
VIRGINIA TECH®

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

DATA GENERATION

Generating data using PyBullet

PREPROCESSING

Methods for preparing data

PROBLEM STATEMENT

Why is this important?

RESULTS

Model results and demo

Github

Code is available here:

https://github.com/agarcia1296/Virginia_Tech_Masters/tree/main/Project_and_Report

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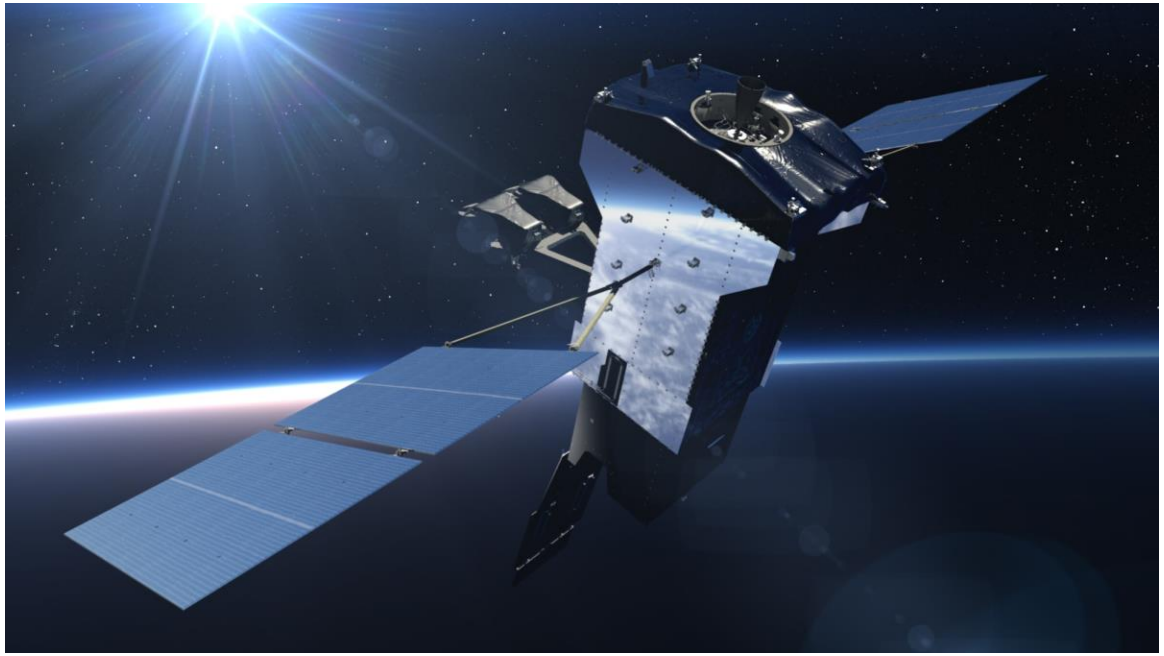
PROBLEM STATEMENT

Early Warning Missile Detection

DSP (Defense Support Program)



SBIRS (Space Based Infrared System)

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Photo Credits:
(DSP) https://en.wikipedia.org/wiki/Defense_Support_Program
(SBIRS) https://www.spoc.spaceforce.mil/About-Us/Fact-Sheets/Display/Article/2381702/space-based-infrared-system

Interest

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Photo Credits:
https://aviationweek.com/defense-space/missile-defense-weapons/us-space-development-agency-awards-ir-missile-tracking

DATA GENERATION

PyBullet

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

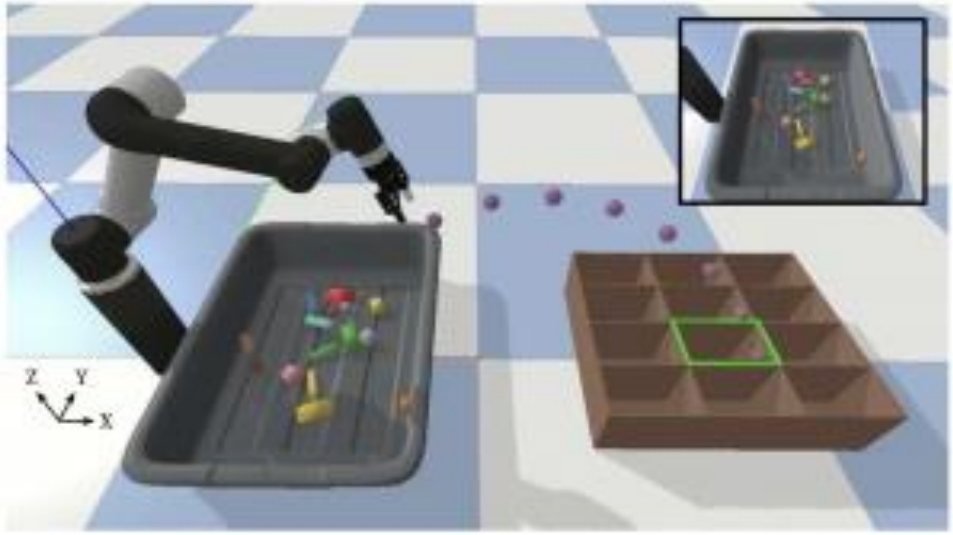

Photo Credits:
https://pybullet.org/wordpress/index.php/2019/03/30/tossingbot-learning-to-throw-arbitrary-objects-with-residual-physics/

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
  - Z: 10 to 20N

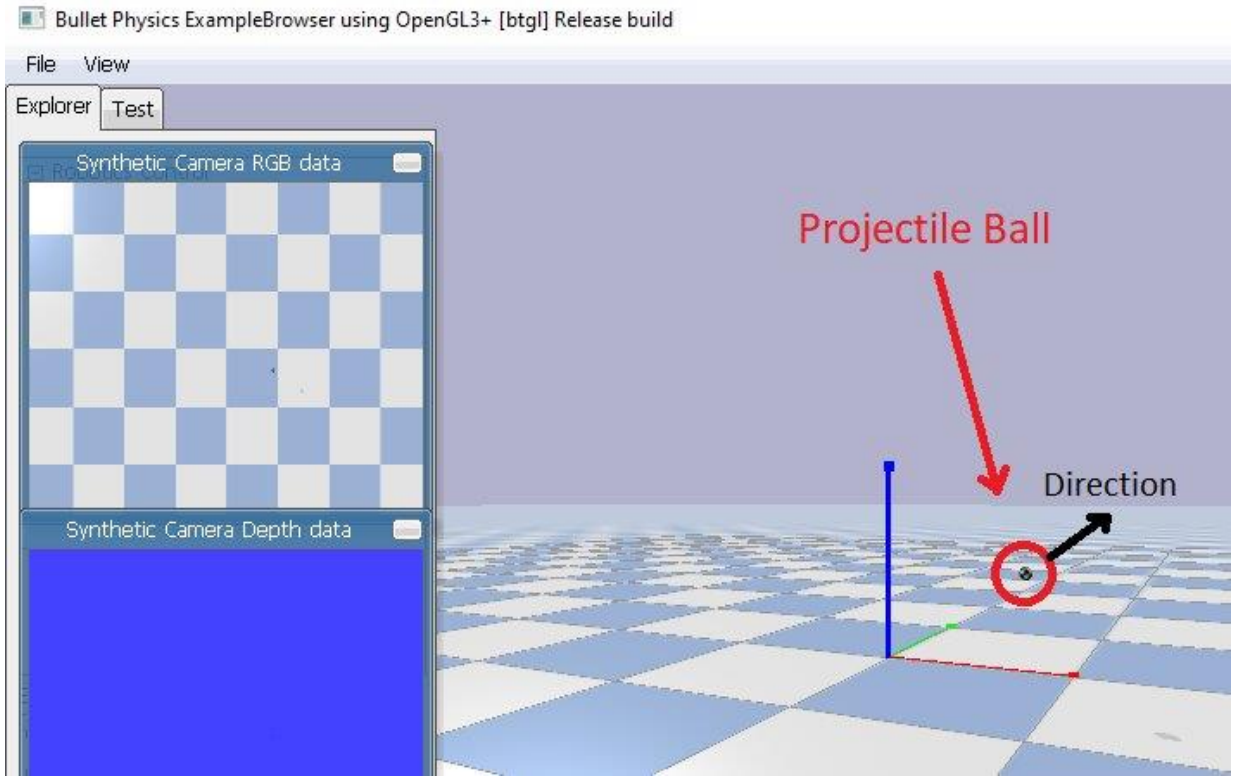

Figure 2: Snapshot of PyBullet while running its simulations.

Collecting Data

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

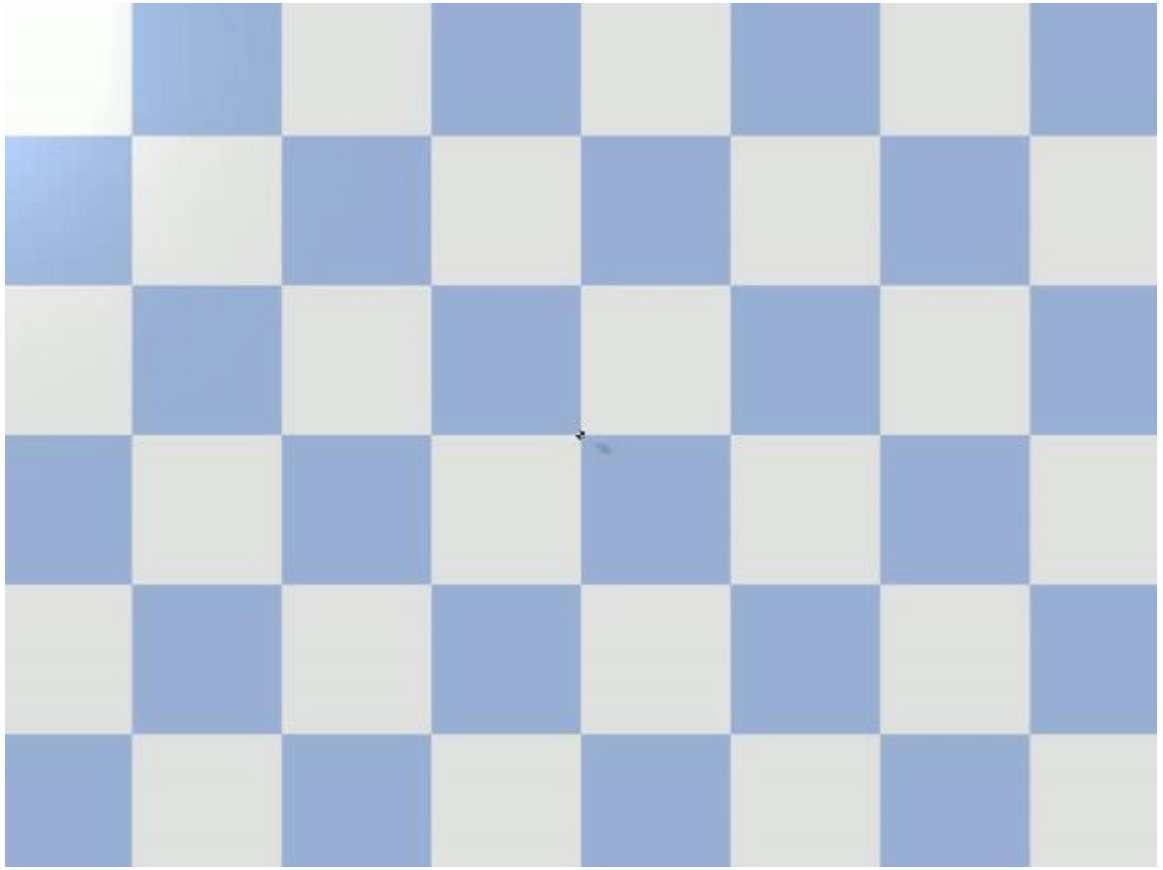

Figure 2: Compilation of 4 different simulations to make a video.

Data Available to Collect

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

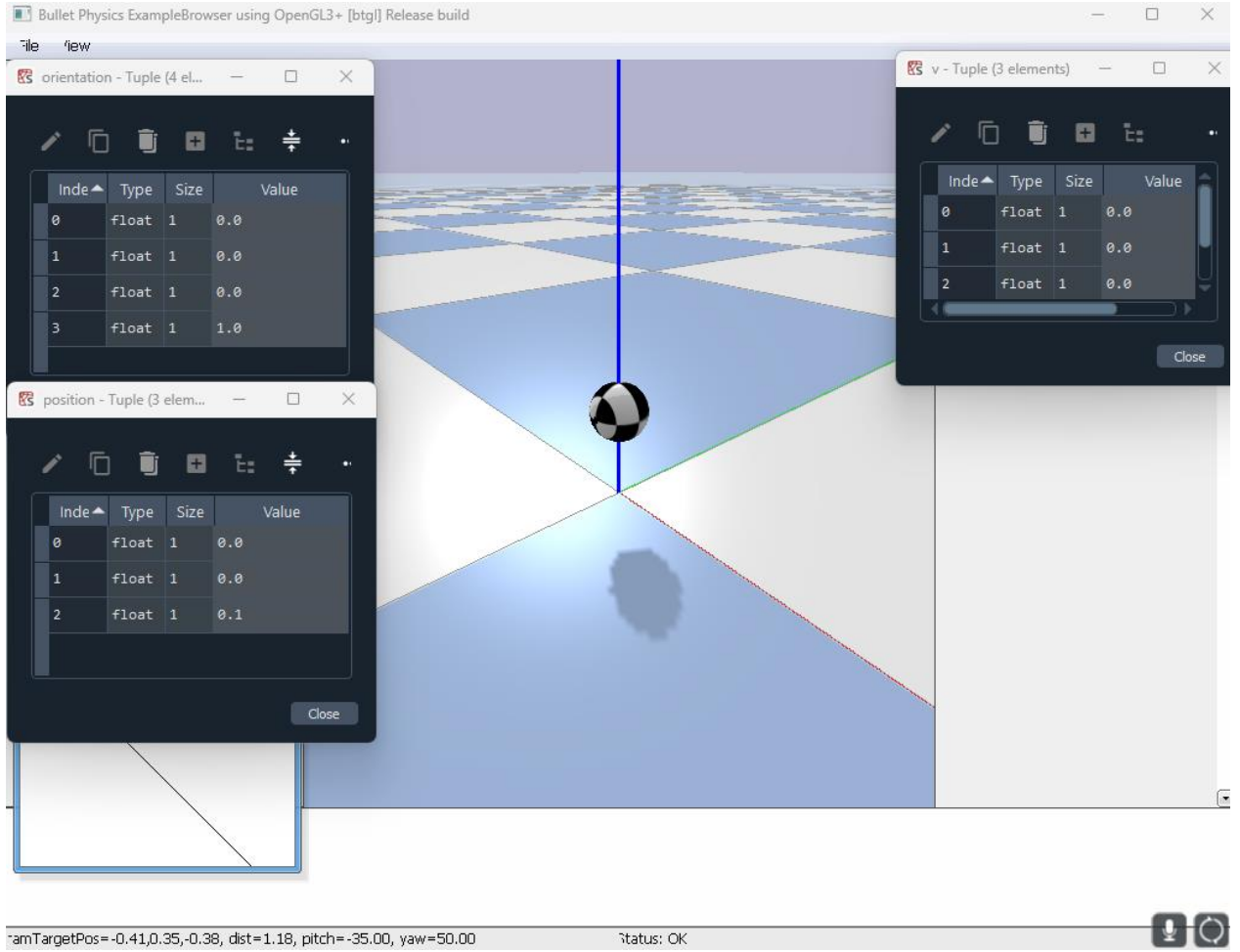

Figure 3: Close-up of Sphere and meta data.

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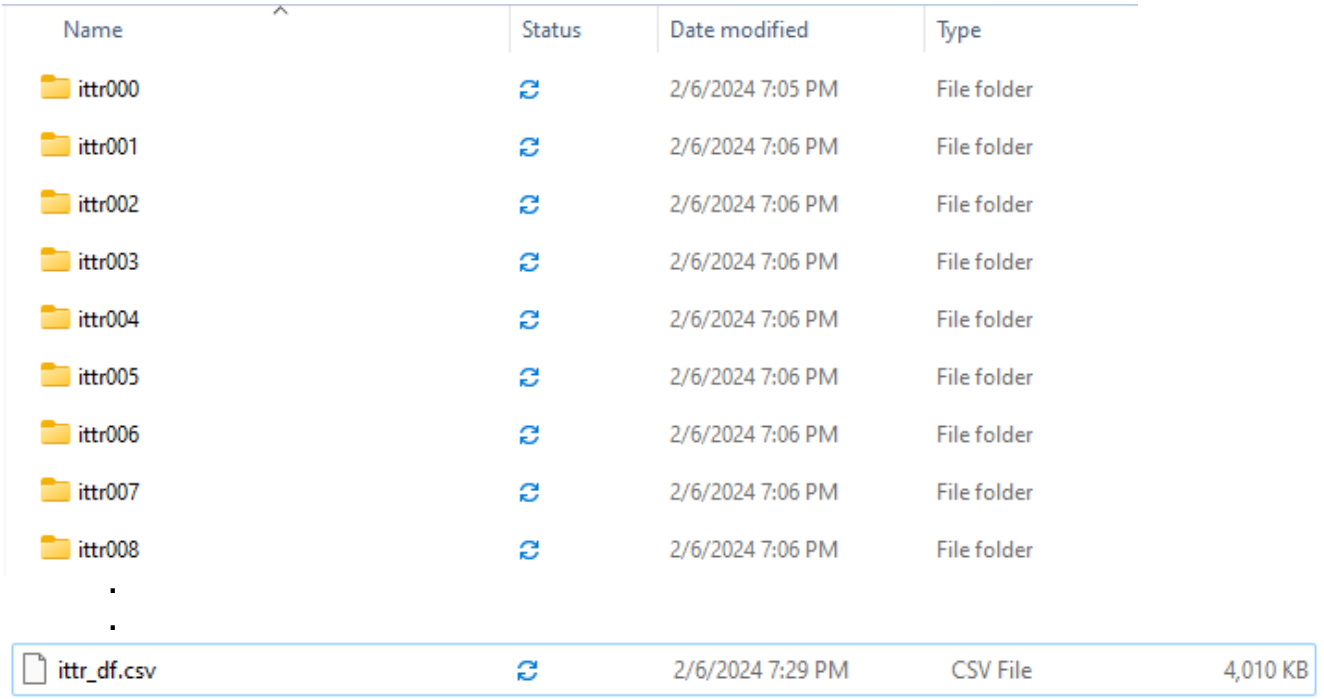
Script Referenced to Generate Data

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



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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	0.005555556	-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	0.005555556	-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

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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	0.005555556	-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

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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.

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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						
2						
3						
4						
5						

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Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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						
2						
3						
4						
5						

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

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Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
3	-2.650512622	0.662628156	1.995835749	-0.132927578	0.033231894	0.208302644
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Special case handling for frames 0-2 where there is not 3 frames of data before.

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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	(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						

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Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
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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	(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						

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Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
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2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
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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	(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)	(0, 0, 0.1)	(0, 0, 0)	(0, 0, 0.1)
2					(0, 0, 0)	(0, 0, 0.1)
3						
4						
5						

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Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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
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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	(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						

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Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
3	-2.650512622	0.662628156	1.995835749	-0.132927578	0.033231894	0.208302644
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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	(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, 0)	(0, 0, 0.1)
3						
4						
5						

VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	0.175038715
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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	(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)
3						
4						
5						

VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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
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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	(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)	(0, 0, 0.1)
3						
4						
5						

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Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
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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	(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						

VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)					
4						
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)				
4						
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)			
4						
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)		
4						
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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						
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)					
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)				
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)			
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)		
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)	(-2.67, 0.67, 2.33)	
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VIRGINIA TECH

Adding Previous Frame Data

frame	velocity_x	velocity_y	velocity_z	position_x	position_y	position_z
0	0	0	0	0	0	0.1
1	-2.666666667	0.666666667	2.3365	-0.044444444	0.011111111	0.138941667
2	-2.658475375	0.664618844	2.165822893	-0.088752367	0.022188092	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

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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	(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)	(-2.67, 0.67, 2.33)	(-0.04, 0.01, 0.13)
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VIRGINIA TECH

Adding Final Position Data

- For each iteration, the final position is added.

frame	position_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	-0.044444444	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
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29	-1.241838643	0.310459661	0.106753928	-1.324029709	0.331007427	0.023893309
30	-1.282995963	0.320748991	0.066625876	-1.324029709	0.331007427	0.023893309
31	-1.324029709	0.331007427	0.023893309	-1.324029709	0.331007427	0.023893309

VIRGINIA TECH

Adding Final Position Data

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

frame	position_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	-0.044444444	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	0.310459661	0.106753928	-1.324029709	0.331007427	0.023893309
30	-1.282995963	0.320748991	0.066625876	-1.324029709	0.331007427	0.023893309
31	-1.324029709	0.331007427	0.023893309	-1.324029709	0.331007427	0.023893309

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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

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Models Tested

- Conv2DPlus1
- Linear Regression
- Multi-layer Perceptron Classifier

Conv2DPlus1

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

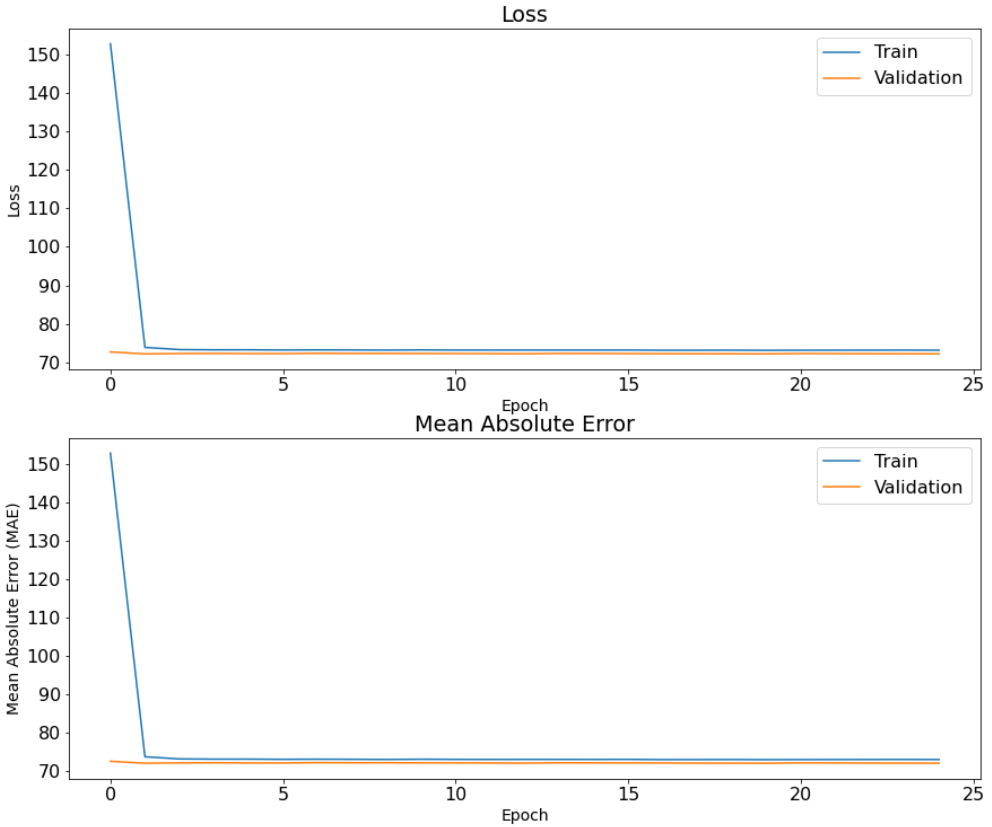

Figure 4: Loss and MEA of CNN model.

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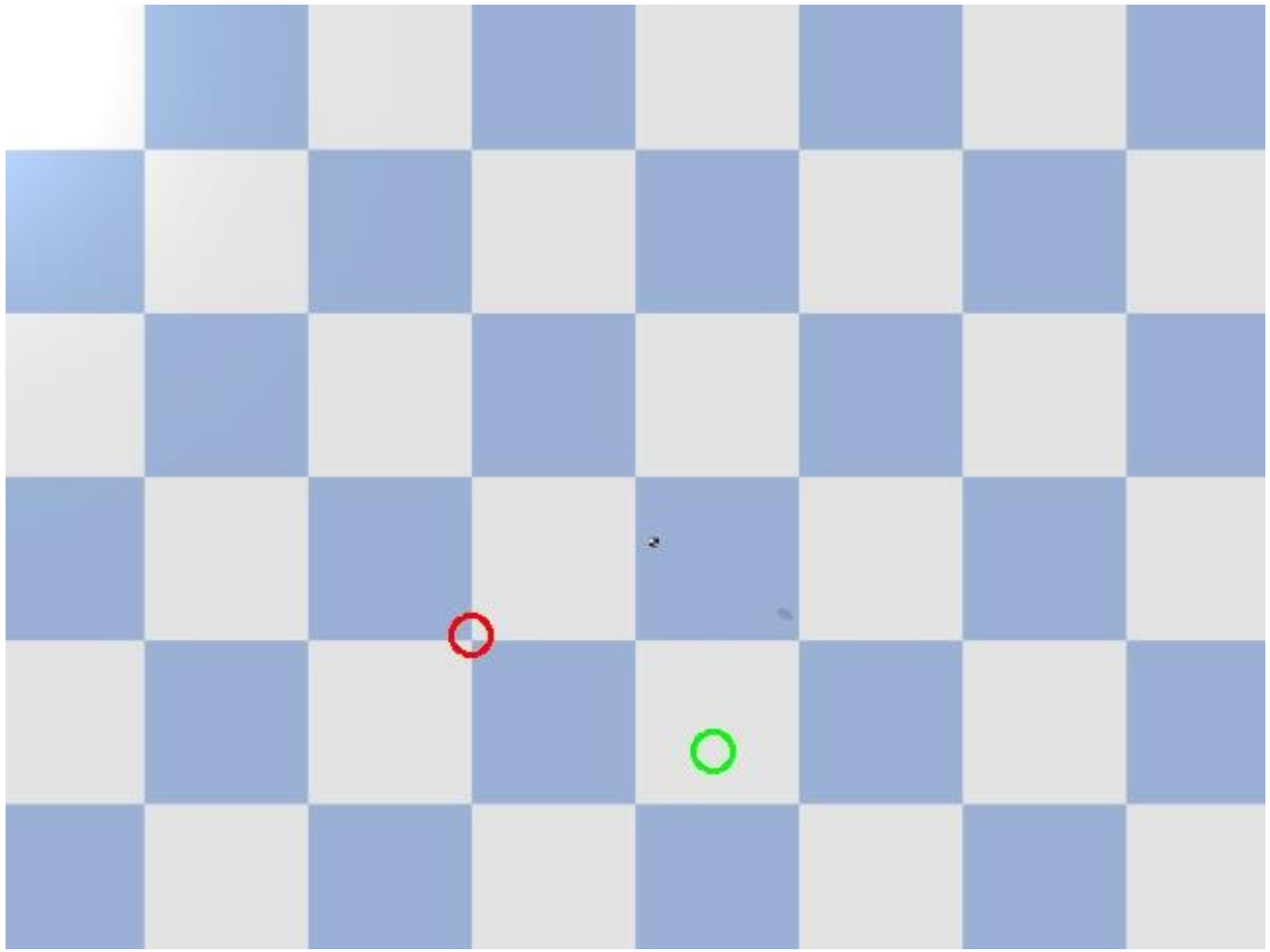
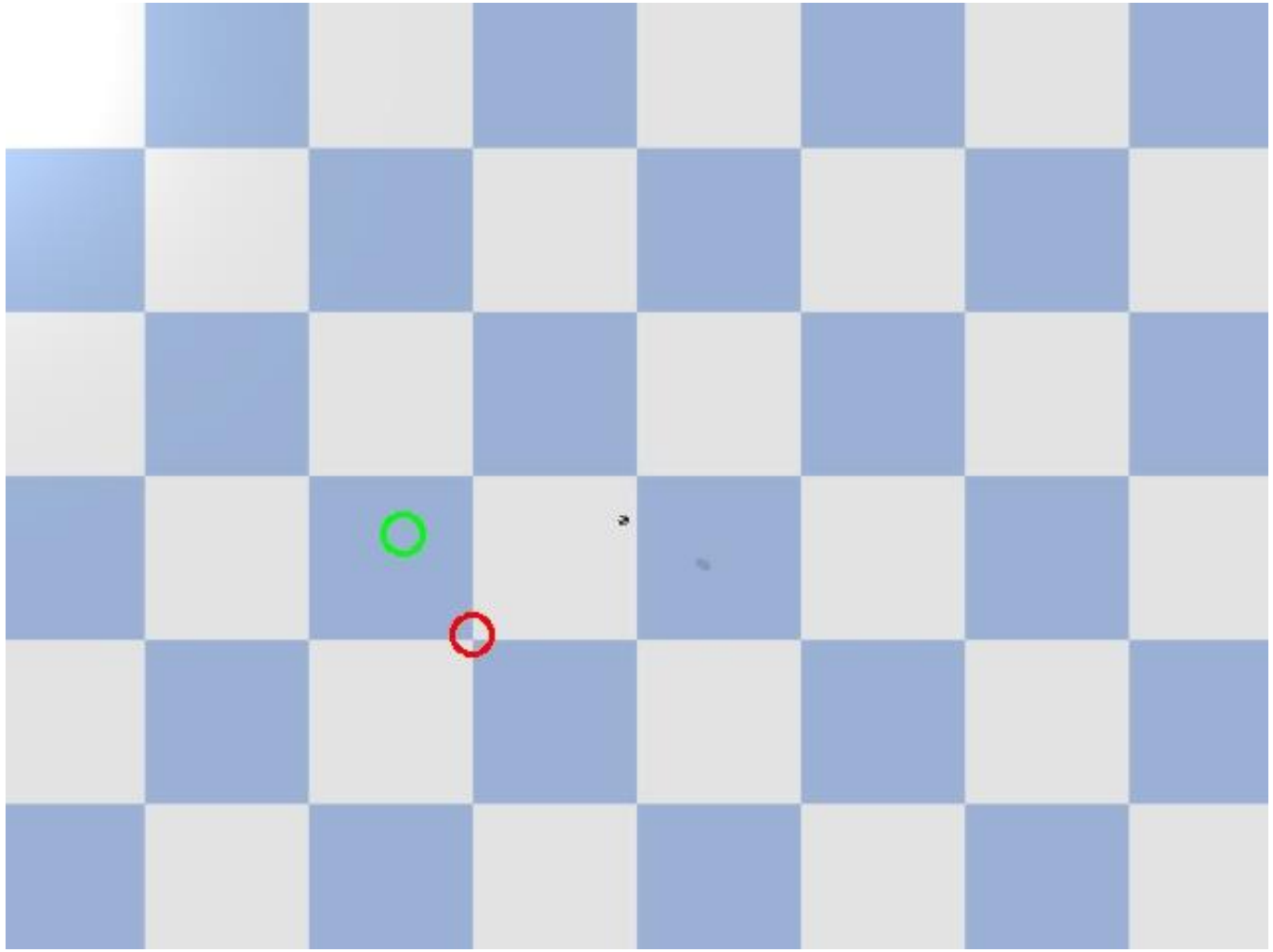
Red: Predicted
Green: Actual



VIRGINIA TECH

Predicting same location every time...

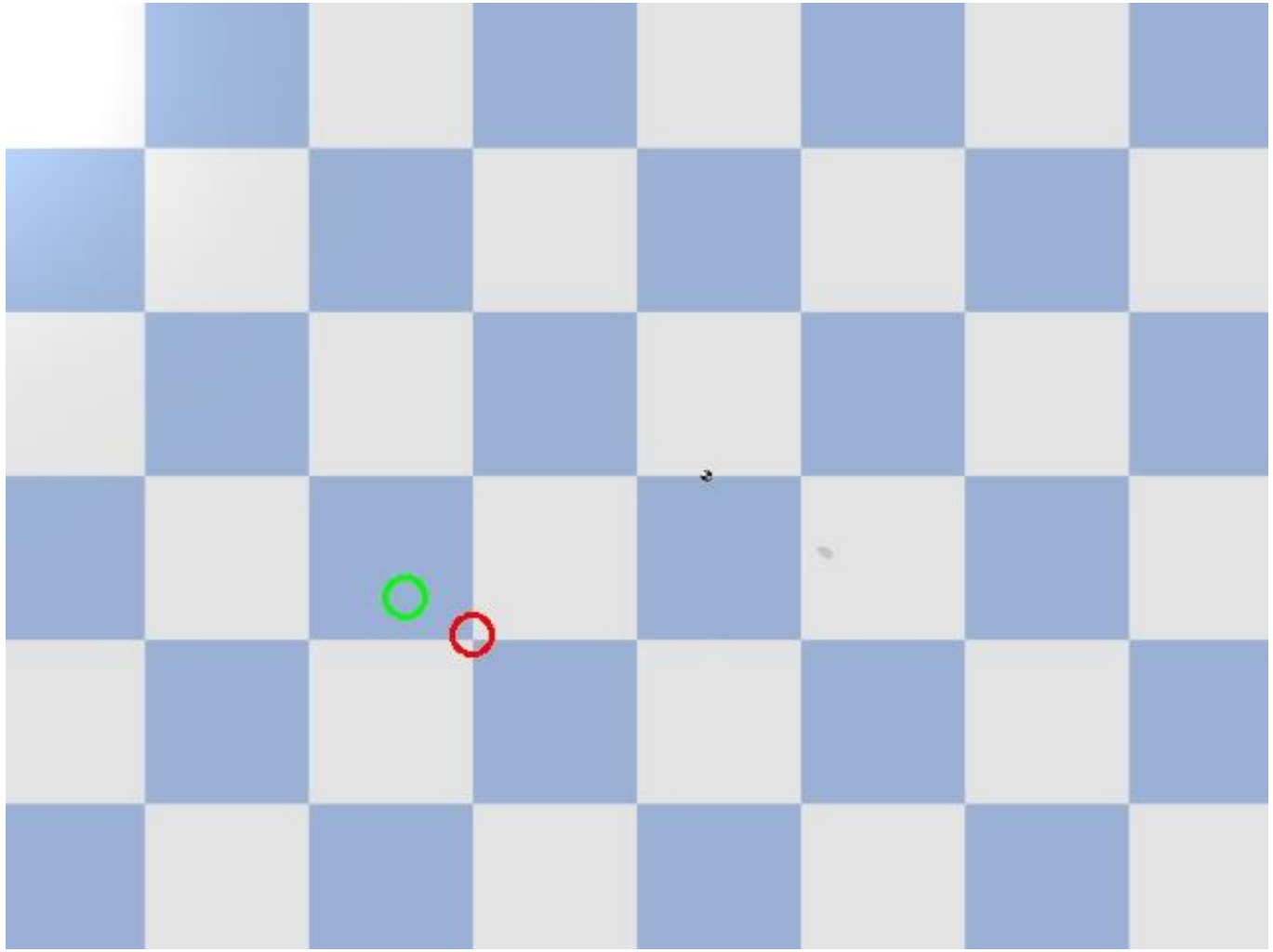
Red: Predicted
Green: Actual



VIRGINIA TECH

Predicting same location every time...

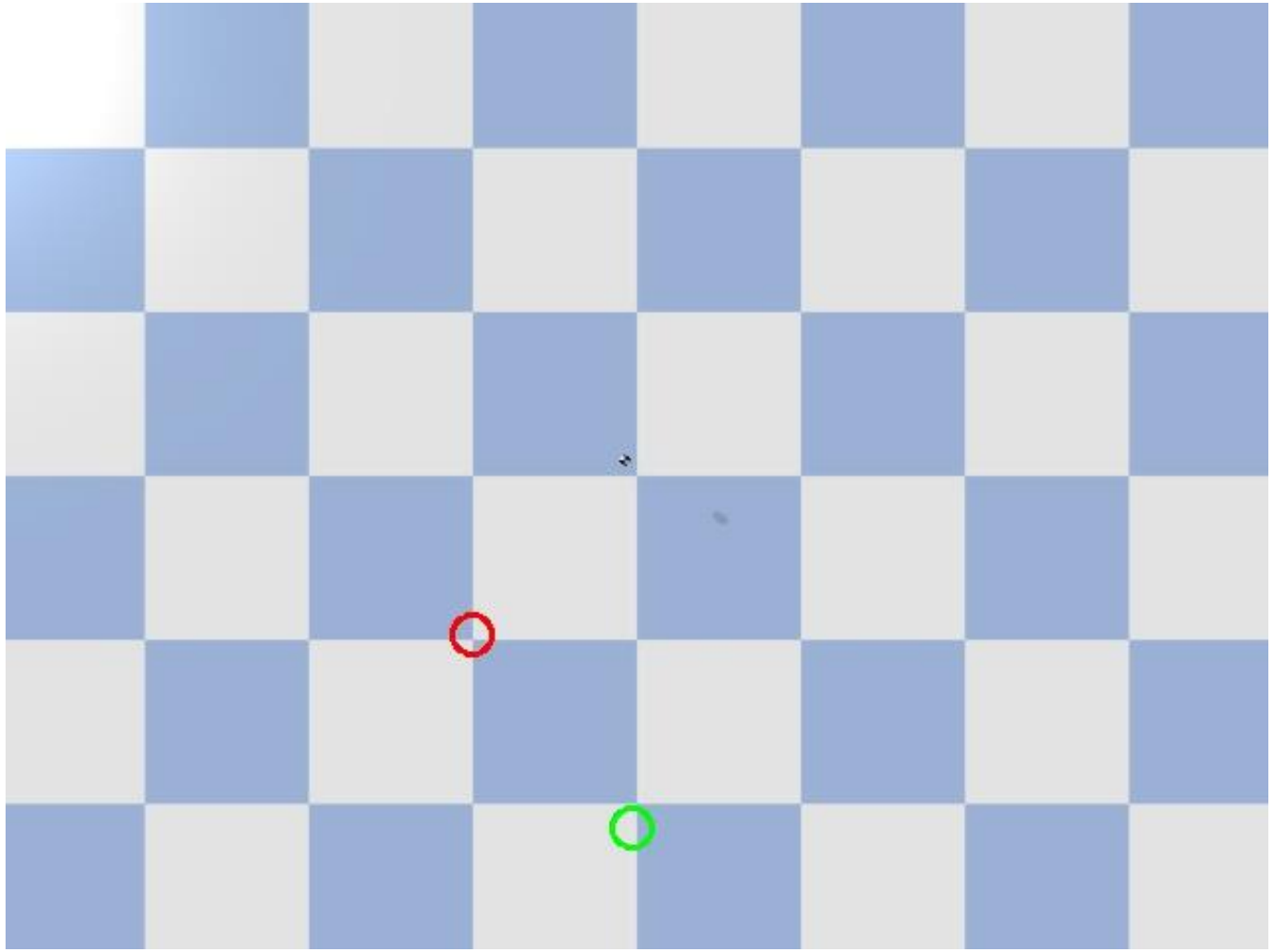
Red: Predicted
Green: Actual



VIRGINIA TECH

Predicting same location every time...

Red: Predicted
Green: Actual



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Linear Regression Results

- **Coefficient of Determination (R2):** 73.02%
- **MSE:** 0.035

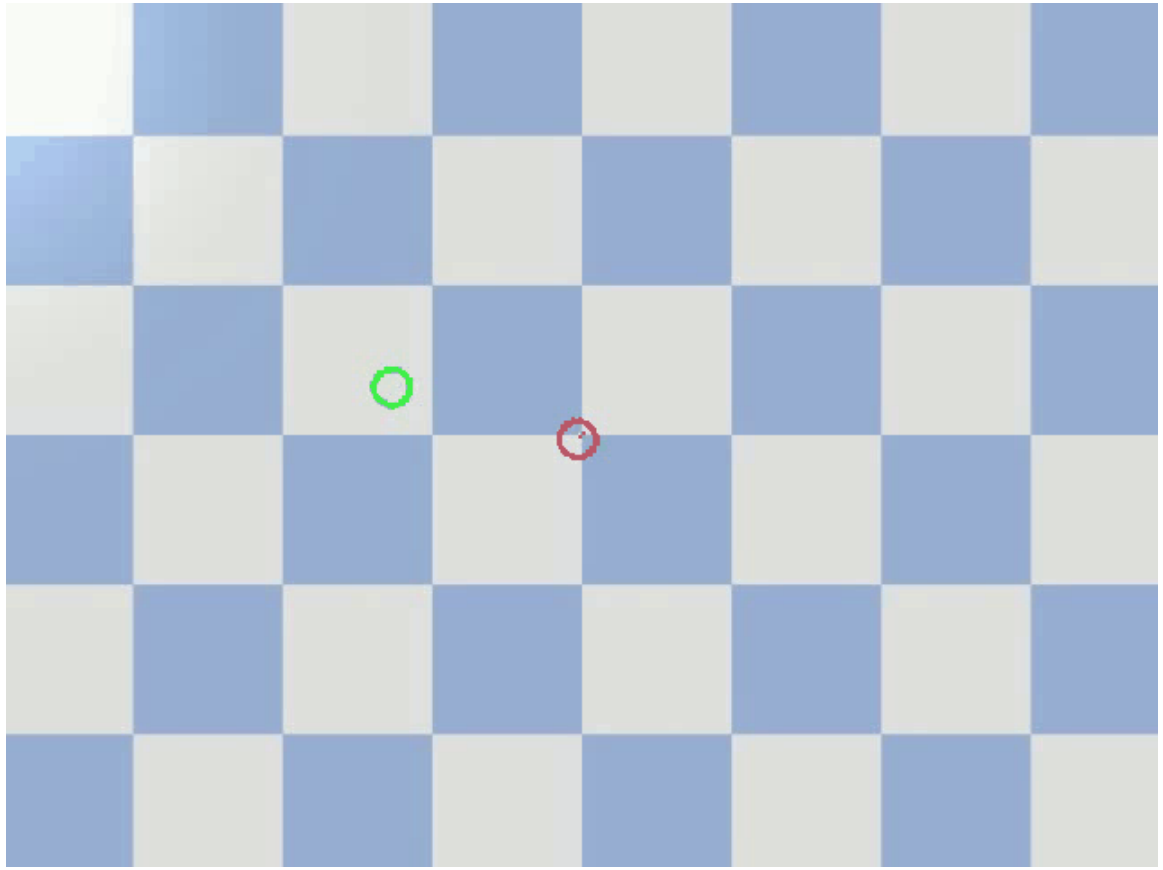

Figure 5: Green is actual, and Red is predicted landing zone of projectile.

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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%

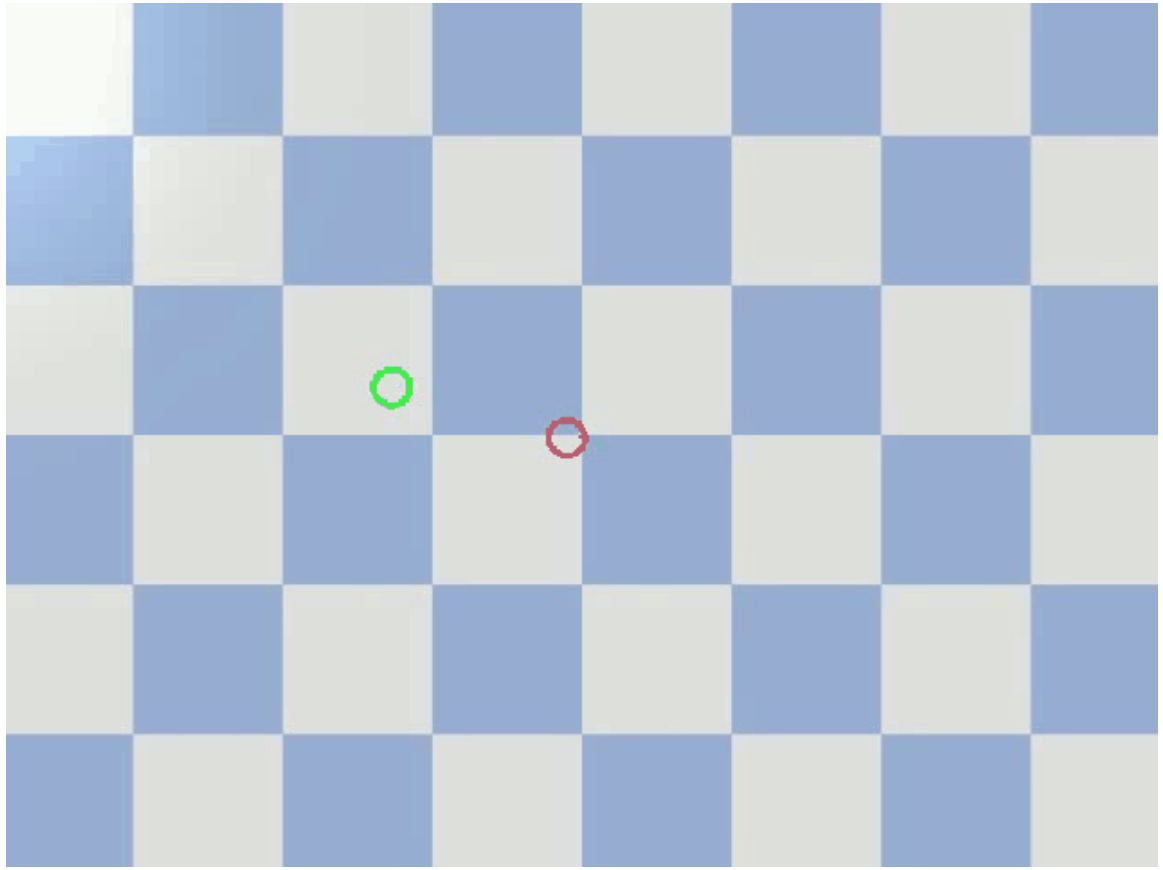

Figure 6: Green is actual, and Red is predicted landing zone of projectile.

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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.


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