judgment day

```
library(reticulate)
library(data.table)
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.0 --
```

```
## v ggplot2 3.3.3      v purrr   0.3.4
## v tibble  3.1.0      v dplyr   1.0.5
## v tidyr   1.1.3      v stringr 1.4.0
## v readr   1.4.0      v forcats 0.5.1
```

```
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::between()   masks data.table::between()
## x dplyr::filter()    masks stats::filter()
## x dplyr::first()     masks data.table::first()
## x dplyr::lag()       masks stats::lag()
## x dplyr::last()      masks data.table::last()
## x purrr::transpose() masks data.table::transpose()
```

```
library(pROC)
```

```
## Type 'citation("pROC")' for a citation.
```

```
##
## Attaching package: 'pROC'
```

```
## The following objects are masked from 'package:stats':
##
##     cov, smooth, var
```

```
use_virtualenv("../venv/", required = TRUE)
source_python("util.py")
source_python("models.py")
```

Functions

```
calculate_yhat_sklearn <- function(model, x) {
  return(model$predict_proba(x)[,2])
}

calculate_yhat_NN <- function(model, x) {
  return(model$predict(x))
}

calculate_TPR <- function(y, yhat) {
  P <- sum(y == 1)
  TP <- sum(((yhat > 0.5) == 1) & (y == 1))
  TPR <- TP / P
```

```r
  return(TPR)
}

calculate_AUC <- function(y, yhat) {
  df <- data.frame(a=y, p=yhat)
  df <- df[order(df$a),]
  roc_obj <- roc(df$a, df$p)
  AUC <- auc(roc_obj)
  TPR10 <- coords(roc_obj, x=0.9, input="specificity")$sensitivity
  return(c(AUC=AUC, TPR10=TPR10))
}

# This function assumes that the data variables are already defined in the environment.
# E.g. Black_x, AsianPI_y, etc.
calculate_results <- function(model, model_yhat_fn) {
  # (1) Prepare results matrix
  race_eth_all <- c('White', 'Black', 'AsianPI', 'AmeriIndian')
  results <- matrix(nrow = length(race_eth_all), ncol = 4)
  rownames(results) <- race_eth_all
  colnames(results) <- c('TPR', 'AUC', 'TPR10', 'Accuracy')

  # (2) Calculate TPR, AUC, and TPR10 for each race/ethnicity
  for (i in 1:length(race_eth_all)) {
    race_eth <- race_eth_all[i]
    x <- get(paste0(race_eth, '_x'))  # get() gets a variable in the environment by name
    y <- get(paste0(race_eth, '_y'))
    yhat <- model_yhat_fn(model, x)  # Note this depends on function arguments

    results[i, 1] <- calculate_TPR(y, yhat)
    results[i, c(2, 3)] <- calculate_AUC(y, yhat)
    results[i, 4] <- mean((yhat > 0.5) == y)
  }

  return(data.frame(results))
}
```

Fairness evaluations

Early Stillbirth

```r
x <- fread('../data/final/stillbirth_test.csv')
outcome <- 'early stillbirth'
x$outcome <- as.numeric(x$outcome == outcome)

AmeriIndian_x <- x %>% filter(race_AmeriIndian == 1)
AmeriIndian_y <- AmeriIndian_x$outcome
AmeriIndian_x <- AmeriIndian_x %>% select(-outcome)

AsianPI_x <- x %>% filter(race_AsianPI == 1)
AsianPI_y <- AsianPI_x$outcome
AsianPI_x <- AsianPI_x %>% select(-outcome)
```

```
Black_x <- x %>% filter(race_Black == 1)
Black_y <- Black_x$outcome
Black_x <- Black_x %>% select(-outcome)

White_x <- x %>% filter(race_White == 1)
White_y <- White_x$outcome
White_x <- White_x %>% select(-outcome)
```

Logistic Regression

```
lr_early <- load_pickle("../models/lr_early")
calculate_results(model = lr_early, model_yhat_fn = calculate_yhat_sklearn)
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

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##                   TPR       AUC     TPR10   Accuracy
## White       0.6319825 0.7740625 0.4764513 0.7994961
## Black       0.8699187 0.8124215 0.5249710 0.5047357
## AsianPI     0.6153846 0.8053455 0.5219780 0.8615261
## AmeriIndian 0.5666667 0.6735228 0.3666667 0.7518387
```

LightGBM

```
gb_early <- load_pickle("../models/gb_early")
calculate_results(model = gb_early, model_yhat_fn = calculate_yhat_sklearn)
```

```
## Setting levels: control = 0, case = 1

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## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                   TPR       AUC     TPR10   Accuracy
## White       0.6056955 0.8513484 0.6193866 0.9122414
## Black       0.8466899 0.8948861 0.7026713 0.7356864
## AsianPI     0.6813187 0.9000883 0.7417582 0.9384617
## AmeriIndian 0.6666667 0.8369764 0.6666667 0.8961124
```

ReLU Network

```r
relu_early <- load_NN("../models/lrelu_early")
calculate_results(relu_early, calculate_yhat_NN)
```

```
## Setting levels: control = 0, case = 1

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## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                   TPR       AUC     TPR10  Accuracy
## White       0.4775465 0.7401706 0.5180723 0.9336763
## Black       0.6643438 0.7865401 0.6097561 0.8131343
## AsianPI     0.4780220 0.7664236 0.5769231 0.9650928
## AmeriIndian 0.4333333 0.6814822 0.5000000 0.9513396
```

SELU Network

```r
selu_early <- load_NN("../models/selu_early")
calculate_results(selu_early, calculate_yhat_NN)
```

```
## Setting levels: control = 0, case = 1

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## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                   TPR       AUC     TPR10  Accuracy
## White       0.6100767 0.8435614 0.6226725 0.9142501
## Black       0.8536585 0.8881560 0.7073171 0.7175685
## AsianPI     0.6813187 0.8872953 0.7307692 0.9510226
## AmeriIndian 0.5666667 0.7920680 0.6000000 0.9659180
```

Late Stillbirth

```r
x <- fread('../data/final/stillbirth_test.csv')
outcome <- 'late stillbirth'
x$outcome <- as.numeric(x$outcome == outcome)

AmeriIndian_x <- x %>% filter(race_AmeriIndian == 1)
```

```
AmeriIndian_y <- AmeriIndian_x$outcome
AmeriIndian_x <- AmeriIndian_x %>% select(-outcome)

AsianPI_x <- x %>% filter(race_AsianPI == 1)
AsianPI_y <- AsianPI_x$outcome
AsianPI_x <- AsianPI_x %>% select(-outcome)

Black_x <- x %>% filter(race_Black == 1)
Black_y <- Black_x$outcome
Black_x <- Black_x %>% select(-outcome)

White_x <- x %>% filter(race_White == 1)
White_y <- White_x$outcome
White_x <- White_x %>% select(-outcome)
```

Logistic Regression

```
lr_late <- load_pickle("../models/lr_late")
calculate_results(model = lr_late, model_yhat_fn = calculate_yhat_sklearn)
```

```
## Setting levels: control = 0, case = 1

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## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                  TPR       AUC     TPR10  Accuracy
## White      0.6483376 0.7532278 0.4437340 0.7623739
## Black      0.8432836 0.7725808 0.4440299 0.4859167
## AsianPI    0.5267176 0.7463088 0.4045802 0.8350773
## AmeriIndian 0.8292683 0.8016243 0.5609756 0.5587076
```

LightGBM

```
gb_late <- load_pickle("../models/gb_late")
calculate_results(model = gb_late, model_yhat_fn = calculate_yhat_sklearn)
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1
```

```
## Setting direction: controls < cases

##                  TPR       AUC      TPR10 Accuracy
## White       0.6413043 0.8367200 0.6259591 0.8857706
## Black       0.7630597 0.8426006 0.6063433 0.7287307
## AsianPI     0.6641221 0.8848103 0.7022901 0.9425237
## AmeriIndian 0.7073171 0.8677560 0.6341463 0.8233517
```

ReLU Network

```r
relu_late <- load_NN("../models/lrelu_late")
calculate_results(relu_late, calculate_yhat_NN)
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                   TPR       AUC      TPR10 Accuracy
## White       0.05051151 0.6649044 0.3804348 0.9976499
## Black       0.31716418 0.7086099 0.4645522 0.9867025
## AsianPI     0.09923664 0.7195041 0.4885496 0.9907414
## AmeriIndian 0.34146341 0.7525820 0.5121951 0.9791174
```

SELU Network

```r
selu_late <- load_NN("../models/selu_late")
calculate_results(selu_late, calculate_yhat_NN)
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                  TPR       AUC      TPR10 Accuracy
## White       0.6585678 0.8320714 0.6131714 0.8576026
## Black       0.8190299 0.8416441 0.6082090 0.6423109
## AsianPI     0.6564885 0.8642600 0.6717557 0.9326270
## AmeriIndian 0.8292683 0.8766467 0.7073171 0.7385080
```

Preterm Birth

```
x <- fread('../data/final/preterm_test.csv')
outcome <- 'preterm'
x$outcome <- as.numeric(x$outcome == outcome)

AmeriIndian_x <- x %>% filter(race_AmeriIndian == 1)
AmeriIndian_y <- AmeriIndian_x$outcome
AmeriIndian_x <- AmeriIndian_x %>% select(-outcome)

AsianPI_x <- x %>% filter(race_AsianPI == 1)
AsianPI_y <- AsianPI_x$outcome
AsianPI_x <- AsianPI_x %>% select(-outcome)

Black_x <- x %>% filter(race_Black == 1)
Black_y <- Black_x$outcome
Black_x <- Black_x %>% select(-outcome)

White_x <- x %>% filter(race_White == 1)
White_y <- White_x$outcome
White_x <- White_x %>% select(-outcome)
```

Logistic Regression

```
lr_preterm <- load_pickle("../models/lr_preterm")
calculate_results(model = lr_preterm, model_yhat_fn = calculate_yhat_sklearn)
```

```
## Setting levels: control = 0, case = 1

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## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases
```

```
##                     TPR       AUC     TPR10  Accuracy
## White         0.3713707 0.6285827 0.2661478 0.7711041
## Black         0.8916200 0.6197046 0.2465778 0.2900029
## AsianPI       0.3102148 0.6308708 0.2689366 0.8140581
## AmeriIndian   0.5899497 0.6274294 0.2422111 0.5925188
```

LightGBM

```
gb_preterm <- load_pickle("../models/gb_preterm")
calculate_results(model = gb_preterm, model_yhat_fn = calculate_yhat_sklearn)
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                 TPR       AUC     TPR10  Accuracy
## White       0.4273950 0.6418888 0.2705877 0.7445816
## Black       0.8511784 0.6345674 0.2520533 0.3489737
## AsianPI     0.3724463 0.6425101 0.2801467 0.7823997
## AmeriIndian 0.6055276 0.6382355 0.2462312 0.5885988
```

ReLU Network

```
relu_preterm <- load_NN("../models/lrelu_preterm")
calculate_results(relu_preterm, calculate_yhat_NN)
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

##                 TPR       AUC     TPR10  Accuracy
## White       0.2857222 0.6266735 0.2656780 0.8252099
## Black       0.6912570 0.6190991 0.2456553 0.4848123
## AsianPI     0.2588790 0.6303297 0.2728130 0.8467595
## AmeriIndian 0.3693467 0.6254665 0.2402010 0.7559631
```

SELU Network

```
selu_preterm <- load_NN("../models/selu_preterm")
calculate_results(selu_preterm, calculate_yhat_NN)
```

```
## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1

## Setting direction: controls < cases

## Setting levels: control = 0, case = 1
```

```
## Setting direction: controls < cases
##                    TPR       AUC     TPR10  Accuracy
## White         0.3491525 0.6407108 0.2698968 0.7946045
## Black         0.6738781 0.6330132 0.2505059 0.5247979
## AsianPI       0.2735464 0.6377759 0.2768989 0.8412582
## AmeriIndian   0.4869347 0.6357260 0.2467337 0.6820809
```

Notes

"Further research would also include inspecting the reproducibility of the results beyond the population of the United States with different ML models. The best machine learning models (SELU network, LGBM and averaged ensemble) were able to produce repeatable performance over two data sets. Using these machine learning models, especially for early stillbirth, could provide earlier identification of at-risk pregnancies with high accuracy and provide tools for better utilization of healthcare resources targeted to those needing it most."