::Button& button,int type=Type::RealTime
|Type::Pressed);

        bool test()const;

        bool operator==(const sf::Event& event)const;
        bool operator==(const Action& other)const;

    private:
        friend class ActionTarget;
        sf::Event _event;
        int _type;
};
```

Let us follow this code step-by-step:

- First, we define enum that will be used as flags in and by the constructors.
- Then, we make the copy constructor and the copy operator.
- Next are the constructors. For the moment, we need to manage inputs from pe
  of event.
- The `test()` function will allow us to test whether the event is satisfied in real time, and the comparison operators will allow us to compare the event with others.

We shall now take a look at the implementation:

```
Action::Action(const Action& other) : _type(other._type)
{
    std::memcpy(&_event,&other._event,sizeof(sf::Event));
}
Action& Action::operator=(const Action& other)
{
    std::memcpy(&_event,&other._event,sizeof(sf::Event));
    _type = other._type;
    return *this;
}
```

These two functions simply copy the content of `Action` to another `Action` instance. Because the `sf::Event` class doesn't implement the copy operator/constructor, we use the `std::memcpy()` function from the C string module. This allows us to copy the entire content of `sf::Event` simply by knowing its size, which can be known using the `sizeof()` operator. Notice that this is technically correct in this case only because `sf::Event` doesn't contain any pointers:

```
Action::Action(const sf::Keyboard::Key& key,int type) : _type(type)
{
    _event.type = sf::Event::EventType::KeyPressed;
    _event.key.code = key;
}
```

Here is the constructor for the keyboard events. The `key` parameter defines the key to bind, and the `type` parameter defines the state of the input: real-time, pressed, released, or a combination of them. Because the `type` value is a flag, it can take the value of `Pressed` and `Released` at the same time; this creates a problem because the type of an event can't be `sf::Event::EventType::KeyPressed` and `sf::Event::EventType::KeyReleased` at the same time. We need to bypass this limitation.

To do this, set the event type to `sf::Event::EventType::KeyPressed` no matter ith later
(in `test()` and comparison operator):

```
Action::Action(const sf::Mouse::Button& button,int type) : _type(type)
{
    _event.type = sf::Event::EventType::MouseButtonPressed;
    _event.mouseButton.button = button;
}
```

s that `event.mouseButton` cannot be copied. So here we need to use `std::memcpy()` again:

```
bool Action::operator==(const sf::Event& event)const
{
    bool res = false;
    switch(event.type)
    {
        case sf::Event::EventType::KeyPressed:
        {
            if(_type & Type::Pressed and _event.type == sf::Event::Eve
ntType::KeyPressed)
                res = event.key.code == _event.key.code;
        }break;
        case sf::Event::EventType::KeyReleased:
        {
```

```
            if(_type & Type::Released and _event.type == sf::Event::Ev
entType::KeyPressed)
                res = event.key.code == _event.key.code;
        }break;
        case sf::Event::EventType::MouseButtonPressed:
        {
            if(_type & Type::Pressed and _event.type == sf::Event::Eve
ntType::MouseButtonPressed)
                res = event.mouseButton.button == _event.mouseButton.
button;
        }break;
        case sf::Event::EventType::MouseButtonReleased:
        {
            if(_type & Type::Released and _event.type == sf::Event::Ev
entType::MouseButtonPressed)
                res = event.mouseButton.button == _event.mouseButton.
button;
        }break;
        default: break;
    }
    return res;
}
```

`Action::operator==()` is an interesting function. This function will test if two events are equivalent. But, because we have previously fixed the value for the keyboard and the mouse to `sf::Event::EventType::[Key/Button]Pressed`, we need to check these special cases. These cases are represented by the `if` statements:

```
bool Action::operator==(const Action& other)const
{
    return _type == other._type and other == _event;
}
```

This function is pretty simple, first we check the type, and then, we forward the comparison to the comparison operator previously defined:

```
bool Action::test()const
{
    bool res = false;
    if(_event.type == sf::Event::EventType::KeyPressed)
    {
        if(_type & Type::Pressed)
            res = sf::Keyboard::isKeyPressed(_event.key.code);
    }
    else if (_event.type == sf::Event::EventType::MouseButtonPressed)
    {
```

```
            if(_type & Type::Pressed)
                res = sf::Mouse::isButtonPressed(_event.mouseButton.
button);
        }
        return res;
    }
```

This function is made for checking real-time events. As I have already mentioned,
atic
functions `sf::Keyboard::isKeyPressed()` and `sf::Mouse::isButtonPressed()`.
and that's it.

Now that the `Action` class was made, let's move on to the next step: binding them to a functionality.

Action target

We will now need a system to bind a functionality to an event. So let's think about what a functionality is.

ion is satisfied.
Here the criterion is an action and thanks to our freshly defined class, we can now know whether the event is satisfied or not. But what about the piece of code? If we think a little bit about it, the functionality can be put in a function or method, so here we are: a functionality is nothing but a function. So to store the code, and be able to bind it at runtime, we will use the generic function wrapper from the C++11: the template class `std::function`.

> `std::function` is a generic wrapper for any type of function, method,
>
> we will use another new class from the C++11, the template class `std::pair`, and a container. Due to our needs, a `std::` list will be perfectly fine.

container
to store as many actions paired with `std::function` as we want:

```
class ActionTarget
{
    public:
        using FuncType = std::function<void(const sf::Event&)>;
```

```
        ActionTarget();

        bool processEvent(const sf::Event& event)const;
        void processEvents()const;

        void bind(const Action& action,const FuncType& callback);
        void unbind(const Action& action);

    private:
        std::list<std::pair<Action,FuncType>> _eventsRealTime;
        std::list<std::pair<Action,FuncType>> _eventsPoll;
};
```

Let's see what happens step by step:

- Firstly, we define the type of the function that will be managed with the new C++11 use of the `using` keyword. This syntax is equivalent to `typedef` except that it is more explicit.
- Secondly, we define a default constructor and the methods to verify the vents
  (polling), and the other is for real-time events.
- Then we add a method to bind an event to a function, and another to remove any existing event.

al-time
events to avoid some `if` statements. The goal is to win some readability and computing power.

Now take a look at the implementation:

```
ActionTarget::ActionTarget()
{
}

bool ActionTarget::processEvent(const sf::Event& event)const
{
    bool res = false;
    for(auto& action : _eventsPoll)
    {
        if(action.first == event)
        {
            action.second(event);
            res = true;
            break;
        }
```

```
    }
    return res;
}

void ActionTarget::processEvents()const
{
    for(auto& action : _eventsRealTime)
    {
        if(action.first.test())
            action.second(action.first._event);
    }
}
```

The two `ActionTarget::processEvent[s]()` methods are not difficult and simply check the validity of the events by using the functions that have been made in the `Action` class. If the event is satisfied, we call the associated function with the `sf::Event` as a parameter.

Here a new `for` loop, syntax is used. It's the `foreach` style of the C++11 `for` loop coupled with the `auto` keyword. This is both a very powerful and succinct syntax:

```
void ActionTarget::bind(const book::Action& action,const FuncType&
callback)
{
    if(action._type & Action::Type::RealTime)
        _eventsRealTime.emplace_back(action,callback);
    else
        _eventsPoll.emplace_back(action,callback)
}
```

This method adds a new event and its callback to the internal container. To avoid some `if` statements in the `processEvent[s]()` methods, I make the choice to separate the real-time event from the others:

```
void ActionTarget::unbind(const book::Action& action)
{
    auto remove_func = [&action](const std::pair<book::Action,FuncTy
pe>& pair) -> bool
    {
        return pair.first == action;
    };

    if(action._type & Action::Type::RealTime)
        _eventsRealTime.remove_if(remove_func);
    else
        _eventsPoll.remove_if(remove_func);
}
```

s the idea of
this function. I use the `std::list::remove_if()` method here to remove all the actions of the internal list that match the parameter. It takes a function such as the
 from the
C++11. Their syntax is a little special, as follows:

```
[captured, variables](parameters) -> returnType { definition };
```

Let's go through the preceding syntax in detail:

- A lambda is like any other function, except it doesn't have a name (also named anonymous functions). Because of this, a lambda doesn't know the

  calling context. These variables have to be specified in the `[]` part. You can prefix them with a `=` or `&` symbol depending on whether you want to access them by copy or by reference.
- Second is the parameters part. Nothing is new in this part. The parameter type is fixed by the `std::list::remove_if()` function to the same type of template parameter of the `std::list` used.
- Then it's the return type. It's not an obligation, because this type can be deduced from the return statement, but here I've made the choice to explicitly write it, as a complete example. The return type is also fixed by the `std::list::remove_if()` method to `bool`.
- And finally, between { and } is the implementation of the lambda. This
  ne
  in the `Action` class.

And here we are. We have our complete new `ActionTarget` class ready to be used. There are some new C++ features used in this part (`using`, `foreach`, `auto`, and `lambdae`
C++11 that can be find on this website : `http://en.cppreference.com/w/cpp/language` on.
So if need be, take as much time as required.

Now that we have built the system to manage the events, let's use it. We will change our player, and extend it from `ActionTarget`. We will need to change the code in the `.hpp` fi, let's use
it, and change the class from:

```
class Player : public sf::Drawable {…};
```

to

```
class Player : public sf::Drawable , public ActionTarget {…};.
```

By doing this, the functionalities of the `ActionTarget` class are added to the `Player` class. Now, we need to update two functions: `Player::Player()` and `Player::processEvents()`. Notice, that this change imply a modification on the `isMoving` and `rotation` attributes that are now private members of the `Player` class.

```
Player::Player() : _shape(sf::Vector2f(32,32))
                   ,_isMoving(false)
                   _rotation(0)
{
    _shape.setFillColor(sf::Color::Blue);
    _shape.setOrigin(16,16);

    bind(Action(sf::Keyboard::Up),[this](const sf::Event&){
         _isMoving = true;
    });

    bind(Action(sf::Keyboard::Left),[this](const sf::Event&){
         _rotation-= 1;
     });

    bind(Action(sf::Keyboard::Right),[this](const sf::Event&){
         _rotation+= 1;
     });
}
```

. As you
ecause this has
already been done in the `ActionTarget::proccessEvents()` method. The callback is called only when the event is satisfied, in this case, when the key is pressed. So we can directly set the value because we know that the key is pressed.

The idea here is to be able to change the inputs without any change in the callbacks. This will be really interesting to build a custom input configuration in the future:

```
void Player::processEvents()
{
    _isMoving = false;
    _rotation = 0;
    ActionTarget::processEvents();
}
```

In this method, we remove all of the codes that check the inputs states, and delegate this to the `ActionTaget::processEvents()` method. The only new thing to do is reset the variable that can be changed by the events.

There is no difference in the final result of our application, but now we have a good starting point to manage our events, and it simplifies our work.

Event map

Now that we have defined a system to check our event, it would be great to change to create a
system where the user can choose which key/button he wants to associate with a specific action. For the moment, we have hardcoded the inputs.

To do this, we will need something that can associate a key with an action. This is what the `std::map` and `std::unordered_map` classes do. Because `std::unordered_map` is quicker than `std::map` at runtime, we prefer to use it. This class comes from the C++ 11.

As previously mentioned, we need to associate a key with an action, so we will create a new class named `ActionMap` that will contain the association map and offer ts key:

```
template<typename T = int>
class ActionMap
{
    public:
        ActionMap(const ActionMap<T>&) = delete;
        ActionMap<T>& operator=(const ActionMap<T>&) = delete;

        ActionMap() = default;

        void map(const T& key,const Action& action);
        const Action& get(const T& key)const;

    private:
        std::unordered_map<T,Action> _map;
};
```

ake
nstructor.
y type. In
esting to have
a string as the key. This is the reason why the template type is `int` by default. Now, let's look at its implementation:

```
template<typename T>
void ActionMap<T>::map(const T& key,const Action& action)
{
    _map.emplace(key,action);
}
```

```
template<typename T>
const Action& ActionMap<T>::get(const T& key)const
{
    return _map.at(key);
}
```

t
we want to do to the internal container. Because `std::unordered_map` throws
need
any test.

> be
> made in the header file. But, in order to not lose readability in the header, there is another way; put the code in a `.tpl` file (`tpl` is the short form for
> we
> e,
> and I recommend you to apply it. The `.inl` file extension is also common (shortcut for inline word) instead of `.tpl`.

ted. This is so
that it will allow us to use multiple `ActionMap` class in our project, for example, one to store the player inputs, and another to store the system inputs. But this approach clashes with our actual `ActionTarget` class, so we need to modify it a little bit.

Back to action target

to modify
our `ActionTarget` class a bit:

- Firstly, the `ActionTaget` class needs to be linked to `ActionMap`. This will allow us to use multiple `ActionMap` in a single project, and this can be very interesting.
- Moreover, because the action is now stored in `ActionMap`, `ActionTarget`
  y to
  get them.
- And finally, because `ActionMap` is a template class, we will need to turn `ActionTaget` into a template class too.

The new header looks like this:

```
template<typename T = int>
class ActionTarget
{
    public:
        ActionTarget(const ActionTarget<T>&) = delete;
        ActionTarget<T>& operator=(const ActionTarget<T>&) = delete;

        using FuncType = std::function<void(const sf::Event&)>;

        ActionTarget(const ActionMap<T>& map);

        bool processEvent(const sf::Event& event)const;
        void processEvents()const;

        void bind(const T& key,const FuncType& callback);
        void unbind(const T& key);

    private:
        std::list<std::pair<T,FuncType>> _eventsRealTime;
        std::list<std::pair<T,FuncType>> _eventsPoll;

        const ActionMap<T>& _actionMap;
};
```

The major change is to turn all the references of the `Action` class to the template type. The action will now be identified by its key. Because we need to access the `Action` instances at runtime, we need to have a way to reach them.

t. The big
object is `ActionMap` and the frontend is `ActionTarget`. So, we internally store a reference to `ActionMap` used to store the events, and because we don't need to modify it, we make it as constant.

All these changes affect our class implementation. Instead of directly accessing an `Action` instance, we need to get it by calling `ActionMap::get()`, but nothing more difficult than this. The really important changes are made in the `Player` class, because now, we have the possibility to change the inputs at runtime, but we also need some default inputs, so we need to add a function to initialize the inputs.

Since a player doesn't have infinite possible control, we can create `enum` that will
e only one
at `ActionMap`
internally used has to be static as well. This `ActionMap` will be added as a static attribute of the `Player` class. This is the new header of the class:

```
class Player : public sf::Drawable , public ActionTarget<int>
{
    public:
        Player(const Player&) = delete;
        Player& operator=(const Player&) = delete;

        Player();

        template<typename ... Args>
        void setPosition(Args&& ... args);

        void processEvents();

        void update(sf::Time deltaTime);

        enum PlayerInputs {Up,Left,Right};
        static void setDefaultsInputs();

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

        sf::RectangleShape  _shape;
        sf::Vector2f        _velocity;

        bool _isMoving;
        int _rotation;

        static ActionMap<int> _playeInputs;
};
```

As you can see, the `Player::PlayerInputs` enum, the `Player::setDefaultsInputs()` function, and the `Player::_playerInputs` attribute have been added. We also change the `ActionMap` type to `ActionMap<int>`, because we will use the newly created `enum` as a key; the default type of `enum` is `int`.
nstructor.
Instead of directly creating an action and binding it, we first initialize `ActionMap` (in `Player::setDefaultsInputs`) and then use the key store in `enum` to refer to the action.

So here is the new constructor:

```
Player::Player() : ActionTarget(_playerInputs)
                   ,_shape(sf::Vector2f(32,32))
                   ,_isMoving(false)
                   ,_rotation(0)
{
    _shape.setFillColor(sf::Color::Blue);
    _shape.setOrigin(16,16);

    bind(PlayerInputs::Up,[this](const sf::Event&){
         _isMoving = true;
    });

    bind(PlayerInputs::Left,[this](const sf::Event&){
         _rotation-= 1;
     });

    bind(PlayerInputs::Right,[this](const sf::Event&){
         _rotation+= 1;
     });
}
```

As you can see, we also need to specify the `_playerInputs` parameter of the `ActionTarget` constructor, and we change all the `Action` constructions to their associated key:

```
void Player::setDefaultsInputs()
{
    _playerInputs.map(PlayerInputs::Up,Action(sf::Keyboard::Up));
    _playerInputs.map(PlayerInputs::Right,Action(sf::Keyboard::Rig
ht));
    _playerInputs.map(PlayerInputs::Left,Action(sf::Keyboard::Left));
}
```

Here we simply initialize the `_playerInputs` with some default keys. These keys are similar to the previous ones, but because `_playerInputs` is a static member of the `Player` class it has to be created somewhere. A good practice is to define it in the `.cpp` file. So the last change in the `Player.cpp` file is this line:

```
ActionMap<int> Player::_playerInputs;
```

This will create the object as expected.

We also need to initialize `ActionMap` by calling `Player::setDefaultsInputs()`. To do this, simply add this call to `main` before the game creation. The main should look like this by now:

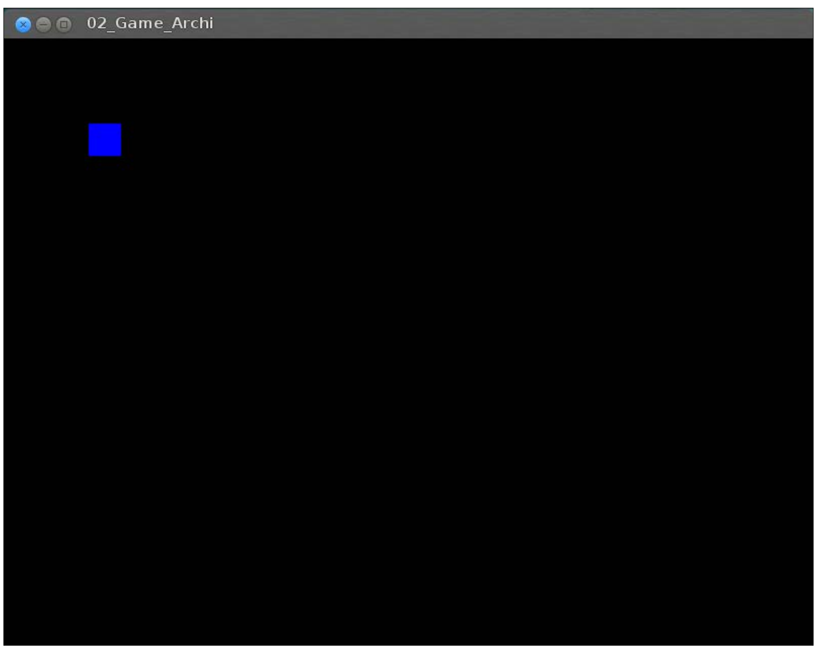
```
int main(int argc,char* argv[])
{
    book::Player::setDefaultsInputs();

    book::Game game;
    game.run();

    return 0;
}
```

The final result doesn't change, but I think that you can understand the power of the and change
the key binding at runtime, this will be really useful in the future.

The result of the actual application should look like this:



You should also be able to rotate the square using the right and left arrows of your keyboard, and make it move by pressing the up arrow. The next step will be to turn this stupid square into a nice spaceship.

Keeping track of resources

In general game development, the term **resource** defines an external component that will be loaded at runtime within the application. Most of the time, a resource is a multimedia file such as music and image, but it can also be a script or a configuration file. Throughout this book, the term resource will mostly refer to a multimedia resource.

The resources require more memory, and one of the consequences of this is that all
 we don't want
to have the same resource loaded multiple times in the memory. To avoid all this,
r. Most of
the time, a resource is loaded from a file to the hard disk, but there are other ways to load them, for example, from the memory or the network.

Resources in SFML

The SFML library deals with a great numbers of different resources:

Graphics module	**Audio module**
Texture	SoundBuffer
Image	Music
Font	
Shader	

All of these resources have some common points. Firstly, we can't use them directly
ass that
mplications
sses share
the same SFML API (Application Programming Interface) with some deviations sometimes. A typical example is loading the resources from the hard disk, which has the following signature:

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

This function takes the complete path (relative or absolute) of the file to load, and returns `true` if the loading is successful and `false` if there is an error. It's very
ost of the
time, an invalid path.

to load the
resource from different kinds of media. The function `bool loadFromMemory(const void *data, std::size_t size);` allows the user to load the resource from a RAM. A typical use of this function is to load the resource from hardcoded data. The other option with the SFML is to load the resource from a custom stream:

```
bool loadFromStream(sf::InputStream& stream);
```

This allows the user to fully define the load process. It can be used to load the data from a compressed or encrypted file, from the network, or from whatever device you want. But for now, we will focus on the file way (`loadFromFile()`) to design our future resources manager. Before starting to create it, take a look at each SFML resource class.

The texture class

The `sf::Texture` class represents an image as a pixel array. Each pixel is an **RGBA** (**red, green, blue, alpha**) value that defines the color at a specific position of the
ry so it does
not use any RAM. Because `sf::Texture` is stored in the video memory, the graphic card can access it quickly for each draw, but `sf::Texture` can't be manipulated (changed) as freely as `sf::Image` can. Every time we want to change it, we will need to reupload it on the video memory using the `sf::Texture::upload()` function.
are several
common image formats sported by the SFML: `.bmp`, `.png`, `.tga`, `.jpg`, `.gif`, `.psd`, `.hdr`, and `.pic`. Notice that the `.png` images can be transparent, and can have an alpha channel to smooth edges again a transparent background.

The frontend class used to display `sf::Texture` is `sf::Sprite`. It's the texture
ortant thing
is that `sf::Texture` must be alive as long as `sf::Sprite` that used it is alive in order to avoid undefined behaviors. This is because `sf::Sprite` doesn't copy the texture data, but instead keeps a reference of it.

The image class

The `sf::Image` class behaves as the `sf::Texture` class but with some important
tead of the
graphic card. The implications are multiple. The first implication is that it's possible
at it's
possible to save the image back to a file placed on the hard drive. The last is that
perform the
following steps:

1. First, convert it to `sf::Texture`
2. Then, create `sf::Sprite` referring to the texture
3. Finally, display this sprite.

to use only a part
file formats
are exactly the same for `sf::Texture` and `sf::Image`.

It's important to limit the use of `sf::Image` only when you really need it, for
s, or to split
it into multiple `sf::Texture` classes. In other cases, it's advisable to directly use `sf::Texture` for performance issues.

The font class

The `sf::Font` class allows us to load and manipulate character fonts. Most of the common types of fonts are supported such as `TrueType`, `Type 1`, `CFF`, `OpenType`, `SFNT`, `X11 PCF`, `Windows FNT`, `BDF`, `PFR`, and `Type 42`. The `sf::Font` class holds the
frontend class
`sf::Text`, like `sf::Sprite` for `sf::Texture`. This class has some properties such as the font size, color, position, rotation, and so on. The `sf::Font` class must remain accessible as long as all of `sf::Text` that refer to it are alive.

> In SFML 2.1, there is no default font for `sf::Text`, so you need at least one font file to display them in your application. The default system font will not be used at all. Moreover, `sf:Text` is actually an object that inherits from `sf::Drawable`, and is physically represented by an OpenGL texture. You have to pay attention to the fact that updating the
> y
> when it's changed.

The shader class

, that is
written in a specific language, GLSL, which is very similar to the C. There are two of them:

- **Fragment shaders**: This modifies the geometry of an object
- **Pixel shaders**: This modifies the pixel's value of the scene

lations
on our scene, such as light. To use them, you only need to specify it on the `RenderTarget.draw(sf::drawable&, sf::shader)` function.

I recommend you read the entire description of `sf::Shader` in the documentation before starting to use them.

The sound buffer class

The `sf::SoundBuffer` class is used to store a sound effect. This class is especially
bits signed
integers. Use it for short audio samples that require no latency and that can fit in the memory, for example, foot steps or gun shots.

Many audio formats are supported, such as `.ogg`, `.wav`, `.flac`, `.aiff`, `.au`, `.raw`, `.paf`, `.svx`, `.nist`, `.voc`, `.ircam`, `.w64`, `.mat4`, `.mat5 pvf`, `.htk`, `.sds`, `.avr`, `.sd2`, `.caf`, `.wve`, `.mpc2k`, and `.rf64`. Notice that the `.mp3` format is not supported because of its restrictive license.

Like `sf::Texture`, `sf::SoundBuffer` holds data, but does not allow us to play it directly. We need to use the `sf::Sound` class to do this. The `sf::Sound` class provides some common functionalities, such as play, stop, and pause but we can also change its volume, pitch, and position. A `sf::Sound` class refers to `ssf::SoundBuffer` that must stay valid as long as `sf::Sound` is played.

The music class

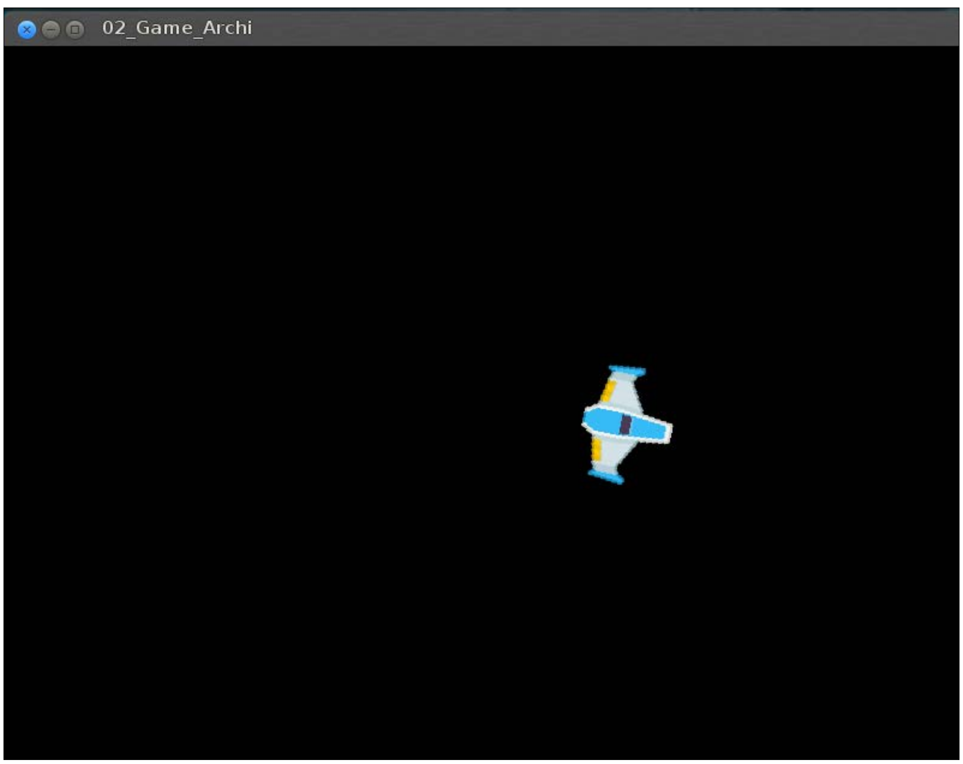
The `sf::Music` class is the class used to play music. Unlike `sf::SoundBuffer` that is appropriate for short effects, `sf::Music` is designed to deal with long music themes.
to hold
them completely. To overcome this, `sf::Music` does not load the entire resource
files that take
hundreds of MBs to avoid saturating the memory. Moreover, `sf::Music` has almost no loading delay.

Unlike other resources, `sf::Music` does not have any lightweight class. You can directly use it. It allows us to use the same features as `sf::SoundBuffer` and `sf::Soundd`
osition).

As a sound stream, a music file is played in its own thread in order to not block the rest of the program. This means that you can leave the music file alone after calling `play()`, it will manage itself very well.

Use case

Earlier in this chapter, I've explained that we will turn the blue square into a nice
ed:



It's not a big change, but it's a starting point for our future game.

To do this, we need to turn `sf::RectangleShape` that represents the `Player` class into `sf::Sprite`. We will also change the `_shape` attribute name into `_ship`; but make an
attribute of the player of it can be a solution because there is only one player, but we will use another approach: a resources manager.

Before starting to create the manager, let's talk about the **Resource Acquisition Is Initialization** (**RAII**) idiom.

RAII idiom

RAII is a principle in which a resource is acquired and released with a class
lly called.
e, even
the C++11,
and can be performed with every type of resource such as files, or in our case, SFML resources.

Building a resources manager

at all the
resources are loaded only once to avoid any more copies.

As previously mentioned, we focus on the resources loaded from the hard drive, so a good way to avoid any duplication is to use an identifier for the resource.

We will use `std::unordered_map` again, and build a wrapper around it, as the `ActionMap` class. Because SFML provides a lot of different types of resources, and
nager as a
template class again. But this time, the template type will be the resource and the key
sources.

The class looks like this:

```
template<typename RESOURCE,typename IDENTIFIER = int>
class ResourceManager
{
    public:
        ResourceManager(const ResourceManager&) = delete;
        ResourceManager& operator=(const ResourceManager&) = delete;

        ResourceManager() = default;
```

```
        template<typename ... Args>
        void load(const IDENTIFIER& id,Args&& ... args);

        RESOURCE& get(const IDENTIFIER& id)const;

    private:
        std::unordered_map<IDENTIFIER,std::unique_ptr<RESOURCE>> _map;
};
```

some
SFML resource
classes don't have the exact same parameters for the `loadFromFile()` function
(`sf::Shader`
as `Player::setPosition()`.

Moreover, some classes cannot be copied, so we need to use a pointer to store them in a container. Because of the RAII idiom, the choice has been made to use the `std::unique_ptr` template class.

> A new class from the C++11 is `std::unique_ptr` and it is one of the smart pointers. Its internals use the RAII idiom, so we don't need to manage the memory deallocation.

Now the implementation is as follows:

```
template<typename RESOURCE,typename IDENTIFIER>
template<typename ... Args>
void ResourceManager<RESOURCE,IDENTIFIER>::load(const IDENTIFIER&
id,Args&& ... args)
{
    std::unique_ptr<RESOURCE> ptr(new RESOURCE);
    if(not ptr->loadFromFile(std::forward<Args>(args)...))
        throw std::runtime_error("Impossible to load file");
    _map.emplace(id,std::move(ptr));
}
```

A feature from the C++11 is `std::move` and it allows us to use the `move` constructor instead of the `copy` constructor. The `std::unique_ptr` template class supports the type of constructor, so using it seems to be a good idea. The idea under the move copying it.
The result is a gain in performance.

Here, we create a new resource using the template parameter `RESOURCE` as `std::unique_ptr`. Then we load the resource from the hard drive using the parameter pack `args`. Finally, we store it internally.

Notice that if the load fails, an exception is thrown rather than returning `false` as value:

```
template<typename RESOURCE,typename IDENTIFIER>
RESOURCE& ResourceManager<RESOURCE,IDENTIFIER>::get(const IDENTIFIER&
id)const
{
    return *_map.at(id);
}
```

This function simply delegates the job to the `std::unordered_map::at()` function by passing the `id` argument to it. The `::at()` method throws an exception when no object is found.

Because our actual `ResourceManager` class uses `loadFromFile()` in the `load()` method, we have a problem with the `sf::Music` class. `LoadFromFile()`, which doesn't exist in the `sf::Music` class and is replaced with `openFromFile()`. So we need to fix that.

To do this, we will use the `partial` specialization. The partial specialization is a technical used in template programming to make some special case, exactly like this one. We need to specialize the `load()` method when `RESOURCE` is set to `sf::Music`. The problem is that we can't do it directly because the `ResourceManager` class has two template parameters, and the other one doesn't need to be fixed. So instead, we have to specialize the entire class by creating a new one:

```
template<typename IDENTIFIER>
class ResourceManager<sf::Music,IDENTIFIER>
{
    public:
        ResourceManager(const ResourceManager&) = delete;
        ResourceManager& operator=(const ResourceManager&) = delete;

        ResourceManager() = default;

        template<typename ... Args>
        void load(const IDENTIFIER& id,Args&& ... args);

        sf::Music& get(const IDENTIFIER& id)const;

    private:
        std::unordered_map<IDENTIFIER,std::unique_ptr<sf::Music>> _
map;
};
```

ed one
template parameter to fix it to `sf::Music`. Here is the implementation:

```
template<typename IDENTIFIER>
template<typename ... Args>
void ResourceManager<sf::Music,IDENTIFIER>::load(const IDENTIFIER&
id,Args&& ... args)
{
    std::unique_ptr<sf::Music> ptr(new sf::Music);

    if(not ptr->openFromFile(std::forward<Args>(args)...))
        throw std::runtime_error("Impossible to load file");
    _map.emplace(id,std::move(ptr));
};

template<typename IDENTIFIER>
sf::Music& ResourceManager<sf::Music,IDENTIFIER>::get(const
IDENTIFIER& id) const
{
    return *_map.at(id);
}
```

Here again, this is exactly the same, except that we have changed `loadFromFile()` to `openFromFile()`.

th all the
SFML resources types, and use the RAII idiom to free memory when required.

r.

Changing the player's skin

's use
, we need
to change `sf::RectangleShapethat`, represent the `Player` class in `sf::Sprite`, and then set the texture source of `sf::Sprite` loaded by the texture manager. So we need a texture manager.

If we think about it, all the managers will be global to our application, so we will group them into a static class named `Configuration`. This class will hold all the game configurations and the managers. `ActionMap` can also be stored inside this class, so we will move `ActionMap` inside the player into this new class, and create an `initialize()` method to initialize all the inputs and textures.

This class is really simple, and can't be instantiated, so all the attributes and methods will be static:

```
class Configuration
{
    public:
        Configuration() = delete;
        Configuration(const Configuration&) = delete;
        Configuration& operator=(const Configuration&) = delete;

        enum Textures : int {Player};
        static ResourceManager<sf::Texture,int> textures;

        enum PlayerInputs : int {Up,Left,Right};
        static ActionMap<int> player_inputs;

        static void initialize();

    private:

        static void initTextures();
        static void initPlayerInputs();
};
```

As you can see, the class is not really difficult. We only move the `_playerInputs` and `enum` from the `Player` class and add `ResourceManager` for textures. Here is the implementation:

```
ResourceManager<sf::Texture,int> Configuration::textures;
ActionMap<int> Configuration::player_inputs;

void Configuration::initialize()
{
    initTextures();
    initPlayerInputs();
}

void Configuration::initTextures()
{
    textures.load(Textures::Player,"media/Player/Ship.png");
}

void Configuration::initPlayerInputs()
{
```

```
        player_inputs.map(PlayerInputs::Up,Action(sf::Keyboard::Up));
        player_inputs.map(PlayerInputs::Right,Action
          (sf::Keyboard::Right));
        player_inputs.map(PlayerInputs::Left,Action
          (sf::Keyboard::Left));
    }
```

n the
player class to draw it as a spaceship. We need to replace `sf::RectangleShape _shape` with `sf::Sprite _ship;`.

In the constructor, we need to set the texture and the origin of the sprite as follows:

```
_ship.setTexture(Configuration::textures.get(Configuration::Textures::Player));
_ship.setOrigin(49.5,37.5);
```

Don't forget to call `Configuration::initialize()` from `main()` before anything else. We now have a nice spaceship as a player.

There is a lot of code and different classes to get this result, but if you think about
e lines in our
final applications.

Summary

agement,
and the resources. You also learned about the RAII idiom and some C++11 features such as lambda, variadic templates, smart pointers, move syntax, and perfect forwarding.

will make
asteroid
game, and we will also build a Tetris game.

3
Making an Entire 2D Game

In this chapter, we will finally make our first game. In fact, we will build two games, as follows:

- We will build our first game, an Asteroid clone game, by improving our actual application of SFML
- Our next game will be a Tetris clone game

We will also learn some skills such as:

- Entity models
- Board management

We are all fans of old school games, so let's get loaded to create some of them right away. In addition, each of these two games has a completely different architecture. It's really interesting as far as the learning process is concerned.

Turning our application to an Asteroid clone

Asteroid is an arcade "shoot 'em up" game created in 1979 by Atari Inc., and is considered a classic. The player controls a spaceship in an asteroid field with some fle goal
them. Each
level increases the number of asteroids in the field, and the game becomes harder and harder.

need to add a
lot of things to it.

The Player class

to rotate
. The player
pear in a
ing on top
of an asteroid.

fe is won. If the
lose one life. It
will reappear at the starting point, that is, the middle of the screen.

The levels

Each level starts with some big asteroids in random places that are drifting in various directions. Each level will have an increased number of asteroids. This number is four for the first level and eleven starting from the fifth level.

The board is a bit special because it's a Euclidean torus (see the definition on Wikipedia for more detail: `http://en.wikipedia.org/wiki/Torus`). The top and
ht sides,
except that the top right meets the bottom left, and vice versa. The level is finished when there are no more meteors on the screen.

The enemies

There are two kinds of enemies: meteors and flying saucers. Both of them can
stroy
them by shooting at them.

The meteors

a points
different
meteors' properties:

Size	**Big**	**Medium**	**Small**
Speed	Slow	Medium	Fast
Split	2~3 medium	2~3 smalls	-
Base Points	20	60	100

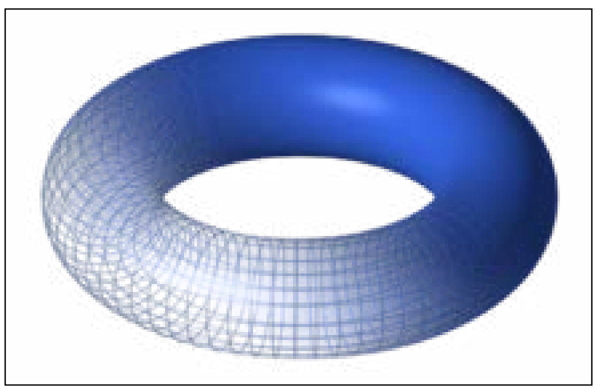
the small ones.
The big meteors are also those that represent the starting meteor field of each level.

The flying saucers

Time to time! A flying saucer appears and tries to disturb the player. There are two e, that the chance that small saucers recision of the saucers.

Modifying our application

tart to change it. The first step is to change our world to a Euclidean torus with a fixed size. Here is a representation of a torus taken from the Wikipedia page:



To do this, we will need some information from inside the game, such as the world size. We will add the information inside the `Game` class as two integer values, `height` and `width`:

```
const int _x, const _y;
```

for this class:

```
Game(int x=800, int y=600);
```

the
following code snippet:

```
Game::Game(int x, int y) :
  _window(sf::VideoMode(x,y),"03_Asteroid"),x(x),y(y){
     _player.setPosition(100,100);
}
```

Okay, now we can choose the size of the world, but how do we make it a torus?
each entity
sitions.

Let's try this with the player, as shown in the following code snippet:

```
void Game::update(sf::Time deltaTime)
{
  _player.update(deltaTime);
  sf::Vector2f player_pos = _player.getPosition();
  if(player_pos.x < 0){
    player_pos.x = _x;
    player_pos.y = _y - player_pos.y;
  } else if (player_pos.x > _x){
    player_pos.x = 0;
    player_pos.y = _y - player_pos.y;
  }
  if(player_pos.y < 0)
  player_pos.y = _y;
  else if(player_pos.y > _y)
  player_pos.y = 0;
  _player.setPosition(player_pos);
}
```

As you can see here, firstly, we call the `update()` method on the player, and then we correct its position if it's out of the world range. We now have an infinite world.

The `Player::getPosition()` method used is as follows:

```
const sf::Vector2f& Player::getPosition()const{return
  _ship.getPosition();}
```

ide the `Game`
isn't it? Wrong! If
you think a bit about this, you will understand that the player doesn't care about the
its entity, not
the contrary.

Here we have two options: keep our code as it is or establish a more flexible system. If we quickly think about what will be required for the managements of the meteors and saucers, the second option seems best. So let's build a more flexible system.

this.
They are as follows:

- The hierarchical entity system
- The entity component system

e them right
after the world class.

The World class

All our logic is actually made in the `Game` class. This is a good way, but we can do better. If we think about it, the `Game` class has to not only process events, create the window, and delegate other classes to the pause and menu systems, but also perform all the entity management.

To be more explicit, the game doesn't have to manage any entity, but can create a world and populate it. Then, all the work is done by the world class.

The world is a container of entities but also of sounds effects. It has a specific size, shape, and rules (such as physics). It can also be displayed on screen. Finally, the class looks similar to the following code snippet:

```
class World : public sf::Drawable
{
  public:
  World(const World&) = delete;
  World& operator=(const World&) = delete;
  World(float x,float y);
  ~World();
  void add(Entity* entity);
  void clear();
  bool isCollide(const Entity& other);
  int size();

  void add(Configuration::Sounds sound_id);

  const std::list<Entity*> getEntities()const;
  int getX()const;
  int getY()const;
  void update(sf::Time deltaTime);
```

```
    private:
    std::list<Entity*>  _entities;
    std::list<Entity*>  _entities_tmp;

    std::list<std::unique_ptr<sf::Sound>> _sounds;
    virtual void draw(sf::RenderTarget& target, sf::RenderStates
    states) const override;

    const int _x;
    const int _y;
};
```

Like the other classes, we make the `World` class non-replicable. We add some
em all as
well. Because it's possible to have some sounds in the world, we also add a method to add them. It takes an ID from the `Configuration` class, exactly like the IDs for `Textures`. We also add some functions to get information such as the number of entities, the size of the world, and so on.

Now if we take a look at the attributes, we can see two containers for the entities.
e implementation.
The other container is for `sf::Sound` that can be added to the world. I will also explain it in the implementation.

Now, take a look at the implementation. This class is a bit long, and some functions have been reduced to not take a lot of space in this chapter:

```
World::World(float x,float y): _x(x),_y(y){}
World::~World(){clear();}
```

There is no difficulty in these functions. The constructor simply sets the size of the world, and the destructor clears it; as shown in the following code snippet:

```
void World::add(Entity* entity) {
    _entities_tmp.push_back(entity);
}
```

the `_entites`
y the entities
e explained in
the `update()` function:

```
void World::clear()
{
  for(Entity* entity :_entities)
  delete entity;
```

```
    _entities.clear();
    for(Entity* entity :_entities_tmp)
    delete entity;
    _entities_tmp.clear();
    _sounds.clear();
  }
```

Here, we clean the entire world by deleting all its entities and sounds. Because we
ike sf::Sound:

```
  void World::add(Configuration::Sounds sound_id)
  {
    std::unique_ptr<sf::Sound> sound(new
      sf::Sound(Configuration::sounds.get(sound_id)));
    sound->setAttenuation(0);
    sound->play();
    _sounds.emplace_back(std::move(sound));
  }
```

This function creates a `sf::Sound` parameter from a `sf::SoundBuffer` parameter contained in the `Configuration` class, initialize it, and play it. Because each `sf::Sounds` has its own thread, the `sf::Sound::play()` parameter will not interrupt our main thread. And then, we store it in the appropriate container:

```
  bool World::isCollide(const Entity& other)
  {
      for(Entity* entity_ptr : _entities)
          if(other.isCollide(*entity_ptr))
              return true;
      return false;
  }
```

The `World::isCollide()` function is a helper to check whether an entity is
e beginning
of the game:

```
  int World::size(){return _entities.size() + _entities_tmp.size();}
  int World::getX()const{return _x;}
  int World::getY()const {return _y;}
  const std::list<Entity*> World::getEntities()const {return
    _entities;}
```

thing that is
particular is `size()` because it returns the total number of entities:

```
void World::update(sf::Time deltaTime)
{
  if(_entities_tmp.size() > 0)
  _entities.merge(_entities_tmp);
  for(Entity* entity_ptr : _entities)
  {
    Entity& entity = *entity_ptr;
    entity.update(deltaTime);
    sf::Vector2f pos = entity.getPosition();
    if(pos.x < 0)
    {
      pos.x = _x;
      pos.y = _y - pos.y;
    } else if (pos.x > _x) {
      pos.x = 0;
      pos.y = _y - pos.y;
    }
    if(pos.y < 0)
    pos.y = _y;
    else if(pos.y > _y)
    pos.y = 0;
    entity.setPosition(pos);
  }
  const auto end = _entities.end();
  for(auto it_i = _entities.begin(); it_i != end; ++it_i)
  {
    Entity& entity_i = **it_i;
    auto it_j = it_i;
    it_j++;
    for(; it_j != end;++it_j)
    {
      Entity& entity_j = **it_j;
      if(entity_i.isAlive() and entity_i.isCollide(entity_j))
      entity_i.onDestroy();
      if(entity_j.isAlive() and entity_j.isCollide(entity_i))
      entity_j.onDestroy();
    }
```

```
    }
    for(auto it = _entities.begin(); it != _entities.end();)
    {
      if(not (*it)->isAlive())
      {
        delete *it;
        it = _entities.erase(it);
      }
      else
      ++it;
    }
    _sounds.remove_if([](const std::unique_ptr<sf::Sound>& sound) ->
      bool {
      return sound->getStatus() != sf::SoundSource::Status::Playing;
    });
  }
```

Let's explain it
in detail:

1. We merge the entities' container together into the main container.
2. We update all entities, and then verify that their positions are correct.
   If this is not the case, we correct them.
3. We check the collision between all the entities and dead entities are removed.
4. Sounds that have been played are removed from the container.

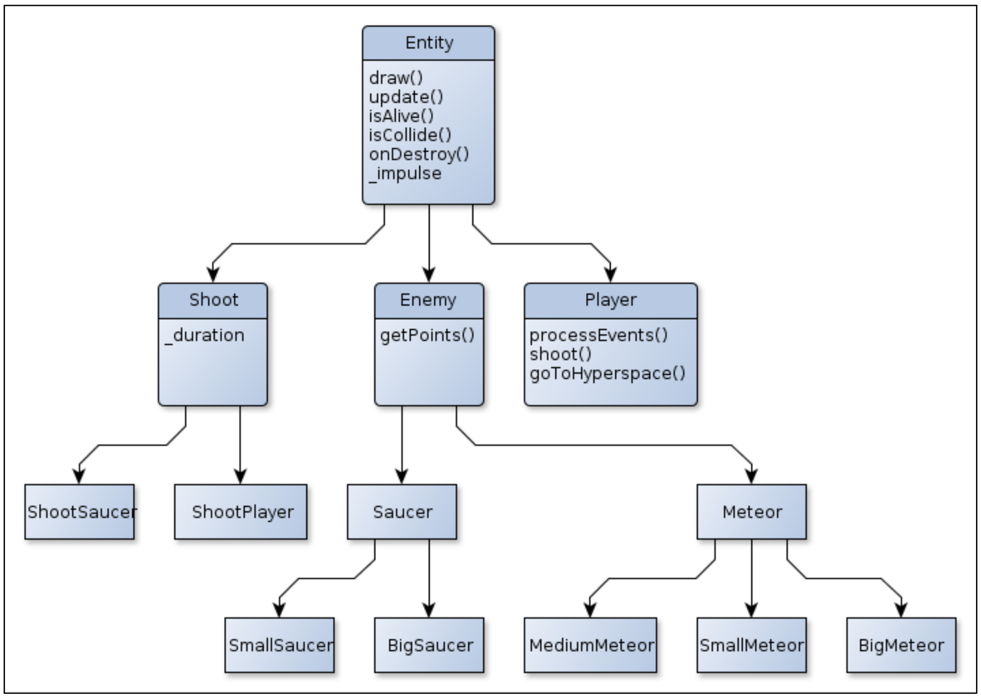
In the update and collision loops, some entities can create others. That's the reason for the `_entities_tmp` container. In this way, we are sure that our iterator is not broken at any time, and we do not update/collide entities that have not experienced a single frame, as shown in the following code snippet:

```
void World::draw(sf::RenderTarget& target, sf::RenderStates
  states) const
{
  for(Entity* entity : _entities)
  target.draw(*entity,states);
}
```

This function is simple, and forwards its job to all the entities. As you can see, the `World`ll
sounds. By doing this, we can remove a lot of tasks from the `Game` class, and delegate it to the `World` class.

The hierarchical entity system

ass in your code,
and all of them are extended from a common virtual class, most of the time called **Entity**. All the logic is made inside the class in the `Entity::update()` function. For our project, the hierarchical tree could be similar to the following figure:



and because we
n.

The entity component system

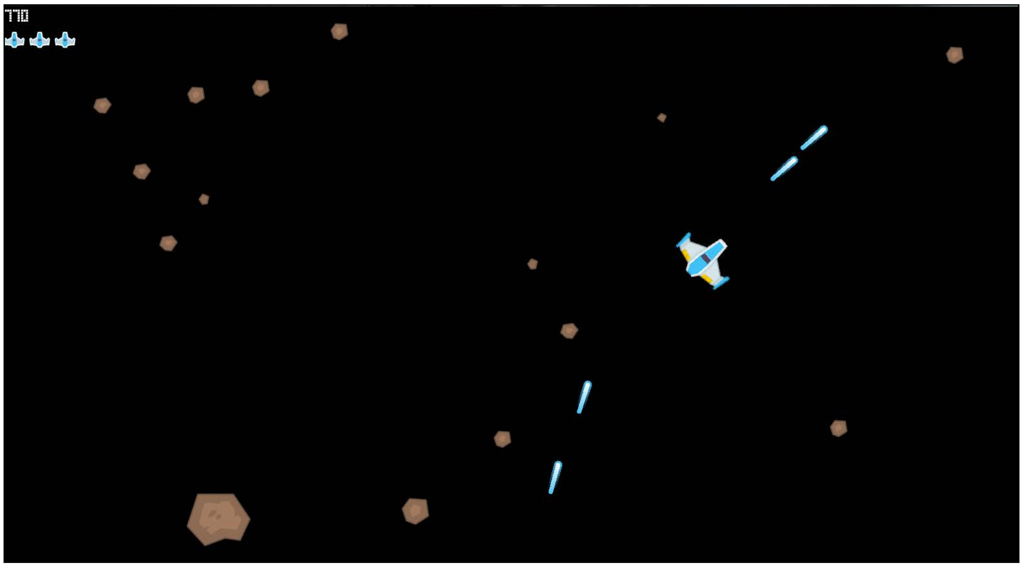
ity represented
as a class, there is only one class: entity. To this entity, we attach some property such as the position, ability to be draw, a gun, and whatever you want. This system is
ficult to build.
ack to it in the
next chapter. So even if we don't use it right now, don't be frustrated, we will build and use it in the next project.

Designing our game

a
world that will be populated by them, let's think about the needs. Following table summarizes the needs:

Entity	Parent	Specificities
`Entity`		This can move This can be drawn This can collide with another entity
`Player`	Entity	This can shoot This is controlled by inputs This can collide with everything except the one it shoots
`Enemy`	Entity	This can be destroyed by shooting This gets the player some points when destroyed by shooting
`Saucer`	Enemy	This has a bigger chance to spawn a small saucer when the point number increases This can collide with everything except saucer shoots
`BigSaucer`	Saucer	This has a special skin
`SmallSaucer`	Saucer	This can shoot the `Player` entity This has a special skin
`Meteors`	Enemy	This can collide with everything except other meteors
`BigMeteor`	Meteors	This splits into some `MediumMeteor` when destroyed This has a special skin
`MediumMeteor`	Meteors	This splits into `SmallMetors` when destroyed This has a special skin
`SmallMeteor`	Meteors	This has a special skin
`Shoot`	Entity	This lives for a specific time
`ShootPlayer`	Shoot	This can only collide with enemies This has a specific skin
`ShootSaucer`	Shoot	This can collide with `Meteor` and `Player` This has a special skin

Now that we have all the information needed for each class, let's build them. The final result will look similar to the following:



Prepare the collisions

In this project we will use a simple collision detection: collision between circles. As just said this is very basic and can be improved a lot, but is sufficient for now. Take a look to the class:

```
class Collision
{
  public:
    Collision() = delete;
    Collision(const Collision&) = delete;
    Collision& operator=(const Collision&) = delete;
    static bool circleTest(const sf::Sprite& first, const sf::Sprite&
second);
};
```

The is no member here, and the class can't be instantiate. The aim of the class is to group some helper function used by other classes. So here, only one collision test is describe that take two `sf::Sprite` as parameters. Take a look to the implementation.

```
bool Collision::circleTest(const sf::Sprite& first, const sf::Sprite&
second)
{
```

```
    sf::Vector2f first_rect(first.getTextureRect().width,
    first.getTextureRect().height);
    first_rect.x *= first.getScale().x;
    first_rect.y *= first.getScale().y;

    sf::Vector2f second_rect(second.getTextureRect().width,
    second.getTextureRect().height);
    second_rect.x *= second.getScale().x;
    second_rect.y *= second.getScale().y;

    float radius1 = (first_rect.x + first_rect.y) / 4;
    float radius2 = (second_rect.x + second_rect.y) / 4;
    float xd = first.getPosition().x - second.getPosition().x;
    float yd = first.getPosition().y - second.getPosition().y;

    return std::sqrt(xd * xd + yd * yd) <= radius1 + radius2;
  }
```

The function first computes the radius for each of the sprite. Then it checks if the
) is less
on, on the other
side, there is one, even if we don't exactly know the exact point.

The Entity class

To build our system, we need the base class, so let's start with the `Entity` class:

```
class Entity :  public sf::Drawable
{
  public:
//Constructors
  Entity(const Entity&) = delete;
  Entity& operator=(const Entity&) = delete;
  Entity(Configuration::Textures tex_id,World& world);
  virtual ~Entity();

//Helpers
  virtual bool isAlive()const;

  const sf::Vector2f& getPosition()const;
  template<typename ... Args>
  void setPosition(Args&& ... args);
  virtual bool isCollide(const Entity& other)const = 0;
```

```
//Updates
  virtual void update(sf::Time deltaTime) = 0;
  virtual void onDestroy();

  protected:
  sf::Sprite _sprite;
  sf::Vector2f _impulse;
  World& _world;
  bool _alive;

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

Let's discuss this class step by step:

1. Firstly, we make the class noncopyable.
2. Then we make the destructor virtual. This is a really important point because the `Entity` class will be used as a polymorphic class. So we need to set the y it's `Entity` base.
3. We also define some helper functions to know if the entity is alive and also to set/get its position. The code is the same as we have in the `Player` class. We also define some virtual methods that will be overridden in other classes.
4. The virtual function `onDestroy()` is important. Its goal is to execute some code before the destruction on the entity by shooting it or whatever. For example, the ability of a `Meteor` entity to be split will be put in this function, and so will all kind of sounds caused by the destruction of the object.

Now take a look to the implementation of the `Entity` class:

```
Entity::Entity(Configuration::Textures tex_id,World& world) :
  _world(world),_alive(true)
{
  sf::Texture& texture = Configuration::textures.get(tex_id);
  _sprite.setTexture(texture);
  _sprite.setOrigin(texture.getSize().x/2.f,texture.getSize
    ().y/2.f);
}
```

The constructor sets the texture to the internal `sf::Sprite` function, and then center ue:

```
const sf::Vector2f& Entity::getPosition()const {return
  _sprite.getPosition();}
void Entity::draw(sf::RenderTarget& target, sf::RenderStates
  states) const {target.draw(_sprite,states);}
```

These two functions are the exact same as those in the `Player` class. So no surprises here:

```
bool Entity::isAlive()const {return _alive;}
void Entity::onDestroy(){_alive = false;}
```

These two functions are new. It's simply a helper function. `IsAlive()` is used to know if an entity have to be removed from the world, and the `onDestroy()` function r `Entity`. Nothing complicated for now.

The Player class

Now that we have the `Entity` class, let's change the `Player` class to extend it from `Entity`:

```
class Player : public Entity , public ActionTarget<int>
{
  public:
  Player(const Player&) = delete;
  Player& operator=(const Player&) = delete;
  Player(World& world);

  virtual bool isCollide(const Entity& other)const;
  virtual void update(sf::Time deltaTime);
  void processEvents();
  void shoot();
  void goToHyperspace();
  virtual void onDestroy();

  private:
  bool _isMoving;
  int _rotation;
  sf::Time _timeSinceLastShoot;
}
```

As you can see, we removed all the functions and attributes related to the position and the display. The `Entity` class already does it for us. And now the implementation of this class is as follows:

```
Player::Player(World& world) : Entity(Configuration::Textures::Player
,world)
  ,ActionTarget(Configuration::player_inputs),_isMoving(false)
    ,_rotation(0)
{
  //bind ..
  bind(Configuration::PlayerInputs::Shoot,[this](const
    sf::Event&){
    shoot();
  });
  bind(Configuration::PlayerInputs::Hyperspace,[this](const
    sf::Event&){
    goToHyperspace();
  });
}
```

Here we remove all the code that initializes the `_sprite` function, and delegate the job to the `Entity` constructor. We also add two new abilities, to shoot and to go to hyperspace:

```
bool Player::isCollide(const Entity& other)const
{
  if(dynamic_cast<const ShootPlayer*>(&other) == nullptr) {
    return Collision::circleTest(_sprite,other._sprite);
  }
  return false;
}
```

ype of the
`Entity` as a parameter. To do this we use the virtual table lookup by trying to convert the `Entity` class to a specific pointer type. If this is not possible, `nullptr` is returned by `dynamic_cast()`. There are other approaches to do this, such as double
ut is a slow
operation. Once the real type of entity is known, the collision test is made. In this
e. This is a pretty
good approximation:

```
void Player::shoot()
{
  if(_timeSinceLastShoot > sf::seconds(0.3))
  {
```

```
      _world.add(new ShootPlayer(*this));
      _timeSinceLastShoot = sf::Time::Zero;
    }
  }
```

This function creates a `ShootPlayer` instance and adds it to the world. Because we don't want that the player to create a shoot in every frame, we add a timer that is updated in the `Player::update()` method, as shown:

```
void Player::goToHyperspace()
{
  _impulse = sf::Vector2f(0,0);
  setPosition(random(0,_world.getX()),random(0,_world.getY()));
  _world.add(Configuration::Sounds::Jump);
}
```

removes all
irection after
a teleportation:

```
void Player::update(sf::Time deltaTime)
{
  float seconds = deltaTime.asSeconds();
  _timeSinceLastShoot += deltaTime;
  if(_rotation != 0)
  {
    float angle = _rotation*250*seconds;
    _sprite.rotate(angle);
  }

  if(_isMoving)
  {
    float angle = _sprite.getRotation() / 180 * M_PI - M_PI / 2;
    _impulse += sf::Vector2f(std::cos(angle),std::sin(angle)) * 300.f
*
    seconds;
  }
  _sprite.move(seconds * _impulse);
}
```

This method updates the position and the rotation of a `Player` according to the
st shoot to be
able to shoot again.

```
void Player::onDestroy()
{
  Entity::onDestroy();
  Configuration::lives--;
  _world.add(Configuration::Sounds::Boom);
}
```

To better understand the `Entity::onDestroy()` method, remember that this
or) of an `Entity`
instance when a collision occurs. So here we call the `onDestroy()` function of the
`Entity`s reduce
the number of lives, set the player value to `nullptr`, and finally, add an explosion sound to the world. The other methods of the `Player` class have not changed.

The Enemy class

We will now create the Enemy class as we have already described, in the table at the beginning of the `Design our game part`:

```
class Enemy : public Entity
{
  public:
  Enemy(const Enemy&) = delete;
  Enemy& operator=(const Enemy&) = delete;
  Enemy(Configuration::Textures tex_id,World& world);

  virtual int getPoints()const = 0;
  virtual void onDestroy();
};
```

This class is pretty small because it doesn't need a lot of new logic compared to the `Player` class. We only need to briefly specify the `onDestroy()` method by adding points to the global score of the game. So we create a `getPoints()` method that will simply return the number of points for an enemy.

```
Enemy::Enemy(Configuration::Textures tex_id,World& world) :
  Entity(tex_id,world)
{
  float angle = random(0.f,2.f*M_PI);
  _impulse = sf::Vector2f(std::cos(angle),std::sin(angle));
}
```

The constructor simply initializes the `_impulse` vector to a random one, but with the length as `1`. This vector will be multiplied by the speed of the `Saucers/Meteor` entity in their respective constructors:

```
void Enemy::onDestroy()
{
  Entity::onDestroy();
  Configuration::addScore(getPoints());
}
```

This method simply calls the `onDestroy()` function from the `Entity` base of the object, and then adds the points won by destroying the object.

The Saucer class

Now that we have the `Enemy` class made, we can build the `Saucer` base class corresponding to our expectations:

```
class Saucer : public Enemy
{
  public:
  Saucer(const Saucer&) = delete;
  Saucer& operator=(const Saucer&) = delete;
  using Enemy::Enemy;

  virtual bool isCollide(const Entity& other)const;
  virtual void update(sf::Time deltaTime);
  virtual void onDestroy();
  static void newSaucer(World& world);
};
```

built in the
`Entity` and `Enemy` class. Because the class will not specify the constructor, we use the using-declaration to refer to the one from `Enemy`. Here, we introduce a new function,
`newSaucer()`
score and add it to the world.

Now, take a look to the implementation of this class:

```
bool Saucer::isCollide(const Entity& other)const
{
  if(dynamic_cast<const ShootSaucer*>(&other) == nullptr) {
    return Collision::circleTest(_sprite,other._sprite);
  }
  return false;
}
```

The same technique as in `Player::isCollide()` is used here, so no surprises. We specify this function in the `Saucer` base class because the collisions are the same for any of the saucers. It avoids code duplication as follows:

```
void Saucer::update(sf::Time deltaTime)
{
  float seconds = deltaTime.asSeconds();
  Entity* near = nullptr;
  float near_distance = 300;
  for(Entity* entity_ptr : _world.getEntities())
  {
    if(entity_ptr != this and(dynamic_cast<const
      Meteor*>(entity_ptr) or dynamic_cast<const
        ShootPlayer*>(entity_ptr)))
    {
      float x = getPosition().x - entity_ptr->getPosition().x;
      float y = getPosition().y - entity_ptr->getPosition().y;
      float dist = std::sqrt(x*x + y*y);
      if(dist < near_distance) {

           near_distance = dist;
           near = entity_ptr;
     }
  }
}
if(near != nullptr)
{
  sf::Vector2f pos = near->getPosition() - getPosition();
  float angle_rad = std::atan2(pos.y,pos.x);
  _impulse -=
    sf::Vector2f(std::cos(angle_rad),std::sin(angle_rad)) * 300.f
      * seconds;
} else {
  sf::Vector2f pos = Configuration::player->getPosition() -
    getPosition();
  float angle_rad = std::atan2(pos.y,pos.x);
  _impulse +=
    sf::Vector2f(std::cos(angle_rad),std::sin(angle_rad)) * 100.f
      * seconds;
  }
_sprite.move(seconds * _impulse);
}
```

This function is pretty long but not really complicated. It manages the movement of the saucer. Let's explain it step by step:

1. We look for the nearest object of the saucer into which it may crash.
2. If there is an object found too close, we add an impulse to the saucer in the opposite direction of this object. The goal is to avoid a crash.
3. Let's now continue with the other functions.

```
void Saucer::onDestroy()
{
    Enemy::onDestroy();
    _world.add(Configuration::Sounds::Boom2);
}
```

4. This function is simple. We simply call the `onDestroy()` method from the `Enemy` base of the class, and then add an explosion sound to the world:

```
void Saucer::newSaucer(World& world)
{
  Saucer* res = nullptr;
  if(book::random(0.f,1.f) > Configuration::getScore()/
    40000.f)
  res = new BigSaucer(world);
  else
  res = new SmallSaucer(world);
  res->setPosition(random(0,1)*world.getX(),
    random(0.f,(float)world.getY()));
  world.add(res);
}
```

5. As previously mentioned, this function creates a saucer randomly and adds it to the world. The more the points the player has, the greater the chance to create a `SmallSaucer` entity. When the score reaches 40,000 `SmallSaucer` is created as explained in the description of the game.

Now that we have created the `Saucer` base class, let's make the `SmallSaucer` class. I'll not explain the `BigSaucer` class because this is the same as the `SmallSaucer` class but simpler (no shooting), as shown in the following code snippet:

```
class SmallSaucer : public Saucer
{
  public :
  SmallSaucer(World& world);
  virtual int getPoints()const;
  virtual void update(sf::Time deltaTime);
```

```
    private:
    sf::Time_timeSinceLastShoot;
};
```

Because we know the skin of the `SmallSaucer` entity, we don't need the texture ID as a parameter, so we remove it from the constructor parameter. We also add an attribute to the class that will store the elapsed time since the last shoot was made, as in `Player` entity.

Now take a look at the implementation:

```
SmallSaucer::SmallSaucer(World& world) : Saucer(Configuration::Texture
s::SmallSaucer,world)
{
  _timeSinceLastShoot = sf::Time::Zero;
  _world.add(Configuration::Sounds::SaucerSpawn2);
  _impulse *= 400.f;
}
```

This constructor is simple because a great part of the job is already done in the base of the class. We just initialize the impulsion and add a sound to the world
 some
fun to the game:

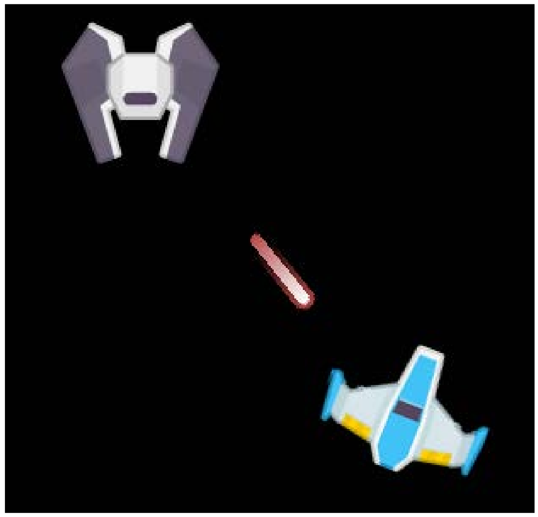
```
int SmallSaucer::getPoints()const {return 200;}
```

This function simply sets the number of points that are won when the `SmallSaucer` entity is destroyed:

```
void SmallSaucer::update(sf::Time deltaTime)
{
  Saucer::update(deltaTime);
  _timeSinceLastShoot += deltaTime;
  if(_timeSinceLastShoot > sf::seconds(1.5))
  {
    if(Configuration::player != nullptr)
    _world.add(new ShootSaucer(*this));
    _timeSinceLastShoot = sf::Time::Zero;
  }
}
```

ing the
`update()` function from the `Saucer` base, then shoot the player as soon as we can, and that's all.

Here is a screenshot of the saucer behavior:



The Meteor class

l start by
the virtual `Meteor` class. Here is its definition:

```
class Meteor : public Enemy
{
  public:
  Meteor(const Meteor&) = delete;
  Meteor& operator=(const Meteor&) = delete;
  using Enemy::Enemy;

  virtual bool isCollide(const Entity& other)const;
  virtual void update(sf::Time deltaTime);
};
```

As you can see, this class is very short. We only specify the collision rules and the
mentation:

```
bool Meteor::isCollide(const Entity& other)const
{
  if(dynamic_cast<const Meteor*>(&other) == nullptr) {
    return Collision::circleTest(_sprite,other._sprite);
  }
  return false;
}
```

The collisions are tested with all `Entity` except the `Meteors` as it was specified. Here again, we use the `circleTest()` function to test the collision with the other objects:

```
void Meteor::update(sf::Time deltaTime)
{
  float seconds = deltaTime.asSeconds();
  _sprite.move(seconds * _impulse);
}
```

This function couldn't be more simple. We only move the `meteor` entity by
omplicated to
 in its direction.

Now that we have the base of all the meteors, let's make the big one. I will not
ppet
explains it:

```
class BigMeteor : public Meteor
{
  public :
  BigMeteor(World& world);
  virtual int getPoints()const;
  virtual void onDestroy();
};
```

You can see this class is also very concise. We only need to define the constructor,
ation of
this class is as follows:

```
BigMeteor::BigMeteor(World& world) :
  Meteor((Configuration::Textures)random
    (Configuration::Textures::BigMeteor1,
      Configuration::Textures::BigMeteor4),world)
{
  _impulse *= 100.f;
}
```

The constructor is not difficult, but the choice of the texture ID is. Because there are several textures possible for a `BigMeteor`, we choose one of them randomly, as shown in the following code snippet:

```
int BigMeteor::getPoints()const {return 20;h}
void BigMeteor::onDestroy()
{
  Meteor::onDestroy();
  int nb = book::random(2,3);
  for(int i=0;i<nb;++i)
```

```
    {
      MediumMeteor* meteor = new MediumMeteor(_world);
      meteor->setPosition(getPosition());
      _world.add(meteor);
    }
    _world.add(Configuration::Sounds::Explosion1);
  }
```

This method is the most important one. It creates some other meteors when a big one is destroyed, and adds them to the world. We also add an explosion sound for more fun during the game.

The Shoot class

e Shoot.

A Shoot is very simple. It's nothing but an entity that goes straight, and lives only for a specific time:

```
class Shoot : public Entity
{
  public:
  Shoot(const Shoot&) = delete;
  Shoot& operator=(const Shoot&) = delete;
  using Entity::Entity;
  virtual void update(sf::Time deltaTime);
  protected:
  sf::Time _duration;
};
```

Nothing surprising here, we only add a `_duration` attribute that will store the elapsed time since the creation of the `Shoot` class. Now, the implementation of the update function is as follows:

```
void Shoot::update(sf::Time deltaTime)
{
  float seconds = deltaTime.asSeconds();
  _sprite.move(seconds * _impulse);
  _duration -= deltaTime;
  if(_duration < sf::Time::Zero)
  _alive = false;
}
```

This function moves the shoot and adjusts the `_duration` attribute by removing the d the world will do the rest.

Now, let's build the `ShootPlayer` class:

```
class ShootPlayer : public Shoot
{
  public :
  ShootPlayer(const ShootPlayer&) = delete;
  ShootPlayer& operator=(const ShootPlayer&) = delete;
  ShootPlayer(Player& from);

  virtual bool isCollide(const Entity& other)const;
};
```

As you can see, the constructor has changed here. There is no more a `World` instance
a look at the
implementation to better understand the reason for this:

```
ShootPlayer::ShootPlayer(Player& from) : Shoot(Configuration::Textures
::ShootPlayer,from._world)
{
  _duration = sf::seconds(5);
  float angle = from._sprite.getRotation() / 180 * M_PI - M_PI /
    2;
  _impulse = sf::Vector2f(std::cos(angle),std::sin(angle)) *
    500.f;
  setPosition(from.getPosition());
  _sprite.setRotation(from._sprite.getRotation());
  _world.add(Configuration::Sounds::LaserPlayer);
}
```

As you can see, the world instance is copied from the source. Moreover, the initial
position of the bullet is set to the position of the `Player` class when it is created. We
ain the collision
ed
functions.

The `ShootSaucer` class uses the same logic as the `ShootPlayer` class, but there is a
 the player.
So we need to add a bit of randomness. Let's take a look to the constructor:

```
ShootSaucer::ShootSaucer(SmallSaucer& from) :
  Shoot(Configuration::Textures::ShootSaucer,from._world)
{
  _duration = sf::seconds(5);
  sf::Vector2f pos = Configuration::player->getPosition() -
    from.getPosition();
```

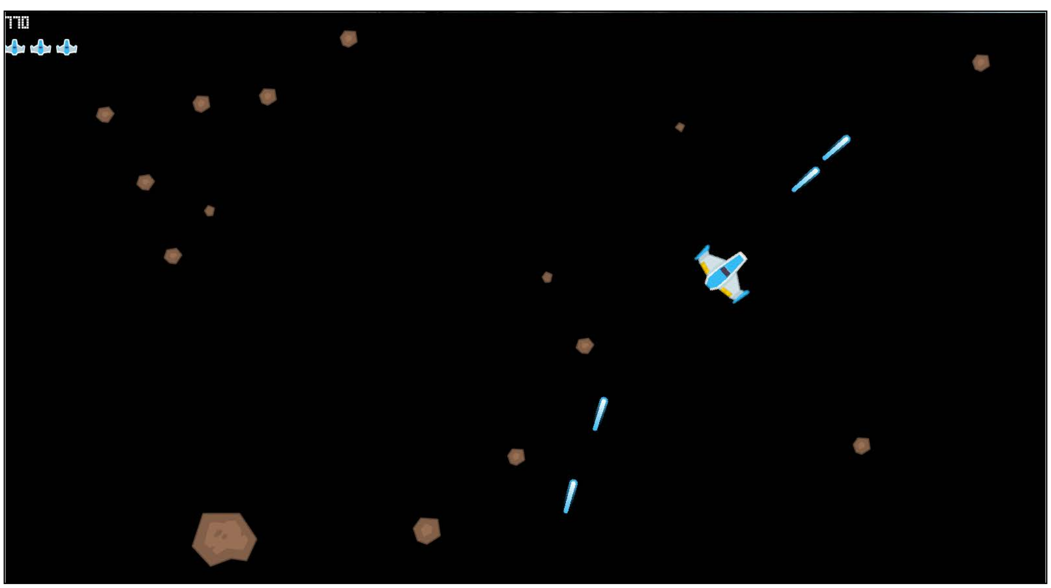
```
    float accuracy_lost = book::random(-
      1.f,1.f)*M_PI/((200+Configuration::getScore())/100.f);
    float angle_rad = std::atan2(pos.y,pos.x) + accuracy_lost;
    float angle_deg = angle_rad * 180 / M_PI;

    _impulse = sf::Vector2f(std::cos(angle_rad),std::sin(angle_rad))
      * 500.f;
    setPosition(from.getPosition());
    _sprite.setRotation(angle_deg + 90);
    _world.add(Configuration::Sounds::LaserEnemy);
}
```

Let's explain this function step by step:

1. We compute the direction vector of the bullet.
2. We add to it a little loss of accuracy depending of the current score.
3. We set the `_impulsion` vector depending on the computed direction.
4. We set the position and the rotation of the sprite as needed.
5. And finally, we release it to the world.

Now that all the classes have been made, you will be able to play the game. The final result should look like this:



Pretty nice, isn't it?

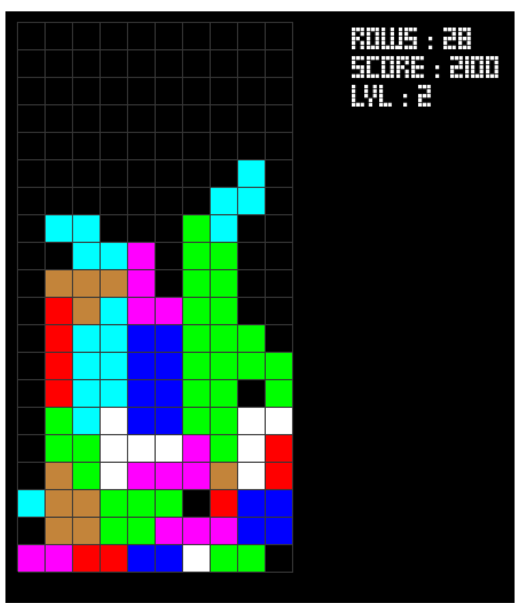
Building a Tetris clone

Now that we've created a complete game, let's build another one, a **Tetris** clone. This
but is still
very interesting. In fact, the internal architecture of this game is really different from
m of the game is
to fill lines of a grid with pieces made of four squares. Each time a line in completed,
fferent kind
ies in this
he game logic
only. So I will not reuse the previously made classes such as `Action`, `ActionMap`, `ActionTarget`, `Configuration`, and `ResourceManager` to be more concise. Of course, you can use them to improve the proposed source code.

So, to build this game we will need to build some classes:

- `Game`: This class will be very similar to the `Game` class from the previous project and will manage the rendering
- `Board`: This class will manage all the logic of the game
- `Piece`: This class will represent all the different kinds of tetrimino (pieces formed by four squares)
- `Stats`: This class will be used to show different information to the player

The final game will look like the following screenshot:



Now that we know how to structure a game, we will directly think about the need of each class.

The Stats class

This class will be used to display the game information to the player such as the level, the number of rows, and the score. We will also use this class to display the **Game Over** message if it's needed. Because this class will display some information d it from
`sf::Drawable` and `sf::Transformable`. Here is the header of this class:

```
class Stats : public sf::Transformable,public sf::Drawable
{
  public:
  Stats();
  void addLines(int lines);
  unsigned int getLvl()const;
  void gameOver();

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

  unsigned int _nbRows;
  unsigned int _nbScore;
  unsigned int _nbLvl;
  bool _isGameOver;

  sf::Text _textRows;
  sf::Text _textScore;
  sf::Text _textLvl;
  sf::Text _textGameOver;
  sf::Font _font;
};
```

There is no real surprise for this class. We have some `sf::Text` that will be used to display information, and their values as numbers. We also add the point calculation to this class with the `addLines()` function.

As previously mentioned, for the Tetris game, we need to focus on the game logic, so we are not going to use any manager for the font.

Now take a look at the implementation of this class:

```
constexpr int  FONT_SIZE 24;
Stats::Stats() : _nbRows(0), _nbScore(0), _nbLvl(0),
  _isGameOver(false)
{
  _font.loadFromFile("media/fonts/trs-million.ttf");
  _textRows.setFont(_font);
  _textRows.setString("rows : 0");
  _textRows.setCharacterSize(FONT_SIZE);
  _textRows.setPosition(0,0);

  _textScore.setFont(_font);
  _textScore.setString("score : 0");
  _textScore.setCharacterSize(FONT_SIZE);
  _textScore.setPosition(0,FONT_SIZE + 1);

  _textLvl.setFont(_font);
  _textLvl.setString("lvl : 0");
  _textLvl.setCharacterSize(FONT_SIZE);
  _textLvl.setPosition(0,(FONT_SIZE + 1)*2);

  _textGameOver.setFont(_font);
  _textGameOver.setString("Game Over");
  _textGameOver.setCharacterSize(72);
  _textGameOver.setPosition(0,0);
}
```

The constructor of the class set all the attributes to no surprise:

```
void Stats::gameOver(){_isGameOver = true;}
```

Here again, there are no surprises. We just assigned the `_isGameOver` value to true:

```
void Stats::addLines(int lines)
{
  if(lines > 0)
  {
    _nbRows += lines;
    _textRows.setString("rows : "+std::to_string(_nbRows));
    _textScore.setString("score : "+std::to_string(_nbScore));
    switch (lines)
    {
      case 1 : _nbScore += 40 * (_nbLvl+1);break;
      case 2 : _nbScore += 100 * (_nbLvl+1);break;
```

```
        case 3 : _nbScore += 300 * (_nbLvl+1);break;
        case 4 : _nbScore += 1200 * (_nbLvl+1);break;
        default :break;
      }
      _nbLvl = _nbRows / 10;
      _textLvl.setString("lvl : "+std::to_string(_nbLvl));
    }
}
```

global score
e text value
and the level. Because a piece is composed of four squares, the maximum number
the switch
statement, we only need to check these four possibilities:

```
unsigned int Stats::getLvl()const{return _nbLvl;}
void Stats::draw(sf::RenderTarget& target, sf::RenderStates
  states) const
{
  if(not _isGameOver)
  {
    states.transform *= getTransform();
    target.draw(_textRows,states);
    target.draw(_textScore,states);
    target.draw(_textLvl,states);
  }
  else
  target.draw(_textGameOver,states);
}
```

As all the other `sf::Drawable::draw()` functions, this function draws the object on the screen. If the game is complete, we print the **Game Over** message, in other cases,
.

In conclusion, this class is very simple and its job is to display all the game information on the screen.

The Piece class

Now, let's build the first important class of this game, the `Piece` class. In Tetris, there
but only one.
The idea is to show you another way to make your entities.

But, what is a piece exactly? If you think about it, you will find that a piece can be ere are
three ways to do this: calculate the rotation at runtime, pre-calculate the rotation at the startup or predefine them in the code. Because in our game, each piece is known rotation. It
implementation as
you will see later in this chapter, but keep in mind that it's not a fantastic idea to hard code items in every game.

Now let's take a look at the class:

```
class Piece
{
  public:
  static const unsigned short int NB_ROTATIONS = 4; //< number of
    rotations
  static const unsigned short int MATRIX_SIZE = 4; //< size of the
    matrix
  static const unsigned int PIVOT_Y = 1;
  static const unsigned int PIVOT_X = 2;
  enum TetriminoTypes {O=0,I,S,Z,L,J,T,SIZE}; //< different kind
    of pieces
  static const sf::Color TetriminoColors[TetriminoTypes::SIZE];
    //< different colors for each kind of piece
  static const char
    TetriminoPieces[TetriminoTypes::SIZE]
      [NB_ROTATIONS][MATRIX_SIZE][MATRIX_SIZE];//< store all the
        different shapes

  Piece(const Piece&) = delete;
  Piece& operator=(const Piece&) = delete;
  Piece(TetriminoTypes type,short int rotation);
  TetriminoTypes getType()const;
  void setRotation(short int rotation); //< set the rotation
  short int getRotation()const;
  void setPosition(int x,int y);//< set the position in the
  //board

  int getPosX()const;
  int getPosY()const;
  sf::Time getTimeSinceLastMove()const;

  private:
  const TetriminoTypes _type; //< the piece type
  short int _rotation; //< the piece rotation
```

```
  int _positionX; //< position in the board
  int _positionY;//< position in the board
  sf::Clock _clockSinceLastMove;
};
```

This class is a bit long. Let's explain it step by step:

1. We will define some constant variables that will be used for configuration purposes.
2. We will define an `enum` function with all the different tetrimino pieces.
3. We will define an array of color. Each cell will represent the color of a tetrimino previously defined in the `enum` function.
4. The next line is particular. This defines all the different tetrimino rotations. Because each piece is a 2D array, we also need this information.
5. The other functions are more common: constructor, getter, and setter.
6. We will define some private attributes that store the state of the piece.

choices made,
the implementation will differ a lot with the previous entity in the **Asteroid** game:

```
const sf::Color Piece::TetriminoColors[Piece::TetriminoTypes::SIZE]= {
  sf::Color::Blue,
  sf::Color::Red,
  sf::Color::Green,
  sf::Color::Cyan,
  sf::Color::Magenta,
  sf::Color::White,
  sf::Color(195,132,58)
}
```

This array stores all the different colors for each tetrimino defined by the `TetriminoTypes` enum:

```
const char Piece::TetriminoPieces[Piece::TetriminoTypes::SIZE]
[Piece::NB_ROTATIONS][Piece::MATRIX_SIZE][Piece::MATRIX_SIZE] = {
    { // O
        {
            {0,0,0,0},
            {0,1,2,0},
            {0,1,1,0},
            {0,0,0,0}
        },
        //...
        {
```

```
            {0,0,0,0},
            {0,1,2,0},
            {0,1,1,0},
            {0,0,0,0}
        }
    },
    {//I
        {
            {0,0,0,0},
            {1,1,2,1},
            {0,0,0,0},
            {0,0,0,0}
        },
        {
            {0,0,1,0},
            {0,0,2,0},
            {0,0,1,0},
            {0,0,1,0}
        },
        {
            {0,0,0,0},
            {1,1,2,1},
            {0,0,0,0},
            {0,0,0,0}
        },
        {
            {0,0,1,0},
            {0,0,2,0},
            {0,0,1,0},
            {0,0,1,0}
        }
    },
    //...
};
```

At fiIn fact, each
different piece is defined in the first cell of the array, the second cell represents all the the piece rotation
as a 2D array. The `0` value represents empty, `2` represents the center of the piece, and `1`because it is
pretty long, but you can take a look at it if needed at `03_Simple_2D_game/Tetris/src/SFML-Book/Piece.cpp`.

```
Piece::Piece(TetriminoTypes type,short int rotation) :
  _type(type), _rotation(rotation), _positionX(0), _positionY(0)
    {assert(rotation >= 0 and rotation < NB_ROTATIONS);}
```

> The `assert` function is a macro that will raise an error and exit the program if the expression such as parameter is false. You can remove it by adding `#define NDEBUG` to your code/compiler option to disable this function.
>
> The `assert()` function is useful to do checks in the debug mode only. Use it when you want to be sure that a specific case is respected at run time.

The constructor of the `Piece` class is simple, but we can easily send wrong parameter values to it. So I decided to show you the assert functionality, as follows:

```
Piece::TetriminoTypes Piece::getType()const {return _type;}

short int Piece::getRotation()const {return _rotation;}

int Piece::getPosX()const {return _positionX;}

int Piece::getPosY()const {return _positionY;}
sf::Time Piece::getTimeSinceLastMove()const {return
  _clockSinceLastMove.getElapsedTime();}

void Piece::setRotation(short int rotation)
{
  assert(rotation >= 0 and rotation < NB_ROTATIONS);
  _rotation = rotation;
  _clockSinceLastMove.restart();
}

void Piece::setPosition(int x,int y)
{
  _positionX = x;
  _positionY = y;
  _clockSinceLastMove.restart();
}
```

only particular
thing is the `setPosition/Rotation()` functions because it also resets the internal
ece, in reality it
should not sock you.

The Board class

e them,
the **Board**.

iece). So internally,
 kind of piece
because the kind of piece determines its color (see the `Piece` class). Now take a look at the header of this class:

```
class Board : public sf::Transformable,public sf::Drawable
{
  public:
  static const int DEFAULT_BOARD_COLUMNS = 10;
  static const int DEFAULT_BOARD_LINE = 20;
  static const int DEFAULT_CELL_X = 24;
  static const int DEFAULT_CELL_Y = 24;

  Board(int columns=DEFAULT_BOARD_COLUMNS,int
    line=DEFAULT_BOARD_LINE,int cell_x=DEFAULT_CELL_X,int
      cell_y=DEFAULT_CELL_Y);
  ~Board();

  void spawn(Piece& piece);
  bool move(Piece& piece, int delta_x,int delta_y);
  bool isFallen(const Piece& piece);
  void drop(Piece& piece);
  bool rotateLeft(Piece& piece);
  bool rotateRight(Piece& piece);
  bool isGameOver();
  int clearLines(const Piece& piece); //< clear all possible lines

  private:
  bool rotate(Piece& piece,int rotation);
  void draw(const Piece& piece);
  void clear(const Piece& piece);
  virtual void draw(sf::RenderTarget& target,sf::RenderStates
    states=sf::RenderStates::Default) const override;
  void flood(const Piece& piece,int value);

        void flood(int grid_x,int grid_y,int piece_x,int
piece_y,Piece::Tetrimino_Types type,int rotation,bool visited[]
[Piece::MATRIX_SIZE],int value);
        void flood(int grid_x,int grid_y,int piece_x,int
piece_y,Piece::Tetrimino_Types type,int rotation,bool visited[]
```

```
[Piece::MATRIX_SIZE],bool& flag);

        void clearLine(int y); //< clear a line

        const int _columns;
        const int _lines;
        const int _cellX;
        const int _cellY;

        bool _isGameOver;

        sf::VertexArray _grid;//< grid borders
        int* _gridContent;//< lines * columns
};
```

In the Board class we firstly define some configuration variable. This class is drawable and transformable, so we extend it from the corresponding SFML class. ters and
some methods to add, move and manage a Piece. We also add some private methods that will help use to in the implementation of the publics, and we store the size of the pile time, we
 We also add a
sf::VertexArray that will contain the graphical grid to display on the screen.

Now that the class has been explained, let's implement it.

```
constexpr int  CELL_EMPTY -1;
Board::Board(int columns,int lines,int cell_x,int cell_y): _
columns(columns),_lines(lines),_cellX(cell_x),_cellY(cell_y), _
gridContent(nullptr),_isGameOver(false)
{
    _gridContent = new int[_lines*_columns];
    std::memset(_gridContent,CELL_EMPTY,_lines*_columns*sizeof(int));

    sf::Color gridColor(55,55,55);
    _grid = sf::VertexArray(sf::Lines,(_lines+1+_columns+1)*2);
    for(int i=0;i<=_lines;++i)
    {
        _grid[i*2] = sf::Vertex(sf::Vector2f(0,i*_cellY));
        _grid[i*2+1] = sf::Vertex(sf::Vector2f(_columns*_cellX,i*_
cellY));

        _grid[i*2].color = gridColor;
        _grid[i*2+1].color = gridColor;
    }
```

```
    for(int i=0;i<=columns;++i)
    {
        _grid[(_lines+1)*2 + i*2] = sf::Vertex(sf::Vector2f(i*_
cellX,0));
        _grid[(_lines+1)*2 + i*2+1] = sf::Vertex(sf::Vector2f(i*_
cellX,_lines*_cellY));

        _grid[(_lines+1)*2 + i*2].color = gridColor;
        _grid[(_lines+1)*2 + i*2+1].color = gridColor;
    }
}
```

The constructor initialize all the attributes but also create the grids content and we need to
[][]" operator.

```
Board::~Board() {delete _gridContent;}

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

    for(int y=0; y<_lines; ++y)
        for(int x=0; x<_columns; ++x) {
            if(_gridContent[y*_columns + x] != CELL_EMPTY) {
                sf::RectangleShape rectangle(sf::Vector2f(_cellX,_
cellY));
                rectangle.setFillColor(Piece::TetriminoColors[_
gridContent[y*_columns + x]]);
                rectangle.setPosition(x*_cellX,y*_cellY);
                target.draw(rectangle,states);
            }
        }
    target.draw(_grid,states);
}
```

The draw method is not complex. For each cell, there is some data in it, we construct a rectangle of the right size at the right place, with the right color, and display it. And then we display the grid border.

```
void Board::spawn(Piece& piece)
{
    piece.setPosition(_columns/2,0);
    for(int x=0;x<_columns;++x)
        if(_gridContent[x] != CELL_EMPTY) {
```

```
            _isGameOver = true;
            break;
        }
    draw(piece);
}
```

and adds it to
de snippet:

```
bool Board::move(Piece& piece, int delta_x, int delta_y)
{
  delta_x += piece.getPosX();
  delta_y + piece.getPosY();
  clear(piece);
  bool visited[Piece::MATRIX_SIZE][Piece::MATRIX_SIZE] =
    {{false}};
  bool movable = true
  flood(delta_x,delta_y, (int)Piece::PIVOT_X,(int)Piece::PIVOT_Y,
  piece.getType(),piece.getRotation(),
  visited, movable);
  if (movable)
  piece.setPosition(delta_x,delta_y);
  draw(piece);
  return movable;
}
```

p:

1. We will delete the `Piece` class from the board so that it doesn't collide with itself.
2. We will check if we can move the piece and set its new position if we can.
3. We will read the piece to the board

The flood algorithm will be explained later:

```
bool Board::isFallen(const Piece& piece)
{
  clear(piece);
  bool vision[Piece::MATRIX_SIZE][Piece::MATRIX_SIZE] = {{false}};
  bool fallen = true;
  flood(piece.getPosX(),piece.getPosY()+1
  (int)Piece::PIVOT_X,(int)Piece::PIVOT_Y,
  piece.getType(),piece.getRotation(),
  visited,fallen);
  draw(piece)
  return fallen;
}
```

one
ctions, as
shown in the previous code snippet:

```
void Board::drop(Piece& piece) {while(move(piece,0,1));}
```

down. This is a
special action in the Tetris game, called "Hard drop".

```
bool Board::rotateLeft(Piece& piece)
{
  int rotation = piece.getRotation();
  if(rotation > 0)
  --rotation;
  else
  rotation = Piece::NB_ROTATIONS - 1;
  return rotate(piece,rotation);
}

bool Board::rotateRight(Piece& piece)
{
  int rotation = piece.getRotation();
  if(rotation < Piece::NB_ROTATIONS -1)
  ++rotation;
  else
  rotation = 0;
  return rotate(piece,rotation);
}
```

These two functions rotate the piece to a specific direction. As there are only four different rotations (`NB_ROTATIONS`), we need to adjust the new rotation value using a circular check:

```
bool Board::isGameOver(){return _isGameOver;}
bool Board::rotate(Piece& piece,int rotation)
{
  assert(rotation >= 0 and rotation < Piece::NB_ROTATIONS);
  clear(piece);
  bool visited[Piece::MATRIX_SIZE][Piece::MATRIX_SIZE] =
    {{false}};
  bool rotable = true;
  flood((int)piece.getPosX(),(int)piece.getPosY(),
  (int)Piece::PIVOT_X,(int)Piece::PIVOT_Y,
  piece.getType(),rotation,
```

```
    visited,rotable);
    if(rotable)
    piece.setRotation(rotation);
    draw(piece);
    return rotable;
  }
```

or not, and

```
  void Board::draw(const Piece&
    piece){flood(piece,piece.getType());}
  void Board::clear(const Piece& piece){flood(piece,CELL_EMPTY);}
```

These two functions are very close. Each one modifies the grid with a specific value, to set or remove a piece from the internal grid:

```
  void Board::flood(const Piece& piece,int value)
  {
    bool visited[Piece::MATRIX_SIZE][Piece::MATRIX_SIZE] =
      {{false}};
    flood((int)piece.getPosX(),
    (int)piece.getPosY(),(int)Piece::PIVOT_X,
    (int)Piece::PIVOT_Y,
    piece.getType(),piece.getRotation(),
    visited,value);
  }

  void Board::flood(int grid_x,int grid_y,int piece_x,int
    piece_y,Piece::TetriminoTypes type,int rotation,bool visited[]
  [Piece::MATRIX_SIZE],int value)
  {
    if(piece_x < 0 or piece_x >= Piece::MATRIX_SIZE
    or piece_y < 0 or piece_y > Piece::MATRRIX_SIZE
      Pieces[type][rotation][piece_y][piece_x] == 0)
    return;
  visited[piece_y][piece_x] = true;
    _gridContent[grid_y*_columns + grid_x] = value;
    flood(grid_x, grid_y-1, piece_x, piece_y-1, type, rotation,
      visited, value);
    flood(grid_x+1, grid_y, piece_x+1, piece_y, type, rotation,
      visited, value);
    flood(grid_x, grid_y+1, piece_x, piece_y+1, type, rotation,
      visited, value);
```

```
    flood(grid_x-1, grid_y, piece_x-1, piece_y, type, rotation,
      visited, value);
  }

  void Board::flood(int grid_x,int grid_y,int piece_x,int
    piece_y,Piece::TetriminoTypes type,int rotation,bool visited[]
  [Piece::MATRIX_SIZE],bool& flag)
  {
    if(piece_x < 0 or piece_x >= Piece::MATRIX_SIZE
    or piece_y < 0 or piece_y >= Piece::MATRIX_SIZE
    or visited[piece_y][piece_x] == true
    or Piece::TetriminoPieces[type][rotation][piece_y][piece_x] ==
      0)
    return;
    visited[piece_y][piece_x] = true;
    if(grid_x < 0 or grid_x >= (int)_columns
    or grid_y < 0 or grid_y >= (int)_lines
    or _gridContent[grid_y*_columns + grid_x] != CELL_EMPTY) {
      flag = false;
      return;
    }
    flood(grid_x, grid_y-1, piece_x, piece_y-1, type, rotation,
      visited, flag);
    flood(grid_x+1, grid_y, piece_x+1, piece_y, type, rotation,
      visited, flag);
    flood(grid_x, grid_y+1, piece_x, piece_y+1, type, rotation,
      visited, flag);
    flood(grid_x-1, grid_y, piece_x-1, piece_y, type, rotation,
      visited, flag);
  }
```

This `flood` function is an implementation of the `flood` algorithm. It allows us to fill the shape to
fill in the first one. In our case, the first array is the grid, and the second the piece, as shown in the following code snippet:

```
  void Board::clearLine(int yy)
  {
    assert(yy < _lines);
    for(int y=yy; y>0; --y)
    for(int x=0; x<_columns; ++x)
    _gridContent[y*_columns + x] = _gridContent[(y-1)*_columns + x];
  }
  int Board::clearLines(const Piece& piece)
  {
    int nb_delete = 0;
```

```
    clear(piece);
    for(int y=0; y<_lines; ++y)
    {
      int x =0;
      for(;_gridContent[y*_columns + x] != CELL_EMPTY and
        x<_columns; ++x);
      if(x == _columns) {
        clearLine(y);
        ++nb_delete;
      }
    }
    draw(piece);
    return nb_delete;
  }
```

This function simply removes all the completed lines, and lowers all the upper lines to simulate gravity.

Now, the `board` class is made, and we have all that we need to build the game. So let's do it.

The Game class

The `Game` class is very similar to the `Game` class from Asteroid. Its purpose is the same code snippet:

```
class Game
{
  public:
  Game(); //< constructor
  void run(int minimum_frame_per_seconds);

  private:
  void processEvents();//< Process events
  void update(sf::Time deltaTime); //< do some updates
  void render();//< draw all the stuff
  void newPiece();

  sf::RenderWindow _window; //< the window used to display the
    game
  std::unique_ptr<Piece> _currentPiece; //< the current piece
  Board _board; //< the game board
  Stats _stats; //< stats printer
  sf::Time _nextFall;
};
```

As you can see, we don't change the logic of the `Game` class, but we add it some
games.
board
store the next
fall of a piece.

Now take a look at the implementation of this class:

```
Game::Game() : _window(sf::VideoMode(800, 600),"SFML
  Tetris"),_board()
{
  rand_init()
  _board.setPosition(10,10);
  _stats.setPosition(300,10);
  newPiece();
}
```

ets the position
of the different drawable object. It also creates the first piece to start the game.
We don't manage any menu here:

```
void Game::run(int minimum_frame_per_seconds)
{
  sf::Clock clock;
  sf::Time timeSinceLastUpdate;
  sf::Time TimePerFrame =
    sf::seconds(1.f/minimum_frame_per_seconds);
  while (_window.isOpen())
  {
    processEvents();
    timeSinceLastUpdate = clock.restart();
    while (timeSinceLastUpdate > TimePerFrame)
    {
      timeSinceLastUpdate -= TimePerFrame;
      update(TimePerFrame);
    }
    update(timeSinceLastUpdate);
    render();
  }
}
void Game::processEvents()
{
```

```
  sf::Event event;
  while(_window.pollEvent(event))
  {
    if (event.type == sf::Event::Closed)//Close window
    _window.close();
    else if (event.type == sf::Event::KeyPressed) //keyboard input
    {
      if (event.key.code == sf::Keyboard::Escape) {
        _window.close();
      } else if (event.key.code == sf::Keyboard::Down) {
        _board.move(*_currentPiece,0,1);
      } else if (event.key.code == sf::Keyboard::Up) {
        _board.move(*_currentPiece,0,-1);
      } else if (event.key.code == sf::Keyboard::Left) {
        _board.move(*_currentPiece,-1,0);
      } else if (event.key.code == sf::Keyboard::Right) {
        _board.move(*_currentPiece,1,0);
      } else if (event.key.code == sf::Keyboard::Space) {
        _board.drop(*_currentPiece);
        newPiece();
      } else if (event.key.code == sf::Keyboard::S) {
        _board.rotateRight(*_currentPiece);
      } else if (event.key.code == sf::Keyboard::D) {
        _board.rotateLeft(*_currentPiece);
      }
    }
  }
}
void Game::update(sf::Time deltaTime)
{
  if(not _board.isGameOver())
  {
  _stats.addLines(_board.clearLines(*_currentPiece));
  _nextFall += deltaTime;
  if((not _board.isFallen(*_currentPiece)) and (_currentPiece-
    >getTimeSinceLastMove() > sf::seconds(1.f)))
  newPiece();
  sf::Time max_time = sf::seconds(std::max(0.1,0.6-
    0.005*_stats.getLvl()));
  while(_nextFall > max_time)
  {
```

```
        _nextFall -= max_time;
        _board.move(*_currentPiece,0,1);
      }
        } else {
          _stats.gameOver();
        }
    }
```

ic of the game is
here. Let's see this in the following steps:

1. The first step is to clear lines and update the score.
2. Then, we will check whether we need to spawn another piece or not
3. We will calculate the time needed by the current level to force a movement downward and apply it if necessary.
4. Of course, if the game is over, we don't do all this stuff, but tell the stats printer that the game is over:

   ```
   void Game::render()
   {
     _window.clear();
     if(not _board.isGameOver())
     _window.draw(_board);
     _window.draw(_stats);
     _window.display();
   }
   ```

5. Here again, there is nothing new. We just draw all that can be drawn depending on the situation:

   ```
   void Game::newPiece()
   {
     _currentPiece.reset(new
     Piece((Piece::TetriminoTypes)random
       (0,Piece::TetriminoTypes::SIZE-1),0));
     _board.spawn(*_currentPiece);
   }
   ```

6. This last function creates a piece at random, and adds it to the grid, which will set its default position.

And here we are. The game is finished!

Summary

As you surely noticed, there are some common points with the previous game we
re is no
"super technique" that will work in every kind of game. You have to adapt your
o build.
I hope you understand that.

it in the
Tetris game to build a new kind of game.

4

Playing with Physics

e. In this
By doing this,
we will learn:

- What is a physics engine
- How to install and use the Box2D library
- How to pair the physics engine with SFML for the display
- How to add physics in the game

In this chapter, we will learn the magic of physics. We will also do some mathematics but relax, it's for conversion only. Now, let's go!

A physics engine – késako?

In this chapter, we will speak about physics engine, but the first question is "what is a physics engine?" so let's explain it.

cs, for example,
physics
engine is also able to manage collisions, and some of them can deal with soft bodies and even fluids.

al-time
engine and non-real-time engine. The first one is mostly used in video games or simulators and the second one is used in high performance scientific simulation, in the conception of special effects in cinema and animations.

me-based
engine. Here again, there are two important types of engines. The first one is for
, but
e plenty of
engines, but not all of them are open source.

3D physics engines

For 3D games, I advise you to use the `Bullet` physics library. This was integrated in the Blender software, and was used in the creation of some commercial games and also in the making of films. This is a really good engine written in C/C++ that can deal with rigid and soft bodies, fluids, collisions, forces… and all that you need.

2D physics engines

; you just
have to ignore the depth (Z axes). However, the most interesting thing is to use an
this one
and the most famous ones are Box2D and Chipmunk. Both of them are really good and none of them are better than the other, but I had to make a choice, which was Box2D. I've made this choice not only because of its C++ API that allows you to use

Physics engine comparing game engine

simulates
, only
ludes
ectX).
Some predefined logics depend on the goal of the engine (RPG, FPS, and so on) and sometimes artificial intelligence. So as you can see, a game engine is more complete
engine,
usage.

So why don't we directly use a game engine? This is a good question. Sometimes,
g it. However,
ect? More
importantly, what do we need it for? Let's see the following:

- A graphic output
- Physics engine that can manage collision

s project
would be like killing a fly with a bazooka. I hope that you have understood the aim and the
reason for the choices made for the project described in this chapter.

Using Box2D

As previously said, Box2D is a physics engine. It has a lot of features, but the most entation):

- **Collision**: This functionality is very interesting as it allows our tetrimino to interact with each other
    - Continuous collision detection
    - Rigid bodies (convex polygons and circles)
    - Multiple shapes per body
- **Physics**: This functionality will allow a piece to fall down and more
    - Continuous physics with the time of impact solver
    - Joint limits, motors, and friction
    - Fairly accurate reaction forces/impulses

As you can see, Box2D provides all that we need in order to build our game. There are a lot of other features usable with this engine, but they don't interest us right now ou can take a
look at the official website for more details on the Box2D features (`http://box2d.org/about/`).

It's important to note that Box2D uses meters, kilograms, seconds, and radians for the angle as units; SFML uses pixels, seconds, and degrees. So we will need to make some conversions. I will come back to this later.

Preparing Box2D

Now that Box2D is introduced, let's install it. You will find the list of available versions on the Google code project page at `https://code.google.com/p/box2d/downloads/list`. Currently, the latest stable version is 2.3. Once you have downloaded the source code (from compressed file or using SVN), you will need to build it.

Build

Here is the good news, Box2D uses CMake as build process so you just have to follow the exact same steps as the SFML build described in the first chapter of this book and you will successfully build Box2D. If everything is fine, you will find the example project at this place: `path/to/Box2D/build/Testbed/Testbed`. Now, let's install it.

Install

Once you have successfully built your Box2D library, you will need to configure your system or IDE to find the Box2D library and headers. The newly built library can be found in the `/path/to/Box2D/build/Box2D/` directory and is named `libBox2D.a`. On the other hand, the headers are located in the `path/to/Box2D/Box2D/` directory. If everything is okay, you will find a `Box2D.h` file in the folder.

On Linux, the following command adds Box2D to your system without requiring any configuration:

```
sudo make install
```

Pairing Box2D and SFML

Now that Box2D is installed and your system is configured to find it, let's build the physics "hello world": a falling square.

It's important to note that Box2D uses meters, kilograms, seconds, and radian for angle as units; SFML uses pixels, seconds, and degrees. So we will need to make some conversions.

Converting radians to degrees or vice versa is not difficult, but pixels to meters…
ter, unless if the
number of pixels per meter is fixed. This is the technique that we will use.

convert radians
to degrees, degrees to radians, meters to pixels, and finally pixels to meters. We will also need to fix the pixel per meter value. As we don't need any class for these functions, we will define them in a namespace converter. This will result as the following code snippet:

```
namespace converter
{
    constexpr double PIXELS_PER_METERS = 32.0;
```

```
    constexpr double PI = 3.14159265358979323846;

    template<typename T>
    constexpr  T pixelsToMeters(const T& x){return x/PIXELS_PER_
METERS;};

    template<typename T>
    constexpr T metersToPixels(const T& x){return x*PIXELS_PER_
METERS;};

    template<typename T>
    constexpr T degToRad(const T& x){return PI*x/180.0;};

    template<typename T>
    constexpr T radToDeg(const T& x){return 180.0*x/PI;}
}
```

As you can see, there is no difficulty here. We start to define some constants
e to
allow the use of any number type. In practice, it will mostly be `double` or `int`.
The conversion functions are also declared as `constexpr` to allow the compiler to
 constant as a
parameter). It's interesting because we will use this primitive a lot.

Box2D, how does it work?

air
Box2D with SFML. But first, how exactly does Box2D work?

Box2D works a lot like a physics engine:

1. You start by creating an empty world with some gravity.
2. Then, you create some object patterns. Each pattern contains the shape of the
ristics
such as its density, friction, and energy restitution.
3. You ask the world to create a new object defined by the pattern.
4. In each game loop, you have to update the physical world with a small step
such as our world in the games we've already made.

ill need to
loop all the objects and display them by ourselves.

nd and square.
The ground will be fixed and the squares will not. The square will be generated by a user event: mouse click.

This project is very simple, but the goal is to show you how to use Box2D and SFML together with a simple case study. A more complex one will come later.

We will need three functionalities for this small project to:

- Create a shape
- Display the world
- Update/fill the world

s start with the
main function:

1. As always, we create a window for the display and we limit the FPS number to 60. I will come back to this point with the `displayWorld` function.
2. We create the physical world from Box2D, with gravity as a parameter.
3. We create a container that will store all the physical objects for the memory clean purpose.
4. We create the ground by calling the `createBox` function (explained just after).
5. Now it is time for the minimalist `game` loop:
    - Close event managements
    - Create a box by detecting that the right button of the mouse is pressed
6. Finally, we clean the memory before exiting the program:

```
int main(int argc,char* argv[])
{
    sf::RenderWindow window(sf::VideoMode(800, 600, 32), "04_
Basic");
    window.setFramerateLimit(60);
    b2Vec2 gravity(0.f, 9.8f);
    b2World world(gravity);
```

```
    std::list<b2Body*> bodies;
    bodies.emplace_back(book::createBox(world,400,590,800,20,b2_
staticBody));

    while(window.isOpen()) {
        sf::Event event;
        while(window.pollEvent(event)) {
            if (event.type == sf::Event::Closed)
                window.close();
        }
        if (sf::Mouse::isButtonPressed(sf::Mouse::Left)) {
            int x = sf::Mouse::getPosition(window).x;
            int y = sf::Mouse::getPosition(window).y;
            bodies.emplace_back(book::createBox(world,x,y,32,32));
        }
        displayWorld(world,window);
    }

    for(b2Body* body : bodies) {
        delete static_cast<sf::RectangleShape*>(body-
>GetUserData());
        world.DestroyBody(body);
    }
    return 0;
}
```

et's
continue with the box creation.

This function is under the `book` namespace.

```
b2Body* createBox(b2World& world,int pos_x,int pos_y, int size_x,int
size_y,b2BodyType type = b2_dynamicBody)
{
    b2BodyDef bodyDef;
    bodyDef.position.Set(converter::pixelsToMeters<double>(pos_x),
                         converter::pixelsToMeters<double>(pos_y));
    bodyDef.type = type;
    b2PolygonShape b2shape;
    b2shape.SetAsBox(converter::pixelsToMeters<double>(size_x/2.0),
                     converter::pixelsToMeters<double>(size_y/2.0));
```

```
    b2FixtureDef fixtureDef;
    fixtureDef.density = 1.0;
    fixtureDef.friction = 0.4;
    fixtureDef.restitution= 0.5;
    fixtureDef.shape = &b2shape;

    b2Body* res = world.CreateBody(&bodyDef);
    res->CreateFixture(&fixtureDef);

    sf::Shape* shape = new sf::RectangleShape(sf::Vector2f(size_x,siz
e_y));
    shape->setOrigin(size_x/2.0,size_y/2.0);
    shape->setPosition(sf::Vector2f(pos_x,pos_y));

    if(type == b2_dynamicBody)
        shape->setFillColor(sf::Color::Blue);
    else
        shape->setFillColor(sf::Color::White);

    res->SetUserData(shape);

    return res;
}
```

te a rectangle of a
specific size at a predefined position. The type of this rectangle is also set by the user
ep:

1. We create `b2BodyDef`. This object contains the definition of the body to
   lation
   to the gravity center of the object.
2. Then, we create `b2Shape`. This is the physical shape of the object, in our case, a box. Note that the `SetAsBox()` method doesn't take the same parameter as `sf::RectangleShape`. The parameters are half the size of the box. This is why we need to divide the values by two.
3. We create `b2FixtureDef` and initialize it. This object holds all the physical
   , and shape.
4. Then, we properly create the object in the physical world.
5. Now, we create the display of the object. This will be more familiar because
   n,
   and color.

6. As we need to associate and display SFML object to the physical object, we use a functionality of Box2D: the `SetUserData()` function. This function takes `void*` as a parameter and internally holds it. So we use it to keep track of our SFML shape.
7. Finally, the body is returned by the function. This pointer has to be stored to clean the memory later. This is the reason for the body's container in `main()`.

ld. Now,
let's render it to the screen. This is the goal of the `displayWorld` function:

```
void displayWorld(b2World& world,sf::RenderWindow& render)
{
    world.Step(1.0/60,int32(8),int32(3));
    render.clear();
    for (b2Body* body=world.GetBodyList(); body!=nullptr; body=body-
>GetNext())
    {
        sf::Shape* shape = static_cast<sf::Shape*>(body-
>GetUserData());
        shape->setPosition(converter::metersToPixels(body-
>GetPosition().x),
        converter::metersToPixels(body->GetPosition().y));
        shape->setRotation(converter::radToDeg<double>(body-
>GetAngle()));
        render.draw(*shape);
    }
    render.display();
}
```

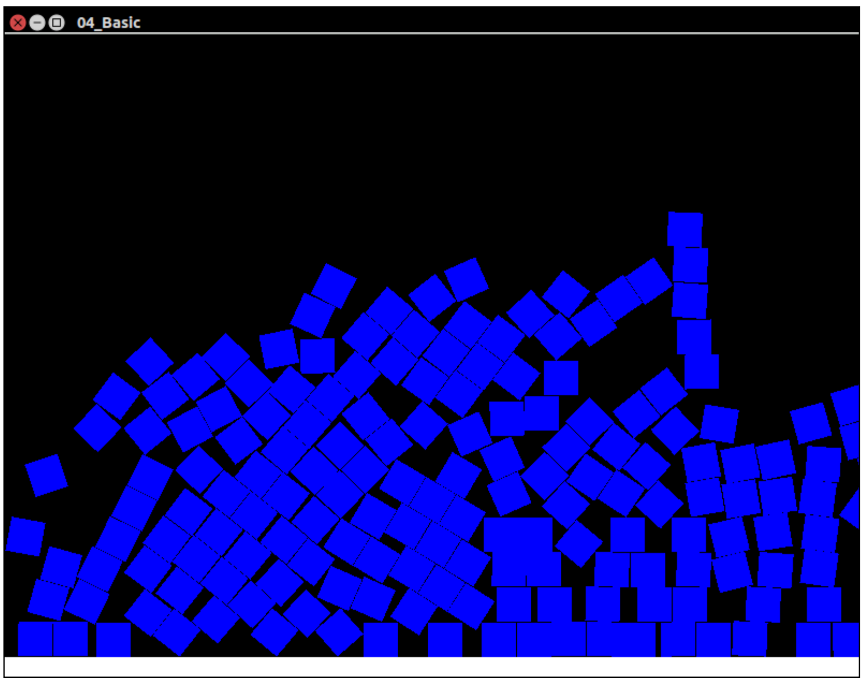
This function takes the physics world and window as a parameter. Here again, let's explain this function step-by-step:

1. We update the physical world. If you remember, we have set the frame rate

   for precision only. In a good code, the time step should not be hardcoded
   the
   sics.
   lay
   loop as already said in *Chapter 2, General Game Architecture, User Inputs, and Resource Management*. I will come back to this point in the next section.

2. We reset the screen, as usual.
3. Here is the new part: we loop the body stored by the world and get back the SFML shape. We update the SFML shape with the information taken from the physical body and then render it on the screen.
4. Finally, we render the result on the screen.

That's it. The final result should look like the following screenshot:



As you can see, it's not really difficult to pair SFML with Box2D. It's not a pain
the real
trap. Pay attention to the precision required (`int`, `float`, `double`) and everything should be fine.

Now that you have all the keys in hand, let's build a real game with physics.

Adding physics to a game

al one.
he game
We will
replace the board with a real physical engine.

dy said,
the goal of some of our classes is to be reusable in any game using SFML. Here, this will be made without any difficulties as you will see. The classes concerned are those you deal with user event `Action`, `ActionMap`, `ActionTarget`—but also `Configuration` and `ResourceManager`. Because all these classes have already been
xplain them
again in this one.

There are still some changes that will occur in the `Configuration` class, more precisely, in the enums and `initialization` methods of this class because we don't use the exact same sounds and events that were used in the Asteroid game. So we need to adjust them to our needs.

Enough with explanations, let's do it with the following code:

```
class Configuration
{
    public:
        Configuration() = delete;
        Configuration(const Configuration&) = delete;
        Configuration& operator=(const Configuration&) = delete;

        enum Fonts : int {Gui};
        static ResourceManager<sf::Font,int> fonts;

        enum PlayerInputs : int { TurnLeft,TurnRight, MoveLeft,
MoveRight,HardDrop};
        static ActionMap<int> playerInputs;

        enum Sounds : int {Spawn,Explosion,LevelUp,};
        static ResourceManager<sf::SoundBuffer,int> sounds;

        enum Musics : int {Theme};
        static ResourceManager<sf::Music,int> musics;
```

```
            static void initialize();

        private:
            static void initTextures();
            static void initFonts();
            static void initSounds();
            static void initMusics();
            static void initPlayerInputs();
    };
```

As you can see, the changes are in the `enum`, more precisely in `Sounds` and `PlayerInputs`. We change the values into more adapted ones to this project.
zation
methods that have changed:

```
    void Configuration::initSounds()
    {
        sounds.load(Sounds::Spawn,"media/sounds/spawn.flac");
        sounds.load(Sounds::Explosion,"media/sounds/explosion.flac");
        sounds.load(Sounds::LevelUp,"media/sounds/levelup.flac");
    }
    void Configuration::initPlayerInputs()
    {
        playerInputs.map(PlayerInputs::TurnRight,Action(sf::Keyboard::
    Up));
        playerInputs.map(PlayerInputs::TurnLeft,Action(sf::Keyboard::Do
    wn));
        playerInputs.map(PlayerInputs::MoveLeft,Action(sf::Keyboard::Le
    ft));
        playerInputs.map(PlayerInputs::MoveRight,Action(sf::Keyboard::Rig
    ht));
        playerInputs.map(PlayerInputs::HardDrop,Action(sf::Keyboard::Spa
    ce,
        Action::Type::Released));
    }
```

No real surprises here. We simply adjust the resources to our needs for the project. As you can see, the changes are really minimalistic and easily done. This is the aim of all reusable modules or classes. Here is a piece of advice, however: keep your code as modular as possible, this will allow you to change a part very easily and also to import any generic part of your project to another one easily.

The Piece class

Now that we have the configuration class done, the next step is the `Piece` class. This class will be the most modified one. Actually, as there is too much change
n ensemble
s to split
a piece at runtime. Each of these squares will be a different fixture attached to the same body, the piece.

We will also need to add some force to a piece, especially to the current piece,
ontally
or can rotate it.

Finally, we will need to draw the piece on the screen.

The result will show the following code snippet:

```
constexpr int BOOK_BOX_SIZE = 32;
constexpr int BOOK_BOX_SIZE_2 = BOOK_BOX_SIZE / 2;
class Piece : public sf::Drawable
{
    public:
        Piece(const Piece&) = delete;
        Piece& operator=(const Piece&) = delete;

        enum TetriminoTypes {O=0,I,S,Z,L,J,T,SIZE};
        static const sf::Color TetriminoColors[TetriminoTypes::SIZE];

        Piece(b2World& world,int pos_x,int pos_y,TetriminoTypes 
type,float rotation);
        ~Piece();
        void update();
        void rotate(float angle);
        void moveX(int direction);
        b2Body* getBody()const;

    private:
        virtual void draw(sf::RenderTarget& target, sf::RenderStates 
states) const override;
        b2Fixture* createPart((int pos_x,int pos_y,TetriminoTypes 
type); ///< position is relative to the piece int the matrix 
coordinate (0 to 3)
        b2Body * _body;
        b2World& _world;
};
```

Some parts of the class don't change such as the `TetriminoTypes` and `TetriminoColors` enums. This is normal because we don't change any piece's shape or colors. The rest is still the same.

om the
precedent version. Let's see it:

```
Piece::Piece(b2World& world,int pos_x,int pos_y,TetriminoTypes
type,float rotation) : _world(world)
{
    b2BodyDef bodyDef;
    bodyDef.position.Set(converter::pixelsToMeters<double>(pos_x),
    converter::pixelsToMeters<double>(pos_y));
    bodyDef.type = b2_dynamicBody;
    bodyDef.angle = converter::degToRad(rotation);
    _body = world.CreateBody(&bodyDef);

    switch(type)
    {
        case TetriminoTypes::O : {
            createPart((0,0,type); createPart((0,1,type);
            createPart((1,0,type); createPart((1,1,type);
        }break;
        case TetriminoTypes::I : {
            createPart((0,0,type); createPart((1,0,type);
            createPart((2,0,type); createPart((3,0,type);
        }break;
        case TetriminoTypes::S : {
            createPart((0,1,type); createPart((1,1,type);
            createPart((1,0,type); createPart((2,0,type);
        }break;
        case TetriminoTypes::Z : {
            createPart((0,0,type); createPart((1,0,type);
            createPart((1,1,type); createPart((2,1,type);
        }break;
        case TetriminoTypes::L : {
            createPart((0,1,type); createPart((0,0,type);
            createPart((1,0,type); createPart((2,0,type);
        }break;
        case TetriminoTypes::J : {
            createPart((0,0,type); createPart((1,0,type);
            createPart((2,0,type); createPart((2,1,type);
        }break;
```

```
        case TetriminoTypes::T : {
            createPart((0,0,type); createPart((1,0,type);
            createPart((1,1,type); createPart((2,0,type);
        }break;
        default:break;
    }
    body->SetUserData(this);
    update();
}
```

The constructor is the most important method of this class. It initializes the physical body and adds each square to it by calling `createPart()`. Then, we set the user sics to SFML
ble by
calling the `update()` function:

```
Piece::~Piece()
{
    for(b2Fixture* fixture=_body->GetFixtureList();fixture!=nullptr;
    fixture=fixture->GetNext())
{
        sf::ConvexShape* shape = static_
cast<sf::ConvexShape*>(fixture->GetUserData());
        fixture->SetUserData(nullptr);
        delete shape;
    }
    _world.DestroyBody(_body);
}
```

The destructor loop on all the fixtures attached to the body, destroys all the SFML shapes and then removes the body from the world:

```
b2Fixture* Piece::createPart((int pos_x,int pos_y,TetriminoTypes type)
{
    b2PolygonShape b2shape;
    b2shape.SetAsBox(converter::pixelsToMeters<double>(BOOK_BOX_
SIZE_2),
    converter::pixelsToMeters<double>(BOOK_BOX_SIZE_2)
    ,b2Vec2(converter::pixelsToMeters<double>(BOOK_BOX_
SIZE_2+(pos_x*BOOK_BOX_SIZE)),
converter::pixelsToMeters<double>(BOOK_BOX_SIZE_2+(pos_y*BOOK_BOX_
SIZE))),0);
```

```
    b2FixtureDef fixtureDef;
    fixtureDef.density = 1.0;
    fixtureDef.friction = 0.5;
    fixtureDef.restitution= 0.4;
    fixtureDef.shape = &b2shape;

    b2Fixture* fixture = _body->CreateFixture(&fixtureDef);

    sf::ConvexShape* shape = new sf::ConvexShape((unsigned int)
b2shape.GetVertexCount());
    shape->setFillColor(TetriminoColors[type]);
    shape->setOutlineThickness(1.0f);
    shape->setOutlineColor(sf::Color(128,128,128));
    fixture->SetUserData(shape);

    return fixture;
}
```

This method adds a square to the body at a specific place. It starts by creating a
o creates the
s user data to
the fixture. We don't set the initial position because the constructor will do it.

```
void Piece::update()
{
    const b2Transform& xf = _body->GetTransform();

    for(b2Fixture* fixture = _body->GetFixtureList(); fixture !=
nullptr;
    fixture=fixture->GetNext())
{
        sf::ConvexShape* shape = static_
cast<sf::ConvexShape*>(fixture->GetUserData());
        const b2PolygonShape* b2shape = static_
cast<b2PolygonShape*>(fixture->GetShape());
        const uint32 count = b2shape->GetVertexCount();
        for(uint32 i=0;i<count;++i)
{
            b2Vec2 vertex = b2Mul(xf,b2shape->m_vertices[i]);
            shape->setPoint(i,sf::Vector2f(converter::metersToPixels(
vertex.x),
            converter::metersToPixels(vertex.y)));
        }
    }
}
```

This method synchronizes the position and rotation of all the SFML shapes from
ce is
composed of several parts—fixture—we need to iterate through them and update them one by one.

```
void Piece::rotate(float angle) {
    body->ApplyTorque((float32)converter::degToRad(angle),true);
}
void Piece::moveX(int direction) {
    body->ApplyForceToCenter(b2Vec2(converter::pixelsToMeters(directi
on),0),true);
}
```

These two methods add some force to the object to move or rotate it. We forward the job to the Box2D library.

```
b2Body* Piece::getBody()const {return _body;}

void Piece::draw(sf::RenderTarget& target, sf::RenderStates states)
const
{
    for(const b2Fixture* fixture=_body->GetFixtureList();fixture!=null
ptr; fixture=fixture->GetNext())
    {
        sf::ConvexShape* shape = static_
cast<sf::ConvexShape*>(fixture->GetUserData());
        if(shape)
            target.draw(*shape,states);
    }
}
```

This function draws the entire piece. However, because the piece is composed of
der to
display the entire piece. This is done by using the user data saved in the fixtures.

The World class

Now that we have built our pieces, let's make a world that will be populated by them. This class will be very similar to the one previously made in the Tetris clone.
s and the
display updates. To do this, two `update` methods will be used.

The big change is that the board is no longer a grid, but a physical world. Because of this, a lot of internal logic will be changed. Now, let's see it:

```
class World : public sf::Drawable
{
    public:
        World(const World&) = delete;
        World& operator=(const World&) = delete;

        World(int size_x,int size_y);
        ~World();
        void update(sf::Time deltaTime);
        void updatePhysics(sf::Time deltaTime);
        Piece* newPiece();
        int clearLines(bool& del,const Piece& current);
        void updateGravity(int level);
        void add(Configuration::Sounds sound_id);
        bool isGameOver()const;

    private:
        virtual void draw(sf::RenderTarget& target, sf::RenderStates
states) const override;
        b2World _physicalWorld;
        void createWall(int pos_x, int pos_y, int size_x, int size_y);
        const int _x;
        const int _y;
        std::list<std::unique_ptr<sf::Sound>> _sounds;
};
```

ee, there
are now two `update` methods. One for the physics and another one for the SFML objects. We still have some methods specific for the game such as `newPiece()`, `clearLines()`, `isGameOver()`, a new one relative to the `updateGravity()` physic, and a method to add sounds to our world. This method directly comes from the Meteor game by copying and pasting it.

 following
ds some
walls to it:

```
World::World(int size_x,int size_y) : _physicalWorld(b2Vec2(0.f,
1.5f)),_x(size_x), _y(size_y)
{
```

```
    createWall(0,0,BOOK_BOX_SIZE,_y*BOOK_BOX_SIZE);
    createWall(BOOK_BOX_SIZE*(_x+1.2),0,BOOK_BOX_SIZE,_y*BOOK_BOX_
SIZE);
    createWall(0,BOOK_BOX_SIZE*_y,BOOK_BOX_SIZE*(_x+2.2),BOOK_BOX_
SIZE);
}
```

The destructor removes all the SFML shapes attached to the bodies still present in the world:

```
World::~World()
{
    for (b2Body* body=_physicalWorld.GetBodyList(); body!=nullptr;)
{
        b2Body* next = body->GetNext();
        if(body->GetType() == b2_dynamicBody)
            delete static_cast<Piece*>(body->GetUserData());
        else
            delete static_cast<sf::RectangleShape*>(body-
>GetUserData());
        body = next;
    }
}
```

cts
that display it. It also removes all the sounds effects that are finished, as already explained in the previous chapter:

```
void World::update(sf::Time deltaTime)
{
    for (b2Body* body=_physicalWorld.GetBodyList(); body!=nullptr;
    body=body->GetNext())
{
        if(body->GetType() == b2_dynamicBody){
            Piece* piece = static_cast<Piece*>(body->GetUserData());
            piece->update();
        }
    }
    _sounds.remove_if([](const std::unique_ptr<sf::Sound>& sound) ->
bool {
          return sound->getStatus() != sf::SoundSource::Status::Playi
ng;
        });
}
```

Now, we construct a class inside the `World.cpp` file because we don't need the class anywhere else. This class will be used to query the physical world by getting all the fixtures inside an area. This will be used more, especially to detect the completed lines:

```
Class _AABB_callback  : public b2QueryCallback
{
    public :
        std::<b2Fixture*> fixtures;

        virtual bool ReportFixture(b2Fixture* fixture) override {
            if(fixture->GetBody()->GetType() == b2_dynamicBody)
                fixtures.emplace_back(fixture);
            return true;
        }
};
```

specially
with the made class. Then, we count the number of fixtures (squares) on each line; if this number satisfies our criteria, we delete all the fixtures and the line. However, by doing this, we could have some bodies with no fixture. So, if we remove the last
fimove all
e fun, we
add some sounds to the world if needed:

```
int World::clearLines(bool& del,const Piece& current)
{
    int nb_lines = 0;
    _AABB_callback callback;
    del = false;
    for(int y=0;y<=_y;++y)
{ //loop on Y axies
        b2AABB aabb; //world query
        //set the limit of the query
        aabb.lowerBound = b2Vec2(converter::pixelsToMeters<double>(0),
        converter::pixelsToMeters<double>((y+0.49)*BOOK_BOX_SIZE));
        aabb.upperBound = b2Vec2(converter::pixelsToMeters<double>(_x*
BOOK_BOX_SIZE),
             converter::pixelsToMeters<double>((y+0.51)*BOOK_BOX_
SIZE));
        //query the world
        _physicalWorld.QueryAABB(&callback,aabb);
```

```
        if((int)callback.fixtures.size() >= _x)
{
            for(b2Fixture* fixture : callback.fixtures)
{
                b2Body* body = fixture->GetBody();
                del |= body == current.getBody();

                if(body->GetFixtureList()->GetNext() != nullptr)
               {//no more fixture attached to the body
                    sf::ConvexShape* shape = static_
cast<sf::ConvexShape*>(fixture->GetUserData());
                    body->DestroyFixture(fixture);
                    delete shape;
                } else {
                    Piece* piece = static_cast<Piece*>(body-
>GetUserData());
                    delete piece;
                }
                fixture = nullptr;
            }
            ++nb_lines;
        }
        callback.fixtures.clear();
    }
    if(nb_lines > 0)
        add(Configuration::Sounds::Explosion);
    return nb_lines;
}
```

Bigger the
level, stronger is the gravity:

```
void World::updateGravity(int level) {
    physical_world.SetGravity(b2Vec2(0,1.5+(level/2.0)));
}
```

s already
explained. It just adds sound to our world:

```
void World::add(Configuration::Sounds sound_id)
{
    std::unique_ptr<sf::Sound> sound(new
sf::Sound(Configuration::sounds.get(sound_id)));
    sound->setAttenuation(0);
    sound->play();
    _sounds.emplace_back(std::move(sound));
}
```

This method checks if the game is over with a simple criterion, "are there any bodies out of the board?":

```
bool World::isGameOver()const
{
    for (const b2Body* body=_physicalWorld.GetBodyList();
body!=nullptr;
    body=body->GetNext())
{
        if(body->GetType() == b2_staticBody)
            continue;
        if(body->GetPosition().y < 0)
            return true;
    }
    return false;
};
```

ox2D:

```
void World::updatePhysics(sf::Time deltaTime)
{
    float seconds = deltaTime.asSeconds();
    _physicalWorld.Step(seconds,8,3);
}
```

ard. We also
add a sound to alert the player about this:

```
Piece* World::newPiece()
{
    add(Configuration::Sounds::Spawn);
    return new Piece(_physicalWorld,_x/2*BOOK_BOX_SIZE, BOOK_BOX_
SIZE,static_cast<Piece::TetriminoTypes>( random(0, Piece::TetriminoTyp
es::SIZE-1)), random(0.f,360.f));
}
```

The `draw()` function is pretty simple. We iterate on all the bodies still alive in the world and display the SFML object attached to them:

```
void World::draw(sf::RenderTarget& target, sf::RenderStates states)
const
{
    for (const b2Body* body=_physicalWorld.GetBodyList();
body!=nullptr;body=body->GetNext())
{
        if(body->GetType() == b2_dynamicBody){
```

```
            Piece* piece = static_cast<Piece*>(body->GetUserData());
            target.draw(*piece,states);
        } else {//static body
            sf::RectangleShape* shape = static_
cast<sf::RectangleShape*>(body->GetUserData());
            target.draw(*shape,states);
        }
    }
}
```

that will
represent a wall. All the functionalities used were already explained in the first part of this chapter, so nothing should surprise you:

```
void World::creatWeall(int pos_x, int pos_y,int size_x,int size_y)
{
    b2BodyDef bodyDef;
    bodyDef.position.Set(converter::pixelsToMeters<double>(pos_x),
    converter::pixelsToMeters<double>(pos_y));
    bodyDef.type = b2_staticBody;

    b2PolygonShape b2shape;
    double sx = converter::pixelsToMeters<double>(size_x)/2.0;
    double sy = converter::pixelsToMeters<double>(size_y)/2.0;
    b2shape.SetAsBox(sx,sy,b2Vec2(sx,sy),0);

    b2FixtureDef fixtureDef;
    fixtureDef.density = 1.0;
    fixtureDef.friction = 0.8;
    fixtureDef.restitution= 0.1;
    fixtureDef.shape = &b2shape;

    b2Body* body = _physicalWorld.CreateBody(&bodyDef);
    body->CreateFixture(&fixtureDef);

    sf::Shape* shape = new sf::RectangleShape(sf::Vector2f(size_x,siz
e_y));
    shape->setOrigin(size_x/2.0,size_y/2.0);
    shape->setPosition(sf::Vector2f(pos_x+size_x/2.0,pos_
y+size_y/2.0));
    shape->setFillColor(sf::Color(50,50,50));
    body->SetUserData(shape);
}
```

The Game class

he last
important class—the `Game` class.

There is a big change in this class. If you remember, in *Chapter 2, General Game Architecture, User Inputs, and Resource Management*, I said that a game with physics should use two game loops instead of one. The reason for this is that most of the physical engine works well with a fixed time step. Moreover, this can avoid a really bad thing. Imagine that your physical engine takes 0.01 second to compute the new
rgument to
your `update`ath
state and will finally freeze.

ysics will run
re is not
but this will
be done later, in the sixth chapter.

Take a look at the `Game` header file:

```
class Game: public ActionTarget<int>
{
    public:
        Game(const Game&) = delete;
        Game& operator=(const Game&) = delete;
        Game(int x,int y,int word_x=10,int word_y=20);
        void run(int minimum_frame_per_seconds=30,int phyiscs_frame_
per_seconds=60);

    private:
        void processEvents();
        void update(const sf::Time& deltaTime,const sf::Time&
timePerFrame);
        void updatePhysics(const sf::Time& deltaTime,const sf::Time&
timePerFrame);
        void render();

        sf::RenderWindow _window;
        int _moveDirection;
        int _rotateDirection;
        Piece* _currentPiece;
        World _world;
        Stats _stats;
        sf::Time timeSinceLastFall;
};
```

No surprises here. The usual methods are present. We just duplicate the `update` function, one for logic and the other for physics.

Now, let's see the implementation. The constructor initializes `World` and binds the player inputs. It also creates the initial piece that will fall on the board:

```
Game::Game(int X, int Y,int word_x,int word_y) : ActionTarget(Config
uration::playerInputs), _window(sf::VideoMode(X,Y),"04_Gravitris"),_
currentPiece(nullptr), _world(word_x,word_y)
{
    bind(Configuration::PlayerInputs::HardDrop,[this](const
sf::Event&){
         _currentPiece = _world.newPiece();
         timeSinceLastFall = sf::Time::Zero;
    });
    bind(Configuration::PlayerInputs::TurnLeft,[this](const
sf::Event&){
         _rotateDirection-=1;
    });
    bind(Configuration::PlayerInputs::TurnRight,[this](const
sf::Event&){
         _rotateDirection+=1;
    });
    bind(Configuration::PlayerInputs::MoveLeft,[this](const
sf::Event&){
         _moveDirection-=1;
    });
    bind(Configuration::PlayerInputs::MoveRight,[this](const
sf::Event&){
         _moveDirection+=1;
    });
    _stats.setPosition(BOOK_BOX_SIZE*(word_x+3),BOOK_BOX_SIZE);
    _currentPiece = _world.newPiece();
}
```

The following function has nothing new except that the two `update()` functions are called instead of one:

```
void Game::run(int minimum_frame_per_seconds, int physics_frame_per_
seconds)
{
    sf::Clock clock;
    const sf::Time timePerFrame = sf::seconds(1.f/minimum_frame_per_
seconds);
```

```
    const sf::Time timePerFramePhysics = sf::seconds(1.f/physics_
frame_per_seconds);

    while (_window.isOpen())
    {
        sf::Time time = clock.restart();
        processEvents();
        if(not _stats.isGameOver())
{
            updatePhysics(time,timePerFramePhysics);
            update(time,timePerFrame);
        }
        render();
    }
}
```

The following function updates the logic of our game:

```
void Game::update(const sf::Time& deltaTime,const sf::Time&
timePerFrame)
{
    sf::Time timeSinceLastUpdate = sf::Time::Zero;

    timeSinceLastUpdate+=deltaTime;
    timeSinceLastFall+=deltaTime;
    if(timeSinceLastUpdate > timePerFrame)
    {
        if(_currentPiece != nullptr)
        {
            _currentPiece->rotate(_rotateDirection*3000);
            _currentPiece->moveX(_moveDirection*5000);

            bool new_piece;
            int old_level =_stats.getLevel();
            _stats.addLines(_world.clearLines(new_piece,*_
currentPiece));
            if(_stats.getLevel() != old_level) //add sound
                _world.add(Configuration::Sounds::LevelUp);

            if(new_piece or timeSinceLastFall.asSeconds() >
std::max(1.0,10-_stats.getLevel()*0.2))
            {//create new piece
                _currentPiece = _world.newPiece();
```

```
                timeSinceLastFall = sf::Time::Zero;
            }
        }
        _world.update(timePerFrame);
        _stats.setGameOver(_world.isGameOver());
        timeSinceLastUpdate = sf::Time::Zero;
    }
    _rotateDirection=0;
    _moveDirection=0;
}
```

Here is the step-by-step evaluation of the preceding code:

1. We start by updating some time value by adding the `deltaTime` parameter to them.
2. Then, we apply some forces to the current piece if needed.
3. We update the world by cleaning all the complete lines and also update the score.
4. If needed, we create a new piece that will replace the current one.

Now, take a look at the physics:

```
void Game::updatePhysics(const sf::Time& deltaTime,const sf::Time&
timePerFrame)
{
    static sf::Time timeSinceLastUpdate = sf::Time::Zero;
    timeSinceLastUpdate+=deltaTime;
    _world.updateGravity(_stats.getLevel());

    while (timeSinceLastUpdate > timePerFrame)
{
        _world.updatePhysics(timePerFrame);
        timeSinceLastUpdate -= timePerFrame;
    }
}
```

This function updates all the physics, including the gravity that changes with the current level. Here again, nothing is too complicated.

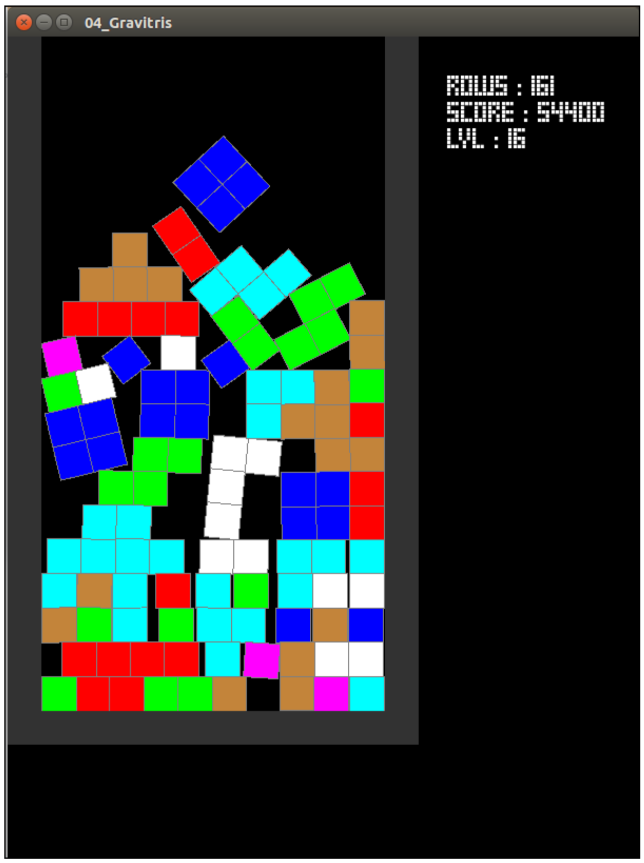
The `processEvents()` and `render()` functions don't change at all, and are exactly the same as in the first Tetris.

As you can see, the `Game` class doesn't change a lot and is very similar to the one previously made. The two loops—logics and physics—are the only real changes that occur.

The Stats class

Now, the last thing to build is the `Stats` class. However, we have already made it in the previous version of Tetris, so just copy and paste it. A little change has been made for the game over, by adding a getter and setter. That's it.

and
gravity. The final result should look like the following screenshot:



Summary

the units and
w to pair
oject, and
build a new funny game.

me in order to
interact with the user easily, by creating our own game user interface or by using an existing one.

5
Playing with User Interfaces

In the previous chapters, we have learned how to build some simple games. This
ace to
ace:

- Creating your own objects
- Using a library that already exists–**Simple and Fast Graphical User Interface** (**SFGUI**)

ex interfaces
to communicate with the player.

What is a GUI?

A **Graphical User Interface** (**GUI**) is a mechanism that allows the user to visually interact with a software through graphical objects such as icons, text, buttons, and so on. Internally, a GUI handles some events and binds them to functions, mostly called callbacks. These functions define the reaction of the program.

GUI, such as
o you what a
button, window, or label is, but I will explain to you in short what a layout is.

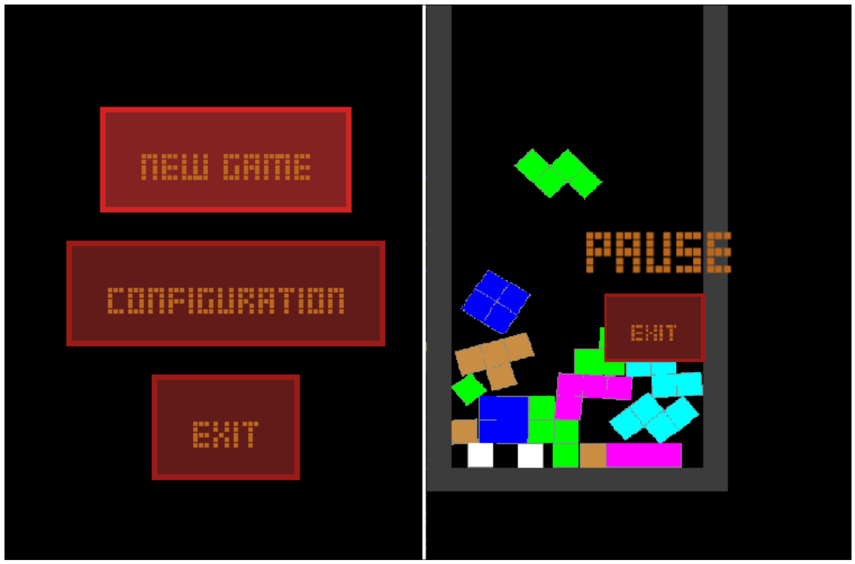
phical
and the position
of the objects by managing a part of them. It's like a table that makes sure none of these objects are on top of the others, and which adapts their size to fill the screen as proportionately as possible.

Creating a GUI from scratch

build

t, and the

result will be similar to the following two screenshots:



the game.

To build this GUI, only four different objects have been used: `TextButton`, `Label`, `Frame`, and `VLayout`. We will now see how to structure our code to be as flexible as possible to be able to extend this GUI in future if needed.

Class hierarchy

Each one

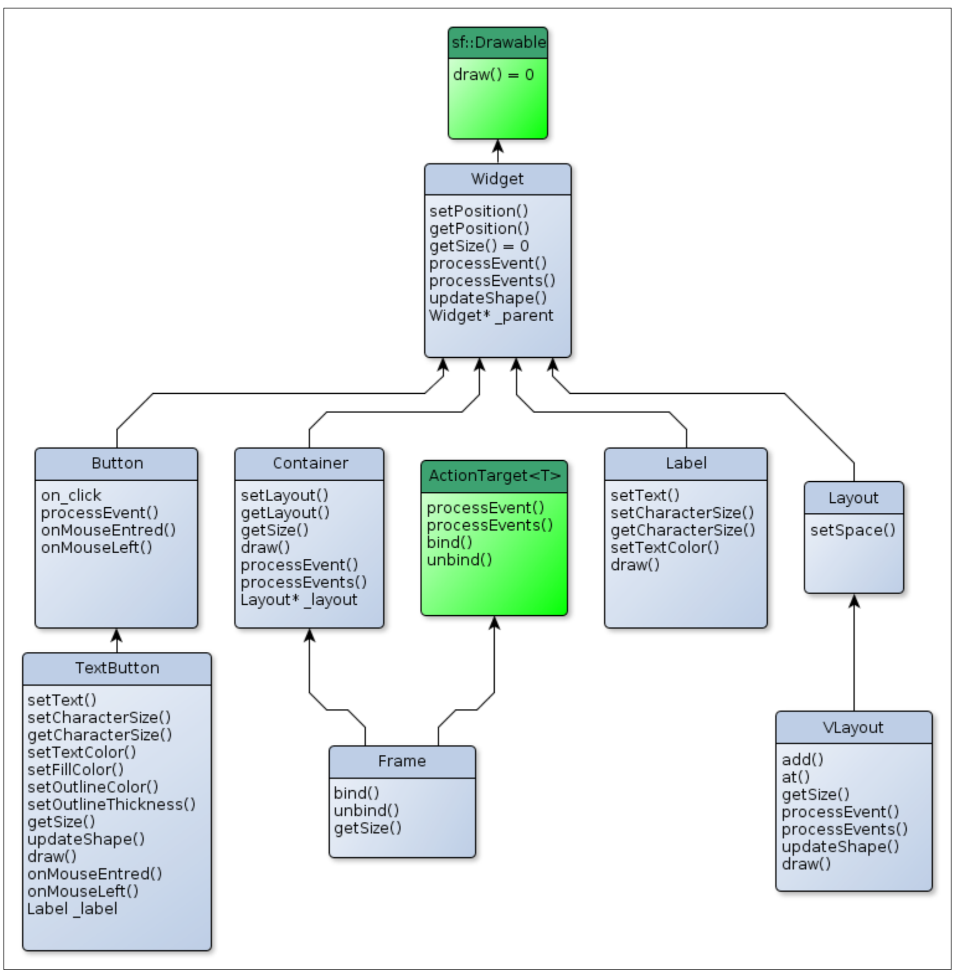
from the others.

Following are some characteristics of these components:

- `TextButton`: This class will represent a button that can trigger an "on click" event when clicked on. Graphically, it's a box with text inside it.
- `Label`: This accepts simple text that can be displayed on the screen.

- `Frame`: This class is an invisible container that will contain some object d will fill the entire window. This class can also process events (like catching the resize of the window, the click of the *Esc* key, and so on).
- `Vlayout`: This class's functionality has already been explained–it displays all the objects attached to it.

Because we want to build a GUI reusable and it needs to be as flexible as possible, we need to think bigger than our 4 classes to build it. For example, we should be able make use of addition of new components easily. Here is a possible solution:



I.

In the GUI system, each component is a `Widget`. This class is the base of all the other components and defines the common methods to interact with them. We also define some virtual classes, such as `Button`, `Container`, and `Layout`. Each of these classes adapts the `Widget` class and adds the possibility of growing our system without too much effort. For example, adding an `HLayout` class will be made possible by extending it from `Layout`. Other examples include some specific buttons such as `RadioButton` and `CheckBox`, which use the `Button` class.

In this hierarchy, the `Frame` class extends the `ActionTarget` class. The idea is to be able to use the bind methods of `ActionTarget` to catch some events such as when working in some window and the *Esc* key is pressed.

`Widget` class.

The Widget class

As already explained, this class is the common trunk of all the other GUI components. It provides some common methods with default behaviors that can be customized or improved on. A `Widget` class not only has a position and can
k at its
header source:

```
class Widget : public sf::Drawable
{
  public:
  Widget(Widget* parent=nullptr);
  virtual ~Widget();

  void setPosition(const sf::Vector2f& pos);
  void setPosition(float x,float y);
  const sf::Vector2f& getPosition()const;
  virtual sf::Vector2f getSize()const = 0;

  protected:
  virtual bool processEvent(const sf::Event& event,const
    sf::Vector2f& parent_pos);
  virtual void processEvents(const sf::Vector2f& parent_pos);
  virtual void updateShape();

  Widget* _parent;
  sf::Vector2f _position;
};
```

This first class is simple. We define a construct and a virtual destructor. The virtual
e GUI
logic. Then we define some getters and setters on the internal variables. A widget
 reference
to it for updating purposes. Now take a look at the implementation for a better understanding:

```
Widget::Widget(Widget* parent) : _parent(parent){}
Widget::~Widget(){}
void Widget::setPosition(const sf::Vector2f& pos) {_position =
  pos;}
void Widget::setPosition(float x,float y)
{
  _position.x = x;
  _position.y = y;
}
const sf::Vector2f& Widget::getPosition()const {return _position;}
bool Widget::processEvent(const sf::Event& event,const sf::Vector2f&
parent_pos) {return false;}
void Widget::processEvents(const sf::Vector2f& parent_pos) {}
```

Up to this point, nothing should surprise you. We only defined some getters/setters and coded the default behavior for event handling.

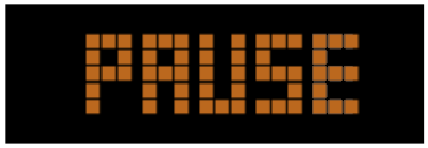
Now have a look at the following function:

```
void Widget::updateShape()
{
  if(_parent)
  _parent->updateShape();
}
```

opagate the
update request through the GUI tree. For example, from a button with a change in its size due to a text change, to its layout, to the container. By doing this, we are sure that each component will be updated without further efforts.

The Label class

Now that the `Widget` class has been introduced, let's build our first widget, a label.
c of GUI
through it. The result will be as follows:



For doing this we will run the following code:

```
class Label : public Widget
{
  public:
  Label(const std::string& text, Widget* parent=nullptr);
  virtual ~Label();

  void setText(const std::string& text);
  void setCharacterSize(unsigned int size);
  unsigned int getCharacterSize()const;
  void setTextColor(const sf::Color& color);
  virtual sf::Vector2f getSize()const override;

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

As you can see this class is nothing other than a box around `sf::Text`. It defines some methods taken from the `sf::Text` API with the exact same behavior. It also implements the requirements of `Widget` class such as the `getSize()` and `draw()` methods. Now let's have a look at the implementation:

```
Label::Label(const std::string& text, Widget* parent) :
  Widget(parent)
{
  _text.setFont(Configuration::fonts.get
    (Configuration::Fonts::Gui));
  setText(text);
  setTextColor(sf::Color(180,93,23));
}
```

font taken from
the `Configuration` class, and sets a color.

```
Label::~Label() {}
void Label::setText(const std::string& text)
{   _text.setString(text);
  updateShape();
}
void Label::setCharacterSize(unsigned int size)
{
  _text.setCharacterSize(size);
  updateShape();
}
```

These two functions forward their jobs to `sf::Text` and request for an update because of the possible change of size.

```
unsigned int Label::getCharacterSize()const {return
  _text.getCharacterSize();}

void Label::setTextColor(const sf::Color& color)
  {_text.setColor(color);}

sf::Vector2f Label::getSize()const
{
  sf::FloatRect rect = _text.getGlobalBounds();
  return sf::Vector2f(rect.width,rect.height);
}
```

SFML already provides a function to get the size of a `sf::Text` parameter, so we
owing code
snippet:

```
void Label::draw(sf::RenderTarget& target, sf::RenderStates
  states) const
{
  states.transform.translate(_position);
  target.draw(_text,states);
}
```

ts own
position, but is relative to the parent. So when we display the object, we need to update the `sf::RenderStates` parameter by translating the transform matrix by
but important.

The Button class

Now, we will build another `Widget` class that is very useful: the `Button` class. This class will be a virtual one because we want to be able to build several button classes.
the "on
o the header of
this class:

```
class Button : public Widget
{
  public:
  using FuncType = std::function<void(const sf::Event&
    event,Button& self)>;
  static FuncType defaultFunc;
  Button(Widget* parent=nullptr);

  virtual ~Button();
  FuncType onClick;

  protected:
  virtual bool processEvent(const sf::Event& event,const
    sf::Vector2f& parent_pos)override;
  virtual void onMouseEntered();
  virtual void onMouseLeft();

  private:
  enum Status {None =0,Hover = 1};
  int _status;
};
```

As usual, we declare the constructor and the destructor. We also declare an `onClick` attribute, which is an `std::function` that will be triggered when the button is pushed. This is our callback. The callback type is kept as `typedef` and
ok at the
implementation:

```
Button::FuncType Button::defaultFunc = [](const
  sf::Event&,Button&)->void{};
```

n that will
be used as the default for the `onClick` attribute. This function does nothing:

```
Button::Button(Widget* parent) : Widget(parent),
  onClick(defaultFunc), _status(Status::None) {}
```

and also
sets the `onClick` value to the default empty function previously defined to avoid undefiwn in
the following code snippet:

```
Button::~Button() {}
bool Button::processEvent(const sf::Event& event,const
sf::Vector2f& parent_pos)
{
  bool res = false;
  if(event.type == sf::Event::MouseButtonReleased)
  {
    const sf::Vector2f pos = _position + parent_pos;
    const sf::Vector2f size = getSize();
    sf::FloatRect rect;
    rect.left = pos.x;
    rect.top = pos.y;
    rect.width = size.x;
    rect.height = size.y;
    if(rect.contains(event.mouseButton.x,event.mouseButton.y))
{
      onClick(event,*this);
        res = true;
    }
  } else if (event.type == sf::Event::MouseMoved) {
    const sf::Vector2f pos = _position + parent_pos;
    const sf::Vector2f size = getSize();
    sf::FloatRect rect;
    rect.left = pos.x;
    rect.top = pos.y;
    rect.width = size.x;
    rect.height = size.y;
    int old_status = _status;
    _status = Status::None;
    const sf::Vector2f
    mouse_pos(event.mouseMove.x,event.mouseMove.y);
    if(rect.contains(mouse_pos))
      _status=Status::Hover;
    if((old_status & Status::Hover) and not (_status &
      Status::Hover))
        onMouseLeft();
    else if(not (old_status & Status::Hover) and (_status &
      Status::Hover))
        onMouseEntered();
  }
  return res;
}
```

This function is the heart of our class. It manages the events by triggering some callbacks when some criteria are satisfied. Let's take a look at it step by step:

1. If the event received as the parameter is a click, we have to check whether it happens in the button area. If so, we trigger our `onClick` function.
2. On the other hand, if the event is caused by moving the pointer, we verify if the mouse pointer is hovering over the button. If so, we set the status value to `Hover`, and here is the trick:
3. If this flag was newly defined to `Hover`, then we call the `onMouseEntered()` method, which can be customized.
4. If the flag was previously defined to `Hover` but is not set to it anymore, it's
   :
   `onMouseLeft()`.

> The value returned by the `processEvent()` method will stop the propagation of the event on the GUI if it's set to `true`. Returning false will continue the propagation of the event, so it's also possible to use an event without stopping its propagation; on the mouse moving away, for example. But in this case, we simply can't click on multiple widget objects at the same time, so we stop if needed.

I hope the logic of the `processEvent()` function is clear, because our GUI logic is based on it.

Following two functions are the default empty behavior of the button with a mouse move event. Of course, we will customize them in the specialized `Button` classes:

```
void Button::onMouseEntered() {}
void Button::onMouseLeft() {}
```

The TextButton class

This class will extend our previously defined `Button` class. The result will be a
ing screenshot:

Now take a look at the implementation. Remember that our `Button` class extends from `sf::Drawable`:

```
class TextButton : public
{
  public:
  TextButton(const std::string& text, Widget* parent=nullptr);
  virtual ~TextButton();

  void setText(const std::string& text);
  void setCharacterSize(unsigned int size);

  void setTextColor(const sf::Color& color);
  void setFillColor(const sf::Color& color);
  void setOutlineColor(const sf::Color& color);
  void setOutlineThickness(float thickness);
  virtual sf::Vector2f getSize()const override;

  private:
  sf::RectangleShape _shape;
  Label _label;
  void updateShape()override;
  virtual void draw(sf::RenderTarget& target, sf::RenderStates
    states) const override;
  sf::Color _fillColor;
  sf::Color _outlineColor;
  virtual void onMouseEntered()override;
  virtual void onMouseLeft()override;
};
```

This class extends the `Button` class and adds a rectangle shape and a label to it. It also implements the `onMouseEntered()` and `onMouseLeft()` functions. These two functions will change the color of the button, making them a bit lighter:

```
TextButton::TextButton(const std::string& text,Widget* parent) :
  Button(parent), _label(text,this)
{
  setFillColor(sf::Color(86,20,19));
  setOutlineThickness(5);
  setOutlineColor(sf::Color(146,20,19));
}
```

The constructor initializes the different colors and the initial text:

```
TextButton::~TextButton() {}
void TextButton::setText(const std::string& text)
  {_label.setText(text);}
void TextButton::setCharacterSize(unsigned int size)
  {_label.setCharacterSize(size);}
```

```
void TextButton::setTextColor(const sf::Color& color)
  {_label.setTextColor(color);}

void TextButton::setFillColor(const sf::Color& color)
{
  _fillColor = color;
  _shape.setFillColor(_fillColor);
}

void TextButton::setOutlineColor(const sf::Color& color)
{
  _outlineColor = color;
  _shape.setOutlineColor(_outlineColor);
}

void TextButton::setOutlineThickness(float thickness)
  {_shape.setOutlineThickness(thickness);}

sf::Vector2f TextButton::getSize()const
{
  sf::FloatRect rect = _shape.getGlobalBounds();
  return sf::Vector2f(rect.width,rect.height);
}
```

All these functions set the different attributes by forwarding the job. It also calls the `updateShape()` method to update the container:

```
void TextButton::updateShape()
{
  sf::Vector2f label_size = _label.getSize();
  unsigned int char_size = _label.getCharacterSize();
  _shape.setSize(sf::Vector2f(char_size*2 + label_size.x
    ,char_size*2 + label_size.y));
  _label.setPosition(char_size,char_size);
  Widget::updateShape();
}
```

rom the
internal label and adding some padding to it:

```
void TextButton::draw(sf::RenderTarget& target, sf::RenderStates
states) const
{
  states.transform.translate(_position);
  target.draw(_shape,states);
  target.draw(_label,states);
}
```

This method has the same logic as Label. It moves `sf::RenderStates` to the position of the button and draws all the different `sf::Drawable` parameters:

```
void TextButton::onMouseEntered()
{
  const float light = 1.4f;
  _shape.setOutlineColor(sf::Color(_outlineColor.r*light,
  _outlineColor.g*light,
  _outlineColor.b*light));
  _shape.setFillColor(sf::Color(_fillColor.r*light,
  _fillColor.b*light,
  _fillColor.b*light));
}

void TextButton::onMouseLeft()
{
  _shape.setOutlineColor(_outlineColor);
  _shape.setFillColor(_fillColor);
}
```

vering over
 for the user,
because he knows which button will be clicked easily.

As you can see, implementation of a `TextButton` is pretty short, all thanks to the changes made in the parent classes, `Button` and `Widget`.

The Container class

This class is another type of `Widget` and will be abstract. A `Container` class is a `Widget` class that will store other widgets through a `Layout` class. The purpose of this class is to group all the common operations between the different possible `Container` classes, even as in our case, we only implement a `Frame` container.

```
class Container  : public Widget
{
  public:
  Container(Widget* parent=nullptr);
  virtual ~Container();

  void setLayout(Layout* layout);
  Layout* getLayout()const;

  virtual sf::Vector2f getSize()const override;

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

```
    virtual bool processEvent(const sf::Event& event,const
      sf::Vector2f& parent_pos)override;
    virtual void processEvents(const sf::Vector2f&
      parent_pos)override;

    private:
    Layout* _layout;
};
```

As usual, we define the constructor and destructor. We also add accessors to the internal `Layout` class. We will also implement the `draw()` method and the event snippet:

```
Container::Container(Widget* parent) : Widget(parent),
  _layout(nullptr) {}
Container::~Container()
{
  if(_layout != nullptr and _layout->_parent == this) {
    _layout->_parent = nullptr;
    delete _layout;
  }
}
```

The destructor deletes the internal `Layout` class, but only if the parent of the `Layout` class is the current container. This avoids double free corruption and respects the RAII idiom:

```
void Container::setLayout(Layout* layout)
{
  if(_layout != nullptr and _layout->_parent == this) {
    _layout->_parent = nullptr;
  }
  if((_layout = layout) != nullptr) {
    _layout->_parent = this;
    _layout->updateShape();
  }
}
```

The previous function sets the layout of the container and deletes it from the memory
ernal
pointer to it.

```
Layout* Container::getLayout()const {return _layout;}
sf::Vector2f Container::getSize()const
{
  sf::Vector2f res(0,0);
  if(_layout)
```

```
    res = _layout->getSize();
    return res;
  }
  void Container::draw(sf::RenderTarget& target, sf::RenderStates
    states) const
  {
    if(_layout)
    target.draw(*_layout,states);
  }
```

The three previous functions do the usual job, just as with the other `Widgets`:

```
  bool Container::processEvent(const sf::Event& event,const
    sf::Vector2f& parent_pos)
  {
      bool res = false;
      if(and _layout)
          res = _layout->processEvent(event,parent_pos);
      return res;
  }
  void Container::processEvents(const sf::Vector2f& parent_pos)
  {
      if(_layout)
          _layout->processEvents(parent_pos);
  }
```

These two previous functions process for the events. Because a `Layout` class doesn't have any event to deal with, it forwards the job to all the internal `Widget` classes. If an event is processed by a `Widget` class, we stop the propagation, because logically no other widget should be able to deal with it.

The Frame class

a special one.

The following `Widget` class will be attached to `sf::RenderWindow` and will be the main widget. It will manage the render target and the events by itself. Take a look at its header:

```
  class Frame : public Container, protected ActionTarget<int>
  {
    public:
    using ActionTarget<int>::FuncType;
    Frame(sf::RenderWindow& window);
    virtual ~Frame();

    void processEvents();
```

```
    bool processEvent(const sf::Event& event);

    void bind(int key,const FuncType& callback);
    void unbind(int key);

    void draw();
    virtual sf::Vector2f getSize()const override;

    private:
    sf::RenderWindow& _window;

    virtual bool processEvent(const sf::Event& event,const
      sf::Vector2f& parent_pos)override;
    virtual void processEvents(const sf::Vector2f&
      parent_pos)override;
};
```

As you can see, this class is a bit more complex than the previous `Widget`. It extends the `Container` class to be able to attach a `Layout` class to it. Moreover, it also extends the `ActionTarget` class, but as protected. This is an important point. In fact, we want to allow the user to bind/unbind events, but we don't want to allow them to cast the `Frame` to an `ActionTarget`, so we hide it to the user and rewrite all the methods of the `ActionTarget` class. This is why there is a protected keyword.

his explains
why we need to keep a reference to it, as seen here:

```
Frame::Frame(sf::RenderWindow& window) : Container(nullptr),
  ActionTarget(Configuration::gui_inputs), _window(window) {}
Frame::~Frame(){}

void Frame::draw() {_window.draw(*this);}

void Frame::bind(int key,const FuncType& callback)
  {ActionTarget::bind(key,callback);}

void Frame::unbind(int key) {ActionTarget::unbind(key);}

sf::Vector2f Frame::getSize()const
{
  sf::Vector2u size = _window.getSize();
  return sf::Vector2f(size.x,size.y);
}
```

All these methods are simple and don't require a lot of explanation. You simply initialize all the attributes with the constructor and forward the job to the attributes stored inside the class for the others, as done here:

```
void Frame::processEvents()
{
    sf::Vector2f parent_pos(0,0);
    processEvents(parent_pos);
}
bool Frame::processEvent(const sf::Event& event)
{
    sf::Vector2f parent_pos(0,0);
    return processEvent(event,parent_pos);
}
```

b to the
override functions inherited from `Widget` by constructing the missing ones or the already known arguments.

```
bool Frame::processEvent(const sf::Event& event,const
  sf::Vector2f& parent_pos)
{
  bool res = ActionTarget::processEvent(event);
  if(not res)
  res = Container::processEvent(event,parent_pos);
  return res;
}

void Frame::processEvents(const sf::Vector2f& parent_pos)
{
  ActionTarget::processEvents();
  Container::processEvents(parent_pos);
  sf::Event event;
  while(_window.pollEvent(event))
  Container::processEvent(event,parent_pos);
}
```

f the
`ActionTarget` and `Container` bases of the class, but also take in charge the polling
 automatic.

The `Frame` class is now over. As you can see, it's not a complex task, thanks to our hierarchical tree and because we reused code here.

The Layout class

g, let's build
the class that will be in charge of their arrangement:

```
class Layout : protected Widget
{
  public:
  Layout(Widget* parent=nullptr);
  virtual ~Layout();

  void setSpace(float pixels);

  protected:
  friend class Container;
  float _space;
};
```

As you can see, the abstract class is very simple. The only new feature is the ability to set spacing. We don't have any `add(Widget*)` method, for example. The reason is that the argument will be slightly different depending on the kind of `Layout` used. For example, we just need a `Widget` class as argument for the layout with a single
 need two other
integers that represent the cell in which the widget can be placed. So, no common API is designed here. As you will see, the implementation of this class is also very
`Widget` class
we previously created.

```
Layout::Layout(Widget* parent): Widget(parent), _space(5) {}

Layout::~Layout() {}
void Layout::setSpace(float pixels)
{
    if(pixels >= 0) {
        _space = pixels;
        updateShape();
    }
    else
        throw std::invalid_argument("pixel value must be >= 0");
}
```

The VLayout class

This Layoute
s size and the
alignment of all its internal objects:

```
class VLayout : public Layout
{
  public:
  VLayout(const VLayout&) = delete;
  VLayout& operator=(const VLayout&) = delete;
  VLayout(Widget* parent = nullptr);
  ~Vlayout();

  void add(Widget* widget);
  Widget* at(unsigned int index)const;
  virtual sf::Vector2f getSize()const override;

  protected:
  virtual bool processEvent(const sf::Event& event,const
    sf::Vector2f& parent_pos) override;
  virtual void processEvents(const sf::Vector2f& parent_pos)
    override;

  private:
  std::vector<Widget*> _widgets;
  virtual void updateShape() override;
  virtual void draw(sf::RenderTarget& target, sf::RenderStates
    states) const override;
};
```

The class will implement all the requirements from the widget and will also add
ent. To
keep a trace of the widgets attached to the Layout class, we will internally store them in a container. The choice of the std::vector class makes sense here because of the random access of the elements for the at() method and the great number
rmance, since
an std::list will also be able to do the same job. Now, let's have a look at the implementation:

```
VLayout::VLayout(Widget* parent) : Layout(parent) {}
VLayout::~VLayout()
{
    for(Widget* widget : _widgets) {
        if(widget->_parent == this)
            delete widget;
    }
}
```

The destructor will free the memory from the objects attached to the `Layout` class, with the same criteria as the ones explained in the `Container` class:

```
void VLayout::add(Widget* widget)
{
  widget->_parent = this;
  _widgets.emplace_back(widget);
  updateShape();
}
Widget* VLayout::at(unsigned int index)const {return
  _widgets.at(index);}
```

These two previous functions add the possibility to add and get access to the widget stored by the class instance. The `add()` method additionally takes ownership of the added object:

```
sf::Vector2f VLayout::getSize()const
{
  float max_x = 0;
  float y = 0;
  for(Widget* widget : _widgets)
  {
    sf::Vector2f size = widget->getSize();
    if(size.x > max_x)
    max_x = size.x;
    y+= _space + size.y;
  }
  return sf::Vector2f(max_x+_space*2,y+_space);
}
```

This method calculates the total size of the layout, taking into account the spacing. Because our class will display all the objects in a single column, the height will be ng has to be
taken into account each time.

```
bool VLayout::processEvent(const sf::Event& event,const sf::Vector2f&
parent_pos)
{
  for(Widget* widget : _widgets)
{
    if(widget->processEvent(event,parent_pos))
    return true;
  }
    return false ;
}
```

```
void VLayout::processEvents(const sf::Vector2f& parent_pos)
{
  for(Widget* widget : _widgets)
  widget->processEvents(parent_pos);
}
```

These two previous methods forward the job to all the stored widget , but we stop the propagation when it's needed.

```
void VLayout::updateShape()
{
  float max_x = (_parentparent->getSize().x:0);
  for(Widget* widget : _widgets) {
  sf::Vector2f size = widget->getSize();
  float widget_x = size.x;
  if(widget_x > max_x)
  max_x = widget_x;
}
  float pos_y = _space;
  if(_parent)
  pos_y = (_parent->getSize().y - getSize().y)/2.f;
  for(Widget* widget : _widgets)
{
    sf::Vector2f size = widget->getSize();
    widget->setPosition((max_x-size.x)/2.0,pos_y);
    pos_y += size.y + _space;
  }
  Widget::updateShape();
}
```

This method is the most important for this class. It resets the different positions of all the objects by calculating it based on all the other widgets. The final result will be a column of widgets centered vertically and horizontally.

```
void VLayout::draw(sf::RenderTarget& target, sf::RenderStates states)
const
{
  for(Widget* widget : _widgets)
  target.draw(*widget,states);
}
```

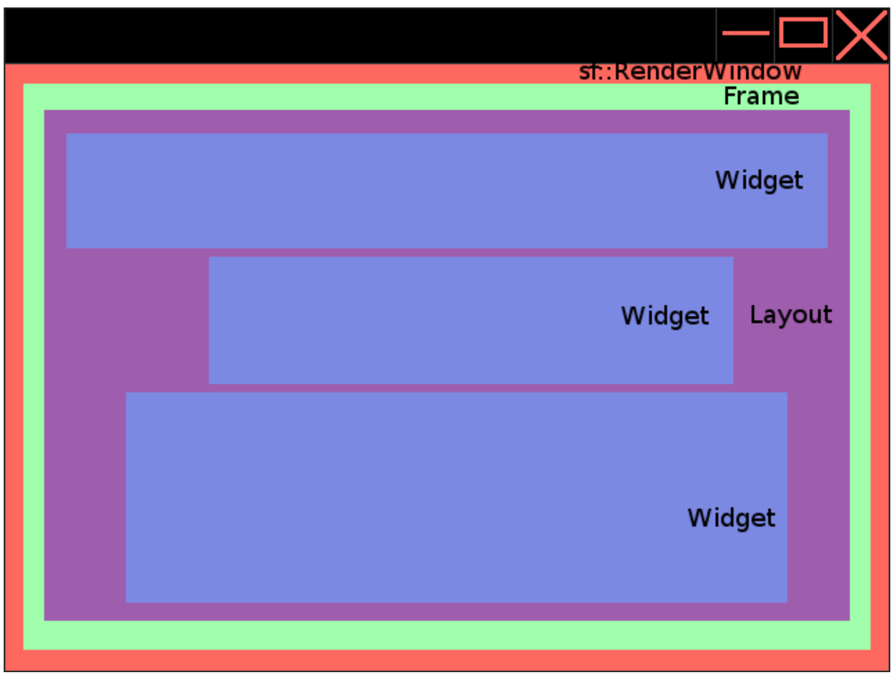
This last function asks each `Widget` to render itself by forwarding the parameter.
 layout is the
same as its parent.

user to use
them and add a menu to our game.

Adding a menu to the game

it with our
pause
GUI.

noticed
that the base component of our GUI is `Frame`. All the other widgets will be displayed
y:



Each color represents a different type of component. The trunk is **sf::RenderWindow** and then we have a **Frame** attached to it with its **Layout**. And finally we have some different **Widget**. Now that the usage has been explained, let's create our main menu.

Building the main menu

To build the main menu, we will need to add an attribute to the `Game` class. Let's call it `_mainMenu`.

```
gui::Frame _mainMenu;
```

We then create an `enum` function with different possibilities of values in order to know the currently displayed status:

```
enum Status
  {StatusMainMenu,StatusGame,StatusConfiguration,StatusPaused,
    StatusExit} _status
```

Now let's create a function to initialize the menu:

```
void initGui();
```

nstructor that
is calling. Now that we have all that we need in the header file, let's move on to the implementation of all this stuff.

First of all, we need to update the constructor by adding in the initialization of `_mainMenu` and `_status`. It should look like this:

```
Game::Game(int X, int Y,int word_x,int word_y) :
ActionTarget(Configuration::player_inputs),
_window(sf::VideoMode(X,Y),"05_Gui"), _current_piece(nullptr),
_world(word_x,word_y), _mainMenu(_window),
_status(Status::StatusMainMenu)
{
  //...
  initGui();
}
```

Now we need to implement the `initGui()` function as follows:

```
void Game::initGui()
{
  book::gui::VLayout* layout = new book::gui::VLayout;
  layout->setSpace(25);
  book::gui::TextButton* newGame = new book::gui::TextButton("New
    Game");
  newGame->onClick = [this](const sf::Event&, book::gui::Button&
    button){
  initGame();
  _status = Status::StatusGame;
};
```

```
layout->add(newGame);
book::gui::TextButton* configuration = new
  book::gui::TextButton("Configuration");
configuration->onClick = [this](const sf::Event&,
  book::gui::Button& button){
  _status = Status::StatusConfiguration;
};

layout->add(configuration);
book::gui::TextButton* exit = new book::gui::TextButton("Exit");
exit->onClick = [this](const sf::Event&, book::gui::Button&
  button){
  _window.close();
};
layout->add(exit);
_mainMenu.setLayout(layout);
_mainMenu.bind(Configuration::GuiInputs::Escape,[this](const
    sf::Event& event){
    this->_window.close();
  });
}
```

Let's discuss this function step by step:

1. We create a `Vlayout` class and set its spacing.
2. We create a button with `New Game` as its label.
3. We set the `onClick` callback function that initializes the game.
4. We add the button to the layout.
5. With the same logic, we create two other buttons with different callbacks.
6. Then we set the layout to the `_mainMenu` parameter.
7. And we finally add an event directly to the frame that will handle the *Esc* key. This key is defined in the `GuiInputs enum` contained in the `Configuration` class, which was constructed as `PlayerInputs`.

existing
`run()`, `processEvents()`, and `render()` methods. Let's start with `run()`. The
modifiall of
the update methods, adding verification on the `_status` variable. The new line is now as follows:

```
if(_status == StatusGame and not _stats.isGameOver())
```

The next function is `processEvents()`, which will require a little more modification, but not too much. In fact, we need to call `_mainMenu::processEvent(const f::Event&)` and `_mainMenu::processEvents()`, but only when the game is in `StatusMainMenu` mode. The new method is now as follows:

```
void Game::processEvents()
{
  sf::Event event;
  while(_window.pollEvent(event))
  {
    if (event.type == sf::Event::Closed)
    _window.close();
    else if (event.type == sf::Event::KeyPressed and
      event.key.code == sf::Keyboard::Escape and _status ==
        Status::StatusGame)
    _status = StatusPaused;
    else
    {
      switch(_status)
      {
        case StatusMainMenu: _mainMenu.processEvent(event);break;
        case StatusGame : ActionTarget::processEvent(event);break;
        default : break;
      }
    }
  }
  switch(_status)
  {
    case StatusMainMenu: _mainMenu.processEvents();break;
    case StatusGame :  ActionTarget::processEvents();break;
    default : break;
  }
}
```

As you can see, the modification is not too complicated, and easily understandable.

And now, the last change in the `render()` method. The logic is the same, a switch on the `_status` value.

```
void Game::render()
{
  _window.clear();
  switch(_status)
  {
    case StatusMainMenu: _window.draw(_mainMenu);break;
```

```
        case StatusGame :
        {
    if(not _stats.isGameOver())
      _window.draw(_world);
      _window.draw(_stats);
        }break;
        default : break;
      }
    _window.display();
    }
```

much
effort. The result should be like the figure shown here:

Now, let's build the second menu.

Building the pause menu

skip the
constructor part and directly move on to the `initGui()` function:

```
void Game::initGui()
{
  //...
  book::gui::VLayout* layout = new book::gui::VLayout;
  layout->setSpace(50);
  book::gui::Label* pause = new book::gui::Label("Pause");
  pause->setCharacterSize(70);
```

```
    layout->add(pause);
    book::gui::TextButton* exit = new book::gui::TextButton("Exit");
    exit->onClick = [this](const sf::Event&, book::gui::Button&
      button)
    {
      _status = StatusMainMenu;
    };

    layout->add(exit);
    _pauseMenu.setLayout(layout);
    _pauseMenu.bind(Configuration::GuiInputs::Escape,[this](const
      sf::Event& event){
    _status = StatusGame;
    });
  }
```

here we
use a `Label` and a `TextButton` class. The callback of the button will also change the `_status` value. Here, again, we catch the *Esc* key. The result is to leave this menu. In the `processEvents()`, we only need to add one line to the first switch:

```
case StatusPaused :_pauseMenu.processEvent(event);break;
```

And add another line to the second switch:

```
case StatusPaused : _pauseMenu.processEvents();break;
```

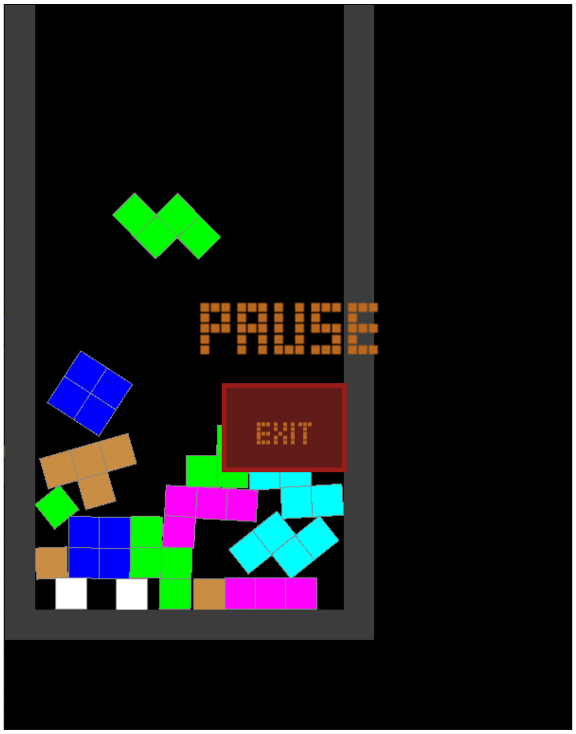
And that's it. We are done with this function.

The next step is the `render()` function. Here again it will be very quick. We add a case in the switch statement as follows:

```
case StatusPaused :
{
    if(not _stats.isGameOver())
        _window.draw(_world);
    _window.draw(_pauseMenu);
}break;
```

The request to draw `_world` means to set the current game state in the background on the menu. This is useless, but pretty cool, so why not?

The final result is the second screenshot shown at the beginning of this chapter. Have a look at what appears on my screen:



Building the configuration menu

I), but
we need a way to exit the configuration menu. So we simply have to create a _configurationMenu as the two others and bind the Escape event to set the status to the main menu. The code in the initGui() to add is shown as follows:

```
_configurationMenu.bind(Configuration::GuiInputs::Escape,[this]
  (const sf::Event& event){
    _status = StatusMainMenu;
});
```

I'm sure you are now able to update the processEvents() and render() functions by yourself using your new skills.

That's all concerning our home-made GUI. Of course, you can improve it as you wish. That's one of its advantages.

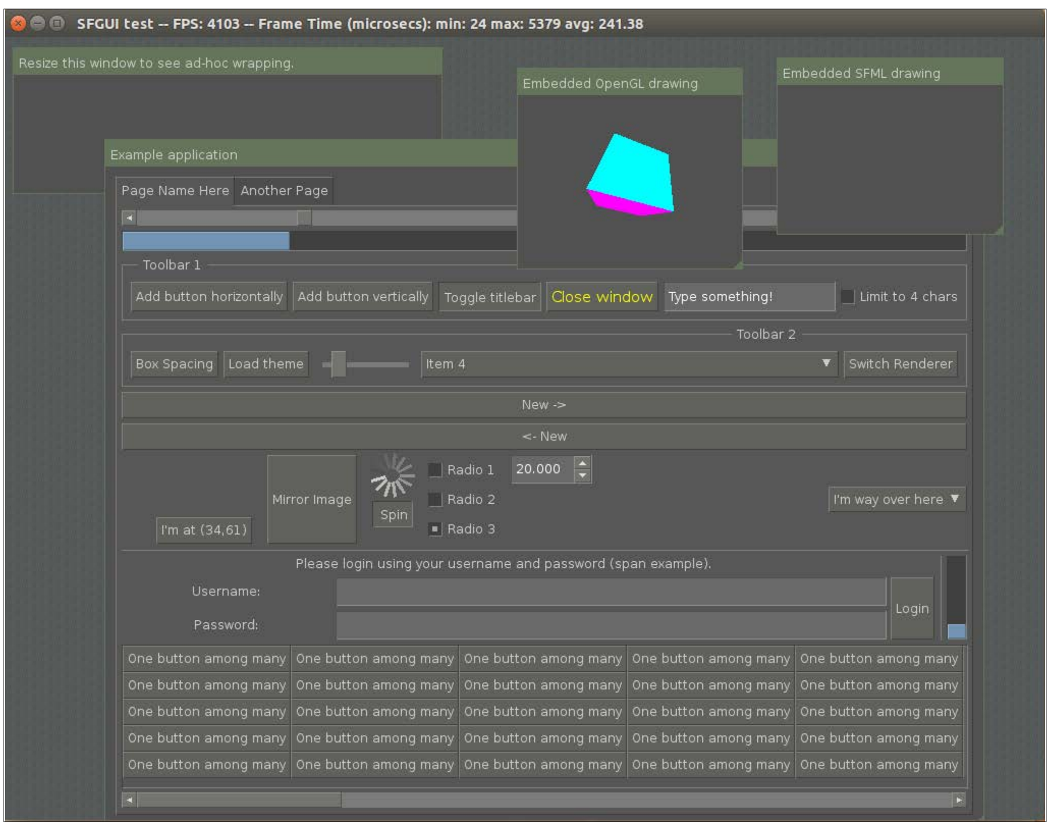
[l
library made regrouping all our custom game framework at http://
github.com/Krozark/SFML-utils/.]

ut keep
his GUI
is enough.

Using SFGUI

sed
on the top of SFML. Its goal is to provide a rich set of widgets and to be easily customizable and extensible. It also uses modern C++, so it's easy to use in any SFML project without too much effort.

provided
with the source:



Installing SFGUI

The first step is to download the source code. You will find it on the official website of the library: `http://sfgui.sfml-dev.de/`. The current version is 0.2.3 (Feb 20,
with the
`cmake` fi
to use it.

screenshot
during the build step:

```
CMake Error at CMakeLists.txt:26 (find_package):
  By not providing "FindSFML.cmake" in CMAKE_MODULE_PATH this project has
  asked CMake to find a package configuration file provided by "SFML", but
  CMake did not find one.

  Could not find a package configuration file provided by "SFML" (requested
  version 2) with any of the following names:

    SFMLConfig.cmake
    sfml-config.cmake

  Add the installation prefix of "SFML" to CMAKE_PREFIX_PATH or set
  "SFML_DIR" to a directory containing one of the above files.  If "SFML"
  provides a separate development package or SDK, be sure it has been
  installed.
```

In this case, you have to set the `CMAKE_MODULE_PATH` variable to `/path/to/SFML/cmake/Modules` using the `add entry` parameter. This should fix the problem.

> For other similar problems, take a look at this page: `http://sfgui.sfml-dev.de/p/faq#findsfml`. It should be helpful.

Now that SFGUI is configured, you need to build it and finally install it exactly as SFML and Box2D. You should now be pretty familiar with this.

Using the features of SFGUI

to show you
that you don't always need to reinvent the wheel when a good one already exists.

SFGUI use a lot of C++11 features, such as `shared_pointers`, `std::functions`, and some others that have already been covered in this book, and uses the RAII idiom
ot be lost
when it comes to using SFGUI optimally.

re all the others:
`sfg::SFGUI`. This class holds all the information needed for the rendering. Except from this point, the library can be used pretty much like ours. So let's try it.

Building the starting level

level. The
goal of this section is to add a simple form that takes a number as parameter and sets it as the starting level of the game. The final result will look like this:

Before starting with SFGUI, we need to make an update to our `Stats` class. In fact, this class doesn't allow us to start at a specific level, so we need to add that functionality. This will be done by adding a new attribute to it as follows:

```
unsigned int _initialLvl;
```

We will also need a new method:

```
void setLevel(int lvl);
```

That's it for the header. Now we need to initialize `_initialLvl` to `0` by default. And then change the calculation of the current level in the `addLines()` function. To do this, go to the following line:

```
_nbLvl = _nbRows / 10;
```

Change the preceding line to the following:

```
_nbLvl = _initialLvl + (_nbRows / 10);
```

And filevel
as follows:

```
void Stats::setLevel(int lvl)
{
  _initialLvl = lvl;
  _textLvl.setString("lvl : "+std::to_string(lvl));
}

int Stats::getLevel()const
{
  return _initialLvl + _nbLvl;
}
```

And that's it for the update on this class. Now let's go back to SFGUI.

: label,
text input, and button. But we will also use a layout and a desktop, which is the equivalent of our `Frame` class. All the initialization will be done in the `initGui()` function, just as before.

We also need to add two new attributes to our game:

```
sfg::SFGUI _sfgui;
sfg::Desktop _sfgDesktop;
```

The reason for adding `_sfgui` was previously explained. We add `_sfDesktop` for the exact same reason we add `Frame` to contain the objects.

Now take a look at the code needed to create the form:

```
void Game::initGui()
{
  //...
  auto title = sfg::Label::Create("Enter your starting level");
  auto level = sfg::Entry::Create();
  auto error = sfg::Label::Create();
```

```
    auto button = sfg::Button::Create( "Ok" );
    button->GetSignal( sfg::Button::OnLeftClick ).Connect(
      [level,error,this](){
        int lvl = 0;
        std::stringstream sstr(static_cast<std::string>(level-
          >GetText()));
        sstr >> lvl;
        if(lvl < 1 or lvl > 100)
        error->SetText("Enter a number from 1 to 100.");
        else
        {
          error->SetText("");
          initGame();
          _stats.setLevel(lvl);
          _status = Status::StatusGame;
        }
      }
    );

    auto table = sfg::Table::Create();
    table->SetRowSpacings(10);
    table->Attach(title,sf::Rect<sf::Uint32>(0,0,1,1));
    table->Attach(level,sf::Rect<sf::Uint32>(0,1,1,1));
    table->Attach(button,sf::Rect<sf::Uint32>(0,2,1,1));
    table->Attach(error,sf::Rect<sf::Uint32>(0,3,1,1));
    table->SetAllocation(sf::FloatRect((_window.getSize().x-
      300)/2,
    (_window.getSize().y-200)/2,
    300,200));
    _sfgDesktop.Add(table);
  }
```

Okay, a lot of new features here, so I will explain them step by step:

1. First of all, we create the different components needed for this form.
2. Then we set the callback of the button on a press event. This callback does a lot of things:
   - We get back the text entered by the user
   - We convert this text to an integer using `std::stringstream`
   - We check the validity of the input
   - If the input is not valid, we display an error message
   - On the other hand, if it is valid, we reset the game, set the starting level, and start the game

3. Until all the objects are created, we add them into a layout one by one.
4. We change the size of the layout and center it on the window.
5. Finally, we attach the layout to the desktop.

As all the object are created and stored into `std::shared_` we don't need to keep a trace of them. SFGUI does it for us.

I: events
and rendering. Good news, the logic is the same! However, we do have to code the `processEvents()` and `render()` functions again.

In the `processEvents()` method, we only need to complete the first switch as shown in the following code snippet:

```
case StatusConfiguration :
{
  _configurationMenu.processEvent(event);
  _sfgDesktop.HandleEvent(event);
}break;
```

As you can see, the logic is the same as our GUI, so the reasoning is clear.

And finally, the rendering. Here, again, the switch has to be completed by using the following code snippet:

```
case StatusConfiguration:
{
  _sfgDesktop.Update(0.0);
  _sfgui.Display(_window);
  _window.draw(_configurationMenu);
}break;
```

The new thing is the `Update()` call. This is for animations. Since in our case, we don't have any animation, we can put `0` as the parameter. It would be good practice to add this in the `Game::update()` function, but it's okay for our needs–and it also avoids changes.

You should now be able to use this new form in the configuration menu.

I. It packs in
ke a look at
the documentation and the examples given with the library. It's very interesting.

Summary

Congratulations, you have now finished this chapter and have gained the ability
e some
the user. You
also know the basics to create your own GUI and how to use SFGUI.

In the next chapter, we will learn how to use the full power of the CPU by using more than one thread, and see its implications in game programming.

6
Boost Your Code Using Multithreading

In this chapter, we will gain skills about:

- How to run multiple parts of your program in parallel
- How to protect memory access to avoid data race
- How to incorporate those functionalities into Gravitris

At the end of this chapter, you will be able to use all the power offered by the CPU of the computer, by paralyzing your code in a smart way. But first, let's describe the theory.

What is multithreading?

exit point.
Each software starts its life with the `main()` function in C/C++. This is the entry point of your program. Until this point, you are able to do whatever you want;
starting
r stream
is created and has its own life, but they are not equivalent.

The fork() function

This functionality is pretty simple. Calling `fork()` will duplicate your entire running
ed from its
will start just
after the `fork()` call. The return value of the `fork()` function is the only difference between the two executions.

Following is an example of the `fork()` function:

```
int main()
{
  int pid = fork();
  if(pid == -1)
    std::cerr<<"Error when calling fork()"<<std::endl;
  else if (pid == 0)
    std::cout<<"I'm the child process"<<std::endl;
  else
    std::cout<<"I'm the parent process"<<std::endl;
  return 0;
}
```

tions with this
use. The most important one concerns the sharing of memory. Because each process
n them.
A solution to this is to use files as sockets, pipes, and so on. Moreover, if the parent process dies, the child will still continue its own life without paying attention to its parent.

So this solution is interesting only when you don't want to share anything between your different executions, even their states.

The exec() family functions

The `exec()` family functions (`execl()`, `execlp()`, `execle()`, `execv()`, `execvp()`, `execvpe()`
with `fork()`, these functions become very powerful. Following is an example of these functions:

```
int main()
{
  int pid = fork();
  if(pid == -1)
  =  std::cerr<<"Error when calling fork()"<<std::endl;
  else if (pid == 0) {
    std::cout<<"I'm the child process"<<std::endl;
  }
  else {
    std::cout<<"I'm the parent process"<<std::endl;
    execlp("Gravitris", "Gravitris", "arg 1", "arg 2",NULL);
    std::cout<<"This message will never be print, except if
      execl() fail"<<std::endl;
  }
  return 0;
}
```

ly mentioned.
a call of any
of the `exec()`
the code under the `exec` call will not be executed, except if an error occurs.

Thread functionality

close to the
ew stream to
your running process. Its starting point is a function that is specified as a parameter.
in implication
is that the memory is the same, but it's not the only one. If the parent process dies, all its threads will die too.

m. Let's
take an example of the concurrent memory access.

Let's say that you have a global variable in your program named `var`. The main process will then create a thread. This thread will then write into `var` and at the same time, the main process can write in it too. This will result in an undefined behavior. There are different solutions to avoid this behavior and the common one is to lock the access to this variable with a mutex.

To put it simply, a mutex is a token. We can try to take (lock) it or release it
the first one will
ock function
is called on the mutex by the first one. To sum up, if you want to access to a shared
n, each time
you want to access it, lock the mutex, access the variable, and finally unlock the
rupt.

The second problem concerns the synchronization of the end of the execution of your
is. At the end
of the main stream, you need to wait until the end of all the running threads. The
tly will
not die.

Here is an example of usage of a thread's functionality:

```
#include <SFML/System.hpp>
static sf::Mutex mutex;
static int i = 0;

void f()
{
```

```
    sf::Lock guard(mutex);
    std::cout<<"Hello world"<<std::endl;
    std::cout<<"The value of i is "<<(++i)<<" from f()"<<std::endl;
  }

  int main()
  {
    sf::Thread thread(f);
    thread.launch();
    mutex.lock();
    std::cout<<"The value of i is "<<(++i)<<" from main"<<std::endl;
    mutex.unlock();
    thread.wait();
    return 0;
  }
```

Now that the theory has been explained, let's explain what is the motivation to use multithreading.

Why do we need to use the thread functionality?

ral threads
a CPU. Each
of these units are able to do a task independently from the others.

Let's pretend that your CPU has only four calculation units.

a single
thread. So only one core is used over the four present. This is a shame, because all
ed. We
can make it better by splitting our code into several parts. Each of these parts will be
m. Then, the
m of four in
our case). So the work is now done in parallel.

Creating several threads offers you the possibility to exploit all the power offered
such as
artificial intelligence.

ting for
s that the
ecution. To
 This is exactly
how `sf::Music`
the reason why our games do not freeze when we play a sound or music. Each time a thread is created for this task, it appears transparent to the user. Now that the theory has been explained, let's use it in practice.

Using threads

In *Chapter 4*, *Playing with Physics*, we have introduced physics to our game. For this
 one for
 were made
tinct threads.

We will need to create a thread, and protect our variables using a `Mutex` class. There are two options:

- Using object from the standard library
- Using object from the SFML library

rsion from a
standard C++ library to SFML.

The `thread` class:

Library	Header	Class	Start	Wait
C++	`<thread>`	`std::thread`	Directly after construction	`::join()`
SFML	`<SFML/System.hpp>`	`sf::Thread`	`::launch()`	`::wait()`

The `mutex` class:

Library	Header	Class	Lock	Unlock
C++	`<mutex>`	`std::mutex`	`::lock()`	`::unlock()`
SFML	`<SFML/System.hpp>`	`sf::Mutex`	`::lock()`	`::unlock()`

There is a third class that can be used. It automatically calls `mutex::lock()` on construction and `mutex::unlock()` on destruction, in respect of the RAII idiom. This class is called a lock or guard. Its use is simple, construct it with mutex as a parameter and it will automatically lock/unlock it. Following table explains the details of this class:

Library	**Header**	**Class**	**Constructor**
C++	`<mutex>`	`std::lock_guard`	`std::lock_guard(std::mutex&)`
SFML	`<SFML/System.hpp>`	`sf::Lock`	`sf::Lock(sf::Mutex&)`

anged a bit for
the `thread` class, but nothing really important.

his choice,
s.

xample to
apply our new skills as follows:

```
#include <SFML/System.hpp>
static sf::Mutex mutex;
static int i = 0;

void f()
{
  sf::Lock guard(mutex);
  std::cout<<"Hello world"<<std::endl;
  std::cout<<"The value of i is "<<(++i)<<" from f()"<<std::endl;
}

int main()
{
  sf::Thread thread(f);
  thread.launch();
  mutex.lock();
  std::cout<<"The value of i is "<<(++i)<<" from main"<<std::endl;
  mutex.unlock();
  thread.wait();
  return 0;
}
```

There are several parts in this simple example. The first part initializes the global variables. Then, we create a function named `f()` that prints **"Hello world"** and then prints another message. In the `main()` function, we create a thread attached to the `f()` function, we launch it, and print the value of `i`. Each time, we protect the access sed).

The print message from the `f()` function is unpredictable. It could be **"The value of i is 1 from f()"** or **"The value of i is 2 from f()"**. We are not able to say which one of the `f()` or `main()` prints will be made first, so we don't know the value that will be printed. The only point that we are sure of is that there is no concurrent access to `i` and the thread will be ended before the `main()` function, thanks to the `thread.wait()` call.

odify our
games to use them.

Adding multithreading to our games

om the rest
of the program. We will need to change only two files: `Game.hpp` and `Game.cpp`.

In the header file, we will not only need to add the required header, but also change the prototype of the `update_physics()` function and finally add some attributes to the class. So here are the different steps to follow:

1. Add `#include <SFML/System.hpp>`, this will allow us to have access to all the classes needed.
2. Then, change the following code snippet:

   ```
   void updatePhysics(const sf::Time& deltaTime,const
     sf::Time& timePerFrame);
   ```

   to:

   ```
   void updatePhysics();
   ```

   apped
   function so we will use another solution: member variables.

3. Add the following variables into the `Game` class as private:

   ```
   sf::Thread _physicsThread;
   sf::Mutex _mutex;
   bool _isRunning;
   int _physicsFramePerSeconds;
   ```

   All these variables will be used by the physics thread, and the `_mutex`
   is
   made. We will also need to protect the access to the `_world` variable for the same reasons.

4. Now that the header contains all the requirements, let's turn to the implementation.

5. First of all, we will not only need to update our constructor to initialize the `_physicsThread` and `_isRunning` variables, but also protect the access to `_world`.

```
Game::Game(int X, int Y,int word_x,int word_y) :
  ActionTarget(Configuration::player_inputs),
  _window(sf::VideoMode(X,Y),"06_Multithreading"),
  _current_piece(nullptr), _world(word_x,word_y),
  _mainMenu(_window),_configurationMenu(_window),
  _pauseMenu(_window),
  _status(Status::StatusMainMenu),
  _physicsThread(&Game::update_physics,this),
  _isRunning(true)
{
  bind(Configuration::PlayerInputs::HardDrop,[this](const
    sf::Event&){
      sf::Lock lock(_mutex);
      _current_piece = _world.newPiece();
      timeSinceLastFall = sf::Time::Zero;
  });
}
```

6. In the constructor, we will not only initialize the new member variables, but also protect our `_world` variable used in one of the callbacks. This lock is ion.

7. Now that the constructor has been updated, we need to change the `run()` changes
to make. See it by yourself:

```
void Game::run(int minimum_frame_per_seconds, int
  physics_frame_per_seconds)
{
  sf::Clock clock;
  const sf::Time timePerFrame =
    sf::seconds(1.f/minimum_frame_per_seconds);
  const sf::Time timePerFramePhysics =
    sf::seconds(1.f/physics_frame_per_seconds);
  _physics_frame_per_seconds = physics_frame_per_seconds;
  _physicsThread.launch();

  while (_window.isOpen())
  {
    sf::Time time = clock.restart();
    processEvents();
    if(_status == StatusGame and not _stats.isGameOver()){
      updatePhysics(time,timePerFramePhysics);
      update(time,timePerFrame);
```

```
    }
    render();
  }
  _isRunning = false;
  _physicsThread.wait();
}
```

8. Now that the main game loop has been updated, we need to make a small change in the `update()` method to protect the member `_world` variable.

```
void Game::update(const sf::Time& deltaTime,const sf::Time&
timePerFrame)
{
  static sf::Time timeSinceLastUpdate = sf::Time::Zero;
  timeSinceLastUpdate+=deltaTime;
  timeSinceLastFall+=deltaTime;
  if(timeSinceLastUpdate > timePerFrame)
  {
    sf::Lock lock(_mutex);
    if(_current_piece != nullptr)
    {
      _currentPiece->rotate(_rotateDirection*3000);
      _currentPiece->moveX(_moveDirection*5000);
      bool new_piece;
      {
        int old_level =_stats.getLevel();
        _stats.addLines
          (_world.clearLines(new_piece,*_currentPiece));
        if(_stats.getLevel() != old_level)
        _world.add(Configuration::Sounds::LevelUp);
      }
      if(new_piece or timeSinceLastFall.asSeconds() >
        std::max(1.0,10-_stats.getLevel()*0.2))
      {
        _current_piece = _world.newPiece();
        timeSinceLastFall = sf::Time::Zero;
      }
    }
    _world.update(timePerFrame);
    _stats.setGameOver(_world.isGameOver());
    timeSinceLastUpdate = sf::Time::Zero;
  }
  _rotateDirection=0;
  _moveDirection=0;
}
```

9. As you can see there is only one modification. We just need to protect the access to the `_world` variable, that's it. Now, we need to change the `updatePhysics()` function. This one will be changed a lot as shown in the following code snippet:

```
void Game::updatePhysics(const sf::Time& deltaTime,const
  sf::Time& timePerFrame)
void Game::updatePhysics()
{
  sf::Clock clock;
  const sf::Time timePerFrame =
    sf::seconds(1.f/_physics_frame_per_seconds);
  static sf::Time timeSinceLastUpdate = sf::Time::Zero;

  while (_isRunning)
  {
    sf::Lock lock(_mutex);
    timeSinceLastUpdate+=deltaTime;
    timeSinceLastUpdate+= clock.restart();
    _world.updateGravity(_stats.getLevel());

    while (timeSinceLastUpdate > timePerFrame)
    {
      if(_status == StatusGame and not _stats.isGameOver())
      _world.update_physics(timePerFrame);
      timeSinceLastUpdate -= timePerFrame;
    }
  }
}
```

to
for
ogic
developed in the `update()` method. Of course, we also use the mutex to
o be
updated independently from the rest of the game.

10. There are now little changes to be made in other functions where `_world` is used such as `initGame()` and `render()`. Each time, we will need to lock the access of this variable using the mutex.

11. The changes are as follows concerning the `initGame()` function:

```
void Game::initGame()
{
  sf::Lock lock(_mutex);
  timeSinceLastFall = sf::Time::Zero;
  _stats.reset();
```

```
    _world.reset();
    _current_piece = _world.newPiece();
}
```

12. And now take a look at the `render()` function after it is updated:

```
void Game::render()
{
  _window.clear();
  switch(_status)
  {
    case StatusMainMenu:
    {
      _window.draw(_mainMenu);
    }break;
    case StatusGame :
    {
      if(not _stats.isGameOver())
      {
        sf::Lock lock(_mutex);
        _window.draw(_world);
      }
      _window.draw(_stats);
    }break;
    case StatusConfiguration:
    {
      _sfg_desktop.Update(0.0);
      _sfgui.Display(_window);
      _window.draw(_configurationMenu);
    }break;
    case StatusPaused :
    {
      if(not _stats.isGameOver())
      {
        sf::Lock lock(_mutex);
        _window.draw(_world);
      }
      _window.draw(_pauseMenu);
    }break;
    default : break;
  }
  _window.display();
}
```

13. As you can see, the changes made were really minimalistic, but required to avoid any race conditions.

Now that all the changes have been made in the code, you should be able to compile the project and test it. The graphical result will stay unchanged, but the usage of the different cores of your CPU has changed. Now, the project uses two threads instead of only one. The first one used for the physics and another one for the rest of the game.

Summary

our existing
ssible uses,
and the protection of the shared variables.

In our actual game, multithreading is a bit overkill, but in a bigger one for instance
es a
must have.

In the next chapter, we will build an entire new game and introduce new things such as the isometric view, component system, path finding, and more.

7
Building a Real-time Tower Defense Game from Scratch – Part 1

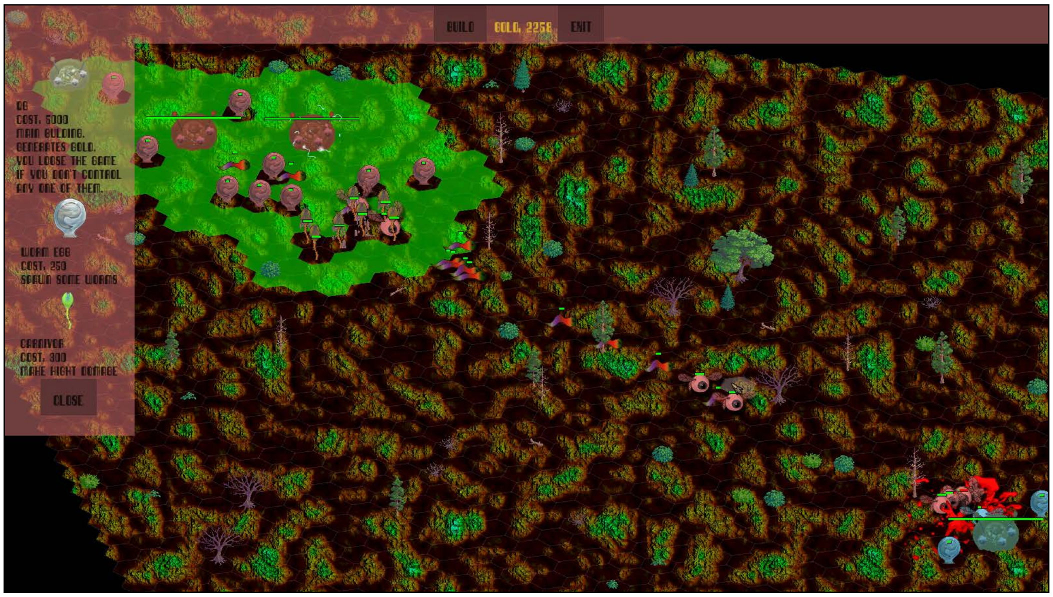
ng new. What
about a mix of a **Real Time Strategy** (**RTS**) and a tower defense? And what about
ly what we
will start building.

split in two
parts. The first one will focus on the game mechanism and logic, and the second on the multiplayer layer. So, in this chapter we will do the following:

- Create animations
- Build and use a generic map system with tile model and dynamic loading
- Build an entity system
- Make the game's logic

This project will reuse a lot of the components made previously, such as `ActionTarget`, `ResourceManager`, our GUI, and the game loop. To allow you to
ed into
a single framework (`SFML-utils`) that has been separated from the code in this book. This framework is available on the GitHub website at `https://github.com/Krozark/SFML-utils`, due to which these components have been moved from the book namespace to `SFML-utils`. Moreover, the map and entity systems that will be explained in this chapter are also part of this framework.

The final result of this chapter will look as follows:



The goal of the game

ld a new game
that will be a mix of a real-time strategy game and tower defense.

The idea is that each team starts with some money/gold and a main building named
ent to build
other buildings with different abilities, or to upgrade them. For example, some of
ldings will
 the area
ing around
in the center
e that once a
rol the different
warriors spawn by it.

Also, each time an enemy is destroyed, some gold is added to your gold stock, allowing you to build more towers, thus increasing your power to defeat your enemies.

Now that the game has been introduced, let's list our needs:

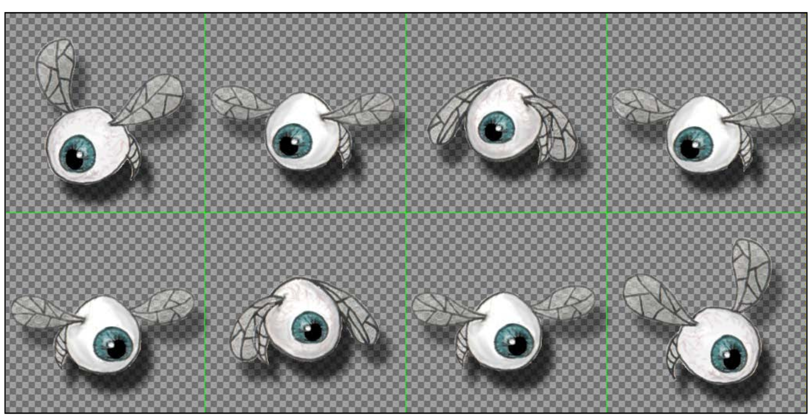
- **Resources and event management**: These two features have been created previously, so we will just reuse them.
- **GUI**: This feature has also been developed already in *Chapter 5*, *Playing with User Interfaces*. We will reuse it as is.
- **Animation**: In SFML, there is no class to manage animated sprites in SFML, nd add
it to our framework.
- **Tile map**: This functionality is very important and has to be as flexible as possible to allow us to reuse it in many other projects.
- **Entity manager**: If you remember, this was introduced in *Chapter 3*, *Making an Entire 2D Game*. Now it's time for us to really see it. This system will avoid a complex inheritance tree.

one due its
complexity, but it will also be much more interesting.

Building animations

creen were
static; at least they were not animated. For a more attractive game, the simplest thing to do is add some animations and different entities on the player. For us, this will be applied on the different buildings and warriors.

pared.
So, our textures will look as shown in the following figure:



> Note that the green grid is not a part of the image and is only shown here for information; the background is transparent in reality.

e can be split in
two lines of four columns. Each line represents a direction of movement, namely left
ation.

The aim of the work for this part is to be able to display a sprite using this sheet as an animation frame.

We will follow the design of the SFML by building two classes. The first one will store the animations and the second one will be used to display works such as `sf::Texture` and `sf::Sprite`. These two classes are named as `Animation` and `AnimatedSprite`.

The Animation class

The `Animation`
the different frames.

As this class is a kind of resource, we will use it through our `ResourceManager` class.

Here is the header of the class:

```
class Animation
{
  public:
  Animation(sf::Texture* texture=nullptr);
  ~Animation();

  void setTexture(sf::Texture* texture);
  sf::Texture* getTexture()const;

  Animation& addFrame(const sf::IntRect& rect);
  Animation& addFramesLine(int number_x,int number_y,int line);
  Animation& addFramesColumn(int number_x,int number_y,int
    column);
  size_t size()const;
  const sf::IntRect& getRect(size_t index)const;

  private:
  friend class AnimatedSprite;
  std::vector<sf::IntRect> _frames;
  sf::Texture* _texture;
};
```

As you can see, this class is nothing but a container for a texture and some rectangles. To simplify the usage of this class, some helper functions have been created, namely `addFramesLines()` and `addFramesColumn()`. Each of these functions add a complete line or column to the internal `_frames` list. The implementation of this class is also very simple and is as follows:

```
Animation::Animation(sf::Texture* texture) : _texture(texture){}

Animation::~Animation(){}

void Animation::setTexture(sf::Texture* texture){ _texture =
  texture;}

sf::Texture* Animation::getTexture() const {return _texture;}

size_t Animation::size() const {return _frames.size();}

const sf::IntRect& Animation::getRect(size_t index) const {return
  _frames[index];}

Animation& Animation::addFrame(const sf::IntRect& rect)
{
  _frames.emplace_back(rect);
  return *this;
}

Animation& Animation::addFramesLine(int number_x,int number_y,int
  line)
{
  const sf::Vector2u size = _texture->getSize();
  const float delta_x = size.x / float(number_x);
  const float delta_y = size.y / float(number_y);

  for(int i = 0;i<number_x;++i)
      addFrame(sf::IntRect(i*delta_x,line*delta_y,delta_x,delta_y));
  return *this;
}
Animation& Animation::addFramesColumn(int number_x,int
  number_y,int column)
{
  const sf::Vector2u size = _texture->getSize();
  const float delta_x = size.x / float(number_x);
  const float delta_y = size.y / float(number_y);
  for(int i = 0;i<number_y;++i)
      addFrame(sf::IntRect(column*delta_x,i*delta_y,delta_x,delta_y));
  return *this;
}
```

The three `addFrameXXX()` functions allow us to add frames to our animation. The last two ones are some shortcuts to add an entire line or column. The rest of the methods allow us to access to the internal data.

the
`AnimatedSprite` class.

The AnimatedSprite class

The `AnimatedSprite` class is in charge of the animation displayed on the screen. Due to this, it will keep a reference to an `Animation` class and will change the sub-rectangle of the texture periodically, just like `sf::Sprite`. We will also copy the `sf::Music`/`sf::Sound` API concerning the play/pause/stop ability. An `AnimatedSprite` instance should also be able to display on the screen and be transformable, due to which the class will inherit from `sf::Drawable` and `sf::Transformable`. We will also add a callback that will be triggered when the animation is complete. It could be interesting for the future.

The header looks as follows:

```
class AnimatedSprite : public sf::Drawable, public sf::Transformable
{
  public:
  AnimatedSprite(const AnimatedSprite&) = default;
  AnimatedSprite& operator=(const AnimatedSprite&) = default;
  AnimatedSprite(AnimatedSprite&&) = default;
  AnimatedSprite& operator=(AnimatedSprite&&) = default;

  using FuncType = std::function<void()>;
  static FuncType defaultFunc;
  FuncType onFinished;
  enum Status {Stopped,Paused,Playing};

  AnimatedSprite(Animation* animation = nullptr,Status status=
    Playing,const sf::Time& deltaTime = sf::seconds(0.15),bool
      loop = true,int repeat=0);

  void setAnimation(Animation* animation);
  Animation* getAnimation()const;

  void setFrameTime(sf::Time deltaTime);
  sf::Time getFrameTime()const;

  void setLoop(bool loop);
```

```
    bool getLoop()const;
    void setRepeat(int nb);
    int getRepeat()const;

    void play();
    void pause();
    void stop();
    Status getStatus()const;

    void setFrame(size_t index);
    void setColor(const sf::Color& color);
    void update(const sf::Time& deltaTime);

    private:
    Animation* _animation;
    sf::Time _delta;
    sf::Time _elapsed;
    bool _loop;
    int _repeat;
    Status _status;
    size_t _currentFrame;
    sf::Vertex _vertices[4];

    void setFrame(size_t index,bool resetTime);
    virtual void draw(sf::RenderTarget& target,sf::RenderStates
      states) const override;
};
```

As you can see, this class is bigger than the previous one. Its main functionality is to he associated
two
frames, if the animation is a loop. This is why we need so many little functions. Now, let's see how all these are implemented:

```
AnimatedSprite::AnimatedSprite(Animation* animation,Status
  status,const sf::Time& deltaTime,bool loop,int repeat) :
    onFinished(defaultFunc),_delta(deltaTime),_loop(loop),
      _repeat(repeat),_status(status)
{
  setAnimation(animation);
}
```

The constructor only initializes all the different attributes to their correct values:

```
void AnimatedSprite::setAnimation(Animation* animation)
{
  if(_animation != animation){
    _animation = animation;
    _elapsed = sf::Time::Zero;
    _currentFrame = 0;
    setFrame(0,true);
  }
}
```

different, and
resets the frame to the first one of the new animation. Note that at least one frame has to be stored in the new animation received as a parameter.

```
Animation* AnimatedSprite::getAnimation()const {return
  _animation;}

void AnimatedSprite::setFrameTime(sf::Time deltaTime){_delta =
  deltaTime;}

sf::Time AnimatedSprite::getFrameTime()const {return _delta;}

void AnimatedSprite::setLoop(bool loop){_loop = loop;}

bool AnimatedSprite::getLoop()const {  return _loop;}

void AnimatedSprite::setRepeate(int nb) {_repeat = nb;}

int AnimatedSprite::getRepeate()const{  return _repeat;}

void AnimatedSprite::play() {_status = Playing;}

void AnimatedSprite::pause() {_status = Paused;}

void AnimatedSprite::stop()
{
  _status = Stopped;
  _currentFrame = 0;
  setFrame(0,true);
}

AnimatedSprite::Status AnimatedSprite::getStatus()const {return
  _status;}
```

age basic
elements of the `AnimatedSprite` class, as depicted in the previous code snippet.

```
void AnimatedSprite::setFrame(size_t index)
{
  assert(_animation);
  _currentFrame = index % _animation->size();
  setFrame(_currentFrame,true);
}
```

rnal
`Animation` class.

```
void AnimatedSprite::setColor(const sf::Color& color)
{
  _vertices[0].color = color;
  _vertices[1].color = color;
  _vertices[2].color = color;
  _vertices[3].color = color;
}
```

This function changes the color mask of the displayed image. To do this, we set the color of each internal vertex to the new color received as a parameter:

```
void AnimatedSprite::update(const sf::Time& deltaTime)
{
  if(_status == Playing and _animation)
  {
    _elapsed += deltaTime;

    if(_elapsed > _delta)
    {//need to change frame
      _elapsed -= _delta;
      if(_currentFrame + 1 < _animation->size())
          ++_currentFrame;
      else
      {//end of frame list
        _currentFrame = 0;

        if(not _loop)
        {//can we make another loop an the frames?
          --_repeat;
          if(_repeat<=0)
          { //no, so we stop
                _status = Stopped;
                onFinished();
```

```
            }
          }
        }
      }
      //update the frame
      setFrame(_currentFrame,false);
    }
  }
```

me to the next
animation,
you can do the following:

- Reset the animation from the first one, depending of the `_loop` value
- Reset the animation from the first one if the `_repeat` value authorizes us to do it
- In all other cases, we trigger the event "on finish" by calling the internal callback

Now, take a look at the function that updates the frame's skin:

```
void AnimatedSprite::setFrame(size_t index,bool resetTime)
{
  if(_animation)
  {
    sf::IntRect rect = _animation->getRect(index);
    //update vertice position
    _vertices[0].position = sf::Vector2f(0.f, 0.f);
    _vertices[1].position = sf::Vector2f(0.f,
      static_cast<float>(rect.height));
    _vertices[2].position =
      sf::Vector2f(static_cast<float>(rect.width),
        static_cast<float>(rect.height));
    _vertices[3].position =
      sf::Vector2f(static_cast<float>(rect.width), 0.f);

    //compute the texture coords
    float left = static_cast<float>(rect.left);
    float right = left + static_cast<float>(rect.width);
    float top = static_cast<float>(rect.top);
    float bottom = top + static_cast<float>(rect.height);

    //set the texture coords
    _vertices[0].texCoords = sf::Vector2f(left, top);
    _vertices[1].texCoords = sf::Vector2f(left, bottom);
    _vertices[2].texCoords = sf::Vector2f(right, bottom);
    _vertices[3].texCoords = sf::Vector2f(right, top);
```

```
    }
    if(resetTime)
    _elapsed = sf::Time::Zero;
}
```

This function is also an important one. Its aims is to update the attributes of the different vertices to those taken from the internal `Animation` class, namely the position and texture coordinates:

```
void AnimatedSprite::draw(sf::RenderTarget&
  target,sf::RenderStates states) const
{
  if (_animation and _animation->_texture)è
  {
    states.transform *= getTransform();
    states.texture = _animation->_texture;
    target.draw(_vertices, 4, sf::Quads, states);
  }
}
```

The final function of this class manages the display. Because we inherit from `sf::Transformable`, we need to take into account the possible transformation. Then, we set the texture we used and finally draw the internal vertices array.

A usage example

ild a little
usage example.

Now, here's the implementation:

```
int main(int argc,char* argv[])
{
  //Creation of the window
  sf::RenderWindow window(sf::VideoMode(600,800),"Example
    animation");

  //load of the texture image
  ResourceManager<sf::Texture,int> textures;
  textures.load(0,"media/img/eye.png");

  //Creation of the different animations
  Animation walkLeft(&textures.get(0));
  walkLeft.addFramesLine(4,2,0);
  Animation walkRight(&textures.get(0));
```

```
  walkRight.addFramesLine(4,2,1);

  //Creation of the animates sprite
  AnimatedSprite sprite(&walkLeft,AnimatedSprite::Playing,sf::secon
ds(0.1));
  //game loop
  sf::Clock clock;
  while (window.isOpen())
  {
    sf::Time delta = clock.restart();
    sf::Event event;
    while (window.pollEvent(event))
    {
      if (event.type == sf::Event::Closed) //close event
      window.close();
    }
    float speed = 50; // the movement speed of the entity
    if(sf::Keyboard::isKeyPressed(sf::Keyboard::Left)) //move left
    {
      sprite.setAnimation(&walkLeft);
      sprite.play();
      sprite.move(-speed*delta.asSeconds(),0);
    }
    else if(sf::Keyboard::isKeyPressed(sf::Keyboard::Right))
      //move right     {
      sprite.setAnimation(&walkRight);
      sprite.play();
      sprite.move(speed*delta.asSeconds(),0);
    }
    window.clear();
    sprite.update(delta); //update the animate sprite for possible
      frame change
    window.draw(sprite); //display the animation
    window.display();
  }
  return 0;
}
```

For a better understanding of this code snippet, I've written some comments in the code.

This short program displays an animation on the screen. You can also change its
ill also
change depending on the direction of movement.

Now that the first point of this chapter has been explained, let's continue to the second one, building a map.

Building a generic Tile Map

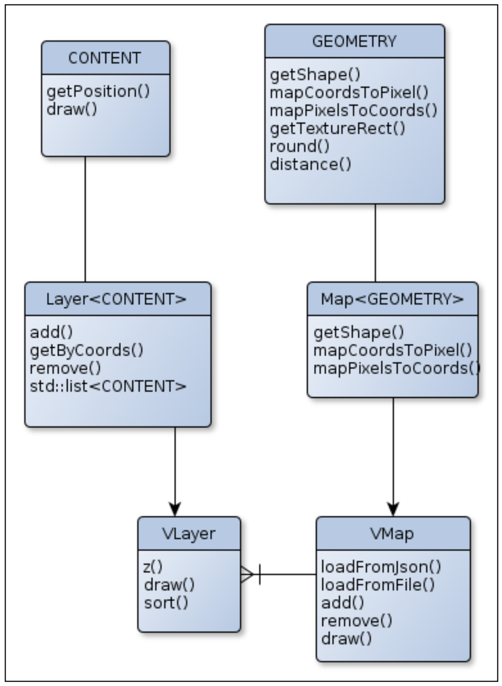
For our project, we need something that will manage the map. In fact, the map is nothing but a big grid. The cells can be of any shape (square, hexagonal, and so on). The only restriction is that all the cells of a single map should have the same geometry.

Moreover, each cell can contain several objects, possibly of different types. For
ee, and a
bird. Because SFML doesn't use a `z` buffer with sprites (also called a depth buffer),
Its principle is
very simple; draw everything but by depth order, starting with the most distant. It's how a tradition art painter would paint.

All this information brings us to the following structure:

- A `Map` class must be of a specific geometry and must contain any number of layers sorted by their `z` buffer.
- A `Layer` contains only a specific type. It also has a `z` buffer and stores a list of content sorted by their positions.
- The `CONTENT` and `GEOMETRY` classes are template parameters but they need to have a specific API.

Here is the flowchart representing the class hierarchy of the previously explained structure:



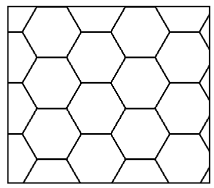
Following is the explanation of the flowchart:

- The `CONTENT` template class can be any class that inherits from `sf::Drawable` and `sf::Transformable`.
- The `GEOMETRY` class is a new one that we will learn about shortly. It only defines the geometric shape and some helper functions to manipulate coordinates.
- The `VLayer` class defines a common class for all the different types of layers.
- The `Layer` class is just a container of a specific type with a depth variable that defines its draw order for the painter algorithm.
- The `VMap` class defines a common API for the entire Map. It also contains a list of `VLayer` that is displayed using the painter algorithm.
- The `Map` class inherits from `VMap` and is of a specific geometry.

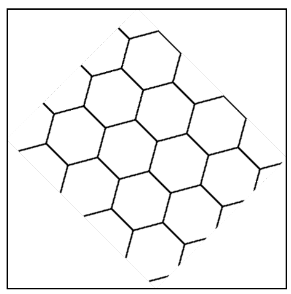
The Geometry class as an isometric hexagon

a hexagon. An
l. Following
are the steps we need to follow:

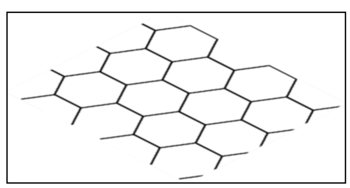
1. First, view your tile from the top view:



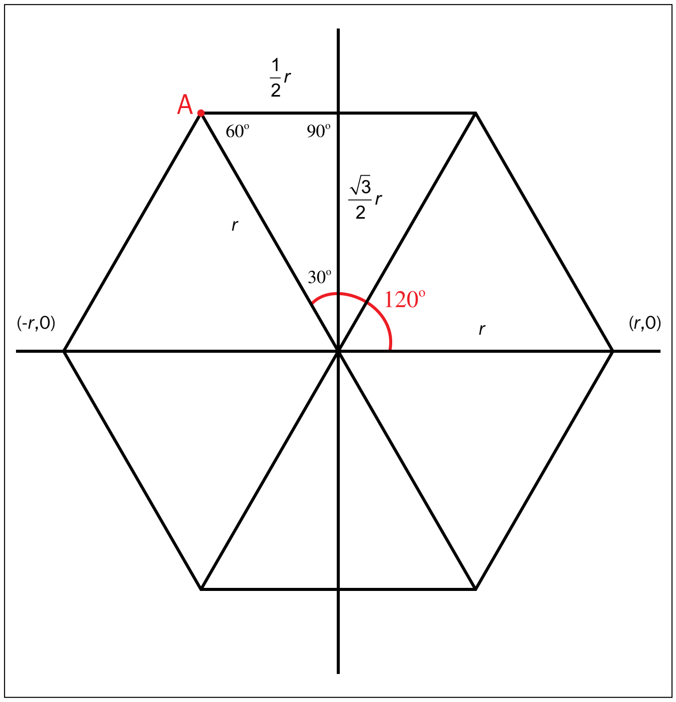
2. Then, rotate it 45 degrees clockwise:



3. Finally, divide its height by 2:



4. You now have a nice isometric view. Now, let's take a look at the hexagon:



As you know, we need to calculate the coordinates of each of the edges using trigonometry, especially the Pythagoras theorem. This is without taking into account the rotation and the height resize. We need to follow two steps to find the right coordinates:

1. Calculate the coordinates from the rotated shape (adding 45 degrees).
2. Divide the total height value by two. By doing this, you will finally be able to build `sf::Shape`:

```
shape.setPointCount(6);
shape.setPoint(0,sf::Vector2f(0,(sin_15+sin_75)/2));
shape.setPoint(1,sf::Vector2f(sin_15,sin_15/2));
shape.setPoint(2,sf::Vector2f(sin_15+sin_75,0));
shape.setPoint(3,sf::Vector2f(sin_15+sin_75+sin_45,sin_45/2
  ));
shape.setPoint(4,sf::Vector2f(sin_75+sin_45,(sin_75+sin_45)
  /2));
shape.setPoint(5,sf::Vector2f(sin_45,(sin_15+sin_75+sin_45)
  /2));
shape.setOrigin(height/2,height/4);
```

3. The major part of the `GEOMETRY` class has been made. What remains is only a conversion from world to pixel coordinates, and the reverse. If you are `SFML-utils/src/SFML-utils/map/HexaIso.cpp` file.

Now that the main geometry has been defined, let's construct a `Tile<GEOMETRY>` class on it. This class will simply encapsulate `sf::Shape`, which is initialized by the geometry, and with the different requirements to be able to be use a `COMPONENT` xplain it
through this book, but you can take a look at its implementation in the `SFML-utils/include/SFML-utils/map/Tile.tpl` file.

VLayer and Layer classes

th. To
also has the
ability to resort the container to respect the painter algorithm. The `VLayer` class is an interface that only defines the API of the layer, allowing the map to store any kind of layer, thanks to polymorphism.

Here is the header of the `Layer` class:

```
template<typename CONTENT>
class Layer : public VLayer
{
  public:
  Layer(const Layer&) = delete;
  Layer& operator=(const Layer&) = delete;
  Layer(const std::string& type,int z=0,bool isStatic=false);
  virtual ~Layer(){};

  CONTENT* add(const CONTENT& content,bool resort=true);
  std::list<CONTENT*> getByCoords(const sf::Vector2i& coords,const
    VMap& map);
  bool remove(const CONTENT* content_ptr,bool resort=true);
  virtual void sort() override;

  private:
  virtual void draw(sf::RenderTarget& target, sf::RenderStates
    states,const sf::FloatRect& viewport) override;
  std::list<CONTENT> _content;
};
```

As mentioned previously, this class will not only store a container of its `template` class argument, but also its depth (`z`) and an is static Boolean member contained in the `Vlayer`the
 the scene each
time. The result is stored in an internal `sf::RenderTexture` parameter and will be refreshed only when the scene moves. For example, the ground never moves nor is it
 on the screen.
This texture will be refreshed when the view is moved/resized.

on the
screen. We don't need do draw something out of the screen. That's why we have the `viewport` attribute of the `draw()` method.

All other functions manage the content of the layer. Now, take a look at its implementation:

```
template<typename CONTENT>
Layer<CONTENT>::Layer(const std::string& type,int z,bool isStatic)
  : Vlayer(type,z,isStatic) {}

template<typename CONTENT>
CONTENT* Layer<CONTENT>::add(const CONTENT& content,bool resort)
{
  _content.emplace_back(content);
  CONTENT* res = &_content.back();
  if(resort)
      sort();
  return res;
}
```

This function adds new content to the layer, sort it if requested, and finally, return a reference to the new object:

```
template<typename CONTENT>
std::list<CONTENT*> Layer<CONTENT>::getByCoords(const sf::Vector2i&
coords,const VMap& map)
{
  std::list<CONTENT*> res;
  const auto end = _content.end();
  for(auto it = _content.begin();it != end;++it)
  {
    auto pos = it->getPosition();
    sf::Vector2i c = map.mapPixelToCoords(pos.x,pos.y);
    if(c == coords)
        res.emplace_back(&(*it));
```

```
  }
  return res;
}
```

is useful to pick
up objects, for example, to pick objects under the cursor:

```
template<typename CONTENT>
bool Layer<CONTENT>::remove(const CONTENT* content_ptr,bool resort)
{
  auto it =
    std::find_if(_content.begin(),_content.end(),
      [content_ptr](const CONTENT& content)->bool
  {
    return &content == content_ptr;
  });
  if(it != _content.end()) {
    _content.erase(it);
    if(resort)
    sort();
    return true;
  }
  return false;
}
```

This is the reverse function of `add()`. Using its address, it removes a component from the container:

```
template<typename CONTENT>
void Layer<CONTENT>::sort()
{
  _content.sort([](const CONTENT& a,const CONTENT& b)->bool{
    auto pos_a = a.getPosition();
    auto pos_b = b.getPosition();
    return (pos_a.y < pos_b.y) or (pos_a.y == pos_b.y and pos_a.x
      < pos_b.x);
    });
  }
}
```

hm order:

```
template<typename CONTENT>
void Layer<CONTENT>::draw(sf::RenderTarget& target, sf::RenderStates
states,const sf::FloatRect& viewport)
```

```
{
  if(_isStatic)
  {//a static layer
    if(_lastViewport != viewport)
    { //the view has change
      sf::Vector2u size(viewport.width+0.5,viewport.height+0.5);
      if(_renderTexture.getSize() != size)
      {//the zoom has change
        _renderTexture.create(size.x,size.y);
        _sprite.setTexture(_renderTexture.getTexture(),true);
      }
      _renderTexture.setView(sf::View(viewport));
      _renderTexture.clear();

      auto end = _content.end();
      for(auto it = _content.begin();it != end;++it)
      {//loop on content
      CONTENT& content = *it;
      auto pos = content.getPosition();
      if(viewport.contains(pos.x,pos.y))
      {//content is visible on screen, so draw it
        _renderTexture.draw(content);
      }
    }
    _renderTexture.display();
    _lastViewport = viewport;
    _sprite.setPosition(viewport.left,viewport.top);
  }
  target.draw(_sprite,states);
}
else
{ //dynamic layer
  auto end = _content.end();
  for(auto it = _content.begin();it != end;++it)
  {//loop on content
    const CONTENT& content = *it;
    auto pos = content.getPosition();
    if(viewport.contains(pos.x,pos.y))
    {//content is visible on screen, so draw it
      target.draw(content,states);
    }
  }
}
```

ome
optimizations. Let's explain it step by step:

- First, we separate two cases. In the case of a static map we do as follows:
    - Check if the view port has changed
    - Resize the internal texture if needed
    - Reset the textures
- Draw each object with a position inside the view port into the `textureDisplay` the texture for the `RenderTarget` argument.
- Draw each object with a position inside the view port into the `RenderTarget` argument if the layer contains dynamic objects (not static).

As you can see, the `draw()` function uses a naive algorithm in the case of dynamic content and optimizes the statics. To give you an idea of the benefits, with a layer of
 it reaches
this function is
justified by the enormous performance benefits.

Now that the `layer` class has been exposed to you, let's continue with the `map` class.

VMap and Map classes

A map is a container of `VLayer`. It will implement the usual `add()`/`remove()` functions. This class can also be constructed from a file (described in the *Dynamic board loading* section) and handle unit conversion (coordinate to pixel and vice versa).

Internally, a `VMap` class store has the following layers:

```
std::vector<VLayer*> _layers;
```

There are only two interesting functions in this class. The others are simply shortcuts,
ns:

```
void VMap::sortLayers()
{
  std::sort(_layers.begin(),_layers.end(),[](const VLayer* a,
    const VLayer* b)->bool{
    return a->z() < b->z();
  });
  const size_t size = _layers.size();
  for(size_t i=0;i<size;++i)
    _layers[i]->sort();
}
```

This function sorts the different layers by their `z` buffer with respect to the Painter's to call it each
time a layer is added to the map.

```
void VMap::draw(sf::RenderTarget& target, sf::RenderStates
states,const sf::FloatRect& viewport) const
{
  sf::FloatRect delta_viewport(viewport.left - _tile_size,
  viewport.top - _tile_size,
  viewport.width + _tile_size*2,
  viewport.height + _tile_size*2);
  const size_t size = _layers.size();
  for(size_t i=0;i<size;++i)
    _layers[i]->draw(target,states,delta_viewport);
}
```

The function draws each layer by calling its draw method; but first, we adjust the screen view port by adding a little delta on each of its borders. This is done to display all the tiles that appear on the screen, even partially (when its position is out on the screen).

Dynamic board loading

I've chosen
the `JSON` format. There are two reasons for this choice:

- It can be read by humans
- The format is not verbose, so the final file is quite small even for big map

We will need some information to construct a map. This includes the following:

- The map's geometry
- The size of each tile (cell)
- Define the layers as per the following:
    - The `z` buffer
    - If it is static or dynamic
    - The content type

Depending on the content type of the layer, some other information to build this content could be specified. Most often, this extra information could be as follows:

- Texture
- Coordinates
- Size

So, the `JSON` file will look as follows:

```
{
  "geometry" : {
    "name" :"HexaIso", "size" : 50.0
  },
  "layers" : [{
    "content" : "tile", "z" : 1, "static" : true,
    "data" : [{"img" :"media/img/ground.png", "x" : 0, "y" : 0,
      "width" : 100, "height" : 100}]
  },{
    "content" : "sprite", "z" : 3,
    "data" : [
    {"x" : 44, "y" : 49, "img" : "media/img/tree/bush4.png"},
    {"x" : 7, "y" : 91, "img" : "media/img/tree/tree3.png"},
    {"x" : 65, "y" : 58, "img" : "media/img/tree/tree1.png"}
    ]
  }]
}
```

the isometric
hexagon geometry with two layers. The first layer contains the grid with the ground texture and the second one contains some sprite for decoration.

To use this file, we need a `JSON` parser. You can use any existing one, build yours, or take the one built with this project. Next, we need a way to create an entire map from a file or update its content from a file. In the second case, the geometry will be ignored because we can't change the value of a template at runtime.

So, we will add a static method to the `VMap` class to create a new `Map`, and add another method to update its content. The signature will be as follows:

```
static VMap* createMapFromFile(const std::string& filename);
virtual void loadFromJson(const utils::json::Object& root) = 0;
```

The `loadFromJson()` function has to be virtual and implemented in the `Map` class because of the `GEOMETRY` parameter required by the `Tile` class. The `createMapFromFile()` function will be used internationally. Let's see its implementation:

```
VMap* VMap::createMapFromFile(const std::string& filename)
{
  VMap* res = nullptr;
  utils::json::Value* value =
    utils::json::Driver::parse_file(filename);
  if(value)
  {
    utils::json::Object& root = *value;
    utils::json::Object& geometry = root["geometry"];
    std::string geometry_name = geometry["name"].as_string();
    float size = geometry["size"].as_float();
    if(geometry_name == "HexaIso")
    {
      res = new Map<geometry::HexaIso>(size);
      res->loadFromJson(root);
    }
    delete value;
  }
  return res;
}
```

p depending
on the geometry parameter and forward it the rest of the job.

```
void Map<GEOMETRY>::loadFromJson(const utils::json::Object& root)
{
    const utils::json::Array& layers = root["layers"];
    for(const utils::json::Value& value : layers) //loop through the
rs
    {
        const utils::json::Object& layer = value;
        std::string content = layer["content"].as_string(); //get the
content type

        int z = 0; //default value
        try{
            z = layer["z"].as_int(); //load value
        } catch(...){}

        bool isStatic = false; //default value
```

```
        try {
            isStatic = layer["static"].as_bool(); //load value
        }catch(...){}

        if(content == "tile") //is a layer or tile?
        {
            auto current_layer = new Layer<Tile<GEOMETRY>>(content,z,i
sStatic); //create the layer
            const utils::json::Array& textures = layer["data"];
            for(const utils::json::Object& texture : textures) //loop
through the textures
            {
                int tex_x = texture["x"]; //get the tile position
                int tex_y = texture["y"];
                int height = std::max<int>(0,texture["height"].as_
int()); //get the square size
                int width = std::max<int>(0,texture["width"].as_
int());
                std::string img = texture["img"]; //get texture path

                sf::Texture& tex = _textures.getOrLoad(img,img); //
load the texture
                tex.setRepeated(true);

                for(int y=tex_y;y< tex_y + height;++y)//create the
tiles
                {
                    for(int x=tex_x;x<tex_x + width;++x)
                    {
                        Tile<GEOMETRY> tile(x,y,_tileSize);
                        tile.setTexture(&tex);
                        tile.setTextureRect(GEOMETRY::getTextureRect(x
,y,_tileSize));

                        current_layer->add(std::move(tile),false);//
add the new tile to the layer
                    }
                }
            }
            add(current_layer,false);//if it's a layer of images
        }
        else if(content == "sprite")
        {
            auto current_layer = new Layer<sf::Sprite>(content,z,isSta
tic);//create the layer
```

```
            const utils::json::Array& data = layer["data"].as_
array();//loop on data

            for(const utils::json::Value& value : data)
            {
                const utils::json::Object& obj = value;
                int x = obj["x"];//get the position
                int y = obj["y"];
                float ox = 0.5;//default center value (bottom center)
                float oy = 1;

                try{//get value
                    ox = obj["ox"].as_float();
                }catch(...){}

                try{
                    oy = obj["oy"].as_float();
                }catch(...){}

                std::string img = obj["img"];//get texture path

                sf::Sprite spr(_textures.getOrLoad(img,img));//load
texture
                spr.setPosition(GEOMETRY::mapCoordsToPixel(x,y,_
tileSize));

                sf::FloatRect rec = spr.getLocalBounds();
                spr.setOrigin(rec.width*ox,rec.height*oy);

                current_layer->add(std::move(spr),false);//add the
sprite

            }
            add(current_layer,false); //add the new layer to the map
        }
    }
    sortLayers(); //finally sort the layers (recuively)
}
```

comments. It's aimed at building layers and filling them with the data picked from the `JSON` file.

Now that we are able to build a map and fill it from a file, the last thing we need to do is display it on the screen. This will be done with the `MapViewer` class.

The MapViewer class

This class encapsulates a `Map` class and manages some events such as mouse movement, moving the view, zoom, and so on. This is a really simple class with nothing new. This is why I will not go into details about anything but the `draw()` mplementation,
take a look at the `SFML-utils/src/SFML-utils/map/MapViewer.cpp` file.

So here is the draw method:

```
void MapViewer::draw(sf::RenderTarget& target, sf::RenderStates
states) const
{
  sf::View view = target.getView();
  target.setView(_view);
  _map.draw(target,states,sf::FloatRect
  (target.mapPixelToCoords(sf::
    Vector2i(0,0),_view),_view.getSize()));
  target.setView(view);
}
```

As usual, we receive `sf::RenderTarget` and `sf::RenderStates` as parameters. However, here we don't want to interact with the current view of the target, so we en, we call
the draw method of the internal map, forwarding the target, and states but adding
layers for
ered target,
to the
ordinate of the
e all the
need: `sf::View::getSize()`. With this information, we are now able to build the correct view port and pass it to the map `draw()` function.

Once the rendering is complete, we restore the initial view back to the rendered target.

A usage example

.
The following code snippet shows you the minimal steps:

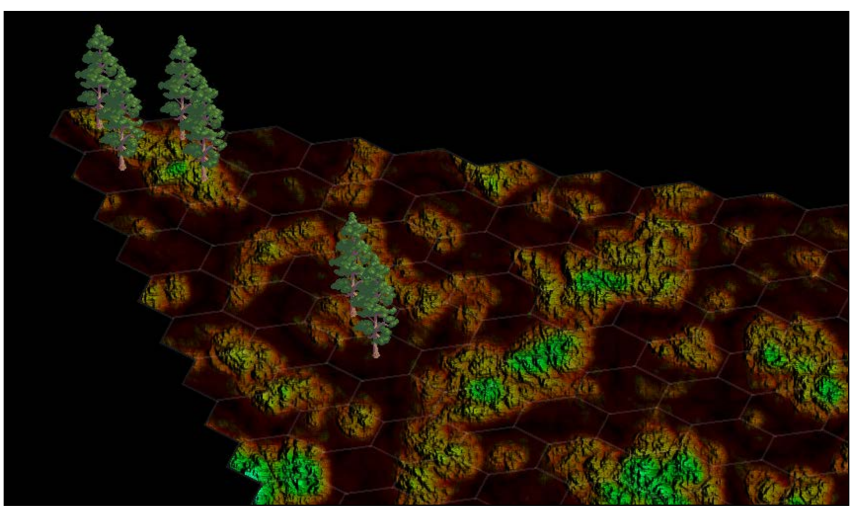
```
int main(int argc,char* argv[])
{
  sf::RenderWindow window(sf::VideoMode(1600,900),"Example Tile");
  sfutils::VMap* map =
    sfutils::VMap::createMapFromFile("./map.json");
  sfutils::MapViewer viewer(window,*map);
```

```
    sf::Clock clock;
    while (window.isOpen())
    {
      sf::Event event;
      while (window.pollEvent(event))
      {
        if (event.type == sf::Event::Closed)   // Close window :
          exit
        window.close();
      }
      window.clear();
      viewer.processEvents();
      viewer.update(clock.restart().asSeconds());
      viewer.draw();
      window.display();
    }
    return 0;
  }
```

The different steps of this function are as follows:

1. Creating a window
2. Creating a map from a file
3. Process the events and quit if requests
4. Update the viewer
5. Display the viewer on the screen

The result will be as follows:



Now that the map is done, we need to fill it with some entities.

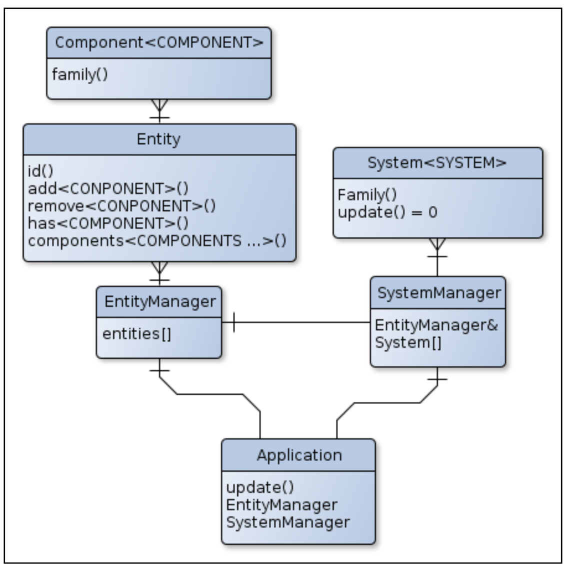
Building an entity system

First of all, what is an entity system?

An **entity system** is a design pattern that focuses on data. Instead of creating a
 a system that
allows us to add components to an entity at runtime. These components could be anything such as health points, artificial intelligence, skin, weapon, and everything but data.

ere are they
stored? The answer is in the systems. Each system manages at least one component, and all the logic is inside these systems. Moreover, it is not possible to build an entity directly. You have to create or update it using an entity manager. It will be in charge
on.

The structure is represented by the following chart:



template
and polymorphism.

Use of the entity system

t with
or, and
inherit from `Component` as follows:

```
struct CompHp : Component<CompHp>
{
  explicit Hp(int hp) : _hp(hp){};
  int _hp;
};
```

The inheritance is important to have a common base class between all the components. The same idea is used to create `System`:

```
struct SysHp : sfutils::System<SysHp>
{
  virtual void update(sfutils::EntityManager& manager,const
    sf::Time& dt) override;
};
```

`update`
function). Finally, to create an entity, you will have to do the following:

```
EntityManager entities;
std::uint32_t id = entities.create();
entities.addComponent<CompHp>(id,42); //the first argument is
  always the entity id
```

If we continue this example, when an entity has no `hp`, we have to remove it from the board. This part of the logic is implemented inside the `SysHp::update()` function:

```
void SysHp::update(sfutils::EntityManager& manager,const sf::Time&
  dt)
{
  CompHp::Handle hp; //Handler is a kind of smart pointer which
    ensure access to valid data
  auto view = manager.getByComponents(hp); //this object is a
    filter on all our entities by there components
  auto end = view.end();
  for(auto current = view.begin(); current != end;++current)
  {
    if(hp->_hp <= 0)
    manager.remove(current->id());
  }
}
```

This `SysHp::update()` function is used to create a specific functionality. Its aim is to remove all the entities with `hp` under or equal to zero. To do this, we initialize `ComponentHandler<CompHp>` using the `CompHp::Handle` shortcut (defined in the `Component` class). Then we create our query on the world. In our case, we need to get all the entities with `CompHp` attached to them. The multiple criteria query is also possible for more complex systems.

to `Entity` and to the `hp` handler is equivalent to the following:

```
manager.getComponent<CompHp>(current->id())
```

Then, we check the `_hp` value and remove the entity if needed.

It's important to note that the entity will actually be removed only when the `EntityManager::update()` function is called to keep data consistent inside the system loops.

Now that the `SysHp` parameter has been completed, we need to register it to `SystemManager` that is linked to `EntityManager`:

```
EntityManager entities;
SystemManager systems(entities);
systems.add<SysHp>();
```

We have now built an entity manager, a component, a system, and an entity. Putting them all together will result in the following code:

```
int main()
{
  EntityManager entities;
  SystemManager systems(entities);
  systems.add<SysHp>();

  for(int i =0; i<10; ++i)
  {//create entities
    std::uint32_t id = entities.create();
    entities.addComponent<CompHp>(id,i*10);
  }
  sf::Clock clock;
  while(/* some criterion*/)
  {//game loop
    systems.updateAll(clock.restart());
    entities.update();
  }
  return 0;
}
```

te 10 entities
and add them to the `CompHp` component. Finally, we enter the game loop.

ystem; focus
t complex, take
a look at the files in the `SFML-utils/include/SFML-utils/es` directory. This is
header only library.

Advantages of the entity system approach

nteger
mple to create
made very
simple with this approach but it's not the only point.

To create a flwo
different classes, namely car and flying vehicle. Each of these classes could inherit
ierarchical
tree is too much. For the same example, create an entity with the entity system,
entity system
can be difficult, but its usage simplifies a lot the game's complexity.

Building the game logic

events
s to group
them into a single project.

ously
an build
many of them, but the main components for the project are as follows:

Components	**Entities**
Skin	Animation
Health points	Current health
	Maximum health
Team	Identifier for the team
Build area	The authorized range around the entity
Movement	Speed
	Destination

Components	Entities
Artificial intelligence for warriors	Delta time
	Damage
	Length of hit

The interesting ones are artificial intelligence (to damage) and movement.
t in
addition/replacement of those proposed.

Building our components

teresting
components, namely the `walker AI` and the `warrior AI`:

```
struct CompAIWalker : Component<CompAIWalker>
{
  explicit CompAIWalker(float speed);
  const float _speed;
  sf::Vector2i _pathToTake;
};
```

This component handles the speed and destination. The destination can be updated by anything (for example, when an enemy is detected at proximity):

```
struct CompAIWarrior : Component<CompAIWarrior>
{
  explicit CompAIWarrior(int hitPoint,const sf::Time&
    timeDelta,int range);
  const int _hitPoint;
  const sf::Time _delta;
  sf::Time _elapsed;
  const int _range;
};
```

This component stores the aggressiveness of an entity, with its damaged, attack speed and area of aggressively.

the `CompSkin`
component. This component stores an `AnimatedSkin` and different possible `Animation` that could be applied to it:

```
struct CompSkin : sfutils::Component<CompSkin,Entity>
{
  enum AnimationId : int{ Stand,Spawn, MoveLeft, MoveRight,
    HitLeft, HitRight};
```

```
  sfutils::AnimatedSprite _sprite;
  std::unordered_map<int,sfutils::Animation*> _animations;
};
```

Now that the components have been built, take a look at the systems.

Creating the different systems

We need as many systems as the number of components. The skin system simply calls the update function on the animation. We have already built the related system for the health. For the team component, we don't need any system because this component is used only by artificial intelligence. The two systems left are more complex.

Let's start with the movement:

```
struct SysAIWalker : sfutils::System<SysAIWalker,Entity>
{
  explicit SysAIWalker(Level& level);
  virtual void update(sfutils::EntityManager<Entity>&
    manager,const sf::Time& dt) override;
  Level& _level;
};
```

Notice that the `Level` class has not yet been introduced. This class regroups an `EntityManager` and a `SystemManager` classes and gives us access to some functions concerning the map geometry, without having to know it. I will explain it later.
In our case, we will need some information about the distance between the actual
ep a
reference to the level.

Here's the implementation of the walker system:

```
SysAIWalker::SysAIWalker(Level& level) :_level(level) {}
void SysAIWalker::update(EntityManager& manager,const sf::Time&
  dt)
{
  CompAIWalker::Handle AI;
  CompSkin::Handle skin;
  auto view = manager.getByComponents(AI,skin);
  auto end = view.end();
  const float seconds = dt.asSeconds();

  for(auto begin = view.begin();begin != end;++begin)
  {
    sf::Vector2f PosCurrent = skin->_sprite.getPosition();
    sf::Vector2i CoordCurrent =
      _level.mapPixelToCoords(PosCurrent);
```

```
        sf::Vector2i CoordDest = AI->_pathToTake;
        if(CoordDest != CoordCurrent) //need to move
        {
          sf::Vector2f PosDest = _level.mapCoordsToPixel(CoordDest);
          //calculation of the direction to take
          sf::Vector2f directon = PosDest - PosCurrent;
          //calculation of the distance
          const float distance =
            std::sqrt((directon.x*directon.x)+(directon.y*directon.y));
          const float frameDistance = AI->_speed * seconds;
          if(distance > frameDistance)
              skin->_sprite.setPosition(PosCurrent +
            directon*(frameDistance/distance));
          else
          {
            skin->_sprite.setPosition(PosDest);
            AI->_pathToTake = CoordCurrent;
          }

          if(directon.x >0) //update skin direction
              skin->_sprite.setAnimation(skin-
            >_animations.at(CompSkin::MoveRight));
          else
              skin->_sprite.setAnimation(skin-
            >_animations.at(CompSkin::MoveLeft));
        }
      }
    }
```

This system doesn't just move the entity but also makes different things. The position is stored inside the `CompSkin` component, so we need to iterate on the entities by getting the `CompAIWalker` and `CompSkin` components attached to them. Then, we
f a move
is needed. If we need to move, we calculate the vector corresponding to the total displacement (direction). This vector gives us the direction that the entity needs
 current
new one.

he one
matching the movement direction taken by the entity.

Now, let's take an interest in the `Warrior AI`:

```
SysAIWarrior::SysAIWarrior(Level& level) : _level(level){}
void SysAIWarrior::update(sfutils::EntityManager<Entity>&
  manager,const sf::Time& dt)
```

```
{
  CompAIWarrior::Handle AI;
  CompTeam::Handle team;
  CompSkin::Handle skin;
  auto view = manager.getByComponents(AI,team,skin);
  auto end = view.end();
  for(auto begin = view.begin();begin != end;++begin)
  {
    AI->_elapsed += dt;
    std::vector<Team*> teamEnemies = team->_team->getEnemies();

    //if no enemies
    if(teamEnemies.size() <=0)
        continue;
    std::uint32_t id = std::uint32_t(-1);

    /* ….set id to the nearest enemy ... */

    if(not manager.isValid(id))
        continue;

    //update path
    Entity& enemy = manager.get(id);
    const sf::Vector2f pos = enemy.component<CompSkin>()-
      >_sprite.getPosition();
    const sf::Vector2i coord = _level.mapPixelToCoords(pos);
    const int distance = _level.getDistance(myPosition,coord);
    if(distance <= range) //next me
    {
      //shoot it
      if(AI->_elapsed >= AI->_delta)
      {
        AI->_elapsed = sf::Time::Zero;
        CompHp::Handle hp = enemy.component<CompHp>();
        hp->_hp -= AI->_hitPoint;
        Entity& me = **begin;
        if(enemy.onHitted != nullptr)
        enemy.onHitted(enemy,coord,me,myPosition,_level);
        if(me.onHit != nullptr)
        me.onHit(me,myPosition,enemy,coord,_level);
        //win some gold
        if(hp->_hp <=0){
            team->_team->addGold(hp->_maxHp/50);
        }
      }

      //no need to move more
      if(begin->has<CompAIWalker>())
      begin->component<CompAIWalker>()->_pathToTake = myPosition;
```

```
        }
        else
        {//too far
            sf::Vector2i path = _level.getPath1(myPosition,coord);
            //move closer
            if(begin->has<CompAIWalker>())
                begin->component<CompAIWalker>()->_pathToTake = path;
      }
    }
```

This system requires three components, namely `CompSkin` (for position), `CompTeam` (for detect enemy), and `CompAIWarrior`. The first thing to do is update the delta time. Then, we check if we have some enemies to defeat. Next, we search for
ur own
the enemy.
tting each
frame. We also trigger some events (for example, to create sound) and add gold to the team if we just kill the enemy. We also set the destination of the `CompAIWarrior` to the current position (to stay fighting) if we can, or move closer to the next enemy.

We now have all the components and systems to manage them. So, we will continue with the game architecture.

The level class

As usual, we split the game into several parts. The `level` class represents a map. This class stores all the entities, systems, viewers, maps, sounds, and so on. As previously
y.

hers. It registers all
the systems, constructs the map, initializes a `MapViewer`, events, and regroups all the different update calls into one method. This class also offers users the ability to create new entities, by creating them through the internal `EntityManager`, and adding them to a map layer. The map is always synchronized with the `EntityManager` while doing this.

If you are interested in this implementation, take a look at the `SFML-book/07_2D_iso_game/src/SFML-Book/Level.cpp` file.

The game class

Now, the `game` class! You should be familiar with this class by now. Its global behavior hasn't changed and still contains the same functionalities (`update()`, `processEvents()`, and `render()`).

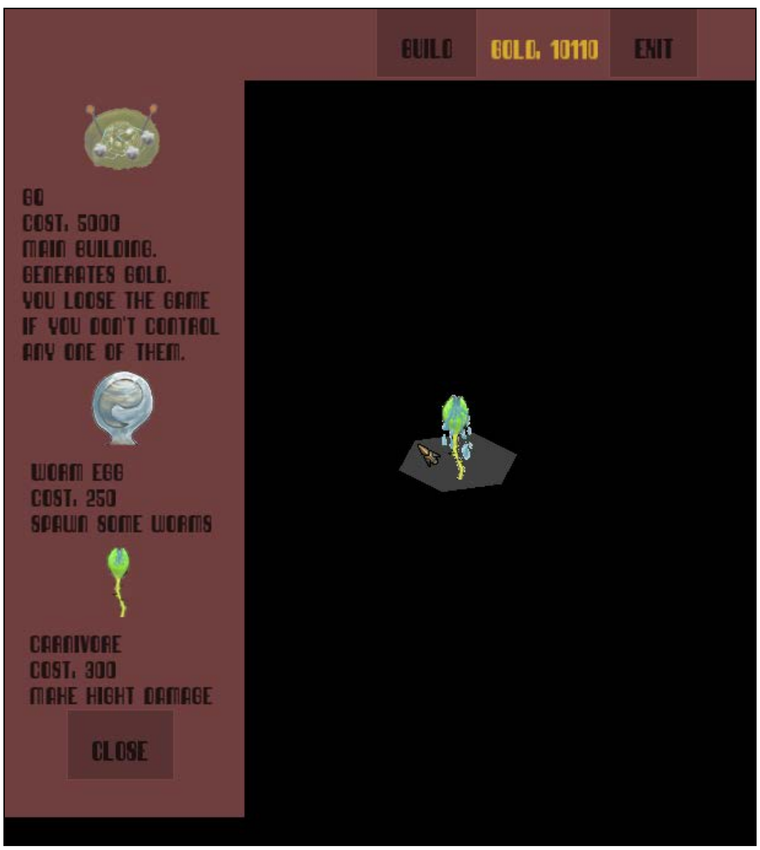
The big change here is that the game class will initialize a `Level` and `Team`. One of these will be the one controlled by the player, and the GUI depends on it. This is the he entire game.
I won't say that it's the best way, but it's the simplest and allows us to jump from one team to another.

If you are interested in this implementation, take a look at the `SFML-book/07_2D_iso_game/src/SFML-Book/Game.cpp` file.

The Team GUI class

This class handles different information and is the interface between the game and the player. It should allow the player to build some entities and interact with them.

The following screen shows you the **Build** menu. This menu shows the player the different entities that can be created and the current gold amount:



rmation
task a lot.

ng in mind the
following criteria:

- The amount of gold
- The build area

After this, everything will run easily. Don't hesitate to make some helper functions that create different entities by adding some components with specific values.

Summary

In this chapter, we covered different things, such as creating animations. This class allowed us to display animated characters on screen. Then, we built a `Map` class that was fi
creating some components and systems to build our game logic. Finally, we put all
tificial
intelligence, a user interface, sounds, and animations.

With all this knowledge, you are now able to build any kind of game based on a tile system without too much effort.

In the next chapter, we will turn this game in a multiplayer one by using networking.

8
Build a Real-time Tower Defense Game from Scratch – Part 2, Networking

 limitation
olve this
limitation in the present chapter by adding networking to our game to allow it to
interact with players other than you. At the end of this chapter, you will be able to
topics:

- Network architectures
- Network communication using sockets
- Creating a communication protocol
- Modifying our game by applying the client-server concept
- Saving and loading our game

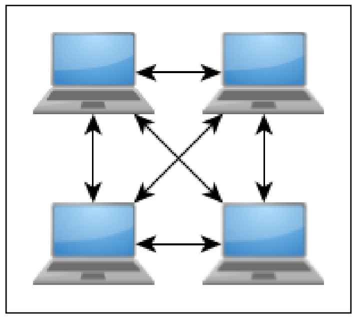
Now let's dive into this pretty complicated chapter.

Network architectures

t kind
of network architectures are commonly used in a game, and their specificities.
y greatly
n
 their strengths
and weaknesses. Let's analyze them individually.

Peer-to-peer architecture

In this
architecture, players know the addresses of each other and directly communicate
our
:



f the other
players. When a client does something, it notifies the others of this action, and they update the simulation (game) consequently.

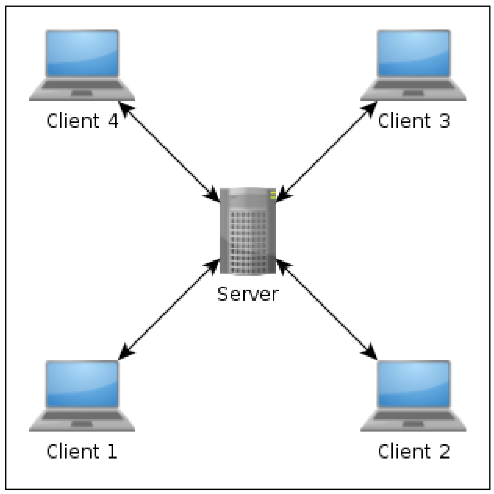
This approach is efficient for communications, but comes with some limitations that
. A client can
do whatever it wants by notifying the other of that action, even if it's impossible, such as teleporting itself by sending an arbitrary position. A possible result is that the fun of the game is completely destroyed for the other players.

able to have
a kind of referee that can decide if an action is legal.

Client-server architecture

completely destroy the experience of the game for the player. To be able to
client-
This is
one reason that justifies the importance of this part. One other point is that this
e players
le host
called the server. Because all other players will also do the same, we will be able to communicate with them, but with an intermediary.

ction is legal.
ers, the
t have to be
eract with. The
following chart represents the architecture:



kind of
actions to the other players.

ers (clients), and
ing the tasks
erver.

Some games require so many resources that it can't handle only a limited amount
e game; for
fic area of the
map, and so on. We will now see how to use this architecture for our game.

When creating a multiplayer architecture, the first thing to have in mind is that we
ver. We will
, possibly
on different matches.

To be able to have this kind of result, let's first think about what is needed by
each part.

Client

s program will
have to do the following:

- Display the game state
- Handle the different user inputs
- Play effects (sounds, bloodshed, and so on)
- Update its game status according to the information received from the server
- Send requests to the server (build, destroy)

ill need to
adapt them; but there are also some new features:

- Request the creation of a new match
- Request to join a match

Here I use the word *request* because that's what it really is. As a player will not handle the game in totality, it can only send requests to the server to take action.
ke a look at
the server.

Server

ll have to
manage the following functionalities:

- Store all the different matches
- Process each game's steps
- Send updates of the game to players
- Handle player requests

But a server also has to take care of the following:

- Managing connection/disconnection
- Game creation
- Adding a player as a controller for a team

As you can see, there is no need for any kind of display, so the server output will be
oming from the
ember this
rule: *don't trust user inputs.*

time in
nd you
random data such as cheats or anything else that you're not supposed to receive. So don't take the inputs at face value.

Now that the functionalities have been exposed, we need a way to communicate
k about.

Network communication using sockets

To be able to interact with other players, we will need a way to communicate with
h any
computer, we have to use sockets. In short, a socket enables communication with other processes/computers through the network as long as there is an existing way
ets: non-
connected (UDP) or connected (TCP). Both these need an IP address and a port number to communicate with their destination.

ween 0 and
65535. A piece of advice is to avoid the use of ports with a number lesser than 1024. The reason is that most of them are reserved by the system or used by common applications, such as 80 for a web browser, 21 for FTP, and so on. You also have to be able to
y introduced.

UDP

As already said, **User Datagram Protocol** (**UDP**) is a way of sending data through the network without connections. We can visualize the communication achieved
message to
someone, you have to specify the destination address (IP and port). The message can then be sent, but you don't know if it really arrives at its destination. This kind of communication is really quick, but comes with some limitations:

- You don't even know if the message has arrived at its destination
- A message can be lost
- A big message will be split in smaller messages
- Messages can be received in a different order than the original order
- A message can be duplicated

Because of these limitations, the messages can't be exploited as soon as they are received. There is a need for verification. A simple way to resolve a majority of message
identifier. This identifier will allow us to identify precisely a message, remove ensure that
data.

SFML provides us the `sf::UdpSocket` class to communicate using the UDP protocol. ed in it, take a
look at the SFML tutorial on the official website (`www.sfml-dev.org`).

TCP

Transmission Control Protocol (**TCP**) is a connected protocol. This can be compared is protocol:

- Ask for a connection to an address (phone is ringing)
- Accept the connection (pick up the phone)
- Exchange data (talk)
- Stop the conversation (hang up)

stination is in
the same ordering, structure, and consistency as at its source. By the way, we need over, if the
can detect it as
soon as it happens. The downside of this protocol is that the communication speed is reduced.

SFML provides us the `sf::TcpSocket` class to deal with the TCP protocol easily. This is the one that we will use in our project. I will discuss its usage in the next section.

Selector

SFML provides us with another utility class: `sf::SocketSelector`. This class works ckets, as
explained in the following steps:

1. Use the `sf::SocketSelector::add(sf::Socket)` method to add a socket to observe.

2. Then, when one or more of the observed sockets receive data, the `sf::SocketSelector::wait()function` return. Finally, using `sf::Socket Selector::isReady(sf::Socket)`, we can identify which one of the sockets received data. This allows us to avoid pooling and use real-time reaction.

We will use this class in this chapter paired with `sf::TcpSocket`.

The Connection class

Now that all the basic network bricks have been introduced, it's time for us to think about our game. We need to decide the way in which our game will exchange data with another player. We will need to send and receive data. To achieve this, we will use the `sf::TcpSocket` class. As each action on the socket will block the execution of our game, we will need to create a system to disable the blocking. SFML provides a `sf::Socket::setBlocking()` function, but our solution will use a different method.

The goal of the Connection class

If you remember, in *Chapter 6*, *Boost Your Code Using Multithreading*, I told you that
llow this
transparently
to SFML
event management from the `sf::Window` class. The result of these constraints is the construction of a `Connection` class. This class will then be specialized by the architecture that we will choose (described in the next section).

Let's now take a look at the header of this new class:

```
class Connection
{
  public:
  Connection();
  virtual ~Connection();

  void run();
  void stop();
  void wait();

  bool pollEvent(sf::Packet& event);
  bool pollEvent(packet::NetworkEvent*& event);

  void send(sf::Packet& packet);
  void disconnect();
  int id()const;
```

```
        virtual sf::IpAddress getRemoteAddress()const = 0;

        protected:
        sf::TcpSocket _sockIn;
        sf::TcpSocket _sockOut;

        private:
        bool _isRunning;

        void _receive();
        sf::Thread _receiveThread;
        sf::Mutex _receiveMutex;
        std::queue<sf::Packet> _incoming;

        void _send();
        sf::Thread _sendThread;
        sf::Mutex _sendMutex;
        std::queue<sf::Packet> _outgoing;

        static int _numberOfCreations;
        const int _id;
    };
```

Let's explain this class step by step:

1. We start by defining a constructor and a destructor. Notice that the destructor is set to virtual because the class will be specialized.
2. Then we define some common functions to deal with the internal thread for synchronization issues.
3. Some methods to deal with events are then defined. We build two methods

   overload on the `pollEvent()` function allows us to use raw or parsed data. The `packet::NetworkEvent` class will be described later in this chapter. For now, take it as a message similar to `sf::Event` with type and data, but coming from the network.
4. We define a function to close the communication properly.
5. Finally, we define some functions to get information on the connection.

to be as
responsive as possible, we will use two sockets: one for incoming messages and the other for outgoing messages. This will allow us to send and receive data at the same time and accelerate the responsiveness of the game. Because of this choice, we will
so on). Let's
discuss the goal of each one:

- `sf::TcpSocket`: It handles the communication between the two sides.
- `sf::Thread`: It allows us to be non-blocking as previously exposed. It will remain alive as long as the connection instance.
- `sf::Mutex`: It protects the queue of data to avoid data race or use them afterwards for free.
- `std::queue<sf::Packet>`: This is the queue of events to processes. Each time it is accessed, the associated mutex is locked.

Now that the different objects have been explained, we can continue with the implementation of the class, as follows:

```
Connection::Connection() :_isRunning(false),
  _receiveThread(&Connection::_receive,this),
  _sendThread(&Connection::_send,this),_id(++_numberOfCreations)
      {}
Connection::~Connection() {}
```

alizes with
on for that,
which is as follows:

```
void Connection::run()
{
  _isRunning = true;
  _receiveThread.launch();
  _sendThread.launch();
}

void Connection::stop() {_isRunning  = false;}

void Connection::wait()
{
  _receiveThread.wait();
  _sendThread.wait();
}
```

unching,
stopping, or keeping them waiting. Notice that a mutex to protect `_isRunning` is not necessary because we don't write in it outside of those functions.

```
int Connection::id()const {return _id;}

bool Connection::pollEvent(sf::Packet& event)
{
  bool res = false;
```

```
    sf::Lock guard(_receiveMutex);
    if(_incoming.size() > 0)
    {
      std::swap(event,_incoming.front());
      _incoming.pop();
      res = true;
    }
    return res;
  }

  bool Connection::pollEvent(packet::NetworkEvent*& event)
  {
    bool res = false;
    sf::Packet msg;
    if(Connection::pollEvent(msg))
    {
      event = packet::NetworkEvent::makeFromPacket(msg);
      if(event != nullptr)
        res = true;
    }
    return res;
  }
```

These two functions are important and copy the behavior of the `sf::Window::pollEvent()` function, so their usage will not surprise you. What we one enabled.
The second function also parses the receiving message to a `NetworkEvent` function. Most often, we will prefer to use the second method in our code, because all the verifijust adds
a packet to the outgoing queue. The job is then done by the `_sendThread` object, as shown in the following code snippet:

```
  void Connection::send(sf::Packet& packet)
  {
    sf::Lock guard(_sendMutex);
    _outgoing.emplace(packet);
  }
```

This function closes the different sockets used. Because we used a connected and manage
this at its convenience.

```
  void Connection::disconnect()
  {
    _sockIn.disconnect();
    _sockOut.disconnect();
  }
```

own thread—
this is the reason for the loop. Moreover, we use the `sf::SocketSelector` function to observe our socket. Using this, we avoid useless operations that consume CPU coming
socket. We also add a timeout of one second to avoid a deadlock, as seen in the following code snippet:

```
void Connection::_receive()
{
  sf::SocketSelector selector;
  selector.add(_sockIn);
  while(_isRunning)
  {
if(not selector.wait(sf::seconds(1)))
  continue;
if(not selector.isReady(_sockIn))
  continue;
    sf::Packet packet;
    sf::Socket::Status status = _sockIn.receive(packet);
    if(status == sf::Socket::Done)
    {
      sf::Lock guard(_receiveMutex);
      _incoming.emplace(std::move(packet));
    }
    else if (status == sf::Socket::Disconnected)
    {
      packet.clear();
      packet<<packet::Disconnected();
      sf::Lock guard(_receiveMutex);
      _incoming.emplace(std::move(packet));
      stop();
    }
  }
}
```

A deadlock is a situation encountered in multithreaded programs where two threads wait indefinitely because they are both waiting for a resource that only the other thread can free up. The most common is a double lock on the same mutex in the same thread, with a recursive call, for example. In the present case, imagine that you use the `stop()` function. The thread is not aware of this change, and will still be waiting for data, maybe forever, because no new data will be received on the socket. An easy solution is to add a timeout to not wait forever, but only a small amount of time that allows us to recheck the loop condition and get out if necessary.

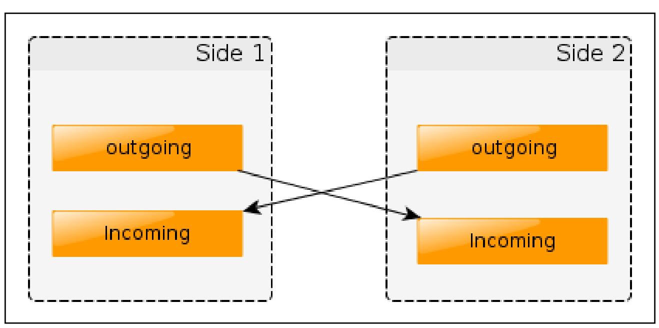
Once a packet is received, or a disconnection is detected, we add the corresponding packet to the queue. The user will then be able to pool in from its own thread and treat it as he wants. The disconnection shows you a specific `NetworkEvent : Disconnected` function. Later in the chapter, I will explain in detail the logic behind this.

```
void Connection::_send()
{
  while(_isRunning)
  {
    _sendMutex.lock();
    if(_outgoing.size() > 0)
    {
      sf::Packet packet = _outgoing.front();
      _outgoing.pop();
      _sendMutex.unlock();
      _sockOut.send(packet);
    }
    else
    {
      _sendMutex.unlock();
    }
  }
}
```

This function complements the previous one. It picks up events from the outgoing queue and sends it through the network using its socket.

As you can see, with the use of classes, we can send and receive data very easily in a multi-threaded environment. Moreover, the disconnection is managed like any
trength of this
ding on client and
server sides.

To sum it up, we can visualize the usage of this class as shown in the following chart:



s build our
custom protocol.

Creating a communication protocol

It's now time for us to create our own custom protocol. We will use an SFML class sf::Packet to transport our data, but we have to define their shapes. Let's first focus on the sf::Packet class and then on the shapes.

Using the sf::Packet class

The sf::Packet class is like a buffer that contains our data. It comes with already-
if you are
that the
arrangement is not the same everywhere. This is called endianness. You can see it
e network,
onvention is
to send data as a big-endian arrangement over the network. I suggest you to take a look at the Wikipedia page (https://en.wikipedia.org/wiki/Endianness) for more details.

easy for us.
primitive
types. Following is a table that shows you the primitive types, and the corresponding type to use with sf::Packet:

Primitive	**SFML overload**
char	sf::Int8
unsigned char	sf::Uint8
short int	sf::Int16
unsigned short int	sf::Uint16
Int	sf::int32
unsigned int	sf::Uint32
float	float
double	double
char*	char*
std::string	std:string
bool	bool

The `sf::Packet` class is used like the standard c++ I/O streams using the `>>` and `<<` operators
the SFML documentation of the `sf::Packet` class that shows you how simple it is in terms of usage:

```
void sendDatas(sf::Socket& socket)
{
  sf::Uint32 x = 24;
  std::string s = "hello";
  double d = 5.89;
  // Group the variables to send into a packet
  sf::Packet packet;
  packet << x << s << d;
  // Send it over the network (socket is a valid sf::TcpSocket)
  socket.send(packet);
}

void receiveDatas(sf::Socket& socket)
{
  sf::Packet packet;
  socket.receive(packet);
  // Extract the variables contained in the packet
  sf::Uint32 x;
  std::string s;
  double d;
  if (packet >> x >> s >> d)
  {
    // Data extracted successfully...
  }
}
```

e structure/
at we will use
to send/receive data, an example of which is as follows:

```
struct MyStruct
{
  float number;
  sf::Int8 integer;
  std::string str;
};

sf::Packet& operator <<(sf::Packet& packet, const MyStruct& m){
  return packet << m.number << m.integer << m.str;
}
```

```
sf::Packet& operator >>(sf::Packet& packet, MyStruct& m){
  return packet >> m.number >> m.integer >> m.str;
}

int main()
{
  MyStruct toSend;
  toSend.number = 18.45f;
  toSend.integer = 42;
  toSend.str = "Hello world!";

  sf::Packet packet;
  packet << toSend;

  // create a socket

  socket.send(packet);
  //...
}
```

ization/
ture changes,
there is only one place to update: the operators.

Now that we have seen the system to transport our data, let's think about a way to construct it so that it is as generic as possible.

RPC-like protocol

. We have
already pretty much completed the job in the first part of this chapter by separating the tasks of the client and the server, but it's not sufficient. We now need a list of all the different possibilities, which have been enlisted here.

Both sides:

- Connection
- Disconnection
- Client event

Log out

- Get game list
- Request for the creation of a game (match)
- Request to join the game
- Request to create an entity
- Request to destroy an entity

Server events

- Entity update
- Entity's events (onHit, onHitted, onSpawn)
- Update team (gold, game over)
- Respond to client events

s is that
one event,
r own data.

Well, we
need an identifier that allows this. An `enum` function will do the job perfectly,
as follows:

```
namespace FuncIds{
  enum FUNCIDS {
    //both side
    IdHandler = 0, IdDisconnected, IdLogOut,
    //client
    IdGetListGame, IdCreateGame, IdJoinGame,IdRequestCreateEntity,
      IdRequestDestroyEntity,
    //server events
    IdSetListGame, IdJoinGameConfirmation, IdJoinGameReject,
    IdDestroyEntity, IdCreateEntity,  IdUpdateEntity,
    IdOnHittedEntity, IdOnHitEntity,  IdOnSpawnEntity,
    IdUpdateTeam
  };
}
```

ith a
common part for all these actions. This part (header) will contain the identifier of
e way that
`sf::Event` works with the `sf::Event::type` attribute.

alled
`NetworkEvent`. This class works as `sf::Event` does, except that it also adds serialization/unserialization with the `sf::Packet` class, allowing us to send that

The NetworkEvent class

The `NetworkEvent` class is built inside the `book::packet` namespace. Now that we
o build some
classes that will help us to deal with them.

We will build one class for each event, with a common parent, the `NetworkEvent` class. This class will allow us to use polymorphism. Following is its header:

```
class NetworkEvent
{
  public:
  NetworkEvent(FuncIds::FUNCIDS type);
  virtual ~NetworkEvent();

  FuncIds::FUNCIDS type()const;
  static NetworkEvent* makeFromPacket(sf::Packet& packet);

  friend sf::Packet& operator>>(sf::Packet&, NetworkEvent& self);
  friend sf::Packet& operator<<(sf::Packet&, const NetworkEvent&
    self);

  protected:
  const FuncIds::FUNCIDS _type;
};
```

As you can see, this class is very short and only contains its type. The reason is
ontains some
default operator and an important function: `makeFromPacket()`. This function, as
 inside the
`sf::Packet` received as parameter. Now take a look at the implementation:

```
NetworkEvent::NetworkEvent(FuncIds::FUNCIDS type) : _type(type){}
NetworkEvent::~NetworkEvent(){}
```

As usual, the constructor and the destructor are very simple and should be familiar:

```
NetworkEvent* NetworkEvent::makeFromPacket(sf::Packet& packet)
{
  sf::Uint8 type;
  NetworkEvent* res = nullptr;
  packet>>type;
  switch(type)
```

```
    {
      case FuncIds::IdDisconnected :
      {
        res = new Disconnected();
        packet>>(*static_cast<Disconnected*>(res));
      }break;

      //... test all the different  FuncIds

      case FuncIds::IdUpdateTeam :
      {
        res = new UpdateTeam();
        packet>>(*static_cast<UpdateTeam*>(res));
      }break;
    }
  return res;
  }
```

e data
received from the network to an instance of `NetworkEvent` with respect to the type received. The programmer will then use this instance instead of `sf::Packet`. Notice
ade on the
returned object after use:

```
FuncIds::FUNCIDS NetworkEvent::type()const {return _type;}
```

The previous function return the type associated to the `NetworkEvent`. It allows the programmer to cast the instance into the correct class.

```
sf::Packet& operator>>(sf::Packet& packet, NetworkEvent& self)
{
    return packet;
}

sf::Packet& operator<<(sf::Packet& packet, const NetworkEvent&
  self)
{
  packet<<sf::Uint8(self._type);
  return packet;
}
```

unctionality.
Because the unserialization function (`>>` operator) is only called inside the `makeFromPacket()` function and the type has already been extracted, this one does nothing. On the other hand, the serialization function (`<<` operator) adds the type of the event to the packet, as there is no other data.

n the same
logic, and I'm sure that you already understand how it is done.

Let's take the `RequestCreateEntity` class. This class contains the different data to request the creation of an entity on the battlefield:

```
namespace EntityType {
  enum TYPES {IdMain = 0,IdEye,IdWormEgg,IdWorm,IdCarnivor,};
}

class RequestCreateEntity : public NetworkEvent
{
  public :
  RequestCreateEntity();
  RequestCreateEntity(short int type,const sf::Vector2i& coord);

  short int getType()const;
  const sf::Vector2i& getCoord()const;

  friend sf::Packet& operator>>(sf::Packet&, RequestCreateEntity&
    self);
  friend sf::Packet& operator<<(sf::Packet&, const
    RequestCreateEntity& self);

  private:
  short int _entitytype;
  sf::Vector2i _coord;
};
```

First of all, we define an `enum` function that will contain all the identifiers
he
`RequestCreateEntity` class inherits from the previous `NetworkEvent` class and defines the same functions, plus those specific to the event. Notice that there are two constructors. The default is used in the `makeFromPacket()` function, and the other by the programmer to send an event. Take a look now at the following implementation:

```
RequestCreateEntity::RequestCreateEntity() :
  NetworkEvent(FuncIds::IdRequestCreateEntity){}

RequestCreateEntity::RequestCreateEntity(short int type,const
  sf::Vector2i& coord) : NetworkEvent(FuncIds::IdRequestCreateEntity),
_entitytype(type),
  _coord(coord) {}

short int RequestCreateEntity::getType()const
```

```
{
    return _entitytype;
}

const sf::Vector2i& RequestCreateEntity::getCoord()const {return
  _coord;}

sf::Packet& operator>>(sf::Packet& packet, RequestCreateEntity&
  self)
{
  sf::Int8 type;
  sf::Int32 x,y;
  packet>>type>>x>>y;

  self._entitytype = type;
  self._coord.x = x;
  self._coord.y = y;
  return packet;
}
```

This function unpacks the different data specific to the event and stores them internally. That's all:

```
sf::Packet& operator<<(sf::Packet& packet, const
  RequestCreateEntity& self)
{
  packet<<sf::Uint8(self._type)
  <<sf::Int8(self._entitytype)
  <<sf::Int32(self._coord.x)
  <<sf::Int32(self._coord.y);
  return packet;
}
```

ponding to the
primitive types used.

only requires
an identifier for its class along with some parsing functions. All the other events are built on the same model as this one, so I will not explain them. To see the complete code, you can take a look at the `include/SFML-Book/common/Packet.hpp` file if you want.

Now that we have all the keys in hand to build the multiplayer part, it's time for us to modify our game.

Modifying our game

nal structure
ograms. All the
common classes (such as those used for communication) will be put into a common directory. All the other functionalities will be put into the server or client folder with server.

Server

e will reside
g multiple
ions/
disconnections and player events.

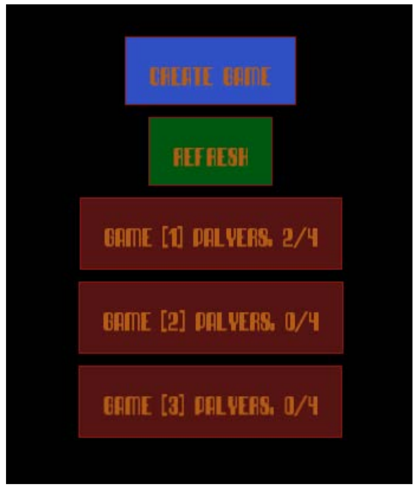
lass
anymore on this side. So the `AnimatedSprite` function in the `CompSkin` component will have to be removed, as will the `sf::RectangleShape` component in the `CompHp` function.

Because the positions of the entities were stored by the `CompSkin` component (more precisely `_sprite`), we have to add an `sf::Vector2f` function in each entity that will store its position.

e
multiple clients and matches and listen for a new connection on a specific port. So to be able to do this, we will build a `Server` class, and each match will have its own game instance running in its own thread. So let's do this:

Building the Server entry point

matches and
to add clients to existing matches. This class can be seen like the main menu of the
as follows:



So, we will need to:

- Store the running match (games)
- Store the new clients
- Listen for new clients
- Respond to some request (create a new match, joint a match, get the list of running match)

Let's now build the server class.

```
class Server
{
    public:
        Server(int port);
        ~Server();
        void run();

    private:
        const unsigned int _port;
        void runGame();
        void listen();
```

```
        sf::Thread _gameThread;
        sf::Mutex _gameMutex;
        std::vector<std::shared_ptr<Game>> _games;

        sf::Mutex _clientMutex;
        std::vector<std::shared_ptr<Client>> _clients;

        sf::Thread _listenThread;
        sf::TcpListener _socketListener;
        std::shared_ptr<Client> _currentClient;
};
```

This class handle all the information describe above, and some threads to run
e a look
to its implementation:

lowed:

```
sig_atomic_t stop = false;
void signalHandler(int sig) {stop = true;}
```

rver by
pressing the *Ctrl* + *C* key. This mechanism is initialized in the `Server::run()` function as you will see in a moment..

```
Server::Server(int port) :
  _port(port),_gameThread(&Server::runGame,this),_listenThread(&Server
::listen,this)
{
  rand_init();
  _currentClient = nullptr;
}
```

unction.

```
Server::~Server()
{
  _gameMutex.lock();
  for(Game* game : _games)
  game->stop()
  _gameMutex.unlock();
  _clientMutex.lock();
  for(Client* client : _clients)
  client->stop();
  _clientMutex.unlock();
}
```

properly.

```
void Server::run()
{
  std::signal(SIGINT,signalHandler);
  _gameThread.launch();
  _listenThread.launch();
  _gameThread.wait();
  _listenThread.terminate();
}
```

This function start the server that is blocked until the `SIGINT` (*Ctrl* + *c*) signal is sent to it:

```
void Server::runGame()
{
  while(!stop)
  {
    sf::Lock guard(_clientMutex);
    for(auto it = _clients.begin(); it !=
      _clients.end();++it)//loop on clients
    {
      std::shared_ptr<Client> client = *it; //get iteration
        current client
      packet::NetworkEvent* msg;
      while(client and client->pollEvent(msg)) //some events
        incomings
      {
        switch(msg->type()) //check the type
        {
          case FuncIds::IdGetListGame :
          {
            sf::Packet response;
            packet::SetListGame list;
            sf::Lock guard(_gameMutex);
            for(Game* game : _games) { //send match informations
            list.add(game->id(),game->getPlayersCount(),game-
              >getTeamCount());
          }
          response<<list;
          client->send(response);
        }break;
        case FuncIds::IdCreateGame :
        {
          sf::Packet response;
          packet::SetListGame list;
```

```
          sf::Lock guard(_gameMutex);
          _games.emplace_back(new Game("./media/map.json"));
            //create a new match
          for(Game* game : _games){ //send match informations
          list.add(game->id(),game->getPlayersCount(),game-
            >getTeamCount());
        }
        //callback when a client exit a match
        _games.back()->onLogOut = [this](std::shared_ptr<Client>
          client){
          _clients.emplace_back(client);
        };
        _games.back()->run(); //start the match
        response<<list;
        for(auto it2 = _clients.begin(); it2 !=
          _clients.end();++it2){ //send to all client
        (*it2)->send(response);
      }
    }break;
    case FuncIds::IdJoinGame :
    {
      int gameId = static_cast<packet::JoinGame*>(msg)->gameId()
      sf::Lock guard(_gameMutex);
      //check if the player can really join the match
      for(auto game : _games) {
        if(game->id() == gameId) {
          if(game->addClient(client)){ //yes he can
          client = nullptr;
          it = _clients.erase(it); //stop to manage the client
            here. Now the game do it
          --it;
        }
        break;
      }
    }
  }break;
  case FuncIds::IdDisconnected : //Oups, the client leave the game
  {
    it = _clients.erase(it);
    --it;
    client = nullptr;
  }break;
  default : break;
}
delete msg;
}
```

This function is the server's most important function. This is the one that handles all event waiting
ons. Thanks
to our `NetworkEvent` class, the parsing on the event is easy, and we can reduce the code to the functionalities only:

```
void Server::listen()
{
  if(_socketListener.listen(_port) != sf::Socket::Done) {
    stop = true;
    return;
  }
  _currentClient =   new Client;
  while(!stop)
  {
    if (_socketListener.accept(_currentClient->getSockIn()) ==
      sf::Socket::Done) {
      if(_currentClient->connect()) {
        sf::Lock guard(_clientMutex);
        _clients.emplace_back(_currentClient);
        _currentClient->run();
        _currentClient = new Client;
      }
      else {
        _currentClient->disconnect();
      }
    }
  }
}
```

This function is the final function of the server. Its job is to wait for a new connection, initialize the client, and add it to the list managed by the previous function.

Nothing else has to be done in this class since as soon as the client joins a match, it's the match and no more the `Server` class that will have to deal with it. Each match is managed by a `Game` instance. Let's now take a look at it.

Reacting to players' actions during a match

The `Game` class hasn't changed a lot. The event processing has changed, but is still very similar to the original system. Instead of using `sf::Event`, we now use `NetworkEvent`. And because the API is very close, it should not disturb you too much.

The first function that interacts with a player is the one that receives the match information. For example, we need to send it to the map file and all the different entities. This task is created by the `Game::addClient()` function, as follows:

```
bool Game::addClient(Client* client)
{
    sf::Lock guard(_teamMutex);
    Team* clientTeam = nullptr;
    for(Team* team : _teams)
    {
        // is there any team for the player
        if(team->getClients().size() == 0 and team->isGameOver())
        { //find it
            clientTeam = team;
            break;
        }
    }

    sf::Packet response;
    if(clientTeam != nullptr)
    {
        //send map informations
        std::ifstream file(_mapFileName);
        //get file content to as std::string
        std::string content((std::istreambuf_iterator<char>(file)),(st
d::istreambuf_iterator<char>()));

        packet::JoinGameConfirmation conf(content,clientTeam->id());//
send confirmation

        for(Team* team : _teams)
        { //send team datas
            packet::JoinGameConfirmation::Data data;
            data.team = team->id();
            data.gold = team->getGold();
            data.color = team->getColor();
            conf.addTeam(std::move(data));
        }
```

```
            response<<conf;
            client->send(response);
            {
                //send initial content
                response.clear();
                sf::Lock gameGuard(_gameMutex);
                packet::CreateEntity datas; //entites informations
                for(auto id : entities)
                    addCreate(datas,id);
                response<<datas;
                client->send(response);
            }

            client->setTeam(clientTeam);
            sf::Lock guardClients(_clientsMutex);
            _clients.emplace_back(client);
        }
        else
        { //Oups, someone the match is already full
            response<<packet::JoinGameReject(_id);
            client->send(response);
        }
        return clientTeam != nullptr;
    }
```

This function is separated into four parts:

1. Checking if we can add a new player to the match.
2. Sending map data.
3. Sending entity informations.
4. Adding the client to the team.
5. Once a client has been added to the game, we have to manage its incoming events. This task is made by the new function `processNetworkEvents()`. It works exactly as the old `processEvents()` function, but with `NetworkEvent` instead of `sf::Events`:

   ```
   void Game::processNetworkEvents()
   {
       sf::Lock guard(_clientsMutex);
        for(auto it = _clients.begin(); it != _clients.end();++it)
       {
            auto client = *it;
            packet::NetworkEvent* msg;
   ```

```
            while(client and client->pollEvent(msg))
           {
                switch(msg->type())
                {
                     case FuncIds::IdDisconnected :
                     {
                         it = _clients.erase(it);
                         --it;
                         delete client;
                         client = nullptr;
                     }break;

                     case FuncIds::IdLogOut :
                     {
                         it = _clients.erase(it);
                         --it;
                         client->getTeam()->remove(client);
                         onLogOut(client); //callback to the server
                          client = nullptr;
                     }break;

                     case FuncIds::IdRequestCreateEntity :
                     {
                         packet::RequestCreateEntity* event =
static_cast<packet::RequestCreateEntity*>(msg);
                         sf::Lock gameGuard(_teamMutex);
                          // create the entity is the team as enough
money
                     }break;

                     case FuncIds::IdRequestDestroyEntity :
                     {
                         packet::RequestDestroyEntity* event =
static_cast<packet::RequestDestroyEntity*>(msg);
                         // destroy the entity if it shares the same
team as the client
                     }break;
                      default : break;
               } //end switch           } //end while       } //
end for
}
```

nnection/
logout, and then with all the different events. I don't have to put the entire code of
are interested,
take a look at the `src/SFML-Book/server/Game.cpp` file.

Notice that we never send any confirmation to the client for any request. The synchronization of the game will ensure this.

Synchronization between clients and the server

A big change in the `Game` class is the way to manage the synchronization between the
d data. Now we
have some of the clients, and the logic changes. To ensure synchronization, we have to send updates to clients.

ring the
change the
ints we don't
eed to keep
track of the following:

- Entity creation
- Entity destruction
- Entity updates
- Entity events (onHitted, onHit, onSpawn)
- Update of team status, gold amount, and so on

Most of these events only require the entity ID without any other information
ired, but the
logic is still the same: add the information to a container.

Then, in the `Game::update()` function, we have to send the updates to all the
in the
`Connection` class). Another thread will be in charge of their propagation.

Here is a code snippet that makes the destruction event:

```
if(_destroyEntityId.size() > 0)
{
  packet::DestroyEntity update;
  for(auto id : _destroyEntityId)
  update.add(id);
  sf::Packet packet;
```

```
    packet<<update;
    sendToAll(packet);
    _destroyEntityId.clear();
  }
```

y the
`sendToAll()` function. As you can suppose, its aim is to broadcast the message to all the different players by adding the packet to the outgoing queue. Another thread will then enter that queue to broadcast the message.

entity system
and the map to manage the level. Only the graphical elements have been deleted. It is the client's job to display on the screen the game state to the player, speaking of which, let's now look into this part in detail.

The Client class

This is the fince
it only has one player to manage but is still a bit complex. The client will have a
ent is
handling player inputs and updating the game states with the incoming network events.

Because starting a client is now not sufficient to start a match, we have to
atch. In fact,
a client is composed of two main components: the connection menu and the game.
s, which is
why I will now show you the new `Game` header before continuing the explanation:

```
class Game
{
  public:
  Game(int x=1600, int y=900);
  ~Game();
  bool connect(const sf::IpAddress& ip, unsigned short
    port,sf::Time timeout=sf::Time::Zero);
  void run(int frame_per_seconds=60);
  private:
  void processEvents();
  void processNetworkEvents();
  void update(sf::Time deltaTime);
  void render();
  bool _asFocus;
  sf::RenderWindow _window;
```

```
    sf::Sprite _cursor;
    Client _client;
    bool _isConnected;
    enum Status {StatusMainMenu,StatusInGame, StatusDisconnected}
      _status;
    MainMenu _mainMenu;
    GameMenu _gameMenu;
    Level* _level;
    Level::FuncType _onPickup;
    int _team;
};
```

the GUI
has been separated in other classes (`MainMenu`, `GameMenu`). On the other hand, some classes such as `Level` haven't changed.

Now let's take a look at the main menu.

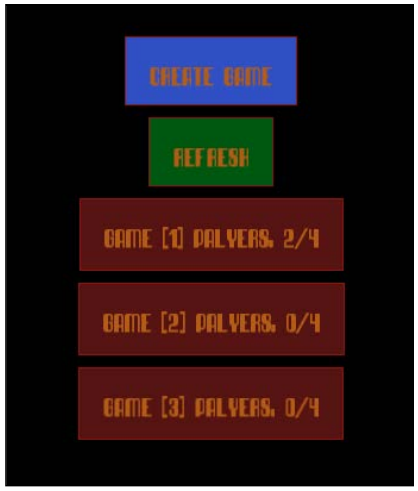
Connection with the server

ng which we
have to choose which match we want to play. The connection is achieved exactly as
 vice versa).

The choice of the match is then made by the player. He has to be able to create a new match and join it as well. To simplify this, we will use our GUI by creating a `MainMenu` class:

```
class MainMenu : public sfutils::Frame
{
  public:
  MainMenu(sf::RenderWindow& window,Client& client);
  void fill(packet::SetListGame& list);
  private:
  Client& _client;
};
```

This class is very small. It's a frame with several buttons, as you can see in the following image:



The implementation of this class is not too complicated; rather much more consequential:

```
MainMenu::MainMenu(sf::RenderWindow& window,Client& client) : sfutils:
:Frame(window,Configuration::guiInputs), _client(client)
{
        setLayout(new sfutils::Vlayout);
}

void MainMenu::fill(packet::SetListGame& list)
{
    clear();
    sfutils::VLayout* layout = static_cast<sfutils::VLayout*>(Frame::
getLayout());
    {
        sfutils::TextButton* button = new sfutils::TextButton("Create
game");
        button->setCharacterSize(20);
        button->setOutlineThickness(1);
        button->setFillColor(sf::Color(48,80,197));
        button->on_click = [this](const sf::Event&, sfutils::Button&
button){
            sf::Packet event;
            event<<packet::CreateGame();
            _client.send(event);
        };
        layout->add(button);
```

```
        }

        {
            sfutils::TextButton* button = new
    sfutils::TextButton("Refresh");
            button->setCharacterSize(20);
            button->setOutlineThickness(1);
            button->setFillColor(sf::Color(0,88,17));
            button->on_click = [this](const sf::Event&, sfutils::Button&
    button){
                sf::Packet event;
                event<<packet::GetListGame();
                _client.send(event);
            };
            layout->add(button);
        }

        for(const autoe& game : list.list())
        {
            std::stringstream ss;
            ss<<"Game ["<<game.id<<"] Players: "<<game.
    nbPlayers<<"/"<<game.nbTeams;
            sfutils::TextButton* button = new sfutils::TextButton(ss.
    str());
            button->setCharacterSize(20);
            button->setOutlineThickness(1);
            button->on_click = [this,game](const sf::Event&,
    sfutils::Button& button){
                sf::Packet event;
                event<<packet::JoinGame(game.id);
                _client.send(event);
            };
            layout->add(button);
        } //end for
    }
```

All the logic of the class is coded within the `fill()` function. This function receives
o the player.
t the creation
of a game.

side, the
client receives a `JoinGameConfirmation` event with the data to initialize its level
(remember the `addClient()` function in the server):

```
    void Game::processNetworkEvents()
    {
      packet::NetworkEvent* msg;
```

```
while(_client.pollEvent(msg))
{
  if(msg->type() == FuncIds::IdDisconnected) {
    _isConnected = false;
    _status = StatusDisconnected;
  }
  else
  {
    switch(_status)
    {
      case StatusMainMenu:
      {
        switch(msg->type())
        {
          case FuncIds::IdSetListGame :
          {
            packet::SetListGame* event =
              static_cast<packet::SetListGame*>(msg);
            _mainMenu.fill(*event);
          }break;
          case FuncIds::IdJoinGameConfirmation :
          {
            packet::JoinGameConfirmation* event =
              static_cast<packet::JoinGameConfirmation*>(msg);
            // create the level from event
            if(_level != nullptr) {
              _team = event->getTeamId();
              // initialize the team menu
              _status = StatusInGame;
            }
          }break;
          case FuncIds::IdJoinGameReject :
          {
            //...
          }break;
          default : break;
        }
      }break;
      case StatusInGame :
      {
        _gameMenu.processNetworkEvent(msg);
        _level->processNetworkEvent(msg);
      }break;
```

```
            case StatusDisconnected :
            {
              // ...
                    }break;
                } //end switch
            } //end else
            delete msg;
        } //end while
    }
```

This function handles the events coming from the server and dispatches them depending on the internal states. As you can see, a `JoinGameConfirmation` event which shows by
displaying the game to the player.

The Level class

Some additions have been made to the `Level` class to handle network events. We so have to
manage events coming from the server, such as position update, entity creation/destruction, and entity events.

namism to
function:

```
void Level::processNetworkEvent(packet::NetworkEvent* msg)
{
  switch(msg->type())
  {
    case FuncIds::IdDestroyEntity :
    {//need to destroy an entity
      packet::DestroyEntity* event =
        static_cast<packet::DestroyEntity*>(msg);
         for(auto id : event->getDestroy())
           {
                destroyEntity(id);
            }
    }break;
    case FuncIds::IdCreateEntity :
    {//need to create an entity
      packet::CreateEntity* event =
      static_cast<packet::CreateEntity*>(msg);
      for(const autoa& data : event->getCreates())
      {
        Entity& e = createEntity(data.entityId,data.coord);
          //create the entity
```

```
    makeAs(data.entityType,e,&_teamInfo.at(data.entityTeam),
      *this,data); //add the components
  }
}break;
case FuncIds::IdUpdateEntity :
{//an entity has changed
  packet::UpdateEntity* event =
    static_cast<packet::UpdateEntity*>(msg);
  for(const auto& data : event->getUpdates())
  {
    if(entities.isValid(data.entityId)) //the entity is still
      here, so we have to update it
    {
      CompSkin::Handle skin =
        entities.getComponent<CompSkin>(data.entityId);
      CompHp::Handle hp =
        entities.getComponent<CompHp>(data.entityId);
      //... and other updates
      hp->_hp = data.hp;
    }
  }
}break;
case FuncIds::IdOnHittedEntity :
{//entity event to launch
  packet::OnHittedEntity* event =
  static_cast<packet::OnHittedEntity*>(msg);
  for(const auto& data : event->getHitted())
  {
    if(entities.isValid(data.entityId))
    {
      Entity& e = entities.get(data.entityId);
      if(e.onHitted and entities.isValid(data.enemyId)) //to
        avoid invalid datas
      {
        Entity& enemy = entities.get(data.enemyId);
        //call the callback
        e.onHitted(e,_map->mapPixelToCoords(e.getPosition()),
          enemy, _map->mapPixelToCoords
            (enemy.getPosition()),*this);
      }
    }
  }
}break;
case FuncIds::IdOnHitEntity :
{//another event
  //same has previous with e.onHit callback
}break;
case FuncIds::IdOnSpawnEntity :
```

```
        { //other event
          packet::OnSpawnEntity* event =
            static_cast<packet::OnSpawnEntity*>(msg);
          for(auto id : event->getSpawn())
          {
            if(entities.isValid(id))
            {
              Entity& e = entities.get(id);
              CompAISpawner::Handle spawn =
                entities.getComponent<CompAISpawner>(id);
              if(spawn.isValid() and spawn->_onSpawn) //check data
                validity
              {//ok, call the call back
                spawn->_onSpawn(*this,_map-
                  >mapPixelToCoords(e.getPosition()));
              }
            }
          }
        }break;
        default : break;
      }
    }
```

manage six
are easy to
make because the major part of the job is done by the `EntityManager` function.
he new
one, one by one, or activate the callbacks for the entity events with all the necessary verifications; remember *don't trust user inputs*, even if they come from the server.

all the
unnecessary components from the client to only have `CompTeam`, `CompHp`, and `CompSkin`

The final result of this chapter will not change a lot from the previous one, but you will now be able to play with friends, and the game will become interesting to play because the difficulties are now real:

Adding data persistence to the game

If, like me, you can't imagine a game without a save option, this part couldn't interest you more. In this final part of the book, I will introduce you to the persistence of data. Data persistence is the ability of a program to save its internal state for future restoration. This is exactly what a save option does in a game. In our particular case, because the client received data directly from the server, all the jobs have to be done on the server part. First of all, let's think a bit about what we need to save:

- The entities and their components
- The teams
- The games

We then need a way to store that data to be able to restore it later. The solution is to use fi
functionality, I've made the choice of using `Sqlite`. This is a database engine available as library. More information can be found on the website at `https://sqlite.org/`.

the goal here
e it for more
complex projects of your creation. The persistence data will be stored in a database that is a single file, which can easily be copied or modified using some GUI for `Sqlite`.

guage
e to you an
alternative usage: **Object-relational Mapping** (**ORM**).

What is ORM?

the API of
ut the
se engines,
allowing you to change the engine with only one or two lines of code.

ode). First,
using a standard library:

```
String sql = "SELECT * from Entity WHERE id = 10"
SqlQuery query(sql);
SqlResults res = query.execute();
Entity e;
e.color = res["color"];
//.. other initializations
```

And now using an ORM:

```
Entity e = Entity::get(10);
// color is already load and set
```

As you can see, all is made by the ORM without the need to write anything. This remains exactly the same when it comes to saving data. Just use the `save()` method, and that's it.

Using cpp-ORM

We will use the `cpp-ORM` library which was written by me, so there is no trouble to use it in our project. It can be found at `https://github.com/Krozark/cpp-ORM`.

is is why
some custom types have to be used for the data that you want to save.

ORM types	**C++ types**
orm::BooleanField	bool
orm::CharField<N>	std::string (of length N)
orm::DateTimeField	struct tm
orm::AutoDateTimeField	
orm::AutoNowDateTimeField	
orm::IntegerField	int
orm::FloatField	float
orm::DoubleField	double
orm::TextField	std::string
orm::UnsignedIntegerField	unsigned int
orm::FK<T,NULLABLE=true>	std::shared_ptr<T> NULLABLE specify if T can be null
orm::ManyToMany<T,U>	std::vector<std::shared_ptr<U>> Use it when T need to keep an unknown number of reference of U class

Moreover, your class will need to have a default constructor with no parameters, and extends from `orm::SqlObject<T>` where `T` is your class name. To understand well, let's build a component as persistent, such as `CompHp`:

```
class CompHp : public sfutils::Component<CompHp,Entity>, public
orm::SqlObject<CompHp>
{
  public:
  CompHp(); //default constructor
  explicit CompHp(int hp);
  orm::IntegerField _hp; //change the type to be persistent
  orm::IntegerField _maxHp; //here again
  //create column for the query ability (same name as your
    attributes)
  MAKE_STATIC_COLUMN(_hp,_maxHp);
};
```

There is not much to explain. We just add `orm::SqlObject<CompHp>` as the parent class and change `int` to `orm::IntegerField`. The `MAKE_STATIC_COLUMN` is used to create some additional fields that will contain the column name of each field in
 to avoid
repetitive work: `REGISTER_AND_CONSTRUCT`. Its usage is as follows:

```
REGISTER_AND_CONSTRUCT(CompHp,"CompHp",\
_hp,"hp",\
_maxHp,"maxHp")
```

This macro will construct the entire default constructor implementation. Then, in your code, use the field as usual. There is no need to change anything concerning your class.

 case, we will
use the `Sqlite3` engine, so we need to create it somewhere, for example, in the `main.cpp` file:

```
#include <ORM/backends/Sqlite3.hpp>
orm::Sqlite3DB def("./08_dataPersistence.sqlite"); //create the
  database (need to be include before file that use SqlObject)
orm::DB& orm::DB::Default = def;//set the default connection
  (multi connection is possible)
#include <ORM/core/Tables.hpp>
#include <SFML-Book/server/Server.hpp>
int main(int argc, char* argv[])
{
  // get port parameter
  orm::DB::Default.connect(); //connect to the database
  orm::Tables::create(); //create all the tables if needed
  book::Server server(port);
  server.run();
  orm::DB::Default.disconnect(); //disconnect the database
  return 0;
}
```

ted to it.
use the default
connection by default.

Turning our object persistent

let's
re them.

Saving an object in a database

e our previous
`CompHp` class. Create an instance of it and call the `.save()` method on it. If you want to update an object already stored in the database, use `save()` as well. Only the field that changes will be updated:

```
CompHp chp;
chp._hp = 42;
chp.save();
//oups I've forgotten the other field
chp._maxHp = 42;
chp.save();
std::cout<<"My id is now "<<chp.getPk()<<std::endl;
```

Now let's move on to the object loading.

Loading an object from the database

There are basically two ways to load an object. The first one is when you know its primary key (identifier), and the second one is to search all the objects corresponding to a specific criterion:

```
CompHp::type_ptr chp = CompHp::get(10); //load from database
//chp.getPk() = -1 on error, but chp is a valid object so you can use
  it
std::cout<<"My id is "<<chp->getPk()<<" And my content is
  "<<*chp<<std::endl;
```

These two lines of code load an object from the database and then display its content to the console output. On the other hand, if you don't know the identifier value but you have a specific criterion, you can also load objects in the following manner:

```
CompHp::result_type res;
CompHp::query()
.filter(
  orm::Q<CompHp>(25,orm::op::gt,CompHp::$_hp)
  and orm::Q<CompHp>(228,orm::op::lte,CompHp::$_maxHp)
  or (orm::Q<CompHp>(12,orm::op::gt,CompHp::$_hp) and
    orm::Q<CompHp>(25,orm::op::exact,CompHp::$_maxHp))
```

```
)// (_hp > 25) and (_maxHp <= 228) or (_hp > 12 and _maxHp ==25 )
. orderBy(CompHp::$_hp,'+')// could be +,-,?
.limit(12) //only the first 12 objects
.get(res);
for(auto chp : res)
std::cout<<"My id is "<<chp->getPk()<<" And my content is
  "<<*chp<<std::endl;
```

In this example, we get the entire `CompHp` component through a complex query and then display the content to the console output.

game
on details.

Summary

In this fi
new
real time.

You have also learned how to add persistence to your data using an ORM, and how
of game
f game
you want in 2D.

part of the
framework made across this book, the code is available on GitHub at `https://github.com/Krozark/SFML-utils`.

I wish
you good luck for your future games!

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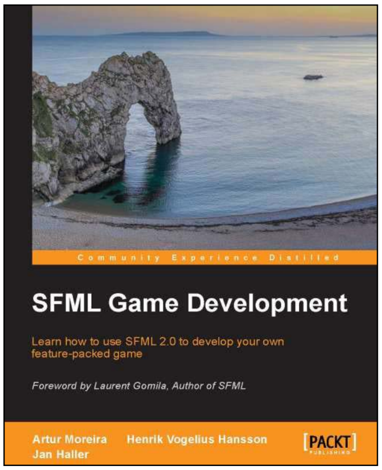

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