



# MEng. Project and Report Defense

Presenter: Andrew Garcia

Board Members: Dr. Tim Talty, Dr. Creed Jones, Dr. Yue Wang



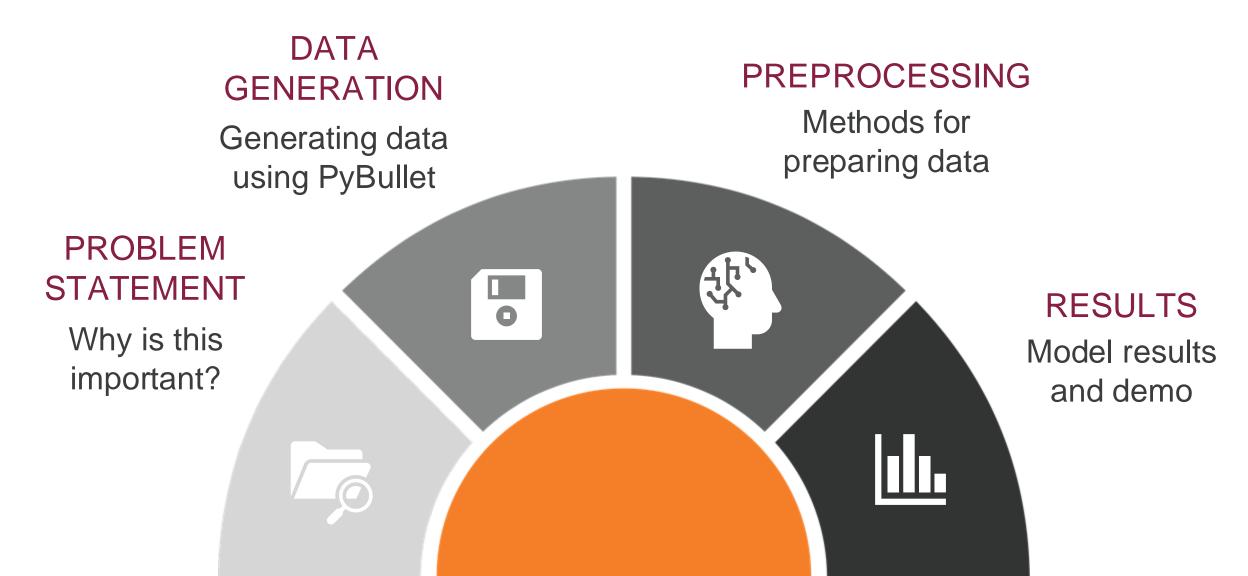
# Predicting the Landing Zone of a Projectile Object

**Andrew Garcia** 

February 9th, 2024



#### OUTLINE





#### Github

Code is available here:

https://github.com/agarcia1296/Virginia\_Tech\_Masters/tree/main/Project\_and\_Report



#### PROBLEM STATEMENT





# Early Warning Missile Detection



DSP (Defense Support Program)



**SBIRS (Space Based Infrared System)** 



Photo Credits:

(DSP) <a href="https://en.wikipedia.org/wiki/Defense Support Program">https://en.wikipedia.org/wiki/Defense Support Program</a>

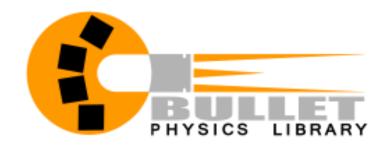
(SBIRS) https://www.spoc.spaceforce.mil/About-Us/Fact-Sheets/Display/Article/2381702/space-based-infrared-system



# DATA GENERATION

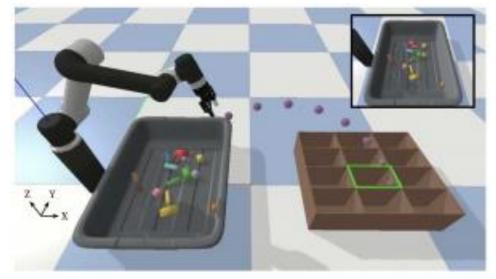






# PyBullet

- A Real-Time Physics Simulator
- Popular tool for training Deep Reinforcement Learning models
- Extensive library of objects

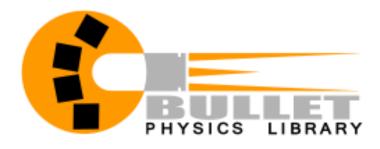


#### **Photo Credits:**

https://pybullet.org/wordpress/index.php/2019/03/30/tossingbot-learning-to-throw-arbitrary-objects-with-residual-physics/

Figure 1: PyBullet robot arm tossing objects



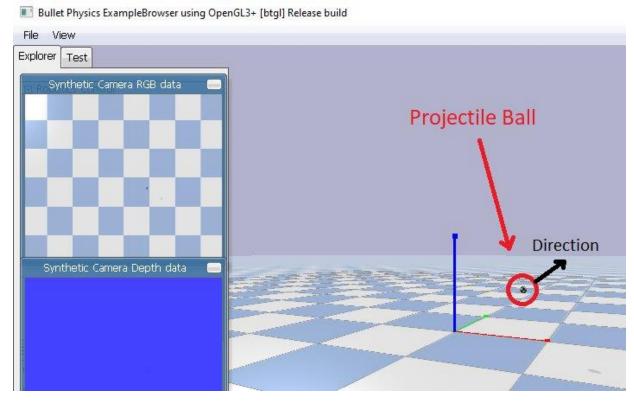


# Running Simulation

- 1000 simulations ran all with random input forces on the ball
- Random input force range:

X and Y: -20 to 20N

o Z: 10 to 20N



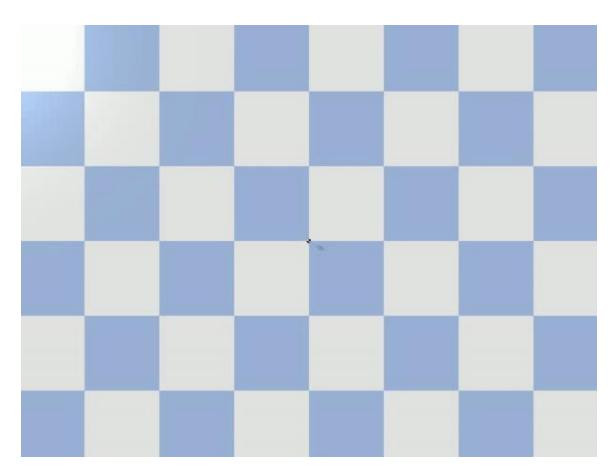
**Figure 2:** Snapshot of PyBullet while running its simulations.





# Collecting Data

- Camera fixed to topdown view
- 60 frames captured every second and saved as jpeg files
- XYZ position saved into dataframe.



**Figure 2:** Compilation of 4 different simulations to make a video.



# Data Available to Collect

- At every frame
   PyBullet provides the
   following data for any
   object:
  - Position
  - Orientation
  - Velocity

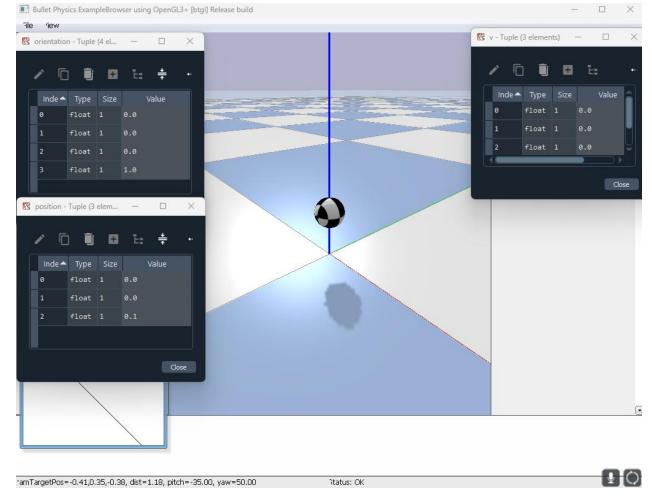


Figure 3: Close-up of Sphere and meta data.



# Script Referenced to Generate Data

- Python Script: run\_simulation.py
  - Generates 1000 simulations of data each in an individual folder.
  - Saves meta data in a csv file.

Name	Status	Date modified	Туре	
ittr000	£	2/6/2024 7:05 PM	File folder	
ittr001	£	2/6/2024 7:06 PM	File folder	
ittr002	S	2/6/2024 7:06 PM	File folder	
ittr003	ខ	2/6/2024 7:06 PM	File folder	
ittr004	ຊ	2/6/2024 7:06 PM	File folder	
ittr005	S	2/6/2024 7:06 PM	File folder	
ittr006	S	2/6/2024 7:06 PM	File folder	
ittr007	S	2/6/2024 7:06 PM	File folder	
ittr008	£	2/6/2024 7:06 PM	File folder	
ittr_df.csv	e	2/6/2024 7:29 PM	CSV File	4,010 KB



# PREPROCESSING





# Meta Data Collected

Iteration	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
0	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
0	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
0	-2.650512622	0.662628156	1.995835749	-0.132927578	0.033231894	0.208302644
			:			
0	-2.469439236	0.617359809	-2.407683125	-1.282995963	0.320748991	0.066625876
0	-2.46202476	0.61550619	-2.563954071	-1.324029709	0.331007427	0.023893309
1	0	0	0	0	0	0.1
1	0.333333333	-2.166666667	2.3365	0.00555556	-0.036111111	0.138941667
1	0.33239914	-2.160594409	2.166451771	0.011095541	-0.072121018	0.175049196
1	0.331495526	-2.154720921	1.99706236	0.016620467	-0.108033033	0.208333569
			:			
999	2.185453524	-1.717142055	-1.928719467	0.940734164	-0.739148272	0.106584891
999	2.179067618	-1.712124557	-2.086583739	0.977051958	-0.767683681	0.071808495
999	2.172575538	-1.707023637	-2.243867196	1.01326155	-0.796134075	0.034410708



### Meta Data Collected

Iteration	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
0	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
0	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
0	-2.650512622	0.662628156	1.995835749	-0.132927578	0.033231894	0.208302644
			•			
0	-2.469439236	0.617359809	-2.407683125	-1.282995963	0.320748991	0.066625876
0	-2.46202476	0.61550619	-2.563954071	-1.324029709	0.331007427	0.023893309
1	0	0	0	0	0	0.1
1	0.333333333	-2.166666667	2.3365	0.00555556	-0.036111111	0.138941667
1	0.33239914	-2.160594409	2.166451771	0.011095541	-0.072121018	0.175049196
1	0.331495526	-2.154720921	1.99706236	0.016620467	-0.108033033	0.208333569
			•			
999	2.185453524	-1.717142055	-1.928719467	0.940734164	-0.739148272	0.106584891
999	2.179067618	-1.712124557	-2.086583739	0.977051958	-0.767683681	0.071808495
999	2.172575538	-1.707023637	-2.243867196	1.01326155	-0.796134075	0.034410708

Simulation restarts when value of z position is below 0.05 meters



# Meta Data Collected

Iteration	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
0	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
0	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
0	-2.650512622	0.662628156	1.995835749	-0.132927578	0.033231894	0.208302644
			•			
0	-2.469439236	0.617359809	-2.407683125	-1.282995963	0.320748991	0.066625876
0	-2.46202476	0.61550619	-2.563954071	-1.324029709	0.331007427	0.023893309
1	0	0	0	0	0	0.1
1	0.333333333	-2.166666667	2.3365	0.00555556	-0.036111111	0.138941667
1	0.33239914	-2.160594409	2.166451771	0.011095541	-0.072121018	0.175049196
1	0.331495526	-2.154720921	1.99706236	0.016620467	-0.108033033	0.208333569
	_		•			
999	2.185453524	-1.717142055	-1.928719467	0.940734164	-0.739148272	0.106584891
999	2.179067618	-1.712124557	-2.086583739	0.977051958	-0.767683681	0.071808495
999	2.172575538	-1.707023637	-2.243867196	1.01326155	-0.796134075	0.034410708



Collects a total of 1000 simulations

#### What should our Meta Data look like?

- Know:
  - Each row represents 1 frame.
- Want:
  - Each row should have the target (final xyz position).
  - Should incorporate a type of "memory" by adding previous frame data.



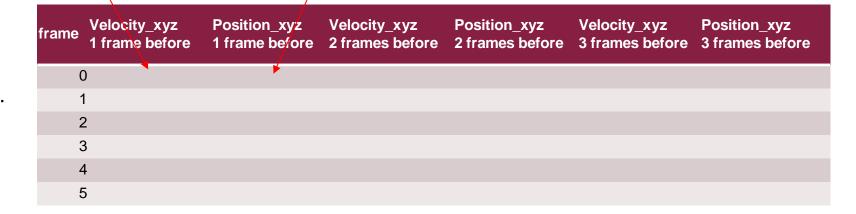
frame	V	elocity_x	velocity_y v	elocity_z	position_x	position_y	position_z
	0	0	0	C	) (	) (	0 0.1
	1	-2.666666667	0.666666667	2.3365	-0.04444444	0.01111111	1 0.138941667
	2	-2.658475375	0.664618844	2.165822893	-0.088752367	7 0.022188092	2 0.175038715
	3	-2.650512622	0.662628156	1.995835749	-0.132927578	0.03323189	4 0.208302644
	4	-2.64276705	0.660691763	1.826503334	-0.176973695	0.044243424	4 0.238744366
	5	-2.635226773	0.658806693	1.657792	-0.22089414	0.05522353	5 0.266374233

frame	Velocity_xyz 1 frame before	Position_xyz 1 frame before	Velocity_xyz 2 frames before	Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
(	0					
1	1					
2	2					
3	3					
4	4					
Ę	5					



frame	V	elocity_x	velocity_y	velocity_z	position_x	position_y	position_z
	0	0	0	0	0	C	0.1
	1	-2.666666667	0.666666667	2.3365	-0.044444444	0.01 <mark>/</mark> 1111111	0.138941667
	2	-2.658475375	0.664618844	2.165822893	-0.088752367	0. <mark>ø</mark> 22188092	0.175038715
	3	-2.650512622	0.662628156	1.995835749	-0.132927578	0.033231894	0.208302644
	4	-2.64276705	0.660691763	1.826503334	-0.176973695	0.044243424	0.238744366
	5	-2.635226773	0.658806693	1.657792	-0.220894141	0.055223535	0.266374233
				\		/	

Special case handling for frames 0-2 where there is not 3 frames of data before.





frame	V	elocity_x	velocity_y	velocity_z	positi	on_x	position_y	position_z	
	0	C	)	0	0	(	)	0	0.1
	1	-2.666666667	0.6666666	7 2.3	3365 -0	0.044444444	4 0.0111111	11 0.1389	41667
	2	-2.658475375	0.66461884	4 2.16582	2893 -0	0.08875236	7 0.0221880	0.1750	38715
	3	-2.650512622	0.66262815	6 1.99583	5749 -0	.132927578	8 0.0332318	94 0.2083	02644
	4	-2.64276705	0.66069176	3 1.82650	3334 -0	.17697369	5 0.0442434	24 0.2387	44366
	5	-2.635226773	0.65880669	3 1.65°	7792 -0	.22089414	1 0.0552235	0.2663	74233

Special case handling for frames 0-2 where there is not 3 frames of data before.

frame	Velocity_xyz 1 frame before	Position_xyz 1 frame before		Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
0	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
1			(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2					(0, 0, 0)	(0, 0, 0.1)
3						
4						
5						



. .

frame	ve	elocity_x	velocity_y	velocity_z	position_x	position_y	position_z
	0	C	0	0	0		0 0.1
	1	-2.666666667	0.666666667	2.3365	-0.04444444	0.01111111	1 0.138941667
	2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.02218809	2 0.175038715
	3	-2.650512622	0.662628156	1.995835749	-0.132927578	0.03323189	4 0.208302644
	4	-2.64276705	0.660691763	1.826503334	-0.176973695	0.04424342	4 0.238744366
	5	-2.635226773	0.658806693	1.657792	-0.220894141	0.05522353	5 0.266374233

frame	Velocity_xyz 1 frame before	_		_	Velocity_xyz 3 frames before	Position_xyz 3 frames before
(	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
1			(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2	2				(0, 0, 0)	(0, 0, 0.1)
3	3					
4						
5	5					



	ocity_x v	elocity_y v	elocity_z p	osition_x	position_y	position_z
0	0	0	0		0	0 0.1
1	-2.666666667	0.666666667	2.3365	-0.0444444	144 0.01 <mark>/</mark> 11111	11 0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.0887523	367 0.0 <mark>221880</mark>	92 0.175038715
3	-2.650512622	0.662628156	1.995835749	-0.132927	578 0. <mark>0</mark> 332318	94 0.208302644
4	-2.64276705	0.660691763	1.826503334	-0.1769736	695 <mark>0</mark> .0442434	24 0.238744366
5	-2.635226773	0.658806693	1.657792	-0.220894	141 <b>/</b> 0.0552235	35 0.266374233

frame	Velocity_xyz 1 frame before		Velocity_xyz 2 frames before			Position_xyz 3 frames before
(	(0, 0, 0)	) (0, 0, <mark>∮</mark> .1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
•	(0, 0, 0)		(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2	2				(0, 0, 0)	(0, 0, 0.1)
(	3					
4	1					
	5					



frame	V€	elocity_x	velocity_	y velo	city_z	position_	с р	osition_y	position_z
	0		0	0	0		0	(	0.1
	1	-2.6666666	667 0.6666	666667	2.3365	-0.044	444444	0.01111111	1 0.138941667
	2	-2.6584753	375 0.664	18844 2	.165822893	-0.088	752367	0.022188092	2 0.175038715
	3	-2.6505126	0.6626	62 <mark>8</mark> 156 1	.995835749	-0.132	927578	0.03323189	4 0.208302644
	4	-2.642767	705 0.6606	691763 1	.826503334	-0.176	973695	0.044243424	4 0.238744366
	5	-2.6352267	73 0.6588	306693	1.657792	-0.220	894141	0.05522353	5 0.266374233

frame	Velocity_xyz 1 frame before	Position_xyz 1 frame before			Velocity_xyz 3 frames before	Position_xyz 3 frames before
C	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2					(0, 0, 0)	(0, 0, 0.1)
3						
4						
5						



	n_z
0 0 0 0 0 0	0.1
1 -2.666666667 0.6666666667 2.3365 -0.044444444 0.011111111 0.1	138941667
2 -2.658475375 0.664618844 2.165822893 -0.088752367 0.022188092 0.	175038715
3 -2.650512622 0.662628156 1.995835749 -0.132927578 0.03/3231894 0.2	208302644
4 -2.64276705 0.660691763 1.826503334 -0.176973695 0.044243424 0.2	238744366
5 -2.635226773 0.658806693 1.657792 -0.220894141 0. <mark>0</mark> 55223535 0.2	266374233

f	rame	Velocity_xyz 1 frame before	Position_xyz 1 frame before		Position_xyz 2 frames before		Position_xyz 3 frames before
	0	(0, 0, 0)	(0, 0, <mark>/</mark> 0	0.1) (0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0)	(0, <mark>9</mark> , 0	0.1) (0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2	(-2.67, 0.67, 2.33)	)			(0, 0, 0)	(0, 0, 0.1)
	3						
	4						
	5						



frame	V	elocity_x	velocity_y	velocity_	z positio	n_x	position_y	position_z
	0		0	0	0	0	(	0.1
	1	-2.6666666	67 0.666666	667	2.3365 -0.	04444444	0.011111111	0.138941667
	2	-2.6584753	75 0.664618	844 2.165	822893 -0.	088752367	0.022188092	0.175038715
	3	-2.6505126	22 0.662628	156 1.995	835749 -0.	132927578	0.033231894	0.208302644
	4	-2.642767	0.660691	763 1.826	503334 -0.	176973695	0.044243424	0.238744366
	5	-2.6352267	73 0.658806	693 1.0	657792 -0.	220894141	0.055223535	0.266374233

frai	me )	Velocity_xyz I frame before	Position_xyz 1 frame before	Velocity_xyz 2 frames before	Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
	0	(0, 0, 0)	(0, 0, 0.1	1) (0, 0, 0	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0)	(0, 0, 0.1	1) (0, 0, 0	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13	3)		(0, 0, 0)	(0, 0, 0.1)
	3						
	4						
	5						



frame	V€	elocity_x	velocity_y	velocity_z	position_x	position_	_y position_	z
	0		0	0	0	0	0	0.1
	1	-2.66666666	0.6666666	7 2.33	65 -0.044	444444 0.011	1111 <mark>1</mark> 11 0.13	8941667
	2	-2.65847537	75 0.66461884	4 2.1658228	93 -0.088	752367 0.022	2188092 0.17	'5038715
	3	-2.65051262	22 0.66262815	6 1.9958357	49 -0.132	927578 0.033	3231894 0.20	8302644
	4	-2.6427670	0.66069176	3 1.8265033	34 -0.176	973695 0.044	4243424 0.23	8744366
	5	-2.63522677	73 0.65880669	3 1.6577	92 -0.220	894141 0.055	5223535 0.26	6374233

frame				Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
C	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2	2 (-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)		(0, 0, 0)	(0, 0, 0.1)
3	3					
4	1					
5	5					



. .

frame	V	elocity_x	velocity_y	veloci	ty_z po	osition_x	position_y	y positi	ion_z
	0		0	0	0		0	0	0.1
	1	-2.6666666	67 0.66666	6667	2.3365	-0.0444444	44 0.0111	11111 (	0.138941667
	2	-2.6584753	75 0.66461	8844 2.10	65822893	-0.0887523	67 0.0221	88092	0.175038715
	3	-2.6505126	22 0.66262	8156 1.99	95835749	-0.1329275	78 0.0332	231894 (	0.208302644
	4	-2.642767	05 0.66069	1.82	26503334	-0.1769736	95 0.0442	243424 (	0.238744366
	5	-2.6352267	73 0.65880	6693	1.657792	-0.2208941	41 0.0552	223535 (	0.266374233

frame					Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
	0	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2 (	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
:	3						
	4						
	5						



fra	me '	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
	0		0 0	0		0	0 0.1
	1	-2.66666666	7 0.666666667	2.3365	-0.0444444	44 0.0111111	11 0.138941667
	2	-2.65847537	5 0.664618844	2.165822893	-0.0887523	67 0.0221880	92 0.175038715
	3	-2.65051262	2 0.662628156	1.995835749	-0.1329275	78 0.03 <mark>8</mark> 2318	94 0.208302644
	4	-2.6427670	5 0.660691763	1.826503334	-0.1769736	95 0.0 <mark>4</mark> 42434	24 0.238744366
	5	-2.635226773	3 0.658806693	1.657792	-0.2208941	41 0. <mark>ø</mark> 552235	0.266374233

fra	ame	Velocity_xyz 1 frame before	Position_xyz 1 frame before		Position_xyz 2 frames before		Position_xyz 3 frames before
	0	(0, 0, 0)	(0, 0, 0.1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0)	(0, 0 <mark>,</mark> 0.1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2	(-2.67, 0.67, 2.33)	(-0.04, 0.01 <mark>,</mark> 0.13	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	3	(-2.65, 0.66, 2.16)					
	4						
	5						



frame	VE	elocity_x	velocity_y	, velo	city_z	position_x	pos	ition_y	position_z
	0		0	0	0		0	0	0.1
	1	-2.6666666	667 0.6666	66667	2.3365	-0.0444	44444	0.011111111	0.138941667
	2	-2.6584753	375 0.6646	18844 2.	165822893	-0.0887	52367	0.022188092	0.175038715
	3	-2.6505126	0.6626	28156 1.	995835749	-0.1329	27578	0.033231894	0.208302644
	4	-2.642767	705 0.6606	91763 1.	826503334	-0.1769	73695	0.044243424	0.238744366
	5	-2.6352267	773 0.6588	06693	1.657792	-0.2208	94141	0.055223535	0.266374233

fram	Velocity_xy:			Velocity_xyz 2 frames before	Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
	0 (0	0, 0, 0)	(0, 0, 0.1)	(0, 0,	0) (0, 0, 0.1	(0, 0, 0)	(0, 0, 0.1)
	1 (0	), 0, 0)	(0, 0, 0.1)	(0, 0,	0) (0, 0, 0.1	(0, 0, 0)	(0, 0, 0.1)
	2 (-2.67, 0.67,	, 2.33) (-0	0.04, 0.01, 0.13)	(0, 0,	0) (0, 0, 0.1	(0, 0, 0)	(0, 0, 0.1)
	3 (-2.65, 0.66,	, 2.16) (-0	0.08, 0.02, 0.17)	*			
	4						
	5						



frame	V€	elocity_x	velocity_y	velocity_z	position_x	position	_y posit	tion_z
	0	0	0		0	0	0	0.1
	1	-2.666666667	0.666666667	2.336	5 -0.04444	44444 0.01 <i>°</i>	1111111	0.138941667
	2	-2.658475375	0.664618844	2.16582289	3 -0.0887	52367 0.022	2188092	0.175038715
	3	-2.650512622	0.662628156	1.99583574	9 -0.13292	27578 0.033	3231894	0.208302644
	4	-2.64276705	0.660691763	1.82650333	4 -0.17697	73695 0.044	4243424	0.238744366
	5	-2.635226773	0.658806693	1.65779	2 -0.22089	94141 0.05	5223535	0.266374233

frame	Velocity 1 frame				Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
(	)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
•	1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2	2 (-2.67,	0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
3	3 (-2.65,	0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)			
4	1						
5	5						



frame	V	elocity_x	velocity_y	velocity_z	position_x	position_y	position_z
	0		0 (	) 0	0	(	0.1
	1	-2.66666666	7 0.66666667	2.3365	-0.04444444	0.01111111	1 0.138941667
	2	-2.65847537	5 0.664618844	2.165822893	-0.088752367	0.022188092	2 0.175038715
	3	-2.65051262	2 0.662628156	1.995835749	-0.132927578	0.033231894	4 0.208302644
	4	-2.6427670	5 0.660691763	3 1.826503334	0.176973695	0.044243424	4 0.238744366
	5	-2.63522677	3 0.658806693	3 1.657792	-0.220894141	0.05522353	5 0.266374233

frame	Velocity_xyz 1 frame before			Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
(	(0, 0, 0	0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
1	(0, 0, 0	0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2	2 (-2.67, 0.67, 2.33	3) (-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
3	3 (-2.65, 0.66, 2.16	6) (-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)		
4	1					
5	5					



frame	V	elocity_x	velocity_y	velo	city_z	pos	ition_x	p	osition_y p	oosition_z
	0		0	0	(	)		0	0	0.1
	1	-2.66666666	0.66666	66667	2.3365	5	-0.0444444	144	0.011111111	0.138941667
	2	-2.65847537	75 0.6646°	18844 2	2.165822893	3	-0.0887523	367	0.022188092	0.175038715
	3	-2.65051262	22 0.66262	28156 1	.995835749	9	-0.1329275	578	0.033231894	0.208302644
	4	-2.6427670	0.66069	91763 1	.826503334	1	-0.1769736	95	0.044243424	0.238744366
	5	-2.63522677	73 0.65880	06693	1.657792	2	-0.2208941	141	0.055223535	0.266374233

frame	Velocit 1 frame				Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
	0	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2 (-2.67,	0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	3 (-2.65,	0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	*
	4						
	5						



frame	V	elocity_x	velocity_y	velocity_z	position_x	position_y	position_z
	0		0 (	) 0		0	0 0.1
	1	-2.66666666	7 0.666666667	2.3365	-0.04444444	4 0.01111111	11 0.138941667
	2	-2.65847537	5 0.664618844	2.165822893	-0.08875236	7 0.02218809	0.175038715
	3	-2.65051262	2 0.662628156	1.995835749	-0.13292757	8 0.03323189	0.208302644
	4	-2.6427670	5 0.66 <mark>0</mark> 691763	3 1.826503334	-0.17697369	5 0.04424342	0.238744366
	5	-2.63522677	3 0.658806693	3 1.657792	-0.22089414	1 0.05522353	0.266374233

fran						Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
	0		(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1		(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2	(-2.67,	0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	3	(-2.65,	0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)
	4							
	5							



0 0 0 0 0 0	0.1
	• • •
1 -2.666666667 0.666666667 2.3365 -0.044444444 0.011111111 0.13894	41667
2 -2.658475375 0.664618844 2.165822893 -0.088752367 0.022188092 0.17503	38715
3 -2.650512622 0.662628156 1.995835749 -0.132927578 0.033231894 0.20830	02644
4 -2.64276705 0.660691763 1.826503334 -0.176973695 0.044243424 0.23874	44366
5 -2.635226773 0.658806693 1.657792 -0.220894141 0.0 <mark>5</mark> 5223535 0.26637	74233

frame	Velocity 1 frame	_xyz before	Position_xyz 1 frame before	Velocity_xyz 2 frames before	Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
	0	(0, 0, 0)	(0, 0, 0.1)	(0, 0,	0, 0, 0.	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0)	(0, 0/0.1)	(0, 0,	0, 0, 0.	(0, 0, 0)	(0, 0, 0.1)
	2 (-2.67, 0	0.67, 2.33)	(-0.04, 0.01/0.13)	(0, 0,	0, 0, 0.	(0, 0, 0)	(0, 0, 0.1)
:	3 (-2.65, 0	0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.3	3) (-0.04, 0.01, 0.13	(0, 0, 0)	(0, 0, 0.1)
	4 (-2.65, 0	0.66, 1.99)	•				
	5						



frame	V	elocity_x	velocity_y	velocity_z	position_x	position_y	position_	_z
	0		0 0	) (	)	0	0	0.1
	1	-2.66666666	7 0.666666667	2.3365	-0.044444	0.0111	11111 0.13	38941667
	2	-2.65847537	5 0.664618844	2.165822893	-0.088752	2367 0.0221	88092 0.17	75038715
	3	-2.65051262	2 0.662628156	1.995835749	0.132927	7578 0.0332	31894 0.20	08302644
	4	-2.6427670	5 0.660691763	1.826503334	-0.176973	3695 0.0442	43424 0.23	38744366
	5	-2.63522677	3 0.658806693	1.657792	2 -0.220894	1141 0.0552	23535 0.26	66374233

f	rame	Velocity_xyz 1 frame befor	e '		Velocity_xyz 2 frames before	Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
	C	(0,	0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0,	0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2	2 (-2.67, 0.67, 2	.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	3	3 (-2.65, 0.66, 2	.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)
	4	(-2.65, 0.66, 1	.99)	(-0.13, 0.03, 0.20)				
	5	<b>,</b>						



frame	V€	elocity_x	velocity_y v	elocity_z	position_x	position	_y positio	n_z
	0	0	0	(	)	0	0	0.1
	1	-2.666666667	0.666666667	2.3365	-0.04444	4444 0.01 <i>°</i>	1111111 0.	.138941667
	2	-2.658475375	0.664618844	2.165822893	3 -0.08875	2367 0.022	2188092 0.	.175038715
	3	-2.650512622	0.662628156	1.995835749	-0.13292	7578 0.033	3231894 0.	.208302644
	4	-2.64276705	0.660691763	1.826503334	4 -0.17697	3695 0.044	42434 <mark>2</mark> 4 0.	.238744366
	5	-2.635226773	0.658806693	1.657792	2 -0.22089	4141 0.055	5223535 0.	.266374233

fi	rame	Velocity_xyz 1 frame before	Position_xyz 1 frame before	<b>\</b>	Position_xyz 2 frames before		Position_xyz 3 frames before
	C	(0, 0, 0	0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0	0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2	(-2.67, 0.67, 2.33	3) (-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	3	3 (-2.65, 0.66, 2.16	6) (-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)
	4	(-2.65, 0.66, 1.99	9) (-0.13, 0.03, 0.20)	(-2.65, 0.66, 2.16)			
	5	, ,					



frame	V€	elocity_x	velocity_y	velocity	y_z p	osition_x	position	_y positio	on_z
	0		0	0	0		0	0	0.1
	1	-2.66666666	67 0.666666	667	2.3365	-0.044444	444 0.011	1111111 0	.138941667
	2	-2.65847537	75 0.664618	344 2.16	5822893	-0.088752	367 0.022	2188092 0	.175038715
	3	-2.65051262	22 0.662628°	156 1.99	5835749	-0.132927	578 0.033	3231894 0	.208302644
	4	-2.6427670	0.6606917	763 1.82	26503334	-0.176973	695 0.044	4243424 0	.238744366
	5	-2.63522677	73 0.6588066	693 ·	1.657792	-0.220894	141 0.055	5223535 0	.266374233

fr	ame	Velocity_xyz 1 frame before				Velocity_xyz 3 frames before	Position_xyz 3 frames before
	C	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	2	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
	3	(-2.65, 0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)
	4	(-2.65, 0.66, 1.99)	(-0.13, 0.03, 0.20)	(-2.65, 0.66, 2.16)	(-0.08, 0.02, 0.17)	•	
	5						



frame	V€	elocity_x	velocity_y	velocity_z	pos	sition_x	position_y	ро	sition_z
	0	(	)	0	0		0	0	0.1
	1	-2.66666666	7 0.6666666	7 2.3	365	-0.04444444	4 0.01111	1111	0.138941667
	2	-2.65847537	5 0.66461884	4 2.165822	893	-0.08875236	7 0.02218	8092	0.175038715
	3	-2.650512622	2 0.66262815	6 1.995835	749	-0.13292757	8 0.03323	1894	0.208302644
	4	-2.64276705	0.66069176	3 1.826503	334	-0.17697369	5 0.04424	3424	0.238744366
	5	-2.635226773	0.65880669	3 1.657	792	-0.22089414	1 0.05522	3535	0.266374233

frame	Velocity 1 frame			Velocity_xyz 2 frames before	Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
(	)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0	(0, 0, 0.1	(0, 0, 0)	(0, 0, 0.1)
1		(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0	(0, 0, 0.1	(0, 0, 0)	(0, 0, 0.1)
2	2 (-2.67, 0	0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0	(0, 0, 0.1	(0, 0, 0	(0, 0, 0.1)
3	3 (-2.65, 0	0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33	3) (-0.04, 0.01, 0.13	(0, 0, 0)	(0, 0, 0.1)
4	4 (-2.65, 0	0.66, 1.99)	(-0.13, 0.03, 0.20)	(-2.65, 0.66, 2.16	6) (-0.08, 0.02, 0.17	7) (-2.67, 0.67, 2.33	)
5	5						



frame	V€	elocity_x	velocity_y	velocity_z	positi	on_x	position_y	position_z	
	0		0	0	0	(	0	0	0.1
	1	-2.66666666	7 0.6666666	67 2.3	3365 -0	.04444444	4 0.0111111	11 0.138	941667
	2	-2.65847537	5 0.66461884	14 2.165822	2893 -0	.08875236	7 0.0221880	92 0.175	038715
	3	-2.65051262	2 0.66262815	56 1.995835	5749 -C	.13292757	8 0.0332318	94 0.208	302644
	4	-2.6427670	5 0.66069176	3 1.826503	3334 -0	.17697369	5 0.0442434	24 0.238	744366
	5	-2.63522677	3 0.65880669	93 1.657	7792 -0	.22089414	1 0.0552235	35 0.266	374233

frame	Velocit 1 frame	y_xyz before			Position_xyz 2 frames before	Velocity_xyz 3 frames before	Position_xyz 3 frames before
(	)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
•	1	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2	2 (-2.67,	0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
;	3 (-2.65)	0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)	(0, 0, 0)	(0, 0, 0.1)
4	4 (-2.65,	0.66, 1.99)	(-0.13, 0.03, 0.20)	(-2.65, 0.66, 2.16)	(-0.08, 0.02, 0.17)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)
	5						



### Adding Final Position Data

 For each iteration, the final position is added.

frame	pos	sition_x	position_y	position_z	final_pos_x	final_pos_y	final_pos_z
	0	0	0	0.1	-1.324029709	0.331007427	0.023893309
	1	-0.04444444	0.011111111	0.138941667	-1.324029709	0.331007427	0.023893309
	2	-0.088752367	0.022188092	0.175038715	-1.324029709	0.331007427	0.023893309
	3	-0.132927578	0.033231894	0.208302644	-1.324029709	0.331007427	0.023893309
	4	-0.176973695	0.044243424	0.238744366	-1.324029709	0.331007427	0.023893309
	5	-0.220894141	0.055223535	0.266374233	-1.324029709	0.331007427	0.023893309
	29	-1.241838643	0.310459661	0.106753928	3 -1.32402970	9 0.331007427	7 0.023893309
	30	-1.282995963	0.320748991	0.066625876	-1.32402970	9 0.331007427	7 0.023893309
	31	-1.324029709	0.331007427	0.023893309	-1.32402970	9 0.331007427	7 0.023893309



### Adding Final Position Data

- For each iteration, the final position is added.
- This will be the target data.

fu a un a		itian			inal naa n		::
frame	pos	sition_x	position_y	position_z f	inal_pos_x fi	nal_pos_y f	inal_pos_z
	0	0	0	0.1	-1.324029709	0.331007427	0.023893309
	1	-0.044444444	0.011111111	0.138941667	-1.324029709	0.331007427	0.023893309
	2	-0.088752367	0.022188092	0.175038715	-1.324029709	0.331007427	0.023893309
	3	-0.132927578	0.033231894	0.208302644	-1.324029709	0.331007427	0.023893309
	4	-0.176973695	0.044243424	0.238744366	-1.324029709	0.331007427	0.023893309
	5	-0.220894141	0.055223535	0.266374233	-1.324029709	0.331007427	0.023893309
				_			
	29	-1.241838643	3 0.310459661	0.106753928	-1.324029709	0.331007427	0.023893309
	30	-1.282995963	3 0.320748991	0.066625876	-1.324029709	0.331007427	0.023893309
	31	-1.324029709	9 0.331007427	0.023893309	-1.324029709	0.331007427	0.023893309



# Script Referenced to Prepare Meta Data

- Python Script: adding\_data.py
  - Reads in simulation meta data CSV
  - Outputs meta data CSV with previous frame data



# MODELS & RESULTS



#### Models Tested

- Conv2DPlus1
- Linear Regression
- Multi-layer Perceptron Classifier



#### Conv2DPlus1

- Mean Absolute Error: 75.42
  - This is not a good result (lower is better)

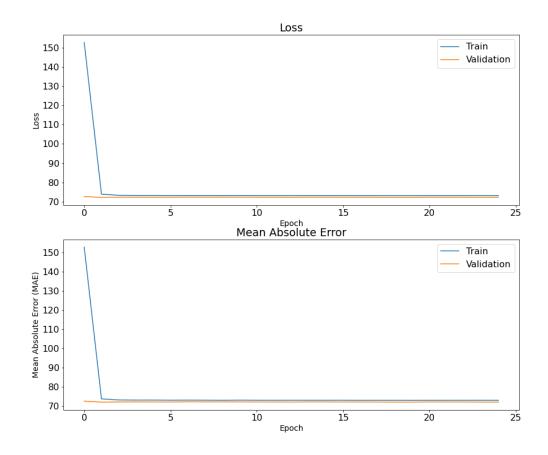
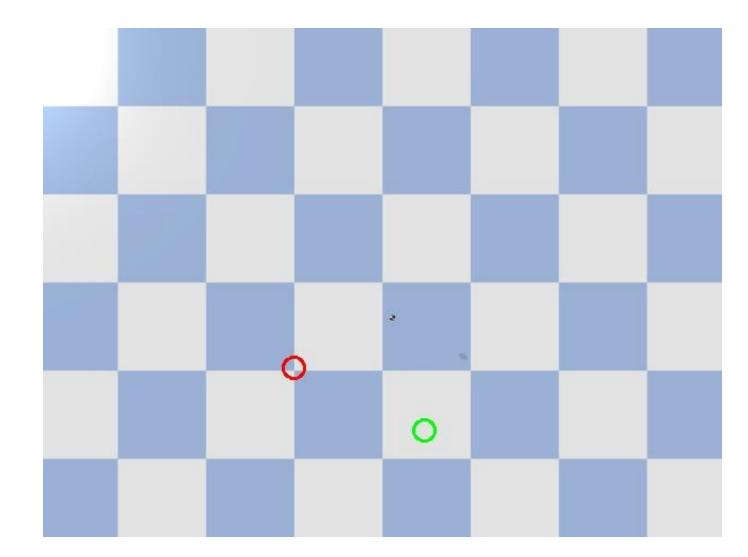


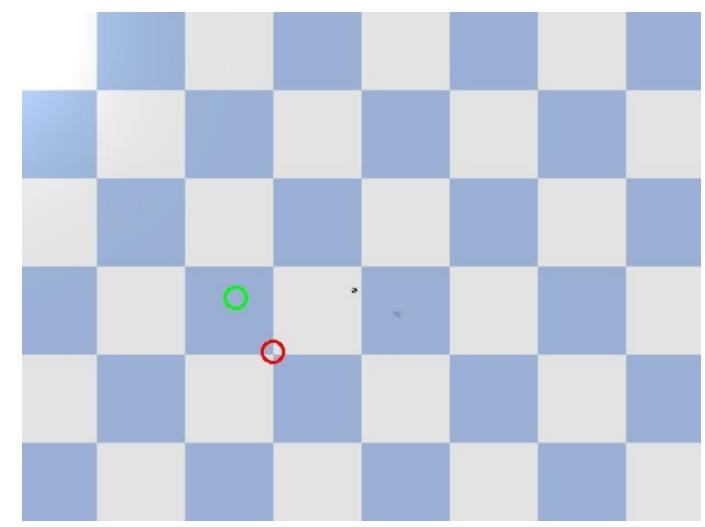
Figure 4: Loss and MEA of CNN model.





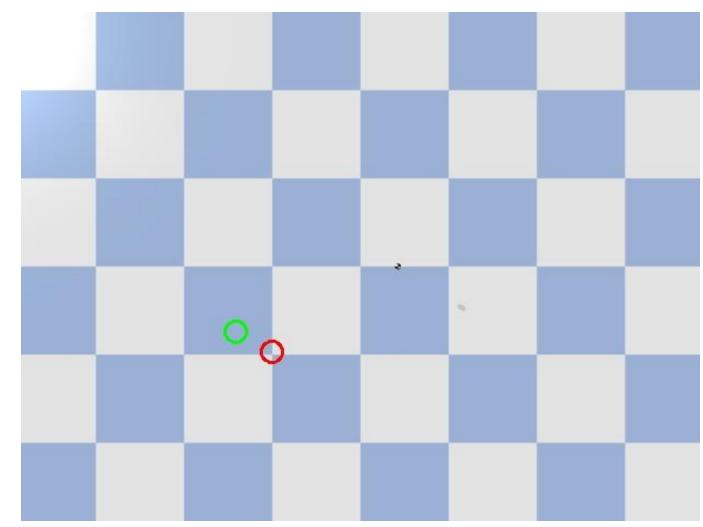


#### Predicting same location every time...



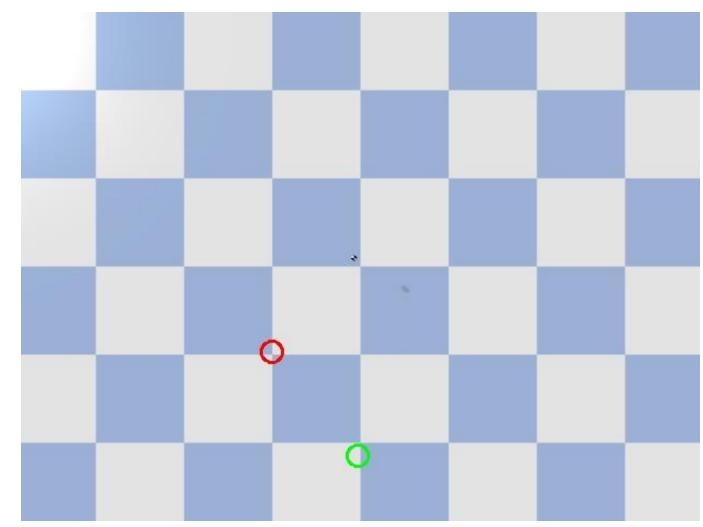


#### Predicting same location every time...





#### Predicting same location every time...

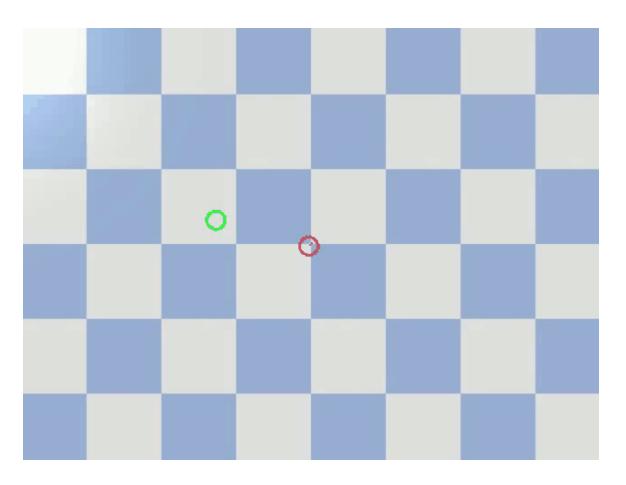




# Linear Regression Results

 Coefficient of Determination (R2): 73.02%

• **MSE**: 0.035



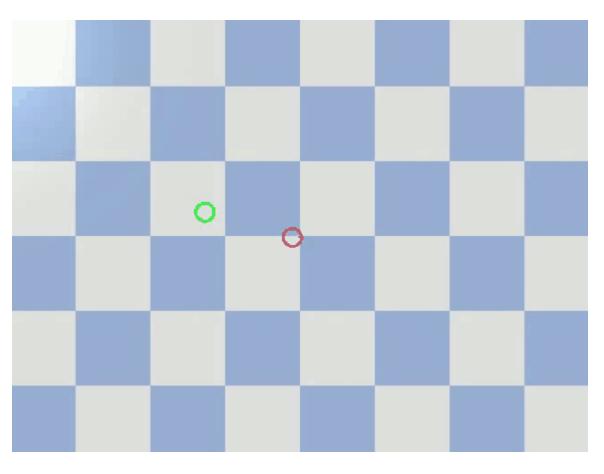
**Figure 5:** Green is actual, and Red is predicted landing zone of projectile.



# Multi-layer Perceptron Classifier

#### Model Details:

- Activation: relu
- Hidden Layers: 3
- Neurons: 200 each layer
- Coefficient of Determination (R2): 73.02%
- **MSE**: 0.020
- Test Accuracy: 82.8%



**Figure 6:** Green is actual, and Red is predicted landing zone of projectile.



# Script Referenced to Train and Test Models

- Python Script: run\_ML\_prediction.py
  - Reads in meta data CSV
  - Trains and Scores models
  - Outputs videos of each model



# **FUTURE WORK**





#### **Future Work**

- Adding external forces to the ball to change direction.
  - This can simulate wind or atmospheric affects.
- Set the origin to be other locations rather than (0,0)
- Train a CNN only on image data.



#### Lessons Learned

- Data preparation is paramount.
- Understanding what inputs are needed for models.



