Robot Parallel Motion Planning

Milestone 3

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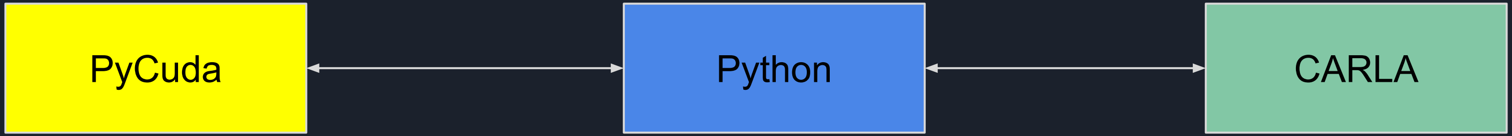
Roadmap

Goal: Enable autonomous robot to navigate to a goal in an unknown environment using the power of the GPU

- Milestone 1 (11/18):
    - Simulation infrastructure
    - Understanding GMT*
- Milestone 2 (11/25):
    - Motion planning (GMT*)
- Milestone 3 (12/2):
    - ~~Perception and localization~~ → Finish GMT* 🟨 ✓
    - Optimizations 🟨 ✓
- Final Submission (12/8):
    - Presenstation
    - Performance analysis
    - Perception

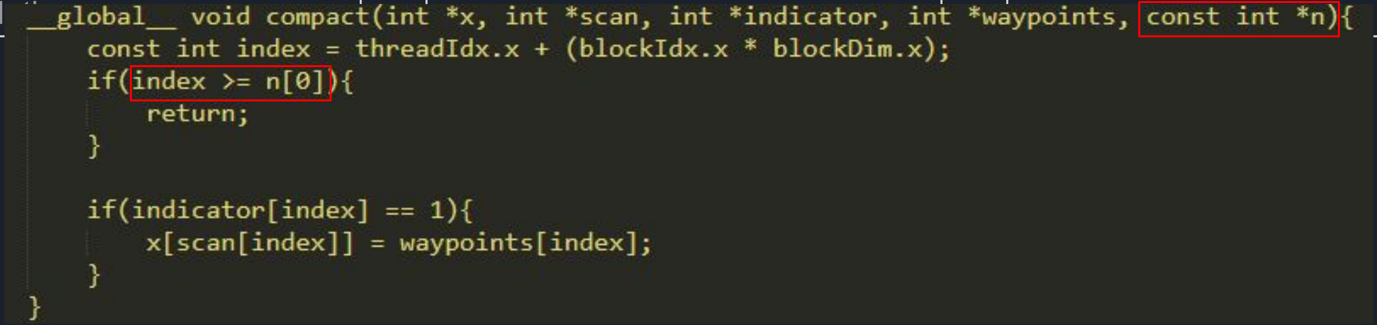
Over 1200 lines of code, lots of bugs



- In Python but C++ code
- Like Cuda but weird differences
  - Everything has to be passed as a pointer
- Include problems
  - GLM
  - M

- Perfect
- Except in dealing with PyCuda and CARLA interactions

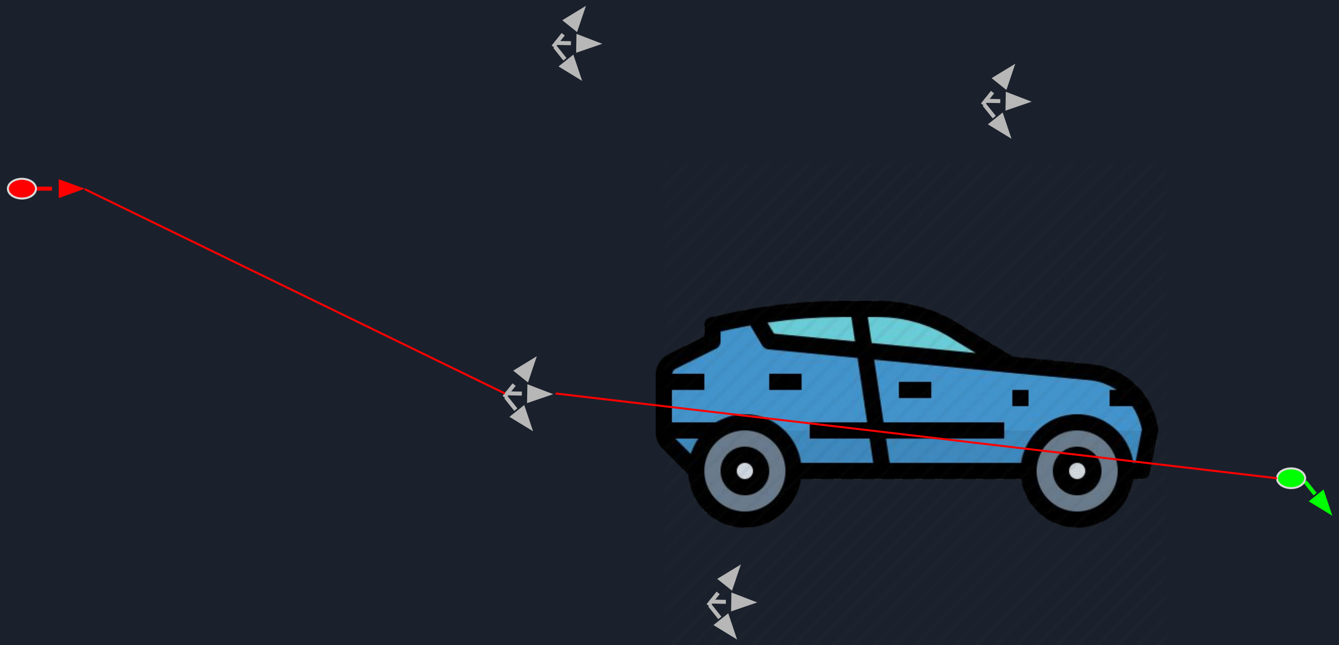
- Syncing problem causes slow simulation



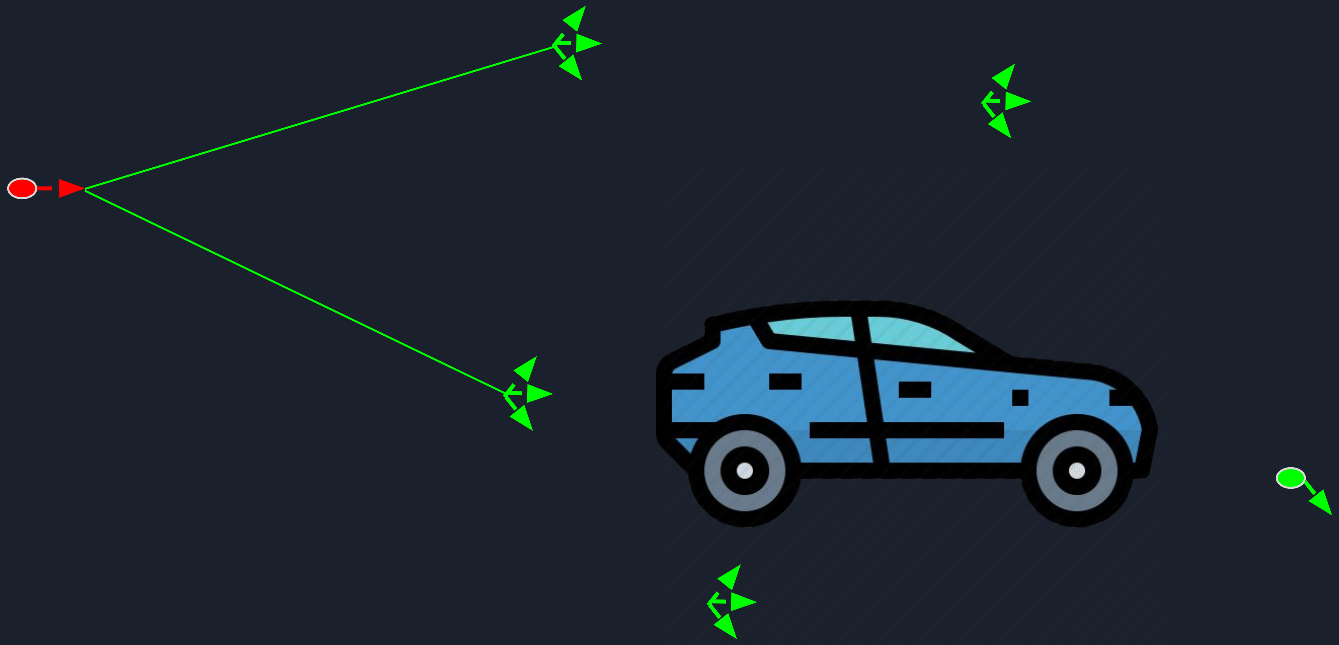
```
__global__ void compact(int *x, int *scan, int *indicator, int *waypoints, const int *n){
    const int index = threadIdx.x + (blockIdx.x * blockDim.x);
    if(index >= n[0]){
        return;
    }

    if(indicator[index] == 1){
        x[scan[index]] = waypoints[index];
    }
}
```

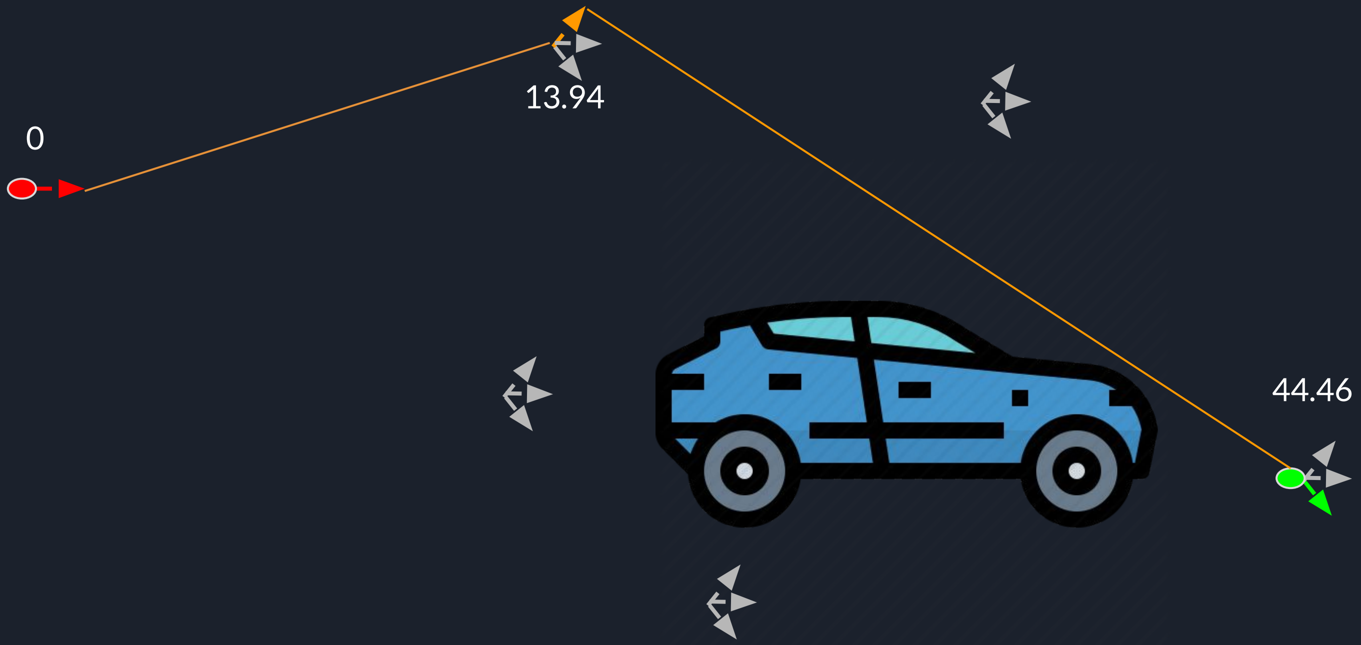
GMT* Implementation / Example



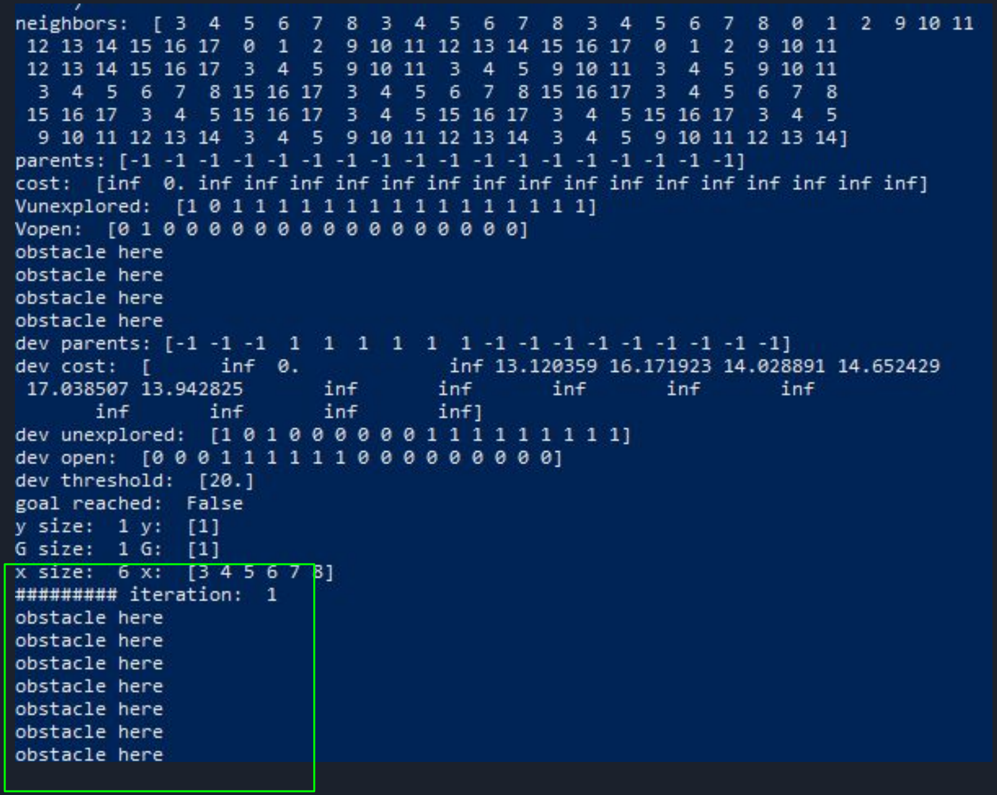
GMT* Implementation / Example



GMT* Implementation / Example

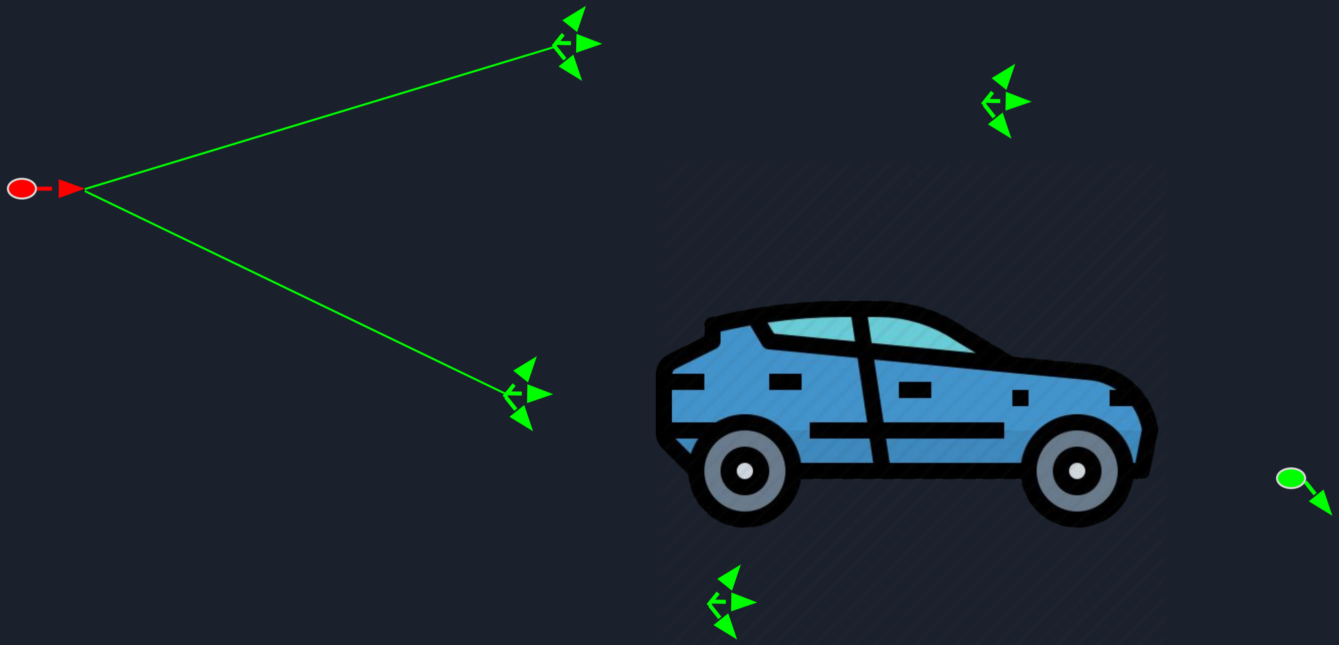


Proof of work

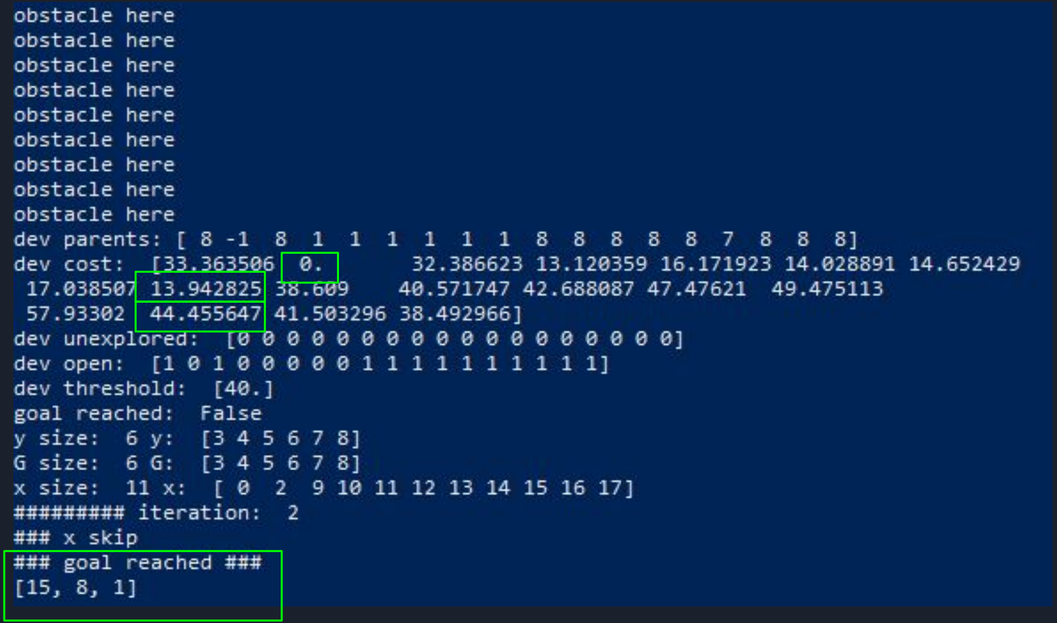


```
neighbors:  [ 3  4  5  6  7  8  3  4  5  6  7  8  3  4  5  6  7  8  0  1  2  9 10 11
 12 13 14 15 16 17  0  1  2  9 10 11 12 13 14 15 16 17  0  1  2  9 10 11
 12 13 14 15 16 17  3  4  5  9 10 11  3  4  5  9 10 11  3  4  5  9 10 11
  3  4  5  6  7  8 15 16 17  3  4  5  6  7  8 15 16 17  3  4  5  6  7  8
 15 16 17  3  4  5 15 16 17  3  4  5 15 16 17  3  4  5 15 16 17  3  4  5
  9 10 11 12 13 14  3  4  5  9 10 11 12 13 14  3  4  5  9 10 11 12 13 14]
parents: [-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1]
cost:  [inf  0. inf inf inf inf inf inf inf inf inf inf inf inf inf inf inf inf]
Vunexplored:  [1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
Vopen:  [0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
obstacle here
obstacle here
obstacle here
obstacle here
dev parents: [-1 -1 -1  1  1  1  1  1  1 -1 -1 -1 -1 -1 -1 -1 -1 -1]
dev cost:  [       inf  0.              inf 13.120359 16.171923 14.028891 14.652429
 17.038507 13.942825       inf       inf       inf       inf       inf
       inf       inf       inf       inf]
dev unexplored:  [1 0 1 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1]
dev open:  [0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0]
dev threshold:  [20.]
goal reached:  False
y size:  1 y:  [1]
G size:  1 G:  [1]
x size:  6 x:  [3 4 5 6 7 8]
######### iteration:  1
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
```

GMT* Implementation / Example



Proof of work



```
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
obstacle here
dev parents: [ 8 -1  8  1  1  1  1  1  1  8  8  8  8  8  7  8  8  8]
dev cost:  [33.363506  0.         32.386623 13.120359 16.171923 14.028891 14.652429
 17.038507 13.942825 38.609     40.571747 42.688087 47.47621  49.475113
 57.93302  44.455647 41.503296 38.492966]
dev unexplored:  [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
dev open:  [1 0 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1]
dev threshold:  [40.]
goal reached:  False
y size:  6 y:  [3 4 5 6 7 8]
G size:  6 G:  [3 4 5 6 7 8]
x size:  11 x:  [ 0  2  9 10 11 12 13 14 15 16 17]
######### iteration:  2
### x skip
### goal reached ###
[15, 8, 1]
```

Future Work

- Milestone 1 (11/18):
  - Simulation infrastructure
  - Understanding GMT*
- Milestone 2 (11/25):
  - Motion planning (GMT*)
- Milestone 3 (12/2):
  - ~~Perception and localization~~ → Finish GMT*
  - Optimizations
- Final Submission (12/8):
  - Presentation
  - Performance analysis
  - ~~Perception~~

Until Final Submission:

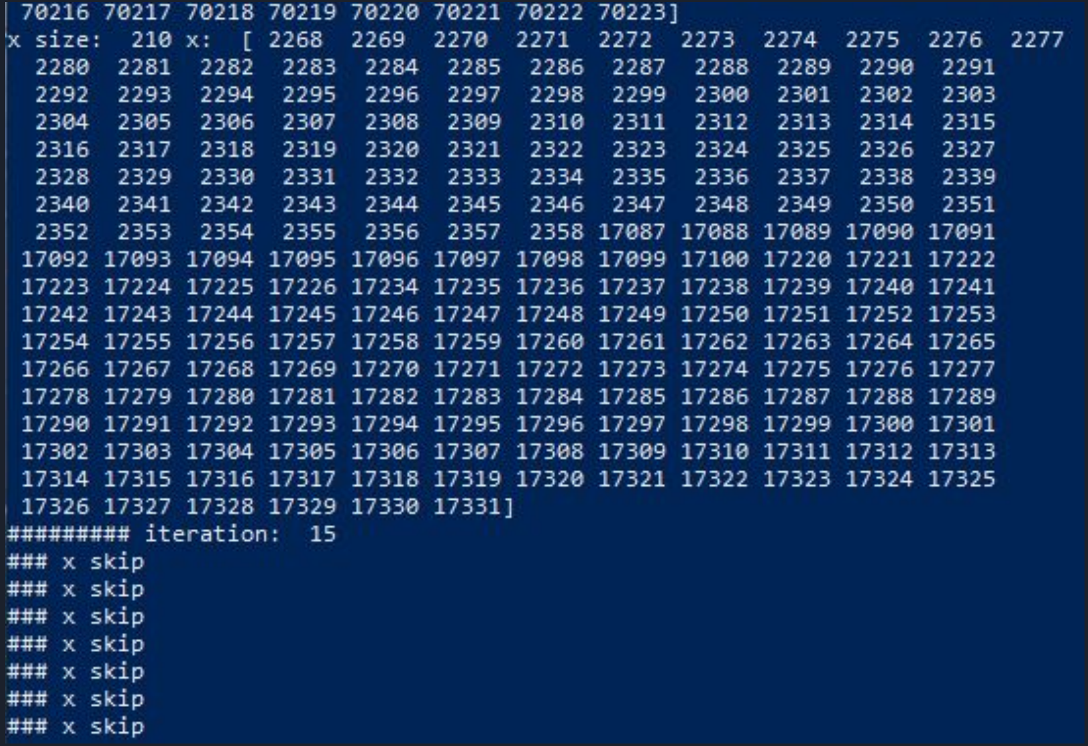
- Debug GMT* work with Carla
- Optimization
- Performance analysis
- Presentation

References

1. CARLA
   a. http://carla.org/
   b. https://carla.readthedocs.io/en/latest/
2. PyCuda
   a. https://documen.tician.de/pycuda/
   b. https://wiki.tiker.net/PyCuda
3. GMT*
   a. https://arxiv.org/pdf/1705.02403.pdf
4. Dubins
   a. https://gieseanw.files.wordpress.com/2012/10/dubins.pdf
5. FMT*
   a. https://arxiv.org/pdf/1306.3532.pdf

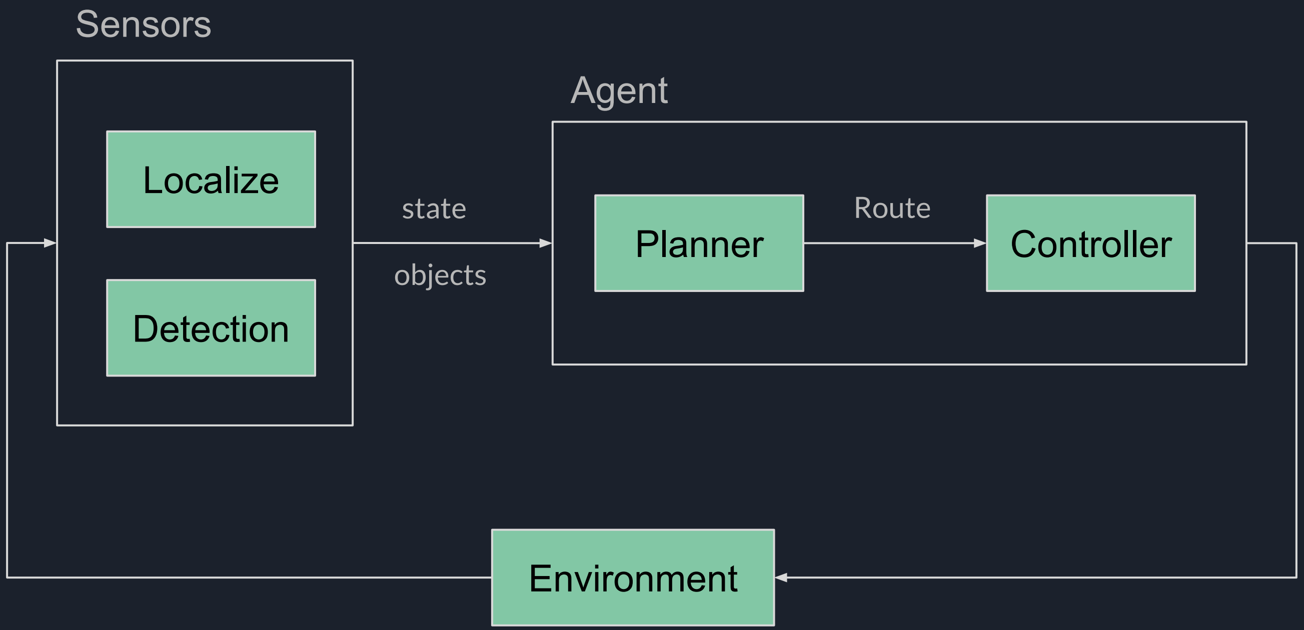
Q & A

CARLA Error

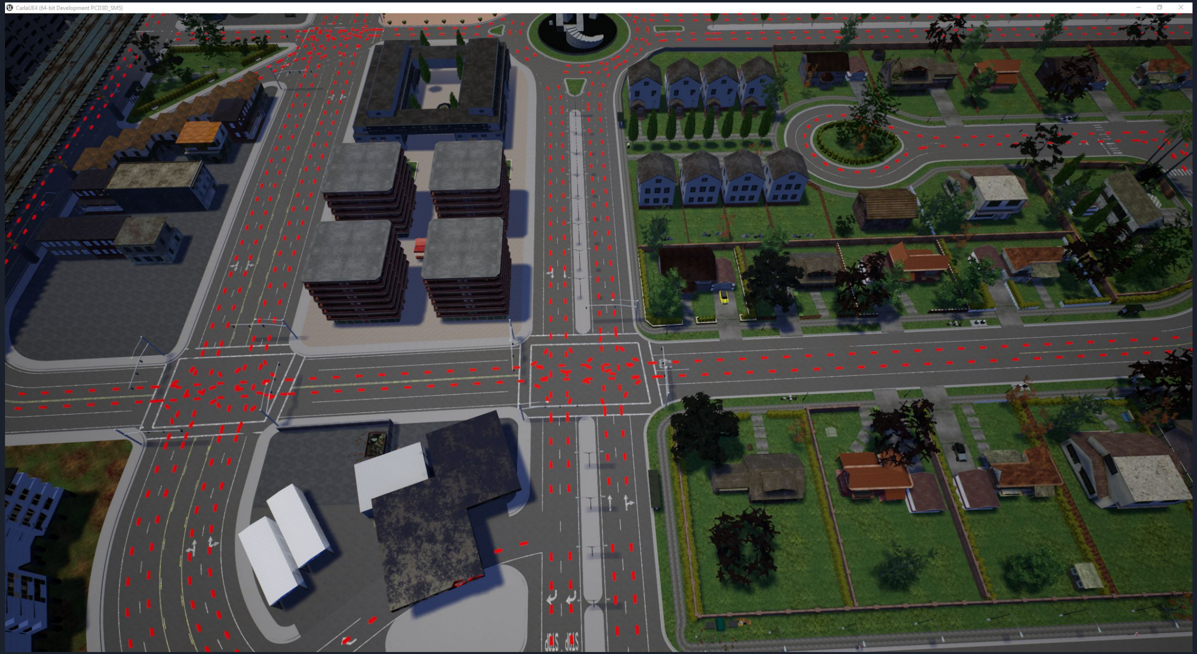


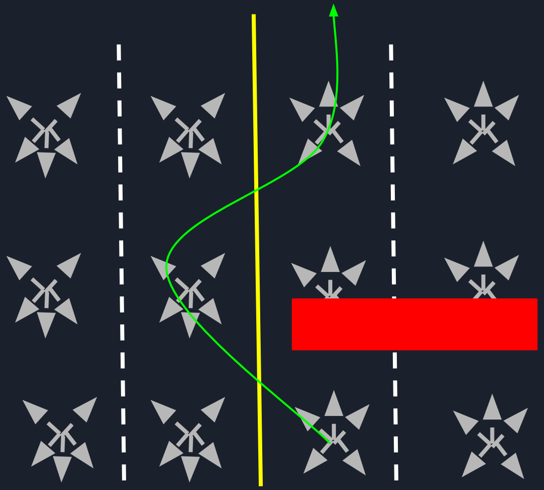
```
 70216 70217 70218 70219 70220 70221 70222 70223]
x size:  210 x:  [ 2268  2269  2270  2271  2272  2273  2274  2275  2276  2277
  2280  2281  2282  2283  2284  2285  2286  2287  2288  2289  2290  2291
  2292  2293  2294  2295  2296  2297  2298  2299  2300  2301  2302  2303
  2304  2305  2306  2307  2308  2309  2310  2311  2312  2313  2314  2315
  2316  2317  2318  2319  2320  2321  2322  2323  2324  2325  2326  2327
  2328  2329  2330  2331  2332  2333  2334  2335  2336  2337  2338  2339
  2340  2341  2342  2343  2344  2345  2346  2347  2348  2349  2350  2351
  2352  2353  2354  2355  2356  2357  2358 17087 17088 17089 17090 17091
 17092 17093 17094 17095 17096 17097 17098 17099 17100 17220 17221 17222
 17223 17224 17225 17226 17234 17235 17236 17237 17238 17239 17240 17241
 17242 17243 17244 17245 17246 17247 17248 17249 17250 17251 17252 17253
 17254 17255 17256 17257 17258 17259 17260 17261 17262 17263 17264 17265
 17266 17267 17268 17269 17270 17271 17272 17273 17274 17275 17276 17277
 17278 17279 17280 17281 17282 17283 17284 17285 17286 17287 17288 17289
 17290 17291 17292 17293 17294 17295 17296 17297 17298 17299 17300 17301
 17302 17303 17304 17305 17306 17307 17308 17309 17310 17311 17312 17313
 17314 17315 17316 17317 17318 17319 17320 17321 17322 17323 17324 17325
 17326 17327 17328 17329 17330 17331]
######### iteration:  15
### x skip
### x skip
### x skip
### x skip
### x skip
### x skip
### x skip
```

Pipeline


Sensors
Localize
Detection
state
objects
Agent
Planner
Route
Controller
Environment

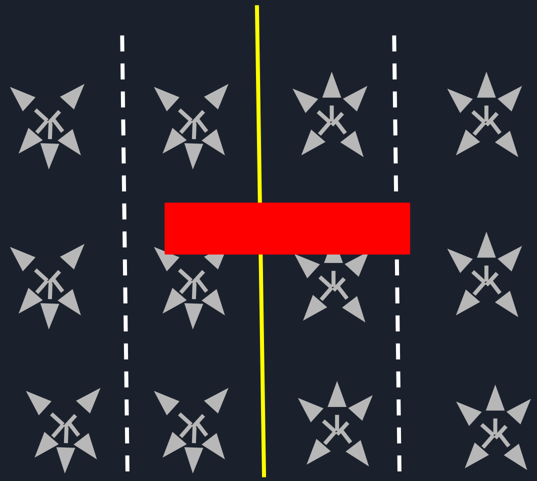
Samples





How do we decide how costly each movement is?

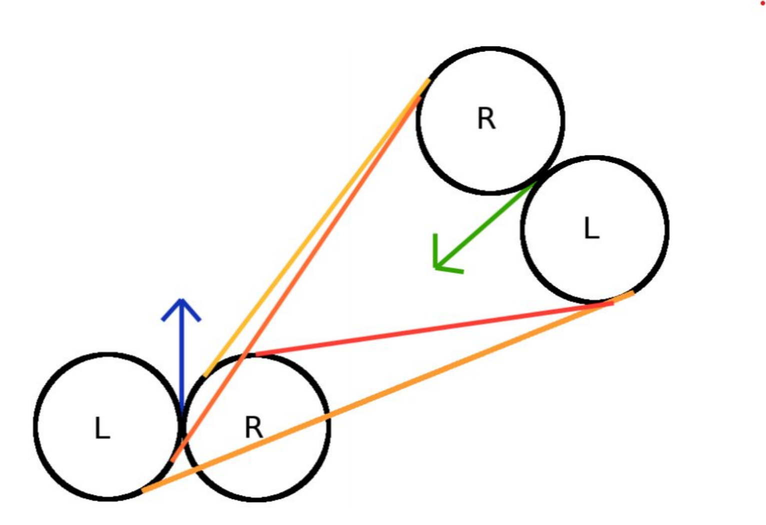
- Car is a non-holonomic robot
- We assume that our car can only go forward
- It is proven then the most optimal path is going to be one of the Dubins paths as long as some constraints are met



Dubins Paths

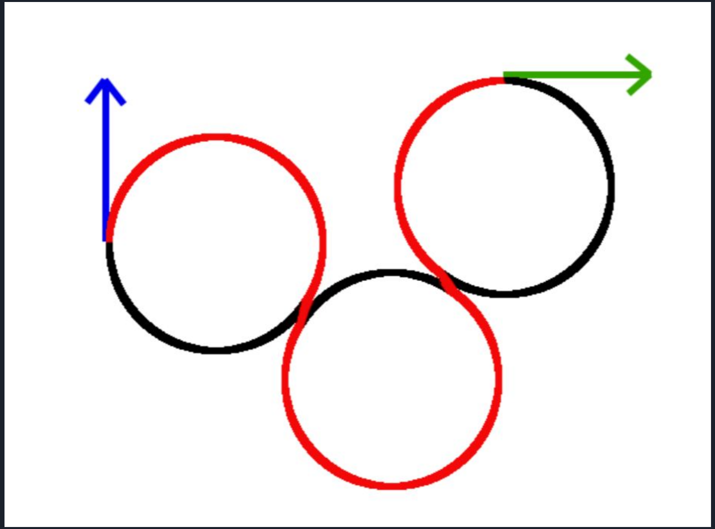
$(X_0, Y_0, \theta_0) \longrightarrow (X_1, Y_1, \theta_1)$

Curve-Straight-Curve



LSL, RSR, LSR, RSL

Curve-Curve-Curve



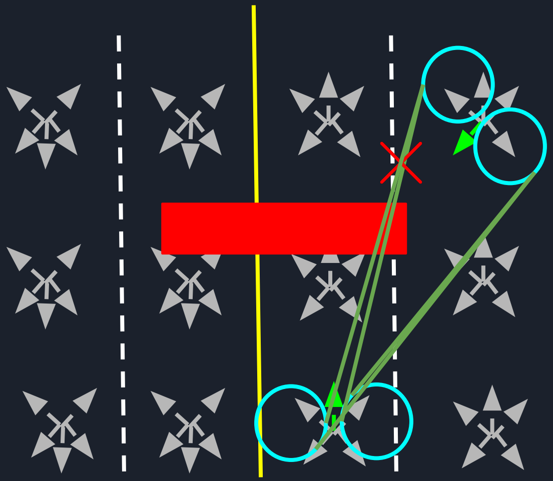
LRL, RLR

https://gieseanw.files.wordpress.com/2012/10/dubins.pdf

Dubins Paths + Collision Check

Let’s look at the Curve-Straight-Curve paths!

- Right->Straight->Left ✓
- Right ->Straight->Right ✗
- Left ->Straight->Right ✗
- Left->Straight->Left ✓



GMT*

0	1	2	3	4	5	waypoints
[1,2]	[0,3]	[0,3,4]	[1,2,4]	[2,3,5]	[4]	neighbors
-1	-1	-1	-1	-1	-1	parent
0	∞	∞	∞	∞	∞	cost

0	1	1	1	1	1	unexplored
0	0	0	0	0	0	closed
1	0	0	0	0	0	open
1	0	0	0	0	0	wave front

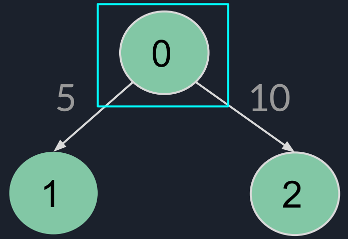
Cost threshold: 0

0	1	1	0	0	0	unexplored neighbors

1	2

X

stream compact



GMT*

0	1	2	3	4	5	waypoints
[1,2]	[0,3]	[0,3,4]	[1,2,4]	[2,3,5]	[4]	neighbors
-1	0	0	-1	-1	-1	parent
0	5	10	∞	∞	∞	cost

0	0	0	1	1	1	unexplored
1	0	0	0	0	0	closed
0	1	1	0	0	0	open
0	1	1	0	0	0	wave front

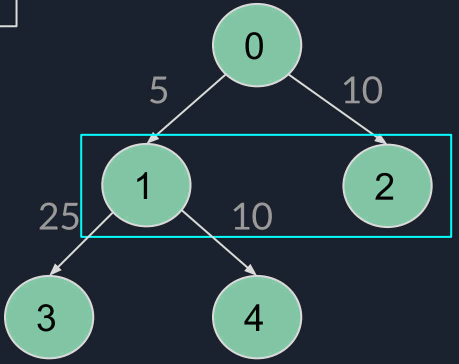
Cost threshold: 10

0	0	0	1	1	0	unexplored neighbors

3	4

X

stream compact



GMT*

0	1	2	3	4	5	waypoints
[1,2]	[0,3]	[0,3,4]	[1,2,4]	[2,3,5]	[4]	neighbors
-1	0	0	1	1	-1	parent
0	5	10	30	15	∞	cost

0	0	0	0	0	1	unexplored
1	1	1	0	0	0	closed
0	0	0	1	1	0	open
0	0	0	1	1	0	wave front

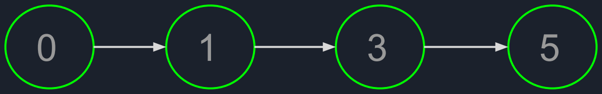
Cost threshold: 30

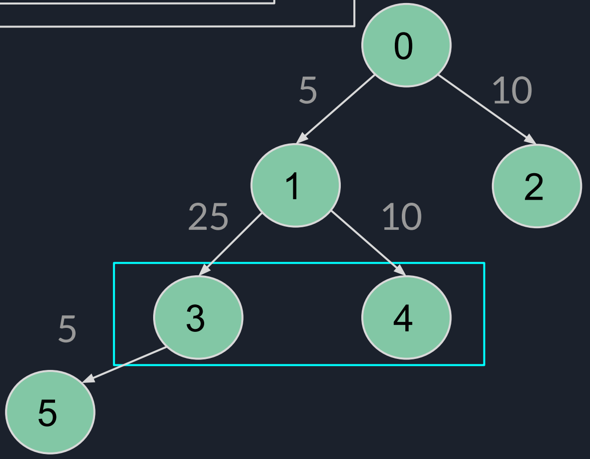
0	0	0	0	0	1	unexplored neighbors

5

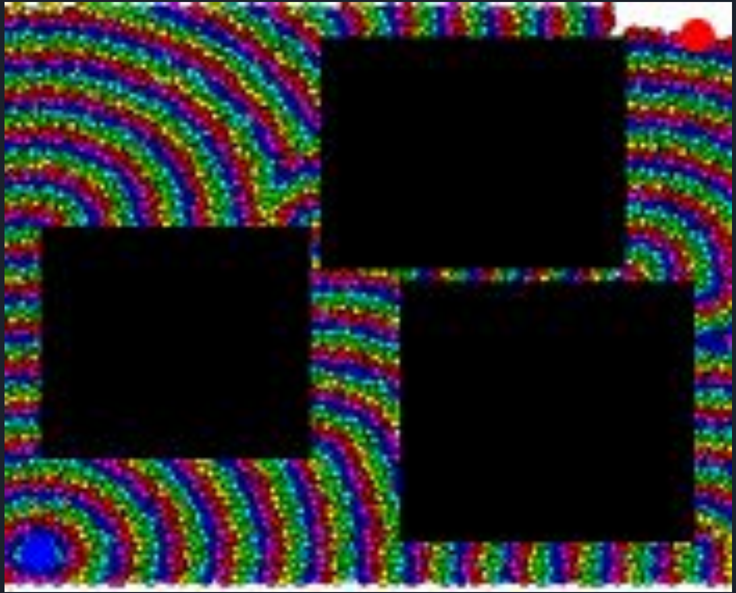
X

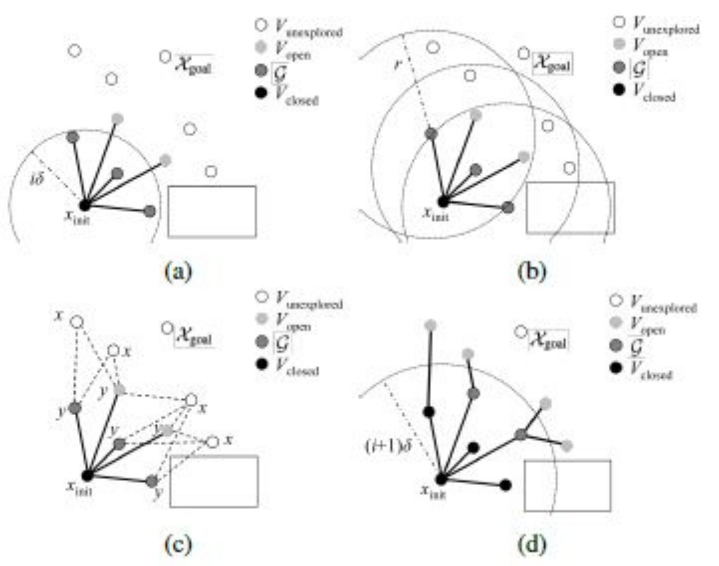
stream compact





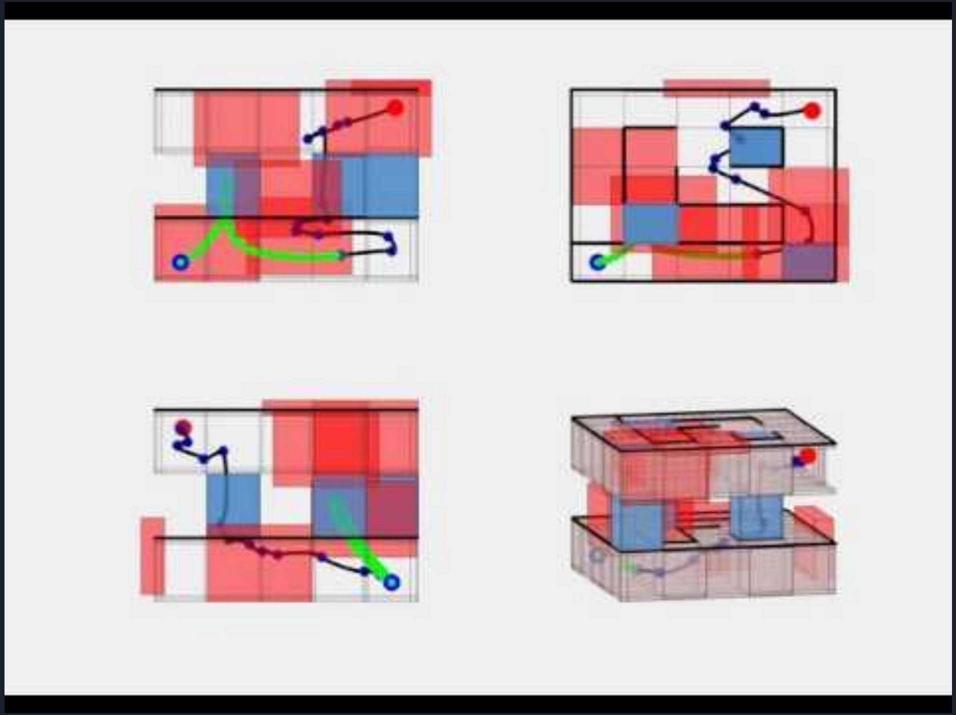
Wavefront Parallelization





https://arxiv.org/pdf/1705.02403.pdf

Previous Work



https://arxiv.org/pdf/1705.02403.pdf