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Project 3

User Guide

Download the zipped folder and extract the code to a user accessible folder (i.e. c:\Users\<UserName>\Desktop). This guide was developed using VSCode as the IDE. I will focus on use from within that IDE, but all methods can be implemented in other tools. Once the code is extracted, open the folder in VSCode.

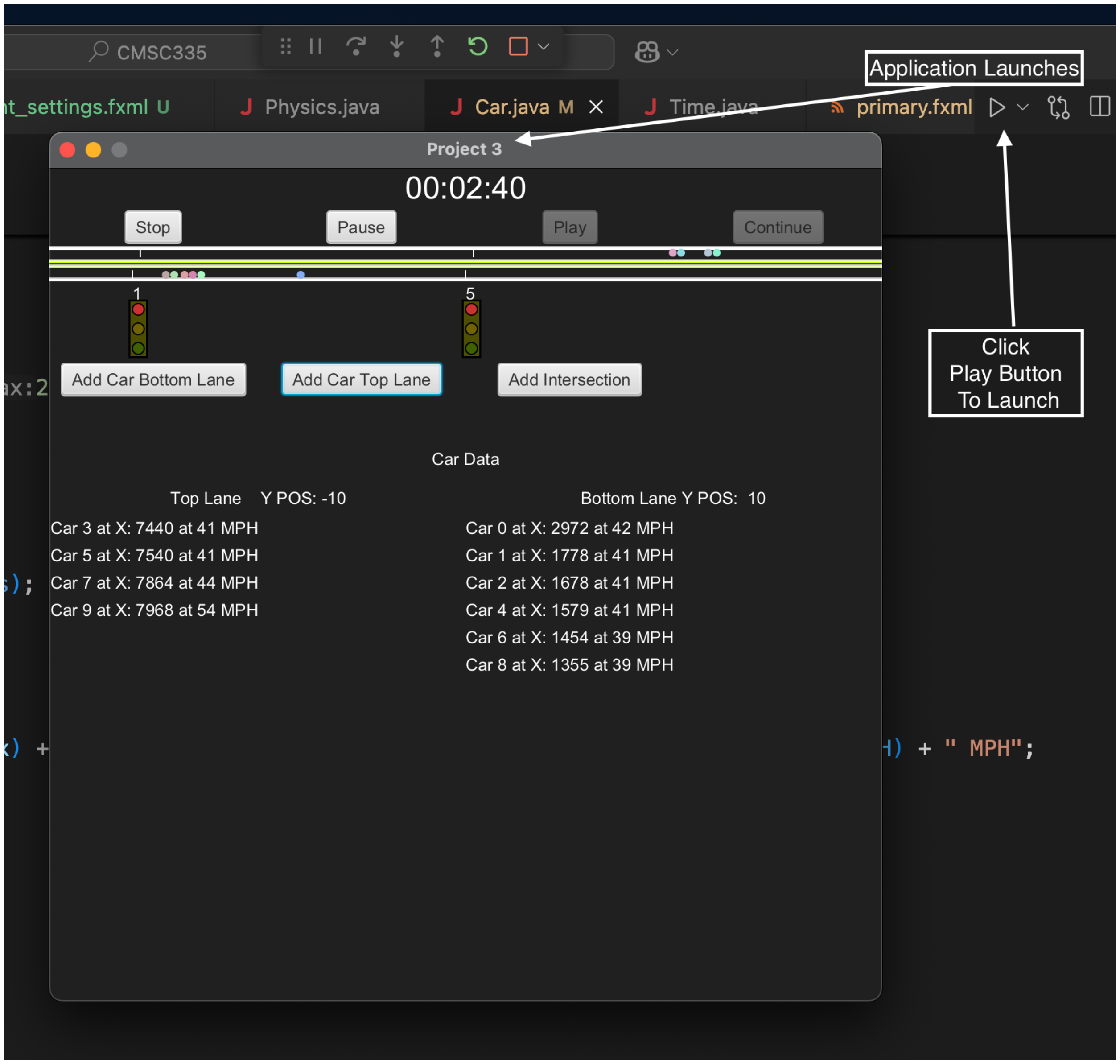
Once opened, install the Extension Pack for Java (v0.29.0) extension. The environment utilized to create and test this project is below.

- Mac macOS 12.7.6
- Java Open-JDK : 21.0.6

You can select the play button on the top right of VSCode to start the project and select project 3 from the bar at the top if asked, see the image below.

Figure 1

Starting project in VSCode



00:02:40

Car Data

```
Top Lane    Y POS: -10                  Bottom Lane Y POS:  10
Car 3 at X: 7440 at 41 MPH              Car 0 at X: 2972 at 42 MPH
Car 5 at X: 7540 at 41 MPH              Car 1 at X: 1778 at 41 MPH
Car 7 at X: 7864 at 44 MPH              Car 2 at X: 1678 at 41 MPH
Car 9 at X: 7968 at 54 MPH              Car 4 at X: 1579 at 41 MPH
                                        Car 6 at X: 1454 at 39 MPH
                                        Car 8 at X: 1355 at 39 MPH
```

Simulation Design

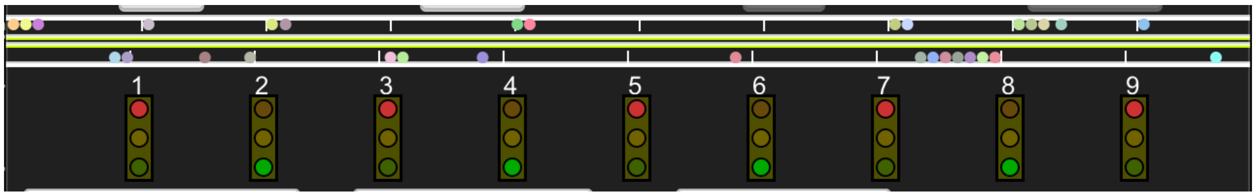
I chose to create this simulation using only a few threads. The main thread, the UI thread, a time keeping thread, and a physics thread. The time and physics threads operate using the observer pattern. The timekeeper thread sends out notifications on the second. The physics thread operates on 16ms intervals, giving a physics update of roughly 60 frames per second. Each physics listener is notified every tick and they will perform their physics calculations, collision checks, and intersection polling then send their UI updates to the UI thread for processing. The road in my simulation covers 10,000 meters (6.22 miles), possibly giving the appearance the cars are slow.

Cars can be added to a lane heading left to right (bottom) or right to left (top). Cars will get a random speed assigned at instantiation between 35 and 55 MPH. They will look ahead in their lane to locate the next vehicle and poll it per physics calculation to determine if they need to slow down to avoid collision. Cars will also poll the next intersection to determine if the light is red. I added the ability to allow the application to add cars on a random interval in a random direction. This can be toggled by a checkbox in the UI.

Lights are physics objects as well. They required a fine-tuned constant time that was not aligned with seconds. Using physics delta time to calculate time since last light change, the lights are able to operate on any time scale. Light timings can be adjusted by double clicking and editing the timings. A light can be removed by right clicking on it or in the setting menu by clicking the remove button. Lights will be added with a pattern that tries to half a section. The pattern is 5, 1, 9, 3, 7, 4, 6, 2, 8 with these numbers aligning to thr lights in the image. If a light is removed and a new one added, the new light will be added to the first available slot in the pattern above.

Figure 2

Light numberings to show matchup of next to be enabled



Assumptions

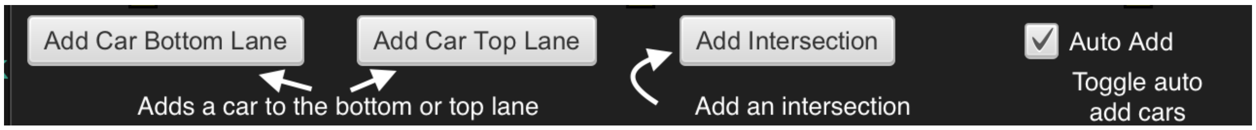
- The road is not to scale. Lane width is magnitudes larger to allow for the huge cars that allow users to see the simulation. The length of the road is 10,000 meters and the road is 640 pixels, making one pixel roughly 16 meters. This means a car moving at 35 miles per hour will travel ~0.261 meters per frame, at times it may appear cars are not moving at low speeds they may need several frames to move one pixel.
- Cars are not to scale, the scale is so users can see them, they would be almost 100 meters long at this scale
- Cars maintain a 100-meter distance, unrealistic but this prevents them from appearing to occupy the same space at the same time
- Cars can start and stop without G forces or Earth based physics applied

Usage

Launch the application in your editor. Once the application is running the simulation will be in a stopped state. Press the play button to start the simulation. By default, the simulation will add cars automatically. You can press the add car to "X" lane button to add cars to the road manually. You can disable the auto add feature by clicking the Auto Add checkbox, shown below.

Figure 3

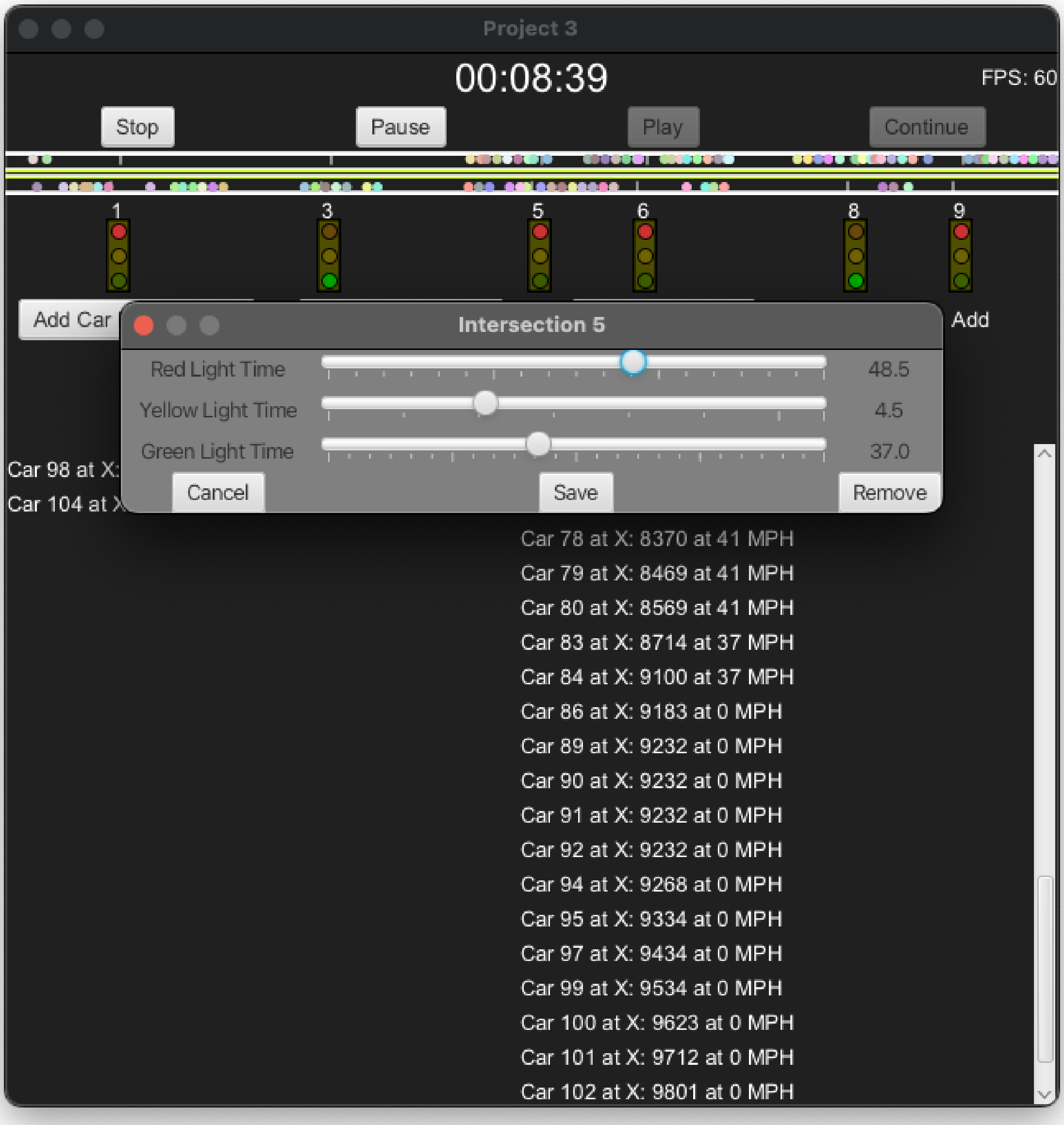
Menu buttons to modify simulation entities



You can add up to 9 intersections to the simulation with the add intersection button. To remove an intersection, right click it or you can also remove it using the settings menu. If you wish to edit an intersection's light timing, double click on the light.

Figure 4

Editing an intersection light timing



Red Light Time 48.5
Yellow Light Time 4.5
Green Light Time 37.0

```
Car 98 at X:
Car 104 at X
Car 78 at X: 8370 at 41 MPH
Car 79 at X: 8469 at 41 MPH
Car 80 at X: 8569 at 41 MPH
Car 83 at X: 8714 at 37 MPH
Car 84 at X: 9100 at 37 MPH
Car 86 at X: 9183 at 0 MPH
Car 89 at X: 9232 at 0 MPH
Car 90 at X: 9232 at 0 MPH
Car 91 at X: 9232 at 0 MPH
Car 92 at X: 9232 at 0 MPH
Car 94 at X: 9268 at 0 MPH
Car 95 at X: 9334 at 0 MPH
Car 97 at X: 9434 at 0 MPH
Car 99 at X: 9534 at 0 MPH
Car 100 at X: 9623 at 0 MPH
Car 101 at X: 9712 at 0 MPH
Car 102 at X: 9801 at 0 MPH
```

Note: The simulation above is running six lights and over 100 cars and while maintains 60 frames per second.

The controls for the simulation allow users to Play, Pause, Continue or Stop the simulation. The following are the definitions for this applications buttons:

- Play – Starts a new simulation from a stopped state; all data is new.
- Pause – Halt the timing and physics of a simulation maintaining all the data
- Continue – Only from a pause state! Resumes the simulation from where it was paused.
- Stop – Reset the simulation, erasing all the data.

Figure 5

Simulation currently running, only pause and stop are available

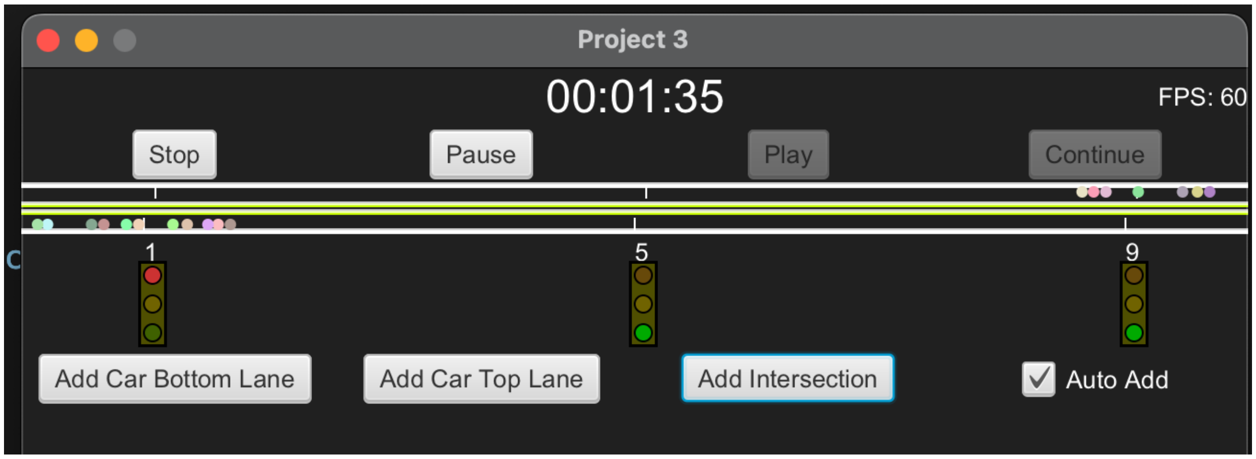
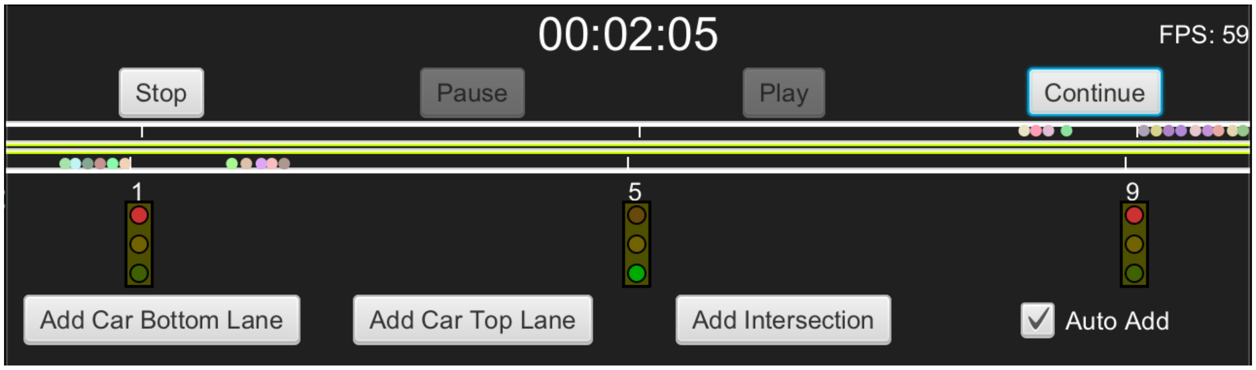


Figure 6

Simulation in pause state, notice the enabled buttons (continue and stop)

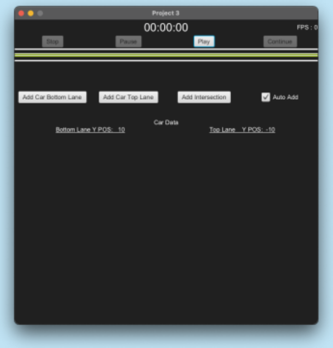
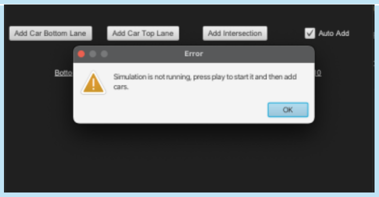


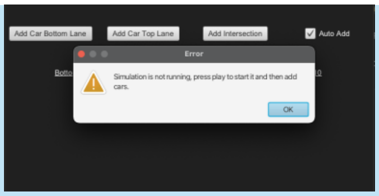
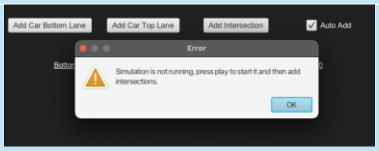
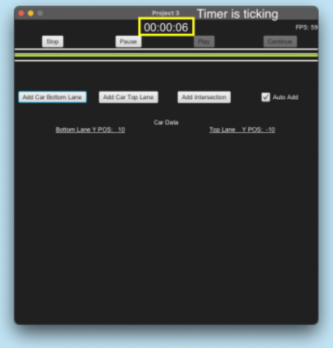
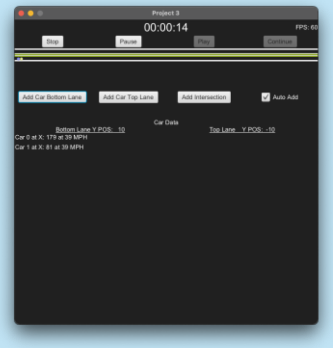
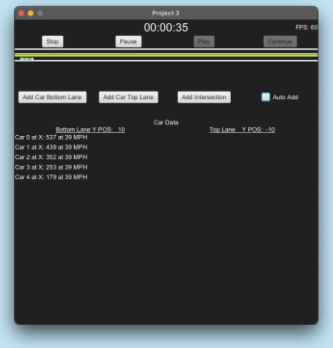
Test Plan

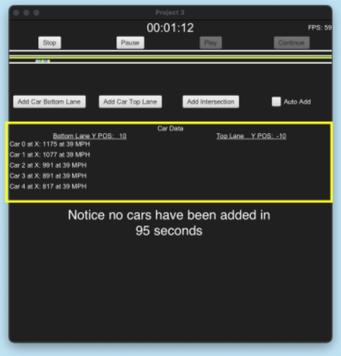
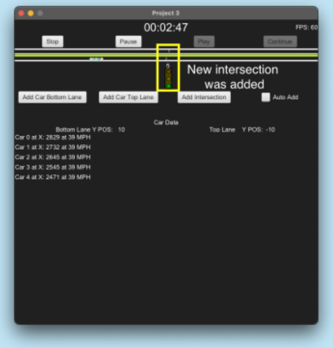
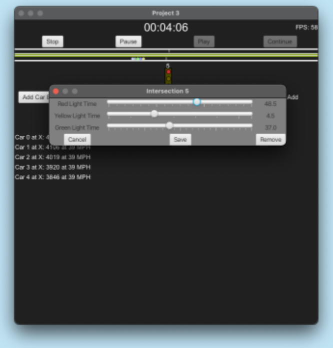
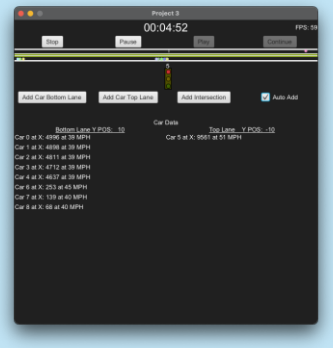
Due to the interactive nature of this application, I chose to do the testing manually. I tried to assist the user during the design process and stop them from having the ability to perform improper actions. In the testing notice that some cases are there to show that the blocking worked, whether disabling buttons when in a specific state or using modals to lock the user into a specific set of actions. For timing tests, I changed the light timing and snapped a screenshot when the light changed and waited for the specified time and snapped another screenshot. In these cases, I did the math for my situation and placed it in the description.

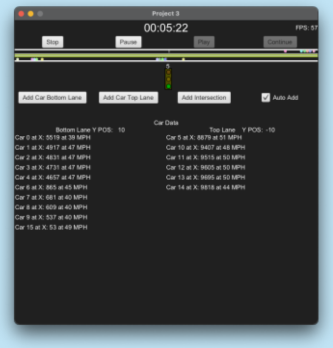
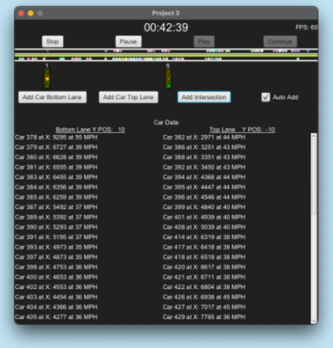
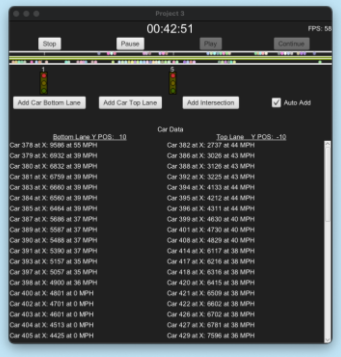
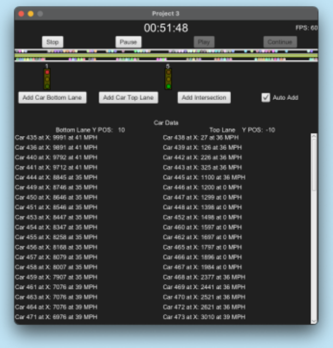
Table 1

Project3 Manual Testing

Test #	Description	Screenshot	Pass/Fail
1	Launch Project 3 Program	 Project 3 00:00:00 FPS : 0 Stop Pause Play Continue Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add Car Data Bottom Lane Y POS: 10 Top Lane Y POS: -10	PASS
2	Ensure program is in stop state	Checked buttons from above, while in stop state only the play button should be available	PASS
3	Attempt to add car to bottom lane (Should Be Denied)	 Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add Error OK Simulation is not running, press play to start it and then add cars.	PASS

4	Attempt to add car to top lane (Should Be Denied)	 Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add Error OK Simulation is not running, press play to start it and then add cars.	PASS
5	Attempt to add intersection (Should Be Denied)	 Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add Error OK Simulation is not running, press play to start it and then add intersections.	PASS
6	Press play and check that timer ticks	 Project 3 Timer is ticking 00:00:06 FPS: 59 Stop Pause Play Continue Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add Car Data Bottom Lane Y POS: 10 Top Lane Y POS: -10	PASS
7	Watch auto add cars, car should be added around 5 seconds	 Project 3 00:00:14 FPS: 60 Stop Pause Play Continue Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add Car Data Bottom Lane Y POS: 10 Top Lane Y POS: -10 Car 0 at X: 179 at 39 MPH Car 1 at X: 81 at 39 MPH	PASS
8	Disable Auto Add, no cars should be added. Notice the time difference and no cars were added.	 Project 3 00:00:35 FPS: 60 Stop Pause Play Continue Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add Car Data Bottom Lane Y POS: 10 Top Lane Y POS: -10 Car 0 at X: 537 at 39 MPH Car 1 at X: 439 at 39 MPH Car 2 at X: 352 at 39 MPH Car 3 at X: 253 at 39 MPH Car 4 at X: 179 at 39 MPH	PASS

		 Project 3 FPS: 59 Stop Pause Play Continue Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add 00:01:12 Car Data Bottom Lane Y POS: 10 Top Lane Y POS: -10 Car 0 at X: 1175 at 39 MPH Car 1 at X: 1077 at 39 MPH Car 2 at X: 991 at 39 MPH Car 3 at X: 891 at 39 MPH Car 4 at X: 817 at 39 MPH Notice no cars have been added in 95 seconds	
9	Add Intersection	 Project 3 FPS: 60 Stop Pause Play Continue 5 Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add 00:02:47 New intersection was added Car Data Bottom Lane Y POS: 10 Top Lane Y POS: -10 Car 0 at X: 2829 at 39 MPH Car 1 at X: 2732 at 39 MPH Car 2 at X: 2645 at 39 MPH Car 3 at X: 2545 at 39 MPH Car 4 at X: 2471 at 39 MPH	PASS
10	Double click Intersection to edit settings	 Project 3 FPS: 58 Stop Pause Play Continue 5 Add Car B Add Intersection 5 Cancel Save Remove 00:04:06 Red Light Time 48.5 Yellow Light Time 4.5 Green Light Time 37.0 Car 0 at X: 4 Car 1 at X: 4106 at 39 MPH Car 2 at X: 4019 at 39 MPH Car 3 at X: 3920 at 39 MPH Car 4 at X: 3846 at 39 MPH	PASS
11	Set Red light time to 30, watch for changes Set to 30 seconds 322-292=30	 Project 3 FPS: 59 Stop Pause Play Continue 5 Add Car Bottom Lane Add Car Top Lane Add Intersection Auto Add 00:04:52 Car Data Bottom Lane Y POS: 10 Top Lane Y POS: -10 Car 0 at X: 4996 at 39 MPH Car 5 at X: 9561 at 51 MPH Car 1 at X: 4898 at 39 MPH Car 2 at X: 4811 at 39 MPH Car 3 at X: 4712 at 39 MPH Car 4 at X: 4637 at 39 MPH Car 6 at X: 253 at 45 MPH Car 7 at X: 139 at 40 MPH Car 8 at X: 68 at 40 MPH	PASS

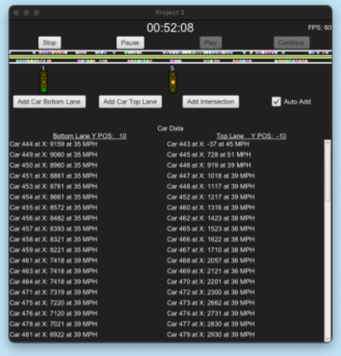
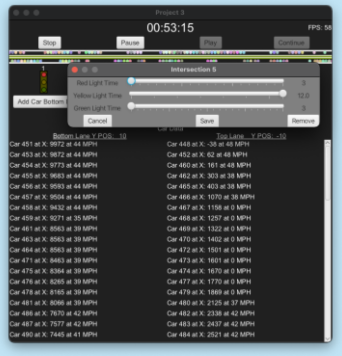
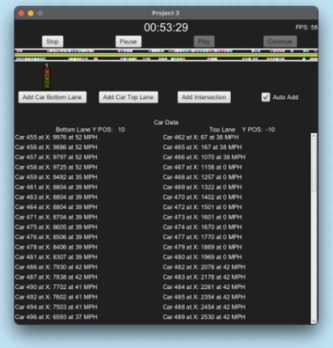
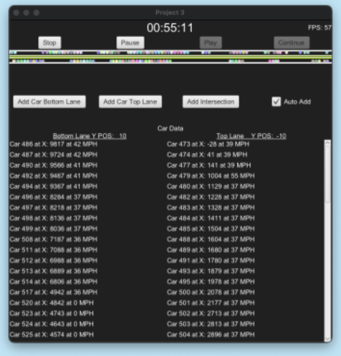
			
12	Set Yellow Light Time to 12, watch for changes Set to 12 seconds 51-39 = 12	 	PASS
13	Set Green Light Time to 20, Watch for changes Set to 20 seconds : 3128 - 3108 = 20		PASS

```
Project 3
00:05:22                                        FPS: 57
Stop        Pause        Play        Continue
5
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add

                          Car Data
        Bottom Lane Y POS:  10                Top Lane   Y POS: -10
Car 0 at X: 5519 at 39 MPH          Car 5 at X: 8879 at 51 MPH
Car 1 at X: 4917 at 47 MPH          Car 10 at X: 9407 at 48 MPH
Car 2 at X: 4831 at 47 MPH          Car 11 at X: 9515 at 50 MPH
Car 3 at X: 4731 at 47 MPH          Car 12 at X: 9605 at 50 MPH
Car 4 at X: 4657 at 47 MPH          Car 13 at X: 9695 at 50 MPH
Car 6 at X: 865 at 45 MPH           Car 14 at X: 9818 at 44 MPH
Car 7 at X: 681 at 40 MPH
Car 8 at X: 609 at 40 MPH
Car 9 at X: 537 at 40 MPH
Car 15 at X: 53 at 49 MPH
```

```
Project 3
00:42:39                                        FPS: 60
Stop        Pause        Play        Continue
1                5
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add

                          Car Data
        Bottom Lane Y POS:  10                Top Lane   Y POS: -10
Car 378 at X: 9295 at 55 MPH        Car 382 at X: 2971 at 44 MPH
Car 379 at X: 6727 at 39 MPH        Car 386 at X: 3251 at 43 MPH
Car 380 at X: 6628 at 39 MPH        Car 388 at X: 3351 at 43 MPH
Car 381 at X: 6555 at 39 MPH        Car 392 at X: 3450 at 43 MPH
Car 383 at X: 6455 at 39 MPH        Car 394 at X: 4368 at 44 MPH
Car 384 at X: 6356 at 39 MPH        Car 395 at X: 4447 at 44 MPH
Car 385 at X: 6259 at 39 MPH        Car 396 at X: 4546 at 44 MPH
Car 387 at X: 5492 at 37 MPH        Car 399 at X: 4840 at 40 MPH
Car 389 at X: 5392 at 37 MPH        Car 401 at X: 4939 at 40 MPH
Car 390 at X: 5293 at 37 MPH        Car 408 at X: 5039 at 40 MPH
Car 391 at X: 5195 at 37 MPH        Car 414 at X: 6319 at 38 MPH
Car 393 at X: 4973 at 35 MPH        Car 417 at X: 6418 at 38 MPH
Car 397 at X: 4873 at 35 MPH        Car 418 at X: 6518 at 38 MPH
Car 398 at X: 4753 at 36 MPH        Car 420 at X: 6617 at 38 MPH
Car 400 at X: 4653 at 36 MPH        Car 421 at X: 6711 at 38 MPH
Car 402 at X: 4553 at 36 MPH        Car 422 at X: 6804 at 38 MPH
Car 403 at X: 4454 at 36 MPH        Car 426 at X: 6938 at 45 MPH
Car 404 at X: 4366 at 36 MPH        Car 427 at X: 7017 at 45 MPH
Car 405 at X: 4277 at 36 MPH        Car 429 at X: 7785 at 36 MPH
```

```
Project 3
00:42:51                                        FPS: 58
Stop        Pause        Play        Continue
1                5
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add

                          Car Data
        Bottom Lane Y POS:  10                Top Lane   Y POS: -10
Car 378 at X: 9586 at 55 MPH        Car 382 at X: 2737 at 44 MPH
Car 379 at X: 6932 at 39 MPH        Car 386 at X: 3026 at 43 MPH
Car 380 at X: 6832 at 39 MPH        Car 388 at X: 3126 at 43 MPH
Car 381 at X: 6759 at 39 MPH        Car 392 at X: 3225 at 43 MPH
Car 383 at X: 6660 at 39 MPH        Car 394 at X: 4133 at 44 MPH
Car 384 at X: 6560 at 39 MPH        Car 395 at X: 4212 at 44 MPH
Car 385 at X: 6464 at 39 MPH        Car 396 at X: 4311 at 44 MPH
Car 387 at X: 5686 at 37 MPH        Car 399 at X: 4630 at 40 MPH
Car 389 at X: 5587 at 37 MPH        Car 401 at X: 4730 at 40 MPH
Car 390 at X: 5488 at 37 MPH        Car 408 at X: 4829 at 40 MPH
Car 391 at X: 5390 at 37 MPH        Car 414 at X: 6117 at 38 MPH
Car 393 at X: 5157 at 35 MPH        Car 417 at X: 6216 at 38 MPH
Car 397 at X: 5057 at 35 MPH        Car 418 at X: 6316 at 38 MPH
Car 398 at X: 4900 at 36 MPH        Car 420 at X: 6415 at 38 MPH
Car 400 at X: 4801 at 0 MPH         Car 421 at X: 6509 at 38 MPH
Car 402 at X: 4701 at 0 MPH         Car 422 at X: 6602 at 38 MPH
Car 403 at X: 4601 at 0 MPH         Car 426 at X: 6702 at 38 MPH
Car 404 at X: 4513 at 0 MPH         Car 427 at X: 6781 at 38 MPH
Car 405 at X: 4425 at 0 MPH         Car 429 at X: 7596 at 36 MPH
```

```
Project 3
00:51:48                                        FPS: 60
Stop        Pause        Play        Continue
1                5
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add

                          Car Data
        Bottom Lane Y POS:  10                Top Lane   Y POS: -10
Car 435 at X: 9991 at 41 MPH        Car 438 at X: 27 at 36 MPH
Car 436 at X: 9891 at 41 MPH        Car 439 at X: 126 at 36 MPH
Car 440 at X: 9792 at 41 MPH        Car 442 at X: 226 at 36 MPH
Car 441 at X: 9712 at 41 MPH        Car 443 at X: 325 at 36 MPH
Car 444 at X: 8845 at 35 MPH        Car 445 at X: 1100 at 36 MPH
Car 449 at X: 8746 at 35 MPH        Car 446 at X: 1200 at 0 MPH
Car 450 at X: 8646 at 35 MPH        Car 447 at X: 1299 at 0 MPH
Car 451 at X: 8546 at 35 MPH        Car 448 at X: 1398 at 0 MPH
Car 453 at X: 8447 at 35 MPH        Car 452 at X: 1498 at 0 MPH
Car 454 at X: 8347 at 35 MPH        Car 460 at X: 1597 at 0 MPH
Car 455 at X: 8258 at 35 MPH        Car 462 at X: 1697 at 0 MPH
Car 456 at X: 8168 at 35 MPH        Car 465 at X: 1797 at 0 MPH
Car 457 at X: 8079 at 35 MPH        Car 466 at X: 1896 at 0 MPH
Car 458 at X: 8007 at 35 MPH        Car 467 at X: 1984 at 0 MPH
Car 459 at X: 7907 at 35 MPH        Car 468 at X: 2377 at 36 MPH
Car 461 at X: 7076 at 39 MPH        Car 469 at X: 2441 at 36 MPH
Car 463 at X: 7076 at 39 MPH        Car 470 at X: 2521 at 36 MPH
Car 464 at X: 7076 at 39 MPH        Car 472 at X: 2621 at 36 MPH
Car 471 at X: 6976 at 39 MPH        Car 473 at X: 3010 at 39 MPH
```

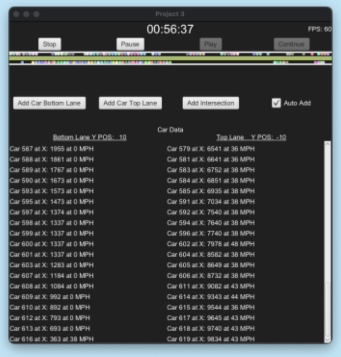
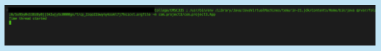
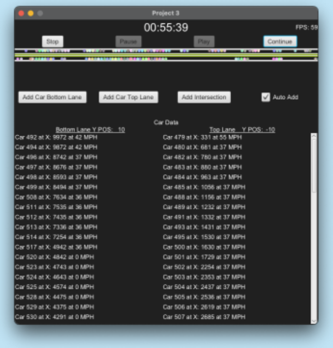
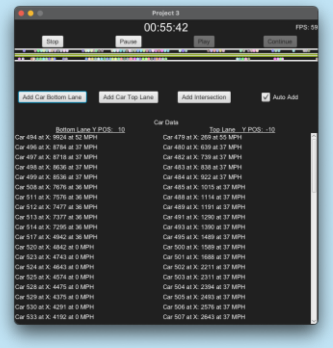
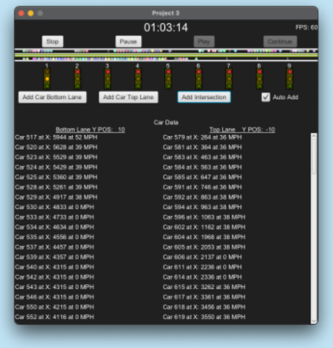
			
14	Remove Intersection from menu Open menu for intersection 5, clicked remove. Intersection is removed.	 	PASS
15	Remove intersection by right click Right click on intersection one. Intersection is removed		PASS

```
Project 3
00:52:08                                   FPS: 60
Stop    Pause    Play    Continue
1   5
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add
                         Car Data
Bottom Lane Y POS:  10              Top Lane   Y POS: -10
Car 444 at X: 9159 at 35 MPH        Car 443 at X: -37 at 45 MPH
Car 449 at X: 9060 at 35 MPH        Car 445 at X: 728 at 51 MPH
Car 450 at X: 8960 at 35 MPH        Car 446 at X: 919 at 39 MPH
Car 451 at X: 8861 at 35 MPH        Car 447 at X: 1018 at 39 MPH
Car 453 at X: 8761 at 35 MPH        Car 448 at X: 1117 at 39 MPH
Car 454 at X: 8661 at 35 MPH        Car 452 at X: 1217 at 39 MPH
Car 455 at X: 8572 at 35 MPH        Car 460 at X: 1316 at 39 MPH
Car 456 at X: 8482 at 35 MPH        Car 462 at X: 1423 at 38 MPH
Car 457 at X: 8393 at 35 MPH        Car 465 at X: 1523 at 38 MPH
Car 458 at X: 8321 at 35 MPH        Car 466 at X: 1622 at 38 MPH
Car 459 at X: 8221 at 35 MPH        Car 467 at X: 1710 at 38 MPH
Car 461 at X: 7418 at 39 MPH        Car 468 at X: 2057 at 36 MPH
Car 463 at X: 7418 at 39 MPH        Car 469 at X: 2121 at 36 MPH
Car 464 at X: 7418 at 39 MPH        Car 470 at X: 2201 at 36 MPH
Car 471 at X: 7319 at 39 MPH        Car 472 at X: 2300 at 36 MPH
Car 475 at X: 7220 at 39 MPH        Car 473 at X: 2662 at 39 MPH
Car 476 at X: 7120 at 39 MPH        Car 474 at X: 2731 at 39 MPH
Car 478 at X: 7021 at 39 MPH        Car 477 at X: 2830 at 39 MPH
Car 481 at X: 6922 at 39 MPH        Car 479 at X: 2930 at 39 MPH
```

```
Project 3
00:53:15                                   FPS: 58
Stop    Pause    Play    Continue
1
Add Car Bottom
Intersection 5
Red Light Time      3
Yellow Light Time   12.0
Green Light Time    3
Cancel    Save    Remove
                         Car Data
Bottom Lane Y POS:  10              Top Lane   Y POS: -10
Car 451 at X: 9972 at 44 MPH        Car 448 at X: -38 at 48 MPH
Car 453 at X: 9872 at 44 MPH        Car 452 at X: 62 at 48 MPH
Car 454 at X: 9773 at 44 MPH        Car 460 at X: 161 at 48 MPH
Car 455 at X: 9683 at 44 MPH        Car 462 at X: 303 at 38 MPH
Car 456 at X: 9593 at 44 MPH        Car 465 at X: 403 at 38 MPH
Car 457 at X: 9504 at 44 MPH        Car 466 at X: 1070 at 38 MPH
Car 458 at X: 9432 at 44 MPH        Car 467 at X: 1158 at 0 MPH
Car 459 at X: 9271 at 35 MPH        Car 468 at X: 1257 at 0 MPH
Car 461 at X: 8563 at 39 MPH        Car 469 at X: 1322 at 0 MPH
Car 463 at X: 8563 at 39 MPH        Car 470 at X: 1402 at 0 MPH
Car 464 at X: 8563 at 39 MPH        Car 472 at X: 1501 at 0 MPH
Car 471 at X: 8463 at 39 MPH        Car 473 at X: 1601 at 0 MPH
Car 475 at X: 8364 at 39 MPH        Car 474 at X: 1670 at 0 MPH
Car 476 at X: 8265 at 39 MPH        Car 477 at X: 1770 at 0 MPH
Car 478 at X: 8165 at 39 MPH        Car 479 at X: 1869 at 0 MPH
Car 481 at X: 8066 at 39 MPH        Car 480 at X: 2125 at 37 MPH
Car 486 at X: 7670 at 42 MPH        Car 482 at X: 2338 at 42 MPH
Car 487 at X: 7577 at 42 MPH        Car 483 at X: 2437 at 42 MPH
Car 490 at X: 7445 at 41 MPH        Car 484 at X: 2521 at 42 MPH
```

```
Project 3
00:53:29                                   FPS: 56
Stop    Pause    Play    Continue
1
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add
                         Car Data
Bottom Lane Y POS:  10              Top Lane   Y POS: -10
Car 455 at X: 9976 at 52 MPH        Car 462 at X: 67 at 38 MPH
Car 456 at X: 9886 at 52 MPH        Car 465 at X: 167 at 38 MPH
Car 457 at X: 9797 at 52 MPH        Car 466 at X: 1070 at 38 MPH
Car 458 at X: 9725 at 52 MPH        Car 467 at X: 1158 at 0 MPH
Car 459 at X: 9492 at 35 MPH        Car 468 at X: 1257 at 0 MPH
Car 461 at X: 8804 at 39 MPH        Car 469 at X: 1322 at 0 MPH
Car 463 at X: 8804 at 39 MPH        Car 470 at X: 1402 at 0 MPH
Car 464 at X: 8804 at 39 MPH        Car 472 at X: 1501 at 0 MPH
Car 471 at X: 8704 at 39 MPH        Car 473 at X: 1601 at 0 MPH
Car 475 at X: 8605 at 39 MPH        Car 474 at X: 1670 at 0 MPH
Car 476 at X: 8506 at 39 MPH        Car 477 at X: 1770 at 0 MPH
Car 478 at X: 8406 at 39 MPH        Car 479 at X: 1869 at 0 MPH
Car 481 at X: 8307 at 39 MPH        Car 480 at X: 1969 at 0 MPH
Car 486 at X: 7930 at 42 MPH        Car 482 at X: 2078 at 42 MPH
Car 487 at X: 7838 at 42 MPH        Car 483 at X: 2178 at 42 MPH
Car 490 at X: 7702 at 41 MPH        Car 484 at X: 2261 at 42 MPH
Car 492 at X: 7602 at 41 MPH        Car 485 at X: 2354 at 42 MPH
Car 494 at X: 7503 at 41 MPH        Car 488 at X: 2454 at 42 MPH
Car 496 at X: 6593 at 37 MPH        Car 489 at X: 2530 at 42 MPH
```

```
Project 3
00:55:11                                   FPS: 57
Stop    Pause    Play    Continue
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add
                         Car Data
Bottom Lane Y POS:  10              Top Lane   Y POS: -10
Car 486 at X: 9817 at 42 MPH        Car 473 at X: -28 at 39 MPH
Car 487 at X: 9724 at 42 MPH        Car 474 at X: 41 at 39 MPH
Car 490 at X: 9566 at 41 MPH        Car 477 at X: 141 at 39 MPH
Car 492 at X: 9467 at 41 MPH        Car 479 at X: 1004 at 55 MPH
Car 494 at X: 9367 at 41 MPH        Car 480 at X: 1129 at 37 MPH
Car 496 at X: 8284 at 37 MPH        Car 482 at X: 1228 at 37 MPH
Car 497 at X: 8218 at 37 MPH        Car 483 at X: 1328 at 37 MPH
Car 498 at X: 8136 at 37 MPH        Car 484 at X: 1411 at 37 MPH
Car 499 at X: 8036 at 37 MPH        Car 485 at X: 1504 at 37 MPH
Car 508 at X: 7187 at 36 MPH        Car 488 at X: 1604 at 37 MPH
Car 511 at X: 7088 at 36 MPH        Car 489 at X: 1680 at 37 MPH
Car 512 at X: 6988 at 36 MPH        Car 491 at X: 1780 at 37 MPH
Car 513 at X: 6889 at 36 MPH        Car 493 at X: 1879 at 37 MPH
Car 514 at X: 6806 at 36 MPH        Car 495 at X: 1978 at 37 MPH
Car 517 at X: 4942 at 36 MPH        Car 500 at X: 2078 at 37 MPH
Car 520 at X: 4842 at 0 MPH         Car 501 at X: 2177 at 37 MPH
Car 523 at X: 4743 at 0 MPH         Car 502 at X: 2713 at 37 MPH
Car 524 at X: 4643 at 0 MPH         Car 503 at X: 2813 at 37 MPH
Car 525 at X: 4574 at 0 MPH         Car 504 at X: 2896 at 37 MPH
```

16	Allow simulation to run for extended time and watch for errors and warnings Simulation has run for almost one hour Notice that 600+ cars have been simulated Second image shows console output, no errors or warnings after all this time	 	PASS
17	Pause the simulation ensure: Cars, intersections, and timer stop. Notice the pause action is no longer available and continue is. Resume by pressing continue, simulation continues		PASS
18	Resume the simulation ensure: Everything remains in same state and cars, intersections, and timer start again		PASS
19	Stop the simulation ensure: All cars and intersections are removed Pressed stop and see all cars and intersections are removed.		PASS

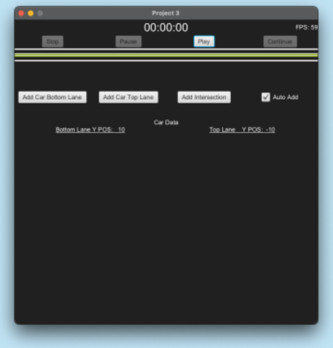
```
Project 3
00:56:37                                   FPS: 60
Stop        Pause        Play        Continue
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add
                          Car Data
Bottom Lane Y POS:  10                  Top Lane   Y POS:  -10
Car 587 at X: 1955 at 0 MPH             Car 579 at X: 6541 at 36 MPH
Car 588 at X: 1861 at 0 MPH             Car 581 at X: 6641 at 36 MPH
Car 589 at X: 1767 at 0 MPH             Car 583 at X: 6752 at 38 MPH
Car 590 at X: 1673 at 0 MPH             Car 584 at X: 6851 at 38 MPH
Car 593 at X: 1573 at 0 MPH             Car 585 at X: 6935 at 38 MPH
Car 595 at X: 1473 at 0 MPH             Car 591 at X: 7034 at 38 MPH
Car 597 at X: 1374 at 0 MPH             Car 592 at X: 7540 at 38 MPH
Car 598 at X: 1337 at 0 MPH             Car 594 at X: 7640 at 38 MPH
Car 599 at X: 1337 at 0 MPH             Car 596 at X: 7740 at 38 MPH
Car 600 at X: 1337 at 0 MPH             Car 602 at X: 7978 at 48 MPH
Car 601 at X: 1337 at 0 MPH             Car 604 at X: 8582 at 38 MPH
Car 603 at X: 1283 at 0 MPH             Car 605 at X: 8649 at 38 MPH
Car 607 at X: 1184 at 0 MPH             Car 606 at X: 8732 at 38 MPH
Car 608 at X: 1084 at 0 MPH             Car 611 at X: 9082 at 43 MPH
Car 609 at X: 992 at 0 MPH              Car 614 at X: 9343 at 44 MPH
Car 610 at X: 892 at 0 MPH              Car 615 at X: 9544 at 36 MPH
Car 612 at X: 793 at 0 MPH              Car 617 at X: 9645 at 43 MPH
Car 613 at X: 693 at 0 MPH              Car 618 at X: 9740 at 43 MPH
Car 616 at X: 363 at 38 MPH             Car 619 at X: 9834 at 43 MPH
```

```
[redacted] [illegible] com.project3/com.project3.App
Time thread started
```

```
Project 3
00:55:39                                   FPS: 59
Stop        Pause        Play        Continue
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add
                          Car Data
Bottom Lane Y POS:  10                  Top Lane   Y POS:  -10
Car 492 at X: 9972 at 42 MPH            Car 479 at X: 331 at 55 MPH
Car 494 at X: 9872 at 42 MPH            Car 480 at X: 681 at 37 MPH
Car 496 at X: 8742 at 37 MPH            Car 482 at X: 780 at 37 MPH
Car 497 at X: 8676 at 37 MPH            Car 483 at X: 880 at 37 MPH
Car 498 at X: 8593 at 37 MPH            Car 484 at X: 963 at 37 MPH
Car 499 at X: 8494 at 37 MPH            Car 485 at X: 1056 at 37 MPH
Car 508 at X: 7634 at 36 MPH            Car 488 at X: 1156 at 37 MPH
Car 511 at X: 7535 at 36 MPH            Car 489 at X: 1232 at 37 MPH
Car 512 at X: 7435 at 36 MPH            Car 491 at X: 1332 at 37 MPH
Car 513 at X: 7336 at 36 MPH            Car 493 at X: 1431 at 37 MPH
Car 514 at X: 7254 at 36 MPH            Car 495 at X: 1530 at 37 MPH
Car 517 at X: 4942 at 36 MPH            Car 500 at X: 1630 at 37 MPH
Car 520 at X: 4842 at 0 MPH             Car 501 at X: 1729 at 37 MPH
Car 523 at X: 4743 at 0 MPH             Car 502 at X: 2254 at 37 MPH
Car 524 at X: 4643 at 0 MPH             Car 503 at X: 2353 at 37 MPH
Car 525 at X: 4574 at 0 MPH             Car 504 at X: 2437 at 37 MPH
Car 528 at X: 4475 at 0 MPH             Car 505 at X: 2536 at 37 MPH
Car 529 at X: 4375 at 0 MPH             Car 506 at X: 2619 at 37 MPH
Car 530 at X: 4291 at 0 MPH             Car 507 at X: 2685 at 37 MPH
```

```
Project 3
00:55:42                                   FPS: 59
Stop        Pause        Play        Continue
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add
                          Car Data
Bottom Lane Y POS:  10                  Top Lane   Y POS:  -10
Car 494 at X: 9924 at 52 MPH            Car 479 at X: 269 at 55 MPH
Car 496 at X: 8784 at 37 MPH            Car 480 at X: 639 at 37 MPH
Car 497 at X: 8718 at 37 MPH            Car 482 at X: 739 at 37 MPH
Car 498 at X: 8636 at 37 MPH            Car 483 at X: 838 at 37 MPH
Car 499 at X: 8536 at 37 MPH            Car 484 at X: 922 at 37 MPH
Car 508 at X: 7676 at 36 MPH            Car 485 at X: 1015 at 37 MPH
Car 511 at X: 7576 at 36 MPH            Car 488 at X: 1114 at 37 MPH
Car 512 at X: 7477 at 36 MPH            Car 489 at X: 1191 at 37 MPH
Car 513 at X: 7377 at 36 MPH            Car 491 at X: 1290 at 37 MPH
Car 514 at X: 7295 at 36 MPH            Car 493 at X: 1390 at 37 MPH
Car 517 at X: 4942 at 36 MPH            Car 495 at X: 1489 at 37 MPH
Car 520 at X: 4842 at 0 MPH             Car 500 at X: 1589 at 37 MPH
Car 523 at X: 4743 at 0 MPH             Car 501 at X: 1688 at 37 MPH
Car 524 at X: 4643 at 0 MPH             Car 502 at X: 2211 at 37 MPH
Car 525 at X: 4574 at 0 MPH             Car 503 at X: 2311 at 37 MPH
Car 528 at X: 4475 at 0 MPH             Car 504 at X: 2394 at 37 MPH
Car 529 at X: 4375 at 0 MPH             Car 505 at X: 2493 at 37 MPH
Car 530 at X: 4291 at 0 MPH             Car 506 at X: 2576 at 37 MPH
Car 533 at X: 4192 at 0 MPH             Car 507 at X: 2643 at 37 MPH
```

```
Project 3
01:03:14                                   FPS: 60
Stop        Pause        Play        Continue
  1    2    3    4    5    6    7    8    9
Add Car Bottom Lane   Add Car Top Lane   Add Intersection   ✓ Auto Add
                          Car Data
Bottom Lane Y POS:  10                  Top Lane   Y POS:  -10
Car 517 at X: 5944 at 52 MPH            Car 579 at X: 264 at 36 MPH
Car 520 at X: 5628 at 39 MPH            Car 581 at X: 364 at 36 MPH
Car 523 at X: 5529 at 39 MPH            Car 583 at X: 463 at 36 MPH
Car 524 at X: 5429 at 39 MPH            Car 584 at X: 563 at 36 MPH
Car 525 at X: 5360 at 39 MPH            Car 585 at X: 647 at 36 MPH
Car 528 at X: 5261 at 39 MPH            Car 591 at X: 746 at 36 MPH
Car 529 at X: 4917 at 38 MPH            Car 592 at X: 863 at 38 MPH
Car 530 at X: 4833 at 0 MPH             Car 594 at X: 963 at 38 MPH
Car 533 at X: 4733 at 0 MPH             Car 596 at X: 1063 at 38 MPH
Car 534 at X: 4634 at 0 MPH             Car 602 at X: 1162 at 38 MPH
Car 535 at X: 4556 at 0 MPH             Car 604 at X: 1968 at 38 MPH
Car 537 at X: 4457 at 0 MPH             Car 605 at X: 2053 at 38 MPH
Car 539 at X: 4357 at 0 MPH             Car 606 at X: 2137 at 0 MPH
Car 540 at X: 4315 at 0 MPH             Car 611 at X: 2236 at 0 MPH
Car 542 at X: 4315 at 0 MPH             Car 614 at X: 2336 at 0 MPH
Car 543 at X: 4315 at 0 MPH             Car 615 at X: 3262 at 36 MPH
Car 546 at X: 4315 at 0 MPH             Car 617 at X: 3361 at 36 MPH
Car 550 at X: 4215 at 0 MPH             Car 618 at X: 3456 at 36 MPH
Car 552 at X: 4116 at 0 MPH             Car 619 at X: 3550 at 36 MPH
```

Auto Add [✓]

```
                Car Data
Bottom Lane Y POS:  10          Top Lane   Y POS: -10
```

Lessons Learned

This project taught me a ton. I have worked in multithreaded environments before but Java, despite all the tools they expose to the developers, has created their own challenges to contend with. One such challenge for me was adding listeners to the list of physics or timer listeners for the observer to call. In the physics loop, each tick iterates through the list of listeners. If an iterator is doing the iteration process and you attempt to add an element, you hit a ConcurrentModificationException. The way I got around this is to cache the additions and removals. At the end of each physics tick I lock the list and perform additions and removals then return control of the list to the physics loop. Had I waited for the reading in week 6, synchronized methods could have been used to allow me to do this without all the manual elbow grease.