```
!pip install shap pyDOE2
from IPython.core.display import display, HTML
import regex as re
import lightgbm
import pandas as pd
import shap
import sklearn

import xgboost as xgb
from sklearn.model_selection import train_test_split
import lightgbm as lgb
```

```
Requirement already satisfied: shap in /usr/local/lib/python3.11/dist-packages
Requirement already satisfied: pyDOE2 in /usr/local/lib/python3.11/dist-packag
Requirement already satisfied: numpy in /usr/local/lib/python3.11/dist-package
Requirement already satisfied: scipy in /usr/local/lib/python3.11/dist-package
Requirement already satisfied: scikit-learn in /usr/local/lib/python3.11/dist-
Requirement already satisfied: pandas in /usr/local/lib/python3.11/dist-packag
Requirement already satisfied: tqdm>=4.27.0 in /usr/local/lib/python3.11/dist-
Requirement already satisfied: packaging>20.9 in /usr/local/lib/python3.11/dis
Requirement already satisfied: slicer==0.0.8 in /usr/local/lib/python3.11/dist
Requirement already satisfied: numba>=0.54 in /usr/local/lib/python3.11/dist-p
Requirement already satisfied: cloudpickle in /usr/local/lib/python3.11/dist-p
Requirement already satisfied: typing-extensions in /usr/local/lib/python3.11/
Requirement already satisfied: llvmlite<0.44,>=0.43.0dev0 in /usr/local/lib/py
Requirement already satisfied: python-dateutil>=2.8.2 in /usr/local/lib/python
Requirement already satisfied: pytz>=2020.1 in /usr/local/lib/python3.11/dist-
Requirement already satisfied: tzdata>=2022.7 in /usr/local/lib/python3.11/dis
Requirement already satisfied: joblib>=1.2.0 in /usr/local/lib/python3.11/dist
Requirement already satisfied: threadpoolctl>=3.1.0 in /usr/local/lib/python3.
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.11/dist-pack
```

Patch to match style consistency

```
import matplotlib
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd

from shap import Explanation
from shap.utils import format_value
from shap.plots import colors
from shap.plots._labels import labels
```

```
plt.rcParams['figure.dpi'] = 300

# TODO: If we make a JS version of this plot then we could let users click on a ba
# plot that is associated with that feature get overlaid on the plot...it would q
# why a feature is pushing down or up. Perhaps the best way to do this would be w
# of the bar...
def patch_waterfall(shap_values, max_display=10, show=True):
    """Plots an explanation of a single prediction as a waterfall plot.

    The SHAP value of a feature represents the impact of the evidence provided by
    output. The waterfall plot is designed to visually display how the SHAP value
    move the model output from our prior expectation under the background data di
    prediction given the evidence of all the features.

    Features are sorted by the magnitude of their SHAP values with the smallest
    magnitude features grouped together at the bottom of the plot when the number
    features in the models exceeds the ``max_display`` parameter.

    Parameters
    ----------
    shap_values : Explanation
        A one-dimensional :class:`.Explanation` object that contains the feature

    max_display : str
        The maximum number of features to plot (default is 10).

    show : bool
        Whether ``matplotlib.pyplot.show()`` is called before returning.
        Setting this to ``False`` allows the plot to be customized further after
        has been created, returning the current axis via plt.gca().

    Examples
    --------

    See `waterfall plot examples <https://shap.readthedocs.io/en/latest/example_n

    """

    # Turn off interactive plot
    #if show is False:
    #    plt.ioff()

    # make sure the input is an Explanation object
    if not isinstance(shap_values, Explanation):
        emsg = (
```

```
            "The waterfall plot requires an `Explanation` object as the "
            "`shap_values` argument."
        )
        raise TypeError(emsg)

    # make sure we only have a single explanation to plot
    sv_shape = shap_values.shape
    if len(sv_shape) != 1:
        emsg = (
            "The waterfall plot can currently only plot a single explanation, but
            f"matrix of explanations (shape {sv_shape}) was passed! Perhaps try "
            "`shap.plots.waterfall(shap_values[0])` or for multi-output models, "
            "try `shap.plots.waterfall(shap_values[0, 0])`."
        )
        raise ValueError(emsg)

    base_values = float(shap_values.base_values)
    features = shap_values.display_data if shap_values.display_data is not None e
    feature_names = shap_values.feature_names
    lower_bounds = getattr(shap_values, "lower_bounds", None)
    upper_bounds = getattr(shap_values, "upper_bounds", None)
    values = shap_values.values

    # unwrap pandas series
    if isinstance(features, pd.Series):
        if feature_names is None:
            feature_names = list(features.index)
        features = features.values

    # fallback feature names
    if feature_names is None:
        feature_names = np.array([labels['FEATURE'] % str(i) for i in range(len(v

    # init variables we use for tracking the plot locations
    num_features = min(max_display, len(values))
    row_height = 0.5
    rng = range(num_features - 1, -1, -1)
    order = np.argsort(-np.abs(values))
    pos_lefts = []
    pos_inds = []
    pos_widths = []
    pos_low = []
    pos_high = []
    neg_lefts = []
    neg_inds = []
```

```
    neg_widths = []
    neg_low = []
    neg_high = []
    loc = base_values + values.sum()
    yticklabels = ["" for _ in range(num_features + 1)]

    # size the plot based on how many features we are plotting
    plt.gcf().set_size_inches(8, num_features * row_height + 1.5)

    # see how many individual (vs. grouped at the end) features we are plotting
    if num_features == len(values):
        num_individual = num_features
    else:
        num_individual = num_features - 1

    # compute the locations of the individual features and plot the dashed connec
    for i in range(num_individual):
        sval = values[order[i]]
        loc -= sval
        if sval >= 0:
            pos_inds.append(rng[i])
            pos_widths.append(sval)
            if lower_bounds is not None:
                pos_low.append(lower_bounds[order[i]])
                pos_high.append(upper_bounds[order[i]])
            pos_lefts.append(loc)
        else:
            neg_inds.append(rng[i])
            neg_widths.append(sval)
            if lower_bounds is not None:
                neg_low.append(lower_bounds[order[i]])
                neg_high.append(upper_bounds[order[i]])
            neg_lefts.append(loc)
        if num_individual != num_features or i + 4 < num_individual:
            plt.plot([loc, loc], [rng[i] - 1 - 0.4, rng[i] + 0.4],
                     color="#bbbbbb", linestyle="--", linewidth=0.5, zorder=-1)
        if features is None:
            yticklabels[rng[i]] = feature_names[order[i]]
        else:
            if np.issubdtype(type(features[order[i]]), np.number):
                yticklabels[rng[i]] = format_value(float(features[order[i]]), "%0
            else:
                yticklabels[rng[i]] = str(features[order[i]]) + " = " + str(featu

    # add a last grouped feature to represent the impact of all the features we d
```

```
    if num_features < len(values):
        yticklabels[0] = "%d other features" % (len(values) - num_features + 1)
        remaining_impact = base_values - loc
        if remaining_impact < 0:
            pos_inds.append(0)
            pos_widths.append(-remaining_impact)
            pos_lefts.append(loc + remaining_impact)
        else:
            neg_inds.append(0)
            neg_widths.append(-remaining_impact)
            neg_lefts.append(loc + remaining_impact)

    points = pos_lefts + list(np.array(pos_lefts) + np.array(pos_widths)) + neg_l
        list(np.array(neg_lefts) + np.array(neg_widths))
    dataw = np.max(points) - np.min(points)

    # draw invisible bars just for sizing the axes
    label_padding = np.array([0.1*dataw if w < 1 else 0 for w in pos_widths])
    plt.barh(pos_inds, np.array(pos_widths) + label_padding + 0.02*dataw,
             left=np.array(pos_lefts) - 0.01*dataw, color=colors.red_rgb, alpha=0
    label_padding = np.array([-0.1*dataw if -w < 1 else 0 for w in neg_widths])
    plt.barh(neg_inds, np.array(neg_widths) + label_padding - 0.02*dataw,
             left=np.array(neg_lefts) + 0.01*dataw, color=colors.blue_rgb, alpha=

    # define variable we need for plotting the arrows
    head_length = 0.08
    bar_width = 0.8
    xlen = plt.xlim()[1] - plt.xlim()[0]
    fig = plt.gcf()
    ax = plt.gca()
    bbox = ax.get_window_extent().transformed(fig.dpi_scale_trans.inverted())
    width = bbox.width
    bbox_to_xscale = xlen/width
    hl_scaled = bbox_to_xscale * head_length
    renderer = fig.canvas.get_renderer()

    # draw the positive arrows
    for i in range(len(pos_inds)):
        dist = pos_widths[i]
        arrow_obj = plt.arrow(
            pos_lefts[i], pos_inds[i], max(dist-hl_scaled, 0.000001), 0,
            head_length=min(dist, hl_scaled),
            color=colors.red_rgb, width=bar_width,
            head_width=bar_width,
        )
```

```
        if pos_low is not None and i < len(pos_low):
            plt.errorbar(
                pos_lefts[i] + pos_widths[i], pos_inds[i],
                xerr=np.array([[pos_widths[i] - pos_low[i]], [pos_high[i] - pos_w
                ecolor=colors.light_red_rgb,
            )

        txt_obj = plt.text(
            pos_lefts[i] + 0.5*dist, pos_inds[i], format_value(pos_widths[i], '%+
            horizontalalignment='center', verticalalignment='center', color="whit
            fontsize=12,
        )
        text_bbox = txt_obj.get_window_extent(renderer=renderer)
        arrow_bbox = arrow_obj.get_window_extent(renderer=renderer)

        # if the text overflows the arrow then draw it after the arrow
        if text_bbox.width > arrow_bbox.width:
            txt_obj.remove()

            txt_obj = plt.text(
                pos_lefts[i] + (5/72)*bbox_to_xscale + dist, pos_inds[i], format_
                horizontalalignment='left', verticalalignment='center', color=col
                fontsize=12,
            )

    # draw the negative arrows
    for i in range(len(neg_inds)):
        dist = neg_widths[i]

        arrow_obj = plt.arrow(
            neg_lefts[i], neg_inds[i], -max(-dist-hl_scaled, 0.000001), 0,
            head_length=min(-dist, hl_scaled),
            color=colors.blue_rgb, width=bar_width,
            head_width=bar_width,
        )

        if neg_low is not None and i < len(neg_low):
            plt.errorbar(
                neg_lefts[i] + neg_widths[i], neg_inds[i],
                xerr=np.array([[neg_widths[i] - neg_low[i]], [neg_high[i] - neg_w
                ecolor=colors.light_blue_rgb,
            )

        txt_obj = plt.text(
```

```
            neg_lefts[i] + 0.5*dist, neg_inds[i], format_value(neg_widths[i], '%+
            horizontalalignment='center', verticalalignment='center', color="whit
            fontsize=12,
        )
        text_bbox = txt_obj.get_window_extent(renderer=renderer)
        arrow_bbox = arrow_obj.get_window_extent(renderer=renderer)

        # if the text overflows the arrow then draw it after the arrow
        if text_bbox.width > arrow_bbox.width:
            txt_obj.remove()

            txt_obj = plt.text(
                neg_lefts[i] - (5/72)*bbox_to_xscale + dist, neg_inds[i], format_
                horizontalalignment='right', verticalalignment='center', color=co
                fontsize=12,
            )

    # draw the y-ticks twice, once in gray and then again with just the feature n
    # The 1e-8 is so matplotlib 3.3 doesn't try and collapse the ticks
    ytick_pos = list(range(num_features)) + list(np.arange(num_features)+1e-8)
    plt.yticks(ytick_pos, yticklabels[:-1] + [label.split('=')[-1] for label in y

    # put horizontal lines for each feature row
    for i in range(num_features):
        plt.axhline(i, color="#cccccc", lw=0.5, dashes=(1, 5), zorder=-1)

    # mark the prior expected value and the model prediction
    plt.axvline(base_values, 0, 1/num_features, color="#bbbbbb", linestyle="--",
    fx = base_values + values.sum()
    plt.axvline(fx, 0, 1, color="#bbbbbb", linestyle="--", linewidth=0.5, zorder=

    # clean up the main axis
    plt.gca().xaxis.set_ticks_position('bottom')
    plt.gca().yaxis.set_ticks_position('none')
    plt.gca().spines['right'].set_visible(False)
    plt.gca().spines['top'].set_visible(False)
    plt.gca().spines['left'].set_visible(False)
    ax.tick_params(labelsize=13)
    #plt.xlabel("\nModel output", fontsize=12)

    #ax.set_xlim(0.00,1.00)

    # draw the E[f(X)] tick mark
    xmin, xmax = ax.get_xlim()
    ax2 = ax.twiny()
```

```
    ax2.set_xlim(xmin, xmax)
    #ax2.set_xlim(0.00,1.00)
    ax2.set_xticks([base_values, base_values+1e-8])  # The 1e-8 is so matplotlib 
    ax2.set_xticklabels(["\n$base$ $value$", "\n\t $ =  "+format_value(base_value
    ax2.spines['right'].set_visible(False)
    ax2.spines['top'].set_visible(False)
    ax2.spines['left'].set_visible(False)

    # draw the f(x) tick mark
    ax3 = ax2.twiny()
    ax3.set_xlim(xmin, xmax)
    #ax3.set_xlim(0.00,1.00)
    # The 1e-8 is so matplotlib 3.3 doesn't try and collapse the ticks
    ax3.set_xticks([base_values + values.sum(), base_values + values.sum() + 1e-8
    ax3.set_xticklabels(["$prediction$", "\t\t $  = $"+ "$" + format_value(fx, "%
    tick_labels = ax3.xaxis.get_majorticklabels()
    tick_labels[0].set_transform(tick_labels[0].get_transform(
    ) + matplotlib.transforms.ScaledTranslation(-10/72., 0, fig.dpi_scale_trans))
    tick_labels[1].set_transform(tick_labels[1].get_transform(
    ) + matplotlib.transforms.ScaledTranslation(12/72., 0, fig.dpi_scale_trans))
    tick_labels[1].set_color("#999999")
    ax3.spines['right'].set_visible(False)
    ax3.spines['top'].set_visible(False)
    ax3.spines['left'].set_visible(False)

    # adjust the position of the E[f(X)] = x.xx label
    tick_labels = ax2.xaxis.get_majorticklabels()
    tick_labels[0].set_transform(tick_labels[0].get_transform(
    ) + matplotlib.transforms.ScaledTranslation(-20/72., 0, fig.dpi_scale_trans))
    tick_labels[1].set_transform(tick_labels[1].get_transform(
    ) + matplotlib.transforms.ScaledTranslation(22/72., -1/72., fig.dpi_scale_tra

    tick_labels[1].set_color("#999999")

    # color the y tick labels that have the feature values as gray
    # (these fall behind the black ones with just the feature name)
    tick_labels = ax.yaxis.get_majorticklabels()
    for i in range(num_features):
        tick_labels[i].set_color("#999999")

    if show:
        plt.show()
    else:
        return plt.gca()
shap.plots.waterfall = patch_waterfall
```

Set up tutorial examples

Start by training the "should you bring an umbrella?" model

```
preX = pd.read_csv("Umbrella.csv")
preX = preX.sample(frac=1)
X_display = preX.iloc[:,:-1]
y_display = preX.iloc[:,-1]

PRECIPITATION = {
    "none": 0,
    "drizzle": 1,
    "rain": 2,
    "snow": 3,
    "sleet": 4,
    "hail": 5
}

y = y_display
X = X_display
X = X.replace({"Precipitation":PRECIPITATION})

X_train = X.iloc[:300]
y_train = y.iloc[:300]

X_test = X.iloc[300:]
y_test = y.iloc[300:]

d_train = lightgbm.Dataset(X_train, label=y_train)
d_test = lightgbm.Dataset(X_test, label=y_test)

params = {
    "max_bin": 512,
    "learning_rate": 0.05,
    "boosting_type": "gbdt",
    "objective": "binary",
    "metric": "binary_logloss",
    "num_leaves": 10,
    "verbose": -1,
    "min_data": 100,
    "boost_from_average": True,
    "keep_training_booster": True
}
```

```
#model = lgb.train(params, d_train, 10000, valid_sets=[d_test]) #early_stopping_r
model = lightgbm.LGBMClassifier(max_bin= 512,
    learning_rate= 0.05,
    boosting_type= "gbdt",
    objective= "binary",
    metric= "binary_logloss",
    num_leaves= 10,
    verbose= -1,
    min_data= 100,
    boost_from_average= True)
model.fit(X_train, y_train)
```

```
<ipython-input-8-59731d8556ad>:17: FutureWarning: Downcasting behavior in `rep
  X = X.replace({"Precipitation":PRECIPITATION})
```

```
LGBMClassifier

LGBMClassifier(boost_from_average=True, learning_rate=0.05, max_bin=512,
               metric='binary_logloss', min_data=100, num_leaves=10,
               objective='binary', verbose=-1)
```

Find the location of one of the two tutorial examples

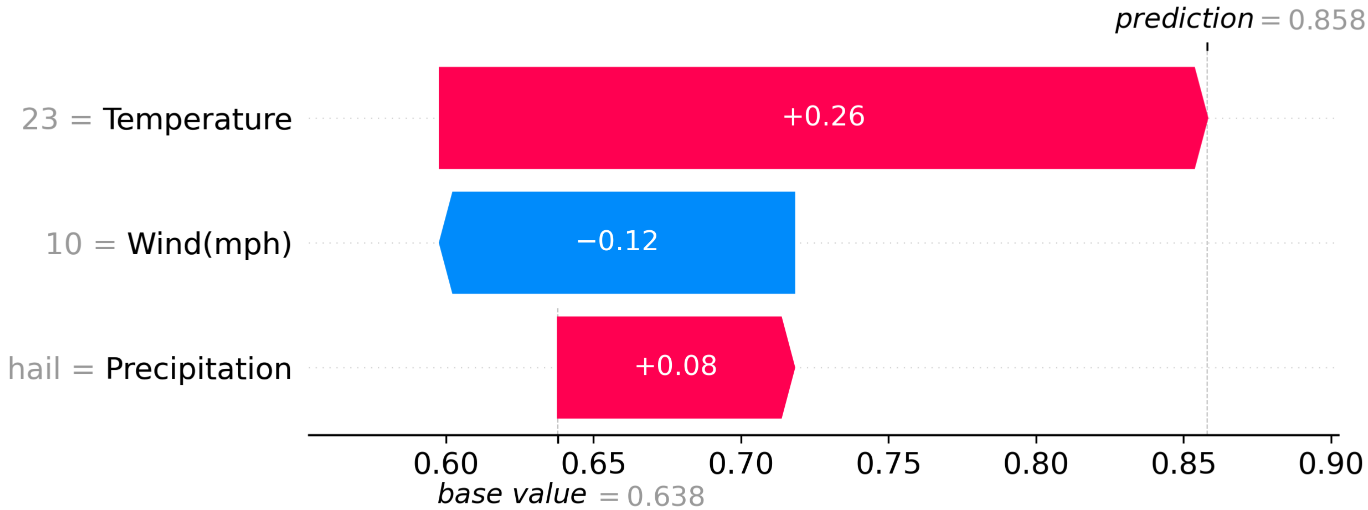
```
print(X.loc[(X['Precipitation'] == 5) & (X['Temperature'] == 23) & (X['Wind(mph)'
print(X.loc[(X['Precipitation'] == 0) & (X['Temperature'] == 70) & (X['Wind(mph)'
theloc = X.index.get_loc(330)
```

```
     Precipitation  Temperature  Wind(mph)
330              5           23         10
    Precipitation  Temperature  Wind(mph)
96              0           70         30
```

Generate a tutorial explanation

```
explainer = shap.Explainer(model, X, model_output="probability")
#shap_values = explainer(X)
mynewexp = shap._explanation.Explanation(values=np.array([0.08, 0.26, -0.12]), ba

shap.plots.waterfall(mynewexp, max_display=20)
```



Loan Instances

Edit and prepare dataset

```
# load dataset
```

```
X,y = shap.datasets.adult()
X_display,y_display = shap.datasets.adult(display=True)

EDUCATION_NUM = {
    16.0: "Doctorate",
    15.0: "Prof. School",
    14.0: "Masters",
    13.0: "Bachelors",
    12.0: "Some College",
    11.0: "Associate", #Assoc-acdm
    10.0: "Vocational", #Assoc-voc
    9.0: "HS grad",
    8.0: "12th",
    7.0: "11th",
    6.0: "10th",
    5.0: "9th",
    4.0: "7th-8th",
    3.0: "5th-6th",
    2.0: "1st-4th",
    1.0: "Preschool"
}

OCCUPATION_NUM = {
    "Tech-support": "Tech Support",
    "Craft-repair": "Craft/Repair",
    "Other-service": "Other Service",
    "Sales": "Sales",
    "Exec-managerial": "Exec. Managerial",
    "Prof-specialty": "Prof. Specialty",
    "Handlers-cleaners": "Handler/Cleaner",
    "Machine-op-inspct": "Machine Op. Inspector",
    "Adm-clerical": "Admin. Clerical",
    "Farming-fishing": "Farming/Fishing",
    "Transport-moving": "Transport/Moving",
    "Priv-house-serv": "Private House Service",
    "Protective-serv": "Protective Service",
    "Armed-Forces": "Armed Forces"

}
X_display = X_display.replace({"Education-Num":EDUCATION_NUM})
X_display = X_display.replace({"Occupation":OCCUPATION_NUM})
X = X.rename(columns={"Education-Num": "Education"})
X_display = X_display.rename(columns={"Education-Num": "Education"})#, "Hours per

X = X.drop(['Capital Loss', 'Capital Gain', 'Race', 'Relationship', 'Country', 'W
```

```
X_display = X_display.drop(['Capital Loss', 'Capital Gain', 'Race', 'Relationship

# create a train/test split
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_s
d_train = lgb.Dataset(X_train, label=y_train)
d_test = lgb.Dataset(X_test, label=y_test)
```

Train the model

```
params = {
    "max_bin": 512,
    "learning_rate": 0.05,
    "boosting_type": "gbdt",
    "objective": "binary",
    "metric": "binary_logloss",
    "num_leaves": 10,
    "verbose": -1,
    "min_data": 100,
    'objective':'multi:softprob',
    "boost_from_average": True
}

params_xgb={
    'base_score':0.5,
    'learning_rate':0.05,
    'max_depth':5,
    'min_child_weight':100,
    'n_estimators':200,
    'num_class': 2,
    'nthread':-1,
    'objective':'multi:softprob',
    'seed':2018,
    'eval_metric':'auc'
}

model = lgb.LGBMClassifier(max_bin= 512,
    learning_rate= 0.05,
    boosting_type= "gbdt",
    objective= "binary",
    metric= "binary_logloss",
    num_leaves= 10,
    verbose= -1,
    min_data= 100,
    boost_from_average= True)
model.fit(X_train, y_train)
```

LGBMClassifier

```
LGBMClassifier(boost_from_average=True, learning_rate=0.05, max_bin=512,
               metric='binary_logloss', min_data=100, num_leaves=10,
               objective='binary', verbose=-1)
```

Our 7 loan application instances

```
#val = 610 # Woman Side-by-side
#val = 11116 # Man Side-by-side
#val = 32353 # Man 3
#val = 217 # Man 2
#val = 15040 # Man 1
#val = 32429 # Woman 3
val = 32556 # Woman 2
#val = 91#91 # Woman 1

theloc = val
```

Generate SHAP Explanation

```
explainer = shap.Explainer(model, X, model_output="probability")
shap_values = explainer(X)
```

```
100%|===================| 32418/32561 [01:47<00:00]
```

```
#shap_values_standin0 = pd.Series({'Age': 0.0307, 'Education': -0.0287, 'Occupatior
shap_values_standin0 = pd.Series({'Age': -0.14, 'Education': 0.0416, 'Occupation':
#shap_values_standin0 = pd.Series({'Age': 0.1209, 'Education': 0.3008, 'Occupation'
#shap_values_standin0 = pd.Series({'Age': -0.2119, 'Education': 0.0011, 'Occupatior
#shap_values_standin0 = pd.Series({'Age': 0.0565, 'Education': 0.1427, 'Occupation'
#shap_values_standin0 = pd.Series({'Age': -0.0012, 'Education': -0.189, 'Occupatior
#shap_values_standin0 = pd.Series({'Age': 0.0774, 'Education': 0.1962, 'Occupation'
#shap_values_standin0 = pd.Series({'Age': 0.0668, 'Education': 0.1619, 'Occupation'

mynewexp = shap._explanation.Explanation(values=shap_values_standin0, base_values =

shap.plots.waterfall(mynewexp, max_display=20)
```

```
<ipython-input-7-465cce54bdf2>:118: FutureWarning: Series.__getitem__ treatinc
  sval = values[order[i]]
<ipython-input-7-465cce54bdf2>:140: FutureWarning: Series.__getitem__ treatinc
  if np.issubdtype(type(features[order[i]]), np.number):
<ipython-input-7-465cce54bdf2>:141: FutureWarning: Series.__getitem__ treatinc
  yticklabels[rng[i]] = format_value(float(features[order[i]]), "%0.03f") + "
<ipython-input-7-465cce54bdf2>:143: FutureWarning: Series.__getitem__ treatinc
  yticklabels[rng[i]] = str(features[order[i]]) + " = " + str(feature_names[oı
```