Using Neural Networks for Time-Series Prediction

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PyData NYC 2017

Outline

1. Introduce problem
2. Phrase problem as an ML problem
3. Collect and apply data
4. Feature selection
5. Train the model
6. Improve the model
7. Tips

Who am I?

Quantopian

- Works with storage and manipulation of time series data
- Integrates third-party data sets

The Problem

Osu!

Elements

Figure 1: A hit circle

Elements

Figure 1: A hit circle

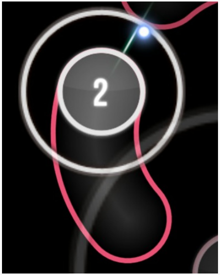


Figure 2: A slider

Elements

Figure 1: A hit circle

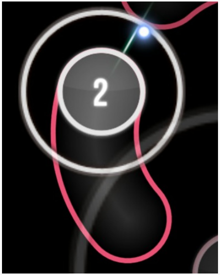


Figure 2: A slider

Figure 3: Mouse cursor

Osu! (cont.)

Scoring

300 points if on the beat

Osu! (cont.)

Scoring

300 points if on the beat

100 points if slightly off the beat

Osu! (cont.)

Scoring

300 points if on the beat

100 points if slightly off the beat

Osu! (cont.)

Scoring

300 points if on the beat

100 points if slightly off the beat

50 points if really off the beat

Osu! (cont.)

Scoring

300 points if on the beat

100 points if slightly off the beat

50 points if really off the beat

Osu! (cont.)

Scoring

300 points if on the beat

100 points if slightly off the beat

50 points if really off the beat

0 points for missing entirely

Osu! (cont.)

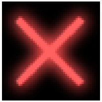
Scoring

300 points if on the beat

100 points if slightly off the beat

50 points if really off the beat

0 points for missing entirely



Osu! (cont.)

Sample

```
$ mpv videos/osu-example.avi
```

Problem

Predict my score on a beatmap

Problem

Predict my score on a beatmap

Need to compute accuracy %

Problem

Predict my score on a beatmap

- Need to compute accuracy %
- Temporal Accuracy

Problem

Predict my score on a beatmap

- Need to compute accuracy %
- Temporal Accuracy
- Aim Accuracy

Phrasing the Problem

Machine Learning Models

Classifiers
Label a sample as a member of one of a finite set of classes.

Machine Learning Models

Regressors
Approximate a numerical function.

LSTM Models

Order dependent data

LSTM Models

Order dependent data

Sequence of observations

LSTM Models

Order dependent data

Sequence of observations

Uses windows of time-sorted observations

Our Problem

For each hit-object, predict..

Our Problem

For each hit-object, predict..

Classifier
A label.

- 300
- 100
- 50
- 0 (miss)

Our Problem

For each hit-object, predict..

Classifier
A label.

- 300
- 100
- 50
- 0 (miss)

Regressor
A numeric error metric.

1. Aim Error ((x, y) error)
2. Accuracy Error (punctuality)

Data Collection

Beatmaps

Hit objects in (x, y, time) space.

Beatmaps

Hit objects in (x, y, time) space.

Circle Size (CS)

Beatmaps

Hit objects in (x, y, time) space.

Circle Size (CS)

Approach Rate (AR)

Beatmaps

Hit objects in (x, y, time) space.

Circle Size (CS)

Approach Rate (AR)

Overall Difficulty (OD) (score thresholds)

Beatmap

```
[HitObjects]
103,272,52926,6,0,L|111:176,1,67.5000025749208
93,95,53279,1,2,0:3:0:0:
194,131,53455,2,0,B|263:160|264:100|337:135,1,135.000005149
437,204,53985,2,0,L|432:286,1,67.5000025749208
394,105,54338,6,0,L|399:17,1,67.5000025749208
286,62,54690,1,2,0:3:0:0:
177,54,54867,2,0,B|110:74|110:30|41:53,1,135.000005149842,0
70,213,55396,2,0,L|77:132,1,67.5000025749208
161,215,55749,6,0,P|175:273|247:314,1,135.000005149842,0|2
341,286,56279,1,0,0:0:0:0:
308,183,56455,2,0,P|268:201|245:238,1,67.5000025749208,0|2
```

Mods

- Hard Rock (HR)

Mods

- Hard Rock (HR)
- Double Time (DT)

Mods

- Hard Rock (HR)
- Double Time (DT)
- Hidden (HD)

Mods

- Hard Rock (HR)
- Double Time (DT)
- Hidden (HD)
- etc...

Replays

Time series of...

Replays

Time series of...

Cursor location

Replays

Time series of...

- Cursor location
- Keyboard state

Replays

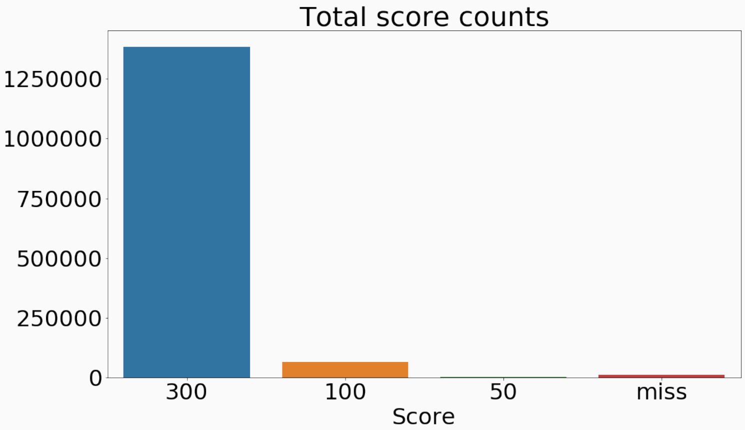
I had about seven years of replays laying around!

Understanding our data

Accuracy thresholds (milliseconds)

OD	300	100	50
1	73.5	131.5	189.5
2	67.5	123.5	179.5
3	61.5	115.5	169.5
4	55.5	107.5	159.5
5	49.5	99.5	149.5
6	43.5	91.5	139.5
7	37.5	83.5	129.5
8	31.5	75.5	119.5
9	25.5	67.5	109.5
10	19.5	59.5	99.5

Understanding our data (cont.)



Prediction Targets

Joining Data

Prediction Targets

Joining Data

Find all clicks by taking times where key state changes

Prediction Targets

Joining Data

Find all clicks by taking times where key state changes

Match click with the nearest hit object (ignores hit locking!)

Prediction Targets

Accuracy Error

Absolute difference in time.

Prediction Targets

Accuracy Error

Absolute difference in time.

Comparable across different OD

Prediction Targets

Aim Error

Euclidean distance between click and center of circle.

Prediction Targets

Aim Error

Euclidean distance between click and center of circle.

Comparable across different CS

Feature Selection

What is a feature?

Numeric inputs to the ML model

What is a feature?

Numeric inputs to the ML model

- What are we observing

What is a feature?

Numeric inputs to the ML model

- What are we observing
- Focus the model on aspects of the data

What is a feature?

Numeric inputs to the ML model

- What are we observing
- Focus the model on aspects of the data
- Chance to use domain knowledge

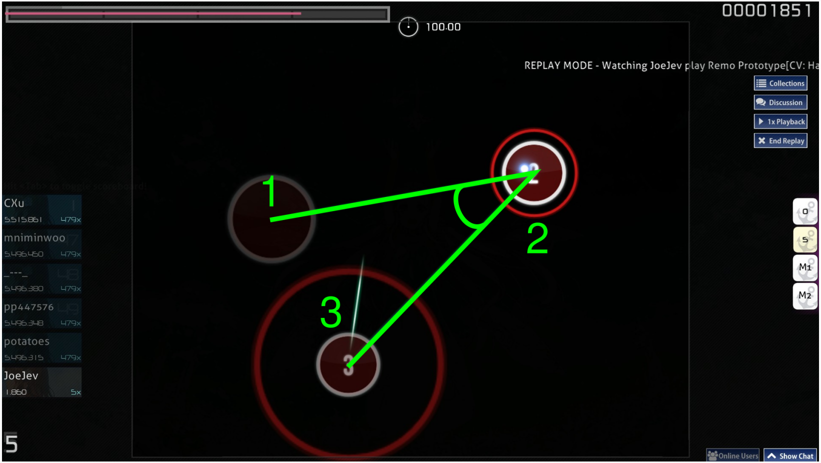
Simple Features

`absolute_x`

`absolute_y`

`absolute_time`

Domain Specific Features



Window-Normalization

time	x	y
00:37.366	372	94
00:37.763	447	205
00:38.027	217	299
00:38.291	229	171
00:38.424	274	358
00:38.688	149	221
00:38.952	330	186

Window-Normalization

time	x	y
00:37.366	372	94
00:37.763	447	205
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00:38.424	274	358
00:38.688	149	221
00:38.952	330	186

Window-Normalization

time	x	y	relative x	relative y
00:37.366	372	94	98	-264
00:37.763	447	205	173	-153
00:38.027	217	299	-57	-59
00:38.291	229	171	-45	-187
00:38.424	274	358	0	0
00:38.688	149	221	-125	-137
00:38.952	330	186	56	-172

Training

Keras

```
input_ = keras.layers.Input(
    shape=(window_length, len(features))
)
```

Keras

```
input_ = keras.layers.Input(
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)
lstm = keras.layers.LSTM(lstm_layer_size)(input_)
```

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```
input_ = keras.layers.Input(
    shape=(window_length, len(features))
)
lstm = keras.layers.LSTM(lstm_layer_size)(input_)
aim_error = keras.layers.Dense(
    1,
    activation='linear',
    name='aim_error',
)(lstm)
```

Keras

```
input_ = keras.layers.Input(
    shape=(window_length, len(features))
)
lstm = keras.layers.LSTM(lstm_layer_size)(input_)
aim_error = keras.layers.Dense(
    1,
    activation='linear',
    name='aim_error',
)(lstm)
accuracy_error = keras.layers.Dense(
    1,
    activation='linear',
    name='accuracy_error',
)(lstm)
```

Keras (cont.)

```
model = keras.models.Model(
    inputs=input_,
    outputs=[aim_error, accuracy_error],
)
```

Keras (cont.)

```
model = keras.models.Model(
    inputs=input_,
    outputs=[aim_error, accuracy_error],
)
model.compile(
    loss='mse',
    optimizer='rmsprop',
)
```

Keras (cont.)

```
# compute features, aim_error, accuracy_error
model.fit(
    features,
    {
        'aim_error': aim_error,
        'accuracy_error': accuracy_error,
    },
)
```

Keras (cont.)

```
# compute features, aim_error, accuracy_error
model.fit(
    features,
    {
        'aim_error': aim_error,
        'accuracy_error': accuracy_error,
    },
)

model.predict(features)
```

How does it look?

How does it look?

bad

Feature Scaling

Sensitive to input ranges

Feature Scaling

Sensitive to input ranges

```
(data - data.mean()) / data.std()
```

Feature Scaling

Sensitive to input ranges

`(data - data.mean()) / data.std()`

Save the mean and std of the training data!

Data (again)

```
features:
    absolute_x:
      mean: 256.93
      std:  581144.54
      min:  -26.25
      max:  4297802023696152.0
    absolute_y:
      mean: 188.67
      std:  96280.10
      min:  -12.20
      max:  1075466319017187 4.0
```

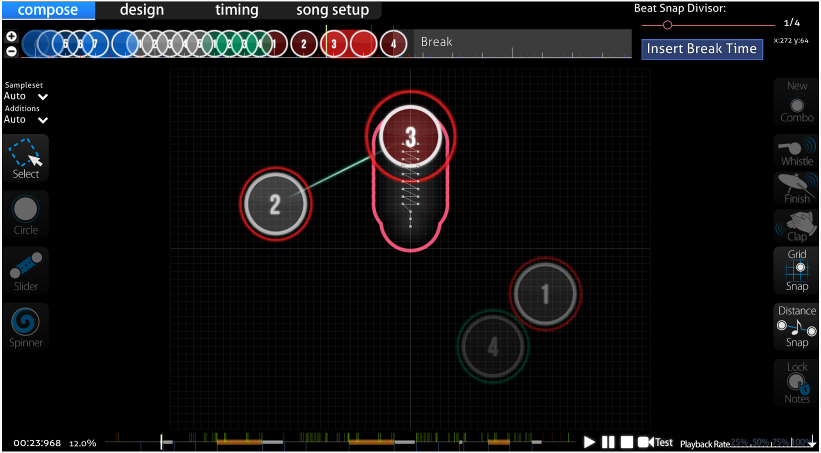
Data (again)

osu! playfield:

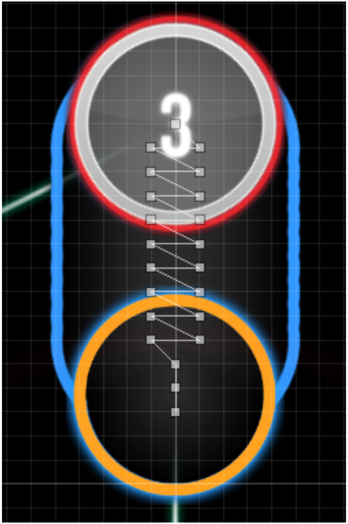
(512, 384)

```
features:
    absolute_x:
      mean: 256.93
      std:  581144.54
      min:  -26.25
      max:  42978020236964152.0
    absolute_y:
      mean: 188.67
      std:  96280.10
      min:  -12.20
      max:  10754663190171874.0
```

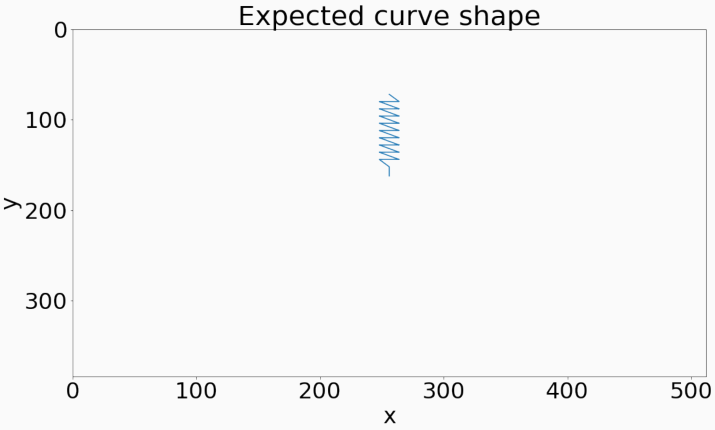
Slider Curves



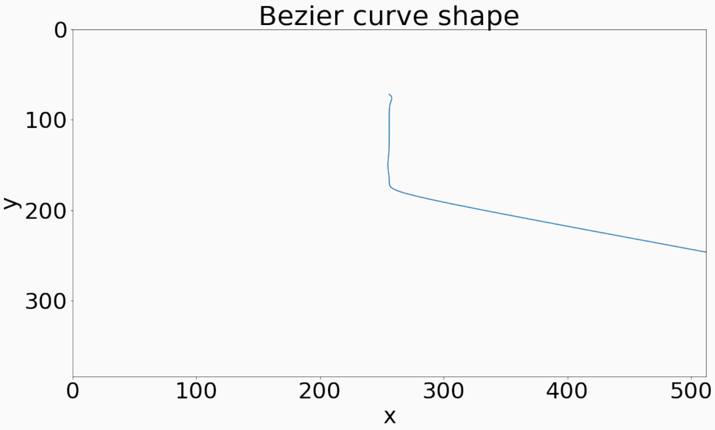
Slider Curves



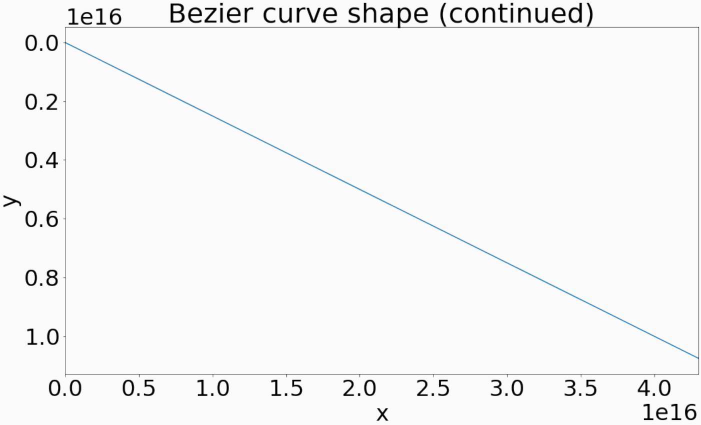
Slider Curves



Slider Curves



Slider Curves



Discretizing scores

Accuracy thresholds (milliseconds)

OD	300	100	50
1	73.5	131.5	189.5
2	67.5	123.5	179.5
3	61.5	115.5	169.5
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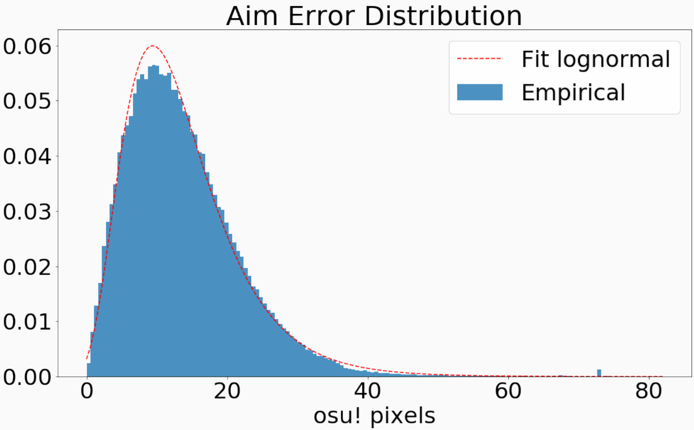
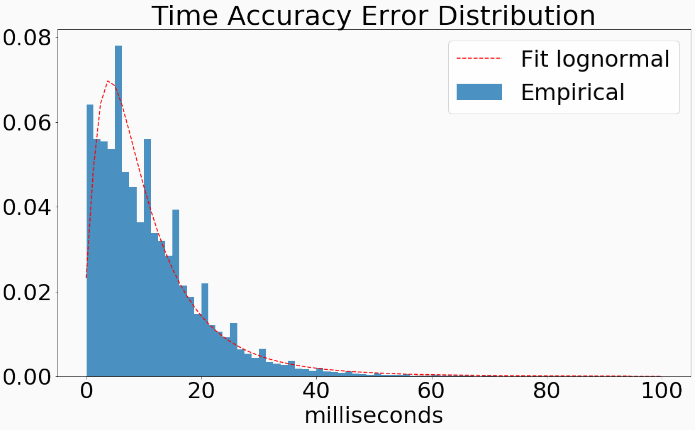
Data (again)



Aim Error Distribution
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
20
40
60
80
osu! pixels
Fit lognormal
Empirical

Data (again)

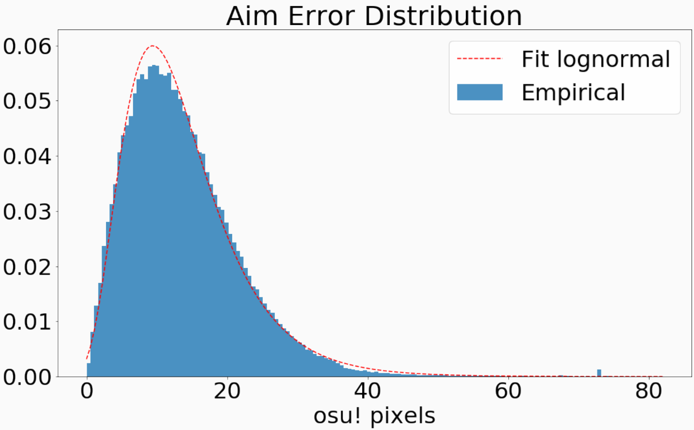


Time Accuracy Error Distribution
0.08
0.06
0.04
0.02
0.00
0
20
40
60
80
100
milliseconds
Fit lognormal
Empirical

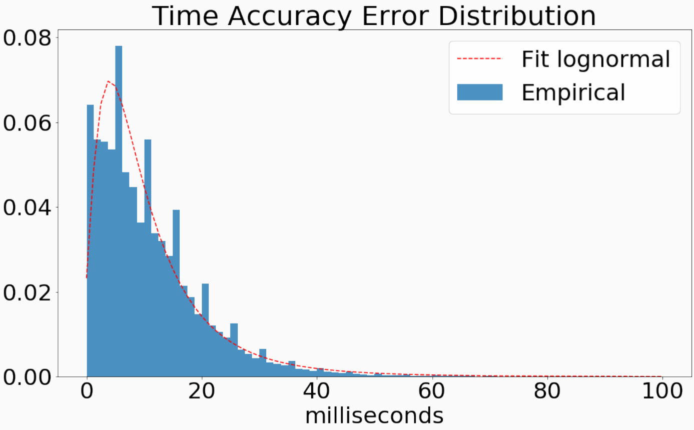
Fit a distribution

`lain/lstm.py:658`

Sample Weights



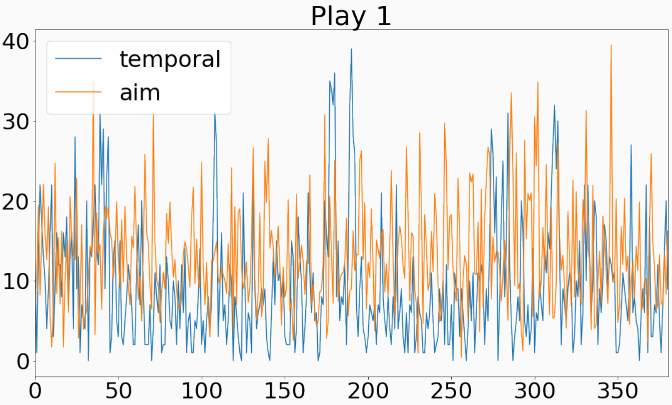
Sample Weights



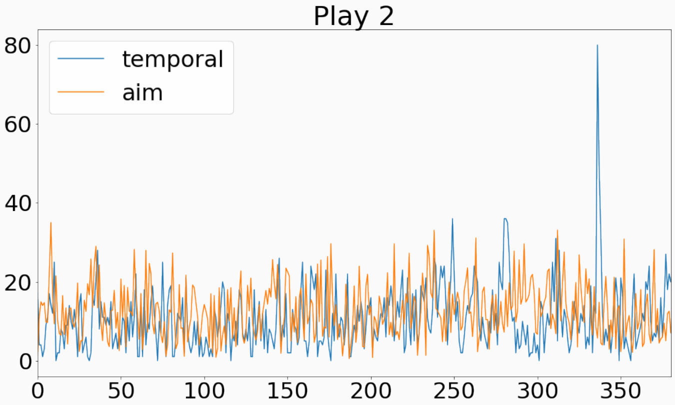
Sample Weights (cont.)

```
model.fit(
    ...
    {
        'aim_error:': aim_error_weights,
        'accuracy_error': accuracy_error_weights,
    },
)
```

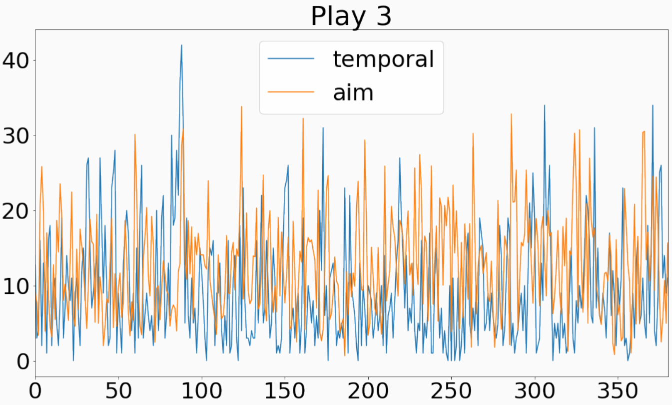
Example Output



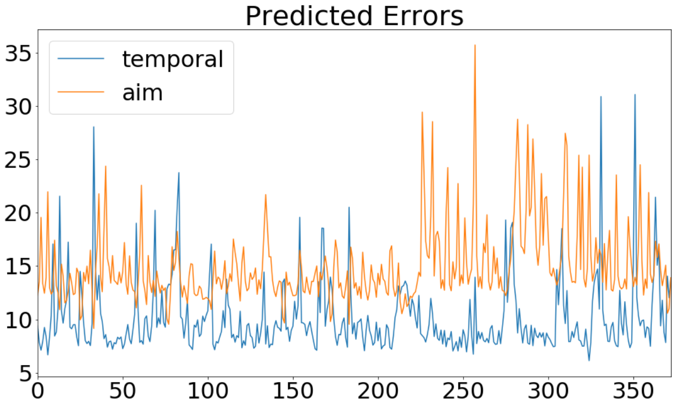
Example Output



Example Output



Example Output



Example Output

```
$ mpv videos/wolf.avi
```

Example Output (cont.)

Prediction	Actual	Stars
99.85%	99.13%	5.34
99.85%	99.08%	5.34
99.85%	98.51%	5.34
95.95%	96.57%	6.03
98.30%	97.09%	6.24

Tips

Understanding the process

`verbose` flags that log information

Understanding the process

`verbose` flags that log information

progress indicators (`click.progressbar`)

Understanding the process

`verbose` flags that log information

progress indicators (`click.progressbar`)

print summary statistics early in process

Software Engineering Matters

Group code into a domain-aware `Model` class.

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feature extraction

Software Engineering Matters

Group code into a domain-aware `Model` class.

- feature extraction
- label extraction

Software Engineering Matters

Group code into a domain-aware `Model` class.

- feature extraction
- label extraction
- managing keras

Serialization

save models to disk

Serialization

save models to disk

train on ec2 and use locally

Serialization

save models to disk

train on ec2 and use locally

train locally then deploy

Serialization

save models to disk

train on ec2 and use locally

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supported by keras

Key Points

1. Most of the work is before or after keras

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2. Understand the data and the data collection processes

Key Points

1. Most of the work is before or after keras
2. Understand the data and the data collection processes
3. Osu! is a fun game

Thank You

Questions?

`github.com/llllllllll` **(10 lowercase L's)**

- `/lain` (model implementation)
- `/slider` (tools for working with osu! data and API)
- `/combine` (irc server running lain-as-a-service)