Program a Game Engine from Scratch

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Chapter 4 - Engine

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Chapter 4

Engine

Introduction understood (Chapter 1), development environment setup (Chapter 2) and tutorial complete (Chapter 3) means it is time start coding an engine! This chapter begins with an overview of Dragonfly then proceeds with sections on the design and development of each of the major game engine concepts and components.

4.1 Overview

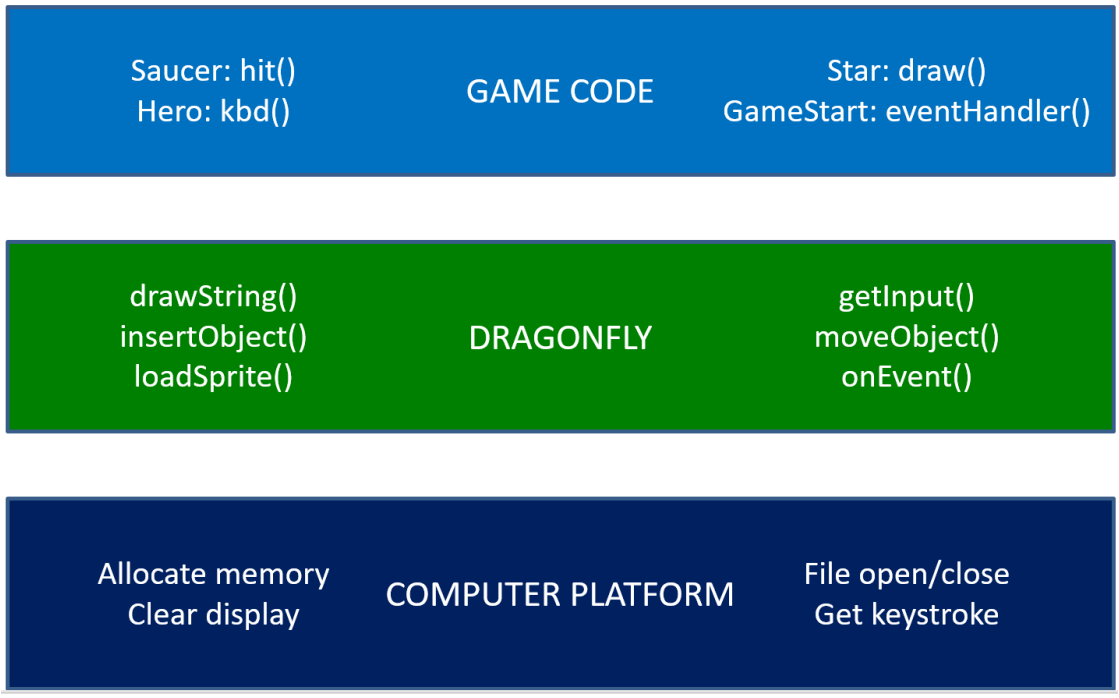


Figure 4.1: Dragonfly architectural overview

Figure 4.1 depicts an overview of the Dragonfly game engine relative to other parts of

Table 4.1: Dragonfly Classes

Type	Class	Description
Utility	Box	2d rectangle
	Vector	2d vector
	Clock	Timing support
	Music	Store and play music
	Sound	Store and play sound effects
	Frame	2d character image
	Sprite	Sequence of frames for animated image
	Animation	Control for animating Sprite
Event	Event	Base class for engine events
	EventCollision	Event generated solid objects collide
	EventKeyboard	Event generated when keyboard has input
	EventMouse	Event generated when mouse has input
	EventOut	Event generated when object goes outside world
	EventStep	Event generated each game loop
	EventView	Event generated when updating ViewObjects
Manager	Manager	Base class for engine managers
	DisplayManager	Manager of the graphics display
	GameManager	Manager of the game loop
	InputManager	Manager of player input (keyboard and mouse)
	LogManager	Manager of the logfile
	ResourceManager	Manager of resources (sprites, sounds, music)
	WorldManager	Manager of the game world
Object	Object	Base class for game engine objects
	ViewObject	View objects displayed on the Heads Up Display
	ObjectList	List container for Objects

the system and game. The top layer, GAME CODE, depicts functionality that is handled by the game programmer, the middle layer, DRAGONFLY, by the game engine and the bottom layer, COMPUTER PLATFORM, by the operating system and computer hardware.

As discussed in Section 1.2, code in the GAME CODE layer provides specific game functionality that is not, and often cannot, be handled by the game engine. For example, for *Saucer Shoot* in Chapter 3.3, the Saucer interprets the action of a collision event in the `hit()` method. This action is specific to this game, as a collision for a Saucer, or any other object, in a different game could have very different results. Similarly, the Hero object must decide what to do on a keyboard event in the `kbd()` method, where other games would likely have different actions for different keyboard inputs.

Game engine code in the DRAGONFLY layer provides for functionality that is general to all games made with this engine. In this way, the engine provides convenient game functionality that makes it easier for the game programmer to develop the game and may provide more efficient implementations in some cases. For Dragonfly, functionality for

drawing characters on the screen, loading sprites into the engine, moving objects through the game world, and triggering events from one object to another, provide core functionality needed by the game programmer.

Low-level system functionality in the COMPUTER PLATFORM layer provides for hardware-specific features, such as creating a graphics window, opening and closing files, allocating memory and gathering keystrokes. A game engine, such as Dragonfly, may be ported to different platforms (e.g., Mac) by re-writing platform-specific engine code. Once done, in many cases, this allows the same game code to then run on multiple, different computer platforms allowing a game to be easily ported.

Table 4.1 lists the Dragonfly classes for the core engine, grouped hierarchically and by function. Utilities are designed to provide convenient, low-level functionality used by many other classes. Events convey actions in the game engine to appropriate objects. Managers are responsible for the different functionalities of the game engine. Game objects, with some support classes, are managed by the game engine, with some specialized classes for custom displays (e.g., a "heads-up" display, or user interface buttons). The scene graph organizes Objects in the world for more efficient management and rendering.

4.2 Managers

Managers are the support systems for game engines, handling crucial tasks. This includes handling input, rendering graphics, logging data, managing the game world and game objects and more. Logically, the different functions can be broken up into different managers. The main class, Manager, is not instantiated. Instead, it serves as a base class for all derived game engine managers. Refer to Table 4.1 on page 50 for details.

The interface for the Dragonfly Manager class is shown in Listing 4.1. The Manager class provides `startUp()` and `shutDown()` methods, allowing the game programmer to control initialization and termination of all derived manager objects. For the base Manager, in `Manager.cpp` the `startUp()` sets `is_started` to `true` and `shutDown()` sets `is_started` to `false`. The method `isStarted()` allows for a query to check if the manager has been successfully started (via `startUp()`). As this is the base class, in Manager, the methods for starting up and shutting do not do any "real" work – instead just manipulating the `is_started` boolean variable. The method `setType()` sets the private attribute `type` to the name `"Manager"`. The method is `protected` since only the base class and derived classes are allowed to change a manager's type (typically, this is done in the constructor for each derived Manager).

Listing 4.1: Manager.h

```
0  namespace df {
1
2  class Manager {
3
4   private:
5    std::string m_type;        // Manager type identifier.
6    bool m_is_started;         // True when started successfully.
7
8   protected:
9    // Set type identifier of Manager.
10   void setType(std::string type);
11
12  public:
13   Manager();
14   virtual ~Manager();
15
16   // Get type identifier of Manager.
17   std::string getType() const;
18
19   // Startup Manager.
20   // Return 0 if ok, else negative number.
21   virtual int startUp();
22
23   // Shutdown Manager.
24   virtual void shutDown();
25
26   // Return true when startUp() was executed ok, else false.
27   bool isStarted() const;
28 };
29
30 } // end of namespace df
```

Tip 3! Naming in Dragonfly. Dragonfly uses the following naming convention: classes always begin with an upper case letter (e.g., Manager), single word variables, methods and functions use lower case (e.g., `distance()`), classes and methods that are more than one word use upper case letters without underscores to separate words (e.g., `isStarted()`, also known as "camel case"), variables use underscores between words (e.g., `is_started`, also known as "snake case"), and class attributes are prefixed with an "m_" (e.g., `m_type`), with the name indicating a "member" variable.

Line 0 of Listing 4.1 defines the Dragonfly namespace using the `df::` tag. This requires code outside of the namespace (e.g., game code) to use `df::` to access elements inside the namespace (e.g., `setSolidness(df::SPECTRAL)`). Typically, large, 3rd-party libraries (such as a game engine) use namespaces to help developers avoid conflicts in names their own code may use with names the libraries use. The Dragonfly namespace is meant to prevent potential name conflicts with game code.

Note, for brevity in all future Listings in this book (with the exception of `Logfile.h`), the Dragonfly namespace `df::` is not shown, but it does appear in the actual engine `.h` files.

Tip 4! Dragonfly header files. The Dragonfly header files (`.h`) for all engine classes and utilities are available for download at the book Web page (`http://dragonfly.wpi.edu/book`). These headers are also shown in the Appendix (page 279), provided in alphabetic order. These header files reveal the design of the engine, providing the exact methods and attributes that need to be implemented. Note, however, that these header files represent Dragonfly in its final, fully implemented, full-featured form. For development, the recommended path is to build the header files (and engine) by hand following the sections in Chapter 4 in order.

Many managers depend upon each other, so the startup order of individual managers matters. For example, a logfile manager is often needed first since all the other managers write log messages upon startup, either noting successful startup in the logfile or reporting errors in the logfile when there are problems. Or, a display manager may need memory allocated for sprites, so a memory manager would need to be invoked before the display managers.

In addition, unlike many game objects, it often makes sense to have only one instance of each manager. For example, having two display managers simultaneously writing to the graphics card/display device may not make sense nor even be supported by the hardware/operating system. Similarly, having two independent managers handle input from the keyboard and mouse may yield undesirable (or at least unpredictable) results.

Managers are generally global in scope because the service the manager provides may be sought in many places in both game and engine code. For example, the engine code and game code may both write messages to the logfile via the LogManager, and both the engine code and game code may draw characters on the screen via the DisplayManager. Given this, a natural inclination may be to make the manager instances global variables, as depicted in Listing 4.2.

Listing 4.2: Managers declared as global variables

```
// Outside main(), these are global variables.
df::DisplayManager display_manager;
df::LogManager log_manager;

main() {
  ...
}
```

While declaring managers as global variables does provide for global scope, it does not give control over the order of invocation. The order of instantiation of global variables is determined by the compiler and not by the program order. For example, if the code in Listing 4.2 is compiled and run, the `log_manager` may be instantiated first and then the `display_manager` or vice versa. Moreover, using global variables from the engine – say, if DisplayManager wanted to write to the logfile – would *require* the game programmer to use the same names as expected by the engine, making the game code more brittle.

4.2.1 Singletons

The *singleton* design pattern can be used for the game engine manager to solve all the above problems: 1) the singleton restricts instantiation of a class to one, and only one, object; 2) the singleton allows control of the order of manager initialization for dependency cases where the order matters; and 3) the singleton allows for global access.

In order to restrict instantiation to one (and only one) instance, the singleton class needs to disallow typical operations that enable object creation from a class. In particular, access must be denied for public access to the constructor, copy and assignment operators – otherwise, a programmer can use them to make additional instances of the class. Restricting creation is done by making the specific operations `private` to the class.

In order to instantiate a singleton class in C++, the keyword `static` is used as a modifier to the variable representing the one instance of the class. Remember, `static` variables retain their value even after the function terminates – in effect, the lifetime extends across the entire run of the program. However, a `static` variable is not allocated until the function is first called. This last feature allows explicit control as to when the manager is started up. Also remember, the keyword `static` in front of a method or function is quite different. A `static` method does not require an instance of the class to use it, and a `static` function (or a `static` global variable) has a scope that restricted to the `.cpp` file it is declared in.

Listing 4.3 depicts the class template for a singleton class.

Listing 4.3: A Singleton class

```
// Note, this would typically be defined in Singleton.h.
```

```
class Singleton {
 private:
   Singleton();                          // No constructing.
   Singleton(Singleton const &copy);     // No copying.
   void operator=(Singleton const &assign); // No assigning.
 public:
   static Singleton &getInstance();      // Return instance.
};

// Return the one and only instance of the class.
// Note, this would typically be defined in Singleton.cpp.
Singleton &Singleton::getInstance() {
  // Note, a static variable persists after method ends.
  static Singleton single;
  return single;
}
```

While the singleton class guarantees there will be one and only one instance of the class, when a manager is actually instantiated (the first time `getInstance()` is called for that class), there can sometimes be a lot of work to be done. Thus, most of the initialization work for any manager is done in the `startUp()` method, called after the first `getInstance()` call.

Each specific manager class (e.g., DisplayManager) inherits from the base Manager class using the singleton template. The virtual methods `startUp()` and `shutDown()` are defined in the derived class and are specific to that particular manager. For example, the logfile manager might open the logfile for writing, while the display manager might ready the display for graphical output.

4.3 Logfile Management

If a game is working well, meaning all game engine code and game programmer code is doing what it is supposed to, all meaningful output typically goes to the screen in the form of game actions – characters moving, bullets flying, menus popping up, etc. However, during development this is often not the case, as code (even game engine code) can have bugs, or confirmation of working code is needed before proceeding. While debuggers are essential for effective programming, many game programmers do not have the luxury of having the source code for the game engine so a debugger cannot trace through the engine code. Moreover, some bugs are timing dependent meaning they only happen at full speed or are caused by a long sequence of events, making them hard to trace by a debugger.

What is helpful in these cases is a game engine that provides meaningful output as to the workings (or not) of the engine, and also provides a flexible, easy-to-use mechanism for a game programmer to get output. However, standard methods of printing to the screen can often interfere with the game itself or are not even possible when a display device is in graphics mode. In order to get around this limitation, logfiles are often used, where descriptive messages from the engine are written to a file, and the engine provides a flexible, easy-to-use mechanism for their own messages. This is the essence of the LogManager, often the first manager developed since all other engine components make use of it.

For base functionality, upon startup the LogManager opens up the logfile, making sure

writing is allowed to the appropriate directory. Advanced features could allow appending or overwriting of previous logfiles, name the logfile with a timestamp, and check if there is sufficient disk space for normal operations. Upon shutdown, the logfile is closed, effectively flushing any outstanding data to the disk.

For attributes, the LogManager only needs a file structure (e.g., `FILE *`) for access to the logfile.

4.3.1 Variable Number of Arguments

The most frequently used LogManager method is to support writing general-purpose messages to the logfile – whether the messages come from other parts of the engine or from the game programmer – via a `writeLog()` method. For example, the game programmer may want to write a string such as "Player is moving", which is effectively one argument to `writeLog()`. Or, the game programmer may want to write "Player is moving to (x, y)" where x and y are `float` variables that are passed in. In other words, the number of arguments that `writeLog()` supports is not known ahead of time, but can be one or more.

A function that supports a variable number of arguments is depicted in Listing 4.4. Note the "..." characters in the parameter list for the function. Handling a variable number of arguments in this way requires `#including` the system header file `stdarg.h`, and the system header file `stdio.h` is needed for `fprintf()`. In the body of the function, a `va_list` structure is created, then initialized with arguments in the `va_start` command, provided with the name of the last known argument (`fmt`, in this case). At this point, the function is ready to call a `printf()` to produce output, but instead of a fixed string, the `va_list` structure has the formatting parameters, so `vfprintf()` is used instead. When finished, the `va_end()` must be called to clean up the stack.

Listing 4.4: Function taking variable number of arguments

```
0 #include <stdio.h>
1 #include <stdarg.h>
2
3 void writeMessage(const char *fmt, ...) {
4   fprintf(stderr, "Message: ");
5   va_list args;
6   va_start(args, fmt);
7   vfprintf(stderr, fmt, args);
8   va_end(args);
9 }
```

Note, Listing 4.4 uses standard error (`stderr`), which typically defaults to the console Window, while a game engine (e.g., Dragonfly) will usually write to a file. The code can be adjusted, accordingly, to use a file.

4.3.2 Human-friendly Time Strings (optional)

For a long running game, it is often helpful to have timestamps associated with messages in the logfile. These times can be in "game time", such as game loop iterations, or in "wall-clock time" corresponding to the actual time of the day. Dragonfly does both, displaying a human-friendly time and game loop iteration in front of each message.

An easy way to associate a time with a written message is to have a function, say `getTimeString()`, that `writeLog()` calls to get a string with a timestamp. The `getTimeString()` method uses the `time()` system call, which returns the number of seconds since January 1, 1970. In order to turn that big number into something that is easier for humans to read, the `localtime()` system call converts the seconds into calendar time, allowing extraction of hours, minutes and seconds. Listing 4.5 depicts the `getTimeString()` method. Note, no error checking is provided for the system calls.[1] The function `sprintf()` on line 12 is similar to `printf()`, but instead of printing to `stdout`, `sprintf()` prints to a string,[2] in this case `time_str`.

Listing 4.5: Function to provide human-readable time string

```
0  // Return a nicely-formatted time string: HH:MM:SS
1  char *getTimeString() {
2
3    // String to return, made 'static' so persists.
4    static char time_str[30];
5
6    // System calls to get time.
7    time_t now;
8    time(&now);
9    struct tm *p_time = localtime(&now);
10
11   // '02' gives two digits, '%d' for integers.
12   sprintf(time_str, "%02d:%02d:%02d",
13     p_time -> tm_hour,
14     p_time -> tm_min,
15     p_time -> tm_sec);
16
17   return time_str;
18 }
```

A complementary message in the logfile is the "game clock" – the number of iterations of the game loop – obtained from the GameManager. This can be displayed as an integer pre-pended to the log message. See the GameManager in Section 4.4.4 on page 4.4.4 for details.

The presence of both the time string and the game clock in the logfile can be setup to be controlled by the game programmer by having the LogManager keep two boolean variables, `log_time_string` and `log_step_count`, which, if `true`, pre-pend the time string or game clock, respectively, to the game programmer's log message.

While the printing of time has been presented in the context of the logfile, functions like `getTimeString()` are useful beyond the LogManager class and do not access any attributes of the class. As such, they should be placed in a file called `utility.cpp` (with a corresponding `utility.h`). Other functions that provide utility services, but are not part of any class definitions, will reside in `utility.cpp` as they are created.

[1] *All* system calls should be error-checked, and errors handled appropriately, in case they fail.
[2] The 's' in front of `printf()` is for 'string.'

4.3.3 Flushing Output

Generally, writing data to a file does not immediately write the data out to the disk. The operating system typically buffers data, writing when the device is idle or when internal memory buffers are filled. Such buffering generally improves overall system performance, but can cause unexpected output (or, more precisely, lack of it) if a program, say a game engine, crashes before all data is written. For example, if the line `log_manager.writeLog("Doing stuff")` is executed and then the program crashes (e.g., from a segfault), the string "Doing stuff" may not appear in the logfile even though that line has been executed. This can make it hard to trace where, exactly, the error (in this case, the error that caused the segfault) might have occurred.

To force the operating system to immediately write out buffered data to the disk, the `fflush()` system call can be used after each write. Used during development, this helps provide complete logfiles even during system crashes. Note, this does decrease efficiency (speed) somewhat, so might not be used when game development (or game engine development) is complete. Thus, the LogManager can provide the game programmer with an option to flush the logfile after each disk, or not.

The attributes and methods for the LogManager can now be described in Listing 4.6. The destructor closes the file if `m_p_f` is not `NULL`.

Listing 4.6: LogManager attributes and methods

```
0  private:
1    bool m_do_flush; // True if fflush after each write.
2    FILE *m_p_f;     // Pointer to logfile structure.
3
4  public:
5    // If logfile is open, close it.
6    ~LogManager();
7
8    // Start up the LogManager (open logfile "dragonfly.log").
9    int startUp();
10
11   // Shut down the LogManager (close logfile).
12   void shutDown();
13
14   // Set flush of logfile after each write.
15   void setFlush(bool do_flush=true);
16
17   // Write to logfile. Supports printf() formatting.
18   // Return number of bytes written, -1 if error.
19   int writeLog(const char *fmt, ...);
```

4.3.4 Conditional Compilation

Once implemented, using the newly-minted LogManager throughout the engine (or in game code) will quickly reveal a problem – the LogManager header file, `LogManager.h`, likely gets included by the compiler pre-processor multiple times, resulting in compiler warnings about "redeclaration of class LogManager". In order to fix this, directives to the pre-processor can limit class (and other) definitions to be included only once by having code only compiled

during certain conditions. For the LogManager (and other Dragonfly header files), this is done by using an `#ifndef` wrapper and a unique identifier. Consider the sample code in Listing 4.7. When `foo.h` is seen by the compiler the first time, `FILE_FOO_SEEN` is not defined, so the pre-processor defines it in the next line and proceeds to parse and processes the foo file (and defining `class Foo`), normally. The next time `foo.h` is seen by the pre-processor, `FILE_FOO_SEEN` is already defined so the contents of the foo file are not included, avoiding a duplicate definition of `class Foo`.

Listing 4.7: Once-only header files

```
0 // File foo.h
1 #ifndef FILE_FOO_SEEN
2 #define FILE_FOO_SEEN
3
4 // The entire foo file appears next.
5 class Foo {};
6
7 #endif // !FILE_FOO_SEEN
```

Such conditional compilation directives are often used for platform-specific parts of code. Listing 4.8 shows a code stub that would compile Linux-specific code if `LINUX` was defined (say, with a `-DLINUX` flag to a `g++` compiler), or Windows-specific code if either `_WIN32` or `_WIN64` was defined.

Listing 4.8: Conditional compilation for platform-specific code

```
0 #if defined(_WIN32) || defined(_WIN64)
1
2 // Windows specific code here.
3
4 #elif defined(LINUX)
5
6 // Linux specific code here.
7
8 #endif
```

Note, there is no real functional difference between `#ifdef NAME` and `#if defined(NAME)`, but `#ifdef` can only use a single condition while `#if defined` can use compound conditions (as in the example in Listing 4.8).

When using `#define` directives in Dragonfly for literal replacement (e.g., for the engine version number), the convention is to prefix names with a `DF_` (e.g., `DF_VERSION`). This naming convention is to reduce the risk of potential namespace conflicts between the engine programmer and the game programmer.

When using conditional compilation for header files, the convention is for system utilities to use underscores before and after the name (e.g., `_STRING_H_`), while user code (game code) should never use initial/post underscores. This naming convention is to avoid potential namespace conflicts between the engine developer and the game programmer. For Dragonfly, a double initial underscore and double post underscore is used.

4.3.5 The LogManager

The complete header file for the LogManager is shown in Listing 4.9. Notice the `#ifndef` and `#define` statements at the top for conditional compilation.[3]

The `#include <stdio.h>` on line 6 is for the `FILE` variable, `m_p_f`. `LOGFILE_NAME` on line 13 provides the name of the logfile, "dragonfly.log".

The methods in the `private` section that allow implementation of the singleton pattern. The attributes provide the file descriptor and whether or not to flush output after each write. Whether flushing is done or not is specified in the `setFlush()` method, but defaults to not flushing (`m_do_flush` is `false`).

The LogManager constructor should set the type of the Manager to "LogManager" (i.e., `setType("LogManager")`. As in most classes, the constructor should also initialize all attributes, in this case `m_p_f` to `NULL` and `m_do_flush` to `false`.

While `startUp()` and `shutDown()` are defined in the Manager class, they are redefined in the LogManager to open the logfile and close the logfile, respectively. Manager `startUp()` and Manager `shutDown()` should be called from LogManager `startUp()` and LogManager `shutDown()`, respectively. Remember, in C++ even if a method is defined in a derived class (e.g., `startUp()` in the LogManager), the parent method can still be called explicitly (e.g., `Manager::startUp()`).

Listing 4.9: LogManager.h

```
0  // The logfile manager.
1
2  #ifndef __LOG_MANAGER_H__
3  #define __LOG_MANAGER_H__
4
5  // System includes.
6  #include <stdio.h>
7
8  // Engine includes.
9  #include "Manager.h"
10
11 namespace df {
12
13 const std::string LOGFILE_NAME = "dragonfly.log";
14
15 class LogManager : public Manager {
16
17  private:
18   LogManager();                       // Private since a singleton.
19   LogManager(LogManager const&);      // Don't allow copy.
20   void operator=(LogManager const&); // Don't allow assignment.
21   bool m_do_flush;           // True if flush to disk after each write.
22   FILE *m_p_f;               // Pointer to logfile struct.
23
24  public:
25   // If logfile is open, close it.
26   ~LogManager();
27
28   // Get the one and only instance of the LogManager.
```

[3] For brevity, subsequent Dragonfly header files are not shown with `#ifndef` directives.

```
29    static LogManager &getInstance();
30
31    // Start up the LogManager (open logfile "dragonfly.log").
32    int startUp();
33
34    // Shut down the LogManager (close logfile).
35    void shutDown();
36
37    // Set flush of logfile after each write.
38    void setFlush(bool do_flush=true);
39
40    // Write to logfile. Supports printf() formatting of strings.
41    // Return number of bytes written, -1 if error.
42    int writeLog(const char *fmt, ...) const;
43 };
44
45 } // end of namespace df
46 #endif // _LOG_MANAGER_H_
```

Tip 5! Writing logfile messages. When calling `writeLog()`, it is often helpful to include information on from where the call is being made. This is especially important when Dragonfly gets large and there are lots of logfile messages written. A good convention to follow is to include the class name and the method name as part of the log message. An example is shown in Listing 4.10, with the corresponding expected output at the bottom of the Listing starting on line 19.

Listing 4.10: Example of using the LogManager writelog()

```
0  // Get singleton instance of LogManager.
1  df::LogManager &log_manager = df::LogManager::getInstance();
2
3  // Example call with 1 argument.
4  log_manager.writeLog(
5    "DisplayManager::startUp(): Current window set");
6
7  // Example call with 2 arguments.
8  log_manager.writeLog(
9    "WorldManager::isValid(): WorldManager does not handle '%s'",
10     event_name.c_str());
11
12 // Example call with 3 arguments.
13 log_manager.writeLog(
14   "DisplayManager::startUp(): max X is %d, max Y is %d",
15     max_x, max_y);
16
17 ...
18
19 // Sample logfile output:
20 LogManager started
21 DisplayManager::startUp(): Current window set
```

```
WorldManager::isValid(): WorldManager does not handle 'mud event'
DisplayManager::startUp(): max X is 80, max Y is 24
```

Note, for code readability, from here on, a macro is created for each derived manager, providing a two letter acronym for accessing the singleton instance of each manager. For example, Listing 4.11 shows the definition for the `LM` acronym, which should be placed in the `LogManager.h` header file. With this in place, a game programmer could then invoke `LM.writeLog()` without needing to call `getInstance()`.

Listing 4.11: Two-letter acronym for accessing LogManager singleton

```
// Two-letter acronym for easier access to manager.
#define LM df::LogManager::getInstance()
```

4.3.6 Controlling Verbosity (optional)

Logfile messages can be invaluable for debugging, performance tuning or verifying that engine code or game code is working properly. However, logfiles can also be "noisy," with many, many innocuous lines of information hiding the ones that may offer true value. This is especially true of messages that are printed each step of the game loop (typically, 30 times per second), or for messages printed each step of a loop that iterates through all game objects!

While messages can be removed to decrease some of this noise, sometimes messages are useful during later debugging and take time to put back into place. So, instead of removing messages what is often better is to control the verbosity level of messages written to the log – with low verbosity, only essential messages are printed, while with high verbosity, all messages are printed. One way to do this is to have an explicit verbosity setting, depicted in Listing 4.12, via an attribute named `log_level`, with get/set methods, in the LogManager. Verbosity is controlled by changing the log level, even dynamically during run time, with logfile messages only written out when the LogManager log level is greater than or equal to that of the message.

Listing 4.12: Controlling verbosity with log level

```
  // (attribute of LogManager)
 private:
  int log_level;                // Logging level.
  ...

// (Modify  writeLog to take log level as a parameter.)
// Write to logfile.
// Only write if indicated log level >= LogManager log level.
// Supports printf() formatting of strings.
// Return number of bytes written (excluding pre-pends), -1 if error.
void LogManager::writeLog(int log_level, char *fmt, ...)

  // Only print message when verbosity level high enough.
  if log_level > this.log_level then
    va_list args
    ...
  end if
```

In order to avoid repeating code, the version of `writeLog()` without the `log_level` should just invoke the `writeLog()` in Listing 4.12, providing `INT_MAX`, the maximum integer (found in `limits.h`), as the log level.

Tip 6! Naming global variables. Global variables should be used sparingly. However, when they are used, given that their declarations do not appear in the local block of code (e.g., not in the method or class body), it is helpful to have a naming convention that indicates which variables are global variables. A suggestion is to use the prefix '`g_`', with 'g' standing for "global". Also, the use of `extern`, while not strictly needed for scoping, is helpful to indicate to the programmer that the variable is declared outside the block of code (e.g., see `extern int g_verbosity` in Listing 4.12).

The method of controlling verbosity in Listing 4.12 is effective but does have a bit of additional overhead, notably a comparison check against the global variable holding the verbosity level for each call. It is not likely this overhead is onerous, but it can be significant, particularly for messages written each step and for each iteration of an object list.

An alternative method is to use conditional compilation, as described in Section 4.3.4 (page 58), with `#ifdef` directives used to decide whether or not to compile in logfile messages. An example is shown in Listing 4.13.

Listing 4.13: Controlling verbosity with conditional compilation

```
0 #ifdef DEBUG_1
1 LM.writeLog("WorldManager::markForDelete(): deleting object %d",
2     p_o -> getId());
3 #endif
```

The first line indicates the following lines (that actually write the logfile message) are to be compiled in *only* if `DEBUG_1` is defined. The developer can define `DEBUG_1` when testing code, looking for bugs, verifying functionality and so on. When the game is ready to ship, `DEBUG_1` can be left undefined and the code is not compiled into the game. This approach has none of the overhead in Listing 4.12 when messages are not to be written since the messages to write to the logfile are not included at all. As a downside, code can be slightly less readable if there are many `#ifdef` messages.

4.3.7 Development Checkpoint #1!

At this point, development of Dragonfly should commence! The setup from Chapter 2, used for the tutorial, can be used to setup the development environment for your engine. Steps:

1. Setup your development environment, as specified in Chapter 2. Successfully compiling the first tutorial game in Section 3.3.1 on page 15 will ensure that the necessary tools are in place and configured.

2. Discard the pre-compiled Dragonfly libraries and header files from step 1 and prepare a directory structure for your own engine development.

3. Create a Manager base class, both `Manager.h` and `Manager.cpp`. See Listing 4.1 for details on the class definition.

4. Create a LogManager derived class, inheriting from the Manager class. Use Listing 4.9 as a reference.

5. Implement a `writeLog()` function, initially, not part of the LogManager. Have `writeLog()` just produce output to the screen (standard output). Test thoroughly, with no arguments, single arguments and multiple arguments. Be sure to test with different data types (`int`s, `float`s, etc.), too.

6. Move `writeLog()` into the LogManager class as a method. In `game.cpp`, have `#include "LogManager.h"` at the top of the file to include the class definition. Then, instantiate (via `getInstance()`) and start up (via `startUp()`) the LogManager. Check the return values to ensure the calls are working.

7. Test with various calls to `writeLog()` in the LogManager are working, testing single and multiple arguments with different types. Verify that the expected output appears in the logfile, "dragonfly.log".

8. Implement and test any optional elements (e.g., `getTimeString()`), as desired.

Make sure all the code is working thoroughly and is clearly written (indented and commented). As suggested earlier, the LogManager is used heavily during development, both for engine code and for game code, and needs to be robust and reliable before moving forward. This is true of each Development Checkpoint – make sure code is debugged and tested thoroughly before proceeding!

Tip 7! Testing. Testing is critical for complex software development. A good software development process will have testing proceed hand-in-hand with coding. Designing test cases and implementing and maintaining code that runs tests on an existing code base will pay-off in the long run. See Section 6.1 on page 258 for more details, including a possible unit testing framework that may be of use.

4.4 Game Management

At a high level, "managing the game" is the job description of the entire game engine. Game programmers (and players) often think of this as "running the game".

4.4.1 The Game Loop

The game manager "runs" the game, doing so by repeating the same basic set of actions in a loop (the *game loop*), over and over. A 10,000 foot view of the game loop is presented in Listing 4.14. Each iteration of the game loop is called a "step" (or a "tick", as in the tick of a clock). During one step, the game loop: 1) gets input, say from the keyboard or the mouse (these are player actions in the game); 2) updates the game world state to move objects around, generate needed actions, respond to the input; 3) draws a new image (the current scene) on the graphics buffer; and 4) swaps out the old image for the new image. This process is repeated in the loop until the game is over.

Listing 4.14: The game loop

```
0 while (game not over) do
1   Get input // e.g., from keyboard/mouse
2   Update game world state
3   Draw current scene to back buffer
4   Swap back buffer to current buffer
5 end while
```

Note that the loop in Listing 4.14 runs as fast as it can, updating and drawing the game world as fast as the computer can get through the code. Early game development efforts were often targeted for a machine with a specific speed, where the time to execute a loop was known and objects could be moved an appropriate amount of time each loop. Of course, running the same game code on a faster machine (as would happen when computer speeds improved) meant the game would run faster! Moreover, if a step took more or less time than expected, the update rate of game objects would vary, causing them to move faster or slower.

In order to rectify this problem, the game loop is enhanced with loop timing information, shown in Listing 4.15. In this version of the game loop, one step of the loop is expected to take a fixed amount of time – a `TARGET_TIME` (e.g., 33 milliseconds). So, the time to execute the first 4 instructions is carefully measured and, at the end of the loop on line 6, the game is put to sleep (effectively, doing nothing) for whatever is remaining of the `TARGET_TIME`.

Listing 4.15: The game loop with timing

```
0 while (game not over) do
1   Get input // e.g., keyboard/mouse
2   Update game world state
3   Draw current scene to back buffer
4   Swap back buffer to current buffer
5   Measure loop_time // i.e., how long above steps took
6   Sleep for (TARGET_TIME - loop_time)
7 end while
```

An important decision is how long `TARGET_TIME` should be. Setting it too high will result in the game loop progressing slowly, limiting animation rates and game update rates – the game will look less "smooth" and will feel sluggish to the player. Setting it too low will result in the game loop progressing rapidly, giving a smooth, responsive game, but may unnecessarily burden the computer and cause problems, such as visual glitches or unintended game slowdowns, if the game world is too complicated to be fully updated in one step.

Guidelines for setting `TARGET_TIME` can be drawn from video. Video performance is often reported in units of frame rate, the rate at which video images are updated on the screen. The units are typically frames per second (f/s). "Full motion" video, the rate seen in movies or television, is approximately 30 f/s. Frame rates higher than this provides little benefit to visual quality, while frame rates lower than this look "jerky" for some kinds of video content. Considering the rendered game images as video images, the game loop rate is analogous to video frame rates, provided guidance on the game loop rates. Notably, a reasonable expectation is to update the game screen 30 times per second – equivalently, setting `TARGET_TIME` to 33 milliseconds.

4.4.2 Measuring Computer Time

In order to step through the game loop 30 times per second, the time for one loop iteration must be measured precisely. Modern operating systems provide several different ways (system calls) to measure time. For example, on Unix systems, the `time()` call returns the number of seconds since January 1st, 1970. Subsequent system calls can use that number to extract the hours, minutes and seconds or even the month, day, year. However, the resolution of the `time()` system call is only 1 second, meaning it is too coarse to provide timing on the order of the milliseconds needed for the game loop.

Fortunately, modern computer processors have high-resolution timers provided by hardware registers that count processor cycles, providing resolutions in the nanoseconds. For instance, a 3 GHz processor increments the timer register 3 billion times per second, providing a resolution of 0.3 nanoseconds – plenty of precision for the game loop! The actual system calls to access these high-resolution timers varies with platform. Windows uses `QueryPerformanceCounter()` to get the timer value, and `QueryPerformanceFrequency()` to get the processor cycle rate. Xbox 360 and PS3 game consoles use the `mftb` (which stands for "move from time base") register to obtain the timer value, with the hardware having a known processor cycle time. Linux uses `clock_gettime()` to get a high-resolution time value (needing to be linked in with the real-time library, `-lrt`, when compiling).

In order to measure the time the game loop takes (everything between line 1 "Get input" and line 4 "Swap" in Listing 4.15), the method in Listing 4.16 is used. The method starts by recording the time (storing it in a variable). Next, the tasks to be timed are run (for a game loop, this is input, update and so forth). When the tasks are done, the time is again recorded. The elapsed time is obtained by subtracting the "before" time from the "after" time.

Listing 4.16: Method to measure elapsed time

```
0   Record before time
1   Do processing stuff // e.g., get input, update ...
```

```
    Record after time
    Compute elapsed time // after - before
```

For Linux, Listing 4.17 provides a code fragment to compute the elapsed time of a block of computation. Note, in this example, the units for elapsed time are in microseconds, which is often used for timing in game engines, but it could easily be adjusted to seconds or milliseconds. For compilation, the system header file <time.h> is needed for the timing routines and -lrt is needed to link in the real-time library. The timing function, clock_gettime(), fills in the components of a timespec structure, which includes fields for seconds (tv_sec) and nanoseconds (tv_nsec). Computing elapsed time is done by converting the seconds and nanoseconds to microseconds, and subtracting the initial value from the final value.

Listing 4.17: Measuring elapsed time in Linux

```
#include <time.h>  // Compile with -lrt

struct timespec before_ts, after_ts;
clock_gettime(CLOCK_REALTIME, &before_ts); // Start timing.
// Do stuff...
clock_gettime(CLOCK_REALTIME, &after_ts);  // Stop timing.

// Compute elapsed time in microseconds.
long int before_msec = before_ts.tv_sec*1000000 + before_ts.tv_nsec/1000;
long int after_msec = after_ts.tv_sec*1000000 + after_ts.tv_nsec/1000;
long int elapsed_time = after_msec - before_msec;
```

For Mac, the system call clock_gettime() does not exist (nor does the rt library). Instead, the system call gettimeofday() (located in <sys/time.h>) should be used, as shown in Listing 4.18. A call to gettimeofday() fills a struct timeval with the number of seconds and microseconds.

Listing 4.18: Measuring elapsed time in Mac OS

```
#include <sys/time.h>

struct timeval before_tv, after_tv;

gettimeofday(&before_tv, NULL); // Start timing.
// Do stuff...
gettimeofday(&after_tv, NULL); // Stop timing.

// Compute elapsed time in microseconds.
long int before_msec = before_tv.tv_sec*1000000 + before_tv.tv_usec;
long int after_msec = after_tv.tv_sec*1000000 + after_tv.tv_usec;
long int elapsed_time = after_msec - before_msec;
```

For Windows, the system call needed is GetSystemTime() (located in <Windows.h>) is used, as shown in Listing 4.19. A call to GetSystemTime() fills a SYSTEMTIME structure with the number of minutes, seconds, and milliseconds.

Listing 4.19: Measuring elapsed time in Windows

```
#include <Windows.h>
```

```
1
2  SYSTEMTIME before_st, after_st;
3  GetSystemTime(&before_st);
4  // Do stuff...
5  GetSystemTime(&after_st);
6
7  // Compute elapsed time in microseconds.
8  long int before_msec = (before_st.wDay * 24 * 60 * 60 * 1000000)
9                       + (before_st.wHour * 60 * 60 * 1000000)
10                      + (before_st.wMinute * 60 * 1000000)
11                      + (before_st.wSecond * 1000000)
12                      + (before_st.wMilliseconds * 1000);
13 long int after_msec = (after_st.wDay * 24 * 60 * 60 * 1000000)
14                     + (after_st.wHour * 60 * 60 * 1000000)
15                     + (after_st.wMinute * 60 * 1000000)
16                     + (after_st.wSecond * 1000000)
17                     + (after_st.wMilliseconds * 1000);
18 long int elapsed_time = after_msec - before_msec;
```

4.4.3 The Clock Class

It is helpful for both the game engine and the game programmer to have a class that provides convenient access to high-resolution timing – the Clock class. Listing 4.20 provides the header file for the Clock class.[4] The clock functions as a sort of "stopwatch", so the time is stored in the variable `previous_time`, initialized to the current time when a Clock object is instantiated. A call to the method `delta()` returns the elapsed time (in microseconds) and resets `previous_time` to the current time. A call to the method `split()` returns the time (in microseconds) since the last `delta()` call, but does not change the value of `previous_time`. The constructor should set `previous_time` to the current time, and both `delta()` and `split()` can be implemented using Listing 4.17, 4.18, or 4.19 (as appropriate to the development platform), as a reference.

Listing 4.20: Clock.h

```
0  // The clock, for timing (such as in the game loop).
1
2  class Clock {
3
4   private:
5    long int m_previous_time; // Previous time delta() called (in microsec).
6
7   public:
8    // Sets previous_time to current time.
9    Clock();
10
11   // Return time elapsed since delta() was last called, -1 if error.
12   // Resets previous time.
13   // Units are microseconds.
14   long int delta();
15
16   // Return time elapsed since delta() was last called, -1 if error.
```

[4] Note, the conditional `#ifdef` directives described in Section 4.3.4 are not shown.

```
17    // Does not reset previous time.
18    // Units are microseconds.
19    long int split() const;
20 };
```

With a Clock class for timing, the last missing piece for providing timing control in the game loop is the ability to sleep (line 6 of Listing 4.15). Linux and Mac provide the `sleep()` system call, but it has only seconds of resolution, meaning it will not allow the game engine to sleep for, say, 20 milliseconds. Since game loop timing needs milliseconds of resolution, so does an appropriate sleep call.

On Linux and Mac, high-resolution sleeping can be done with `nanosleep()` which sleeps for a given number of nanoseconds.[5] A `#include <time.h>` is needed for `nanosleep()`. The system call `nanosleep()` takes in a pointer to a `struct timespec` that has the amount of seconds plus nanoseconds to sleep. The example in Listing 4.21 shows a call to `nanosleep()` for 20 milliseconds.

Listing 4.21: nanosleep() example for Linux and Mac

```
0 // Sleep for 20 milliseconds.
1 struct timespec sleep_time;
2 sleep_time.tv_sec = 0;
3 sleep_time.tv_nsec = 20000000;
4 nanosleep(&sleep_time, NULL);
```

On Windows, sleeping can be done with `Sleep()` which sleeps for a given number of milliseconds. A `#include <Windows.h>` is needed for `Sleep()`. In order to obtain a millisecond resolution using `Sleep()`, the system call `timeBeginPeriod(1)` needs to be called once, when the game engine starts, to set the timer resolution to the minimum possible. The system call `timeEndPeriod(1)` is called when the game engine exits to clear the initial request for a minimal timer resolution. Both functions return `TIMERR_NOERROR` if successful or `TIMERR_NOCANDO` if the resolution specified is out of range. Note, the best places for these calls are when the GameManager starts up and when the GameManager shuts down, respectively (see Section 4.4.4 on page 71). This functions must be linked in via the `Winmm.lib` library.

Listing 4.22: Sleep() example for Windows

```
0 // Sleep for 20 milliseconds.
1 int sleep_time = 20;
2 Sleep(sleep_time);
```

Listing 4.23 provides pseudo-code for how the Clock class and sleep functions can be used together in the game loop. The call to `clock.delta()` at the beginning of the loop starts the timing, while the call to `clock.split()` after most of the loop body provides the elapsed time, measuring how long the game loop took. The game engine then sleeps (via `nanosleep()` for Linux or Mac or `Sleep()` for Windows) for `TARGET_TIME - loop_time`.

Listing 4.23: The game loop with Clock

```
0 Clock clock
```

[5] There are 1 billion nanoseconds in 1 second.

```
1  while (game not over) do
2    clock.delta()
3
4    Get input // e.g., keyboard/mouse
5    Update game world state
6    Draw current scene to back buffer
7    Swap back buffer to current buffer
8
9    loop_time = clock.split()
10   sleep(TARGET_TIME - loop_time)
11 end while
```

The expectation is that `(TARGET_TIME - loop_time)` is positive, since the `sleep()` call on line 10 of Listing 4.23 expects positive number. But what happens when it is not? First off, consider what it means for `(TARGET_TIME - loop_time)` to be negative. This happens when the time to do the processing work in the game loop (the input, update, draw and swap) takes longer than the expected time for one iteration of the game loop (longer than `TARGET_TIME`). When this happens, the game engine cannot keep up with the work required to run the game, resulting, at a minimum, in the displayed frame rate that the player sees to decrease. For example, if the `TARGET_TIME` is 33 milliseconds, providing a frame rate of 30 f/s, but the loop time (`loop_time`) takes 50 milliseconds, the frame rate is only 20 f/s. With longer loop times, the frame rate drops further, decreasing the smoothness of the visual display for the player. The time between getting input from the player also decreases, probably making the game feel less responsive.

If the `loop_time` is greater than the `TARGET_TIME`, do the game objects themselves need to slow down also? Not necessarily. When updating the game world, the engine can be aware of the previous update time, thus knowing how much time has elapsed, and use this to decide how far, say, an object should move. The game engine could pass along timing information to update functions and for those functions to use the information accordingly.

For example, in the Saucer Shoot tutorial (Chapter 3), the Hero decrements a counter each step to restrict the rate of fire. If the goal was to keep the rate of fire consistent with the real-world time (e.g., fire one bullet every second), then the game code could use the elapsed time as in the following listing:

```
0  fire_countdown -= ceil(elapsed_time / TARGET_TIME)
```

This would decrease the `fire_countdown` value by more than 1 each step when the elapsed time (`elapsed_time`) was greater than the target loop time (`TARGET_TIME`).

However, in Dragonfly, the engine does not do this, so if the computer cannot keep up at the expected `TARGET_TIME` pace, the game will look, feel and run slower. Thus, as for programming all games using a game engine, Dragonfly game programmers must work within the constraints of the engine to ensure the load their game places on the engine does not cause performance issues.

4.4.3.1 Fine Tuning the Game Loop (optional)

A subtle timing aspect that is important for some games is that when calling operating system sleep functions (e.g., `nanosleep()` or `Sleep()`), the actual amount of sleep time may be longer than requested depending upon other activity in the system and the operating

system scheduler. In most cases, this does not matter much, since sleep differences are typically being only a matter of a few milliseconds at most. However, in some cases, such as when trying to synchronize game state on two different machines in a multi-player game or when tying to keep game time consistent with real-world time (i.e., external clocks), more precision in the total time a game loop takes is required.

If so, a final adjustment to the loop timing can be made by determining how long the sleep function call actually took. Measurement can be done before and after the sleep call, with any extra time subtracted from the next game loop. Listing 4.24 shows how to put in this adjustment.

Listing 4.24: The game loop with Clock and sleep adjustment

```
0  Clock clock
1  while (game not over) do
2    clock.delta()
3
4    Get input // e.g., keyboard/mouse
5    Update game world state
6    Draw current scene to back buffer
7    Swap back buffer to current buffer
8
9    loop_time = clock.split()
10   intended_sleep_time = TARGET_TIME - loop_time - adjust_time
11   clock.delta()
12   sleep(intended_sleep_time)
13
14   actual_sleep_time = clock.split()
15   adjust_time = actual_sleep_time - intended_sleep_time
16   if adjust_time < 0 then
17     set adjust_time to 0
18   end if
19
20 end while
```

4.4.4 The GameManager

With timing technologies developed for the game loop, implementation of the GameManager can now be started with the class definition provided in Listing 4.25.

The GameManager constructor should set the type of the Manager to "GameManager" (i.e., `setType("GameManager")` and initialize all attributes.

The method `setGameOver()` lets the game programmer set the game over condition when ready (e.g., the player has indicated they want to quit) and `getGameOver()` returns the game over status.

The `run()` method is used to start the game, effectively running the game loop until the game is over, controlled by the boolean attribute `game_over`.

The GameManager needs start up methods, like all engine managers. The GameManager `startUp()` method instantiates (via `getInstance()`) and starts up (via `startUp()`) all the other game managers and in the right order. For now, the GameManager only starts up the LogManager. The `game_over` variable should be set to `false`. Most games typically use the default of 33 milliseconds (line 3), but games that want to run faster or slower may

want to use an alternate frame time.* If developing for Windows, GameManager `startUp()` should invoke `timeBeginPeriod(1)` (see page 69).

The `shutDown()` method does the reverse, shutting down the LogManager. It calls `setGameOver()` to indicate to any game objects that the game is over, which sets the `game_over` variable to `true`. If developing for Windows, GameManager `shutDown()` should invoke `timeEndPeriod(1)` (see page 69).

Upon success, Manager `startUp()` and Manager `shutDown()` should be called from GameManager `startUp()` and GameManager `shutDown()`, respectively.

Listing 4.25: GameManager.h

```
#include "Manager.h"

// Default frame time (game loop time) in milliseconds (33 ms == 30 f/s).
const int FRAME_TIME_DEFAULT = 33;

class GameManager : public Manager {

 private:
  GameManager();                        // Private since a singleton.
  GameManager (GameManager const&);     // Don't allow copy.
  void operator=(GameManager const&); // Don't allow assignment.
  bool game_over;         // True, then game loop should stop.
  int frame_time;         // Target time per game loop, in milliseconds.

 public:
  // Get the singleton instance of the GameManager.
  static GameManager &getInstance();

  // Startup all GameManager services.
  int startUp();

  // Shut down GameManager services.
  void shutDown();

  // Run game loop.
  void run();

  // Set game over status to indicated value.
  // If true (default), will stop game loop.
  void setGameOver(bool new_game_over=true);

  // Get game over status.
  bool getGameOver() const;

  // Return frame time.
  // Frame time is target time for game loop, in milliseconds.
  int getFrameTime() const;
};
```

* **Did you know (#3)?** Large dragonflies have an average cruising speed of about 10 mph, with a maximum speed of about 30 mph. – "Frequently Asked Questions about Dragonflies", *British Dragonfly Society*, 2013.

Tip 8! Acronyms for Dragonfly managers. Comparing Listing 4.25 with the full GameManager.h header file available online will show an extra line:

```
#define GM df::GameManager::getInstance()
```

This allows programmers, both game engine programmers and game programmers, to access the GameManager singleton via `GM`. For example, a game programmer could write `GM.setGameOver()` instead of `df::GameMangager::getInstance().setGameOver()`. The full version of Dragonfly has similar code in the header file for each manager: "GM" for GameManager, "LM" for LogManager, "RM" for ResourceManager, "IM" for InputManager, "DM" for DisplayManager, and "WM" for WorldManager. While such blanket syntax replacement should be used sparingly (remember, `#define` directives are handled by the pre-processor during compilation), in this case the ability to use the two-letter acronym for the singleton managers makes coding more convenient and code more readable. (Note, there is no semi-colon at the end of the above line.)

4.4.5 Development Checkpoint #2!

If you have not kept up already, Dragonfly development should continue! Steps:

1. Create the Clock class. Create a `Clock.h` header file based on Listing 4.20. Add `Clock.cpp` to the project and stub out each method so it compiles.
2. Implement and test, using a simple program that creates a Clock object, waits for awhile (use an appropriate sleep call), and calls `split()` and/or `delta()`. Verify the times meet expectations. A robust LogManager (developed during Development Checkpoint 4.3.7) can be used for output.
3. Create the GameManager class. Create a `GameManager.h` header file based on Listing 4.25. Add `GameManager.cpp` and stub out each method so it compiles.
4. In the `GameManager.cpp` file, have the `startUp()` method start the LogManager, and the `shutDown()` method stop the LogManager and call `setGameOver()`. Test that `startUp()` and `shutDown()` work as expected before proceeding.
5. Implement the game loop inside the GameManager `run()` method. The body of the loop does not do anything yet (although you can add some "dummy" statements), but the loop should time (via `delta()` and `split()`) and sleep properly. Be sure to double-check any conversions of units (e.g., milliseconds to microseconds) used. The game loop uses a Clock object. Test thoroughly by timing (with a clock on the wall) that you get the expected number of loop iterations.
6. Add additional functionality to the GameManager, as desired. The frame time option to `startUp()` can be useful.

Since code developed during this Development Checkpoint drives the entire game, it should be tested thoroughly, making sure it is robust and clearly written before proceeding.

Tip 9! Measuring elapsed time from a shell. From a command shell, such as a Bash shell in Linux and the Power Shell in Windows, the Linux `time` utility and the `Measure-Command` utility can be used to measure the elapsed time for a running program. For example, in a Linux Bash shell the command would be `time a.out` and in Windows Power Shell the command would be `Measure-Command myprogram.exe`. So, for example, having a game loop iterate 100 times and then exit can be timed via a command shell to verify it takes 3.3 seconds.

4.5 The Game World

The game world itself is full of objects: bad guys running around; walls that enclose buildings and spaces; trees, rocks and other obstacles; and the hero, rushing to save the day. The exact types of objects depend upon the genre of game, of course, but in nearly all games, the game engine has many objects to manage (game objects are introduced in Section 4.5.1 on page 75).

The game world needs to store and access groups of objects. In addition, the game programmer needs to access game objects in order to make them react to input or perform game-specific functions. So, the game world needs to manage them efficiently and present them in a convenient fashion. The game programmer might want a list of all the solid game objects, a list of all the game objects within the radius of an explosion, or a list of all the Saucer objects. It is the job of the world manager to store the game objects and provide these lists in response to game programmer queries. Section 4.5.2 on page 79 introduces lists of game objects.

The game world not only stores and provides access to the game objects, it also needs to update them, move them around, see if they collide, and more. Section 4.5.4 (page 90) introduces methods to update game objects, with Section 4.5.5 (page 91) providing details on events, of vital importance for understanding how a game engine connects to game programmer code.

4.5.1 Game Objects

Game objects are a fundamental game programmer abstraction for items in the game. For example, consider Saucer Shoot from Section 3.3. As in many games, there are opponents to defeat (i.e., Saucers), the player character (i.e., the Hero), projectiles that can be launched (i.e., Bullets), and other game objects (e.g., Explosions, Points, etc.). Other games may have obstacles or boundaries to bypass (e.g., walls, doors), items that can be picked up (e.g., gold coins, health packs), and even other characters to interact with (e.g., non-player characters). The game engine needs to access all these game objects, for example, to get an object's position. The game engine also needs to update these objects, for example, to change the location as the game object moves. Thus, a core attribute for a game object, and the first one used in Dragonfly, is the object's position, stored as a 2d vector.

4.5.1.1 The Vector Class

The Vector class represents a 2d vector. When used for a position, the Vector is sufficient to hold a 2d location in the game world. Some future version of Dragonfly could provide a third dimension, z, and/or provide coordinates as floating point numbers. The header file for the Vector class is described in Listing 4.26. Vector mostly holds the attributes `x` and `y`, with methods to get and set them. In addition to the default constructor (which set `x` and `y` to 0), on line 9, Vector has a constructor that sets `x` and `y` to initial values.

Listing 4.26: Vector.h

```
0 class Vector {
1
```

```
2  private:
3   float m_x;  // Horizontal component.
4   float m_y;  // Vertical component.
5
6  public:
7
8   // Create Vector with (x,y).
9   Vector(float init_x, float init_y);
10
11  // Default 2d (x,y) is (0,0).
12  Vector();
13
14  // Get/set horizontal component.
15  void setX(float new_x);
16  float getX() const;
17
18  // Get/set vertical component.
19  void setY(float new_y);
20  float getY() const;
21
22  // Set horizontal & vertical components.
23  void setXY(float new_x, float new_y);
24
25  // Return magnitude of vector.
26  float getMagnitude() const;
27
28  // Normalize vector.
29  void normalize();
30
31  // Scale vector.
32  void scale(float s);
33
34  // Add two Vectors, return new Vector.
35  Vector operator+(const Vector &other) const;
36 };
```

To make a Vector more generally useful, methods and operators on lines 26 to 35 are provided.

Vector `getMagnitude()`, shown in Listing 4.27, returns the magnitude (size) of the vector.

Listing 4.27: Vector getMagnitude()

```
0 // Return magnitude of vector.
1 float Vector::getMagnitude()
2   float mag = sqrt(x*x + y*y)
3   return mag
```

Vector `scale()`, shown in Listing 4.27, resizes (changes the magnitude) of the vector by the scale factor, leaving the direction for the vector unchanged.

Listing 4.28: Vector scale()

```
0 // Scale vector.
1 void Vector::scale(float s)
2   x = x * s
```

```
3   y = y * s
```

Vector `normalize()`, shown in Listing 4.29, takes a vector of any length and, keeping it pointing in the same direction, changes its length to 1 (also called a unit vector). The `if` check is to avoid a possible division by zero.

Listing 4.29: Vector normalize()

```
0 // Normalize vector.
1 void Vector::normalize()
2   length = getMagnitude()
3   if length > 0 then
4     x = x / length
5     y = y / length
6   end if
```

Overloading the addition operator (`+` in `v1 + v2`) for a Vector is shown in Listing 4.30. The method is called on the first vector (the Vector on the left-hand side of the '+') with the second vector provided as an argument (the Vector on the right-hand side of the '+'). The variable `v` holds the new Vector, with `x` and `y` values added from the components of the other two vectors and then returned.

Listing 4.30: Vector operator+

```
0 // Add two Vectors, return new Vector.
1 Vector Vector::operator+(const Vector &other) const {
2   Vector v                // Create new vector.
3   v.x = x + other.x       // Add x components.
4   v.y = y + other.y       // Add y components.
5   return v                // Return new vector.
```

Other Vector operators (optional) The addition operator (`+`) is core since adding two vectors is used for many operations. However, there are other operators that may useful for a general Vector class, including: subtraction (`-`), multiplication (`*`), division (`/`), comparison (`==` and `!=`) and not (`!`). The aspiring programmer may want to implement them, using Listing 4.30 as a reference.

4.5.1.2 The Object Class

With the Vector class in place, the Object class can now be specified. The Object class definition is provided in Listing 4.31.

Listing 4.31: Object.h

```
0 // System includes.
1 #include <string>
2
3 // Engine includes.
4 #include "Vector.h"
5
6 class Object {
7
8  private:
```

```
9   int m_id;             // Unique game engine defined identifier.
10  std::string m_type;   // Game programmer defined type.
11  Vector m_position;    // Position in game world.
12
13 public:
14  // Construct Object. Set default parameters and
15  // add to game world (WorldManager).
16  Object();
17
18  // Destroy Object.
19  // Remove from game world (WorldManager).
20  virtual ~Object();
21
22  // Set Object id.
23  void setId(int new_id);
24
25  // Get Object id.
26  int getId() const;
27
28  // Set type identifier of Object.
29  void setType(std::string new_type);
30
31  // Get type identifier of Object.
32  std::string getType() const;
33
34  // Set position of Object.
35  void setPosition(Vector new_pos);
36
37  // Get position of Object.
38  Vector getPosition() const;
39 };
```

Each Object has a unique id, initialized in the constructor (`Object()`), that may be of use in some games to uniquely identify an game object.[6] The id is obtained from a `static` integer declared in the Object constructor that starts at 0 and is incremented each time `Object()` is called. The method `getId()` can be used to obtain an Object's id. The method `setId()` can be used to set an id manually, but in many games this is never used.[7]

The type is a string primarily used to identify the Object type in game code. For example, a Bullet object can invoke `setType("Bullet")`, allowing a Saucer object to query a collision event to see whether or not the type was a "bullet", destroying oneself as an action. For the base Object constructor, the type can just be set to `"Object"`.

The Object `setPosition()` and `getPosition()` methods allow changing the attribute `m_position` (via set) and retrieving it (via get).

Objects will have many attributes eventually (such as altitude, solidness, bounding boxes for collisions, animations for rendering sprite images, ...) but for now merely storing the position of the game world is sufficient.

Note that the destructor for Object is `virtual` on line 20. This is necessary since

[6] In most cases, the game programmer can uniquely identify an object by its memory address, but an integer may be more convenient. Moreover, a network game cannot count on a game object that is replicated on another computer to have the same memory address.

[7] A common exception is for synchronizing game worlds in a networked computer game.

Objects are deleted by the engine, not the game programmer, and the `virtual` keyword makes sure the right destructor is called for derived game objects. If the destructor was not `virtual`, when an Object was deleted by the engine, only `~Object()` would be invoked and not the destructor for a game programmer object that inherited from it.

4.5.2 Lists of Objects

In order to handle the management and presentation of game objects to the game programmer, the world manager needs a data structure that supports lists of game objects, lists that can be created and passed around (inside the engine and to the game programmer) in a convenient to use and efficient to handle manner. In passing the lists to the game programmer, if the Objects themselves are changed (e.g., say, by decreasing the hit points of Objects damaged in an explosion), updates need to happen to the "real" objects as seen by the world manager. While there are numerous libraries that could be used for building efficient lists (e.g., the *Standard Template Library* or the *Boost C++ Library*), list performance is fundamental to game engine performance, both for Dragonfly as well as for other game engines, so implementing game object lists provides an in-depth understanding that may impact game engine performance. Plus, there are additional programming skills to be gained by implementing lists from scratch.

There are different implementation choices possible for lists of game objects, including linked lists, arrays, hash tables, trees and more. For ease of implementation *and* performance efficiency, an array is used for lists of game objects in Dragonfly. In addition, the *iterator* design pattern can be used to provide a way to access the list without exposing the underlying data representation. In general, separating iteration from the container class keeps the functionality for the collection separate from the functionality for iteration. This simplifies the collection (not having it cluttered with iteration methods), allows several iterations to be active at the same time, and decouples collection algorithms from collection data structures, while still leaving the details of the container implementation encapsulated. This last point means the internals of the list data structure can be changed (e.g., replace the array with a linked list) without changing the rest of the game engine or any dependent game programmer code.

For reference, consider a basic list of integers (`int`s), shown in Listing 4.32.

Listing 4.32: List of integers implemented as an array

```
0  const int MAX = 100;
1
2  class IntList {
3
4  private:
5    int list[MAX];
6    int count;
7
8  public:
9    IntList() {
10     count = 0;
11   }
12
13   // Clear list.
```

```
14    void clear() {
15      count = 0;
16    }
17
18    // Add item to list.
19    bool insert(int x) {
20      if (count == MAX)  // Check if room.
21        return false;
22      list[count] = x;
23      count++;
24      return true;
25    }
26
27    // Remove item from list.
28    bool remove(int x) {
29      for (int i=0; i<count; i++) {
30        if (list[i] == x) {           // Found...
31          for (int j=i; j<count-1; j++) // ...so scoot over
32            list[j] = list[j+1];
33          count--;
34          return true; // Found.
35        }
36      }
37      return false; // Not found.
38    }
39
40    // Index into list.
41    int operator[](int i) {
42      if (i >= m_count || i < 0)
43        throw std::out_of_range("Invalid index!");
44      return list[i];
45    }
46
47  };
```

The list starts out empty, by setting the count of items to 0 in the constructor. Basic operations allow the programmer to `insert()` items, `remove()` items, and `clear()` the entire list. Line 41 uses C++ operator overloading, enabling brackets (e.g., `list[2]`) to index into the list. The `throw` operation at line 41 triggers an exception with the indexed value is out of range.

Clearing the list and adding items to the list are quite efficient. Removing items from the list is rather inefficient, requiring the entire list to be traversed each time. The list is searched from the beginning to find the item to remove and then the rest of the list is traversed to "scoot" the items over one spot. Rather than scoot the items over, a "pop and swap" operation could be used:

```
0     for (int i=0; i<count; i++)
1       if (list[i] == x) // Found...
2         // Pop last item from end and swap over item to delete.
3         list[i] = list[count-1];
```

This has the advantage of not iterating through the remainder of the list, but the disadvantage of changing the list order after the `remove()` operation. Plus, given the search

required to find the item to delete, the `remove()` operation is still $O(n)$, where n is the number of list items.[8] However, perhaps most importantly, copying the list, which in a game engine happens often as many lists are created and destroyed by both the engine and the game programmer, is efficient as compilers (and programmers) handle fixed sized chunks of memory efficiently.

While arrays are efficient, it is still not a good design for the game engine to have entire objects inside the list. In other words, the `int` in Listing 4.32 should *not* be replaced by an `Object` representing a game object. Instead, lists of game objects are handled by having *pointers* to the game objects. So, `int` is replaced with `Object *`. Using pointers allows the game engine to reference the game object's attributes and methods and still remain efficient for creating the many needed lists of objects needed. Basically, copying a list of pointers is much faster (and uses less memory) than copying a list of game objects. In addition, lists passed from the engine to, say, the game code refer to the original Objects (via the pointers) and not copies. Last but not least, having Object pointers allows for polymorphism, as in Listing 1.1 on page 8, when Object methods are resolved.

Listing 4.33 shows the header file for ObjectList. The list data (Objects) is statically declared as a large (e.g., `MAX_OBJECTS` is 1000) array of Object pointers, with the count (`m_count`) set to 0 in the constructor. Implementation of the ObjectList methods is done similarly as the IntList (see Listing 4.32 on 79).

Listing 4.33: ObjectList.h

```
0  const int MAX_OBJECTS = 1000;
1
2  #include "Object.h"
3
4  class ObjectList {
5
6  private:
7    int m_count;                    // Count of objects in list.
8    Object *m_p_obj[MAX_OBJECTS];   // Array of pointers to objects.
9
10 public:
11   // Default constructor.
12   ObjectList();
13
14   // Insert object pointer in list.
15   // Return 0 if ok, else -1.
16   int insert(Object *p_o);
17
18   // Remove object pointer from list.
19   // Return 0 if found, else -1.
20   int remove(Object *p_o);
21
22   // Clear list (setting count to 0).
23   void clear();
24
25   // Return count of number of objects in list.
26   int getCount() const;
```

[8] Tests with the Dragonfly Bounce benchmark modified to delete 50% of items added each time showed negligible performance differences between "pop-and-swap" and "scoot."

```
27
28    // Return true if list is empty, else false.
29    bool isEmpty() const;
30
31    // Return true if list is full, else false.
32    bool isFull() const;
33
34    // Index into list.
35    Object* &operator[](int index);
36 };
```

One implemented, an ObjectList can be created, Objects added to it (via ObjectList `insert()` and removed (via ObjectList `remove()`). When needed, the ObjectList can be iterated through much as would a typical C++ array, as shown in Listing 4.34.

Listing 4.34: C++ Code illustrating iteration through an ObjectList

```
0 ObjectList ol;
1 for (int i=0; i < ol.getCount(); i++)
2   Object *p_o = ol[i];
```

Tip 10! Naming pointers. Debugging pointer errors can be a challenging, frustrating experience. It is better to avoid pointer problems as much as possible in both design and coding, rather than chase down pointer bugs. Given the need to treat pointers with care, it is helpful to have a naming convention that indicates which variables are pointers, even if this is the *only* naming convention followed. In Dragonfly, pointers are indicated by a '`p_`' prefix, standing for "pointer". It is recommended this same convention be followed by game programmers in game code. See Section 5.1.2 on page 249 for other bug-prevention tips.

4.5.2.1 List Iterators (optional)

The *iterator* design pattern can be used to provide a way to access the list without exposing the underlying data representation. In general, separating iteration from the container class keeps the functionality for the collection separate from the functionality for iteration. This simplifies the collection (not having it cluttered with iteration methods), allows several iterations to be active at the same time, and decouples collection algorithms from collection data structures, while still leaving the details of the container implementation encapsulated. This last point means the internals of the list data structure can be changed (e.g., replace the array with a linked list) without changing the rest of the game engine or any dependent game programmer code.

There can be more than one iterator for a given list instance, each keeping its own position. Note, however, that adding or deleting items to a list during iteration may cause the iterator to skip or repeat iteration of an item (not necessarily the one added) – the program should not crash, but the iteration may not touch each item once and only once.

There are 3 primary steps in coding an iterator for a container:

1. Understand container class (e.g., List)
2. Design iterator class for container class
3. Add iterator materials:
    - Add iterator as friend class of container class

To illustrate these steps, consider creating a IntListIterator for the List defined in Listing 4.32 on page 79. Step 1 is to understand the implementation of List, in terms of the attributes `p_obj[]` array and the `count` used to store and keep track of list members. Step 2 is to define an iterator for IntList, provided by IntListIterator in Listing 4.35. The constructor for IntListIterator (line 7) needs a pointer to the IntList object it will iterate over, which it stores in attribute `p_list`. Since the iterator does not change the contents of the list, this pointer is declared as `const`. The `index` attribute is used to keep track of where the iterator resides in the list during iteration. The `first()` method resets the iterator to the beginning of the list. Subsequently, `next()` and `isDone()` allow iteration until the end of the list. The method `currentItem()` returns the current item that the iterator is on. Note, although not shown for brevity, `index` should be error checked for bounds in `currentItem()` and `next()`.

Listing 4.35: Iterator for IntList class

```
0  class IntListIterator {
1
2  private:
3    const IntList *p_list;  // Pointer to IntList iterating over.
4    int index;              // Index of current item.
5
6  public:
7    IntListIterator(const IntList *p_l) {
8      p_list = p_l;
9      first();
10   }
11
12   // Set iterator to first item.
13   void first() {
14     index = 0;
15   }
16
17   // Iterate to next item.
18   void next() {
19     if (index < p_list -> count)
20       index++;
21   }
22
23   // Return true if done iterating, else false.
24   bool isDone() {
25     return (index == p_list -> count);
26   }
27
28   // Return current item.
29   int currentItem() {
```

```
30      return p_list -> item[index];
31    }
32  };
```

For step 3, in order for the IntListIterator to access the private member of the IntList class, namely the `item[]` array and the list `count`, IntListIterator must be declared as a `friend` class inside `IntList.h`.

```
0  friend class IntListIterator;
1  ...
```

Both `IntList.h` and `IntListIterator.h` need forward references to class IntListIterator and class IntList, respectively, for compilation.

Once the IntListIterator is defined, a programmer that wants to iterate over an instance of a List, say `my_list`, first creates an iterator:

```
0  IntListIterator li(&my_list);
```

Then, the programmer calls `first()`, `currentItem()`, and `next()` until `isDone()` returns true.

Listing 4.36: Iterator with while() loop

```
0  li.first();
1  while (!li.isDone()) {
2    int item = li.currentItem();
3    li.next();
4  }
```

A `for` loop has a bit shorter syntax:

Listing 4.37: Iterator with for() loop

```
0  for (li.first(); !li.isDone(); li.next())
1    int item = li.currentItem();
```

ObjectList Iterators (optional) The ObjectList class, as described in Section 4.5.2, is a fine container class, but could be enhanced by defining an *iterator* for the ObjectList class. In general, iterators "know" how to traverse through a container class without exposing the internal data methods and structure publicly. Iterators do this by being a `friend` of the container class, giving them access to the private and protected attributes of the class. Defining an iterator decouples traversing the container from the container iteration. This allows, for instance, the structure of the container to be changed (e.g., from a static array to a linked list) without redefining all the code that uses the container.

The ObjectList sets the ObjectListIterator up as a `friend`:

Listing 4.38: ObjectList extension to add a list iterator

```
0
1  class ObjectListIterator;
2
3  class ObjectList {
4
```

```
5    ...
6   public:
7    friend class ObjectListIterator;
8    ...
9   }
```

Notice that line 1 of Listing 4.38 refers to an "ObjectListIterator" class that has not been defined. This line is needed to act as a forward reference for the compiler, allowing compilation to proceed, as long as the ObjectListIterator class is defined before linking.

For Dragonfly, the complete header file for an ObjectListIterator is defined in Listing 4.39. Having the default constructor `private` on line 8 makes it explicit that an ObjectList must be provided to the iterator when created. The class method implementation follows that of the IntListIterator in Listing 4.35.

Listing 4.39: ObjectListIterator.h

```
0  #include "Object.h"
1  #include "ObjectList.h"
2
3  class ObjectList;
4
5  class ObjectListIterator {
6
7   private:
8    ObjectListIterator();        // Must be given list when created.
9    int m_index;                 // Index into list.
10   const ObjectList *m_p_list; // List iterating over.
11
12  public:
13   // Create iterator, over indicated list.
14   ObjectListIterator(const ObjectList *p_l);
15
16   void first();          // Set iterator to first item in list.
17   void next();           // Set iterator to next item in list.
18   bool isDone() const;   // Return true if at end of list.
19
20   // Return pointer to current Object, NULL if done/empty.
21   Object *currentObject() const;
22 };
```

4.5.2.2 Overloading + for ObjectList (optional)

A useful abstraction for game programmers is to combine two ObjectLists, the result being a third, combined list holding all the elements of the first list and all the elements of the second list. A method named `add()` could combine two lists, written as part of the ObjectList class (e.g., `ObjectList::add()`) or as a stand alone function. However, a natural abstraction is to use the addition ('`+`') operator, overloading it to combine ObjectLists in the expected way.

In C++, operators are just functions, albeit special functions that perform operations on objects without directly calling the objects' methods each time. Unary operators act on a single piece of data (e.g., `my_int++`), while binary operators operate on two pieces of data

(e.g., `new_int = my_int1 + my_int2`). For ObjectLists, overloading the binary addition '(+)' operator is helpful. The syntax for overloading an operator is the same as for declaring a method, except the keyword `operator` is used before the operator itself.

Overloading the addition operator for an ObjectList is shown in Listing 4.40. The method is called on the first list (the ObjectList on the left-hand side of the '+'), with the second list provided as an argument (the ObjectList on the right-hand side of the '+'). The variable `big_list` holds the combined list, starting out by copying the contents of the first list ((`*this`) on line 4). The method then proceeds to iterate through the second list, inserting each element from the second list into the first list on line 10. Once finished iterating over all elements in the second list, the method returns the combined list `big_list` on line 14.

Listing 4.40: ObjectList operator+

```
0  // Add two lists, second appended to first.
1  ObjectList ObjectList::operator+(ObjectList list)
2
3    // Start with first list.
4    ObjectList big_list = *this
5
6    // Iterate through second list, adding each element.
7    ObjectListIterator li(&list)
8    for (li.first(); not li.isDone(); li.next())
9      Object *p_o = li.currentObject()
10     big_list.insert(p_o) // Add element from second, to first list.
11   end for
12
13   // Return combined list.
14   return big_list
```

Since ObjectLists are implemented as arrays, a more efficient '+' operation could allocate one array of memory large enough for both lists, then, using `memcpy()` or something similar, copy the first list then the second list into the allocated memory. Care must be taken to get the pointers and memory block length correct. That is left as option for the reader to explore outside this text.

However, as an advantage, the implementation in Listing 4.40 is agnostic of the actual implementation of ObjectList. The lists could be implemented as either arrays or linked lists with pointers or some other internal structure and the code would still work.

Once defined, the ObjectList '+' operator can be called explicitly, such as:

```
0  ObjectList list_1, list_2;
1  ObjectList list_both = ObjectList+(list_1, list_2);
```

but a more natural representation is to call it as intended:

```
0  ObjectList list_1, list_2;
1  ObjectList list_both = list_1 + list_2;
```

4.5.2.3 Dynamically-sized Lists of Objects (optional)

A significant potential downside of the code shown in Listing 4.32 and Listing 4.33 is that the maximum size of the list needs to be specified at compile time. If the list grows larger

than this maximum, items cannot be added to the list – the container class data structure cannot do anything besides return an error code. This is true even when there is memory available on the computer to store more list items. A full list is potentially problematic – for example, the world manager can no longer manage any more Ogres or the player cannot put more Oranges into a backpack. Specifying a larger maximum size and then recompiling the game engine and the game is hardly an option for most players!

What can be done instead is to make arrays that dynamically resize themselves to be larger as more items are required to be stored in the list. This has two tremendous advantages: 1) the maximum size of the list does not need to be known by the engine ahead of time, and 2) game object lists do not have to all be as large as the potential maximum size, but can instead be small when a small list is required and only become large when a large list is required, thus saving runtime memory and runtime processing time when lists are copied and returned. The downside of this approach is that more runtime overhead is incurred when a list grows. If done right, however, this runtime overhead can be infrequent and fairly small.

The basic idea of dynamically sized lists is to allocate a relatively small array to start. Then, if the array gets full (via `insert()`), the memory is re-allocated to make the array larger. In order to avoid having the re-allocation happen every time a new item is inserted, the re-allocation is for a large chunk of memory. A good guideline for the size of the larger chunk is twice the size of the list that is currently allocated.

In order to make this change, first, the ObjectList attribute for the list needs to be changed from an array to a list of pointers, such as `Object **p_list`.[9]

Next, the ObjectList constructor needs to allocate memory for the list dynamically. This can certainly be done via `new`, but memory can be efficiently resized using C's `realloc()`.[10] The initial allocation uses `malloc()` to create a list of size `MAX_COUNT_INIT`. `MAX_COUNT_INIT` is defined to be 1, but other sizes can certainly be chosen. The ObjectList destructor should `free()` up memory, if it is allocated.

Listing 4.41: Re-declaring list to be dynamic array label

```
0 max_count = MAX_COUNT_INIT;  // Initial list size (e.g., 1).
1 p_item = (Object **) malloc(sizeof(Object *));
```

In the `insert()` method, if the list is full (`isFull()` returns `true`) then the item array is re-allocated to be twice as large, shown in Listing 4.42.

Listing 4.42: Re-allocating list size to twice as large

```
0 Object **p_temp_item;
1 p_temp_item = (Object **)
2               realloc(p_item, 2*sizeof(Object *) * max_count);
3 p_item = p_temp_item;
4 max_count *= 2;
```

[9]The variable name is changed from `list` to explicitly depict that this is a pointer with dynamically allocated memory.

[10]Preliminary investigation running the Bounce benchmark and Saucer Shoot on both Linux Mint and Windows 7 suggests about 20% of the time when a list needs to expand, the memory block can be extended via `realloc()`, while 80% of the time the new block must be allocated elsewhere.

The default copy constructor and assignment operator provided by C++ only do "shallow" copies, meaning any dynamically allocated data items are not copied. Since the revised List class has dynamically allocated memory for the items, a new copy constructor and assignment operator need to be created, each doing a "deep" copy. The copy constructor and assignment operator prototypes look like:

Listing 4.43: Copy and assignment operator prototypes

```
0 ObjectList::ObjectList(const ObjectList &other);
1 ObjectList &operator=(const ObjectList &rhs);
```

In the assignment operator, memory for the copy needs to be dynamically allocated and copied over, along with the static attributes:

Listing 4.44: Deep copy of list memory

```
0 p_item = (Object **) malloc(sizeof(Object *) * other.max_count);
1 memcpy(p_item, other.p_item, sizeof(Object *) * other.max_count);
2 max_count = other.max_count;
3 count = other.count;
```

The assignment operator is similar, but with two additions before doing the deep copy: 1) the item being copied, `rhs`, must be checked to see if it is the same object (`*this`) to avoid copying the list over itself. Doing this check makes sense for efficiency and can also prevent some crashes in copying the memory over itself; 2) if the current object (`*this`) has memory allocated (`p_item` is not `NULL`), then that memory should be `free()`'d. Not doing this results in a memory leak.

Note, the above code needs additional error checking (not shown) since calls to `malloc()` and `realloc()` can fail (returning `NULL`).

Lastly, the ObjectList destructor is not shown, but needs to check if (`p_item` is not `NULL`), and, if so, then that memory needs to be `free()`'d.

4.5.3 Development Checkpoint #3!

If you have not continued to do so, resume development now.

1. Create the Vector and Object classes, using the headers from Listing 4.26 and Listing 4.31, respectively. Add `Vector.cpp` and `Object.cpp` to the project and stub out each method so it compiles.

2. Implement both Vector and Object. Then, test even though the logic is fairly simple in both of these classes since they are primarily holders of attributes.

3. Create the ObjectList class, using the header from Listing 4.33. Refer to Listing 4.32 for method implementation details, remembering that ObjectList uses a static array of Object pointers. Add `.cpp` code to the project and stub out each method so it compiles.

4. Implement ObjectList and test. At this point, write a test program that inserts and removes elements from an ObjectList. Be sure to test boundary conditions (e.g., index the list out of bounds - it should throw an exception). Check if the `isFull()` method

works, too, when the list reaches maximum size. Test cases where the list is empty, too.

Tip 11! Array index in C++. Remember that in C/C++, arrays begin at 0 and end at one less than the allocated size. For example, given an array of integers allocated as `int item[3]`, the first array item is `item[0]` and the last array item is `item[2]`. In particular, for code that iterates through the entire array, make sure that the ends of the array are not crossed. In general, when iterating through arrays, the boundary conditions (beginning and end of the loop) should be double-checked carefully.

Make sure to test all the above code thoroughly to be sure it is trustworthy (robust). Make sure the code is easy to read and commented sufficiently so it can be re-factored later as needed – the Object class is definitely re-visited as game objects grow in attributes and functionality.

4.5.4 Updating Game Objects

The world in real-life is dynamic, with objects changing continuously over time. Game worlds are often viewed the same way since they are also dynamic, but the game engine advances the game world in discrete steps, one step each game loop. Viewed another way, each iteration of the game loop updates game objects to produce a sample of the dynamic game world, with Dragonfly taking 30 samples per second. At the end of a game loop, the static representation of the world is displayed to the player on the screen. Objects are consistent with each other at that time. However, while updating the world (so, in the middle of a game loop iteration), the game world may be in an inconsistent state. This latter fact is important in handling how game objects are deleted (more on this, later).

Updating the objects in the game world is one of the core functions of a game engine. Such updates: 1) Make the game dynamic since many objects change state during the course of the game. For example, an enemy can change position, moving towards the player's avatar. 2) Make the game interactive, since objects can respond to player input. For example, a player avatar object can be moved north in response to the player pressing the up arrow.

The simple approach to updating game objects is to have each object have an `Update()` method. In the game loop, the engine then iterates over all objects in the world, calling `Update()` for each object, as shown in Listing 4.45. In this case, the `Update()` method is responsible for updating the state of the object as appropriate. This could mean moving the object in a certain direction at a certain speed, or gathering input from the keyboard or mouse or doing whatever other unique action needs to happen each step of the game loop. Some actions, such as movement and keyboard input, could be generalized and handled by the game engine (as will be shown later in this chapter). Other actions, such as AI behavior specific to a game, would need to happen in the game code.

Listing 4.45: Game loop with update

```
0 ObjectList world_objects
1 while (game not over) {
2   ...
3   // Update world state.
4   for i = 0 to world_objects count
5     Object p_o = world_objects[i]
6     p_o -> Update()
7   end for
8   ...
9 }
```

As an abstraction, use of the `Update()` method for all game objects is useful, since it gets at the heart of what a game engine does. However, the specific implementation of this straightforward idea has complications. These complications arise from subsystems that operate on behalf of all objects. For example, an update for a game object often consists of: moving the object (including checking and responding to collisions), then drawing the object on the screen. For a Saucer from Saucer Shoot in Section 3.3, this might look like the code in Listing 4.46. The proposed implementation looks harmless enough, but consider what is happening for all objects. Each object is moved, collided and drawn completely before the next object is handled. This serial behavior does not allow for drawing efficiency.

For example, it may be that an object is not drawn at all because it is occluded by another object or even destroyed by another object that moves later in the same game loop iteration. The serial nature of updates for each game does not allow for tuning. Worse, in some cases, game objects cannot be drawn until the position of other game objects are known. For example, drawing a passenger must be done once the position of the vehicle is known, or the limbs of a 3d model may not be drawable until the position of the skeleton is known. Thus, efficiency and functionality require another solution.

Listing 4.46: Possible Update() method for Saucer

```
// Update saucer (should be called once per game loop).
void Saucer::Update()
  WorldManager move(this)
  WorldManager drawSaucer(this)
```

Instead, the subsystems that handle each task (e.g., move, draw) are done as separate functions by the game engine. The `Update()` method for each object does not need to ask the game engine to move, collide or draw the game object itself. These are instead handled in phases by the game engine, depicted in Listing 4.47. Note, the *Update()* method for each game object can still be invoked, calling game code, to do any game-specific functionality that is needed.

Listing 4.47: Game loop with phases

```
ObjectList world_objects
while (game not over) do
  ...
  // Update Objects
  for i = 0 to world_objects count
    // Update
  end for

  // Move Objects
  for i = 0 to world_objects count
    // Move
  end for

  // Draw Objects
  for i = 0 to world_objects count
    // Draw
  end for
  ...

end while
```

4.5.5 Events

Games are inherently event-driven. In the previous section, each iteration of the game loop is often treated as an event. In other words, in Listing 4.47, each iteration of the game loop triggers an event that is the `Update()` method for each object. A typical game has many events, such as a key is pressed, a mouse is clicked, an object collides with another object, a bomb explodes, an avatar picks up a health pack, a network packet arrives, etc.

Generally, when an event occurs, an engine: 1) notifies all interested objects, and 2) those objects respond as appropriate, also called called *event handling*. When a specific event occurs, different objects respond in different ways, and in some cases, may not even respond at all. For example, when a keypress event occurs, the hero object the player is controlling may move or fire, but most other objects do not respond. When a car object collides with a rock object, the car object may stop and take damage while the rock object may move slightly backward and remain unharmed.

The simple approach to dealing with game events is for the game engine to call the appropriate method for each game object when the event occurs. In Listing 4.47, this means that each step of the game loop (a step event) invokes the `Update()` method of each game object. Consider another example, where there is an explosion in a game, handled in the `Update()` method of an Explosion object, shown in Listing 4.48. In this case, all game objects within the radius of the explosion have their `onExplosion()` method invoked.

Listing 4.48: Explosion Update()

```
0  void Explosion::Update()
1    ...
2    if (explosion_went_off) then
3
4      // Get list of all Objects in range.
5      ObjectList damaged_objects = getObjectsInRange(radius)
6
7      // Have them each react to explosion.
8      for i = 0 to damaged_objects count
9        damaged_objects[i] -> onExplosion()
10     end for
11
12     ...
13   end if
```

Listing 4.48 illustrates *statically typed, late binding*. The code is "late binding" since the compiler does not know what code is to be invoked at compile time – invocation is bound to the right method, depending upon the object (e.g., Saucer or Hero), at run time. The code is "statically typed" since the type of the object (an Object) and name of the method (`onExplosion()`, on line 9) are known at compile time. All this sounds ok, and Listing 4.48 looks ok, so what is the problem?

In a nutshell, for a general purpose game engine the problem with this approach is *inflexibility*. The statically typed requirement means that all game objects must have methods for all events. Specifically, for this example, it means every game object needs an `onExplosion()` method, even if not all objects use it. The fact that an game object may not use it is perhaps not so bad, since it can just be ignored (the `onExplosion()` method essentially being a "no-op" for that object). However, some games will not even *have* explosions, but this approach still requires all game objects to have that method. In fact, it requires that all events that any game made with the engine be known, and defined, at compile time. If a game is to be made using an event that is not defined, then too bad for the game programmer – the engine will not support it. That makes it quite difficult for the game engine to be general purpose, able to support a variety of games, much less a variety of game genres.

What is needed is *dynamically* typed, late binding. While some languages support dynamic typing automatically (e.g., C#), others, such as C++, must implement dynamic typing manually. Fortunately, this can be done fairly easily by treating events as objects. When an event occurs, it is passed to all game objects that are interested in that event. In the event handler, the event object is inspected for the event type and attributes, and an appropriate action is taken. This paradigm is often called *message passing*.

In order to provide the flexibility needed without forcing the engine to recognize all event types at compile time, the event is encapsulated in an Event object. The Event object has the information required to represent the event type (e.g., explosion, health pack, collision, ...) with the ability to have additional attributes unique to each event (e.g., radius and damage, healing amount, location, ...), and can be extended by the game programmer. Representing events this way has several advantages over the approach in Listing 4.48.

1. *Single event handler:* Each game object does not need a separate method for each event (for example, objects do not all need an `onExplosion()` method). Instead, game objects have a generic event handler method (e.g., `virtual int eventHandler(Event *p_e)`), declared as `virtual` so it can be overridden, as needed, by derived game code objects.

2. *Persistence:* Event data pertaining to the event can be easily stored (say, in a list inside an object) and handled later.

3. *Blind forwarding:* An object can pass along an event without even "understanding" what the event does. Note, this is *exactly* what the game engine does when it passes events to game objects! For example, a jeep object may get a "dismount" event. The jeep itself does not know how to dismount nor have any code to recognize such an event, but it can pass the event, unmodified, to each of the passengers that it does know about. The passengers, say people objects, know how to handle a dismount event, and so take the appropriate action.

There are several options for representing the "type" for each event. One approach is to make each type an integer. Integers are small and are efficiently handled by the computer during runtime. Using an `enum` can make the integer type more programmer-friendly. For example, an `enum EventType` can be declared with values of `COLLISION`, `MOVE_UP`, `MOUSE_CLICK`, ... declared. Each "name" is assigned a unique integer value by the compiler. Game programmers can extend the types to include game specific definitions (e.g., `EXPLOSION`). While easy to read and efficient, `enum` types are relatively brittle in that the actual values are order dependent, meaning if the order of the names is re-arranged, the integer values corresponding to each change. This is not a problem if the code using them is re-compiled accordingly, but can cause problems for things like save game files or databases, or types stored in source code across systems. Worse, C++ does not readily allow for `enums` to be extended, meaning the game programmer cannot easily add custom event types to types already declared by the engine.

Another option, one used in Dragonfly, is to store event types as strings (e.g., `std::string event_type`). Strings as a type are dynamic in that they are parsed at runtime, allowing free form use by game programmers. Thus, events can be added easily, such as "explosion"

or "the dog ate my homework". The downside is that strings are relatively expensive to parse compared with integers. However, string comparisons (the most common operation when checking events at runtime) are usually fast. Another downside is that game programmers, especially for large teams, may have potential event name conflicts with each other or even with the engine. A bit of care where a team of game programmers agrees upon a naming convention can usually solve this problem. For event names, Dragonfly uses a "df::" prefix, as it does for a `namespace` (see page 53), in front of game engine event names (e.g., `"df::step"`). If needed (or for really large development efforts), more elaborate software tools can even be used to avoid conflicts, checking code for conflicts ahead of time and detecting human errors.

The arguments needed for each event depend upon the type. For example, an explosion event may need a radius and damage, while a collision event needs the two objects involved and perhaps a force vector. The easiest mechanism to support this is to have a new derived class for each event, where the class inherits from the base event class. Listing 4.49 shows how this might be declared.[11] In the game code, an event handler looks at the event type. If it is, for example, an "explosion" and the object should recognize and handle explosion events, then the object can be inspected for a location, damage and radius.

Listing 4.49: Simple event class

```
0 class Event {
1   std::string event_type;
2 };
3
4 class EventExplosion : public Event {
5   Vector location;
6   int damage;
7   float radius;
8 };
```

As discussed earlier, game objects are often connected to each other, so a vehicle may get a "dismount" event, but it is really intended for the passengers, or a solider may get a "heal" event that does not need to be passed to her backpack or to the pistol inside. A dependency chain, often called a *chain of responsibility* design pattern, can be drawn between events, illustrating their relationship. In this case, vehicle–soldier–backpack–pistol. Events that start at the head of the chain are passed down the chain, stopping when "consumed" or when the end of the chain is reached. For example, a "heal" event starts at the vehicle, is forwarded blindly to the soldier where it is consumed, and not passed further. An "explosion" event starts at the vehicle, where it takes damage, but then is passed along to each object in the chain since all take damage, too.

Listing 4.50 illustrates how a chain of responsibility might look for a particular game. On line 2, some events are "consumed" (completely handled) by the base class and no further action is required. On line 6, damage events invoke a response from someGameObject, but are not consumed in that other objects can respond to the damage, too. On line 10, health pack events are consumed, so other objects in the chain do not handle them. Unrecognized events, line 15, are not handled.

[11] Note, methods to set the event type are not shown.

Listing 4.50: Chain of responsibility

```
0  bool someGameObject::eventHandler(Event *p_event)
1    // Call base class' handler first.
2    if (BaseClass::eventHandler(p_event))
3      return true  // If base consumed, then done.
4
5    // Otherwise, try to handle event myself.
6    if p_event -> getType() is EVENT_DAMAGE then
7      takeDamage(p_event -> getDamageInfo())
8      return false  // Responded to event, but ok to forward.
9    end if
10   if p_event -> getType() is EVENT_HEALTH_PACK then
11     doHeal(p_event -> getHealthInfo())
12     return true  // Consumed event, so don't forward.
13   end if
14   ...
15   return false  // Didn't recognize this event.
```

The code in Listing 4.50 is almost right – but the compiler will throw up an error at lines 7 and 11.

4.5.5.1 Events in Dragonfly

Listing 4.51 provides the header file for the Event class. The event type `string_type` is a string and is set to `UNDEFINED_EVENT` on line 2 in the constructor. The `setType()` and `getType()` methods change and return the event type, respectively. The `virtual` keyword in front of the destructor in line 14 ensures that if a pointer to a base Event is deleted (say, in the engine), the destructor to the child gets called, as appropriate.

Listing 4.51: Event.h

```
0  #include <string>
1
2  const std::string UNDEFINED_EVENT = "df::undefined";
3
4  class Event {
5
6   private:
7    std::string m_event_type;  // Holds event type.
8
9   public:
10   // Create base event.
11   Event();
12
13   // Destructor.
14   virtual ~Event();
15
16   // Set event type.
17   void setType(std::string new_type);
18
19   // Get event type.
20   std::string getType() const;
21
22 };
```

The base Event class is passed around to game objects. It is expected that game code inherits from Event in defining game specific events, such as EventNuke in Saucer Shoot (Section 3.3.8 on page 34). Dragonfly recognizes (and pass several) specific events that are derived from Event. These "built in" events are depicted in Figure 4.2. Most of them are defined later in this chapter as they are introduced, except for the "step" event, which is defined next in Section 4.5.5.2.

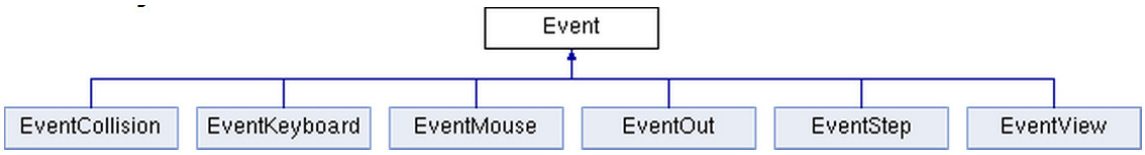


Figure 4.2: Dragonfly events

4.5.5.2 Step Event

Often, a game object does something every step of the game loop. For example, a sentry object may look around to see if there is a bad guy is within sight, or a bomb object may see if enough time has passed and it is time to explode. Dragonfly supports this by providing a "step" event each game loop for game objects that want to handle it.

Listing 4.52 provides the header file for the EventStep class. EventStep is derived from the Event base class. The `private` attribute `m_step_count` is to record the current iteration number of the game loop. Methods are provided to get and set `m_step_count`, as well as a constructor to set the initial `m_step_count`, if desired. Other "work" done in the constructor is to set the base event type (using `setType()`) to `STEP_EVENT`.

Listing 4.52: EventStep.h

```
0  #include "Event.h"
1
2  const std::string STEP_EVENT = "df::step";
3
4  class EventStep : public Event {
5
6   private:
7    int m_step_count; // Iteration number of game loop.
8
9   public:
10   // Default constructor.
11   EventStep();
12
13   // Constructor with initial step count.
14   EventStep(int init_step_count);
15
16   // Set step count.
17   void setStepCount(int new_step_count);
18
19   // Get step count.
20   int getStepCount() const;
```

```
21 };
```

Inside the engine, the step event is handled like any other event, in terms of being stored and sent to Objects' event handlers. Inside the event handler code for an Object is where, if required, the step event is recognized and acted upon. For example, as shown in Listing 4.53, the Points object in Saucer Shoot (Chapter 3) recognizes the step event in its `eventHandler()`, counting the number of times called so it can increment the score every 30 steps (1 second).

Tip 12! Dereferencing pointers and invoking methods. To invoke an Object method from inside the game engine, the object pointer is dereferenced. Normal dereferencing uses '`*`', and normal method invocation uses '`.`'. However, combined, the preferred syntax is to use '`->`'. For example, to check the type of a game object named `p_e`, the code could be written as `(*p_e).getType()`. However, the preferred syntax, and identical functionality, is written as `p_e->getType()`.

Listing 4.53: Points eventHandler()

```
0 int Points::eventHandler(const Event *p_e) {
1   ...
2   // If step, increment score every second (30 steps).
3   if (p_e -> getType() == df::STEP_EVENT) {
4     if (p_e -> getStepCount() % 30 == 0)
5       setValue(getValue() + 1)
6     ...
7   }
```

The GameManager sends step events to each interested game object, once per game loop. Basically, inside the game loop, the GameManager iterates over each of the Objects in the game world and sends each of them an EventStep, with the step count set (via `setStepCount()`) to the current game loop iteration count. Listing 4.54 shows pseudo code for sending step events to all objects in the game world. Line 2 gets all the Objects to iterate over from the WorldManager (see Section 4.5.6 on page 99). Line 3 creates an instance of the step event (EventStep) that will be passed to each Object, with `loop_count` referring to the current iteration number of the game loop. Lines 4 to 7 iterate through all Objects in the world, passing the step event to the Object event handlers in line 5.

Listing 4.54: Sending step events

```
0   ...
1   // Send step event to all Objects.
2   all_objects = WorldManager getAllObjects()
3   create EventStep s(game_loop_count)
4   for i = 0 to all_objects count
5     all_objects[i] -> eventHandler() with s
6     li.next()
7   end for
8   ...
```

4.5.5.3 Casting

C++ is a strongly typed language. Among other things, this means that values of one type (e.g., `float`) can only be assigned to variables that are of the same type (e.g., `float f`) or of a different type that has a known conversion (e.g., `int i`, where values after the decimal point are truncated). When a type is assigned to a variable of a different type where there is no known conversion, one of two things can happen. If the types are of different sizes and structures, such as a `struct` type being assigned to an `int`, then the compiler produces an error message and halts. If the types are the same size, such as a `enum` type being assigned to an `int`, then the compiler produces a warning message but continues to compile the code. At runtime, then, the conversion does happen (`enum` to `int`, in this example) even if that is not what the programmer intended.

> **Tip 13! Heeding warnings.** In general, warning messages from a compiler should *not* be ignored. The compiler is indicating something is potentially amiss when it throws up a warning. A programmer should pay attention to any warning, resolving it whenever possible (and usually it *is* possible), such as, for example, casting to indicate to the compiler that an implicit conversion is intended. Even if the current warnings are harmless in that the code still executes fine, by ignoring them, it makes it more likely that future warnings, that may *not* be harmless go unnoticed.

In game code, when the engine provides a generic event, the event handler often needs to convert the generic event to a specific event when it determines what type it is. With Dragonfly, the `eventHandler()` for an Object is invoked with a pointer to a generic event (e.g., an `Event *`). Once the `eventHandler()` determines the event type (e.g., a step event, `EventStep`) by invoking the `getType()` method, it can treat the event as the specific type.

In C++, this can be done with a *type-cast* (or just *cast* for short) which converts one type to another. C++ has different varieties of type-casts, but the one needed in this case is the *dynamic cast*.[12] The syntax for a dynamic cast is `dynamic_cast <new_type> (expression)`. For example, a dynamic cast from a base class to a derived class is written as in Listing 4.55. The value of `p_b` of type `Base *` is converted to a different type, type `p_d`.

Listing 4.55: Cast from base class to derived class

```
0 class Base {};
1 class Derived : public Base {};
2 Base *p_b = new Base;
3 Derived *p_d = dynamic_cast <Derived *> (p_b);
```

Generally, a `dynamic_cast` is used for converting pointers within an inheritance hierarchy, almost exclusively for handling polymorphism (see Chapter 1).

For a game developed using Dragonfly, a cast is often needed in a game object's `eventHandler()`. The `eventHandler()` takes as input a pointer to a generic event, or

[12] The C-style cast (e.g., `int x = (int) 4.2`) is generally replaced with a `static_cast` in C++.

an `Event *`. Once the type of the event is determined by invoking the method `getType()` and examining the string returned, the game code often acts on the event, as appropriate. For example, in Listing 4.56 the Bullet's `eventHandler()` from Saucer Shoot (Section 3.3 on page 15) checks if the event type is a collision event (`COLLISION_EVENT` – see Section 4.10.1.2 for details on the collision event). If so, it acts upon it in the `hit()` method. Since the Bullet needs to access methods specific to the collision event to obtain the Object collided with for destruction, the `hit()` method takes a pointer to a collision event, not a generic event. This means the `Event *` passed to the `eventHandler()` must be cast as an `EventCollision *`.

Listing 4.56: Cast from Event to EventCollision

```
0 int Bullet::eventHandler(const df::Event *p_e)
1   ...
2   if p_e->getType() is df::COLLISION_EVENT then
3     EventCollision *p_col_e = dynamic_cast <const df::EventCollision *> (
          p_e)
4     hit(p_col_e)
5     return 1
6   end if
7   ...
```

4.5.6 The WorldManager

At this point, development of the game world has provided game objects, lists for those game objects, and events along with a means of passing them to game objects. For Dragonfly, this means the WorldManager can be designed and implemented. The WorldManager manages game objects, inserting them into the game world, removing them when done, moving them around, and passing along events generated by the game code. For now, this is all the WorldManager does. Soon, however, the WorldManager's functionality will expand to manage world attributes, such as size and camera location, drawing and animating objects and providing collisions and other game engine events.

The WorldManager is a singleton (see Section 4.2.1), so the methods on lines 6 to 8 are private and line 15 provides the instance of the WorldManager. For now, the WorldManager only has two attributes: 1) Line 10 `m_updates` is a list holding all the game objects in the world; and 2) Line 11 `m_deletions` is a list of the game objects to delete at the end of the current update phase.

The WorldManager constructor should set the type of the Manager to "WorldManager" (i.e., `setType("WorldManager")` and initialize all attributes.

Listing 4.57: WorldManager.h

```
0 #include "Manager.h"
1 #include "ObjectList.h"
2
3 class WorldManager : public Manager {
4
5  private:
6   WorldManager(); // Private (a singleton).
7   WorldManager(WorldManager const&);     // Don't allow copy.
8   void operator=(WorldManager const&);  // Don't allow assignment.
```

```
9
10   ObjectList m_updates;     // All Objects in world to update.
11   ObjectList m_deletions; // All Objects in world to delete.
12
13  public:
14   // Get the one and only instance of the WorldManager.
15   static WorldManager &getInstance();
16
17   // Startup game world (initialize everything to empty).
18   // Return 0.
19   int startUp();
20
21   // Shutdown game world (delete all game world Objects).
22   void shutDown();
23
24   // Insert Object into world. Return 0 if ok, else -1.
25   int insertObject(Object *p_o);
26
27   // Remove Object from world. Return 0 if ok, else -1.
28   int removeObject(Object *p_o);
29
30   // Return list of all Objects in world.
31   ObjectList getAllObjects() const;
32
33   // Return list of all Objects in world matching type.
34   ObjectList objectsOfType(std::string type) const;
35
36   // Update world.
37   // Delete Objects marked for deletion.
38   void update();
39
40   // Indicate Object is to be deleted at end of current game loop.
41   // Return 0 if ok, else -1.
42   int markForDelete(Object *p_o);
43 };
```

The methods `insertObject()` and `removeObject()` provide a means to insert and remove objects in the world, respectively.

The `markForDelete()` method is called whenever an Object needs to be destroyed in the course of running the game. For example, when a projectile object collides with a target object (e.g., Bullet with Saucer), the projectile may mark both itself and the target for deletion.

The method `getAllObjects()` returns the `m_updates` ObjectList. A similar method, `objectsOfType()` returns a list of Objects matching a certain type. This method, shown in Listing 4.58, iterates through all Objects in the `m_updates` list and each Object that matches in type is added to the ObjectList, returned at the end.

Listing 4.58: WorldManager objectsOfType()

```
0 // Return list of Objects matching type.
1 // List is empty if none found.
2 ObjectList objectsOfType(std::string type) const
3
4   ObjectList list
```

```
  for i = 0 to m_updates count
    if m_updates[i] equals type then
      list.insert(m_updates[i])
    end if
  end for

  return list
```

The update() method is called from the GameManager (Section 4.4.4) once per game loop. In general, the update phase moves objects, generates collision events, etc. For now, it will only remove objects that have been marked for deletion.

The GameManager invokes WorldManager startUp() right after the LogManager is started. At this point, the WorldManager does not do much in startUp(), except for calling Manager::startUp(). Later versions of the WorldManager will set some of the game world attributes.

When invoked (typically by the GameManager), WorldManager shutDown() deletes all the Objects in the game world. Typically, the game code does not preserve the addresses of game objects created to populate the world so only the WorldManager can do so. Pseudo code for WorldManager shutDown() is shown in Listing 4.59.

Listing 4.59: WorldManager shutDown()

```
// Shutdown game world (delete all game world Objects).
void WorldManager::shutDown()

  // Delete all game objects.
  ObjectList ol = m_updates // Copy list so can delete during iteration.
  for i = 0 to ol count
    delete ol[i]
  end for

  Manager::shutDown()
```

At this point, the Object class needs to be extended to support events. A public event handling method, eventHandler() is declared as in Listing 4.60.

Listing 4.60: Event handler prototype

```
// Handle event (default is to ignore everything).
// Return 0 if ignored, else 1 if handled.
virtual int eventHandler(const Event *p_e);
```

The implementation body of the eventHandler() method should do nothing, merely returning 0 indicating that the event was not handled. However, the keyword virtual ensures that derived classes (such as Saucer and Hero) can define their own specific event handlers. The keyword const indicates the event handler cannot modify the attributes of the event pointed to (p_e) – this is because the same event may be passed to multiple Objects.

The Object constructor needs to be modified also. Specifically, it needs to add the Object itself to the game world. A code fragment for this is shown in Listing 4.61. Since parent constructors are automatically called from derived classes, a derived object created

by the game programmer (e.g., a Hero) calls the Object constructor, causing the object to automatically have itself added to the game world.

Listing 4.61: Object Object()

```
// Construct Object. Set default parameters and
// add to game world (WorldManager).
Object::Object()

  // Add self to game world.
  WorldManager insertObject(this)
```

Similarly, the destructor needs to remove the Object from the game world. A code fragment for this is shown in Listing 4.62. In a fashion similar to the constructor, when a derived object is destroyed, the parent destructor is called, removing the Object from the game world.

Listing 4.62: Object ~Object()

```
// Destroy Object.
// Remove from game world (WorldManager).
Object::~Object()

  // Remove self from game world.
  WorldManager removeObject(this)
```

4.5.6.1 Deferred Deletion

During the update phase of a game loop, a game object (with a base Object class) may be tempted to delete itself (calling `delete`) or another game object, perhaps as a result of a collision or after a fixed amount of time. But such an operation would likely be carried out somewhere in the middle of the update loop, so the iteration would be in the middle of going through the list of game world Objects. This may mean other Objects that are later in the iteration act on the recently deleted Object!

To illustrate these issues, consider an example game where darts are thrown at colored balloons for points. When a dart and a balloon collide, the WorldManager sends a collision event to both the dart and the balloon. The balloon, upon getting the collision event, destroys itself. The dart upon getting a collision, may also destroy itself. So far so good. However, what if the dart also queries the balloon to see check the balloon's color so as to add the right number of points (say, popping red balloons earns more points than popping green balloons). If the balloon has been deleted there is no way to do this! In fact, the code will compile and run, but will most likely result in a memory violation error and crash during gameplay. Moreover, objects, in general, should very rarely use `delete this` to be removed. It is legal, but should only be done carefully under delicate circumstances.

A cleaner, safer method of removing game objects from the game world is via the `markForDelete()` method in the WorldManager. Basically, an Object that is ready to be destroyed or an Object that is ready to destroy another Object indicates this by telling the WorldManager to delete the Object at the end of the current update phase. Pseudo-code for the WorldManager's `markForDelete()` is shown in Listing 4.63. The top code block

makes sure not to add the Object more than once. Failure to do so would mean that if an Object was marked more than once, `delete` would be called on an already de-allocated block of memory. If the last line of the method is reached, the Object had not been added so the list so it is added.

Listing 4.63: WorldManager markForDelete()

```
0  // Indicate Object is to be deleted at end of current game loop.
1  // Return 0 if ok, else -1.
2  int WorldManager::markForDelete(Object *p_o)
3
4    // Object might already have been marked, so only add once.
5    for i = 0 to m_deletions count
6      if m_delections[i] is p_o then // Object already in list.
7        return 0                     // This is still "ok".
8      end if
9    end for
10
11   // Object not in list, so add.
12   m_deletions.insert(p_o)
```

With the addition of the above code, some "unusual" code in the tutorial can be explained. Specifically, when a Saucer is created via `new` the pointer is not saved (i.e., `new Saucer;`). Normally, this would look like a potential source of a memory leak in that memory is allocated, but it is not clear it can be de-allocated with a corresponding `delete` since the pointer value is lost. However, having now written the constructor for Object, the pointer `this` is passed to the WorldManager where it is stored in the `m_updates` list. When the time comes to destroy the Object, the request is made to the WorldManager to mark this Object for deletion, which then does call `delete`.

4.5.6.2 The Update Phase

With the new Object code in place, and the `markForDelete()` method available, the WorldManager's `update()` can be defined. Pseudo-code for WorldManager `update()` is shown in Listing 4.64.

Lines 5 to 8 iterate through all Objects that have been marked for deletion, actually deleting them by calling `delete` in line 8. Line 11 clears the deletion list (so there are no Objects in it) to get ready for the next phase.

Listing 4.64: WorldManager update()

```
0  // Update world.
1  // Delete Objects marked for deletion.
2  void WorldManager::update()
3
4    // Delete all marked Objects.
5
6    for i = 0 to m_deletions count
7      delete m_deletions[i]
8    end for
9
10   // Clear list for next update phase.
11   m_deletions.clear()
```

4.5.7 Program Flow for Game Object Lifetime

This section provides a summary of the lifetime in Dragonfly for Objects when they are created and destroyed.

When a game object, derived from Object (e.g., Saucer), is created:

1. The game program (e.g., `game.cpp`) invokes `new`, say `new Saucer`.
2. The base Object constructor, `Object()`, is invoked first before the game object constructor, (e.g., before `Saucer()`).
3. The Object constructor, `Object()`, calls WorldManager `insertObject()` to request being added to the game world.
4. WorldManager `insertObject()` calls `insert()` on the `m_updates` ObjectList, thus adding the game object to the game world.
5. Any remaining code is the derived constructor, `Saucer()`, is run.

When a game object is finished, ready to be destroyed:

1. The game program (e.g., game code in Saucer) calls WorldManager `markForDelete()`, indicating the Object is ready to be deleted.
2. WorldManager `markForDelete()` calls `m_deletions.insert()` to add the object to the `m_deletions` ObjectList.
3. GameManager `run()` calls WorldManager `update()` at the end of the current game loop iteration.
4. At the end of the `update()` method, the WorldManager iterates through the `m_deletions` ObjectList, calling `delete` on each Object in the list. The `delete` triggers the derived Object's destructor (e.g., `~Saucer()`).[13]
5. After the derived Object's destructor (e.g., `~Saucer()`) is run, it calls the base class destructor, Object `~Object()`.
6. The Object destructor, `~Object()`, calls WorldManager `removeObject()`, requesting the WorldManager to remove the Saucer from the game world.
7. WorldManager `removeObject()` calls `remove()` on the `m_updates` ObjectList, removing the saucer from the game world.

[13] Remember, in C++, `delete` invokes an object's destructor *and* frees memory allocated by `new`.

4.5.8 Dragonfly Testing

This section provides some basic advice for getting started with game engine testing suitable for completing Dragonfly Egg. The idea is to test functionality, both large and small, in a modular fashion and, where possible, isolate the test code from the game engine code. Small here, means individual methods, but also building up combined use of methods to test integrated functionality. Large here means integrating functionality from several classes (e.g., testing the GameManager). A detailed treatment of testing is provided in the "Taking Flight" chapter.

For Dragonfly Egg development, initial testing is most easily done by isolating test code in a function and calling it from `main()`. Each test, large and small, should be in a *separate* function, allowing each function to be called individually. Commenting out individually test functions can be done to "turn off" tests that are not needed at that time, but still keeping the code around for later use. This latter idea – running a full set of tests, including tests that have previously "passed" – is commonly called regression testing and can be valuable for catching bugs that might arise in previously written code when adding new, seemingly unrelated, code.

An example of the suggested testing is shown in Listing 4.65. There are two tests written, `testClock_timing()` and `testStepEvent()`, that correspondingly test if the timing aspects of the Clock class and step events are working properly. Each function returns `true` if the test passes and `false` if it fails. In `main()`, the individual functions are called with the success/failure of the individual tests indicated. A tally of passes and failures could easily be added (e.g., `tests_taken++` and `tests_passed++`) and a summary provided (e.g., `test_passed` out of `test_taken`). The test functions themselves should write liberally to the logfile in order to confirm that tests pass and, when they fail, help to figure out *why*.

Listing 4.65: Isolating test functions

```
0  // Test fucntion prototypes.
1  bool testClock_timing()
2  bool testStepEvent()
3
4  main() {
5    if (testClock_timing())
6      puts("Pass")
7    else
8      puts("Fail")
9
10   if (testStepEvent())
11     puts("Pass")
12   else
13     puts("Fail")
14 }
```

An example of a `testClock_timing()` function is shown in Listing 4.66. The function creates a Clock object, with the timing aspects in the `sleep()` and `split()` calls starting on line 6. If the split time is not 1 on line 13, then an error is logged and `false` is returned. Otherwise, the function passes and `true` is returned. Note, `__func__` on line 19 is a built-in constant string that holds the name of the calling function (i.e., "testClock_timing()" in this example).

Listing 4.66: testClock_timing()

```
// Test the Clock class using second granularity.
// (Note, finer timer granularity should be tested, too.)
bool testClock_timing(void) {
  df::Clock clock;

  clock.delta(); // Start time.
  sleep(1); // Adjust to Mac/Linux/Windows.
  int t = (int) clock.split() / 1000000; // About 1 second.

  // Print time to logfile for debugging.
  LM.writeLog("split time t is %d", t);

  // See if reported 1 second as expected.
  if (t != 1) {
    LM.writeLog("split time t is %d", t);
    return false;
  }

  // If we get here, test has passed.
  LM.writeLog("%s passed.\n", __func__);
  return true;
}
```

As a final note, be aware that writing good tests – tests that inform whether or not code is working – takes time and skill, just like writing game engine code. The more you do, the better you get. Similarly, interpreting test failures takes time and skill. For tests that fail, additional work is involved in fixing the bugs they might be revealed. Make sure to re-run failed test after fixing the bug to be sure it is really fixed! And keep such tests around for future regression testing. All of this becomes easier with practice.

4.6 Development Checkpoint #4 – Dragonfly Egg!

Your Dragonfly development should continue!

1. Create the base Event class referring to the header file in Listing 4.51. Add `Event.cpp` to the project and stub out each method so it compiles. Testing should primarily ensure that it compiles, but make a stand alone program that sets (`setType()`) and gets (`getType()`) the event type for thoroughness.

2. Create the derived EventStep class based on the header file in Listing 4.52. Add `EventStep.cpp` to the project and stub out each method so it compiles. As for the Event class, testing should primarily ensure that it compiles, but create test code to be sure event types can be get and set for this derived class.

3. Add an event handler method to the Object class, based on Listing 4.60. Test by creating a simple game object derived from the Object class (e.g., a Saucer) and spawning (via `new`) several in a program. Define the class' `eventHandler()` methods to recognize a step event. Pass in both EventStep events and Events and see that

they are recognized properly. Verify this with output messages to the screen and/or logfile.

4. Create the WorldManager class based on the header file in Listing 4.57. Add `WorldManager.cpp` to the project and stub out all methods, making sure the code compiles.

5. Write the bodies for WorldManager methods `insertObject()`, `removeObject()`, `getAllObjects()` and `objectsOfType()`. Create a stand alone program that tests that these methods work. Test by inserting multiple objects and removing some and then all, verifying each method works as expected. Use messages written to either the screen or logfile, both inside the methods and outside the WorldManager to get feedback.

6. Write code to extend the Object constructor and destructor to add and remove itself from the WorldManager automatically. Refer to Listing 4.61 and Listing 4.62 as needed. Test by using the derived game objects (e.g., Saucers) and spawning (via `new`) them in a program. Verify they are removed when deleted via `delete` for now.

7. Write the WorldManager `markForDelete()` method, referring to Listing 4.63 as needed. Write the WorldManager `update()`, too, at this time since `update()` and `markForDelete()` are easiest to test together. Test by spawning several derived game objects (e.g., Saucers), then marking some of them for deletion. Calling `update()` should see those Objects removed. Verify this with extensive messages to the screen and/or logfile.

8. Add functionality to the GameManager run loop. This includes doing the following once per game loop: 1) getting a list of all Objects from the WorldManager and sending each Object a step event (see Listing 4.54), and 2) calling WorldManager `update()`.

At this point, it is suggested to review the Dragonfly code base thus developed. First, to refresh the design and implementation done thus far. Second, to be sure code has been integrated into a single engine and the full set of functionalities implemented have been tested. If implementation has keep pace with the book, development should have come a long way! A game programmer can write game code to:

1. Start the GameManager. The GameManager should start the LogManager and the WorldManager, in that order.

2. Populate the game world. This means creating a class derived from Object (e.g., a Saucer) and spawning one or more objects (via `new`). The class constructor for Object has each instance add itself to the WorldManager. The Objects can set their initial positions.

3. Run the GameManager (via `run()`). The GameManager executes the game loop with controlled timing (using the Clock class). Each iteration, the GameManager gets the list of game objects from the WorldManager, then iterates through the list, sending each Object a step event.

4. The GameManager also calls `update()` in the WorldManager, which iterates through the list of all Objects marked for deletion, removing each of them via `delete`.

5. Objects handle the step event in their `eventHandler()` methods. The derived game object (e.g., Saucer) should actually define the behavior. At this point, a game object can "move" itself by changing its position to demonstrate functionality. Objects can write messages (e.g., (x,y) position) to the screen or logfile to show behavior.

6. After some condition (e.g., a game object has moved 100 steps), the game can be stopped by invoking GameManager `setGameOver()` method.

7. The engine can gracefully shut everything down by invoking GameManager `shutDown()`. This should shutdown the WorldManager and the LogManager, in that order.

For the game programmer, this means creating one or more derived game objects classes (derived from Object), and one or more "games" (each with a separate `main()`) that can be used to test, debug and demonstrate robust behavior from the engine.

The full set of the above functionality is a good start – the foundation of a game engine. Put another way, the base code thus far is a Dragonfly egg* that, with the help of the rest of this book, will hatch and grow into a fully functioning Dragonfly game engine.

Tip 14! Source code control. In developing Dragonfly (and most other software projects of significant size), it is strongly urged to use a source code control (also called *version control*) system. Source code control systems help mange changes to computer programs, associating files by time and version names. While such features are critical for development teams, they are often helpful for independent developers, too, providing invaluable check pointing for working code. Checking in working versions of Dragonfly, say *Egg*, can help by preserving working code if future development breaks the code base. Similarly, source code control can provide a backup in case code is lost (e.g., a disk failure). Local source code control systems that do not back up over the network (e.g., `RCS`) should be periodically copied to another location (alternate local storage or, better, offline to another machine or cloud storage) in case of computer hardware failure.

* **Did you know (#4)?** Dragonflies start out their lives as eggs laid in water. A Dragonfly can lay as many as 100,000 eggs. – "Frequently Asked Questions about Dragonflies", *British Dragonfly Society*, 2013.

4.7 Sending Events

While the only event Dragonfly handles right now is the step event, sent to each Object every iteration of the game loop, the engine will soon have more events and will need to send those events to Objects, as well. For efficiency and convenience, the code that currently resides in the GameManager to send events should be moved into the base Manager class. That way, derived Managers that handle events, say keyboard events, can send the events to the game objects.

To do this, the Manager is extended with an `onEvent()` method, shown in Listing 4.67. The code is the same as that in the GameManager that sends the step event to all Objects (Listing 4.54).

Listing 4.67: Manager onEvent()

```
// Send event to all Objects.
// Return count of number of events sent.
int Manager::onEvent(const Event *p_event) const
  count = 0

  all_objects = WorldManager getAllObjects()
  for i = 0 to all_objects count
    all_objects[i] -> eventHandler() with p_event
    increment count
  end for

  return count
```

Once `onEvent()` is defined, the GameManager code in Listing 4.54) needs to be removed and replaced with:

Listing 4.68: GameManager providing step event

```
  ...
  // Provide step event to all Objects.
  EventStep s;
  onEvent(&s);
  ...
```

Note, the return value from `onEvent()` is not used here. However, the same `onEvent()` method can be used for user-defined events, such as the "nuke" event in the Saucer Shoot tutorial (see Section 3.3.8 on page 34). The count of events sent returned by `onEvent()` may be useful for game programmer code.

4.8 Display Management

While games are much more than just pretty visuals, graphical output is an important, if not the *most* important, element of a computer game. As previously noted, Dragonfly is a text-based game engine (see Section 3.2 for why), using the Simple and Fast Multimedia Library (SFML) to help with drawing characters on the screen, described next.

4.8.1 Simple and Fast Multimedia Library – Graphics

The Simple and Fast Multimedia Library (SFML) provides a relatively easy interface for displaying graphics and playing sounds, as well as gathering input from the keyboard and mouse. SFML has been ported to most major platforms, including Windows, Linux and Mac, and even to iOS and Android mobile platforms. SFML is free and open-source, under the zlib/png license.

For graphics output, SFML provides a graphics module for 2D drawing. The graphics module makes use of a specialized window class, `sf::RenderWindow`. Creating a window (which will pop open on the screen) can be done with the code in Listing 4.69.

Listing 4.69: SFML window

```
#include <SFML/Graphics.hpp>
...
// Create SFML window.
int window_horizontal = 1024
int window_vertical = 768
sf::RenderWindow window(sf::VideoMode({horizontal, vertical}), "Title -
    Dragonfly", sf::Style::Titlebar)

// Turn off mouse cursor for window.
window.setMouseCursorVisible(false)

// Synchronize refresh rate with monitor.
window.setVerticalSyncEnabled(true)

...

// When done.
window.close()
```

The first argument for an `sf::RenderWindow` is the video mode that defines the size of the window (the inner size, not including the title bar and borders). Listing 4.69 creates a window of 1024x768 pixels. The second argument, the string "Title - Dragonfly", is the title of the window. The third argument provides the window style, here in the form of a title bar. The third argument is actually optional – not including it will provide the default style of a title bar with resize and close buttons.

For a text-only window, such as in Dragonfly, it is often useful to hide the mouse cursor when the mouse is over the window. This is done with the `setMouseCursorVisible()` call, passing in `false`. The cursor can be shown, of course, by passing in `true`, too.

If the game engine drawing rate is faster than the monitor's refresh rate, there may be visual artifacts such as tearing. Synchronizing the SFML refresh rate with the monitor's refresh rate is done by `setVerticalSyncEnabled()`. This is only called once, after creating the window.

When use of the window is done, `close()` closes the window and destroys all the attached resources.

Before drawing any text, SFML needs to have the font loaded using the `sf::Font` class. Typically, the font is loaded from the file system using the `openFromFile()` method as in

Listing 4.70. The string "df-font.ttf"[14] is the name of the font file, supporting most standard formats. Note, the exact path to the font file must be provided since SFML cannot directly access any standard fonts installed on the system.

Listing 4.70: SFML font

```
sf::Font font
if (font.openFromFile("df-font.ttf") == false) then
  // Error.
end if
```

To draw text, the `sf::Text` class is used, as in Listing 4.71. The `sf::Text` object is created using a previously loaded font, as in Listing 4.70. The method `setString()` provides the string to be displayed. The method `setCharacterSize()` sets the character size, in pixels not point size. The method `setFillColor()` sets the text color to a type `sf::Color`, with built in color choices of Black, White, Red, Green, Blue, Yellow, Magenta and Cyan (each needs to be pre-pended with `sf::Color::`). The method `setStyle()` sets the text style, in this case bold and underlined. `setPosition()` sets the location on the window (in pixels) to draw the text.

Listing 4.71: SFML text

```
// Create text with pre-loaded font (from Listing 4.70).
sf::Text text(font)

// Set display string.
text.setString("Hello, world!")

// Set character size (in pixels).
text.setCharacterSize(24)

// Set color.
text.setFillColor(sf::Color::Red)

// Set style.
text.setStyle(sf::Text::Bold | sf::Text::Underlined)

// Set position on window (in pixels).
text.setPosition({100, 50})
```

[14] The Dragonfly engine (`http://dragonfly.wpi.edu/engine/`) includes the default Dragonfly font file "df-font.ttf" that can be used for development.

Tip 15! SFML text positions. By default, SFML entities (such as text) are positioned relative to their top-left corner. For example, if a character is drawn at SFML location (0,0), this means the upper left corner of the character is at pixel location (0,0) and the character will be fully visible. This is probably what is wanted in most cases. However, it does mean that any SFML lines (that are pixel-based) drawn from, say, the location of one character (space) to another will not appear centered on the character. If needed, the drawing of a character relative to the SFML position can be adjusted by the `setOrigin()` call. Or, an SFML position could be adjusted to reflect the character center by moving it down by half the character height and right by half the character width.

Once setup, the text can be drawn on the window. Drawing text requires a few steps, illustrated by example in Listing 4.72. The `clear()` method clears the window and is usually called each game loop right before drawing commences. Note, as an option, `clear()` can also be given a background color to paint the window (e.g., `clear(sf::Color::Blue)`). The `draw()` method draws the text on the window, but does not actually display it yet. The `display()` method displays on the window everything that has been drawn.

Listing 4.72: SFML drawing text

```
// Clear window and draw text.
window.clear();
window.draw(text);
window.display();
```

Putting it together, a "Hello, world!" sample is shown in Listing 4.73, demonstrating the basic SFML graphics needed for Dragonfly. In Listing 4.73, the top part loads the font, as in Listing 4.70. The next part sets up the text field to display, as in Listing 4.71. The main loop at the `while()` repeats drawing the text as in Listing 4.72, then checking if the window has been closed. Once the window is closed, `main()` will return and the process stopped.

Listing 4.73: SFML Hello, world!

```
#include <iostream> // for std::cout
#include <SFML/Graphics.hpp>

int main() {

  // Load font.
  sf::Font font;
  if (font.openFromFile("df-font.ttf") == false) {
    std::cout << "Error! Unable to load font 'df-font.ttf'." << std::endl;
    return -1;
  }

  // Setup text to display.
  sf::Text text(font);
  text.setString("Hello, world!"); // Set string to display.
  text.setCharacterSize(32); // Set character size (in pixels).
  text.setFillColor(sf::Color::Green); // Set text color.
```

```
17    text.setStyle(sf::Text::Bold); // Set text style.
18    text.setPosition({96,134}); // Set text position (in pixels).
19
20    // Create window to draw on.
21    sf::RenderWindow *p_window =
22      new sf::RenderWindow(sf::VideoMode({400, 300}), "SFML - Hello, world!")
          ;
23    if (!p_window) {
24      std::cout << "Error! Unable to allocate RenderWindow." << std::endl;
25      return -1;
26    }
27
28    // Turn off mouse cursor for window.
29    p_window -> setMouseCursorVisible(false);
30
31    // Synchronize refresh rate with monitor.
32    p_window -> setVerticalSyncEnabled(true);
33
34    // Repeat forever (as long as window is open).
35    while (1) {
36
37      // Clear window and draw text.
38      p_window -> clear();
39      p_window -> draw(text);
40      p_window -> display();
41
42      // See if window has been closed.
43      while (const std::optional<sf::Event> p_event = p_window -> pollEvent()
            ) {
44        if (p_event -> is<sf::Event::Closed>()) {
45          p_window -> close();
46          delete p_window;
47          return 0;
48        }
49      } // End of while (event).
50
51    } // End of while (1).
52
53  } // End of main().
```

Note, treating the SFML window as a pointer (`sf::RenderWindow *`) starting on Line 21 is not strictly necessary (after all, it is not a pointer in Listing 4.69), but it more closely mimics use by the DisplayManager (described in the next section) so is used in this example.

4.8.2 The DisplayManager

This section introduces the DisplayManager. Before doing so, however, a way for Dragonfly to support color is provided.

4.8.2.1 Color

Life is better with color, and so are most games!* Since the DisplayManager will support such game-enhancing color, it is helpful for the engine and the game programmer to define Dragonfly colors in a separate header file. Listing 4.74 shows `Color.h` which has an `enum Color` that provides for the built-in colors Dragonfly recognizes. For drawing functions where no color is specified, `COLOR_DEFAULT` is used. The `enum Color` should be in the `df::` namespace, too, similar to the other Dragonfly type and class definitions.

Listing 4.74: Color.h

```
0  // Colors Dragonfly recognizes.
1  enum Color {
2    UNDEFINED_COLOR = -1,
3    BLACK = 0,
4    RED,
5    GREEN,
6    YELLOW,
7    BLUE,
8    MAGENTA,
9    CYAN,
10   WHITE,
11 };
12
13 // If color not specified, will use this.
14 const Color COLOR_DEFAULT = WHITE;
```

The DisplayManager is a singleton class derived from Manager. Thus, as described in Section 4.2.1 on page 54, the DisplayManager has private constructors and a `getInstance()` method to return the one and only instance. The header file, including class definition, is provided in Listing 4.75.

The DisplayManager constructor should set the type of the Manager to "DisplayManager" (i.e., `setType("DisplayManager")` and initialize all attributes.

Line 6 has a `#include` for `Vector.h` since the DisplayManager draws characters on the screen at a given (x,y) location provided by a Vector object. A `#include` for `Color.h` is also included since the Dragonfly colors are used for drawing.

The next section, starting at line 8, provides the default settings for the Dragonfly window rendered on the screen. These include horizontal and vertical pixels, horizontal and vertical characters, window style, color and title and the font file to used for drawing characters. Note, the background color (`WINDOW_BACKGROUND_COLOR_DEFAULT` on on Line 14) is actually of type `sf::Color` and not type `df::Color` in order to make drawing more efficient by not having to map the background color, which does not change much, for every character drawn.

The private attributes starting on line 24 store the important window attributes. Note that the SFML window is stored as a pointer on line 25 since this allows the window to be allocated during startup, instead of when the DisplayManager is instantiated.

* **Did you know (#5)?** Newly-emerged dragonflies usually have muted colors and can take days to gain their bright, adult colors. Some adults change color as they age. – "Frequently Asked Questions about Dragonflies", *British Dragonfly Society*, 2013.

The `startUp()` method gets the SFML display ready, calling many of the SFML functions shown in Listings 4.69 and 4.70.

The `shutDown()` method closes the SFML window calling `close()` and de-allocates memory.

The `drawCh()` method uses SFML fonts and the SFML `draw()` method (see Listing 4.72) to draw the indicated character at the (x,y) location specified by the position and color.

The methods `getHorizontal()` and `getVertical()` return the horizontal and vertical character limits of the window, respectively. Similarly, the methods `getHorizontalPixels()` and `getVerticalPixels()` return the horizontal and vertical pixel limits of the window, respectively.

For drawing, the DisplayManager uses `p_window`, a pointer to an SFML `sf::RenderWindow`. Most 2d and 3d graphics setups have two buffers – one for the current window being displayed and the second for the one being drawn. When the new window is ready to be displayed, it is swapped with the current window. The DisplayManager does not need this mechanism since the `draw()` method effectively does this swapping. The `swapBuffers()` provides this feature. The method `getWindow()` returns the SFML window, which can be useful for game code that wants to make use of additional SFML features beyond drawing characters.

Listing 4.75: DisplayManager.h

```
0  // System includes.
1  #include <SFML/Graphics.hpp>
2
3  // Engine includes.
4  #include "Color.h"
5  #include "Manager.h"
6  #include "Vector.h"
7
8  // Defaults for SFML window.
9  const int WINDOW_HORIZONTAL_PIXELS_DEFAULT = 1024;
10 const int WINDOW_VERTICAL_PIXELS_DEFAULT =  768;
11 const int WINDOW_HORIZONTAL_CHARS_DEFAULT = 80;
12 const int WINDOW_VERTICAL_CHARS_DEFAULT = 24;
13 const int WINDOW_STYLE_DEFAULT = sf::Style::Titlebar;
14 const sf::Color WINDOW_BACKGROUND_COLOR_DEFAULT = sf::Color::Black;
15 const std::string WINDOW_TITLE_DEFAULT =  "Dragonfly";
16 const std::string FONT_FILE_DEFAULT = "df-font.ttf";
17
18 class DisplayManager : public Manager {
19
20  private:
21   DisplayManager();                          // Private (a singleton).
22   DisplayManager(DisplayManager const&);     // Don't allow copy.
23   void operator=(DisplayManager const&);     // Don't allow assignment
24   sf::Font m_font;                 // Font used for ASCII graphics.
25   sf::RenderWindow *m_p_window;    // Pointer to SFML window.
26   int m_window_horizontal_pixels; // Horizontal pixels in window.
27   int m_window_vertical_pixels;   // Vertical pixels in window.
28   int m_window_horizontal_chars;  // Horizontal ASCII spaces in window.
29   int m_window_vertical_chars;    // Vertical ASCII spaces in window.
30
```

```
31  public:
32    // Get the one and only instance of the DisplayManager.
33    static DisplayManager &getInstance();
34
35    // Open graphics window, ready for text-based display.
36    // Return 0 if ok, else -1.
37    int startUp();
38
39    // Close graphics window.
40    void shutDown();
41
42    // Draw character at window location (x,y) with color.
43    // Return 0 if ok, else -1.
44     int drawCh(Vector world_pos, char ch, Color color) const;
45
46    // Return window's horizontal maximum (in characters).
47    int getHorizontal() const;
48
49    // Return window's vertical maximum (in characters).
50    int getVertical() const;
51
52    // Return window's horizontal maximum (in pixels).
53    int getHorizontalPixels() const;
54
55    // Return window's vertical maximum (in pixels).
56    int getVerticalPixels() const;
57
58    // Render current window buffer.
59    // Return 0 if ok, else -1.
60    int swapBuffers();
61
62    // Return pointer to SFML graphics window.
63    sf::RenderWindow *getWindow() const;
64  };
```

In more detail, the `startUp()` method does the steps shown in Listing 4.76. The first block of code is a redundancy check to see if the SFML window (`p_window`) is already allocated. If so, that indicates an SFML window was already created (probably, due to DisplayManager `startup()` already having been called) and the method returns, but indicates no error. Note, `p_window` should be initialized to `NULL` in the DisplayManager constructor.

After that, the mouse cursor is turned off and the drawing refresh rate is synchronized with the monitor and the engine font is loaded from the file (`FONT_FILE_DEFAULT`). **Important!** Make sure to use the DisplayManager attribute for the font variable (i.e., `m_font`) and *not* the locally declared font variable (i.e., `font`).

If the window can be created and the font loaded, the Manager `startUp()` method is called, which sets `is_started` is to `true`. Later, upon a successful `shutDown()` it is set to `false` by calling Manager `shutDown()`.

Listing 4.76: DisplayManager startUp()

```
0  // Open graphics window, ready for text-based display.
1  // Return 0 if ok, else return -1.
2  int DisplayManager::startUp()
3
```

```
  // If window already created, do nothing.
  if p_window is not NULL then
    return ok // no more work to do, but ok
  end if

  create window // an sf::RenderWindow for drawing

  turn off mouse cursor

  synchronize refresh rate with monitor

  load font

  if everything successful then
    call Manager::startUp()
    return ok
  else
    return error
  end if
```

As noted, Dragonfly is text-based in that game programmers render graphics through displaying 2d ASCII art on the game window. Since SFML is fundamentally pixel based, not text-based, it is useful to have functions that convert (x,y) pixel coordinates to (x,y) text coordinates and vice versa. In turn, these functions make use of helper functions to compute the character height and width (in pixels) based on the dimensions of the game window. Listing 4.77 shows the full list of helper functions. These are declared in `DisplayManager.h` and defined in `DisplayManager.cpp`, but are utility-type functions, not methods in the DisplayManager class. Since they are not general game-programmer utilities, but instead depend upon the display characteristics (e.g., the horizontal and vertical pixels of the window), they are also not part of `utility.h`.

Listing 4.77: DisplayManager drawing helper functions

```
// Compute character height in pixels, based on window size.
float charHeight();

// Compute character width in pixels, based on window size.
float charWidth();

// Convert ASCII spaces (x,y) to window pixels (x,y).
Vector spacesToPixels(Vector spaces);

// Convert window pixels (x,y) to ASCII spaces (x,y).
Vector pixelsToSpaces(Vector pixels);
```

The function `charHeight()` computes and returns the height (in pixels) of each character, which is number of vertical pixels (DisplayManager `getVerticalPixels()`) divided by the number of vertical characters (DisplayManager `getVertical()`). Similarly the function `charWidth()` computes and returns the width (in pixels) of each character, which is number of horizontal pixels (DisplayManager `getHorizontalPixels()`) divided by the number of horizontal characters (DisplayManager `getHorizontal()`).

Then, to convert spaces to pixels in `spacesToPixels()`, the x coordinate is multiplied by `charWidth()` and the y coordinate is multiplied by `charHeight()`. Conversely, in

pixelsToSpaces(), the x coordinate is divided by charWidth() and the y coordinate is divided by charHeight().

With the helper functions in place, the drawCh() method does the steps shown in Listing 4.78.

The first step starting on line 4 makes sure the SFML window has been allocated (it should have been if the DisplayManager has been successfully started).

Next, on line 10 spaces are converted to pixels. This provides the location on the SFML window where the character will be drawn.

In SFML, ASCII text is "see through" in that any characters behind show through, generally unexpected for the Dragonfly game programmer. To avoid this, a rectangle in the same color as the window background is drawn, effectively hiding any previously drawn characters. An sf::RectangleShape is used for this, setting the size, color and position with setSize(), setFillColor() and setPosition(), respectively. The charWidth()/10 and charHeight()/5 statements are micro-adjustments (added to the x,y pixel position) to put the rectangle directly under the character. Without these, the rectangle is a bit off-center in relation to the character. The method draw() on line 12 draws the rectangle on the window first, before the character is drawn on top.

The character to be drawn is embedded in an sf::Text object in the steps starting on line 20, using setString() to actually set the text string to the desired character. Making the character bold with on line 23 is optional, but it tends to make all the graphics "pop" a bit more.

Before actually drawing the text character, it needs to be scaled to the right size using setCharacterSize(). The scaling depends upon whichever is smaller, the character width or the character height, checked in line 26.

The drawing color specified in Dragonfly (e.g., df::YELLOW) needs to be mapped to the corresponding SFML color (e.g., sf::Color::Yellow). This is easily and efficiently done in a switch() statement, shown on line 32. If the df::Color in color code is not defined by the engine (the switch's default), the engine should log a warning message and draw with the default color (i.e., the same as df::COLOR_DEFAULT, specified in Listing 4.74).

Lastly, the text is positioned at the right pixel location (line 43) and the character is drawn with the sf::Text draw() method.

Note, although not strictly necessary, both the sf::rectangle and the sf::text objects are declared as static so as not to re-allocate them each time.

Listing 4.78: DisplayManager drawCh()

```
0  // Draw a character at window location (x,y) with color.
1  // Return 0 if ok, else -1.
2  int DisplayManager::drawCh(Vector world_pos, char ch, Color color) const
3
4    // Make sure window is allocated.
5    if p_window is NULL then
6      return error
7    end if
8
9    // Convert spaces (x,y) to pixels (x,y).
10   Vector pixel_pos = spacesToPixels(world_pos)
11
12   // Draw background rectangle since text is "see through" in SFML.
```

```
13  static sf::RectangleShape rectangle
14  rectangle.setSize(sf::Vector2f(charWidth(), charHeight()))
15  rectangle.setFillColor(WINDOW_BACKGROUND_COLOR_DEFAULT)
16  rectangle.setPosition({pixel_pos.getX() - charWidth()/10,
17                         pixel_pos.getY() + charHeight()/5})
18  p_window -> draw(rectangle)
19
20  // Create character text to draw.
21  static sf::Text text(m_font)
22  text.setString(ch)
23  text.setStyle(sf::Text::Bold) // Make bold, since looks better.
24
25  // Scale to right size.
26  if (charWidth() < charHeight()) then
27    text.setCharacterSize(charWidth() * 2)
28  else
29    text.setCharacterSize(charHeight() * 2)
30  end if
31
32  // Set SFML color based on Dragonfly color.
33  switch (color)
34  case YELLOW:
35    text.setFillColor(sf::Color::Yellow)
36    break;
37  case RED:
38    text.setFillColor(sf::Color::Red)
39    break;
40  ...
41  end switch
42
43  // Set position in window (in pixels).
44  text.setPosition({pixel_pos.getX(), pixel_pos.getY()})
45
46  // Draw character.
47  p_window -> draw(text)
48
49  return 0 // Success.
```

Note, the multiplier 2 on Lines 27 and 29 scale the text to typical terminal dimensions (such as you might see in a Linux shell). These characters, and characters in general, tend to be rectangle shaped, somewhat taller than they are wide. For a game that needs square cells, the multiplier can be set to 1. The characters will still appear normal, but there will be some horizontal (empty) padding to make the characters effectively squares on the screen.

The `swapBuffers()` method does the steps shown in Listing 4.79. Basically, after checking if the window `p_window` is allocated, the SFML `display()` method is invoked to make all changes since the previous refresh visible to the player). Then, the SFML method `clear()` is called immediately to get ready for the next drawing. It may seem counter-intuitive to clear the window right after drawing, but remember that there are actually two buffers in use here – one that is currently being displayed, made so by the `display()` call, and one that is going to be drawn on and then displayed the next game loop. This second buffer is the one that is cleared with the `clear()` call.

Listing 4.79: DisplayManager swapBuffers()

```
0 // Render current window buffer.
1 // Return 0 if ok, else -1.
2 int DisplayManager::swapBuffers()
3
4   // Make sure window is allocated.
5   if p_window is NULL then
6     return error
7   end if
8
9   // Display current window.
10  p_window -> display()
11
12  // Clear other window to get ready for next draw.
13  p_window -> clear()
14
15  return 0 // Success.
```

4.8.3 Using the DisplayManager

With the DisplayManager in place, the Object class can be extended to support using it. Specifically, the Object is given a `virtual` method for drawing, shown in Listing 4.80.

Listing 4.80: Object draw()

```
0 public:
1   virtual int draw();
```

The Object `draw()` method does nothing itself, but can be overridden by derived classes. For example, the Star in Saucer Shoot (Section 3.3) defines the `draw()` method as in Listing 3.6 on page 39. When the `draw()` method for a Star is called, the Star invokes the `drawCh()` method of the DisplayManager, giving it the position of the Star and the character to be drawn (a '`.`').

With `draw()` defined for each game object, the engine can handle redrawing each Object every game loop. To do this, the WorldManager is extended with a `draw()` method of its own which iterates through all game objects, calling an Object's `draw()` method each iteration. Listing 4.81 illustrates the pseudo code.

Listing 4.81: WorldManager draw()

```
0 // Draw all Objects.
1 void WorldManager::draw()
2
3   for i = 0 to m_updates count
4     m_updates[i] -> draw()
5   end for
```

The game loop in the GameManager needs a couple of additional lines, first to invoke the WorldManager `draw()` method and then to call the DisplayManager `swapBuffers()` method. Listing 4.82 shows the game loop, with line 5 calling WorldManager `draw()` and line 6 calling DisplayManager `swapBuffers()`. Note, line 4 calls the WorldManager

update() method, as described in Section 4.5.6.2 on page 103. Line 3 gets the input from the player, which is described next in Section 4.9.

Listing 4.82: The game loop with drawing

```
0 Clock clock
1 while (game not over) do
2 clock.delta()
3   Get input // e.g., keyboard/mouse
4   WorldManager update()
5   WorldManager draw()
6   DisplayManager swapBuffers()
7   loop_time = clock.split()
8   sleep(TARGET_TIME - loop_time)
9 end while
```

4.8.4 Drawing Strings

Note, for now, the DisplayManager only supports drawing a single character (like a Star '.'). Later, the DisplayManager will be extended to support drawing sprite frames. However, at this time, a practical exercise is to extended the DisplayManager to draw a string at a given (x,y) location. Specifically, it will be used for ViewObjects in Section 4.16 (page 211). More generally, a string drawing routine is useful for a game that wants to draw strings on the screen, such as for instructions or the player's name. Listing 4.83 shows the drawString() method prototype. The enumerated type enum Justification allows drawing the string to the left of the (x,y) position, centered on the (x,y) position or to the right of the (x,y) position.

Listing 4.83: DisplayManager extensions to support drawing strings

```
0  enum Justification {
1    LEFT_JUSTIFIED,
2    CENTER_JUSTIFIED,
3    RIGHT_JUSTIFIED,
4  };
5
6  ...
7
8  class DisplayManager : public Manager {
9
10   ...
11
12   // Draw string at window location (x,y) with default color.
13   // Justified left, center or right.
14   // Return 0 if ok, else -1.
15   int drawString(Vector pos, std::string str, Justification just,
16                  Color color) const;
17   ...
18 };
```

Listing 4.84 shows the code for drawString(). The opening switch statement determines the starting position for the string. If it is center justified, the starting position is moved to the left by one-half the length of the string. If it is right justified, the starting position

is moved to the left by the length of the string. If it is left justified no modifications to the starting position are made. This is the default (and is also the behavior if any invalid `Justification` value is given).

Once the starting position is determined, the `for` loop starting on line 21 writes out the string a character at a time, moving the x position over by one each time.

Listing 4.84: DisplayManager drawString()

```
0  // Draw string at window location (x,y) with color.
1  // Justified left, center or right.
2  // Return 0 if ok, else -1.
3  int DisplayManager::drawString(Vector pos, std::string str,
4                                 Justification just,
5                                 Color color) const
6    // Get starting position.
7    Vector starting_pos = pos
8    switch (just)
9    case CENTER_JUSTIFIED:
10     starting_pos.setX(pos.getX() - str.size()/2)
11     break
12   case RIGHT_JUSTIFIED:
13     starting_pos.setX(pos.getX() - str.size())
14     break
15   case LEFT_JUSTIFIED:
16   default:
17     break
18   end switch
19
20   // Draw string character by character.
21   for i = 0 to str.size()
22     Vector temp_pos(starting_pos.getX() + i, starting_pos.getY())
23     drawCh(temp_pos, str[i], color)
24   end for
25
26   // All is well.
27   return ok
```

4.8.5 Drawing in Layers

Up until now, there is no easy way to make sure one Object is drawn before another. For example, if the Saucer Shoot game from Section 3.3 was made, a Star could appear on top of the Hero. In order to provide layering control that allows the game programmer to explicitly determine which Objects are drawn on top of which, Dragonfly has an "altitude" feature. Objects at low altitude are drawn before Objects at higher altitude. Higher altitude Objects drawn in the same location "overwrite" the lower ones before the screen is refreshed. For example, in Saucer Shoot, Stars are always drawn at low altitude so that they will always appear to be behind all other Objects (e.g., Saucers and Bullets). Note that this feature is not a 3rd dimension – Dragonfly is still a 2d game engine – since layering is only used for drawing and not for moving and, more importantly, not for collisions. In other words, Objects can potentially collide with any Object, regardless of altitude.

In order to implement altitude, each game Object is given an altitude attribute and

methods allow for getting and setting the altitude, all shown in Listing 4.85. The method `setAltitude()` checks that the new altitude is within the supported range, 0 to the maximum supported. The maximum supported should be defined as `const int MAX_ALTITUDE` in `WorldManager.h` and set to 4. In the Object constructor, the initial altitude should be set to 1/2 of `MAX_ALTITUDE`.

Listing 4.85: Object class extensions to support altitude

```
private:
 int m_altitude;        // 0 to MAX supported (lower drawn first).

public:
 // Set altitude of Object, with checks for range [0, MAX_ALTITUDE].
 // Return 0 if ok, else -1.
 int setAltitude(int new_altitude);

 // Return altitude of Object.
 int getAltitude() const;
```

With the altitude attributes and methods in place, in the WorldManager `draw()` method, an outer loop is added to go through each of the altitudes, low to high, as shown in Listing 4.86. If the Object's altitude matches the loop iterator, it is drawn. Drawing from low to high means Objects at higher altitudes are drawn "on top" of Objects at lower altitudes.

Listing 4.86: WorldManager extensions to support altitude

```
// In draw()...
for alt = 0 to MAX_ALTITUDE

  // Normal iteration through all Objects.
  ...

    if all_objects[i] -> getAltitude() is alt then

      // Normal draw.
      ...

    end if

end for // Altitude outer loop.
```

While the looping method in Listing 4.86 is effective and simple (good attributes for most programs), it is not particularly efficient. Each object is drawn only once, just as it was before altitude was added. However, as specified by the outer loop, the WorldManager `draw()` method iterates through all Objects 5 times (0 to `MAX_ALTITUDE`). This can be fixed by storing the Objects according to their altitudes and fetching them only once. Such efficiency is a common feature of a scene graph and is addressed in the Dragonfly SceneGraph in Section 4.17.1 (page 228).

4.8.6 Colored Backgrounds (optional)

The default color scheme for Dragonfly has a black background. For some games – for example, a game of naval warfare on the high seas – a different color background, perhaps

blue, may be more appropriate. To add support for alternate background colors, the DisplayManager can be extended as shown in Listing 4.87. The extension includes a private attribute for the background is added as well as a method to set it.

Listing 4.87: DisplayManager extension to support background colors

```
private:
 sf::Color m_window_background_color; // Background window color.
 ...

public:
 // Set default background color.  Return true if ok, else false.
 bool setBackgroundColor(int new_color);
 ...
```

The `setBackgroundColor()` method maps the Dragonfly color, of type `Color` to the SFML color, of type `sf::Color`. The call to `clear()` in `swapBuffers()` is modified to pass in `m_window_background_color`.

Once in place, the game programmer can make a different colored background, say blue, by adding the call:

```
DM.setBackgroundColor(df::BLUE);
```

after starting up the game engine.

4.8.7 Development Checkpoint #5!

Continue with your Dragonfly development by extending your *Dragonfly Egg*[*] from Section 4.6, by adding functionality for managing graphics from Section 4.8. Steps:

1. Modify GameManager `run()` to provide step events as in Listing 4.68. Create a test game object that receives these events. Verify with logfile or game object output, counting the number of step events that should be received multiplied by the wall clock time (e.g., running for 30 seconds should yield 900 step events).

2. Create a DisplayManager derived class, inheriting from the Manager class. Implement DisplayManager as a singleton, described in Section 4.2.1 on page 54. Add `DisplayManager.cpp` to the project, and include stubs for all methods in Listing 4.75. Make sure the class (with stubs) compiles.

3. Write `startUp()` and `shutDown()` methods for the DisplayManager, referring to Listing 4.76 as needed. Implement `getWindow()` and then `swapBuffers()` based on Listing 4.79. Outside the GameManager, test that the DisplayManager can be started up, writing a character on the window using `getWindow()`, an `sf::Text` object and `draw()`, and then shut down.

[*] **Did you know (#6)?** There are about 5000 known species of dragonflies and damselflies, with an estimate of about 5500 and 6500 species in total. – "The Dragonfly Website", http://dragonflywebsite.com/faq.htm

4. Implement `getHorizontal()` and `getVertical()`. Test by starting the DisplayManager, making calls to `getHorizontal()` and `getVertical()` and writing them to the logfile. Verify the values reported correspond to the window size.

5. Implement `drawCh()` as in Listing 4.78. Verify that it works by replacing the drawing test code in the previous steps with calls to `drawCh()`. Once tested, implement `drawString()` which utilizes `drawCh()`. Test with a variety of strings and justifications.

6. Add the empty `draw()` method and create a game object derived from Object (e.g., a Star) with a `draw()` method that calls the DisplayManager `drawCh()`. Implement the `draw()` method in the WorldManager based on Listing 4.81. Modify the game loop in the GameManager to call the WorldManager `draw()` method and the DisplayManager `swapBuffers()`, as in Listing 4.82. Test that the custom game object is drawn properly as the game runs.

7. For implementing drawing in layers, add support for Object altitude, as in Listing 4.85. Extend the WorldManager to support altitude also, referring to Listing 4.86 as needed. Make an derived object (e.g., a Star) at a lower altitude than another derived object. Place the objects on top of each other and verify that the background object is obscured by the foreground object. Test several different layers at several different locations, along with an object that changes its altitude as the game runs. Verify that objects cannot set their altitude outside of the `[0, MAX_ALTITUDE]` range limits.

Tip 16! DisplayManager testing. In testing the DisplayManager to verify SFML is working properly, it can be helpful to isolate DisplayManager tests outside of the other engine components. For example, the test program in Listing 4.88 uses just the DisplayManager without the other Dragonfly components. When Listing 4.88 is successfully executed, it should pop up an SFML window, draw a green '`*`' at (10,5) for 2 seconds, then close the window. Note, as indicated, `sleep()` should be used if on Linux. **Warning!** This sample code will not work as intended on a Mac since the sleep call will block and the window will not be updated.

Listing 4.88: Testing the DisplayManager

```
#include <unistd.h> // If using Linux.

#include "DisplayManager.h"

// Warning!  This example doesn't work on a Mac.
int main() {
  DM.startUp();
  DM.drawCh(df::Vector({10,5}), '*', df::GREEN);
  DM.swapBuffers();
  Sleep(2000);  // Sleep for 2 seconds (use sleep(2) in Linux).
```

```
10    DM.shutDown();
11 }
```

At this point, you should now be able to actually see game objects in the window! This is an important milestone in development of an engine, and one that lets you develop and test by verifying object interactions visually. However, output to the logfile becomes even more important as writing debugging messages to window is more difficult.

4.9 Input Management

In order to get input from the player, a game could poll an input device directly. For example, for a platformer game on a PC, the code could check if the space bar was pressed and, if so, perform a "jump" action. The advantage of such a polling method is simplicity – the game code checks the input device right when it needs it and knows exactly what device to check. However, there are also significant disadvantages. First off, code to poll hardware devices is typically device dependent. If the device was swapped out, such as changing the keyboard for a joystick, the game would not work (at least, not without changing the game code and recompiling). Even with the same device, if the key was remapped, such as making the 'j' key execute a "jump" operation instead, then, again, the game code would need to be changed. Also, if there were supposed to be duplicate mappings for a single event, such as the left mouse button also being a "jump", then the code to do the polling (and maybe the jump action) would need to be duplicated.

The primary role of the game engine is to avoid such drawbacks by generalizing input from a variety of hardware-specific devices and code into general game code. The input flow generally goes as follows:

1. The player provides input via a specific device (e.g., a button press).
2. The game engine detects that input has occurred. The engine determines whether to process the input or ignore it (e.g., player input may be ignored during a cut-scene).
3. If input is to be processed, the data is decoded from the device. This may mean dealing with device-specific details (e.g., the degrees of rotation on an analog joystick).
4. The device-specific input is encoded into a more abstract, device-independent form suitable for the game.

After the above steps, all game objects that are interested in the input are notified – in Dragonfly, this means passing an input event to an Object using Manager `onEvent()`. The information in the input event depends upon the type. For example, a keyboard input needs the value of the key pressed while a mouse input needs the button type (left, right or middle) and the mouse (x,y) location.

4.9.1 Simple and Fast Multimedia Library – Input

While there are several options for getting user input, for Dragonfly, since the Simple and Fast Multimedia Library (SFML) is already used for graphical output (see Section 4.8.1 on page 110), it is also used for input. Specifically, SFML supports the ability to get keyboard input without waiting/blocking. In traditional keyboard input (e.g., `cin` or `scanf()`), a program waiting for input is blocked/suspended until the user presses the "enter" key. With SFML, the program can either be notified of a keypress event and/or the program can check if a particular key is being held down. SFML also supports mouse actions, tracking the current position of the mouse cursor and notifying when mouse buttons are pressed and released.

In order to use SFML input suitable for games, there are only two initial actions that need to be taken. SFML input events are provided for an SFML window, so such a window needs to be created (in Dragonfly, the window needed is created by the DisplayManager upon startup (see Listing 4.69 on page 110)). Also, by default, when a user holds down a key, after a small delay, the built-in "repeat" functionality of the keyboard will generate a log of keypress events. Since many games allow the user to hold down a key as an action (e.g., hold down arrow keys to move an avatar), it is useful to disable the repeat functionality, and can be done in SFML as shown in Listing 4.89.

Listing 4.89: SFML disable keyboard repeat

```
0 // Disable keyboard repeat.
1 p_window -> setKeyRepeatEnabled(false)
```

When disabled, a program only gets a single event when the key is pressed. To re-enable key repeat, `true` is passed into to `setKeyRepeatEnabled()`, enabling repeated KeyPressed events while keeping a key pressed.

Once initialized, SFML for game-type input proceeds first by using window input events, as shown in Listing 4.90. SFML provides event attributes through the `sf::Event` object, which is populated with the `pollEvent()` call. Each call to `pollEvent()` provides exactly one event, so to check all such events, it is placed inside a `while()` loop, as on line 1. The type of each event is checked through the `type` field. While SFML provides many window events, only some of them are useful for input – specifically, `sf::Event::KeyPressed`, `sf::Event::KeyReleased`, `sf::Event::MouseMoved`, and `sf::Event::MouseClicked`. When there is a `MouseClicked` event, the button can be checked for which mouse button is clicked, shown for the right mouse button on line 45. For the keyboard, the key that is pressed/released is in the SFML event `code`, and for the mouse, the button that pressed/released is in the SFML event `button`.

Listing 4.90: SFML input for games

```
0  // Loop, handling all events in window.
1  while (const std::optional<sf::Event> p_event = p_window -> pollEvent()) do
2
3    // Get event.
4    sf::Event e = p_event.value()
5
6    // Window closed?
7    if p_event -> is<sf::Event::Closed>() then
8      // Do close stuff.  e.g., set game over
9    end if
10
11   // Key was pressed?
12   if p_event -> is<sf::Event::KeyPressed>() then
13
14     // Setup as KeyPressed event.
15     sf::Event::KeyPressed *p_kb_event =
16         reinterpret_cast<sf::Event::KeyPressed *> (&e)
17
18     // Get SFML keyboard code.
19     sf::Keyboard::Key key
20     key = p_kb_event -> code
```

```
21
22      // Do other keypress stuff.
23    end if
24
25    // Key was released?
26    (similar to key pressed)
27    ...
28
29    // Mouse moved?
30    if p_event -> is<sf::Event::MouseMoved>() then
31
32      // Setup as MouseMoved event.
33      sf::Event::MouseMoved *p_mse_event =
34          reinterpret_cast<sf::Event::MouseMoved *> (&e)
35
36      // Get pixel location.
37      sf::Vector2i pixel_pos = p_mse_event -> position
38
39      // Do other mouse moved stuff.
40
41    fi
42
43    // Mouse clicked?
44    (similar to mouse moved, but also check buttons ...)
45      if p_mse_event -> button == sf::Mouse::Button::Right then
46        // Do mouse button stuff
47    ...
48
49  end while
```

4.9.1.1 SFML – Polled Input (optional)

While the code in Listing 4.90 provides all window based events, trying to move an avatar by pressing and holding a key using `sf::Event::KeyPressed` will not work since only one such event is provided – when the key is first pressed. Instead, SFML provides methods to directly check if a key or mouse button is currently pressed by polling it. This is illustrated in Listing 4.91. Note, this code is *outside* of the `while()` loop in Listing 4.90. Here, a specific key can be polled (e.g., `sf::Keyboard::Key::Left`) to see if it is currently being held down. Similarly, a specific mouse button can be polled (e.g., `sf::Mouse::Button:Left`) to see if it is currently being held down

Listing 4.91: SFML input – polling key/mouse pressed

```
0  // Key is pressed.
1  if sf::Keyboard::isKeyPressed(keycode) then
2    // Do key is pressed stuff.
3  end if
4
5  // Mouse button is pressed.
6  if sf::Mouse::isButtonPressed(button) then
7    // Do mouse is pressed stuff.
8  end if
```

4.9.2 The InputManager

The InputManager is a singleton derived from the Manager class, with private constructors and a `getInstance()` method to return the one and only instance (see Section 4.2.1 on page 54). The header file, including class definition, is provided in Listing 4.92.

The InputManager constructor should set the type of the Manager to "InputManager" (i.e., `setType("InputManager")` and initialize all attributes.

The `startUp()` method gets the display ready for input using SFML, as per Section 4.9.1. Similarly, the `shutDown()` method reverts to normal use. Finally, the method `getInput()` uses SFML to obtain keyboard and mouse input and is called by the GameManager once per game loop.

Listing 4.92: InputManager.h

```
#include "Manager.h"

class InputManager : public Manager {

 private:
  InputManager();                          // Private (a singleton).
  InputManager (InputManager const&);      // Don't allow copy.
  void operator=(InputManager const&);     // Don't allow assignment

 public:
  // Get the one and only instance of the InputManager.
  static InputManager &getInstance();

  // Get window ready to capture input.
  // Return 0 if ok, else return -1.
  int startUp();

  // Revert back to normal window mode.
  void shutDown();

  // Get input from the keyboard and mouse.
  // Pass event along to all Objects.
  void getInput() const;
};
```

For starting up, an SFML window needs to be created first. However, the InputManager does not do this – rather, the InputManager assumes this was done already by the DisplayManager. Thus, there is now a starting order dependency for the Dragonfly managers in that the DisplayManager must be started before the InputManager. The InputManager checks that the DisplayManager has successfully been started via a check to `isStarted()` – if it has not, then the InputManager does not start up successfully, either.

In general, the startup order for the Managers defined thus far should be:

1. LogManager
2. DisplayManager
3. InputManager

Remember, as described in Section 4.4.4, the game programmer instantiates (via `getInstance()`) and starts up (via `startUp()`) the GameManager, and the GameManager in its `startUp()` instantiates and starts up the other managers in the proper order. Only if they all start up successfully should the game manager report a successful startup.

In more detail, the InputManager `startUp()` method does the steps shown in Listing 4.93. First, the DisplayManager is checked to see if it has been started. If so, the SFML window (of type `sf::RenderWindow` is obtained from it. The window is used to disable key repeat. If everything succeeds, `Manager::startUp()` is called to indicate successful startup.

Listing 4.93: InputManager startUp()

```
// Get window ready to capture input.
// Return 0 if ok, else return -1.
int InputManager::startUp()

  if DisplayManager is not started then
    return error
  end if

  sf::RenderWindow window = DisplayManager getWindow()

  disable key repeat in window

  call Manager::startUp()
```

The InputManager `shutDown()` method re-enables key repeat and invokes Manager `shutDown()` to indicate the InputManager is no longer started.

Steps in the InputManager's `getInput()` method are provided in Listing 4.94 and are similar to those in Listing 4.90 (on page 128).

In the while loop, SFML window events are checked. If there are respective keyboard and/or mouse actions, a corresponding Dragonfly keyboard or mouse event is generated. To "send" the event to Objects, the `onEvent()` method is used. See Listing 4.67 on page 109 for a refresher on what it does. The keyboard and mouse events themselves are described in upcoming Section 4.9.2.1 and Section 4.9.2.2, respectively.

Listing 4.94: InputManager getInput()

```
// Get input from the keyboard and mouse.
// Pass event along to all Objects.
void InputManager::getInput() const

  // Check past window events.
  while event do

    if key press then

      create EventKeyboard (key and action)
      send EventKeyboard to all Objects

    else if key release then

      create EventKeyboard (key and action)
```

```
15        send EventKeyboard to all Objects
16
17      else if mouse moved then
18
19        create EventMouse (x, y and action)
20        send EventMouse to all Objects
21
22      else if mouse clicked then
23
24        create EventMouse (x, y and action)
25        send EventMouse to all Objects
26
27      end if
28
29    end while // Window events.
```

To use the InputManager, the GameManager adds a call to `getInput()` in the game loop (inside GameManager `run()`):

```
0   ...
1   // (Inside GameManager run())
2   // Get input.
3   InputManager getInput()
4   ...
```

4.9.2.1 Keyboard Event

Listing 4.95 provides the header file for the EventKeyboard class.

The top part of the header file defines two `enum` types.

The first, `enum EventKeyboardAction`, specifies the types of keyboard actions Dragonfly recognizes, namely: `KEY_PRESSED`, and `KEY_RELEASED`. The `UNDEFINED_KEYBOARD_ACTION` action is used for the default.

The second, `Keyboard::Key`, specifies the keys Dragonfly recognizes. It is placed inside its own namespace, `Keyboard`, for clarity. All major keys are recognized, with `UNDEFINED_KEY` used for the default. Note, the key types here are all Dragonfly attributes and not SFML (i.e., not `sf::Keyboard::Key`) in order to encapsulate the SFML code inside the engine. This way, game code that examines what keys are pressed is not dependent (nor even aware) of the underlying SFML. This would allow, say, a change in the input layer, say by replacing SFML with something else, without changing the game code.[15]

For the class body, as for all Dragonfly events, EventKeyboard is derived from the Event base class. It stores the keystroke in `key_val` and the keyboard action in `keyboard_action`. Each attribute has a pair of methods to get and set it. For example, the method `setKey()` takes on the value of the key based on what is pressed (typically only done by the InputManager), and the method `getKey()` is used by game code for retrieving the key value. The constructor sets `event_type` to `KEYBOARD_EVENT`, defined in the top of the header file.

[15] In fact, an earlier version of Dragonfly used Curses, a set of library functions that enable controlling text output in terminal windows.

Listing 4.95: EventKeyboard.h

```
#include "Event.h"

const std::string KEYBOARD_EVENT = "df::keyboard";

// Types of keyboard actions Dragonfly recognizes.
enum EventKeyboardAction {
  UNDEFINED_KEYBOARD_ACTION = -1, // Undefined.
  KEY_PRESSED,                    // Was down.
  KEY_RELEASED,                   // Was released.
};

// Keys Dragonfly recognizes.
namespace Keyboard {
enum Key {
  UNDEFINED_KEY = -1,
  SPACE, RETURN, ESCAPE, TAB, LEFTARROW, RIGHTARROW, UPARROW, DOWNARROW,
  PAUSE, MINUS, PLUS, TILDE, PERIOD, COMMA, SLASH, LEFTCONTROL,
  RIGHTCONTROL, LEFTSHIFT, RIGHTSHIFT, F1, F2, F3, F4, F5, F6, F7, F8,
  F9, F10, F11, F12, A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q,
  R, S, T, U, V, W, X, Y, Z, NUM1, NUM2, NUM3, NUM4, NUM5, NUM6, NUM7,
  NUM8, NUM9, NUM0,
};
} // end of namespace Keyboard

class EventKeyboard : public Event {

 private:
  Keyboard::Key m_key_val;                // Key value.
  EventKeyboardAction m_keyboard_action;  // Key action.

 public:
  EventKeyboard();

  // Set key in event.
  void setKey(Keyboard::Key new_key);

  // Get key from event.
  Keyboard::Key getKey() const;

  // Set keyboard event action.
  void setKeyboardAction(EventKeyboardAction new_action);

  // Get keyboard event action.
  EventKeyboardAction getKeyboardAction() const;
};
```

4.9.2.2 Mouse Event

Listing 4.96 provides the header file for the EventMouse class, also derived from the Event base class. Dragonfly only recognizes a fixed set of mouse actions and buttons, defined by `MouseAction` defined by `MouseButton`, respectively. Mouse actions recognized are `CLICKED` and `MOVED`, with `UNDEFINED_MOUSE_ACTION` being the default. Mouse buttons recognized are

LEFT, RIGHT, MIDDLE, with UNDEFINED_MOUSE_BUTTON being the default. As for EventKeyboard, the mouse buttons are Dragonfly attributes to encapsulate the SFML code inside the engine.

The mouse action is stored in the attribute mouse_action, the mouse button in mouse_button, and the (x,y) location in mouse_xy.

Methods are provided to get and set each attribute. The "set" methods are typically only used by the InputManager, while the "get" methods are used in the game code to retrieve values and act appropriately for the game. The EventMouse constructor sets event_type to MSE_EVENT.[16]

Listing 4.96: EventMouse.h

```
#include "Event.h"

const std::string MSE_EVENT = "df::mouse";

// Set of mouse actions recognized by Dragonfly.
enum EventMouseAction {
  UNDEFINED_MOUSE_ACTION = -1,
  CLICKED,
  MOVED,
};

// Set of mouse buttons recognized by Dragonfly.
namespace Mouse {
enum Button {
  UNDEFINED_MOUSE_BUTTON = -1,
  LEFT,
  RIGHT,
  MIDDLE,
};
} // end of namespace Mouse

class EventMouse : public Event {

 private:
  EventMouseAction m_mouse_action;  // Mouse action.
  Mouse::Button m_mouse_button;     // Mouse button.
  Vector m_mouse_xy;                // Mouse (x,y) coordinates.

 public:
  EventMouse();

  // Load mouse event's action.
  void setMouseAction(EventMouseAction new_mouse_action);

  // Get mouse event's action.
  EventMouseAction getMouseAction() const;

  // Set mouse event's button.
  void setMouseButton(Mouse::Button new_mouse_button);
```

[16] MSE_EVENT is used instead of MOUSE_EVENT since the latter can conflict with a macro if developing in Windows.

```
39
40    // Get mouse event's button.
41    Mouse::Button getMouseButton() const;
42
43    // Set mouse event's position.
44    void setMousePosition(Vector new_mouse_xy);
45
46    // Get mouse event's position.
47    Vector getMousePosition() const;
48 };
```

At this point, a view of complete version of the game loop is warranted, shown in Listing 4.97. Unlike in early versions of the game loop shown, code can be constructed for each game loop element based, as indicated in the comments.

Listing 4.97: The complete game loop

```
0  Clock clock                          // Section 4.4.3 on page 68.
1  while (game not over) do             // Line 11 of Listing 4.25 on page 72.
2    clock.delta()                      // Line 14 of Listing 4.20 on page 68.
3    GameManager onEvent(EventStep)     // Listing 4.67 on page 109.
4    InputManager getInput()            // Listing 4.94 on page 131.
5    WorldManager update()              // Listing 4.64 on page 103.
6    WorldManager draw()                // Listing 4.81 on page 120.
7    DisplayManager swapBuffers()       // Listing 4.79 on page 119.
8    loop_time = clock.split()          // Line 19 of Listing 4.20 on page 68.
9    sleep(TARGET_TIME - loop_time)     // Listings 4.21 and 4.22 on page 69+.
10 end while
```

4.9.3 Development Checkpoint #6!

Continue with Dragonfly development by adding functionality for managing input from Section 4.9. Steps:

1. Create an InputManager derived class, inheriting from the Manager class. Implement InputManager as a singleton, described in Section 4.2.1 on page 54. Add `InputManager.cpp` to the project and include stubs for all methods in Listing 4.92. Make sure the class, with stubs, compiles.

2. Write `startUp()` and `shutDown()` methods for the InputManager, referring to Listing 4.93 as needed. Write a small test program (with only an InputManager and DisplayManager) that verifies the InputManager can only start successfully when the DisplayManager is started first.

3. Create EventKeyboard and EventMouse classes, referring to Sections 4.9.2.1 and 4.9.2.2, as needed. Add `EventKeyboard.cpp` and `EventMouse.cpp` to the project and stub out each method so it compiles. Verify both classes can get and set all values in a stand alone program (running outside of the other engine components).

4. Implement InputManager `getInput()`, referring to Listing 4.94 for the structure and Listing 4.90 for the SFML code, as appropriate. First, get `getInput()` implemented

and tested with one key (e.g., the letter '`A`') and then one mouse button. Once that is working properly, continue implementation for all keys and all mouse buttons.

5. Test the InputManager `getInput()` outside of a running game loop creating a program that starts the DisplayManager and the InputManager, then repeatedly calls `getInput()`, writing the return values to the logfile. This can be tested extensively with different mouse and keyboard inputs.

6. Integrate the InputManager with the GameManager by having the GameManager start up the InputManager in the proper order. Write a game object that takes input from the keyboard, responds to input by changing position and have that change in position be visible on the screen.

Tip 17! Reticle for testing mouse input. The Reticle from the Saucer Shoot tutorial (Chapter 3) is a good game object to use as a start for testing mouse input. You can copy the `Reticle.cpp` and `Reticle.h` code from that project and test your newly-implemented Input Manager once integrated with the engine. (Note, you'll need to remove the `registerInterest()` call from the Reticle constructor unless and until you implement filtering of events, Section 4.15 on page 201.) The "game" can just be a `new Reticle` and the player should be see a `+` character moving around the screen with the mouse. Add handling of mouse button presses in the Reticle `eventHandler()`, writing a message to the LogManager or changing the Reticle color.

At this point, the engine should now be able to get input from a player and have game objects respond to the input! This means, coupled with the DisplayManager, the engine supports game objects a player can move (e.g., via the arrow keys or the mouse) around the screen. This closes the interaction loop, taking user input, updating the game world, and displaying the resulting output – basic interaction!

4.10 Kinematics

Kinematics is the physics that describes the motion of objects without taking into account forces or masses. In relation to our engine, up until now, moving an object has to be done in game code with the game programmer writing code to move an game object each step event. For example, if a Saucer needs to move, say 1 space to the left every 4 steps (0.25 spaces per step), when the Saucer receives the step event in the `eventHandler()`, it moves, as in Listing 4.98.

Listing 4.98: Saucer movement without velocity support

```
// Move 0.25 spaces per step.
int Saucer::eventHandler(const df::Event *p_e) override {
  if (p_e->getType() == df::STEP_EVENT) {
    df::Vector pos = getPosition();
    pos.setX(pos.getX() - 0.25);
    setPosition(pos);
    return 1; // Event handled.
  }
  return 0; // Event not handled.
}
```

While this can work, all of it can be tedious for a game programmer and prone to errors. Fortunately, a significant service provided by most game engines, including Dragonfly, is moving game objects automatically, in the right direction at the right speed. This allows a game programmer to provide a game object with a velocity and have the object move an appropriate amount in an appropriate direction each game step.

To support this, Object is extended with additional attributes for velocity, shown in Listing 4.99 – namely `m_direction` as a vector and `m_speed` as a float, initialized to `(0,0)` and `0`, respectively, in the Object constructor. They can be set by normal getters and setters.

Listing 4.99: Object extensions to support kinematics

```
 private:
  Vector m_direction;  // Direction vector.
  float m_speed;       // Object speed in direction.

 public:
  // Set speed of Object.
  void setSpeed(float speed);

  // Get speed of Object.
  float getSpeed() const;

  // Set direction of Object.
  void setDirection(Vector new_direction);

  // Get direction of Object.
  Vector getDirection() const;

  // Set direction and speed of Object.
  void setVelocity(Vector new_velocity);
```

```
19
20   // Get velocity of Object based on direction and speed.
21   Vector getVelocity() const;
22
23   // Predict Object position based on speed and direction.
24   // Return predicted position.
25   Vector predictPosition()
```

In addition, getting and setting the Object velocity is done via `getVelocity()` and `setVelocity()`, respectively, which use Vector operations `scale()` and `normalize()` (see Listing 4.28 on page 76 and Listing 4.29 on page 77), as appropriate. Specifically: a) speed is just the magnitude of the velocity, a float, b) direction is the normalized velocity, a vector, and c) velocity is the direction scaled by the speed. So, with the developed Vector methods:

```
0   speed = velocity.getMagnitude()
1   direction = velocity.normalize()
2   velocity = direction.scale(speed)
```

The real magic happens in an Object support method – one that computes where an Object will be after a game loop's worth of velocity is added, but without actually moving it. This method, called `predictPosition()`, is shown in Listing 4.100. Basically, it indicates where an Object will be after it moves given the speed and direction attributes (i.e., the velocity)*.

Listing 4.100: Object predictPosition()

```
0  // Predict Object position based on speed and direction.
1  // Return predicted position.
2  Vector Object::predictPosition()
3
4    // Add velocity to position.
5    Vector new_pos = m_position + getVelocity()
6
7    // Return new position.
8    return new_pos
```

Once support for velocities is in the Object class, the WorldManager needs to be updated to use it. This is done by adding functionality to the `update()` method (see Section 4.5.6.2 on page 103). Listing 4.101 shows the necessary pseudo code.

Listing 4.101: WorldManager extensions to update() to support kinematics

```
0    // Update Object positions based on their velocities.
1
2    // Iterate through all Objects.
3    for i = 0 to m_updates count
4
5      // Add velocity to position.
6      Vector new_pos = m_updates[i] -> predictPosition()
7
8      // If Object should change position, then move.
```

* **Did you know (#7)?** Much like humans, dragonflies use predictive models to intercept prey. – David Shultz. "Watch: A Dragonfly Predicts the Movements of Its Prey", *Science Magazine*, December 10, 2014.

```
    if new_pos != getPosition() then
      moveObject() to new_pos
    end if

  end for // End iterate.
  ...
```

Basically, `update()` iterates through all Objects. For each, it calls `predictPosition()` to check if the Object should move or not. If so, it moves the object by calling `moveObject()`. The functionality inside `moveObject()` is discussed in the next section, Section 4.10.1.

Using velocity support in Dragonfly for the game programmer is easy. Instead of a game object having to move itself by handling every step event in the `eventHandler()` and determining when and where to move, the game programmer can just set the speed and direction for game objects (derived from the Object class, of course). For example, for a Saucer traveling right to left across the screen, the programmer sets the speed and direction (or setting the velocity) of the Object, as in Listing 4.102. There is no longer a need for a game object to handle the step event for moving.

Listing 4.102: Saucer movement with velocity support

```
// Set movement left 1 space left every 4 frames.
setSpeed(0.25);
setDirection(df::Vector(-1.0, 0));

// Note: the above two lines are equivalent to:
setVelocity(df::Vector(-0.25, 0));
```

Newtonian Mechanics Physics (optional) Velocity support is complete, but could be enhanced. Possible options could extend the velocity support to include a acceleration component (another `Vector`) for each game object. With acceleration, a game object's velocity would change slightly (it would accelerate or decelerate according to the direction) each step. This could be especially useful for providing, say, gravity pulling an avatar down (a fixed acceleration in the vertical direction) for a platformer game.

While the kinematics in Dragonfly provides support for a lot of games, additional classical Newtonian physics mechanics include forces and masses. In fact, while acceleration can simply be added to objects as mentioned in the previous paragraph, in the real world it is achieved through application of a force on an object through the equation:

$$F = m \cdot a$$

where F is the applied force, m is the object mass and a is the acceleration. Adding a mass attribute to game objects would be a first step to using forces as a precursor so acceleration and velocity.

And that is really just the tip of the iceberg. More advanced physics techniques that could be incorporated into Dragonfly include elastic and non-elastic collisions, rigid body, soft body and ragdoll simulation, joints as constraints, and more. The aspiring programmer is encouraged to check out one of the many books on physics for game engines, such as the *Game Physics Engine Development* by Ian Millington [6].

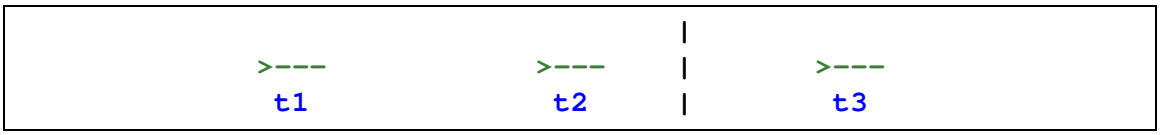
4.10.1 Collisions

A closely related service to moving a game object is detecting when two or more game objects collide and, when they do, triggering object responses as appropriate. However, determining when objects collide is not as easy as it may seem:

- Geometries of objects can be complex – square or circular objects are efficient in terms of computing area (or volume, if 3d) and locations in the game world, but more complex objects, for example humanoids and trees, take many more computations to compute exact locations in the game world.
- Objects can be moving fast – objects that move great distances mean there is a larger area (or volume, if 3d) from the old position to the new position that may result in potential collisions.
- There can be many objects – the more objects there are, the more opportunities there are for collisions and the more computations the game engine needs to do each step to determine if objects collide. A naïve solution could take $O(n^2)$, meaning every object (all n of them) is checked for a collision with every other object, so $n \times n$ comparisons are made each step.

There are many possibilities when it comes how to implement to collision detection. Dragonfly uses what is perhaps the most commonly used technique for games – *overlap testing*. Overlap testing is relatively easy, both conceptually (for the game programmer as well as the game engine programmer) and in terms of implementation. However, it may exhibit more errors than some other forms of collision. Basically, with overlap testing, when an game object moves, the engine checks whether or not its area (or volume, if 3d) overlaps that of any other object. If so, there has been a collision. If not, then the object can move unimpeded. When a collision has occurred, both game objects get notified of the event.

Despite the advantages (simplicity and speed of execution), overlap testing can fail when game objects move too fast relative to their size. Consider the game example below where an arrow is fired at a window. The arrow has a velocity of 15, meaning it moves 15 spaces horizontally each step.



At time $t1$, the arrow (>---), moving left to right, approaches the window (|). One step later, at time $t2$, the arrow's velocity moves it 15 spaces to the right and a collision seems imminent. However, there is not yet an overlap between the arrow and the glass, so no collision is detected. At time $t3$, the arrow's velocity carries it another 15 spaces to the right, past the window and as there is still no overlap, no collision is detected. Effectively, the arrow appears to have gone right through the glass window with breaking it (or even hitting it)!

There are several possible solutions to this problem. A game programmer, knowing that the engine is using overlap testing, can put a constraint on game object sizes and speeds

such that the fastest object moves slow enough (per step) to overlap with the thinnest object. For the example above, the window would need to be 13 spaces thick, the arrow would need to be 13 spaces long, or the arrow would need to only move 3 spaces per step, or some combination of the above. While this would ensure the arrow would always hit the window, it might not be practical for all games (e.g., the arrow speed might be too slow for other uses and/or the window too thick for the environment).

Another solution is to reduce the step size. The step size dictates how often the game world is updated. Game programmers want aspects such as the speed of an object to be relative to real time in terms of how fast the player sees the arrow move across the window, and not relative to the game step. This means, for example, that a velocity of 1 with a step frequency of 30 f/s moves 30 spaces per second. If the frequency was doubled, to 60 f/s, then the game programmer would want to adjust the velocity to be 0.5 so the player still sees the object move 30 spaces per second. What this will do, however, is make the object move fewer spaces each step, making it less likely for overlap testing to fail. However, this comes at a cost – namely, increased computation as the game loop runs more often (in this example, twice as often), possibly leading to the engine not being able to keep up with the update rate. *

A more complex solution (incidentally, *not* supported by Dragonfly) is to have a different step size for different objects. Thus, fast objects and/or small objects would be updated more frequently than slow objects. This adds complexity and computation overhead in the update step, as well, but could be applied selectively.

The overlap test itself is fairly easy to compute with simple volumes, like circles (or spheres, if 3d). More complex volumes can require more computation. For example, a humanoid-shaped object and a tree-shaped object may be made up of hundreds or even thousands of smaller polygons. If every polygon in an object needs to be tested for overlap with the polygons of every other object to determine if the objects collide, this scales $O(n^2)$ for n polygons per object.

To overcome this, complex geometries are often simplified in order to reduce the number of comparisons needed. Rather than doing this simplification in the model itself (which can compromise how it looks), each object can instead be given a bounding volume that approximates the object. For example, the humanoid-shaped object or a tree can be approximated by an ellipsoid. For a depiction of this last case, consider the brown, ASCII tree in Figure 4.3. Computing whether a single character collides with this tree would involve checking all the nooks and crannies of the branches – effectively examining every character in the tree for a collision as if each character was a separate object. Instead, the entire tree can be bound by a simpler shape for computing collisions – in this case, an ellipse, shown by the dashed oval surrounding the tree. Determining if another object collides with this tree is now much simpler, merely computing if it intersects the ellipse. It might be noted that the oval itself does not fully encompass the tree – some of the branches are poking out. This would mean that an object could hit those external branches and not collide with the tree. For many games, this might be just fine and could be preferred over drawing a bigger ellipse.

* **Did you know (#8)?** Adult dragonflies have 6 legs but cannot walk. – "30,000 Facets Give Dragonflies a Different Perspective: The Big Compound Eye in the Sky", *ScienceBlogs*, July 8, 2009.

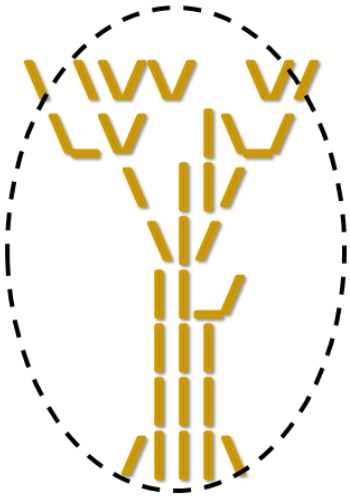


Figure 4.3: Object with bounding ellipse

Commonly used bounding volumes are circles (or spheres, if 3d) where an overlap test compares the distances between the centers with the sum of the radii. Another common bounding volume is a rectangular box, or a *bounding box*.[17] In Dragonfly, each Object has a bounding box encompassing the game object, representing the Object with a simplified geometry.

In Dragonfly, if the edges of any two boxes overlap, there is a collision. A optional refinement could be to provide an game programmer option for precise collision testing. In this case, the bounding boxes would be tested for overlap normally. If there was an overlap, then a more refined test could be done to see if the individual characters in the object sprite overlapped, indicating a collision. Depicting this, consider the two objects in Figure 4.4 on the left. The Saucer and the Hero ship are clearly not touching – boxes around each do not intersect. However, a short time later, the game world state may be as on the right. Here, the boxes do overlap. Under normal Dragonfly operation, this overlap itself would indicate a collision. However, looking more closely, the characters themselves do not overlap. So, an alternative option could be that if the boxes overlap, then more precise consideration of each character is done to see if there is, in fact, a collision.

Once a collision is detected, action is taken to resolve the collision. What the actions are, exactly, often depends upon what the game objects are. For example, if two billiard balls collide, then computation as to where, exactly they hit is done first, followed by computation of new velocities for both balls, accompanied by playing a "clinking" sound. As another example, if a rocket slams into a rock wall, the rocket is destroyed, the wall takes on a charred texture and an explosion animation object is created. As a third example, a character walks through an invisible wall, a magic, propagating ripple effect is triggered, but no velocities or other impacts are recorded.

In Dragonfly, the engine detects collisions through overlap testing of bounding boxes,

[17] Bounding boxes are also known as *hitboxes* since they are used to determine if an object is "hit".

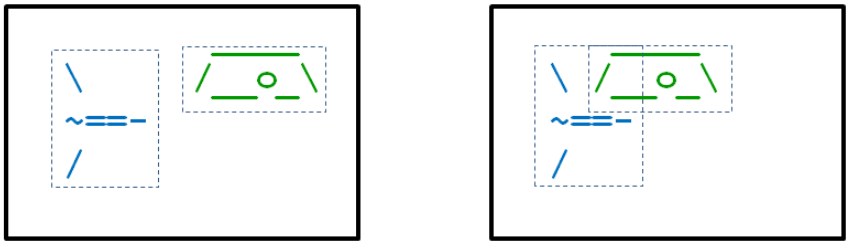


Figure 4.4: Refined collision detection with boxes

then provides a collision event to both Objects involved in the collision. Resolution involves sending the collision event to both Objects. The Objects themselves receive the event in their `eventHandler()` methods and can react appropriately.

4.10.1.1 Collidable Entities

However, not all Objects are collidable entities. Consider display elements on the screen, such as player score or indication of time left. In most cases, these objects do not collide with, say, the player avatar. Similarly, background objects that provide scenery, such as the Stars in Saucer Shoot (Section 3.3), do not collide with other game elements. To support this, Dragonfly has a notion of "solidness", with three states defined via an `enum`, as in Listing 4.103. This `enum` is defined in `Object.h`.

Listing 4.103: Solidness states

```
0 enum Solidness {
1   HARD,     // Object causes collisions and impedes.
2   SOFT,     // Object causes collisions, but doesn't impede.
3   SPECTRAL, // Object doesn't cause collisions.
4 };
```

Collisions only happen between solid Objects – Objects that are `SPECTRAL` cannot collide. So, for example, Saucer Shoot's Stars are `SPECTRAL` and not solid. Solid Objects are either `HARD` or `SOFT`. A `HARD` object cannot occupy the same space as another other `HARD` Object, but any number of `SOFT` Objects can occupy a space, with our without at most one `HARD` Object.

In addition to notifying colliding solid (`HARD` or `SOFT`) Objects of the event, resolution then disallows two `HARD` objects to occupy the same space. Basically, if a first solid Object moves onto (collides with) a second `HARD` Object, the first object is moved back to its original location – the collision still happens, but the movement does not take place.

The Object class extensions needed to support solidness are shown in Listing 4.104. The attribute `solidness` determines if the Object is treated as solid (`HARD` or `SOFT`) or non-solid (`SPECTRAL`). By default, Objects should be `HARD` (set in the Object constructor). The method `isSolid()` provides a convenient boolean test for whether or not the Object is solid. Methods to get and set the solidness are provided in `getSolidness()` and `setSolidness()`, respectively. For `setSolidness()`, if the new value passed in is one of `HARD`, `SOFT` or

SPECTRAL then 0 is returned and the solidness is changed, otherwise -1 is returned and the solidness is unchanged.

Listing 4.104: Object class extensions to support solidness

```
private:
  Solidness m_solidness; // Solidness of object.

public:
  bool isSolid() const; // True if HARD or SOFT, else false.

  // Set object solidness, with checks for consistency.
  // Return 0 if ok, else -1.
  int setSolidness(Solidness new_solid);

  // Return object solidness.
  Solidness getSolidness() const;
```

4.10.1.2 Collision Event

When Dragonfly detects a collision, it sends a collision event to each Object involved. Listing 4.105 provides the header file for the EventCollision class, derived from the Event class (Listing 4.51 on page 95). Like other event classes, the EventCollision is a "container" and does not have any significant functionality itself. The attributes store information about the collision: m_pos stores the position where the collision occurred; m_p_obj1 is a pointer to the Object moving, the one causing collision; and m_p_obj2 is a pointer to the Object being collided with. Methods are provided to get and set each of the attributes.

Listing 4.105: EventCollision.h

```
#include "Event.h"
#include "Object.h"

const std::string COLLISION_EVENT = "df::collision";

class EventCollision : public Event {

 private:
  Vector m_pos;     // Where collision occurred.
  Object *m_p_obj1; // Object moving, causing collision.
  Object *m_p_obj2; // Object being collided with.

 public:
  // Create collision event at (0,0) with o1 and o2 NULL.
  EventCollision();

  // Create collision event between o1 and o2 at position p.
  // Object o1 'caused' collision by moving into object o2.
  EventCollision(Object *p_o1, Object *p_o2, Vector p);

  // Set object that caused collision.
  void setObject1(Object *p_new_o1);

  // Return object that caused collision.
```

```
24    Object *getObject1() const;
25
26    // Set object that was collided with.
27    void setObject2(Object *p_new_o2);
28
29    // Return object that was collided with.
30    Object *getObject2() const;
31
32    // Set position of collision.
33    void setPosition(Vector new_pos);
34
35    // Return position of collision.
36    Vector getPosition() const;
37 };
```

4.10.1.3 Collisions in the WorldMananger

Dragonfly handles collisions inside the WorldManager. In order to do this, the WorldManager needs to be extended with several methods.

The first method is `getCollisions()` which tests whether or not an Object moving to a given location has a collision there. If so, all Objects at that location are returned in an ObjectList (there can be more than one Object at a location since multiple `SOFT` Objects can occupy the same location, with up to one `HARD` Object).

The second method is `moveObject()` that moves an Object to another location, as long as there is not a collision between two `HARD` Objects at this location.

Listing 4.106: WorldManager extensions for collision support

```
0  public:
1    // Return list of Objects collided with at position 'where'.
2    // Collisions only with solid Objects.
3    // Does not consider if p_o is solid or not.
4    ObjectList getCollisions(const Object *p_o, Vector where);
5
6    // Move Object.
7    // If collision with solid, send collision events.
8    // If no collision with solid, move ok else don't move Object.
9    // If Object is Spectral, move ok.
10   // Return 0 if move ok, else -1 if collision with solid.
11    int moveObject(Object *p_o, Vector where);
```

An additional utility function (in `utility.h` and `utility.cpp`) called `positionsIntersect()` is helpful for the WorldManager `getCollisions()` method, as shown in Listing 4.107. Basically, if two Positions are the same (their x coordinates are within 1 space of each other *and* their y coordinates are within 1 space of each other) then the method returns `true`, otherwise it returns `false`. This method may seem somewhat trivial, but it serves as a placeholder for a method introduced in Section 4.151 on page 180, `boxIntersectsBox()`, that will test whether or not two bounding boxes overlap.

Listing 4.107: Utility positionsIntersect()

```
0 // Return true if two positions intersect, else false.
```

```
bool positionsIntersect(Vector p1, Vector p2)
  if abs(p1.getX() - p2.getX()) <= 1 and
     abs(p1.getY() - p2.getY()) <= 1 then
    return true
  else
    return false
  end if
```

The WorldManager `getCollisions()` method is provided in Listing 4.108. Since the method returns a list of all Objects that are collided with, line 6 creates an empty list (`collision_list`) to start. The next block of code iterates through all the Objects in the game. Each Object is first checked if it is the same Object passed into `getCollisions()` – if it is, it is ignored since an Object cannot collide with itself. If it is not, then the Object is checked to see if it is at the same location, and that it is solid. If both of these are true, the Object is added to the `collision_list`. When the loop is finished, the list of all Objects collided with are returned in `collision_list`. Note, if no Objects have been collided with, `collision_list` is an empty list.

Listing 4.108: WorldManager getCollisions()

```
0  // Return list of Objects collided with at position 'where'.
1  // Collisions only with solid Objects.
2  // Does not consider if p_o is solid or not.
3  ObjectList getCollisions(const Object *p_o, Vector where)
4
5    // Make empty list.
6    ObjectList collision_list
7
8    // Iterate through all Objects.
9
10   for i = 0 to m_updates count
11
12     Object *p_temp_o = m_updates[i]
13
14     if p_temp_o is not p_o then  // Do not consider self.
15
16       // Same location and both solid?
17       if positionsIntersect(p_temp_o->getPosition(), where)
18          and p_temp_o -> isSolid() then
19
20         add p_temp_o to collision_list
21
22       end if // No solid collision.
23
24     end if // Not self.
25
26   end for // End iterate.
27
28   return collision_list
```

The `getCollisions()` method is used in the `moveObject()` method, shown in Listing 4.109. The `moveObject()` method first checks if the calling Object (the one that wants to be moved) is solid (calling `isSolid()`) – if not, there are no further checks needed and the Object can move. If the Object is solid, `getCollisions()` is called to produce a list

of solid Objects collided with. That collision list is iterated through,[18] and each Object is sent a collision event starting at line 23. If both Objects are HARD (line 31), then the move will not be allowed by setting do_move to false in line 32. If a move is allowed (no HARD collisions), then the actual move happens at the end of the method, on line 47.

Listing 4.109: WorldManager moveObject()

```
0  // Move Object.
1  // If collision with solid, send collision events.
2  // If no collision with solid, move ok.
3  // If all collided objects soft, move ok.
4  // If Object is spectral, move ok.
5  // If move ok, move.
6  // Return 0 if moved, else -1 if collision with solid.
7  int WorldManager::moveObject(Object *p_o, Vector where)
8
9    if p_o -> isSolid() then // Need to be solid for collisions.
10
11     // Get collisions.
12     ObjectList list = getCollisions(p_o, where)
13
14     if not list.isEmpty() then
15
16       boolean do_move = true  // Assume can move.
17
18       // Iterate over list.
19       for i = 0 to list count
20
21         Object *p_temp_o = list[i]
22
23         // Create collision event.
24         EventCollision c(p_o, p_temp_o, where)
25
26         // Send to both objects.
27         p_o -> eventHandler(&c)
28         p_temp_o -> eventHandler(&c)
29
30         // If both HARD, then cannot move.
31         if p_o is HARD and p_temp_o is HARD then
32           do_move = false  // Can't move.
33
34         end if
35
36       end for // End iterate.
37
38       if do_move is false then
39         return -1 // Move not allowed.
40       end if
41
42     end if // No collision.
43
44   end if // Object not solid.
45
```

[18] Note, if the collision list is empty, the iteration loop immediately ends since there is nothing to collide with.

```
46   // If here, no collision between two HARD objects so allow move.
47   p_o -> setPosition(where)
48
49   // All is well.
50   return ok // Move was ok.
```

Disallow Movement onto Soft Objects (optional) The construct of soft Objects allows many solid objects to reside in one location (if they are `SOFT`). This allows a solid Object to move onto a group of soft objects, generating collisions for each one in the process.

However, a game programmer may not want to allow some Objects to move onto the soft Objects. Dragonfly can be extended to support this functionality, first by adding an additional attribute to the Object class, shown in Listing 4.110, along with basic functions to get and set the attribute. If the attribute `m_no_soft` is `true` (it should default to `false`), the Object is not allowed to move onto soft game objects (but will still generate collisions – effectively, soft game objects are treated as hard game objects in this case).

Listing 4.110: Object class extensions to support no soft

```
0  private:
1    bool m_no_soft;    // True if won't move onto soft objects.
2
3  public:
4    // Set 'no soft' setting (true - cannot move onto SOFT Objects).
5    void setNoSoft(bool new_no_soft=true);
6
7    // Get 'no soft' setting (true - cannot move onto SOFT Objects).
8    bool getNoSoft() const;
```

Then, the WorldManager `moveObject()` method is refactored. In Listing 32 on page 147, similar to the block of code around line 32 that indicates the Object should not move if both Objects are solid, an additional check is made if the Object being moved is soft and the Objects are soft. This is shown in Listing 4.111.

Listing 4.111: WorldManager extensions to moveObject() to support no soft

```
0   ...
1   // If object does not want to move onto soft objects, don't move.
2   if p_o->getNoSoft() and p_temp_o->getSolidness() is SOFT then
3     do_move = false
4   end if
5   ...
```

4.10.1.4 World Boundaries – Out of Bounds Event

Generally, game objects expect to stay inside the game world. This is not to say that all game objects are on the *screen* at the same time – for example, think of a side scroller where a lot of the level is off the screen – but game objects stay in the known game world. As such, when a game object moves outside of the game world it is helpful to tell indicate this via an event. The out of bounds object still has the option to ignore the event and stay outside the game world, but in many cases, it will want to take action, such as moving

back inside the game world or, in the case of a bullet that would otherwise fly off forever, destroy itself.

Specifically for Dragonfly, when an Object inside the game world moves outside the game world, the WorldManager generates an out of bounds event, an EventOut. The move is still allowed, giving the Object freedom to stay outside of the game world should it so choose, but providing the information in the form of the event in case the Object wants to act.

Listing 4.112 provides the header file for the EventOut class. As for all Dragonfly events, EventOut is derived from the base Event class. Unlike some other events, EventOut only has information that the event occurred – i.e., that the object moved from inside to outside the game world. The Object itself already knows where (it has its (x,y) position) so that does not need to be indicated. The constructor sets `event_type` to `OUT_EVENT`. There are no other attributes and no additional methods – the game programmer merely needs to consult the Event type (defined in the parent class, `Event::getType()`) to determine what happened.

Listing 4.112: EventOut.h

```
0 #include "Event.h"
1
2 const std::string OUT_EVENT = "df::out";
3
4 class EventOut : public Event {
5
6  public:
7   EventOut();
8 };
```

As suggested above, game world boundaries can be different than window boundaries – this functionality is supported by Dragonfly in subsequent development (see Section 4.13.4 on page 184). However, at this point in Dragonfly, the game world boundaries are determined by the window boundaries. In order to determine the boundaries of the world, the DisplayManager routines `getHorizontal()` and `getVertical()` can be used.

The WorldManager `moveObject()` is extended slightly. After a move is allowed (line 47 in Listing 4.109), the Object's position is checked against the horizontal and vertical limits obtained from the DisplayManager. If the Object is out of bounds, an EventOut object is generated and sent to the Object's event handler as in Listing 4.113.

Listing 4.113: Generate and send EventOut

```
0   ...
1   // Generate out of bounds event and send to Object.
2   EventOut ov
3   p_o -> eventHandler(&ov)
4   ...
```

Note, the WorldManager only sends an EventOut once, when the Object first moves from inside to outside the game world. If the Object moves outside then stays outside, no additional events are generated. Presumably, the Object already knows it is outside the game world upon receiving the first out event, so if it stays outside it does not need to be reminded.

4.10.2 Program Flow for Moving Objects

We can step back and summarize from a high level the program flow that goes into moving game Objects, depicted in Listing 4.114.

Listing 4.114: Program Flow for Moving Objects

```
GM.run()
  ...
  WM update()
    Object predictPosition()
      new_pos += velocity
    moveObject()
    getCollisions()
    // Send any needed collision events.
    if can_move then
      Object setPosition(new_pos)
    end
    // Send any needed out of bounds events.
  ...
  ...
```

Inside the game loop, the game manager calls WorldManager `update()`. For each Object, the world manager asks each Object to predict its position by calling Object `predictPosition()`, which computes the predicted position by adding the Object's velocity to the current position. The world manager then calls `moveObject()` calls `getCollisions()` to get a list of any collisions that would result if the Object moved to the predicted position. The world manager then sends a collision event (EVentCollision) to any and all Objects in that list. If the Object can actually move to the predicted position (i.e., there are not two `HARD` Objects in the same location), the world manager actually changes the Object's position by calling `setPosition()`. Lastly, the world manager computes if the Object was inside the game world and then went out and, if so, sends it an out of bounds event (EventOut).

4.11 Development Checkpoint #7 – Dragonfly Naiad!

Continue with your Dragonfly development by adding to your code base to create a *Dragonfly Naiad*.* Steps:

1. Extend the Object class to support kinematics, as in Listing 4.99. Add code to Object to predict the position if it applies a step of velocity, as in Listing 4.100. Add extensions to `update()` to do the velocity step for all Objects, as in Listing 4.101.

2. Test the velocity code thoroughly by making Objects with different starting locations and different velocities. Verify visually and via logfile messages that Objects move an appropriate amount each step. Test with different velocity values (x and y), positive and negative and greater than 1 and less than 1.

* **Did you know (#9)?** A *naiad* is a dragonfly in larval stage.

3. Extend the WorldManager to support collisions, as in Listing 4.106. Implement support function `positionsIntersect()` in `utility.cpp`, as per Listing 4.107. Implement `getCollisions()` in the WorldManager based on Listing 4.108. Support for solidness needs to be added to the Object class, based on Listing 4.104 and Listing 4.103. Lastly, write `moveObject()` based on Listing 4.109. EventCollision needs to be created for this, following Listing 4.105, and can be tested outside of the game engine before using it in `moveObject()`. Since the code for all the above is fairly extensive, add liberal `writeLog()` statements to provide meaningful output to verify it is working.

4. Write numerous test cases to verify that collisions work properly. Start first with a solid Object that attempts to move onto another solid Object. Verify the move is not allowed (visually and in the logfile) and make sure both Objects get an event with appropriate pointers. Next, test that soft Objects can move on each other, but that all soft Objects colliding get collision events. Lastly, check with test examples that spectral Objects do not generate collisions.

5. Create an EventOut class based on Listing 4.112. Add `EventOut.cpp` to the project and stub out each method so it compiles. Add code to the WorldManager `moveObject()` method that sends the out of bounds event to objects that move out of the game world. Refer to Listing 4.113, as needed.

6. Test the out of bounds additions by making a game object that starts inside the game world, but soon moves out. Output messages should be seen in the logfile, but events should checked and handled by the Object `eventHandler()` method. Make different Objects that move in and out, multiple times and verify only one EventOut message is generated each time an Object moves from inside to outside.

After completing the above steps (and all the previous Development Checkpoints), you will have a fully functional game engine!

Features include:

- Objects can draw themselves in 2d, as colored text characters.
- Objects can appear above (foreground) or behind (background) when drawing.
- Objects can get input from the keyboard and mouse.
- Objects are moved automatically based on their velocities.
- Objects that move out of the game world get an "out of bounds" event.
- Objects have solidness – soft, hard, or spectral – affecting movement and collisions.
- Solid Objects that collide get a collision event, providing information on both Objects enabling them to react appropriately.

The above functionality to support objects, graphics, input, and interaction with collisions allows creation of a wide variety of games. Consider, for example, making the game Saucer Shoot from Section 3.3. The core gameplay for Saucer Shoot can be made (aside from the Points and Nuke ViewObjects), with the main exception that Dragonfly Naiad only supports single character game objects without animation, rather than animated, multi-character sprites.

4.12 Resource Management

Games have a wide variety and often large number of resources, also known as *assets* or *media*. Examples include meshes, models, textures, animations, audio clips, level layouts, dialog snippets and more. Offline, most game studios use tools to help create, store and archive assets during game development. When the game is running, however, the game engine needs to manage the assets itself in an efficient manner, loading, unloading and manipulating the assets as needed.

Since many assets are large, for efficiency, a game engine uses the *flyweight* design pattern, sharing as much data as possible with similar objects. For the game engine, this means keeping only one copy of each asset in memory and having all game objects that need the asset to refer to this one copy. This helps manage memory resources, which can be scarce for high-end games, or on resource constrained devices, such as mobile hand-helds. Similarly, a game engine often manages the lifetime of the asset, bringing it in from memory on demand ("streaming"), and removing it from memory when it is no longer needed. Some game engines, particularly 3d game engines, handle composite resources, such as keeping a mesh, skeleton and animations all grouped with a 3d model. Assets that have been loaded into memory sometimes need additional processing before rendering. Ideally, support for all of the above is provided in a single, unified interface for both the game programmer and for other components in the engine.

In Dragonfly, one of the assets managed are sprites, stored as text files. A game studio using Dragonfly could have offline tools that help create, edit and store sprites as part of the development environment. Such tools could help artists correctly animate and color text-based sprites, and provide revision control and archival functions for sharing and developing the sprites.

However, the Dragonfly engine itself needs to only be able to understand the format of a sprite file so that it can load it into the game when requested. To do this, data structures (classes) are required for *Frames* (see Section 4.12.1 on page 153) that provide the dimensions of the sprite and hold the data, *Sprites* (Section 4.12.2 on page 155) that provide identifiers for the asset and hold the frames, and *Animations* (Section 4.12.5 page 174) for providing support for per-Object sprite animation. The *ResourceManager* (Section 4.12.3 on page 160) provides methods for the game programmer to use the sprite assets.

4.12.1 The Frame Class

Frames in Dragonfly are simply text rectangles of any dimension that know how to draw themselves on the screen. The frames themselves do not have any color, nor do individual characters – color is an attribute associated with a Sprite. Some frame examples are shown in Listing 4.115. Frames are not animated. In order to achieve animation, sequences of frames are shown in rapid succession so it looks like animation (see Figure 3.2 on page 14).

Listing 4.115: Frame examples

```
0
1      ____          \            _____
2     /__o_\         ~==-        / ___/____ ___  __________  _____
3                    /          \__ \/ __ `/ / / / ___/ _ \/ ___/
4                              ___/ / /_/ / /_/ / /__/  __/ /
5                             /____/\__,_/\__,_/\___/\___/_/
```

The individual cells in a frame are characters. These could be stored in a two dimensional array. However, in order to use the speed and efficiency of the C++ string library class, Dragonfly stores the entire frame as a single string.

The definition for the Frame class is provided in Listing 4.116. While the attribute `m_frame_str` holds the frame data in a one dimensional list of characters, the attributes `m_width` and `m_height` determine the shape of the frame rectangle. There are two constructors: the default constructor creates an empty frame (`m_height` and `m_width` both zero with an empty `m_frame_str`)), while the method on line 14 allows construction of a frame with an initial string of characters and a given width and height. Frames know how to draw themselves at a given position with a given color, via `draw()`. Most of the rest of the Frame methods allow getting and setting the attributes.

Listing 4.116: Frame.h

```
0  #include <string>
1
2  class Frame {
3
4   private:
5    int m_width;              // Width of frame.
6    int m_height;             // Height of frame.
7    std::string m_frame_str; // All frame characters stored as string.
8
9   public:
10   // Create empty frame.
11   Frame();
12
13   // Create frame of indicated width and height with string.
14   Frame(int new_width, int new_height, std::string frame_str);
15
16   // Set width of frame.
17   void setWidth(int new_width);
18
19   // Get width of frame.
20   int getWidth() const;
21
22   // Set height of frame.
23   void setHeight(int new_height);
24
25   // Get height of frame.
26   int getHeight() const;
27
28   // Set frame characters (stored as string).
29   void setString(std::string new_frame_str);
30
31   // Get frame characters (stored as string).
32   std::string getString() const;
33
34   // Draw self, centered at position (x,y) with color.
35   // Return 0 if ok, else -1.
36   // Note: top-left coordinate is (0,0).
37   int draw(Vector position, Color color) const;
```

```
38 };
```

Most of the Frame methods are straightforward getters/setters, except for `draw()`, shown as pseudo code in Listing 4.117.

Listing 4.117: Frame draw()

```
0  // Draw self, centered at position (x,y) with color.
1  // Return 0 if ok, else -1.
2  // Note: top-left coordinate is (0,0).
3  int Frame::draw(Vector position, Color color) const;
4
5    // Error check empty string.
6    if frame is empty then
7      return error
8    end if
9
10   // Determine offset since centered at position.
11   x_offset = frame.getWidth() / 2
12   y_offset = frame.getHeight() / 2
13
14   // Draw character by character.
15   for (int y=0; y<m_height; y++)
16     for (int x=0; x<m_width; x++)
17       Vector temp_pos(position.getX() + x - x_offset,
18                       position.getY() + y - y_offset);
19       DM.drawCh(temp_pos, m_frame_str[y*m_width + x], color)
20     end for // x
21   end for // y
```

The first block of code starting on line 5 checks if the Frame is empty to avoid subsequent parsing errors. This can be checked with the `empty()` method call on the Frame string (`m_frame_str`) and, if true, an error (-1) is returned.

Subsequently, the method computes the x and y offsets since the frame is always drawn centered at the position.

The bulk of the method iterates through the frame characters one by one, drawing them on the screen by calling DisplayManager `drawCh()` with the appropriate (x,y) position, character and color.

4.12.2 The Sprite Class

Sprites are sequences of frames, typically rendered such that if a sequence is drawn fast enough, it looks animated to the eye. The Sprite class in Dragonfly is primarily a repository for the Frame data, and that knows how to draw one frame. Sprites do not know what the display rate should be for the frames for animation nor do they keep track of the last frame that was drawn – that functionality is tracked by the Animation class. Sprites record the dimension of the Sprite (typically, the same dimension of the Frames), provide the ability to add and retrieve individual Frames, and give a method to draw a Frame. A Sprite sequence may look like the example in Listing 4.118.

Listing 4.118: Sprite sequence example

```
 ____      ____      ____      ____      ____
/____\    /___o\    /__o_\    /_o__\    /o___\
```

The Sprite class header file is shown in Listing 4.119. The class needs `Frame.h` as well as `<string>`. The attributes `m_width` and `m_height` typically mirror the sizes of the frames composing the sprite. The frames themselves are stored in an array, `m_frame[]`, which is dynamically allocated when the Sprite object is created. In fact, the default constructor, `Sprite()`, is `private` since it *cannot* be called – instead, Sprites must be instantiated with the maximum number of frames they can hold as an argument (e.g., Sprite(5)). This maximum is stored in `m_max_frame_count`, while the actual number of frames is stored in `m_frame_count`. The color, which is the color of all frames in the sprite, is stored in `m_color`. Each sprite can be identified by a text label, `m_label` – for example, "ship" for the Hero's sprite in Saucer Shoot (Section 3.3).

In the normal course of animation, drawing proceeds sequentially through all the frames in a sprite until the end, then loops. By default, a sprite frame is advanced sequentially each game loop (so, 30 frames per second). However, for many animations, this will be too fast. In order to slow down the animation, the attribute `m_slowdown` provides a slowdown rate. For example, a slowdown of 5 would mean the animation is only advanced by 1 frame for every 5 steps of the game loop. A slowdown of 1 means no slowdown, and a slowdown of 0 has a special meaning, to stop the animation altogether.

Most of the methods are to get and set the attributes, with `addFrame()` putting a new frame at the end of the Sprite's `m_frame` array.

Listing 4.119: Sprite.h

```
// System includes.
#include <string>

// Engine includes.
#include "Frame.h"

class Sprite {

 private:
  int m_width;           // Sprite width.
  int m_height;          // Sprite height.
  int m_max_frame_count; // Max number frames sprite can have.
  int m_frame_count;     // Actual number frames sprite has.
  Color m_color;         // Optional color for entire sprite.
  int m_slowdown;        // Animation slowdown (1=no slowdown, 0=stop).
  Frame *m_frame;        // Array of frames.
  std::string m_label;   // Text label to identify sprite.
  Sprite();              // Sprite always has one arg, the frame count.

 public:
  // Destroy sprite, deleting any allocated frames.
  ~Sprite();

  // Create sprite with indicated maximum number of frames.
  Sprite(int max_frames);

  // Set width of sprite.
```

```
27    void setWidth(int new_width);
28
29    // Get width of sprite.
30    int getWidth() const;
31
32    // Set height of sprite.
33    void setHeight(int new_height);
34
35    // Get height of sprite.
36    int getHeight() const;
37
38    // Set sprite color.
39    void setColor(Color new_color);
40
41    // Get sprite color.
42    Color getColor() const;
43
44    // Get total count of frames in sprite.
45    int getFrameCount() const;
46
47    // Add frame to sprite.
48    // Return -1 if frame array full, else 0.
49    int addFrame(Frame new_frame);
50
51    // Get next sprite frame indicated by number.
52    // Return empty frame if out of range [0, m_frame_count-1].
53    Frame getFrame(int frame_number) const;
54
55    // Set label associated with sprite.
56    void setLabel(std::string new_label);
57
58    // Get label associated with sprite.
59    std::string getLabel() const;
60
61    // Set animation slowdown value.
62    // Value in multiples of GameManager frame time.
63    void setSlowdown(int new_sprite_slowdown);
64
65    // Get animation slowdown value.
66    // Value in multiples of GameManager frame time.
67    int getSlowdown() const;
68
69    // Draw indicated frame centered at position (x,y).
70    // Return 0 if ok, else -1.
71    // Note: top-left coordinate is (0,0).
72    int draw(int frame_number, Vector position) const;
73 };
```

The Sprite constructor is shown in Listing 4.120. The width, height and frame count are initialized to zero. The `m_frame` array is allocated by `new` to the indicated size. Like all memory allocation, this should be checked for success – if the needed memory cannot be allocated (not shown), an error message is written to the logfile and the maximum frame count is set to 0. The Sprite should initially have the default color, `COLOR_DEFAULT`, as defined in `Color.h` (Listing 4.74 on page 114).

Listing 4.120: Sprite Sprite()

```
// Create sprite with indicated maximum number of frames.
Sprite::Sprite(int max_frames)
  set m_frame_count to 0
  set m_width to 0
  set m_height to 0
  m_frame = new Frame [max_frames]
  set max_frame_count to max_frames
  set m_color to COLOR_DEFAULT
```

The Sprite destructor is shown in Listing 4.121. The only logic the destructor has is to check if frames are actually allocated (`frame` is not `NULL`) and, if so, `delete` the `frame` array.

Listing 4.121: Sprite ~Sprite()

```
// Destroy sprite, deleting any allocated frames.
Sprite::~Sprite()
  if m_frame is not NULL then
    delete [] m_frame
  end if
```

Once a Sprite is created, frames are typically added to it one at a time until the entire animation sequence has all been added. Pseudo code for Sprite `addFrame()`, which adds one Frame, is shown in Listing 4.122. The method first checks if the frame array (`m_frame`) is filled – if so, an error is returned. Otherwise, the new frame is added and the frame count is incremented. Remember, as in all C++ arrays, the index of the first item is 0, not 1.

Listing 4.122: Sprite addFrame()

```
// Add a frame to the sprite.
// Return -1 if frame array full, else 0.
int Sprite::addFrame(Frame new_frame)
  if m_frame_count is m_max_frame_count then // Is Sprite full?
    return error
  else
    m_frame[m_frame_count] = new_frame
    increment m_frame_count
  end if
```

Sprite `getFrame()` is shown in Listing 4.123. The first block of code checks if the frame number is outside of the range [0, `m_frame_count`-1] – if so, am empty frame is returned. Otherwise, the frame at the index indicated by `frame_number` is returned.

Listing 4.123: Sprite getFrame()

```
// Get next sprite frame indicated by number.
// Return empty frame if out of range [0, m_frame_count-1].
Frame Sprite::getFrame(int frame_number) const

  if ((frame_number < 0) or (frame_number >= frame_count)) then
    Frame empty  // Make empty frame.
    return empty // Return it.
  end if

```

```
9   return frame[frame_number]
```

The Sprite `draw()` method makes a straightforward call to Frame `draw()` for the indicated frame and position, using the Sprite `m_color`. For error checking, make sure `frame_number` is within the Sprite bounds before accessing the frame.

4.12.2.1 Transparency (optional)

In some cases, the characters making up a sprite do not occupy the full extent of their box. For example, a stick figure will have a bounding box around the whole figure, but there will be empty regions around the head, under the arms, etc. By default, Dragonfly will draw such blank spaces, occluding whatever characters may have been drawn below it (e.g., the background), when it may look better to not draw the blanks. For images, providing this functionality is typically done by declaring one color to be "transparent" where that color, wherever found in the image, is not rendered on the window, allowing any underlying image to be seen instead. For Dragonfly, transparency is done in a similar fashion, with the option of a *character* being specified as the transparency character – whenever this character is part of the sprite frames it is not rendered, thus not occluding any underlying characters.

In order to support drawing with transparency, the Frame `draw()` method must be refactored as shown in Listing 4.124 (refer to Listing 4.117 on page 155 for the original method). The refactored `draw()` method takes an additional parameter indicating the transparent character, with a default value of 0 (*not* the character '`0`') meaning no transparency. Inside the loops iterating over the frame, before a character is drawn (via `drawCh()`), it is verified that either the transparency is not 0 or the character is not the transparent character.

Listing 4.124: Frame extension to support transparency

```
0  // Draw self centered at position (x,y) with color.
1  // Don't draw transparent characters (0 means none).
2  // Return 0 if ok, else -1.
3  // Note: top-left coordinate is (0,0).
4  int Frame::draw(Vector position, Color color, char transparent) const;
5
6    ...
7
8    // Draw character by character.
9    for (int y=0; y<m_height; y++)
10     for (int x=0; x<m_width; x++)
11       if (transparent not defined) or
12          (str[y*frame.getWidth() + x] != transparent) then
13
14          // drawCh normally
15          ...
16       end if
17       ...
```

The transparency character itself is an attribute of an Sprite. Extensions needed to the Sprite class are shown in Listing 4.125. Transparency is stored in a `char` attribute, `m_transparency` (set to 0 in the constructor), with methods to get and set it.

Listing 4.125: Sprite class extensions to support transparency

```
 private:
  char m_transparency; // Sprite transparent character (0 if none).

 public:
  // Set Sprite transparency character (0 means none).
  void setTransparency(char new_transparency);

  // Get Sprite transparency character (0 means none).
  char getTransparency() const;
```

Lastly, the Sprite `draw()` method needs to be modified pass in the transparency character to Frame `draw()`.

The actual transparency character is typically defined in the sprite file (e.g., transparency #). See the ResourceManager code (Section 4.12.3) for parsing sprite files, adding in the ability to handle an optional transparency character.

4.12.3 The ResourceManager

With data structures for frames and sprites in place, a manager to handle resources is needed – the ResourceManager. The ResourceManager is a singleton derived from Manager, with private constructors and a `getInstance()` method to return the one and only instance (see Section 4.2.1 on page 54). The header file, including class definition, is provided in Listing 4.126.

The ResourceManager constructor should set the type of the Manager to "ResourceManager" (i.e., `setType("ResourceManager")` and initialize all attributes.

Listing 4.126: ResourceManager.h

```
// System includes.
#include <string>

// Engine includes.
#include "Manager.h"
#include "Sprite.h"

// Maximum number of unique assets in game.
const int MAX_SPRITES = 500;

class ResourceManager : public Manager {

 private:
  ResourceManager();                        // Private (a singleton).
  ResourceManager(ResourceManager const&); // Don't allow copy.
  void operator=(ResourceManager const&);  // Don't allow assignment.
  Sprite *m_p_sprite[MAX_SPRITES];          // Array of sprites.
  int m_sprite_count;              // Count of number of loaded sprites.

 public:
  // Get the one and only instance of the ResourceManager.
  static ResourceManager &getInstance();

  // Get ResourceManager ready to manager for resources.
```

```
24    int startUp();
25
26    // Shut down ResourceManager, freeing up any allocated Sprites.
27    void shutDown();
28
29    // Load Sprite from file.
30    // Assign indicated label to sprite.
31    // Return 0 if ok, else -1.
32    int loadSprite(std::string filename, string label);
33
34    // Unload Sprite with indicated label.
35    // Return 0 if ok, else -1.
36    int unloadSprite(std::string label);
37
38    // Find Sprite with indicated label.
39    // Return pointer to it if found, else NULL.
40    Sprite *getSprite(std::string label) const;
41 };
```

The ResourceManager uses strings for labels so needs `#include <string>`. In addition, it inherits from `Manager.h` and has methods and attributes to handle Sprites, so also `#includes` `Sprite.h`.

The ResourceManager stores Sprites in an array of pointers (the attribute `m_p_sprite[]`), bounded by `MAX_SPRITES`.

Media files, such as sprite files but also `jpeg`, `wmv` and `mp3` files, typically have three parts: 1) a header that contains key parameters for the media file, such as number of frames and playback rate, 2) a body that had the media data, often with delimiter tags, and 3) a footer with any final wrap-up information.

Listing 4.127: Saucer sprite file

```
0   5
1   6
2   2
3   4
4   green
5    ____
6   /____\
7    ____
8   /___o\
9    ____
10  /__o_\
11   ____
12  /_o__\
13   ____
14  /o___\
```

Listing 4.127 shows an example of a sprite file for the Saucer in the Dragonfly tutorial. The first four lines (with numbers) and the line right after the numbers (saying "green") are the header, containing information needed to animate the sprite. The meaning of the header lines are as follows:

1. Frames - the number of frames in the sprite.

2. Width - the width of the sprite frames.
3. Height - the height of the sprite frames.
4. Slowdown - the number of frames to "pause" between frame animations.
5. Color - the Dragonfly color (a string).

The lines following the header are the body with contents for the sprite frames. The width of each of the body lines is the same as the number on line 2 in the header (the width parameter, 6 in Listing 4.127). The number of lines for each frame is specified by the number on line 3 in the header (the height parameter, 2 in Listing 4.127). The lines are combined to makeup the frame, with the total frames specified by the number on line 1 in the header (the frames parameter, 5 in Listing 4.127).

Note, sprite files using this format are provided for most of the sprites in the Dragonfly Saucer Shoot tutorial. They are available for download with versions of the game (e.g., `https://dragonfly.wpi.edu/tutorials/saucer-shoot/game-final.zip`) and from the book web page (`https://dragonfly.wpi.edu/book/sprites.zip`), available under the `sprites-simple/` directory.

Tip 18! File input in C++. There are many ways to read from a file in C++. One example of reading from a text file (such as a Sprite file) is in Listing 4.128. The sample code treats the file as an `ifstream`, using `getline()` to read the file a line at a time. Note, the function `getline()` automatically removes the newline ('`\n`') delimiter. After each line is read, it is added to a vector (`data`) via the method `push_back()` - this is not strictly needed for just reading from a file, but is useful when the file data is later parsed (e.g., as is a sprite file). The method `good()` is true if the file still has data (and there are no other file errors) – when the end of the file is reached, `good()` returns `false`.

Listing 4.128: Example of file input

```
0  // Example of reading text file.
1  // Read one line at a time, writing each line to stdout.
2  #include <iostream>
3  #include <fstream>
4  #include <string>
5
6  using std::cout;
7  using std::endl;
8
9  int main() {
10   std::string line;
11   std::ifstream myfile ("example.txt");
12   std::vector<std::string> data;
13
14   // Open file.
```

```
15   if (myfile.is_open()) {
16
17     // Repeat until end of file.
18     while (myfile.good()) {
19
20       getline(myfile, line);  // Read line from file.
21       data.push_back(line);   // Add line to vector.
22       cout << line << endl;   // Display line to screen.
23
24     }
25
26     // Close file when done.
27     myfile.close();
28
29   } else
30
31     // If here, unable to open file.
32     cout << "unable to open file" << endl;
33 }
```

4.12.3.1 Loading Sprites

The method `startUp()` gets the ResourceManager ready for use – basically, just setting `m_sprite_count` to 0 and calling `Manager::startUp()`.

The method `loadSprite()` reads in a sprite from a file indicated by `filename`, stores it in a Sprite and associates a label string with it. The method `unloadSprite()` unloads a Sprite with a given `label` from memory, freeing it up. The method `getSprite()` returns a pointer to a Sprite with the given label.

The ResourceManager `loadSprite()` is shown in Listing 4.129. The name of the sprite file is passed in as a string (`filename`), along with a string with the label name to associate with the sprite once it is successfully loaded (`label`).

Listing 4.129: ResourceManager loadSprite()

```
0  // Load Sprite from file.
1  // Assign indicated label to sprite.
2  // Return 0 if ok, else -1.
3  int ResourceManager::loadSprite(std::string filename, std::string label)
4
5    // Check if room in array.
6    if m_sprite_count is MAX_SPRITES then // Sprite array full?
7      return error
8    end if
9
10   open file
11
12   // Read sprite Header.
13   Get first line from file
14   frames = atoi() on line
15   get second line from file
16   width = atoi() on line
17   get third line from file
18   height = atoi() on line
```

```
19    get fourth line from file
20    slowdown = atoi() on line
21    get fifth line from file
22    if line is "black" then
23      color = BLACK
24    else if line is "red" then
25      color = RED
26    ...
27    end if
28
29    // Make new Sprite.
30    new Sprite (with frame count)
31    set sprite height
32    set sprite width
33    set sprite slowdown
34    set sprite color
35
36    // Read and add frames to Sprite.
37    for f = 1 to frame count
38      create empty string
39      for h = 1 to height
40        get line from file
41        append line to string
42      end for
43      set frame string to string
44      set frame height
45      set frame width
46      add frame to Sprite
47    end for
48
49    close file
50
51    // If no errors in any of above, add to resource manager.
52    add label to Sprite
53    m_p_sprite[m_sprite_count] = p_sprite
54    increment m_sprite_count
55
56    return ok
```

The method starts by opening the file indicated by `filename`. After that, all the lines in the header are read in and parsed one by one, lines 13 to 27. Once the number of frames is known from the header, on line 30 a new Sprite is created (e.g., if the sprite has 5 frames, then `new Sprite(5)`). Then, the method loops for each frame (starting on line 37), reading each line and adding it to the frame string (lines 39 to 42). When a complete frame is read in, the frame attributes are set (lines 43 to 45) and the frame is added to the Sprite (line 46). When the specified (in the header) number of frames are read in, the file is closed. Assuming everything above went well, the final steps from line 52 are to: 1) associate `label` with the Sprite, 2) add the Sprite to the `m_p_sprite` array, and 3) increase `m_sprite_count`.

Note, error checking should be done throughout, checking header information, (e.g., header lines corresponding to expected parameters), length of lines (e.g., body lines exactly as long as the frame width), number of lines (e.g., exactly enough for the specified number of frames, each the specified height), and general file read errors. If any errors are

encountered, the line number in the file where the error occurred should be reported along with a descriptive error in the logfile. Listing 4.130 shows an example of a possible error message. In this example, line 12 of the file has "`/o___\ `" which is 7 characters (there is an extra ' ' at the end, a common error), while the header had indicated the width was only 6. Making the error message as descriptive as possible is helpful to game programmers to help "debug" their sprite files. Upon encountering an error, all resources should be cleaned up (i.e., `delete` the Sprite and close the file), as appropriate.

Listing 4.130: Example error reported when parsing Sprite file

```
0  Loading 'explosion' from file 'sprites/explosion-spr.txt'.
1  Error line 12.  Line width 7, expected 6.
2  Line is: "/o___\ "
3  Sprite 'explosion' not loaded.
```

Dragonfly can run on Windows, Linux or Mac computers. Unfortunately, text files are treated slightly differently on Windows versus Linux and Mac. In Windows text files, the end of each line has a newline ('`\n`') character *and* a carriage return ('`\r`') character, while in Unix and Mac, the end of each line only has a newline character. In order to allow Dragonfly to work with text files created on any of the three operating systems, pseudo code for an optional utility, `discardCR()`, is shown in Listing 4.131. A `string`, typically just read in from a file, is passed in via reference (`&str`). The function examines the last character of this string and, if it is a carriage return, it removes it via `str.erase()`.

Listing 4.131: discardCR() (optional)

```
0  // Remove the carriage return ('\r') from line
1  // (if there - typical of Windows).
2  void discardCR(std::string &str)
3    if str.size() > 0 and str[str.size()-1] is '\r' then
4       str.erase(str.size() - 1)
5    end if
```

Once in place, `discardCR()` can be called each time after reading a line from a file.

The complement of `loadSprite()` is `unloadSprite()`, which is much simpler. `unLoadSprite()` is shown in Listing 4.132. The method loops through the Sprites in the ResourceManager. If the label being looked for (`label`) matches the label of one of the Sprites (`getLabel()`) then that is the Sprite to be unloaded. The Sprite's memory is deleted via `delete`. Then, in a loop starting on line 11, the rest of the Sprites in the array are moved down one. Since one Sprite was unloaded, the sprite count is decremented on line 11. If the loop terminates without a label match, the sprite to be unloaded is not in the ResourceManager and an error is returned.

Listing 4.132: ResourceManager unLoadSprite()

```
0  // Unload Sprite with indicated label.
1  // Return 0 if ok, else -1.
2  int ResourceManager::unloadSprite(std::string label)
3
4    for i = 0 to m_sprite_count-1
5
6      if label is m_p_sprite[i] -> getLabel() then
```

```
7
8       delete m_p_sprite[i]
9
10      // Scoot over remaining sprites.
11      for j = i to m_sprite_count-2
12        m_p_sprite[j] = m_p_sprite[j+1]
13      end for
14
15      decrement m_sprite_count
16
17      return ok
18
19    end if
20
21  end for
22
23  return error // Sprite not found.
```

The final method needed by the ResourceManager is `getSprite()`, with pseudo code show in Listing 4.133. The method loops through all the Sprites in the ResourceManager. The first Sprite that matches the label `label` is returned. If line 10 is reached, the label was not found and an error (`NULL`) is returned.

Listing 4.133: ResourceManager getSprite()

```
0 // Find Sprite with indicated label.
1 // Return pointer to it if found, else NULL.
2 Sprite *ResourceManager::getSprite(std::string label) const
3
4   for i = 0 to m_sprite_count-1
5     if label is m_p_sprite[i] -> getLabel() then
6       return m_p_sprite[i]
7     end if
8   end for
9
10  return NULL // Sprite not found.
```

Lastly, ResourceManager `shutDown()`, shown in Listing 4.134 frees up any allocated Sprites by iterating through the `m_p_sprite` array and calling `delete` on each. After that, it sets the array count to zero and calls `Manager::shutDown()`.

Listing 4.134: ResourceManager shutdown()

```
0 // Shut down manager, freeing up any allocated assets.
1 void ResourceManager::shutDown()
2   for i = 0 to m_sprite_count-1
3     if m_p_sprite[i] not NULL then
4       delete m_p_sprite[i]
5     end if
6   end for
7
8   set m_sprite_count to 0
9
10  call Manager::shutDown()
```

4.12.3.2 Sprites with Robust Formatting (optional)

The trouble with the sprite file format as it is currently specified is that it is not very forgiving of errors for the artists that created the sprites. The header numbers (e.g., width and height) have to be specified in *exactly* the right order (e.g., not height and then width) or the sprite will not parse properly, but there are no keywords or guides to help the artist "debug" their sprite files when they create them. In short, the file format is "brittle". While this makes the code to parse sprite files easier, and hence is used for the initial implementation, a more "robust" format for creating sprites can help facilitate the art-game production pipeline.

See the Dragonfly tutorial for an example of a sprite file with a "robust" format.

For robust Dragonfly sprite files, the delimiters are indicated with all caps (e.g., `HEADER`) in order to make creating and parsing sprite files easier. For parsing code, `HEADER`, `BODY`, and `FOOTER` are used to deliminate the header, body and footer of the sprite, respectively. In the header, the keywords `frames`, `height`, `width`, `slowdown`, and `color` define parameters for the sprite. The header parameters can be in any order. In the body, `end` is used to mark the end of each frame. In the footer, `version` is used to indicate sprite version information.

To provide support for sprites with robust formatting, add the `const`s in Listing 4.135 to the ResourceManager header file. These are delimiters used to parse the sprite files – the ResourceManager "understands" the file format and uses the delimiters as tokens during parsing.

Listing 4.135: ResourceManager.h extensions to support a robust sprite format

```
// Delimiters used to parse Sprite files -
// the ResourceManager 'knows' file format.
const std::string HEADER_TOKEN = "HEADER";
const std::string BODY_TOKEN = "BODY";
const std::string FOOTER_TOKEN = "FOOTER";
const std::string FRAMES_TOKEN = "frames";
const std::string HEIGHT_TOKEN = "height";
const std::string WIDTH_TOKEN = "width";
const std::string COLOR_TOKEN = "color";
const std::string SLOWDOWN_TOKEN = "slowdown";
const std::string END_FRAME_TOKEN = "end";
const std::string VERSION_TOKEN = "version";
```

Then, a re-factored version of the ResourceManager `loadSprite()` is shown in Listing 4.136.

Listing 4.136: ResourceManager loadSprite()

```
// Load Sprite from file.
// Assign indicated label to sprite.
// Return 0 if ok, else -1.
int ResourceManager::loadSprite(std::string filename, std::string label)

  open file filename

  read all header lines // header has sprite format data
  parse header

```

```
10   read all body lines // body has frame data
11   new Sprite (with frame count)
12   set sprite height
13   set sprite width
14   set sprite slowdown
15   set sprite color
16   for f = 1 to frame count
17     parse frame
18     add frame to Sprite
19   end for
20
21   read all footer lines // footer has sprite version
22   parse footer
23
24   close file
25
26   // If no errors in any of above, add to resource manager.
27   add label to Sprite
28   m_p_sprite[m_sprite_count] = p_sprite
29   increment m_sprite_count
```

The method proceeds by opening the file indicated by `filename`. After that, all the lines in the header are first read in and then parsed. Once the number of frames is known from the header, on line 11 a new Sprite is created (e.g., if the sprite has 5 frames, then `new Sprite(5)`). Then, the method reads in all the lines in the body, and parses them as frames, one frame at a time. Each frame is added to the Sprite as it is parsed. When the specified (in the header) number of frames are read in, all the lines in the footer are read in and then parsed. Assuming everything above went well, the final steps from line 27 are to: 1) associate `label` with the Sprite, 2) add the Sprite to the `m_p_sprite` array, and 3) increase `m_sprite_count`.

Note, as for the simple format, error checking should be done throughout, looking at file format, length of line, number of lines, frame count and general file read errors. If any errors are encountered, the line number in the file should be reported along with a descriptive error in the logfile.

Coding the `loadSprite()` method is much easier with a few "helper" functions, shown in Listing 4.137.

Function `getLine()` reads a single line from a file and does some error checking.

Function `readData()` reads a section (e.g., the body, recognized by the `delimiter`, such as `BODY`) from the sprite file and stores each line in a vector for later parsing. And error is indicated (an empty vector is returned) of the section beginning and end is not found.

Function `matchLineInt()` matches a specified token from the vector (a sprite file section), returning the associated integer value. For example, the line "frames 5" called with a tag of "frames" would return the integer "5". Lines that match are removed from the vector.

Function `matchLineStr()` does the same thing, but returning associated string found. For example, the line "color green" called with a tag of "color" would return the string "green").

Function `matchFrame()` reads a frame of a given width and height from a file, returning the Frame. The used frame lines are removed from the vector.

All functions should report any parsing errors in the logfile. None of these methods are part of the ResourceManager, but rather are stand alone utility functions. They are not general engine utility functions either (i.e., it is unlikely a game programmer would ever use them), so do not really belong in `utility.cpp`. Instead, they can be placed directly into `ResourceManager.cpp`.

Listing 4.137: ResourceManager helper functions for loading sprites

```
// Get next line from file, with error checking ("" means error).
std::string getLine(std::ifstream *p_file);

// Read in next section of data from file as vector of strings.
// Return vector (empty if error).
std::vector<std::string> readData(std::ifstream *p_file,
                                  std::string delimiter);

// Match token in vector of lines (e.g., "frames 5").
// Return corresponding value (e.g., 5) (-1 if not found).
// Remove any line that matches from vector.
int matchLineInt(std::vector<std::string> *p_data, const char *token);

// Match token in vector of lines (e.g., "color green").
// Return corresponding string (e.g., "green") ("" if not found).
// Remove any line that matches from vector.
std::string matchLineStr(std::vector<std::string> *p_data, const char *
    token);

// Match frame lines until "end", clearing all from vector.
// Return Frame.
Frame matchFrame(std::vector<std::string> *p_data, int width, int height);
```

Function `getLine()` is shown in Listing 4.138. The function reads one line from the file into the string `line`. The code also needs to `#include` the `fstream` header file. Note, error checking (`m_p_file -> good()` is done to catch any file input errors.

Listing 4.138: getLine()

```
// Get next line from file, with error checking ("" means error).
std::string getLine(std::ifstream *p_file)

  string line
  getline(*p_file, line)
  if not (p_file -> good()) then
    return error
  end if

  return line
```

Function `readData()` is shown in Listing 4.139. The function takes in a token that is used to delimit the section of the sprite file (i.e., HEADER, BODY, FOOTER) and the file to be read from. It then pulls all the lines from the file using the delimiter to mark the beginning and end, storing the "good" lines as data in an `std::vector`. That vector is returned. Errors are checked for missing the delimiter beginning or end and file errors.

Listing 4.139: readData()

```
// Read in next section of data from file as vector of strings.
// Return vector (empty if error).
std::vector<std::string> readData(std::ifstream *p_file,
                                  std::string delimiter)

  beginning = "<" + delim + ">"  // Section beginning
  ending = "</" + delim + ">"    // Section ending

  // Check for beginning.
  s = getLine()
  if s not equal beginning then
    return error
  end if

  // Read in data until ending (or not found).
  s = getLine()
  while (s not equal ending) and (not s.empty()) do
    push_back(s) onto data
    s = getLine()
  end while

  // If ending not found, then error.
  if s.empty() then
    return error
  end if

  return data
```

Function `matchLineInt()` is shown in Listing 4.140. The function examines the data vector one line at a time, looking for a match of the indicated `token`. The match on Line 9 can be made using `compare()`, – e.g.,

```
  i -> compare(0, strlen(token), token)
```

If the token is the one expected, the remainder of the string after the token is converted on Line 10 into an integer using `atoi()` – e.g.,

```
  atoi(line.substr(strlen(token)+1).c_str())
```

The number extracted with `atoi()` is returned.

Listing 4.140: matchLineInt()

```
// Match token in vector of lines (e.g., "frames 5").
// Return corresponding value (e.g., 5) (-1 if not found).
// Remove any line that matches from vector.
int matchLineInt(std::vector<std::string> *p_data,
                 const char *token)

  // Loop through all lines.
  auto i = p_data -> begin() // vector iterator
  while i not equals p_data -> end()
    if i equals token then
      number = atoi() on line.substr()
```

```
11        i = p_data -> erase(i) // clear from vector
12      else
13        increment i
14      end if
15    end while
16
17    return number
```

The same logic is used for `matchLineStr()` with the exception that the final string after the token is not converted to an integer, but is instead just returned (e.g., `line.substr( strlen(token) + 1 )`).

The method `matchFrame()` is shown in Listing 4.141. The function is provided the height of the frame via the `height` parameter. So, using a `for` loop, the function loops for a count of the height of the frame, handling a line at a time. Each line represents one row of the frame. If any line is not the right width (also passed in as a parameter, via `width`), an error is returned in the form of an "empty" Frame. If the frame is read in successfully, an additional line is handled, shown on line 20. Since the frame is over, this line should be `END_FRAME_TOKEN` ("end"), otherwise there is an error in the file format.

Errors of any kind should result in an error code (empty Frame) returned by the function. If line 26 is reached, the frame has been read and parsed successfully, so a Frame object containing the frame is created and returned. The line number should be used to report (in the logfile) where any errors occurred in the input file, and should be appropriately incremented as the parsing progresses.

Listing 4.141: matchFrame()

```
0  // Match frame lines until "end", clearing all from vector.
1  // Return Frame (empty if error).
2  Frame matchFrame(std::vector<std::string> *p_data, int width, int height)
3
4    string line, frame_str
5
6    for h = 1 to height
7
8      line = p_data -> front()
9
10     if line width != width then
11       return error
12     end if
13
14     p_data -> erase(p_data->begin())
15
16     frame_str += line
17
18   end for
19
20   line = p_data -> front()
21   if line is not  END_FRAME_TOKEN then
22     return error
23   end if
24   p_data -> erase(p_data->begin())
25
26   create frame (width, height, frame_str)
```

```
27
28  return frame
```

With robust sprite formatting in place, it can be convenient for Dragonfly to support both the original simple sprite file format as well as the robust sprite file format. A technique that can "auto-detect" whether a sprite file is in the simple format or the robust format is shown in Listing 4.142. Basically, the first line of the file is read. If this line is the string "¡HEADER¿", it is assumed the file has a robust sprite file format and loading proceeds assuming this format. Otherwise, it is assumed the file has a simple sprite file format. In this (simple) case, the first line should be an integer (the number of frames), so the line is converted to a number (using `atoi()`) and checked. If the number is not a positive, an error is indicated – the file may not be a sprite file at all.

Listing 4.142: Auto-detecting sprite file format.

```
0
1   get line from file
2
3   if line is "<HEADER>" then
4     loadRobustSprite()
5   else if atoi() on line > 0
6     loadSimpleSprite()
7   else
8     error // unknown format
9   end if
```

4.12.4 Development Checkpoint #8!

Continue Dragonfly development. Steps:

1. Make the Frame class, referring to Listing 4.116. Add `Frame.cpp` to the project and stub out each method so it compiles. Implement and test the Frame class outside of any game engine components, making sure it can be loaded with different strings and frame dimensions.

2. Implement the Frame `draw()`, referring to Listing 4.117. Test with a variety of Frames and positions outside of an actual Sprite or game Object.

3. Make the Sprite class, referring to Listing 4.119. Add `Sprite.cpp` to the project and stub out each method so it compiles. Code and test the simple attributes first (`int`s and `label`).

4. Implement the constructor `Sprite(int max_frames)` next, allocating the array. Implement `addFrame()` based on Listing 4.122 and `getFrame()` based on Listing 4.123. Test that you can create Sprites of different numbers of frames and add individual Frames to them. Be sure the upper limit on frame count is protected. Testing should be done outside of the other engine components, and Frames can be arbitrary strings at this point.

5. Implement the Sprite`draw()` and test with a variety of Sprites (use those from Chapter3 – Saucer Shoot), again still outside of a game Object.

6. Make the ResourceManager, as a singleton (described in Section 4.2.1 on page 54), referring to Listing 4.126. Add `ResourceManager.cpp` to the project and stub out each method so it compiles.

7. Implement `loadSprite()` referring to Listing 4.129. For testing, sprites with a simple format can be made from the Sprite files from Saucer Shoot by keeping the line orders the same, but removing all keywords (e.g., "width", "height" and "end"). Test thoroughly. Purposefully introduce errors – to the headers (e.g., count, number), body (frame data), and footer – and verify that all errors are caught and helpful error messages reported in the logfile on the right lines.

8. Implement `getSprite()` based on Listing 4.133 and `unloadSprite()` based on Listing 4.132. Test each method thoroughly. Write test code that uses all the ResourceManager methods, loading a Sprite, getting frames, and unloading a Sprite. Repeat for multiple sprites.

4.12.5 Using Sprites and the Animation Class

At this point, the game programmer can load sprites into the ResourceManager in a few simple steps. The first step is to create a sprite file, such as the one in Listing 3.3 on page 18. The second is to load the sprite into the ResourceManager so the game can make use of it. Example code to load the saucer sprite for Saucer Shoot (Section 3.3) is shown in Listing 3.2 on page 17.

To actually use Sprites, say to draw them in an animated fashion on the window, Dragonfly needs to be extended in a couple of ways. A Sprite holds the "static" properties of an animation in that they are fixed for all Objects that use the sprite. To actually animate the Sprite, an Animation class is created to provide control of the Sprite animation for each associated Object.

Animation is shown in Listing 4.143. The class needs `Sprite.h` as well as `<string>`. The attribute `m_p_sprite` indicates what Sprite is associated with the Animation and `m_name` the corresponding name. The attribute `m_index` keeps track of which frame is currently being drawn. The attribute `m_slowdown_count` is a counter used in conjunction with the Sprite slowdown rate (see Section 4.12.2 on page 155) to provide animation through cycling the frames. Methods to get and set each attribute are also provided. The `setSprite()` methods also sets the bounding box for the Object (described in the upcoming Section 4.13.2).

Listing 4.143: Animation.h

```
// System includes.
#include <string>

// Engine includes.
#include "Sprite.h"

class Animation {

 private:
  Sprite *m_p_sprite;     // Sprite associated with Animation.
  std::string m_name;     // Sprite name in ResourceManager.
  int m_index;            // Current index frame for Sprite.
  int m_slowdown_count;   // Slowdown counter.

 public:
  // Animation constructor
  Animation();

  // Set associated Sprite to new one.
  // Note, Sprite is managed by ResourceManager.
  // Set Sprite index to 0 (first frame).
  void setSprite(Sprite *p_new_sprite);

  // Return pointer to associated Sprite.
  Sprite *getSprite() const;

  // Set Sprite name (in ResourceManager).
  void setName(std::string new_name);

  // Get Sprite name (in ResourceManager).
  std::string getName() const;
```

```
31
32    // Set index of current Sprite frame to be displayed.
33    void setIndex(int new_index);
34
35    // Get index of current Sprite frame to be displayed.
36    int getIndex() const;
37
38    // Set animation slowdown count (-1 means stop animation).
39    void setSlowdownCount(int new_slowdown_count);
40
41    // Set animation slowdown count (-1 means stop animation).
42    int getSlowdownCount() const;
43
44    // Draw single frame centered at position (x,y).
45    // Drawing accounts for slowdown, and advances Sprite frame.
46    // Return 0 if ok, else -1.
47    int draw(Vector position);
48 };
```

The Animation `draw()` method, shown in Listing 4.144, basically makes a call to Sprite `draw()` then advances the sprite index to the next frame. Line 12 asks the Sprite to draw the current frame at the indicated position. The block of code at line 15 checks if the sprite slowdown count is set to -1 – if so, this indicates the animation is frozen, not to be advanced, so the method is done. Otherwise, the slowdown counter is advanced ,and on line 24 checked against the slowdown value to see if it is time to advance the sprite frame. Advancing increments the index, with the code starting at line 31 taking care of looping from the end of the animation sequence to the beginning. The last two actions at the end of the method set the slowdown counter and the sprite indices to their values for the next call to `draw()`.

Listing 4.144: Animation draw()

```
0  // Draw single frame centered at position (x,y).
1  // Drawing accounts for slowdown, and advances Sprite frame.
2  // Return 0 if ok, else -1.
3  int Animation::draw(Vector position)
4
5    // If sprite not defined, don't continue further.
6    if m_p_sprite is NULL then
7      return
8    end if
9
10   // Ask Sprite to draw current frame.
11   index = getIndex()
12   Sprite draw(index, pos)
13
14   // If slowdown count is -1, then animation is frozen.
15   if getSlowdownCount() is -1 then
16     return
17   end if
18
19   // Increment counter.
20   count = getSlowdownCount()
21   increment count
```

```
22
23    // Advance sprite index, if appropriate.
24    if count >= getSlowdown() then
25
26      count = 0  // Reset counter.
27
28      increment index  // Advance frame.
29
30      // If at last frame, loop to beginning.
31      if index >= p_sprite -> getFrameCount() then
32        index = 0
33      end if
34
35      // Set index for next draw().
36      setIndex(index)
37
38    end if
39
40    // Set counter for next draw().
41    setSlowdownCount(count)
```

With Frame, Sprite and Animation defined, Object can be extended to support sprite animations. The Object is provided with an Animation object (`m_animation`) with corresponding `setAnimation()` and `getAnimation()` methods, and a method to set the associated sprite (`setSprite()`). Up until now, game objects needed to define their own `draw()` methods to display something on the window. But with a Sprite now associated with an Object, the `draw()` method can now be defined to draw the animated sprite.

Listing 4.145: Object class extensions to support Sprites

```
0  private:
1    Animation m_animation;  // Animation associated with Object.
2
3  public:
4
5    // Set Sprite for this Object to animate.
6    // Return 0 if ok, else -1.
7    int setSprite(std::string sprite_label);
8
9    // Set Animation for this Object to new one.
10   // Set bounding box to size of associated Sprite.
11   void setAnimation(Animation new_animation);
12
13   // Get Animation for this Object.
14   Animation getAnimation() const;
15
16   // Draw Object Animation.
17   // Return 0 if ok, else -1.
18   virtual int draw();
```

The revised Object `draw()` method shown in Listing 4.146 method simply calls the Animation `draw()` method, passing in the Object position.

Listing 4.146: Object draw()

```
// Draw Object Animation.
// Return 0 if ok, else -1.
int Object::draw()
  pos = getPosition()
  return  m_animation.draw(pos)
```

Note, `draw()` is still defined as `virtual`. This allows a derived class (a game object) to define its own `draw()` method, should it so choose. In such a case, the game object's `draw()` would get called. The game programmer could write code for object-specific functionality (say, displaying a health bar above an avatar), and still call the built-in Object `draw()` explicitly, via `Object::draw()`).

The `setSprite()` method is shown in Listing 4.147. The first block of code retrieves the Sprite by name (`sprite_label`) from the Resource Manager, checking that the Sprite can be found. Then, the Sprite is associated with the `m_animation` object.

Listing 4.147: Object setSprite()

```
// Set Sprite for this Object to animate.
// Return 0 if ok, else -1.
int Object::setSprite(std::string sprite_label)

  p_sprite = RM.getSprite(sprite_label)
  if p_sprite == NULL then
    return error
  end if

  m_animation.setSprite(p_sprite)

  // All is well.
  return ok
```

4.12.6 Development Checkpoint #9!

Continue Dragonfly development, getting the engine to support Sprites. Steps:

1. Create an Animation class, following Listing 4.143 and stubbing out the methods. Make sure that it compiles, first. Then, implement the methods to get and set the simple attributes
2. Next, implement Animation `draw()` as per Listing 4.144 testing it carefully.
3. Extend the Object class to support Sprites, as per Listing 4.145.
4. Write the code for the revised Object `draw()` in Listing 4.146 that uses Animation to draw. Write code for a game object (inherited from Object) that associates with a Sprite. Integrate this game object into a game and test the functionality of the Object `draw()`. Debugging can be visual (what is seen on the screen), but use logfile messages to help determine when/where there are problems.
5. Test a variety of game objects with a variety of Sprites (from the Saucer Shoot tutorial or created by hand). Verify the Sprites can be advanced, slowed down and stopped and are drawn without visual glitches. Test and debug thoroughly before proceeding.

4.13 Boxes

Boxes (also known as rectangles) are useful for providing a variety of 2d or 3d game features. Boxes can be used to determine the bounds of an object for collisions, as discussed in Section 4.10.1. Boxes can also be used to determine the boundary of the game world, helping detect when a game object goes out of bounds and/or off the boundary of the visual window. This latter feature is useful for when the game world is larger than what can be seen on the window, such as is typically the case for adventure-type games that feature exploring a large work, or for side-scrolling platformers. In this case, the player's view of the world is through a view window that moves with, say, the player's avatar. In order to support these features, Dragonfly has a Box class.

4.13.1 The Box Class

The definition for the Box class is provided in Listing 4.148. The Box uses a Vector attribute (`corner`) for the upper left corner, with horizontal and vertical attributes stored as integers. The default constructor creates an empty (zero width, zero height) box at (0,0). It is often useful to create a Box with given attributes, so the other constructor allows specification of position, horizontal and vertical attributes upon instantiation. Since the Box is just a container, the rest of the methods just get and set the attribute values.

Listing 4.148: Box.h

```
0  #include "Vector.h"
1
2  class Box {
3
4   private:
5    Vector m_corner;      // Upper left corner of box.
6    float m_horizontal;   // Horizontal dimension.
7    float m_vertical;     // Vertical dimension.
8
9   public:
10   // Create box with (0,0) for the corner, and 0 for horiz and vert.
11   Box();
12
13   // Create box with an upper-left corner, horiz and vert sizes.
14   Box(Vector init_corner, float init_horizontal, float init_vertical);
15
16   // Set upper left corner of box.
17   void setCorner(Vector new_corner);
18
19   // Get upper left corner of box.
20   Vector getCorner() const;
21
22   // Set horizontal size of box.
23   void setHorizontal(float new_horizontal);
24
25   // Get horizontal size of box.
26   float getHorizontal() const;
27
28   // Set vertical size of box.
```

```
29   void setVertical(float new_vertical);
30
31   // Get vertical size of box.
32   float getVertical() const;
33 };
```

4.13.2 Bounding Boxes

Boxes are used for the "size" of an Object, also known as a *bounding box* since it bounds the borders of a game object. The bounding box determines the region an Object occupies and is used in the computation to figure out if an Object collides with another Object.

Extensions to the Object class to support bounding boxes are shown in Listing 4.149. The bounding box is stored in the `private` attribute `m_box`, with methods provided to get and set it.

Listing 4.149: Object class extensions to support bounding boxes

```
0  private:
1   Box m_box;  // Box for sprite boundary & collisions.
2
3  public:
4   // Set Object's bounding box.
5   void setBox(Box new_box);
6
7   // Get Object's bounding box.
8   Box getBox() const;
```

The Object bounding box is initialized to a unit square (a Box with horizontal and vertical of 1), but typically the game programmer wants the bounding box to be the size of the Object as drawn. Thus, by default, the `setSprite()` method from Listing 4.145 (page 176) sets `m_box` to the width and height of the indicated sprite (as computed by the Animation object, `m_animation`). This can be done by adding the following line:

```
0   setBox(m_animation.getBox())
```

to the end of the method in Listing 4.147, right before the return. Animation should be extended with a `getBox()` method shown in Listing 4.150.

Listing 4.150: Animation class extensions to support bounding boxes

```
0  // Get bounding box of associated Sprite.
1  Box Animation::getBox() const
2
3    // If no Sprite, return unit Box centered at (0,0).
4    if not m_p_sprite then
5      Box box(Vector(-0.5,-0.5), 0.99, 0.99)
6      return box
7    end if
8
9    // Create Box around centered Sprite.
10   Vector corner(-1 * m_p_sprite->getWidth()/2.0,
11                 -1 * m_p_sprite->getHeight()/2.0)
12   Box box(corner, m_p_sprite->getWidth(),
```

```
                    m_p_sprite->getHeight())

  // Return box.
  return box
```

A major change needed to support bounding boxes regards collisions. Instead of Objects only colliding if their positions overlap, with boxes, Objects collide if their bounding boxes overlap. The idea is to replace the call to `positionsIntersect()` in the WorldManager `moveObject()` method (Listing 4.109 on page 147) with `boxIntersectsBox()`.

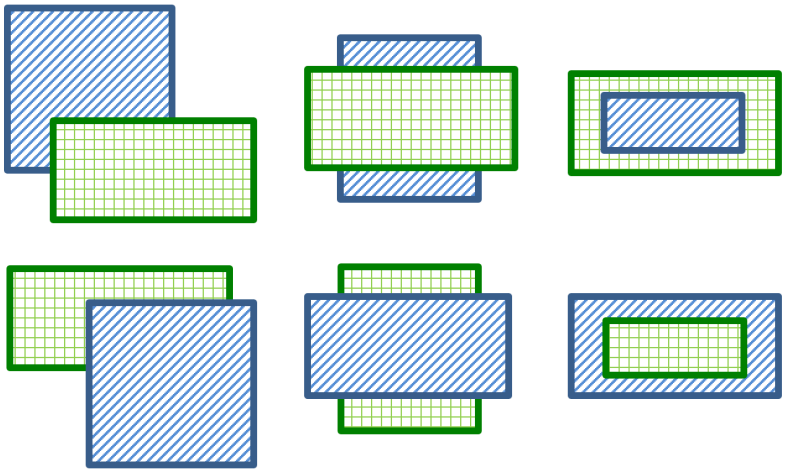


Figure 4.5: Positional possibilities for two overlapping boxes

There are several positional possibilities that must be considered when devising an algorithm to detect box overlap, as depicted by Figure 4.5. Any algorithm designed to detect overlap between two boxes in general should be carefully checked against these cases, both by hand and by coding up specific examples.

For the actual algorithm to test if two boxes overlap, while there are numerous possibilities, an intuitive and fairly fast method is as follows: consider Figure 4.6, where the upper left corner of a box is (`x1`, `y1`) and the bottom right corner is (`x2`, `y2`). An overlap of box A and box B only occurs if the left edge of B is contained within the width of A *and* the top edge of box B is contained within the height of box A. If both of those are true, then the two boxes overlap, otherwise they do not. And vice versa for A within B.

Using this idea, a new function `boxIntersectsBox()` is created in `utility.cpp`, with pseudo code shown in Listing 4.151.

Listing 4.151: boxIntersectsBox()

```
// Return true if boxes intersect, else false.
bool boxIntersectsBox(Box A, Box B)

  // Test horizontal overlap (x_overlap).
  Bx1 <= Ax1 && Ax1 <= Bx2     // Either left side of A in B?
  Ax1 <= Bx1 && Bx1 <= Ax2     // Or left side of B in A?

```

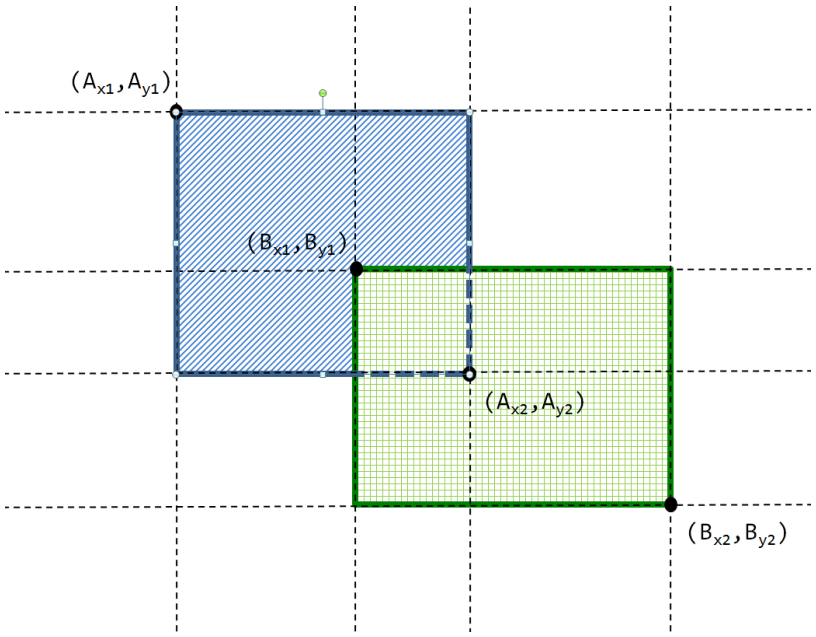


Figure 4.6: Corner notation used to determine if boxes overlap

```
  // Test vertical overlap (y_overlap).
  By1 <= Ay1 && Ay1 <= By2     // Either top side of A in B?
  Ay1 <= By1 && By1 <= Ay2     // Or top side of B in A?

  if (x_overlap) and (y_overlap) then
    return true          // Boxes do intersect.
  else
    return false         // Boxes do not intersect.
  end if
```

In replacing the call to `positionsIntersect()` in the WorldManager `getCollisions()` method (Listing 4.108 on page 146) with `boxIntersectsBox()`, it is important to remember that the bounding boxes for Objects are relative to the Objects themselves. For example, the top left corner of a bounding box for an Object with a 1-character Sprite is (0,0) and the top left corner of a bounding box for a 3x3 character Sprite (centered on the Object) is (-1.5,-1.5). Neither of these boxes are in terms of the game world coordinates.

In order to compute collisions, the bounding box position needs to be converted to a game world position. A useful utility (in `utility.cpp`) for this conversion is `getWorldBox()` that converts the bounding box positioned relative to an Object to a bounding box positioned relative to the game world.

Listing 4.152: getWorldBox()

```
// Convert relative bounding Box for Object to absolute world Box.
Box getWorldBox(const Object *p_o)

  Box box = p_o -> getBox()
  Vector corner = box.getCorner()
```

```
5   corner.setX(corner.getX() + p_o -> getPosition().getX())
6   corner.setY(corner.getY() + p_o -> getPosition().getY())
7   box.setCorner(corner)
8
9   return box
```

In addition, a similar version can be made that converts a relative bounding box for an Object to an absolute world Box at position `where`.

```
0 // Convert relative bounding Box for Object to absolute world Box.
1 Box getWorldBox(const Object *p_o, Vector where)
```

For ease of implementation, the first `getWorldBox()` can call the second, providing `p_o->getPosition()` as the argument to `where`.

Once created, collision detection in the WorldManager `getCollisions()` method is modified as in Listing 4.153.

Listing 4.153: WorldManager getCollisions() with bounding boxes

```
0  // Return list of Objects collided with at position 'where'.
1  // Collisions only with solid Objects.
2  // Does not consider if p_o is solid or not.
3  ObjectList getCollisions(const Object *p_o, Vector where)
4     ...
5
6     // World position bounding box for object at where
7     Box b = getWorldBox(p_o, where)
8
9     // World position bounding box for other object
10    Box b_temp = getWorldBox(p_temp_o)
11
12    if boxIntersectsBox(b, b_temp) and p_temp_o->isSolid() then
13       ...
```

Tip 19! Visually Debugging Bounding Boxes. While debugging bounding boxes can be done using `writeLog()` messages via the LogManager, sometimes it is easier to see the problems with a bounding box rather than figure it out through print messages. A fairly easy way to do this is to display part of the bounding box on the screen, above any sprite that is drawn. Specifically, after in Object `draw()`, after drawing a Sprite frame, place a symbol (e.g., a '+') for each corner of the bounding box, with an additional symbol for the Object position. Listing **??** provides code to do just this. The visual bounding box can be compiled in and out of the engine using conditional compilation (see Section 4.3.4 on page 58).

4.13.3 Utility Functions (optional)

The function `boxIntersectsBox()` is not only helpful for Dragonfly in detecting collisions, it can be a generally useful utility for a game programmer. The name suggests other utilities

shown in Listing 4.154 that are not necessarily used by the game engine but can be used by game programmers. Line 1 has a simple function that tests whether a value lies between the other two, useful in computing whether or not two Boxes intersect (see Listing 4.151). Line 4 has a function that converts the relative bounding box of an Object along with its position into a Box placed in the world (see Listing 4.152).

Listing 4.154: Utility functions

```
0  // Return true if value is between min and max (inclusive).
1  bool valueInRange(float value, float min, float max);
2
3  // Convert relative bounding Box for Object to absolute world Box.
4  Box getWorldBox(const Object *p_o);
5  Box getWorldBox(const Object *p_o, Vector where);
6
7  // Return true if Box contains Position.
8  bool boxContainsPosition(Box b, Vector p);
9
10 // Return true if Box 1 completely contains Box 2.
11 bool boxContainsBox(Box b1, Box b2);
12
13 // Return true if Line segments intersect.
14 // (Parallel line segments don't intersect).
15 bool lineIntersectsLine(Line line1, Line line2);
16
17 // Return true if Line intersects Box.
18 bool lineIntersectsBox(Line line, Box b);
19
20 // Return true if Circle intersects or contains Box.
21 bool circleIntersectsBox(Circle circle, Box b);
22
23 // Return distance between any two positions.
24 float distance(Vector p1, Vector p2);
```

The rest of the utility function prototypes shown in Listing 4.154 are not needed for Dragonfly, but may be useful to game programmers. Lines 7 through 21 are variations of the `boxIntersectsBox()` function, but with different shapes.[19] Line 24 has a function that returns the distance between any two positions.

[19] Classes for Line and Circle are not provided in this book, but are left as exercises for the aspiring programmer.

Tip 20! Line of sight. Many games employ the use of line of sight to determine if one object can "see" another. For example, can the hero see the treasure chest behind a wall? Can the bad guy see the hero sneaking up? Can the mummy see an intruder in the halls of its tomb? In order to check if a first object can "see" a second object, a common technique is to draw a line from the first to the second. If the line does not intersect any other objects, the second object is spotted. In Dragonfly, the function `lineIntersectsBox()` can be used for this, checking each Object to see if a line from the position of the first Object to the position of the second Object for intersection with any other Object. If so, the intersected Object occludes the vision. If not, there is a clear line of sight.

4.13.4 Views

In a game like *Pac-Man*, the entire game board is visible on the computer screen. However, there are many games where this is not the case, games in which the game world is larger than what can be seen on the screen. Think of a game where the player explores a game-world, too vast to be contained to one, single computer screen. In such a case, the game shows a "window" that acts as a "viewport" over the world, with the camera moving to show different world *views* in response to player actions. Sometimes, the camera will move with an avatar, say, keeping the avatar in the window as the world behind it moves. This is what happens in a platformer such as *Super Mario*, where the player controls the main avatar (Mario), jumping and falling vertically and running left and right in a large game world while the camera follows the avatar. Similarly, in the case of an adventure game such as *The Legend of Zelda*, the player controls the main avatar (Link), exploring a very large world in the course of rescuing the princess. Omnipresent games, where the player has a top-down view of part of the game world, such as is the case of many real time strategy games, have the camera show part of the game world on the window while the entire game world is much larger. For Dragonfly, since it uses text-based cells, the view afforded by the camera is limited to the size of the initial window. When the game world is larger than this window, the game engine needs to map the world coordinates to the window coordinates.

Extensions to the WorldManager to support views are shown in Listing 4.155. The limit provided by the terminal window is called the *view boundary* and the limit provided by the game world is called the *world boundary*. Both boundaries are stored as Box attributes, privately kept in the WorldManager. Methods to get and set the boundaries are provided. By default, in the WorldManager constructor, the size of both boundaries, length and width, should be set to 0.

Listing 4.155: WorldManager extensions to support views

```
0 private:
1  Box boundary;  // World boundary.
2  Box view;      // Player view of game world.
3
4 public:
5  // Set game world boundary.
6  void setBoundary(Box new_boundary);
```

```
7
8   // Get game world boundary.
9   Box getBoundary() const;
10
11  // Set player view of game world.
12  void setView(Box new_view);
13
14  // Get player view of game world.
15  Box getView() const;
```

The GameManager sets the default world boundary and the view boundary to be the size of the initial window, obtained from the DisplayManager via `getHorizontal()` and `getVertical()` (see Section 4.8.2 on page 113).* The GameManager does this in its own `startUp()` method, after both the DisplayManager and WorldManager have been successfully started.

The world boundary as a Box provides an immediate opportunity to refactor the "out of bounds" event from Section 4.10.1.4 (page 148). Listing 4.156 depicts the new pseudo-code.

Listing 4.156: WorldManager moveObject() refactored for EventOut

```
0  // Move Object.
1  // ...
2  // If moved from inside world boundary to outside, generate EventOut.
3  int WorldManager::moveObject(Object *p_o, Vector where)
4
5     ...
6
7     // Do move.
8     Box orig_box = getWorldBox(p_o)  // original bounding box
9     p_o -> setPosition(where)        // move object
10    Box new_box = getWorldBox(p_o)   // new bounding box
11
12    // If object moved from inside to outside world, generate
13    // "out of bounds" event.
14    if boxIntersectsBox(orig_box, boundary) and // Was in bounds?
15       not boxIntersectsBox(new_box, boundary)  // Now out of bounds?
16       EventOut ov                              // Create "out" event
17      p_o -> eventHandler(&ov)                  // Send to Object
18    end if
19
20    ...
```

Game objects' positions are specified in relation to the world coordinates. In other words, the position attribute in an Object that provides an (x,y) location means that object should be at (x,y) in the world, but not necessarily at (x,y) on the window. With views, the world (x,y) position need to be mapped to the view/window (x,y) position.

Consider an example in Figure 4.7. The game world is 35x25 and the origin (0,0) is in the upper left corner. There are three Objects in the world: A is at (15,10), B is at

* **Did you know (#10)?** The *Globe Skimmer* dragonfly has the longest migration of any insect, back and forth across the Indian Ocean, about 11,000 miles. – "14 Fun Facts About Dragonflies", *Smithsonian.com*, October 5, 2011.

(8,5) and C is at (25,2). The coordinates depicted for all the Objects are relative to the game world. The view, 10x10, what the player sees on the window, is smaller than the game world, 35x25. The view origin, position (0,0) on the window, is at position (10,3) in game world coordinates. To correctly display Objects on the window, the view origin position is subtracted from each Object's position before drawing. For example, for Object A, subtracting (10,3) from (15,10) puts A at location (5,7) on the window. For Object B, subtracting (10,3) from (8,5) puts B at (-2,2). Since the x coordinate is negative, B is not drawn. For Object C, subtracting (10,3) from (25,2) puts C at (15,-1). Since the y coordinate is negative and 15 is greater than the window width, C is not drawn.

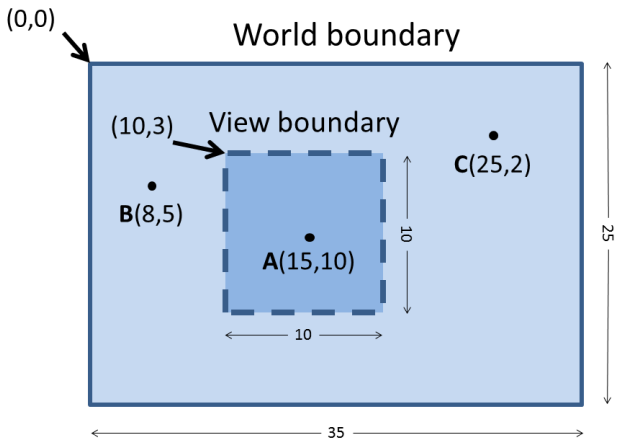


Figure 4.7: View boundary in relation to world boundary

This world-to-view translation is most easily done in the DisplayManager right before drawing a character on the window. The `utility.cpp` method `worldToView()`, shown in Listing 4.157, converts a world (x,y) position to a view (x,y) position on the window based on the current view.

Listing 4.157: worldToView()

```
0 // Convert world position to view position.
1 Vector worldToView(Vector world_pos)
2   view_origin = WorldManager getView().getCorner()
3   view_x = view_origin.getX()
4   view_y = view_origin.getY()
5   Vector view_pos(world_pos.getX()-view_x, world_pos.getY()-view_y)
6   return view_pos
```

The DisplayManager `drawCh()` is re-factored to call `worldToView()` right before each character is drawn, shown in Listing 4.158.

Listing 4.158: DisplayManager extensions to drawCh() to support views

```
0 int DisplayManager::drawCh(Vector world_pos, char ch, Color color) const
1   Vector view_pos = worldToView(world_pos)
```

```
  ...
```

Then, the subsequent calls to draw (e.g., the rectangle and the character) use `view_pos` instead of `world_pos`.

With views, not all Objects need to be drawn every loop. For example, in Figure 4.7, objects B and C are off the visible window so while calling `drawCh()` would not cause errors, it is a waste of time. In the WorldManager `draw()` method, instead of automatically drawing all objects, first the bounding box for each object is checked for intersection with the current view. If there is intersection, the Object is drawn. If there is not intersection, the Object is not drawn. This logic, done inside the "altitude" loop, is shown in Listing 4.159.

Listing 4.159: WorldManager extensions to draw() to support views

```
  ...
  // Bounding box coordinates are relative to Object,
  // so convert to world coordinates.
  temp_box = getWorldBox(p_temp_o)

  // Only draw if Object would be visible on window (intersects view).
  if boxIntersectsBox(temp_box, view) then
    p_temp_o -> draw()
  end if
  ...
```

In order to give the game programmer control over the view, the WorldManager is extended as indicated in Listing 4.160. The method `setViewPosition()` positions the view at a specific (x,y) world coordinate, and `setViewFollowing()` automatically moves the view to keep the indicated game object, stored in the private attribute `p_view_following`, in the center of the window. The latter is useful when the game programmer wants the camera to follow an avatar as it moves around the world, such as is typical in a platformer game.

Listing 4.160: WorldManager extensions to support view following Object

```
private:
 Object *p_view_following;  // Object view is following.

public:
 // Set view to center window on position view_pos.
 // View edge will not go beyond world boundary.
 void setViewPosition(Vector view_pos);

 // Set view to center window on Object.
 // Set to NULL to stop following.
 // If p_new_view_following not legit, return -1 else return 0.
 int setViewFollowing(Object *p_new_view_following);
```

Pseudo code for the method `setViewPosition()` is shown in Listing 4.161. The method takes in a position in the game world and sets the view to be centered on that position. In the first two blocks of code, the method makes sure that the edges of the view do not go outside of the edges of the game world, horizontally and then vertically. If it does, then the boundary is moved to flush with the edge.

Listing 4.161: WorldManager setViewPosition()

```
0  // Set view to center window on position view_pos.
1  // View edge will not go beyond world boundary.
2  void WorldManager::setViewPosition(Vector view_pos)
3
4    // Make sure horizontal not out of world boundary.
5    x = view_pos.getX() - view.getHorizontal()/2
6    if x + view.getHorizontal() > boundary.getHorizontal() then
7      x = boundary.getHorizontal() - view.getHorizontal()
8    end if
9    if x < 0 then
10     x = 0
11   end if
12
13   // Make sure vertical not out of world boundary.
14   y = view_pos.getY() - view.getVertical()/2
15   if y + view.getVertical() > boundary.getVertical() then
16     y = boundary.getVertical() - view.getVertical()
17   end if
18   if y < 0 then
19     y = 0
20   end if
21
22   // Set view.
23   Vector new_corner(x, y)
24   view.setCorner(new_corner)
```

Pseudo code for the method `setViewFollowing()` is shown in Listing 4.162. The first block of code starting on line 6 checks if `p_new_view_following` is `NULL` – if so, this indicates the game programmer intends to stop having the view follow any particular Object.

The second block of code starting on line 12 iterates over all the Objects in the world. Each Object is compared to the `p_new_view_following` to make sure the game programmer has requested to follow a legitimate object. The boolean variable `found` is set to true if the Object is matched with one of the known game objects.

The third block of code starting on line 17 sets the `p_view_following` variable if the Object has been found and, if so, sets the view position to be centered on that Object.

If the Object is not found, the method returns -1 (an error).

Listing 4.162: WorldManager setViewFollowing()

```
0  // Set view to follow Object.
1  // Set to NULL to stop following.
2  // If p_new_view_following not legit, return -1 else return 0.
3  int WorldManager::setViewFollowing(Object *p_new_view_following)
4
5    // Set to NULL to turn 'off' following.
6    if p_new_view_following is NULL then
7      p_view_following = NULL
8      return ok
9    end if
10
11   // ...
12   // Iterate over all Objects.   Make sure p_new_view_following
13   // is one of the Objects, then set found to true.
```

```
  // ...

  // If found, adjust attribute accordingly and set view position.
  if found then
    p_view_following = p_new_view_following
    setViewPosition(p_view_following -> getPosition)
    return ok
  end if

  // If we get here, was not legit.  Don't change current view.
  return error
```

The last adjustment is to the WorldManager `moveObject()` method. Here, at the very end of the method, if the Object has been successfully moved and the Object being moved is the same as the Object being followed, then the view is adjusted to the new position of the Object. This logic is shown in Listing 4.163.

Listing 4.163: WorldManager extensions to moveObject() to support views

```
  ...
  // If view is following this object, adjust view.
  if p_view_following is p_o then
    setViewPosition(p_o -> getPosition())
  end if
  ...
```

4.13.4.1 Advanced View Control (optional)

As implemented, when following an Object with the view, the camera keeps the Object dead-center on the screen at all times (subject to the world boundaries, of course). For the player, a camera locked in this mode can be tedious for a game where the player is moving the view a lot. There are a variety of advanced camera control techniques that could be incorporated into Dragonfly to provide for more advanced camer control techniques, including *zoning*, *blending* and *rails*. The interested developer is encouraged to see Phil Wilkins excellent talk on dynamic camera systems [9] with many more details in Mark Haigh-Hutchinson's book on real-time cameras [5].

An additional camera technique shown here is *dynamics*. With dynamics, the camera still follows an Object, but does not require the Object to be strictly in the middle of the screen. Instead, the Object can stay within a smaller rectangle inside the screen without the camera moving. This provides some "slack" that allows the Object to be within a center area before the camera needs to move.

To support these dynamics, the WorldManager is extended with a `view_slack` attribute which is a Vector representing the (x, y) dimensions of the inner rectangle. The default value for `view_slack`, set in the WorldManager constructor, should be (0, 0). Attributes to get and set `view_slack`, (`getViewSlack()` and `setViewSlack()`, respectively) should also be created.

Then, WorldManager `moveObject()` is re-factored to support dynamics, as shown in Listing 4.164.

Listing 4.164: WorldManager extensions to moveObject() to support view dynamics

```
0  ...
1  // If view is following this object, adjust view as appropriate.
2  if p_view_following is p_o then
3
4    // Get center of view.
5    view_center_x = view.getCorner().getX() + view.getHorizontal()/2
6    view_center_y = view.getCorner().getY() + view.getVertical()/2
7
8    // Compute inner "slack" Box edges.
9    left = view_center_x - view.getHorizontal() * view_slack.getX()/2
10   right = view_center_x + view.getHorizontal() * view_slack.getX()/2
11   top = view_center_y - view.getVertical() * view_slack.getY()/2
12   bottom = view_center_y + view.getVertical() * view_slack.getY()/2
13
14   new_pos = p_o -> getPosition()
15
16   // Move view right/left?
17   if (new_pos.getX() < left)
18     view_center_x -= left - new_pos.getX()
19   else if (new_pos.getX() > right)
20     view_center_x += new_pos.getX() - right
21
22   // Move up/down?
23   if (new_pos.getY() < top)
24     view_center_y -= top - new_pos.getY()
25   else if (new_pos.getY() > bottom)
26     view_center_y += new_pos.getY() - bottom
27
28   // Set new view position.
29   setViewPosition(Vector(view_center_x, view_center_y))
30 end if  // following p_o
31 ...
```

The first block of code, lines 4 to 12, compute the edges of the inner Box (the "slack" in the camera dynamics). The next block of code, lines 16 to 26, compare the position of the Object the camera is following to these edges, moving the edge as appropriate to keep the Object within the inner Box. The last bit of code, line 29, actually adjusts the view to the new location.

4.13.4.2 Using Views

The view support added to Dragonfly can be used by the game programmer to provide the player with a game world larger than the window. Assume, for example, that in Saucer Shoot (see Section 3.3 on page 15), the game programmer wants the game world to be about twice as large vertically as a window. This can be done by explicitly setting the world boundary in `game.cpp`, as shown in Listing 4.165, setting the view boundary to be the typical size of 80x24.

Listing 4.165: Explicitly setting game world boundaries

```
0 // Set world boundaries to 80 horizontal, 50 vertical.
1 Vector corner(0,0)
```

```
Box world_boundary(corner, 80, 50)
WorldManager setBoundary(world_boundary)

// Set view to 80 horizontal, 24 vertical.
Box view(corner, 80, 24)
WorldManager setView(view)
```

With the WorldManager controlling the world boundaries, code that generates the out event (see Section 4.10.1.4 on page 148) should be refactored to use the WorldManager `getBoundary()` instead of the DisplayManager window limits.

With the world larger than the window, the intent is probably to always keep the Hero centered vertically in the window. This could be done by extending the original `move()` method (Listing 3.11 on page 46) with the code defined in Listing 4.166. Basically, when the Hero moves vertically, the new code adjusts the view by the same vertical amount.

Listing 4.166: Example Hero extension to move() to support views

```
// Always keep Hero centered in window.
void Hero::move(float dy)
  // Move as before...

  // Adjust view.
  Box new_view = WorldManager getView();
  Vector corner = new_view.getCorner();
  corner.setY(corner.getY() + dy);
  new_view.setCorner(corner);
  WorldManager setView(new_view);
```

Alternatively, the WorldManager can just be told to follow the Hero by calling @@ `setViewFollowing()` in the Hero's constructor, as in Listing 4.167.

Listing 4.167: Example Hero extension to support views

```
// Always keep Hero centered in window.
void Hero::Hero()
  // ...
  WorldManager setViewFollowing(this);
```

Tip 21! Player camera control. Game programmers can give the player camera control without having an avatar with the following trick: a `SPECTRAL` game object is created without a sprite. The Object is programmed to respond to mouse or arrow keys by changing position – left, right, up, down. Then, Dragonfly is told to follow the game object via `setViewFollowing()`. To the player, it appears as if the controls are changing the camera!

4.13.5 Development Checkpoint #10!

Continue Dragonfly development, using Boxes to first provide bounding boxes for Objects and next to provide view and world boundaries. Steps:

1. Add the Box class, referring to `Box.h` in Listing 4.148. Add `Box.cpp` to the project and stub out each method so it compiles. The Box is really just a container, but test the Box class thoroughly, anyway. Do this outside of the engine, making sure that the attributes can all be get and set properly and that the constructor with corner, horizontal and vertical dimensions specified works.

2. Extend the Object class support bounding Boxes, referring to Listing 4.149. Test that Object bounding boxes can be set and retrieved properly. Be sure to extend `setSprite()` to set the Object Box to the dimensions of the associated Sprite, linked to the Animation attribute (`m_animation`).

3. Write the utility function `boxIntersectsBox()` (Listing 4.151) that determines if two Boxes overlap. Test this with a program that uses Boxes of a variety of dimensions and locations with all sorts of intersection combinations (including containment). Verify all test cases work before proceeding – this function gets called a *lot* in a typical game.

4. Replace `positionsIntersect()` with `boxIntersectsBox()` in the WorldManager. First, verify using former test code that the engine still works with single character Objects. Then, create test code with multi-character Sprites, testing a variety of Objects and collisions. Use one non-moving Object with one moving Object at first to make debugging simpler.

5. Add views, starting by extending the WorldManager to support views as in Listing 4.155. Test the get and set methods for the `view` and `boundary` attributes.

6. Write and test the DisplayManager `worldToView()`, referring to Listing 4.157 as needed. Put calls to `worldToView` in the DisplayManager `drawCh()`, as per Listing 4.158. Test that previous code without views still works, then test that having a view that is not positioned at the world's origin works as expected. At this point, use just a hard-coded view in the WorldManager.

7. Extend the WorldManager `draw()` method to only draw Objects that are in the view, as shown in Listing 4.159. Test with a variety of Objects that are in the view, completely out of the view, and partially in/out of the view.

8. Add settings to the WorldManager that enable setting the view, including attributes and methods from Listing 4.160. Refer to details from Listing 4.161 and Listing 4.162, as needed. Extend WorldManager `moveObject()` as in Listing 4.163.

9. For an integrated test, modify the Saucer Shoot tutorial to use views. First, set the game world boundaries as in Listing 4.165, then modify the Hero `move()` method as in Listing 4.166. Test thoroughly, making sure the window is smaller than the game world settings. Once convinced all works, revert back to the former `move()` method and have the view follow the `Hero()` as in Listing 4.167. Test this thoroughly, too.

4.14 Audio

While sight and feel (interaction) are core elements of most games, sound is nearly as important. Dragonfly supports audio* using the built-in capabilities of the Simple and Fast Multimedia Library (SFML).

4.14.1 Simple and Fast Multimedia Library – Audio

SFML provides audio support and recognizes two distinct types: 1) *sound effects*, which are typically small (fitting in the computer's main memory) and, for games, are typically played in response to a game action. Examples from Saucer Shoot (Section 3.3) include the "fire" sound when the Hero shoots a Bullet and the "explode" sound when a Saucer is destroyed. The class `sf::Sound` supports this type of audio (i.e., sound effects). 2) *music*, which is typically longer (e.g., an entire song) and, for games, is often played continuously in the background, either during game loading screens or as game action takes place. An example from Saucer Shoot is the background music that plays during the initial game start screen. The class `sf::Music` supports this type of audio. These differences between sound effects and music influence how they are handled technically by the SFML classes. For example, sound effects are usually small enough to load into memory, while music, being larger, is streamed directly from disk. SFML supports most common audio file formats – the full list can be found in online documentation. Note, `<SFML/Audio.hpp>` is needed as an `#include` for all SFML audio.

For `sf::Sound`, the sound data is not stored directly in the object but via a separate class called `sf::SoundBuffer`. The sound buffer holds the audio samples in an array of 16-bit integers. Each audio sample is the amplitude of the sound wave at a given point in time. Sound data from a file (e.g., a `.wav` file) can be loaded into a `sf::SoundBuffer` with the method `loadFromFile()`. Use of this method is shown in the top part of Listing 4.168.

Once the audio data is loaded, the buffer can be assigned to an `sf::Sound` object via `setBuffer()` and then played via `play()`. The latter half of Listing 4.168 shows a code fragment to do this. Note, sounds can also be played simultaneously without any issues.

Listing 4.168: SFML playing a sound

```
0 #include <SFML/Audio.hpp>
1
2 sf::SoundBuffer buffer;
3 if (buffer.loadFromFile("sound.wav") == false)
4   // Error!
5
6 sf::Sound sound(buffer);
7 sound.play();
```

Unlike `sf::Sound`, `sf::Music` does not pre-load audio data but instead streams directly from a file. So, this means opening a file and then just playing it, as in Listing 4.169.

* **Did you know (#11)?** Dragonflies cannot hear, at least not the same way humans can. However, dragonflies do have receptors in their antennae and legs that are sensitive to pressure changes, such as air pressure changes from sounds. These receptors supplement their vision. – Ann Cooper. *Dragonflies – Q&A Guide: Fascinating Facts About Their Life in the Wild*, Stackpole Books, September 2014.

Listing 4.169: SFML playing music

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

sf::Music music;
if (music.openFromFile("music.wav") == false)
  // Error!

music.play();
```

Looping for both sound and music can be done with `setLooping()`, indicating `true` to loop (repeat) the audio from the beginning when at the end and `false` to stop the audio when at the end. Both sounds and music can be stopped with `stop()` and paused with `pause()`.

One key difference between `sf::Music` and `sf::Sound` is that SFML does not allow copying of `sf::Music` objects (presumably, this is to help SFML manage resources more efficiently). To illustrate how this constrains use, the code samples in Listing 4.170 provide examples of compile-time errors, if tried.

Listing 4.170: SFML sf::Music not copyable

```
sf::Music music;
sf::Music music_copy = music; // Error!

void makeItSo(sf::Music music_parameter) {
    ...
}
makeItSo(music); // Error!
```

4.14.2 Dragonfly Audio

To add Dragonfly support for audio, SFML audio support is wrapped by two classes (Sound and Music), with sound and and music assets managed by the ResourceManager. Wrapping the SFML audio classes in this way provides for a simpler interface for game programming and, equally important, means that if Dragonfly were to use an alternate library for audio support, game code written for Dragonfly would not need to be changed. For game code that wishes to exploit alternate features of SFML audio, the base SFML types (`sf::Sound` and `sf::Music`) are exposed.

4.14.2.1 The Sound Class

Dragonfly provides a Sound class for supporting basic sound effects, with the header file shown in Listing 4.171. The primary attributes provide for a `sf::Sound` (`sound`) and a `sf::SoundBuffer` (`sound_buffer`). Note, the `sf::Sound` attribute is a pointer since the `sf::Sound` allocation needs to allocated buffer upon instantiating. The attribute `m_p_sound` should be set to `NULL` in the Sound constructor. The method `loadSound()` calls `loadFromFile()`, using the indicated filename and then allocates the `sf::Sound` and sets the sound buffer. See Listing 4.168 for examples. The `string label` is text to identify the sound for the game programmer, similar to the label used by the game programmer to identify a Sprite (see Listing 4.119 on page 156). The methods `setLabel()` and `getLabel()`

are used to set and get the label, respectively. The methods `play()`, `stop()`, and `pause()`, call the corresponding methods on the `sound` object. The method `play()` has an option to loop the sound, too, which is done via `setLooping()`. Looping is off by default. To allow the game programmer to manipulate the `sf::Sound` object directly, `getSound()` returns `sound`. The Sound destructor (`~Sound()`) should `delete` the `sf::Sound` object pointed to by `m_p_sound`, if allocated.

Listing 4.171: Sound.h

```
// System includes.
#include <string>
#include <SFML/Audio.hpp>

class Sound {

 private:
  sf::Sound *m_p_sound;            // The SFML sound.
  sf::SoundBuffer m_sound_buffer; // SFML sound buffer associated with
      sound.
  std::string m_label;             // Text label to identify sound.

 public:
  Sound();
  ~Sound();

  // Load sound buffer from file.
  // Return 0 if ok, else -1.
  int loadSound(std::string filename);

  // Set label associated with sound.
  void setLabel(std::string new_label);

  // Get label associated with sound.
  std::string getLabel() const;

  // Play sound.
  // If loop is true, repeat play when done.
  void play(bool loop=false);

  // Stop sound.
  void stop();

  // Pause sound.
  void pause();

  // Return SFML sound.
  sf::Sound getSound() const;
};
```

4.14.2.2 The Music Class

Dragonfly provides a Music class for supporting music, with the header file shown in Listing 4.172. The primary attribute is `sf::Music` (`music`). The method `loadMusic()` calls

`openFromFile()`, using the indicated filename. See Listing 4.169 for examples.

Note, as mentioned above, SFML does not allow copying of `sf::Music` objects (See Listing 4.170). That is why the Music copy and assignment operators are private. As a note, making the non-private can work, too, but then exposes potentially confusing SFML errors to the game program when linking.

The `string label` is text to identify the music for the game programmer, as for Sounds (see Listing 4.171) and Sprites (see Listing 4.119 on page 156). The methods `setLabel()` and `getLabel()` are used to set and get the label, respectively. The methods `play()`, `stop()`, and `pause()`, call the corresponding methods on the `music` object. The method `play()` has an option to loop the sound, too, which is done via `setLooping()`. Looping is on by default. To allow the game programmer to manipulate the `sf::Music` object directly, `getMusic()` returns a pointer to `music`. A pointer is used because SFML does not allow `music` to be copied.

Listing 4.172: Music.h

```
0  // System includes.
1  #include <string>
2  #include <SFML/Audio.hpp>
3
4  class Music {
5
6   private:
7    Music(Music const&);           // SFML doesn't allow music copy.
8    void operator=(Music const&); // SFML doesn't allow music assignment.
9    sf::Music m_music;            // The SFML music.
10   std::string m_label;          // Text label to identify music.
11
12  public:
13   Music();
14
15   // Associate music buffer with file.
16   // Return 0 if ok, else -1.
17   int loadMusic(std::string filename);
18
19   // Set label associated with music.
20   void setLabel(std::string new_label);
21
22   // Get label associated with music.
23   std::string getLabel() const;
24
25   // Play music.
26   // If loop is true, repeat play when done.
27   void play(bool loop=true);
28
29   // Stop music.
30   void stop();
31
32   // Pause music.
33   void pause();
34
35   // Return pointer to SFML music.
36   sf::Music *getMusic();
```

```
};
```

4.14.2.3 Extending the ResourceManager for Audio

With Sound and Music in place, the ResourceManager is extended to manage sound and music resources. The needed extensions are shown in Listing 4.173. Audio is handled similarly to Sprites, with fixed sized arrays for Sound and Music objects and count variables for each. The counts should be initialized to 0 upon `startUp()`. The "load" methods load the Sound and Music resources from files and the "unload" methods do the reverse. Two "get" methods provide pointers to both Sound and Music objects identified by a label.

Listing 4.173: ResourceManager extensions to support audio

```
const int MAX_SOUNDS = 50;
const int MAX_MUSICS = 50;

 private:
  Sound sound[MAX_SOUNDS];       // Array of sound buffers.
  int sound_count;               // Count of number of loaded sounds.
  Music music[MAX_MUSICS];       // Array of music buffers.
  int music_count;               // Count of number of loaded musics.

 public:
  // Load Sound from file.
  // Return 0 if ok, else -1.
  int loadSound(std::string filename, std::string label);

  // Remove Sound with indicated label.
  // Return 0 if ok, else -1.
  int unloadSound(std::string label);

  // Find Sound with indicated label.
  // Return pointer to it if found, else NULL.
  Sound *getSound(std::string label);

  // Associate file with Music.
  // Return 0 if ok, else -1.
  int loadMusic(std::string filename, std::string label);

  // Remove label for Music with indicated label.
  // Return 0 if ok, else -1.
  int unloadMusic(std::string label);

  // Find Music with indicated label.
  // Return pointer to it if found, else NULL.
  Music *getMusic(std::string label);
```

The `loadSound()` method to load a sound from a file is shown in Listing 4.174. Error checking is done to ensure the `sound` array is not filled. On line 9, the call to `Sound loadSound()` is made. If successful, the Sound is added to the array. Any error condition returns -1, while success returns 0.

Listing 4.174: ResourceManager loadSound()

```
// Load Sound from file.
// Return 0 if ok, else -1.
int ResourceManager::loadSound(std::string filename, std::string label)

  if sound_count is MAX_SOUNDS then
    writeLog("Sound array full.")
    return error
  end if

  if sound[sound_count].loadSound(filename) is -1 then
    writeLog("Unable to load from file")
    return error
  end if

  // All is well.
  sound[sound_count].setLabel(label)
  increment sound_count
  return ok
```

blah

The complement of `loadSound()` is `unloadSound()`, shown in Listing 4.175. The method loops through the Sounds in the ResourceManager. If the label being looked for (`label`) matches the label of one of the Sounds (`getLabel()`) then that is the Sound to be unloaded. SFML does not have a method to actually free up memory for sounds, so the rest of the Sounds in the array are moved down one. Lastly, the sound count is decremented by one. If the loop terminates without a label match, the sound to be unloaded is not in the ResourceManager and an error is returned.

Listing 4.175: ResourceManager unloadound()

```
// Remove Sound with indicated label.
// Return 0 if ok, else -1.
int ResourceManager::unloadSound(std::string label)

  for i = 0 to sound_count-1

    if label is sound[i].getLabel() then

      // Scoot over remaining sounds
      for j = i to sound_count-2
        sound[j] = sound[j+1]
      end for

      decrement sound_count

      return ok

    end if

  end for

  return error // Sound not found.
```

The final method needed by the ResourceManager for sound is `getSound()`, with pseudo code show in Listing 4.176. The method loops through all the Sounds in the ResourceManager. The first Sound that matches `label` is returned. If line 10 is reached, the label was not found and an error (`NULL`) is returned.

Listing 4.176: ResourceManager getSound()

```
0  // Find Sound with indicated label.
1  // Return pointer to it if found, else NULL.
2  Sound *getSound(std::string label);
3
4    for i = 0 to sound_count-1
5      if label is sound[i].getLabel() then
6        return (&sound[i])
7      end if
8    end for
9
10   return NULL // Sound not found.
```

Methods to `loadMusic()`, `unloadMusic()` and `getMusic()` are similar to `loadSound()`, `unloadSound()` and `getSound()`, respectively. The exception is that since Music is not copyable, the elements cannot be "scooted over" in the array. Instead, the found label is just set to empty (`""`). This means that the empty label is not allowed in `loadMusic()` to distinguish from an unloaded Music.

4.14.3 Using Audio

At this point, the game programmer can load sounds and music into the ResourceManager in a few simple steps. The first step is to obtain/create an audio file, such as those provided by the Dragonfly tutorial (see Section 3). The second step is to load the audio file, as a Sound or Music, into the ResourceManager so the game can make use of it. Example code to load sound effects for Saucer Shoot is shown in Listing 3.7 on page 44 and example code to load music is shown in Listing 3.9 on page 45.

Once loaded, the game programmer can play audio at an appropriate point. For example, Saucer Shoot plays music during the game start screen (see Listing 3.8 on page 44) and plays a sound effect when the player fires a bullet (see Listing 3.10 on page 45).

4.14.4 Development Checkpoint #11!

Continue Dragonfly development to support audio. Steps:

1. Make the Sound and Music classes, referring to Listings 4.171 and 4.172, respectively. Separately implement and test both classes outside of the game engine. This means playing various sound effects and music. The audio files from the Saucer Shoot tutorial (see Section 3.3.12 on page 43) can be used for this. Make sure to test error conditions (e.g., the file cannot be found), too.

2. Extend the ResourceManager to support sound effects, referring to Listing 4.173 as needed. Write and test methods to `loadSound()`, `unloadSound()`, and `getSound()`. Refer to Listings 4.174, 4.175, and 4.176, as needed.

3. Extend the ResourceManager to support music, referring to Listing 4.173 as needed. Write and test methods to `loadMusic()`, `unloadMusic()`, and `getMusic()`. Base the music support implementation off the corresponding sound support previously implemented.

4.15 Filtering Events (optional)

Up to now, all game objects get every event when Manager `onEvent()` is called. For example, in the GameManager game loop, all Objects get a step event every loop iteration. This is useful for Objects that need to do something each step, like the Saucer Shoot Hero that uses step events to determine when it can shoot again (see Listing 3.5 on page 25). But many game objects do not need to update themselves each step event – such as walls, trees or rocks. The general idea, that not all objects want all step events, holds for other events, too. For example, keyboard events, generated when a player presses keys, are usually only handled by the object that the player controls (e.g., the Hero). The way the event handler works (see Listing 4.60), an event that is not acted upon can just be ignored, but that still means the Object `eventHandler()` method is invoked, which is inefficient at best, and can lead to unexpected errors if the game code does not ignore events properly, at worst.

The solution is to filter events, only passing specific events to Objects if they have indicated interested in events of that type. When an Object does want a specific event, it registers with the manager in charge of that event. For example, an Object that wants to get step events registers interest in that event with the GameManager. When the event occurs, the manager invokes the `eventHandler()` method only for those Objects that are interested. Continuing the example, every game loop, the GameManager does not send an EventStep to all Objects (as it does currently), but only to those Objects that have registered interest. When an Object is no longer interested in an event, it explicitly un-registers interest. Note, the engine will do this un-registration automatically, too, when an Object is removed from the game world. Otherwise, an Object would receive an event even though it had been removed and deleted, a certain error.

From another vantage, providing for updates to Objects when events occur, and only providing the updates to interested objects is a form of an *observer* design pattern (sometimes called a *publish-subscribe* design pattern).

Figure 4.8 depicts the general idea. Objects, depicted by the grey boxes on the bottom, register their interest in an event with the appropriate manager, depicted by the ovals at the top. Objects may be interested in more than one event or in no events at all. For example, Object 1 is interested in only one event managed by Manager A, while Object 3 is interested in two events managed by Manager C and one event managed by Manager B, and Object n is interested in no events at all. Managers keep track of which Objects are interested in the events they manage, hence the two-way arrows. Managers may be responsible for no events (e.g., the LogManager), or many events. Even Managers that are responsible for one or more events may still have no Objects that are interested. For example, this may be the case for Manager *X* in Figure 4.8.

Figure 4.9 depicts a close-up view of data structures inside Object and Manager needed to support filtering events. The Object on the left, using Object 3 from Figure 4.8, keeps the names of the events in which it is interested in an array of strings, called `event_name[]`. It also has an attribute, `event_count`, for stores a count of the number of events in which it is interested.

The Manager on the right, Manager C from Figure 4.8, has an array, `event_name[]`, of the names of interested events as strings which aligns via a parallel array with `obj_list[]` which stores the Objects that are interested in that event. The attribute `event_count`

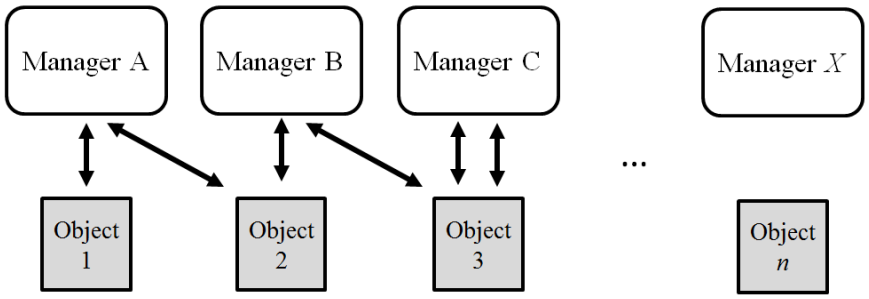


Figure 4.8: Event interest

stores the count of the number of events in which it is interested.

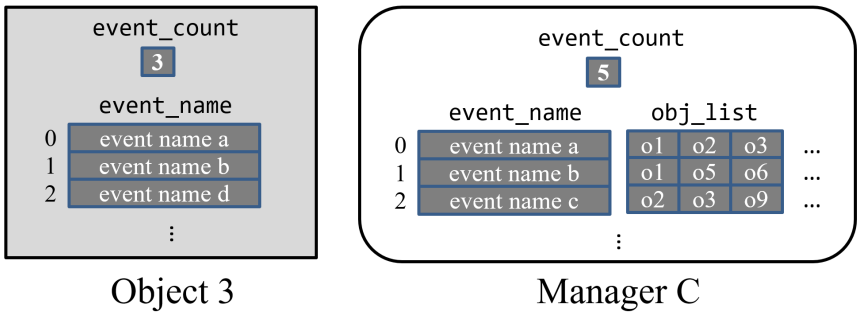


Figure 4.9: Event interest (zoom)

In order to build this functionality, the Manager class needs to be extended to support event interest management. To start, the Manager stores a list of all the events in which Objects have registered interest and, for each event, a list of the Objects that have registered interest. Listing 4.177 shows code fragments that provide attributes and methods for the Manager class to support interest management.

Listing 4.177: Manager extensions to support interest management

```
0  const int MAX_EVENTS = 100   // Maximum number of different events.
1
2  private:
3   int event_count;                          // Number of events.
4   std::string event[MAX_EVENTS];            // List of events.
5   ObjectList obj_list[MAX_EVENTS];          // Objects interested in event.
6
7   // Check if event is handled by this Manager.
8   // If handled, return true else false.
9   // (Base Manager always returns false.)
10  virtual bool isValid(std::string event_name) const;
11
12 public:
13  // Indicate interest in event.
14  // Return 0 if ok, else -1.
```

```
15   // (Note, doesn't check to see if Object is already registered.)
16   int registerInterest(Object *p_o, std::string event_type);
17
18   // Indicate no more interest in event.
19   // Return 0 if ok, else -1.
20   int unregisterInterest(Object *p_o, std::string event_type);
21
22   // Send event to all interested Objects.
23   // Return count of number of events sent.
24   int onEvent(const Event *p_event) const;
```

MAX_EVENTS is defined to be 100, which is large enough for most games. In fact, most games have far fewer than 100 different types of events – typically no more than 10 – but any extra, unused capacity has little overhead.

The private attributes provide data structures to store the events. The variable event_list_count keeps track of how many unique events this manager has been asked to register for (initialized to 0 in the constructor). The events themselves are stored as strings (the event type, as specified in Listing 4.51) in the array event[], and the objects registered for the corresponding event are held in obj_list[]. Note that event[] and obj_list[] are parallel arrays, so that the ith element of event[] corresponds to the ith element of obj_list[].

When an Object is interested in an event handled by a particular Manager, it invokes the method registerInterest(), providing a pointer to the Object itself (i.e., this) and the event name.

When an Object is no longer interested in an event (and when it is being deleted), it invokes the method unregisterInterest(), providing a pointer to itself and the event name.

In order to protect a game programmer from registering for interest in an event with a manager that does not handle that event, the Manager checks the isValid() function before accepting the registration. This method is virtual so that derived managers can specify which game events, if any, they manage. When an event occurs, the onEvent() method iterates through the list of all Objects that had registered for interest in the event and sends each of them the event by invoking their eventHandler() methods.

The method registerInterest() is provided in Listing 4.178. The first block of code, lines 4 to 9, checks to see if there is already an Object that has registered interest in this event. If so, line 6 adds the indicated Object to the list.

The second block of code, lines 12 to 18, is triggered when the event being registered for has no other Objects in the list. In this case, the arrays are first checked to see if the maximum number of events has been reached. If so, the routine needs to return an error – it will be up to the game code to figure out how to proceed.[20] If there is room, the event and Object are added to the end the lists and the number of events (event_count) is incremented.

Listing 4.178: Manager registerInterest()

```
0  // Indicate interest in event.
1  int Manager::registerInterest(Object *p_o, std::string event_type)
```

[20] Another reason that all system and engine calls should be error checked!

```
2
3   // Check if previously added this event.
4   for i = 0 to event_count-1
5     if event_name[i] is event_type then
6       insert object into obj_list[i]
7       return // Ok.
8     end if
9   end for
10
11  // Otherwise, this is new event.
12  if event_count >= MAX_EVENTS then
13    return // Error, list is full.
14  end if
15  event_name[event_count] = event_type
16  clear obj_list[event_count]  // In case ''re-using'' scooted list.
17  insert object into obj_list[event_count]
18  increment event_count
19
20  return // Ok.
```

`unregisterInterest()` is shown in Listing 4.179. The first block of code, lines 4 to 8, looks for the event that is being unregistered for. When found, the corresponding Object is removed in line 6. Note, if event is not found, the method returns an error (e.g., -1) – this is *not* shown in the pseudo code. Also, if the Object to be removed is not found in `obj_list`, an error should be returned.

The second block of code, lines 11 to 15, checks if the Object list at the spot of the event is empty. If so, it "scoots" the items in `event` and `obj_list` over and reduces the list count by one. Line 31 of Listing 4.32 shows an example of how this is done for an array of integers.

Listing 4.179: Manager unregisterInterest()

```
0 // Indicate no more interest in event.
1 int Manager::unregisterInterest(Object *p_o, std::string event_type)
2
3   // Check for event.
4   for i = 0 to event_count-1
5     if event_name[i] is event_type then
6       remove object from obj_list[i]
7     end if
8   end for
9
10  // Is list now empty?
11  if obj_list[i] is empty then
12    scoot over all items in object_list[]
13    scoot over all items in event_name[]
14    decrement event_count
15  end if
16
17  return // Ok.
```

With the Manager storing events and Objects registered for them, the `onEvent()` method can be refactored, as shown in Listing 4.180. Line 5 iterates through all the events that have been registered for, and line 7 compares the type of the event (via the `getType()`

method of Event) to the event list items. If the event is found, the code on lines 7 to 10 iterates through all Objects, invoking the `eventHandler()` method for each Object, passing in the event (`p_event`). The count of events sent is also incremented, and returned when the method ends.

Listing 4.180: Manager onEvent() refactored to support filtering events

```
0  // Send event to all interested Objects.
1  // Return count of number of events sent.
2  int Manager::onEvent(const Event *p_event) const
3    count = 0
4
5    for i = 0 to event_count-1
6      if event_name[i] is p_event type then
7        for j = 0 to object_list[i] count
8          call object_list[i][j] -> eventHandler() with p_event
9          increment count
10       end for (j)
11   end for (i)
12
13   return count
```

With the above code in place, all Objects no longer receive a step event. Instead, only those that have done a `registerInterest(STEP_EVENT)` with the GameManager get the step event. Similarly for the keyboard and mouse events.

Not all managers handle all events. For example, it makes no sense for a game object to register for interest in a step event with the WorldManager (or LogManager!). In order to help the game programmer from making the mistake of registering for interest with the wrong manager, each manager defines an `isValid()` function. The base class Manager `isValid()` method is declared as in Listing 4.181. The method is declared `virtual` so that derived classes, such as the GameManager, can define their own `isValid()` methods, as appropriate. The base Manager `isValid()` always returns `false` – there are no real instances of the base Manager class and, if there were, it would not handle any events.

Listing 4.181: Manager isValid()

```
0    // Check if event is handled by this Manager.
1    // If handled, return true else false.
2    virtual bool isValid(std::string event_type) const;
```

The pseudo code for each derived manager class `isValid()` is shown in Listing 4.182. Note, the "DerivedManager" is not the real name of the class – rather, the name is replaced with the actual manager name (e.g., GameManager) when defined. The body of the method checks if the event is a valid event (e.g., a STEP_EVENT in the GameManager). If so, it returns `true`. Otherwise, it returns `false`.

Listing 4.182: Derived manager isValid()

```
0  // Check if event is allowed by this Manager.
1  // If allowed, return true else false.
2  bool DerivedManager::isValid(std::string event_type) const
3
4    if event_type is VALID EVENT1 then
```

```
    return true
  end if

  if event_type is VALID EVENT2 then
    return true
  end if

  ...

  return false
```

As a specific example, pseudo code for the InputManager `isValid()` method is shown in Listing 4.183.

Listing 4.183: InputManager isValid()

```
// Input manager only accepts keyboard and mouse events.
// Return false if not one of them.
bool isValid(std::string event_name) const

  if event_name is keyboard event
    return true
  else if event_name is mouse event then
    return true
  else
    return false
  end if
```

The `isValid()` method needs to be defined for the GameManager, Input Manager and WorldManager (which accepts all events the other two Managers do not).

With `isValid()` defined, the Manager method `registerInterest()` is extended to call `isValid()` before adding the game object to the list of interested objects. If `isValid()` returns `false`, the Object (and event) are not added.

The last bit of bookkeeping that needs to be done is to extend the Object class so each Object keeps track of the events it has in which it has registered interest. That way, if an Object goes out of scope (is deleted) it can automatically unregister for interest in all events. Not doing this automatic unregistration would mean if the event occurred, the manager would try to send the event to the Object, but since the Object was deleted and the memory no longer allocated, a segfault (a spurious memory error) would occur.

Methods `registerInterest()` and `unregisterInterest()` are declared as in Listing 4.184. Like the Manager's methods, the Object's interest management methods both return 0 if successful, and -1 if there is an error. Unlike in the Manager, the Object's methods only take the event string they are interested in. The array on line 2 and associated integer on line 1, are to keep track of the events this Object has registered in. Only the string is needed here, since each event type matches up uniquely with a specific manager. For example, if the Object is interested in a step event, that is registered only with the GameManager.

Listing 4.184: Object class extensions for registerInterest()

```
 private:
  int event_count;
```

```
2   std::string event_name[MAX_OBJ_EVENTS];
3
4  public:
5   // Register for interest in event.
6   // Keeps track of manager and event.
7   // Return 0 if ok, else -1
8   int registerInterest(std::string event_type);
9
10  // Unregister for interest in event.
11  // Return 0 if ok, else -1
12  int unregisterInterest(std::string event_type);
```

The Object's `registerInterest()` method is provided in Listing 4.185. The first block of code checks to see if there is room in the array of events by comparing `event_count` to the maximum (`MAX_OBJ_EVENTS`, defined in `Object.h` to be some reasonable maximum say, 100).

The next block of code checks to see if the event is a step event. If so, it registers for interest with the GameManager by calling `registerInterest()`, passing in the pointer to the current Object (`this`) as well as the event string. As more managers are defined (e.g., InputManager), more cases can be handled similarly to the step event (in the "..." region in line 14). By default, all remaining events are handled by the WorldManager – that way, user defined events (such as the "nuke" in Saucer Shoot, see Section 3.3.8 on page 34) can be accommodated. Note, the `registerInterest()` method call to each individual manager can fail, depending upon their definition of `isValid()` and the number of Objects already registered, so the calls should be error checked.

The last block of code starting at line 20 keeps track of the event name that has been registered by adding it to the array and incrementing the count of events.

Listing 4.185: Object registerInterest()

```
0  // Register for interest in event.
1  // Keeps track of manager and event.
2  // Return 0 if ok, else -1
3  int Object::registerInterest(std::string event_type)
4
5    // Check if room.
6    if event_count is MAX_OBJ_EVENTS then
7      return error
8    end if
9
10   // Register with appropriate manager.
11   if event_type is STEP_EVENT then
12     GameManager registerInterest(this, event_type)
13   else if
14     ...
15   else
16     WorldManager registerInterest(this, event_type)
17   end if
18
19   // Keep track of added event.
20   event_name[event_count] = event
21   increment event_count
22
```

```
23    // All is well.
24    return ok
```

The Object's `unregisterInterest()` method is provided in Listing 4.186. The first block of code checks to see if the event was previously registered – if it was not, an error (-1) is returned. Similar to `registerInterest()`, the next block of code checks first to see if the event is a step event and, if so, unregistering for interest with the GameManager. Other Managers are handled similarly, in the '`...`' region. By default, any remaining event is unregistered with the WorldManager. The last block of code starting at line 25 removes the event from the `event_name` array (at spot `index`), scooting over the following items. See line 31 in Listing 4.32 on page 79 for an example of doing "scooting" for an array of integers.

Listing 4.186: Object unregisterInterest()

```
0  // Unregister for interest in event.
1  // Return 0 if ok, else 1.
2  int Object::unregisterInterest(std::string event_type)
3
4    // Check if previously registered.
5    found = false
6    for index = 0 to event_count-1
7      if event_name[index] is event
8        found = true
9      end if
10   end for
11   if not found then
12     return error
13   end if
14
15   // Unregister with appropriate manager.
16   if event is STEP_EVENT then
17     call GameManager unregisterInterest with "this" and "event"
18   else if
19   ...
20   else
21     call WorldManager unregisterInterest with "this" and "event"
22   end if
23
24   // Keep track.
25   scoot over all items in event_name
26   decrement event_count
27
28   // All is well.
29   return ok
```

When an Object is deleted, it is important to remove registration for all events it was interested in – failure to do so will result in the Object getting the event (by having its `eventHandler()` method called) even if it has been deleted. In fact, while game objects can certainly unregister for events they are no longer interested in, in many cases unregistration *only* happens when the Object is deleted. Thus, the destructor of the Object is extended to automatically unregister for all events the Object had registered for interest in, as shown in Listing 4.187. Thus defined, game objects will typically register for interest in events,

but not explicitly unregister since unregistration for all events happens when the life of the Object is over.

Listing 4.187: Unregistering from all registered events

```
for index = event_count-1 to 0
  call unregisterInterest with event_name[index]
end for
```

In order to use the new methods, game objects that are interested in input, say, from the keyboard, would register for interest:

```
  // Inside a game object's constructor.
  registerInterest(KEYBOARD_EVENT)
```

Registering for interest in a mouse event is similar, except that `MSE_EVENT` is used instead of `KEYBOARD_EVENT`.

4.15.1 Program Flow for Events

This section provides a summary of the program flow in Dragonfly for events.

Consider an event that needs to be sent to all interested Objects – for example, a step event or even a user defined event such as "nuke".

1. The event is created, say `EventNuke e`.
2. WorldManager `onEvent()` is called, invoked with the address of the event (i.e., `&e`).
3. Since WorldManager `onEvent()` is only defined in the Manager base class, Manager `onEvent()` is invoked.
4. Manager `onEvent()` iterates through the `event_name[]` array until a match for the event type (via `p_event->getType()`) is found at index `i`.
5. Manager `onEvent()` then iterates through the `obj_list[]` ObjectList at index `i`.
6. For each Object (via `currentObject()`) in the list, its `eventHandler()` is invoked with the event (`*p_event`).
7. The derived Object `eventHandler()` (e.g., Saucer `eventHandler()`) inspects (via `p_e->getType()`) and handles the event, as appropriate.

4.15.2 Development Checkpoint #12!

Continue with your Dragonfly development. Specifically, develop functionality for filtering events from Section 4.15. Steps:

1. Refactor the Manager to support registration for interest in events. See Listing 4.177 for the methods needed. Add the necessary attributes, then write `registerInterest()` and `unregisterInterest()` based on Listing 4.178 and Listing 4.179, respectively. Test that Objects can successfully register and unregister successfully, verifying working code with logfile output.

2. Refactor the Manager `onEvent()` method, referring to Listing 4.180 as needed. Test that Objects can register for step events and receive step events each game loop while the game is running.

3. Implement Manager `isValid()` to accept no events, but define `isValid()` for the GameManager, InputManager and WorldManager to handle step, keyboard and mouse and every other event, respectively. Refer to Listing 4.182 as needed. Verify that a game object cannot explicitly register for interest in events with inappropriate Manager (e.g, a step event with the InputManager), but can register for interest in events with an appropriate Manager (e.g., a keyboard and a mouse event with the InputManager). Create a user-defined event (e.g., a "nuke" event) and verify that this event can only be registered with the WorldManager.

4. Add attributes and methods supporting the Object's ability to register and unregister for events based on the Listing 4.184. Implement the `registerInterest()` and `unregisterInterest()` methods, referring to Listing 4.185 and Listing 4.186, respectively. Verify code functionality by having game code register and unregister for an event, both the step event and user-defined event, successfully.

5. Add code to the Object's destructor to unregister from all registered events, referring to Listing 4.187 as needed. Verify working code by having an object register for a step event, then destroying the Object. Repeat with multiple events, such as a step event and a user-defined event.

4.16 View Objects

Thus far, Dragonfly has been discussed in terms of game objects – objects that interact with each other in the game world. Examples from the Saucer Shoot tutorial (Chapter 3) include Saucers, Bullets and the Hero. Game objects are the basic building blocks for games and so are the primary types of objects that a game engine must support.

However, most games include other types of objects that do not interact with other objects in the game world. Such objects may display information or allow a player to control game settings. For example, an object that displays a player's score does not collide with the hero, spaceships, rocks or any other typical game objects. Buttons and other menu objects that let players choose settings, weapons or other game options do not interact with game objects in the world.

In Dragonfly, supporting such view-only objects is done through a new engine object type, a ViewObject. ViewObjects inherit from the base Object class. This allows the rest of the engine code, such as the WorldManager and all the utilities such as lists, to handle ViewObjects as they would standard Objects without change. What ViewObjects do have that is different are additional attributes that make it more convenient for game programmers to create "heads-up display" (or HUD) types of interfaces.

While game objects are positioned in game world coordinates, ViewObjects are positioned relative to the screen coordinates. For example, the game programmer may want to display the points in the upper right corner of the screen, or the health in the bottom left corner of the screen. To support the abstraction of screen placement rather than game world position, ViewObjects use an `enum` named `ViewObjectLocation` (as defined on line 8 of Listing 4.188) with positions of top or bottom and left, center and right.

Beyond what is available for Objects, ViewObjects have additional attributes shown starting on line 24 of Listing 4.188. These include a string (`view_string`) that provides a text label for the ViewObject (e.g., "points"), an integer (`value`) to hold the ViewObject value (e.g., the player's points, say 150), a boolean (`draw_value`) that indicates if said value should be drawn or not, a boolean (`border`) that indicates if the ViewObject should be drawn with a decorative border, and an integer (`color`) that provides an optional color for the ViewObject (if different than the default color). Methods to get and set `view_string`, `value`, `border`, `draw_value`, and `color` are provided.

The ViewObject has a custom `eventHandler()` (line 42) since ViewObjects respond to special view events provided by the game programmer to, say, update the player's points or other game-specific value.

Listing 4.188: ViewObject.h

```
0 // System includes.
1 #include <string>
2
3 // Engine includes.
4 #include "Object.h"
5 #include "Event.h"
6
7 // General location of ViewObject on screen.
8 enum ViewObjectLocation {
9   UNDEFINED=-1,
```

```
  TOP_LEFT,
  TOP_CENTER,
  TOP_RIGHT,
  CENTER_LEFT,
  CENTER_CENTER,
  CENTER_RIGHT,
  BOTTOM_LEFT,
  BOTTOM_CENTER,
  BOTTOM_RIGHT,
};

class ViewObject : public Object {

 private:
  std::string view_string;          // Label for value (e.g., "Points").
  int m_value;                      // Value displayed (e.g., points).
  bool m_draw_value;                // True if should draw value.
  bool m_border;                    // True if border around display.
  Color m_color;                    // Color for text (and border).
  ViewObjectLocation m_location;    // Location of ViewObject.

 public:
  // Construct ViewObject.
  // Object settings: SPECTRAL, max alt.
  // ViewObject defaults: border, top_center, default color, draw_value.
  ViewObject();

  // Draw view string and value.
  virtual int draw() override;

  // Handle 'view' event if tag matches view_string (others ignored).
  // Return 0 if ignored, else 1 if handled.
  virtual int eventHandler(const Event *p_e) override;

  // General location of ViewObject on screen.
  void setLocation(ViewObjectLocation new_location);

  // Get general location of ViewObject on screen.
  ViewObjectLocation getLocation() const;

  // Set view value.
  void setValue(int new_value);

  // Get view value.
  int getValue() const;

  // Set view border (true = display border).
  void setBorder(bool new_border);

  // Get view border (true = display border).
  bool getBorder() const;

  // Set view color.
  void setColor(Color new_color);

```

```
65    // Get view color.
66    Color getColor() const;
67
68    // Set view display string.
69    void setViewString(std::string new_view_string);
70
71    // Get view display string.
72    std::string getViewString() const;
73
74    // Set true to draw value with display string.
75    void setDrawValue(bool new_draw_value = true);
76
77    // Get draw value (true if draw value with display string).
78    bool getDrawValue() const;
79
80 };
```

Listing 4.189 shows the ViewObject constructor. First, it makes Object settings appropriate for a ViewObject. Specifically, it puts the Object at the highest altitude so it is visible above any other game objects, makes the ViewObject spectral so it does not collide with any other objects and sets its type to "ViewObject". Second, the ViewObject-specific settings are made, with a value of 0, a border being drawn, the location in the top center of the screen and the default color. Lastly, the ViewObject registers for interest in a view event, described in Section 4.16.1 on page 216.

Listing 4.189: ViewObject ViewObject()

```
0  // Construct ViewObject.
1  // Object settings: SPECTRAL, max altitude.
2  // ViewObject defaults: border, top_center, default color, draw_value.
3  ViewObject::ViewObject()
4
5     // Initialize Object attributes.
6     setSolidness(SPECTRAL)
7     setAltitude(MAX_ALTITUDE)
8     setType("ViewObject")
9
10    // Initialize ViewObject attributes.
11    setValue(0)
12    setDrawValue()
13    setBorder(true)
14    setLocation(TOP_CENTER)
15    setColor(COLOR_DEFAULT)
16
17    // Register interest in view events.
18    registerInterest(VIEW_EVENT) // if Section 4.15 implemented.
```

Pseudo code for ViewObject `setLocation()` method is shown in Listing 4.190. Basically, the switch statement starting on line 4 determines the (x,y) location. Only the first 2 (of 9 total) entries of the statement are shown, with the missing pieces following the same pattern. The y coordinate is at 1 if on the top of the window, or `world_manager.getView().getVertical()`-1 if on the bottom.

The x coordinate is at 1/6th, 3/6th, and 5/6th the horizontal distance (`world_manager.getView().getHorizontal()`), depending on if it is left, right or center, respectively. The

y_delta variable is used to adjust the vertical distance by -1 if the ViewObject is at the top and does not have a border, and by +1 if the ViewObject is at the bottom and does not have a border. On line 21, the position is actually shifted and on line 24 the position of the ViewObject is moved to the new position. Note, as given, Listing 4.190 assumes new_location is one of the nine valid locations whereas in actual code this should be checked and no action should be taken if new_location is invalid.

Listing 4.190: ViewObject setLocation()

```
0  // General location of ViewObject on screen.
1  ViewObject::setLocation(ViewObjectLocation new_location)
2
3    // Set new position based on location.
4    switch (new_location)
5    case TOP_LEFT:
6      p.setXY(WorldManager getView().getHorizontal() * 1/6, 1)
7      if getBorder() is false then
8        y_delta = -1
9      end if
10     break;
11   case TOP_CENTER:
12     p.setXY(WorldManager getView().getHorizontal() * 3/6, 1)
13     if getBorder() is false then
14       y_delta = -1
15     end if
16     break;
17   ...
18   end switch
19
20   // Shift, as needed, based on border.
21   p.setY(p.getY() + y_delta)
22
23   // Set position of object to new position.
24   setPosition(p)
25
26   // Set new location.
27   location = new_location
```

The corresponding ViewObject getLocation() is not shown, but should merely return location.

ViewObject setBorder() does a bit more than just set border to the new value. As shown in Listing 4.191, it also calls setLocation() since, if the border has changed, the (x,y) location on the screen needs to be adjusted based on the new border value.

Listing 4.191: ViewObject setBorder()

```
0  // Set view border (true = display border).
1  void ViewObject::setBorder(bool new_border)
2
3    if border != new_border then
4
5      border = new_border
6
7      // Reset location to account for border setting.
8      setLocation(getLocation())
```

```
9
10   end if
```

The ViewObject `draw()` method is shown in Listing 4.192. The first code block constructs the string to draw, created from the display string and the integer holding the value. The second block of code actually draws the string, invoking the `drawString()` (see Listing 4.84 on page 122) method from the DisplayManager, along with a border (if appropriate). Note, since the ViewObject's (x,y) location is in *screen* (or window) coordinates, as opposed to game world coordinates like most Objects, the ViewObject position needs to be translated to world coordinates via the utility function `viewToWorld()`. The function `viewToWorld()` does the reverse translation as `worldToView()`, in Listing 4.157 on page 186.

Listing 4.192: ViewObject draw()

```
0  // Draw view string and value.
1  int ViewObject::draw()
2
3    // Display view_string + value.
4    if border is true then
5      temp_str = " " + getViewString() + " " + toString(value) + " "
6    else
7      temp_str = getViewString() + " " + toString(value)
8    end if
9
10   // Draw centered at position.
11   Vector pos = viewToWorld(getPosition())
12   DisplayManager drawString(pos, temp_str, CENTER_JUSTIFIED,
13                             getColor())
14   if border is true then
15     // Draw box around display.
16     ...
17   end if
```

The `toString()` function used in Listing 4.192 on line 5 and line 7 is a useful utility function to put in `utility.cpp`. Basically, it creates a `stringstream`, adds a number to it, and return a string with the new contents. The full function is shown in Listing 4.193.

Listing 4.193: Utility toString()

```
0  #include <sstream>
1  using std::stringstream;
2
3  // Convert int to a string, returning string.
4  std::string toString(int i) {
5     std::stringstream ss;  // Create stringstream.
6     ss << i;               // Add number to stream.
7     return ss.str();  // Return string with contents of stream.
8  }
```

While thus far, view objects could be done entirely outside the engine in "game programmer" code space, there is one part of the engine that is aware of ViewObjects – the WorldManager's `draw()` method. The extension required of the WorldManager to support views is shown in Listing 4.194. Without views, the `draw()` method checked each Object to

see if they intersect the visible screen (see Listing 4.159 on page 187). ViewObjects may fail this check since their positions are relative to the screen, not the game world. So, instead, after checking for intersection, a `dynamic_cast` is made to see if the Object is a ViewObject. If so, it is drawn. In other words, all ViewObjects are drawn each game loop, regardless of position.

Listing 4.194: WorldManager extensions to draw() to support ViewObjects

```
0  ...
1  // Only draw if Object would be visible (intersects view).
2  if boxIntersectsBox(box, view) or           // Object in view,
3    dynamic_cast <ViewObject *> (p_temp_o))    // or is ViewObject.
4    p_temp_o -> draw()
5  end if
6  ...
```

Tip 22! Dynamic cast. Dynamic casts can be used to ensure that a type conversion is valid. When a class is polymorphic (it is a derived class with a virtual function), a dynamic cast to the derived class returns the address of the derived object, which can be interpreted as `true`, otherwise it returns `NULL`, which can be interpreted as `false`. For example, consider Listing **??**. In the first `if-then`, the pointer `p_o` points to the base Object so the dynamic cast returns `false`. In the second `if-then`, the pointer `p_o` points to the derived ViewObject so the dynamic cast returns `true`. Note! A dynamic cast will fail if there is not at least one method marked as `virtual` in the base class. Having at least one `virtual` method makes the class *polymorphic*.

4.16.1 View Event

View events are used by game programmers to signal the change in a view value. For example, if the player scored 10 points, say by destroying a Saucer, a view event would be created, given a value of 10, and passed to all ViewObjects (using `onEvent()`). Listing 4.195 provides the header file for the EventView class, derived from the Event class (Listing 4.51 on page 95). Remember, in the constructor of a ViewObject, the Object already registered for interest in a `VIEW_EVENT` (see Listing 4.189 on page 213). `VIEW_EVENT` is defined in Listing 4.195 on line 2.

Like many other Events, the EventView is mostly a container, holding a string (`tag`) which is a label associated with a specific ViewObject, an integer (`value`) that is used to modify the value in the ViewObject, and a boolean (`delta`) that determines whether the value either adjusts the ViewObject value (if `delta` is `true`) or replaces it (if `delta` is `false`). Methods are provided to get and set these values. The default constructor assigns `VIEW_EVENT`, 0 and `false` to `tag`, `value` and `delta`, respectively, and an alternate constructor is provided to create an EventView with attribute values specified.

Listing 4.195: EventView.h

```
0  #include "Event.h"
1
2  const std::string VIEW_EVENT = "df::view";
3
4  class EventView : public Event {
5
6   private:
7    std::string m_tag;  // Tag to associate.
8    int m_value;        // Value for view.
9    bool m_delta;       // True if change in value, else replace value.
10
11  public:
12   // Create view event with tag VIEW_EVENT, value 0 and delta false.
13   EventView();
14
15   // Create view event with tag, value and delta as indicated.
16   EventView(std::string new_tag, int new_value, bool new_delta);
17
18   // Set tag to new tag.
19   void setTag(std::string new_tag);
20
21   // Get tag.
22   std::string getTag() const;
23
24   // Set value to new value.
25   void setValue(int new_value);
26
27   // Get value.
28   int getValue() const;
29
30   // Set delta to new delta.
31   void setDelta(bool new_delta);
32
33   // Get delta.
34   bool getDelta() const;
35 };
```

With EventView specified, the ViewObject `eventHandler()` can now be defined as shown in Listing 4.196. The first `if` statement confirms that the event is a `VIEW_EVENT`. If so, line 7 needs to cast the generic Event pointer as an EventView pointer. This cast could either be a `dynamic_cast` (i.e., `dynamic_cast <const EventView *>`) (as described in Section 4.5.5.3, page 98) or a `static_cast` (i.e., `static_cast <const EventView *>`) – the latter is a compile-time cast that performs conversions that are safe and well-defined, and it can often be faster than other types of casts Remember, the `EventView *` used here needs to be declared `const`, too, in order to match the incoming type for `p_e`. This `const` restriction is to ensure the `eventHandler()` is not modifying the attributes of the Event.

An EventView is then be checked to see if its tag matches the view string associated with this ViewObject – if so, this event was intended for this ViewObject. At that point, the two options are for `delta` to indicate that the EventView value is to change the ViewObject's value by that amount (if `true`), or that the EventView value is to replace the ViewObject's value (if `false`). Either way, the event his handled and ok is returned at line 20. If line 27

is reached, the event was not handled so 0 is returned.[21].

Listing 4.196: ViewObject eventHandler()

```
0  // Handle 'view' events if tag matches view_string (others ignored).
1  // Return 0 if ignored, else 1 (ok) if handled.
2  int ViewObject::eventHandler(const Event *p_e)
3
4    // See if this is 'view' event.
5    if p_e->getType() is VIEW_EVENT then
6
7      EventView *p_ve = p_e
8
9      // See if this event is meant for this object.
10     if p_ve -> getTag() is getViewString() then
11
12       if p_ve -> getDelta() then
13         setValue(getValue() + p_ve->getValue())  // Change in value.
14       else
15         setValue(p_ve->getValue())               // New value.
16
17       end if
18
19       // Event was handled, return ok.
20       return ok
21
22     end if
23
24   end if
25
26   // If here, event was not handled. Call parent eventHandler().
27   return error
```

An example helps illustrate the use of ViewObjects and EventViews. Say a game programmer wants to have points associated with player achievements in a game and have the points displayed in the top right of the screen. The game programmer might use the code in Listing 4.197 at the top to create the view object, before the game actually starts. This code creates a ViewObject, associates "points" with the object, initializes the value to 0, positions it at the top right of the screen and makes it yellow. The ViewObject code automatically registers the object for interest in view events.

To change the value of the points ViewObject, say when an enemy object is destroyed, the game programmer places the second block of code (starting on line 8) into the enemy object destructor. When the enemy object is destroyed and the destructor is called, an EventView is created, intended for the points ViewObject, providing a value of 10 that will be added to the ViewObject value, since `delta`, the last parameter, is `true`. The event is given to the ViewObject (actually all ViewObjects, but only the "points" ViewObject will react) via the `onEvent()` call in the WorldManager.

Listing 4.197: Using ViewObjects

```
0  // Before starting game...
```

[21] If the parent Object `eventHandler()` did any work, it should be called but in the case of the engine at this point, it does not

```
df::ViewObject *p_vo = new df::ViewObject; // Used for points.
p_vo -> setViewString("Points");
p_vo -> setValue(0);
p_vo -> setLocation(df::TOP_RIGHT);
p_vo -> setColor(df::COLOR_YELLOW);
...

// In destructor of enemy object...
df::EventView ev("Points", 10, true);
df::WorldManager onEvent(&ev);
```

4.16.2 Buttons (optional)

A common user interface option is the button, represented graphically on the screen and selected with a mouse. Computer users and game players are familiar with buttons, using them for all sorts of game-related input. Buttons can provide in-game input, for example for casting a spell, or before the game starts, for example for choosing what character to be.

For Dragonfly, the button is similar to a ViewObject in that it is drawn on top of the rest of the game objects and does not interact with the game world. The button needs to respond to the mouse, too, so that it can recognize when the mouse hovers over it and when it has been clicked.

Listing 4.198 shows the Button class, derived from the ViewObject class. The Button adds two attributes for colors – one for the Button color when the button is highlighted (the mouse is over it) (`highlight_color`, and one to keep track of the default color when the button is not highlighted (`default_color`). Methods to get and set these attributes are provided. The constructor needs to set default attribute values and register for interest in mouse events.

Listing 4.198: Button.h

```
class Button : public ViewObject {

 private:
  Color m_highlight_color;    // Color when highlighted.
  Color m_default_color;      // Color when not highlighted.

 public:
  Button();

  // Handle "mouse" events.
  // Return 0 if ignored, else 1.
  int eventHandler(const Event *p_e) override;

  // Set highlight (when mouse over) color for Button.
  void setHighlightColor(Color new_highlight_color);

  // Get highlight (when mouse over) color for Button.
  Color getHighlightColor() const;

  // Set color of Button.
```

```
20    void setDefaultColor(Color new_default_color);
21
22    // Get color of Button
23    Color getDefaultColor() const;
24
25    // Return true if mouse over Button, else false.
26    bool mouseOverButton(const EventMouse *p_e) const;
27
28    // Called when Button clicked.
29    // Must be defined by derived class.
30    virtual void callback() = 0;
31  };
```

The `mouseOverButton()` method is a helper to facilitate the Button in changing between the highlight (when the mouse moves over it) and default colors (when the mouse is not over it). Its functionality is depicted in Listing 4.199. A pointer to EventMouse event is a parameter, with the return type `boolean` as `true` if the mouse is inside the button, otherwise `false`.

The first block of code creates a bounding box for the Button which is wide enough for the string and adjusted for with width and height if the Button has borders (an attribute of the parent ViewObject). The next block of code simply calls `boxContainsPosition()` (see Listing 4.154 on page 183) using the newly constructed Box and the mouse's position, and returns the appropriate boolean.

Listing 4.199: Button mouseOverButton()

```
0  // Return true if mouse over Button, else false.
1  bool MouseOverButton::mouseOverButton(const EventMouse *p_e) const
2
3    // Create Box for Button.
4    width = getViewString().size()
5    height = 1
6    if getBorder() then     // if Button has border
7      width = width + 4     // box wider by 2 spaces and |
8      height = height + 2   // box taller by 2 rows of ---
9    end if
10   Vector corner(getPosition().getX() - width/2,
11                 getPosition().getY() - height/2)
12   Box b(corner, width, height)
13
14   // If mouse inside button box, return true, else false.
15   if boxContainsPosition(b, p_e -> getMousePosition())
16     return true
17   else
18     return false
```

With that method in place, the `eventHandler()` method, shown in Listing 4.200, is ready to handle mouse actions. Since the Button only handles mouse events, this is checked at the start, and any non-mouse event is not handled (`return 0`).

Next, the mouse event is checked to see if the mouse is inside the Button using `mouseOverButton()`. If it is not, then the Button color is changed to the default and the method returns (having still handled the event).

If the mouse is inside the Button, the Button color is changed to the highlight color and if the mouse action is `CLICKED`, then the Button `callback()` is invoked.

Remember, although not shown, the Event pointer `p_e` needs to be casted when used as an EventMouse (see Section 4.5.5.3 on page 98).

Listing 4.200: Button eventHandler()

```
0  // Handle "mouse" events.
1  // Return 0 if ignored, else 1.
2  int Button::eventHandler(const Event *p_e)
3
4    // Check if mouse event.
5    if p_e -> getType() is not MSE_EVENT then
6      return 0  // not handled
7    end if
8
9    // Check if mouse over button.
10   if mouseOverButton(p_e) then
11
12     // Highlight on.
13     setColor(highlight_color)
14
15     // Check if clicked.
16     if p_e -> getMouseAction() is CLICKED then
17
18       // Invoke callback.
19       callback()
20
21     end if
22
23   // Highlight off.
24   setColor(default_color)
25
26   // Event handled.
27   return 1
```

Lastly, note that the `callback()` method on line 30 of Listing 4.198 is declared as pure virtual (`=0`) meaning `callback()` *must* be defined before Button can be used. This is because there is really no generic behavior common for all buttons when clicked, but instead the game programmer must implement the button-specific behavior wanted.

An example can help illustrate how the Button class can be used. Consider a typical start screen in a game, such as the start screen for Saucer Shoot in Section 3.3.11 on page 39, where the player can choose to either "play" or "quit". A quit button can be made as in Listings 4.202 (header file) and 4.201 (code). In the header file, QuitButton is derived from Button. The only method that must be defined is `callback()`, but in this case there is a default constructor since some Button defaults are changed (such as the button text).

Listing 4.201: QuitButton.h – Example Quit button for game start screen

```
0  #include "Button.h"
1
2  class QuitButton : public df::Button {
3
4   public:
```

```
  QuitButton();
  void callback();
};
```

In the source code (Listing 4.201), the constructor sets the text displayed in the button to "quit" and places the button in the bottom center of the screen. Other options could include changing the button's color(s) and the presence of a border. The `callback()` method is invoked when the button is clicked. In this case, it sets game over to true, which causes the game loop to exit and the game engine to shutdown (see Section 4.4.4 on page 71).

Listing 4.202: QuitButton.cpp – Example Quit button for game start screen

```
#include "GameManager.h"
#include "QuitButton.h"

QuitButton::QuitButton() {
  setViewString("Quit");
  setLocation(df::BOTTOM_CENTER);
}

// On callback, set game over to true.
void QuitButton::callback() {
  GM.setGameOver();
```

4.16.3 Text Entry (optional)

Another common user interface option is the text entry widget, typically represented as a blank box that allows players to type in a string. Text entry is sometimes used for in-game options, such as typing in an action for a classic text adventure, but more often for extra-game options, such as entering the network address of a server in a multi-player game or typing in player initials in a high score table.

Like buttons, text entry widgets are presented to the player above the rest of the game objects and do not interact with the game world, like the Dragonfly ViewObject. Unlike the Button, the text entry widget does not need a mouse, but does need to respond to keyboard input as keys are pressed.

Listing 4.203 shows the TextEntry class, derived from the ViewObject class. TextEntry adds three attributes related to the text – `text` for the text characters, `limit` to limit how many characters can be entered and `numbers_only`, a boolean that if true, indicates that only numbers are accepted. Methods to get and set these attributes are provided. The constructor needs to set default attribute values and register for interest in keyboard events and step events (the latter to handle blinking the cursor). The `text` attribute needs to be initialized with all spaces (up to length `limit`) so that the text entry box is drawn properly – this is done in `setLimit()`, in case the game programmer changes the limit.

Listing 4.203: TextEntry.h

```
// Engine includes.
#include "EventMouse.h"
#include "ViewObject.h"

class TextEntry : public ViewObject {
```

```
5
6  private:
7   std::string m_text;              // Text entered.
8   int m_limit;                     // Character limit in text.
9   bool m_numbers_only;             // True if only numbers.
10  int m_cursor;                    // Cursor location.
11  char m_cursor_char;              // Cursor character.
12  int m_blink_rate;                // Cursor blink rate.
13
14 public:
15  TextEntry();
16
17  // Set text entered.
18  void setText(std::string new_text);
19
20  // Get text entered.
21  std::string getText() const;
22
23  // Handle "keyboard" events.
24  // Return 0 if ignored, else 1.
25  int eventHandler(const Event *p_e) override;
26
27  // Called when TextEntry enter hit.
28  // Must be defined by derived class.
29  virtual void callback() = 0;
30
31  // Set limit of number of characters allowed.
32  void setLimit(int new_limit);
33
34  // Get limit of number of characters allowed.
35  int getLimit() const;
36
37  // Set cursor to location.
38  void setCursor(int new_cursor);
39
40  // Get cursor location.
41  int getCursor() const;
42
43  // Set blink rate for cursor (in ticks).
44  void setBlinkRate(int new_blink_rate);
45
46  // Get blink rate for cursor (in ticks).
47  int getBlinkRate() const;
48
49  // Return true if only numbers can be entered.
50  bool numbersOnly() const;
51
52  // Set to allow only numbers to be entered.
53  void setNumbersOnly(bool new_numbers_only = true);
54
55  // Set cursor character.
56  void setCursorChar(char new_cursor_char);
57
58  // Get cursor character.
59  char getCursorChar() const;
```

```
60
61    // Draw viewstring + text entered.
62    virtual int draw() override;
63  };
```

The `callback()` method on line 29 is as for the Button class – declared as pure virtual (`=0`) meaning `callback()` *must* be defined before TextEntry can be used. As for a Button, the text entry specific behavior wanted must be implemented by the game programmer.

Most of the methods are implemented in a straightforward manner, with the exception of the `eventHandler()`, shown in Listing 4.204.

If the event is a step event, the code block from lines 7 to 17 handles the cursor blinking –the cursor in this case, is a character that toggles between an underscore (or whatever the cursor character is set to) and a space. The method uses a `static` variable to keep track of the blink count, counting up from a negative value. When the count passes zero, it toggles the cursor (blinks it).

Listing 4.204: TextEntry eventHandler()

```
0  // Handle "keyboard" events.
1  // Return 0 if ignored, else 1.
2  int TextEntry::eventHandler(const Event *p_e)
3
4    // If step event, blink cursor.
5    if p_e -> getType() is df::STEP_EVENT then
6
7      // Blink on or off based on rate.
8      static int blink = -1 * getBlinkRate()
9      if blink >= 0 then
10       text.replace(cursor, 1, 1, getCursorChar())
11     else
12       text.replace(cursor, 1, 1, ' ')
13     end if
14     blink = blink + 1
15     if blink == getBlinkRate() then
16       blink = -1 * getBlinkRate()
17     end if
18
19     return 1
20
21   end if
22
23   // If keyboard event, handle.
24   if p_e -> getType() is KEYBOARD_EVENT and
25      p_e -> getKeyboardAction() is KEY_PRESSED then
26
27     // If return key pressed, then callback.
28     if p_e -> getKey() is Keyboard::RETURN then
29       callback()
30       return 1
31     end if
32
33     // If backspace, remove character.
34     if p_e -> getKey() is Keyboard::BACKSPACE then
35       if cursor > 0  then
```

```
36    if cursor < limit then
37      text.replace(cursor, 1, 1, ' ')
38         end if
39    cursor = cursor - 1
40    text.replace(cursor, 1, 1, ' ')
41       end if
42       return 1
43     end if
44
45     // If no room, cannot add characters.
46     if cursor >= limit then
47       return 1
48     end if
49
50     // Get key as string.
51     std::string str = toString(p_k -> getKey())
52
53     // If entry should be number, confirm.
54     if numbers_only && not isdigit(str[0]) then
55       return 1
56     end if
57
58     // Replace spaces with characters.
59     text.replace(cursor, 1, str)
60     cursor++
61
62     // All is well.
63     return 1
64   end if
65
66   // If we get here, event is not handled.
67   return 0
```

If the event is a keyboard event, there are several possible actions. Remember, although not shown, the Event pointer `p_e` needs to be casted when used as an EventKeyboard (see Section 4.5.5.3 on page 98).

The code starting on Line 27 checks if the return key is pressed. If so, the `callback()` method is invoked.

The code starting on Line 33 checks if the backspace key is pressed. If so, there is an additional check if the cursor is at the beginning of the string. If not, the character immediately to the left of the cursor is replaced.

The code on Line 45 makes sure that there is still room to add more text. If not (the limit is reached) the method ends.

Otherwise, the code at the bottom of the method adds the keyboard character pressed by replacing the space in the string at cursor with the character pressed.

The TextEntry `draw()` method also has a bit of work to do beyond the ViewObject `draw()` method. The required logic is shown in Listing 4.205. Basically, the original ViewObject text (set to "Enter text:" or something similar in the child class constructor) is loaded, the text entered so far is added, and then drawn.

Listing 4.205: TextEntry draw()

```
// Draw viewstring + text entered.
int TextEntry::draw()

  // Get original view string.
  std::string view_str = getViewString()

  // Add text.
  setViewString(view_str + text)

  // Draw.
  ViewObject::draw()

  // Restore original view string.
  setViewString(view_str)
```

An example can help illustrate how the TextEntry class can be used. Consider a high score table where the player, upon hitting a score worthy of the table, is asked to enter his/her initials (3 characters). A text entry widget can be made as in Listings 4.206 (header file) and 4.207 (code). In the header file, NameEntry is derived from TextEntry. The only method that must be defined is `callback()`, but in this case the limit (3 characters) needs to be set, too.

Listing 4.206: NameEntry.h – Example TextEntry for player initials

```
#include "TextEntry.h"

class NameEntry : public df::TextEntry {

 public:
  NameEntryButton();
  void callback();
};
```

In the source code, the constructor sets the text entry widget in the center of the screen and indicates the player should enter initials (setting the character limit to 3). The `callback()` method is invoked when the return key is pressed – in this case, a message is written to the logfile, but probably the game programmer would do something else with the initials, such as add them to a table.

Listing 4.207: NameEntry.cpp – Example TextEntry for player initials

```
#include "LogManager.h"
#include "NameEntry.h"

NameEntry::NameEntry() {
  setViewString("Enter initials");
  setLocation(df::CENTER_CENTER);
  setLimit(3);
}

// On callback, write initials to logfile.
void QuitButton::callback() {
  LM.writeLog("High score: %s", getText().c_str());
}
```

4.16.4 Development Checkpoint #13!

Continue development of Dragonfly, incorporating ViewObjects. Steps:

1. Create a ViewObject class (`ViewObject.h` and `ViewObject.cpp`), inheriting from Object, based on Listing 4.188. Add `ViewObject.cpp` to the project. Stub out all the methods first and get it to compile.

2. Write the ViewObject constructor, based on Listing 4.189 and then `setLocation()`, based on Listing 4.190. Get your code to compile and verify by visual inspection of code.

3. Based on Listing 4.193, write the utility function `toString()` and put it in `utility.cpp` and `utility.h`. Test with a stand alone program, outside of any other aspect of the game engine, to be sure it properly converts a range of integers to string values.

4. Write the ViewObject `draw()` method, referring to Listing 4.192. Remember, since `draw()` gets called automatically in WorldManager `draw()`, first test your code by creating a ViewObject (via `new`) before calling the GameManager `run()` method. Verify that the ViewObject appears, testing its location in all six fixed locations around the screen, for arbitrary strings and values.

5. Create a EventView class, based on Listing 4.195. Add `EventView.cpp` to the project. Define the `eventHandler()` based on Listing 4.196. Verify the code compiles and use visual inspection on the methods.

6. Referring to Listing 4.197, construct an example that uses a ViewObject with a test program that changes the value of the object. Test with a variety of view events, with different values and deltas. Verify that a ViewObject only handles events that are targeted toward it, ignoring others.

4.17 End Game (optional)

Up to this point, Dragonfly is a fairly full-featured, completely functional game engine. A few potential enhancements remain, however, that bring in elements common to many game engines and improve performance, appearance and functionality.

4.17.1 Scene Graphs (optional)

Scene graphs are data structures that arrange elements of a graphics scene in order to provide more efficient rendering. For example, when drawing objects in a 3d scene, a scene graph might arrange the objects based on distance from the camera. Rendering the frame then draws the objects that are farthest away from the camera first, proceeding to the objects that are closest to the camera since the closer objects may occlude those behind.

Consider Dragonfly, where Objects have altitude (see Section 4.8.5 on page 122). Objects that are at lower altitude are drawn first before Objects at higher altitude, allowing the higher altitude to be layered "on top" of the lower ones, as necessary. Without a scene graph, Dragonfly implements altitude by iterating through all the Objects for each altitude implementation, as in Listing 4.86 on page 123 – effectively, doing $n\times$ `MAX_ALTITUDE` comparisons, where n is the number of Objects in the game world. With a scene graph, the objects can be arranged by altitude, making the WorldManager `draw()` method only go through the list of Objects once, so only doing n comparisons.

For a game engine, a scene graph often arranges objects for more efficient queries, also. Objects that are not solid do not cause collisions. Without any other organization, detecting whether a moving object collides with any other object must look through all objects, regardless of whether they are solid or not. Thus far, Dragonfly is implemented this way, too, as in Listing 4.108 (page 146), iterating through all Objects, checking for collision with every Object, even the non-solid ones. Other common organizations group Objects by location in the game world, allowing selection and iteration over only those Objects at or near a specific location.

Since a scene graph organizes Objects, whether for drawing or query efficiency, it is naturally part of the WorldManager. In fact, an easy way of viewing a scene graph is that it replaces a simple list of game Objects with a more complex data structure where the Objects are organized and indexed in different ways. In Dragonfly, this means replacing `ObjectList m_updates` on line 10 of Listing 4.57 (page 100) with `SceneGraph scene_graph`.

The header file for `SceneGraph` is shown in Listing 4.208. SceneGraph needs to `#include` both `Object.h` and `ObjectList.h`. The definition of `MAX_ALTITUDE` on line 3 has been moved from `WorldManager.h` to `SceneGraph.h`.

To support efficient queries by the WorldManager (e.g., to provide a list of all the solid objects), starting at line 8, the SceneGraph defines three lists of Objects. The first, `objects`, is a list of all the Objects in the game – formerly, this was `m_updates` in the WorldManager. The second, `solid_objects`, is a list of just the solid Objects in the game. The third, `visible_objects`, is an array of ObjectLists, with each element being a list of Objects at that altitude. Methods to add and remove objects to the scene graph are provided by `insertObject()` and `removeObject()`, respectively.

To support queries that may be made by the WorldManager (or even the game programmer), SceneGraph includes methods: `activeObjects()`, which returns all active Objects; `inactiveObjects()`, which returns all inactive Objects; `solidObjects()`, which returns all solid Objects; and `visibleObjects()`, which returns all visible Objects at a given altitude. The methods all return an empty ObjectList if there are no Objects matching the query. The method `updateAltitude()` is invoked when an Object re-positions itself to a new altitude and the method `updateSolidness()` is invoked when an Object updates its solidness.

Listing 4.208: SceneGraph.h

```
#include "Object.h"
#include "ObjectList.h"

const int MAX_ALTITUDE = 4;

class SceneGraph {

 private:
  ObjectList m_objects;                          // All Objects
  ObjectList m_solid_objects;                    // Solid objects.
  ObjectList m_visible_objects[MAX_ALTITUDE+1];  // Visible objects.

 public:
  SceneGraph();
  ~SceneGraph();

  // Insert Object into SceneGraph.
  int insertObject(Object *p_o);

  // Remove Object from SceneGraph.
  int removeObject(Object *p_o);

  // Return all active Objects. Empty list if none.
  ObjectList activeObjects() const;

  // Return all active, solid Objects. Empty list if none.
  ObjectList solidObjects() const;

  // Return all active, visible Objects at altitude. Empty list if none.
  ObjectList visibleObjects(int altitude) const;

  // Return all inactive Objects. Empty list if none.
  ObjectList inactiveObjects() const;

  // Re-position Object in SceneGraph to new altitude.
  // Return 0 if ok, else -1.
  int updateAltitude(Object *p_o, int new_alt);

  // Re-position Object in SceneGraph to new solidness.
  // Return 0 if ok, else -1.
  int updateSolidness(Object *p_o, Solidness new_solidness);

  // Re-position Object in SceneGraph to new visibility.
  // Return 0 if ok, else -1.
```

```
44    int updateVisible(Object *p_vo, bool new_visible);
45
46    // Re-position Object in SceneGraph to new activeness.
47    // Return 0 if ok, else -1.
48    int updateActive(Object *p_o, bool new_active);
49 };
```

Implementation of SceneGraph `insertObject()` is shown in Listing 4.209. The method first inserts the Object into the `objects` list, since that is the "master" list that contains all Objects. Then, if the Object is solid, it is added to the `solid_objects` list. Next, the Object's altitude is checked – if it is not in range (calling `valueInRange(altitude, 0, MAX_ALTITUDE)`, see line 1 in Listing 4.154 on page 183), it returns an error (-1). Otherwise, the object is inserted into the `visible_objects` list at the correct altitude. Note, the calls to `ObjectList::insert()` need to be error checked. If they encounter an error, an appropriate message should be written to the logfile and `insertObject()` should return -1.

While it may seem that keeping 3 object lists is inefficient, remember that game objects are stored as pointers to Objects, thus manipulating and copying such lists is not actually doing the much more expensive operation of copying the memory space for each Object. As a refresher, see Section 4.5.2 on page 4.5.2 for details on the ObjectList implementation.

Listing 4.209: SceneGraph insertObject()

```
0  // Insert Object into SceneGraph.
1  int SceneGraph::insertObject(Object *p_o)
2
3    // Add object to list.
4    insert p_o into objects list
5
6    // If solid, add to solid objects list.
7    if p_o -> isSolid() then
8      insert p_o into solid_objects list
9    end if
10
11   // Check altitude.
12   if not valueInRange(p_o->getAltitude(), 0, MAX_ALTITUDE) then
13     return error
14   end if
15
16   // Add to visible objects at right altitude.
17   insert p_o into visible_objects[p_o->getAltitude()] list
```

Implementation of the SceneGraph `removeObject()` is basically the "undo" of the `insertObject()` method, as shown in Listing 4.210. The indicated Object (`p_o`) is removed from the `objects`, `solid_objects` and `visible_objects` lists. As always, the calls to `ObjectList::remove()` need to be error checked, writing an appropriate message to the logfile and returning -1 on encountering an error.

Listing 4.210: SceneGraph removeObject()

```
0  // Remove Object from SceneGraph.
1  int SceneGraph::removeObject(Object *p_o)
2
3    remove p_o from objects list
```

```
4
5   if p_o is solid then
6     remove p_o from solid_objects list
7   end if
8
9   remove p_o from visible_objects[p_o->getAltitude()] list
10
11  if no errors then // means no errors in any of the above
12    return ok
13  else
14    return error
15  end if
```

The methods `allObjects()` and `solidObjects()` just return `objects` and `solid_objects`, respectively. `visibleObjects()` first checks that the parameter `altitude` is in range (calling `valueInRange(altitude, 0, MAX_ALTITUDE)`, see line 1 in Listing 4.154 on page 183), then returns `visible_objects[altitude]`.

Objects may change their attributes, such as a `SPECTRAL` Object becoming `SOFT` or an Object changing altitude from 3 to 4. All such changes need to modify the contents of the SceneGraph lists, `solid_objects` and `visible_objects[]`, respectively. Listing 4.211 shows the implementation for updating the solidness of an Object. The first block of code checks if the Object is solid and, if so, removes it from the `solid_objects` list. The second block of code checks if the new solidness value for the Object is solid (`HARD` or `SOFT`) and, if so, inserts it into the `solid_objects` list. Error checking on the `ObjectList::insert()` calls is needed, as usual. Note, the solidness attribute for the Object is *not* changed – that is a private value for Object and is done in the Object `setSolidness()` method.

Listing 4.211: SceneGraph updateSolidness()

```
0 // Re-position Object in SceneGraph to new solidness.
1 // Return 0 if ok, else -1.
2 int SceneGraph::updateSolidness(Object *p_o, Solidness new_solidness)
3
4   // If was solid, remove from solid objects list.
5   if p_o->isSolid() then
6     remove p_o from solid_objects list
7   end if
8
9   // If is solid, add to list.
10  if new_solidness is HARD or new_solidness is SOFT then
11    insert p_o into solid_objects list
12  end if
13
14  // All is well.
15  return ok
```

Listing 4.212 shows the implementation for updating the altitude of an Object. First, the altitude values for both the new and old altitudes are checked for validity. It may seem odd to check the old value, since it seems it must be right, but it could have been corrupted someplace – if it was, trying to remove the Object from the `visible_objects[]` list at the altitude may result in a crash. If both old and new are in the valid range, the Object is first removed from `visible_objects[]` at the old altitude, then added to `visible_objects[]`

at the new altitude. Error checking on the `ObjectList::insert()` calls are needed, as usual.

Listing 4.212: SceneGraph updateAltitude()

```
// Re-position Object in scene graph to new altitude.
// Return 0 if ok, else -1.
int SceneGraph::updateAltitude(Object *p_o, int new_alt)

  // Check if new altitude in valid range.
  if not valueInRange(new_alt, 0, MAX_ALTITUDE) then
    return error
  end if

  // Make sure old altitude in valid range.
  if not valueInRange(p_o->getAltitude(), 0, MAX_ALTITUDE)) then
    return error
  end if

  // Remove from old altitude.
  remove p_o from visible_objects[p_o->getAltitude()]

  // Add to new altitude.
  insert p_o into visible_objects[new_alt]

  // All is well.
  return ok
```

Calls to `updateSolidness()` and `UpdateAltitude()` are made from Object, specifically Object `setSolidness()` and Object `setAltitude()`, respectively. The needed extension to Object `setSolidness()` to support SceneGraph is shown in Listing 4.213. The first block of code checks if the new solidness is valid (`HARD`, `SOFT` or `SPECTRAL`). If not, an error is returned. Otherwise, the `updateSolidness()` method of the SceneGraph is called and `solidness` is set in the Object.

Listing 4.213: Object class extension to setSolidness() to support SceneGraph

```
// Set object solidness, with checks for consistency.
// Return 0 if ok, else -1.
int Object::setSolidness(Solidness new_solidness)

  // If solidness not valid, then ignore.
  if new_solidness not (HARD or SOFT or SPECTRAL) then
    return error
  end if

  // Update scene graph and solidness.
  scene_graph.updateSolidness(this, new_solidness)
  solidness = new_solidness

  // All is well.
  return ok
```

Extension to Object `setAltitude()` to support SceneGraphs is shown in Listing 4.214. The first block of code checks if the new altitude is in a valid range. If not, an error is

returned. Otherwise, the SceneGraph `updateAltitude()` method is called and `altitude` is set in the Object.

Listing 4.214: Object class extension to setAltitude() support SceneGraphs

```
// Set Object altitude.
// Checks for in range [0, MAX_ALTITUDE].
// Return 0 if ok, else -1.
int Object::setAltitude(int new_altitude)

  // If altitude outside of range, then ignore.
  if not valueInRange(new_altitude, 0, MAX_ALTITUDE) then
    return error
  end if

  // Update scene graph and altitude.
  scene_graph.updateAltitude(this, new_altitude)
  altitude = new_altitude

  // All is well.
  return ok
```

With the SceneGraph in place, the Dragonfly WorldManager needs to be refactored to use the SceneGraph to manage game world Objects instead of storing the ObjectLists directly. Listing 4.215 shows the change in the WorldManager needed to use a SceneGraph. Basically, the attribute `ObjectList m_updates` is replaced with `SceneGraph scene_graph`. The method `getSceneGraph()` returns a reference to `scene_graph`.

Listing 4.215: WorldManager extensions to support SceneGraph

```
 private:
  SceneGraph scene_graph; // Storage for all Objects.

 public:
  // Return reference to the SceneGraph.
  SceneGraph &getSceneGraph() const;
```

Then, internally, each of the WorldManager methods in Listing 4.216 needs to be refactored to support the SceneGraph. The methods `insertObject()` and `removeObject()` call and return `scene_graph.insertObject()` and `scene_graph.removeObject()`, respectively. The methods `update()` and `setViewFollowing()` call `scene_graph.allObjects()` to iterate through all the world Objects. The method `draw()` iterates through each altitude, calling `scene_graph.visibleObjects()` for each altitude. The method `getCollisions()` checks for collisions only with Objects in the ObjectList returned from `scene_graph.solidObjects()`.

Listing 4.216: WorldManager methods to refactor to support SceneGraph

```
ObjectList getAllObjects()
int insertObject(Object *p_o)
int removeObject(Object *p_o)
int setViewFollowing(Object *p_new_view_following)
void update()
void draw()
ObjectList getCollisions(const Object *p_o, Vector where)
```

4.17.1.1 Inactive Objects (optional)

For many games, it is useful for the game program to have some game objects be ignored by the engine for some time, but without removing the objects from the game world altogether. For example, the Saucer Shoot tutorial game (Section 3.3.11 on page 39) has the main menu become inactive when the game is being played, becoming active again after the player's ship has been destroyed. Such inactive objects are not drawn by the engine, are neither moved nor considered in collisions, nor do they receive any events.

In order to support inactive Objects in Dragonfly, the Object class is extended with an attribute and methods to support whether an Object is active or inactive, shown in Listing 4.217. The boolean attribute `is_active` is `true` when the Object is active (note, all the Objects that have been dealt with to this point are active) and `false` when the Object is inactive and not acted upon by the engine. This value can be set via the `setActive()` method and queried via the `isActive()` method.

Listing 4.217: Object class extensions to support inactive objects

```
private:
 bool is_active;     // If false, Object not acted upon.

public:
 // Set activeness of Object.  Objects not active are not acted upon
 // by engine.
 // Return 0 if ok, else -1.
 int setActive(bool active=true);

 // Return activeness of Object.  Objects not active are not acted upon
 // by engine.
 bool isActive() const;
```

As shown in Listing 4.218, the method `setActive()` allows the game programmer to set the Object activeness, changing `is_active` as appropriate. Objects are active (`is_active` is `true`) by default, set in the constructor. In addition, the SceneGraph is obtained from the WorldManager and the SceneGraph `updateActive()` method is called.

Listing 4.218: Object setActive()

```
// Set activeness of Object.  Objects not active are not acted upon
// by engine.
// Return 0 if ok, else -1.
int Object::setActive(bool active)

  // Update scene graph.
  scene_graph = WorldManager getSceneGraph()
  scene_graph.updateActive(this, active)

  // Set active value.
  is_active = active
```

The SceneGraph is refactored to have an additional ObjectList, one that holds only inactive Objects while the main object list will hold active Objects. Listing 4.219 shows the changes to the SceneGraph attributes for this. The `objects` ObjectList has been renamed

to active_objects to differentiate it from the ObjectList holding the inactive objects, inactive_objects.

Listing 4.219: SceneGraph extensions to support inactive Objects

```
private:
  ObjectList active_objects;      // All active Objects.
  ObjectList inactive_objects;    // All inactive Objects.

public:
  // Return all active Objects. Empty list if none.
  ObjectList activeObjects() const;

  // Return all inactive Objects. Empty list if none.
  ObjectList inactiveObjects() const;

  // Re-position Object in SceneGraph to new activeness.
  // Return 0 if ok, else -1.
  int updateActive(Object *p_o, bool new_active);
```

The methods activeObjects() and inactiveObjects() return active_objects and inactive_objects, respectively.

Listing 4.220 shows the SceneGraph updateActive() method. The first block of code checks if the activeness is being changed. If not, there is nothing more to do and an "ok" (0) is returned. The second block of code does the actual work. If the Object was active and became inactive, remove() is called on active_objects, visible_objects[] and, if solid, solid_objects and the Object is inserted into the inactive_objects list. Otherwise, if the Object was inactive and became inactive, insert() is called on active_objects, visible_objects[] and, if solid, solid_objects and the Object is removed from the inactive_objects list. All method calls should be error checked and an error (-1) returned, as appropriate. Otherwise, "ok" is returned at the end.

Listing 4.220: SceneGraph updateActive()

```
// Re-position Object in SceneGraph to new activeness.
// Return 0 if ok, else -1.
int SceneGraph::updateActive(Object *p_o, bool new_active)

  // If activeness unchanged, nothing to do (but ok).
  if p_o->isActive() is new_active then
    return ok
  end if

  // If was active then now inactive, so remove from lists.
  if p_o->isActive() then

    active_objects.remove(p_o)

    visible_objects[p_o->getAltitude()].remove(p_o)

    if p_o->isSolid() then
      solid_objects.remove(p_o)
    end if

```

```
20      // Add to inactive list
21      inactive_objects.insert(p_o)
22
23    else // Was active, so add to lists.
24
25      active_objects.insert(p_o)
26
27      visible_objects[p_o->getAltitude()].insert(p_o)
28
29      if p_o->isSolid() then
30        solid_objects.insert(p_o)
31      end if
32
33      // Remove from inactive list
34      inactive_objects.remove(p_o)
35
36    end if
37
38    // All is well.
39    return ok
```

The WorldManager `getAllObjects()` method is refactored, as in Listing 4.221. A boolean parameter `inactive` is provided to indicate whether the method should return only active Objects (`inactive` is `false`, the default) or both active and inactive Objects (`inactive` is `true`).

Listing 4.221: WorldManager extensions to support inactive Objects

```
0   // Return list of all Objects in world.
1   // If inactive is true, include inactive Objects.
2   // Return NULL if list is empty.
3   ObjectList getAllObjects(bool inactive=false);
```

The revised `getAllObjects()` is shown in Listing 4.222. The inactive case can use the overloaded '+' operator from Section 4.5.2.2 (page 85).

Listing 4.222: WorldManager extensions to getAllObjects() to support inactive Objects

```
0 // Return list of all Objects in world.
1 // If inactive is true, include inactive Objects.
2 // Return NULL if list is empty.
3 ObjectList WorldManager::getAllObjects(bool inactive) const
4
5   if inactive then
6     return scene_graph.activeObjects() + scene_graph.inactiveObjects()
7   else
8     return scene_graph.activeObjects()
9   end if
```

The Manager `onEvent()` method needs to be modified to check if an interested Object is actually active before sending it an event. This is shown on line 2 of Listing 4.223.

Listing 4.223: Manager extension to onEvent() to support inactive Objects

```
0   ...
1   for j = 0 to object_list[i]
```

```
    if object_list[i][j] -> isActive() then
      call object_list[i][j] -> eventHandler() with p_event
    end if
  end for
  ...
```

Lastly, WorldManager `shutDown()` should be revised to call `getAllObjects(true)` to delete both active and inactive Objects when the engine is shut down.

4.17.1.2 Invisible Objects (optional)

Another useful property for many game objects is to become invisible. For a game object, invisibility could be a special power, say, for the hero or a bad guy to vanish from sight – but as such, it is rather rare. However, invisibility is commonly used to limit the player's ability to see objects that may be on the window, but should not yet be shown to the player because of the player's avatar's orientation, or because of terrain or other "fog of war" type of effect. From a game engine perspective, an invisible game object is not drawn, but is still updated each game loop and can be collided with, if solid, as appropriate.

To support invisibility, a new attribute is added to Object with methods for getting and setting it, shown in Listing 4.224. The method `isVisible()` returns the value of `is_visible`.

Listing 4.224: Object class extensions to support invisibility

```
private:
 bool is_visible;      // If true, object gets drawn.

public:
 // Set visibility of Object. Objects not visible are not drawn.
 // Return 0 if ok, else -1.
 int setVisible(bool visible=true);

 // Return visibility of Object. Objects not visible are not drawn.
 bool isVisible() const;
```

As shown in Listing 4.225, the method `setVisible()` allows the game programmer to set the Object visibility, changing `is_visible` as appropriate. Objects are visible (`is_visible` is `true`) by default. In addition, the SceneGraph is obtained from the WorldManager and the SceneGraph `updateVisible()` method is called.

Listing 4.225: Object setVisible()

```
// Set visibility of Object. Objects not visible are not drawn.
// Return 0 if ok, else -1.
int Object::setVisible(bool visible)

  // Update scene graph.
  scene_graph = WorldManager getSceneGraph()
  scene_graph.updateVisible(this, visible)

  // Set visibility value.
  is_visible = visible
```

Listing 4.226 shows the SceneGraph `updateVisible()` method. The first block of code checks if the visibility is being changed. If not, there is nothing more to do and an "ok" (0) is returned. The second block of code does the actual work. If the Object was visible and went invisible, `remove()` is called on the ObjectList, otherwise `insert()` is called, at the right altitude (`p_o->getAltitude()`). All method calls should be error checked and an error (-1) returned, as appropriate. Otherwise, "ok" is returned at the end.

Listing 4.226: SceneGraph updateVisible()

```
// Re-position Object in scene graph based on visibility.
// Return 0 if ok, else -1.
int SceneGraph::updateVisible(Object *p_o, bool new_visible)

  // If visibility unchanged, nothing to do (but ok).
  if p_o->isVisible() is new_visible then
    return ok
  end if

  // If was visible then now invisible, so remove from list.
  if p_o->isVisible() then
    visible_objects[p_o->getAltitude()].remove(p_o)
  else // Was invisible, so add to list.
    visible_objects[p_o->getAltitude()].insert(p_o)
  end if

  // All is well.
  return ok
```

4.17.2 Development Checkpoint #14!

To develop the SceneGraph for Dragonfly, use the following steps:

1. Create the SceneGraph class, referring to Listing 4.208 as needed. Add `SceneGraph.cpp` to the project and stub out each method so the SceneGraph compiles.
2. Implement the SceneGraph `insertObject()` and `removeObject()` methods based on Listing 4.209 and Listing 4.210, respectively. Test outside of the game engine by adding and removing Objects.
3. Implement the SceneGraph `updateSolidness()` method, based on Listing 4.211 and `updateAltitude()`, based on Listing 4.212.
4. Extend the Object class `setSolidness()` to support a SceneGraph, referring to Listing 4.213. Do the same for `setAltitude()`, referring to Listing 4.214.
5. Extend the WorldManager to support a SceneGraph, as in Listing 4.215. Refactor the methods shown in Listing 4.216, as appropriate.
6. Test by verifying that previous code that worked without SceneGraphs *still* works, such as test code from the last development checkpoint (on page 227).

If support for inactive Objects is desired (optional), continue development:

1. Extend Object to support activeness based on Listing 4.217, implementing `setActive()` based on Listing 4.218.
2. Refactor the SceneGraph based on Listing 4.219, implementing `updateActive()` based on Listing 4.220.
3. Refactor the WorldManager based on Listing 4.221, extending `getAllObjects()()` to return inactive Objects, too, based on Listing 4.222.
4. Test with game code that sets another game object to inactive and back, say, based upon key presses.

If support for invisibility is desired (optional), continue development:

1. Extend Object to support invisibility based on Listing 4.224.
2. Implement Object `setVisible()` based on Listing 4.225 and SceneGraph `updateVisible()`, based on Listing 4.226.
3. Test with game code that has game objects set themselves to invisible and back, say, depending upon key presses or positions on the screen.

4.17.3 Gracefully Shutting Down (optional)

As of now, the game programmer needs to provide the mechanism for the player to exit the game and terminate the engine.. For example, in Saucer Shoot (Chapter 3, the player can press 'Q' to exit. However, it can be useful for the player (and the developer) to allow standard method of closing windows to work with Dragonfly, also.

4.17.3.1 Closing the Game Window (optional)

In many cases, a user will close an application window by clicking on the "close" button, typically a button with a 'x' in the upper right corner of the window border. However, up until this point, the Dragonfly window opened by the DisplayManager does not provide for a close button. However, SFML does support both providing and handling a windows close button, so Dragonfly can be extended to support the same.

In order to provide support for the close button, first, in `DisplayManager.h` `WINDOW_STYLE_DEFAULT` is modified to also include `sf::Style::Close` bitwise or-ed with the `Titlebar`. In other words, `WINDOW_STYLE_DEFAULT` should look like:

```
const int WINDOW_STYLE_DEFAULT = sf::Style::Titlebar|sf::Style::Close;
```

This provides a close button in the SFML game window that a user can click. When the user does so, this sends a `sf::Event::Closed` event to the window that can be detected along with other keyboard and mouse input in the InputManager. Needed extensions to the InputManager `getInput()` are shown in Listing 4.227. Basically, within the `while(event)` loop, the event type `sf::Event::Closed` is looked for (in addition to the keyboard and mouse events – see Listing 4.94 on page 131). If it is found, Dragonfly is shut down by calling GameManager `setGameOver()`. The header file `GameManager.h` needs to be `#include`d.

Listing 4.227: InputManager extensions to getInput() to window close

```
// Get input from the keyboard and mouse.
// Pass event along to all Objects.
void InputManager::getInput() const

  // Check past window events.
  while event do

    // Special case - see if Window closed.
    if event.type is sf::Event::Closed then
      GameManager  setGameOver()
      return
    end if
    ...
```

4.17.3.2 Catching Ctrl-C (optional)

In Linux and Mac, a common way to terminate a programming running in a terminal window (also called a "shell') is by holding down the control key and pressing 'c' (also known as `ctrl-c`). Pressing `ctrl-c` actually sends a signal to the program that is currently running – called a *process* – in the window. The signal is a simple form of communication

between the operating system and the process, basically signaling to the process that this event (the `ctrl-c`) occurred.

Most programs interpret the `ctrl-c` as an indication to terminate – Dragonfly is no exception and it will end when `ctrl-c` is pressed. However, by recognizing a signal, a process has a chance to take some actions before being terminated. In particular, for Dragonfly, this means it can call `shutDown()` for each Manager, closing the logfile and reverting and settings back to standard mode before the process exits. Not responding to `ctrl-c` in this way means that the process terminates abruptly, possibly leaving the system in settings changed and leaving unwritten data that is still in memory out of the logfile.

The mechanism to "catch" `ctrl-c` is to setup a signal handler, giving a function name to the operating system so that function can be called when a signal is passed to the process. The specific system call to do this depends upon what operating system the process is running on. On Linux, the system call is `system()`. For Windows, the system call is `SetConsoleCtrlHandler()`. The general semantics are that when the signal occurs, the current execution of the program is interrupted and the signal handler function is called. When the signal handler finishes, the program resumes where it left off. In the case of Dragonfly, and many other programs, the signal handler will terminate the process (via `exit()`) so it will not return.

Note, if a process does not handle `ctrl-c`, which is the default behavior, the operating system will terminate the process anyways – it is just that the process loses the opportunity to gracefully shutdown. In fact, when a computer is shutdown, the operating system first sends a `ctrl-c` signal to all processes, allowing them to shut themselves down. If they do not terminate, it next sends a "kill" signal that forcibly shuts them down, a signal they cannot handle.

First, the signal handler function is defined. Since the signal handler can be invoked from anywhere, it cannot be a method of any class, but must be a global function. This could suggest it be placed in `utility.cpp`, but since it only calls GameManager `shutDown()`, it should be placed in `GameManager.cpp`. The definition is shown in Listing 4.228 where, as stated earlier, the GameManager is shutdown and the process exits via the `exit()` system call.

Listing 4.228: Function doShutDown() in GameManager.cpp

```
0 // Called explicitly to catch ctrl-c, so exit when done.
1 void doShutDown(int sig)
2   GameManager shutDown()
3   exit(sig)
```

The second step is to tell the operating system to call the signal handler, `doShutDown()`, when it receives a `ctrl-c`. This is done by adding code to `startUp()`, shown in Listing 4.229. A `#include` of `signal.h` is needed for the system calls. In `startUp()`, a variable of type `struct sigaction` is created (here, named `action`) to hold the parameters for the system call. In this case, the main parameter to specify is the name of the handler, `doShutDown`. Note, `doShutdown()` must be defined above `startUp()` in `GameManager.cpp` or a function prototype must appear before `startUp()` – not doing this will result in a compiler error complaining about `doShutDown()` being undefined. The call `sigemptyset()` initializes the set of signals to empty, and setting `sa_flags` to 0 indicates there are no spe-

cial modifiers to the behavior when the signal comes. The final call, `sigaction()` enables the signal, with the first parameter, `SIGINT`, referring to `ctrl-c`, the second the `struct sigaction` data structure, and the third, `NULL`, indicating there is no interest in storing the previous action. The call to `sigaction()` should be error checked as it returns -1 on error and 0 on success.

Listing 4.229: GameManager extensions to support handling ctrl-c (Linux and Mac)

```
...
#include <signal.h>
...
// Startup all GameManager services.
int GameManager::startUp()
  ...
  // Catch ctrl-C (SIGINT) and shutdown.
  struct sigaction action
   action.sa_handler = doShutDown   // The signal handler.
  sigemptyset(&action.sa_mask)     // Clear signal set.
  action.sa_flags = 0              // No special modification to behavior.
  sigaction(SIGINT, &action, NULL) // Enable the handler.
  ...
```

Windows handles signals a bit differently with the system call `SetConsoleCtrlHandler()` taking the name of a general-purpose signal handler, where it matches the signal type to `CTRL_C_EVENT` before calling GameManager `shutDown()`. Other signals that may be of interest for Windows processes are `CTRL_CLOSE_EVENT` (the program is being closed), `CTRL_LOGOFF_EVENT` (the user is logging off), and `CTRL_SHUTDOWN_EVENT` (the operating system is shutting down).

4.17.4 Random Numbers (optional)

Many games make frequent use of random numbers. For example, spins of a virtual roulette wheel needs to bounce the ball randomly to different numbers each time; a maze generation algorithm needs randomness to decide on how to carve twists and turns; or a computer opponent needs some random behavior to make it difficult to figure out its next move. Without randomness, the roulette wheel will always fall on the same number, the maze will always be exactly the same, and the computer opponent will be boringly predictable.

However, true randomness is difficult for computers – after all, at their core, computers are binary – either a 0 or a 1 and nothing in between. Instead, computers provide *pseudo-randomness* by generating sequences of numbers that, to the eye (and to the game player) look random. The most sophisticated of such algorithms even withstand external tests that make it difficult to tell the sequences apart from true randomness. For example, consider the sequence generated by:

$$X_n = ((5 \times X_{n-1}) + 1) \; mod \; 16 \tag{4.1}$$

Assume X_0 is 5. Then $X_1 = ((5 \times 5) + 1)$ mod 16, or $X_1 = 26$ mod 16, or $X_1 = 10$. Doing the same computation for $n = 1, 2, ...$ gives the numbers 10, 3, 0, 1, 6, 15, 12, 13, 2, 11, 8, 9, 14... It is difficult to look at this pattern and guess what number is next – to the eye (and to the game player) it looks random. If the sequence was restarted, say, the next time

a game was played, the sequence would be the same and the game player might then be able to predict what number would come next having seen the sequence during the previous game. Note, however, that the sequence generated totally depends upon the starting value (X_0). The starting value, also called the "seed" since it provides the basis for the sequence that follows, can be changed each time the game is run to provide a different, unpredictable sequence. Of course, being able to make the seed random would appear to put us back at square one. However, a good "random" seed is to start the sequence based on the time of day in seconds. Since each time the game is run the time will be different, thus providing a different seed and, hence, a different random sequence.

Tip 23! Random seeds. For most games, players expect games have different behavior each time they are run. Otherwise, for example, a bad guy might always start by "turning right" in a maze game. Developers, however, mostly do *not* want different behavior from run to run, particularly when debugging – note that "reproducing the problem consistently" is the first step in debugging![a] In such cases, providing the same random seed provides the same not-so-random behavior, making it easier to reproduce a game's behavior from run to run. In addition, multiplayer games, where separate computers may be computing "random" events, are often started with the same random seed in order for all players to see the same behavior.

[a] See Section 5.1.1 on page 248 for details.

In order to make the "random" sequence easy to use, two functions are provided – one to set the seed, and one to return the next number in the sequence. An example of a `rand()` function to generate random numbers is shown in Listing 4.230. The variable `g_next` is declared globally since it needs to be maintained from call to call. By default, `g_next` is initialized to a value in seconds since 1970 (see `time()` described in Section 4.3.2 on page 56), a starting value that will seem random to the player and vary from game run to game run. If the starting value (or actually at any time) needs to be explicitly controlled by the programmer, the function `srand()` sets `g_next` explicitly to the value `seed`.

Listing 4.230: Pseudo-random number functions

```
0 // Global variable to hold random number for sequence.
1 static unsigned long g_next = time()
2
3 //  Set seed to get a different starting point in sequence.
4 void srand(int seed)
5   g_next = seed
6
7 // Generate ''random'' number.
8 int rand()
9   g_next = ((5 * g_next) + 1) mod 16
```

While aspiring programmers could research good random number generating algorithms and code their own `rand()` and `srand()` functions, standard library functions already exist that do a good job. Namely, `srand()` can be used set the seed and `rand()` can be used

to return the next random number in the sequence. The random function returns an arbitrarily large integer, but typically a game programmer wants a random number bounded to something smaller. For example, a dice roll would be in the range 1–6. In order to map, say, `rand()` to the range 1–6, the game programmer calls `(rand() % 6) + 1`.

Dragonfly itself does not use `rand()`. Instead, all the engine needs to do is control the seed, setting it to the time (in seconds) by default, while providing a means for the game programmer to control the starting seed value when the engine starts up. This is done by extending the GameManager `startUp()` in a couple of ways.

First, GameManager `startUp()` calls `srand()` with the `time()` call (e.g., `srand(time(NULL))`) in order to provide a random-looking starting point for the programmer to make subsequent calls to `rand()`. `GameManager.cpp` needs to `#include` both `<time.h>` and `<stdlib.h>` for the `time()` and `rand()`, `srand()` function calls, respectively.

Second, as shown in Listing 4.231, a new `startUp()` method is provided, this one allowing the game programmer to set the seed explicitly (by calling `srand(seed)`).[22] The rest of the method is exactly the same as the normal GameManager `startUp()` method.

Listing 4.231: GameManager extension to support random seeds

```
0 public:
1   // Startup all GameManager services.
2   // seed = random seed (default is seed with system time).
3   int startUp(time_t seed=0);
```

4.18 Development Checkpoint #15 – Dragonfly!

(Optional)

Finish off your Dragonfly development!

1. Implement the `doShutDown()` function based on Listing 4.228. Test by having a game object call `doShutDown()` explicitly and verify in the logfiles that the engine shuts down properly.

2. Extend the GameManager to support handling closing the game window and `ctrl-c` (Linux), following guidelines from Listing 4.227 and Listing 4.229, respectively. Be sure to error as appropriate, writing informative errors to the logfile as needed. Test with a simple "game" that does not terminate, but can be ended by closing and/or `ctrl-c`. Verify these actions are actually caught via messages in the logfile.

3. Extend the GameManager to support random seeds, based on Listing 4.231. Test with a simple "game" that generates random numbers. Verify that the numbers produced are the same each run by using a fixed, explicit seed.

After completing the above steps (and all the previous Development Checkpoints), you will have a fully functional, full featured game engine! Features include everything from Dragonfly Naiad (Section 4.11 on page 150), plus:

[22] The type `time_t` is the type returned by `time()`, but can be thought of as an integer.

- Velocity support for game objects.
- Objects with bounding boxes, enabling multi-character-sized objects.
- Collisions for bounding boxes, not just single characters.
- Objects with sprites, giving them animated frames.
- Support for audio, including sound effects and music.
- View objects for display elements, each with a value and HUD-type location.
- Camera control for the game world, enabling "views" over a subset of the world with explicit camera control and support for the camera following a specific object.
- (Optional) Objects register for interest in events (e.g., step events), getting notification for only those events.
- (Optional) Scene graph support for more efficient queries.
- (Optional) An inactive feature for game objects to temporarily not have the engine act upon them.
- (Optional) Invisible objects that are not drawn but otherwise interact with the world normally.
- (Optional) Ability to gracefully close the game through closing the window and/or catching `ctrl-c`.
- (Optional) Automatic random number seeding, with the ability of the game programmer to control initial seeds.

If implemented fully, including all the optional components, the Saucer Shoot game from Chapter 3 should compile and run with *your* Dragonfly. Of course, that is just the start – bigger and better games are waiting to be built using your engine! Or, your new found engine knowledge is ready to be applied to learning a commercial engine or in a related game development project.

Have fun!