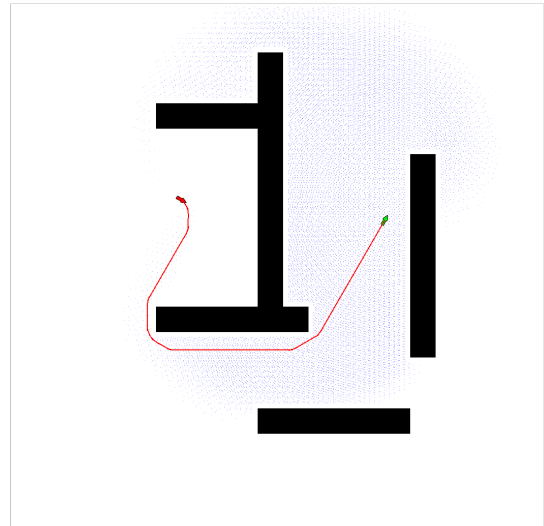
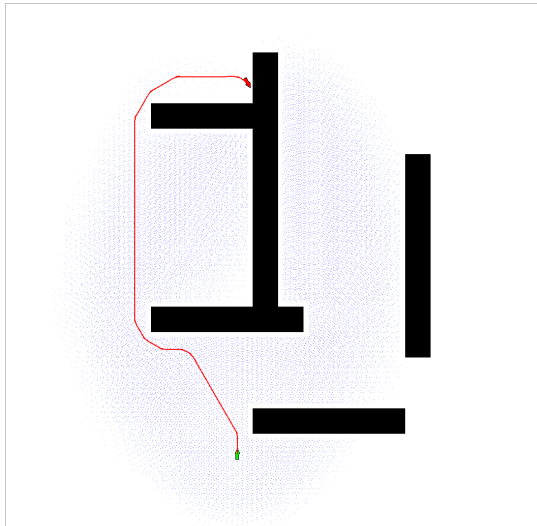


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# City Based CBS Documentation

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<https://github.com/Faywyn/city-CBS-Astar>



<b>1 Class Index</b>	<b>1</b>
1.1 Class List	1
<b>2 File Index</b>	<b>3</b>
2.1 File List	3
<b>3 Class Documentation</b>	<b>4</b>
3.1 _aStarConflict Struct Reference	4
3.1.1 Detailed Description	4
3.2 _aStarNode Struct Reference	5
3.2.1 Detailed Description	5
3.3 _cityGraphNeighbor Struct Reference	5
3.3.1 Detailed Description	5
3.4 _cityGraphPoint Struct Reference	5
3.4.1 Detailed Description	6
3.5 _cityMapBuilding Struct Reference	6
3.5.1 Detailed Description	6
3.6 _cityMapGreenArea Struct Reference	6
3.6.1 Detailed Description	6
3.7 _cityMapIntersection Struct Reference	6
3.7.1 Detailed Description	7
3.8 _cityMapRoad Struct Reference	7
3.8.1 Detailed Description	7
3.9 _cityMapSegment Struct Reference	7
3.9.1 Detailed Description	8
3.10 _cityMapWaterArea Struct Reference	8
3.10.1 Detailed Description	8
3.11 _data Struct Reference	8
3.11.1 Detailed Description	8
3.12 _managerCBSNode Struct Reference	8
3.12.1 Detailed Description	9
3.13 AStar Class Reference	9
3.13.1 Detailed Description	9
3.13.2 Constructor & Destructor Documentation	9
3.13.3 Member Function Documentation	9
3.14 Car Class Reference	10
3.14.1 Detailed Description	11
3.14.2 Member Function Documentation	11
3.15 CityGraph Class Reference	15
3.15.1 Detailed Description	15
3.15.2 Member Function Documentation	15
3.16 CityMap Class Reference	16
3.16.1 Detailed Description	17

3.16.2 Member Function Documentation . . . . .	17
3.17 ConstraintController Class Reference . . . . .	19
3.17.1 Detailed Description . . . . .	19
3.17.2 Member Function Documentation . . . . .	19
3.18 DataManager Class Reference . . . . .	21
3.18.1 Detailed Description . . . . .	21
3.18.2 Constructor & Destructor Documentation . . . . .	21
3.18.3 Member Function Documentation . . . . .	21
3.19 Dubins Class Reference . . . . .	22
3.19.1 Detailed Description . . . . .	22
3.19.2 Constructor & Destructor Documentation . . . . .	22
3.19.3 Member Function Documentation . . . . .	23
3.20 DubinsPath Class Reference . . . . .	24
3.20.1 Detailed Description . . . . .	24
3.20.2 Constructor & Destructor Documentation . . . . .	25
3.21 FileSelector Class Reference . . . . .	25
3.21.1 Detailed Description . . . . .	25
3.22 Manager Class Reference . . . . .	25
3.22.1 Detailed Description . . . . .	26
3.22.2 Constructor & Destructor Documentation . . . . .	26
3.22.3 Member Function Documentation . . . . .	27
3.23 Renderer Class Reference . . . . .	29
3.23.1 Detailed Description . . . . .	29
3.23.2 Member Function Documentation . . . . .	30
3.24 Test Class Reference . . . . .	30
3.24.1 Detailed Description . . . . .	31
3.25 TimedAStar Class Reference . . . . .	31
3.25.1 Detailed Description . . . . .	31
3.25.2 Constructor & Destructor Documentation . . . . .	31
3.25.3 Member Function Documentation . . . . .	31
<b>4 File Documentation . . . . .</b>	<b>32</b>
4.1 aStar.h File Reference . . . . .	32
4.1.1 Detailed Description . . . . .	32
4.2 aStar.h . . . . .	32
4.3 car.h File Reference . . . . .	34
4.3.1 Detailed Description . . . . .	34
4.4 car.h . . . . .	34
4.5 cityGraph.h File Reference . . . . .	35
4.5.1 Detailed Description . . . . .	35
4.6 cityGraph.h . . . . .	35
4.7 cityMap.h . . . . .	36

4.8 config.h File Reference . . . . .	37
4.8.1 Detailed Description . . . . .	37
4.9 config.h . . . . .	37
4.10 dataManager.h File Reference . . . . .	38
4.10.1 Detailed Description . . . . .	38
4.11 dataManager.h . . . . .	38
4.12 dubins.h File Reference . . . . .	39
4.12.1 Detailed Description . . . . .	39
4.13 dubins.h . . . . .	39
4.14 fileSelector.h File Reference . . . . .	40
4.14.1 Detailed Description . . . . .	40
4.15 fileSelector.h . . . . .	40
4.16 manager.h File Reference . . . . .	40
4.16.1 Detailed Description . . . . .	41
4.17 manager.h . . . . .	41
4.18 renderer.h File Reference . . . . .	42
4.18.1 Detailed Description . . . . .	42
4.18.2 Function Documentation . . . . .	42
4.19 renderer.h . . . . .	43
4.20 test.h File Reference . . . . .	43
4.20.1 Detailed Description . . . . .	44
4.21 test.h . . . . .	44
4.22 utils.h File Reference . . . . .	44
4.22.1 Detailed Description . . . . .	44
4.22.2 Function Documentation . . . . .	44
4.23 utils.h . . . . .	47
4.24 index.py . . . . .	47
4.25 aStar.cpp File Reference . . . . .	49
4.25.1 Detailed Description . . . . .	49
4.26 aStar.cpp . . . . .	49
4.27 car.cpp File Reference . . . . .	50
4.27.1 Detailed Description . . . . .	51
4.28 car.cpp . . . . .	51
4.29 cityGraph.cpp File Reference . . . . .	53
4.29.1 Detailed Description . . . . .	53
4.30 cityGraph.cpp . . . . .	53
4.31 cityMap.cpp File Reference . . . . .	57
4.31.1 Detailed Description . . . . .	57
4.32 cityMap.cpp . . . . .	58
4.33 constraintController.cpp File Reference . . . . .	62
4.33.1 Detailed Description . . . . .	62
4.34 constraintController.cpp . . . . .	62

4.35 dataManager.cpp File Reference . . . . .	64
4.35.1 Detailed Description . . . . .	64
4.36 dataManager.cpp . . . . .	64
4.37 dubins.cpp File Reference . . . . .	65
4.37.1 Detailed Description . . . . .	65
4.38 dubins.cpp . . . . .	65
4.39 fileSelector.cpp File Reference . . . . .	67
4.39.1 Detailed Description . . . . .	67
4.40 fileSelector.cpp . . . . .	67
4.41 main.cpp File Reference . . . . .	68
4.41.1 Detailed Description . . . . .	69
4.42 main.cpp . . . . .	69
4.43 manager.cpp File Reference . . . . .	70
4.43.1 Detailed Description . . . . .	70
4.44 manager.cpp . . . . .	70
4.45 managerCBS.cpp File Reference . . . . .	70
4.45.1 Detailed Description . . . . .	71
4.46 managerCBS.cpp . . . . .	71
4.47 renderer.cpp File Reference . . . . .	75
4.47.1 Detailed Description . . . . .	75
4.48 renderer.cpp . . . . .	75
4.49 test.cpp File Reference . . . . .	80
4.49.1 Detailed Description . . . . .	80
4.50 test.cpp . . . . .	80
4.51 timedAStar.cpp File Reference . . . . .	81
4.51.1 Detailed Description . . . . .	81
4.52 timedAStar.cpp . . . . .	81
4.53 utils.cpp File Reference . . . . .	83
4.53.1 Detailed Description . . . . .	83
4.53.2 Function Documentation . . . . .	83
4.54 utils.cpp . . . . .	84
<b>Index</b>	<b>87</b>

## 1 Class Index

### 1.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

<b><a href="#">_aStarConflict</a></b>	
<b>A conflict for the A* algorithm</b>	<b>4</b>
<b><a href="#">_aStarNode</a></b>	
<b>A node for the A* algorithm</b>	<b>5</b>

<a href="#">_cityGraphNeighbor</a>	
A neighbor of a point in the city graph	5
<a href="#">_cityGraphPoint</a>	
A point in the city graph	5
<a href="#">_cityMapBuilding</a>	
A building in the city map	6
<a href="#">_cityMapGreenArea</a>	
A green area in the city map	6
<a href="#">_cityMapIntersection</a>	
An intersection in the city map	6
<a href="#">_cityMapRoad</a>	
A road in the city map	7
<a href="#">_cityMapSegment</a>	
A segment in the city map	7
<a href="#">_cityMapWaterArea</a>	
A water area in the city map	8
<a href="#">_data</a>	
Data structure	8
<a href="#">_managerCBSNode</a>	
A node for the CBS algorithm	8
<a href="#">AStar</a>	
A* algorithm	9
<a href="#">Car</a>	
A car in the city	10
<a href="#">CityGraph</a>	
A graph representing the city's streets and intersections using a graph	15
<a href="#">CityMap</a>	
A city map	16
<a href="#">ConstraintController</a>	
Controller for constraints	19
<a href="#">DataManager</a>	
Data manager	21
<a href="#">Dubins</a>	
Dubins path used to calculate the path between two points in the city graph	22
<a href="#">DubinsPath</a>	
Dubins path used to calculate the path between two points in the city graph	24
<a href="#">FileSelector</a>	
A file selector	25
<a href="#">Manager</a>	
A manager for the cars	25
<a href="#">Renderer</a>	
A renderer for the city	29

<a href="#">Test</a>	
A class for testing the project	30
<a href="#">TimedAStar</a>	
Timed A* algorithm	31

## 2 File Index

### 2.1 File List

Here is a list of all documented files with brief descriptions:

<a href="#">aStar.h</a>	
A* algorithm	32
<a href="#">car.h</a>	
A car in the city	34
<a href="#">cityGraph.h</a>	
A graph representing the city's streets and intersections using a graph	35
<a href="#">cityMap.h</a>	36
<a href="#">config.h</a>	
Configuration file	37
<a href="#">dataManager.h</a>	
Data manager	38
<a href="#">dubins.h</a>	
Dubins path	39
<a href="#">fileSelector.h</a>	
File selector	40
<a href="#">manager.h</a>	
Manager for the cars	40
<a href="#">renderer.h</a>	
A renderer for the city	42
<a href="#">test.h</a>	
A header file for the <a href="#">Test</a> class	43
<a href="#">utils.h</a>	
Utility functions	44
<a href="#">index.py</a>	47
<a href="#">aStar.cpp</a>	
A* algorithm implementation	49
<a href="#">car.cpp</a>	
Car class implementation	50
<a href="#">cityGraph.cpp</a>	
City graph implementation	53
<a href="#">cityMap.cpp</a>	
CityMap class implementation	57

<a href="#">constraintController.cpp</a>	
ConstraintController class implementation	62
<a href="#">dataManager.cpp</a>	
Data manager	64
<a href="#">dubins.cpp</a>	
Dubins path implementation	65
<a href="#">fileSelector.cpp</a>	
File selector implementation	67
<a href="#">main.cpp</a>	
Main file	68
<a href="#">manager.cpp</a>	
Implementation of the Manager class	70
<a href="#">managerCBS.cpp</a>	
CBS algorithm implementation	70
<a href="#">renderer.cpp</a>	
Implementation of the Renderer class	75
<a href="#">test.cpp</a>	
A file for testing the project	80
<a href="#">timedAStar.cpp</a>	
Timed A* algorithm implementation	81
<a href="#">utils.cpp</a>	
Utility functions implementation	83

## 3 Class Documentation

### 3.1 `_aStarConflict` Struct Reference

A conflict for the A\* algorithm.

```
#include <aStar.h>
```

#### Public Attributes

- [CityGraph::point](#) **point**  
*The point in the graph.*
- int **time**  
*The time of the conflict.*
- int **car**  
*The car that caused the conflict.*

#### 3.1.1 Detailed Description

A conflict for the A\* algorithm.

This struct represents a conflict for the A\* algorithm. It contains the point in the graph, the time of the conflict and the car that caused the conflict.

Definition at line 41 of file [aStar.h](#).

The documentation for this struct was generated from the following file:

- [aStar.h](#)



## 3.2 `_aStarNode` Struct Reference

A node for the A\* algorithm.

```
#include <aStar.h>
```

### Public Attributes

- [CityGraph::point](#) **point**  
*The point in the graph.*
- double **speed**  
*The speed of the car.*
- std::pair< [CityGraph::point](#), [CityGraph::neighbor](#) > **arcFrom**  
*The arc from which the node was reached.*

### 3.2.1 Detailed Description

A node for the A\* algorithm.

This struct represents a node for the A\* algorithm. It contains the point in the graph, the speed of the car and the arc from which the node was reached.

Definition at line 20 of file [aStar.h](#).

The documentation for this struct was generated from the following file:

- [aStar.h](#)

## 3.3 `_cityGraphNeighbor` Struct Reference

A neighbor of a point in the city graph.

```
#include <cityGraph.h>
```

### Public Attributes

- [\\_cityGraphPoint](#) **point**  
*The neighbor point.*
- double **maxSpeed**  
*The maximum speed to reach the neighbor point.*
- double **turningRadius**  
*The turning radius to reach the neighbor point.*
- double **distance**  
*The distance to reach the neighbor point.*
- bool **isRightWay**  
*If it is the right way.*

### 3.3.1 Detailed Description

A neighbor of a point in the city graph.

This struct represents a neighbor of a point in the city graph. It contains the neighbor point, the maximum speed to reach it, the turning radius to reach it, the distance to reach it and if it is the right way.

Definition at line 43 of file [cityGraph.h](#).

The documentation for this struct was generated from the following file:

- [cityGraph.h](#)

## 3.4 `_cityGraphPoint` Struct Reference

A point in the city graph.

```
#include <cityGraph.h>
```

### Public Attributes

- `sf::Vector2f` **position**  
*The position of the point.*
- `double` **angle**  
*The angle of the point.*

#### 3.4.1 Detailed Description

A point in the city graph.

This struct represents a point in the city graph. It contains the position and the angle of the point.

Definition at line 20 of file [cityGraph.h](#).

The documentation for this struct was generated from the following file:

- [cityGraph.h](#)

## 3.5 `_cityMapBuilding` Struct Reference

A building in the city map.

```
#include <cityMap.h>
```

### Public Attributes

- `std::vector< sf::Vector2f >` **points**  
*The points of the building.*

#### 3.5.1 Detailed Description

A building in the city map.

Definition at line 34 of file [cityMap.h](#).

The documentation for this struct was generated from the following file:

- [cityMap.h](#)

## 3.6 `_cityMapGreenArea` Struct Reference

A green area in the city map.

```
#include <cityMap.h>
```

### Public Attributes

- `std::vector< sf::Vector2f >` **points**  
*The points of the green area.*
- `int` **type**  
*The type of the green area.*

#### 3.6.1 Detailed Description

A green area in the city map.

Definition at line 42 of file [cityMap.h](#).

The documentation for this struct was generated from the following file:

- [cityMap.h](#)

## 3.7 `_cityMapIntersection` Struct Reference

An intersection in the city map.

```
#include <cityMap.h>
```

### Public Attributes

- **int** **id**  
*The id of the intersection.*
- **sf::Vector2f** **center**  
*The center of the intersection.*
- **double** **radius**  
*The radius of the intersection.*
- **std::vector< std::pair< int, int > >** **roadSegmentIds**  
*The ids of the road segments (roadId, segmentId). The segments are the same for both directions of the road.*

#### 3.7.1 Detailed Description

An intersection in the city map.

Definition at line 59 of file [cityMap.h](#).

The documentation for this struct was generated from the following file:

- [cityMap.h](#)

## 3.8 `_cityMapRoad` Struct Reference

A road in the city map.

```
#include <cityMap.h>
```

### Public Attributes

- **int** **id**  
*The id of the road.*
- **std::vector< [\\_cityMapSegment](#) >** **segments**  
*The segments of the road.*
- **double** **width**  
*The width of the road.*
- **int** **numLanes**  
*The number of lanes of the road.*

#### 3.8.1 Detailed Description

A road in the city map.

Definition at line 23 of file [cityMap.h](#).

The documentation for this struct was generated from the following file:

- [cityMap.h](#)

## 3.9 `_cityMapSegment` Struct Reference

A segment in the city map.

```
#include <cityMap.h>
```

### Public Attributes

- **sf::Vector2f** **p1**  
*The first point of the segment.*
- **sf::Vector2f** **p2**  
*The second point of the segment.*
- **sf::Vector2f** **p1\_offset**  
*The offset of the first point, used for the intersection.*
- **sf::Vector2f** **p2\_offset**

*The offset of the second point, used for the intersection.*

- double **angle**

*The angle of the segment.*

### 3.9.1 Detailed Description

A segment in the city map.

Definition at line 11 of file [cityMap.h](#).

The documentation for this struct was generated from the following file:

- [cityMap.h](#)

## 3.10 [\\_cityMapWaterArea](#) Struct Reference

A water area in the city map.

```
#include <cityMap.h>
```

### Public Attributes

- `std::vector< sf::Vector2f >` **points**

*The points of the water area.*

### 3.10.1 Detailed Description

A water area in the city map.

Definition at line 51 of file [cityMap.h](#).

The documentation for this struct was generated from the following file:

- [cityMap.h](#)

## 3.11 [\\_data](#) Struct Reference

Data structure.

```
#include <dataManager.h>
```

### 3.11.1 Detailed Description

Data structure.

This struct represents the data structure.

Definition at line 18 of file [dataManager.h](#).

The documentation for this struct was generated from the following file:

- [dataManager.h](#)

## 3.12 [\\_managerCBSNode](#) Struct Reference

A node for the CBS algorithm.

```
#include <manager.h>
```

### Public Attributes

- `std::vector< std::vector< sf::Vector2f > >` **paths**

*The paths for all agents.*

- [ConstraintController](#) **constraints**

*The constraints for all agents.*

- `std::vector< double >` **costs**

*The individual path costs.*

- double **cost**

*The total cost.*

- int **depth**

*The depth in the CBS tree.*

- bool **hasResolved**

*If the node has resolved conflicts.*

### 3.12.1 Detailed Description

A node for the CBS algorithm.

This struct represents a node for the CBS algorithm. It contains the paths for all agents, the constraints for all agents, the individual path costs, the total cost, the depth in the CBS tree and if the node has resolved conflicts.

Definition at line 24 of file [manager.h](#).

The documentation for this struct was generated from the following file:

- [manager.h](#)

## 3.13 AStar Class Reference

A\* algorithm.

```
#include <aStar.h>
```

### Public Member Functions

- [AStar](#) ([CityGraph::point](#) start, [CityGraph::point](#) end, const [CityGraph](#) &cityGraph)

*Constructor.*

- `std::vector< node > findPath ()`

*Find the path.*

### 3.13.1 Detailed Description

A\* algorithm.

This class represents the A\* algorithm. It is used to find the shortest path between two points in a graph.

Definition at line 74 of file [aStar.h](#).

### 3.13.2 Constructor & Destructor Documentation

#### AStar()

```
AStar::AStar (
    CityGraph::point start,
    CityGraph::point end,
    const CityGraph & cityGraph)
```

Constructor.

#### Parameters

<i>start</i>	The start point
<i>end</i>	The end point
<i>cityGraph</i>	The graph

Definition at line 21 of file [aStar.cpp](#).

### 3.13.3 Member Function Documentation

#### findPath()

```
std::vector< node > AStar::findPath () [inline]
```

Find the path.

## Returns

The path

Definition at line 91 of file [aStar.h](#).

The documentation for this class was generated from the following files:

- [aStar.h](#)
- [aStar.cpp](#)

## 3.14 Car Class Reference

A car in the city.

```
#include <car.h>
```

### Public Member Functions

- **Car ()**  
*Constructor.*
- void [assignStartEnd](#) ([CityGraph::point](#) start, [CityGraph::point](#) end)  
*Assign the start and end points.*
- void [chooseRandomStartEndPath](#) ([CityGraph](#) &graph, [CityMap](#) &cityMap)  
*Choose a random start and end point in the graph.*
- void [assignPath](#) (std::vector< [AStar::node](#) > path)  
*Assign a path to the car.*
- void [assignExistingPath](#) (std::vector< sf::Vector2f > path)  
*Assign an existing path to the car.*
- void **move** ()  
*Move the car, move to the next point in the path.*
- void [render](#) (sf::RenderWindow &window)  
*Render the car.*
- [CityGraph::point](#) [getStart](#) ()  
*Get the start point.*
- [CityGraph::point](#) [getEnd](#) ()  
*Get the end point.*
- double [getSpeed](#) ()  
*Get the current point in the path.*
- double [getSpeedAt](#) (int index)  
*Get the speed at a certain index in the path.*
- double [getAverageSpeed](#) ([CityGraph](#) &graph)  
*Get the average speed of the car.*
- double [getRemainingTime](#) ()  
*Get the remaining time to reach the end point.*
- double [getElapsedTime](#) ()  
*Get the elapsed time since the start of the car.*
- double [getPathTime](#) ()  
*Get the time to reach the end point from the start point.*
- double [getRemainingDistance](#) ()  
*Get the remaining distance to reach the end point.*
- double [getElapsedDistance](#) ()  
*Get the elapsed distance since the start of the car.*
- double [getPathLength](#) ()  
*Get the distance to reach the end point from the start point.*
- sf::Vector2f [getPosition](#) ()

*Get the position of the car.*

- `std::vector< sf::Vector2f > getPath ()`

*Get the path of the car.*

- `std::vector< AStar::node > getAStarPath ()`

*Get the path of the car from the A\* algorithm.*

- `void toggleDebug ()`

*Toggle the debug mode. In debug mode, the path of the car is rendered and the car is rendered in red.*

### 3.14.1 Detailed Description

A car in the city.

This class represents a car in the city. It contains the start and end points of the car, the path of the car and the current point in the path.

Definition at line 23 of file [car.h](#).

### 3.14.2 Member Function Documentation

#### assignExistingPath()

```
void Car::assignExistingPath (
    std::vector< sf::Vector2f > path)
```

Assign an existing path to the car.

##### Parameters

<i>path</i>	The path
-------------	----------

Definition at line 87 of file [car.cpp](#).

#### assignPath()

```
void Car::assignPath (
    std::vector< AStar::node > path)
```

Assign a path to the car.

##### Parameters

<i>path</i>	The path
-------------	----------

Definition at line 76 of file [car.cpp](#).

#### assignStartEnd()

```
void Car::assignStartEnd (
    CityGraph::point start,
    CityGraph::point end) [inline]
```

Assign the start and end points.

##### Parameters

<i>start</i>	The start point
<i>end</i>	The end point

Definition at line 35 of file [car.h](#).

**chooseRandomStartEndPath()**

```
void Car::chooseRandomStartEndPath (  
    CityGraph & graph,  
    CityMap & cityMap)
```

Choose a random start and end point in the graph.

**Parameters**

<i>graph</i>	The graph
<i>cityMap</i>	The city map

Definition at line 142 of file [car.cpp](#).

**getAStarPath()**

```
std::vector< AStar::node > Car::getAStarPath () [inline]
```

Get the path of the car from the A\* algorithm.

**Returns**

The path

Definition at line 154 of file [car.h](#).

**getAverageSpeed()**

```
double Car::getAverageSpeed (  
    CityGraph & graph)
```

Get the average speed of the car.

**Parameters**

<i>graph</i>	The graph
--------------	-----------

**Returns**

The average speed

Definition at line 172 of file [car.cpp](#).

**getElapsedDistance()**

```
double Car::getElapsedDistance ()
```

Get the elapsed distance since the start of the car.

**Returns**

The elapsed distance

Definition at line 122 of file [car.cpp](#).

**getElapsedTime()**

```
double Car::getElapsedTime ()
```

Get the elapsed time since the start of the car.

**Returns**

The elapsed time

Definition at line 109 of file [car.cpp](#).



**getEnd()**

```
CityGraph::point Car::getEnd () [inline]
```

Get the end point.

**Returns**

The end point

Definition at line 80 of file [car.h](#).

**getPath()**

```
std::vector< sf::Vector2f > Car::getPath () [inline]
```

Get the path of the car.

**Returns**

The path

Definition at line 148 of file [car.h](#).

**getPathLength()**

```
double Car::getPathLength ()
```

Get the distance to reach the end point from the start point.

**Returns**

The distance

Definition at line 132 of file [car.cpp](#).

**getPathTime()**

```
double Car::getPathTime ()
```

Get the time to reach the end point from the start point.

**Returns**

The time

Definition at line 110 of file [car.cpp](#).

**getPosition()**

```
sf::Vector2f Car::getPosition () [inline]
```

Get the position of the car.

**Returns**

The position

Definition at line 142 of file [car.h](#).

**getRemainingDistance()**

```
double Car::getRemainingDistance ()
```

Get the remaining distance to reach the end point.

**Returns**

The remaining distance

Definition at line 112 of file [car.cpp](#).

**getRemainingTime()**

```
double Car::getRemainingTime ()
```

Get the remaining time to reach the end point.

**Returns**

The remaining time

Definition at line 108 of file [car.cpp](#).

**getSpeed()**

```
double Car::getSpeed ()
```

Get the current point in the path.

**Returns**

The current point in the path

Definition at line 92 of file [car.cpp](#).

**getSpeedAt()**

```
double Car::getSpeedAt (  
    int index)
```

Get the speed at a certain index in the path.

**Parameters**

<i>index</i>	The index
--------------	-----------

**Returns**

The speed at the index

Definition at line 100 of file [car.cpp](#).

**getStart()**

```
CityGraph::point Car::getStart () [inline]
```

Get the start point.

**Returns**

The start point

Definition at line 74 of file [car.h](#).

**render()**

```
void Car::render (  
    sf::RenderWindow & window)
```

Render the car.

**Parameters**

<i>window</i>	The window
---------------	------------

Definition at line 28 of file [car.cpp](#).

The documentation for this class was generated from the following files:

- [car.h](#)
- [car.cpp](#)

## 3.15 CityGraph Class Reference

A graph representing the city's streets and intersections using a graph.

```
#include <cityGraph.h>
```

### Public Member Functions

- void [createGraph](#) (const [CityMap](#) &cityMap)  
*Create a city graph.*
- std::unordered\_map< [point](#), std::vector< [neighbor](#) > > [getNeighbors](#) () const  
*Get neighbors map.*
- std::unordered\_set< [point](#) > [getGraphPoints](#) () const  
*Get graph points.*
- [point](#) [getRandomPoint](#) () const  
*Get random point.*
- double [getHeight](#) () const  
*Get the height of the city graph.*
- double [getWidth](#) () const  
*Get the width of the city graph.*

### 3.15.1 Detailed Description

A graph representing the city's streets and intersections using a graph.

This class represents the city graph. It contains the neighbors of each point in the graph and the graph points.

Definition at line 82 of file [cityGraph.h](#).

### 3.15.2 Member Function Documentation

#### **createGraph()**

```
void CityGraph::createGraph (  
    const CityMap & cityMap)
```

Create a city graph.

This constructor creates a city graph from a city map.

#### Parameters

<i>cityMap</i>	The city map
----------------	--------------

Definition at line 23 of file [cityGraph.cpp](#).

#### **getGraphPoints()**

```
std::unordered_set< point > CityGraph::getGraphPoints () const [inline]
```

Get graph points.

#### Returns

Graph points

Definition at line 106 of file [cityGraph.h](#).

#### **getHeight()**

```
double CityGraph::getHeight () const [inline]
```

Get the height of the city graph.

#### Returns

The height of the city graph

Definition at line 118 of file [cityGraph.h](#).

**getNeighbors()**

```
std::unordered_map< point, std::vector< neighbor > > CityGraph::getNeighbors () const [inline]
```

Get neighbors map.

**Returns**

Neighbors map

Definition at line 100 of file [cityGraph.h](#).

**getRandomPoint()**

```
CityGraph::point CityGraph::getRandomPoint () const
```

Get random point.

**Returns**

Random point

Definition at line 274 of file [cityGraph.cpp](#).

**getWidth()**

```
double CityGraph::getWidth () const [inline]
```

Get the width of the city graph.

**Returns**

The width of the city graph

Definition at line 124 of file [cityGraph.h](#).

The documentation for this class was generated from the following files:

- [cityGraph.h](#)
- [cityGraph.cpp](#)

## 3.16 CityMap Class Reference

A city map.

```
#include <cityMap.h>
```

**Public Member Functions**

- **CityMap ()**  
*Constructor.*
- void **loadFile** (const std::string &filename)  
*Load a city map from a file.*
- bool **isCityMapLoaded** () const  
*Check if the city map is loaded.*
- std::vector< [road](#) > **getRoads** () const  
*Get the roads.*
- std::vector< [intersection](#) > **getIntersections** () const  
*Get the intersections.*
- std::vector< [building](#) > **getBuildings** () const  
*Get the buildings.*
- std::vector< [greenArea](#) > **getGreenAreas** () const  
*Get the green areas.*
- std::vector< [waterArea](#) > **getWaterAreas** () const  
*Get the water areas.*
- sf::Vector2f **getMinLatLon** () const

- Get the minimum latitude and longitude.*
  - `sf::Vector2f getMaxLatLon () const`  
*Get the maximum latitude and longitude.*
- `int getWidth () const`  
*Get the width of the city map.*
- `int getHeight () const`  
*Get the height of the city map.*

### 3.16.1 Detailed Description

A city map.

This class represents the city map. It contains the roads, intersections, buildings, green areas and water areas of the city.

Definition at line 74 of file [cityMap.h](#).

### 3.16.2 Member Function Documentation

#### **getBuildings()**

```
std::vector< building > CityMap::getBuildings () const [inline]
```

Get the buildings.

##### Returns

The buildings

Definition at line 116 of file [cityMap.h](#).

#### **getGreenAreas()**

```
std::vector< greenArea > CityMap::getGreenAreas () const [inline]
```

Get the green areas.

##### Returns

The green areas

Definition at line 122 of file [cityMap.h](#).

#### **getHeight()**

```
int CityMap::getHeight () const [inline]
```

Get the height of the city map.

##### Returns

The height of the city map

Definition at line 152 of file [cityMap.h](#).

#### **getIntersections()**

```
std::vector< intersection > CityMap::getIntersections () const [inline]
```

Get the intersections.

##### Returns

The intersections

Definition at line 110 of file [cityMap.h](#).

**getMaxLatLon()**

```
sf::Vector2f CityMap::getMaxLatLon () const [inline]
```

Get the maximum latitude and longitude.

**Returns**

The maximum latitude and longitude

Definition at line 140 of file [cityMap.h](#).

**getMinLatLon()**

```
sf::Vector2f CityMap::getMinLatLon () const [inline]
```

Get the minimum latitude and longitude.

**Returns**

The minimum latitude and longitude

Definition at line 134 of file [cityMap.h](#).

**getRoads()**

```
std::vector< road > CityMap::getRoads () const [inline]
```

Get the roads.

**Returns**

The roads

Definition at line 104 of file [cityMap.h](#).

**getWaterAreas()**

```
std::vector< waterArea > CityMap::getWaterAreas () const [inline]
```

Get the water areas.

**Returns**

The water areas

Definition at line 128 of file [cityMap.h](#).

**getWidth()**

```
int CityMap::getWidth () const [inline]
```

Get the width of the city map.

**Returns**

The width of the city map

Definition at line 146 of file [cityMap.h](#).

**isCityMapLoaded()**

```
bool CityMap::isCityMapLoaded () const [inline]
```

Check if the city map is loaded.

**Returns**

True if the city map is loaded, false otherwise

Definition at line 98 of file [cityMap.h](#).

**loadFile()**

```
void CityMap::loadFile (  
    const std::string & filename)
```

Load a city map from a file.

## Parameters

<i>filename</i>	The filename
-----------------	--------------

Definition at line 23 of file [cityMap.cpp](#).

The documentation for this class was generated from the following files:

- [cityMap.h](#)
- [cityMap.cpp](#)

## 3.17 ConstraintController Class Reference

Controller for constraints.

```
#include <aStar.h>
```

### Public Member Functions

- **ConstraintController ()**  
*Constructor.*
- [ConstraintController copy \(\)](#)  
*Copy constructor.*
- [ConstraintController copy \(std::vector< int > cars\)](#)  
*Copy constructor.*
- void [addConstraint \(AStar::conflict constraints\)](#)  
*Add a constraint.*
- bool [hasConstraint \(AStar::conflict constraint\)](#)  
*Check if a constraint exists.*
- bool [checkConstraints](#) (int car, double speed, double newSpeed, double time, [CityGraph::point](#) from, [CityGraph::neighbor](#) to)  
*Check if a car can move to a certain point in the graph at a certain time.*

### 3.17.1 Detailed Description

Controller for constraints.

This class is used to control the constraints of the A\* algorithm. It is used to check if a car can move to a certain point in the graph at a certain time.

Definition at line 114 of file [aStar.h](#).

### 3.17.2 Member Function Documentation

#### **addConstraint()**

```
void ConstraintController::addConstraint (
    AStar::conflict constraints)
```

Add a constraint.

## Parameters

<i>constraints</i>	The constraint to add
--------------------	-----------------------

Definition at line 15 of file [constraintController.cpp](#).

**checkConstraints()**

```
bool ConstraintController::checkConstraints (
    int car,
    double speed,
    double newSpeed,
    double time,
    CityGraph::point from,
    CityGraph::neighbor to)
```

Check if a car can move to a certain point in the graph at a certain time.

**Parameters**

<i>car</i>	The car
<i>speed</i>	The speed of the car
<i>newSpeed</i>	The new speed of the car
<i>time</i>	The time
<i>from</i>	The point from which the car is moving
<i>to</i>	The point to which the car is moving

**Returns**

True if the car can move to the point, false otherwise

Definition at line 74 of file [constraintController.cpp](#).

**copy() [1/2]**

```
ConstraintController ConstraintController::copy ()
```

Copy constructor.

**Returns**

A copy of the object

Definition at line 52 of file [constraintController.cpp](#).

**copy() [2/2]**

```
ConstraintController ConstraintController::copy (
    std::vector< int > cars)
```

Copy constructor.

**Parameters**

<i>cars</i>	The cars to copy
-------------	------------------

**Returns**

A copy of the object

Definition at line 60 of file [constraintController.cpp](#).

**hasConstraint()**

```
bool ConstraintController::hasConstraint (
    AStar::conflict constraint)
```

Check if a constraint exists.



## Parameters

<i>constraint</i>	The constraint to check
-------------------	-------------------------

## Returns

True if the constraint exists, false otherwise

Definition at line 32 of file [constraintController.cpp](#).

The documentation for this class was generated from the following files:

- [aStar.h](#)
- [constraintController.cpp](#)

## 3.18 DataManager Class Reference

Data manager.

```
#include <dataManager.h>
```

### Public Member Functions

- [DataManager](#) (std::string filename)  
*Constructor.*
- void [createData](#) (int numData, int numCarsMin, int numCarsMax, std::string mapName)  
*Create data. It launches multiple simulations with different number of cars and car densities. Then, it calculates different statistics and stores them in a file.*

### 3.18.1 Detailed Description

Data manager.

This class represents the data manager. It creates data and stores it in a file.

Definition at line 30 of file [dataManager.h](#).

### 3.18.2 Constructor & Destructor Documentation

#### DataManager()

```
DataManager::DataManager (
    std::string filename)
```

Constructor.

## Parameters

<i>filename</i>	The filename
-----------------	--------------

Definition at line 20 of file [dataManager.cpp](#).

### 3.18.3 Member Function Documentation

#### createData()

```
void DataManager::createData (
    int numData,
    int numCarsMin,
    int numCarsMax,
    std::string mapName)
```

Create data. It launches multiple simulations with different number of cars and car densities. Then, it calculates different statistics and stores them in a file.

## Parameters

<i>numData</i>	The number of data
<i>numCarsMin</i>	The minimum number of cars
<i>numCarsMax</i>	The maximum number of cars
<i>mapName</i>	The map name

Definition at line 28 of file [dataManager.cpp](#).

The documentation for this class was generated from the following files:

- [dataManager.h](#)
- [dataManager.cpp](#)

### 3.19 Dubins Class Reference

[Dubins](#) path used to calculate the path between two points in the city graph.

```
#include <dubins.h>
```

#### Public Member Functions

- [Dubins](#) ([CityGraph::point](#) start, [CityGraph::neighbor](#) end)  
*Constructor with start and end points.*
- [Dubins](#) ([CityGraph::point](#) start, [CityGraph::neighbor](#) end, double startSpeed)  
*Constructor with start point, end point and start speed.*
- [Dubins](#) ([CityGraph::point](#) start, [CityGraph::neighbor](#) end, double startSpeed, double endSpeed)  
*Constructor with start point, end point, start speed and end speed.*
- [~Dubins](#) ()  
*Destructor.*
- double [distance](#) ()  
*Get the distance to reach the end point.*
- double [time](#) ()  
*Get the time to reach the end point.*
- [CityGraph::point](#) [point](#) (double [time](#))  
*Get the point at a certain time in the path using interpolation.*
- `std::vector< CityGraph::point >` [path](#) ()  
*Get the path using interpolation.*

#### 3.19.1 Detailed Description

[Dubins](#) path used to calculate the path between two points in the city graph.

This class represents a [Dubins](#) path used to calculate the path between two points in the city graph. Given the start and end points, it calculates the path, the distance and the time to reach the end point.

Definition at line 26 of file [dubins.h](#).

#### 3.19.2 Constructor & Destructor Documentation

##### [Dubins\(\)](#) [1/3]

```
Dubins::Dubins (
    CityGraph::point start,
    CityGraph::neighbor end)
```

Constructor with start and end points.

The class will be initialized with the start and end points. The car will run without speed limits.

## Parameters

<i>start</i>	The start point
--------------	-----------------

<i>end</i>	The end point
------------	---------------

Definition at line 11 of file [dubins.cpp](#).

### Dubins() [2/3]

```
Dubins::Dubins (
    CityGraph::point start,
    CityGraph::neighbor end,
    double startSpeed)
```

Constructor with start point, end point and start speed.

The class will be initialized with the start and end points and the start speed. The car will accelerate to the maximum speed.

#### Parameters

<i>start</i>	The start point
<i>end</i>	The end point
<i>startSpeed</i>	The start speed

Definition at line 14 of file [dubins.cpp](#).

### Dubins() [3/3]

```
Dubins::Dubins (
    CityGraph::point start,
    CityGraph::neighbor end,
    double startSpeed,
    double endSpeed)
```

Constructor with start point, end point, start speed and end speed.

The class will be initialized with the start and end points, the start and end speeds. The car will accelerate uniformly to the maximum speed.

#### Parameters

<i>start</i>	The start point
<i>end</i>	The end point
<i>startSpeed</i>	The start speed
<i>endSpeed</i>	The end speed

Definition at line 34 of file [dubins.cpp](#).

## 3.19.3 Member Function Documentation

### distance()

```
double Dubins::distance () [inline]
```

Get the distance to reach the end point.

#### Returns

The distance

Definition at line 72 of file [dubins.h](#).

**path()**

```
std::vector< CityGraph::point > Dubins::path ()
```

Get the path using interpolation.

**Returns**

The path

Definition at line 85 of file [dubins.cpp](#).

**point()**

```
CityGraph::point Dubins::point (  
    double time)
```

Get the point at a certain time in the path using interpolation.

**Parameters**

<i>time</i>	The time
-------------	----------

**Returns**

The point

Definition at line 64 of file [dubins.cpp](#).

**time()**

```
double Dubins::time ()
```

Get the time to reach the end point.

**Returns**

The time

Definition at line 62 of file [dubins.cpp](#).

The documentation for this class was generated from the following files:

- [dubins.h](#)
- [dubins.cpp](#)

## 3.20 DubinsPath Class Reference

[Dubins](#) path used to calculate the path between two points in the city graph.

```
#include <dubins.h>
```

**Public Member Functions**

- [DubinsPath](#) (std::vector< [AStar::node](#) > path)  
*Constructor with path.*
- std::vector< [CityGraph::point](#) > path ()  
*Get the path.*

### 3.20.1 Detailed Description

[Dubins](#) path used to calculate the path between two points in the city graph.

This class represents a [Dubins](#) path used to calculate the path between two points in the city graph. Given the start and end points, it calculates the path, the distance and the time to reach the end point.

Definition at line 112 of file [dubins.h](#).

### 3.20.2 Constructor & Destructor Documentation

#### DubinsPath()

```
DubinsPath::DubinsPath (
    std::vector< AStar::node > path)
```

Constructor with path.

The class will be initialized with the path.

#### Parameters

<i>path</i>	The path
-------------	----------

Definition at line 95 of file [dubins.cpp](#).

The documentation for this class was generated from the following files:

- [dubins.h](#)
- [dubins.cpp](#)

## 3.21 FileSelector Class Reference

A file selector.

```
#include <fileSelector.h>
```

### 3.21.1 Detailed Description

A file selector.

This class represents a file selector. It allows the user to select a file from a folder.

Definition at line 19 of file [fileSelector.h](#).

The documentation for this class was generated from the following files:

- [fileSelector.h](#)
- [fileSelector.cpp](#)

## 3.22 Manager Class Reference

A manager for the cars.

```
#include <manager.h>
```

### Public Member Functions

- [Manager](#) (const [CityGraph](#) &cityGraph, const [CityMap](#) &[CityMap](#), bool log)  
*Constructor.*
- [Manager](#) (const [CityGraph](#) &cityGraph, const [CityMap](#) &[CityMap](#), std::vector< [Car](#) > cars, bool log)  
*Constructor.*
- void [createCarsAStar](#) (int numCars)  
*Create cars using A\* pathfinding, no collision avoidance.*
- std::pair< bool, [DataManager::data](#) > [createCarsCBS](#) (int numCars)  
*Create cars using CBS pathfinding.*
- [CBSNode](#) [createSubCBS](#) ([CBSNode](#) &node, int subNodeDepth)  
*Create a sub-CBS node.*
- [CBSNode](#) [processCBS](#) ([ConstraintController](#) constraints, int subNodeDepth)  
*Process a CBS node.*
- bool [hasConflict](#) (std::vector< std::vector< sf::Vector2f > > paths, int \*car1, int \*car2, sf::Vector2f \*p1, sf::Vector2f \*p2, double \*a1, double \*a2, int \*time)  
*Check if two cars have a conflict.*
- void [moveCars](#) ()

- *Move the cars to the next point in the path.*  
void `renderCars` (sf::RenderWindow &window)
- *Render the cars.*  
void `toggleCarDebug` (sf::Vector2f mousePos)
- *Toggle the debug of one car.*  
int `getNumCars` ()
- *Get the number of cars.*  
std::vector< `Car` > `getCars` ()
- *Get the cars.*

### 3.22.1 Detailed Description

A manager for the cars.

The manager class is used to manage the cars during the CBS pathfinding. It creates the cars and resolves conflicts using the CBS algorithm.

Definition at line 45 of file [manager.h](#).

### 3.22.2 Constructor & Destructor Documentation

#### Manager() [1/2]

```
Manager::Manager (
    const CityGraph & cityGraph,
    const CityMap & CityMap,
    bool log) [inline]
```

Constructor.

#### Parameters

<i>cityGraph</i>	The city graph
<i>CityMap</i>	The city map
<i>log</i>	If the manager should log

Definition at line 55 of file [manager.h](#).

#### Manager() [2/2]

```
Manager::Manager (
    const CityGraph & cityGraph,
    const CityMap & CityMap,
    std::vector< Car > cars,
    bool log) [inline]
```

Constructor.

#### Parameters

<i>cityGraph</i>	The city graph
<i>CityMap</i>	The city map
<i>cars</i>	The cars
<i>log</i>	If the manager should log

Definition at line 66 of file [manager.h](#).

### 3.22.3 Member Function Documentation

#### createCarsAStar()

```
void Manager::createCarsAStar (
    int numCars)
```

Create cars using A\* pathfinding, no collision avoidance.

##### Parameters

<i>numCars</i>	The number of cars
----------------	--------------------

Definition at line 13 of file [manager.cpp](#).

#### createCarsCBS()

```
std::pair< bool, DataManager::data > Manager::createCarsCBS (
    int numCars)
```

Create cars using CBS pathfinding.

##### Parameters

<i>numCars</i>	The number of cars
----------------	--------------------

##### Returns

The data for the cars (success, data)

Definition at line 15 of file [managerCBS.cpp](#).

#### createSubCBS()

```
Manager::CBSNode Manager::createSubCBS (
    CBSNode & node,
    int subNodeDepth)
```

Create a sub-CBS node.

##### Parameters

<i>node</i>	The parent CBS node
<i>subNodeDepth</i>	The depth of the sub-CBS node

##### Returns

The sub-CBS node

This function creates a sub-CBS node from a parent CBS node. It creates a new node with the same paths and constraints as the parent node, but with less agents.

Definition at line 89 of file [managerCBS.cpp](#).

#### getCars()

```
std::vector< Car > Manager::getCars () [inline]
```

Get the cars.

##### Returns

The cars

Definition at line 150 of file [manager.h](#).

**getNumCars()**

```
int Manager::getNumCars () [inline]
```

Get the number of cars.

**Returns**

The number of cars

Definition at line 144 of file [manager.h](#).

**hasConflict()**

```
bool Manager::hasConflict (
    std::vector< std::vector< sf::Vector2f > > paths,
    int * car1,
    int * car2,
    sf::Vector2f * p1,
    sf::Vector2f * p2,
    double * a1,
    double * a2,
    int * time)
```

Check if two cars have a conflict.

**Parameters**

<i>paths</i>	The paths of the cars
<i>car1</i>	The first car
<i>car2</i>	The second car
<i>p1</i>	The position of the first car
<i>p2</i>	The position of the second car
<i>a1</i>	The angle of the first car
<i>a2</i>	The angle of the second car
<i>time</i>	The time of the conflict

**Returns**

If the cars have a conflict

Definition at line 325 of file [managerCBS.cpp](#).

**processCBS()**

```
Manager::CBSNode Manager::processCBS (
    ConstraintController constraints,
    int subNodeDepth)
```

Process a CBS node.

**Parameters**

<i>constraints</i>	The constraints
<i>subNodeDepth</i>	The depth of the sub-CBS node

**Returns**

The processed CBS node

This function processes a CBS node. It resolves conflicts and returns a new CBS node with the resolved conflicts.  
Definition at line 166 of file [managerCBS.cpp](#).



**renderCars()**

```
void Manager::renderCars (
    sf::RenderWindow & window)
```

Render the cars.

**Parameters**

<i>window</i>	The window
---------------	------------

Definition at line 37 of file [manager.cpp](#).

**toggleCarDebug()**

```
void Manager::toggleCarDebug (
    sf::Vector2f mousePos)
```

Toggle the debug of one car.

**Parameters**

<i>mousePos</i>	The mouse position
-----------------	--------------------

This function toggles the debug of a car. If the mouse is over a car, the debug of the car is toggled.

Definition at line 43 of file [manager.cpp](#).

The documentation for this class was generated from the following files:

- [manager.h](#)
- [manager.cpp](#)
- [managerCBS.cpp](#)

**3.23 Renderer Class Reference**

A renderer for the city.

```
#include <renderer.h>
```

**Public Member Functions**

- void **startRender** (const [CityMap](#) &cityMap, const [CityGraph](#) &cityGraph, [Manager](#) &manager)  
*Start the rendering.*
- void **renderCityMap** (const [CityMap](#) &cityMap)  
*Render the city map.*
- void **renderCityGraph** (const [CityGraph](#) &cityGraph, const sf::View &view)  
*Render the city graph.*
- void **renderManager** ([Manager](#) &manager)  
*Render the cars.*
- void **renderTime** ()  
*Render the time.*
- void **setConflicts** (const std::vector< [AStar::conflict](#) > &conflicts)  
*Render the conflicts.*

**3.23.1 Detailed Description**

A renderer for the city.

The renderer class is used to render the city map, the city graph and the cars.

Definition at line 19 of file [renderer.h](#).

### 3.23.2 Member Function Documentation

#### renderCityGraph()

```
void Renderer::renderCityGraph (
    const CityGraph & cityGraph,
    const sf::View & view)
```

Render the city graph.

##### Parameters

<i>cityGraph</i>	The city graph
<i>view</i>	The view

Definition at line [250](#) of file [renderer.cpp](#).

#### renderCityMap()

```
void Renderer::renderCityMap (
    const CityMap & cityMap)
```

Render the city map.

##### Parameters

<i>cityMap</i>	The city map
----------------	--------------

Definition at line [147](#) of file [renderer.cpp](#).

#### renderManager()

```
void Renderer::renderManager (
    Manager & manager)
```

Render the cars.

##### Parameters

<i>manager</i>	The manager
----------------	-------------

Definition at line [341](#) of file [renderer.cpp](#).

The documentation for this class was generated from the following files:

- [renderer.h](#)
- [renderer.cpp](#)

### 3.24 Test Class Reference

A class for testing the project.

```
#include <test.h>
```

#### Public Member Functions

- void **runTests** ()  
*Run the tests.*

### 3.24.1 Detailed Description

A class for testing the project.

This class is used to test the project.

Definition at line 13 of file [test.h](#).

The documentation for this class was generated from the following files:

- [test.h](#)
- [test.cpp](#)

## 3.25 TimedAStar Class Reference

Timed A\* algorithm.

```
#include <aStar.h>
```

### Public Member Functions

- [TimedAStar](#) ([CityGraph::point](#) start, [CityGraph::point](#) end, const [CityGraph](#) &cityGraph, [ConstraintController](#) \*constraints, int carIndex)

*Constructor.*

- `std::vector< AStar::node > findPath ()`

*Find the path.*

### 3.25.1 Detailed Description

Timed A\* algorithm.

This class represents the timed A\* algorithm. It is used to find the shortest path between two points in a graph while taking into account the constraints of the cars.

Definition at line 171 of file [aStar.h](#).

### 3.25.2 Constructor & Destructor Documentation

#### TimedAStar()

```
TimedAStar::TimedAStar (
    CityGraph::point start,
    CityGraph::point end,
    const CityGraph & cityGraph,
    ConstraintController * constraints,
    int carIndex)
```

Constructor.

#### Parameters

<i>start</i>	The start point
<i>end</i>	The end point
<i>cityGraph</i>	The graph
<i>constraints</i>	The constraints
<i>carIndex</i>	The car index

Definition at line 16 of file [timedAStar.cpp](#).

### 3.25.3 Member Function Documentation

#### findPath()

```
std::vector< AStar::node > TimedAStar::findPath () [inline]
```

Find the path.

**Returns**

The path

Definition at line 188 of file [aStar.h](#).

The documentation for this class was generated from the following files:

- [aStar.h](#)
- [timedAStar.cpp](#)

## 4 File Documentation

### 4.1 aStar.h File Reference

A\* algorithm.

```
#include "cityGraph.h"
```

**Classes**

- struct [\\_aStarNode](#)  
*A node for the A\* algorithm.*
- struct [\\_aStarConflict](#)  
*A conflict for the A\* algorithm.*
- class [AStar](#)  
*A\* algorithm.*
- class [ConstraintController](#)  
*Controller for constraints.*
- class [TimedAStar](#)  
*Timed A\* algorithm.*

#### 4.1.1 Detailed Description

A\* algorithm.

This file contains the A\* algorithm. It is used to find the shortest path between two points in a graph. It also contains the timed A\* algorithm, which is used to find the shortest path between two points in a graph while taking into account the constraints of the cars.

Definition in file [aStar.h](#).

### 4.2 aStar.h

[Go to the documentation of this file.](#)

```
00001
00009 #pragma once
00010
00011 #include "cityGraph.h"
00012
00020 typedef struct _aStarNode {
00021     CityGraph::point point;
00022     double speed;
00023     std::pair<CityGraph::point, CityGraph::neighbor> arcFrom;
00024
00025     bool operator==(const _aStarNode &other) const {
00026         double s = std::round(speed / SPEED_RESOLUTION);
00027         double oS = std::round(other.speed / SPEED_RESOLUTION);
00028
00029         return point == other.point && s == oS && arcFrom.first == other.arcFrom.first &&
00030             arcFrom.second == other.arcFrom.second;
00031     }
00032 } _aStarNode;
00033
00041 typedef struct _aStarConflict {
00042     CityGraph::point point;
00043     int time;
00044     int car;
00045 }
```

```

00046     bool operator==(const _aStarConflict &other) const {
00047         return point == other.point && time == other.time && car == other.car;
00048     }
00049 } _aStarConflict;
00050
00051 namespace std {
00052 template <> struct hash<_aStarNode> {
00053     std::size_t operator()(const _aStarNode &point) const {
00054         double s = std::round(point.speed / SPEED_RESOLUTION);
00055
00056         return std::hash<CityGraph::point>()(point.point) ^ std::hash<double>()(s) ^
00057             std::hash<CityGraph::point>()(point.arcFrom.first) ^
00058             std::hash<CityGraph::neighbor>()(point.arcFrom.second);
00059     };
00060 template <> struct hash<_aStarConflict> {
00061     std::size_t operator()(const _aStarConflict &conflict) const {
00062         return std::hash<CityGraph::point>()(conflict.point) ^ std::hash<int>()(conflict.time) ^
00063             std::hash<int>()(conflict.car);
00064     };
00065 };
00066 } // namespace std
00067
00074 class AStar {
00075 public:
00076     using node = _aStarNode;
00077     using conflict = _aStarConflict;
00078
00085     AStar(CityGraph::point start, CityGraph::point end, const CityGraph &cityGraph);
00086
00091     std::vector<node> findPath() {
00092         if (!processed)
00093             process();
00094         return path;
00095     }
00096 private:
00097     bool processed = false;
00098     node start;
00099     node end;
00100     std::vector<node> path;
00101     CityGraph graph;
00102
00104     void process();
00105 };
00106
00114 class ConstraintController {
00115 public:
00119     ConstraintController() { this->constraints.clear(); }
00120
00125     ConstraintController copy();
00126
00132     ConstraintController copy(std::vector<int> cars);
00133
00138     void addConstraint(AStar::conflict constraints);
00139
00145     bool hasConstraint(AStar::conflict constraint);
00146
00157     bool checkConstraints(int car, double speed, double newSpeed, double time, CityGraph::point from,
00158                           CityGraph::neighbor to);
00159 private:
00161     std::vector<std::vector<std::vector<AStar::conflict>>> constraints; // [car][time][constraints]
00162 };
00163
00171 class TimedAStar {
00172 public:
00181     TimedAStar(CityGraph::point start, CityGraph::point end, const CityGraph &cityGraph,
00182               ConstraintController *constraints, int carIndex);
00183
00188     std::vector<AStar::node> findPath() {
00189         if (!processed)
00190             process();
00191         return path;
00192     }
00193 private:
00194     bool processed = false;
00195     AStar::node start;
00196     AStar::node end;
00197     std::vector<AStar::node> path;
00198     ConstraintController *conflicts;
00199     int carIndex;
00200     CityGraph graph;
00201
00203     void process();
00204 };

```

## 4.3 car.h File Reference

A car in the city.

```
#include <SFML/Graphics.hpp>
#include <vector>
#include "aStar.h"
#include "cityGraph.h"
```

### Classes

- class [Car](#)

*A car in the city.*

#### 4.3.1 Detailed Description

A car in the city.

This file contains the declaration of the [Car](#) class. This class represents a car in the city. It contains the start and end points of the car, the path of the car and the current point in the path.

Definition in file [car.h](#).

## 4.4 car.h

[Go to the documentation of this file.](#)

```
00001
00008 #pragma once
00009
00010 #include <SFML/Graphics.hpp>
00011 #include <vector>
00012
00013 #include "aStar.h"
00014 #include "cityGraph.h"
00015
00023 class Car {
00024 public:
00028     Car();
00029
00035     void assignStartEnd(CityGraph::point start, CityGraph::point end) {
00036         this->start = start;
00037         this->end = end;
00038     }
00039
00045     void chooseRandomStartEndPath(CityGraph &graph, CityMap &cityMap);
00046
00051     void assignPath(std::vector<AStar::node> path);
00052
00057     void assignExistingPath(std::vector<sf::Vector2f> path);
00058
00062     void move();
00063
00068     void render(sf::RenderWindow &window);
00069
00074     CityGraph::point getStart() { return start; }
00075
00080     CityGraph::point getEnd() { return end; }
00081
00086     double getSpeed();
00087
00093     double getSpeedAt(int index);
00094
00100     double getAverageSpeed(CityGraph &graph);
00101
00106     double getRemainingTime();
00107
00112     double getElapsedTime();
00113
00118     double getPathTime();
00119
00124     double getRemainingDistance();
00125
00130     double getElapsedDistance();
00131
00136     double getPathLength();
00137
00142     sf::Vector2f getPosition() { return path[currentPoint]; }
00143
```

```

00148     std::vector<sf::Vector2f> getPath() { return path; }
00149
00154     std::vector<AStar::node> getAStarPath() { return aStarPath; }
00155
00160     void toggleDebug() { debug = !debug; }
00161
00162 private:
00163     CityGraph::point start;
00164     CityGraph::point end;
00165     std::vector<sf::Vector2f> path;
00166     std::vector<AStar::node> aStarPath;
00167     int currentPoint = 0;
00168     bool debug = false;
00169     sf::Color color;
00170 };

```

## 4.5 cityGraph.h File Reference

A graph representing the city's streets and intersections using a graph.

```

#include <unordered_set>
#include "cityMap.h"
#include "config.h"
#include "utils.h"

```

### Classes

- [struct \\_cityGraphPoint](#)  
A point in the city graph.
- [struct \\_cityGraphNeighbor](#)  
A neighbor of a point in the city graph.
- [class CityGraph](#)  
A graph representing the city's streets and intersections using a graph.

### 4.5.1 Detailed Description

A graph representing the city's streets and intersections using a graph.

This file contains the definition of the [CityGraph](#) class.

Definition in file [cityGraph.h](#).

## 4.6 cityGraph.h

[Go to the documentation of this file.](#)

```

00001
00007 #pragma once
00008 #include <unordered_set>
00009
00010 #include "cityMap.h"
00011 #include "config.h"
00012 #include "utils.h"
00013
00020 typedef struct _cityGraphPoint {
00021     sf::Vector2f position;
00022     double angle;
00023
00024     bool operator==(const _cityGraphPoint &other) const {
00025         int x = std::round(position.x / CELL_SIZE);
00026         int y = std::round(position.y / CELL_SIZE);
00027         int a = std::round(normalizeAngle(angle) / ANGLE_RESOLUTION);
00028         int oX = std::round(other.position.x / CELL_SIZE);
00029         int oY = std::round(other.position.y / CELL_SIZE);
00030         int oA = std::round(normalizeAngle(other.angle) / ANGLE_RESOLUTION);
00031
00032         return x == oX && y == oY && a == oA;
00033     }
00034 } _cityGraphPoint;
00035
00043 typedef struct _cityGraphNeighbor {
00044     _cityGraphPoint point;
00045     double maxSpeed;
00046     double turningRadius;
00047     double distance;

```

```

00048     bool isRightWay;
00049
00050     bool operator==(const _cityGraphNeighbor &other) const {
00051         return point == other.point && maxSpeed == other.maxSpeed && turningRadius == other.turningRadius
00052         && distance == other.distance && isRightWay == other.isRightWay;
00053     }
00054
00055 } _cityGraphNeighbor;
00056
00057 namespace std {
00058     template <> struct hash<_cityGraphPoint> {
00059         std::size_t operator()(const _cityGraphPoint &point) const {
00060             int x = std::round(point.position.x / CELL_SIZE);
00061             int y = std::round(point.position.y / CELL_SIZE);
00062             int a = std::round(normalizeAngle(point.angle) / ANGLE_RESOLUTION);
00063
00064             return std::hash<int>()(x) ^ std::hash<int>()(y) ^ std::hash<int>()(a);
00065         }
00066     };
00067     template <> struct hash<_cityGraphNeighbor> {
00068         std::size_t operator()(const _cityGraphNeighbor &neighbor) const {
00069             return std::hash<_cityGraphPoint>()(neighbor.point) ^ std::hash<double>()(neighbor.maxSpeed) ^
00070             std::hash<double>()(neighbor.turningRadius) ^ std::hash<double>()(neighbor.distance) ^
00071             std::hash<bool>()(neighbor.isRightWay);
00072         }
00073     };
00074 } // namespace std
00075
00082 class CityGraph {
00083 public:
00084     using point = _cityGraphPoint;
00085     using neighbor = _cityGraphNeighbor;
00086
00094     void createGraph(const CityMap &cityMap);
00095
00100     std::unordered_map<point, std::vector<neighbor>> getNeighbors() const { return neighbors; }
00101
00106     std::unordered_set<point> getGraphPoints() const { return graphPoints; }
00107
00112     point getRandomPoint() const;
00113
00118     double getHeight() const { return height; }
00119
00124     double getWidth() const { return width; }
00125
00126 private:
00127     std::unordered_map<point, std::vector<neighbor>> neighbors;
00128     std::unordered_set<point> graphPoints;
00129
00130     void linkPoints(const point &point1, const point &point2, int direction,
00131                     bool subPoints); // direction: 0 -> point1 to point2, 1 -> point2 to point1, 2 ->
00132     both
00133     bool canLink(const point &point1, const point &point2, double speed, double *distance) const;
00134
00134     double width;
00135     double height;
00136 };

```

## 4.7 cityMap.h

```

00001 #pragma once
00002
00003 #include <SFML/Graphics.hpp>
00004 #include <string>
00005 #include <vector>
00006
00011 typedef struct {
00012     sf::Vector2f p1;
00013     sf::Vector2f p2;
00014     sf::Vector2f p1_offset;
00015     sf::Vector2f p2_offset;
00016     double angle;
00017 } _cityMapSegment;
00018
00023 typedef struct {
00024     int id;
00025     std::vector<_cityMapSegment> segments;
00026     double width;
00027     int numLanes;
00028 } _cityMapRoad;
00029
00034 typedef struct {
00035     std::vector<sf::Vector2f> points;
00036 } _cityMapBuilding;

```



```

00037
00042 typedef struct {
00043     std::vector<sf::Vector2f> points;
00044     int type;
00045 } _cityMapGreenArea;
00046
00051 typedef struct {
00052     std::vector<sf::Vector2f> points;
00053 } _cityMapWaterArea;
00054
00059 typedef struct {
00060     int id;
00061     sf::Vector2f center;
00062     double radius;
00063     std::vector<std::pair<int, int> roadSegmentIds;
00064 } _cityMapIntersection;
00065
00074 class CityMap {
00075 public:
00076     using segment = _cityMapSegment;
00077     using road = _cityMapRoad;
00078     using building = _cityMapBuilding;
00079     using greenArea = _cityMapGreenArea;
00080     using waterArea = _cityMapWaterArea;
00081     using intersection = _cityMapIntersection;
00082
00086     CityMap();
00087
00092     void loadFile(const std::string &filename);
00093
00098     bool isCityMapLoaded() const { return isLoaded; }
00099
00104     std::vector<road> getRoads() const { return roads; }
00105
00110     std::vector<intersection> getIntersections() const { return intersections; }
00111
00116     std::vector<building> getBuildings() const { return buildings; }
00117
00122     std::vector<greenArea> getGreenAreas() const { return greenAreas; }
00123
00128     std::vector<waterArea> getWaterAreas() const { return waterAreas; }
00129
00134     sf::Vector2f getMinLatLon() const { return minLatLon; }
00135
00140     sf::Vector2f getMaxLatLon() const { return maxLatLon; }
00141
00146     int getWidth() const { return width; }
00147
00152     int getHeight() const { return height; }
00153
00154 private:
00155     bool isLoaded = false;
00156
00157     std::vector<road> roads;
00158     std::vector<intersection> intersections;
00159     std::vector<building> buildings;
00160     std::vector<greenArea> greenAreas;
00161     std::vector<waterArea> waterAreas;
00162
00163     sf::Vector2f minLatLon;
00164     sf::Vector2f maxLatLon;
00165     double width; // in meters
00166     double height; // in meters
00167 };

```

## 4.8 config.h File Reference

Configuration file.

```
#include <string>
```

### 4.8.1 Detailed Description

Configuration file.

Definition in file [config.h](#).

## 4.9 config.h

[Go to the documentation of this file.](#)

```

00001
00005 #pragma once
00006
00007 #include <string>
00008
00009 constexpr int ENVIRONMENT = 0; // 0 = development, 1 = production
00010 constexpr int SCREEN_WIDTH = 2880;
00011 constexpr int SCREEN_HEIGHT = 1864;
00012 constexpr double LOG_CBS_REFRESH_RATE = 0.3; // in seconds
00013
00014 constexpr int EARTH_RADIUS = 6371000; // in meters
00015
00016 constexpr double DEFAULT_ROAD_WIDTH = 7.0; // in meters
00017 constexpr double DEFAULT_LANE_WIDTH = 3.5; // in meters
00018 constexpr double MIN_ROAD_WIDTH = 4.0; // in meters
00019 constexpr bool ROAD_ENABLE_RIGHT_HAND_TRAFFIC = false;
00020
00021 constexpr double ZOOM_SPEED = 0.1;
00022 constexpr double MOVE_SPEED = 0.01;
00023
00024 constexpr double SIM_STEP_TIME = 0.15; // in seconds
00025 constexpr int CBS_PRECISION_FACTOR = 1; // CBS_PRECISION_FACTOR * SIM_STEP_TIME must not be too high
00026 constexpr double CBS_MAX_SUB_TIME = 30; // in seconds
00027
00028 // For hash functions (to reduce items that are really close to each other)
00029 constexpr double CELL_SIZE = 0.5; // in meters
00030 constexpr double SPEED_RESOLUTION = 0.3; // in m/s
00031 constexpr double ANGLE_RESOLUTION = 0.1; // in radians
00032 constexpr double TIME_RESOLUTION = SIM_STEP_TIME; // in seconds
00033
00034 constexpr double CAR_MIN_TURNING_RADIUS = 1.5; // in meters
00035 constexpr double CAR_MAX_SPEED_KM = 30.0; // in km/h
00036 constexpr double CAR_MAX_SPEED_MS = CAR_MAX_SPEED_KM / 3.6; // in m/s
00037 constexpr double CAR_MAX_G_FORCE = 5.0; // in m/s^2
00038 constexpr double CAR_ACCELERATION = 3.0; // in m/s^2
00039 constexpr double CAR_DECELERATION = 4.0; // in m/s^2
00040 constexpr double CAR_LENGTH = 4.2; // in meters
00041 constexpr double CAR_WIDTH = 1.6; // in meters

```

## 4.10 dataManager.h File Reference

Data manager.

```
#include <string>
#include <vector>
```

### Classes

- [struct \\_data](#)  
*Data structure.*
- [class DataManager](#)  
*Data manager.*

### 4.10.1 Detailed Description

Data manager.

This file contains the data manager class.

Definition in file [dataManager.h](#).

## 4.11 dataManager.h

[Go to the documentation of this file.](#)

```

00001
00007 #pragma once
00008
00009 #include <string>
00010 #include <vector>
00011
00018 struct _data {
00019     double numCars;
00020     double carDensity;
00021     std::vector<double> carAvgSpeed;
00022 };
00023

```

```

00030 class DataManager {
00031 public:
00032     using data = _data;
00033
00038     DataManager(std::string filename);
00039
00048     void createData(int numData, int numCarsMin, int numCarsMax, std::string mapName);
00049
00050 private:
00051 };

```

## 4.12 dubins.h File Reference

Dubins path.

```

#include "aStar.h"
#include "cityGraph.h"
#include <ompl/base/State.h>
#include <ompl/base/StateSpace.h>
#include <ompl/base/spaces/DubinsStateSpace.h>

```

### Classes

- class [Dubins](#)  
*Dubins path used to calculate the path between two points in the city graph.*
- class [DubinsPath](#)  
*Dubins path used to calculate the path between two points in the city graph.*

### 4.12.1 Detailed Description

Dubins path.

This file contains the [Dubins](#) class. It is used to calculate the path between two points in the city graph. It will be used to render cars in the city and check for collisions.

Definition in file [dubins.h](#).

## 4.13 dubins.h

[Go to the documentation of this file.](#)

```

00001
00008 #pragma once
00009
00010 #include "aStar.h"
00011 #include "cityGraph.h"
00012
00013 #include <ompl/base/State.h>
00014 #include <ompl/base/StateSpace.h>
00015 #include <ompl/base/spaces/DubinsStateSpace.h>
00016
00017 namespace ob = ompl::base;
00018
00026 class Dubins {
00027 public:
00036     Dubins(CityGraph::point start, CityGraph::neighbor end);
00037
00048     Dubins(CityGraph::point start, CityGraph::neighbor end, double startSpeed);
00049
00061     Dubins(CityGraph::point start, CityGraph::neighbor end, double startSpeed, double endSpeed);
00062
00066     ~Dubins();
00067
00072     double distance() { return endPoint.distance; }
00073
00078     double time();
00079
00085     CityGraph::point point(double time);
00086
00091     std::vector<CityGraph::point> path();
00092
00093 private:
00094     ob::DubinsStateSpace *space;
00095     ob::State *start;
00096     ob::State *end;

```

```

00097
00098     CityGraph::point startPoint;
00099     CityGraph::neighbor endPoint;
00100     double startSpeed;
00101     double endSpeed;
00102     double avgSpeed;
00103 };
00104
00112 class DubinsPath {
00113 public:
00121     DubinsPath(std::vector<AStar::node> path);
00122
00126     std::vector<CityGraph::point> path();
00127
00128 private:
00129     void process();
00130
00131     std::vector<AStar::node> path_;
00132     std::vector<CityGraph::point> pathProcessed_;
00133 };

```

## 4.14 fileSelector.h File Reference

File selector.

```

#include <iostream>
#include <termios.h>
#include <unistd.h>
#include <vector>

```

### Classes

- class [FileSelector](#)

*A file selector.*

### 4.14.1 Detailed Description

File selector.

This file contains the [FileSelector](#) class. It is used to select a file from a folder.

Definition in file [fileSelector.h](#).

## 4.15 fileSelector.h

[Go to the documentation of this file.](#)

```

00001
00007 #pragma once
00008 #include <iostream>
00009 #include <termios.h>
00010 #include <unistd.h>
00011 #include <vector>
00012
00019 class FileSelector {
00020 private:
00021     std::string folderPath;
00022     std::vector<std::string> files;
00023     int selectedIndex;
00024
00025     void loadFiles();
00026     char getKeyPress();
00027     void moveCursorUp();
00028     void moveCursorDown();
00029     void displayFiles();
00030
00031 public:
00032     FileSelector(const std::string &path) : folderPath(path), selectedIndex(0) { loadFiles(); }
00033     ~FileSelector() { std::cout << "\033[?25h"; }
00034
00035     std::string selectFile();
00036 };

```

## 4.16 manager.h File Reference

[Manager](#) for the cars.

```
#include <SFML/Graphics.hpp>
#include <vector>
#include "car.h"
#include "cityGraph.h"
#include "dataManager.h"
```

## Classes

- struct [\\_managerCBSNode](#)  
A node for the CBS algorithm.
- class [Manager](#)  
A manager for the cars.

### 4.16.1 Detailed Description

[Manager](#) for the cars.

This file contains the declaration of the [Manager](#) class. This class is used to manage the cars during the CBS pathfinding. It creates the cars and resolves conflicts using the CBS algorithm.

Definition in file [manager.h](#).

## 4.17 manager.h

[Go to the documentation of this file.](#)

```
00001
00008 #pragma once
00009
00010 #include <SFML/Graphics.hpp>
00011 #include <vector>
00012
00013 #include "car.h"
00014 #include "cityGraph.h"
00015 #include "dataManager.h"
00016
00024 typedef struct _managerCBSNode {
00025     std::vector<std::vector<sf::Vector2f>> paths;
00026     ConstraintController constraints;
00027     std::vector<double> costs;
00028     double cost;
00029     int depth;
00030     bool hasResolved;
00031
00032     bool operator<(const _managerCBSNode &other) const {
00033         return cost > other.cost || (cost == other.cost && depth > other.depth);
00034     }
00035
00036 } _managerCBSNode;
00037
00045 class Manager {
00046 public:
00047     using CBSNode = _managerCBSNode;
00048
00055     Manager(const CityGraph &cityGraph, const CityMap &CityMap, bool log) : graph(cityGraph),
00056     map(CityMap) {
00057         this->log = log;
00058     }
00066     Manager(const CityGraph &cityGraph, const CityMap &CityMap, std::vector<Car> cars, bool log)
00067     : graph(cityGraph), map(CityMap), cars(cars) {
00068         this->numCars = cars.size();
00069         this->log = log;
00070     }
00071
00076     void createCarsAStar(int numCars);
00077
00083     std::pair<bool, DataManager::data> createCarsCBS(int numCars);
00084
00094     CBSNode createSubCBS(CBSNode &node, int subNodeDepth);
00095
00104     CBSNode processCBS(ConstraintController constraints, int subNodeDepth);
00105
00118     bool hasConflict(std::vector<std::vector<sf::Vector2f>> paths, int *car1, int *car2, sf::Vector2f
00119     *p1,
00120                     sf::Vector2f *p2, double *a1, double *a2, int *time);
```

```

00124 void moveCars();
00125
00130 void renderCars(sf::RenderWindow &window);
00131
00138 void toggleCarDebug(sf::Vector2f mousePos);
00139
00144 int getNumCars() { return numCars; }
00145
00150 std::vector<Car> getCars() { return cars; }
00151
00152 private:
00153     int numCars;
00154     std::vector<Car> cars;
00155     CityGraph graph;
00156     CityMap map;
00157     bool log;
00158 };

```

## 4.18 renderer.h File Reference

A renderer for the city.

```

#include <SFML/Graphics.hpp>
#include "cityGraph.h"
#include "cityMap.h"
#include "manager.h"

```

### Classes

- class [Renderer](#)

*A renderer for the city.*

### Functions

- void [drawArrow](#) (sf::RenderWindow &window, sf::Vector2f position, double rotation, double length, double thickness, sf::Color color=sf::Color::Red, bool outline=false)

*Draw an arrow.*

#### 4.18.1 Detailed Description

A renderer for the city.

Definition in file [renderer.h](#).

#### 4.18.2 Function Documentation

##### drawArrow()

```

void drawArrow (
    sf::RenderWindow & window,
    sf::Vector2f position,
    double rotation,
    double length,
    double thickness,
    sf::Color color = sf::Color::Red,
    bool outline = false) [inline]

```

Draw an arrow.

##### Parameters

<i>window</i>	The window
<i>position</i>	The position
<i>rotation</i>	The rotation
<i>length</i>	The length
<i>thickness</i>	The thickness

## Parameters

<i>color</i>	The color
<i>outline</i>	If the arrow should have an outline

Definition at line 74 of file [renderer.h](#).

## 4.19 renderer.h

[Go to the documentation of this file.](#)

```

00001
00005 #pragma once
00006
00007 #include <SFML/Graphics.hpp>
00008
00009 #include "cityGraph.h"
00010 #include "cityMap.h"
00011 #include "manager.h"
00012
00019 class Renderer {
00020 public:
00024     void startRender(const CityMap &cityMap, const CityGraph &cityGraph, Manager &manager);
00025
00030     void renderCityMap(const CityMap &cityMap);
00031
00037     void renderCityGraph(const CityGraph &cityGraph, const sf::View &view);
00038
00043     void renderManager(Manager &manager);
00044
00048     void renderTime();
00049
00053     void setConflicts(const std::vector<AStar::conflict> &conflicts) { this->conflicts = conflicts; }
00054
00055 private:
00056     sf::RenderWindow window;
00057     double time;
00058
00059     std::vector<AStar::conflict> conflicts;
00060
00061     bool debug = false;
00062 };
00063
00074 inline void drawArrow(sf::RenderWindow &window, sf::Vector2f position, double rotation, double length,
double thickness,
sf::Color color = sf::Color::Red, bool outline = false) {
00075     sf::ConvexShape arrow;
00076
00077     arrow.setFillColor(color);
00078     arrow.setOrigin(-length / 2, 0);
00079     arrow.setPosition(position);
00080     arrow.setRotation(rotation);
00081
00082     arrow.setPointCount(7);
00083     arrow.setPoint(0, sf::Vector2f(0, 0));
00084     arrow.setPoint(1, sf::Vector2f(-2 * length / 5, thickness));
00085     arrow.setPoint(2, sf::Vector2f(-2 * length / 5, thickness / 2));
00086     arrow.setPoint(3, sf::Vector2f(-length, thickness / 2));
00087     arrow.setPoint(4, sf::Vector2f(-length, -thickness / 2));
00088     arrow.setPoint(5, sf::Vector2f(-2 * length / 5, -thickness / 2));
00089     arrow.setPoint(6, sf::Vector2f(-2 * length / 5, -thickness));
00090
00091     if (outline) {
00092         arrow.setOutlineThickness(thickness / 10);
00093         arrow.setOutlineColor(sf::Color::Black);
00094     }
00095
00096     window.draw(arrow);
00097 }
00098

```

## 4.20 test.h File Reference

A header file for the [Test](#) class.

## Classes

- class [Test](#)

*A class for testing the project.*

### 4.20.1 Detailed Description

A header file for the [Test](#) class.  
Definition in file [test.h](#).

## 4.21 test.h

[Go to the documentation of this file.](#)

```
00001
00005 #pragma once
00006
00013 class Test {
00014 public:
00018     void runTests();
00019
00020 private:
00021     void testSpdlog();
00022     void testTinyXML2();
00023     void testSFML();
00024 };
```

## 4.22 utils.h File Reference

Utility functions.

```
#include "config.h"
#include <SFML/Graphics.hpp>
```

### Functions

- sf::Vector2f [latLonToXY](#) (double lat, double lon)  
*Convert latitude and longitude to x and y.*
- double [distance](#) (sf::Vector2f p1, sf::Vector2f p2)  
*Get the distance between two points.*
- double [normalizeAngle](#) (double angle)  
*Normalize an angle to -PI to PI.*
- double [turningRadius](#) (double speed)  
*Get the turning radius from the speed.*
- double [turningRadiusToSpeed](#) (double radius)  
*Get the speed from the turning radius.*
- bool [carsCollided](#) (Car car1, Car car2, int time)
- bool [carConflict](#) (sf::Vector2f carPos, double carAngle, sf::Vector2f confPos, double confAngle)  
*Check if two cars have a conflict.*
- sf::Font [loadFont](#) ()  
*Load a font.*

### 4.22.1 Detailed Description

Utility functions.

Definition in file [utils.h](#).

### 4.22.2 Function Documentation

#### carConflict()

```
bool carConflict (
    sf::Vector2f carPos,
    double carAngle,
    sf::Vector2f confPos,
    double confAngle)
```

Check if two cars have a conflict.



## Parameters

<i>carPos</i>	The position of the car
<i>carAngle</i>	The angle of the car
<i>confPos</i>	The position of the conflicting car
<i>confAngle</i>	The angle of the conflicting car

## Returns

If the cars have a conflict

Definition at line 49 of file [utils.cpp](#).

**carsCollided()**

```
bool carsCollided (  
    Car car1,  
    Car car2,  
    int time)
```

@brief Check if two cars collided

## Parameters

<i>car1</i>	The first car
<i>car2</i>	The second car

Definition at line 23 of file [utils.cpp](#).

**distance()**

```
double distance (  
    sf::Vector2f p1,  
    sf::Vector2f p2) [inline]
```

Get the distance between two points.

## Parameters

<i>p1</i>	The first point
<i>p2</i>	The second point

Definition at line 29 of file [utils.h](#).

**latLonToXY()**

```
sf::Vector2f latLonToXY (  
    double lat,  
    double lon) [inline]
```

Convert latitude and longitude to x and y.

## Parameters

<i>lat</i>	The latitude
<i>lon</i>	The longitude

## Returns

The x and y

Definition at line 17 of file [utils.h](#).

**loadFont()**

```
sf::Font loadFont ()
```

Load a font.

**Returns**

The font

Definition at line 13 of file [utils.cpp](#).

**normalizeAngle()**

```
double normalizeAngle (
    double angle) [inline]
```

Normalize an angle to -PI to PI.

**Parameters**

<i>angle</i>	The angle
--------------	-----------

Definition at line 37 of file [utils.h](#).

**turningRadius()**

```
double turningRadius (
    double speed) [inline]
```

Get the turning radius from the speed.

**Parameters**

<i>speed</i>	The speed
--------------	-----------

**Returns**

The turning radius

Definition at line 52 of file [utils.h](#).

**turningRadiusToSpeed()**

```
double turningRadiusToSpeed (
    double radius) [inline]
```

Get the speed from the turning radius.

**Parameters**

<i>radius</i>	The turning radius
---------------	--------------------

**Returns**

The speed

Definition at line 59 of file [utils.h](#).

## 4.23 utils.h

[Go to the documentation of this file.](#)

```

00001
00005 #pragma once
00006 #include "config.h"
00007 #include <SFML/Graphics.hpp>
00008
00009 class Car;
00010
00017 inline sf::Vector2f latLonToXY(double lat, double lon) {
00018     sf::Vector2f xy;
00019     xy.x = EARTH_RADIUS * lon * M_PI / 180;
00020     xy.y = EARTH_RADIUS * std::log(std::tan((90.0f + lat) * M_PI / 360.0f));
00021     return xy;
00022 }
00023
00029 inline double distance(sf::Vector2f p1, sf::Vector2f p2) {
00030     return std::sqrt(std::pow(p2.x - p1.x, 2) + std::pow(p2.y - p1.y, 2));
00031 }
00032
00037 inline double normalizeAngle(double angle) { // -PI to PI
00038     while (angle > M_PI) {
00039         angle -= 2 * M_PI;
00040     }
00041     while (angle <= -M_PI) {
00042         angle += 2 * M_PI;
00043     }
00044     return angle;
00045 }
00046
00052 inline double turningRadius(double speed) { return speed * speed / CAR_MAX_G_FORCE; }
00053
00059 inline double turningRadiusToSpeed(double radius) { return std::sqrt(radius * CAR_MAX_G_FORCE); }
00060
00066 bool carsCollided(Car car1, Car car2, int time);
00067
00076 bool carConflict(sf::Vector2f carPos, double carAngle, sf::Vector2f confPos, double confAngle);
00077
00082 sf::Font loadFont();

```

## 4.24 index.py

```

00001
00014 import sys
00015 import os
00016 import matplotlib.pyplot as plt
00017 import numpy as np
00018 from collections import defaultdict
00019
00020 # =====
00021 # User-Configurable Parameters
00022 # =====
00023
00024 # Parameters for the vertical bars representing individual data points
00025 BAR_COLOR = 'blue' # Color of the vertical bars
00026 BAR_WIDTH = 1 # Width of the bars (in data units)
00027 BAR_VERTICAL_OFFSET = 0.3 # Vertical offset: each bar spans from (y - offset) to (y + offset)
00028 BAR_ALPHA = 0.1 # Opacity of the bars (0.0 to 1.0)
00029
00030 # Parameters for the mean speed trend line
00031 MEAN_LINE_COLOR = 'red' # Color of the mean speed line
00032 MEAN_LINE_STYLE = '-' # Style of the mean speed line
00033 MEAN_LINE_WIDTH = 2 # Thickness of the mean speed line
00034
00035 # Parameters for the trend line (interpolation)
00036 TREND_LINE_COLOR = 'green' # Color of the trend line
00037 TREND_LINE_STYLE = '-' # Style of the trend line
00038 TREND_LINE_WIDTH = 2 # Thickness of the trend line
00039 TREND_DEGREE = 1 # Degree of the polynomial for the trend line (1 = linear)
00040
00041 # Parameters for the standard deviation bands
00042 STD_LINE_COLOR = 'purple' # Color of the standard deviation lines
00043 STD_LINE_STYLE = '--' # Style of the standard deviation lines
00044 STD_LINE_WIDTH = 1.5 # Thickness of the standard deviation lines
00045
00046 # Parameters for the x-axis labels
00047 X_LABEL_STEP = 4
00048
00049 # =====
00050 # Main Code
00051 # =====
00052
00053 def main():

```

```

00054     # Check if a filename is provided as a command-line argument
00055     if len(sys.argv) < 2:
00056         print("Usage: python script.py <filename>")
00057         sys.exit(1)
00058
00059     filename = sys.argv[1]
00060
00061     # Validate that the file exists
00062     if not os.path.isfile(filename):
00063         print(f"Error: File '{filename}' does not exist.")
00064         sys.exit(1)
00065
00066     # Lists to store data points
00067     x_points = []           # Number of vehicles (numCar)
00068     y_points = []           # Converted speeds (km/h)
00069     speed_data = defaultdict(list) # Dictionary mapping numCar to a list of speeds
00070     density_mapping = {}    # Store density values for each numCar
00071
00072     # Read the file
00073     with open(filename, 'r', encoding='utf-8') as file:
00074         for line_number, line in enumerate(file, start=1):
00075             line = line.strip()
00076             if not line:
00077                 continue
00078
00079             # Split the line using ';' as the delimiter and remove empty tokens
00080             tokens = [token.strip() for token in line.split(';') if token.strip()]
00081
00082             if len(tokens) < 2:
00083                 continue
00084
00085             # Parse numCar (the number of vehicles) and density
00086             try:
00087                 num_car = int(tokens[0])
00088                 density = float(tokens[1]) # Store density for the x-axis label
00089                 density_mapping[num_car] = density # Ensure each numCar has a unique density mapping
00090             except ValueError:
00091                 print(f"Error on line {line_number}: Cannot parse numCar or density '{tokens[:2]}'.")
00092                 continue
00093
00094             expected_token_count = 2 + num_car
00095             if len(tokens) < expected_token_count:
00096                 print(f"Error on line {line_number}: Expected {expected_token_count} values, found {len(tokens)}.")
00097                 continue
00098
00099             # Process each speed value (tokens from index 2 onward), converting from m/s to km/h
00100             for token in tokens[2:]:
00101                 try:
00102                     speed_kmh = float(token) * 3.6
00103                     x_points.append(num_car) # Use numCar as the x-value
00104                     y_points.append(speed_kmh) # Store the speed (km/h)
00105                     speed_data[num_car].append(speed_kmh) # Group speeds by numCar for averaging
00106                 except ValueError:
00107                     print(f"Error on line {line_number}: Cannot convert '{token}' to float.")
00108                     continue
00109
00110             if not x_points:
00111                 print("No valid data found. Exiting.")
00112                 sys.exit(1)
00113
00114             # Compute the mean speed and standard deviation for each unique numCar
00115             unique_x = sorted(speed_data.keys())
00116             mean_y = [np.mean(speed_data[num]) for num in unique_x]
00117             std_y = [np.std(speed_data[num]) for num in unique_x] # Compute standard deviation
00118
00119             # Compute upper and lower bounds (±1 standard deviation)
00120             upper_y = [mean + std for mean, std in zip(mean_y, std_y)]
00121             lower_y = [mean - std for mean, std in zip(mean_y, std_y)]
00122
00123             # Fit a linear trend line (degree 1)
00124             trend_poly = np.polyfit(unique_x, mean_y, TREND_DEGREE)
00125             trend_func = np.poly1d(trend_poly)
00126
00127             # Generate smooth x values for plotting the trend curve
00128             x_smooth = np.linspace(min(unique_x), max(unique_x), 300)
00129             y_smooth = trend_func(x_smooth)
00130
00131             # Create the plot
00132             fig, ax = plt.subplots(figsize=(10, 6))
00133
00134             # Plot the individual data points as vertical bars using plt.bar
00135             bottoms = [y - BAR_VERTICAL_OFFSET for y in y_points]
00136             heights = [2 * BAR_VERTICAL_OFFSET for _ in y_points]
00137             ax.bar(x_points, heights, width=BAR_WIDTH, bottom=bottoms, color=BAR_COLOR,
00138                 alpha=BAR_ALPHA, align='center')
00139

```

```

00140     # Plot the mean speed as a continuous red line
00141     ax.plot(unique_x, mean_y, color=MEAN_LINE_COLOR, linestyle=MEAN_LINE_STYLE,
00142             linewidth=MEAN_LINE_WIDTH, label="Mean Speed")
00143
00144     # Plot the trend (interpolation) curve
00145     ax.plot(x_smooth, y_smooth, color=TREND_LINE_COLOR, linestyle=TREND_LINE_STYLE,
00146             linewidth=TREND_LINE_WIDTH, label="Trend Curve")
00147
00148     # Plot  $\pm 1$  standard deviation lines
00149     ax.plot(unique_x, upper_y, color=STD_LINE_COLOR, linestyle=STD_LINE_STYLE,
00150             linewidth=STD_LINE_WIDTH, label="+1 Std Dev")
00151     ax.plot(unique_x, lower_y, color=STD_LINE_COLOR, linestyle=STD_LINE_STYLE,
00152             linewidth=STD_LINE_WIDTH, label="-1 Std Dev")
00153
00154     # Set x-axis labels with "numCar (density)"
00155     x_labels = [f"{num} ({density_mapping[num]:.0f})" if i % X_LABEL_STEP == 0 else ""
00156                 for i, num in enumerate(unique_x)]
00157     ax.set_xticks(unique_x)
00158     ax.set_xticklabels(x_labels, rotation=45, ha='right') # Rotate for better readability
00159     ax.set_xlim(min(unique_x)-0.5, max(unique_x)+0.5)
00160
00161     ax.set_xlabel("Number of Vehicles (Density)")
00162     ax.set_ylabel("Average Speed (km/h)")
00163     ax.set_title("Number of Vehicles vs Average Speeds with Std Deviation")
00164     ax.legend()
00165
00166     # Display the plot (grid is not added)
00167     plt.show()
00168
00169 if __name__ == '__main__':
00170     main()

```

## 4.25 aStar.cpp File Reference

A\* algorithm implementation.

```

#include "aStar.h"
#include "config.h"
#include "dubins.h"
#include "utils.h"
#include <ompl/base/State.h>
#include <ompl/base/StateSpace.h>
#include <ompl/base/spaces/DubinsStateSpace.h>
#include <spdlog/spdlog.h>
#include <unordered_set>

```

### 4.25.1 Detailed Description

A\* algorithm implementation.

This file contains the implementation of the A\* algorithm. It is used to find the shortest path between two points in a graph.

Definition in file [aStar.cpp](#).

## 4.26 aStar.cpp

[Go to the documentation of this file.](#)

```

00001
00008 #include "aStar.h"
00009 #include "config.h"
00010 #include "dubins.h"
00011 #include "utils.h"
00012
00013 #include <ompl/base/State.h>
00014 #include <ompl/base/StateSpace.h>
00015 #include <ompl/base/spaces/DubinsStateSpace.h>
00016 #include <spdlog/spdlog.h>
00017 #include <unordered_set>
00018
00019 namespace ob = ompl::base;
00020
00021 AStar::AStar(CityGraph::point start, CityGraph::point end, const CityGraph &cityGraph) {
00022     this->start.point = start;
00023     this->start.speed = 0;
00024     this->end.point = end;

```

```

00025     this->end.speed = 0;
00026     this->graph = cityGraph;
00027 }
00028
00029 void AStar::process() {
00030     path.clear();
00031
00032     std::unordered_map<AStar::node, AStar::node> cameFrom;
00033     std::unordered_map<AStar::node, double> gScore;
00034     std::unordered_map<AStar::node, double> fScore;
00035
00036     auto heuristic = [&](const AStar::node &a) {
00037         CityGraph::neighbor end_;
00038         end_.point = end.point;
00039         end_.maxSpeed = 0;
00040         end_.turningRadius = CAR_MIN_TURNING_RADIUS;
00041         Dubins dubins(a.point, end_);
00042         return dubins.distance();
00043     };
00044     auto compare = [&](const AStar::node &a, const AStar::node &b) { return fScore[a] > fScore[b]; };
00045
00046     std::priority_queue<AStar::node, std::vector<AStar::node>, decltype(compare)> openSet(compare);
00047     std::unordered_set<AStar::node> isInOpenSet;
00048
00049     openSet.push(start);
00050     gScore[start] = 0;
00051     fScore[start] = heuristic(start);
00052
00053     auto neighbors = graph.getNeighbors();
00054
00055     int nbIterations = 0;
00056     while (!openSet.empty() && nbIterations++ < 1e5) {
00057         AStar::node current = openSet.top();
00058         openSet.pop();
00059         isInOpenSet.erase(current);
00060
00061         if (current.point == end.point) {
00062             AStar::node currentCopy = current;
00063
00064             while (!(currentCopy == start)) {
00065                 path.push_back(currentCopy);
00066                 currentCopy = cameFrom[currentCopy];
00067             }
00068             path.push_back(currentCopy);
00069             std::reverse(path.begin(), path.end());
00070             break;
00071         }
00072
00073         for (const auto &neighborGraphPoint : neighbors[current.point]) {
00074             AStar::node neighbor;
00075             neighbor.point = neighborGraphPoint.point;
00076             neighbor.speed = neighborGraphPoint.maxSpeed;
00077             neighbor.arcFrom = {current.point, neighborGraphPoint};
00078
00079             double tentativeGScore = gScore[current] + neighborGraphPoint.distance;
00080
00081             if (gScore.find(neighbor) == gScore.end() || tentativeGScore < gScore[neighbor]) {
00082                 cameFrom[neighbor] = current;
00083                 gScore[neighbor] = tentativeGScore;
00084                 fScore[neighbor] = gScore[neighbor] + heuristic(neighbor);
00085
00086                 if (isInOpenSet.find(neighbor) == isInOpenSet.end()) {
00087                     openSet.push(neighbor);
00088                     isInOpenSet.insert(neighbor);
00089                 }
00090             }
00091         }
00092     }
00093 }

```

## 4.27 car.cpp File Reference

**Car** class implementation.

```

#include "car.h"
#include "config.h"
#include "dubins.h"
#include "utils.h"
#include <iostream>
#include <random>

```

### 4.27.1 Detailed Description

[Car](#) class implementation.

This file contains the implementation of the [Car](#) class.

Definition in file [car.cpp](#).

## 4.28 car.cpp

[Go to the documentation of this file.](#)

```

00001
00007 #include "car.h"
00008 #include "config.h"
00009 #include "dubins.h"
00010 #include "utils.h"
00011
00012 #include <iostream>
00013 #include <random>
00014
00015 Car::Car() {
00016     std::vector<sf::Color> colors = {sf::Color(50, 120, 190), sf::Color(183, 132, 144), sf::Color(105,
101, 89),
00017                                     sf::Color(182, 18, 34), sf::Color(24, 25, 24), sf::Color(17,
86, 122)};
00018     color = colors[rand() % colors.size()];
00019 }
00020
00021 void Car::move() {
00022     if (currentPoint >= (int)path.size())
00023         return;
00024
00025     currentPoint++;
00026 }
00027
00028 void Car::render(sf::RenderWindow &window) {
00029     if (1 + currentPoint >= (int)path.size())
00030         return;
00031
00032     sf::Vector2f point = path[currentPoint];
00033     sf::Vector2f nextPoint = path[currentPoint + 1];
00034
00035     sf::RectangleShape shape(sf::Vector2f(CAR_LENGTH, CAR_WIDTH));
00036     shape.setOrigin(CAR_LENGTH / 2.0f, CAR_WIDTH / 2.0f);
00037     shape.setPosition(point);
00038     shape.setRotation(atan2(nextPoint.y - point.y, nextPoint.x - point.x) * 180.0f / M_PI);
00039     if (debug)
00040         shape.setFillColor(sf::Color(255, 0, 0));
00041     else
00042         shape.setFillColor(color);
00043     window.draw(shape);
00044
00045     if (!debug)
00046         return;
00047
00048     // Render speed, elapsed time, remaining time, and distance
00049     int speed = (int)(getSpeed() * 3.6f);
00050     int dSpeed = (getSpeed() * 3.6f - (double)speed) * 100;
00051     sf::Font font = loadFont();
00052     sf::Text text;
00053     text.setFont(font);
00054     text.setCharacterSize(24);
00055     text.setFillColor(sf::Color::White);
00056     text.setPosition(getPosition());
00057     text.setString(std::to_string(speed) + "." + std::to_string(dSpeed) + " km/h" + "\n" +
std::to_string((int)getElapsedTime()) + "s / " +
std::to_string((int)getRemainingTime()) + "s" + "\n" +
std::to_string((int)getElapsedDistance()) + "m / " +
std::to_string((int)getRemainingDistance()) +
"m");
00061     text.setOutlineColor(sf::Color::Black);
00062     text.setOutlineThickness(1.0f);
00063     text.scale(0.1f, 0.1f);
00064     text.setOrigin(text.getLocalBounds().width / 2.0f, text.getLocalBounds().height / 2.0f);
00065     window.draw(text);
00066
00067     // Render path
00068     for (int i = currentPoint; i < (int)path.size() - 1; i++) {
00069         sf::Vertex line[] = {sf::Vertex(path[i]), sf::Vertex(path[i + 1])};
00070         line[0].color = sf::Color(255, 255, 255);
00071         line[1].color = sf::Color(255, 255, 255);
00072         window.draw(line, 2, sf::Lines);
00073     }
00074 }
00075

```

```

00076 void Car::assignPath(std::vector<AStar::node> path) {
00077     this->path.clear();
00078     this->aStarPath = path;
00079     DubinsPath dubins(path);
00080     std::vector<CityGraph::point> dubinsPath_ = dubins.path();
00081     for (CityGraph::point point : dubinsPath_) {
00082         this->path.push_back(point.position);
00083     }
00084     currentPoint = 0;
00085 }
00086
00087 void Car::assignExistingPath(std::vector<sf::Vector2f> path) {
00088     this->path = path;
00089     currentPoint = 0;
00090 }
00091
00092 double Car::getSpeed() {
00093     if (currentPoint >= (int)path.size() - 1)
00094         return 0;
00095     sf::Vector2f diff = path[currentPoint + 1] - path[currentPoint];
00096     return sqrt(diff.x * diff.x + diff.y * diff.y) / SIM_STEP_TIME;
00097 }
00098
00099 double Car::getSpeedAt(int index) {
00100     if (index >= (int)path.size() - 1)
00101         return 0;
00102     sf::Vector2f diff = path[index + 1] - path[index];
00103     return sqrt(diff.x * diff.x + diff.y * diff.y) / SIM_STEP_TIME;
00104 }
00105
00106 double Car::getRemainingTime() { return (double)(path.size() - currentPoint) * SIM_STEP_TIME; }
00107 double Car::getElapsedTime() { return (double)currentPoint * SIM_STEP_TIME; }
00108 double Car::getPathTime() { return (double)path.size() * SIM_STEP_TIME; }
00109
00110 double Car::getRemainingDistance() {
00111     double dist = 0;
00112     for (int i = currentPoint; i < (int)path.size() - 1; i++) {
00113         sf::Vector2f diff = path[i + 1] - path[i];
00114         dist += sqrt(diff.x * diff.x + diff.y * diff.y);
00115     }
00116     return dist;
00117 }
00118
00119 double Car::getElapsedDistance() {
00120     double dist = 0;
00121     for (int i = 0; i < currentPoint; i++) {
00122         sf::Vector2f diff = path[i + 1] - path[i];
00123         dist += sqrt(diff.x * diff.x + diff.y * diff.y);
00124     }
00125     return dist;
00126 }
00127
00128 double Car::getPathLength() {
00129     double dist = 0;
00130     for (int i = 0; i < (int)path.size() - 1; i++) {
00131         sf::Vector2f diff = path[i + 1] - path[i];
00132         dist += sqrt(diff.x * diff.x + diff.y * diff.y);
00133     }
00134     return dist;
00135 }
00136
00137 void Car::chooseRandomStartEndPath(CityGraph &graph, CityMap &cityMap) {
00138     CityGraph::point start;
00139     CityGraph::point end;
00140     double minDistance = std::max(graph.getWidth(), graph.getHeight()) / 2.0;
00141     std::vector<AStar::node> path;
00142     do {
00143         path.clear();
00144         start = graph.getRandomPoint();
00145         end = graph.getRandomPoint();
00146         if (std::sqrt(std::pow(start.position.x - end.position.x, 2) + std::pow(start.position.y -
00147             end.position.y, 2)) <
00148             minDistance)
00149             continue;
00150         AStar aStar(start, end, graph);
00151         path = aStar.findPath();
00152         if (!path.empty() && (int)path.size() >= 3) {

```



```

00162         TimedAStar timedAStar(start, end, graph, nullptr, 0);
00163         path.clear();
00164         path = timedAStar.findPath();
00165     }
00166     } while (path.empty() || (int)path.size() < 3);
00167
00168     this->assignStartEnd(start, end);
00169     this->assignPath(path);
00170 }
00171
00172 double Car::getAverageSpeed(CityGraph &graph) {
00173     double dist = 0;
00174     double time = 0;
00175     auto outOfBounds = [&](sf::Vector2f p) {
00176         return p.x < 0 || p.y < 0 || p.x > graph.getWidth() || p.y > graph.getHeight();
00177     };
00178
00179     for (int i = 0; i < (int)path.size() - 1; i++) {
00180         if (outOfBounds(path[i]) || outOfBounds(path[i + 1]))
00181             continue;
00182
00183         sf::Vector2f diff = path[i + 1] - path[i];
00184         dist += sqrt(diff.x * diff.x + diff.y * diff.y);
00185         time += SIM_STEP_TIME;
00186     }
00187
00188     if (time == 0)
00189         return 0;
00190
00191     return dist / time;
00192 }

```

## 4.29 cityGraph.cpp File Reference

City graph implementation.

```

#include <iostream>
#include <ompl/base/State.h>
#include <ompl/base/StateSpace.h>
#include <ompl/base/spaces/DubinsStateSpace.h>
#include <ompl/geometric/SimpleSetup.h>
#include <ompl/geometric/planners/rrt/RRT.h>
#include <random>
#include <spdlog/spdlog.h>
#include "cityGraph.h"
#include "config.h"
#include "utils.h"

```

### 4.29.1 Detailed Description

City graph implementation.

This file contains the implementation of the [CityGraph](#) class. This class represents the graph of the city. It contains the points of the graph and the neighbors of each point.

Definition in file [cityGraph.cpp](#).

## 4.30 cityGraph.cpp

[Go to the documentation of this file.](#)

```

00001
00008 #include <iostream>
00009 #include <ompl/base/State.h>
00010 #include <ompl/base/StateSpace.h>
00011 #include <ompl/base/spaces/DubinsStateSpace.h>
00012 #include <ompl/geometric/SimpleSetup.h>
00013 #include <ompl/geometric/planners/rrt/RRT.h>
00014 #include <random>
00015 #include <spdlog/spdlog.h>
00016
00017 #include "cityGraph.h"
00018 #include "config.h"
00019 #include "utils.h"
00020
00021 namespace ob = ompl::base;

```

```

00022
00023 void CityGraph::createGraph(const CityMap &cityMap) {
00024     auto roads = cityMap.getRoads();
00025     auto intersections = cityMap.getIntersections();
00026
00027     this->height = cityMap.getHeight();
00028     this->width = cityMap.getWidth();
00029
00030     // Graph's points are evenly distributed along a road segment
00031     for (const auto &road : roads) {
00032         if (road.segments.empty()) {
00033             continue;
00034         }
00035
00036         int numSeg = 0;
00037         for (const auto &segment : road.segments) {
00038             if (numSeg > 0) { // Link to the previous one
00039                 for (int i_lane = 0; i_lane < road.numLanes; i_lane++) {
00040                     double offset = ((double)i_lane - (double)road.numLanes / 2.0f) * road.width /
road.numLanes;
00041                     offset += road.width / (2 * road.numLanes);
00042
00043                     point point1;
00044                     point1.angle = road.segments[numSeg - 1].angle;
00045                     point1.position =
00046                         sf::Vector2f(road.segments[numSeg - 1].p2_offset.x + offset * sin(road.segments[numSeg -
1].angle),
00047                                     road.segments[numSeg - 1].p2_offset.y + offset * -cos(road.segments[numSeg
- 1].angle));
00048
00049                     point point2;
00050                     point2.angle = road.segments[numSeg].angle;
00051                     point2.position =
00052                         sf::Vector2f(road.segments[numSeg].p1_offset.x + offset *
sin(road.segments[numSeg].angle),
00053                                     road.segments[numSeg].p1_offset.y + offset *
-cos(road.segments[numSeg].angle));
00054
00055                     linkPoints(point1, point2, 2, true);
00056                 }
00057             }
00058             numSeg++;
00059
00060             double segmentLength =
00061                 sqrt(pow(segment.p2_offset.x - segment.p1_offset.x, 2) + pow(segment.p2_offset.y -
segment.p1_offset.y, 2));
00062             double pointDistance = 15;
00063             int numPoints = segmentLength / pointDistance;
00064             double dx_s = (segment.p2_offset.x - segment.p1_offset.x) / numPoints;
00065             double dy_s = (segment.p2_offset.y - segment.p1_offset.y) / numPoints;
00066             double dx_a = sin(segment.angle);
00067             double dy_a = -cos(segment.angle);
00068
00069             if (dx_a < 0) {
00070                 dx_a = -dx_a;
00071                 dy_a = -dy_a;
00072             }
00073
00074             for (int i_lane = 0; i_lane < road.numLanes; i_lane++) {
00075                 double offset = ((double)i_lane - (double)road.numLanes / 2.0f) * road.width / road.numLanes;
00076                 offset += road.width / (2 * road.numLanes);
00077
00078                 if (numPoints == 0) {
00079                     point point1;
00080                     point1.angle = segment.angle;
00081                     point1.position = sf::Vector2f(segment.p1_offset.x + offset * dx_a, segment.p1_offset.y +
offset * dy_a);
00082
00083                     point point2;
00084                     point2.angle = segment.angle;
00085                     point2.position = sf::Vector2f(segment.p2_offset.x + offset * dx_a, segment.p2_offset.y +
offset * dy_a);
00086
00087                     linkPoints(point1, point2, 2, true);
00088                     continue;
00089                 }
00090
00091                 for (int i = 0; i <= numPoints; i++) {
00092                     point point1;
00093                     point1.position = sf::Vector2f(segment.p1_offset.x + i * dx_s + offset * dx_a,
segment.p1_offset.y + i * dy_s + offset * dy_a);
00094                     point1.angle = segment.angle;
00095
00096                     if (i > 0) {
00097                         for (int i2_lane = 0; i2_lane < road.numLanes; i2_lane++) {
00098                             double offset2 = ((double)i2_lane - (double)road.numLanes / 2.0f) * road.width /
road.numLanes;

```

```

00100         offset2 += road.width / (2 * road.numLanes);
00101
00102         point point2;
00103         point2.position = sf::Vector2f(segment.pl_offset.x + (i - 1) * dx_s + offset2 * dx_a,
00104                                     segment.pl_offset.y + (i - 1) * dy_s + offset2 * dy_a);
00105         point2.angle = segment.angle;
00106
00107         int direction = 2;
00108         double a = normalizeAngle(atan2(dy_a, dx_a));
00109         if (offset == offset2 || (offset >= 0 && offset2 >= 0)) {
00110             if (dy_s >= 0) {
00111                 direction = offset > 0 ? 0 : 1;
00112             } else {
00113                 direction = offset > 0 ? 1 : 0;
00114             }
00115             linkPoints(point1, point2, direction, offset == offset2);
00116         } else {
00117             if (!ROAD_ENABLE_RIGHT_HAND_TRAFFIC) {
00118                 linkPoints(point1, point2, 2, true);
00119             }
00120         }
00121     }
00122 }
00123 }
00124 }
00125 }
00126 }
00127
00128 // Connect the intersections
00129 for (const auto &intersection : intersections) {
00130     for (const auto &roadSegmentId1 : intersection.roadSegmentIds) {
00131         for (const auto &roadSegmentId2 : intersection.roadSegmentIds) {
00132             const auto &road1 = roads[roadSegmentId1.first];
00133             const auto &road2 = roads[roadSegmentId2.first];
00134             const auto &segment1 = road1.segments[roadSegmentId1.second];
00135             const auto &segment2 = road2.segments[roadSegmentId2.second];
00136
00137             // Find the point of the segment2 closest to the intersection
00138             point point1;
00139             point1.angle = segment1.angle;
00140             point1.position = (distance(segment1.pl, intersection.center) < distance(segment1.p2,
intersection.center))
00141                 ? segment1.pl_offset
00142                 : segment1.p2_offset;
00143
00144             point point2;
00145             point2.angle = segment2.angle;
00146             point2.position = (distance(segment2.pl, intersection.center) < distance(segment2.p2,
intersection.center))
00147                 ? segment2.pl_offset
00148                 : segment2.p2_offset;
00149
00150             for (int iL_1 = 0; iL_1 < road1.numLanes; iL_1++) {
00151                 double offset1 = ((double)iL_1 - (double)road1.numLanes / 2.0f) * road1.width /
road1.numLanes;
00152                 offset1 += road1.width / (2 * road1.numLanes);
00153
00154                 for (int iL_2 = 0; iL_2 < road2.numLanes; iL_2++) {
00155                     double offset2 = ((double)iL_2 - (double)road2.numLanes / 2.0f) * road2.width /
road2.numLanes;
00156                     offset2 += road2.width / (2 * road2.numLanes);
00157
00158                     point point1_offset;
00159                     point1_offset.angle = segment1.angle;
00160                     point1_offset.position = sf::Vector2f(point1.position.x + offset1 * sin(segment1.angle),
00161                                                         point1.position.y + offset1 * -cos(segment1.angle));
00162
00163                     point point2_offset;
00164                     point2_offset.angle = segment2.angle;
00165                     point2_offset.position = sf::Vector2f(point2.position.x + offset2 * sin(segment2.angle),
00166                                                         point2.position.y + offset2 * -cos(segment2.angle));
00167
00168                     linkPoints(point1_offset, point2_offset, 2, true);
00169                 }
00170             }
00171         }
00172     }
00173 }
00174
00175 spdlog::info("Graph created with {} points", graphPoints.size());
00176
00177 // Remove all the neighbors that need to turn too much
00178 for (auto &point : graphPoints) {
00179     std::vector<neighbor> newNeighbors;
00180     double distance;
00181     for (auto &neighbor : neighbors[point]) {
00182         double speed = turningRadiusToSpeed(CAR_MIN_TURNING_RADIUS);

```

```

00183     bool can = canLink(point, neighbor.point, speed, &distance);
00184
00185     if (!can)
00186         continue;
00187
00188     while (canLink(point, neighbor.point, speed + 0.1, &distance)) {
00189         speed += 0.1;
00190         if (speed >= CAR_MAX_SPEED_MS) {
00191             speed = CAR_MAX_SPEED_MS;
00192             break;
00193         }
00194     }
00195
00196     if (can) {
00197         neighbor.maxSpeed = speed - 0.1;
00198         neighbor.distance = std::sqrt(std::pow(neighbor.point.position.x - point.position.x, 2) +
00199                                     std::pow(neighbor.point.position.y - point.position.y, 2));
00200
00201         neighbor.turningRadius = turningRadius(speed);
00202         newNeighbors.push_back(neighbor);
00203     }
00204 }
00205
00206 neighbors[point].clear();
00207 for (const auto &neighbor : newNeighbors) {
00208     neighbors[point].push_back(neighbor);
00209 }
00210 }
00211 }
00212
00213 void CityGraph::linkPoints(const point &p, const point &n, int direction, bool subPoints) {
00214     std::vector<double> anglesPoint = {normalizeAngle(p.angle), normalizeAngle(p.angle + M_PI)};
00215     std::vector<double> anglesNeighbor = {normalizeAngle(n.angle), normalizeAngle(n.angle + M_PI)};
00216
00217     point copyPoint = p;
00218     point copyNeighbor = n;
00219
00220     bool isRiP = direction == 2 || direction == 0;
00221     bool isRiN = direction == 2 || direction == 1;
00222     bool isStraight = direction != 2;
00223     isStraight &= (anglesPoint[0] == anglesNeighbor[0] || anglesPoint[0] == anglesNeighbor[1] ||
00224                 anglesPoint[1] == anglesNeighbor[0] || anglesPoint[1] == anglesNeighbor[1]);
00225     isStraight &= subPoints;
00226
00227     if (!isStraight) {
00228         for (const auto &anglePoint : anglesPoint) {
00229             for (const auto &angleNeighbor : anglesNeighbor) {
00230                 copyPoint.angle = anglePoint;
00231                 copyNeighbor.angle = angleNeighbor;
00232
00233                 neighbors[copyPoint].push_back({copyNeighbor, 0, 0, 0, isRiP}); // This fields will be updated
00234             later neighbors[copyNeighbor].push_back({copyPoint, 0, 0, 0, isRiN});
00235
00236             graphPoints.insert(copyPoint);
00237             graphPoints.insert(copyNeighbor);
00238         }
00239     }
00240     return;
00241 }
00242
00243 // Link adding points in the middle
00244 double pointDistance = 3;
00245 double distance = std::sqrt(std::pow(n.position.x - p.position.x, 2) + std::pow(n.position.y -
00246 p.position.y, 2));
00247 int numPoints = distance / pointDistance;
00248 double dx = (n.position.x - p.position.x) / numPoints;
00249 double dy = (n.position.y - p.position.y) / numPoints;
00250
00251 for (const auto &anglePoint : anglesPoint) {
00252     for (const auto &angleNeighbor : anglesNeighbor) {
00253         point previousPoint = p;
00254         previousPoint.angle = anglePoint;
00255
00256         for (int i = 1; i <= numPoints; i++) {
00257             point newPoint;
00258             newPoint.position = sf::Vector2f(p.position.x + i * dx, p.position.y + i * dy);
00259             newPoint.angle = anglePoint;
00260
00261             neighbors[previousPoint].push_back({newPoint, 0, 0, 0, isRiP}); // This fields will be updated
00262             later neighbors[newPoint].push_back({previousPoint, 0, 0, 0, isRiN});
00263
00264             previousPoint = newPoint;
00265             graphPoints.insert(newPoint);
00266         }

```

```

00267
00268     // Add the last point
00269     neighbors[previousPoint].push_back({n, 0, 0, 0, isRiP}); // This fields will be updated later
00270 }
00271 }
00272 }
00273
00274 CityGraph::point CityGraph::getRandomPoint() const {
00275     std::vector<point> graphPointsOut;
00276     for (const auto &point : graphPoints) {
00277         if (point.position.x + CAR_LENGTH < 0 || point.position.x - CAR_LENGTH > width ||
00278             point.position.y + CAR_LENGTH < 0 || point.position.y - CAR_LENGTH > height)
00279             graphPointsOut.push_back(point);
00280     }
00281
00282     auto it = graphPointsOut.begin();
00283     std::random_device rd;
00284     std::mt19937 gen(rd());
00285     std::uniform_int_distribution<> dis(0, graphPointsOut.size() - 1);
00286
00287     std::advance(it, dis(gen));
00288
00289     return *it;
00290 }
00291
00292 bool CityGraph::canLink(const point &point1, const point &point2, double speed, double *distance)
00293     const {
00294     double radius = turningRadius(speed);
00295     ob::DubinsStateSpace space(radius);
00296
00297     ob::State *start = space.allocState();
00298     ob::State *end = space.allocState();
00299
00300     start->as<ob::DubinsStateSpace::StateType>()->setXY(point1.position.x, point1.position.y);
00301     start->as<ob::DubinsStateSpace::StateType>()->setYaw(point1.angle);
00302
00303     end->as<ob::DubinsStateSpace::StateType>()->setXY(point2.position.x, point2.position.y);
00304     end->as<ob::DubinsStateSpace::StateType>()->setYaw(point2.angle);
00305
00306     double total = 0;
00307
00308     // Extract the path
00309     ob::DubinsStateSpace::DubinsPath path = space.dubins(start, end);
00310     for (unsigned int i = 0; i < 3; ++i) // Dubins path has up to 3 segments
00311     {
00312         auto type = path.type_[i];
00313         if (type == ob::DubinsStateSpace::DubinsPathSegmentType::DUBINS_LEFT) {
00314             total += std::abs(path.length_[i]);
00315         } else if (type == ob::DubinsStateSpace::DubinsPathSegmentType::DUBINS_RIGHT) {
00316             total += std::abs(path.length_[i]);
00317         }
00318     }
00319
00320     *distance = space.distance(start, end);
00321     return total < M_PI * 0.75f;
00322 }

```

## 4.31 cityMap.cpp File Reference

[CityMap](#) class implementation.

```

#include <iostream>
#include <math.h>
#include <set>
#include "spdlog/spdlog.h"
#include "tinycl2.h"
#include "cityMap.h"
#include "utils.h"

```

### 4.31.1 Detailed Description

[CityMap](#) class implementation.

This file contains the implementation of the [CityMap](#) class.

Definition in file [cityMap.cpp](#).



```

00087         s.p2 = p;
00088         r.segments.push_back(s);
00089     } else {
00090         segment s;
00091         s.p1 = p;
00092         s.p2 = p;
00093         r.segments.push_back(s);
00094     }
00095
00096     b.points.push_back(p);
00097     g.points.push_back(p);
00098     w.points.push_back(p);
00099     break;
00100 }
00101 node = node->NextSiblingElement("node");
00102 }
00103 nd = nd->NextSiblingElement("nd");
00104 }
00105
00106 // Remove the first segment (it has the same p1 and p2)
00107 r.segments.erase(r.segments.begin());
00108
00109 std::string highwayType;
00110 bool isHighway = false;
00111 bool isBuilding = false;
00112 bool isUnderground = false;
00113 bool isGreenArea = false;
00114 bool isWaterArea = false;
00115 bool widthSet = false;
00116 bool lanesSet = false;
00117 tinyxml2::XMLElement *tag = way->FirstChildElement("tag");
00118 while (tag) {
00119     if (strcmp(tag->Attribute("k"), "width") == 0) {
00120         r.width = tag->FloatAttribute("v");
00121         widthSet = true;
00122     } else if (strcmp(tag->Attribute("k"), "lanes") == 0) {
00123         r.numLanes = tag->IntAttribute("v");
00124         lanesSet = true;
00125     } else if (strcmp(tag->Attribute("k"), "highway") == 0) {
00126         highwayType = tag->Attribute("v");
00127         isHighway = true;
00128     } else if (strcmp(tag->Attribute("k"), "building") == 0) {
00129         isBuilding = true;
00130     } else if (strcmp(tag->Attribute("k"), "layer") == 0) {
00131         int layerValue = tag->IntAttribute("v");
00132         if (layerValue < 0) {
00133             isUnderground = true;
00134         }
00135     } else if (strcmp(tag->Attribute("k"), "landuse") == 0) {
00136         if (strcmp(tag->Attribute("v"), "forest") == 0 || strcmp(tag->Attribute("v"), "grass") == 0 ||
00137             strcmp(tag->Attribute("v"), "meadow") == 0) {
00138             isGreenArea = true;
00139             g.type = 0;
00140         }
00141     } else if (strcmp(tag->Attribute("k"), "leisure") == 0) {
00142         if (strcmp(tag->Attribute("v"), "park") == 0 || strcmp(tag->Attribute("v"), "garden") == 0) {
00143             isGreenArea = true;
00144             g.type = 1;
00145         }
00146     } else if (strcmp(tag->Attribute("k"), "waterway") == 0 &&
00147         (strcmp(tag->Attribute("v"), "river") == 0 || strcmp(tag->Attribute("v"), "stream")
00148 == 0 ||
00149         strcmp(tag->Attribute("v"), "canal") == 0)) {
00149         isWaterArea = true;
00150     } else if (strcmp(tag->Attribute("k"), "natural") == 0 &&
00151         (strcmp(tag->Attribute("v"), "water") == 0 || strcmp(tag->Attribute("v"), "wetland")
00152 == 0) ||
00153         strcmp(tag->Attribute("v"), "river") == 0)) {
00153         isWaterArea = true;
00154     } else if (strcmp(tag->Attribute("k"), "water") == 0 &&
00154         (strcmp(tag->Attribute("v"), "lake") == 0 || strcmp(tag->Attribute("v"), "pond") == 0
00155 ||
00156         strcmp(tag->Attribute("v"), "river") == 0)) {
00156         isWaterArea = true;
00157     }
00158     tag = tag->NextSiblingElement("tag");
00159 }
00160 if (!widthSet && !lanesSet) {
00161     r.width = DEFAULT_ROAD_WIDTH;
00162     r.numLanes = r.width / DEFAULT_LANE_WIDTH;
00163 } else if (!widthSet) {
00164     r.width = r.numLanes * DEFAULT_LANE_WIDTH;
00165 } else if (!lanesSet) {
00166     r.numLanes = r.width / DEFAULT_LANE_WIDTH;
00167 }
00168 r.width = std::max(r.width, MIN_ROAD_WIDTH);
00169 r.numLanes = std::max(r.numLanes, 1);
00170

```

```

00171     if (isUnderground) {
00172         way = way->NextSiblingElement("way");
00173         continue;
00174     }
00175     if (isBuilding) {
00176         buildings.push_back(b);
00177         way = way->NextSiblingElement("way");
00178         continue;
00179     }
00180     if (isGreenArea) {
00181         greenAreas.push_back(g);
00182         way = way->NextSiblingElement("way");
00183         continue;
00184     }
00185     if (isWaterArea) {
00186         waterAreas.push_back(w);
00187         way = way->NextSiblingElement("way");
00188         continue;
00189     }
00190     if (!isHighway || excludedHighways.find(highwayType) != excludedHighways.end()) {
00191         way = way->NextSiblingElement("way");
00192         continue;
00193     }
00194     if (includedHighways.find(highwayType) != includedHighways.end()) {
00195         roads.push_back(r);
00196         roadId++;
00197     }
00198     way = way->NextSiblingElement("way");
00199 }
00200
00201
00202 // Convert lat/lon to meters (using the upper-left corner as origin)
00203 sf::Vector2f minXY = latLonToXY(minLatLon.y, minLatLon.x);
00204 sf::Vector2f maxXY = latLonToXY(maxLatLon.y, maxLatLon.x);
00205 for (auto &r : roads) {
00206     for (auto &s : r.segments) {
00207         s.p1 = latLonToXY(s.p1.y, s.p1.x);
00208         s.p2 = latLonToXY(s.p2.y, s.p2.x);
00209
00210         s.p1.x -= minXY.x;
00211         s.p1.y -= minXY.y;
00212         s.p2.x -= minXY.x;
00213         s.p2.y -= minXY.y;
00214
00215         // Symetri to the x-axis
00216         s.p1.y = maxXY.y - minXY.y - s.p1.y;
00217         s.p2.y = maxXY.y - minXY.y - s.p2.y;
00218
00219         s.p1_offset = s.p1;
00220         s.p2_offset = s.p2;
00221
00222         s.angle = std::atan2(s.p2.y - s.p1.y, s.p2.x - s.p1.x);
00223     }
00224 }
00225 for (auto &b : buildings) {
00226     for (auto &p : b.points) {
00227         p = latLonToXY(p.y, p.x);
00228
00229         p.x -= minXY.x;
00230         p.y -= minXY.y;
00231
00232         // Symetri to the x-axis
00233         p.y = maxXY.y - minXY.y - p.y;
00234     }
00235 }
00236 for (auto &g : greenAreas) {
00237     for (auto &p : g.points) {
00238         p = latLonToXY(p.y, p.x);
00239
00240         p.x -= minXY.x;
00241         p.y -= minXY.y;
00242
00243         // Symetri to the x-axis
00244         p.y = maxXY.y - minXY.y - p.y;
00245     }
00246 }
00247 for (auto &w : waterAreas) {
00248     for (auto &p : w.points) {
00249         p = latLonToXY(p.y, p.x);
00250
00251         p.x -= minXY.x;
00252         p.y -= minXY.y;
00253
00254         // Symetri to the x-axis
00255         p.y = maxXY.y - minXY.y - p.y;
00256     }
00257 }

```



```

00258
00259 std::chrono::steady_clock::time_point end = std::chrono::steady_clock::now();
00260 spdlog::info("Roads and buildings loaded ({} ms)",
00261             std::chrono::duration_cast<std::chrono::milliseconds>(end - begin).count());
00262
00263 spdlog::info("Loading intersections ...");
00264
00265 // Intersections are at any roads' points if they are near another one
00266 // First add the intersections for each node point
00267 // Then merge the intersections that are close to each other
00268 intersections.clear();
00269 int intersectionId = 0;
00270
00271 // Add the intersections for each road segment
00272 spdlog::debug("Adding intersections ...");
00273 for (auto r : roads) {
00274     for (int s_id = 0; s_id < (int)r.segments.size(); s_id++) {
00275         segment s = r.segments[s_id];
00276         std::vector<sf::Vector2f> points = {s.p1, s.p2};
00277         for (auto p : points) {
00278             intersection i = {intersectionId++, p, r.width / 2, {}};
00279             i.roadSegmentIds.push_back({r.id, s_id});
00280             intersections.push_back(i);
00281         }
00282     }
00283 }
00284 spdlog::debug("Intersections added");
00285
00286 // Merge the intersections that are close to each other
00287 spdlog::debug("Merging intersections ...");
00288 for (int distCoef = 5; distCoef > 0; distCoef -= 1) {
00289     for (int i = 0; i < (int)intersections.size(); i++) {
00290         for (int j = i + 1; j < (int)intersections.size(); j++) {
00291             bool is_i = intersections[i].roadSegmentIds.size() > intersections[j].roadSegmentIds.size();
00292
00293             if (intersections[i].roadSegmentIds.size() == intersections[j].roadSegmentIds.size()) {
00294                 is_i = intersections[i].id < intersections[j].id;
00295             }
00296
00297             double minSpace = intersections[i].radius + intersections[j].radius;
00298             minSpace /= distCoef;
00299
00300             if (distance(intersections[i].center, intersections[j].center) < minSpace) {
00301                 // Merge the intersections to i or j (depending on is_i)
00302                 int index_from = is_i ? j : i;
00303                 int index_to = is_i ? i : j;
00304
00305                 for (auto &r : intersections[index_from].roadSegmentIds) {
00306                     intersections[index_to].roadSegmentIds.push_back(r);
00307                 }
00308
00309                 intersections.erase(intersections.begin() + index_from);
00310                 i -= 1;
00311                 break;
00312             }
00313         }
00314     }
00315 }
00316 spdlog::debug("Intersections merged");
00317
00318 // Make the road point to be outside the intersection
00319 spdlog::debug("Adding offsets to the roads ...");
00320 for (auto &i : intersections) {
00321     for (auto &roadInfo : i.roadSegmentIds) {
00322         double dx =
00323             roads[roadInfo.first].segments[roadInfo.second].p2.x -
00324             roads[roadInfo.first].segments[roadInfo.second].p1.x;
00325         double dy =
00326             roads[roadInfo.first].segments[roadInfo.second].p2.y -
00327             roads[roadInfo.first].segments[roadInfo.second].p1.y;
00328         double dd = distance({0, 0}, {(float)dx, (float)dy});
00329         dx /= dd;
00330         dy /= dd;
00331
00332         double radius = i.radius;
00333
00334         if (distance(roads[roadInfo.first].segments[roadInfo.second].p1, i.center) <
00335             distance(roads[roadInfo.first].segments[roadInfo.second].p2, i.center)) {
00336             roads[roadInfo.first].segments[roadInfo.second].p1_offset.x = i.center.x + dx * radius;
00337             roads[roadInfo.first].segments[roadInfo.second].p1_offset.y = i.center.y + dy * radius;
00338         } else {
00339             dx = -dx;
00340             dy = -dy;
00341             roads[roadInfo.first].segments[roadInfo.second].p2_offset.x = i.center.x + dx * radius;
00342             roads[roadInfo.first].segments[roadInfo.second].p2_offset.y = i.center.y + dy * radius;
00343         }
00344     }
00345 }

```

```

00343     }
00344     spdlog::debug("Offsets added");
00345
00346     // Remove the intersections that link the same road
00347     spdlog::debug("Removing intersections that link the same road ...");
00348     for (int i = 0; i < (int)intersections.size(); i++) {
00349         if (intersections[i].roadSegmentIds.size() != 2)
00350             continue;
00351
00352         if (intersections[i].roadSegmentIds[0].first == intersections[i].roadSegmentIds[1].first) {
00353             intersections.erase(intersections.begin() + i);
00354             i -= 1;
00355         }
00356     }
00357     spdlog::debug("Intersections removed");
00358
00359     // Log all the intersections and roads
00360     for (auto r : roads) {
00361         spdlog::debug("Road: id={}, width={}, numLanes={}, segments={}", r.id, r.width, r.numLanes,
00362             r.segments.size());
00363     }
00364     for (auto i : intersections) {
00365         spdlog::debug("Intersection: id={}, center=({}, {}), radius={}, roadSegmentIds={}", i.id,
00366             i.center.x, i.center.y,
00367             i.radius, i.roadSegmentIds.size());
00368     }
00369
00370     std::chrono::steady_clock::time_point end2 = std::chrono::steady_clock::now();
00371     spdlog::info("Intersections loaded ({} ms)",
00372         std::chrono::duration_cast<std::chrono::milliseconds>(end2 - end).count());
00373
00374     spdlog::info("Number of roads: {}", roads.size());
00375     spdlog::info("Number of buildings: {}", buildings.size());
00376     spdlog::info("Number of intersections: {}", intersections.size());
00377
00378     spdlog::info("Width: {} m", width);
00379     spdlog::info("Height: {} m", height);
00380
00381     isLoading = true;
00382 }

```

## 4.33 constraintController.cpp File Reference

[ConstraintController](#) class implementation.

```

#include <iostream>
#include <spdlog/spdlog.h>
#include "aStar.h"
#include "dubins.h"

```

### 4.33.1 Detailed Description

[ConstraintController](#) class implementation.

This file contains the implementation of the [ConstraintController](#) class. This class is used to control the constraints of the A\* algorithm. It is used to check if a car can move to a certain point in the graph at a certain time.

Definition in file [constraintController.cpp](#).

## 4.34 constraintController.cpp

[Go to the documentation of this file.](#)

```

00001
00009 #include <iostream>
00010 #include <spdlog/spdlog.h>
00011
00012 #include "aStar.h"
00013 #include "dubins.h"
00014
00015 void ConstraintController::addConstraint(AStar::conflict constraint) {
00016     if (constraint.car < 0) {
00017         spdlog::error("Invalid car index for constraint");
00018         throw std::runtime_error("Invalid car index for constraint");
00019     }
00020
00021     while (constraints.size() <= constraint.car) {
00022         constraints.push_back(std::vector<std::vector<AStar::conflict>>());
00023     }
00024
00025     constraints[constraint.car].push_back(constraint);
00026 }

```

```

00025     while (constraints[constraint.car].size() <= constraint.time) {
00026         constraints[constraint.car].push_back(std::vector<AStar::conflict>());
00027     }
00028
00029     constraints[constraint.car][constraint.time].push_back(constraint);
00030 }
00031
00032 bool ConstraintController::hasConstraint(AStar::conflict constraint) {
00033     if (constraint.car < 0) {
00034         spdlog::error("Invalid car index for constraint");
00035         throw std::runtime_error("Invalid car index for constraint");
00036     }
00037     if (constraints.size() <= constraint.car) {
00038         return false;
00039     }
00040     for (int t = std::max(0, constraint.time - 1);
00041          t < std::min((int)constraints[constraint.car].size(), constraint.time + 1); t++) {
00042         for (auto c : constraints[constraint.car][t]) {
00043             if (c == constraint) {
00044                 return true;
00045             }
00046         }
00047     }
00048     return false;
00049 }
00050
00051
00052 ConstraintController ConstraintController::copy() {
00053     ConstraintController cc;
00054
00055     cc.constraints = constraints;
00056
00057     return cc;
00058 }
00059
00060 ConstraintController ConstraintController::copy(std::vector<int> cars) {
00061     ConstraintController cc;
00062
00063     for (int car : cars) {
00064         if (constraints.size() > car) {
00065             cc.constraints.push_back(constraints[car]);
00066         } else {
00067             cc.constraints.push_back(std::vector<std::vector<AStar::conflict>>());
00068         }
00069     }
00070
00071     return cc;
00072 }
00073
00074 bool ConstraintController::checkConstraints(int car, double speed, double newSpeed, double time,
CityGraph::point from,
                                CityGraph::neighbor to) {
00075
00076     Dubins dubin = Dubins(from, to, speed, newSpeed);
00077     float duration = 2 * to.distance / (speed + newSpeed);
00078
00079     int tMin = std::round(time / SIM_STEP_TIME);
00080     tMin = tMin < 0 ? 0 : tMin;
00081     int tMax = std::round((time + duration) / SIM_STEP_TIME);
00082     if (constraints.size() > car && constraints[car].size() < tMax) {
00083         tMax = constraints[car].size();
00084     }
00085
00086     if (constraints.size() <= car || constraints[car].size() <= tMin) {
00087         return false;
00088     }
00089
00090     double distance = to.distance;
00091     double acc = (std::pow(newSpeed, 2) - std::pow(speed, 2)) / (2 * distance);
00092     auto xFun = [&](double t) { return (0.5 * acc * t * t + speed * t) / distance; };
00093
00094     for (int t = tMin; t < tMax; t += 1) {
00095         bool precise = false;
00096         sf::Vector2f pos = from.position + (to.point.position - from.position) * (float)xFun(t *
SIM_STEP_TIME - time);
00097         CityGraph::point point;
00098         if (constraints[car].size() <= t)
00099             continue;
00100
00101         for (auto c : constraints[car][t]) {
00102             if (precise) {
00103                 if (carConflict(point.position, point.angle, c.point.position, c.point.angle)) {
00104                     return true;
00105                 }
00106             } else {
00107                 sf::Vector2f diff = pos - c.point.position;
00108                 double dist = std::sqrt(diff.x * diff.x + diff.y * diff.y);
00109

```

```

00110         if (dist < 2 * CAR_LENGTH) {
00111             precise = true;
00112             point = dubin.point(t * SIM_STEP_TIME - time);
00113             if (carConflict(point.position, point.angle, c.point.position, c.point.angle)) {
00114                 return true;
00115             }
00116         }
00117     }
00118 }
00119 }
00120
00121 return false;
00122 }

```

## 4.35 dataManager.cpp File Reference

Data manager.

```

#include <filesystem>
#include <fstream>
#include <iostream>
#include <random>
#include <string>
#include <spdlog/spdlog.h>
#include "cityGraph.h"
#include "cityMap.h"
#include "dataManager.h"
#include "manager.h"

```

### 4.35.1 Detailed Description

Data manager.

This file contains the implementation of the [DataManager](#) class.

Definition in file [dataManager.cpp](#).

## 4.36 dataManager.cpp

[Go to the documentation of this file.](#)

```

00001
00007 #include <filesystem>
00008 #include <fstream>
00009 #include <iostream>
00010 #include <random>
00011 #include <string>
00012
00013 #include <spdlog/spdlog.h>
00014
00015 #include "cityGraph.h"
00016 #include "cityMap.h"
00017 #include "dataManager.h"
00018 #include "manager.h"
00019
00020 DataManager::DataManager(std::string filename) {
00021     // Create /data folder if it doesn't exist
00022     if (!std::filesystem::exists("data")) {
00023         spdlog::debug("Creating data folder");
00024         std::filesystem::create_directory("data");
00025     }
00026 }
00027
00028 void DataManager::createData(int numData, int numCarsMin, int numCarsMax, std::string mapName) {
00029     // If numData is less than 1, default to a very high number (as in your original code).
00030     numData = numData < 1 ? INT_MAX : numData;
00031
00032     // Remove file extension from mapName to construct the output filename.
00033     std::string mapNameNoExt = mapName.substr(0, mapName.find_last_of("."));
00034     std::string filename = "data/" + mapNameNoExt + "_" + std::to_string((int)CBS_MAX_SUB_TIME) +
00035         (ROAD_ENABLE_RIGHT_HAND_TRAFFIC ? "_RHT" : "") + "_data.csv";
00036
00037     // Load the city map.
00038     CityMap cityMap;
00039     cityMap.loadFile("assets/map/" + mapName);
00040
00041     // Create the city graph.

```

```

00042 CityGraph cityGraph;
00043 cityGraph.createGraph(cityMap);
00044
00045 // Open the output file in append mode.
00046 std::ofstream file;
00047 file.open(filename, std::ios::app);
00048 if (!file.is_open()) {
00049     spdlog::error("Failed to open file {}", filename);
00050     return;
00051 }
00052
00053 std::mt19937 rng(std::chrono::steady_clock::now().time_since_epoch().count());
00054 std::uniform_int_distribution<int> dist(numCarsMin, numCarsMax);
00055
00056 for (int i = 0; i < numData; i += 1) {
00057     int numCars = dist(rng);
00058
00059     Manager manager(cityGraph, cityMap, false);
00060     auto resData = manager.createCarsCBS(numCars);
00061     if (!resData.first) {
00062         spdlog::warn("Data {}: CBS failed (numCars: {})", i + 1, numCars);
00063         i--;
00064         continue;
00065     }
00066
00067     data validResData = resData.second;
00068
00069     file << validResData.numCars << ";" << validResData.carDensity;
00070     for (auto speed : validResData.carAvgSpeed) {
00071         file << ";" << speed;
00072     }
00073     file << std::endl;
00074
00075     if (numData == INT_MAX) {
00076         spdlog::info("Data {}: numCars: {}, carDensity: {:0>6.5}", i + 1, validResData.numCars,
00077             validResData.carDensity);
00078     } else {
00079         spdlog::info("Data {}: numCars: {}, carDensity: {:0>6.5}", i + 1, numData, validResData.numCars,
00080             validResData.carDensity);
00081     }
00082
00083     file.close();
00084 }

```

## 4.37 dubins.cpp File Reference

[Dubins](#) path implementation.

```
#include "dubins.h"
#include "utils.h"
```

### 4.37.1 Detailed Description

[Dubins](#) path implementation.

This file contains the implementation of the [Dubins](#) class. It is used to calculate the path between two points in the city graph. It will be used to render cars in the city and check for collisions.

Definition in file [dubins.cpp](#).

## 4.38 dubins.cpp

[Go to the documentation of this file.](#)

```

00001
00008 #include "dubins.h"
00009 #include "utils.h"
00010
00011 Dubins::Dubins(CityGraph::point start, CityGraph::neighbor end)
00012     : Dubins(start, end, CAR_MAX_SPEED_MS, CAR_MAX_SPEED_MS) {}
00013
00014 Dubins::Dubins(CityGraph::point start, CityGraph::neighbor end, double startSpeed)
00015     : Dubins(start, end, startSpeed, CAR_MAX_SPEED_MS) {}
00016
00017 // The distance needed to reach the maximum speed
00018 double distanceToMaxSpeed = (std::pow(CAR_MAX_SPEED_MS, 2) - std::pow(startSpeed, 2)) / (2 *
00019     CAR_ACCELERATION);
00019
00020 double dist = distance();
00021 if (dist == 0) {

```

```

00022     this->avgSpeed = CAR_MAX_SPEED_MS;
00023     return;
00024 }
00025
00026 if (dist < distanceToMaxSpeed) {
00027     this->avgSpeed = CAR_MAX_SPEED_MS;
00028 } else {
00029     double avg = (startSpeed + CAR_MAX_SPEED_MS) / 2;
00030     this->avgSpeed = (avg * distanceToMaxSpeed + CAR_MAX_SPEED_MS * (dist - distanceToMaxSpeed)) /
dist;
00031 }
00032 }
00033
00034 Dubins::Dubins(CityGraph::point start, CityGraph::neighbor end, double startSpeed, double endSpeed) {
00035     this->startPoint = start;
00036     this->endPoint = end;
00037     this->startSpeed = startSpeed;
00038     this->endSpeed = endSpeed;
00039     this->avgSpeed = (startSpeed + endSpeed) / 2;
00040
00041     this->space = new ob::DubinsStateSpace(this->endPoint.turningRadius);
00042
00043     ob::RealVectorBounds bounds(2);
00044     space->setBounds(bounds);
00045
00046     this->start = space->allocState();
00047     this->end = space->allocState();
00048
00049     this->start->as<ob::DubinsStateSpace::StateType>()->setXY(start.position.x, start.position.y);
00050     this->start->as<ob::DubinsStateSpace::StateType>()->setYaw(start.angle);
00051
00052     this->end->as<ob::DubinsStateSpace::StateType>()->setXY(end.point.position.x, end.point.position.y);
00053     this->end->as<ob::DubinsStateSpace::StateType>()->setYaw(end.point.angle);
00054 }
00055
00056 Dubins::~Dubins() {
00057     space->freeState(start);
00058     space->freeState(end);
00059     delete space;
00060 }
00061
00062 double Dubins::time() { return this->distance() / avgSpeed; }
00063
00064 CityGraph::point Dubins::point(double time) {
00065     double distance = this->distance();
00066     double acc = (std::pow(endSpeed, 2) - std::pow(startSpeed, 2)) / (2 * distance);
00067     auto xFun = [distance, acc, this](double t) { return (0.5 * acc * t * t + this->startSpeed * t) /
distance; };
00068
00069     ob::State *state = space->allocState();
00070     space->interpolate(start, end, xFun(time), state);
00071
00072     double x = state->as<ob::DubinsStateSpace::StateType>()->getX();
00073     double y = state->as<ob::DubinsStateSpace::StateType>()->getY();
00074     double yaw = state->as<ob::DubinsStateSpace::StateType>()->getYaw();
00075
00076     space->freeState(state);
00077
00078     CityGraph::point point;
00079     point.position = {(float)x, (float)y};
00080     point.angle = yaw;
00081
00082     return point;
00083 }
00084
00085 std::vector<CityGraph::point> Dubins::path() {
00086     std::vector<CityGraph::point> path;
00087     double time = this->time();
00088     for (double t = 0; t < time; t += SIM_STEP_TIME) {
00089         path.push_back(this->point(t));
00090     }
00091
00092     return path;
00093 }
00094
00095 DubinsPath::DubinsPath(std::vector<AStar::node> path) : path_(path) {}
00096
00097 std::vector<CityGraph::point> DubinsPath::path() {
00098     if (pathProcessed_.empty())
00099         process();
00100
00101     return pathProcessed_;
00102 }
00103
00104 void DubinsPath::process() {
00105     pathProcessed_.clear();
00106     double t = 0;

```

```

00107     double prevTime = 0;
00108
00109     for (int i = 1; i < (int)path_.size(); i++) {
00110         AStar::node prevNode = path_[i - 1];
00111         AStar::node node = path_[i];
00112
00113         CityGraph::point start = node.arcFrom.first;
00114         CityGraph::neighbor end = node.arcFrom.second;
00115
00116         Dubins dubins(start, end, prevNode.speed, node.speed);
00117         double time = dubins.time();
00118
00119         if (t >= prevTime + time) {
00120             continue;
00121         }
00122
00123         while (t < prevTime + time) {
00124             pathProcessed_.push_back(dubins.point(t - prevTime));
00125             t += SIM_STEP_TIME;
00126         }
00127
00128         prevTime += time;
00129     }
00130 }

```

## 4.39 fileSelector.cpp File Reference

File selector implementation.

```

#include "fileSelector.h"
#include <filesystem>
#include <iostream>
#include <spdlog/spdlog.h>
#include <termios.h>
#include <unistd.h>
#include <vector>

```

### 4.39.1 Detailed Description

File selector implementation.

This file contains the implementation of the [FileSelector](#) class. It is used to select a file from a folder.

Definition in file [fileSelector.cpp](#).

## 4.40 fileSelector.cpp

[Go to the documentation of this file.](#)

```

00001
00007 #include "fileSelector.h"
00008
00009 #include <filesystem>
00010 #include <iostream>
00011 #include <spdlog/spdlog.h>
00012 #include <termios.h>
00013 #include <unistd.h>
00014 #include <vector>
00015
00016 namespace fs = std::filesystem;
00017
00018 void FileSelector::loadFiles() {
00019     files.clear();
00020     for (const auto &entry : fs::directory_iterator(folderPath)) {
00021         if (entry.is_regular_file() && entry.path().extension() == ".osm") {
00022             files.push_back(entry.path().filename().string());
00023         }
00024     }
00025     std::sort(files.begin(), files.end());
00026 }
00027
00028 char FileSelector::getKeyPress() {
00029     struct termios oldt, newt;
00030     char ch;
00031     tcgetattr(STDIN_FILENO, &oldt);
00032     newt = oldt;
00033     newt.c_lflag &= ~(ICANON | ECHO);
00034     tcsetattr(STDIN_FILENO, TCSANOW, &newt);
00035     ch = getchar();

```

```

00036     tcsetattr(STDIN_FILENO, TCSANOW, &oldt);
00037     return ch;
00038 }
00039
00040 void FileSelector::moveCursorUp() {
00041     if (selectedIndex > 0) {
00042         std::cout << "\033[2K\r" << files[selectedIndex] << std::flush;
00043         selectedIndex--;
00044         std::cout << "\033[A\033[2K\r>" << files[selectedIndex] << std::flush;
00045     }
00046 }
00047
00048 void FileSelector::moveCursorDown() {
00049     if (selectedIndex < files.size() - 1) {
00050         std::cout << "\033[2K\r" << files[selectedIndex] << std::flush;
00051         selectedIndex++;
00052         std::cout << "\033[B\033[2K\r>" << files[selectedIndex] << std::flush;
00053     }
00054 }
00055
00056 void FileSelector::displayFiles() {
00057     std::cout << "Use UP/DOWN arrow keys to navigate, ENTER to select:\n";
00058     for (size_t i = 0; i < files.size(); i++) {
00059         if (i == selectedIndex) {
00060             std::cout << ">" << files[i] << "\n";
00061         } else {
00062             std::cout << " " << files[i] << "\n";
00063         }
00064     }
00065     std::cout << "\033[" << files.size() << "A";
00066 }
00067
00068 std::string FileSelector::selectFile() {
00069     std::cout << "\033[?25l";
00070     if (files.empty()) {
00071         spdlog::error("No .osm files found in the folder: {}", folderPath);
00072         return "";
00073     }
00074
00075     displayFiles();
00076
00077     while (true) {
00078         char key = getKeyPress();
00079         if (key == 27) {
00080             if (getKeyPress() == '[') {
00081                 switch (getKeyPress()) {
00082                     case 'A':
00083                         moveCursorUp();
00084                         break;
00085                     case 'B':
00086                         moveCursorDown();
00087                         break;
00088                 }
00089             }
00090             } else if (key == '\n') {
00091                 std::cout << "\033[" << selectedIndex + 1 << "A\033[2K\r" << std::flush;
00092                 std::cout << "\033[?25h";
00093                 spdlog::info("Selected file: {}", files[selectedIndex]);
00094                 return files[selectedIndex];
00095             }
00096         }
00097     }

```

## 4.41 main.cpp File Reference

Main file.

```

#include "spdlog/spdlog.h"
#include <SFML/Graphics.hpp>
#include "cityMap.h"
#include "config.h"
#include "dataManager.h"
#include "fileSelector.h"
#include "manager.h"
#include "renderer.h"
#include "test.h"

```



### 4.41.1 Detailed Description

Main file.

This file contains the main function of the project. It is used to run the simulation and create data.

Definition in file [main.cpp](#).

## 4.42 main.cpp

[Go to the documentation of this file.](#)

```

00001
00007 #include "spdlog/spdlog.h"
00008 #include <SFML/Graphics.hpp>
00009
00010 #include "cityMap.h"
00011 #include "config.h"
00012 #include "dataManager.h"
00013 #include "fileSelector.h"
00014 #include "manager.h"
00015 #include "renderer.h"
00016 #include "test.h"
00017
00018 int main(int nArgs, char **args) {
00019     srand(time(NULL));
00020     spdlog::set_pattern("[%d-%m-%C %H:%M:%S.%e] [%^%l%$] [thread %t] %v");
00021
00022     if (nArgs < 1) {
00023         spdlog::error("Usage: {} \"data\" [numCarsMin] [numCarsMax] [numData] || {} \"run\" [numCars]",
00024             args[0]);
00025         return 1;
00026     }
00027
00028     bool data = args[1] == std::string("data");
00029     int runNumCars = 10;
00030     int dataNumCarsMin = 10;
00031     int dataNumCarsMax = 15;
00032     int dataNumData = -1;
00033
00034     if (nArgs > 2) {
00035         runNumCars = std::stoi(args[2]);
00036         dataNumCarsMin = std::stoi(args[2]);
00037     }
00038     if (nArgs > 3) {
00039         dataNumCarsMax = std::stoi(args[3]);
00040     }
00041     if (nArgs > 4) {
00042         dataNumData = std::stoi(args[4]);
00043     }
00044
00045     FileSelector fileSelector("assets/map");
00046     std::string mapFile = fileSelector.selectFile();
00047     // std::string mapFile = "small01.osm";
00048
00049     if (ENVIRONMENT == 0 && false) {
00050         spdlog::set_level(spdlog::level::debug);
00051         Test test;
00052         test.runTests();
00053     } else {
00054         spdlog::set_level(spdlog::level::info);
00055     }
00056
00057     if (data) {
00058         spdlog::info("Creating data for map {}, numData: {}, numCarsMin: {}, numCarsMax: {}", mapFile,
00059             dataNumData,
00060             dataNumCarsMin, dataNumCarsMax);
00061
00062         DataManager dataManager(mapFile);
00063         dataManager.createData(dataNumData, dataNumCarsMin, dataNumCarsMax, mapFile);
00064     } else {
00065         spdlog::info("Running simulation for map {}, numCars: {}", mapFile, runNumCars);
00066
00067         CityMap cityMap;
00068         cityMap.loadFile("assets/map/" + mapFile);
00069
00070         CityGraph cityGraph;
00071         cityGraph.createGraph(cityMap);
00072
00073         Manager manager(cityGraph, cityMap, true);
00074         manager.createCarsCBS(runNumCars);
00075
00076         Renderer renderer;
00077         renderer.startRender(cityMap, cityGraph, manager);
00078     }
00079 }
00080
00081

```

```
00078     return 0;
00079 }
```

## 4.43 manager.cpp File Reference

Implementation of the [Manager](#) class.

```
#include "manager.h"
#include "aStar.h"
#include <iostream>
#include <spdlog/spdlog.h>
```

### 4.43.1 Detailed Description

Implementation of the [Manager](#) class.

This file contains the implementation of the [Manager](#) class.

Definition in file [manager.cpp](#).

## 4.44 manager.cpp

[Go to the documentation of this file.](#)

```
00001
00007 #include "manager.h"
00008 #include "aStar.h"
00009
00010 #include <iostream>
00011 #include <spdlog/spdlog.h>
00012
00013 void Manager::createCarsAStar(int numCars) {
00014     if (log)
00015         spdlog::info("Creating {} AStar cars", numCars);
00016     for (int i = 0; i < numCars; i++) {
00017         Car car;
00018         cars.push_back(car);
00019     }
00020
00021     // Create a path for each car (random start and end points)
00022     for (int i = 0; i < numCars; i++) {
00023         bool valid = false;
00024         cars[i].chooseRandomStartEndPath(graph, map);
00025
00026         if (log)
00027             spdlog::info("Car {} assigned path with {} points", i, cars[i].getPath().size());
00028     }
00029 }
00030
00031 void Manager::moveCars() {
00032     for (Car &car : cars) {
00033         car.move();
00034     }
00035 }
00036
00037 void Manager::renderCars(sf::RenderWindow &window) {
00038     for (Car &car : cars) {
00039         car.render(window);
00040     }
00041 }
00042
00043 void Manager::toggleCarDebug(sf::Vector2f mousePos) {
00044     for (Car &car : cars) {
00045         sf::Vector2f carPos = car.getPosition();
00046         double distance = sqrt(pow(mousePos.x - carPos.x, 2) + pow(mousePos.y - carPos.y, 2));
00047         if (distance < 5.0f) {
00048             car.toggleDebug();
00049         }
00050     }
00051 }
```

## 4.45 managerCBS.cpp File Reference

CBS algorithm implementation.

```
#include "manager.h"
#include "renderers.h"
#include "utils.h"
```

```
#include <iostream>
#include <numeric>
#include <spdlog/spdlog.h>
```

#### 4.45.1 Detailed Description

CBS algorithm implementation.

This file contains the implementation of the CBS algorithm. It is used to resolve conflicts between cars.

Definition in file [managerCBS.cpp](#).

#### 4.46 managerCBS.cpp

[Go to the documentation of this file.](#)

```
00001
00007 #include "manager.h"
00008 #include "renderer.h"
00009 #include "utils.h"
00010
00011 #include <iostream>
00012 #include <numeric>
00013 #include <spdlog/spdlog.h>
00014
00015 std::pair<bool, DataManager::data> Manager::createCarsCBS(int numCars) {
00016     this->createCarsAStar(numCars);
00017     this->numCars = numCars;
00018     bool valid = true;
00019
00020     ConstraintController constraints;
00021
00022     if (log)
00023         spdlog::info("Creating {} CBS cars", numCars);
00024
00025     CBSNode node = processCBS(constraints, 0);
00026     if (!node.hasResolved) {
00027         if (log)
00028             spdlog::error("CBS could not resolve all conflicts");
00029         return std::make_pair(false, DataManager::data());
00030     } else {
00031         if (log)
00032             spdlog::info("CBS resolved all conflicts");
00033     }
00034
00035     // Check if conflicts remain
00036     for (int i = 0; i < numCars; i++) {
00037         for (int j = i + 1; j < numCars; j++) {
00038             int tMin = std::min(cars[i].getPath().size(), cars[j].getPath().size());
00039             for (int t = 0; t < tMin; t++) {
00040                 sf::Vector2f diff = cars[i].getPath()[t] - cars[j].getPath()[t];
00041
00042                 double width = graph.getWidth();
00043                 double height = graph.getHeight();
00044                 auto outOfBounds = [&](sf::Vector2f p) {
00045                     return p.x + CAR_LENGTH < 0 || p.y + CAR_LENGTH < 0 || p.x > width + CAR_LENGTH || p.y >
height + CAR_LENGTH;
00046                 };
00047
00048                 if (outOfBounds(cars[i].getPath()[t]) || outOfBounds(cars[j].getPath()[t])) {
00049                     continue;
00050                 }
00051
00052                 if (std::sqrt(diff.x * diff.x + diff.y * diff.y) < CAR_LENGTH * 1.1) {
00053                     if (log)
00054                         spdlog::error("Cars {} and {} still have a conflict at time {} ({{}}, {{}})", i, j, t *
SIM_STEP_TIME,
cars[i].getPath()[t].x, cars[i].getPath()[t].y);
00055                     valid = false;
00056                 }
00057             }
00058         }
00059     }
00060 }
00061
00062 if (!valid) {
00063     return std::make_pair(false, DataManager::data());
00064 }
00065
00066 DataManager::data data;
00067 data.numCars = 0;
00068 data.carAvgSpeed.clear();
00069
```

```

00070     for (int i = 0; i < numCars; i++) {
00071         double avgSpeed = cars[i].getAverageSpeed(graph);
00072         if (avgSpeed <= 0.01)
00073             continue;
00074
00075         data.carAvgSpeed.push_back(avgSpeed);
00076         data.numCars++;
00077     }
00078
00079     if (data.numCars == 0) {
00080         return std::make_pair(false, DataManager::data());
00081     }
00082
00083     data.carDensity = 1000000 * data.numCars / (graph.getWidth() * graph.getHeight());
00084
00085     return std::make_pair(true, data);
00086 }
00087
00088 // Split the node into 2 subnodes
00089 Manager::CBSNode Manager::createSubCBS(CBSNode &node, int subNodeDepth) {
00090     int numCars = (int)node.paths.size();
00091     int numCars1 = numCars / 2;
00092     int numCars2 = numCars - numCars1;
00093
00094     std::vector<Car> cars1;
00095     std::vector<Car> cars2;
00096
00097     std::vector<int> cars1Index;
00098     std::vector<int> cars2Index;
00099
00100     for (int i = 0; i < numCars1; i++) {
00101         cars1.push_back(cars[i]);
00102         cars1Index.push_back(i);
00103     }
00104     for (int i = numCars1; i < numCars; i++) {
00105         cars2.push_back(cars[i]);
00106         cars2Index.push_back(i);
00107     }
00108
00109     ConstraintController constraints1 = node.constraints.copy(cars1Index);
00110     ConstraintController constraints2 = node.constraints.copy(cars2Index);
00111
00112     Manager manager1(graph, map, cars1, log);
00113     Manager manager2(graph, map, cars2, log);
00114
00115     CBSNode node1 = manager1.processCBS(constraints1, subNodeDepth + 1);
00116     if (!node1.hasResolved) {
00117         return node1;
00118     }
00119
00120     // Push all manager1 cars pos to manager2 constraints
00121     for (int i = 0; i < numCars1; i++) {
00122         std::vector<sf::Vector2f> path = node1.paths[i];
00123         for (int j = 0; j < (int)path.size(); j += CBS_PRECISION_FACTOR) {
00124             AStar::conflict conflict;
00125             conflict.point.position = path[j];
00126             conflict.point.angle = 0;
00127             conflict.time = j;
00128
00129             if (conflict.point.position.x < -CAR_LENGTH || conflict.point.position.y < -CAR_LENGTH ||
00130                 conflict.point.position.x > graph.getWidth() + CAR_LENGTH ||
00131                 conflict.point.position.y > graph.getHeight() + CAR_LENGTH) {
00132                 continue;
00133             }
00134
00135             for (int k = 0; k < numCars2; k++) {
00136                 conflict.car = k;
00137                 constraints2.addConstraint(conflict);
00138             }
00139         }
00140     }
00141
00142     CBSNode node2 = manager2.processCBS(constraints2, subNodeDepth + 1);
00143     if (!node2.hasResolved) {
00144         return node2;
00145     }
00146
00147     // Merge the 2 managers
00148     for (int i = 0; i < numCars1; i++) {
00149         node.costs[i] = node1.costs[i];
00150         node.paths[i] = node1.paths[i];
00151         cars[i].assignExistingPath(node1.paths[i]);
00152     }
00153     for (int i = numCars1; i < numCars; i++) {
00154         node.costs[i] = node2.costs[i - numCars1];
00155         node.paths[i] = node2.paths[i - numCars1];
00156         cars[i].assignExistingPath(node2.paths[i - numCars1]);

```

```

00157     }
00158
00159     node.cost = node1.cost + node2.cost;
00160     node.depth = std::max(node1.depth, node2.depth);
00161     node.hasResolved = node1.hasResolved && node2.hasResolved;
00162
00163     return node;
00164 }
00165
00166 Manager::CBSNode Manager::processCBS(ConstraintController constraints, int subNodeDepth) {
00167     std::priority_queue<CBSNode> openSet;
00168
00169     CBSNode startNode;
00170     startNode.paths.resize(numCars);
00171     startNode.constraints = constraints;
00172     startNode.costs.clear();
00173     startNode.costs.resize(numCars);
00174     startNode.cost = 0;
00175     startNode.depth = 0;
00176     startNode.hasResolved = false;
00177
00178     double maxCarCost = 0;
00179
00180     for (int i = 0; i < numCars; i++) {
00181         TimedAStar aStar(cars[i].getStart(), cars[i].getEnd(), graph, &constraints, i);
00182         std::vector<AStar::node> newPath = aStar.findPath();
00183
00184         cars[i].assignPath(newPath);
00185
00186         startNode.paths[i] = cars[i].getPath();
00187
00188         double carCost = cars[i].getPathTime();
00189         startNode.costs[i] = carCost;
00190         startNode.cost += carCost;
00191
00192         maxCarCost = std::max(maxCarCost, carCost);
00193     }
00194
00195     openSet.push(startNode);
00196
00197     // For logs
00198     std::vector<double> meanCosts;
00199     std::vector<double> meanDepths;
00200     std::vector<double> meanTimes;
00201     auto start = std::chrono::system_clock::now();
00202     double clockLastRefresh = 0;
00203     int numNodeProcessed = 0;
00204
00205     // While there are conflicts in the paths, resolve them
00206     while (!openSet.empty()) {
00207         auto duration =
00208             std::chrono::duration_cast<std::chrono::milliseconds>(std::chrono::system_clock::now() -
00209                 start).count() /
00210             1000.0;
00211
00212         numNodeProcessed++;
00213         CBSNode node = openSet.top();
00214         openSet.pop();
00215
00216         if (duration > CBS_MAX_SUB_TIME) {
00217             CBSNode resSub = createSubCBS(node, subNodeDepth);
00218             if (resSub.hasResolved) {
00219                 return resSub;
00220             }
00221
00222             std::vector<std::vector<sf::Vector2f>> paths = node.paths;
00223             double cost = node.cost;
00224             int depth = node.depth;
00225
00226             int car1, car2;
00227             sf::Vector2f p1, p2;
00228
00229             double a1, a2;
00230             int time;
00231             bool conflict = hasConflict(paths, &car1, &car2, &p1, &p2, &a1, &a2, &time);
00232
00233             if (!conflict) {
00234                 for (int i = 0; i < numCars; i++) {
00235                     cars[i].assignExistingPath(node.paths[i]);
00236                 }
00237                 node.hasResolved = true;
00238                 return node;
00239             }
00240
00241             meanCosts.push_back(cost);
00242             meanDepths.push_back(depth);

```

```

00243     meanTimes.push_back(time);
00244
00245     if (clockLastRefresh + LOG_CBS_REFRESHRATE < duration) {
00246         double meanCost = std::accumulate(meanCosts.begin(), meanCosts.end(), 0.0) / meanCosts.size();
00247         double meanDepth = std::accumulate(meanDepths.begin(), meanDepths.end(), 0.0) /
meanDepths.size();
00248         double meanTime = std::accumulate(meanTimes.begin(), meanTimes.end(), 0.0) / meanTimes.size();
00249         meanTime = meanTime * SIM_STEP_TIME;
00250
00251         double remainingTime = (maxCarCost - meanTime) * (duration / meanTime);
00252         double processPerSecond = numNodeProcessed / (duration - clockLastRefresh);
00253
00254         if (log) {
00255             spdlog::info("Node C: {:0>6.5} | D: {:0>6.5} | CT: {:0>6.5} | SD: {} | ET: {}s | "
00256                 "ETR: ~{}s | Processed nodes: ~{:0>4.5}/s",
00257                 meanCost, meanDepth, meanTime, subNodeDepth, (int)duration, (int)remainingTime,
processPerSecond);
00258             std::cout << "\033[A\033[2K\r";
00259         }
00260
00261         clockLastRefresh = duration;
00262         numNodeProcessed = 0;
00263
00264         meanCosts.clear();
00265         meanDepths.clear();
00266         meanTimes.clear();
00267     }
00268
00269     // Resolve conflict
00270     for (int iCar = 0; iCar < 2; iCar++) {
00271         int car = iCar == 0 ? car1 : car2;
00272
00273         AStar::conflict newConflict;
00274         newConflict.point.position = iCar == 0 ? p2 : p1;
00275         newConflict.point.angle = iCar == 0 ? a2 : a1;
00276         newConflict.time = time;
00277         newConflict.car = iCar == 0 ? car1 : car2;
00278
00279         // If already in constraints, skip
00280         if (node.constraints.hasConstraint(newConflict)) {
00281             continue;
00282         }
00283
00284         ConstraintController newConstraints = node.constraints.copy();
00285         newConstraints.addConstraint(newConflict);
00286
00287         TimedAStar aStar(cars[car].getStart(), cars[car].getEnd(), graph, &newConstraints, car);
00288         std::vector<AStar::node> newPath = aStar.findPath();
00289
00290         if (newPath.empty()) {
00291             continue;
00292         }
00293
00294         cars[car].assignPath(newPath);
00295         double carOldCost = node.costs[car];
00296         double carNewCost = cars[car].getPathTime();
00297
00298         CBSNode newNode;
00299         newNode.paths = paths;
00300         newNode.paths[car] = cars[car].getPath();
00301         newNode.constraints = newConstraints;
00302         newNode.costs = node.costs;
00303         newNode.costs[car] = carNewCost;
00304         newNode.cost = cost - carOldCost + carNewCost;
00305         newNode.depth = depth + 1;
00306         newNode.hasResolved = false;
00307
00308         newNode.cost = 0;
00309         for (int i = 0; i < numCars; i++) {
00310             newNode.cost += newNode.costs[i];
00311         }
00312
00313         // hasConflict(newNode.paths, &car1, &car2, &p1, &p2, &a1, &a2, &time);
00314         // newNode.cost /= time;
00315
00316         // newNode.cost = 1 / (double)time;
00317
00318         openSet.push(newNode);
00319     }
00320 }
00321
00322     return startNode;
00323 }
00324
00325 bool Manager::hasConflict(std::vector<std::vector<sf::Vector2f> paths, int *car1, int *car2,
sf::Vector2f *p1,
00326                         sf::Vector2f *p2, double *a1, double *a2, int *time) {

```

```

00327     int maxPathLength = 0;
00328     int numCars = (int)paths.size();
00329     for (int i = 0; i < numCars; i++) {
00330         maxPathLength = std::max(maxPathLength, (int)paths[i].size());
00331     }
00332
00333     double width = graph.getWidth();
00334     double height = graph.getHeight();
00335     auto outOfBounds = [&](sf::Vector2f p) {
00336         return p.x + CAR_LENGTH < 0 || p.y + CAR_LENGTH < 0 || p.x - CAR_LENGTH > width || p.y -
CAR_LENGTH > height;
00337     };
00338
00339     for (int t = 0; t < maxPathLength; t += CBS_PRECISION_FACTOR) {
00340         for (int i = 0; i < numCars; i++) {
00341             if (t >= (int)paths[i].size() - 1 || outOfBounds(paths[i][t]))
00342                 continue;
00343             for (int j = i + 1; j < numCars; j++) {
00344                 if (t >= (int)paths[j].size() - 1 || outOfBounds(paths[j][t]))
00345                     continue;
00346
00347                 sf::Vector2f diff = paths[i][t] - paths[j][t];
00348                 if (std::sqrt(diff.x * diff.x + diff.y * diff.y) < CAR_LENGTH * 1.1) {
00349                     *car1 = i;
00350                     *car2 = j;
00351                     *p1 = paths[i][t];
00352                     *p2 = paths[j][t];
00353                     *a1 = std::atan2(paths[i][t + 1].y - paths[i][t].y, paths[i][t + 1].x - paths[i][t].x);
00354                     *a2 = std::atan2(paths[j][t + 1].y - paths[j][t].y, paths[j][t + 1].x - paths[j][t].x);
00355                     *time = t;
00356                     return true;
00357                 }
00358             }
00359         }
00360     }
00361     return false;
00362 }
00363 }

```

## 4.47 renderer.cpp File Reference

Implementation of the [Renderer](#) class.

```

#include <algorithm>
#include <iostream>
#include <random>
#include <vector>
#include <ompl/base/State.h>
#include <ompl/base/StateSpace.h>
#include <ompl/base/spaces/DubinsStateSpace.h>
#include <ompl/geometric/SimpleSetup.h>
#include <ompl/geometric/planners/rrt/RRT.h>
#include <spdlog/spdlog.h>
#include "aStar.h"
#include "config.h"
#include "renderer.h"
#include "utils.h"

```

### 4.47.1 Detailed Description

Implementation of the [Renderer](#) class.

This file contains the implementation of the [Renderer](#) class.

Definition in file [renderer.cpp](#).

## 4.48 renderer.cpp

[Go to the documentation of this file.](#)

```

00001
00007 #include <algorithm>
00008 #include <iostream>
00009 #include <random>
00010 #include <vector>

```

```

00011
00012 #include <ompl/base/State.h>
00013 #include <ompl/base/StateSpace.h>
00014 #include <ompl/base/spaces/DubinsStateSpace.h>
00015 #include <ompl/geometric/SimpleSetup.h>
00016 #include <ompl/geometric/planners/rrt/RRT.h>
00017 #include <spdlog/spdlog.h>
00018
00019 #include "aStar.h"
00020 #include "config.h"
00021 #include "renderer.h"
00022 #include "utils.h"
00023
00024 namespace ob = ompl::base;
00025
00026 void Renderer::startRender(const CityMap &cityMap, const CityGraph &cityGraph, Manager &manager) {
00027     window.create(sf::VideoMode(SCREEN_WIDTH, SCREEN_HEIGHT), "City Map");
00028
00029     // Set the view to the center of the city map, allowing some basic camera movement
00030     // Arrow to move the camera, + and - to zoom in and out
00031     double height = cityMap.getHeight();
00032     double width = cityMap.getWidth();
00033     sf::View view(sf::FloatRect(0, 0, width, height));
00034     // Reset view function
00035     auto resetView = [&]() {
00036         double screenRatio = window.getSize().x / (double)window.getSize().y;
00037         double cityRatio = width / height;
00038         view.setCenter(width / 2, height / 2);
00039         if (screenRatio > cityRatio) {
00040             view.setSize(height * screenRatio, height);
00041         } else {
00042             view.setSize(width, width / screenRatio);
00043         }
00044         window.setView(view);
00045     };
00046
00047     resetView();
00048     time = 0;
00049
00050     sf::Clock clockCars;
00051     bool speedUp = false;
00052     bool pause = true;
00053
00054     while (true) {
00055         sf::Event event;
00056         while (window.pollEvent(event)) {
00057             if (event.type == sf::Event::Closed) {
00058                 window.close();
00059                 return;
00060             }
00061
00062             if (event.type == sf::Event::MouseButtonPressed) {
00063                 if (event.mouseButton.button == sf::Mouse::Left) {
00064                     sf::Vector2f mousePos = window.mapPixelToCoords(sf::Mouse::getPosition(window));
00065                     manager.toggleCarDebug(mousePos);
00066                 }
00067             }
00068
00069             if (event.type == sf::Event::KeyPressed) {
00070                 if (event.key.code == sf::Keyboard::Escape) {
00071                     window.close();
00072                     return;
00073                 }
00074                 if (event.key.code == sf::Keyboard::Up) {
00075                     view.move(0, -height * MOVE_SPEED);
00076                 }
00077                 if (event.key.code == sf::Keyboard::Down) {
00078                     view.move(0, height * MOVE_SPEED);
00079                 }
00080                 if (event.key.code == sf::Keyboard::Left) {
00081                     view.move(-width * MOVE_SPEED, 0);
00082                 }
00083                 if (event.key.code == sf::Keyboard::Right) {
00084                     view.move(width * MOVE_SPEED, 0);
00085                 }
00086                 if (event.key.code == sf::Keyboard::Equal) {
00087                     view.zoom(1.0f - ZOOM_SPEED);
00088                 }
00089                 if (event.key.code == sf::Keyboard::Dash) {
00090                     view.zoom(1.0f + ZOOM_SPEED);
00091                 }
00092                 if (event.key.code == sf::Keyboard::R) {
00093                     resetView();
00094                     spdlog::debug("View reset");
00095                 }
00096                 if (event.key.code == sf::Keyboard::D) {
00097                     debug = !debug;

```



```

00098         spdlog::debug("Debug mode: {}", debug);
00099     }
00100     if (event.key.code == sf::Keyboard::S) {
00101         speedUp = !speedUp;
00102     }
00103     if (event.key.code == sf::Keyboard::P) {
00104         pause = !pause;
00105     }
00106 }
00107
00108 // If resizing the window, reset the view
00109 if (event.type == sf::Event::Resized) {
00110     resetView();
00111 }
00112 }
00113
00114 window.setView(view);
00115 window.clear(sf::Color(247, 246, 242));
00116 renderCityMap(cityMap);
00117 renderManager(manager);
00118 if (!pause) {
00119     if (clockCars.getElapsedTime().asSeconds() > SIM_STEP_TIME ||
00120         (speedUp && clockCars.getElapsedTime().asSeconds() > SIM_STEP_TIME / 5)) {
00121         time += SIM_STEP_TIME;
00122         manager.moveCars();
00123         clockCars.restart();
00124     }
00125 }
00126 if (debug) {
00127     renderCityGraph(cityGraph, view);
00128 }
00129 // Remove outside the border (draw blank)
00130 sf::RectangleShape rectangle(sf::Vector2f(width, height));
00131 rectangle.setFillColor(sf::Color(247, 246, 242));
00132
00133 float w = width;
00134 float h = height;
00135
00136 std::vector<sf::Vector2f> border = {{-w, -h}, {0, -h}, {w, -h}, {w, 0}, {w, h}, {0, h}, {-w, h},
00137 {-w, 0}};
00138 for (auto b : border) {
00139     rectangle.setPosition(b);
00140     window.draw(rectangle);
00141 }
00142 renderTime();
00143 window.display();
00144 }
00145 }
00146
00147 void Renderer::renderCityMap(const CityMap &cityMap) {
00148     // Draw buildings
00149     std::vector<sf::Color> randomBuildingColors = {
00150         sf::Color(233, 234, 232), sf::Color(238, 231, 210), sf::Color(230, 229, 226), sf::Color(236,
00151 234, 230),
00152         sf::Color(230, 223, 216), sf::Color(230, 234, 236), sf::Color(210, 215, 222)};
00153
00154     std::vector<sf::Color> greenAreaColor = {sf::Color(184, 230, 144), sf::Color(213, 240, 193)};
00155     sf::Color waterColor(139, 214, 245);
00156
00157     auto greenAreas = cityMap.getGreenAreas();
00158     for (int i = 0; i < (int)greenAreas.size(); i++) {
00159         const auto &greenArea = greenAreas[i];
00160         auto points = greenArea.points;
00161         sf::ConvexShape convex;
00162         convex.setPointCount(points.size());
00163         for (size_t i = 0; i < points.size(); i++) {
00164             convex.setPoint(i, sf::Vector2f(points[i].x, points[i].y));
00165         }
00166         convex.setFillColor(greenAreaColor[greenArea.type]);
00167         window.draw(convex);
00168     }
00169
00170     auto waterAreas = cityMap.getWaterAreas();
00171     for (int i = 0; i < (int)waterAreas.size(); i++) {
00172         const auto &waterArea = waterAreas[i];
00173         auto points = waterArea.points;
00174         sf::ConvexShape convex;
00175         convex.setPointCount(points.size());
00176         for (size_t i = 0; i < points.size(); i++) {
00177             convex.setPoint(i, sf::Vector2f(points[i].x, points[i].y));
00178         }
00179         convex.setFillColor(waterColor);
00180         window.draw(convex);
00181     }
00182 }

```

```

00183     }
00184
00185     auto buildings = cityMap.getBuildings();
00186     for (int i = 0; i < (int)buildings.size(); i++) {
00187         const auto &building = buildings[i];
00188         auto points = building.points;
00189         sf::ConvexShape convex;
00190         convex.setPointCount(points.size());
00191         for (size_t i = 0; i < points.size(); i++) {
00192             convex.setPoint(i, sf::Vector2f(points[i].x, points[i].y));
00193         }
00194         convex.setFillColor(randomBuildingColors[i % randomBuildingColors.size()]);
00195
00196         window.draw(convex);
00197     }
00198
00199     // Draw roads
00200     sf::Color roadColor(194, 201, 202);
00201     for (const auto &road : cityMap.getRoads()) {
00202         for (const auto &segment : road.segments) {
00203             sf::Vector2f basedP1(segment.p1.x, segment.p1.y);
00204             sf::Vector2f basedP2(segment.p2.x, segment.p2.y);
00205
00206             double angle = segment.angle;
00207
00208             sf::Vector2f widthVec(sin(angle), -cos(angle));
00209             widthVec *= (float)road.width / 2;
00210
00211             sf::Vector2f p1 = basedP1 + widthVec;
00212             sf::Vector2f p2 = basedP1 - widthVec;
00213             sf::Vector2f p3 = basedP2 - widthVec;
00214             sf::Vector2f p4 = basedP2 + widthVec;
00215
00216             sf::ConvexShape convex;
00217             convex.setPointCount(4);
00218             convex.setPoint(0, p1);
00219             convex.setPoint(1, p2);
00220             convex.setPoint(2, p3);
00221             convex.setPoint(3, p4);
00222
00223             convex.setFillColor(roadColor);
00224
00225             window.draw(convex);
00226
00227             // Draw a circle at the start end end of the road (for filling the gap)
00228             double radius = road.width / 2;
00229             sf::CircleShape circle(radius);
00230             circle.setFillColor(roadColor);
00231             circle.setPosition(basedP1.x - radius, basedP1.y - radius);
00232             window.draw(circle);
00233             circle.setPosition(basedP2.x - radius, basedP2.y - radius);
00234             window.draw(circle);
00235         }
00236     }
00237
00238     // Draw intersections
00239     if (debug) {
00240         for (const auto &intersection : cityMap.getIntersections()) {
00241             double radius = intersection.radius;
00242             sf::CircleShape circle(radius);
00243             circle.setFillColor(sf::Color(0, 255, 0, 50));
00244             circle.setPosition(intersection.center.x - radius, intersection.center.y - radius);
00245             window.draw(circle);
00246         }
00247     }
00248 }
00249
00250 void Renderer::renderCityGraph(const CityGraph &cityGraph, const sf::View &view) {
00251     std::unordered_set<CityGraph::point> graphPoints = cityGraph.getGraphPoints();
00252     std::unordered_map<CityGraph::point, std::vector<CityGraph::neighbor> neighbors =
cityGraph.getNeighbors();
00253
00254     // Draw a line between each point and its neighbors
00255     for (const auto &point : graphPoints) {
00256         for (const auto &neighbor : neighbors[point]) {
00257             if (!neighbor.isRightWay)
00258                 continue;
00259
00260             double radius = turningRadius(neighbor.maxSpeed);
00261             auto space = ob::DubinsStateSpace(radius);
00262             ob::RealVectorBounds bounds(2);
00263             space.setBounds(bounds);
00264
00265             // Draw only if one of the points is inside the view
00266             sf::Vector2f viewCenter = view.getCenter();
00267             sf::Vector2f viewSize = view.getSize();
00268             sf::Vector2f viewMin = viewCenter - viewSize / 2.0f;

```

```

00269     sf::Vector2f viewMax = viewCenter + viewSize / 2.0f;
00270
00271     if (point.position.x < viewMin.x && neighbor.point.position.x < viewMin.x) {
00272         continue;
00273     }
00274     if (point.position.x > viewMax.x && neighbor.point.position.x > viewMax.x) {
00275         continue;
00276     }
00277
00278     ob::State *start = space.allocState();
00279     ob::State *end = space.allocState();
00280
00281     start->as<ob::DubinsStateSpace::StateType>()->setXY(point.position.x, point.position.y);
00282     start->as<ob::DubinsStateSpace::StateType>()->setYaw(point.angle);
00283
00284     end->as<ob::DubinsStateSpace::StateType>()->setXY(neighbor.point.position.x,
neighbor.point.position.y);
00285     end->as<ob::DubinsStateSpace::StateType>()->setYaw(neighbor.point.angle);
00286
00287     // Draw the Dubins curve
00288     double step = CELL_SIZE / 2.0f;
00289     double distance = space.distance(start, end);
00290     int numSteps = distance / step;
00291     sf::Vector2f lastPosition;
00292     sf::Color randomColor = sf::Color(rand() % 255, rand() % 255, rand() % 255, 60);
00293
00294     for (int k = 0; k < numSteps; k++) {
00295         if (k == 0) {
00296             lastPosition = {point.position.x, point.position.y};
00297             continue;
00298         }
00299
00300         ob::State *state = space.allocState();
00301         space.interpolate(start, end, (double)k / (double)numSteps, state);
00302
00303         double x = state->as<ob::DubinsStateSpace::StateType>()->getX();
00304         double y = state->as<ob::DubinsStateSpace::StateType>()->getY();
00305
00306         double distance = std::sqrt(std::pow(x - lastPosition.x, 2) + std::pow(y - lastPosition.y,
2));
00307         double angle = atan2(y - lastPosition.y, x - lastPosition.x) * 180 / M_PI;
00308
00309         // Draw an arrow between the points
00310         drawArrow(window, lastPosition, angle, distance * 0.9, distance * 0.9 / 2, randomColor,
false);
00311
00312         lastPosition = {(float)x, (float)y};
00313     }
00314
00315     continue;
00316     // Write the speed of the point
00317     sf::Text text;
00318     sf::Font font;
00319     font.loadFromFile("assets/fonts/arial.ttf");
00320     text.setFont(font);
00321     text.setString(std::to_string((int)(neighbor.maxSpeed * 3.6f)) + " km/h");
00322     text.setCharacterSize(24);
00323     text.setFillColor(sf::Color::Black);
00324     text.setOutlineColor(sf::Color::White);
00325     text.setOutlineThickness(1.0f);
00326     text.setPosition(point.position * 0.2f + neighbor.point.position * 0.8f);
00327     text.setScale(0.02f, 0.02f);
00328     text.setOrigin(text.getLocalBounds().width / 2.0f, text.getLocalBounds().height / 2.0f);
00329     window.draw(text);
00330 }
00331
00332 // Draw a dot at each points
00333 double size = 0.3;
00334 sf::CircleShape circle(size);
00335 circle.setFillColor(sf::Color(255, 0, 0, 70));
00336 circle.setPosition(point.position.x - size, point.position.y - size);
00337 window.draw(circle);
00338 }
00339 }
00340
00341 void Renderer::renderManager(Manager &manager) { manager.renderCars(window); }
00342
00343 void Renderer::renderTime() {
00344     // At the top right corner of the view (keep the same size even if the view is resized)
00345     sf::Text text;
00346     sf::Font font = loadFont();
00347     sf::Vector2f viewSize = window.getView().getSize();
00348     text.setFont(font);
00349     text.setCharacterSize(24);
00350     text.setFillColor(sf::Color::White);
00351     text.setPosition(window.getView().getCenter() + sf::Vector2f(viewSize.x / 2, -viewSize.y / 2) +
sf::Vector2f(-viewSize.x * 0.01f, viewSize.y * 0.01f));
00352

```

```

00353     text.setString(std::to_string((int)time) + " s");
00354     text.setOutlineColor(sf::Color::Black);
00355     text.setOutlineThickness(1.0f);
00356     text.scale(viewSize.x * 0.001f, viewSize.x * 0.001f);
00357     text.setOrigin(text.getLocalBounds().width, 0);
00358     window.draw(text);
00359 }

```

## 4.49 test.cpp File Reference

A file for testing the project.

```

#include "test.h"
#include "spdlog/spdlog.h"
#include "tinyxml2.h"
#include <SFML/Graphics.hpp>

```

### 4.49.1 Detailed Description

A file for testing the project.

Definition in file [test.cpp](#).

## 4.50 test.cpp

[Go to the documentation of this file.](#)

```

00001
00005 #include "test.h"
00006 #include "spdlog/spdlog.h"
00007 #include "tinyxml2.h"
00008 #include <SFML/Graphics.hpp>
00009
00010 void Test::runTests() {
00011     testSpdlog();
00012     testTinyXML2();
00013     testSFML();
00014 }
00015
00016 void Test::testSpdlog() {
00017     try {
00018         spdlog::debug("Testing spdlog...");
00019         spdlog::debug("spdlog is working as expected.");
00020     } catch (const std::exception &e) {
00021         throw std::runtime_error("spdlog is not working as expected.");
00022     }
00023 }
00024
00025 void Test::testTinyXML2() {
00026     try {
00027         spdlog::debug("Testing TinyXML2...");
00028         tinyxml2::XMLDocument xmlDoc;
00029         xmlDoc.Parse("<root></root>");
00030         if (xmlDoc.Error()) {
00031             spdlog::error("TinyXML2 is not working as expected.");
00032             throw std::runtime_error("TinyXML2 is not working as expected.");
00033         }
00034         spdlog::debug("TinyXML2 is working as expected.");
00035     } catch (const std::exception &e) {
00036         spdlog::error("TinyXML2 is not working as expected.");
00037         throw std::runtime_error("TinyXML2 is not working as expected.");
00038     }
00039 }
00040
00041 void Test::testSFML() {
00042     try {
00043         spdlog::debug("Testing SFML...");
00044         sf::RenderWindow window(sf::VideoMode(100, 100), "Test");
00045         if (!window.isOpen()) {
00046             spdlog::error("SFML is not working as expected.");
00047             throw std::runtime_error("SFML is not working as expected.");
00048         }
00049         window.close();
00050         spdlog::debug("SFML is working as expected.");
00051     } catch (const std::exception &e) {
00052         spdlog::error("SFML is not working as expected.");
00053         throw std::runtime_error("SFML is not working as expected.");
00054     }
00055 }

```

## 4.51 timedAStar.cpp File Reference

Timed A\* algorithm implementation.

```
#include "aStar.h"
#include "config.h"
#include "dubins.h"
#include "utils.h"
#include <spdlog/spdlog.h>
#include <unordered_set>
```

### 4.51.1 Detailed Description

Timed A\* algorithm implementation.

This file contains the implementation of the Timed A\* algorithm. It is used to find the shortest path between two points in a graph with time constraints.

Definition in file [timedAStar.cpp](#).

## 4.52 timedAStar.cpp

[Go to the documentation of this file.](#)

```
00001
00008 #include "aStar.h"
00009 #include "config.h"
00010 #include "dubins.h"
00011 #include "utils.h"
00012
00013 #include <spdlog/spdlog.h>
00014 #include <unordered_set>
00015
00016 TimedAStar::TimedAStar(CityGraph::point start, CityGraph::point end, const CityGraph &cityGraph,
00017                       ConstraintController *conflicts, int carIndex) {
00018     this->start.point = start;
00019     this->start.speed = 0;
00020     this->end.point = end;
00021     this->end.speed = 0;
00022     this->graph = cityGraph;
00023     this->conflicts = conflicts;
00024     this->carIndex = carIndex;
00025 }
00026
00027 void TimedAStar::process() {
00028     path.clear();
00029
00030     std::unordered_map<AStar::node, AStar::node> cameFrom;
00031     std::unordered_map<AStar::node, double> gScore;
00032     std::unordered_map<AStar::node, double> fScore;
00033
00034     auto heuristic = [&](const AStar::node &a) {
00035         sf::Vector2f diff = end.point.position - a.point.position;
00036         double distance = std::sqrt(diff.x * diff.x + diff.y * diff.y);
00037         return distance / CAR_MAX_SPEED_MS;
00038     };
00039     CityGraph::neighbor end_;
00040     end_.point = end.point;
00041     end_.maxSpeed = CAR_MAX_SPEED_MS;
00042     end_.turningRadius = CAR_MIN_TURNING_RADIUS;
00043     Dubins dubins(a.point, end_, CAR_MAX_SPEED_MS, CAR_MAX_SPEED_MS);
00044     return dubins.time();
00045 };
00046 auto compare = [&](const AStar::node &a, const AStar::node &b) { return fScore[a] > fScore[b]; };
00047
00048 std::priority_queue<AStar::node, std::vector<AStar::node>, decltype(compare)> openSet(compare);
00049 std::unordered_set<AStar::node> isInOpenSet;
00050
00051 openSet.push(start);
00052 gScore[start] = 0;
00053 fScore[start] = heuristic(start);
00054
00055 auto neighbors = graph.getNeighbors();
00056
00057 int nbIterations = 0;
00058 while (!openSet.empty() && nbIterations++ < 1e5) {
00059     AStar::node current = openSet.top();
00060     openSet.pop();
00061     isInOpenSet.erase(current);
00062
00063     if (current.point == end.point) {
```

```

00064     AStar::node currentCopy = current;
00065
00066     while (!(currentCopy == start)) {
00067         path.push_back(currentCopy);
00068         currentCopy = cameFrom[currentCopy];
00069     }
00070     path.push_back(currentCopy);
00071     std::reverse(path.begin(), path.end());
00072     processed = true;
00073     break;
00074 }
00075
00076 for (const auto &neighborGraphPoint : neighbors[current.point]) {
00077     if (current.speed > neighborGraphPoint.maxSpeed)
00078         continue;
00079
00080     if (!neighborGraphPoint.isRightWay && ROAD_ENABLE_RIGHT_HAND_TRAFFIC)
00081         continue;
00082
00083     std::vector<double> newSpeeds;
00084     newSpeeds.push_back(current.speed);
00085
00086     double distance = neighborGraphPoint.distance;
00087     double nSpeedAcc = std::sqrt(std::pow(current.speed, 2) + 2 * CAR_ACCELERATION * distance);
00088     double nSpeedDec = std::sqrt(std::pow(current.speed, 2) - 2 * CAR_DECELERATION * distance);
00089
00090     auto push = [&](double nSpeed) {
00091         int numSpeedDiv = 5;
00092         for (int i = 1; i < numSpeedDiv + 1; i++) {
00093             double s = (current.speed + nSpeed - current.speed) * i / numSpeedDiv;
00094             if (s < SPEED_RESOLUTION)
00095                 continue;
00096             newSpeeds.push_back(s);
00097         }
00098     };
00099
00100     if (nSpeedAcc > neighborGraphPoint.maxSpeed && current.speed < neighborGraphPoint.maxSpeed) {
00101         push(neighborGraphPoint.maxSpeed);
00102         // newSpeeds.push_back(neighborGraphPoint.maxSpeed);
00103         // newSpeeds.push_back((current.speed + neighborGraphPoint.maxSpeed) / 2);
00104     } else if (nSpeedAcc < neighborGraphPoint.maxSpeed) {
00105         push(nSpeedAcc);
00106         // newSpeeds.push_back(nSpeedAcc);
00107         // newSpeeds.push_back((current.speed + nSpeedAcc) / 2);
00108     }
00109
00110     if (nSpeedDec == nSpeedDec && std::isfinite(nSpeedDec)) {
00111         if (nSpeedDec < 0 && current.speed > 0) {
00112             push(0);
00113             // newSpeeds.push_back(0);
00114             // newSpeeds.push_back((current.speed + 0) / 2);
00115         } else if (nSpeedDec >= 0) {
00116             push(nSpeedDec);
00117             // newSpeeds.push_back(nSpeedDec);
00118             // newSpeeds.push_back((current.speed + nSpeedDec) / 2);
00119         }
00120     }
00121
00122     AStar::node neighbor;
00123     neighbor.point = neighborGraphPoint.point;
00124     neighbor.arcFrom = {current.point, neighborGraphPoint};
00125     if (distance == 0) {
00126         neighbor.speed = current.speed;
00127         if (gScore.find(neighbor) == gScore.end() || gScore[current] < gScore[neighbor]) {
00128             cameFrom[neighbor] = current;
00129             gScore[neighbor] = gScore[current];
00130             fScore[neighbor] = gScore[neighbor] + heuristic(neighbor);
00131
00132             if (isInOpenSet.find(neighbor) == isInOpenSet.end()) {
00133                 openSet.push(neighbor);
00134
00135                 isInOpenSet.insert(neighbor);
00136             }
00137         }
00138         continue;
00139     }
00140
00141     for (const auto &newSpeed : newSpeeds) {
00142         if (newSpeed > CAR_MAX_SPEED_MS || newSpeed > neighborGraphPoint.maxSpeed || newSpeed < 0)
00143             continue;
00144
00145         if (newSpeed == current.speed && newSpeed == 0)
00146             continue;
00147
00148         neighbor.speed = newSpeed;
00149
00150         double duration = 2 * distance / (current.speed + newSpeed);

```

```

00151         double tentativeGScore = gScore[current] + duration;
00152
00153         double t = gScore[current];
00154
00155         if (conflicts != nullptr &&
00156             conflicts->checkConstraints(carIndex, current.speed, newSpeed, t, current.point,
neighborGraphPoint))
00157             continue;
00158
00159         if (gScore.find(neighbor) == gScore.end() || tentativeGScore < gScore[neighbor]) {
00160             cameFrom[neighbor] = current;
00161             gScore[neighbor] = tentativeGScore;
00162             fScore[neighbor] = gScore[neighbor] + heuristic(neighbor);
00163
00164             if (isInOpenSet.find(neighbor) == isInOpenSet.end()) {
00165                 openSet.push(neighbor);
00166                 isInOpenSet.insert(neighbor);
00167             }
00168         }
00169     }
00170 }
00171 }
00172 }

```

## 4.53 utils.cpp File Reference

Utility functions implementation.

```

#include <spdlog/spdlog.h>
#include "car.h"
#include "utils.h"

```

### Functions

- sf::Font [loadFont](#) ()  
*Load a font.*
- bool [carsCollided](#) (Car car1, Car car2, int time)
- bool [carConflict](#) (sf::Vector2f carPos, double carAngle, sf::Vector2f confPos, double confAngle)  
*Check if two cars have a conflict.*

#### 4.53.1 Detailed Description

Utility functions implementation.

Definition in file [utils.cpp](#).

#### 4.53.2 Function Documentation

##### carConflict()

```

bool carConflict (
    sf::Vector2f carPos,
    double carAngle,
    sf::Vector2f confPos,
    double confAngle)

```

Check if two cars have a conflict.

##### Parameters

<i>carPos</i>	The position of the car
<i>carAngle</i>	The angle of the car
<i>confPos</i>	The position of the conflicting car
<i>confAngle</i>	The angle of the conflicting car

**Returns**

If the cars have a conflict

Definition at line 49 of file [utils.cpp](#).

**carsCollided()**

```
bool carsCollided (
    Car car1,
    Car car2,
    int time)
```

@brief Check if two cars collided

**Parameters**

<i>car1</i>	The first car
<i>car2</i>	The second car

Definition at line 23 of file [utils.cpp](#).

**loadFont()**

```
sf::Font loadFont ()
```

Load a font.

**Returns**

The font

Definition at line 13 of file [utils.cpp](#).

**4.54 utils.cpp**

[Go to the documentation of this file.](#)

```
00001
00005 #include <spdlog/spdlog.h>
00006
00007 #include "car.h"
00008 #include "utils.h"
00009
00010 bool fontLoaded = false;
00011 sf::Font font;
00012
00013 sf::Font loadFont() {
00014     if (!fontLoaded) {
00015         if (!font.loadFromFile("assets/fonts/arial.ttf")) {
00016             spdlog::error("Failed to load font");
00017         }
00018         fontLoaded = true;
00019     }
00020     return font;
00021 }
00022
00023 bool carsCollided(Car car1, Car car2, int time) {
00024     std::vector<sf::Vector2f> path1 = car1.getPath();
00025     std::vector<sf::Vector2f> path2 = car2.getPath();
00026     sf::Vector2f diff = path1[time] - path2[time];
00027     return std::sqrt(diff.x * diff.x + diff.y * diff.y) < CAR_LENGTH * 1.1;
00028
00029     sf::Vector2f pos1 = path1[time];
00030     sf::Vector2f pos2 = path2[time];
00031
00032     double angle1 = atan2(path1[time + 1].y - path1[time].y, path1[time + 1].x - path1[time].x);
00033     double angle2 = atan2(path2[time + 1].y - path2[time].y, path2[time + 1].x - path2[time].x);
00034
00035     sf::Vector2f p11 = pos1 + sf::Vector2f(CAR_LENGTH / 2.0f * cos(angle1), CAR_LENGTH / 2.0f *
sin(angle1));
00036     sf::Vector2f p12 = pos1 - sf::Vector2f(CAR_LENGTH / 2.0f * cos(angle1), CAR_LENGTH / 2.0f *
sin(angle1));
00037     sf::Vector2f p21 = pos2 + sf::Vector2f(CAR_LENGTH / 2.0f * cos(angle2), CAR_LENGTH / 2.0f *
sin(angle2));
00038     sf::Vector2f p22 = pos2 - sf::Vector2f(CAR_LENGTH / 2.0f * cos(angle2), CAR_LENGTH / 2.0f *
sin(angle2));
```



```
00039
00040     bool colides = false;
00041     colides |= std::sqrt(std::pow(p11.x - p21.x, 2) + std::pow(p11.y - p21.y, 2)) < CAR_LENGTH * 1.1;
00042     colides |= std::sqrt(std::pow(p11.x - p22.x, 2) + std::pow(p11.y - p22.y, 2)) < CAR_LENGTH * 1.1;
00043     colides |= std::sqrt(std::pow(p12.x - p21.x, 2) + std::pow(p12.y - p21.y, 2)) < CAR_LENGTH * 1.1;
00044     colides |= std::sqrt(std::pow(p12.x - p22.x, 2) + std::pow(p12.y - p22.y, 2)) < CAR_LENGTH * 1.1;
00045
00046     return colides;
00047 }
00048
00049 bool carConflict(sf::Vector2f carPos, double carAngle, sf::Vector2f confPos, double confAngle) {
00050     sf::Vector2f diff = carPos - confPos;
00051     return std::sqrt(diff.x * diff.x + diff.y * diff.y) < CAR_LENGTH * 1.1;
00052
00053     sf::Vector2f p11 = carPos + sf::Vector2f(CAR_LENGTH / 2.0f * cos(carAngle), CAR_LENGTH / 2.0f *
sin(carAngle));
00054     sf::Vector2f p12 = carPos - sf::Vector2f(CAR_LENGTH / 2.0f * cos(carAngle), CAR_LENGTH / 2.0f *
sin(carAngle));
00055     sf::Vector2f p21 = confPos + sf::Vector2f(CAR_LENGTH / 2.0f * cos(confAngle), CAR_LENGTH / 2.0f *
sin(confAngle));
00056     sf::Vector2f p22 = confPos - sf::Vector2f(CAR_LENGTH / 2.0f * cos(confAngle), CAR_LENGTH / 2.0f *
sin(confAngle));
00057
00058     bool colides = false;
00059     colides |= std::sqrt(std::pow(p11.x - p21.x, 2) + std::pow(p11.y - p21.y, 2)) < CAR_LENGTH * 1.1;
00060     colides |= std::sqrt(std::pow(p11.x - p22.x, 2) + std::pow(p11.y - p22.y, 2)) < CAR_LENGTH * 1.1;
00061     colides |= std::sqrt(std::pow(p12.x - p21.x, 2) + std::pow(p12.y - p21.y, 2)) < CAR_LENGTH * 1.1;
00062     colides |= std::sqrt(std::pow(p12.x - p22.x, 2) + std::pow(p12.y - p22.y, 2)) < CAR_LENGTH * 1.1;
00063
00064     return colides;
00065 }
```



---

## Index

- [\\_aStarConflict](#), 4
- [\\_aStarNode](#), 5
- [\\_cityGraphNeighbor](#), 5
- [\\_cityGraphPoint](#), 5
- [\\_cityMapBuilding](#), 6
- [\\_cityMapGreenArea](#), 6
- [\\_cityMapIntersection](#), 6
- [\\_cityMapRoad](#), 7
- [\\_cityMapSegment](#), 7
- [\\_cityMapWaterArea](#), 8
- [\\_data](#), 8
- [\\_managerCBSNode](#), 8
- [addConstraint](#)
  - [ConstraintController](#), 19
- [assignExistingPath](#)
  - [Car](#), 11
- [assignPath](#)
  - [Car](#), 11
- [assignStartEnd](#)
  - [Car](#), 11
- [AStar](#), 9
  - [AStar](#), 9
  - [findPath](#), 9
- [aStar.cpp](#), 49
- [aStar.h](#), 32
- [Car](#), 10
  - [assignExistingPath](#), 11
  - [assignPath](#), 11
  - [assignStartEnd](#), 11
  - [chooseRandomStartEndPath](#), 11
  - [getAStarPath](#), 12
  - [getAverageSpeed](#), 12
  - [getElapsedDistance](#), 12
  - [getElapsedTime](#), 12
  - [getEnd](#), 12
  - [getPath](#), 13
  - [getPathLength](#), 13
  - [getPathTime](#), 13
  - [getPosition](#), 13
  - [getRemainingDistance](#), 13
  - [getRemainingTime](#), 13
  - [getSpeed](#), 14
  - [getSpeedAt](#), 14
  - [getStart](#), 14
  - [render](#), 14
- [car.cpp](#), 50, 51
- [car.h](#), 34
- [carConflict](#)
  - [utils.cpp](#), 83
  - [utils.h](#), 44
- [carsCollided](#)
  - [utils.cpp](#), 84
  - [utils.h](#), 45
- [checkConstraints](#)
  - [ConstraintController](#), 19
- [chooseRandomStartEndPath](#)
  - [Car](#), 11
- [CityGraph](#), 15
  - [createGraph](#), 15
  - [getGraphPoints](#), 15
  - [getHeight](#), 15
  - [getNeighbors](#), 15
  - [getRandomPoint](#), 16
  - [getWidth](#), 16
- [cityGraph.cpp](#), 53
- [cityGraph.h](#), 35
- [CityMap](#), 16
  - [getBuildings](#), 17
  - [getGreenAreas](#), 17
  - [getHeight](#), 17
  - [getIntersections](#), 17
  - [getMaxLatLon](#), 17
  - [getMinLatLon](#), 18
  - [getRoads](#), 18
  - [getWaterAreas](#), 18
  - [getWidth](#), 18
  - [isCityMapLoaded](#), 18
  - [loadFile](#), 18
- [cityMap.cpp](#), 57, 58
- [cityMap.h](#), 36
- [config.h](#), 37
- [ConstraintController](#), 19
  - [addConstraint](#), 19
  - [checkConstraints](#), 19
  - [copy](#), 20
  - [hasConstraint](#), 20
- [constraintController.cpp](#), 62
- [copy](#)
  - [ConstraintController](#), 20
- [createCarsAStar](#)
  - [Manager](#), 27
- [createCarsCBS](#)
  - [Manager](#), 27
- [createData](#)
  - [DataManager](#), 21
- [createGraph](#)
  - [CityGraph](#), 15
- [createSubCBS](#)
  - [Manager](#), 27
- [DataManager](#), 21
  - [createData](#), 21
  - [DataManager](#), 21
- [dataManager.cpp](#), 64
- [dataManager.h](#), 38
- [distance](#)
  - [Dubins](#), 23
  - [utils.h](#), 45
- [drawArrow](#)
  - [renderer.h](#), 42
- [Dubins](#), 22
  - [distance](#), 23

- Dubins, 22, 23
  - path, 23
  - point, 24
  - time, 24
- dubins.cpp, 65
- dubins.h, 39
- DubinsPath, 24
  - DubinsPath, 25
- FileSelector, 25
- fileSelector.cpp, 67
- fileSelector.h, 40
- findPath
  - AStar, 9
  - TimedAStar, 31
- getAStarPath
  - Car, 12
- getAverageSpeed
  - Car, 12
- getBuildings
  - CityMap, 17
- getCars
  - Manager, 27
- getElapsedDistance
  - Car, 12
- getElapsedTime
  - Car, 12
- getEnd
  - Car, 12
- getGraphPoints
  - CityGraph, 15
- getGreenAreas
  - CityMap, 17
- getHeight
  - CityGraph, 15
  - CityMap, 17
- getIntersections
  - CityMap, 17
- getMaxLatLon
  - CityMap, 17
- getMinLatLon
  - CityMap, 18
- getNeighbors
  - CityGraph, 15
- getNumCars
  - Manager, 27
- getPath
  - Car, 13
- getPathLength
  - Car, 13
- getPathTime
  - Car, 13
- getPosition
  - Car, 13
- getRandomPoint
  - CityGraph, 16
- getRemainingDistance
  - Car, 13
- getRemainingTime
  - Car, 13
- getRoads
  - CityMap, 18
- getSpeed
  - Car, 14
- getSpeedAt
  - Car, 14
- getStart
  - Car, 14
- getWaterAreas
  - CityMap, 18
- getWidth
  - CityGraph, 16
  - CityMap, 18
- hasConflict
  - Manager, 28
- hasConstraint
  - ConstraintController, 20
- index.py, 47
- isCityMapLoaded
  - CityMap, 18
- latLonToXY
  - utils.h, 45
- loadFile
  - CityMap, 18
- loadFont
  - utils.cpp, 84
  - utils.h, 45
- main.cpp, 68, 69
- Manager, 25
  - createCarsAStar, 27
  - createCarsCBS, 27
  - createSubCBS, 27
  - getCars, 27
  - getNumCars, 27
  - hasConflict, 28
  - Manager, 26
  - processCBS, 28
  - renderCars, 28
  - toggleCarDebug, 29
- manager.cpp, 70
- manager.h, 40, 41
- managerCBS.cpp, 70, 71
- normalizeAngle
  - utils.h, 46
- path
  - Dubins, 23
- point
  - Dubins, 24
- processCBS
  - Manager, 28
- render

- Car, [14](#)
- renderCars
  - Manager, [28](#)
- renderCityGraph
  - Renderer, [30](#)
- renderCityMap
  - Renderer, [30](#)
- Renderer, [29](#)
  - renderCityGraph, [30](#)
  - renderCityMap, [30](#)
  - renderManager, [30](#)
- renderer.cpp, [75](#)
- renderer.h, [42](#), [43](#)
  - drawArrow, [42](#)
- renderManager
  - Renderer, [30](#)
- Test, [30](#)
- test.cpp, [80](#)
- test.h, [43](#), [44](#)
- time
  - Dubins, [24](#)
- TimedAStar, [31](#)
  - findPath, [31](#)
  - TimedAStar, [31](#)
- timedAStar.cpp, [81](#)
- toggleCarDebug
  - Manager, [29](#)
- turningRadius
  - utils.h, [46](#)
- turningRadiusToSpeed
  - utils.h, [46](#)
- utils.cpp, [83](#), [84](#)
  - carConflict, [83](#)
  - carsCollided, [84](#)
  - loadFont, [84](#)
- utils.h, [44](#), [47](#)
  - carConflict, [44](#)
  - carsCollided, [45](#)
  - distance, [45](#)
  - latLonToXY, [45](#)
  - loadFont, [45](#)
  - normalizeAngle, [46](#)
  - turningRadius, [46](#)
  - turningRadiusToSpeed, [46](#)