

Software Testing

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1 Test Plan

1.1 Introduction

MASON is a software library for creating agent-based simulations in Java. The software fits into the category of shrinkwrap meaning it might be in use in a wide range of real-world production environments. The software is freely-available and open-source, which is a special case of shrinkwrap software. A common trait of open-source software is that tasks 'that are not considered "fun" often don't get done'.[1] For MASON in particular, it is likely that the software has not been thoroughly tested as there is no trace of any automated testing, either on the MASON website, or its GitHub repository. This report documents testing of the latest version (19.0) of MASON, which has been obtained from the MASON website, with the aim to discover whether this software is dependable.

1.1.1 Tools

The IntelliJ IDE was used to explore the code and develop automated tests. This IDE gives powerful features, including plugins for generating code metrics and displaying coverage of unit testing. Specifically, the MetricsReloaded plugin[2] has been used for generating the statistics in Fig. 3.

JUnit has been used to create automated testing for the software, this includes both unit and integration testing. Git version control has been used to manage the code for these JUnit tests. For a long term project, this would be particularly advantageous as any automated tests could be updated and versioned alongside any future code changes.

1.2 Test Coverage

1.2.1 System Overview

In order to design appropriate test cases an understanding of all levels of the system was needed. As resources here are significantly limited, with only 8 testcases are allowed, it will be necessary to ensure they are used in the most effective way. As stated in the project brief, the testing only needs to cover the following packages, but not their subpackages:

- `sim.engine` is responsible for the core simulation management, including the agent scheduling.
- `sim.field` provides abstract classes for the representations of space in MASON simulation models, with subpackages managing specific instances of these.
- `sim.field.grid` provides various 2D and 3D grid representations of simulation space.

Fig. 1a shows the proportional sizes of each of these three modules, while Fig. 8 shows their code components.

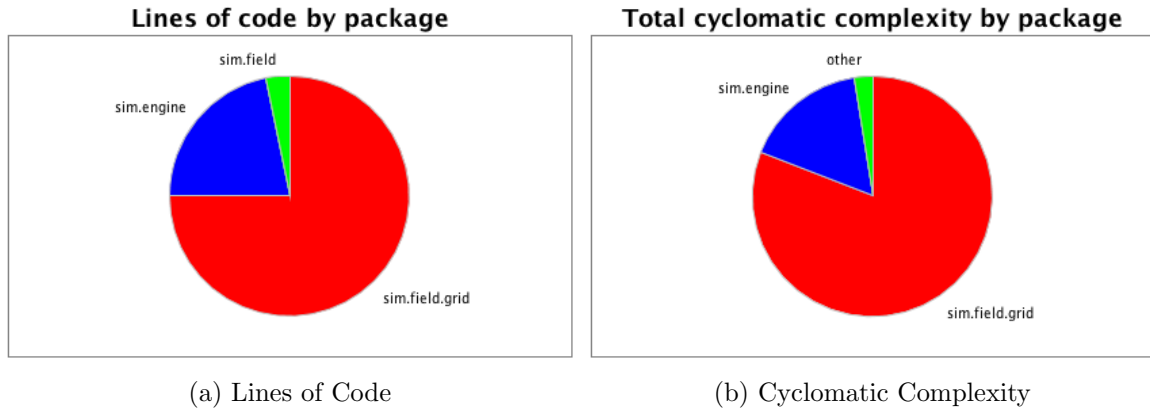


Figure 1: Charts showing various metrics of MASON

It has been shown across software projects that some modules of code may be significantly more error prone than others. The Pareto principle is said to hold with software bugs, with 80% of software bugs being found within 20% of the code[3, pp. 124]. We can use a variety of metrics about our software to predict which parts of the code that these bugs may be hiding in[4]. Unfortunately, a number of these metrics, including a history of bugs are not publicly available.

High cyclomatic complexity (Fig. 1b/Fig. 3c) can be a good indicator of the most bug-ridden sections of applications. The causality here can be easily understood: complexity creates confusion which results in developers misunderstanding the software they are trying to build. This misunderstanding can provoke a large number of bugs in the code. The graphs show that `sim.field.grid` has a slightly higher share of the code's complexity than lines of code. If we investigate this metric in further detail, it becomes clear that the majority of the more complex classes are in the `sim.field.grid` package. This metric has been plotted against the number of changes that have been committed to the class' source file. Files which are subject to frequent change have had more opportunity to develop additional bugs, therefore files with high complexity and frequent changes are particularly worrying and should be looked at.

Fig. 3d shows how the packages in the test scope interact with other packages in the system. In particular, `sim.engine` is directly relied upon by a large number of other packages. Additionally, code coverage (Fig. 9) has provided a good understanding of which parts of the software are regularly used while running simulations. Again `sim.engine` appears to be heavily used by the demo simulations.

1.2.2 Testing Goals

There are a number of goals we could define for our testing, such as finding the maximum number of bugs or complying with regulator set demands. The given requirement here is to verify, with a limited number of resources, that the software is dependable. In general, it's better to test with the aim of showing a product fails, if we cannot do so then the product is reliable enough[5, pp. 20]. As such, the main requirement for our testing is to find any significant undiscovered bugs in commonly used code.

Due to limited resources, the tests will aim to cover the parts of the software which are likely to be used more often by the target users. In this case, our target users are the staff of a private biological research institute. The brief has not provided any specific use cases for the software, so this aim will not be trivial to accomplish. Previous biological implementations which utilised MASON[7] have been used to gain an insight into which MASON features are important to biological simulations.

Additionally I have assumed that MASON's bundled demo simulations give typical use cases for the library. Running these simulations with code coverage detection turned on has given a good overview of which parts of the code are used regularly (Fig. 9). Core simulation code that is used routinely by all simulations regardless of their customisations should be tested the most rigourously. Both the documentation[6, pp.85] and code coverage checks indicate that this type of code can be found within `sim.engine`.

1.2.3 Expected Behaviour

The expected behaviour of the software has been determined using the extensive MASON documentation[6] and first-party example implementations. Many of these examples have been implemented using the ContinuousGrid classes which are outside of the test scope.

The MASON documentation has conflicts, likely caused by parts of the document becoming out of date as the software is updated. One example of this is that in the tutorial section on Page 19, it describes different behaviour for the `-time` command line argument to that described in the formal documentation on page 91. In this case, and in general, the behaviour in the main documentation has been assumed correct and the tutorials assumed to be out of date. If a more ambiguous case had presented itself, exploratory testing could have been used to determine the expected behaviour.

1.2.4 Unit Testing

Unit Testing allows the testing of small sections of source code. In this case, unit tests will help us to isolate the select packages that are within the scope of testing from the rest of the system.

Unit testing should focus on core code that is a dependency for other modules, code that regularly gathers bugs and code that is changed by a number of different developers. It

should not cover trivial code, such as accessors and mutators, code with non-deterministic results or UI code.[8] In this case, we will target our unit testing at ensuring the core software functionality is correct, specifically that simulations can be created and run.

As previously mentioned, it has been shown that approximately 20% of the code, contains 80% of our program's bugs. Our unit testing will aim for 60-70% code coverage of core code and ~20% of the overall application, as recommended in [8].

1.2.5 Integration Testing

Java is a heavily object-oriented (OO) language. This will affect our testing as in this type of software, much of the complexity is moved from algorithms in methods, to the connection of software components[9, pp.236]. We will therefore need a much greater focus on integration testing than unit testing.

1.2.6 System Testing

While testing the system as a whole will not help us find low-level bugs, it will give a high-level view of whether the bulk of the functionality appears to work as expected. System testing of the application will be conducted using the MASON UI as a black-box test. As such, although the test relies on functionality provided by classes outside the test scope, the test cases will only attempt to verify functionality provided by classes which are in scope.

System testing will also help us to verify the non-functional requirements that have been previously determined. In particular, our system testing will cover

Acceptance Testing is a particularly useful form of system testing, which can be used for verifying non-functional requirements. It can be useful for understanding the domain of our software better, but as we are not intending to further develop MASON, this is not particularly relevant here. However, it would be helpful to discover if it is appropriate for the target audience. A particularly important non-functional requirement of our software is that it can be operated effectively by our end users. In particular, our users have supposedly only received a basic level of Java training. It has been stated that MASON is less-suited to beginner programmers, when compared to other tools, such as NetLogo[10].

In order for acceptance testing to be meaningful, it should be performed on potential users. Unfortunately, this means that this type of testing is out of reach for this report as target users are unavailable.

1.2.7 Mutation Testing

Mutation testing is often used to determine the effectiveness of a test-set at discovering bugs in the system. As we already have a very limited number of tests, mutation testing

will not be used.

1.2.8 Regression Testing

Unfortunately neither the website nor the GitHub repository for MASON provide any previously implemented automated testing. Either this testing has not been done, which is common with freely-distributed software, or it has not been publicly distributed. As such, it will not be possible to run any regression testing as part of the project.

2 Test Case Specifications

2.1 Test Case 1

The `AbstractGrid` classes are among those with the highest cyclomatic complexity. The other grid classes inherit code from these abstract classes, except `SparseGrid2D` which duplicates a great deal of code instead (Fig. 6), implying this code is highly important. `AbstractGrid2D` also has the highest number of historic code changes out of the `sim.field.grid` package. These two metrics are worrying given that the simulation runs show that this class is routinely used to some extent. Unit Test cases have been derived to target the methods in this class with the highest complexity (Fig. 7), specifically `getHexagonalLocations`.

`AbstractGrid2D` cannot be directly instantiated for this test, so `DoubleGrid2D` will be used as it extends the class without overriding `getHexagonalLocations`. A new `DoubleGrid2D` object is instantiated with width and height both equal to 150. The method is called with the origin x and y both equal to 120 and dist equal to 20. The grid mode is set to bounded, origin is set to be included and empty `IntBags` are passed to the method. The expected output has been independently calculated using a hexagon point algorithm. These independently calculated point values have been manually verified as correct using a 2D graphing software.

2.2 Test Case 2

Another method of `AbstractGrid2D` which has a high cyclomatic complexity is `getRadialLocations`. This method will also be tested to ensure its behaviour is expected. In particular testing at boundaries is most likely to show ambiguities in the specifications[5, pp.25], thus revealing bugs. In the case of this method, a boundary case is checking that the values correctly wrap around when the grid is in toroidal mode. A new `DoubleGrid2D` is created with width 200 and height 160. The `getRadialLocations` method is invoked with an origin of (150, 150) and a radius of 20 so that the circle should wrap around the end of the grid in the y-direction. In this case, include origin is set to true and empty `IntBags` are passed into the method.

Assertions are made to ensure that the size of the bags for x and y are both equal to 1345. The bags are then compared against the expected values as calculated independently by the midpoint circle algorithm. These independently calculated point values have been manually verified as correct using a 2D graphing software. In order to check that the toroidal wrapping works correctly, the remainder operator is applied to these circle algorithm results with the height/width of the field.

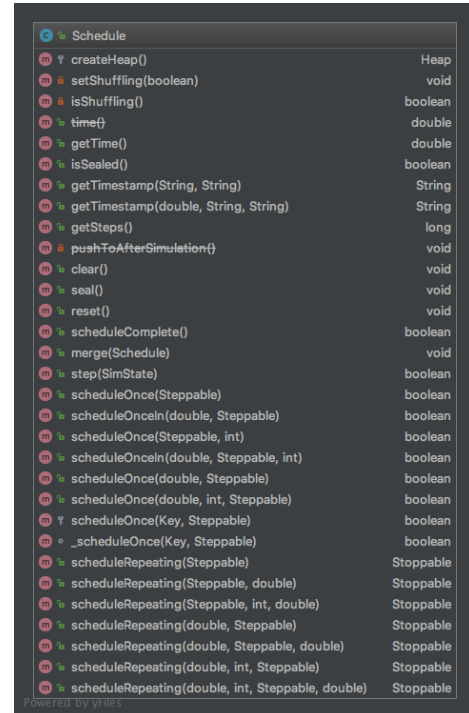
2.3 Test Cases 3-4

As previously stated, our initial integration testing will focus on the simulation scheduler which provides the core functionality for MASON. This scheduler works with the `SimState` class and custom implementations of the `Steppable` interface to provide the functionality that simulates the passing of time.

While this integration between classes may appear to be complex at first glance, with numerous methods available (Fig. 2), many of its methods are simply overloads, due to Java's lack of real support for default function arguments. Testing a single example of `scheduleOnce` function, will provide a reasonable assurance that the functionality works, as code is shared with each overloaded instance calling the private `_scheduleOnce` method.

Test Case 3 will add a `Steppable` object to the `Schedule` and ensure that the `step` method work as expected. A by-product of this test, is the assurance that the `_scheduleOnce` method also works as expected. As `_scheduleOnce` is a private method, it will be called indirectly by one of its overloading methods: `scheduleOnce(Steppable)`. Other overloading methods could be used instead with no difference on the test case as the scheduler skips any empty timesteps. In order to facilitate this test, a simple `Increment` class (Fig. 4) has been created. The scheduler will be stepped a number of times (10) to ensure that the `Increment` value is correctly stepped.

Test Case 4 is similar, but will utilise the `scheduleRepeating(Steppable)` to ensure that the `Schedule` correctly manages recurring events. As mentioned, the scheduler skips any empty timesteps, so providing a different start time or time interval will make little difference to the test. Again, the scheduler will be stepped a number of times (10) to ensure that the value is stepped multiple times as expected.



Method	Return Type
<code>createHeap()</code>	Heap
<code>setShuffling(boolean)</code>	void
<code>isShuffling()</code>	boolean
<code>time()</code>	double
<code>getTime()</code>	double
<code>isSealed()</code>	boolean
<code>getTimestamp(String, String)</code>	String
<code>getTimestamp(double, String, String)</code>	String
<code>getSteps()</code>	long
<code>pushToAfterSimulation()</code>	void
<code>clear()</code>	void
<code>seal()</code>	void
<code>reset()</code>	void
<code>scheduleComplete()</code>	boolean
<code>merge(Schedule)</code>	void
<code>step(SimState)</code>	boolean
<code>scheduleOnce(Steppable)</code>	boolean
<code>scheduleOnceIn(double, Steppable)</code>	boolean
<code>scheduleOnce(Steppable, int)</code>	boolean
<code>scheduleOnceIn(double, Steppable, int)</code>	boolean
<code>scheduleOnce(double, Steppable)</code>	boolean
<code>scheduleOnce(double, int, Steppable)</code>	boolean
<code>scheduleOnce(Key, Steppable)</code>	boolean
<code>_scheduleOnce(Key, Steppable)</code>	boolean
<code>scheduleRepeating(Steppable)</code>	Stoppable
<code>scheduleRepeating(Steppable, double)</code>	Stoppable
<code>scheduleRepeating(Steppable, int, double)</code>	Stoppable
<code>scheduleRepeating(double, Steppable)</code>	Stoppable
<code>scheduleRepeating(double, Steppable, double)</code>	Stoppable
<code>scheduleRepeating(double, int, Steppable)</code>	Stoppable
<code>scheduleRepeating(double, int, Steppable, double)</code>	Stoppable

Figure 2: Schedule Class

2.4 Test Case 5

2.5 Test Case 6

2.6 Test Case 7

This test case will verify that the tool is able to run from the command-line, correctly reacting to user configurations. The example simulation will be run for a specified number of

The documentation here is conflicting. On Page 91, the `-time` argument specifies that it will 'print a timestamp every T simulation steps' whereas page 19 states that the argument means the simulation will 'run for a limited time', behaviour that 19 attributes to the `-until` argument.

2.7 Test Case 8

This test case will verify that the tool works as expected from the User Interface.

3 Test Results

Case	Pass	Level	Expected	Actual	Details
1	✓	Unit	A hexagonal set of points is created, such that the points match the expected values which have been independently calculated.	<i>As Expected</i>	N/A
2	✗	Unit	The circular points that are generated should wrap around to 0 when they become greater than the height of the coordinate system.	The points wrap around, but go past the origin and become negative.	This is a major bug as it may significantly impact the results of simulations.
3	✓	Integration	i variable is incremented once, in first simulation step.	<i>As Expected</i>	N/A
4	✓	Integration	i variable is incremented once for each simulation step.	<i>As Expected</i>	N/A
5	✓	Integration			
6	✓	Integration			
7	✓	System	The simulation runs and stops after 200,000 steps.		Documentation is conflicting.
8	✓	System			

4 Test Summary Report

A wide spectrum of testing has been performed including all levels of the software.

Despite the limited resources, a number of bugs in the code have been detected. This is an indicator that the software may not have been tested as rigorously as could be expected.

Test Case 2 has uncovered a bug in which the calculation of y values is incorrect for grids that are toroidal. This type of grid has previously been used in MASON biological simulations[7] so it can assumed as a dependency of future simulations created by the end users. As this code is *also* duplicated in a different class, it effectively means that two bugs have been found with this test. This is a major bug, which

Test Case 7 covers a case which conflicts in the documentation.

The significant limitations of testing resources reduce the level of confidence with which we can say that the software is free from defects. I can assure that the core functionality, including the simulation scheduler works.

The automated testing have achieved a code coverage of

The MASON package seems to broadly function as expected, with the discovered faults having minimal impact on the core functionality of being able to produce and run agent-based simulations. None of the defects that have been discovered give any real reason to discount MASON as the package of choice for the simulation developers. However, before it is adopted, I recommend that a reasonable amount of acceptance testing is performed with a group of end users from the company. This will help to verify if the software is suitable for users with basic Java programming, as research[10] has suggested otherwise.

5 References

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6 Appendix

Package	Lines of Code
sim.engine	2,961
sim.field	444
sim.field.grid	10,248
Total	13,653
Average	4,551

(a) Lines of Code

Package	Class Count
sim.engine	25
sim.field	6
sim.field.grid	14
Total	45
Average	15

(b) Class Count

Package	v(G)	
	Average	Total
sim.engine	2.43	374
sim.field	2.38	57
sim.field.grid	3.75	1,829
Total		2,260
Average	3.39	753.33

(c) Cyclomatic Complexity

Package	Dependencies	Dependants
sim.engine	2	54
sim.field	1	24
sim.field.grid	2	20
Average	1.67	32.67

(d) Package Dependency

Figure 3: Code Metrics for the relevant MASON libraries

```

class Increment implements Steppable{
    private int i = 0;

    @Override
    public void step(SimState state) {
        i++;
    }
}

```

Figure 4: Simple Increment class used for Unit Testing

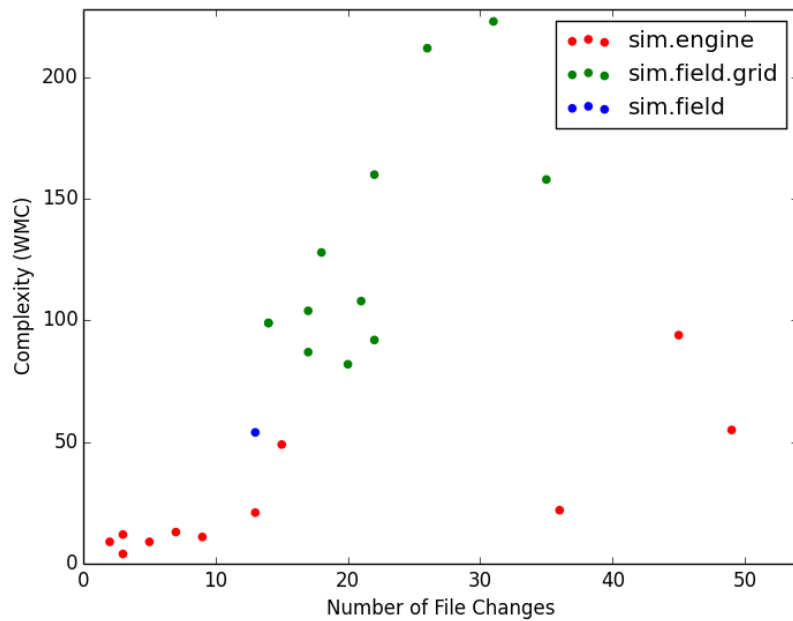


Figure 5: Cyclomatic Complexity and Number of File Revisions for classes in test scope

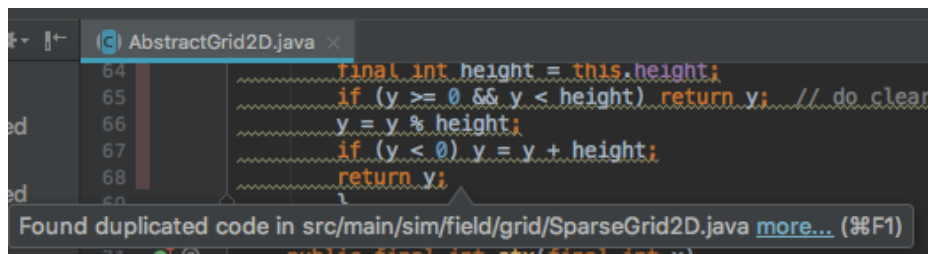


Figure 6: Screenshot showing IntelliJ's detection of duplicated code between AbstractGrid2D and SparseGrid2D

method	ev(G)	iv(G)	v(G)
sim.field.grid.AbstractGrid2D.getHexagonalLocations(int,int,int,int,boolean,IntBag,IntBag)	6	21	49
sim.field.grid.AbstractGrid2D.getVonNeumannLocations(int,int,int,int,boolean,IntBag,IntBag)	5	11	37
sim.field.grid.AbstractGrid2D.getMooreLocations(int,int,int,int,boolean,IntBag,IntBag)	5	8	29
sim.field.grid.AbstractGrid2D.getRadialLocations(int,int,double,int,boolean,IntBag,IntBag)	3	13	29
sim.field.grid.AbstractGrid2D.tx(int,int,int,int,int)	4	1	5
sim.field.grid.AbstractGrid2D.ty(int,int,int,int,int)	4	1	5
sim.field.grid.AbstractGrid2D.tx(int)	2	1	4

Figure 7: AbstractGrid2D methods with greatest cyclomatic complexity

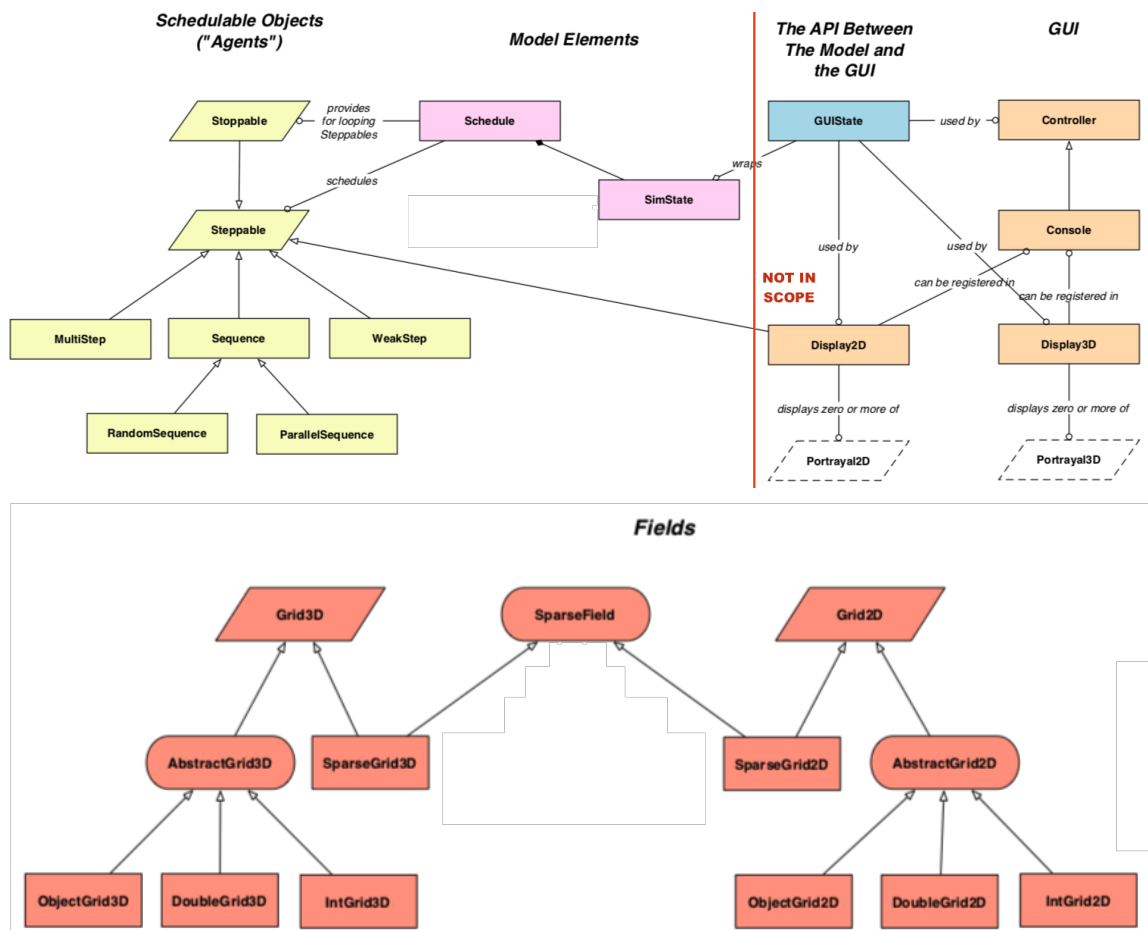


Figure 8: UML diagrams of hierarchy for classes in the test scope[11]

Package	Class	HeatBugs Coverage (%)		Tutorial 4 Coverage (%)		Mouse Traps Coverage (%)	
		Method	Line	Method	Line	Method	Line
sim.engine	AsynchronousSteppable						
	IterativeRepeat	60	70	60	71		
	MethodStep						
	MultiStep						
	ParallelSequence	38	59				
	RandomSequence						
	Repeat						
	Schedule	41	51	38	49	35	46
	Sequence	11	12				
	SimState	31	18	55	48	31	18
	TentativeStep						
	ThreadPool	66	76				
	WeakStep						
sim.field	SparseField	21	34	24	37		
sim.field.grid	AbstractGrid2D	10	1	5	0	5	0
	AbstractGrid3D						
	DenseGrid2D						
	DenseGrid3D						
	DoubleGrid2D	11	7	7	5		
	DoubleGrid3D						
	IntGrid2D					17	10
	IntGrid3D						
	ObjectGrid2D						
	ObjectGrid3D						
	SparseGrid2D	10	2	4	1		
	SparseGrid3D						

Figure 9: Code Coverage from Demo Simulation Runs