NFL Game Simulator

Predicting Plays Using LSTM Neural Networks

Jaume, Cody, Tom and Cyan

All participants contributed evenly.

UNIVERSITY OF COPENHAGEN

Goal

- "Simulate" a game of American football play-by-play
- Given a set of circumstances, what play will be run and what will the results of the play be?

American Football - The Basics

- https://www.youtube.com/watch?v=3t6hM5tRlfA

- Overview
  - Teams individually decide on a pre-planned play
  - Offense initiates play
  - Play stops when
    - Ball carrier is tackled
    - Ball hits the ground (incomplete pass)
  - 4 tries (downs) to advance 10 yards
    - If they fail, turnover of possession
  - Scoring
    - Gain possession of ball in opponent's endzone = touchdown
    - Kick through uprights = field goal

Expectations and Questions

- Expectations
  - Low play-by-play accuracy
    - We are modelling human behaviour
  - Game-by-game accuracy
    - Perhaps the cumulative play-by-play will be accurate?
  - Intracacies of game
    - How does the model handle points of interest (right)?

- Points of Interest
  - Games always start with kickoff
  - Fourth down
    - Punt? Go for it? Field goal?
  - Certain results can only follow certain plays
    - Complete pass can only follow from a pass play
    - Extra point can only follow a touchdown

Raw Data

- 870,384 plays from 5,308 NFL games
- ~20 years
- 44 features

NFLPlay > plays.csv

```
playId,gameId,playSequence,quarter,possessionTeamId,nonpossessionTeamId,playType,playType2,playTypeDetailed,playNumberByTeam,gameClock,gameClockSecondsExpired,gameClockStoppedAfterP
30298,26909,1,1,2200,3200,kickoff,"kickoff, returned","kickoff, returned",1,(15:00),9,1,0,0,IND 30,70.0,0,13-M.Vanderjagt kicks 65 yards from IND 30 to NE 5. 81-B.Johnson pushed ob
30299,26909,2,1,3200,2200,pass,"pass, complete","pass, complete",1,(14:51),46,0,1,10,NE 37,63.0,0,(14:51) 12-T.Brady pass to 87-D.Givens to IND 44 for 19 yards (30-D.Strickland).,"1
30300,26909,3,1,3200,2200,pass,"pass, complete","pass, complete",2,(14:05),38,0,1,10,IND 44,44.0,0,"(14:05) (No Huddle, Shotgun) 12-T.Brady pass to 83-D.Branch to IND 30 for 14 yard
30301,26909,4,1,3200,2200,pass,"pass, incomplete","pass, incomplete",3,(13:27),4,1,1,10,IND 30,30.0,0,"(13:27) (No Huddle, Shotgun) 12-T.Brady pass incomplete to 83-D.Branch.",Pass
30302,26909,5,1,3200,2200,pass,"pass, complete","pass, complete",4,(13:23),31,0,2,10,IND 30,30.0,0,"(13:23) (No Huddle) 12-T.Brady pass to 84-B.Watson to IND 28 for 2 yards (94-R.Mc
30303,26909,6,1,3200,2200,pass,"pass, complete","pass, complete",5,(12:52),40,0,3,8,IND 28,28.0,0,"(12:52) (No Huddle, Shotgun) 12-T.Brady pass to 84-B.Watson to IND 14 for 14 yards
30304,26909,7,1,3200,2200,pass,"pass, complete","pass, complete",6,(12:12),54,0,1,10,IND 14,14.0,0,"(12:12) (No Huddle, Shotgun) 12-T.Brady pass to 83-D.Branch to IND 10 for 4 yards
30305,26909,8,1,3200,2200,penalty,penalty,"penalty, delay of game",7,(11:18),19,0,2,6,IND 10,10.0,1,"(11:18) (Shotgun) PENALTY on NE-12-T.Brady, Delay of Game, 5 yards, enforced at
```

Preprocessing

- Trimmed and removed based on expert knowledge,
  - leaving 27 columns
- Parsed complex lines
- Converted string to numerical values
- Impute Nant
- Split into two categories: circumstance, type, and result

	playId	gameId	playSequence	quarter	possessionTeamId	nonpossessionTeamId	playType	playNumberByTeam	gameClock	gameClockSecondsExpired	...	safety	offensiveYards	ne
0	30298	26909	1	1	2200	3200	0	1	900	9	...	0	0	
1	30299	26909	2	1	3200	2200	1	1	891	46	...	0	19	
2	30300	26909	3	1	3200	2200	1	2	845	38	...	0	14	
3	30301	26909	4	1	3200	2200	1	3	807	4	...	0	0	
4	30302	26909	5	1	3200	2200	1	4	803	31	...	0	2	

	column0	column1	column2	column3	…	column23	column24	column25	column26
Play0 Play1 Play2 …	input	prediction	input	prediction		prediction	input	prediction	input

input

- playSequence
- quarter
- possessionTeamId
- nonpossessionTeamId
- playNumberByTeam
- gameClock
- down
- distance
- distanceToGoalPre
- netYards
- scorePossession
- scoreNonpossession
- fieldGoalProbability

PlayCircumstances

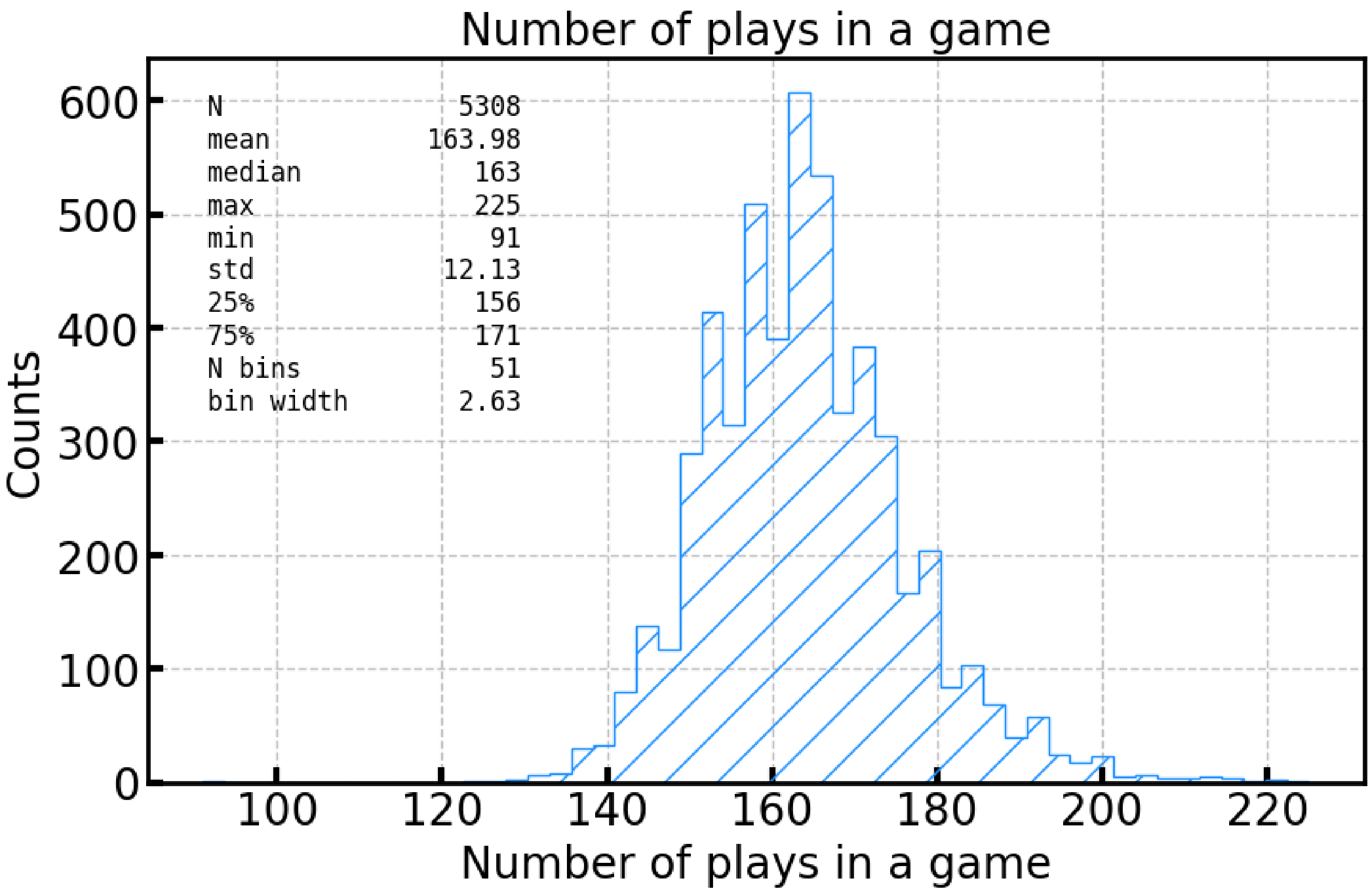
prediction

- playType
- huddle
- formation
- playResult
- †gameClockSecondsExpired
- †gameClockSecondsStopped
- noPlay
- †offensiveYards

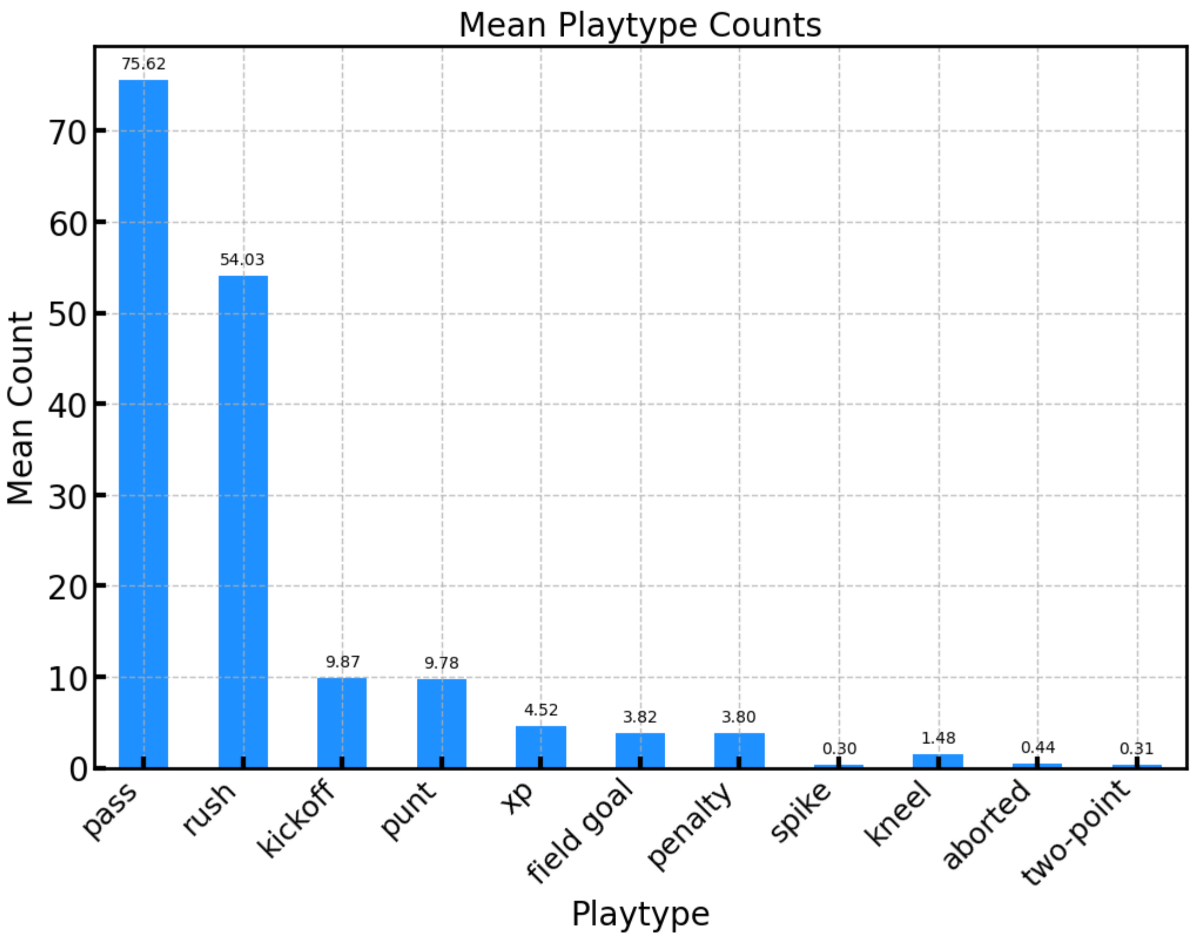
† regression

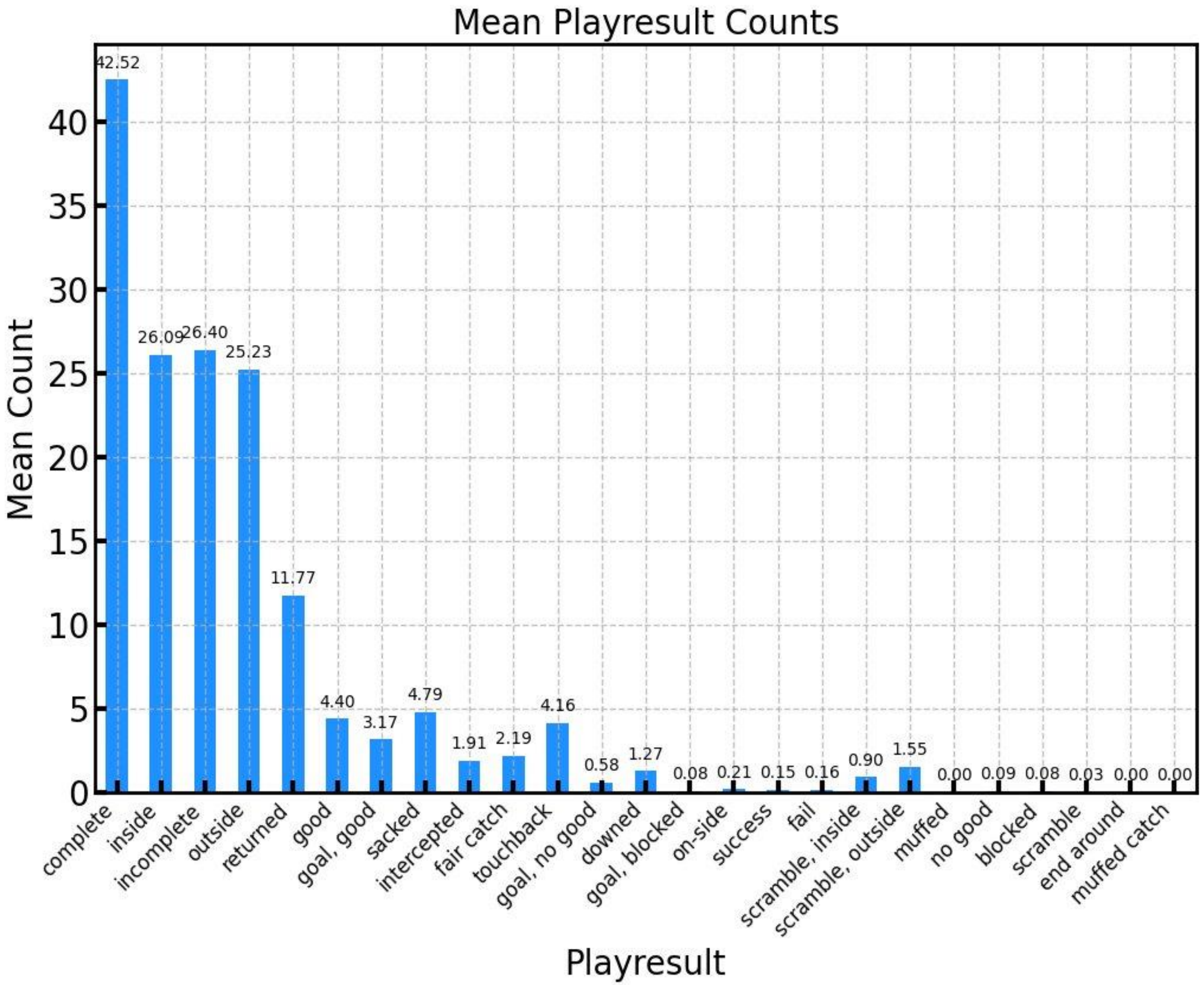
PlayResults

The number of the plays in a game



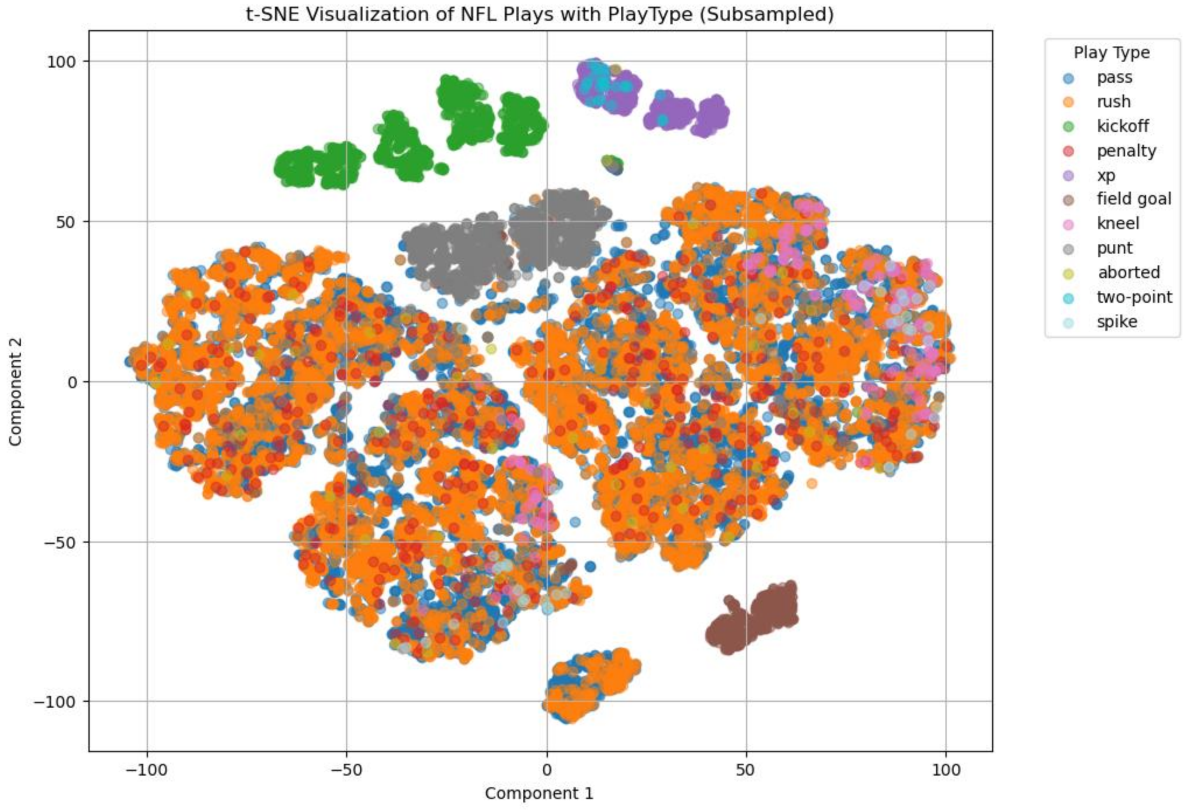
Overview: play type and play result

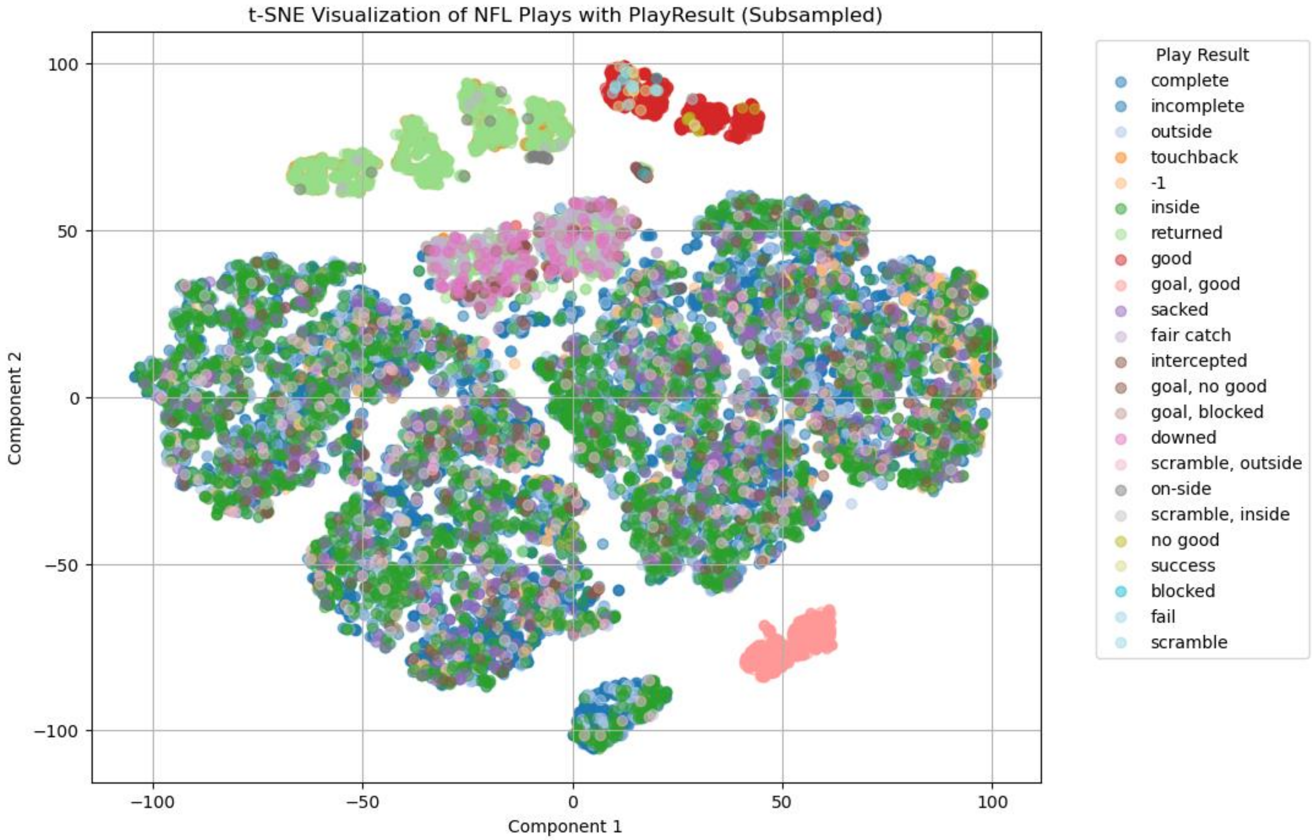




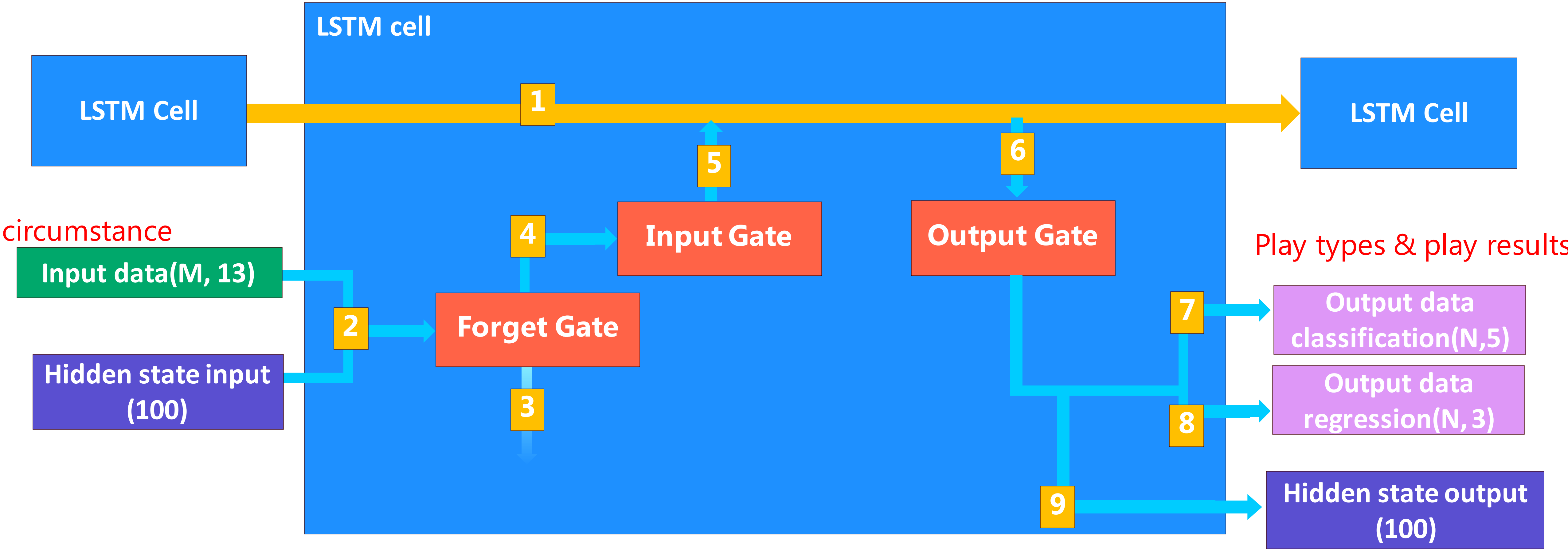
Data exploration

- **Dimensionality reduction**

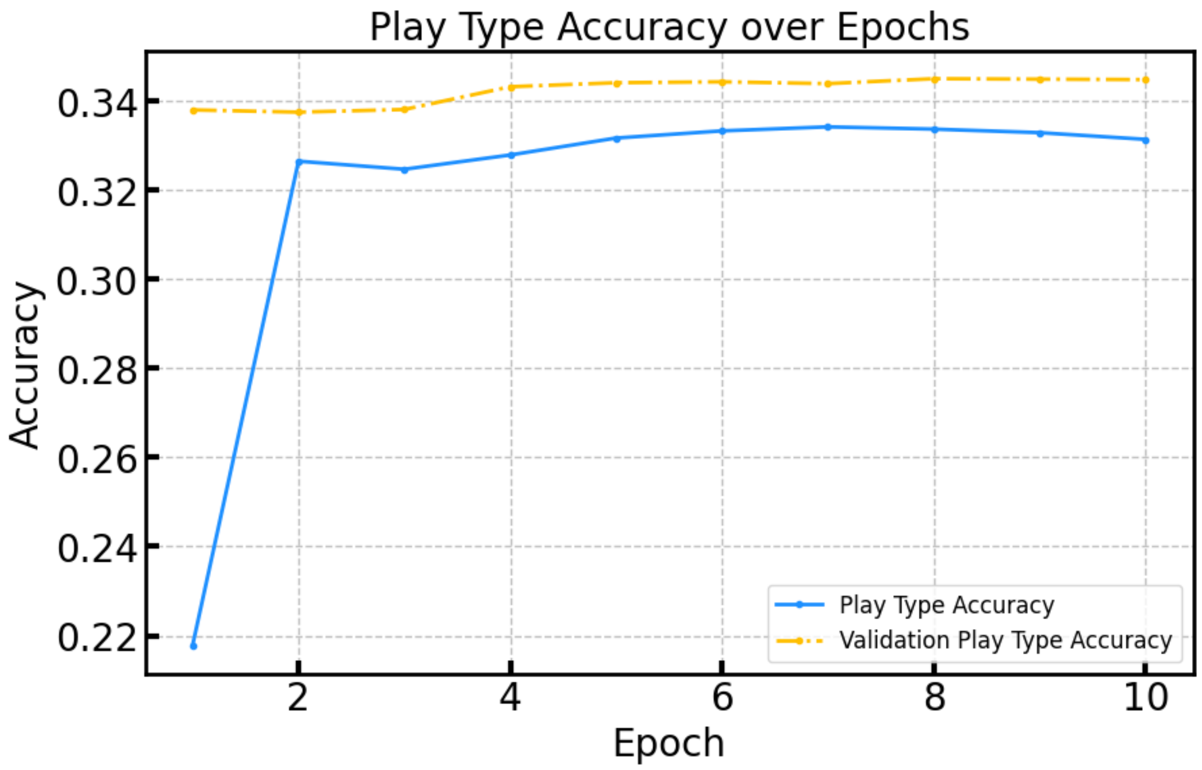


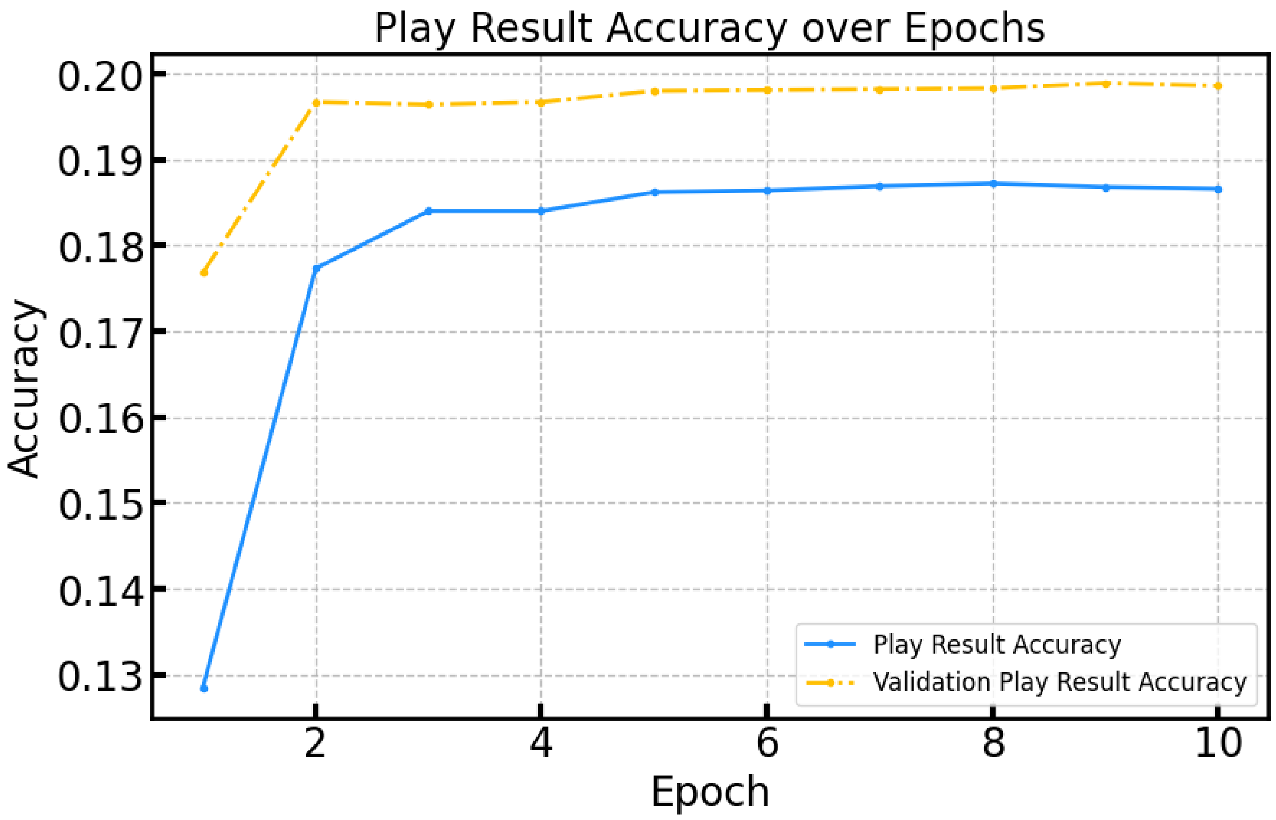


LSTM model(TensorFlow, keras) for NFL play data

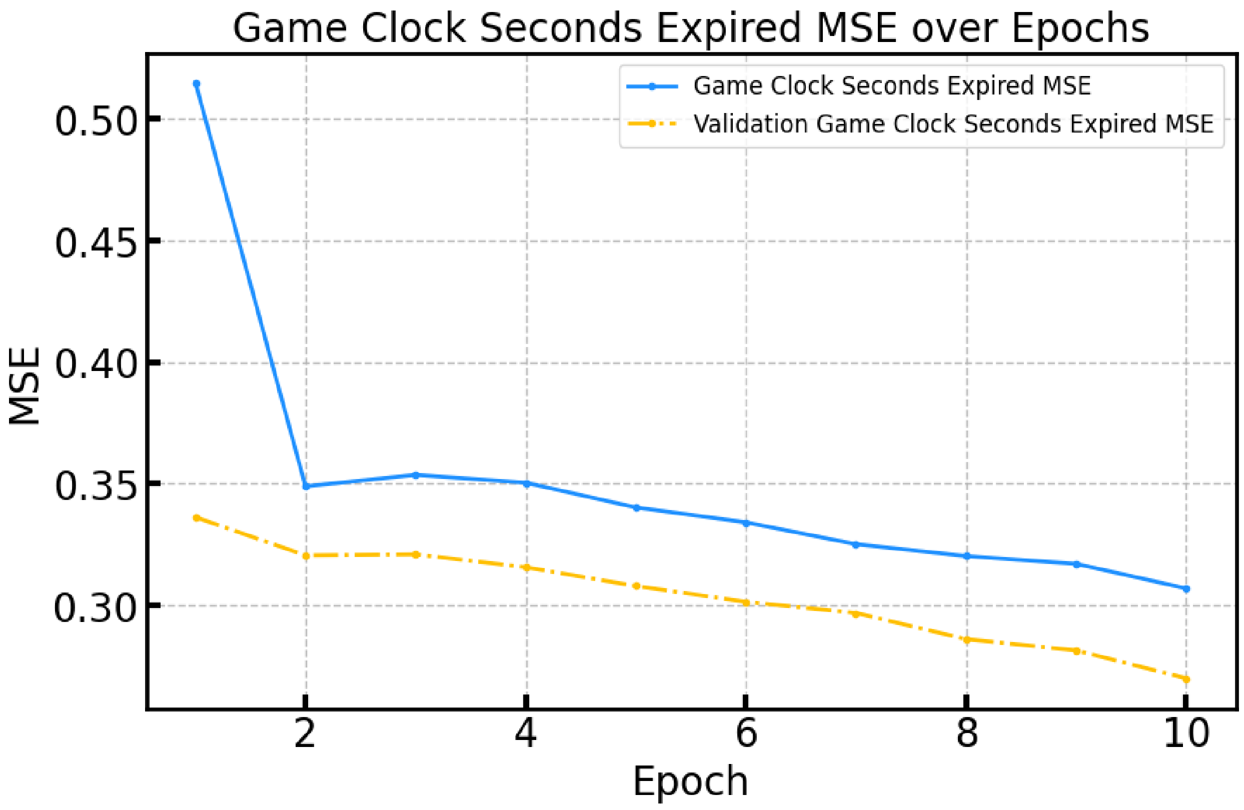


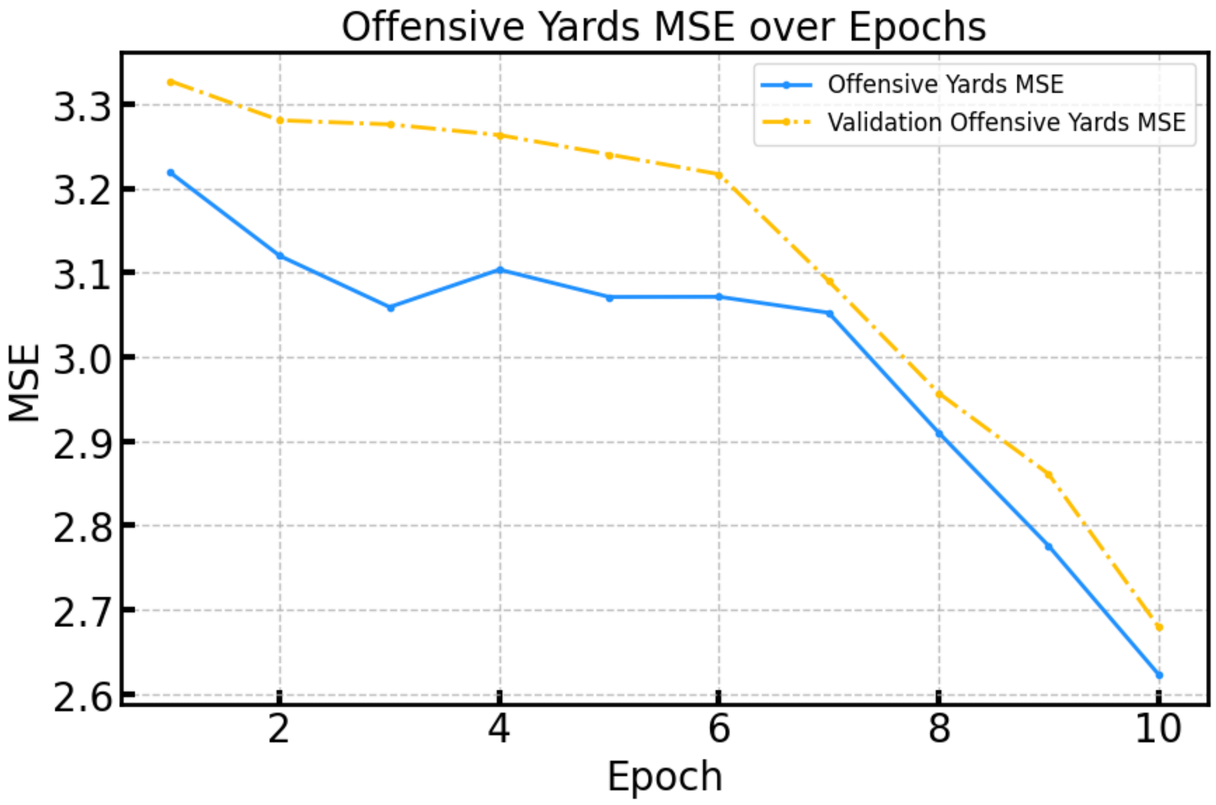
Accuracy of play type and result



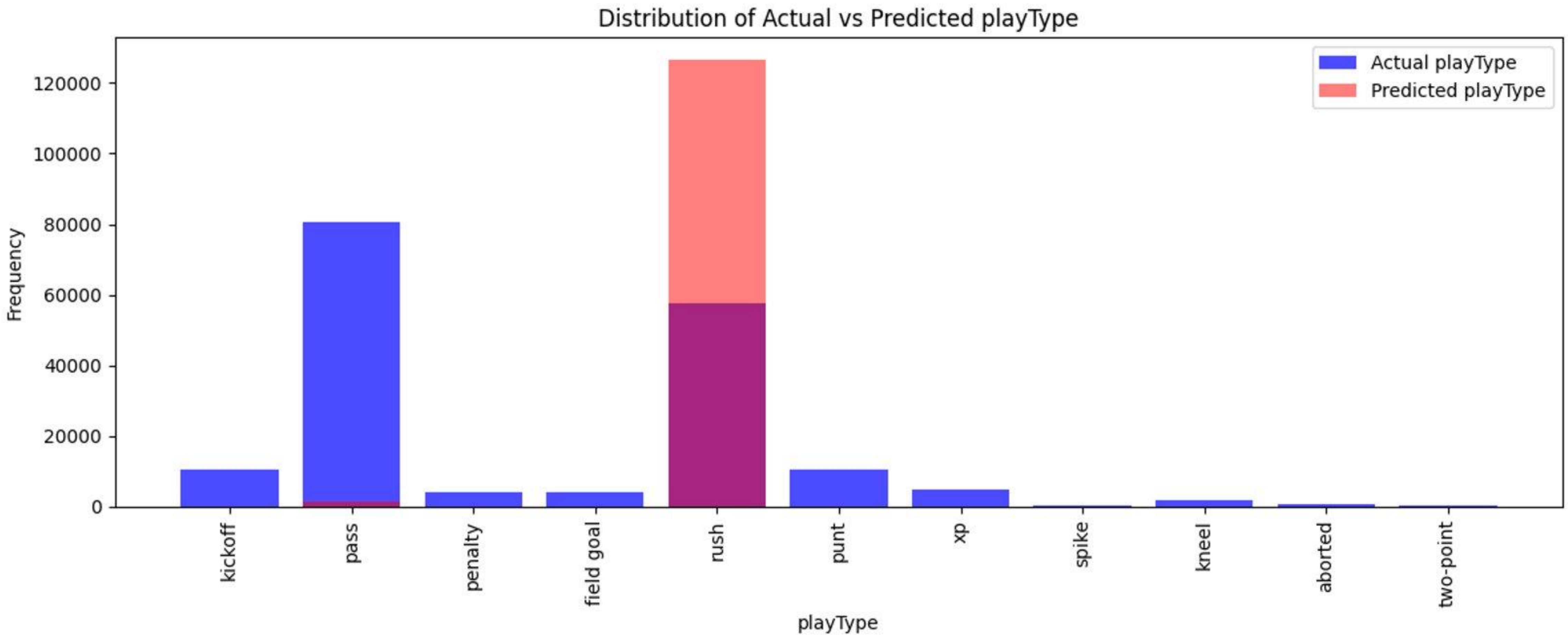


MSE for regression

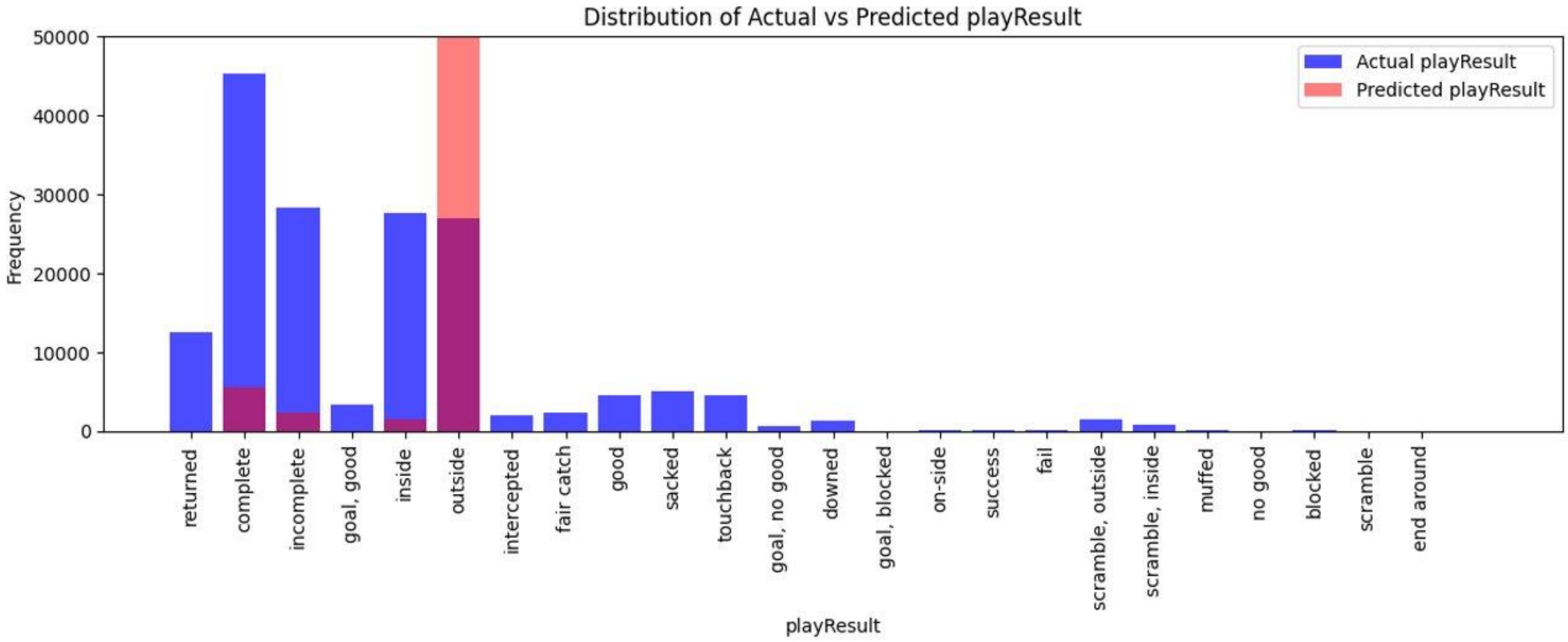




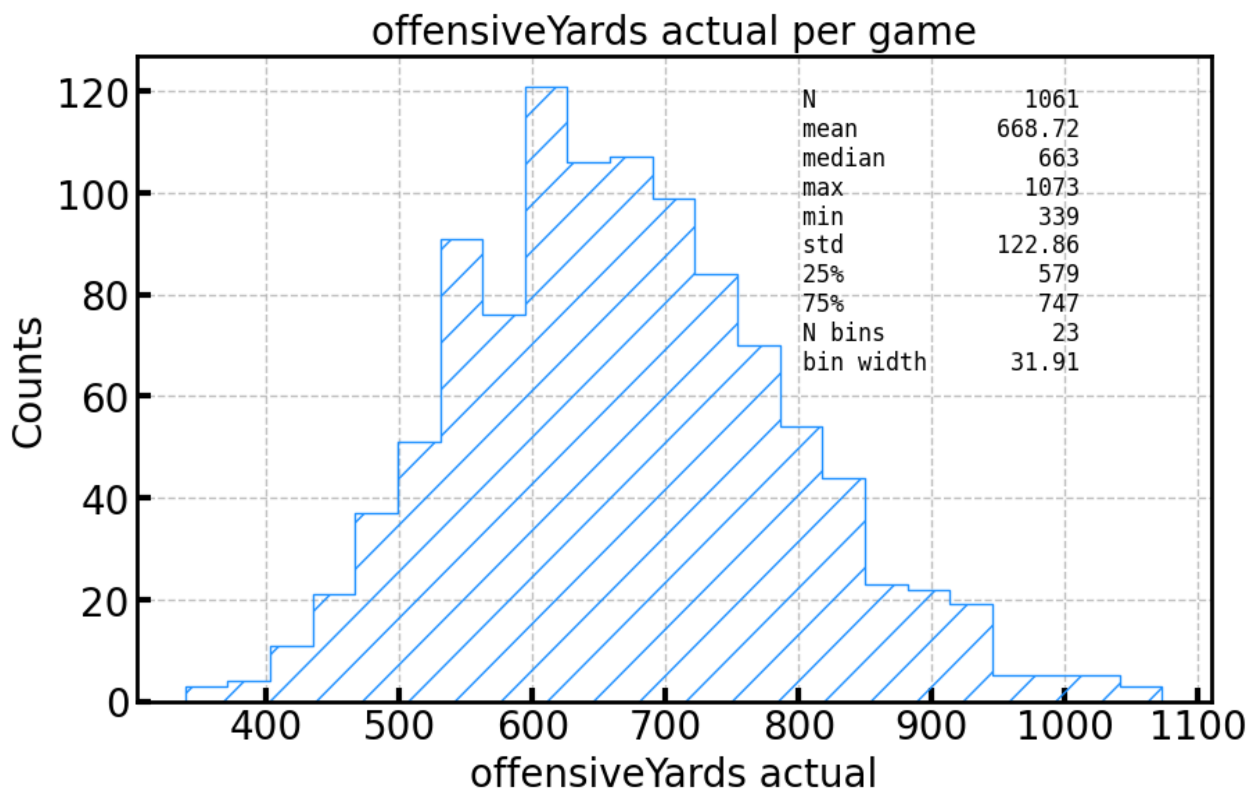
Predicted Play Type

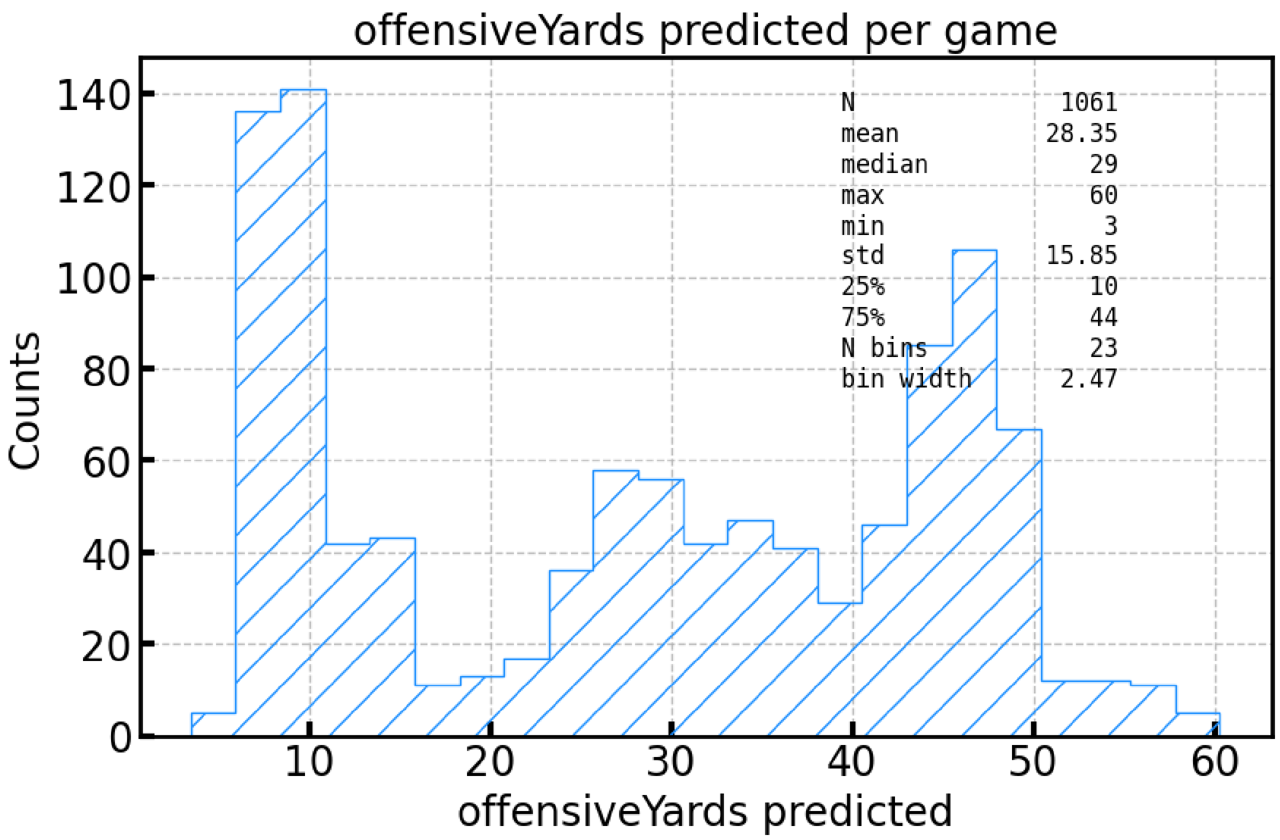


Predicted Play Result



Predicted Offensive Yards





Results – Points of Interest

- Games always start with kickoff
  - Not our games!
  - 1059/1061 games start with a pass
  - 2/1061 games start with a run
  - 0 kickoffs!
- Fourth down
  - 0 punts!
  - 0 field goals!
  - Ran on all 12109 4th downs
- Certain results can only follow certain play types
  - 6606 "complete" or "incomplete" runs
  - 0 extra points

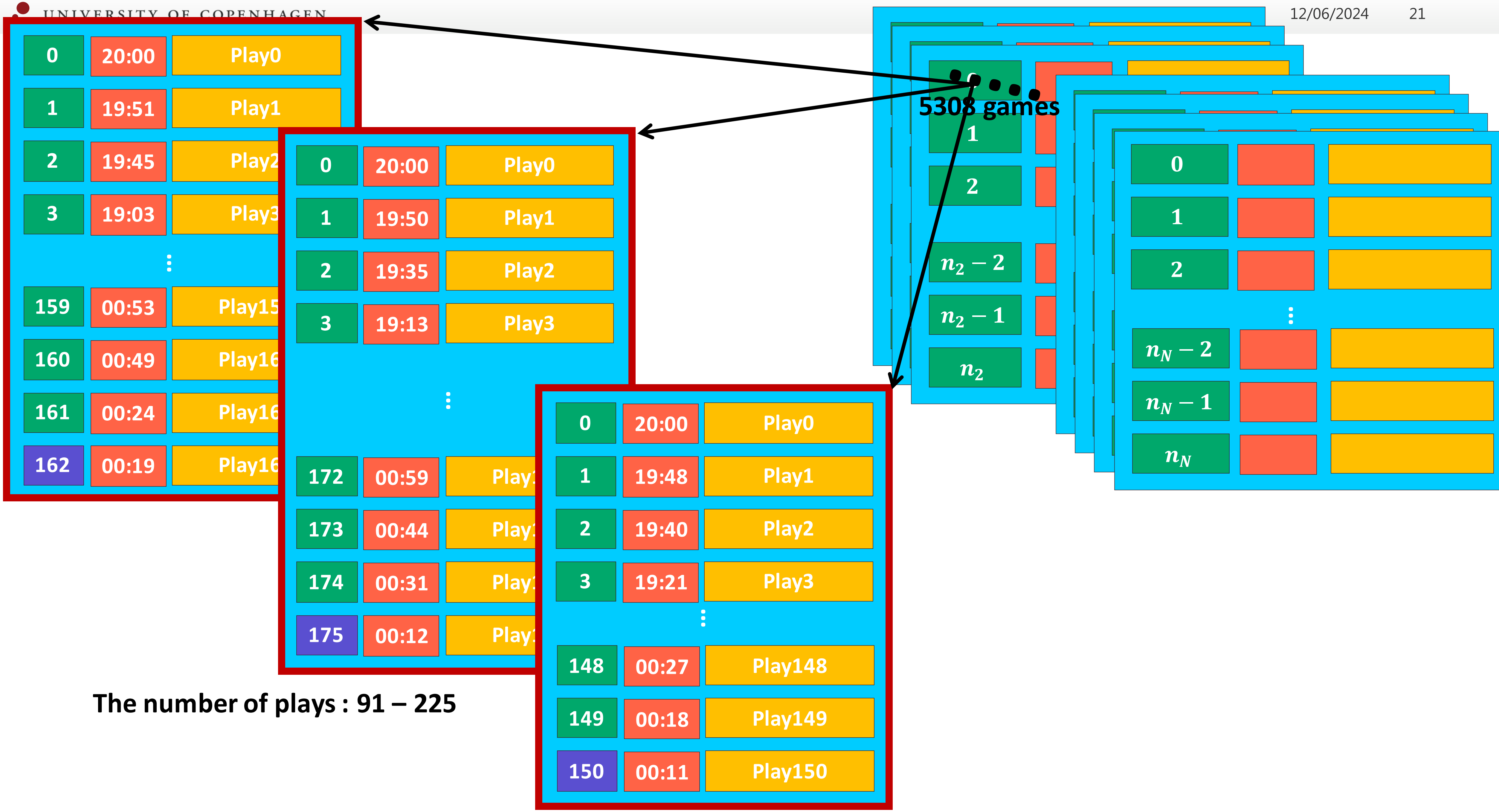
Conclusions

- Our model is a very bad coach
  - Overwhelmingly calls run plays, no matter the circumstance
  - Never punts on 4th down
  - Never attempts any field goals
- Our model is a cheater
  - Disobeys rules about kickoffs and extra points
- Our model is illogical
  - "Complete" and "incomplete" runs
- Ultimately, we did not have time to update and iterate on our initial results

Future work and Take Aways

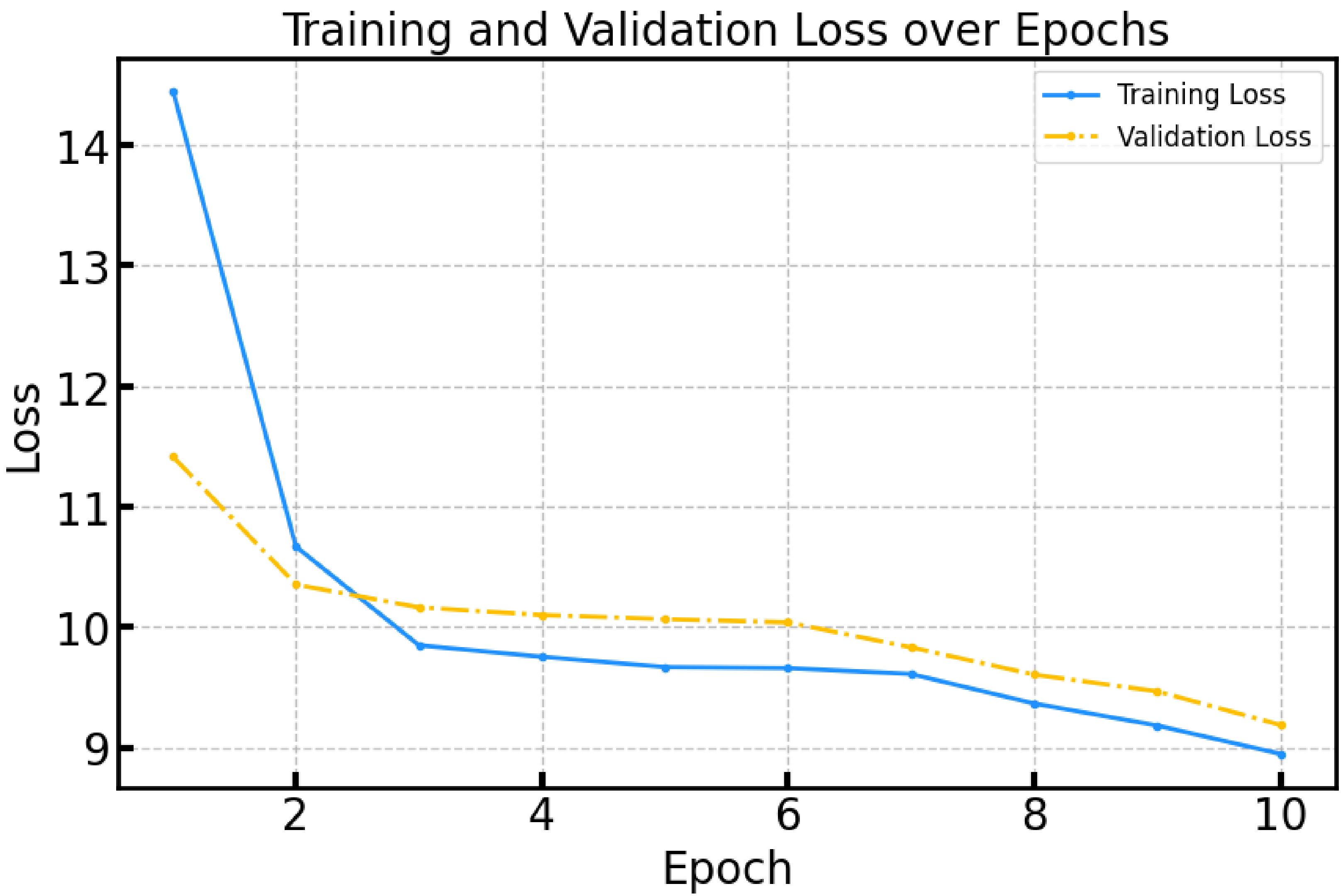
- Basic optimization and exploration of hyper parameters
  - Normalize input data
  - Different loss functions
    - Use full game stats rather than play stats?
- Include historical information about the teams
- Use multiple models
  - One to predict play type
  - Another to predict play results, given the predicted play type
  - Another model to generate circumstances of next play, given the predicted play results

APPENDIX



The number of plays : 91 – 225

Loss over Epochs



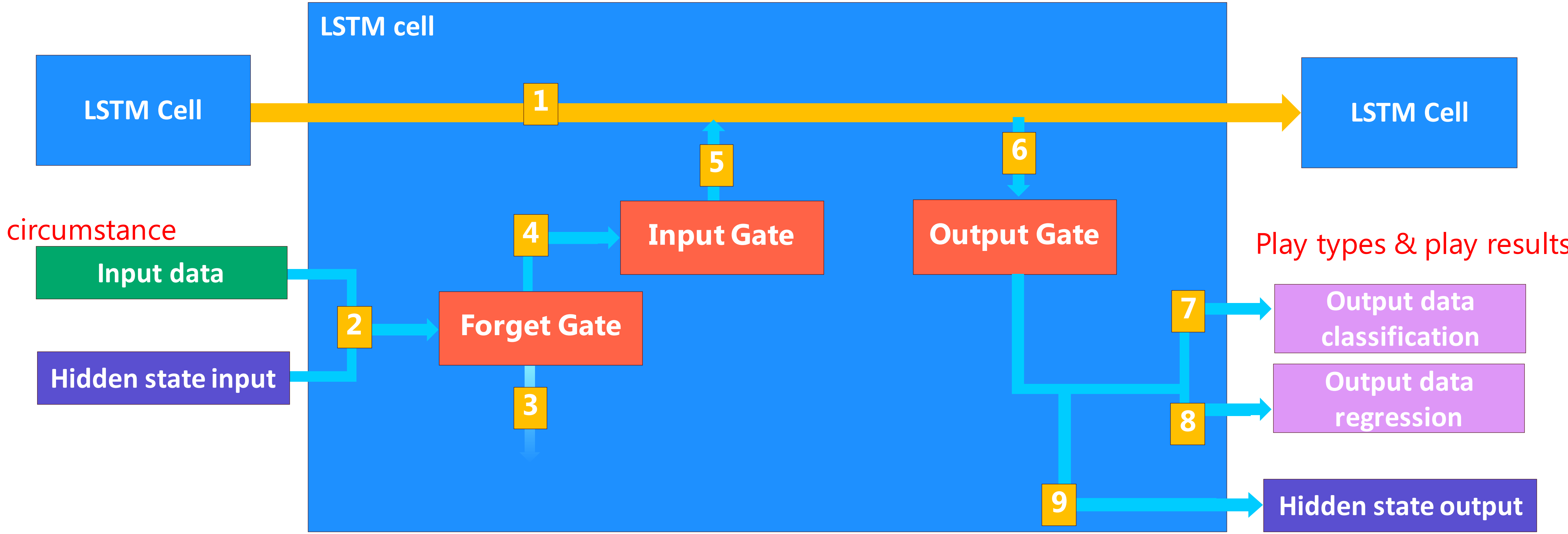
General NN

- **Forward Pass**
  - Input data is passed through layers to generate an output.
  - Output compared to target values using a loss function (L).
- **Loss Function (L)**
  - Measures error between prediction and true value.
  - Examples: MSE for regression, Cross-Entropy Loss for classification.
- **Backpropagation**
  - Error is propagated backward, computing gradients (∇L).
  - **Gradient Descent**
    - Parameters updated to reduce the loss using optimization algorithms like SGD.
- **Vanishing Gradient Problem**
  - Gradients(∇L) diminish exponentially with each layer
  - Small weights lead to exponentially smaller gradients.
  - Makes learning long-term dependencies difficult.

Recursive Neural Network and Long Short-Term Memory

- **LSTM Architecture**
  - Designed to handle long-term dependencies.
  - Consists of gates (Input, Forget, Output) controlling cell state.
  - Maintains gradient flow over long sequences.
- **Advantages over Traditional NN**
  - Mitigates vanishing gradient problem.
  - Effective for sequential data (e.g., time series, language modeling).

LSTM model(TensorFlow, keras) for NFL play data

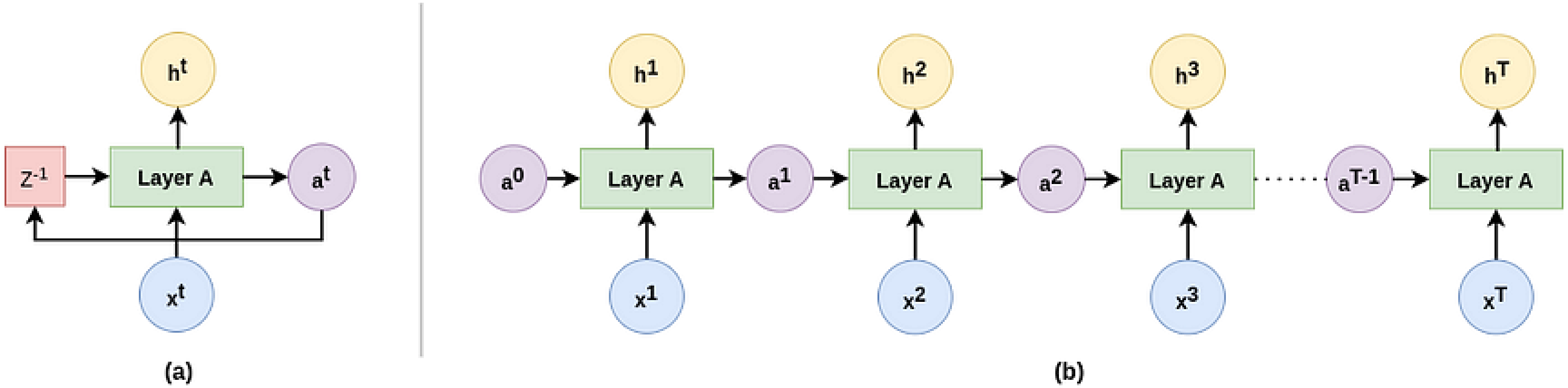


Layer (type)	Output Shape	Param #	Connected to
input_layer (InputLayer)	(None, None, 13)	0	-
not_equal (NotEqual)	(None, None, 13)	0	input_layer[0][0]
masking (Masking)	(None, None, 13)	0	input_layer[0][0]
any (Any)	(None, None)	0	not_equal[0][0]
lstm (LSTM)	(None, None, 100)	45,600	masking[0][0], any[0][0]
playType (Dense)	(None, None, 11)	1,111	lstm[0][0]
huddle (Dense)	(None, None, 3)	303	lstm[0][0]
formation (Dense)	(None, None, 7)	707	lstm[0][0]
playResult (Dense)	(None, None, 25)	2,525	lstm[0][0]
noPlay (Dense)	(None, None, 2)	202	lstm[0][0]
gameClockSecondsEx… (Dense)	(None, None, 1)	101	lstm[0][0]
gameClockStoppedAf… (Dense)	(None, None, 1)	101	lstm[0][0]
offensiveYards (Dense)	(None, None, 1)	101	lstm[0][0]

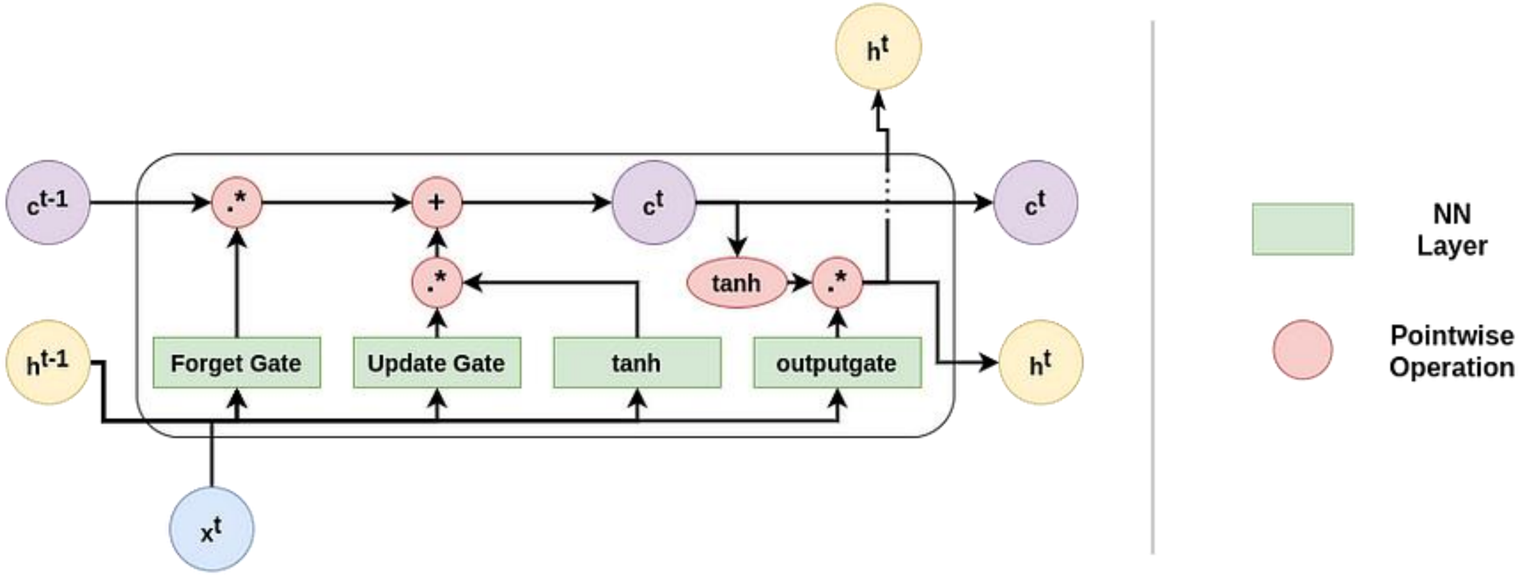
Total params: 50,751 (198.25 KB)
Trainable params: 50,751 (198.25 KB)
Non-trainable params: 0 (0.00 B)

LSTM Cell mechanism

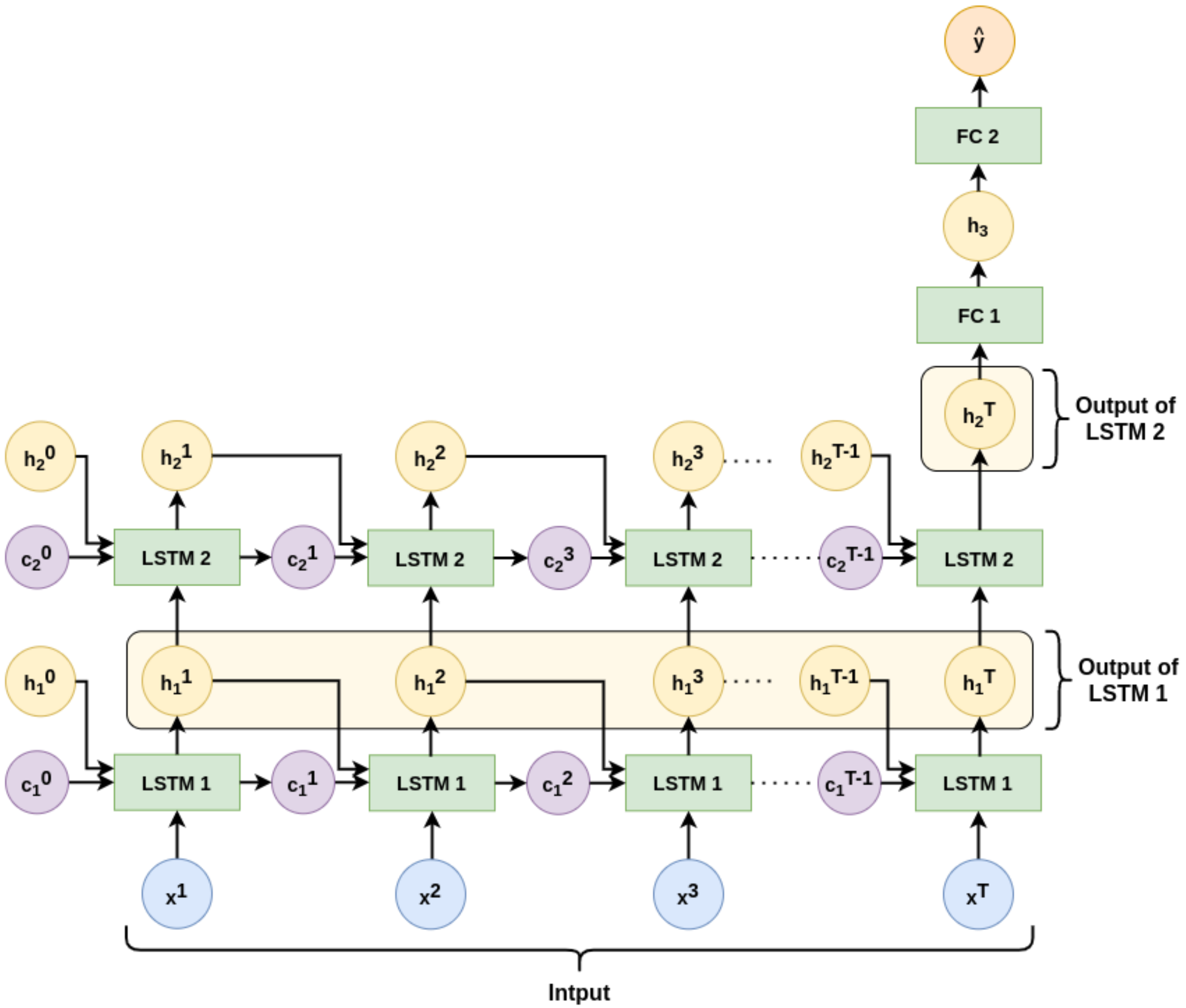
1. **Cell State Update:** updated cell state passes through the forget gate.
2. **Input Data and Hidden State Input:** input data and hidden state input are fed into the LSTM cell.
3. **Forget Gate** (sigmoid): determines what information to discard from the previous cell state.
4. **Input Gate**: decides what new information to store in the cell state and update the cell state
    - **Input Gate:** sigmoid
    - **Cell State:** tanh
5. **Update Cell State**: updates the cell state with new information
6. **Output Gate**: determines which parts of the cell state should be output and hidden state
    - **Output Gate:** sigmoid
    - **Hidden State:** tanh
7. **Classification Output**(softmax): hidden state is fed into a layer to produce classification outputs
8. **Regression Output**: hidden state output is fed into layers to produce regression outputs
    - softplus: gameClockSecondsExpired
    - Relu: offensiveYards
9. **Hidden State Output**: passed to the next time step



A general RNN with loop (z^{-1} symbolizes a unit time delay). (b) Same RNN with time series loop unrolled

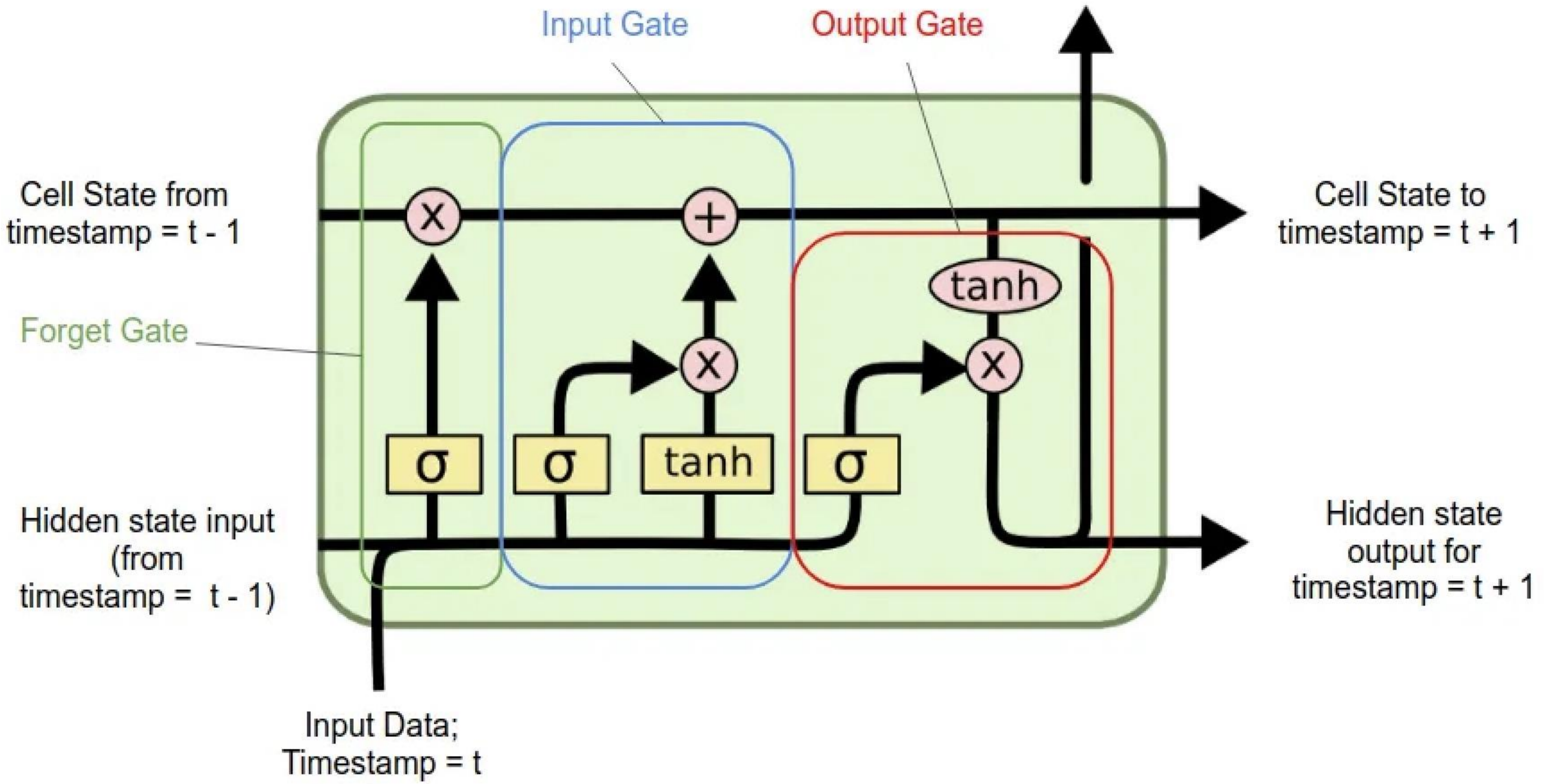


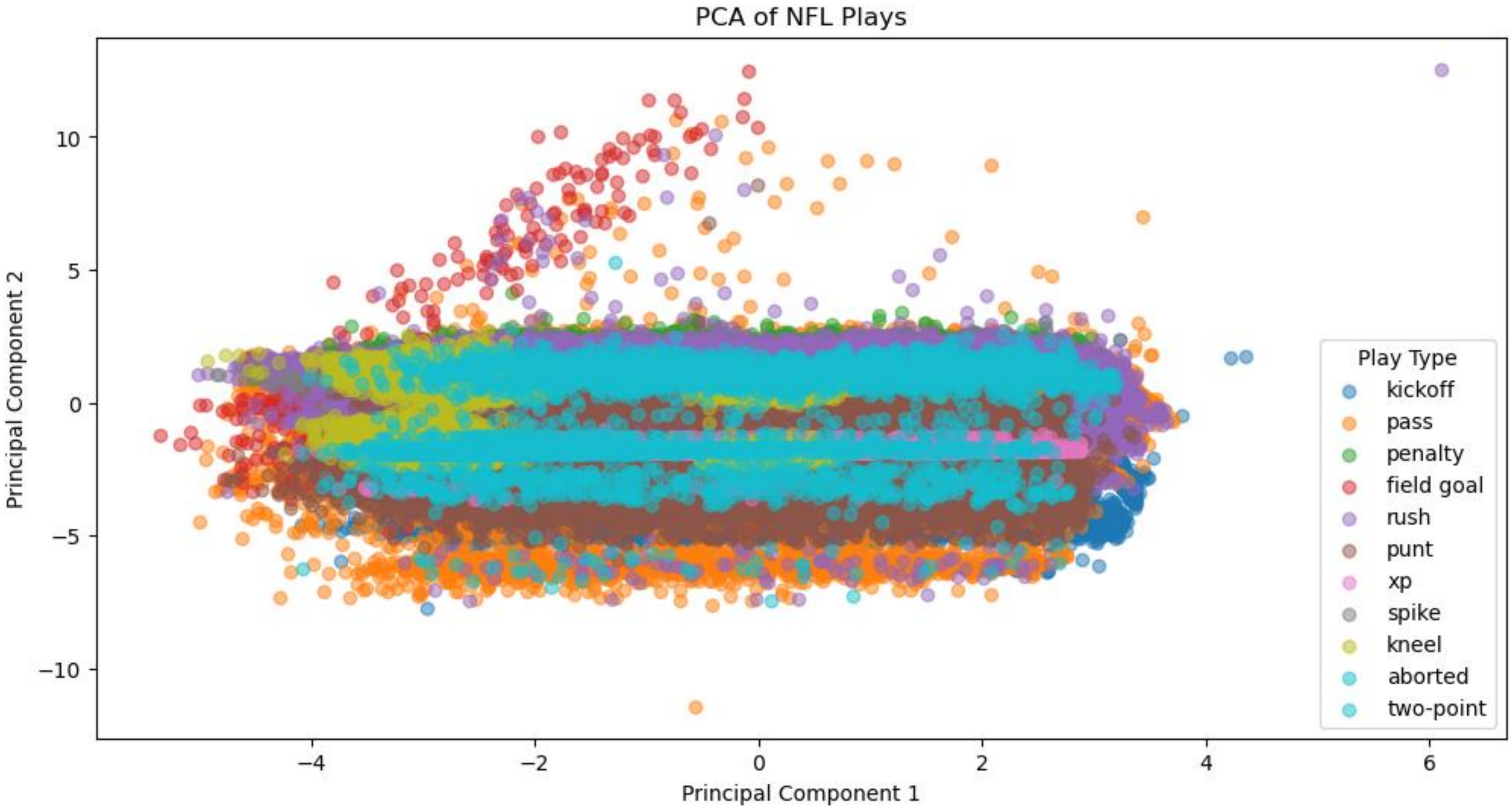
A basic LSTM layer

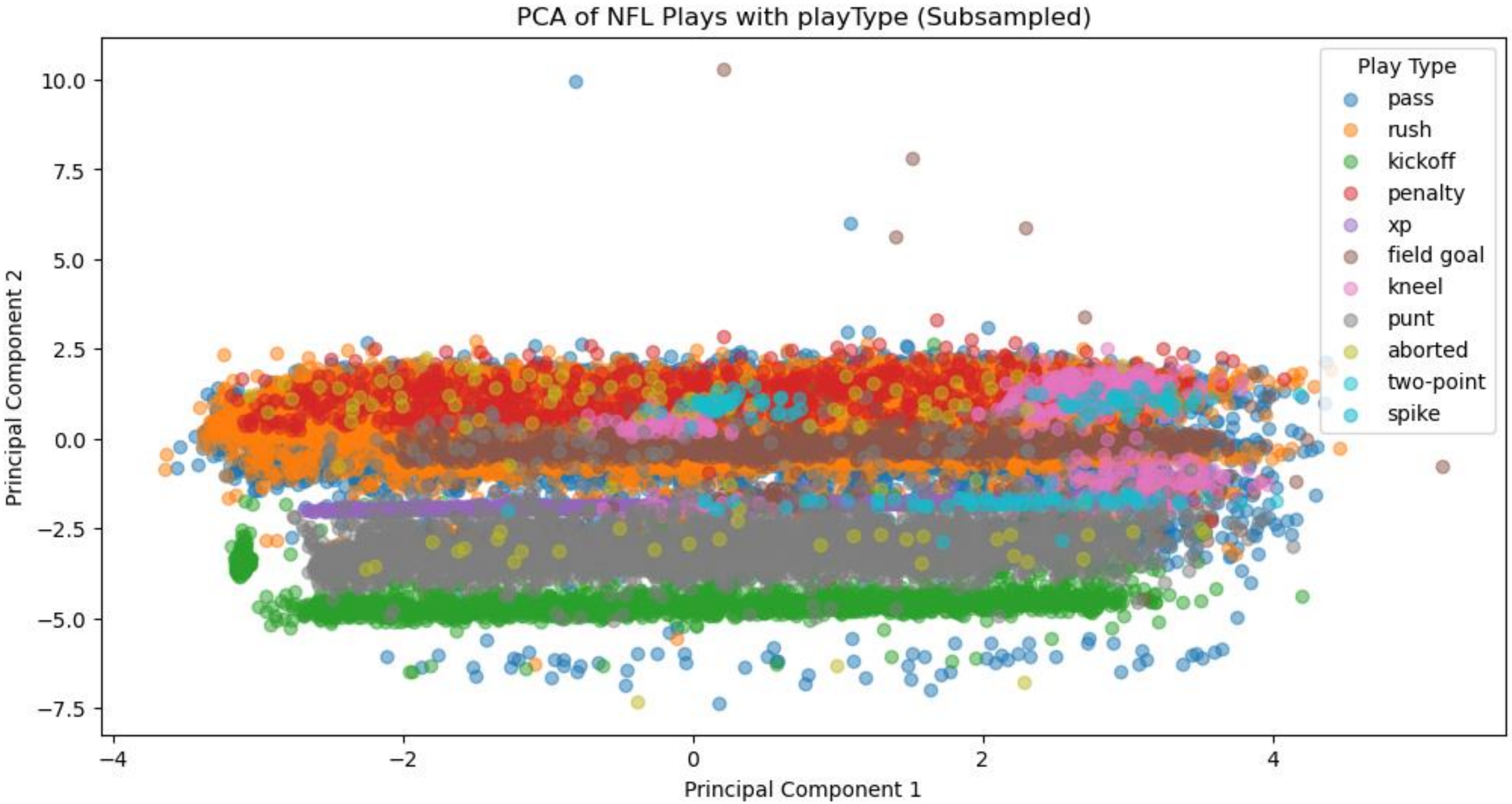


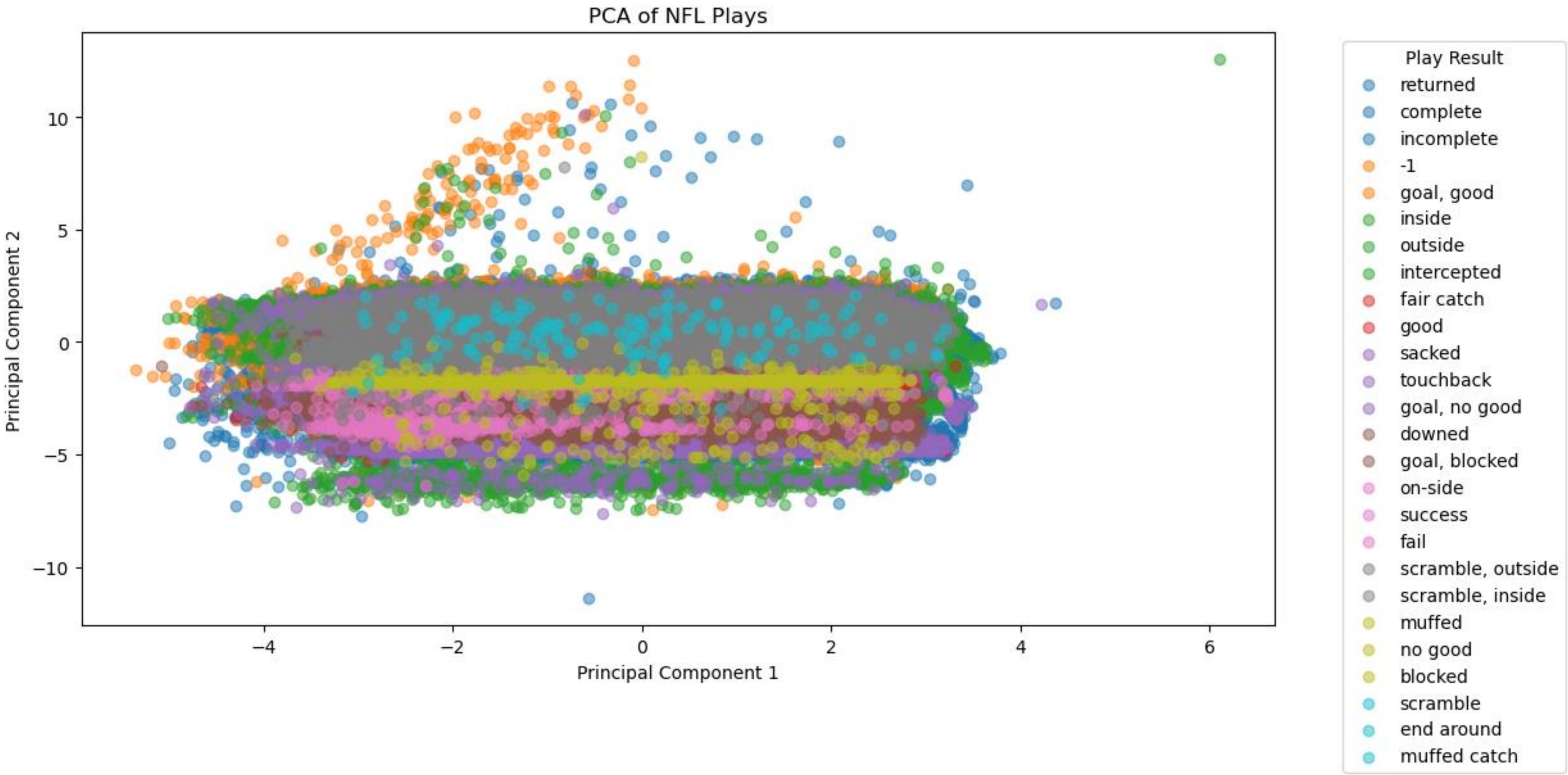
A model with 2 LSTM layers and 2 fully connected layers. Note that LSTM 1 layer outputs a sequence and the LSTM 2 outputs a single vector

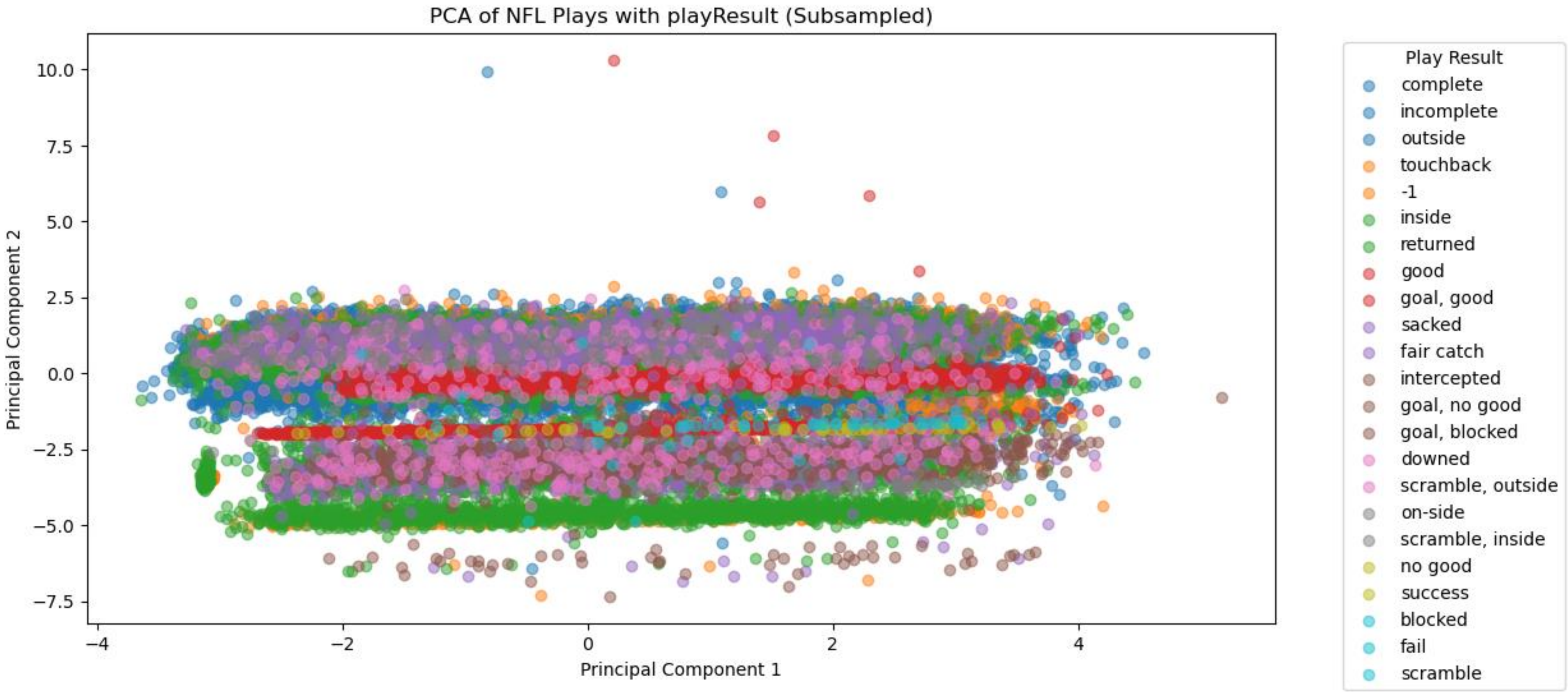
Detailed LSTM model

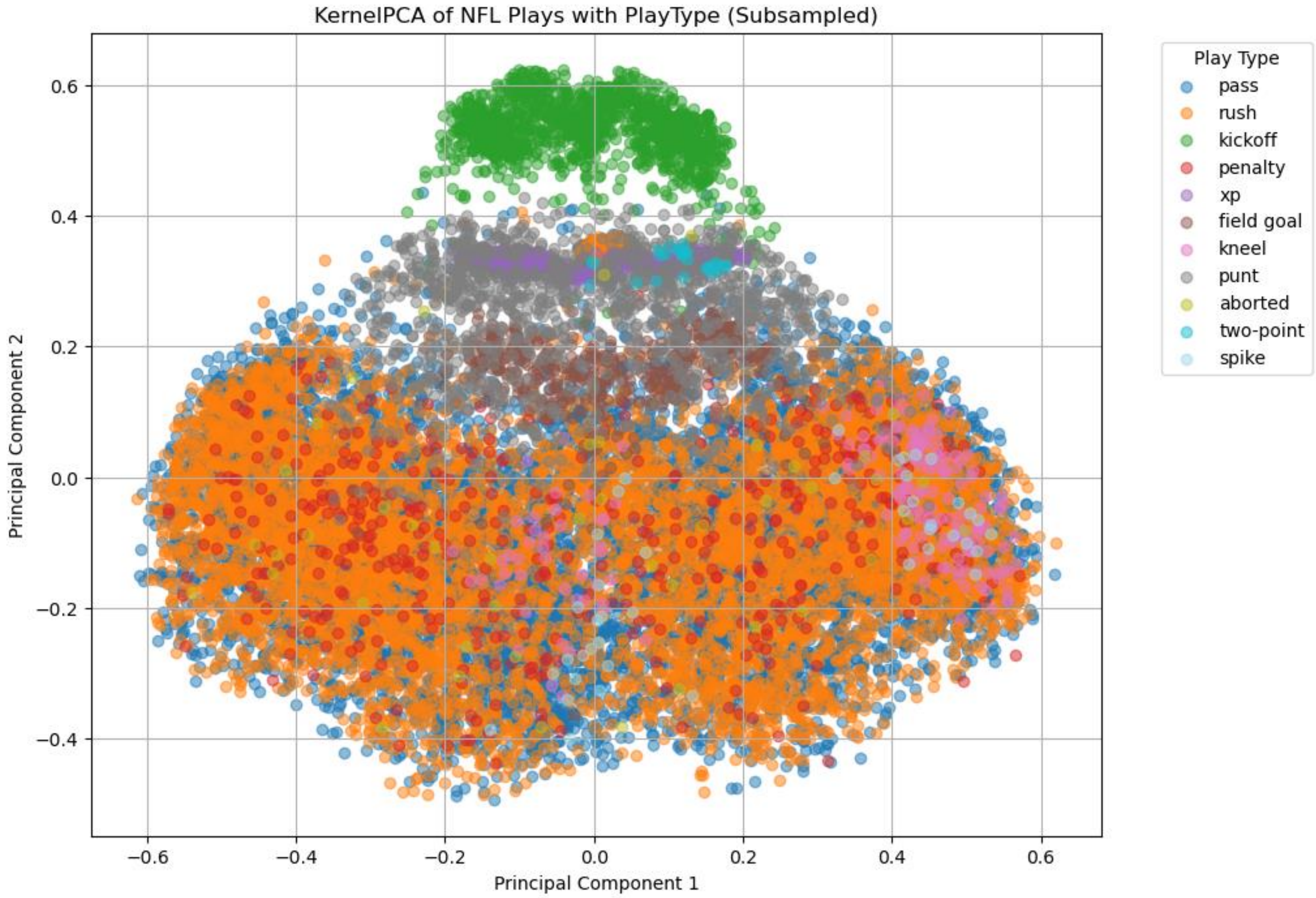


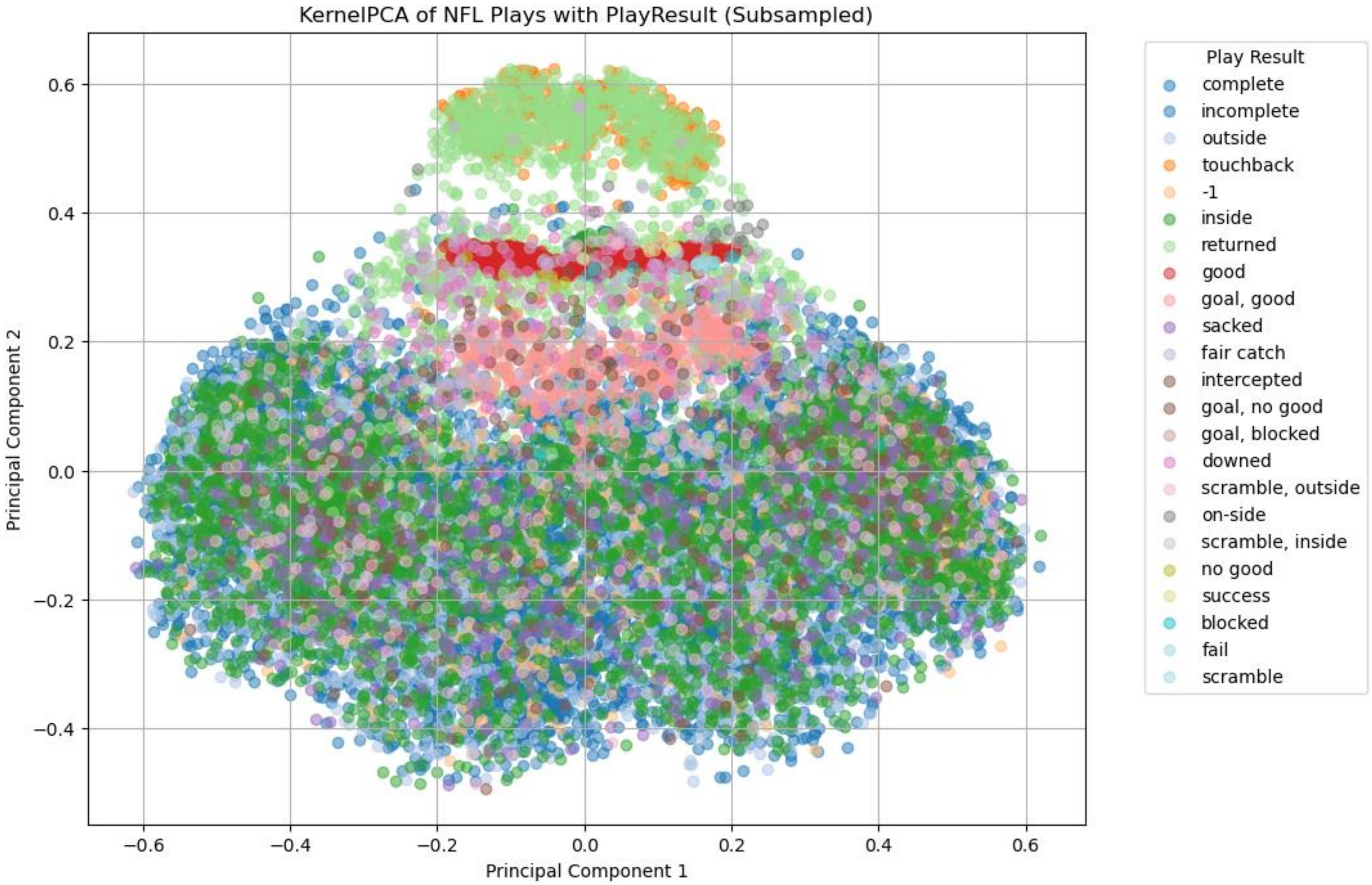

PCA of NFL Plays
Principal Component 1
Principal Component 2
−4
−2
0
2
4
6
10
5
0
−5
−10
Play Type
kickoff
pass
penalty
field goal
rush
punt
xp
spike
kneel
aborted
two-point

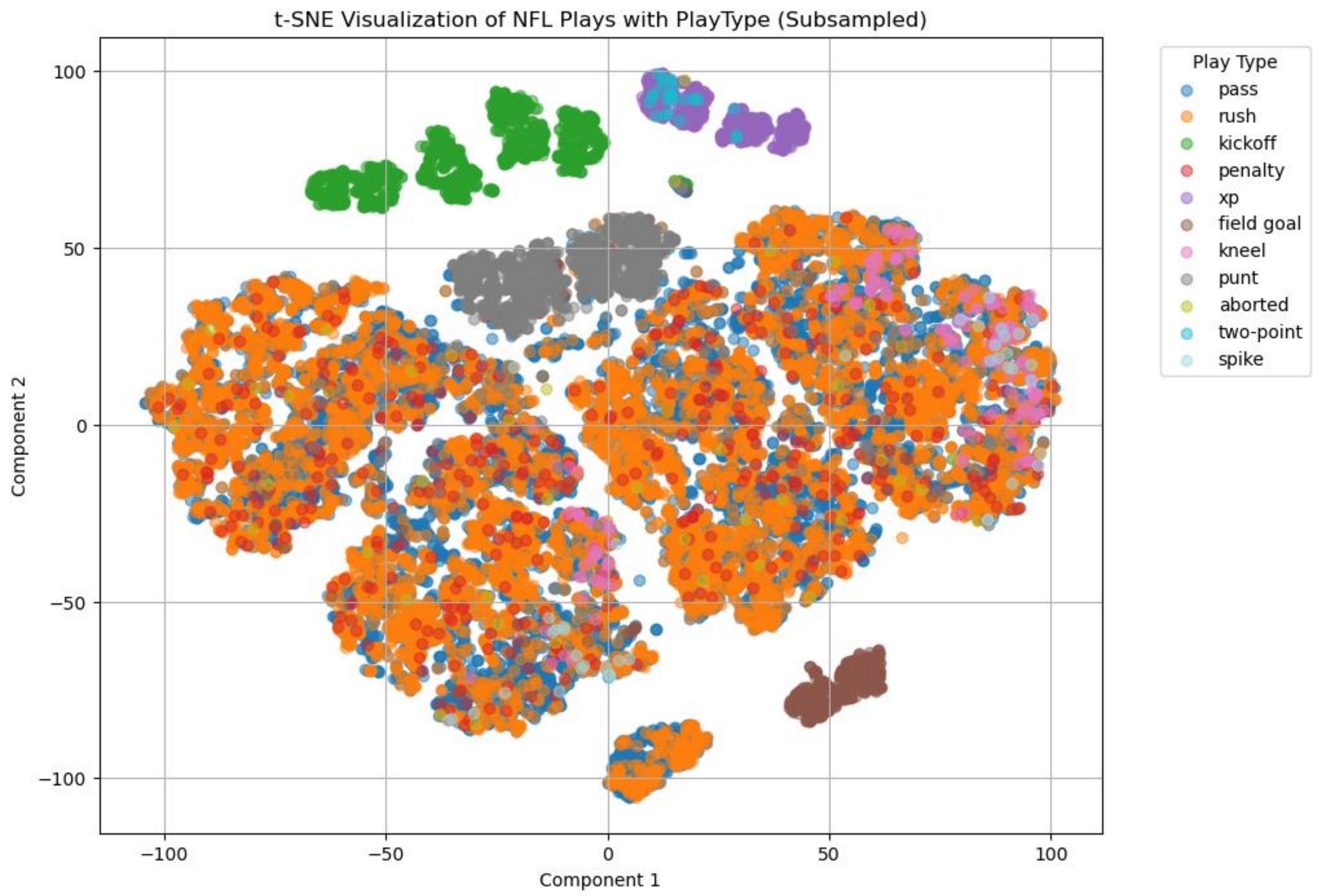

PCA of NFL Plays with playType (Subsampled)
Principal Component 1
Principal Component 2
Play Type
pass
rush
kickoff
penalty
xp
field goal
kneel
punt
aborted
two-point
spike
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−4
−2
0
2
4

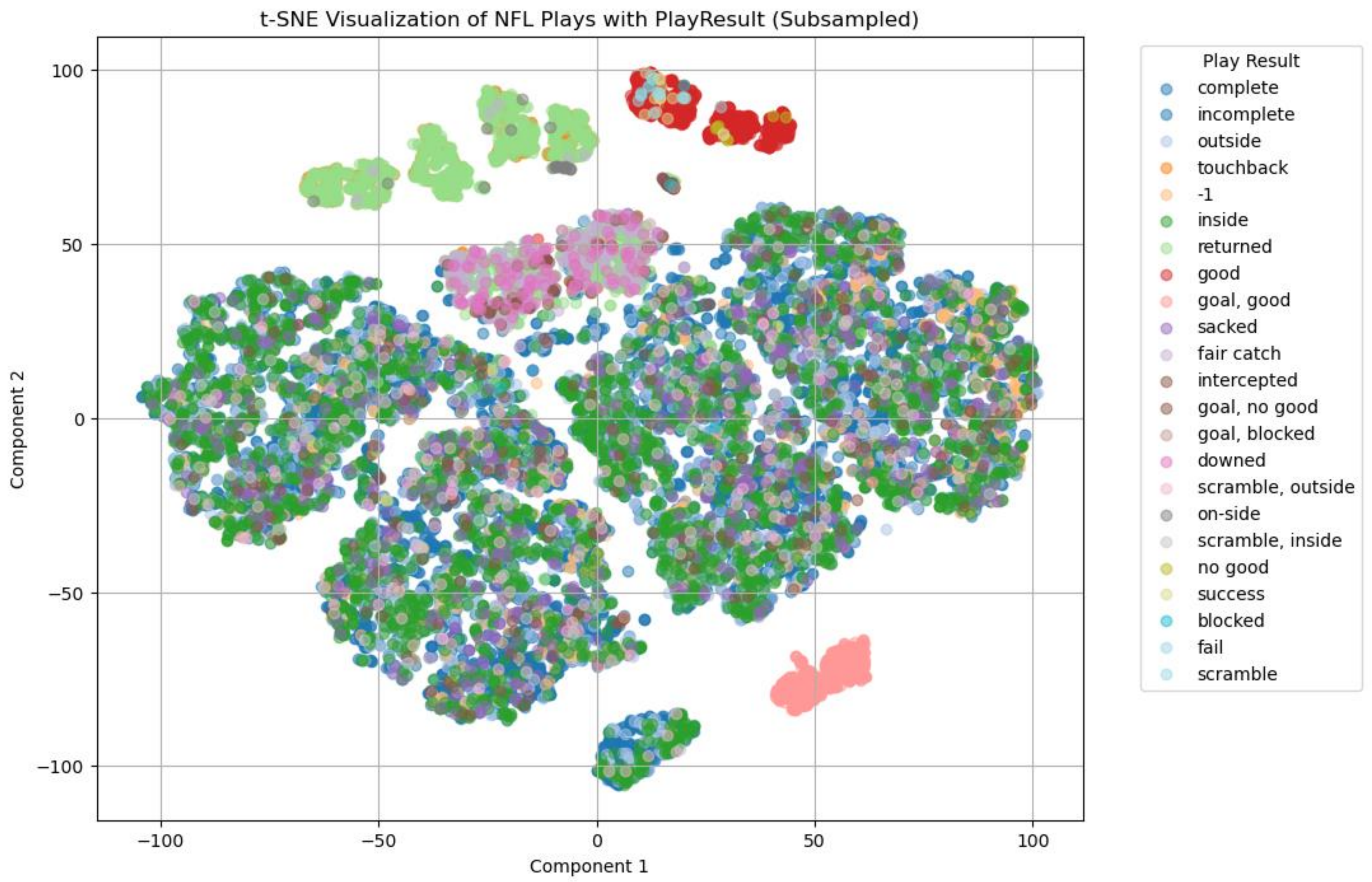

PCA of NFL Plays
Principal Component 2
Principal Component 1
10
5
0
−5
−10
−4
−2
0
2
4
6
Play Result
returned
complete
incomplete
-1
goal, good
inside
outside
intercepted
fair catch
good
sacked
touchback
goal, no good
downed
goal, blocked
on-side
success
fail
scramble, outside
scramble, inside
muffed
no good
blocked
scramble
end around
muffed catch


PCA of NFL Plays with playResult (Subsampled)
Principal Component 1
Principal Component 2
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−4
−2
0
2
4
Play Result
complete
incomplete
outside
touchback
-1
inside
returned
good
goal, good
sacked
fair catch
intercepted
goal, no good
goal, blocked
downed
scramble, outside
on-side
scramble, inside
no good
success
blocked
fail
scramble


KernelPCA of NFL Plays with PlayType (Subsampled)
Principal Component 1
Principal Component 2
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
Play Type
pass
rush
kickoff
penalty
xp
field goal
kneel
punt
aborted
two-point
spike


KernelPCA of NFL Plays with PlayResult (Subsampled)
Principal Component 1
Principal Component 2
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
Play Result
complete
incomplete
outside
touchback
-1
inside
returned
good
goal, good
sacked
fair catch
intercepted
goal, no good
goal, blocked
downed
scramble, outside
on-side
scramble, inside
no good
success
blocked
fail
scramble


t-SNE Visualization of NFL Plays with PlayType (Subsampled)
Component 2
Component 1
100
50
0
−50
−100
−100
−50
0
50
100
Play Type
pass
rush
kickoff
penalty
xp
field goal
kneel
punt
aborted
two-point
spike


t-SNE Visualization of NFL Plays with PlayResult (Subsampled)
Component 2
Component 1
100
50
0
−50
−100
−100
−50
0
50
100
Play Result
complete
incomplete
outside
touchback
-1
inside
returned
good
goal, good
sacked
fair catch
intercepted
goal, no good
goal, blocked
downed
scramble, outside
on-side
scramble, inside
no good
success
blocked
fail
scramble

Source code for analysis

- github.com/KUcyans/AppML_Final