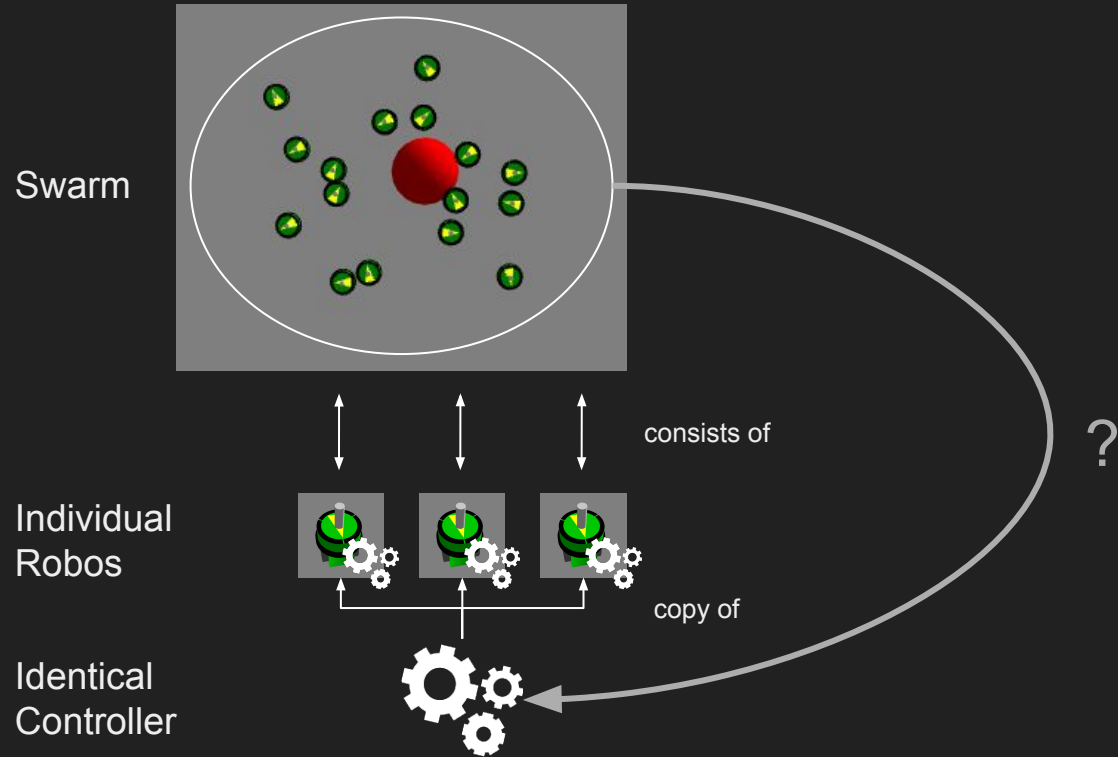


# Creating and Demonstrating a Dataset for Swarm Mission Generation from Natural Language

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Master Project Cyber-Physical-Systems  
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# The Micro-Macro Gap



# Automatic Modular Design (AutoMoDe-Maple)

Elementary Single Robot Behaviors



Reward Function



Behavior Tree

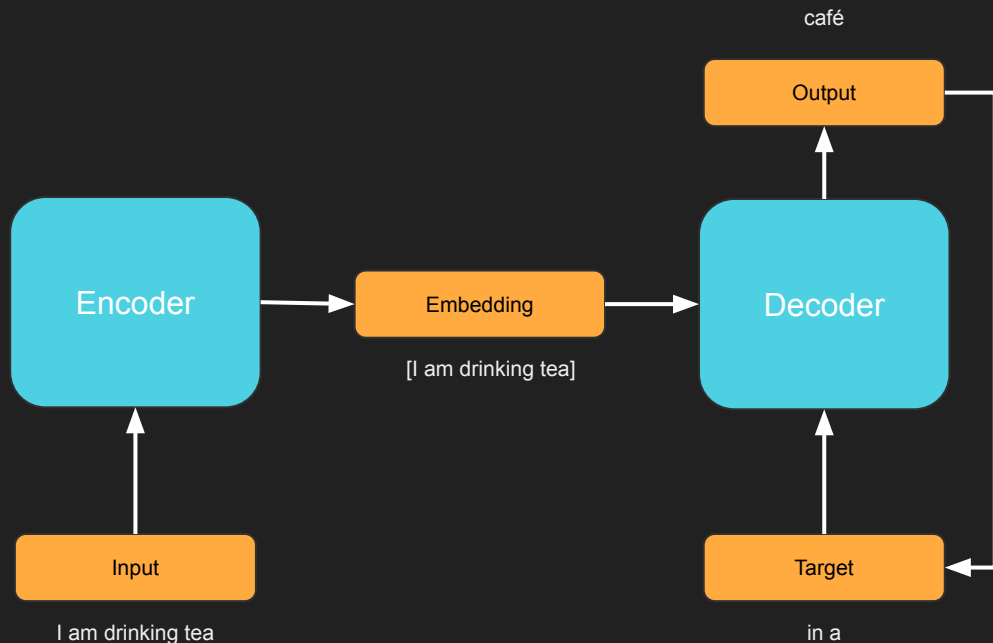


Evolutionary Algorithm



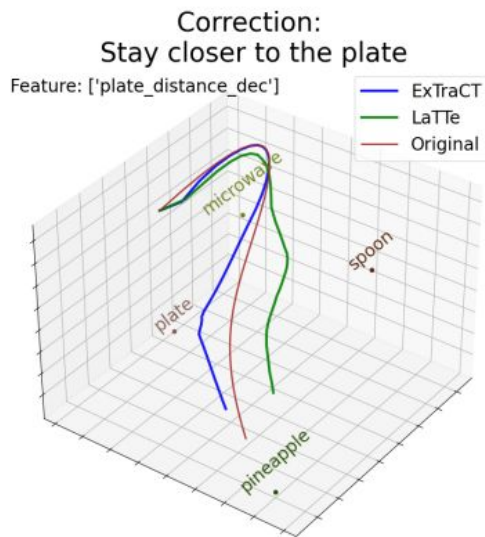
[Kuckling et al. 2018]

# Large Language Models: Transformer Architecture

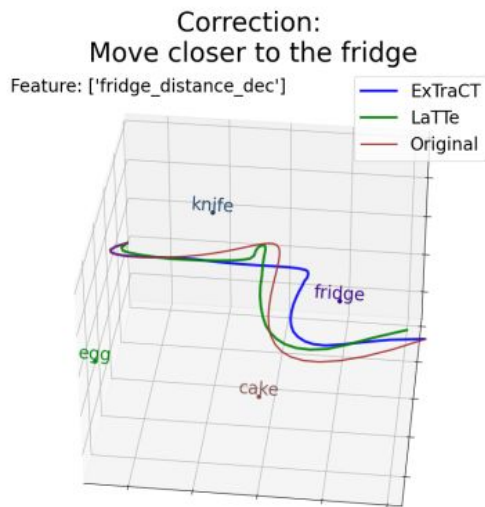


[Vaswani et al. 2017]

# LLMs in Robotics: Trajectory Corrections



(a)



(b)



[Bucker et al. 2023]

# LLMs in Robotics: BT Generation

A human and LLM-BRAIn created the Behavior Tree to set the robot's following behavior:  
"If object is visible, move towards it, take it and process it. Else scan the area."  
Which BT do you think the human-written?

```
<BehaviorTree ID="MobileRobotTask">
  <Fallback>
    <Sequence>
      <Condition ID="IsObjectApproached"/>
      <Action ID="TakeObject"/>
      <SubTree ID="ProcessObject"/>
    </Sequence>
    <Sequence>
      <Condition ID="IsObjectVisible"/>
      <Sequence>
        <Action ID="MoveToObject"/>
        <Action ID="TakeObject"/>
      </Sequence>
    </Sequence>
    <Action ID="ScanAreaForObject"/>
  </Fallback>
</BehaviorTree>
```

```
<BehaviorTree ID="FindAndTakeObject">
  <Fallback>
    <Sequence>
      <Condition ID="IsObjectApproached"/>
      <Action ID="TakeObject"/>
      <SubTree ID="ProcessObject"/>
    </Sequence>
    <Sequence>
      <Condition ID="IsObjectVisible"/>
      <Action ID="MoveToObject"/>
    </Sequence>
    <Action ID="ScanAreaForObject"/>
  </Fallback>
</BehaviorTree>
```

[Lykov et al. 2023]

Can LLMs **directly** generate controllers for robot swarms?

# Contribution

1. Dataset of **Mission Descriptions** with respective **Mission Configuration** for AutoMoDe.
2. Demonstrate application by **finetuning an LLM** to the Dataset.

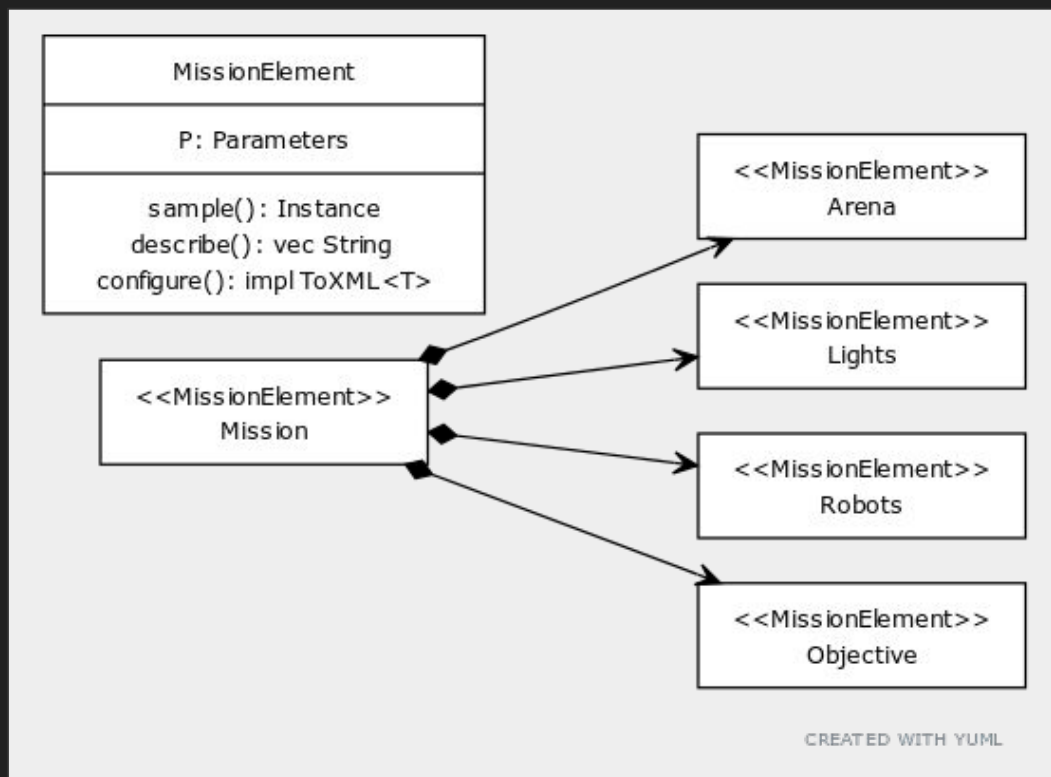


# Swarm Mission Model

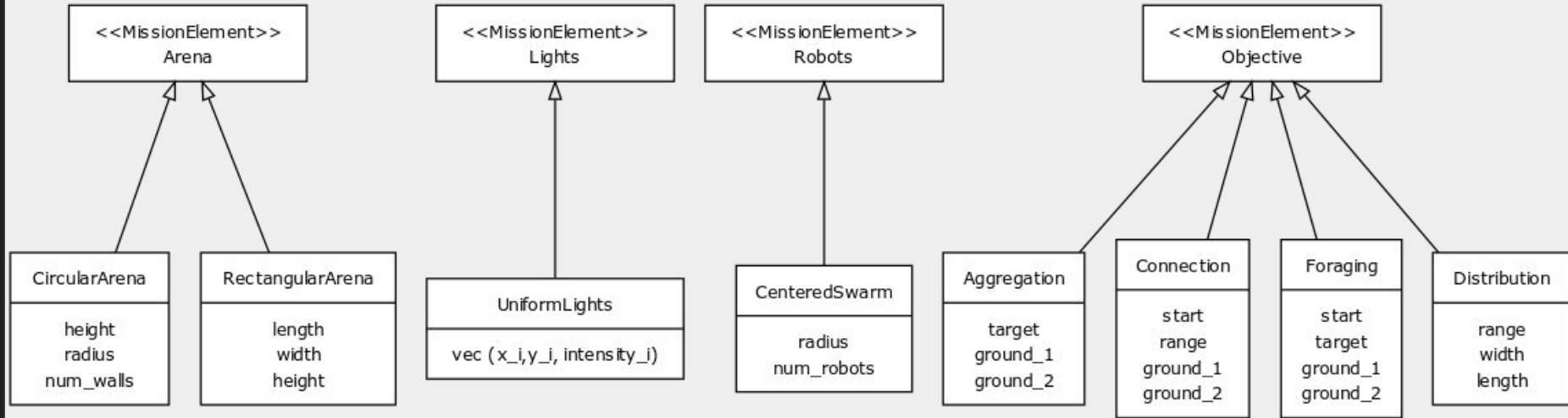
- Arena
- Lights
- Robot Swarm
- Objective

```
C:\Users\John> cd src\Download3\3\shalestorm\3
1  # yaml version="1.0" ?
2  cargo-configuration:
3    <!-- ***** -->
4    <!-- * framework * -->
5    <!-- ***** -->
6    <framework>
7      <experiment length="120" ticks_per_second="10" random_seed="0"/>
8    </framework>
9
10   <!-- ***** -->
11   <!-- * loop functions * -->
12   <!-- ***** -->
13   <loop_functions_library>"/opt/args/AutoWx/build/loop-functions/custom-loopfunctions/libcustom_loopfunc.so" label="template">
14     <loop-placeholder>/loop-placeholder>
15   </loop_functions>
16
17   <!-- ***** -->
18   <!-- * controllers * -->
19   <!-- ***** -->
20   <controllers>
21     <autocode_controller_bt id="autocode_bt" library="/opt/args/AutoWx/build/src/libautocode_bt.so">
22       <factories>
23         <opencv_wheel_implementation="default" noise_std_dev="0.05"/>
24         <opencv_rgh_lsd_implementation="default" medium="lsd"/>
25         <opencv_range_and_bearing_implementation="radius" medium="rgh" data_size="4" range="0.7"/>
26       </factories>
27       <sensors>
28         <opencv_proximity_implementation="default" show rays="false" noise_level="0.05" calibrated="true"/>
29         <opencv_range_and_bearing_implementation="radius" medium="lsd" data_size="4" noise_std_deviation="1.5" loss_probability="0.05" calibrated="true"/>
30         <opencv_lsd_implementation="default" show rays="false" noise_level="0.05" calibrated="true"/>
31         <opencv_ground_implementation="rot_x_only" noise_level="0.05" calibrated="true"/>
32         <opencv_omnidirectional_camera_implementation="rot_x_only" medium="lsd" show rays="false"/>
33       </sensors>
34     </autocode_controller_bt>
35   </controllers>
36
37   <!-- ***** -->
38   <!-- * arena * -->
39   <!-- ***** -->
40   <arena size="10, 10, 1" center="0,0,0">
41
42     <!-- Change the floor here -->
43     <floor id="floor" source="loop_functions" pixels_per_meter="300"/>
44
45     <!-- Change the light here -->
46     <!-- Please note that this light has an intensity equal to 0 -->
47     <!-- and therefore does not affect the experiment -->
48     <!-- ARMS requires at least one light when using the light sensor -->
49     <light id="light" position="0,0,0,0,0" orientation="0,0,0" color="red" intensity="5.0" medium="lsd"/>
50
51     <environment-placeholder>/environment-placeholder>
52   </arena>
53
54   <!-- ***** -->
55   <!-- * physics engines * -->
56   <!-- ***** -->
57   <physics_engines>
58     <dynamic3d id="dym3d" />
59   </physics_engines>
60
61   <!-- ***** -->
62   <!-- * media * -->
63   <!-- ***** -->
64   <media>
65     <!-- 10x10x1 grid size="1,1,1"/>
66     <range_and_bearing id="lrcm"/>
67     <range_and_bearing id="rgh"/>
68   </media>
69
70   <!-- ***** -->
71   <!-- * visualization * -->
72   <!-- ***** -->
73   <visualization>
74     <qt-OpenGL>
75       <camera>
76         <placement id="0">
77           <position="0,0,0,5">
78             <look_at="0,0,0">
79               <lenz_focal_length="30" />
80             </look_at>
81           </position>
82         </placement>
83       </camera>
84     </qt-OpenGL>
85   </visualization>
86
87   </args-configuration>
```

# Mission Elements



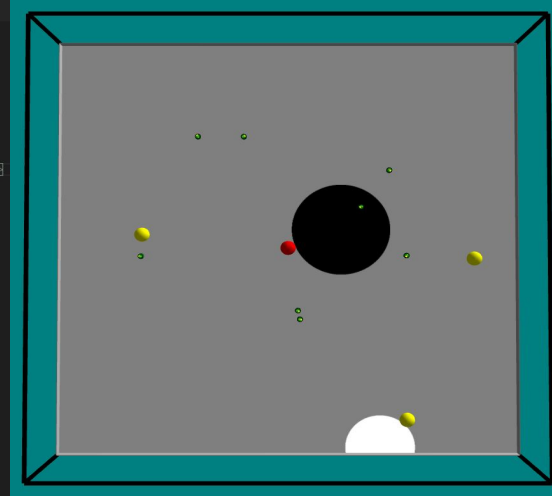
# Mission Element Implementations



CREATED WITH YUML

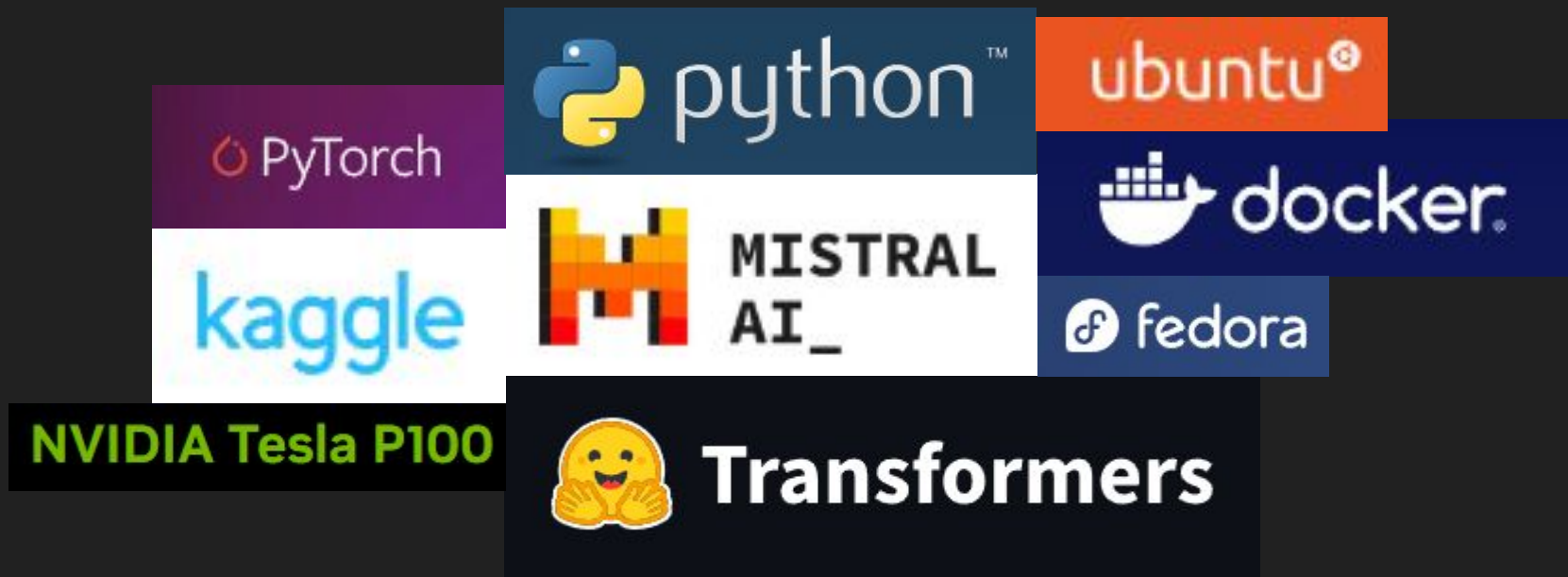
# Example Mission

```
argos_config X
tmp > % argos_config
1  <?xml version="1.0"?>
2  <config>
3    <swarm>
4      <entity quantity="8" max_trials="100">
5        <e-puck id="epuck">
6          <controller configs="automode_bt"/>
7        </e-puck>
8      </entity>
9    </swarm>
10   <env>
11     <light id="light_0" position="2.43,0.154,0.00" orientation="360,0,0" color="yellow" intensity="3.58" medium="leds"/>
12     <light id="light_1" position="0.19,1.90,0.00" orientation="360,0,0" color="yellow" intensity="6.43" medium="leds"/>
13     <light id="light_2" position="-0.15,-2.42,0.00" orientation="360,0,0" color="yellow" intensity="4.48" medium="leds"/>
14     <box id="wall_0" size="0.01,5.80,0.10" movable="false">
15       <body position="0,-2.90,0.00" orientation="90,00,0.00,0.00"/>
16     </box>
17     <box id="wall_1" size="0.01,5.91,0.10" movable="false">
18       <body position="2.90,0.00" orientation="0.00,0.00,0.00"/>
19     </box>
20     <box id="wall_2" size="0.01,5.80,0.10" movable="false">
21       <body position="0,2.90,0" orientation="90.00,0.00,0.00"/>
22     </box>
23     <box id="wall_3" size="0.01,5.91,0.10" movable="false">
24       <body position="-2.90,0.0" orientation="0.00,0.00,0.00"/>
25     </box>
26     <spawn-attrih size="5.80,5.91,2.24"/>
27   </env>
28   <objective>
29     <spawnCircle position="0,0,0" radius="2.06"/>
30     <circle position="2.82,-1.19" radius="0.45" color="white"/>
31     <circle position="0.26,-0.69" radius="0.64" color="black"/>
32     <objective type="connection">
33       <objective-params conn_start="black" conn_end="white" connection_range="0.49"/>
34     </objective>
35   </objective>
36 </config>
```



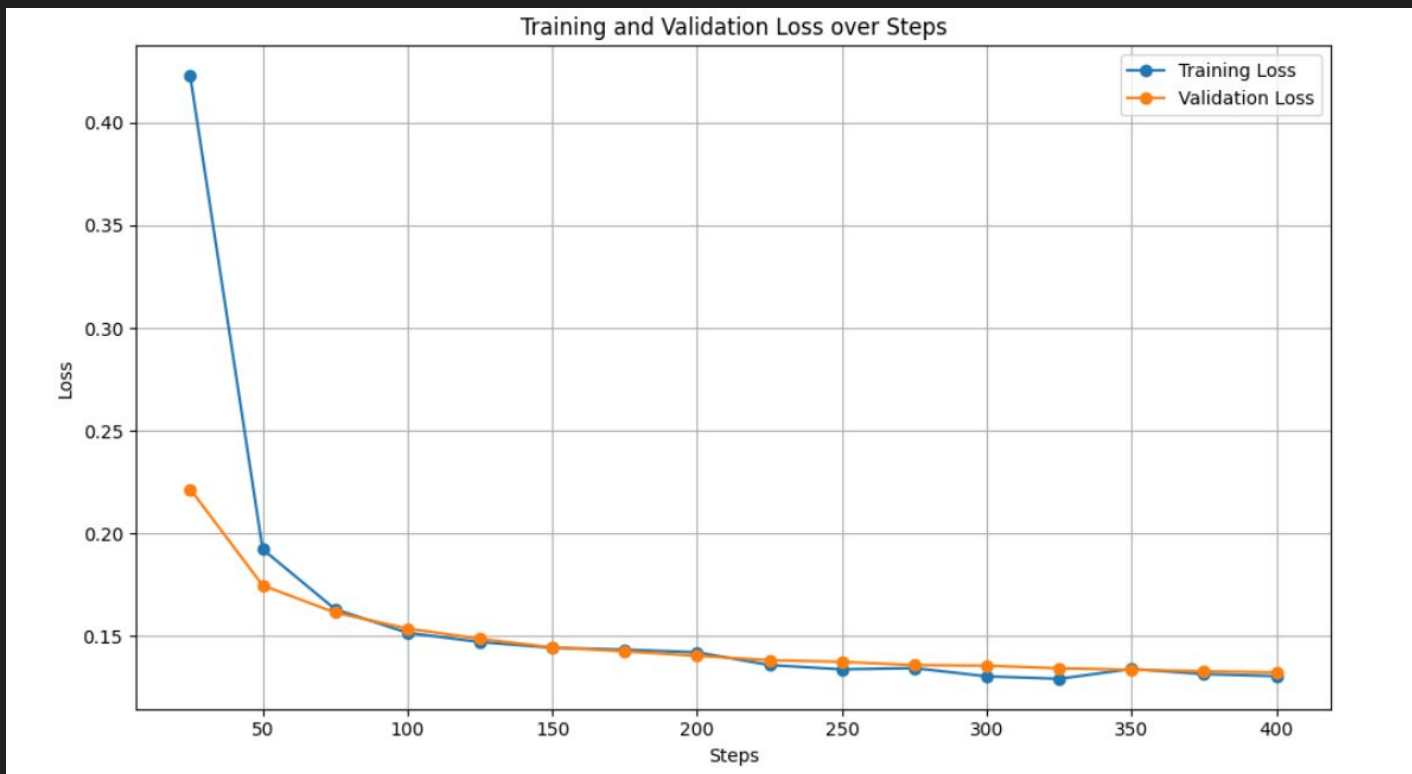
*"The rectangular area has dimensions 5.91 m x 5.80 m x 2.24 m. In the arena, 3 lights are evenly spread out with intensities 3.58, 6.43, 4.48. Within a 2.06-meter radius around the center, 8 robots are evenly positioned. Picture two circles—one at [-2.82, -1.19] with a radius of 0.45 meters, colored in white, and another at [0.26, -0.69] with a radius of 0.64 meters in black. The objective for the robots is to form a connection from the black to the white circle while maintaining a distance of just under 0.49 m."*

# LLM Finetuning - Technology



400 Training Steps, 7.5h training

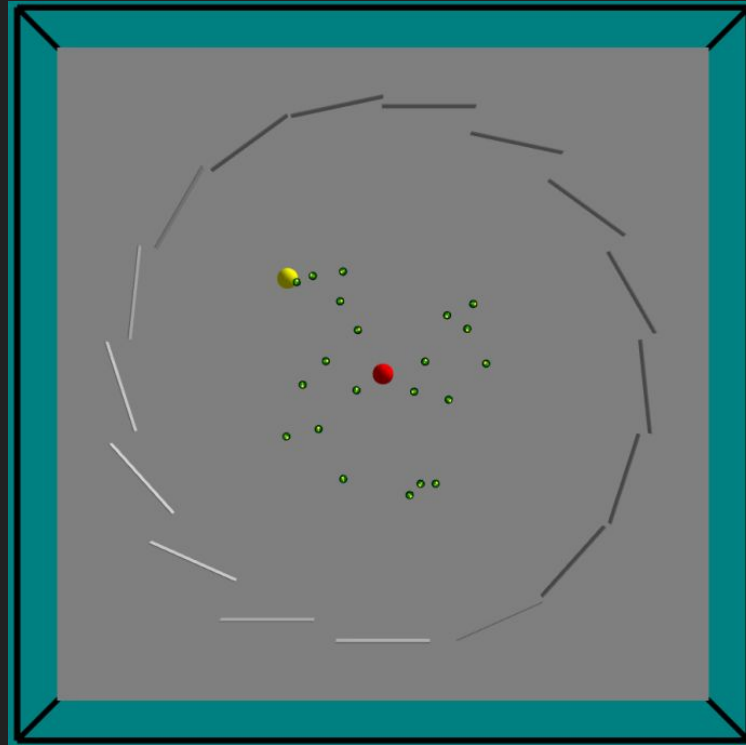
# LLM Finetuning - Training Loss



# Mission Generation Results - Evaluation



# Invalid Circular Walls



Representative example of invalid wall placement



# General Results

- Extensible framework for generating a dataset of swarm mission descriptions with corresponding configurations
- Basis for finetuning an LLM model to approach micro-macro gap
- Demonstrate working model that declaratively allows to configure using natural language
- Clear indications for why result crashes when it does
- Model fills in missing required data

*"The swarm's goal is to cover an area of 0.55 by 1.29 meters while ensuring connectivity"*

```
<objective type="distribution">  
  <objective-params area="0.55,1.29" connection_range="0.25"/>  
</objective>
```

filled in by model →

[https://github.com/julianjandeleit/swarm\\_descriptions](https://github.com/julianjandeleit/swarm_descriptions)