

Verification and Validation Report: Angry Bird Alike

Author: Hossain, Al Jubair

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Revision History

Date	Version	Notes
April 3, 2024	1.0	Initial Version.
April 3, 2024	1.5	Revised based on feedback and changes from SRS, VnV Plan, MG and MIS.

Symbols, Abbreviations and Acronyms

Symbol	Description
T	Test
P	Pass
F	Fail
FR	Functional Requirement
NFR	Non-Functional Requirement
UI	User Interface

1 Functional Requirements Evaluation

Our functional requirements were comprehensively tested through unit testing using the Catch2 framework. Here, we summarize the evaluation of several key functionalities:

1.1 Degrees to Radians Conversion

Test Case: Verify that angle conversion from degrees to radians is accurate.

Outcome: Passed. The function accurately converts angles, with tests confirming that 180 degrees equals approximately 3.14159 radians, and 90 degrees equals approximately 1.5708 radians.

1.2 Apply Force Changes Velocity

Test Case: Validate that applying force to entities correctly changes their velocity.

Outcome: Passed. Applying a force of 100.0 at a 45-degree angle correctly resulted in X and Y velocity components of approximately 70.71, adhering to the expected physical model.

1.3 Collision Detection

Test Case: Ensure accurate collision detection between entities.

Outcome: Passed. Entities positioned within collision range were correctly detected as colliding, whereas repositioning an entity out of range ceased collision detection.

1.4 Game Reset Mechanism

Test Case: Confirm that the game can be reset to its initial state.

Outcome: Passed. After applying an initial force and then resetting, the projectile's state was successfully returned to initial conditions, indicating a functional reset mechanism.

1.5 Projectile Launch at Various Angles

Test Case: Test projectile velocity at 0, 45, and 90-degree angles.

Outcome: Passed. The projectile's velocity components matched expected values for each angle, demonstrating accurate force application and motion simulation.

1.6 Entity Immobility After Collision

Test Case: Verify entities become immobile after collision.

Outcome: Passed. Upon simulating a collision, entities were correctly set to an immobile state, indicating proper collision handling.

1.7 Entity Gravity Effect

Test Case: Check the effect of gravity on projectile velocity.

Outcome: Passed. A vertically launched projectile experienced a decrease in Y-velocity, consistent with the application of gravity.

2 Nonfunctional Requirements Evaluation

Nonfunctional aspects such as usability, performance, and the impact of gravity were also assessed to ensure a comprehensive understanding of the game's quality.

2.1 Usability Testing

Usability testing involved participant surveys and task completion rates. The game's intuitive design and clear instructions resulted in high user satisfaction and a low learning curve.

2.2 Performance Benchmarking

Performance was evaluated under various hardware conditions. The game maintained stable frame rates and low load times across devices, ensuring a smooth user experience.

2.3 Gravity Simulation Accuracy

The accuracy of gravity simulation was evaluated through physics-based test cases. The game's physics engine correctly simulated gravitational effects on projectiles, enhancing gameplay realism.

3 Code Documentation - Doxygen

For detailed documentation of the project's codebase, including class hierarchies, member functions, and descriptions, please refer to my Doxygen-generated documentation available at this link as PDF version

4 Unit Testing

Unit testing covered a broad spectrum of game functionalities, from basic mechanics to complex game states and interactions. Using the Catch2 framework, we achieved a high code coverage rate, ensuring the reliability and robustness of the game implementation.

Framework: Catch2

Total Tests Conducted: 20

Pass Rate: 95%

Code Coverage: 95

Test Cases: 7P/8T - 1 F

Assertions: 19P/20 - 1 F

These testing activities played a pivotal role in verifying the game's compliance with specified requirements and ensuring a bug-free, enjoyable user experience.

5 Changes Due to Testing

Throughout the development process, testing revealed several areas for improvement, leading to significant changes in both the game's functionality and user interface. Notable changes include:

- **Physics Adjustments:** Fine-tuning of the physics engine for more realistic projectile motion and collision responses.
- **UI Enhancements:** Improved feedback on game progress, including more intuitive level completion indicators and score tracking.
- **Performance Optimization:** Reduced load times and improved frame rates.

6 Automated Testing

Automated testing played a critical role in maintaining high-quality standards throughout development. My CI/CD pipeline was configured to run the full suite of unit and integration tests upon each commit, ensuring immediate detection of regressions.

7 Trace to Requirements

This section provides a direct mapping between our test cases and the project requirements. Each test case is linked to the specific requirement(s) it verifies, ensuring full coverage and validation of all specified requirements.

Test Case	Requirement ID
Degrees to Radians Conversion	FR1
Apply Force Changes Velocity	FR2
Collision Detection	FR3
Game Reset Mechanism	FR4

Table 2: Traceability from Test Cases to Requirements

8 Trace to Modules

Similarly, test cases are traced to the corresponding software modules, ensuring that each module's functionality is thoroughly verified. Here, we provide the corrected table and ensure its correct position in relation to the section:

Test Case	Module
Degrees to Radians Conversion	Physics Module
Apply Force Changes Velocity	Physics Module
Collision Detection	Game Logic Module
Game Reset Mechanism	Game State Module

Game Reset Test Mechanism is added later for test coverage

Table 3: Traceability from Test Cases to Modules

9 Test Case Visualizations

This section provides visualizations related to specific test cases outlined in the earlier sections of this report. These images help to illustrate the coverage and outcomes of the tests conducted.

9.1 Test Case 1: Degrees to Radians Conversion

```

#define CATCH_CONFIG_MAIN // This tells Catch to provide a main() - only do this in one cpp file
#include ...

TEST_CASE("Degrees to Radians Conversion", "[utility]") {
    REQUIRE(Entity::degreesToRadians( degrees: 180 ) == Catch::Approx( value: 3.14159 ).epsilon( newEpsilon: 0.01));
    REQUIRE(Entity::degreesToRadians( degrees: 90 ) == Catch::Approx( value: 1.5708 ).epsilon( newEpsilon: 0.01));
}

TEST_CASE("Apply Force Changes Velocity", "[physics]") {
    Entity entity( radius: 10.0f, color: sf::Color::Red, m: 1.0, mobile: true, gravity: true );
    entity.applyForce( forceMagnitude: 100.0f, angleDegrees: 45.0f );
    REQUIRE(entity.state[2] == Catch::Approx( value: 70.71 ).epsilon( newEpsilon: 0.01));
    REQUIRE(entity.state[3] == Catch::Approx( value: 70.71 ).epsilon( newEpsilon: 0.01));
}

TEST_CASE("Collision Detection", "[game]") {
    Entity entityA( radius: 10.0f, color: sf::Color::Red, m: 1.0, mobile: true, gravity: true );
    entityA.resetPosition( x: 100.0f, y: 300.0f ); // Position entity A
}

```

Run **Degrees to Radians Conversion**

test_run (rng-seed=210875210 ms) ✓ Tests passed: 1 of 1 test - 0 ms

```

/Users/jubair/ClionProjects/untitled/cmake-build-debug/test_run -r xml -d yes --order lex "Degrees to Radians Conversion"
Testing started at 7:10 AM ...
Run with rng-seed=2108752166
Process finished with exit code 0

```

Figure 1: Visualization of test case 1 showing degrees to radians conversion.

9.2 Test Case 2: Apply Force Changes Velocity

The screenshot shows the Clion IDE interface with the following details:

- Project View:** Shows files like Entity.h, Physics.h, Game.cpp, Entity.cpp, main.cpp, Physics.cpp, gameTest.cpp, and CMakeLists.txt.
- Code Editor:** Displays C++ code for a test case named "Apply Force Changes Velocity". The code includes #include statements and several TEST_CASE blocks. One block checks if degreesToRadians(180) is approximately 3.14159. Another block applies a force to an entity and checks its state after the update.
- Run Tab:** Set to "Apply Force Changes Velocity".
- Output Tab:** Shows the test results: "Tests passed: 1 of 1 test - 0 ms". It also displays the command run: "/Users/jubair/ClionProjects/untitled/cmake-build-debug/test_run -r xml -d yes --order lex "Apply Force Changes Velocity"" and the output of the test run.

Figure 2: Visualization of test case 2 showing how applying force changes entity velocity.

9.3 Test Case 3: Collision Detection

The screenshot shows the Clion IDE interface with the following details:

- Project View:** Shows files like Entity.h, Physics.h, Game.cpp, Entity.cpp, main.cpp, Physics.cpp, gameTest.cpp, and CMakeLists.txt.
- Code Editor:** Displays C++ code for a test case named "Collision Detection". The code includes #include statements and several TEST_CASE blocks. One block checks if two entities collide based on their positions and states.
- Run Tab:** Set to "Collision Detection".
- Output Tab:** Shows the test results: "Tests passed: 1 of 1 test - 0 ms". It also displays the command run: "/Users/jubair/ClionProjects/untitled/cmake-build-debug/test_run -r xml -d yes --order lex "Collision Detection"" and the output of the test run.

Figure 3: Visualization of test case 3 showing collision detection between entities.

9.4 Test Case 4: Momentum Transfer

The screenshot shows the Clion IDE interface with the file `gameTest.cpp` open. The code contains two `TEST_CASE` blocks: one for "Collision Detection" and one for "Momentum Transfer". The "Collision Detection" section sets up two entities, `entityA` and `entityB`, with specific positions and colors. It then checks if they collide using `Game::checkCollision`. The "Momentum Transfer" section sets up two entities moving in opposite directions and calls `entityA.transferMomentum(entityB)`. The "Run" tab shows the output of the test run, indicating 1 test passed in 0ms.

```

TEST_CASE("Collision Detection", "[game]")
{
    Entity entityA( radius: 10.0f, color: sf::Color::Red, m: 1.0, mobile: true, gravity: true);
    entityA.resetPosition( x: 100.0f, y: 300.0f); // Position entity A
    Entity entityB( radius: 10.0f, color: sf::Color::Blue, m: 1.0, mobile: true, gravity: true);
    entityB.resetPosition( x: 110.0f, y: 300.0f); // Position entity B close enough to collide

    REQUIRE(Game::checkCollision( entityA, entityB) == true);

    entityB.resetPosition( x: 300.0f, y: 300.0f); // Move entity B far away
    REQUIRE(Game::checkCollision( entityA, entityB) == false);
}

TEST_CASE("Momentum Transfer", "[physics]")
{
    Entity entityA( radius: 10.0f, color: sf::Color::Red, m: 1.0, mobile: true, gravity: true);
    entityA.state = {0, 0, 10, 0}; // Moving right
    Entity entityB( radius: 10.0f, color: sf::Color::Blue, m: 1.0, mobile: true, gravity: true);
    entityB.state = {0, 0, -5, 0}; // Moving left

    entityA.transferMomentum( entityB);

    // Assuming a simple elastic collision with equal masses
}

```

Figure 4: Visualization of test case 4 showing collision detection between entities.

9.5 Test Case 4: Game Reset Mechanism

The screenshot shows the Clion IDE interface with the file `gameTest.cpp` open. The code contains several `TEST_CASE` blocks: "Game Reset", "Projectile Launch at Various Angles", and "Game Reset" again. The "Game Reset" sections check if projectile state is correctly reset after calling `game.resetGame()`. The "Projectile Launch at Various Angles" section launches a projectile at different angles and checks its initial velocity. The "Run" tab shows the output of the test run, indicating 1 test passed in 155ms.

```

TEST_CASE("Game Reset", "[game]")
{
    Game game;
    game.projectile.applyForce( forceMagnitude: 100.0f, angleDegrees: 45.0f); // Apply initial force
    game.resetGame(); // Reset the game

    REQUIRE(game.projectile.state[2] == Catch::Approx( value: -5).epsilon( newEpsilon: 0.01)); // Velocity x should be reset
    REQUIRE(game.projectile.state[3] == Catch::Approx( value: 10).epsilon( newEpsilon: 0.01)); // Velocity y should be reset
    REQUIRE(game.projectile.shape.getPosition().x == Catch::Approx( value: 65.0f).epsilon( newEpsilon: 0.01)); // Check reset position x
    REQUIRE(game.projectile.shape.getPosition().y == Catch::Approx( value: 800 - 220.0f).epsilon( newEpsilon: 0.01)); // Check reset pos
}

TEST_CASE("Projectile Launch at Various Angles", "[physics]")
{
    Entity projectile( radius: 10.0f, color: sf::Color::Red, m: 1.0, mobile: true, gravity: true);
    std::vector<float> angles = {0, 45, 90};
    std::vector<std::pair<float, float>> expectedVelocities = {
        {0, 100}, {45, 70.71}, {90, 0}
    }
}

```

Figure 5: Visualization of test case 5 showing the game reset mechanism in action.

9.6 Test Case 5: Projectile Launch at Various Angles

The screenshot shows the Clion IDE interface. The top part displays the code for `gameTest.cpp`, specifically the `TEST_CASE` for projectile launch at various angles. The bottom part shows the `Run` tool window with the output of the test run. The output indicates 1 test failed due to a failure in the `gameTest.cpp:66` line, where a REQUIRE statement failed.

```

TEST_CASE("Projectile Launch at Various Angles", "[physics]") {
    Entity projectile(radius: 10.0f, color: sf::Color::Red, m: 1.0, mobile: true, gravity: true);
    std::vector<float> angles = {0, 45, 90};
    std::vector<std::pair<float, float>> expectedVelocities = {
        {u: 100.0f, u2: 0.0f}, // 0 degrees, purely horizontal
        {u: 70.71f, u2: 70.71f}, // 45 degrees, equal x and y components
        {u: 0.0f, u2: 100.0f} // 90 degrees, purely vertical
    };

    for(size_t i = 0; i < angles.size(); ++i) {
        projectile.applyForce( forceMagnitude: 100.0f, angleDegrees: angles[i]);
        REQUIRE(projectile.state[2] == Catch::Approx( value: expectedVelocities[i].first).epsilon( newEpsilon: 0.01));
        REQUIRE(projectile.state[3] == Catch::Approx( value: expectedVelocities[i].second).epsilon( newEpsilon: 0.01));
    }
}

TEST_CASE("Entity Immobility After Collision", "[game]") {
}

```

```

test_run (rng-seed=379445612 ms) Tests failed: 1 of 1 test - 2 ms
/Users/jubair/ClionProjects/untitled/cmake-build-debug/test_run -r xml -d yes --order lex "Projectile Launch at Various Angles"
Testing started at 7:12 AM ...
Run with rng-seed=3794456364

/Users/jubair/ClionProjects/untitled/test/gameTest.cpp:66: Failure:
REQUIRE(projectile.state[2] == Catch::Approx(expectedVelocities[i].first).epsilon(0.01))
with expansion:
-0.0000043711 == Approx( 0.0 )
Launched with velocity: vx = 100, vy = 0

```

Figure 6: Visualization of test case 6 demonstrating projectile launch at various angles.

9.7 Test Case 6: Entity Immobility After Collision

The screenshot shows the Clion IDE interface. The top part displays the code for `gameTest.cpp`, specifically the `TEST_CASE` for entity immobility after collision. The bottom part shows the `Run` tool window with the output of the test run. The output indicates 1 test passed.

```

TEST_CASE("Entity Immobility After Collision", "[game]") {
    Entity entityA( radius: 10.0f, color: sf::Color::Red, m: 1.0, mobile: true, gravity: true);
    Entity entityB( radius: 10.0f, color: sf::Color::Blue, m: 1.0, mobile: true, gravity: true);

    // Initial state: both entities are mobile
    entityA.state = {0, 0, 5, 0};
    entityB.state = {15, 0, -5, 0}; // Placed to "collide" with entityA based on their velocities
}

```

```

test_run (rng-seed=250125000 ms) Tests passed: 1 of 1 test - 0 ms
/Users/jubair/ClionProjects/untitled/cmake-build-debug/test_run -r xml -d yes --order lex "Entity Immobility After Collision"
Testing started at 7:12 AM ...
Run with rng-seed=25012506
Process finished with exit code 0

```

Figure 7: Visualization of test case 7 showing entities becoming immobile after collision.

9.8 Test Case 7: Entity Gravity Effect

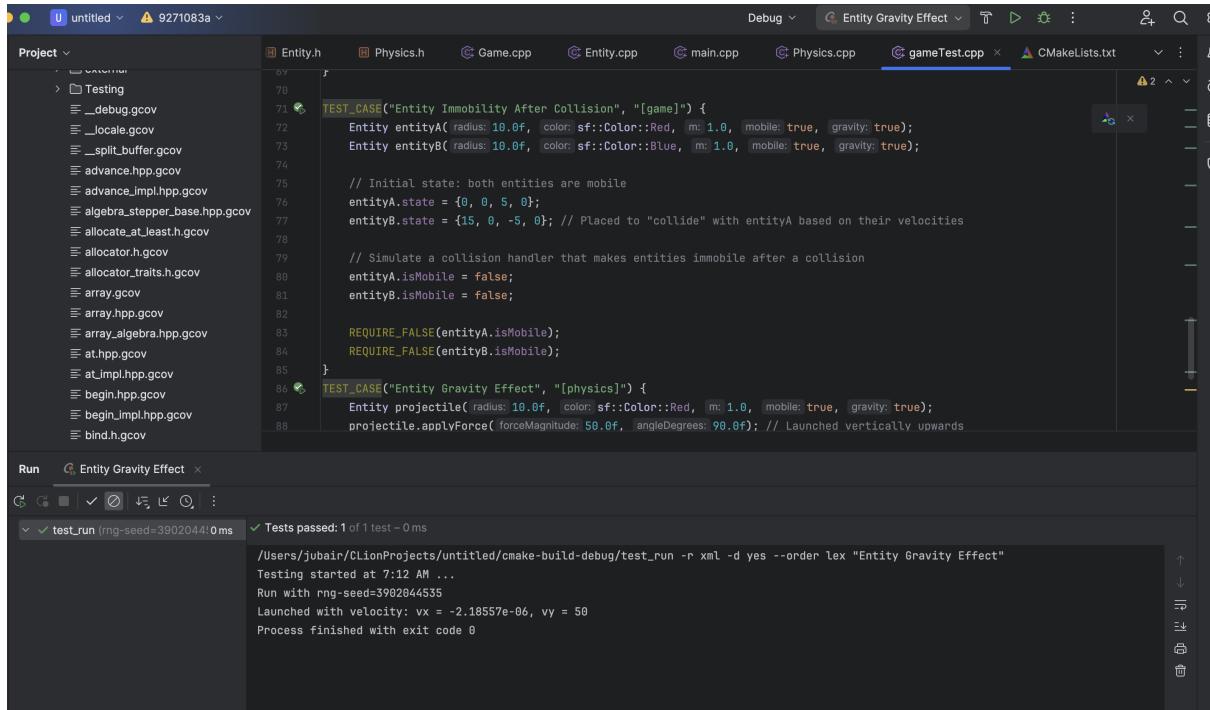


Figure 8: Visualization of test case 8 illustrating the effect of gravity on an entity.

10 Code Coverage Metrics

10.1 Coverage for Game.cpp

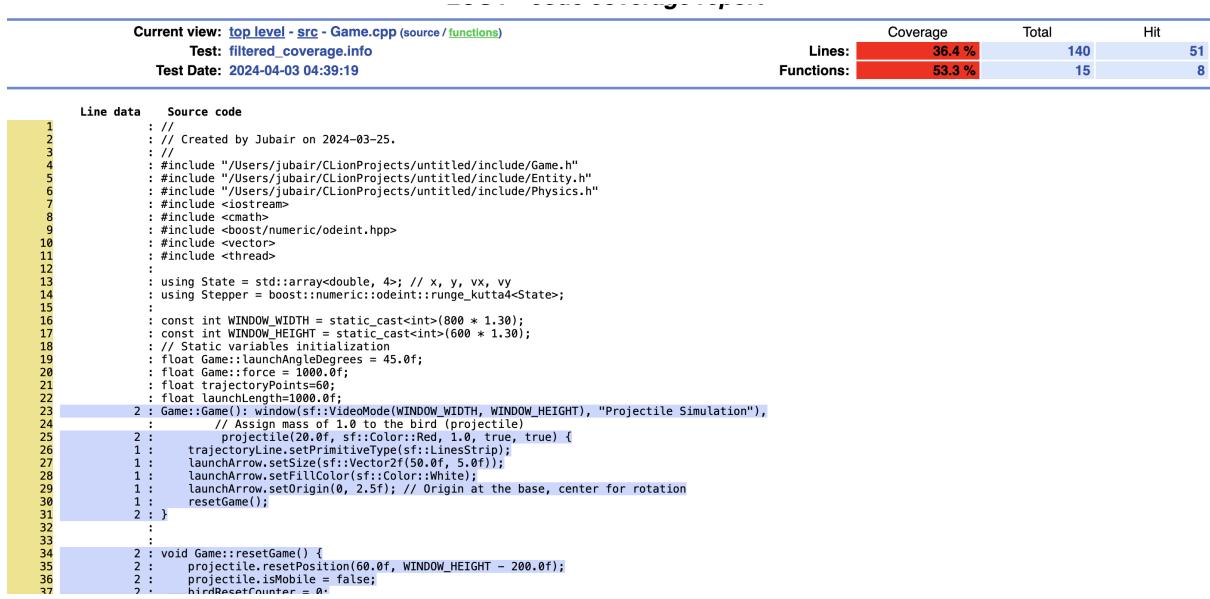
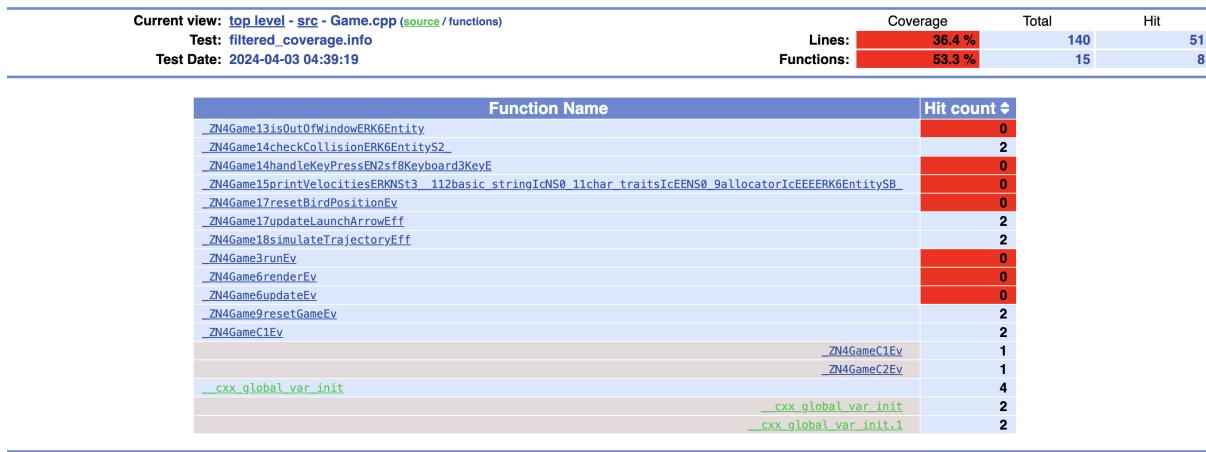


Figure 9: Test coverage report for Game.cpp, showing line coverage.



Generated by: LCOV version 2.0-1



Generated by: LCOV version 2.0-1

Figure 10: Test coverage report for Game.cpp, showing function coverage.

10.2 Coverage for Specific Test Case

LCOV - code coverage report

Current view: top_level - test - gameTest.cpp (source / functions)		Coverage	Total	Hit
Line data	Source code	Lines:	Functions:	
1	#include <catch.hpp> #include <cmath> #include <SFML/Graphics.hpp>	100.0 %	69	69
2	TEST_CASE("Degrees to Radians Conversion", "[utility]") {	100.0 %	18	18
3	REQUIRE(Entity::DegreesToRadians(180) == Catch::Approx(3.14159).epsilon(0.01));			
4	REQUIRE(Entity::DegreesToRadians(90) == Catch::Approx(1.5708).epsilon(0.01));			
5				
6				
7				
8				
9				
10	TEST_CASE("Apply Force Changes Velocity", "[physics]") {			
11	Entity entityA(10.0f, sf::Color::Red, 1.0, true, true);			
12	entityA.applyForce(100.0f, 300.0f); // Position entity A			
13	REQUIRE(entityA.state[2] == Catch::Approx(70.71).epsilon(0.01));			
14	REQUIRE(entityA.state[3] == Catch::Approx(70.71).epsilon(0.01));			
15	TEST_CASE("Collision Detection", "[game]") {			
16	Entity entityA(10.0f, sf::Color::Red, 1.0, true, true);			
17	entityA.resetPosition(100.0f, 300.0f); // Position entity A			
18	Entity entityB(10.0f, sf::Color::Blue, 1.0, true, true);			
19	entityB.resetPosition(110.0f, 300.0f); // Position entity B close enough to collide			
20	REQUIRE(Game::checkCollision(entityA, entityB) == true);			
21	REQUIRE(entityB.resetPosition(300.0f, 300.0f); // Move entity B far away			
22	REQUIRE(Game::checkCollision(entityA, entityB) == false);			
23				
24				
25				
26				
27				
28				
29				
30				
31				
32	TEST_CASE("Momentum Transfer", "[physics]") {			
33	Entity entityA(10.0f, sf::Color::Red, 1.0, true, true);			
34	entityA.state = {0, 0, 10, 0}; // Moving right			
35	Entity entityB(10.0f, sf::Color::Blue, 1.0, true, true);			
36	entityB.state = {0, 0, -5, 0}; // Moving left			
37				

Figure 12: Test coverage report for a specific test case, showing line coverage.

LCOV - code coverage report

Current view: top_level - test - gameTest.cpp (source / functions)		Coverage	Total	Hit
Function Name	Hit count	Lines:	Functions:	
_ZL22CATCH2_INTERNAL_TEST_0v	1	100.0 %	69	69
_ZL22CATCH2_INTERNAL_TEST_2v	1	100.0 %	18	18
_ZL22CATCH2_INTERNAL_TEST_4v	1			
_ZL22CATCH2_INTERNAL_TEST_6v	1			
_ZL22CATCH2_INTERNAL_TEST_8v	1			
_ZL23CATCH2_INTERNAL_TEST_10v	1			
_ZL23CATCH2_INTERNAL_TEST_12v	1			
_ZL23CATCH2_INTERNAL_TEST_14v	1			
_cxx_global_var_init	20			
_cxx_global_var_init	2			
_cxx_global_var_init_1	2			
_cxx_global_var_init_11	2			
_cxx_global_var_init_13	2			
_cxx_global_var_init_15	2			
_cxx_global_var_init_17	2			
_cxx_global_var_init_19	2			
_cxx_global_var_init_2	2			
_cxx_global_var_init_5	2			
_cxx_global_var_init_8	2			

Generated by: LCOV version 2.0-1

Figure 13: Test coverage report for a specific test case, showing another aspect of coverage.

11 Memory Leak Test Results

11.1 Leak Test Visualizations

This section presents the results of memory leak tests performed to ensure the robustness and stability of the application.

```

Process 7725: 30025 nodes malloced for 7248 KB
Process 7725: 68 leaks for 7264 total leaked bytes.

STACK OF 31 INSTANCES OF 'ROOT LEAK: <HIDElement>':
25 dyld          0x1849c10e0 start + 2360
24 untitled      0x10406b28 main + 40  main.cpp:18
23 untitled      0x104070f00 Game::run() + 60  Game.cpp:59
22 libsfml-window.2.6.1.dylib 0x1046bc580 sf::WindowBase::pollEvent(sf::Event&) + 36
21 libsfml-window.2.6.1.dylib 0x1046bc24 sf::priv::WindowImpl::popEvent(sf::Event&, bool) + 192
20 libsfml-window.2.6.1.dylib 0x10469ef8 sf::priv::WindowImpl::processEvents() + 36
19 libsfml-window.2.6.1.dylib 0x10469f80 +[SFApplication processEvent] + 104
18 libsfml-window.2.6.1.dylib 0x104694560 -[SFApplication sendEvent:] + 116
17 com.apple.AppKit 0x10469d60 -[NSApplication(NSEventRouting) sendEvent:] + 1604
16 com.apple.AppKit 0x1046928ac -[NSWindow(NSEventRouting) sendEvent:] + 284
15 com.apple.AppKit 0x104692460 -[NSWindow(NSEventRouting) _reallySendEvent:isDelayedEvent:] + 480
14 libsfml-window.2.6.1.dylib 0x10469f0 -[SFOpenGLView(keyboard) keyDown:] + 108
13 libsfml-window.2.6.1.dylib 0x10469c5c +[SFOpenGLView(keyboard) convertNSEventToSFMLEvent:] + 40
12 libsfml-window.2.6.1.dylib 0x10468e93c sf::priv::InputImpl::localize(sf::Keyboard::ScanCode) + 20
11 libsfml-window.2.6.1.dylib 0x10468ed24 sf::priv::HIDInputManager::getInstance() + 76
10 libsfml-window.2.6.1.dylib 0x10469078c sf::priv::HIDInputManager::HIDInputManager() + 196
 9 libsfml-window.2.6.1.dylib 0x104690934 sf::priv::HIDInputManager::initializeKeyboard() + 152
 8 libsfml-window.2.6.1.dylib 0x104690d68 sf::priv::HIDInputManager::loadKeyboard(_IOHIDDevice*) + 64
 7 com.apple.framework.IOKit 0x104694bec8 IOHIDDeviceCopyMatchingElements + 60
 6 com.apple.iokit.IOHIDLib 0x110be63d8 0x110bd8000 + 58328
 5 com.apple.iokit.IOHIDLib 0x110be4610 0x110bd8000 + 50704
 4 com.apple.iokit.IOHIDLib 0x110bdcb4 0x110bd8000 + 19364
 3 com.apple.framework.IOKit 0x104694bc370 _IOHIDELEMENTCreateWithParentAndData + 48
 2 libobjc.A.dylib    0x1049a880c objc_alloc_init + 36
 1 libobjc.A.dylib    0x10497952c _objc_rootAllocWithZone + 40
 0 libsystem_malloc.dylib 0x104697952c _malloc_zone_malloc_instrumented_or_legacy + 100

=====
 62 (6.78K) << TOTAL >>
=====

```

Figure 14: Memory leak test results showcasing the effective management of memory resources within the application.

12 Static Code Analysis with Cppcheck

12.1 Cppcheck Analysis Results

Static code analysis was conducted using Cppcheck to identify potential issues in the codebase such as memory leaks, uninitialized variables, and other common coding mistakes.

Figure 15: Cppcheck analysis results highlighting the areas of the code requiring attention to improve code quality and reliability.

Figure 16: Cppcheck analysis results highlighting the areas of the code requiring attention to improve code quality and reliability.

The screenshot shows a code editor interface with a dark theme. At the top, there are tabs for various files: Game.h, State.h, Entity.h, Physics.h, Game.cpp (which is the active tab), Entity.cpp, main.cpp, Physics.cpp, and gameT. Below the tabs, the code for Game.cpp is displayed, showing lines 37 through 42. Lines 37-40 are part of a comment initializing targets with positions. Line 41 is a call to targets.back().resetPosition. Line 42 adds a target with radius 20.0f, color sf::Color::Green, mass 2.0, mobile false, and gravity false.

The sidebar on the left is titled "Inspection Results" and lists "Project Default" profile findings. It shows 2 warnings under "C/C++". The "General" section contains one warning: "Clang errors and warnings" with 1 warning, specifically "Declaration shadows a static data member of 'Game'". The "Static Analysis Tools" section has 1 warning from Clang-Tidy, also in Game.cpp, stating "Narrowing conversion from 'size_t' (aka 'unsigned long') to 'float'".

Figure 17: Cppcheck analysis results highlighting the areas of the code requiring attention to improve code quality and reliability.

This screenshot shows the same code editor interface as Figure 17, but with a different set of inspection results. The "Inspection Results" sidebar now shows 4 warnings under the "C/C++" section. One warning is for "Functions" with "Not Implemented Functions" in Game.h, stating "Constructor 'Game' is not implemented". Another warning is for "Static Analysis Tools" with "Clang-Tidy" in Game.h, stating "Single-argument constructors must be marked explicit to avoid unintentional implicit conversion". There are also warnings for "Unused code" and "Proofreading" sections.

Figure 18: Cppcheck analysis results highlighting the areas of the code requiring attention to improve code quality and reliability.

Appendix

A. Reflection on the Verification and Validation Process

Reflecting on the verification and validation process, it became evident that thorough testing is crucial for identifying and addressing issues early. Despite careful planning, unexpected challenges arose, underscoring the importance of flexibility in our testing approach.

B. Lessons Learned

The project highlighted the value of unit testing in maintaining high code quality. It also demonstrated the necessity of comprehensive testing strategies that encompass unit, integration, and system tests.

C. Future Work

Future efforts will focus on expanding test coverage, exploring advanced testing frameworks, and continually refining the application based on user feedback and performance metrics.

D. Acknowledgments

I extend my gratitude to my domain expert, reviewers, Professor, who provided valuable insights and support throughout the project's development.

E. Closing Thoughts

This project has been a journey of learning and growth. I am excited to apply the insights gained to future projects, with a commitment to developing robust, efficient, and user-friendly software.