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# **Gridsim**

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# CONTENTS

<b>1</b>	<b>Index</b>	<b>1</b>
1.1	Getting Started . . . . .	1
1.2	Class Reference . . . . .	12
1.3	Development . . . . .	23
1.4	Changelog . . . . .	25
<b>2</b>	<b>About</b>	<b>29</b>
<b>3</b>	<b>Quick Install</b>	<b>31</b>
<b>4</b>	<b>Links</b>	<b>33</b>
<b>5</b>	<b>Contact</b>	<b>35</b>
	<b>Python Module Index</b>	<b>37</b>
	<b>Index</b>	<b>39</b>



## 1.1 Getting Started

### 1.1.1 Installation

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**Note:** This assumes that you're already familiar with virtual environments and pip.

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#### Virtual Environment Setup

Create a Python 3 virtual environment in the current location in subfolder called `venv`, then set it as the Python source.

```
$ python3 -m venv venv
$ source venv/bin/activate
```

You can deactivate the virtual environment with `deactivate`.

#### Quick Install

This package is available through `pip`, so it's easy to install. With your virtual environment active, run:

```
$ pip install gridsim
```

Within your own code, you can now import the Gridsim library components, such as:

```
import gridsim as gs

# Create an empty World of 100 x 100 grid cells
my_world = gs.World(100, 100)
```

### Potential Issues

If you get an error when trying to install PyGame (possibly due to Python 3.8) that says `sdl-config: not found`, you might need to install system dependencies because PyGame uses an older version (1.2) of SDL. For Ubuntu-like systems, you can use the following:

```
$ sudo apt install libsdl-dev libsdl-image1.2-dev libsdl-mixer1.2-dev libsdl-ttf2.0-  
↳dev libportmidi-dev
```

### 1.1.2 Basic Usage

This will walk you through setting up your first robot and complete simulation.

#### On this page

- [Test using built in examples](#)
- [Creating a simple robot](#)
- [A minimal simulation example](#)
- [Adding the Viewer](#)
- [Using configuration files](#)
- [Logging data](#)
- [Complete example](#)

#### Test using built in examples

The examples are in the `examples` directory of the source code. In the near future, I'll set up a way to run the examples directly when you install the package.

#### Creating a simple robot

For more detailed information about developing custom robots, see [Make your own Robot](#).

To start, we will only need to make a simple robot based on the `GridRobot`. This needs to implement three methods:

- `receive_msg()`: Code that is run when a robot receives a message
- `init()`: Code that is run once when the robot is created
- `loop()`: Code that is run in every step of the simulation

Create a file for your robot class. Let's call it `random_robot.py`. Below is a simple Robot that moves randomly and changes direction every 10 seconds. You can copy this or directly download `random_robot.py`

```
1 import random  
2  
3 from gridsim.grid_robot import GridRobot  
4 import gridsim as gs  
5  
6
```

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```

7 class RandomRobot(GridRobot):
8     # Change direction every 10 ticks
9     DIR_DURATION = 10
10
11     def init(self):
12         self.set_color(255, 0, 0)
13         self._msg_sent = False
14
15         # Next tick when Robot will change direction
16         self._next_dir_change = self.get_tick()
17
18     def receive_msg(self, msg: gs.Message, dist_sqr: float):
19         # This robot got a message from another robot
20         self._msg_sent = True
21
22     def loop(self):
23         # Change direction every DIR_DURATION ticks
24         tick = self.get_tick()
25         if tick >= self._next_dir_change:
26             new_dir = random.choice(GridRobot.DIRS)
27             self.set_direction(new_dir)
28             self._next_dir_change = tick + RandomRobot.DIR_DURATION
29
30         # Broadcast a test message to any robots nearby
31         msg = gs.Message(self.id, {'test': 'hello'})
32         self.set_tx_message(msg)
33
34         # Sample the environment at the current location
35         c = self.sample()
36
37         # Change color depending on whether messages have been sent or received
38         # Robot will be white when it has successfully sent & received a message
39         blue = 255 * self._msg_sent
40         # self.set_color(255, green, 0)
41         self.set_color(255-c[0], 255-c[1], blue)

```

## A minimal simulation example

To run a simulation, you need to create a couple of robots, place them in a *World*. Then you call the `step()` method to execute you simulation step-by-step. `step()` will handle running all of the robots' code, as well as communication and movement.

We also want give our Robots something to sense by adding an environment to the *World*. An environment here is represented with an image. (You'll see what this looks like in the next step.) In each cell, the Robots can sense the color of the cell (i.e., the RGB pixel value) at that location with the `sample()` method. If you set up the environment with an image whose resolution doesn't match the grid dimensions, it will be rescaled, possibly stretching the image. To avoid any surprises, you should use an image whose resolution matches your grid dimensions (e.g., for a  $50 \times 50$  grid, use a  $50\text{px} \times 50\text{px}$  image).

Use the code below or download `minimal_simulation.py` and the example environment `ex_env.png`.

```

1 import gridsim as gs
2
3 from random_robot import RandomRobot
4

```

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```

5
6 def main():
7     grid_width = 50 # Number of cells for the width & height of the world
8     num_robots = 5
9     num_steps = 100 # simulation steps to run
10
11     # Create a few robots to place in your world
12     robots = []
13     for n in range(num_robots):
14         robots.append(RandomRobot(grid_width/2 - n*2,
15                                 grid_width/2 - n*2))
16
17     # Create a 50 x 50 World with the Robots
18     world = gs.World(grid_width, grid_width,
19                     robots=robots,
20                     environment="ex_env.png")
21
22     # Run the simulation
23     for n in range(num_steps):
24         # Execute a simulation step
25         world.step()
26         # To make sure it works, print the tick (world time)
27         print('Time:', world.get_time())
28
29     print('SIMULATION FINISHED')
30
31
32 if __name__ == '__main__':
33     # Run the simulation if this program is called directly
34     main()

```

With these files and `random_robot.py` in the same directory, and `gridsim` installed, you should be able to run the code with:

```
$ python3 minimal_simulation.py
```

## Adding the Viewer

With that simple example, you have no way to see what the robots are doing. For that, we add a *Viewer*. This requires adding only two lines of code to our minimal simulation above.

Use the code below or download `viewer_simulation.py`.

```

1 import gridsim as gs
2
3 from random_robot import RandomRobot
4
5
6 def main():
7     grid_width = 50 # Number of cells for the width & height of the world
8     num_robots = 5
9     num_steps = 100 # simulation steps to run
10
11     # Create a few robots to place in your world
12     robots = []

```

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```

13     for n in range(num_robots):
14         robots.append(RandomRobot(grid_width/2 - n*2,
15                                 grid_width/2 - n*2))
16
17     # Create a 50 x 50 World with the Robots
18     world = gs.World(grid_width, grid_width,
19                     robots=robots,
20                     environment="ex_env.png")
21
22     # Create a Viewer to display the World
23     viewer = gs.Viewer(world)
24
25     # Run the simulation
26     for n in range(num_steps):
27         # Execute a simulation step
28         world.step()
29
30     # Draw the world
31     viewer.draw()
32
33     # To make sure it works, print the tick (world time)
34     print('Time:', world.get_time())
35
36     print('SIMULATION FINISHED')
37
38
39 if __name__ == '__main__':
40     # Run the simulation if this program is called directly
41     main()

```

Notice that adding the Viewer slows down the time to complete the simulation, because the display rate of the Viewer limits the simulation rate. If you want to run lots of simulations, turn off your Viewer.

## Using configuration files

Gridsim also provides the *ConfigParser* for using YAML configuration files. This simplifies loading parameters and (as described in the next section) saving parameters with simulation results data.

The *ConfigParser* is un-opinionated; it doesn't place any restrictions on what your configuration files look like, as long as they're valid YAML files.

Compared to our `minimal_simulation.py`, we only need one line to create our *ConfigParser*, from which we can retrieve any parameter values.

Use the code below or download `config_simulation.py` and YAML configuration file `simple_config.yml`.

```

1 import gridsim as gs
2
3 from random_robot import RandomRobot
4
5
6 def main():
7     config = gs.ConfigParser('simple_config.yml')
8     print(config.get('name'))
9     grid_width = config.get('grid_width')

```

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```

10 num_robots = config.get('num_robots')
11 # You can specify a default value in case a parameter isn't in the
12 # configuration file
13 num_steps = config.get('num_steps', default=100)
14
15 # Create a few robots to place in your world
16 robots = []
17 # Configuration values can also be lists, not just single values.
18 x_pos = config.get('robot_x_pos')
19 for n in range(num_robots):
20     robots.append(RandomRobot(x_pos[n],
21                               grid_width/2 - n*2))
22
23 # Create a 50 x 50 World with the Robots
24 world = gs.World(grid_width, grid_width, robots=robots)
25
26 # Run the simulation
27 for n in range(num_steps):
28     # Execute a simulation step
29     world.step()
30     # To make sure it works, print the tick (world time)
31     print('Time:', world.get_time())
32
33 print('SIMULATION FINISHED')
34
35
36 if __name__ == '__main__':
37     # Run the simulation if this program is called directly
38     main()

```

## Logging data

Gridsim has a built-in *Logger*, designed to easily save data from your simulations to HDF5 files. This allows you to store complex data and simulation configurations together in one place. HDF5 files are also easy to read and write in many different programming languages.

There are three main ways to save data to your log files:

- Save the parameters in your configuration with `log_config()`. (Note that not all data types can be saved with `log_config`. See its documentation for more details.)
- Save a single parameter (that's not in your configuration file) with `log_param()`
- Save the state of your simulation/robots with `log_state()`. (This requires some setup.)

In order to log the state of the World, you first need to tell the *Logger* what you want to save about the `log_state`, this function is called and the result is added to your dataset. You can add as many aggregators as you want, each with their own name.

We can extend our `config_simulation.py` to show the three types of logging described above. Use the code below or download `logger_simulation.py`.

```

1 import gridsim as gs
2 from typing import List
3 import numpy as np
4 from datetime import datetime
5

```

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```

6  from random_robot import RandomRobot
7
8
9  def green_agg(robots: List[gs.Robot]) -> np.ndarray:
10     """
11     This is a dummy aggregator function (for demonstration) that just saves
12     the value of each robot's green color channel
13     """
14     out_arr = np.zeros([len(robots)])
15     for i, r in enumerate(robots):
16         out_arr[i] = r._color[1]
17
18     return out_arr
19
20
21 def main():
22     config = gs.ConfigParser('simple_config.yml')
23     print(config.get('name'))
24     grid_width = config.get('grid_width')
25     num_robots = config.get('num_robots')
26     # You can specify a default value in case a parameter isn't in the
27     # configuration file
28     num_steps = config.get('num_steps', default=100)
29
30     # Create a few robots to place in your world
31     robots = []
32     # Configuration values can also be lists, not just single values.
33     x_pos = config.get('robot_x_pos')
34     for n in range(num_robots):
35         robots.append(RandomRobot(x_pos[n],
36                                   grid_width/2 - n*2))
37
38     # Create a 50 x 50 World with the Robots
39     world = gs.World(grid_width, grid_width, robots=robots)
40
41     # Logger
42     trial_num = config.get('trial_num', default=1)
43     # Create a logger for this world that saves to the `test.h5` file
44     logger = gs.Logger(world, 'test.h5', trial_num=trial_num,
45                        overwrite_trials=True)
46     # Tell the logger to run the `green_agg` function every time that
47     # `log_state` is called
48     logger.add_aggregator('green', green_agg)
49     # Save the contents of the configuration, but leave out the 'name' parameter
50     logger.log_config(config, exclude='name')
51     # Save the date/time that the simulation was run
52     logger.log_param('date', str(datetime.now()))
53
54     # Run the simulation
55     for n in range(num_steps):
56         # Execute a simulation step
57         world.step()
58
59         # Log the state every step
60         logger.log_state()
61
62         # To make sure it works, print the tick (world time)

```

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```
63     print('Time:', world.get_time())
64
65     print('SIMULATION FINISHED')
66
67
68 if __name__ == '__main__':
69     # Run the simulation if this program is called directly
70     main()
```

## Complete example

Most simulations will involve all of these components, and multiple trials. You can download a complete, detailed example here: `complete_simulation.py`, as well as a corresponding YAML configuration file: `ex_config.yml`

Here, the configuration file is used as a command line argument, so it's easy to switch what configuration file you use. Run it like this:

```
$ python3 complete_simulation.py ex_config.yml
```

### 1.1.3 Make your own Robot

---

**Note:** This assumes familiarity with object-oriented programming (particularly inheritance and abstract classes).

---

The Gridsim library provides a `Robot` class that manages underlying behavior and drawing of robots, making it easy for you to quickly implement your own functionality and algorithms.

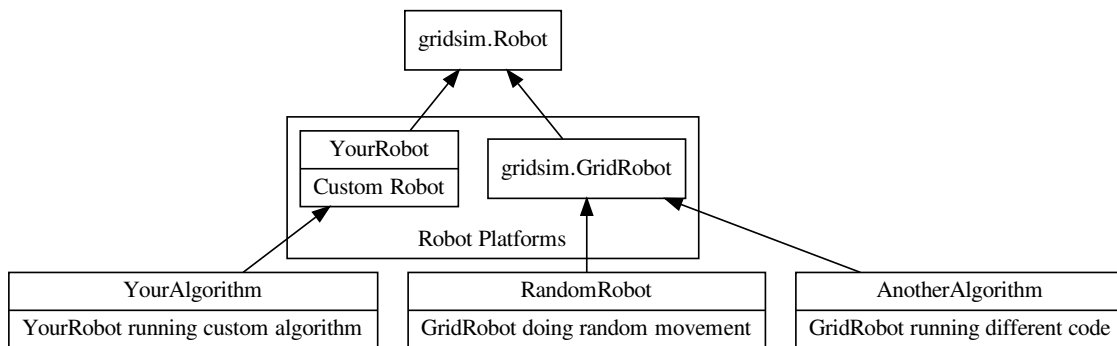
In fact, the default `Robot` class is an abstract class; you must *implement* your own `Robot` subclass. There are five abstract `Robot` methods that you must implement in your own class. (Inputs and outputs are not shown.)

- `move()`: Step-wise movement of the robot on the grid
- `comm_criteria()`: Distance-based criteria for whether or not another robot is within communication range of this robot.
- `receive_msg()`: Code that is run when a robot receives a message
- `init()`: Code that is run once when the robot is created
- `loop()`: Code that is run in every step of the simulation

It also includes an optional method you may want to implement in your subclass:

- `msg_received()`: Code that is run when a robot's successfully sends a message to another robot.

In general, you will likely want to implement your own robots with an additional *two* layers of subclasses, as seen in the graph below. This allows you to separate the physical robot platform you are representing from the algorithms/code you are running on that platform.



First, you create a subclass that represents the physical robot system you are representing (such as a [Turtlebot](#) or [Kilobot](#)). This is still an abstract class. It implements abstract methods that are properties of the physical system, such as the communication range (`comm_criteria()`) and movement restrictions (`move()`). Gridsim include the `GridRobot` as a simple robot platform. You can also create your own, as in the `YourRobot` above.

Second, you create a subclass of your new class for implementing specific algorithms or code on your new robot platform. Here you will implement message handling (`receive_msg()` and optionally `msg_received()`) and onboard code (`init()` and `loop()`). You can have multiple subclasses of your platform to run different code on the same platform, such as `RandomRobot` (created below as an example) and `AnotherAlgorithm`.

### Custom robot example

Below is an example of the structure described above to create a simple robot that bounces around the arena.

First, we create , a robot with a circular communication radius of 5 grid cells that can move in the cardinal directions to any of four cells surrounding it. This robot is already provided in the library as `GridRobot`; you need not re-implement this robot platform if it meets your needs.

```

1  from typing import Tuple
2
3  from .robot import Robot
4  # If you are building your own Robot class, you would instead use:
5  # from gridsim import Robot
6
7
8  class GridRobot(Robot):
9      """
10     A robot that moves along the cardinal directions, with customizable communication_
11     ↪range.
12
13     It provides constants for moving up, down, left, and right.
14
15     Parameters
16     -----
17     x : int

```

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```

17     Starting x position (grid cell) of the robot
18     y : int
19     Starting y position (grid cell) of the robot
20     comm_range : float, optional
21     Communication radius (in grid cells) of the robot, by default 5
22     """
23
24     #: Robot stays where it is
25     STAY = 'stay'
26     #: Robot moves up 1 cell (decrease y position by 1)
27     UP = 'up'
28     #: Robot moves down 1 cell (increase y position by 1)
29     DOWN = 'down'
30     #: Robot moves left 1 cell (decrease x position by 1)
31     LEFT = 'left'
32     #: Robot moves right 1 cell (increase x position by 1)
33     RIGHT = 'right'
34
35     DIRS = [STAY, UP, DOWN, LEFT, RIGHT]
36
37     def __init__(self, x: int, y: int, comm_range: float = 5):
38         # Run all of the initialization for the default Robot class, including
39         # setting the starting position
40         super().__init__(x, y)
41
42         self._comm_range = comm_range
43         # Start with the robot stationary
44         self._move_cmd = GridRobot.STAY
45
46     def set_direction(self, dir: str):
47         """
48         Helper function to set the direction the robot will move. Note that this will
49         ↪persist (the
49         robot will keep moving) until the direction is changed.
50
51         Parameters
52         -----
53         dir : int
54         ↪ Direction to move, one of ``GridRobot.UP``, ``GridRobot.DOWN``,
54         ↪ ``GridRobot.LEFT``,
55         ↪ ``GridRobot.RIGHT``, or ``GridRobot.STAY``
56
57         Raises
58         -----
59         ValueError
60         If given direction is not one of `GridRobot.UP`, `GridRobot.DOWN`,
61         `GridRobot.LEFT`, `GridRobot.RIGHT`, or `GridRobot.STAY`
62         """
63         if dir in GridRobot.DIRS:
64             self._move_cmd = dir
65         else:
66             raise ValueError('Invalid movement direction "{dir}"')
67
68     def move(self) -> Tuple[int, int]:
69         """
70         Determine the cell the Robot will move to, based on the direction set in by
71         :meth:`~gridsim.grid_robot.GridRobot.set_motors`.

```

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```

72     Returns
73     -----
74     Tuple[int, int]
75         (x,y) grid cell the robot will move to, if possible/allowed
76     """
77
78     x, y = self.get_pos()
79     if self._move_cmd == GridRobot.UP:
80         y -= 1
81     elif self._move_cmd == GridRobot.DOWN:
82         y += 1
83     elif self._move_cmd == GridRobot.RIGHT:
84         x += 1
85     elif self._move_cmd == GridRobot.LEFT:
86         x -= 1
87     # else STAY, which keeps current position
88     return x, y
89
90     def comm_criteria(self, dist_sqr: int) -> bool:
91         """
92         Robots can communicate if their Euclidean distance is <= the radius specified.
93         ↪at initialization (by default, 5 cells)
94
95         Parameters
96         -----
97         dist_sqr : int
98             Squared Euclidean distance of the other robot with which to communicate
99
100        Returns
101        -----
102        bool
103            Whether distance is <= the communication radius
104        """
105        return dist_sqr <= self._comm_range**2

```

With our robot platform in place, we can now implement a Robot that implements whatever code we want the robot to run. In this case, it's a simple robot that chooses a random movement every 10 ticks. Its color is based on the color it samples at its current location, and whether it has communicated with another robot.

```

1  import random
2
3  from gridsim.grid_robot import GridRobot
4  import gridsim as gs
5
6
7  class RandomRobot(GridRobot):
8      # Change direction every 10 ticks
9      DIR_DURATION = 10
10
11     def init(self):
12         self.set_color(255, 0, 0)
13         self._msg_sent = False
14
15         # Next tick when Robot will change direction
16         self._next_dir_change = self.get_tick()

```

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```

17
18 def receive_msg(self, msg: gs.Message, dist_sqr: float):
19     # This robot got a message from another robot
20     self._msg_sent = True
21
22 def loop(self):
23     # Change direction every DIR_DURATION ticks
24     tick = self.get_tick()
25     if tick >= self._next_dir_change:
26         new_dir = random.choice(GridRobot.DIRS)
27         self.set_direction(new_dir)
28         self._next_dir_change = tick + RandomRobot.DIR_DURATION
29
30     # Broadcast a test message to any robots nearby
31     msg = gs.Message(self.id, {'test': 'hello'})
32     self.set_tx_message(msg)
33
34     # Sample the environment at the current location
35     c = self.sample()
36
37     # Change color depending on whether messages have been sent or received
38     # Robot will be white when it has successfully sent & received a message
39     blue = 255 * self._msg_sent
40     # self.set_color(255, green, 0)
41     self.set_color(255-c[0], 255-c[1], blue)

```

Notice that the abstraction layers mean that you have to write very little additional code to implement a new algorithm for your robot.

## 1.2 Class Reference

Each page contains details and full API reference for all the classes in the Gridsim library.

For an explanation of how to use all of it together, see *Basic Usage*.

### 1.2.1 World

Simulate the grid-based world, full of robots

The World is where all of the simulation happens. Robots are added to the World, and the Viewer and Logger refer to a World to draw the simulation and save data.

Once the World is created and you have added your robots, you will likely only need to call the `step()` method.

```
class gridsim.world.World(width: int, height: int, robots: List[gridsim.robot.Robot] = [], environ-
                           ment: str = "", allow_collisions: bool = True, observation_stdev: float =
                           0.0)
```

A simulated 2D grid world for simulated Robots.

#### Parameters

- **width** (*int*) – Width of the world (number of cells)
- **height** (*int*) – Height of the world (number of cells)



- **robots** (*List[Robot]*, *optional*) – List of Robots to place in the World to start, by default []. Additional robots can be added after initialization with the `add_robot()` method.
- **environment** (*str*, *optional*) – Filename of an image to use for a background in the World. Robots will be able to sense the color of this image. If the environment dimensions do not match the World dimensions, the image will be re-scaled (and possibly stretched). I recommend using an image with the same resolution as your grid size. This supports using `~` to indicate the user home directory.
- **allow\_collisions** (*bool*, *optional*) – Whether or not to allow Robots to exist in the same grid cell, by default True.
- **observation\_stddev** (*float*, *optional*) – If 0 (this is the default), observations will return the exact RGB value of environment image in each cell. If non-zero (should be  $\geq 0$ ), each component of the observations will be drawn from a normal distribution with mean at the image value, and using this standard deviation. If no image is provided as the `environment`, observations will be returned as 0s, regardless of the `observation_std`.

**add\_environment** (*img\_filename: str*)

Add an image to the environment for the Robots to sense. This will also be shown by the Viewer.

Because sensing is cell-based, images will be scaled to the size of the World's grid. If the aspect ratio does not match, images will be stretched. To avoid any surprises from rescaling, I recommend using an image with the same resolution as your grid size. (e.g., if you have a 50x50 grid, use a 50px x 50px image.)

**Parameters** `img_filename` (*str*) – Filename of the RGB image to use as a background environment. Any transparency (alpha) is ignored by the robot sensing.

**add\_robot** (*robot: gridsim.robot.Robot*)

Add a single robot to the World. Robots can also be added in bulk (as a list) when the World is created, using the `robots` keyword.

**Parameters** `robot` (*Robot*) – Robot to add to the World

**count\_tags** () → int

Count the total number of tagged cells in the World. This is useful for seeing (for example) how many cells in the World have been observed.

**Returns** Number of cells that have been tagged in the World (using the `tag()` method).

**Return type** int

**get\_dimensions** () → Tuple[int, int]

Get the dimensions (in grid cells) of the World

**Returns** (width, height) of the World, in grid cells

**Return type** Tuple[int, int]

**get\_robots** () → pygame.sprite.Group

Get a list of all the robots in the World

**Returns** All Robots currently in the World

**Return type** pygame.sprite.Group

**get\_time** () → float

Get the current time of the World. At the moment, that's just the number of ticks (time steps) since the simulation started, since this is a discrete-time world.

**Returns** Number of ticks (steps) since simulation started

**Return type** float

**step()**

Run a single step of the simulation. This moves the robots, manages the clock, and runs the robot controllers.

**tag** (*pos*: *Tuple[int, int]*, *color*: *Optional[Tuple[int, int, int]] = None*)

Tag a cell position in the World with an RGB color to display in the viewer. There will be a semi-transparent overlay with the given color in that cell in the World. This is primarily for use with the Viewer, to visualize what has been sampled in the World.

**Parameters**

- **pos** (*Tuple[int, int]*) – (x, y) grid cell position to mark.
- **color** (*Tuple[int, int, int]* or *None, optional*) – (R, G, B) color to set as the cell's overlay color (each in the range [0, 255]). If you use `None` instead of a color, this will clear the tag. (If no tag is set at that position, nothing will happen.)

**Raises** **ValueError** – If you give an invalid color, or if you try to tag a position outside the World

## 1.2.2 Robots

Gridsim provides two levels of abstract robot classes. The first, *Robot*, is designed to allow a user full control over their robot platform, specifying to communication criteria and allowed movements.

To get started faster, *GridRobot* implements a simple movement protocol and communication criterion, allowing the user to quickly start implementing their own code on the *GridRobot* platform.

For details on extending the Robot classes to create your own, see *Make your own Robot*.

**class** `gridsim.robot.Robot` (*x*: *int*, *y*: *int*)

Abstract base class for all robot classes

**Parameters**

- **x** (*int*) – Starting x position (grid cell) of the robot
- **y** (*int*) – Starting y position (grid cell) of the robot

**abstract comm\_criteria** (*dist\_sqr*: *int*) → bool

Criterion for whether messages can be communicated (based on distance).

---

**Note:** This takes the squared distance instead of the distance, because it is much less computationally expensive to compute. If you need to take the square root, you can do so here, but because this function is called so much, it will be slow. Instead, consider comparing to the squared communication range.

---

---

**Note:** For simplicity and speed, communication criterion is assumed to be symmetric; therefore, this should return the same value regardless of whether this is called by the sending or receiving robot.

---

**Parameters** **dist\_sqr** (*int*) – SQUARED distance between this robot and the other robot

**Returns** Whether or not the other robot is within communication range

**Return type** bool

**distance** (*pos*: *Tuple[int, int]*) → float

Get the Euclidean distance (in grid cells) between this robot and the specified (x, y) grid cell position.

If you want to change the distance metric (e.g., use Manhattan distance instead), you can override this method when you extend the Robot class.

**Parameters** *pos* (*Tuple[int, int]*) – (x, y) grid cell coordinate to get the distance to

**Returns** Euclidean distance of this robot from the given coordinate

**Return type** float

**get\_pos** () → *Tuple[int, int]*

Get the position of the robot in the grid

**Returns** (x, y) grid position of the robot, from the top left

**Return type** *Tuple[int, int]*

**get\_tick** () → int

Get the current tick of the robot (how many steps since the simulation started).

**Returns** Number of ticks since start of simulation

**Return type** int

**get\_world\_dim** () → *Tuple[int, int]*

Get the dimensions of the World that this Robot is in, so it can plan to avoid hitting the boundaries.

**Returns** (width, height) dimensions of the world, in grid cells

**Return type** *Tuple[int, int]*

**Raises** **ValueError** – Cannot get dimensions if Robot is not in a World. Add it during creation of a World or with *add\_robot* ().

**id**: int = None

Unique ID of the Robot

**abstract init** ()

Robot-specific initialization that will be run when the robot is set up.

This is called when a Robot is added to a `:class:gridsim.world.World``.

**abstract loop** ()

User-implemented loop operation (code the robot runs every loop)

**abstract move** () → *Tuple[int, int]*

User-facing move command, essentially sending a request to move to a particular cell.

The robot will only make this move if it doesn't violate any movement conditions (such as edge of arena or, if enabled, collisions with other robots). Therefore, you do NOT need to implement any collision or edge-of-arena detection in this function.

**Returns** (x, y) grid cell position the robot intends to move to

**Return type** *Tuple[int, int]*

**msg\_received** ()

This is called when a robot successfully sent its message (i.e., when another robot received its message.)

By default, this does nothing. You can override it in your robot class to execute some operation or set a flag when a message is sent.

**abstract receive\_msg** (*msg: Message, dist\_sqr: float*)

Function called when the robot receives a message. This allows the specific robot implementation to choose how to process the messages that it receives, asynchronously.

---

**Note:** This used the squared distance instead of distance. To understand why, see `comm_criteria()`.

---

#### Parameters

- **msg** (*Message*) – Received message from another robot
- **dist\_sqr** (*float*) – Squared distance of the sending robot from this robot

**sample** (*pos: Optional[Tuple[int, int]] = None, tag: Optional[Tuple[int, int, int]] = None*) → *Optional[Tuple[float, float, float]]*

Sample the RGB environment at the given cell location, or (if no `pos` given) and the robot's current position.

This allows you to sample *any* location in the World, but this is **probably cheating**. The robot platform you're modeling likely doesn't have such extensive sensing capabilities. This function is provided so that you can define any custom sensing capabilities (such as within a radius around your robot, or a line of sight sensor).

#### Parameters

- **pos** (*Tuple[int, int], optional*) – (x, y) grid cell position of the World to sample. If not specified, the current robot position is sampled.
- **tag** (*Tuple[int, int, int], optional*) – RGB color to tag this position in the World, by default None. If not provided, the cell in the World won't be tagged with any color. Otherwise, there will be a semi-transparent overlay with the given color in that cell in the World. This is primarily for use with the Viewer, to visualize what has been sampled in the World.

**Returns** (red, green, blue) color at the given coordinate in the range [0, 255]. If the world does not have an environment set, this will return (0, 0, 0). If the given position is outside the boundaries of the World, it will return None.

**Return type** `Tuple[float, float, float]` or None

**set\_color** (*r: int, g: int, b: int*)

Set the color of the robot (as shown in Viewer) with 8-bit RGB values

#### Parameters

- **r** (*int*) – Red channel [0, 255]
- **g** (*int*) – Green channel [0, 255]
- **b** (*int*) – Blue channel [0, 255]

**Raises ValueError** – If all values are not in the range [0, 255]

**set\_tx\_message** (*msg: Message*)

Set the message that will be continuously broadcast. To enable communication, use this function to send a non-empty *Message*. (i.e., a message that doesn't use the empty constructor.)

**Parameters msg** (*Message*) – Message to send to anyone within range

**class** `gridsim.grid_robot.GridRobot` (*x: int, y: int, comm\_range: float = 5*)

A robot that moves along the cardinal directions, with customizable communication range.

It provides constants for moving up, down, left, and right.

**Parameters**

- **x** (*int*) – Starting x position (grid cell) of the robot
- **y** (*int*) – Starting y position (grid cell) of the robot
- **comm\_range** (*float, optional*) – Communication radius (in grid cells) of the robot, by default 5

**DOWN** = 'down'

Robot moves down 1 cell (increase y position by 1)

**LEFT** = 'left'

Robot moves left 1 cell (decrease x position by 1)

**RIGHT** = 'right'

Robot moves right 1 cell (increase x position by 1)

**STAY** = 'stay'

Robot stays where it is

**UP** = 'up'

Robot moves up 1 cell (decrease y position by 1)

**comm\_criteria** (*dist\_sqr: int*) → bool

Robots can communicate if their Euclidean distance is ≤ the radius specified at initialization (by default, 5 cells)

**Parameters** **dist\_sqr** (*int*) – Squared Euclidean distance of the other robot with which to communicate

**Returns** Whether distance is ≤ the communication radius

**Return type** bool

**move** () → Tuple[int, int]

Determine the cell the Robot will move to, based on the direction set in by `set_motors()`.

**Returns** (x,y) grid cell the robot will move to, if possible/allowed

**Return type** Tuple[int, int]

**set\_direction** (*dir: str*)

Helper function to set the direction the robot will move. Note that this will persist (the robot will keep moving) until the direction is changed.

**Parameters** **dir** (*int*) – Direction to move, one of `GridRobot.UP`, `GridRobot.DOWN`, `GridRobot.LEFT`, `GridRobot.RIGHT`, or `GridRobot.STAY`

**Raises** **ValueError** – If given direction is not one of `GridRobot.UP`, `GridRobot.DOWN`, `GridRobot.LEFT`, `GridRobot.RIGHT`, or `GridRobot.STAY`

### 1.2.3 Viewer

The Viewer is a simple way to visualize your simulations. After creating the Viewer, just call `draw()` each step (or less frequently) to see the current state of the World.

---

**Note:** The maximum Viewer refresh rate (set at creation with the `display_rate` argument) also limits the simulation rate. If you want to run faster/higher-throughput simulations, don't use the Viewer, or make it draw less frequently than every tick.

---

```
class gridsim.viewer.Viewer (world: gridsim.world.World, window_width: int = 1080, display_rate: int = 10, show_grid: bool = False, show_network: bool = False, show_time: bool = False)
```

Viewer to display the simulation of a World.

This is optional (for debugging and visualization); simulations can be run much faster if the Viewer is not used.

#### Parameters

- **world** (*World*) – World to display
- **window\_width** (*int, optional*) – Width (in pixels) of the window to display the World, by default 1080
- **display\_rate** (*int, optional*) – How fast to update the view (ticks/s), by default 10. In each tick, robots will move by one cell, so keep this low to be able to interpret what’s going on.
- **show\_grid** (*bool, optional*) – Whether to show the underlying grid in the World, by default False.
- **show\_network** (*bool, optional*) – Whether to visualize the current communication network of the robots, by default False. Communication connections between robots are shown as lines between robots.
- **show\_time** (*bool, optional*) – Whether to draw the time (ticks) as text within the viewer window, by default False. (It is placed in the upper right corner.)

#### **draw** ()

Draw all of the robots in the World into the World and its environment.

This will also draw the World’s environment (if one is set) and any tagged cells in the World.

## 1.2.4 Configuration Parser

The `ConfigParser` is an optional class to help separate your code for experimental configurations by using [YAML](#) files for configuration. This imposes very few restrictions on the way you set up your configuration files; it mostly makes it easier to access their contents and save the configuration parameters with your data using the [Logger](#).

This is useful for managing both values that are fixed through all experiments (e.g., dimensions of the arena) and experimental values that vary between conditions (e.g., number of robots). The latter may be saved as an array and a single value used for different conditions.

While the `ConfigParser` can load any valid [YAML](#) files, the largest restriction is what configuration parameter types can be saved to log files. For details, see the [log\\_config\(\)](#) documentation.

```
class gridsim.config_parser.ConfigParser (config_filename: str, show_warnings: bool = False)
```

Class to handle [YAML](#) configuration files.

This can be directly passed to the [log\\_config\(\)](#) to save all configuration values with the trial data.

#### Parameters

- **config\_filename** (*str*) – Location and filename of the [YAML](#) config file
- **show\_warnings** (*bool*) – Whether to print a warning if trying to get a value that returns `None` (useful for debugging), by default `False`.

**get** (*key: Optional[str] = None, default: Any = None*) → *Any*

Get a parameter value from the configuration, or get a dictionary of the parameters if no parameter name (key) is specified.

---

**Note:** If no default is specified and the key is *not* found in the configuration file, this will return `None` instead of raising an exception.

---

### Parameters

- **key** (*str, optional*) – Name of the parameter to retrieve, by default `None`. If not specified, a dictionary of all parameters will be returned.
- **default** (*Any, optional*) – Default value to return if the key is not found in the configuration, by default `None`.

**Returns** Parameter value for the given key, or the default value if the key is not found. If no key is given, a dictionary of all parameters is returned.

**Return type** `Any`

## 1.2.5 Logger

For logging data out of the simulator using HDF5 files.

The logger provides an interface for easily saving time series data from many simulation trials, along with the parameters used for the simulation. Data is logged in [HDF5](#) (Hierarchical Data Format) files.

Data is stored by trial, in a hierarchy like a file structure, as shown below. Values in `< >` are determined by what you actually log, but the `params` group and `time` dataset are always created.

```
log_file.h5
├── trial_<1>
│   ├── params
│   │   ├── <param_1>
│   │   ├── <param_2>
│   │   └── <param_n>
│   ├── system_info
│   │   ├── datetime_local
│   │   ├── gridsim_version
│   │   └── version
│   ├── time
│   ├── <aggregator_1>
│   ├── <aggregator_2>
│   └── <aggregator_n>
├── trial_<2>
└── trial_<n>
```

All values logged with `log_param()` and `log_config()` are saved in `params`.

Time series data is stored in datasets directly under the `trial_<n>` group. They are created by `add_aggregator()`, and new values are added by `log_state()`. Calling this method also adds a value to the `time` dataset, which corresponds to the *World* time at which the state was saved.

**class** `gridsim.logger.Logger` (*world: gridsim.world.World, filename: str, trial\_num: int, overwrite\_trials: bool = False*)  
 Logger to save data to an HDF5 file, from a single simulation trial.

Note that *creating* this only creates the Logger with which you can save data. You must use the methods below to actually save anything to the file with the Logger.

### Parameters

- **world** (*World*) – World whose simulation data you want to save.
- **filename** (*str*) – Name of the HDF5 file to save data to (.hdf extension). If the file does not exist, it will be created. If it does exist, it will be appended to (with the overwriting caveat specified below). Using ~ to indicate the home directory in the path is supported. If the directory does not exist, it will be created (if possible).
- **trial\_num** (*int*) – Trial number under which to save the data.
- **overwrite\_trials** (*bool, optional*) – Whether to overwrite a trial's data if it already exists, by default False

**add\_aggregator** (*name: str, func: Callable[[List[gridsim.robot.Robot]], numpy.ndarray]*)

Add an aggregator function that will map from the list of all Robots in the world to a 1D array of floats. This will be used for logging the state of the World; the output of the aggregator is one row in the HDF5 Dataset named with the *name*.

The function reduces the state of the Robots to a single or multiple values. It could map to one float per robot (such as a state variable of each Robot) or a single value (length 1 array, such as an average value over all Robots).

Because of Python's dynamic typing, this does not validate whether the subclass of Robot has any parameters or functions that are called by the aggregator. The user is responsible for adding any necessary checks in the aggregator function.

### Notes

The width of the aggregator table is set when this function is called, which is determined by the length of the output of *func*. If the length depends on the number of Robots, all Robots should be added to the *World* *before* adding any aggregators to the Logger.

The aggregator *func* will be applied to all robots in the world, regardless of type. However, if you have multiple types of Robots in your *World*, you can make an aggregator that applies to one type by filtering the robots by type within the *func*.

### Parameters

- **name** (*str*) – Key that will be used to identify the aggregator results in the HDF5 log file.
- **func** (*Callable[[List[Robot]], np.ndarray]*) – Function that maps from a list of Robots to a 1D array to log some state of the Robots at the current time.

**Raises ValueError** – If aggregator *name* uses a reserved name (see above) or if aggregator does not return a 1D numpy array.

**get\_trial** () → int

Get the trial number that this Logger is logging

**Returns** Number of the current trial being logged

**Return type** int

**log\_config** (*config: gridsim.config\_parser.ConfigParser, exclude: List[str] = []*)

Save all of the parameters in the configuration.



## Notes

Due to HDF5 limitations (and my own laziness), only the following datatypes can be saved in the HDF5 parameters:

- string
- integer
- float
- boolean
- list of integers and/or floats

### Parameters

- **config** (*ConfigParser*) – Configuration loaded from a YAML file.
- **exclude** (*List[str], optional*) – Names (keys) of any configuration parameters to exclude from the saved parameters. This can be useful for excluding an array of values that vary by condition, and you want to only include the single value used in this instance.

**log\_param** (*param\_name: str, val: Union[str, int, float, bool, list, dict], sub\_group: Optional[str] = None*)

Save a single parameter value. This is useful for saving fixed parameters that are not part of your configuration file, and therefore not saved with *log\_config()*.

This has the same type restrictions for values as *log\_config()*.

### Parameters

- **param\_name** (*str*) – Name/key of the parameter value to save
- **val** (*Union[str, int, float, bool, list, dict]*) – Value of the parameter to save
- **sub\_group** (*str*) – Name of a sub-group of the “params” group in which to log the parameter. If not given, the parameter will be placed directly in the params group. You can specify multiple levels of sub-groups by concatenating names with /. e.g., sub/subsub

**Warns UserWarning** – If user attempts to save invalid parameter (e.g., invalid data type)

**log\_state** ()

Save the output of all of the aggregator functions. If you have not added any aggregators with *log\_state()*, nothing will be saved by this function.

The runs each previously-added aggregator function and appends the result to the respective HDF5 Dataset. It also saves the current time of the World to the `time` Dataset.

**log\_system\_info** ()

Log system information for future validation and comparison. This saves the following information as individual datasets within the `trial_#/system_info` group:

- `system`: System name (`platform.system()`) (e.g., ‘Linux’, ‘Windows’)
- `node`: System node/host/network name (`platform.node()`)
- `release`: System release (`platform.release`) (e.g., kernel version)
- `version`: System version (`platform.version`)
- `python_version`: Python version (`platform.python_version`) (e.g., ‘3.8.2’)
- `gridsim_version`: Currently installed Gridsim version

- `datetime_local`: Local date and time when trial was run

## 1.2.6 Messages

This provides a basic Message protocol for robot communication. Each message contains the ID of the sender and a dictionary of message contents. The values of the message contents may be any type, so the receiver must know how to process the data.

Additionally, Messages can optionally include a receiver type (`rx_type`). This is only needed if there are multiple types of robots in the World, and you only want certain types of robots to receive the message.

If no arguments are provided when a Message is created, it creates a null message, which signals that the robot is not broadcasting anything.

While it is possible to extend this class, the default Message class should meet most needs.

```
class gridsim.message.Message (tx_id: Optional[int] = None, content: Dict[str, Any] = {}, rx_type: Type[gridsim.robot.Robot] = <class 'gridsim.robot.Robot'>)
```

A message sent by robots

Messages can be either a null (empty) message if no arguments are provided to the constructor. Or it contains the sender's ID, a dictionary of content, and (optionally) the type of robot that receives the message.

### Parameters

- **tx\_id** (*int, optional*) – ID of the sending (transmitting) robot, by default None
- **content** (*Dict[str, Any], optional*) – Dictionary of message keys and values, by default an empty dictionary. Keys must be strings, but values can be of any type (incumbent on receiver to correctly interpret incoming data).
- **rx\_type** (*Type[Robot], optional*) – Type of the receiving robot, by default Robot (i.e., message will be processed by any Robot.)

**Raises** **TypeError** – If `rx_type` is not a subclass of `Robot`, or `content` is not a dictionary with strings for keys

**get** (*key: Optional[str] = None*) → Optional[Dict[str, Any]]

Get the contents of the message

**Parameters** **key** (*str, optional*) – Name of the parameter to retrieve, by default None. If not specified, a dictionary of all parameters will be returned.

**Returns** Dictionary of the message contents

**Return type** Dict[str, Any] or None

**Raises** **KeyError** – If a key is provided but is not in the message contents

**sender** () → Optional[int]

Get the ID (32-bit integer) of the robot that sent the message

**Returns** ID of the sending (transmitting) robot

**Return type** int or None

**set** (*key: Optional[str], value: Any*)

Set the message contents

In the message contents, set the given key to have the given value. If this is an empty (null) message, this will raise an error. If the key already exists, the existing value will be overwritten.

### Parameters

- **key** (*str*) – Key in the message contents for which to set the value
- **value** (*Any*) – Value to set for the given key. This will overwrite any existing value, if the key already exists.

**Raises ValueError** – If the message is null/empty, the message contents cannot be set

**set\_all** (*content: Dict[str, Any]*)

Replace the whole message content of the dictionary.

This will replace *all* of the existing message content.

If you want to clear the message contents, you can pass any empty dictionary as the *content* (`{}`).

**Parameters content** (*Dict[str, Any]*) – Complete dictionary to set as the message contents

**Raises ValueError** – If the message is null/empty, the message contents cannot be set

## 1.3 Development

This is reference material for local development and publishing new versions.

If you just want to use the library, you don't need any of this.

### 1.3.1 Release checklist

- Verify tests and examples work. (It must be [passing on Travis CI](#).)
- Check that all documentation is updated
- Update version number (`__version__`) in `gridsim/__init__.py`
- Update changelog: move “Unreleased” to new version
- Push to master
- Create release on Github. (This will automatically create a new Stable and version-numbered documentation version on Read The Docs and deploy an updated release to PyPi.)

### 1.3.2 Build Documentation

from the `docs` directory, run:

```
make html
```

Then open the documentation:

```
open _build/html/index.html
```

### 1.3.3 Build the distributable for PyPi

(From the [PyPi tutorial](#))

You shouldn't need to do this manually anymore; this will be handled by Travis CI

Make sure the necessary dependencies are installed.

```
pip3 install --upgrade setuptools wheel twine
```

Build the project. From the project root folder, run:

```
python3 setup.py sdist bdist_wheel
```

Upload it to the testing index:

```
python3 -m twine upload --repository-url https://test.pypi.org/legacy/ dist/*
```

Upload it to the actual index:

```
python3 -m twine upload dist/*
```

### 1.3.4 Profiling code

Use the packages [cProfile](#) and [cprofilev](#) to profile Python code. This is useful for finding slow spots in the simulator itself, as well as your own user code.

Note that these are not included as dependencies for Gridsim, so you will have to install them yourself:

```
pip install cprofilev
```

#### Option 1: Using just [cprofilev](#)

Run your code and profile it at the same time.

```
python -m cprofilev main.py test_config.yml
```

#### Option 1: Using [cProfile](#) and [cprofilev](#)

This saves the output as a file, so you can go back and view it later without having to re-run the code.

1. Run your script and save the output to a log file. For example:

```
python -m cProfile -o out_log main.py test_config.yml
```

2. View the output:

```
cprofilev -f out_log
```

And go to [localhost:4000](http://localhost:4000) to view the output

## 1.4 Changelog

This documents changes for each Gridsim release. These can also be found with each [Github release](#).

All notable changes to this project will be documented in this file.

The format is based on [Keep a Changelog](#), and this project adheres to [Semantic Versioning](#).

### Versions

- *Unreleased (probably v0.5)*
- *0.4 (2020-08-20)*
- *0.3 (2020-06-29)*
- *0.2 (2020-04-20)*

### 1.4.1 Unreleased (probably v0.5)

#### Added

- *World* now has the capability for probabilistic observations. For more information, see the *World* constructor documentation.
- New method *count\_tags()* returns the number of tagged locations in the world
- *Logger* now supports logging dictionary parameters (including those saved from config files).
- When logging parameters with *log\_param()*, you can now specify a subgroup of *params* in which to save the data.
- *Message* now has a method *set\_all()* to replace the whole contents of the *Message* without creating a new message. (And as opposed to setting the contents key-by-key with *set\_all()*.)
- Documentation for profiling code (under Development)
- Option in *Viewer* initialization to draw time as text within window
- Option in *Viewer* initialization to draw the communication network between robots

#### Changed

- *comm\_criteria()* and *receive\_msg()* now have an argument of *dist\_sqr* instead of *dist*. This is because the square root call in computing the distance is computationally expensive and is called for communication (an  $N^2$ ) operation.
- For *tag()*, you can now pass *None* instead of a color to remove an existing tag.
- [Under the hood] Convert *World* tagging to use 3D numpy array instead of list of Tuples. This also improves drawing speed ( it doesn't slow down so much when more tags are added), and you don't get gaps between tagged cells for certain window sizes.
- Improve interpolation for resized environment images
- Improved code documentation.
  - Add documentation of errors and warnings

- Move constructor documentation from `__init__` to class documentation. (I think it looks nicer.)
- Move documentation from `*.rst` to `*.py` files, for the sake of having all the documentation in the same place.

### Fixed

- You can now no longer `tag()` cells that are outside of the World dimensions.
- An error is raised when trying to create a `Logger` aggregator (with `add_aggregator()`) using a reserved name (e.g., `params` or `time`).
- Fix Viewer bug that didn't correctly display background color underneath Robots

### 1.4.2 0.4 (2020-08-20)

#### Added

- You can now set the contents of a `Message` by key, without needing to create a new message.
- When creating a `ConfigParser`, you can now choose to show warnings when getting a value that isn't in the config file
- If a data directory (in the path for a `Logger` filename) does not exist, it will be created.
- New method `log_system_info()` allows you to easily save information about the system on which the experiments are being run.
- Paths for both `Logger` and `ImageEnvironment` (used via `World` support using `~` to indicate home directory)

#### Changed

- Trying to have a `Robot` sample outside of the arena now returns `None`. Previously, this threw a lower-level error about an image index being out of range.
- Decrease `World` tag opacity
- Formatting: Changed to 100-character line limit (from 80).
- [Under the hood] Renamed `WorldEnvironment` to `ImageEnvironment`

#### Fixed

- Previously, if you tried to `sample()` a negative position in the `World`, it would loop the index around and give you the value of a position on the other side of the environment. Now, this is considered out of bounds and returns `None`.
- Improve performance for drawing large number of tags in the `Viewer` (by converting coordinates to integers).
- Trying to use the `Viewer` without an environment image in the `World` would cause a crash. Now it doesn't.
- Return type and documentation for `sample()` now matches that of the environment (returns `None` if sampling outside boundaries).
- Fix broken `get_version()` function.
- Time in `Logger` is now stored as an integer (since it's ticks). Previously, it was a float.

### 1.4.3 0.3 (2020-06-29)

#### Added

- Grid cells in the World can now be tagged with a color by the `tag()` method. (The color tag is only used by the `Viewer` when it draws the World.)
- The Robot's `sample()` method now includes an option to tag the sampled location in the `World` with a color.
- `Message` now has “truthiness”: null messages are `False` and non-null messages are `True`.
- Messages contents can be accessed by key with the `get()` method, as well as still being able to retrieve the entire message dictionary contents.
- Created this changelog

#### Changed

- `Message.tx_id()` has been renamed to the (more informative) `sender()`.
- Robot's `init()` isn't run until the robot is placed in the World. This allows robots to have access to World information (like the arena size) in the `init()` method.
- [Under the hood] World's environments are abstracted to have empty and non-empty types, which cleans up code to get rid of reliance on checking for environments being `None`.
- [Under the hood] Reduce reliance on cheating and accessing private variables and methods (underscore-prefixed methods/variables)

#### Removed

- `Message.is_null` has been removed. Instead, directly use the boolean conversion described above.

#### Fixed

- Order of commands run on the robot resulted in incorrect movements (robot-specific `move()`, then Robot controller/loop function, then collision/environment-aware `_move` operation to move the robots which was using a *different* move command)
- Remove `mypy/flake8` from requirements, since they're for local development/linting.

### 1.4.4 0.2 (2020-04-20)

#### Added

- Worlds now have environments (images) that can be sensed by Robots.
- Documentation has been improved, now with complete instructions for basic setup and usage.





## ABOUT

Gridsim is a Python 3 library for simulating robots in a grid-based world. It has a simple, well-documented API, making it easy to implement your own algorithms with minimal overhead.

Key features include:

- Viewer for debugging and visualizing your simulations
- Built-in data logging to HDF5 files
- Support for YAML configuration files
- Extendable robot classes to avoid repeating your code
- Comprehensive documentation and examples



## QUICK INSTALL

```
$ pip install gridsim
```

For more information and instructions, check out the [documentation](#).



**LINKS**

**Documentation:** [Read the Docs](#)

**PyPi:** [gridsim](#)

**Source code:** [Github](#)



## CONTACT

If you have questions, or if you've done something interesting with this package, send me an email: [julia@juliaebert.com](mailto:julia@juliaebert.com).

If you find a problem or want something added to the library, [open an issue on Github](#).





## PYTHON MODULE INDEX

### g

gridsim.config\_parser, 18  
gridsim.logger, 19  
gridsim.message, 22  
gridsim.viewer, 17  
gridsim.world, 12



## A

add\_aggregator() (*gridsim.logger.Logger* method), 20  
 add\_environment() (*gridsim.world.World* method), 13  
 add\_robot() (*gridsim.world.World* method), 13

## C

comm\_criteria() (*gridsim.grid\_robot.GridRobot* method), 17  
 comm\_criteria() (*gridsim.robot.Robot* method), 14  
 ConfigParser (*class in gridsim.config\_parser*), 18  
 count\_tags() (*gridsim.world.World* method), 13

## D

distance() (*gridsim.robot.Robot* method), 14  
 DOWN (*gridsim.grid\_robot.GridRobot* attribute), 17  
 draw() (*gridsim.viewer.Viewer* method), 18

## G

get() (*gridsim.config\_parser.ConfigParser* method), 18  
 get() (*gridsim.message.Message* method), 22  
 get\_dimensions() (*gridsim.world.World* method), 13  
 get\_pos() (*gridsim.robot.Robot* method), 15  
 get\_robots() (*gridsim.world.World* method), 13  
 get\_tick() (*gridsim.robot.Robot* method), 15  
 get\_time() (*gridsim.world.World* method), 13  
 get\_trial() (*gridsim.logger.Logger* method), 20  
 get\_world\_dim() (*gridsim.robot.Robot* method), 15  
 GridRobot (*class in gridsim.grid\_robot*), 16  
 gridsim.config\_parser  
   module, 18  
 gridsim.logger  
   module, 19  
 gridsim.message  
   module, 22  
 gridsim.viewer  
   module, 17  
 gridsim.world  
   module, 12

## I

id (*gridsim.robot.Robot* attribute), 15  
 init() (*gridsim.robot.Robot* method), 15

## L

LEFT (*gridsim.grid\_robot.GridRobot* attribute), 17  
 log\_config() (*gridsim.logger.Logger* method), 20  
 log\_param() (*gridsim.logger.Logger* method), 21  
 log\_state() (*gridsim.logger.Logger* method), 21  
 log\_system\_info() (*gridsim.logger.Logger* method), 21  
 Logger (*class in gridsim.logger*), 19  
 loop() (*gridsim.robot.Robot* method), 15

## M

Message (*class in gridsim.message*), 22  
 module  
   gridsim.config\_parser, 18  
   gridsim.logger, 19  
   gridsim.message, 22  
   gridsim.viewer, 17  
   gridsim.world, 12  
 move() (*gridsim.grid\_robot.GridRobot* method), 17  
 move() (*gridsim.robot.Robot* method), 15  
 msg\_received() (*gridsim.robot.Robot* method), 15

## R

receive\_msg() (*gridsim.robot.Robot* method), 15  
 RIGHT (*gridsim.grid\_robot.GridRobot* attribute), 17  
 Robot (*class in gridsim.robot*), 14

## S

sample() (*gridsim.robot.Robot* method), 16  
 sender() (*gridsim.message.Message* method), 22  
 set() (*gridsim.message.Message* method), 22  
 set\_all() (*gridsim.message.Message* method), 23  
 set\_color() (*gridsim.robot.Robot* method), 16  
 set\_direction() (*gridsim.grid\_robot.GridRobot* method), 17  
 set\_tx\_message() (*gridsim.robot.Robot* method), 16

STAY (*gridsim.grid\_robot.GridRobot attribute*), 17  
step() (*gridsim.world.World method*), 14

## T

tag() (*gridsim.world.World method*), 14

## U

UP (*gridsim.grid\_robot.GridRobot attribute*), 17

## V

Viewer (*class in gridsim.viewer*), 17

## W

World (*class in gridsim.world*), 12