

# **STATS 3DA3**

## **Homework Assignment 6**

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## Question

1)

Our target variable measure the severity of heart disease which can be defined as binary classification problem. Our goal would then to be able to predict the probability of heart disease. This means we can carry out a logistic regression and a random forest classifier to predict the presence and absence of heart disease.

2)

```
from ucimlrepo import fetch_ucirepo
from sklearn.preprocessing import StandardScaler

heart_disease = fetch_ucirepo(id=45)

X = heart_disease.data.features
y = heart_disease.data.targets

scaler = StandardScaler()
X_train_scaled = scaler.fit_transform(X)
```

3)

We have 13 features and 1 target variable. Starting with our features, we have age (age in years), sex (1 = male; 0 = female), cp (1: typical angina, 2: atypical angina, 3: non-anginal pain, 4: asymptomatic), trestbps (resting blood pressure in mm Hg on admission to the hospital), chol (serum cholestoral in mg/dl), fbs (fasting blood sugar > 120 mg/dl where 1 = true; 0 = false), restecg (resting electrocardiographic results), exang (exercise induced angina), oldpeak (ST depression induced by exercise relative to rest), slope (1 = upsloping, 2 = flat, 3 = downsloping), ca (number of major vessels colored by floursopy), thal (3 = normal; 6 = fixed defect; 7 = reversable defect). Finally our target variable, 'num', is the diagnosis of heart disease.

```
print(f"Observations in X: {len(X)}")
print(f"Summary of X:\n{X.describe()}")
print(f"Summary of y:\n{y.describe()}")
```

Observations in X: 303

Summary of X:

	age	sex	cp	trestbps	chol	fbs \
count	303.000000	303.000000	303.000000	303.000000	303.000000	303.000000
mean	54.438944	0.679868	3.158416	131.689769	246.693069	0.148515
std	9.038662	0.467299	0.960126	17.599748	51.776918	0.356198
min	29.000000	0.000000	1.000000	94.000000	126.000000	0.000000
25%	48.000000	0.000000	3.000000	120.000000	211.000000	0.000000
50%	56.000000	1.000000	3.000000	130.000000	241.000000	0.000000
75%	61.000000	1.000000	4.000000	140.000000	275.000000	0.000000
max	77.000000	1.000000	4.000000	200.000000	564.000000	1.000000

	restecg	thalach	exang	oldpeak	slope	ca \
count	303.000000	303.000000	303.000000	303.000000	303.000000	299.000000
mean	0.990099	149.607261	0.326733	1.039604	1.600660	0.672241
std	0.994971	22.875003	0.469794	1.161075	0.616226	0.937438
min	0.000000	71.000000	0.000000	0.000000	1.000000	0.000000
25%	0.000000	133.500000	0.000000	0.000000	1.000000	0.000000
50%	1.000000	153.000000	0.000000	0.800000	2.000000	0.000000
75%	2.000000	166.000000	1.000000	1.600000	2.000000	1.000000
max	2.000000	202.000000	1.000000	6.200000	3.000000	3.000000

	thal
count	301.000000
mean	4.734219
std	1.939706
min	3.000000
25%	3.000000

50%	3.000000
75%	7.000000
max	7.000000

Summary of y:

	num
count	303.000000
mean	0.937294
std	1.228536
min	0.000000
25%	0.000000
50%	0.000000
75%	2.000000
max	4.000000

We find that the average age of patients is 54.4 years old, with a standard deviation of 9.1 years.

```
print(f"Data Types of X: \n{X.dtypes}")
print(f"\nData Types of y: \n{y.dtypes}")
```

Data Types of X:

age	int64
sex	int64
cp	int64
trestbps	int64
chol	int64
fbs	int64
restecg	int64
thalach	int64
exang	int64
oldpeak	float64
slope	int64
ca	float64

```
thal          float64
dtype: object
```

Data Types of y:

```
num          int64
dtype: object
```

All of our data types in X are numerical but some representing categorical variables.

4)

```
print(f"y before transformation: {y['num'].value_counts()}")
y['num'] = y['num'].apply(lambda x: 1 if x > 0 else 0)
print(f"y before transformation: {y['num'].value_counts()}")
```

```
y before transformation: num
```

```
0    164
1     55
2     36
3     35
4     13
```

```
Name: count, dtype: int64
```

```
y before transformation: num
```

```
0    164
1    139
```

```
Name: count, dtype: int64
```

```
/var/folders/5q/w2pw9gp90mldwv2xvm9ml_jc0000gn/T/ipykernel_61415/2854447611.py:2: SettingWithCopyWarning: 
```

A value is trying to be set on a copy of a slice from a DataFrame.

Try using `.loc[row_indexer,col_indexer] = value` instead

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/](https://pandas.pydata.org/pandas-docs/stable/user_guide/)

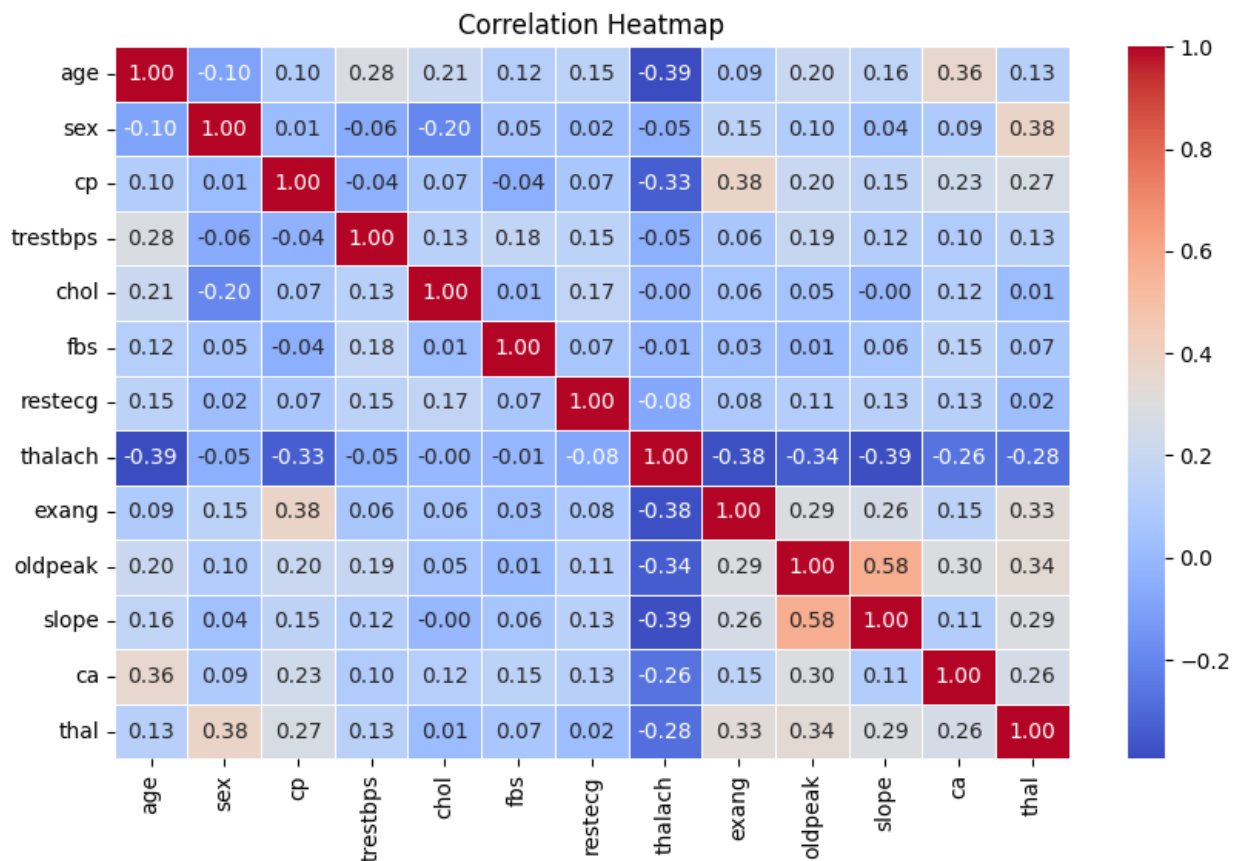
```
y['num'] = y['num'].apply(lambda x: 1 if x > 0 else 0)
```

5)

```
import seaborn as sns
import matplotlib.pyplot as plt

corr_matrix = X.corr()

plt.figure(figsize=(10, 6))
sns.heatmap(corr_matrix, annot=True, cmap='coolwarm', fmt=".2f", linewidths=0.5)
plt.title("Correlation Heatmap")
plt.show()
```



From this correlation matrix, we can conclude that thalach (max heart rate) has a strong negative correlation (-0.39) with age and oldpeak. We can assume that younger individuals tend to have a higher heart rate, while those with more severe heart disease (higher oldpeak) have lower thalach.

We also found that ca (number of major vessels) has a strong positive correlation (0.36) with age. We can say that older individuals are more likely to have more blocked vessels.

6)

```
X = X.dropna()
y = y.loc[X.index]

print(f"Length of X after transformations: {len(X)}")
print(f"Length of y after transformations: {len(y)}")
```

Length of X after transformations: 297

Length of y after transformations: 297

7)

```
import pandas as pd
from sklearn.metrics import silhouette_samples, silhouette_score
from sklearn.preprocessing import StandardScaler
from sklearn.decomposition import PCA
from sklearn.cluster import KMeans
import matplotlib.pyplot as plt

categorical_columns = ['sex', 'cp', 'fbs', 'restecg', 'exang', 'slope', 'thal']
X_cleaned = X.drop(columns=categorical_columns)

scaler = StandardScaler()
X_scaled = scaler.fit_transform(X_cleaned)

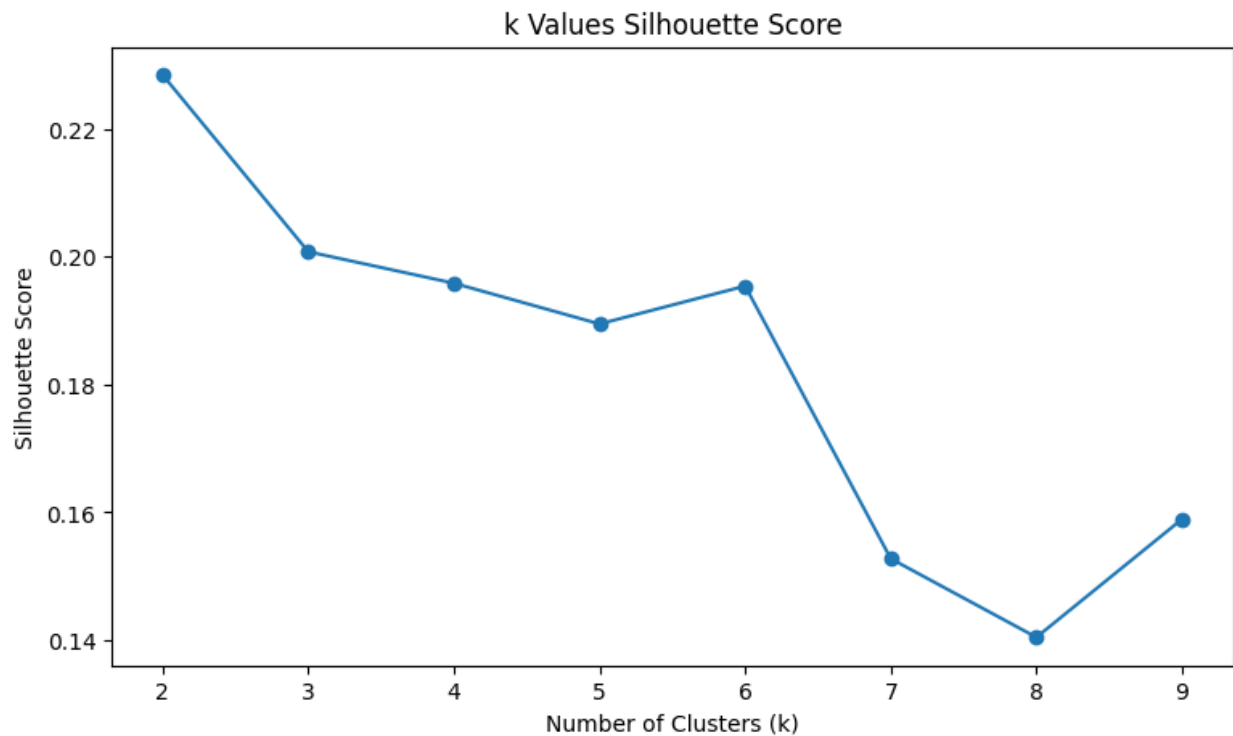
k_range = range(2,10)
silhouette_scores = []
```

```

for k in k_range:
    kmeans = KMeans(n_clusters = k, n_init = 20, random_state = 0)
    cluster_labels = kmeans.fit_predict(X_scaled)
    silhouette_avg = silhouette_score(X_scaled, cluster_labels)
    silhouette_scores.append(silhouette_avg)

plt.figure(figsize=(9, 5))
plt.plot(k_range, silhouette_scores, marker='o')
plt.ylabel("Silhouette Score")
plt.xlabel("Number of Clusters (k)")
plt.title("k Values Silhouette Score")
plt.show()

```



```

# use k = 2 based on the silhouette scores

pca = PCA(n_components=2)
X_pca = pca.fit_transform(X_scaled)

```



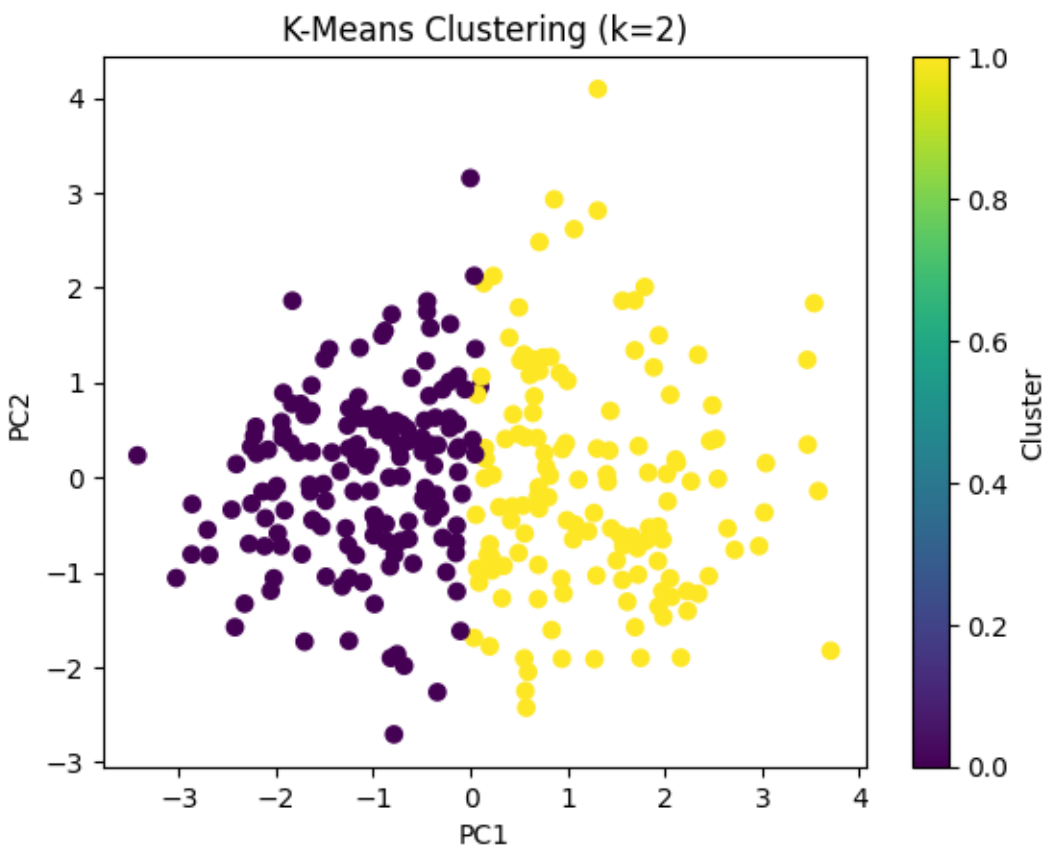
```

kmeans = KMeans(n_clusters=2, random_state=42)
clusters = kmeans.fit_predict(X_scaled)

plt.scatter(X_pca[:, 0], X_pca[:, 1], c=clusters, cmap='viridis')
plt.title("K-Means Clustering (k=2)")
plt.xlabel("PC1")
plt.ylabel("PC2")
plt.colorbar(label="Cluster")
plt.show()

X_scaled_df = pd.DataFrame(X_scaled, columns=X_cleaned.columns)
X_scaled_df['cluster'] = clusters

```



8)

```
from sklearn.model_selection import train_test_split

X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.30, random_state=1)
```

9)

We are going to use logistic regression and random forest. Logistic regression is suitable for this assignment because it predicts a binary outcome, in which case, the target variable is 0 or 1. Random forest is also a good classifier to use because it has high predictive accuracy and does not depend on linear relationships, which is good for this dataset as there are both numerical and categorical variables.

10)

We are going to use accuracy and F1 scores to compare the classifier performance between logistic regression and random forest. We can create the confusion matrix from the predictions to calculate the accuracy and F1 scores. Accuracy scores are calculated by the number of correct predictions over the total number of predictions.

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

Where:

$TP$  = True Positives

$TN$  = True Negatives

$FP$  = False Positives

$FN$  = False Negatives

To obtain the F1 score, we will need to use precision and recall that are derived from the confusion matrix. Once we calculate that, the F1 score can be calculated by:

$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Recall} = \frac{TP}{TP + FN}$$

$$F_1 = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

Using these metrics, we can compare the overall accuracy and balance between the two classifiers to determine which classifier most optimal for predicting heart disease.

11)

```
import numpy as np
from sklearn.model_selection import train_test_split, GridSearchCV
from sklearn.preprocessing import StandardScaler
from sklearn.linear_model import LogisticRegression
from sklearn.metrics import accuracy_score, confusion_matrix, classification_report

scaler = StandardScaler()
X_train_scaled = scaler.fit_transform(X_train)
X_test_scaled = scaler.transform(X_test)

log_reg = LogisticRegression(solver='liblinear', max_iter=1000, random_state=42)

param_grid = {
    'penalty': ['l1', 'l2'],
    'C': np.logspace(-4, 4, 20)
}

grid_search = GridSearchCV(estimator=log_reg, param_grid=param_grid, cv=5, scoring='accuracy',
grid_search.fit(X_train_scaled, y_train)
```

```

print("Best parameters found: ", grid_search.best_params_)
print("Best cross-validation accuracy: {:.4f}".format(grid_search.best_score_))

best_log_reg = grid_search.best_estimator_
y_pred = best_log_reg.predict(X_test_scaled)
y_pred2 = best_log_reg.predict(X_train_scaled)

accuracy = accuracy_score(y_test, y_pred)
train_accuracy = accuracy_score(y_train, y_pred2)
cm = confusion_matrix(y_test, y_pred)
report = classification_report(y_test, y_pred, target_names=['No Heart Disease', 'Heart Disease'])

print(f"Test set accuracy: {accuracy:.4f}")
print(f"Train set accuracy: {train_accuracy:.4f}")
print("Confusion Matrix:")
print(cm)
print("Classification Report:")
print(report)

```

Fitting 5 folds for each of 40 candidates, totalling 200 fits

```

/Users/jasmineho/Library/Python/3.9/lib/python/site-packages/sklearn/utils/validation.py:1408:
  y = column_or_1d(y, warn=True)
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```





[illegible]









[illegible]

[illegible]





Best parameters found: {'C': 0.08858667904100823, 'penalty': 'l2'}

Best cross-validation accuracy: 0.8458

Test set accuracy: 0.8444

Train set accuracy: 0.8551

Confusion Matrix:

```
[[43  8]
 [ 6 33]]
```

Classification Report:

	precision	recall	f1-score	support
No Heart Disease	0.88	0.84	0.86	51
Heart Disease	0.80	0.85	0.82	39
accuracy			0.84	90
macro avg	0.84	0.84	0.84	90
weighted avg	0.85	0.84	0.84	90

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```

```

from sklearn.model_selection import train_test_split, GridSearchCV
from sklearn.preprocessing import StandardScaler
from sklearn.ensemble import RandomForestClassifier, GradientBoostingClassifier
from sklearn.metrics import accuracy_score, confusion_matrix, classification_report

```

```

rf_clf = RandomForestClassifier(random_state=42)
rf_param_grid = {
    'n_estimators': [100, 200, 300],
    'max_depth': [None, 10, 20, 30],
    'min_samples_split': [2, 5, 10],
    'min_samples_leaf': [1, 2, 4],
    'max_features': ['sqrt', 'log2', None],
    'criterion': ['gini', 'entropy']
}

rf_grid_search = GridSearchCV(estimator=rf_clf, param_grid=rf_param_grid, cv=5, scoring='accuracy')
rf_grid_search.fit(X_train_scaled, y_train)

print("Random Forest Best Parameters:", rf_grid_search.best_params_)
print("Random Forest Best Cross-Validation Accuracy:", rf_grid_search.best_score_)

best_rf_clf = rf_grid_search.best_estimator_
rf_y_pred = best_rf_clf.predict(X_test_scaled)

# Evaluate the Random Forest model's performance
rf_accuracy = accuracy_score(y_test, rf_y_pred)
rf_cm = confusion_matrix(y_test, rf_y_pred)
rf_report = classification_report(y_test, rf_y_pred, target_names=[f'Class {i}' for i in np.unique(y_test)])

# Display Random Forest results
print(f"Random Forest Test Accuracy: {rf_accuracy:.4f}")
print("Random Forest Confusion Matrix:")
print(rf_cm)
print("Random Forest Classification Report:")
print(rf_report)

```

/Users/jasmineho/Library/Python/3.9/lib/python/site-packages/sklearn/base.py:1389: DataConversionWarning: A column-vector y was passed when a 1D array was expected. Please change the shape of y to (n\_samples,)

```

    return fit_method(estimator, *args, **kwargs)
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Fitting 5 folds for each of 648 candidates, totalling 3240 fits

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[illegible]

















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/Users/jasmineho/Library/Python/3.9/lib/python/site-packages/sklearn/base.py:1389: DataConversionWarning:
    return fit_method(estimator, *args, **kwargs)

```

KeyboardInterrupt:

```

-----
KeyboardInterrupt                                Traceback (most recent call last)
Cell In[44], line 18
      8 rf_param_grid =          9      'n_estimators': [100, 200, 300],      10      'max_depth': [
    17 rf_grid_search = GridSearchCV(estimator=rf_clf, param_grid=rf_param_grid, cv=5, scoring=
--> 18 rf_grid_search.fit(X_train_scaled, y_train)
    20 print("Random Forest Best Parameters:", rf_grid_search.best_params_)
    21 print("Random Forest Best Cross-Validation Accuracy:", rf_grid_search.best_score_)
File ~/Library/Python/3.9/lib/python/site-packages/sklearn/base.py:1389, in _fit_context.<local>
    1382     estimator._validate_params()
    1384 with config_context(
    1385     skip_parameter_validation=(
    1386         prefer_skip_nested_validation or global_skip_validation
    1387     )
    1388 ):
-> 1389     return fit_method(estimator, *args, **kwargs)
File ~/Library/Python/3.9/lib/python/site-packages/sklearn/model_selection/_search.py:1024, in

```

```

1018     results = self._format_results(
1019         all_candidate_params, n_splits, all_out, all_more_results
1020     )
1022     return results
-> 1024 self._run_search(evaluate_candidates)
1026 # multimetric is determined here because in the case of a callable
1027 # self.scoring the return type is only known after calling
1028 first_test_score = all_out[0]["test_scores"]
File ~/Library/Python/3.9/lib/python/site-packages/sklearn/model_selection/_search.py:1571, in
1569 def _run_search(self, evaluate_candidates):
1570     """Search all candidates in param_grid"""
-> 1571     evaluate_candidates(ParameterGrid(self.param_grid))
File ~/Library/Python/3.9/lib/python/site-packages/sklearn/model_selection/_search.py:970, in
962 if self.verbose > 0:
963     print(
964         "Fitting 0 folds for each of 1 candidates,"
965         " totalling 2 fits".format(
966             n_splits, n_candidates, n_candidates * n_splits
967         )
968     )
--> 970 out = parallel(
971     delayed(_fit_and_score)(
972         clone(base_estimator),
973         X,
974         y,
975         train=train,
976         test=test,
977         parameters=parameters,
978         split_progress=(split_idx, n_splits),
979         candidate_progress=(cand_idx, n_candidates),
980         **fit_and_score_kwargs,
981     )

```

```

982     for (cand_idx, parameters), (split_idx, (train, test)) in product(
983         enumerate(candidate_params),
984         enumerate(cv.split(X, y, **routed_params.splitter.split)),
985     )
986 )
987
988 if len(out) < 1:
989     raise ValueError(
990         "No fits were performed. "
991         "Was the CV iterator empty? "
992         "Were there no candidates?"
993     )

```

File ~/Library/Python/3.9/lib/python/site-packages/sklearn/utils/parallel.py:77, in Parallel.\_

```

72 config = get_config()
73 iterable_with_config = (
74     (_with_config(delayed_func, config), args, kwargs)
75     for delayed_func, args, kwargs in iterable
76 )
--> 77 return super().__call__(iterable_with_config)

```

File ~/Library/Python/3.9/lib/python/site-packages/joblib/parallel.py:2007, in Parallel.\_\_call

```

2001 # The first item from the output is blank, but it makes the interpreter
2002 # progress until it enters the Try/Except block of the generator and
2003 # reaches the first `yield` statement. This starts the asynchronous
2004 # dispatch of the tasks to the workers.
2005 next(output)
-> 2007 return output if self.return_generator else list(output)

```

File ~/Library/Python/3.9/lib/python/site-packages/joblib/parallel.py:1650, in Parallel.\_get\_or

```

1647     yield
1648     with self._backend.retrieval_context():
-> 1650         yield from self._retrieve()
1652 except GeneratorExit:
1653     # The generator has been garbage collected before being fully
1654     # consumed. This aborts the remaining tasks if possible and warn

```

```

1655     # the user if necessary.
1656     self._exception = True
File ~/Library/Python/3.9/lib/python/site-packages/joblib/parallel.py:1762, in Parallel._retri
1757 # If the next job is not ready for retrieval yet, we just wait for
1758 # async callbacks to progress.
1759 if ((len(self._jobs) == 0) or
1760     (self._jobs[0].get_status(
1761         timeout=self.timeout) == TASK_PENDING)):
-> 1762     time.sleep(0.01)
1763     continue
1765 # We need to be careful: the job list can be filling up as
1766 # we empty it and Python list are not thread-safe by
1767 # default hence the use of the lock
KeyboardInterrupt:

```