Root Cause Analysis_v4

September 3, 2024

1 Root Cause Analysis - PyRCA

1.1 Import all the necessary libraries

[ ]:
```
import networkx as nx
import numpy as np
import pyrca

from pyrca.analyzers.ht import HT, HTConfig
from pyrca.analyzers.epsilon_diagnosis import EpsilonDiagnosis,␣
 ↪EpsilonDiagnosisConfig
from pyrca.analyzers.bayesian import BayesianNetwork, BayesianNetworkConfig
from pyrca.analyzers.random_walk import RandomWalk, RandomWalkConfig
from pyrca.analyzers.rcd import RCD, RCDConfig

import matplotlib.pyplot as plt
import seaborn as sns
import pandas as pd
import timeit
import random
import os

# Some functions and libraries throw warnings
from sklearn.exceptions import ConvergenceWarning

import warnings
warnings.filterwarnings("ignore", category=RuntimeWarning)
warnings.filterwarnings("ignore", category=ConvergenceWarning)
warnings.filterwarnings("ignore", category=UserWarning)
warnings.filterwarnings("ignore", category=FutureWarning)
warnings.filterwarnings("ignore")
```

1.2 Custom Functions

1.2.1 Data and Directory Functions

[ ]:
```
def get_file_name(var:str):
    return var[7:-4]

def create_data_from_list(files):
    data_df = pd.DataFrame()
    for file in files:
        to_join_df = file
        data_df = pd.concat([data_df,to_join_df.loc[to_join_df.
 ↪index]],ignore_index=True)
    return data_df

def create_train_data(files,startrow):
    data_df = pd.DataFrame()
    for file_key, file_path in files.items():
        to_join_df =  pd.read_csv(file_path, skiprows=range(1, startrow))
        data_df = pd.concat([data_df,to_join_df.loc[to_join_df.
 ↪index]],ignore_index=True)
    return data_df

def get_from_dir(directory_path):
    # Get a list of all items (files and directories) in the specified path
    all_items = os.listdir(directory_path)
    # Iterate over each item and check if it's a directory
    for item in all_items:
        folder_path = os.path.join(directory_path, item)
        if os.path.isdir(folder_path):
            print(f"\nProcessing folder: {item}")
            folder_contents = os.listdir(folder_path)
            for file in folder_contents:
                file_path = os.path.join(folder_path, file)
                print(f"    -> {file}")

def get_from_folders(directory_path):
    files = {}
    all_folders = os.listdir(directory_path)
    folder_counter = 0
    file_counter = 0
    for folder in all_folders:
        folder_path = os.path.join(directory_path, folder)
        if os.path.isdir(folder_path):
            folder_contents = os.listdir(folder_path)
            folder_counter +=1
            for file in folder_contents:
                file_path = os.path.join(folder_path, file)
```

```
                if file[0:4] == 'data' and file[7:12] != 'event':
                    if file[7:13] != 'normal':
                        file_counter += 1
                        files[f"{get_file_name(file)}-{folder_counter}.
 ↪{file_counter}"] = file_path
                    else:
                        files[f"{get_file_name(file)}-{folder_counter}"] =␣
 ↪file_path

    return files, directory_path

def results_top_3(results,abnormal_set):
    result_columns = results.columns.to_list()
    result_index = results.index.to_list()

    result_data_3top = pd.DataFrame(columns=result_index, index=result_columns)

    for col in result_columns:
        for ind in result_index:
            for elem in results[col][ind]:
                if elem in abnormal_set[col.rsplit('-', 1)[0]].to_list():
                    result_data_3top[ind][col] = 1

    result_data_3top = result_data_3top.fillna(0)

    total_hit = (result_data_3top.sum('index')/len(result_columns)).to_dict()
    result_data_3top = pd.concat([result_data_3top,pd.
 ↪DataFrame(total_hit,index=['Total'])])

    return result_data_3top

def results_top_1(results,abnormal_set):
    result_columns = results.columns.to_list()
    result_index = results.index.to_list()
    result_data_1top = pd.DataFrame(columns=result_index, index=result_columns)
    for col in result_columns:
        for ind in result_index:
            try: elem = results[col][ind][0] # In case where RCD did not␣
 ↪provide any root causes
            except: continue
            if elem in abnormal_set[col.rsplit('-', 1)[0]].to_list():
                result_data_1top[ind][col] = 1

    result_data_1top = result_data_1top.fillna(0)

    total_hit = (result_data_1top.sum('index')/len(result_columns)).to_dict()
```

```
    result_data_1top = pd.concat([result_data_1top,pd.
↪DataFrame(total_hit,index=['Total'])])

    return result_data_1top
```

1.2.2 Plotting Functions

[ ]:
```
def plot_avg_inter(df, save_dir, filename,title):

    os.makedirs(save_dir, exist_ok=True)

    # Ignore the 'Total' row
    df = df[df.index != 'Total']

    # Define the interventions based on the index
    interventions = {
        'size_1': df[df.index.str.contains('size_1')],
        'feeder_3': df[df.index.str.contains('feeder_3')],
        'gripper_1': df[df.index.str.contains('gripper_1')],
        'max_Vel_2': df[df.index.str.contains('max_Vel_2')]
    }

    fig, axes = plt.subplots(2, 2, figsize=(12, 8))
    fig.suptitle(title,fontsize=15,y=0.9)

    accuracy_data = pd.
↪DataFrame(columns=['size_1','feeder_3','gripper_1','max_Vel_2'],index=['HT','ED','RW','RCD'

    for ax, (type, data) in zip(axes.flatten(), interventions.items()):
        # Plot averages
        avg_values = data.mean()

        sns.barplot(x=avg_values.index, y=avg_values.values, ax=ax, color='tab:
↪blue')
        ax.set_title(f'Type: {type}',y=1.10)
        ax.set_xlabel('Algorithm')
        ax.set_ylabel('Accuracy')
        ax.set_ylim(0,1)

        accuracy_data[type] = avg_values

        for i, value in enumerate(avg_values.values):
            ax.text(avg_values.index[i], value, f'{value:.2f}', ha='center',␣
↪va='bottom')

    plt.tight_layout(rect=[0, 0, 1, 0.9])
```

```
    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path+'.png', dpi=300, bbox_inches='tight')
    plt.show()

    accuracy_data.to_csv(full_path+'.csv')

def plot_avg_total(df, save_dir, filename,title):

    os.makedirs(save_dir, exist_ok=True)

    # Extract the 'Total' row
    total_data = df.loc['Total']

    plt.figure(figsize=(6, 4))
    sns.barplot(x=total_data.index, y=total_data.values, color='tab:blue')

    plt.title(title,fontsize=15,y=1.1)
    plt.xlabel('Algorithm')
    plt.ylabel('Accuracy')
    plt.ylim(0,1)

    accuracy_data = pd.DataFrame(total_data)

    for i, value in enumerate(total_data.values):
        plt.text(total_data.index[i], value, f'{value:.2f}', ha='center',␣
 ↪va='bottom')

    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path+'.png', dpi=300, bbox_inches='tight')
    plt.show()

    accuracy_data.to_csv(full_path+'.csv')

def plot_runtime_inter(df, save_dir, filename,x_label,):
    os.makedirs(save_dir, exist_ok=True)

    fig, axes = plt.subplots(2, 2, figsize=(12, 8))
    fig.suptitle('Runtime of Each Algorithm per Intervention␣
 ↪Type',fontsize=15,y=0.95)

    interventions = {
        'size_1': df[df.index.str.contains('size_1')],
        'feeder_3': df[df.index.str.contains('feeder_3')],
        'gripper_1': df[df.index.str.contains('gripper_1')],
        'max_Vel_2': df[df.index.str.contains('max_Vel_2')]
    }
```

```
    box_data = pd.DataFrame(columns=df.
↪columns,index=['size_1','feeder_3','gripper_1','max_Vel_2'])

    for ax, (type, data) in zip(axes.flatten(), interventions.items()):
        sns.boxplot(data=data, ax=ax,color='tab:blue',log_scale=True)
        ax.set_title(f'Intervention: {type}',y=1.12)
        ax.set_xlabel(x_label)
        ax.set_ylabel('Time[s]')
        ax.set_ylim(0,20)

        for column in data.columns:
            box_data_list = []
            box_data_list.append({'min':min(data[column])})
            box_data_list.append({'25%':data[column].quantile(0.25)})
            box_data_list.append({'50%':data[column].quantile(0.5)})
            box_data_list.append({'75%':data[column].quantile(0.75)})
            box_data_list.append({'max':max(data[column])})
            box_data[column][type] = box_data_list

    plt.tight_layout(rect=[0, 0, 1, 0.95])

    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path+'.png', dpi=300, bbox_inches='tight')
    plt.show()

    box_data.to_csv(full_path+'.csv')

def plot_runtime(df, save_dir, filename,x_label):

    os.makedirs(save_dir, exist_ok=True)

    # Create the plot
    plt.figure(figsize=(6, 4))
    ax = sns.boxplot(data=df,color='tab:blue', log_scale=True)


    plt.title('Overall Runtime of Each Algorithm',fontsize=15)
    plt.xlabel(x_label)
    plt.ylabel('Time[s]')
    plt.ylim(0,20)

    box_data = pd.DataFrame(columns=df.columns,␣
↪index=[['min','25quant','median','75quant','max']])

    for column in df.columns:
        box_data[column]['min'] = min(df[column])
        box_data[column]['25quant'] = np.quantile(df[column], 0.25)
```

```
        box_data[column]['median'] = np.median(df[column])
        box_data[column]['75quant'] = np.quantile(df[column], 0.75)
        box_data[column]['max'] = max(df[column])


    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path+'.png', dpi=300, bbox_inches='tight')
    plt.show()

    box_data.to_csv(full_path+'.csv')

def plot_data_runtime(df, save_dir, filename,x_label, algo):

    os.makedirs(save_dir, exist_ok=True)

    # Create the plot
    plt.figure(figsize=(6, 4))
    ax = sns.boxplot(data=df,color='tab:blue', log_scale=True)


    plt.title('Runtime of'+algo+'with different Data',fontsize=15)
    plt.xlabel(x_label)
    plt.ylabel('Time[s]')
    plt.ylim(0,20)

    box_data = pd.DataFrame(columns=df.columns,␣
 ↪index=[['min','25quant','median','75quant','max']])

    for column in df.columns:
        box_data[column]['min'] = min(df[column])
        box_data[column]['25quant'] = np.quantile(df[column], 0.25)
        box_data[column]['median'] = np.median(df[column])
        box_data[column]['75quant'] = np.quantile(df[column], 0.75)
        box_data[column]['max'] = max(df[column])


    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path+'.png', dpi=300, bbox_inches='tight')
    plt.show()

    box_data.to_csv(full_path+'.csv')

def plot_avg_var_inter(df, save_dir, filename,x_label,algo,title):

    os.makedirs(save_dir, exist_ok=True)

    # Ignore the 'Total' row
```

```
    df = df[df.index != 'Total']

    # Define the interventions based on the index
    interventions = {
        'size_1': df[df.index.str.contains('size_1')],
        'feeder_3': df[df.index.str.contains('feeder_3')],
        'gripper_1': df[df.index.str.contains('gripper_1')],
        'max_Vel_2': df[df.index.str.contains('max_Vel_2')]
    }

    fig, axes = plt.subplots(2, 2, figsize=(12, 8))
    fig.suptitle(title+' '+ algo,fontsize=15,y=0.95)

    accuracy_data = pd.
↪DataFrame(columns=['size_1','feeder_3','gripper_1','max_Vel_2'],index=['HT','ED','RW','RCD'

    for ax, (type, data) in zip(axes.flatten(), interventions.items()):
        # Plot averages
        avg_values = data.mean()

        line = sns.lineplot(x=avg_values.index, y=avg_values.values, ax=ax,␣
↪color='tab:blue',marker='o', markersize=8)
        ax.set_title(f'Type: {type}',y=1.10)
        ax.set_xlabel(x_label)
        ax.set_ylabel('Accuracy')
        ax.set_ylim(0,1)

        accuracy_data[type] = avg_values

        for i, value in enumerate(avg_values.values):
            ax.text(avg_values.index[i], value+0.05, f'{value:.2f}',␣
↪ha='center', va='bottom')

    plt.tight_layout(rect=[0, 0, 1, 0.9])

    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path+'.png', dpi=300, bbox_inches='tight')
    plt.show()

    accuracy_data.to_csv(full_path+'.csv')

def plot_avg_var_total(df, save_dir,filename,x_label,algo,title):

    os.makedirs(save_dir, exist_ok=True)

    # Extract the 'Total' row
    total_data = df.loc['Total']
```

```
    plt.figure(figsize=(6, 4))
    line = sns.lineplot(x=total_data.index, y=total_data.values, color='tab:
↪blue',marker='o', markersize=8)

    plt.title(title+' '+algo,fontsize=15)
    plt.xlabel(x_label)
    plt.ylabel('Accuracy')
    plt.ylim(0,1)

    accuracy_data = pd.DataFrame(total_data)

    for i, value in enumerate(total_data.values):
        plt.text(total_data.index[i], value+0.05, f'{value:.2f}', ha='center',␣
↪va='bottom')

    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path+'.png', dpi=300, bbox_inches='tight')
    plt.show()

    accuracy_data.to_csv(full_path+'.csv')

def plot_avg_var_total_combined(dfs, labels, save_dir, filename, x_label,␣
↪title):
    os.makedirs(save_dir, exist_ok=True)
    plt.figure(figsize=(6, 4))
    accuracy_data_out = pd.DataFrame()

    colors = {'HT':'tab:blue', 'ED':'tab:orange', 'RW':'tab:green', 'RCD':'tab:
↪red'}

    for i, df in enumerate(dfs):
        if 'Total' not in df.index:
            raise ValueError(f"'Total' row not found in dataframe {i+1}")

        total_data = df.loc['Total']

        line = sns.lineplot(x=total_data.index, y=total_data.values,␣
↪color=colors[labels[i]], marker='o', markersize=8, label=labels[i])

        accuracy_data = pd.DataFrame(total_data)
        accuracy_data_out = pd.concat([accuracy_data_out, accuracy_data],␣
↪axis=1)

        sns.move_legend(line,'upper left', bbox_to_anchor=(1, 1))
```

```
        for j, value in enumerate(total_data.values):
            plt.text(total_data.index[j], value + 0.05, f'{value:.2f}',␣
↪ha='center', va='bottom')

    plt.title(title , fontsize=15, y=1.1)
    plt.xlabel(x_label)
    plt.ylabel('Accuracy')
    plt.ylim(0, 1)

    full_path = os.path.join(save_dir, filename)
    plt.savefig(full_path + '_all.png', dpi=300, bbox_inches='tight')
    plt.show()


    accuracy_data_out.columns = labels
    accuracy_data_out.to_csv(full_path + '_all.csv')
```

1.2.3 Algorithms

HT - Algorithms

[ ]:
```
# Function run hypothesis testing algorithm
def run_HT(folder_path: str,
           files: dict,
           startrow: int,
           nodes: list,
           edges_list:list,
           key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
```

```
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    runtime = pd.DataFrame(index=file_names, columns=['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        start = 0
        stop = 0
        abnormal_nodes = []


        root_cause_results = []
```

```
        results = pd.DataFrame()

        start = timeit.default_timer()

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)

                results[node] = model.find_root_causes(abnormal_data_df, node,␣
 ↪True).to_list()

        stop = timeit.default_timer()

        runtime['HT'][file_names[file_counter]] = stop - start

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

    return results_out,runtime

def run_HT_overlap(folder_path: str,
           files: dict,
           startrow: int,
           overlap_p:float,
           nodes: list,
           edges_list:list,
           key_nodes: list):

    G_graph = nx.DiGraph()
```

```
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
                     'feeder_3':'interFeeder3',
                     'size_1':'interSize1',
                     'size_2':'interSize2',
                     'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_overlap'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]
```

```
   abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
   results_out = pd.DataFrame(index = ['HT'])

   runtime = pd.DataFrame(index=file_names, columns=['HT'])


   for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
       abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
       abnormal_data_df = abnormal_data_df[nodes]

       start = 0
       stop = 0

       # Replace first N rows with overlap data
       data_length = abnormal_data_df.shape[0]
       overlap_n = int(np.rint(overlap_p*data_length))
       overlap_df = normal_data_df.iloc[-overlap_n:]
       abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

       # Overlap of overlap_p timestamps
       abnormal_data_df = pd.concat([overlap_df,abnormal_data_df],␣
↪ignore_index=True)

       start = timeit.default_timer()
       model = HT(config=HTConfig(adj_matrix_extended_pd))
       model.train(normal_data_df)

       abnormal_nodes = []

       root_cause_results = []

       results = pd.DataFrame()
       for node in key_nodes:
           if (abnormal_data_df[node] <100).any(): # Score instead of EoL
               abnormal_nodes.append(node)

               results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True).to_list()

       stop = timeit.default_timer()

       rank1_root_cause = []
       rank2_root_cause = []
       rank3_root_cause = []
```

```
        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        runtime['HT'][file_names[file_counter]] = stop - start

    return results_out,runtime

def run_HT_size(folder_path: str,
            files: dict,
            startrow: int,
            size_p:float,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
                     'feeder_3':'interFeeder3',
                     'size_1':'interSize1',
                     'size_2':'interSize2',
                     'size_3':'interSize3'}
```

```
    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    runtime = pd.DataFrame(index=file_names, columns=['HT'])

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        start = 0
        stop = 0

        abnormal_data_df = abnormal_data_df.iloc[:size_n]
```

```
        start = timeit.default_timer()
        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []


        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)

                results[node] = model.find_root_causes(abnormal_data_df, node,␣
 ↪True).to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['HT'][file_names[file_counter]] = stop - start

    return results_out,runtime

def run_HT_normal_size(folder_path: str,
           files: dict,
           startrow: int,
           normal_size_p:float,
           nodes: list,
           edges_list:list,
```

```
        key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
                     'feeder_3':'interFeeder3',
                     'size_1':'interSize1',
                     'size_2':'interSize2',
                     'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_normal_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))
```

```
   normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
   normal_data_df = normal_data_df[nodes]

   runtime = pd.DataFrame(index=file_names, columns=['HT'])

   abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
   results_out = pd.DataFrame(index = ['HT'])

   # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
   data_length = 526
   normal_size_n = int(np.rint(normal_size_p*data_length))
   # We take the first N timestamps
   normal_data_df = normal_data_df.iloc[:normal_size_n]


   for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
       abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
       abnormal_data_df = abnormal_data_df[nodes]

       start = 0
       stop = 0

       start = timeit.default_timer()

       model = HT(config=HTConfig(adj_matrix_extended_pd))
       model.train(normal_data_df)

       abnormal_nodes = []


       root_cause_results = []

       results = pd.DataFrame()
       for node in key_nodes:
           if (abnormal_data_df[node] <100).any(): # Score instead of EoL
               abnormal_nodes.append(node)

               results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True).to_list()

       stop = timeit.default_timer()

       rank1_root_cause = []
```

```
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['HT'][file_names[file_counter]] = stop - start


    return results_out,runtime

def run_HT_abnormal_size(folder_path: str,
           files: dict,
           startrow: int,
           abnormal_size_p:float,
           nodes: list,
           edges_list:list,
           key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
```

```
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_abnormal_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    runtime = pd.DataFrame(index=file_names, columns=['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]
```

```
        # Resize abnormal data relative to one cycle time - 26.3 equals 526␣
↪timestamps
        data_length = 526
        abnormal_size_n = int(np.rint(abnormal_size_p*data_length))
        # We take the first N timestamps
        abnormal_data_df = abnormal_data_df.iloc[:abnormal_size_n]

        start = 0
        stop = 0

        start = timeit.default_timer()

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []


        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)

                results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True).to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
```

```
        runtime['HT'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_HT_edges_delete(folder_path: str,
           files: dict,
           startrow: int,
           edges_delete_n:int,
           nodes: list,
           edges_list:list,
           key_nodes: list):

    edges_to_delete = random.sample(edges_list, edges_delete_n)
    edges_list_new = edges_list.copy()

    for edge in edges_to_delete:
        edges_list_new.remove(edge)

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list_new)

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
                     'feeder_3':'interFeeder3',
                     'size_1':'interSize1',
                     'size_2':'interSize2',
                     'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
```

```
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_edges'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    runtime = pd.DataFrame(index=file_names, columns=['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        start = 0
        stop = 0

        start = timeit.default_timer()

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []
        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)
                results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True,).to_list()
```

```
        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['HT'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_HT_normal_data(folder_path: str,
            files: dict,
            startrow: int,
            normal_data:str,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
```

```
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_normal_data'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    runtime = pd.DataFrame(index=file_names, columns=['HT'])

    normal_data_df = pd.read_csv(normal_files[normal_data], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        start = 0
        stop = 0
```

```
        start = timeit.default_timer()


        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []


        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)

                results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True,).to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['HT'][file_names[file_counter]] = stop - start

    return results_out, runtime
```

ED - Algorithms

```
[ ]: # Function run epsilon diagnosis algorithm - Default Parameters
def run_ED(folder_path: str,
           files: dict,
           startrow: int,
```

```
          nodes: list,
          edges_list:list,
          key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
                     'feeder_3':'interFeeder3',
                     'size_1':'interSize1',
                     'size_2':'interSize2',
                     'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))
```

```
  normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
  normal_data_df = normal_data_df[nodes]

  abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
  results_out = pd.DataFrame(index = ['ED'])

  runtime = pd.DataFrame(index=file_names, columns=['ED'])

  for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
      abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
      abnormal_data_df = abnormal_data_df[nodes]


      abnormal_nodes = []

      root_cause_results = []

      start = 0
      stop = 0

      start = timeit.default_timer()

      model = EpsilonDiagnosis(EpsilonDiagnosisConfig(alpha=0.
↪05,root_cause_top_k=3,bootstrap_time=200))

      for node in key_nodes:
          # Basic Anomaly Detection
          if (abnormal_data_df[node] <100).any():
              abnormal_nodes.append(node)


      model.train(normal_data_df)

      results = model.find_root_causes(abnormal_data_df).to_list()

      stop = timeit.default_timer()

      rank1_root_cause = []
      rank2_root_cause = []
      rank3_root_cause = []

      for i in range(0,int(np.trunc(len(results)/3))):
```

```
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        runtime['ED'][file_names[file_counter]] = stop - start

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_ED.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

    return results_out,runtime

def run_ED_overlap(folder_path: str,
           files: dict,
           startrow: int,
           overlap_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
                     'feeder_3':'interFeeder3',
                     'size_1':'interSize1',
                     'size_2':'interSize2',
                     'size_3':'interSize3'}
```

```
  abnormal_files = {}
  normal_files = {}
  file_names = []
  counter = 0

  for file_key, file_path in files.items():
      temp_file_key = file_key.rsplit('-', 1)[0]
      if temp_file_key == 'normal':
          normal_files[file_key] = file_path

          # if normal data available
          folder_name = 'Results_overlap'
          path = os.path.join(folder_path, folder_name)
          os.makedirs(path, exist_ok=True)

      if temp_file_key in interventions:
          counter += 1
          abnormal_files[file_key] = file_path
          file_names.append(file_key+'_'+str(counter))

  normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
  normal_data_df = normal_data_df[nodes]

  normal_data_df = normal_data_df.iloc[:526*2]

  abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
  results_out = pd.DataFrame(index = ['ED'])

  runtime = pd.DataFrame(index=file_names, columns=['ED'])


  for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
      abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
      abnormal_data_df = abnormal_data_df[nodes]

      start = 0
      stop = 0


      # Replace first N rows with overlap data
      data_length = abnormal_data_df.shape[0]
      overlap_n = int(np.rint(overlap_p*data_length))
```

```
        overlap_df = normal_data_df.iloc[-overlap_n:]
        abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

        # Overlap of overlap_p timestamps
        abnormal_data_df = pd.concat([overlap_df,abnormal_data_df],␣
↪ignore_index=True)

        abnormal_nodes = []

        root_cause_results = []

        start = timeit.default_timer()

        model = EpsilonDiagnosis(EpsilonDiagnosisConfig(alpha=0.
↪05,root_cause_top_k=3,bootstrap_time=200))
        model.train(normal_data_df)

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any():
                abnormal_nodes.append(node)


        results = model.find_root_causes(abnormal_data_df).to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_ED.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['ED'][file_names[file_counter]] = stop - start

    return results_out, runtime
```

```python
def run_ED_size(folder_path: str,
           files: dict,
           startrow: int,
           size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
                     'camera_2':'interCamera2',
                     'camera_3':'interCamera3',
                     'conveyor_1':'interConveyor1',
                     'conveyor_2':'interConveyor2',
                     'conveyor_3':'interConveyor3',
                     'feeder_1':'interFeeder1',
                     'feeder_2':'interFeeder2',
                     'feeder_3':'interFeeder3',
                     'size_1':'interSize1',
                     'size_2':'interSize2',
                     'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
```

```
        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    runtime = pd.DataFrame(index=file_names, columns=['ED'])

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['ED'])

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_data_df = abnormal_data_df.iloc[:size_n]

        abnormal_nodes = []

        root_cause_results = []

        start = 0
        stop = 0

        start = timeit.default_timer()

        model = EpsilonDiagnosis(EpsilonDiagnosisConfig(alpha=0.
↪05,root_cause_top_k=3,bootstrap_time=200))
        model.train(normal_data_df)

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any():
                abnormal_nodes.append(node)
```

```
        results = model.find_root_causes(abnormal_data_df).to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_ED.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['ED'][file_names[file_counter]] = stop - start


    return results_out, runtime

def run_ED_normal_data(folder_path: str,
            files: dict,
            startrow: int,
            normal_data: str,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                     'gripper_2':'interGripper2',
                     'max_Vel_1':'interVeloRob1',
                     'max_Vel_2':'interVeloRob2',
                     'camera_1':'interCamera1',
```

```
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files[normal_data], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['ED'])

    runtime = pd.DataFrame(index=file_names, columns=['ED'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]
```

```
        abnormal_nodes = []

        root_cause_results = []

        start = 0
        stop = 0

        start = timeit.default_timer()

        model = EpsilonDiagnosis(EpsilonDiagnosisConfig(alpha=0.
↪05,root_cause_top_k=3,bootstrap_time=200))
        model.train(normal_data_df)

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any():
                abnormal_nodes.append(node)


        results = model.find_root_causes(abnormal_data_df).to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_ED.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['ED'][file_names[file_counter]] = stop - start

    return results_out, runtime
```

RW - Algorithms

```
[ ]: # Function run random walk algorithm
def run_RW(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           nodes: list,
           edges_list:list,
           key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
```

```
            folder_name = 'Results'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RW'])

    runtime = pd.DataFrame(index=file_names, columns=['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]


        abnormal_nodes = []

        root_cause_results = []

        start = 0
        stop = 0

        start = timeit.default_timer()
        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)


        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()
```

```
        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['RW'][file_names[file_counter]] = stop - start

    return results_out,runtime

def run_RW_overlap(folder_path: str,
            files: dict,
            #train_file:pd.DataFrame,
            startrow: int,
            overlap_p: float,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
```

```
        'max_Vel_2':'interVeloRob2',
        'camera_1':'interCamera1',
        'camera_2':'interCamera2',
        'camera_3':'interCamera3',
        'conveyor_1':'interConveyor1',
        'conveyor_2':'interConveyor2',
        'conveyor_3':'interConveyor3',
        'feeder_1':'interFeeder1',
        'feeder_2':'interFeeder2',
        'feeder_3':'interFeeder3',
        'size_1':'interSize1',
        'size_2':'interSize2',
        'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_overlap'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]


    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RW'])

    runtime = pd.DataFrame(index=file_names, columns=['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
```

```
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Replace first N rows with overlap data
        data_length = abnormal_data_df.shape[0]
        overlap_n = int(np.rint(overlap_p*data_length))
        overlap_df = normal_data_df.iloc[-overlap_n:]
        abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

        # Overlap of overlap_p timestamps
        abnormal_data_df = pd.concat([overlap_df,abnormal_data_df],␣
↪ignore_index=True)

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []

        root_cause_results = []

        start = 0
        stop = 0

        start = timeit.default_timer()


        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()
        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
```

```
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['RW'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RW_size(folder_path: str,
            files: dict,
            #train_file:pd.DataFrame,
            startrow: int,
            size_p: float,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
```

```
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RW'])

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    runtime = pd.DataFrame(index=file_names, columns=['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_data_df = abnormal_data_df.iloc[:size_n]

        start = 0
        stop = 0

        start = timeit.default_timer()
```

```
        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []

        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['RW'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RW_normal_size(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           normal_size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list):
```

```
    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_normal_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))
```

```
  normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
  normal_data_df = normal_data_df[nodes]

  abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
  results_out = pd.DataFrame(index = ['RW'])

  # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
  data_length = 526
  normal_size_n = int(np.rint(normal_size_p*data_length))
  # We take the first N timestamps
  normal_data_df = normal_data_df.iloc[:normal_size_n]

  runtime = pd.DataFrame(index=file_names, columns=['RW'])

  for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
      abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
      abnormal_data_df = abnormal_data_df[nodes]

      start = 0
      stop = 0

      start = timeit.default_timer()

      model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))

      abnormal_nodes = []

      root_cause_results = []

      for node in key_nodes:
          # Basic Anomaly Detection
          if (abnormal_data_df[node] <100).any(): # from EoL to score
              abnormal_nodes.append(node)


      results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()

      stop = timeit.default_timer()
```

```
        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['RW'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RW_abnormal_size(folder_path: str,
            files: dict,
            #train_file:pd.DataFrame,
            startrow: int,
            abnormal_size_p: float,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
```

```
        'camera_2':'interCamera2',
        'camera_3':'interCamera3',
        'conveyor_1':'interConveyor1',
        'conveyor_2':'interConveyor2',
        'conveyor_3':'interConveyor3',
        'feeder_1':'interFeeder1',
        'feeder_2':'interFeeder2',
        'feeder_3':'interFeeder3',
        'size_1':'interSize1',
        'size_2':'interSize2',
        'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_abnormal_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RW'])

    runtime = pd.DataFrame(index=file_names, columns=['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]
```

```
        # Resize abnormal data relative to one cycle time - 26.3 equals 526␣
↪timestamps
        data_length = 526
        abnormal_size_n = int(np.rint(abnormal_size_p*data_length))
        # We take the first N timestamps
        abnormal_data_df = abnormal_data_df.iloc[:abnormal_size_n]

        start = 0
        stop = 0
        start = timeit.default_timer()

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))

        abnormal_nodes = []

        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([normal_data_df,abnormal_data_df])).
↪to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
```

```
        runtime['RW'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RW_edges_delete(folder_path: str,
            files: dict,
            #train_file:pd.DataFrame,
            startrow: int,
            edges_delete_n: int,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    edges_to_delete = random.sample(edges_list, edges_delete_n)
    edges_list_new = edges_list.copy()

    for edge in edges_to_delete:
        edges_list_new.remove(edge)

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list_new)

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
```

```
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_edges'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RW'])

    runtime = pd.DataFrame(index=file_names, columns=['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        start = 0
        stop = 0

        start = timeit.default_timer()

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []

        root_cause_results = []

        for node in key_nodes:
```

```
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)


        results = model.
 ↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
 ↪to_list()

        stop = timeit.default_timer()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['RW'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RW_normal_data(folder_path: str,
            files: dict,
            #train_file:pd.DataFrame,
            startrow: int,
            normal_data: str,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
```

```
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_normal_data'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files[normal_data], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
```

```
  results_out = pd.DataFrame(index = ['RW'])

  runtime = pd.DataFrame(index=file_names, columns=['RW'])

  for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
      abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
      abnormal_data_df = abnormal_data_df[nodes]

      start = 0
      stop = 0

      start = timeit.default_timer()

      model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
      abnormal_nodes = []

      root_cause_results = []

      for node in key_nodes:
          # Basic Anomaly Detection
          if (abnormal_data_df[node] <100).any(): # from EoL to score
              abnormal_nodes.append(node)


      results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()

      stop = timeit.default_timer()

      rank1_root_cause = []
      rank2_root_cause = []
      rank3_root_cause = []

      for i in range(0,int(np.trunc(len(results)/3))):
          rank1_root_cause.append(results[i]['root_cause'])
          rank2_root_cause.append(results[i+1]['root_cause'])
          rank3_root_cause.append(results[i+2]['root_cause'])

          root_cause_results.append(results[0]['root_cause'])
          root_cause_results.append(results[1]['root_cause'])
          root_cause_results.append(results[2]['root_cause'])

      results_out[file_names[file_counter]] = [root_cause_results]
```

```
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['RW'][file_names[file_counter]] = stop - start

    return results_out, runtime
```

RCD - Algorithms

[ ]:
```
# Function run Root cause discovery algorithm - Default Parameters
def run_RCD(folder_path: str,
            files: dict,
            startrow: int,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0
```

```
  for file_key, file_path in files.items():
      temp_file_key = file_key.rsplit('-', 1)[0]
      if temp_file_key == 'normal':
          normal_files[file_key] = file_path

          # if normal data available
          folder_name = 'Results'
          path = os.path.join(folder_path, folder_name)
          os.makedirs(path, exist_ok=True)

      if temp_file_key in interventions:
          counter += 1
          abnormal_files[file_key] = file_path
          file_names.append(file_key+'_'+str(counter))

  normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
  normal_data_df = normal_data_df[nodes]

  abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
  results_out = pd.DataFrame(index = ['RCD'])

  runtime = pd.DataFrame(index=file_names, columns=['RCD'])

  for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
      abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
      abnormal_data_df = abnormal_data_df[nodes]

      abnormal_nodes = []

      root_cause_results = []
      start = 0
      stop = 0

      results = pd.DataFrame()
      start = timeit.default_timer()

      for node in key_nodes:
          model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
          if (abnormal_data_df[node] < 100).any():
              error = True
```

```
                while error:
                    abnormal_nodes.append(node)
                    try:
                        results[node] = model.
 ↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                        error = False
                    except:
                        continue

            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])

        stop = timeit.default_timer()

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        runtime['RCD'][file_names[file_counter]] = stop - start

    return results_out,runtime

def run_RCD_overlap(folder_path: str,
            files: dict,
            startrow: int,
            overlap_p: float,
            nodes: list,
```

```
          edges_list:list,
          key_nodes: list):

   G_graph = nx.DiGraph()
   G_graph.add_nodes_from(nodes)
   G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

   adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
   adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
   adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

   interventions = {'gripper_1':'interGripper1',
        'gripper_2':'interGripper2',
        'max_Vel_1':'interVeloRob1',
        'max_Vel_2':'interVeloRob2',
        'camera_1':'interCamera1',
        'camera_2':'interCamera2',
        'camera_3':'interCamera3',
        'conveyor_1':'interConveyor1',
        'conveyor_2':'interConveyor2',
        'conveyor_3':'interConveyor3',
        'feeder_1':'interFeeder1',
        'feeder_2':'interFeeder2',
        'feeder_3':'interFeeder3',
        'size_1':'interSize1',
        'size_2':'interSize2',
        'size_3':'interSize3'}

   abnormal_files = {}
   normal_files = {}
   file_names = []
   counter = 0

   for file_key, file_path in files.items():
       temp_file_key = file_key.rsplit('-', 1)[0]
       if temp_file_key == 'normal':
           normal_files[file_key] = file_path

           # if normal data available
           folder_name = 'Results_overlap'
           path = os.path.join(folder_path, folder_name)
           os.makedirs(path, exist_ok=True)

       if temp_file_key in interventions:
           counter += 1
```

```
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    normal_data_df = normal_data_df.iloc[:526*2]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    runtime = pd.DataFrame(index=file_names, columns=['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Replace first N rows with overlap data
        data_length = abnormal_data_df.shape[0]
        overlap_n = int(np.rint(overlap_p*data_length))
        overlap_df = normal_data_df.iloc[-overlap_n:]
        abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

        # Overlap of overlap_p timestamps
        abnormal_data_df = pd.concat([overlap_df,abnormal_data_df],␣
↪ignore_index=True)

        abnormal_nodes = []

        root_cause_results = []

        start = 0
        stop = 0

        start = timeit.default_timer()

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
```

```
                while error:
                    abnormal_nodes.append(node)
                    try:
                        results[node] = model.
 ↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                        error = False
                    except:
                        continue

            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])

        stop = timeit.default_timer()

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['RCD'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RCD_size(folder_path: str,
            files: dict,
            startrow: int,
            size_p: float,
            nodes: list,
            edges_list:list,
```

```
          key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
```

```
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    runtime = pd.DataFrame(index=file_names, columns=['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_data_df = abnormal_data_df.iloc[:size_n]

        abnormal_nodes = []

        root_cause_results = []

        start = 0
        stop = 0

        start = timeit.default_timer()

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
                while error:
                    abnormal_nodes.append(node)

                    try:
                        results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
```

```
                        error = False
                    except:
                        continue

            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])
        stop = timeit.default_timer()

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['RCD'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RCD_normal_size(folder_path: str,
            files: dict,
            startrow: int,
            normal_size_p: float,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere
```

```
   adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
   adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
   adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

   interventions = {'gripper_1':'interGripper1',
        'gripper_2':'interGripper2',
        'max_Vel_1':'interVeloRob1',
        'max_Vel_2':'interVeloRob2',
        'camera_1':'interCamera1',
        'camera_2':'interCamera2',
        'camera_3':'interCamera3',
        'conveyor_1':'interConveyor1',
        'conveyor_2':'interConveyor2',
        'conveyor_3':'interConveyor3',
        'feeder_1':'interFeeder1',
        'feeder_2':'interFeeder2',
        'feeder_3':'interFeeder3',
        'size_1':'interSize1',
        'size_2':'interSize2',
        'size_3':'interSize3'}

   abnormal_files = {}
   normal_files = {}
   file_names = []
   counter = 0

   for file_key, file_path in files.items():
       temp_file_key = file_key.rsplit('-', 1)[0]
       if temp_file_key == 'normal':
           normal_files[file_key] = file_path

           # if normal data available
           folder_name = 'Results_normal_size'
           path = os.path.join(folder_path, folder_name)
           os.makedirs(path, exist_ok=True)

       if temp_file_key in interventions:
           counter += 1
           abnormal_files[file_key] = file_path
           file_names.append(file_key+'_'+str(counter))

   normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
   normal_data_df = normal_data_df[nodes]
```

```
   abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
   results_out = pd.DataFrame(index = ['RCD'])

   # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
   data_length = 526
   normal_size_n = int(np.rint(normal_size_p*data_length))
   # We take the first N timestamps
   normal_data_df = normal_data_df.iloc[:normal_size_n]

   runtime = pd.DataFrame(index=file_names, columns=['RCD'])

   for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
       abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
       abnormal_data_df = abnormal_data_df[nodes]

       abnormal_nodes = []

       root_cause_results = []

       start = 0
       stop = 0

       start = timeit.default_timer()

       results = pd.DataFrame()
       for node in key_nodes:
           model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
           if (abnormal_data_df[node] < 100).any():
               error = True
               while error:
                   abnormal_nodes.append(node)

                   try:
                       results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                       error = False
                   except:
                       continue

           rank1_root_cause = []
           rank2_root_cause = []
           rank3_root_cause = []
```

```
            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])
        stop = timeit.default_timer()

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['RCD'][file_names[file_counter]] = stop - start


    return results_out, runtime

def run_RCD_abnormal_size(folder_path: str,
            files: dict,
            startrow: int,
            abnormal_size_p: float,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
```

```
        'gripper_2':'interGripper2',
        'max_Vel_1':'interVeloRob1',
        'max_Vel_2':'interVeloRob2',
        'camera_1':'interCamera1',
        'camera_2':'interCamera2',
        'camera_3':'interCamera3',
        'conveyor_1':'interConveyor1',
        'conveyor_2':'interConveyor2',
        'conveyor_3':'interConveyor3',
        'feeder_1':'interFeeder1',
        'feeder_2':'interFeeder2',
        'feeder_3':'interFeeder3',
        'size_1':'interSize1',
        'size_2':'interSize2',
        'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_abnormal_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files['normal-1'], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    runtime = pd.DataFrame(index=file_names, columns=['RCD'])
```

```
   for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
       abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
       abnormal_data_df = abnormal_data_df[nodes]

       # Resize abnormal data relative to one cycle time - 26.3 equals 526␣
↪timestamps
       data_length = 526
       abnormal_size_n = int(np.rint(abnormal_size_p*data_length))
       # We take the first N timestamps
       abnormal_data_df = abnormal_data_df.iloc[:abnormal_size_n]

       abnormal_nodes = []

       root_cause_results = []

       start = 0
       stop = 0

       start = timeit.default_timer()

       results = pd.DataFrame()
       for node in key_nodes:
           model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
           if (abnormal_data_df[node] < 100).any():
               error = True
               while error:
                   abnormal_nodes.append(node)

                   try:
                       results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                       error = False
                   except:
                       continue

           rank1_root_cause = []
           rank2_root_cause = []
           rank3_root_cause = []

           if len(results[node]) == 3:
               rank1_root_cause.append(results[node][0]['root_cause'])
               rank2_root_cause.append(results[node][1]['root_cause'])
               rank3_root_cause.append(results[node][2]['root_cause'])
```

```
                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])

        stop = timeit.default_timer()

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['RCD'][file_names[file_counter]] = stop - start

    return results_out, runtime

def run_RCD_normal_data(folder_path: str,
            files: dict,
            startrow: int,
            normal_data: str,
            nodes: list,
            edges_list:list,
            key_nodes: list):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
```

```
        'camera_3':'interCamera3',
        'conveyor_1':'interConveyor1',
        'conveyor_2':'interConveyor2',
        'conveyor_3':'interConveyor3',
        'feeder_1':'interFeeder1',
        'feeder_2':'interFeeder2',
        'feeder_3':'interFeeder3',
        'size_1':'interSize1',
        'size_2':'interSize2',
        'size_3':'interSize3'}

    abnormal_files = {}
    normal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_files[file_key] = file_path

            # if normal data available
            folder_name = 'Results_abnormal_size'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    normal_data_df = pd.read_csv(normal_files[normal_data], skiprows=range(1,␣
↪startrow))
    normal_data_df = normal_data_df[nodes]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    runtime = pd.DataFrame(index=file_names, columns=['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]
```

```
        abnormal_nodes = []

        root_cause_results = []

        start = 0
        stop = 0

        start = timeit.default_timer()

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
                while error:
                    abnormal_nodes.append(node)

                    try:
                        results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                        error = False
                    except:
                        continue

            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])
```

```
        stop = timeit.default_timer()

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        runtime['RCD'][file_names[file_counter]] = stop - start

    return results_out, runtime
```

1.3 Create the Causal Graph (non-lagged)

1.3.1 Graph Parameters

[ ]:
```
nodes = [
    'cam_1_X', 'cam_2_X', 'cam_3_X',
    'cam_1_Y', 'cam_2_Y', 'cam_3_Y',
    'EoL_1_X', 'EoL_2_X', 'EoL_3_X', 'EoL_4_X', 'EoL_5_X', 'EoL_6_X',
    'EoL_1_Y', 'EoL_2_Y', 'EoL_3_Y', 'EoL_4_Y', 'EoL_5_Y', 'EoL_6_Y',
    'rob_1_1', 'rob_1_2', 'rob_1_3', 'rob_1_4', 'rob_1_maxVel',
    'rob_2_1', 'rob_2_2', 'rob_2_3', 'rob_2_4', 'rob_2_maxVel',
    'rob_1_supply', 'rob_2_supply',
    'rob_1_vacuum', 'rob_2_vacuum',
    'con_1','con_2','con_3',
    'score'
]


edges = [
    ('cam_1_X', 'rob_2_1'), ('cam_1_Y', 'rob_2_1'),
    ('cam_1_X', 'rob_2_2'), ('cam_1_Y', 'rob_2_2'),
    ('cam_1_X', 'rob_2_3'), ('cam_1_Y', 'rob_2_3'),
    ('cam_1_X', 'rob_2_4'), ('cam_1_Y', 'rob_2_4'),

    ('cam_2_X', 'rob_1_1'), ('cam_2_Y', 'rob_1_1'),
    ('cam_2_X', 'rob_1_2'), ('cam_2_Y', 'rob_1_2'),
    ('cam_2_X', 'rob_1_3'), ('cam_2_Y', 'rob_1_3'),
    ('cam_2_X', 'rob_1_4'), ('cam_2_Y', 'rob_1_4'),

    ('cam_3_X', 'rob_1_1'), ('cam_3_Y', 'rob_1_1'),
    ('cam_3_X', 'rob_1_2'), ('cam_3_Y', 'rob_1_2'),
    ('cam_3_X', 'rob_1_3'), ('cam_3_Y', 'rob_1_3'),
    ('cam_3_X', 'rob_1_4'), ('cam_3_Y', 'rob_1_4'),

    ('rob_1_maxVel', 'rob_1_1'), ('rob_1_maxVel', 'rob_1_2'),
    ('rob_1_maxVel', 'rob_1_3'), ('rob_1_maxVel', 'rob_1_4'),

    ('rob_2_maxVel', 'rob_2_1'), ('rob_2_maxVel', 'rob_2_2'),
```

```
   ('rob_2_maxVel', 'rob_2_3'), ('rob_2_maxVel', 'rob_2_4'),

   ('con_2', 'rob_1_1'), ('con_2', 'rob_1_2'), ('con_2', 'rob_1_3'), ('con_2',␣
↪'rob_1_4'),
   ('con_3', 'rob_1_1'), ('con_3', 'rob_1_2'), ('con_3', 'rob_1_3'), ('con_3',␣
↪'rob_1_4'),

   ('con_2', 'rob_2_1'), ('con_2', 'rob_2_2'), ('con_2', 'rob_2_3'), ('con_2',␣
↪'rob_2_4'),
   ('con_1', 'rob_2_1'), ('con_1', 'rob_2_2'), ('con_1', 'rob_2_3'), ('con_1',␣
↪'rob_2_4'),

   ('con_2', 'EoL_1_X'), ('con_2', 'EoL_1_Y'),

   ('rob_1_1', 'rob_2_1'), ('rob_1_1', 'rob_2_2'), ('rob_1_1', 'rob_2_3'),␣
↪('rob_1_1', 'rob_2_4'),
   ('rob_1_2', 'rob_2_1'), ('rob_1_2', 'rob_2_2'), ('rob_1_2', 'rob_2_3'),␣
↪('rob_1_2', 'rob_2_4'),
   ('rob_1_3', 'rob_2_1'), ('rob_1_3', 'rob_2_2'), ('rob_1_3', 'rob_2_3'),␣
↪('rob_1_3', 'rob_2_4'),
   ('rob_1_4', 'rob_2_1'), ('rob_1_4', 'rob_2_2'), ('rob_1_4', 'rob_2_3'),␣
↪('rob_1_4', 'rob_2_4'),

   ('rob_1_supply', 'rob_1_vacuum'),
   ('rob_2_supply', 'rob_2_vacuum'),


   ('rob_1_vacuum', 'rob_2_1'), ('rob_1_vacuum', 'rob_2_2'),
   ('rob_1_vacuum', 'rob_2_3'), ('rob_1_vacuum', 'rob_2_4'),

   ('rob_1_1', 'EoL_2_X'), ('rob_1_2', 'EoL_2_X'),
   ('rob_1_3', 'EoL_2_X'), ('rob_1_4', 'EoL_2_X'),
   ('rob_1_1', 'EoL_2_Y'), ('rob_1_2', 'EoL_2_Y'),
   ('rob_1_3', 'EoL_2_Y'), ('rob_1_4', 'EoL_2_Y'),

   ('rob_2_1', 'EoL_3_X'), ('rob_2_2', 'EoL_3_X'),
   ('rob_2_3', 'EoL_3_X'), ('rob_2_4', 'EoL_3_X'),
   ('rob_2_1', 'EoL_3_Y'), ('rob_2_2', 'EoL_3_Y'),
   ('rob_2_3', 'EoL_3_Y'), ('rob_2_4', 'EoL_3_Y'),

   ('rob_2_1', 'EoL_4_X'), ('rob_2_2', 'EoL_4_X'),
   ('rob_2_3', 'EoL_4_X'), ('rob_2_4', 'EoL_4_X'),
   ('rob_2_1', 'EoL_4_Y'), ('rob_2_2', 'EoL_4_Y'),
   ('rob_2_3', 'EoL_4_Y'), ('rob_2_4', 'EoL_4_Y'),

   ('rob_2_1', 'EoL_5_X'), ('rob_2_2', 'EoL_5_X'),
```

```
    ('rob_2_3', 'EoL_5_X'), ('rob_2_4', 'EoL_5_X'),
    ('rob_2_1', 'EoL_5_Y'), ('rob_2_2', 'EoL_5_Y'),
    ('rob_2_3', 'EoL_5_Y'), ('rob_2_4', 'EoL_5_Y'),

    ('rob_2_1', 'EoL_6_X'), ('rob_2_2', 'EoL_6_X'),
    ('rob_2_3', 'EoL_6_X'), ('rob_2_4', 'EoL_6_X'),
    ('rob_2_1', 'EoL_6_Y'), ('rob_2_2', 'EoL_6_Y'),
    ('rob_2_3', 'EoL_6_Y'), ('rob_2_4', 'EoL_6_Y'),

    ('rob_1_vacuum', 'EoL_2_X'), ('rob_1_vacuum', 'EoL_2_Y'),

    ('rob_2_vacuum', 'EoL_3_X'), ('rob_2_vacuum', 'EoL_3_Y'),
    ('rob_2_vacuum', 'EoL_4_X'), ('rob_2_vacuum', 'EoL_4_Y'),
    ('rob_2_vacuum', 'EoL_5_X'), ('rob_2_vacuum', 'EoL_5_Y'),
    ('rob_2_vacuum', 'EoL_6_X'), ('rob_2_vacuum', 'EoL_6_Y'),

    ('EoL_1_X','score'), ('EoL_2_X','score'), ('EoL_3_X','score'),␣
 ↪('EoL_4_X','score'), ('EoL_5_X','score'), ('EoL_6_X','score'),
    ('EoL_1_Y','score'), ('EoL_2_Y','score'), ('EoL_3_Y','score'),␣
 ↪('EoL_4_Y','score'), ('EoL_5_Y','score'), ('EoL_6_Y','score')
]

print(len(edges))

check_nodes = ['score']
```

```
134
```

1.3.2 Additional Parameters

[ ]:
```
pos = {
    'cam_1_X':(8,4), 'cam_2_X':(-9,6), 'cam_3_X':(-5,6),
    'cam_1_Y':(8,2), 'cam_2_Y':(-7,6), 'cam_3_Y':(-3,6),
    'EoL_1_X':(10,-8), 'EoL_2_X':(-10,-8), 'EoL_3_X':(-6,-8), 'EoL_4_X':
 ↪(-2,-8), 'EoL_5_X':(2,-8), 'EoL_6_X':(6,-8),
    'EoL_1_Y':(12,-8), 'EoL_2_Y':(-8,-8), 'EoL_3_Y':(-4,-8), 'EoL_4_Y':(0,-8),␣
 ↪'EoL_5_Y':(4,-8), 'EoL_6_Y':(8,-8),
    'score':(0,-10),
    'rob_2_1':(-6,-4), 'rob_2_2':(-4,-4), 'rob_2_3':(-2,-4), 'rob_2_4':(-0,-4),␣
 ↪'rob_2_maxVel':(2,-4),
    'rob_1_1':(-9,1), 'rob_1_2':(-7,1), 'rob_1_3':(-5,1), 'rob_1_4':(-3,1),␣
 ↪'rob_1_maxVel':(-1,1),
    'rob_1_vacuum':(2,1), 'rob_2_vacuum':(5,-4),'rob_1_supply':(5,1),␣
 ↪'rob_2_supply':(8,-4),
    'con_1':(8,-1),'con_2':(11,6),'con_3':(3,6)
}
```

```
colors = {
    'cam_1_X':'skyblue', 'cam_2_X':'skyblue', 'cam_3_X':'skyblue',
    'cam_1_Y':'skyblue', 'cam_2_Y':'skyblue', 'cam_3_Y':'skyblue',
    'EoL_1_X':'lightgreen', 'EoL_2_X':'lightgreen', 'EoL_3_X':'lightgreen',␣
 ↪'EoL_4_X':'lightgreen', 'EoL_5_X':'lightgreen', 'EoL_6_X':'lightgreen',
    'EoL_1_Y':'lightgreen', 'EoL_2_Y':'lightgreen', 'EoL_3_Y':'lightgreen',␣
 ↪'EoL_4_Y':'lightgreen', 'EoL_5_Y':'lightgreen', 'EoL_6_Y':'lightgreen',
    'score':'lightsalmon',
    'rob_1_1':'tan', 'rob_1_2':'tan', 'rob_1_3':'tan', 'rob_1_4':'tan',␣
 ↪'rob_1_maxVel':'tan',
    'rob_2_1':'tan', 'rob_2_2':'tan', 'rob_2_3':'tan', 'rob_2_4':'tan',␣
 ↪'rob_2_maxVel':'tan',
    'rob_1_vacuum':'tan', 'rob_2_vacuum':'tan','rob_1_supply':'tan',␣
 ↪'rob_2_supply':'tan',
    'con_1':'lightgrey','con_2':'lightgrey','con_3':'lightgrey'
}
```

1.4 Show datasets in folders

[ ]:
```
# Specify the directory path
directory_path = 'G:\\My Drive\\Master Thesis\\Simulation\\Dataset'
directory_figures_path = 'G:\\My Drive\\Master␣
 ↪Thesis\\Simulation\\Results_Figures'
main_dir = 'G:\My Drive\Master Thesis\Simulation\Results_Analysis'
os.makedirs(main_dir, exist_ok=True)
```

[ ]:
```
files,folder_path = get_from_folders(directory_path)
```

1.5 Run RCA trough folder

A warm-up phase is considered. Each product takes roughly 26.30 seconds from the assembly entry point to the assembly end of line. There is some distance from the drop point of the items to the start and some interventions need time to become stable, thus we need to skip in total roughly 839 rows. Each 8 seconds a new product exits the assembly line.

1.5.1 Algorithm #1 - Hypothesis Testing

[ ]:
```
result_HT,runtime_HT =␣
 ↪run_HT_size(folder_path,files,startrow=950,size_p=1,nodes=nodes,edges_list=edges,key_nodes=
```

1.5.2 Algorithm #2 - Epsilon Diagnosis

[ ]:
```
result_ED,runtime_ED =␣
 ↪run_ED_size(folder_path,files,startrow=950,size_p=1,nodes=nodes,edges_list=edges,key_nodes=
```

1.5.3 Algorithm #3 - Random Walk

[ ]:
```
result_RW,runtime_RW =␣
↪run_RW_size(folder_path,files,startrow=950,size_p=1,nodes=nodes,edges_list=edges,key_nodes=
```

1.5.4 Algorithm #4: RCD

[ ]:
```
result_RCD, runtime_RCD =␣
↪run_RCD_size(folder_path,files,startrow=950,size_p=1,nodes=nodes,edges_list=edges,key_nodes
```

1.6 Data Analysis

1.6.1 Summary Algorithms

[ ]:
```
result_all = pd.DataFrame()
result_all = pd.concat([result_HT,result_ED,result_RW,result_RCD])

runtime_all = pd.DataFrame()
runtime_all = pd.concat([runtime_HT,runtime_ED,runtime_RW,runtime_RCD],axis=1)
```

1.6.2 Intervention - Root Cause

[ ]:
```
abnormal_sets = pd.DataFrame()
abnormal_sets['size_1'] = ['cam_1_X', 'cam_1_Y']
abnormal_sets['feeder_3'] = ['cam_3_X', 'cam_3_Y']
abnormal_sets['gripper_1'] = ['rob_1_supply',None]
abnormal_sets['max_Vel_2'] = ['rob_2_maxVel',None]
```

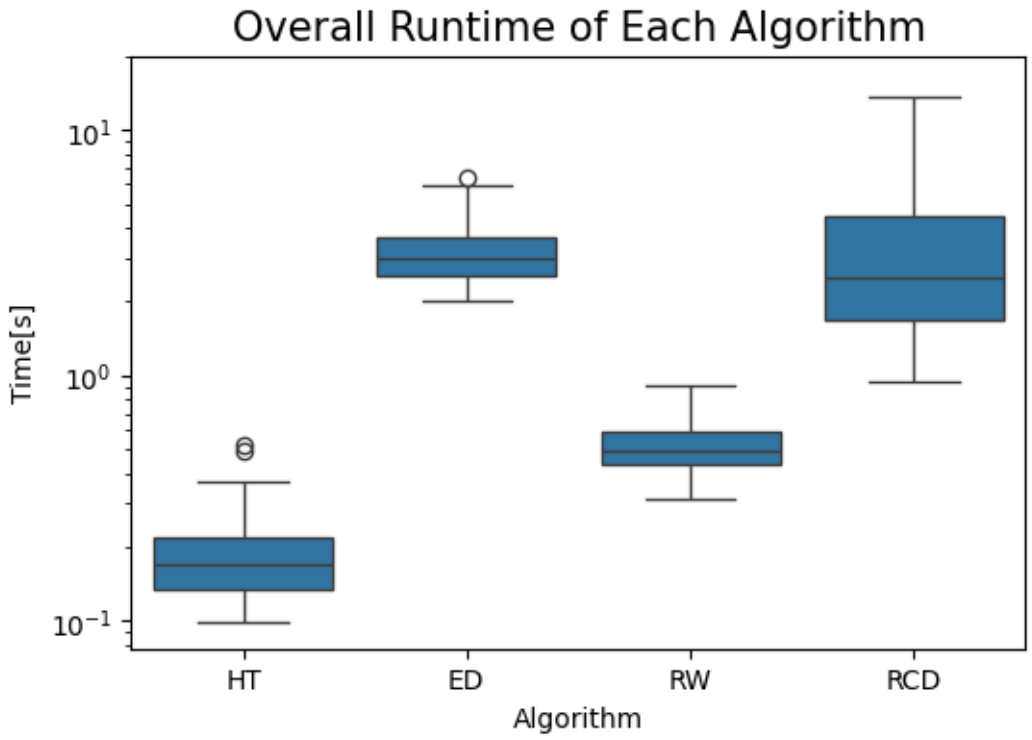
1.6.3 TOP 3 - Root Cause

[ ]:
```
result_data_3top = results_top_3(result_all,abnormal_sets)

result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top.csv'))
```

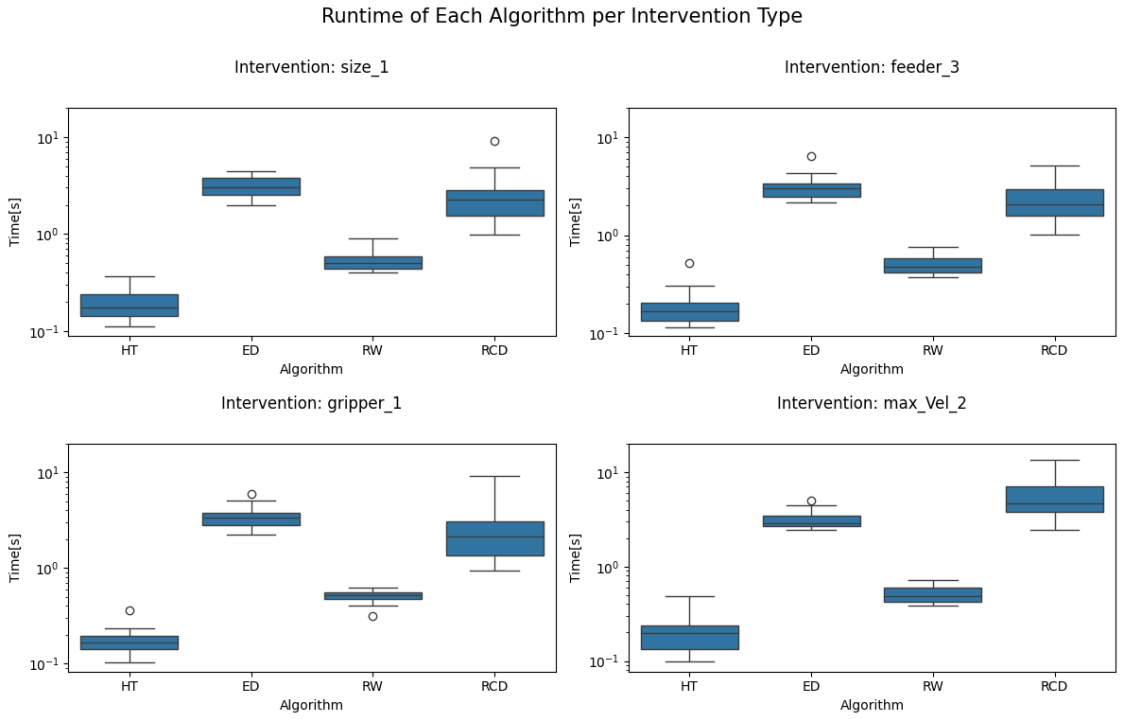
1.6.4 TOP 1 - Root Cause

[ ]:
```
result_data_1top = results_top_1(result_all,abnormal_sets)

result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top.csv'))
```

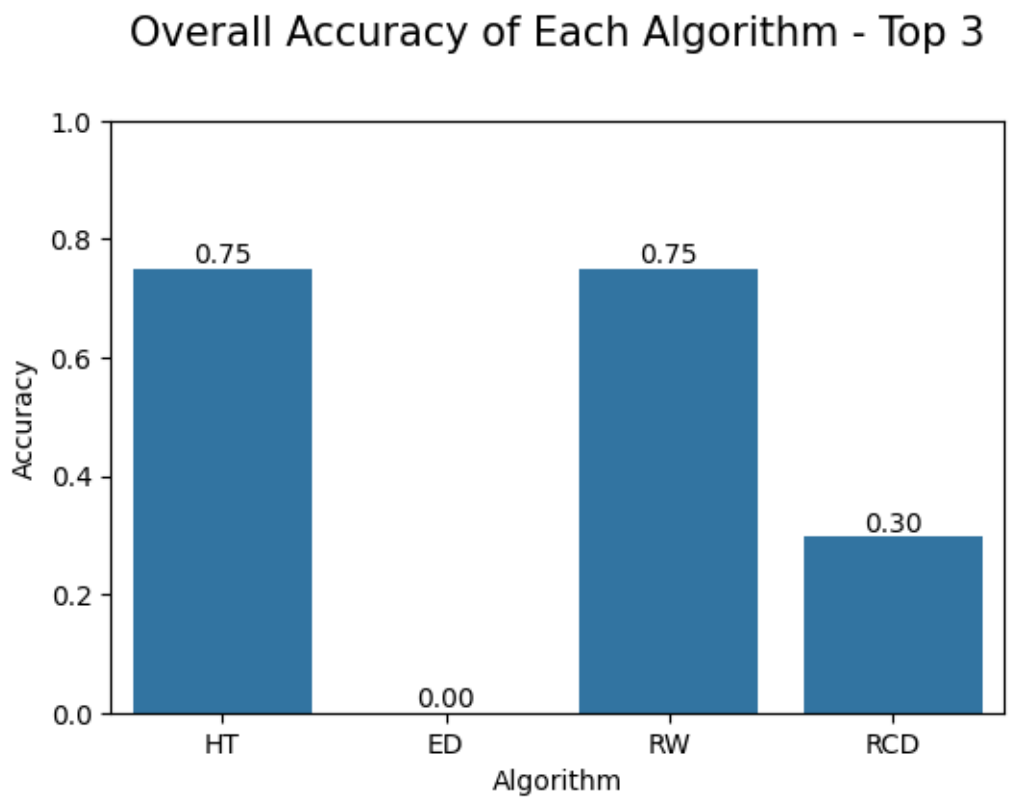
[ ]:
```
plot_runtime(runtime_all,directory_figures_path,'baseline_runtime','Algorithm')
```



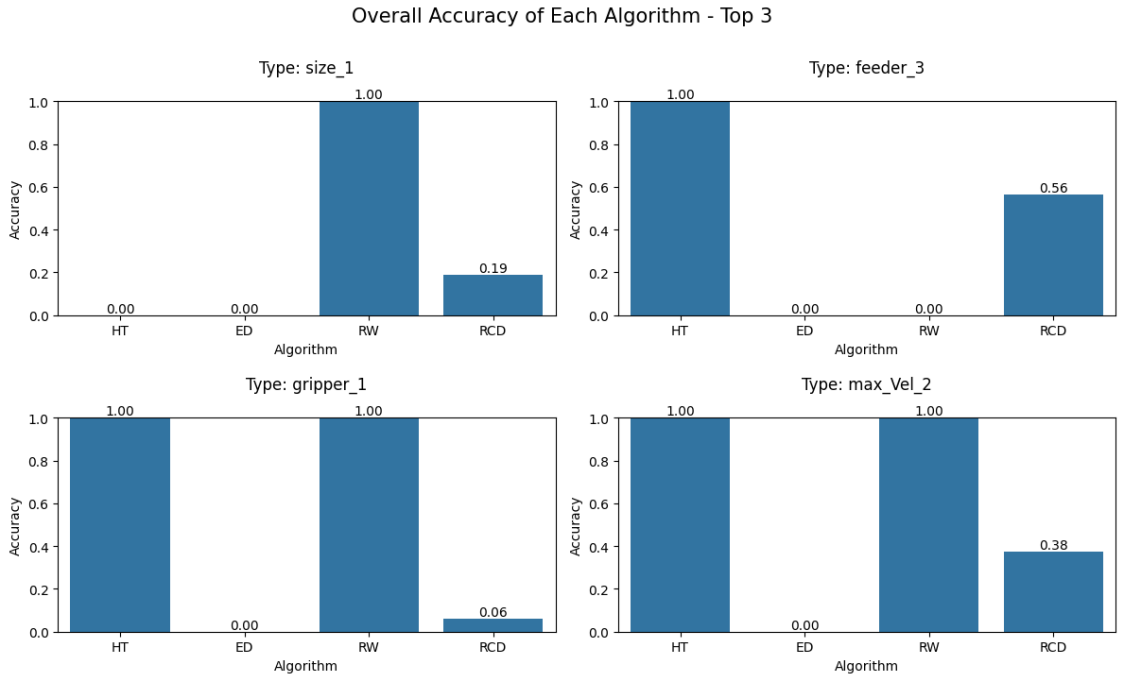
[ ]:
```
plot_runtime_inter(runtime_all,directory_figures_path,'baseline_runtime_inter','Algorithm')
```



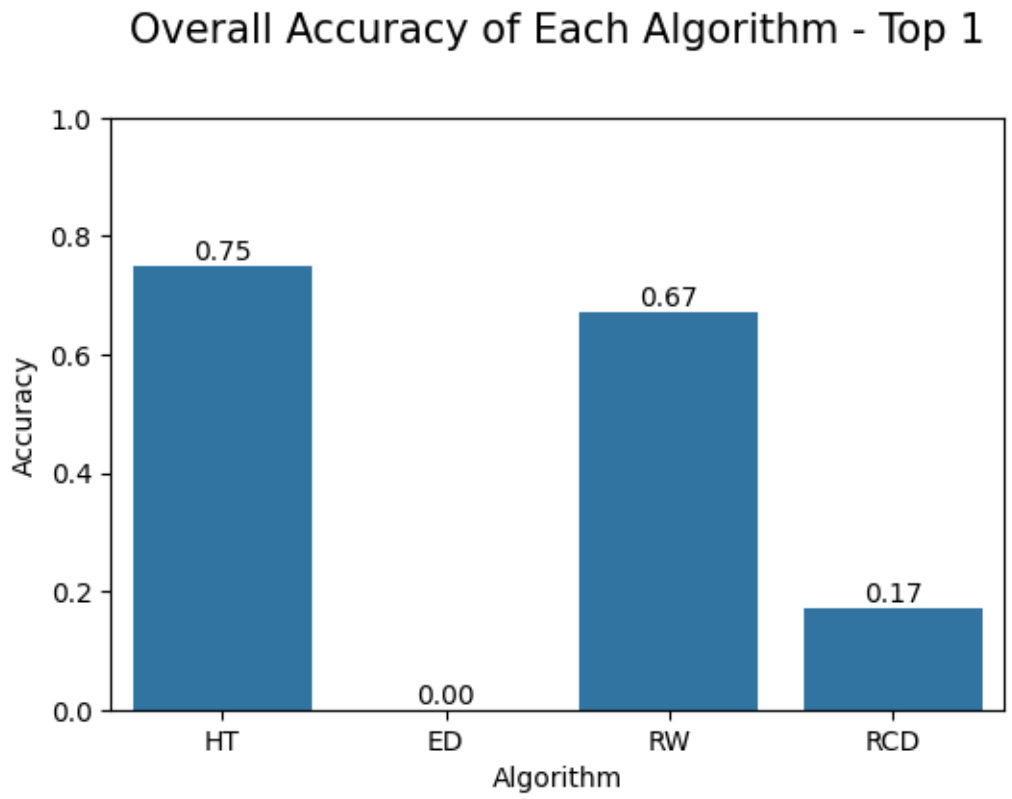
[ ]:
```
plot_avg_total(result_data_3top,directory_figures_path,'baseline_accuracy_3','Overall␣
↪Accuracy of Each Algorithm - Top 3')
```



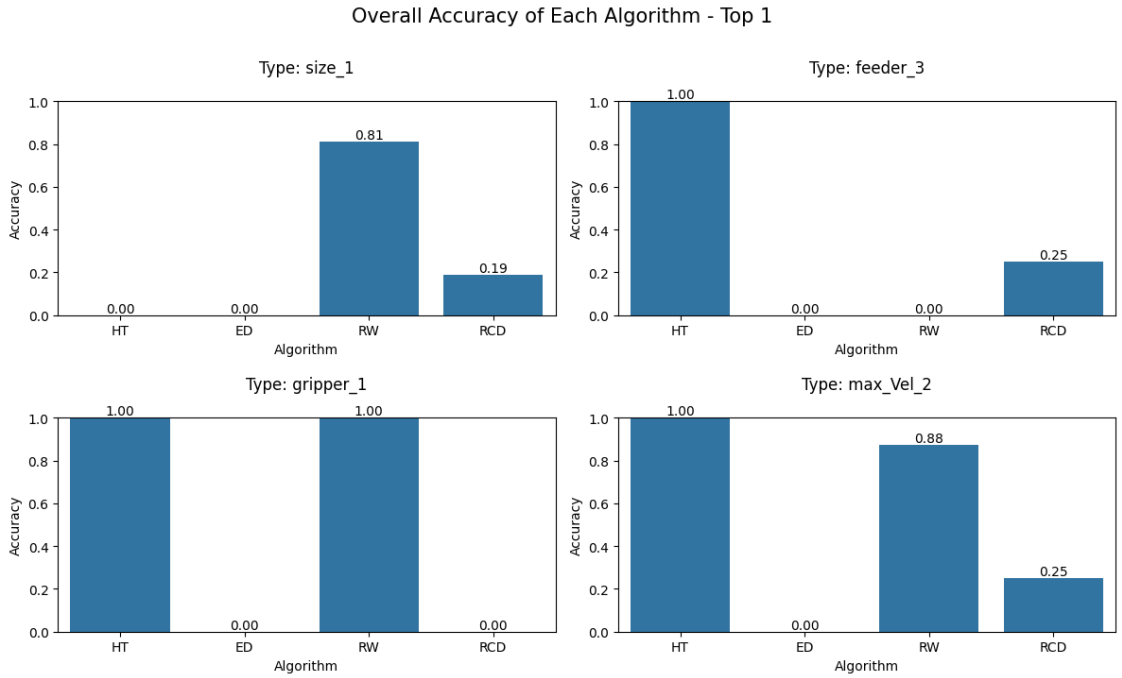
[ ]:
```
plot_avg_inter(result_data_3top,directory_figures_path,'baseline_accuracy_inter_3','Overall␣
↪Accuracy of Each Algorithm - Top 3')
```



[ ]:
```
plot_avg_total(result_data_1top,directory_figures_path,'baseline_accuracy_1','Overall␣
↪Accuracy of Each Algorithm - Top 1')
```



[ ]:
```
plot_avg_inter(result_data_1top,directory_figures_path,'baseline_accuracy_inter_1','Overall␣
↪Accuracy of Each Algorithm - Top 1')
```



1.7 Variation 1 - Overlap

1.7.1 HT -Algorithm

[ ]:
```
result_HT_overlap_1, runtime_HT_overlap_1 =␣
↪run_HT_overlap(folder_path,files,startrow=950,overlap_p=0.
↪10,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_overlap_2, runtime_HT_overlap_2 =␣
↪run_HT_overlap(folder_path,files,startrow=950,overlap_p=0.
↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_overlap_3, runtime_HT_overlap_3 =␣
↪run_HT_overlap(folder_path,files,startrow=950,overlap_p=0.
↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_overlap_4, runtime_HT_overlap_4 =␣
↪run_HT_overlap(folder_path,files,startrow=950,overlap_p=0.
↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_overlap_5, runtime_HT_overlap_5 =␣
↪run_HT_overlap(folder_path,files,startrow=950,overlap_p=0.
↪90,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

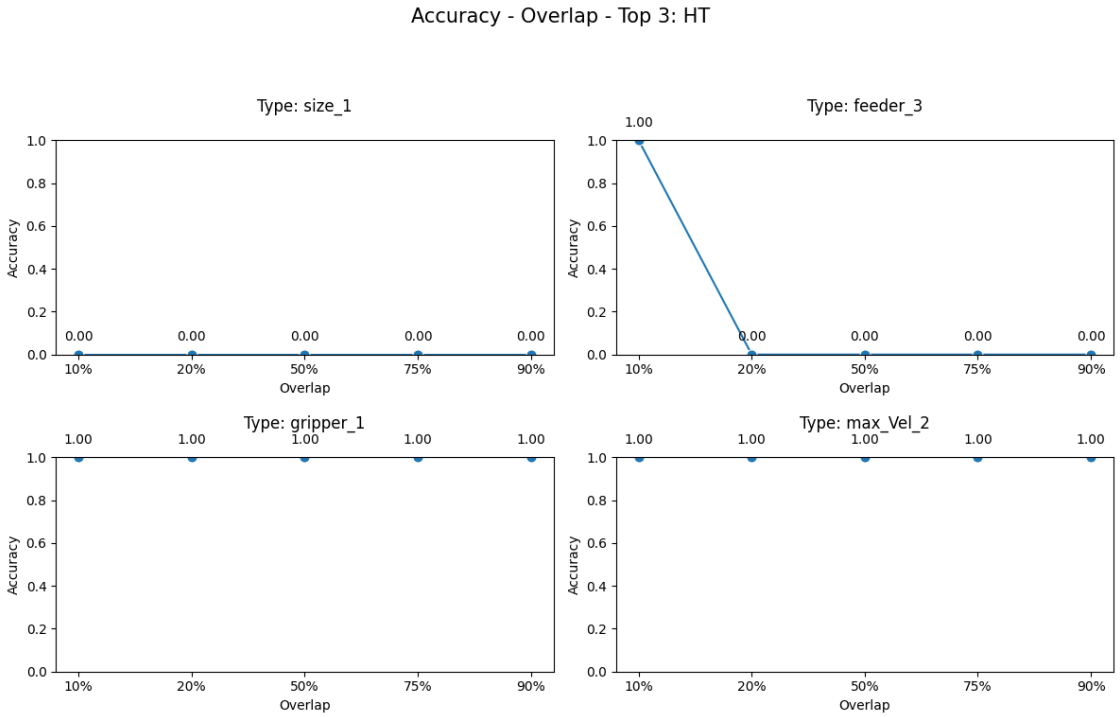
[ ]:
```
result_overlap_HT = pd.DataFrame()
result_overlap_HT = pd.
↪concat([result_HT_overlap_1,result_HT_overlap_2,result_HT_overlap_3,result_HT_overlap_4,res
↪ignore_index=True)
```

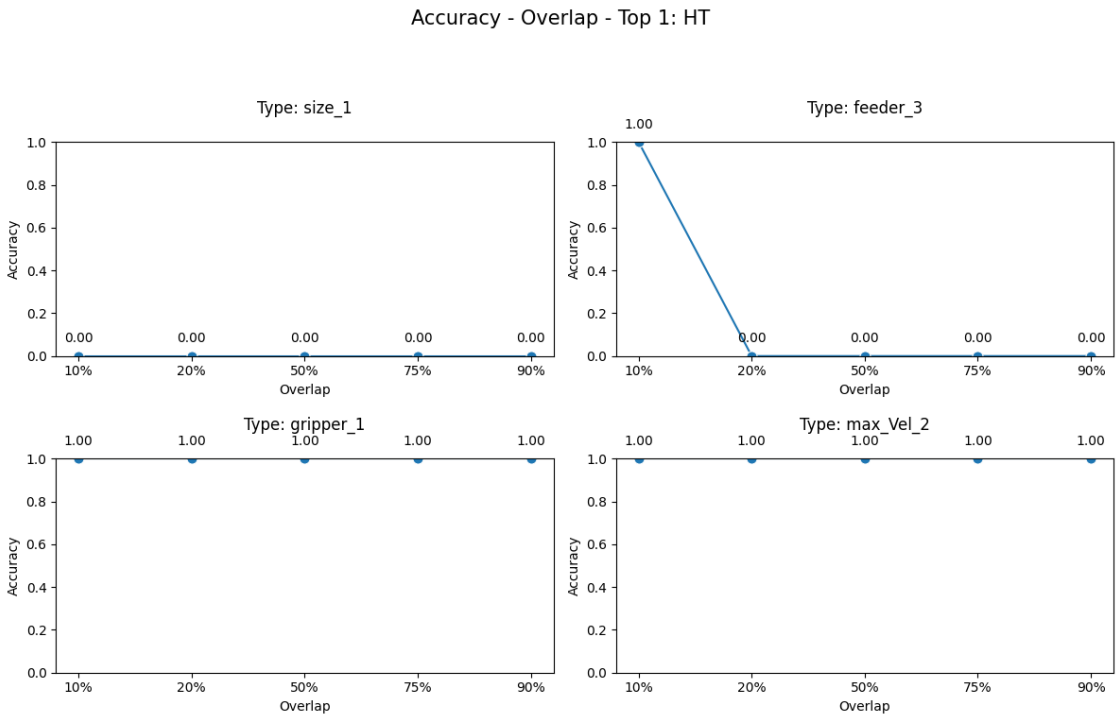
```
result_overlap_HT['Overlap Percent'] = pd.DataFrame({'HT':
 ↪['10%','20%','50%','75%','90%']})
result_overlap_HT.set_index('Overlap Percent', inplace=True)
```

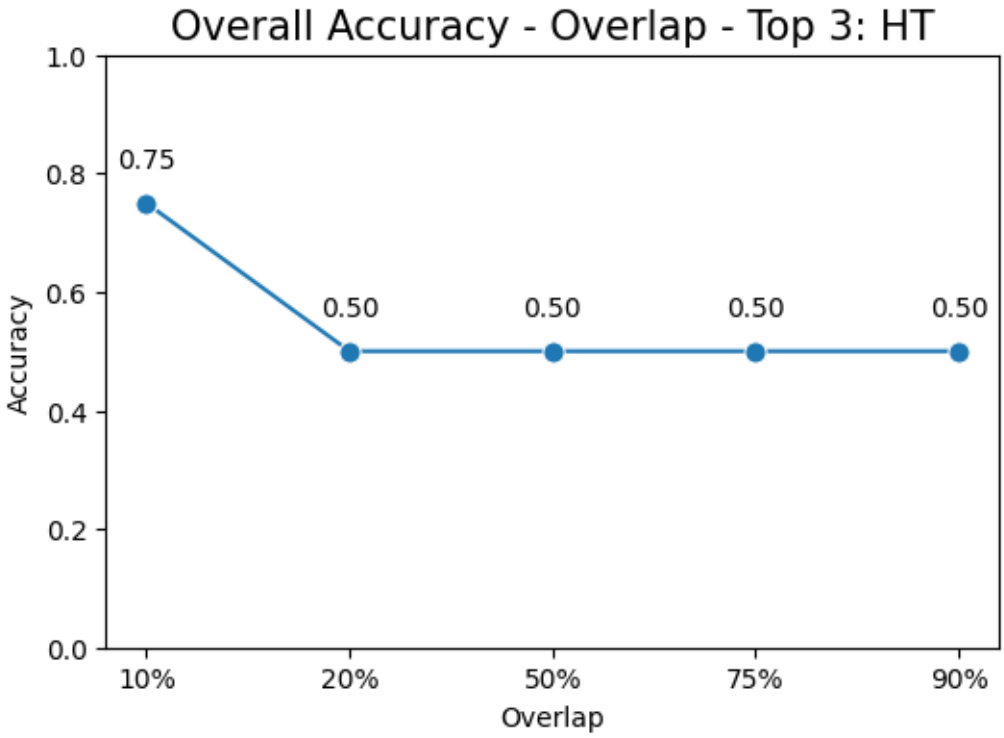
[ ]:
```
runtime_overlap_HT = pd.DataFrame()
runtime_overlap_HT = pd.concat([runtime_HT_overlap_1.T,runtime_HT_overlap_2.
 ↪T,runtime_HT_overlap_3.T,runtime_HT_overlap_4.T,runtime_HT_overlap_5.
 ↪T],ignore_index=True)
runtime_overlap_HT['Overlap Percent'] = pd.DataFrame({'HT':
 ↪['10%','20%','50%','75%','90%']})
runtime_overlap_HT.set_index('Overlap Percent', inplace=True)
```

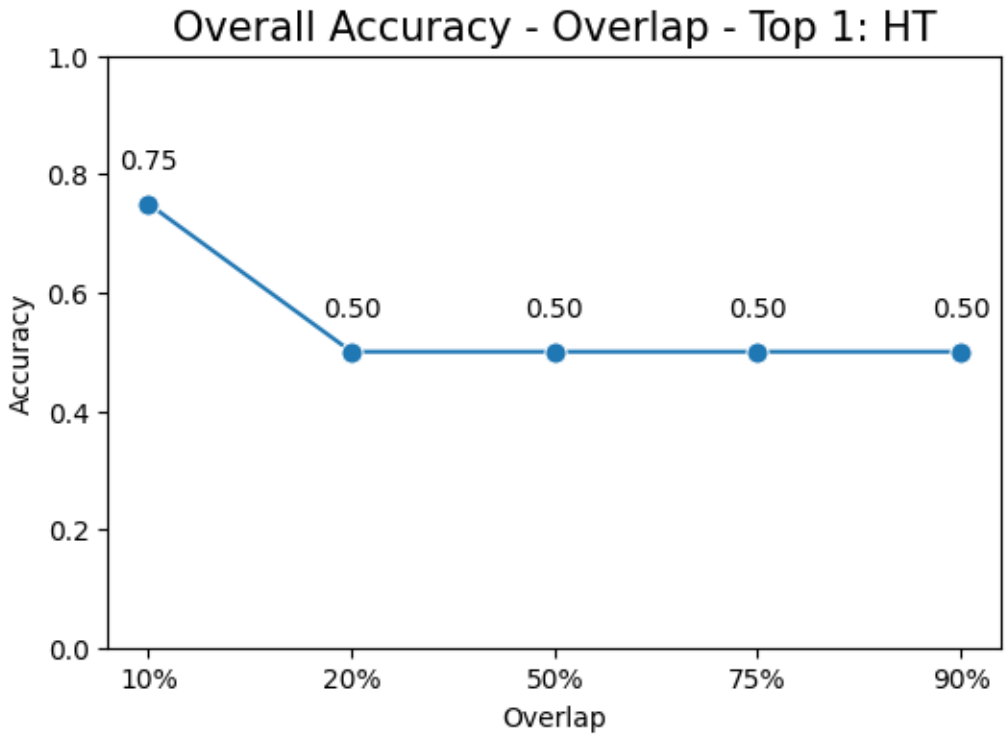
[ ]:
```
result_data_1top = results_top_1(result_overlap_HT,abnormal_sets)
result_data_3top = results_top_1(result_overlap_HT,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_HT.csv'))
```

[ ]:
```
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_overlap_HT','Overlap','HT','A
 ↪- Overlap - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_overlap_HT','Overlap','HT','A
 ↪- Overlap - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_overlap_total_HT','Overlap','
 ↪Accuracy - Overlap - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_overlap_total_HT','Overlap','
 ↪Accuracy - Overlap - Top 1:')
```




Accuracy - Overlap - Top 1: HT
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Overlap
10%
20%
50%
75%
90%
0.00
1.00


Overall Accuracy - Overlap - Top 3: HT
Accuracy
Overlap
0.75
0.50
10%
20%
50%
75%
90%



1.7.2 ED - Algorithm

[ ]:
```
result_ED_overlap_1, runtime_ED_overlap_1 =␣
↪run_ED_overlap(folder_path,files,startrow=950,overlap_p=0.
↪10,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_ED_overlap_2, runtime_ED_overlap_2 =␣
↪run_ED_overlap(folder_path,files,startrow=950,overlap_p=0.
↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_ED_overlap_3, runtime_ED_overlap_3 =␣
↪run_ED_overlap(folder_path,files,startrow=950,overlap_p=0.
↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_ED_overlap_4, runtime_ED_overlap_4 =␣
↪run_ED_overlap(folder_path,files,startrow=950,overlap_p=0.
↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_ED_overlap_5, runtime_ED_overlap_5 =␣
↪run_ED_overlap(folder_path,files,startrow=950,overlap_p=0.
↪90,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

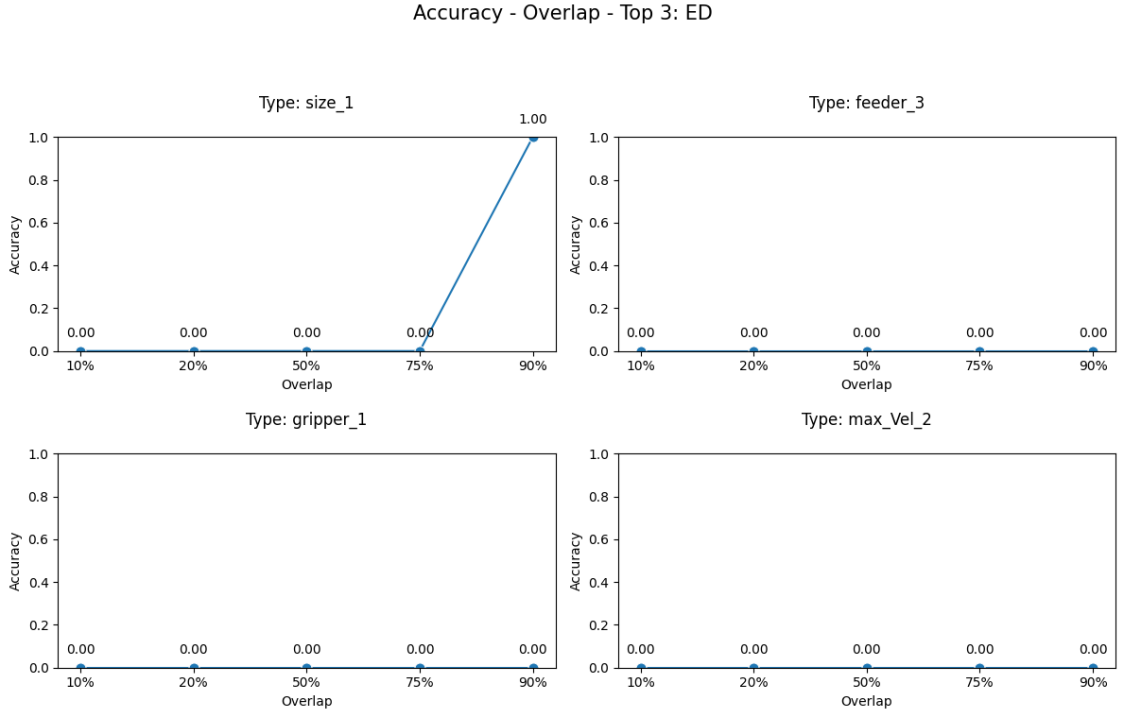
[ ]:
```
result_overlap_ED = pd.DataFrame()
```

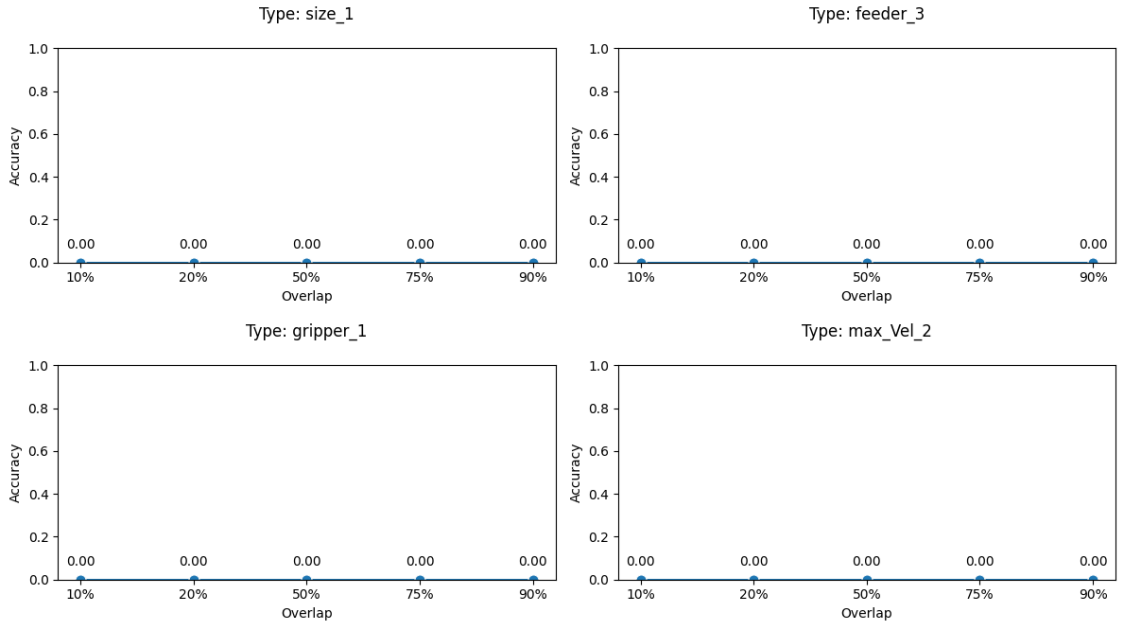
```
result_overlap_ED = pd.
 ↪concat([result_ED_overlap_1,result_ED_overlap_2,result_ED_overlap_3,result_ED_overlap_4,res
 ↪ignore_index=True)
result_overlap_ED['Overlap Percent'] = pd.DataFrame({'ED':
 ↪['10%','20%','50%','75%','90%']})
result_overlap_ED.set_index('Overlap Percent', inplace=True)
```

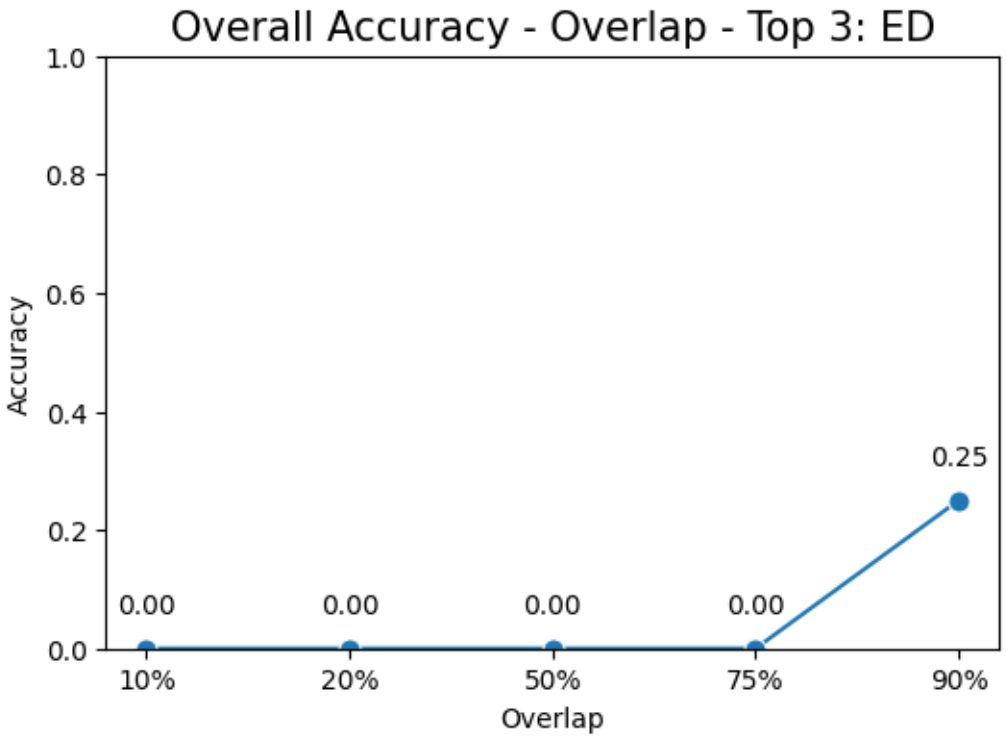
[ ]:
```
runtime_overlap_ED = pd.DataFrame()
runtime_overlap_ED = pd.concat([runtime_ED_overlap_1.T,runtime_ED_overlap_2.
 ↪T,runtime_ED_overlap_3.T,runtime_ED_overlap_4.T,runtime_ED_overlap_5.T],␣
 ↪ignore_index=True)
runtime_overlap_ED['Overlap Percent'] = pd.DataFrame({'ED':
 ↪['10%','20%','50%','75%','90%']})
runtime_overlap_ED.set_index('Overlap Percent', inplace=True)
```

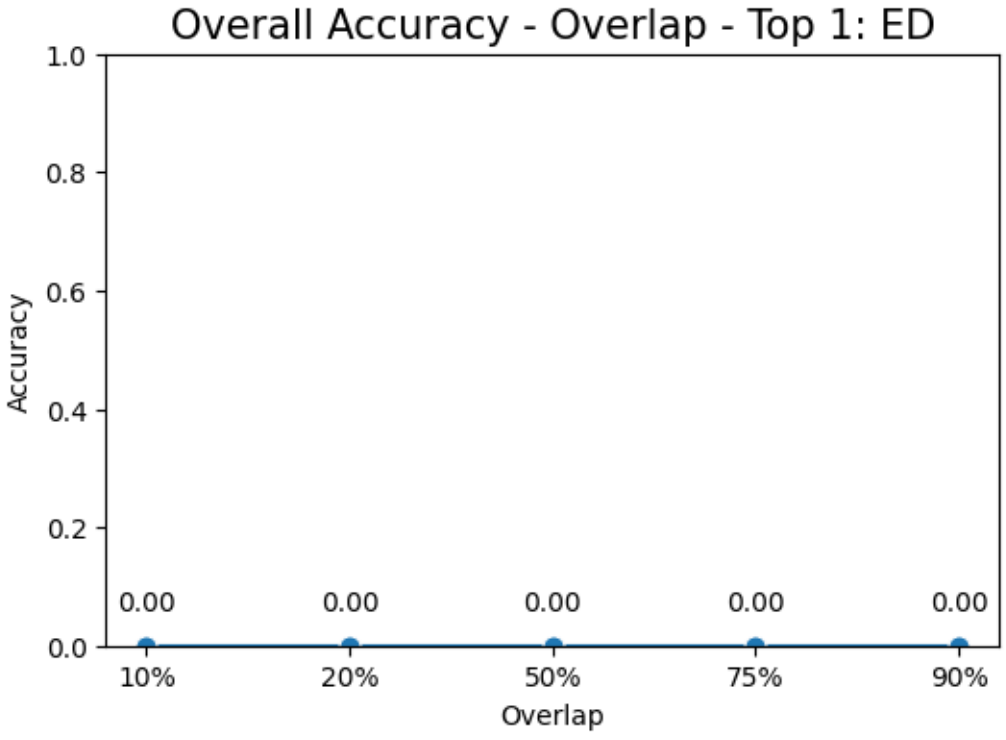
[ ]:
```
result_data_3top = results_top_3(result_overlap_ED,abnormal_sets)
result_data_1top = results_top_1(result_overlap_ED,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_ED.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_ED.csv'))
```

[ ]:
```
algo='ED'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_overlap_'+algo,'Overlap',algo
 ↪- Overlap - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_overlap_'+algo,'Overlap',algo
 ↪- Overlap - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_overlap_total_'+algo,'Overlap
 ↪Accuracy - Overlap - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_overlap_total_'+algo,'Overlap
 ↪Accuracy - Overlap - Top 1:')
```


Accuracy - Overlap - Top 3: ED
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Overlap
10%
20%
50%
75%
90%
0.0
0.2
0.4
0.6
0.8
1.0
0.00
1.00


Accuracy - Overlap - Top 1: ED
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Overlap
10%
20%
50%
75%
90%
0.0
0.2
0.4
0.6
0.8
1.0
0.00


Overall Accuracy - Overlap - Top 3: ED
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.00
0.00
0.00
0.00
0.25
10%
20%
50%
75%
90%
Overlap


Overall Accuracy - Overlap - Top 1: ED
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.00
0.00
0.00
0.00
0.00
10%
20%
50%
75%
90%
Overlap

1.7.3 RW - Algorithm

[ ]:
```
result_RW_overlap_1, runtime_RW_overlap_1 =␣
↪run_RW_overlap(folder_path,files,startrow=950,overlap_p=0.
↪10,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_overlap_2, runtime_RW_overlap_2 =␣
↪run_RW_overlap(folder_path,files,startrow=950,overlap_p=0.
↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_overlap_3, runtime_RW_overlap_3 =␣
↪run_RW_overlap(folder_path,files,startrow=950,overlap_p=0.
↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_overlap_4, runtime_RW_overlap_4 =␣
↪run_RW_overlap(folder_path,files,startrow=950,overlap_p=0.
↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_overlap_5, runtime_RW_overlap_5 =␣
↪run_RW_overlap(folder_path,files,startrow=950,overlap_p=0.
↪90,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

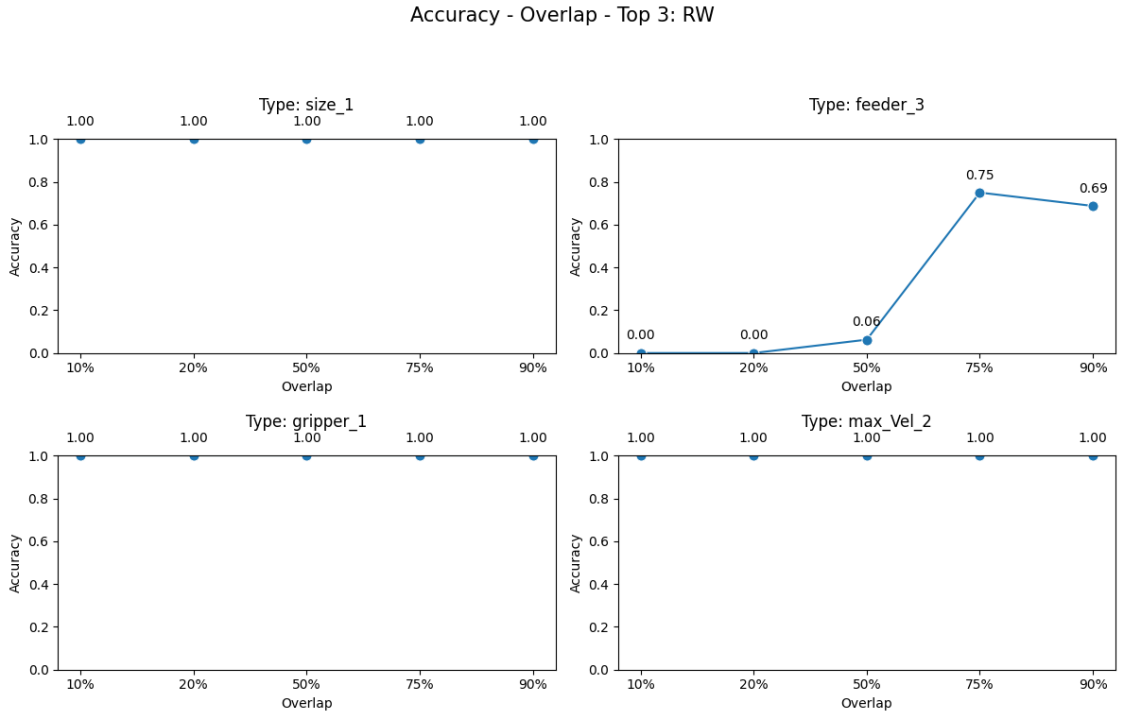
[ ]:
```
result_overlap_RW = pd.DataFrame()
result_overlap_RW = pd.
↪concat([result_RW_overlap_1,result_RW_overlap_2,result_RW_overlap_3,result_RW_overlap_4,res
↪ignore_index=True)
result_overlap_RW['Overlap Percent'] = pd.DataFrame({'RW':
↪['10%','20%','50%','75%','90%']})
result_overlap_RW.set_index('Overlap Percent', inplace=True)
```

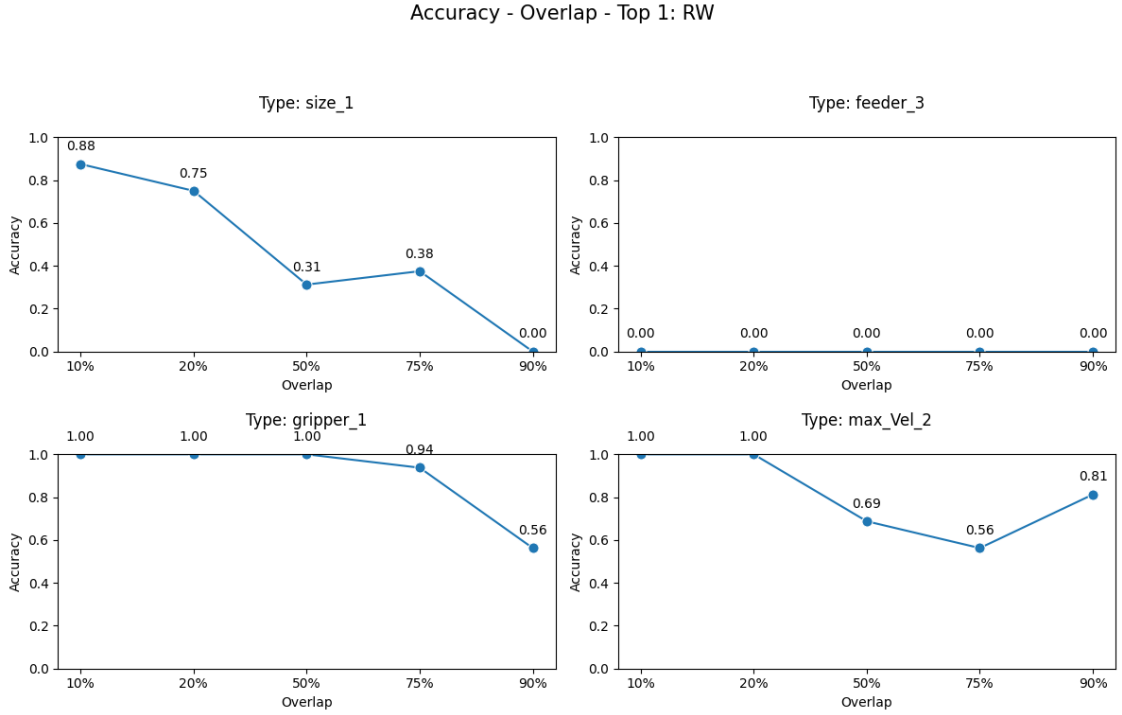
[ ]:
```
runtime_overlap_RW = pd.DataFrame()
runtime_overlap_RW = pd.concat([runtime_RW_overlap_1.T,runtime_RW_overlap_2.
↪T,runtime_RW_overlap_3.T,runtime_RW_overlap_4.T,runtime_RW_overlap_5.T],␣
↪ignore_index=True)
runtime_overlap_RW['Overlap Percent'] = pd.DataFrame({'RW':
↪['10%','20%','50%','75%','90%']})
runtime_overlap_RW.set_index('Overlap Percent', inplace=True)
```

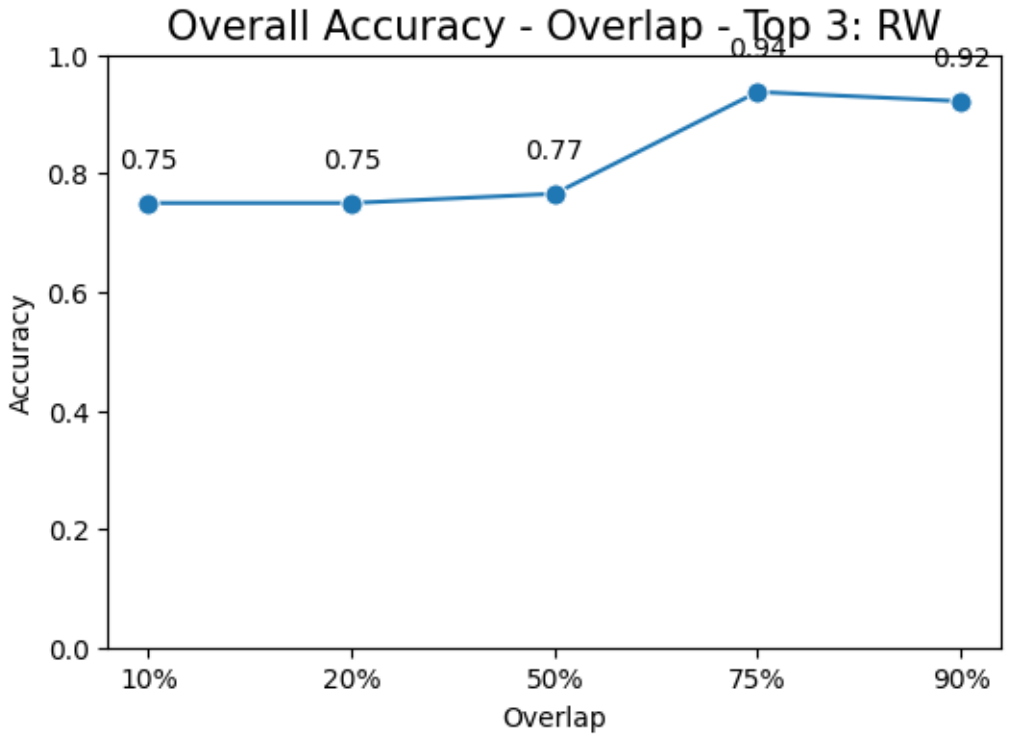
[ ]:
```
result_data_3top = results_top_3(result_overlap_RW,abnormal_sets)
result_data_1top = results_top_1(result_overlap_RW,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_RW.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_RW.csv'))
```

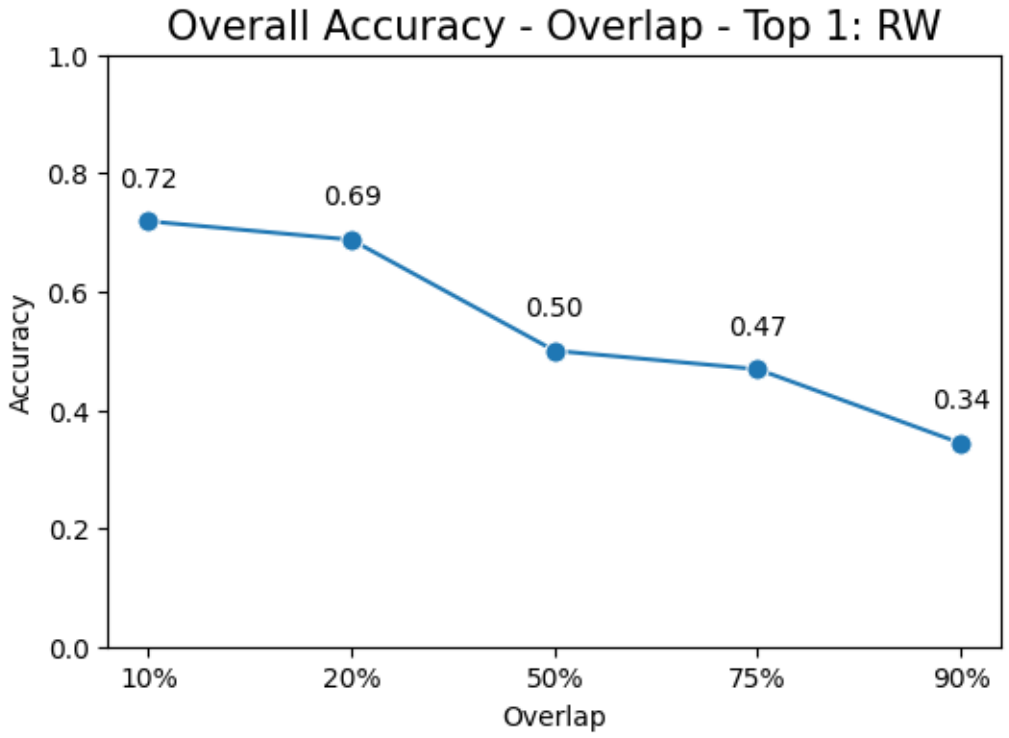
[ ]:
```
algo='RW'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_overlap_'+algo,'Overlap',algo
↪- Overlap - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_overlap_'+algo,'Overlap',algo
↪- Overlap - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_overlap_total_'+algo,'Overlap
↪Accuracy - Overlap - Top 3:')
```

```
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_overlap_total_'+algo,'Overlap
 ↪Accuracy - Overlap - Top 1:')
```






Overall Accuracy - Overlap - Top 3: RW
Accuracy
Overlap
1.0
0.8
0.6
0.4
0.2
0.0
10%
20%
50%
75%
90%
0.75
0.75
0.77
0.94
0.92


Overall Accuracy - Overlap - Top 1: RW
Accuracy
Overlap
1.0
0.8
0.6
0.4
0.2
0.0
10%
20%
50%
75%
90%
0.72
0.69
0.50
0.47
0.34

1.7.4 RCD - Algorithm

[ ]:
```
result_RCD_overlap_1, runtime_RCD_overlap_1 =␣
↪run_RCD_overlap(folder_path,files,startrow=950,overlap_p=0.
↪1,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_overlap_2, runtime_RCD_overlap_2 =␣
↪run_RCD_overlap(folder_path,files,startrow=950,overlap_p=0.
↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_overlap_3, runtime_RCD_overlap_3 =␣
↪run_RCD_overlap(folder_path,files,startrow=950,overlap_p=0.
↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_overlap_4, runtime_RCD_overlap_4 =␣
↪run_RCD_overlap(folder_path,files,startrow=950,overlap_p=0.
↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_overlap_5, runtime_RCD_overlap_5 =␣
↪run_RCD_overlap(folder_path,files,startrow=950,overlap_p=0.
↪90,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

[ ]:
```
result_overlap_RCD = pd.DataFrame()
result_overlap_RCD = pd.
↪concat([result_RCD_overlap_1,result_RCD_overlap_2,result_RCD_overlap_3,result_RCD_overlap_4
↪ignore_index=True)
result_overlap_RCD['Overlap Percent'] = pd.DataFrame({'RCD':
↪['10%','20%','50%','75%','90%']})
result_overlap_RCD.set_index('Overlap Percent', inplace=True)
```

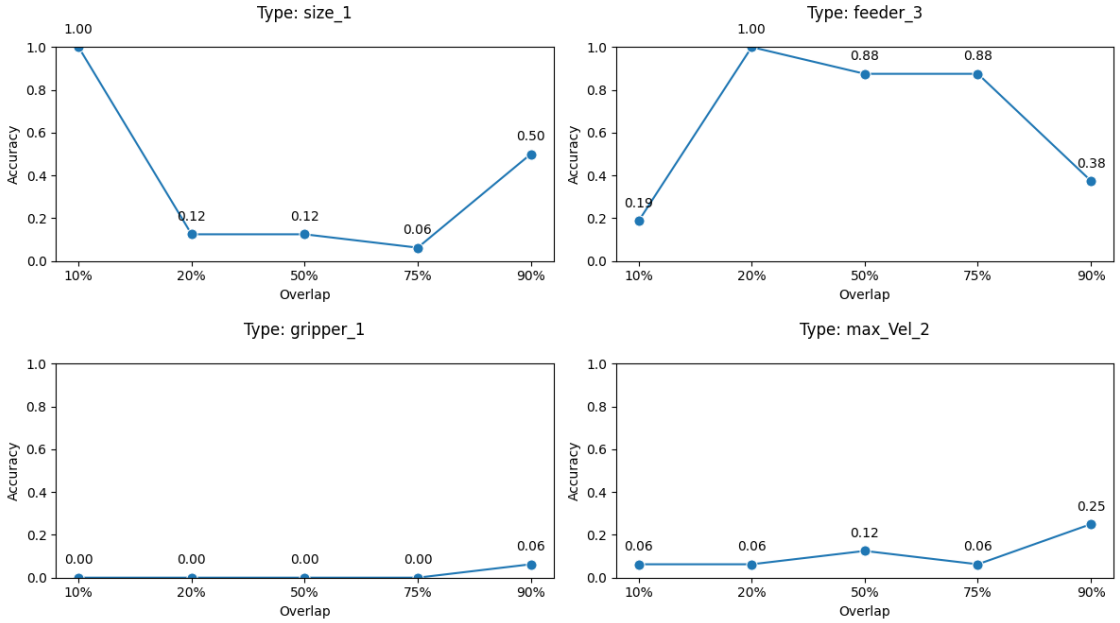
[ ]:
```
runtime_overlap_RCD = pd.DataFrame()
runtime_overlap_RCD = pd.concat([runtime_RCD_overlap_1.T,runtime_RCD_overlap_2.
↪T,runtime_RCD_overlap_3.T,runtime_RCD_overlap_4.T,runtime_RCD_overlap_5.T],␣
↪ignore_index=True)
runtime_overlap_RCD['Overlap Percent'] = pd.DataFrame({'RCD':
↪['10%','20%','50%','75%','90%']})
runtime_overlap_RCD.set_index('Overlap Percent', inplace=True)
```

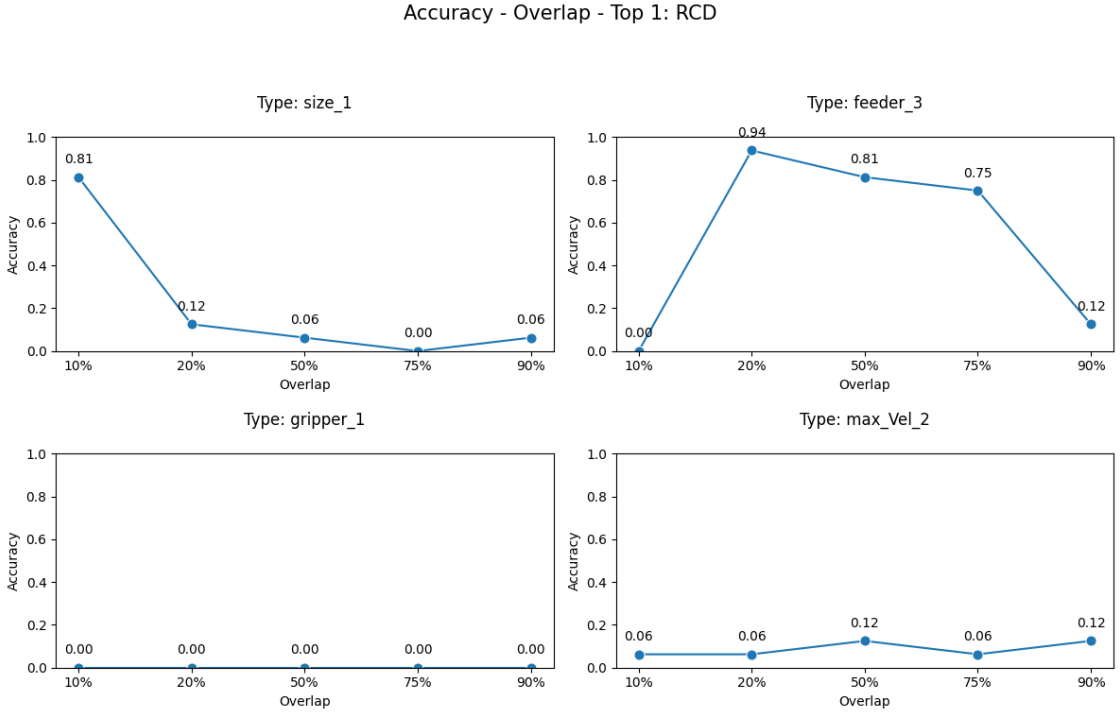
[ ]:
```
result_data_3top = results_top_3(result_overlap_RCD,abnormal_sets)
result_data_1top = results_top_1(result_overlap_RCD,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_RCD.csv'))
```

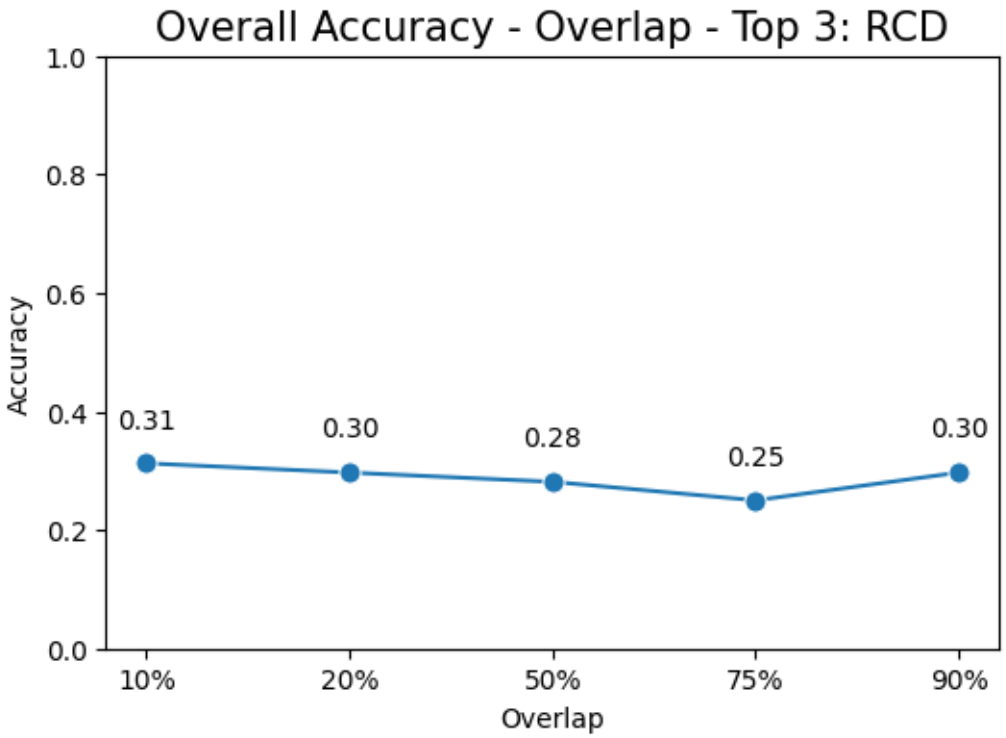
[ ]:
```
algo='RCD'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_overlap_'+algo,'Overlap',algo
↪- Overlap - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_overlap_'+algo,'Overlap',algo
↪- Overlap - Top 1:')
```

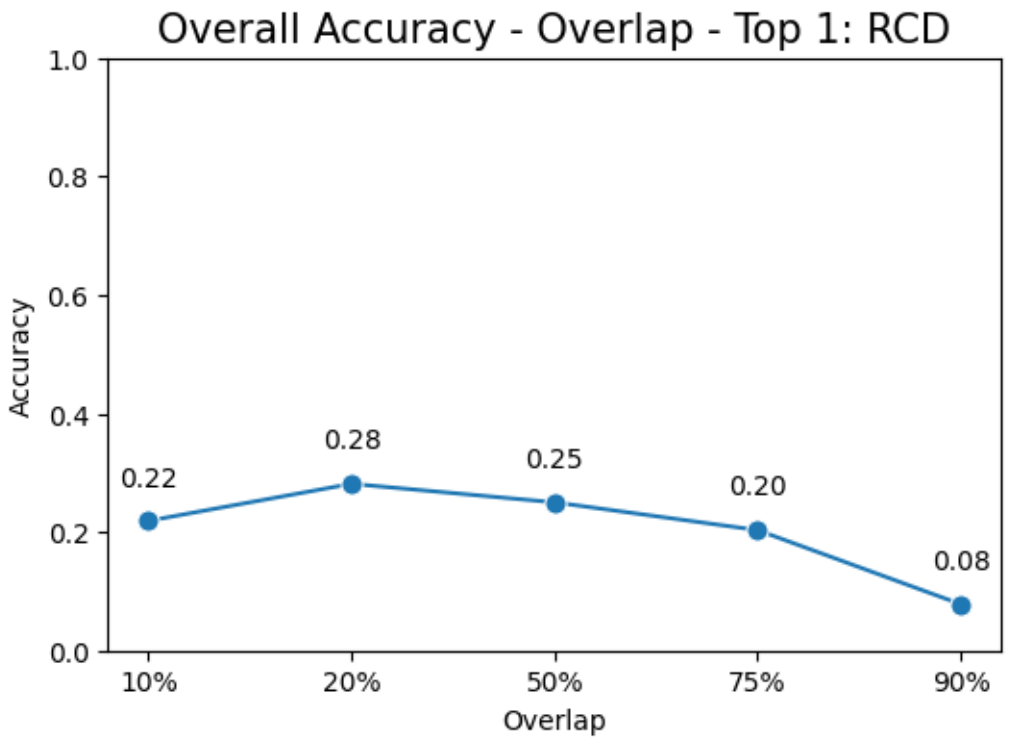
```
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_overlap_total_'+algo,'Overlap
 ↪Accuracy - Overlap - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_overlap_total_'+algo,'Overlap
 ↪Accuracy - Overlap - Top 1:')
```

Accuracy - Overlap - Top 3: RCD



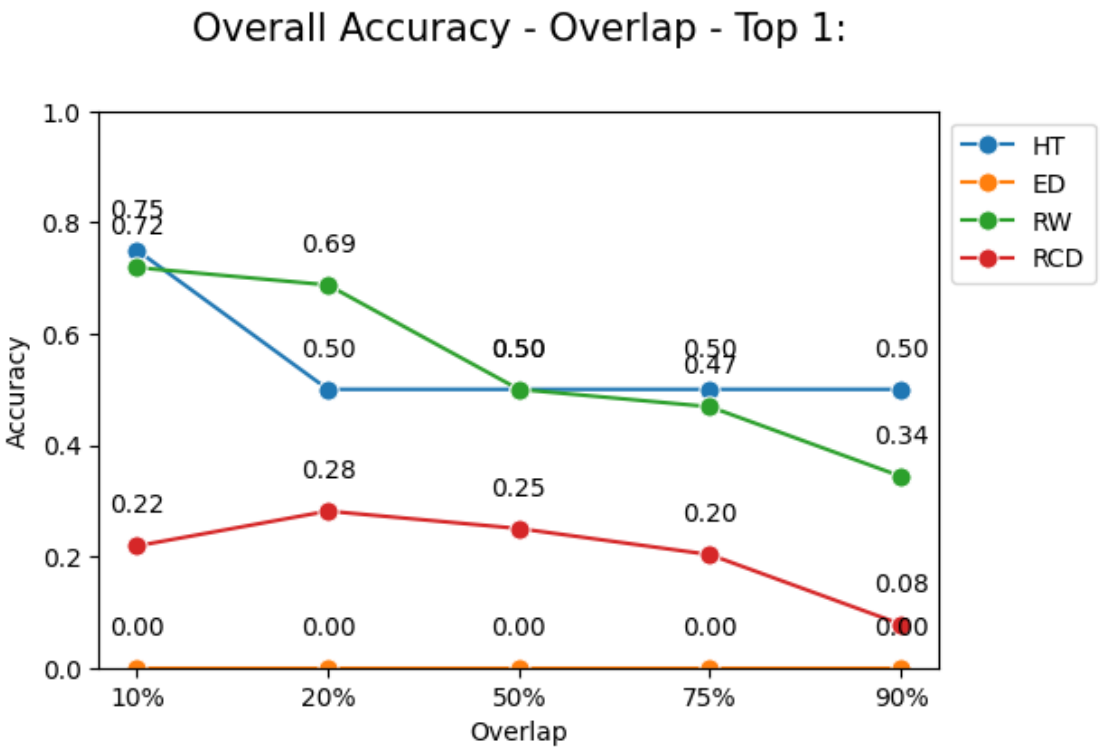

Accuracy - Overlap - Top 1: RCD
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Overlap
10%
20%
50%
75%
90%
0.81
0.12
0.06
0.00
0.06
0.00
0.94
0.81
0.75
0.12
0.00
0.00
0.00
0.00
0.00
0.06
0.06
0.12
0.06
0.12


Overall Accuracy - Overlap - Top 3: RCD
Accuracy
Overlap
10%
20%
50%
75%
90%
0.31
0.30
0.28
0.25
0.30

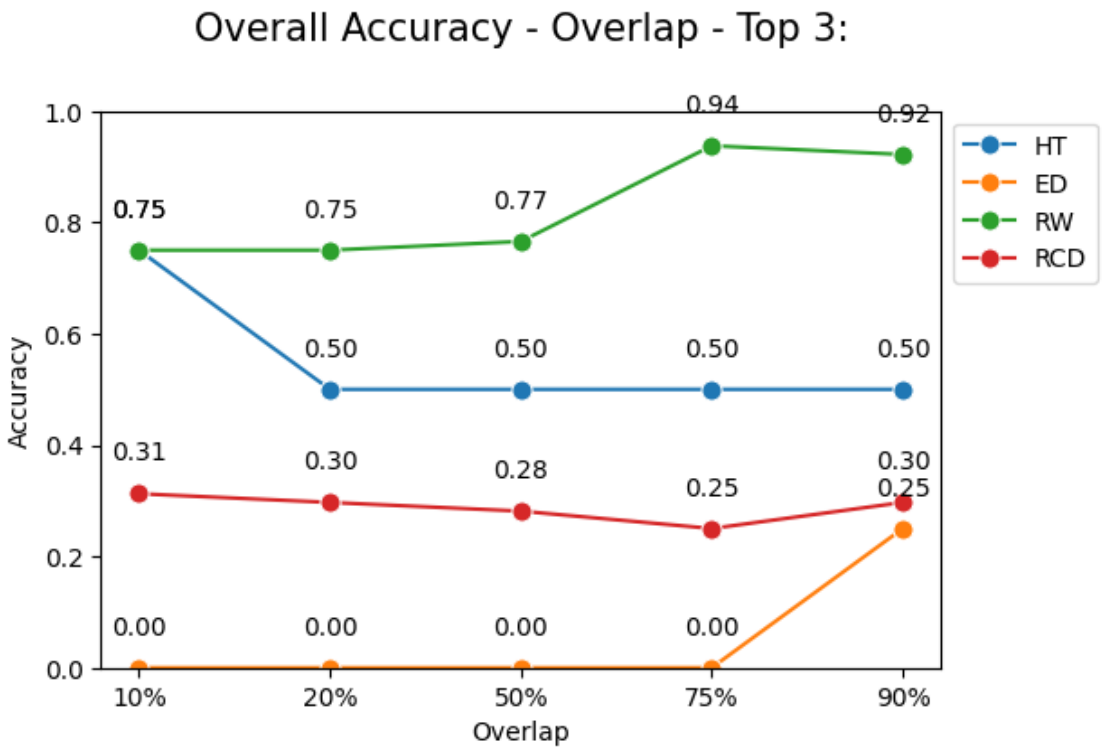


1.7.5 All together

[ ]:
```
result1 = results_top_1(result_overlap_HT,abnormal_sets)
result2 = results_top_1(result_overlap_ED,abnormal_sets)
result3 = results_top_1(result_overlap_RW,abnormal_sets)
result4 = results_top_1(result_overlap_RCD,abnormal_sets)

results_dfs = [result1,result2,result3,result4]
plot_avg_var_total_combined(results_dfs,['HT','ED','RW','RCD']␣
 ↪,directory_figures_path,'1top_overlap_total','Overlap','Overall Accuracy -␣
 ↪Overlap - Top 1:')
```



[ ]:
```
result1 = results_top_3(result_overlap_HT,abnormal_sets)
result2 = results_top_3(result_overlap_ED,abnormal_sets)
result3 = results_top_3(result_overlap_RW,abnormal_sets)
result4 = results_top_3(result_overlap_RCD,abnormal_sets)

results_dfs = [result1,result2,result3,result4]
plot_avg_var_total_combined(results_dfs,['HT','ED','RW','RCD']␣
 ↪,directory_figures_path,'3top_overlap_total','Overlap','Overall Accuracy -␣
 ↪Overlap - Top 3:')
```



1.8 Variation 2 - Normal Size

The ED-algorithm requires the same length for the normal and abnormal data set.

1.8.1 HT - Algorithm

[ ]:
```
result_HT_normal_size_1, runtime_HT_normal_size_1 =␣
↪run_HT_normal_size(folder_path,files,startrow=950,normal_size_p=2.
↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_normal_size_2, runtime_HT_normal_size_2 =␣
↪run_HT_normal_size(folder_path,files,startrow=950,normal_size_p=1.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_normal_size_3, runtime_HT_normal_size_3 =␣
↪run_HT_normal_size(folder_path,files,startrow=950,normal_size_p=1.
↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_normal_size_4, runtime_HT_normal_size_4  =␣
↪run_HT_normal_size(folder_path,files,startrow=950,normal_size_p=0.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_normal_size_5, runtime_HT_normal_size_5=␣
↪run_HT_normal_size(folder_path,files,startrow=950,normal_size_p=0.
↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

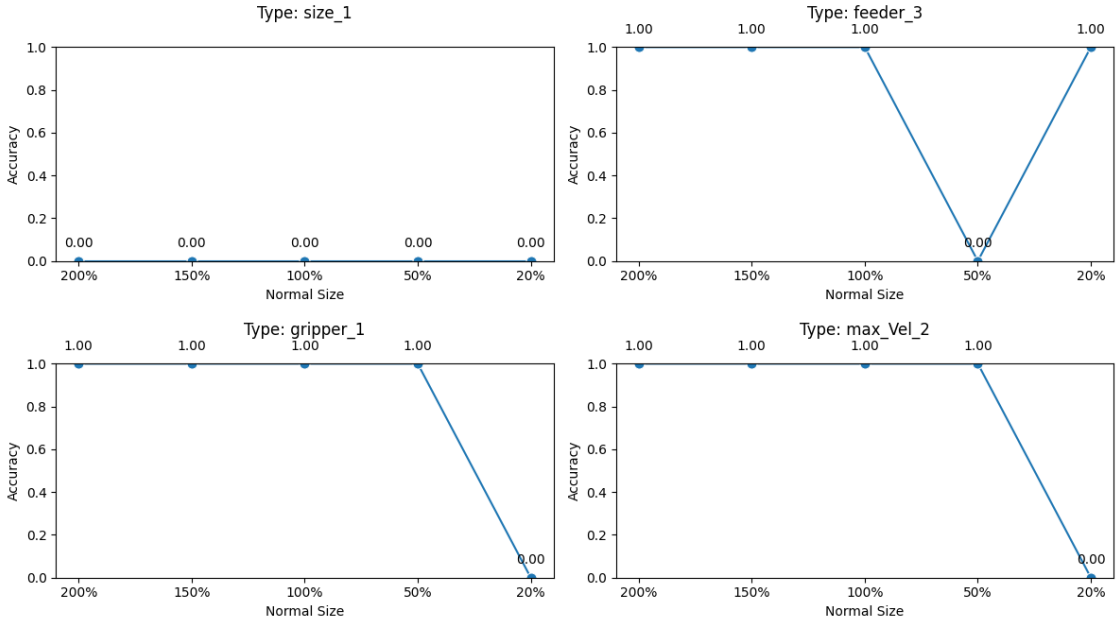
[ ]:
```
result_normal_size_HT = pd.DataFrame()
result_normal_size_HT = pd.
 ↪concat([result_HT_normal_size_1,result_HT_normal_size_2,result_HT_normal_size_3,result_HT_n
 ↪ignore_index=True)
result_normal_size_HT['Normal Size Percent'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
result_normal_size_HT.set_index('Normal Size Percent', inplace=True)
```

[ ]:
```
runtime_normal_size_HT = pd.DataFrame()
runtime_normal_size_HT = pd.concat([runtime_HT_normal_size_1.
 ↪T,runtime_HT_normal_size_2.T,runtime_HT_normal_size_3.
 ↪T,runtime_HT_normal_size_4.T,runtime_HT_normal_size_5.T], ignore_index=True)
runtime_normal_size_HT['Normal Size Percent'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
runtime_normal_size_HT.set_index('Normal Size Percent', inplace=True)
```

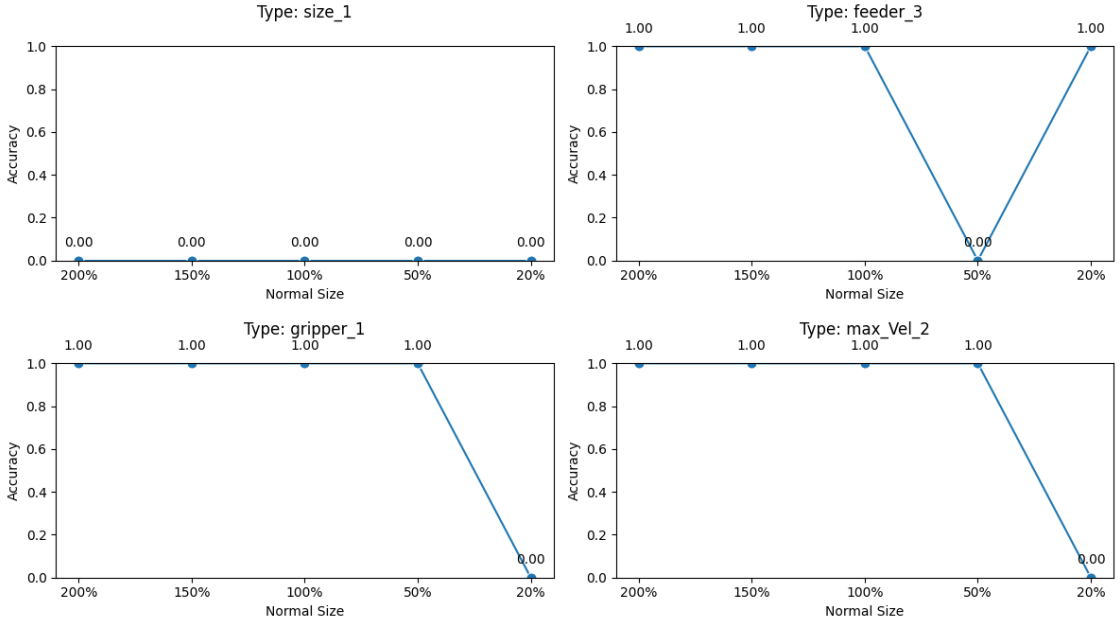
[ ]:
```
result_data_3top = results_top_3(result_normal_size_HT,abnormal_sets)
result_data_1top = results_top_1(result_normal_size_HT,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_2_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_2_HT.csv'))
```

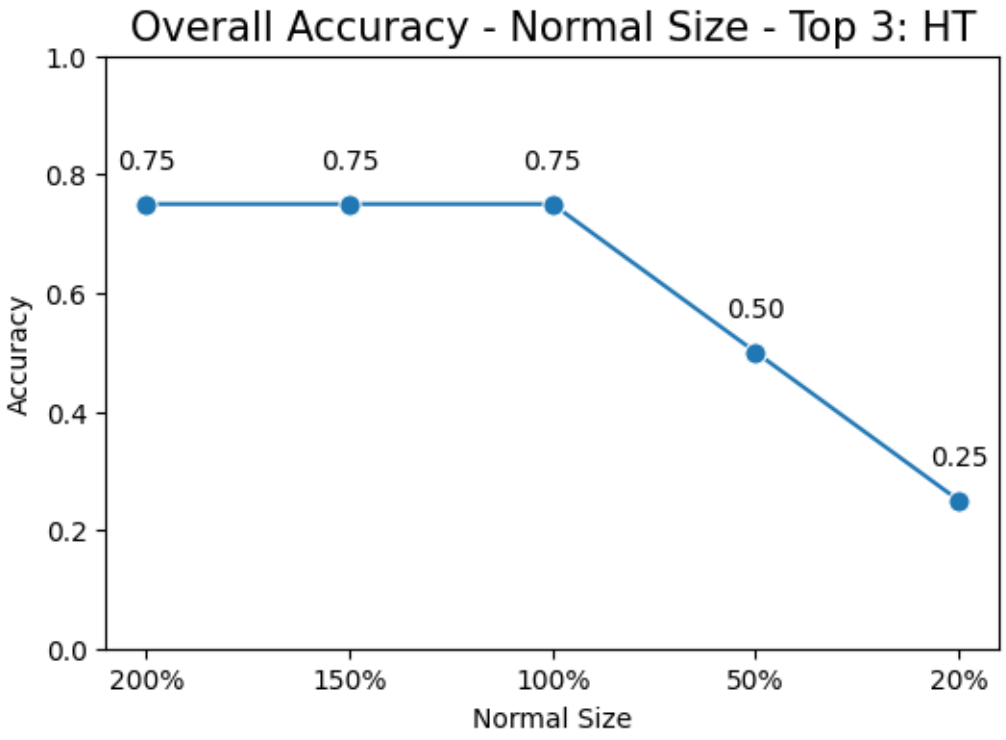
[ ]:
```
algo='HT'
var='Normal Size'
var_save='normal_size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

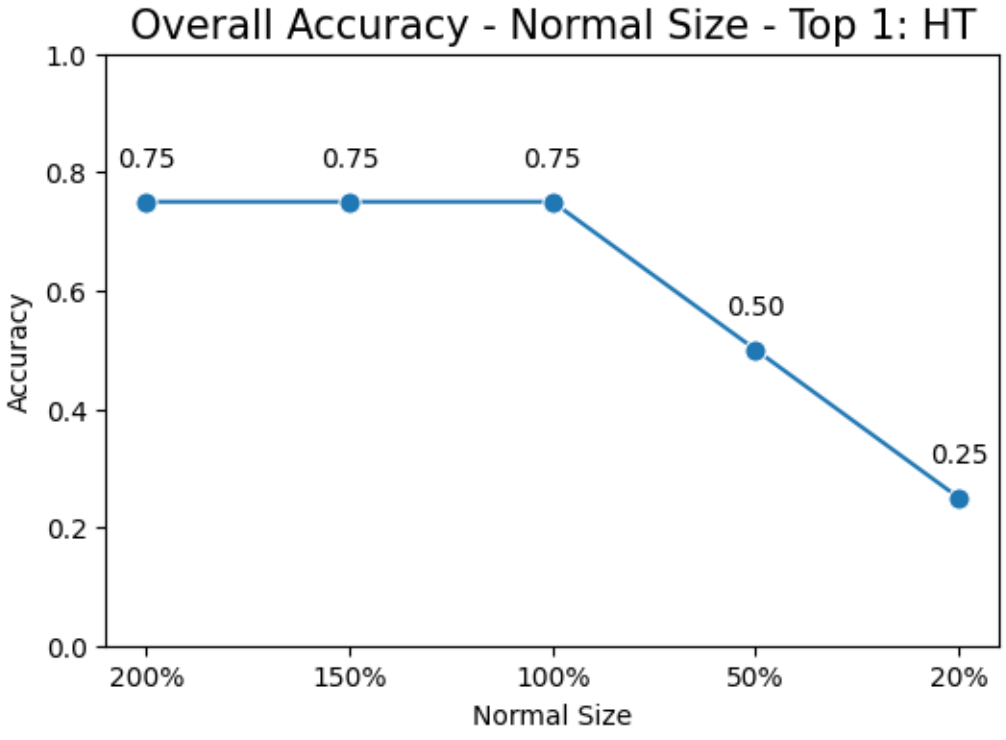
Accuracy - Normal Size - Top 3: HT



Accuracy - Normal Size - Top 1: HT




Overall Accuracy - Normal Size - Top 3: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.50
0.25
200%
150%
100%
50%
20%
Normal Size


Overall Accuracy - Normal Size - Top 1: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.50
0.25
200%
150%
100%
50%
20%
Normal Size

1.8.2 RW - Algorithm

[ ]:
```
result_RW_normal_size_1, runtime_RW_normal_size_1 =␣
↪run_RW_normal_size(folder_path,files,startrow=950,normal_size_p=2.
↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_normal_size_2, runtime_RW_normal_size_2 =␣
↪run_RW_normal_size(folder_path,files,startrow=950,normal_size_p=1.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_normal_size_3, runtime_RW_normal_size_3 =␣
↪run_RW_normal_size(folder_path,files,startrow=950,normal_size_p=1.
↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_normal_size_4, runtime_RW_normal_size_4 =␣
↪run_RW_normal_size(folder_path,files,startrow=950,normal_size_p=0.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_normal_size_5, runtime_RW_normal_size_5 =␣
↪run_RW_normal_size(folder_path,files,startrow=950,normal_size_p=0.
↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

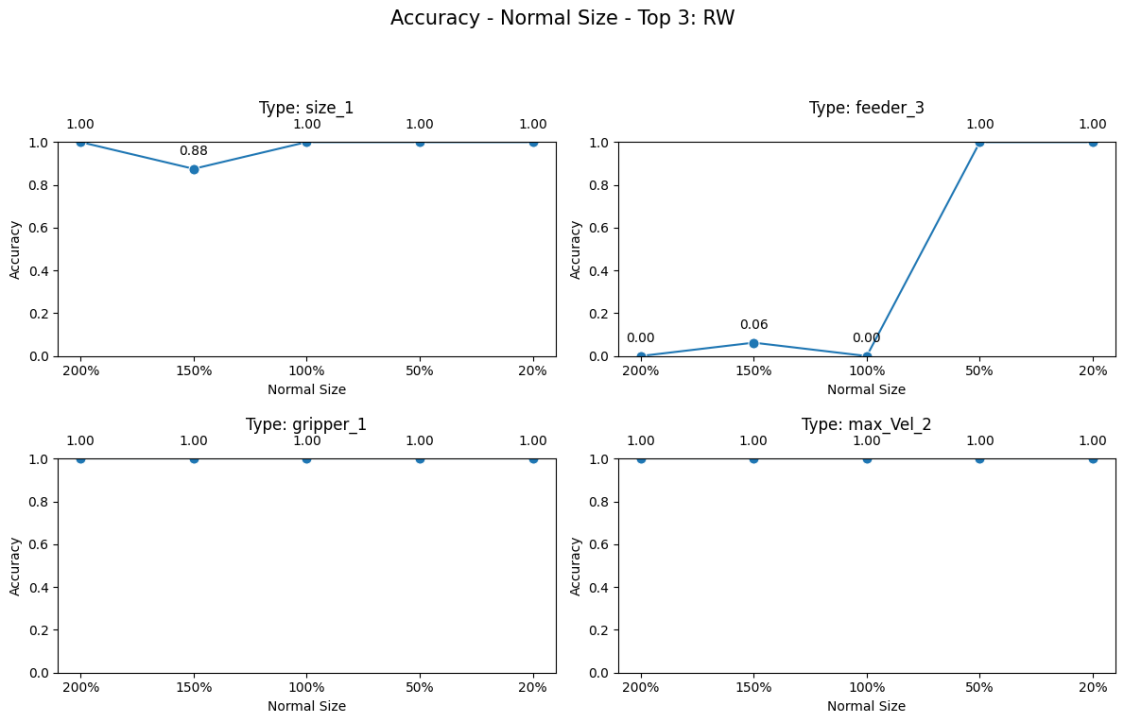
[ ]:
```
result_normal_size_RW = pd.DataFrame()
result_normal_size_RW = pd.
↪concat([result_RW_normal_size_1,result_RW_normal_size_2,result_RW_normal_size_3,result_RW_n
↪ignore_index=True)
result_normal_size_RW['Normal Size Percent'] = pd.DataFrame({'RW':
↪['200%','150%','100%','50%','20%']})
result_normal_size_RW.set_index('Normal Size Percent', inplace=True)
```

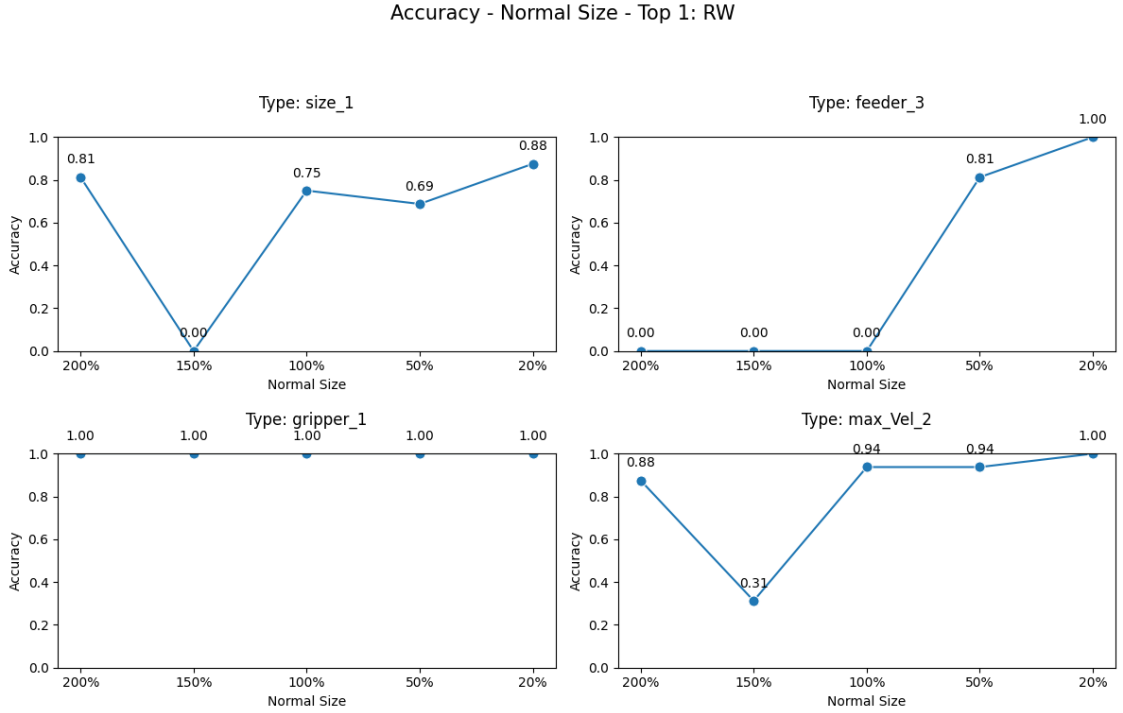
[ ]:
```
runtime_normal_size_RW = pd.DataFrame()
runtime_normal_size_RW = pd.concat([runtime_RW_normal_size_1.
↪T,runtime_RW_normal_size_2.T,runtime_RW_normal_size_3.
↪T,runtime_RW_normal_size_4.T,runtime_RW_normal_size_5.T], ignore_index=True)
runtime_normal_size_RW['Normal Size Percent'] = pd.DataFrame({'RW':
↪['200%','150%','100%','50%','20%']})
runtime_normal_size_RW.set_index('Normal Size Percent', inplace=True)
```

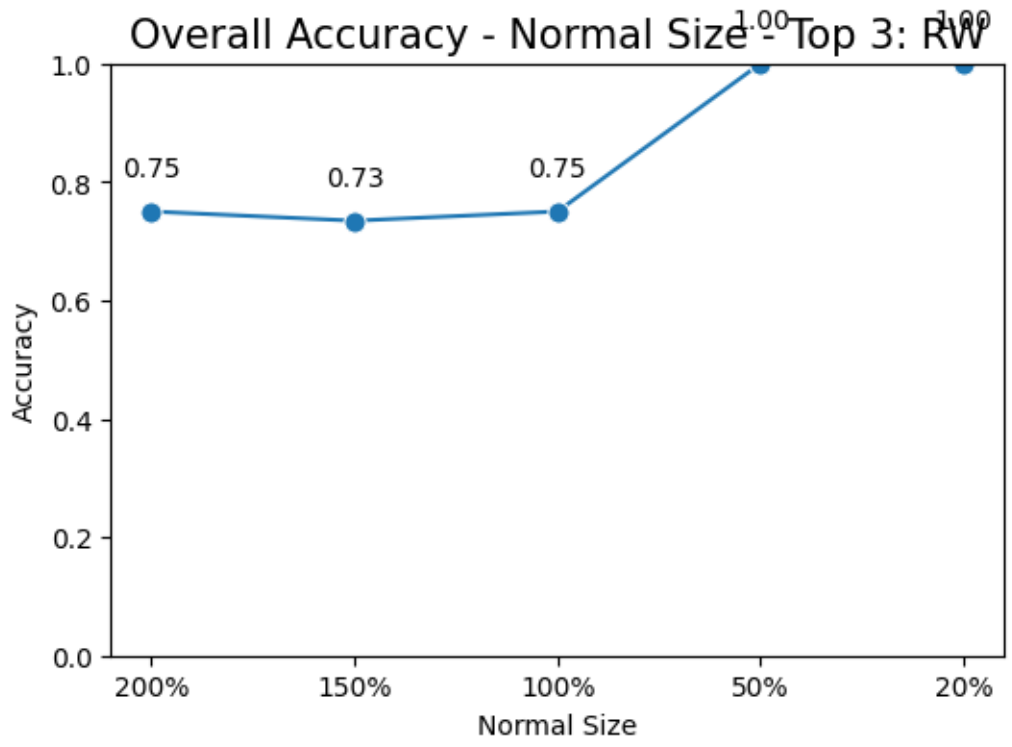
[ ]:
```
result_data_3top = results_top_3(result_normal_size_RW,abnormal_sets)
result_data_1top = results_top_1(result_normal_size_RW,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_2_RW.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_2_RW.csv'))
```

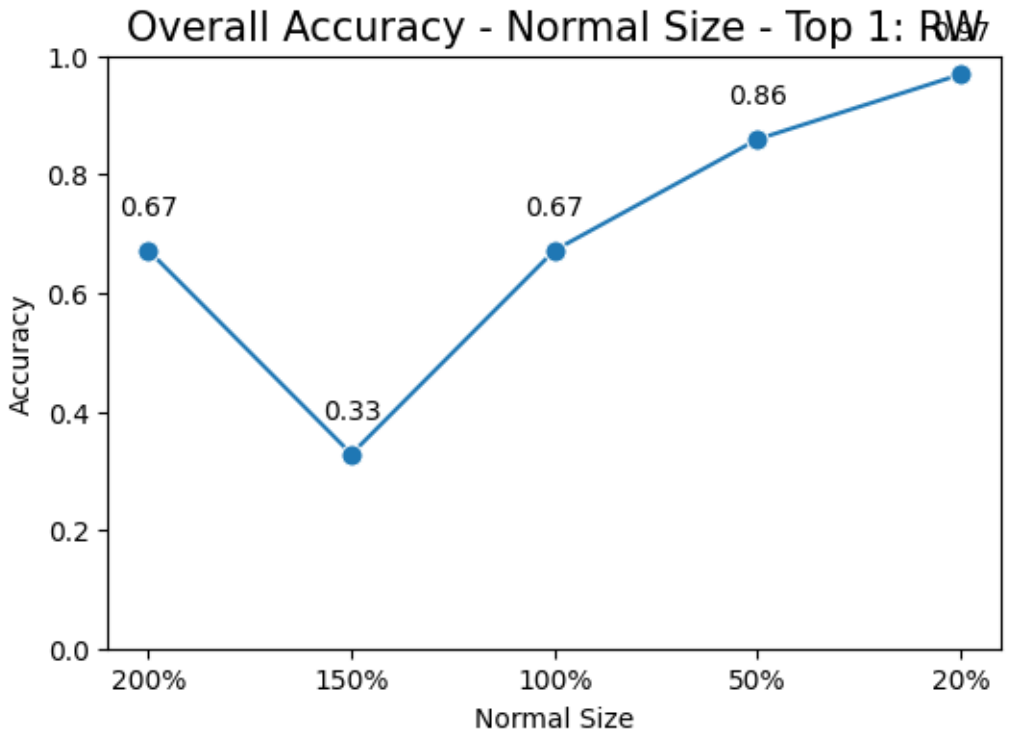
[ ]:
```
algo='RW'
var='Normal Size'
var_save='normal_size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
↪- '+var+' - Top 1:')
```

```
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```




Accuracy - Normal Size - Top 1: RW
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Normal Size
200%
150%
100%
50%
20%
0.81
0.00
0.75
0.69
0.88
0.00
0.00
0.00
0.81
1.00
1.00
1.00
1.00
1.00
1.00
0.88
0.31
0.94
0.94
1.00


Overall Accuracy - Normal Size - Top 3: RW
Accuracy
Normal Size
200%
150%
100%
50%
20%
0.75
0.73
0.75
1.00
1.00



1.8.3 RCD - Algorithm

[ ]:
```
result_RCD_normal_size_1, runtime_RCD_normal_size_1 =␣
↪run_RCD_normal_size(folder_path,files,startrow=950,normal_size_p=2.
↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_normal_size_2, runtime_RCD_normal_size_2 =␣
↪run_RCD_normal_size(folder_path,files,startrow=950,normal_size_p=1.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_normal_size_3, runtime_RCD_normal_size_3 =␣
↪run_RCD_normal_size(folder_path,files,startrow=950,normal_size_p=1.
↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_normal_size_4, runtime_RCD_normal_size_4 =␣
↪run_RCD_normal_size(folder_path,files,startrow=950,normal_size_p=0.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_normal_size_5, runtime_RCD_normal_size_5 =␣
↪run_RCD_normal_size(folder_path,files,startrow=950,normal_size_p=0.
↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

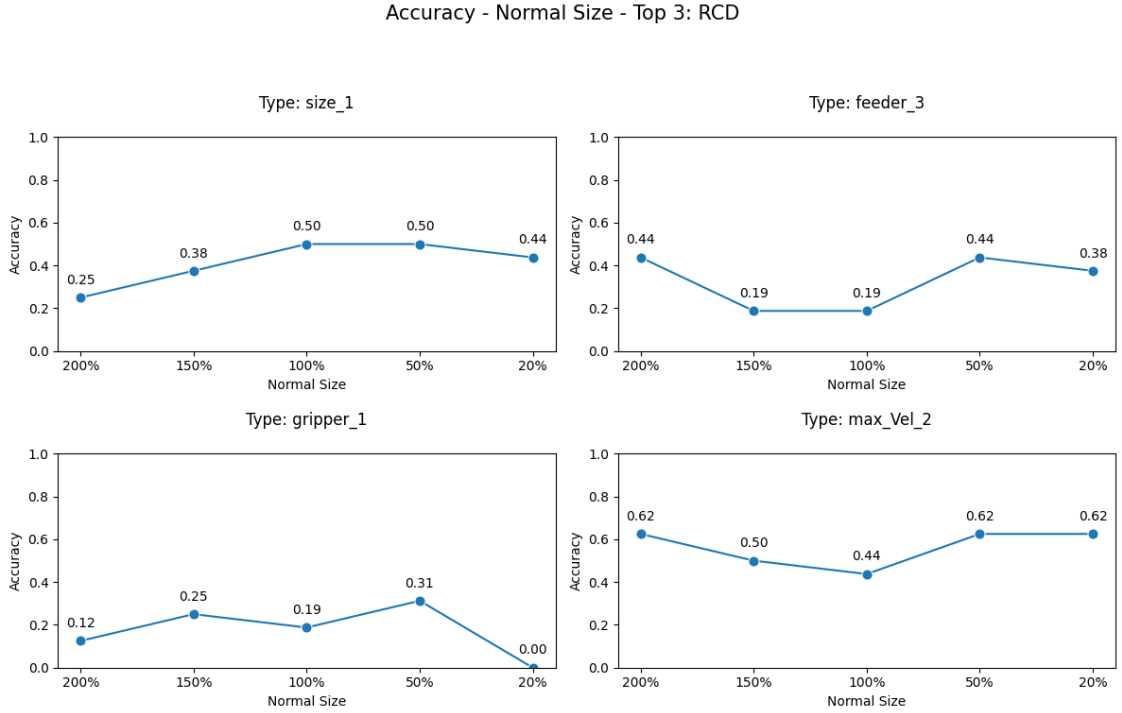
[ ]:
```
result_normal_size_RCD = pd.DataFrame()
result_normal_size_RCD = pd.
↪concat([result_RCD_normal_size_1,result_RCD_normal_size_2,result_RCD_normal_size_3,result_R
↪ignore_index=True)
```

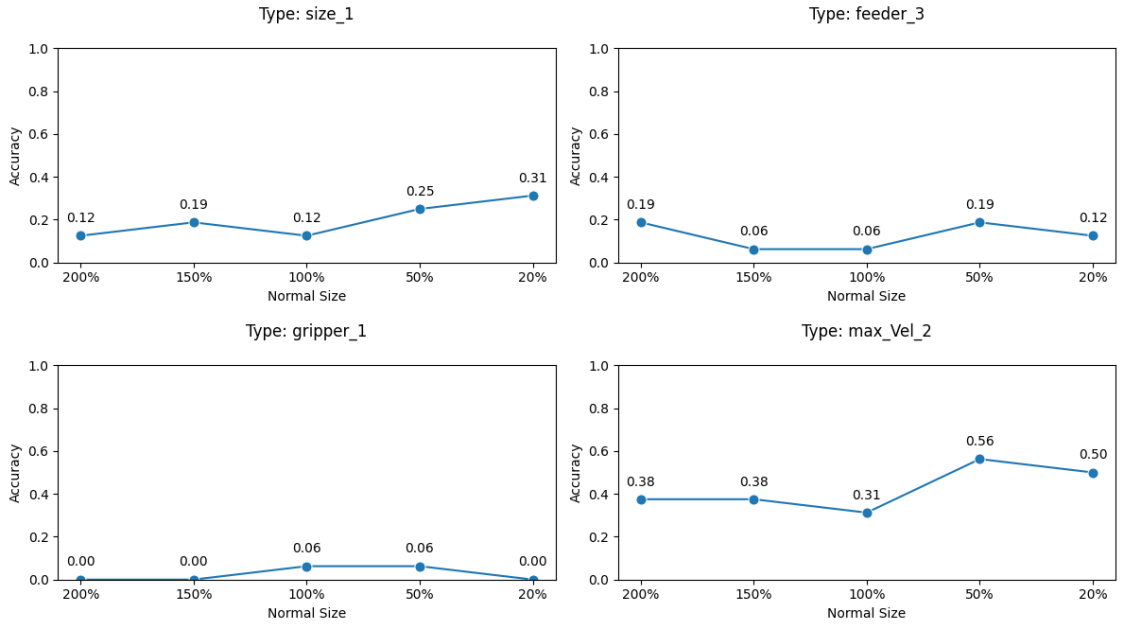
```
result_normal_size_RCD['Normal Size Percent'] = pd.DataFrame({'RCD':
 ↪['200%','150%','100%','50%','20%']})
result_normal_size_RCD.set_index('Normal Size Percent', inplace=True)
```

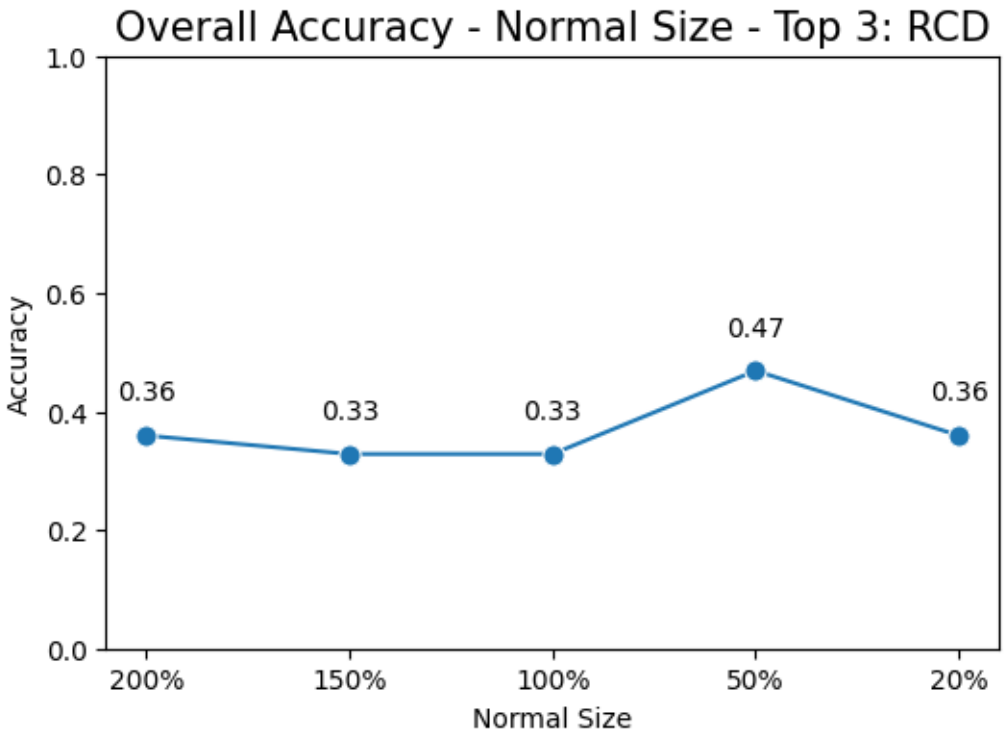
[ ]:
```
runtime_normal_size_RCD = pd.DataFrame()
runtime_normal_size_RCD = pd.concat([runtime_RCD_normal_size_1.
 ↪T,runtime_RCD_normal_size_2.T,runtime_RCD_normal_size_3.
 ↪T,runtime_RCD_normal_size_4.T,runtime_RCD_normal_size_5.T],␣
 ↪ignore_index=True)
runtime_normal_size_RCD['Normal Size Percent'] = pd.DataFrame({'RCD':
 ↪['200%','150%','100%','50%','20%']})
runtime_normal_size_RCD.set_index('Normal Size Percent', inplace=True)
```

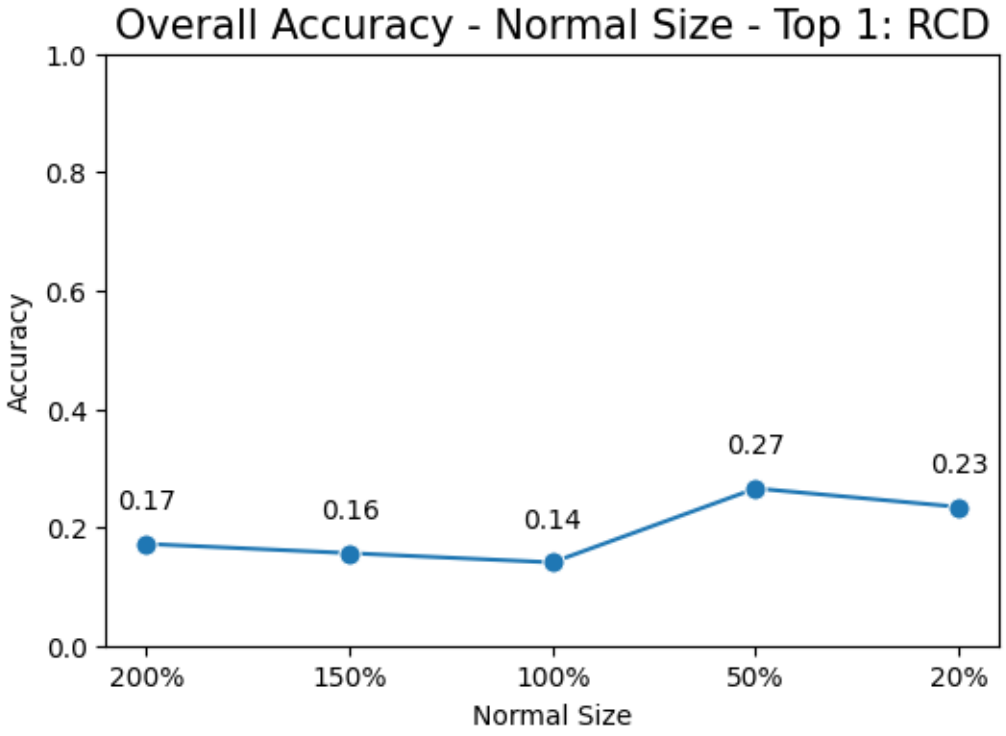
[ ]:
```
result_data_3top = results_top_3(result_normal_size_RCD,abnormal_sets)
result_data_1top = results_top_1(result_normal_size_RCD,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_2_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_2_RCD.csv'))
```

[ ]:
```
algo='RCD'
var='Normal Size'
var_save='normal_size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```


Accuracy - Normal Size - Top 3: RCD
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Normal Size
200%
150%
100%
50%
20%
0.25
0.38
0.50
0.50
0.44
0.44
0.19
0.19
0.44
0.38
0.12
0.25
0.19
0.31
0.00
0.62
0.50
0.44
0.62
0.62

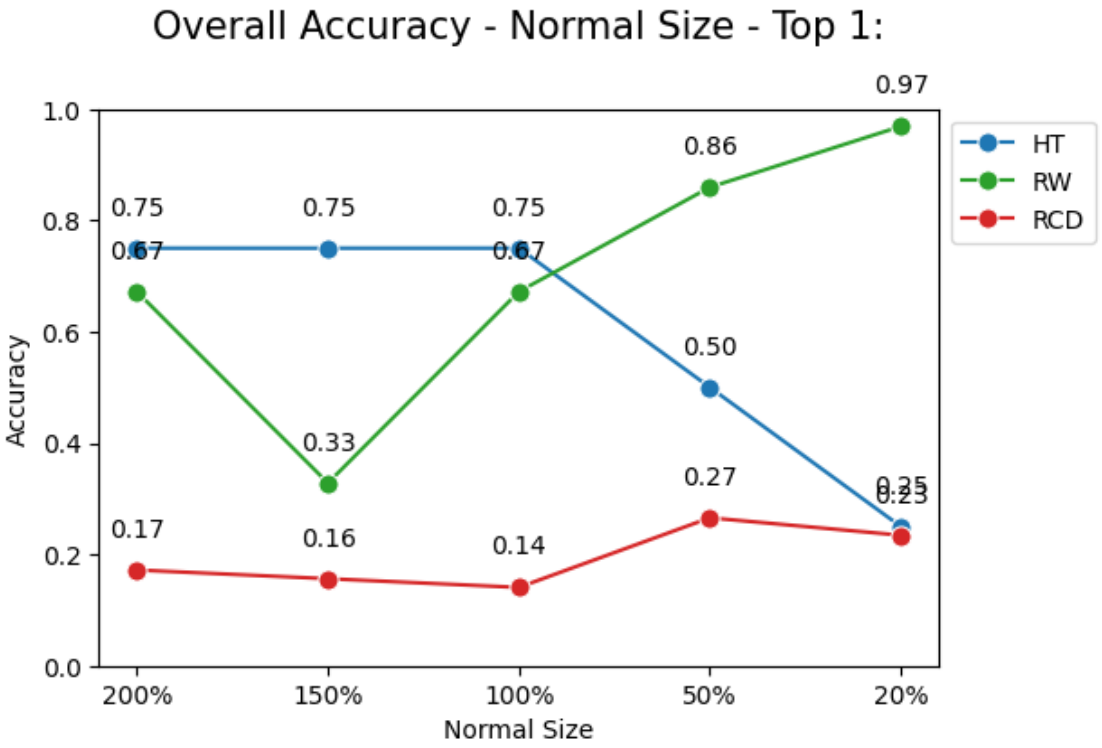

Accuracy - Normal Size - Top 1: RCD
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Normal Size
200%
150%
100%
50%
20%
0.12
0.19
0.12
0.25
0.31
0.19
0.06
0.06
0.19
0.12
0.00
0.00
0.06
0.06
0.00
0.38
0.38
0.31
0.56
0.50


Overall Accuracy - Normal Size - Top 3: RCD
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.36
0.33
0.33
0.47
0.36
200%
150%
100%
50%
20%
Normal Size

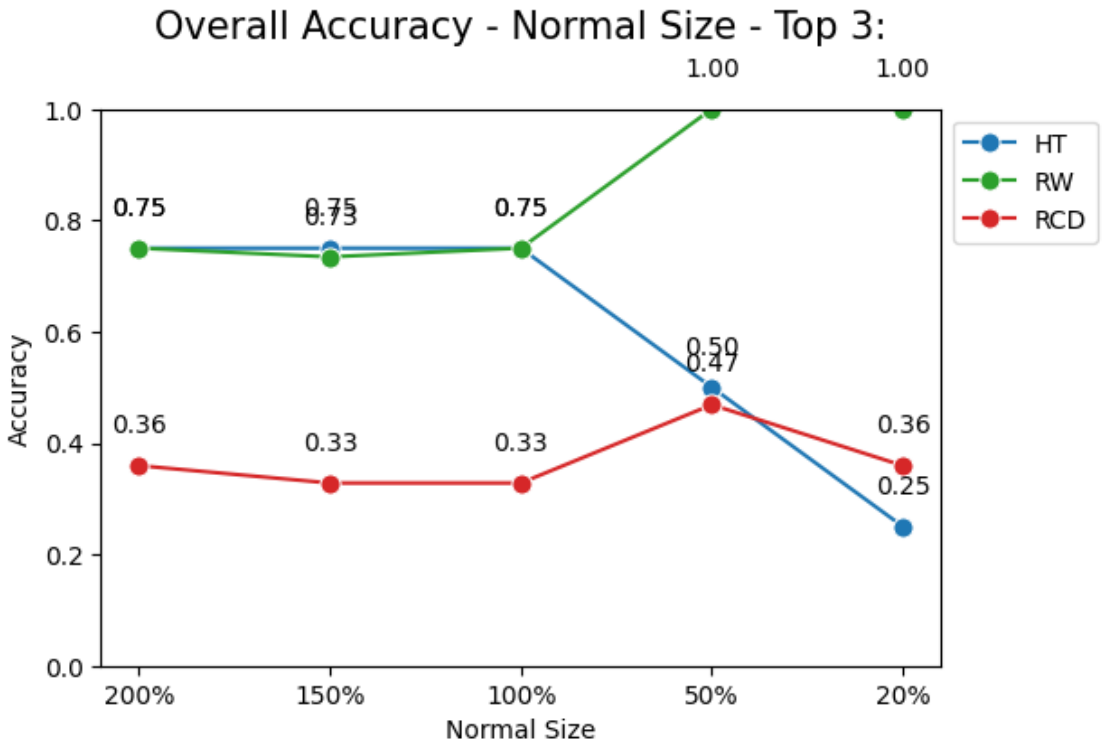

Overall Accuracy - Normal Size - Top 1: RCD
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.17
0.16
0.14
0.27
0.23
200%
150%
100%
50%
20%
Normal Size

1.8.4 All together

[ ]:
```
result1 = results_top_1(result_normal_size_HT,abnormal_sets)
result2 = results_top_1(result_normal_size_RW,abnormal_sets)
result3 = results_top_1(result_normal_size_RCD,abnormal_sets)

results_dfs = [result1,result2,result3]
plot_avg_var_total_combined(results_dfs,['HT','RW','RCD']␣
 ↪,directory_figures_path,'1top_normal_size_total','Normal Size','Overall␣
 ↪Accuracy - Normal Size - Top 1:')
```



[ ]:
```
result1 = results_top_3(result_normal_size_HT,abnormal_sets)
result2 = results_top_3(result_normal_size_RW,abnormal_sets)
result3 = results_top_3(result_normal_size_RCD,abnormal_sets)

results_dfs = [result1,result2,result3]
plot_avg_var_total_combined(results_dfs,['HT','RW','RCD']␣
 ↪,directory_figures_path,'3top_normal_size_total','Normal Size','Overall␣
 ↪Accuracy - Normal Size - Top 3:')
```



1.9 Variation 3 - Abnormal Size

The ED-algorithm requires the same length for the normal and abnormal data set.

1.9.1 HT - Algorithm

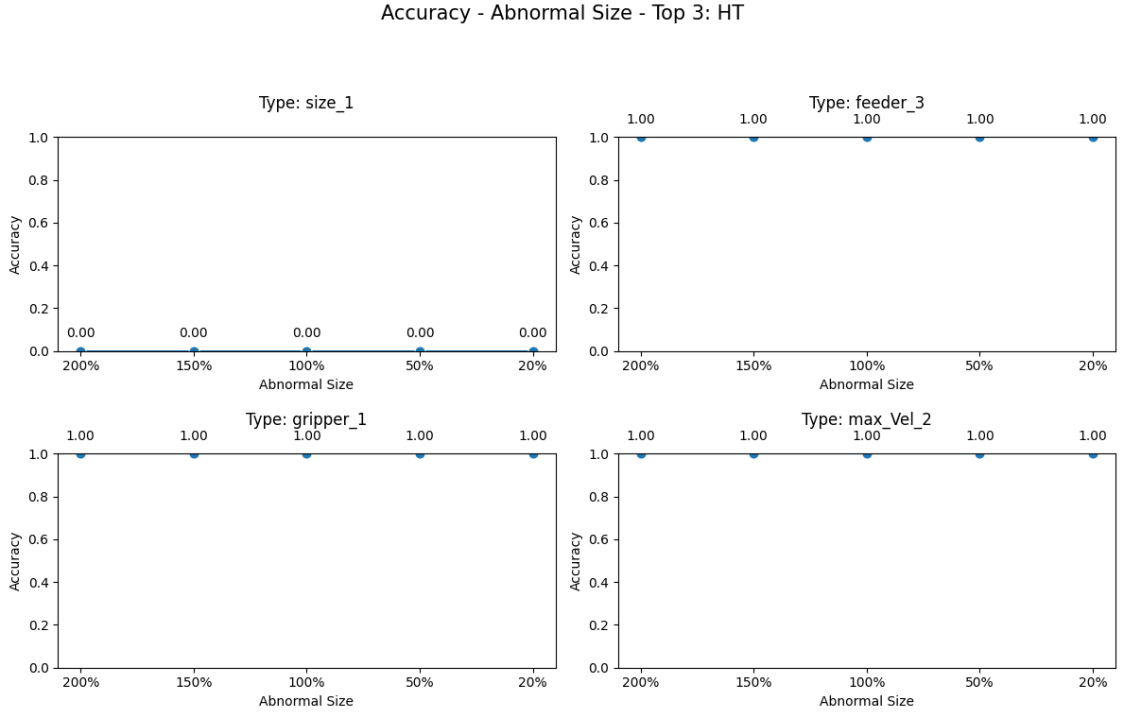
[ ]:
```
result_HT_abnormal_size_1, runtime_HT_abnormal_size_1 =␣
↪run_HT_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=2.
↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_abnormal_size_2, runtime_HT_abnormal_size_2 =␣
↪run_HT_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=1.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_abnormal_size_3, runtime_HT_abnormal_size_3 =␣
↪run_HT_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=1.
↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_abnormal_size_4, runtime_HT_abnormal_size_4 =␣
↪run_HT_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=0.
↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_abnormal_size_5, runtime_HT_abnormal_size_5 =␣
↪run_HT_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=0.
↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

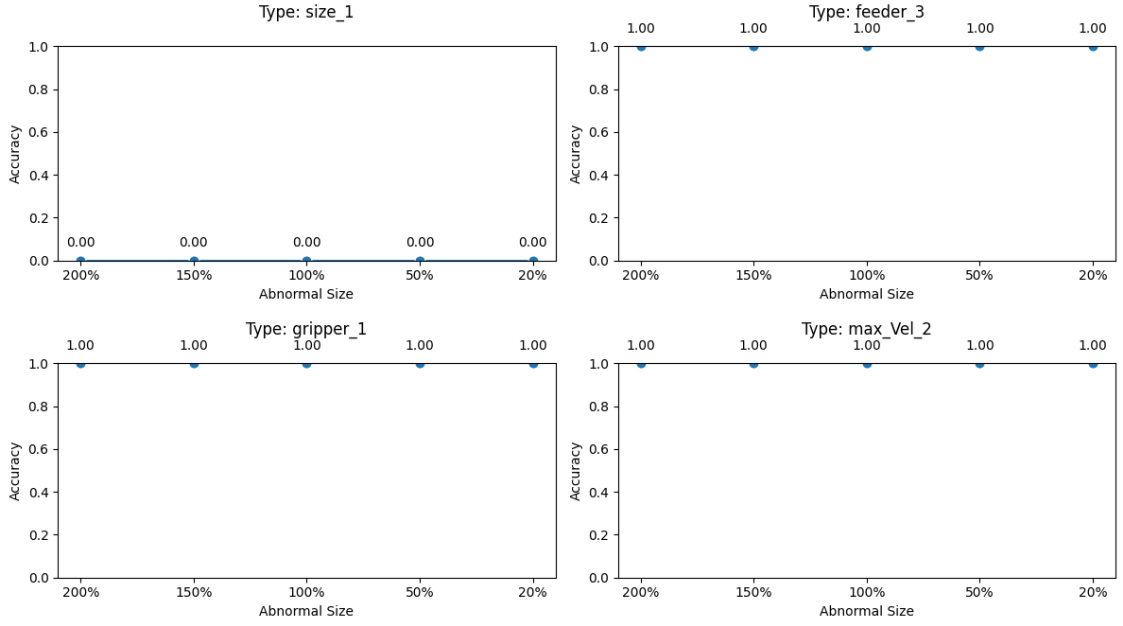
```
[ ]: result_abnormal_size_HT = pd.DataFrame()
result_abnormal_size_HT = pd.
 ↪concat([result_HT_abnormal_size_1,result_HT_abnormal_size_2,result_HT_abnormal_size_3,result
 ↪ignore_index=True)
result_abnormal_size_HT['abnormal Size Percent'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
result_abnormal_size_HT.set_index('abnormal Size Percent', inplace=True)
```

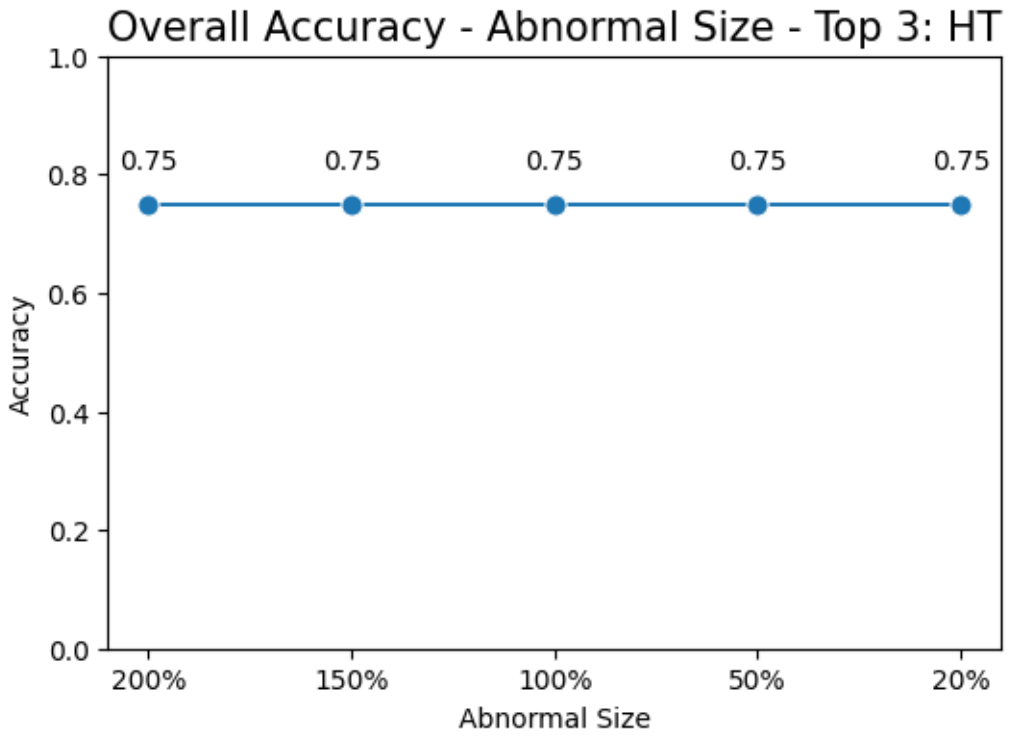
```
[ ]: runtime_abnormal_size_HT = pd.DataFrame()
runtime_abnormal_size_HT = pd.concat([runtime_HT_abnormal_size_1.
 ↪T,runtime_HT_abnormal_size_2.T,runtime_HT_abnormal_size_3.
 ↪T,runtime_HT_abnormal_size_4.T,runtime_HT_abnormal_size_5.T],␣
 ↪ignore_index=True)
runtime_abnormal_size_HT['abnormal Size Percent'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
runtime_abnormal_size_HT.set_index('abnormal Size Percent', inplace=True)
```

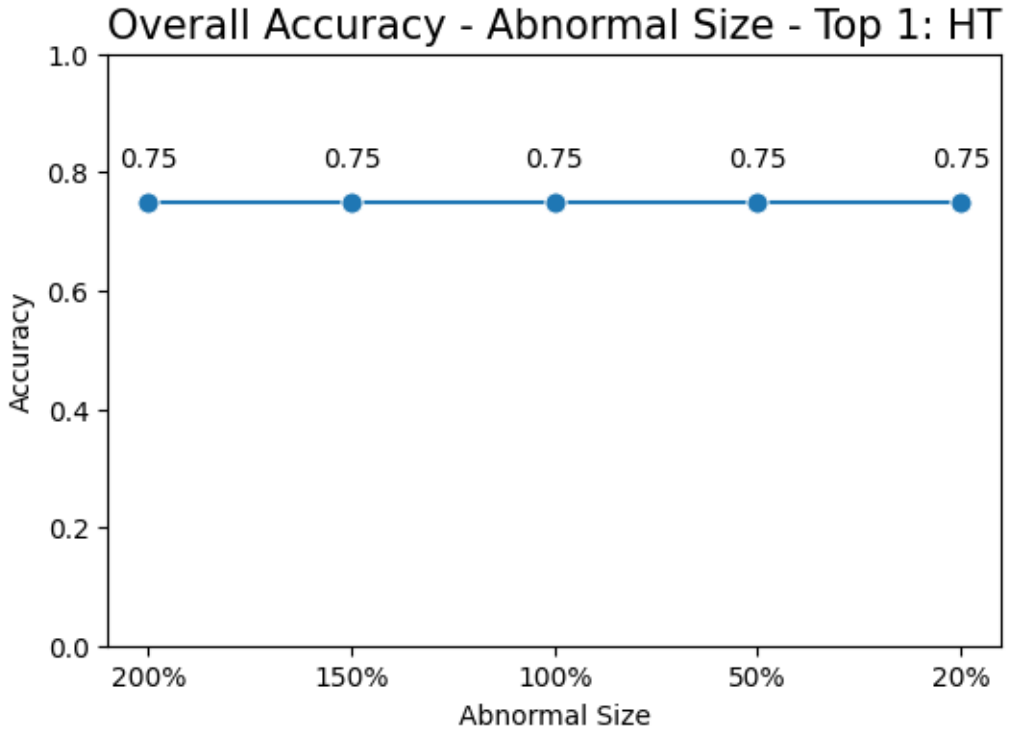
```
[ ]: result_data_3top = results_top_3(result_abnormal_size_HT,abnormal_sets)
result_data_1top = results_top_1(result_abnormal_size_HT,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_3_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_3_HT.csv'))
```

```
[ ]: algo='HT'
var='Abnormal Size'
var_save='abnormal_size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```


Accuracy - Abnormal Size - Top 3: HT
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Abnormal Size
200%
150%
100%
50%
20%
0.00
1.00


Accuracy - Abnormal Size - Top 1: HT
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Abnormal Size
200%
150%
100%
50%
20%
0.00
1.00


Overall Accuracy - Abnormal Size - Top 3: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.75
0.75
200%
150%
100%
50%
20%
Abnormal Size


Overall Accuracy - Abnormal Size - Top 1: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.75
0.75
200%
150%
100%
50%
20%
Abnormal Size

1.9.2 RW - Algorithm

[ ]:
```
result_RW_abnormal_size_1, runtime_RW_abnormal_size_1 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=2.
 ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_abnormal_size_2, runtime_RW_abnormal_size_2=␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_abnormal_size_3, runtime_RW_abnormal_size_3 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_abnormal_size_4, runtime_RW_abnormal_size_4 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_abnormal_size_5, runtime_RW_abnormal_size_5 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=0.
 ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

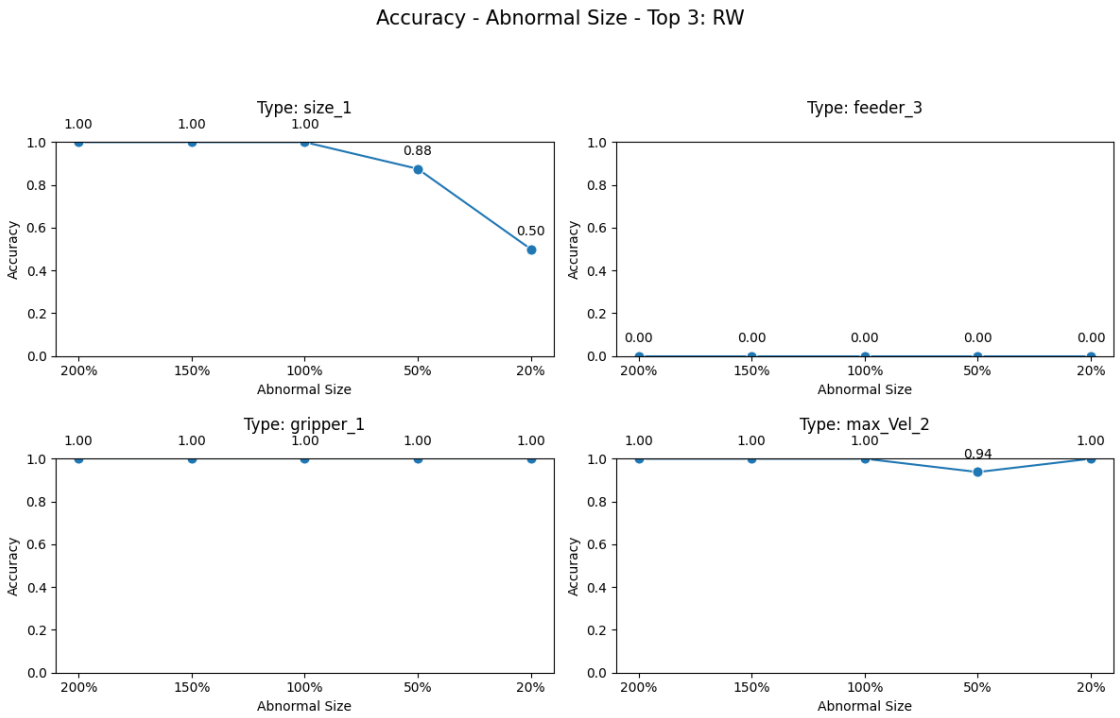
[ ]:
```
result_abnormal_size_RW = pd.DataFrame()
result_abnormal_size_RW = pd.
 ↪concat([result_RW_abnormal_size_1,result_RW_abnormal_size_2,result_RW_abnormal_size_3,result_RW_abnormal_size_4,result_RW_abnormal_size_5],
 ↪ignore_index=True)
result_abnormal_size_RW['abnormal Size Percent'] = pd.DataFrame({'RW':
 ↪['200%','150%','100%','50%','20%']})
result_abnormal_size_RW.set_index('abnormal Size Percent', inplace=True)
```

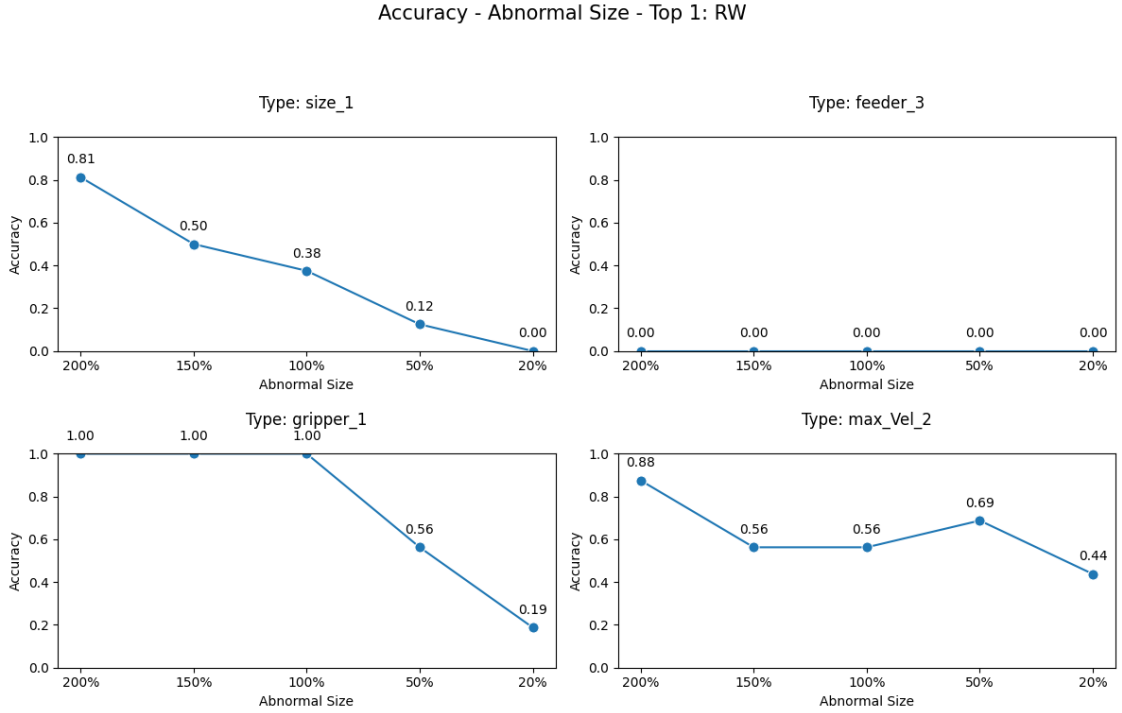
[ ]:
```
runtime_abnormal_size_RW = pd.DataFrame()
runtime_abnormal_size_RW = pd.concat([runtime_RW_abnormal_size_1.
 ↪T,runtime_RW_abnormal_size_2.T,runtime_RW_abnormal_size_3.
 ↪T,runtime_RW_abnormal_size_4.T,runtime_RW_abnormal_size_5.T],␣
 ↪ignore_index=True)
runtime_abnormal_size_RW['abnormal Size Percent'] = pd.DataFrame({'RW':
 ↪['200%','150%','100%','50%','20%']})
runtime_abnormal_size_RW.set_index('abnormal Size Percent', inplace=True)
```

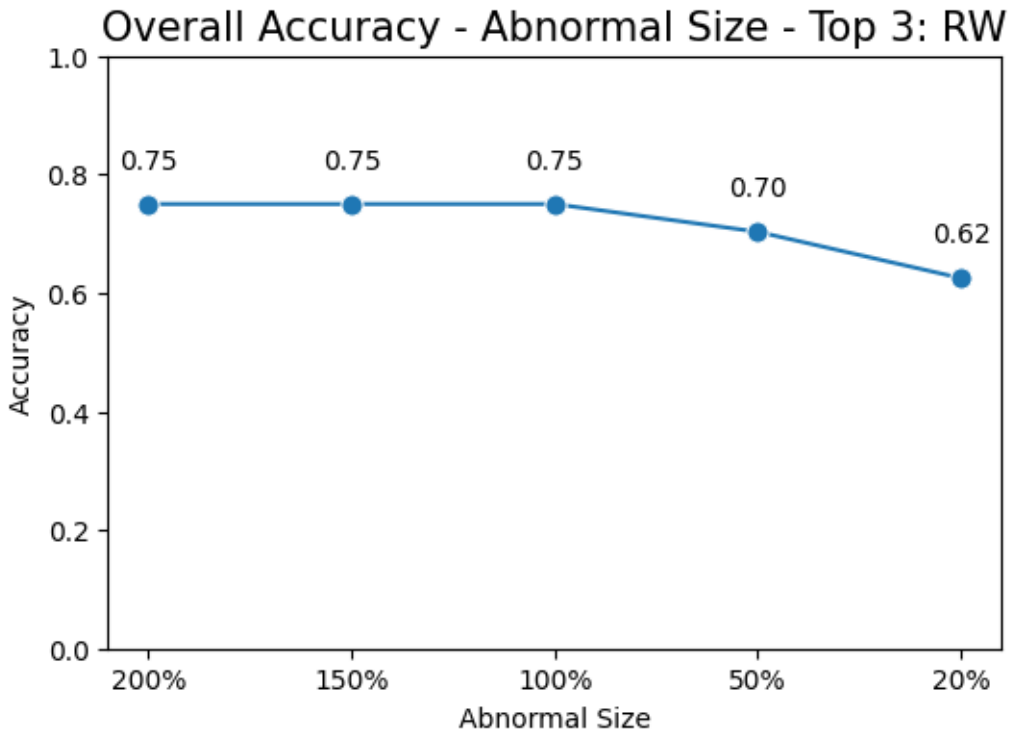
[ ]:
```
result_data_3top = results_top_3(result_abnormal_size_RW,abnormal_sets)
result_data_1top = results_top_1(result_abnormal_size_RW,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_3_RW.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_3_RW.csv'))
```

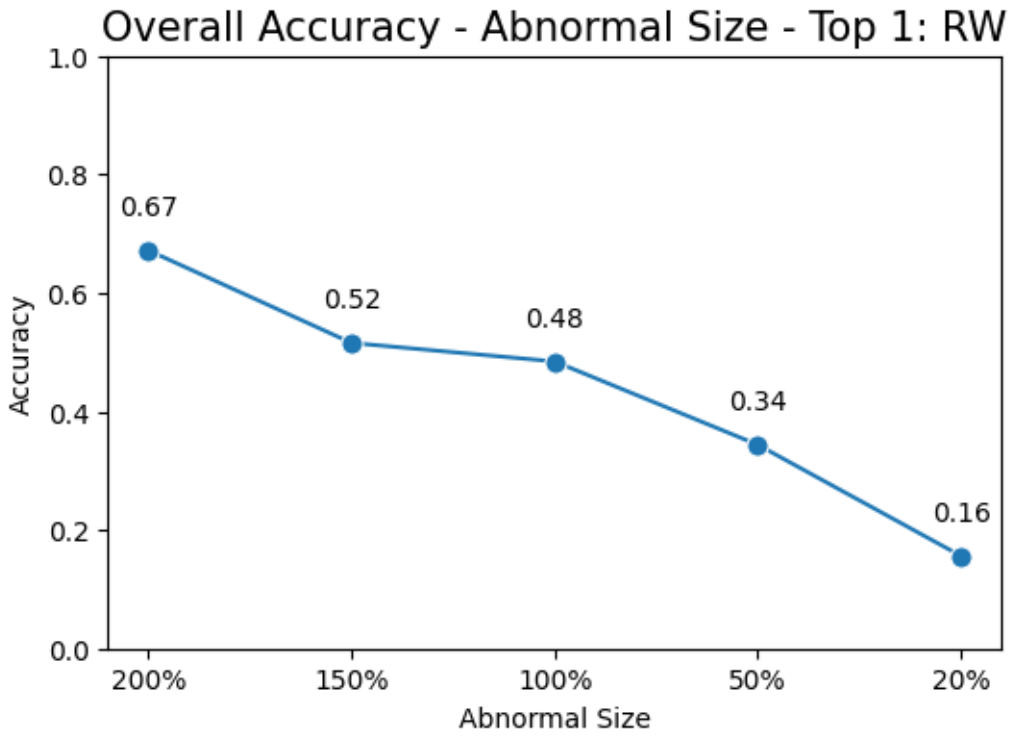
[ ]:
```
algo='RW'
var='Abnormal Size'
var_save='abnormal_size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
```

```
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```




Accuracy - Abnormal Size - Top 1: RW
Type: size_1
0.81
0.50
0.38
0.12
0.00
Type: feeder_3
0.00
0.00
0.00
0.00
0.00
Type: gripper_1
1.00
1.00
1.00
0.56
0.19
Type: max_Vel_2
0.88
0.56
0.56
0.69
0.44
Accuracy
Abnormal Size
200%
150%
100%
50%
20%


Overall Accuracy - Abnormal Size - Top 3: RW
0.75
0.75
0.75
0.70
0.62
Accuracy
Abnormal Size
200%
150%
100%
50%
20%



1.9.3 RCD - Algorithm

```
[ ]: result_RCD_abnormal_size_1, runtime_RCD_abnormal_size_1 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=2.
      ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
     result_RCD_abnormal_size_2, runtime_RCD_abnormal_size_2 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=1.
      ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
     result_RCD_abnormal_size_3, runtime_RCD_abnormal_size_3 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=1.
      ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
     result_RCD_abnormal_size_4, runtime_RCD_abnormal_size_4 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=0.
      ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
     result_RCD_abnormal_size_5, runtime_RCD_abnormal_size_5 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=950,abnormal_size_p=0.
      ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

```
[ ]: result_abnormal_size_RCD = pd.DataFrame()
     result_abnormal_size_RCD = pd.
      ↪concat([result_RCD_abnormal_size_1,result_RCD_abnormal_size_2,result_RCD_abnormal_size_3,re
      ↪ignore_index=True)
```

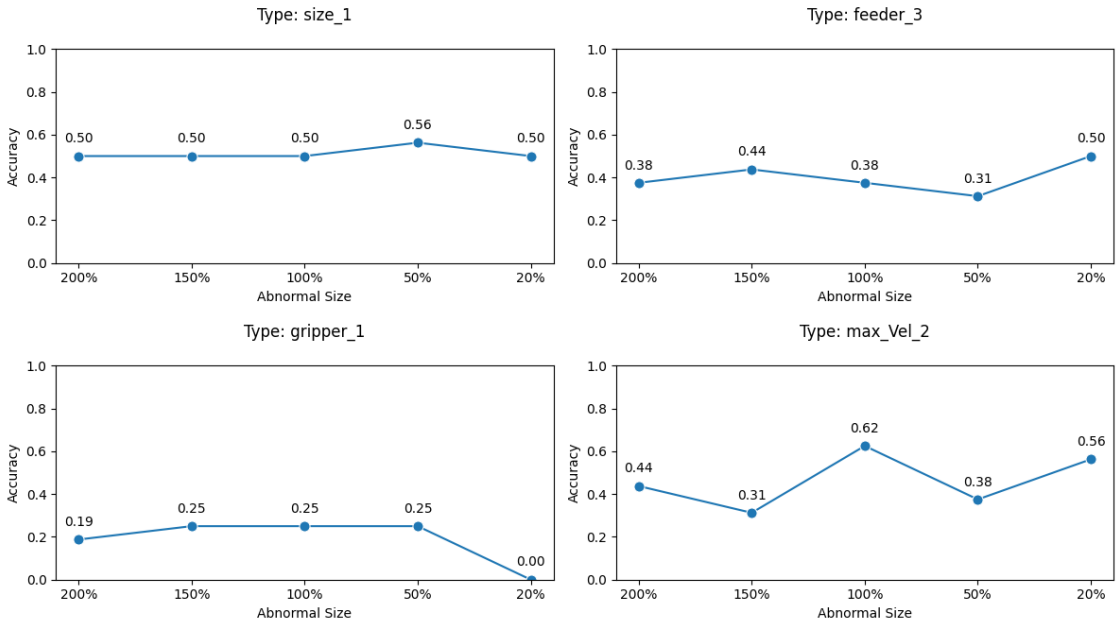
```
result_abnormal_size_RCD['abnormal Size Percent'] = pd.DataFrame({'RCD':
 ↪['200%','150%','100%','50%','20%']})
result_abnormal_size_RCD.set_index('abnormal Size Percent', inplace=True)
```

[ ]:
```
runtime_abnormal_size_RCD = pd.DataFrame()
runtime_abnormal_size_RCD = pd.concat([runtime_RCD_abnormal_size_1.
 ↪T,runtime_RCD_abnormal_size_2.T,runtime_RCD_abnormal_size_3.
 ↪T,runtime_RCD_abnormal_size_4.T,runtime_RCD_abnormal_size_5.T],␣
 ↪ignore_index=True)
runtime_abnormal_size_RCD['abnormal Size Percent'] = pd.DataFrame({'RCD':
 ↪['200%','150%','100%','50%','20%']})
runtime_abnormal_size_RCD.set_index('abnormal Size Percent', inplace=True)
```

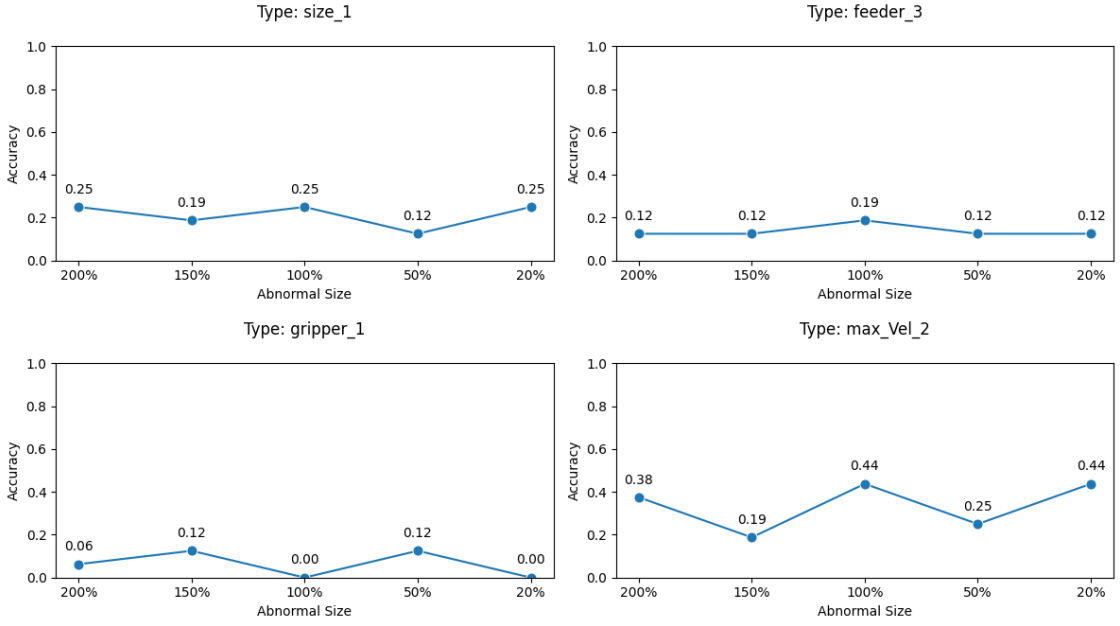
[ ]:
```
result_data_3top = results_top_3(result_abnormal_size_RCD,abnormal_sets)
result_data_1top = results_top_1(result_abnormal_size_RCD,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_3_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_3_RCD.csv'))
```

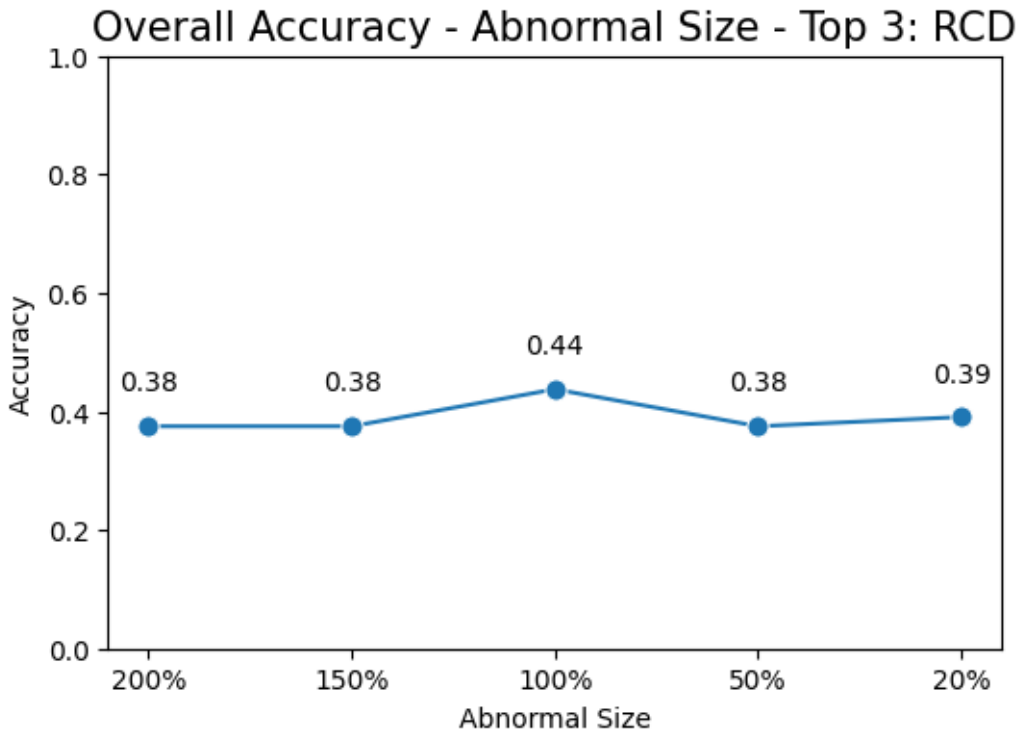
[ ]:
```
algo='RCD'
var='Abnormal Size'
var_save='abnormal_size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

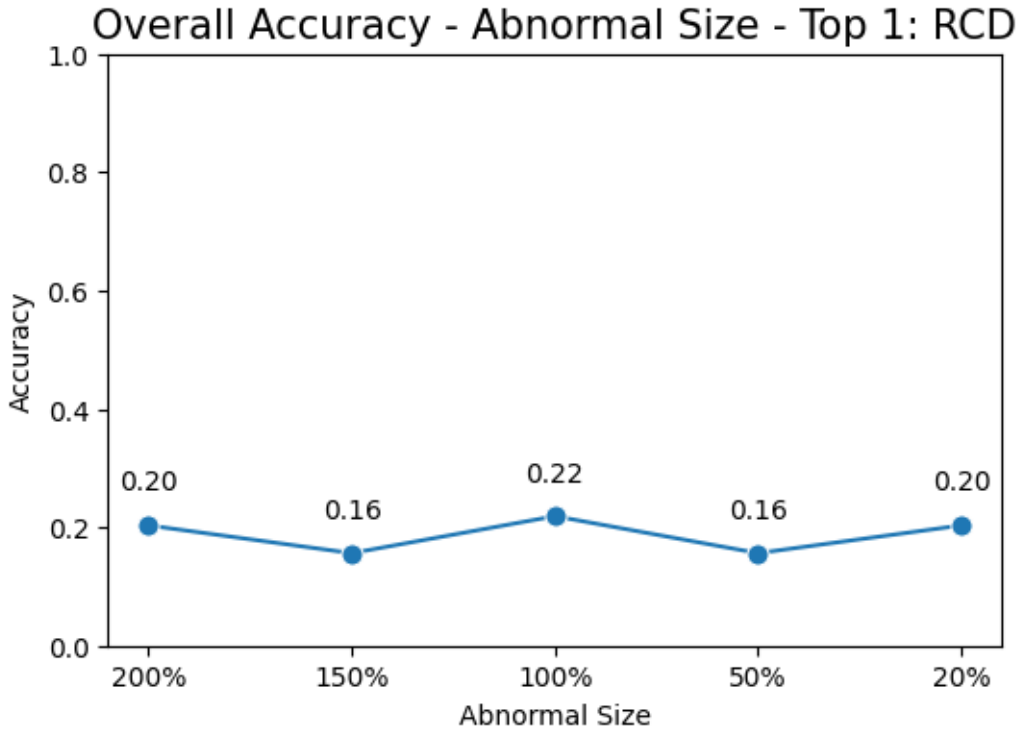
Accuracy - Abnormal Size - Top 3: RCD



Accuracy - Abnormal Size - Top 1: RCD

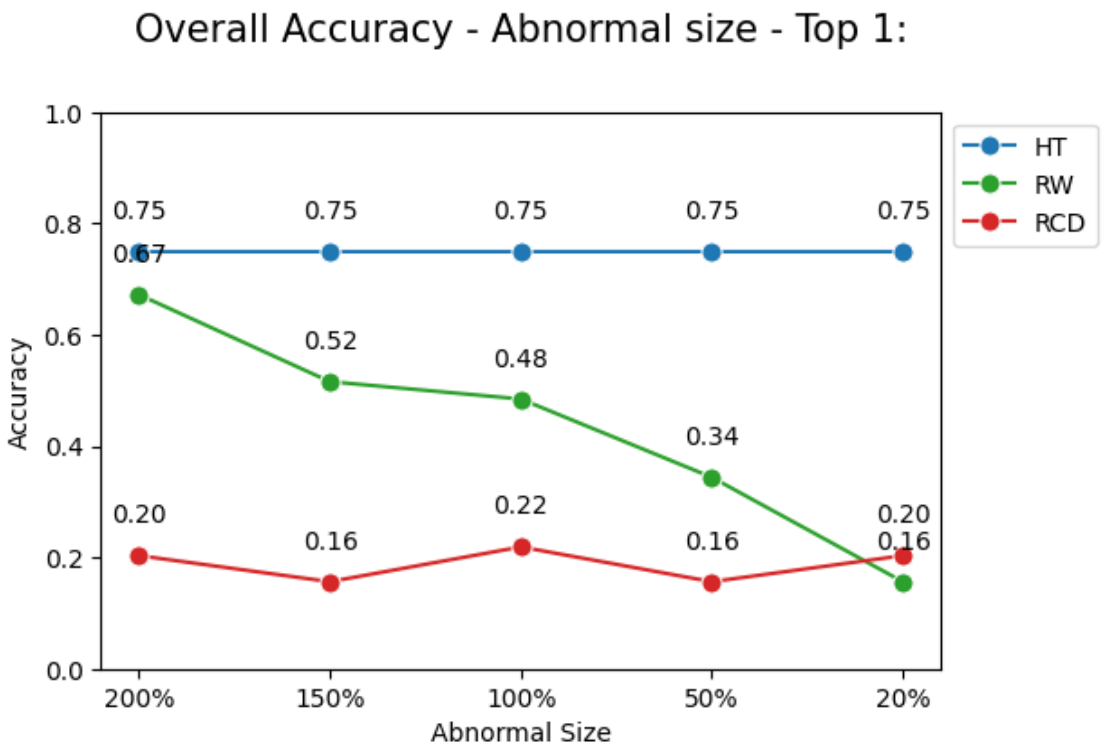



Overall Accuracy - Abnormal Size - Top 3: RCD
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.38
0.38
0.44
0.38
0.39
200%
150%
100%
50%
20%
Abnormal Size

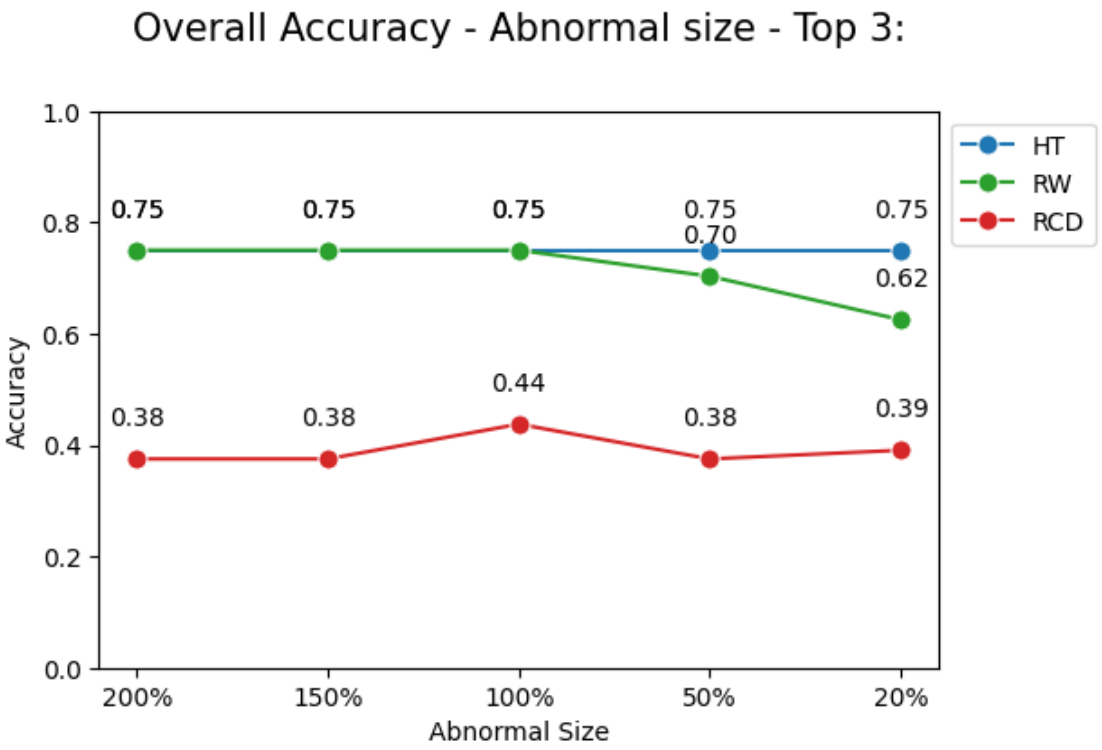

Overall Accuracy - Abnormal Size - Top 1: RCD
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.20
0.16
0.22
0.16
0.20
200%
150%
100%
50%
20%
Abnormal Size

1.9.4 All together

```
[ ]: result1 = results_top_1(result_abnormal_size_HT,abnormal_sets)
result2 = results_top_1(result_abnormal_size_RW,abnormal_sets)
result3 = results_top_1(result_abnormal_size_RCD,abnormal_sets)

results_dfs = [result1,result2,result3]
plot_avg_var_total_combined(results_dfs,['HT','RW','RCD']␣
 ↪,directory_figures_path,'1top_abnormal_size_total','Abnormal Size','Overall␣
 ↪Accuracy - Abnormal size - Top 1:')
```




```
[ ]: result1 = results_top_3(result_abnormal_size_HT,abnormal_sets)
result2 = results_top_3(result_abnormal_size_RW,abnormal_sets)
result3 = results_top_3(result_abnormal_size_RCD,abnormal_sets)

results_dfs = [result1,result2,result3]
plot_avg_var_total_combined(results_dfs,['HT','RW','RCD']␣
 ↪,directory_figures_path,'3top_abnormal_size_total','Abnormal Size','Overall␣
 ↪Accuracy - Abnormal size - Top 3:')
```



1.10 Variation 4 - Causal Graph, adjacency matrix

Only the HT- and RW-Algorithm use an adjacency matrix for training of each model.

1.10.1 HT - Algorithm

[ ]:
```
result_HT_edges_1, runtime_HT_edges_1  =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=950,edges_delete_n=20,nodes=nodes,edges_list
result_HT_edges_2, runtime_HT_edges_2 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=950,edges_delete_n=40,nodes=nodes,edges_list
result_HT_edges_3, runtime_HT_edges_3 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=950,edges_delete_n=60,nodes=nodes,edges_list
result_HT_edges_4, runtime_HT_edges_4 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=950,edges_delete_n=80,nodes=nodes,edges_list
result_HT_edges_5, runtime_HT_edges_5 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=950,edges_delete_n=100,nodes=nodes,edges_lis
```

[ ]:
```
result_edges_HT = pd.DataFrame()
result_edges_HT = pd.
 ↪concat([result_HT_edges_1,result_HT_edges_2,result_HT_edges_3,result_HT_edges_4,result_HT_e
 ↪ignore_index=True)
```

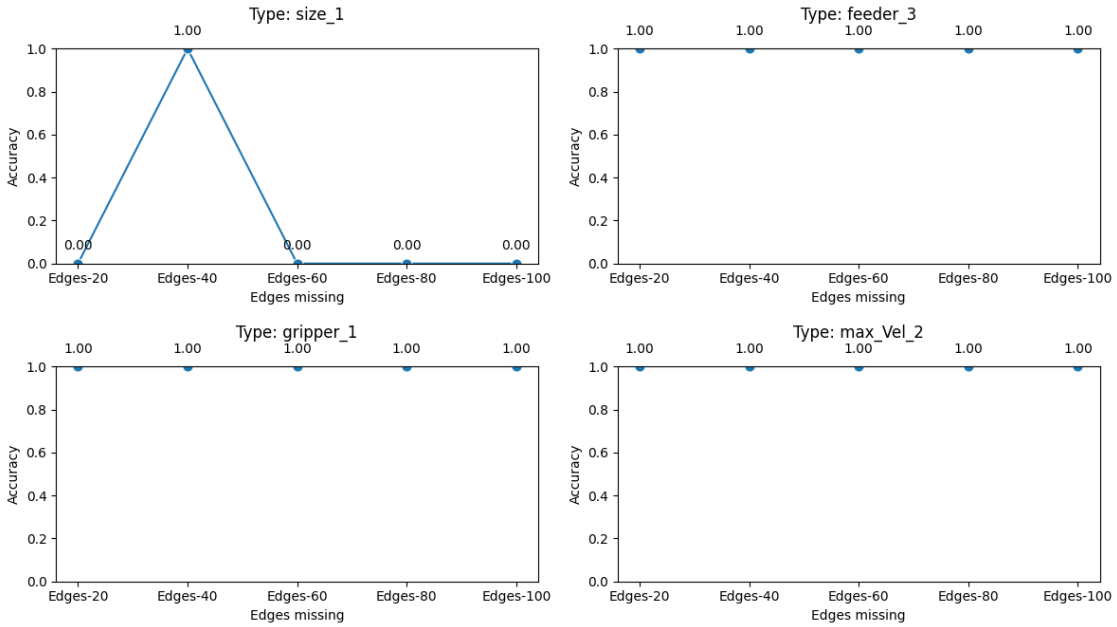
```
result_edges_HT['Edges Missing'] = pd.DataFrame({'HT':
 ↪['Edges-20','Edges-40','Edges-60','Edges-80','Edges-100']})
result_edges_HT.set_index('Edges Missing', inplace=True)
```

[ ]:
```
runtime_edges_HT = pd.DataFrame()
runtime_edges_HT = pd.concat([runtime_HT_edges_1.T,runtime_HT_edges_2.
 ↪T,runtime_HT_edges_3.T,runtime_HT_edges_4.T,runtime_HT_edges_5.T],␣
 ↪ignore_index=True)
runtime_edges_HT['Edges Missing'] = pd.DataFrame({'HT':
 ↪['Edges-20','Edges-40','Edges-60','Edges-80','Edges-100']})
runtime_edges_HT.set_index('Edges Missing', inplace=True)
```

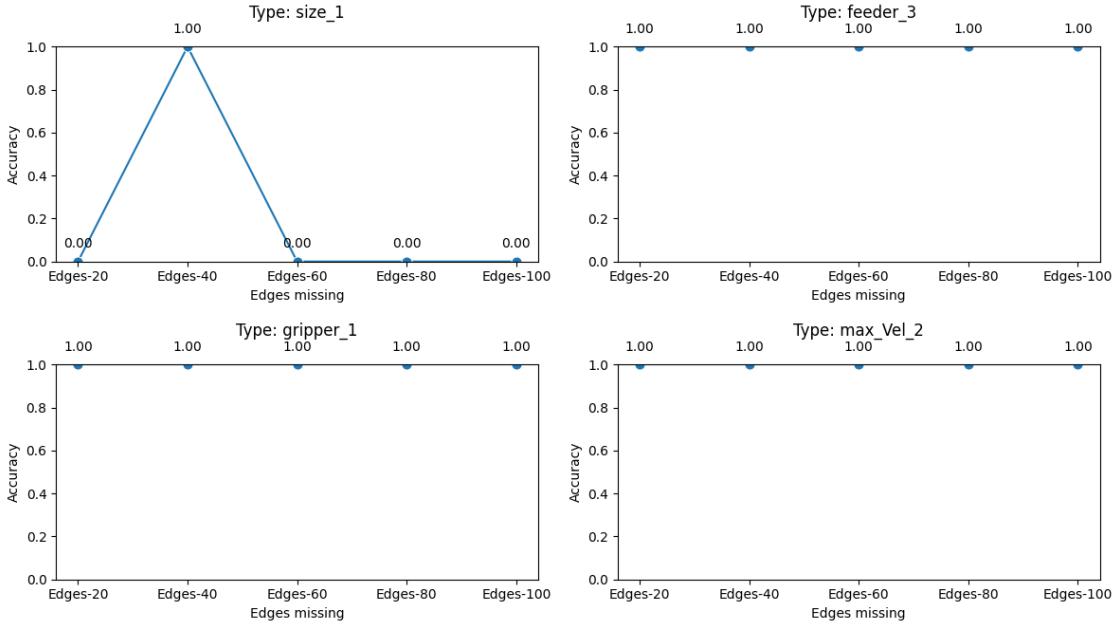
[ ]:
```
result_data_3top = results_top_3(result_edges_HT,abnormal_sets)
result_data_1top = results_top_1(result_edges_HT,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_4_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_4_HT.csv'))
```

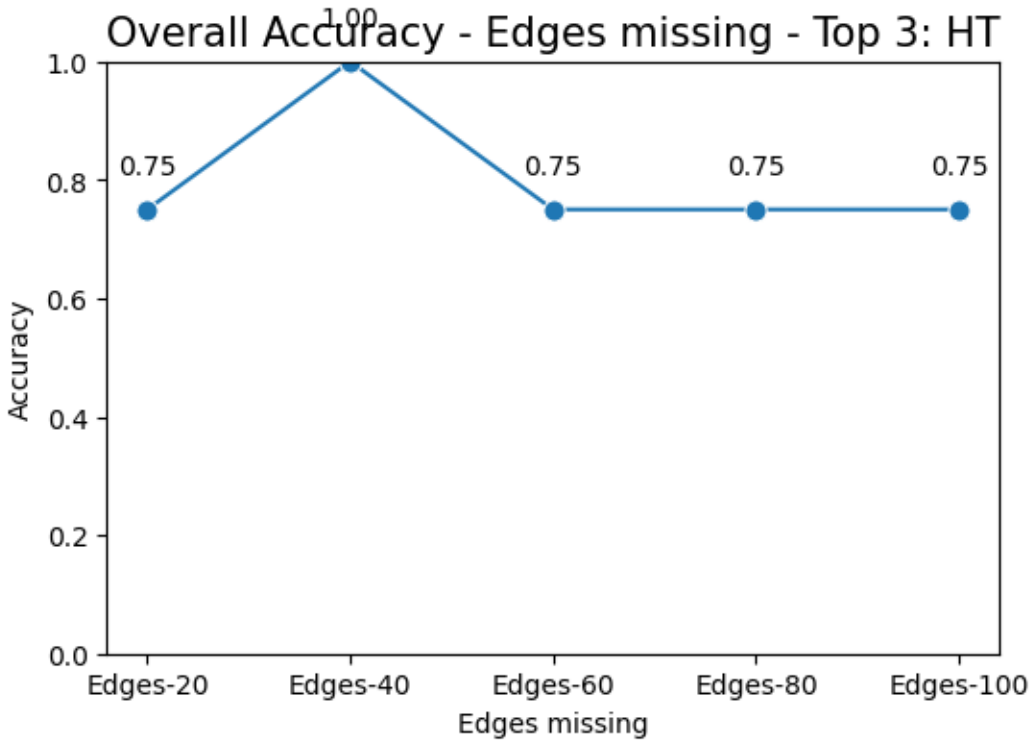
[ ]:
```
algo='HT'
var='Edges missing'
var_save='graph'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

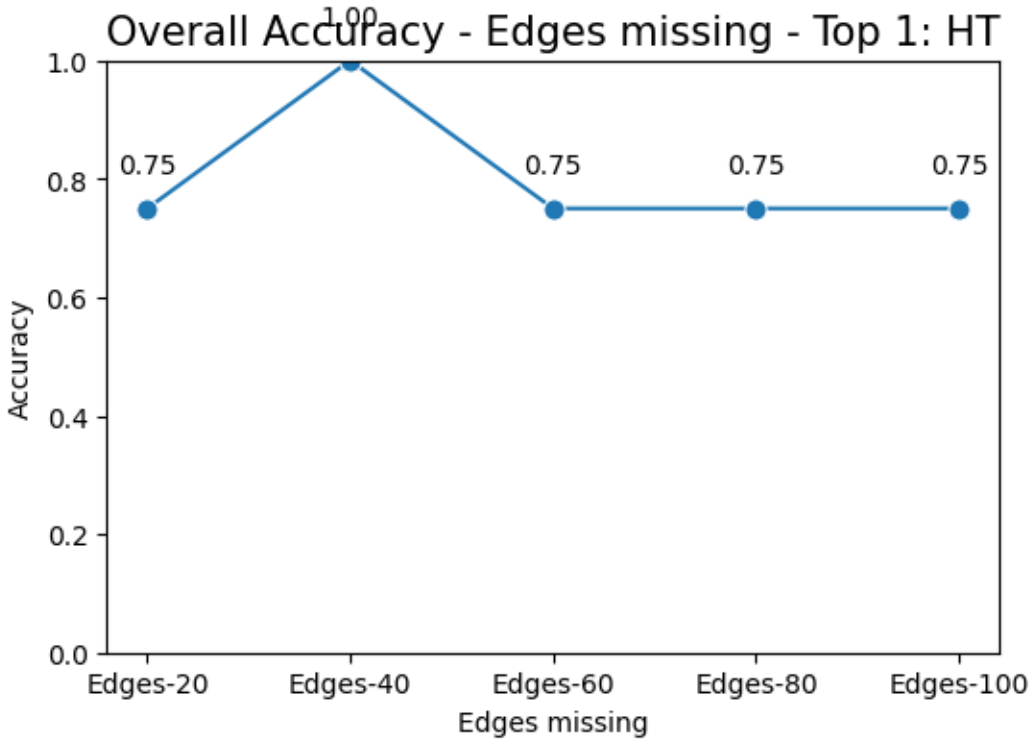
Accuracy - Edges missing - Top 3: HT



Accuracy - Edges missing - Top 1: HT




Overall Accuracy - Edges missing - Top 3: HT
1.00
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.75
Edges-20
Edges-40
Edges-60
Edges-80
Edges-100
Edges missing


Overall Accuracy - Edges missing - Top 1: HT
1.00
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.75
Edges-20
Edges-40
Edges-60
Edges-80
Edges-100
Edges missing

1.10.2 RW - Algorithm

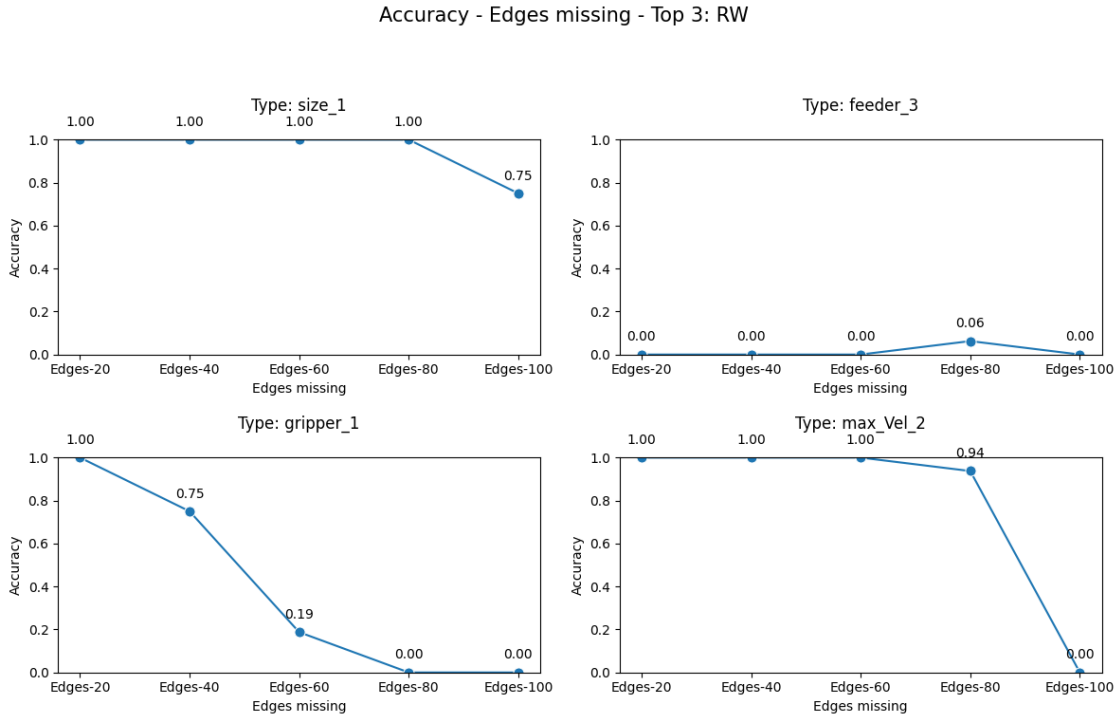
[ ]:
```
result_RW_edges_1, runtime_RW_edges_1 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=950,edges_delete_n=20,nodes=nodes,edges_list
result_RW_edges_2, runtime_RW_edges_2 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=950,edges_delete_n=40,nodes=nodes,edges_list
result_RW_edges_3, runtime_RW_edges_3 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=950,edges_delete_n=60,nodes=nodes,edges_list
result_RW_edges_4, runtime_RW_edges_4 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=950,edges_delete_n=80,nodes=nodes,edges_list
result_RW_edges_5, runtime_RW_edges_5 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=950,edges_delete_n=100,nodes=nodes,edges_lis
```

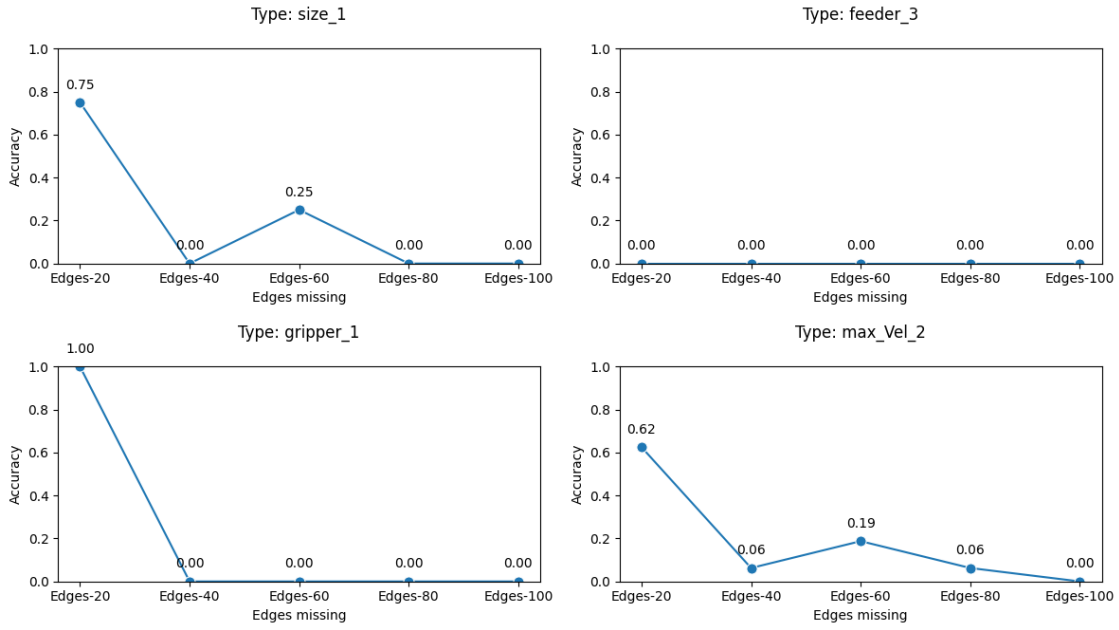
[ ]:
```
result_edges_RW = pd.DataFrame()
result_edges_RW = pd.
 ↪concat([result_RW_edges_1,result_RW_edges_2,result_RW_edges_3,result_RW_edges_4,result_RW_e
 ↪ignore_index=True)
result_edges_RW['Edges Missing'] = pd.DataFrame({'RW':
 ↪['Edges-20','Edges-40','Edges-60','Edges-80','Edges-100']})
result_edges_RW.set_index('Edges Missing', inplace=True)
```

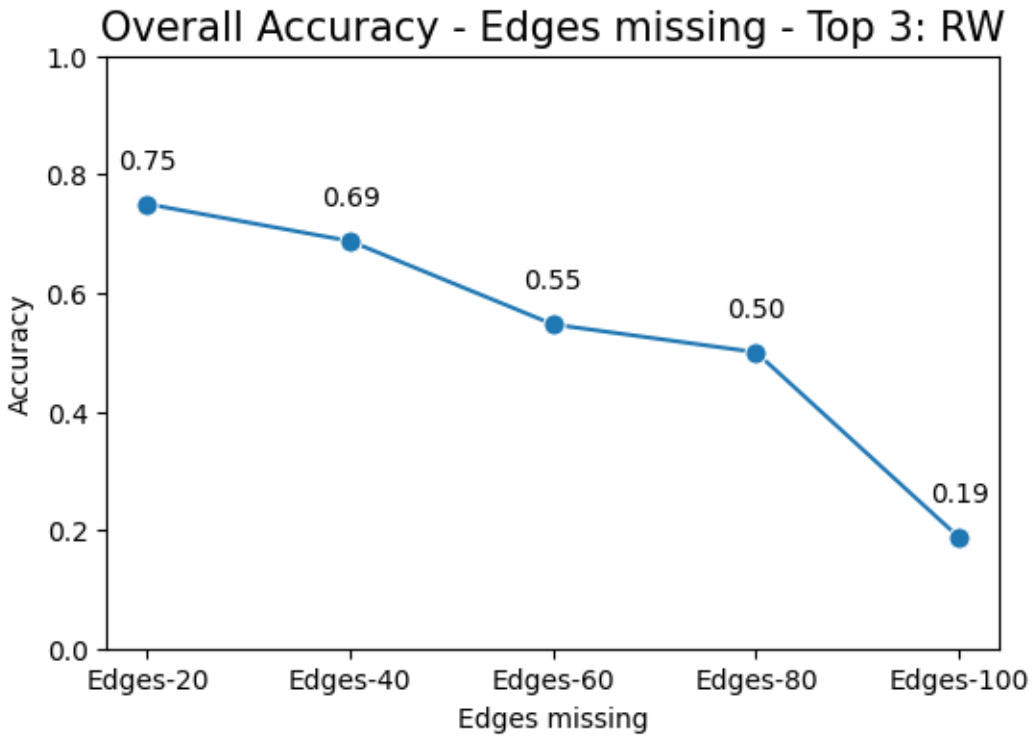
[ ]:
```
runtime_edges_RW = pd.DataFrame()
runtime_edges_RW = pd.concat([runtime_RW_edges_1.T,runtime_RW_edges_2.
 ↪T,runtime_RW_edges_3.T,runtime_RW_edges_4.T,runtime_RW_edges_5.T],␣
 ↪ignore_index=True)
runtime_edges_RW['Edges Missing'] = pd.DataFrame({'RW':
 ↪['Edges-20','Edges-40','Edges-60','Edges-80','Edges-100']})
runtime_edges_RW.set_index('Edges Missing', inplace=True)
```

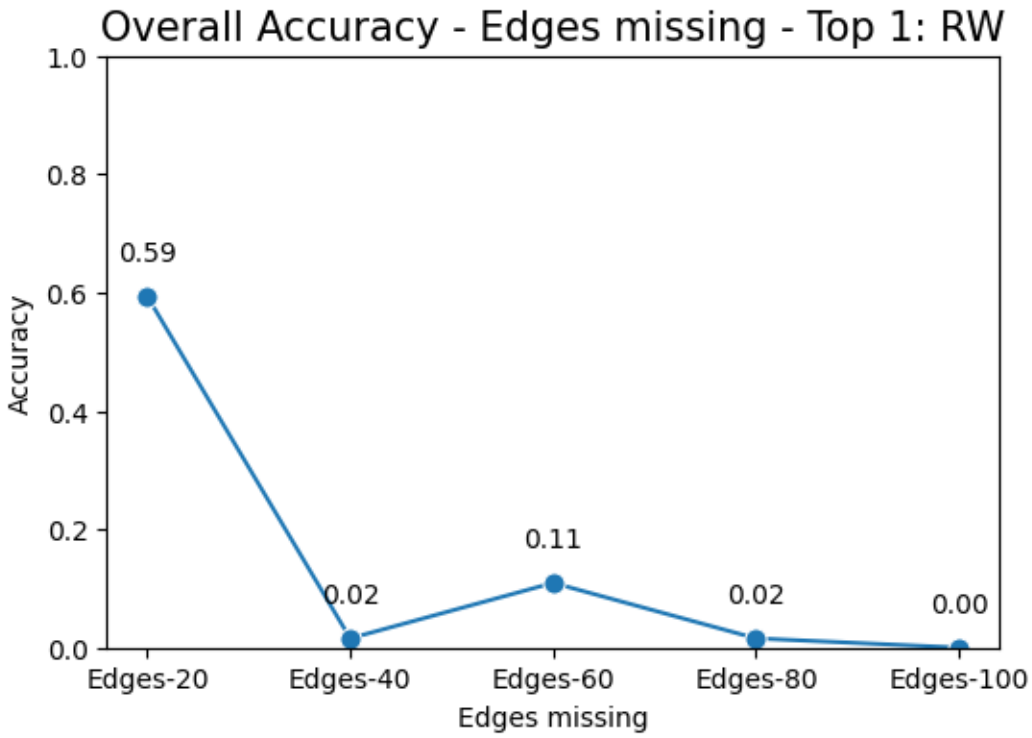
[ ]:
```
result_data_3top = results_top_3(result_edges_RW,abnormal_sets)
result_data_1top = results_top_1(result_edges_RW,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_4_RW.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_4_RW.csv'))
```

[ ]:
```
algo='RW'
var='Edges missing'
var_save='graph'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```


Accuracy - Edges missing - Top 3: RW
Type: size_1
1.00
1.00
1.00
1.00
0.75
Type: feeder_3
0.00
0.00
0.00
0.06
0.00
Type: gripper_1
1.00
0.75
0.19
0.00
0.00
Type: max_Vel_2
1.00
1.00
1.00
0.94
0.00
Accuracy
Edges missing
Edges-20
Edges-40
Edges-60
Edges-80
Edges-100

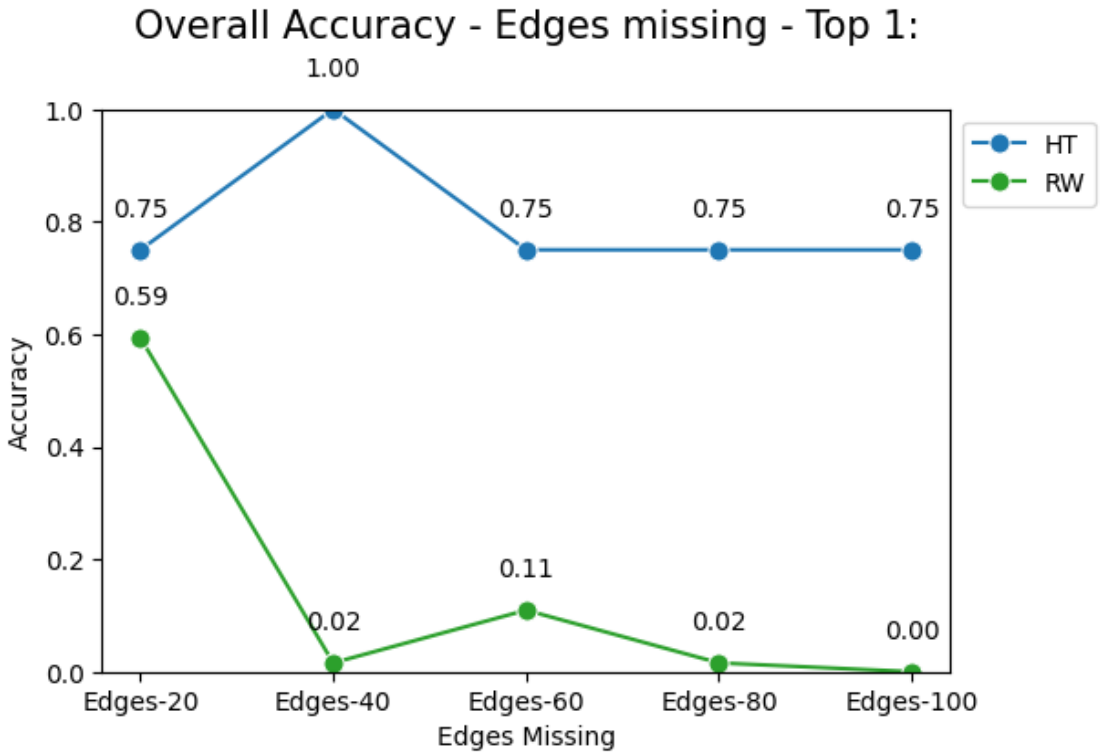

Accuracy - Edges missing - Top 1: RW
Type: size_1
0.75
0.00
0.25
0.00
0.00
Type: feeder_3
0.00
0.00
0.00
0.00
0.00
Type: gripper_1
1.00
0.00
0.00
0.00
0.00
Type: max_Vel_2
0.62
0.06
0.19
0.06
0.00
Accuracy
Edges missing
Edges-20
Edges-40
Edges-60
Edges-80
Edges-100


Overall Accuracy - Edges missing - Top 3: RW
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.75
0.69
0.55
0.50
0.19
Edges-20
Edges-40
Edges-60
Edges-80
Edges-100
Edges missing

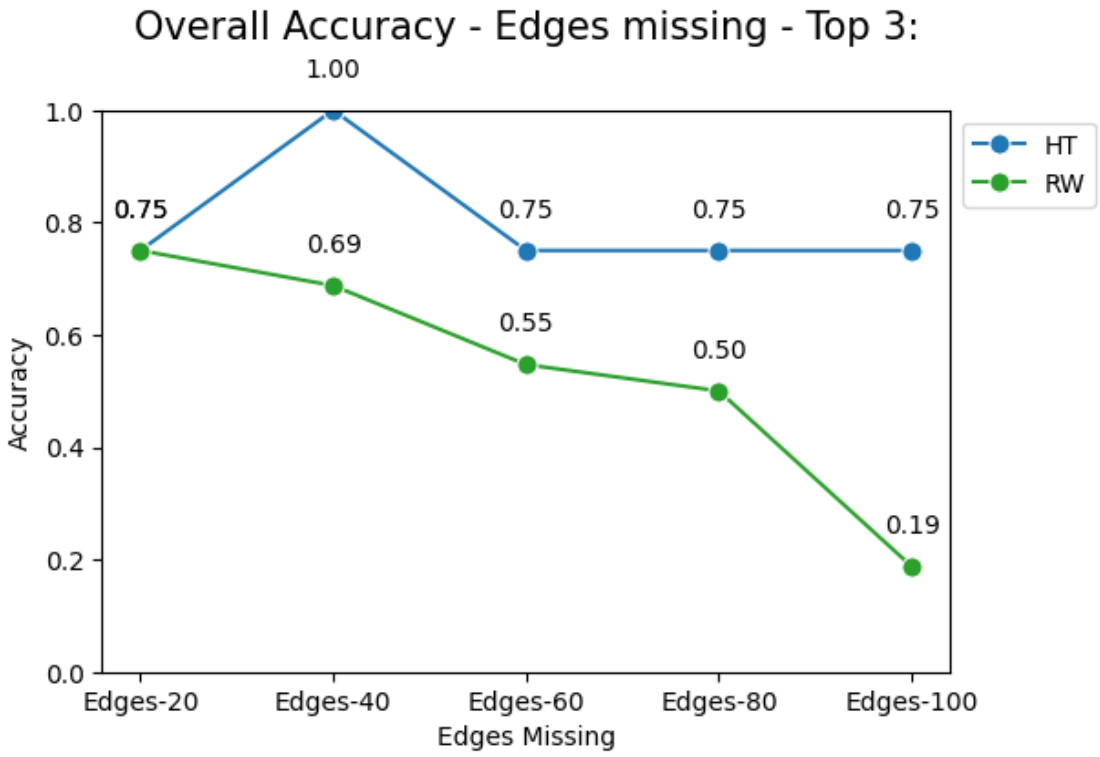

Overall Accuracy - Edges missing - Top 1: RW
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.59
0.02
0.11
0.02
0.00
Edges-20
Edges-40
Edges-60
Edges-80
Edges-100
Edges missing

1.10.3 All together

```
[ ]: result1 = results_top_1(result_edges_HT,abnormal_sets)
     result2 = results_top_1(result_edges_RW,abnormal_sets)

     results_dfs = [result1,result2]
     plot_avg_var_total_combined(results_dfs,['HT','RW']␣
      ↪,directory_figures_path,'1top_edges_total','Edges Missing','Overall Accuracy␣
      ↪- Edges missing - Top 1:')
```




```
[ ]: result1 = results_top_3(result_edges_HT,abnormal_sets)
     result2 = results_top_3(result_edges_RW,abnormal_sets)

     results_dfs = [result1,result2]
     plot_avg_var_total_combined(results_dfs,['HT','RW']␣
      ↪,directory_figures_path,'3top_edges_total','Edges Missing','Overall Accuracy␣
      ↪- Edges missing - Top 3:')
```



1.11 Variation 5 - Size

1.11.1 HT -Algorithm

[ ]:
```
result_HT_size_1, runtime_HT_size_1 =␣
  ↪run_HT_size(folder_path,files,startrow=950,size_p=2,nodes=nodes,edges_list=edges,key_nodes=
result_HT_size_2, runtime_HT_size_2 =␣
  ↪run_HT_size(folder_path,files,startrow=950,size_p=1.
  ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_size_3, runtime_HT_size_3 =␣
  ↪run_HT_size(folder_path,files,startrow=950,size_p=1.
  ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_size_4, runtime_HT_size_4 =␣
  ↪run_HT_size(folder_path,files,startrow=950,size_p=0.
  ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_HT_size_5, runtime_HT_size_5 =␣
  ↪run_HT_size(folder_path,files,startrow=950,size_p=0.
  ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

[ ]:
```
result_size_HT = pd.DataFrame()
```

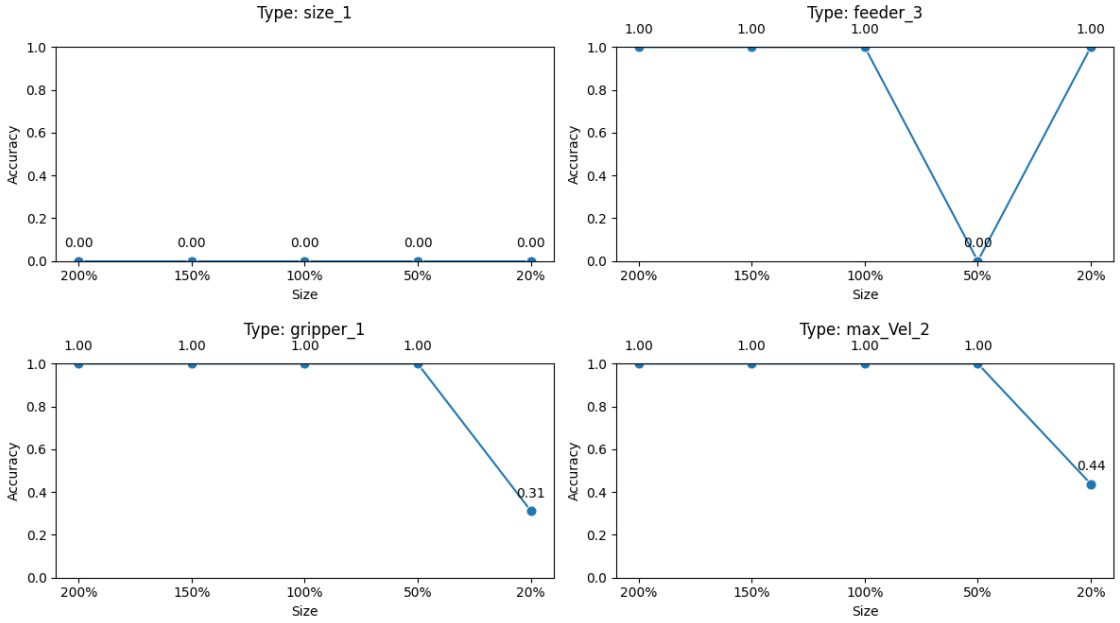
```
result_size_HT = pd.
 ↪concat([result_HT_size_1,result_HT_size_2,result_HT_size_3,result_HT_size_4,result_HT_size_
 ↪ignore_index=True)
result_size_HT['Data Size'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
result_size_HT.set_index('Data Size', inplace=True)
```

[ ]:
```
runtime_size_HT = pd.DataFrame()
runtime_size_HT = pd.concat([runtime_HT_size_1.T,runtime_HT_size_2.
 ↪T,runtime_HT_size_3.T,runtime_HT_size_4.T,runtime_HT_size_5.T],␣
 ↪ignore_index=True)
runtime_size_HT['Data Size'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
runtime_size_HT.set_index('Data Size', inplace=True)
```

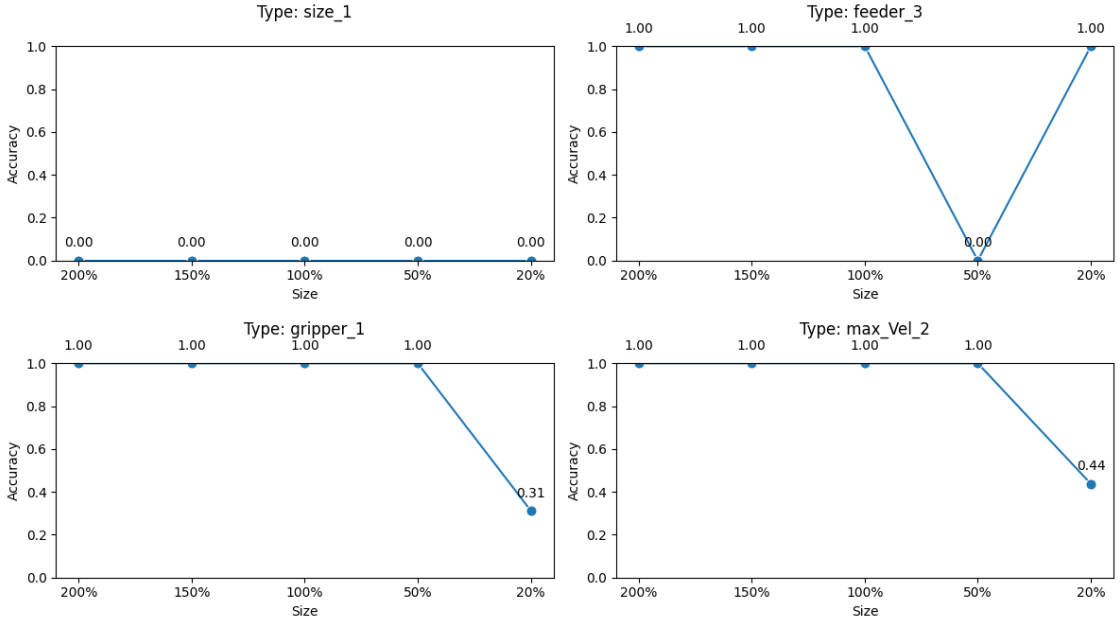
[ ]:
```
result_data_3top = results_top_3(result_size_HT,abnormal_sets)
result_data_1top = results_top_1(result_size_HT,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_HT.csv'))
```

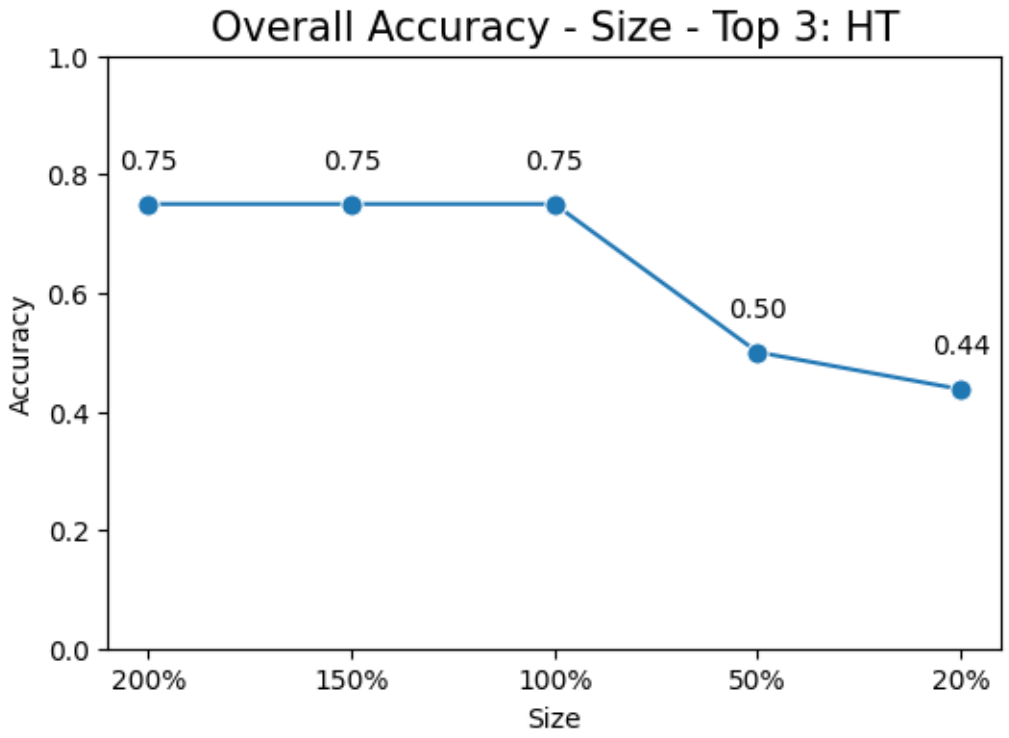
[ ]:
```
algo='HT'
var='Size'
var_save='size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

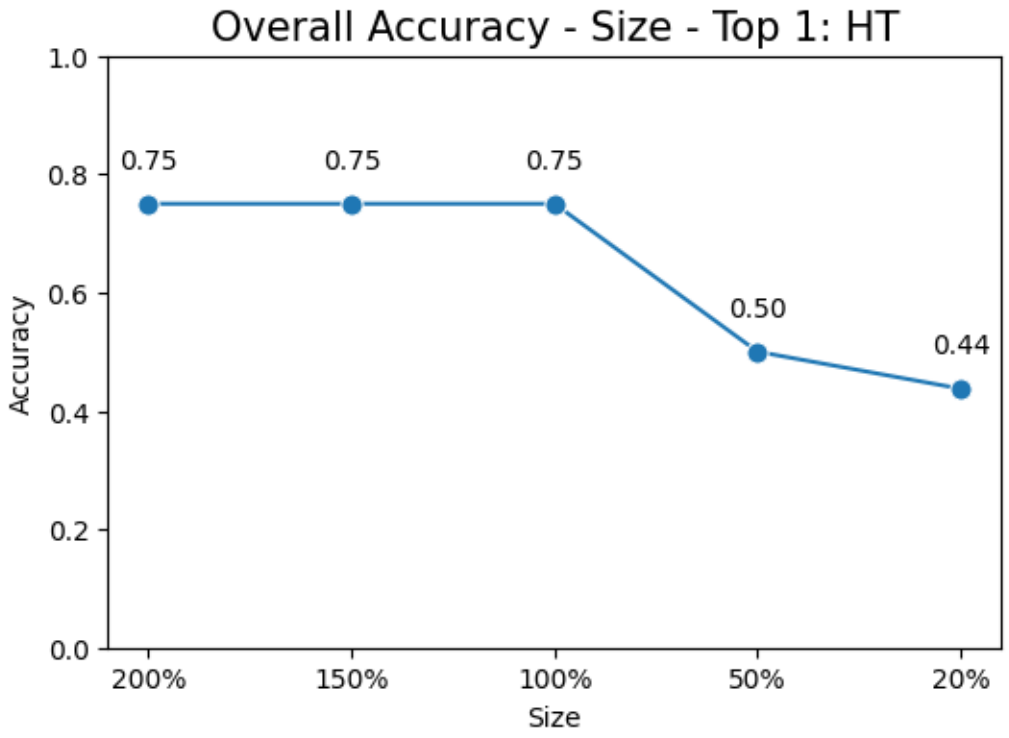
Accuracy - Size - Top 3: HT



Accuracy - Size - Top 1: HT




Overall Accuracy - Size - Top 3: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.50
0.44
200%
150%
100%
50%
20%
Size


Overall Accuracy - Size - Top 1: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.50
0.44
200%
150%
100%
50%
20%
Size

1.11.2 ED - Algorithm

[ ]:
```
result_ED_size_1, runtime_ED_size_1 =␣
 ↪run_ED_size(folder_path,files,startrow=950,size_p=2,nodes=nodes,edges_list=edges,key_nodes=
result_ED_size_2, runtime_ED_size_2 =␣
 ↪run_ED_size(folder_path,files,startrow=950,size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_ED_size_3, runtime_ED_size_3 =␣
 ↪run_ED_size(folder_path,files,startrow=950,size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_ED_size_4, runtime_ED_size_4 =␣
 ↪run_ED_size(folder_path,files,startrow=950,size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_ED_size_5, runtime_ED_size_5 =␣
 ↪run_ED_size(folder_path,files,startrow=950,size_p=0.
 ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

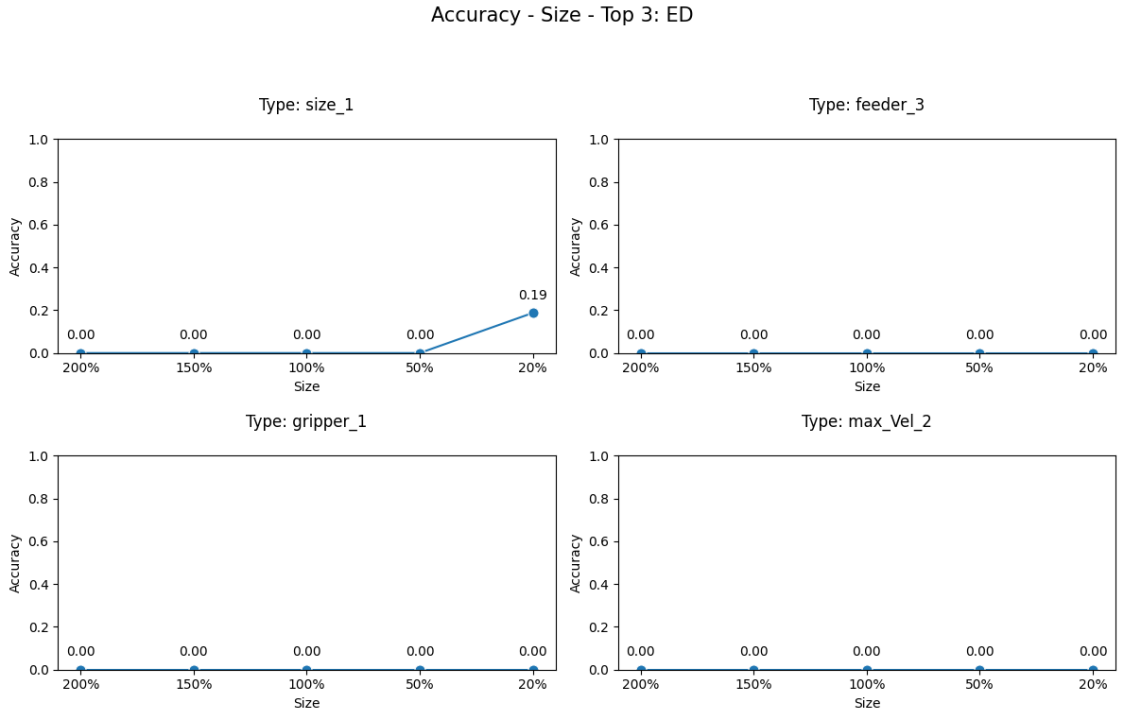
[ ]:
```
result_size_ED = pd.DataFrame()
result_size_ED = pd.
 ↪concat([result_ED_size_1,result_ED_size_2,result_ED_size_3,result_ED_size_4,result_ED_size_
 ↪ignore_index=True)
result_size_ED['Data Size'] = pd.DataFrame({'ED':
 ↪['200%','150%','100%','50%','20%']})
result_size_ED.set_index('Data Size', inplace=True)
```

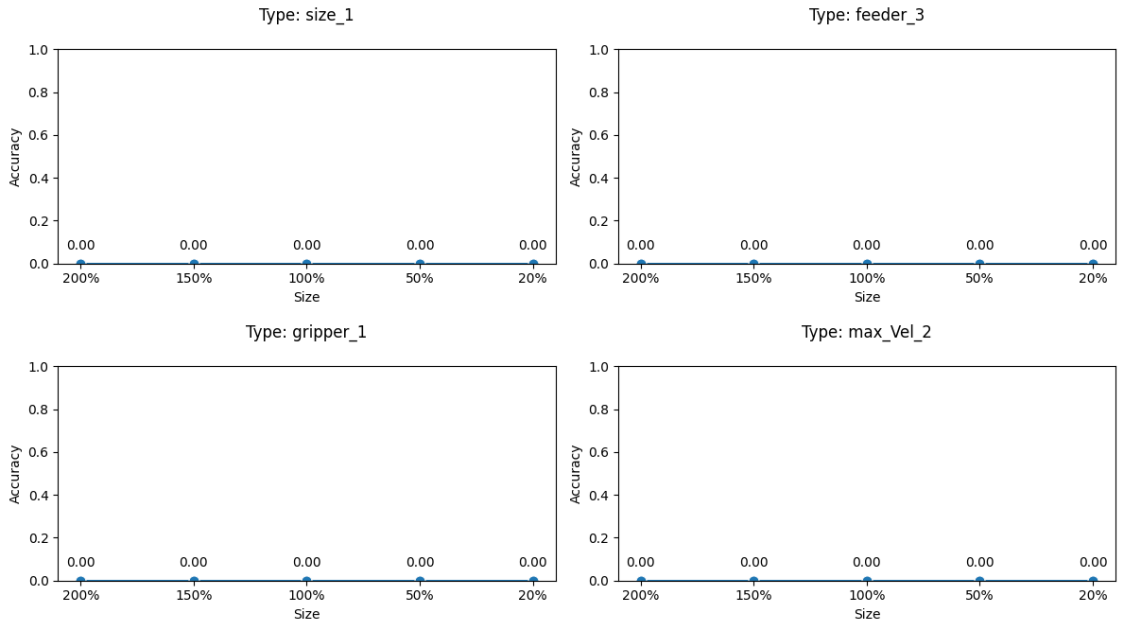
[ ]:
```
runtime_size_ED = pd.DataFrame()
runtime_size_ED = pd.concat([runtime_ED_size_1.T,runtime_ED_size_2.
 ↪T,runtime_ED_size_3.T,runtime_ED_size_4.T,runtime_ED_size_5.T],␣
 ↪ignore_index=True)
runtime_size_ED['Data Size'] = pd.DataFrame({'ED':
 ↪['200%','150%','100%','50%','20%']})
runtime_size_ED.set_index('Data Size', inplace=True)
```

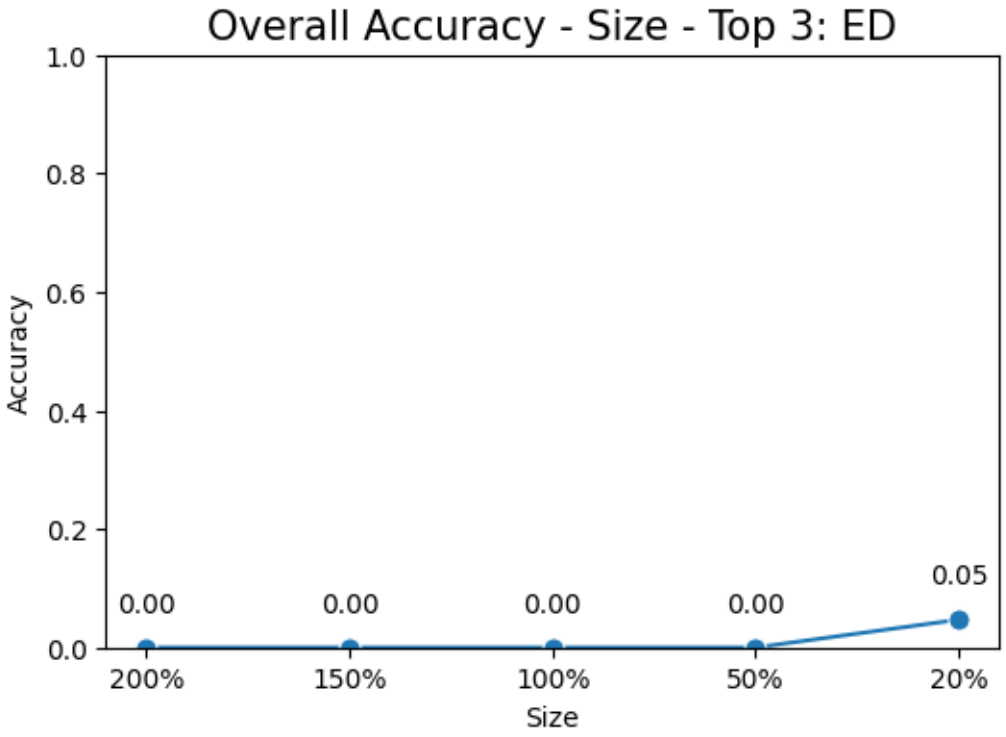
[ ]:
```
result_data_3top = results_top_3(result_size_ED,abnormal_sets)
result_data_1top = results_top_1(result_size_ED,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_ED.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_ED.csv'))
```

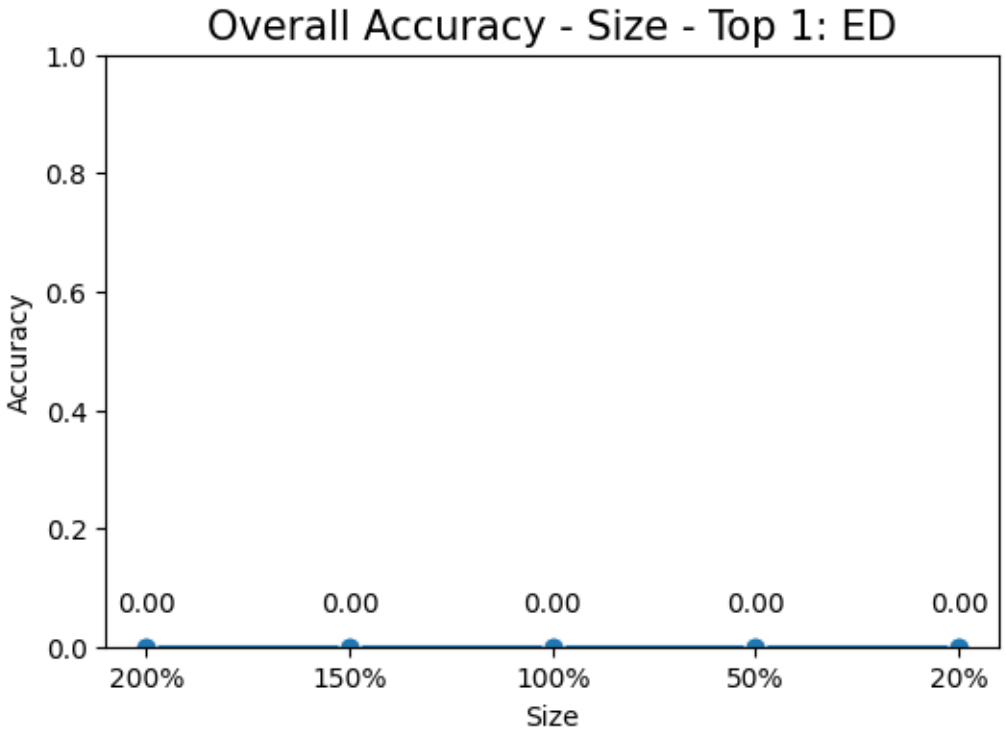
[ ]:
```
algo='ED'
var='Size'
var_save='size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
```

```
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```






Overall Accuracy - Size - Top 3: ED
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.00
0.00
0.00
0.05
200%
150%
100%
50%
20%
Size


Overall Accuracy - Size - Top 1: ED
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.00
0.00
0.00
0.00
200%
150%
100%
50%
20%
Size

1.11.3 RW - Algorithm

[ ]:
```
result_RW_size_1, runtime_RW_size_1 =␣
 ↪run_RW_size(folder_path,files,startrow=950,size_p=2,nodes=nodes,edges_list=edges,key_nodes=
result_RW_size_2, runtime_RW_size_2 =␣
 ↪run_RW_size(folder_path,files,startrow=950,size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_size_3, runtime_RW_size_3 =␣
 ↪run_RW_size(folder_path,files,startrow=950,size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_size_4, runtime_RW_size_4 =␣
 ↪run_RW_size(folder_path,files,startrow=950,size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RW_size_5, runtime_RW_size_5 =␣
 ↪run_RW_size(folder_path,files,startrow=950,size_p=0.
 ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

[ ]:
```
result_size_RW = pd.DataFrame()
result_size_RW = pd.
 ↪concat([result_RW_size_1,result_RW_size_2,result_RW_size_3,result_RW_size_4,result_RW_size_
 ↪ignore_index=True)
result_size_RW['Data Size'] = pd.DataFrame({'RW':
 ↪['200%','150%','100%','50%','20%']})
result_size_RW.set_index('Data Size', inplace=True)
```

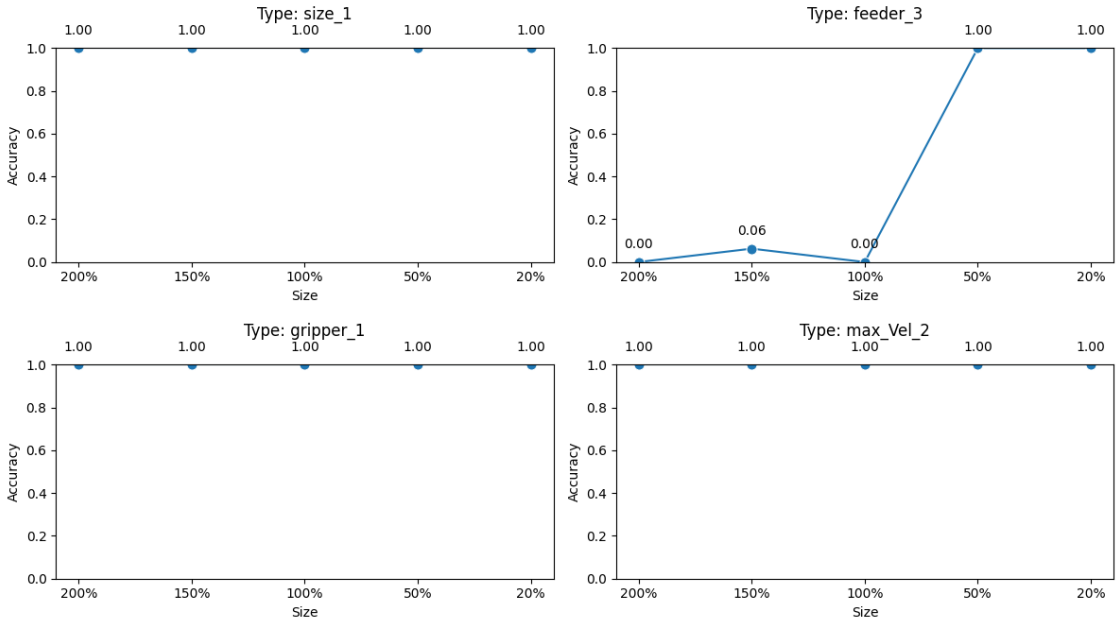
[ ]:
```
runtime_size_RW = pd.DataFrame()
runtime_size_RW = pd.concat([runtime_RW_size_1.T,runtime_RW_size_2.
 ↪T,runtime_RW_size_3.T,runtime_RW_size_4.T,runtime_RW_size_5.T],␣
 ↪ignore_index=True)
runtime_size_RW['Data Size'] = pd.DataFrame({'RW':
 ↪['200%','150%','100%','50%','20%']})
runtime_size_RW.set_index('Data Size', inplace=True)
```

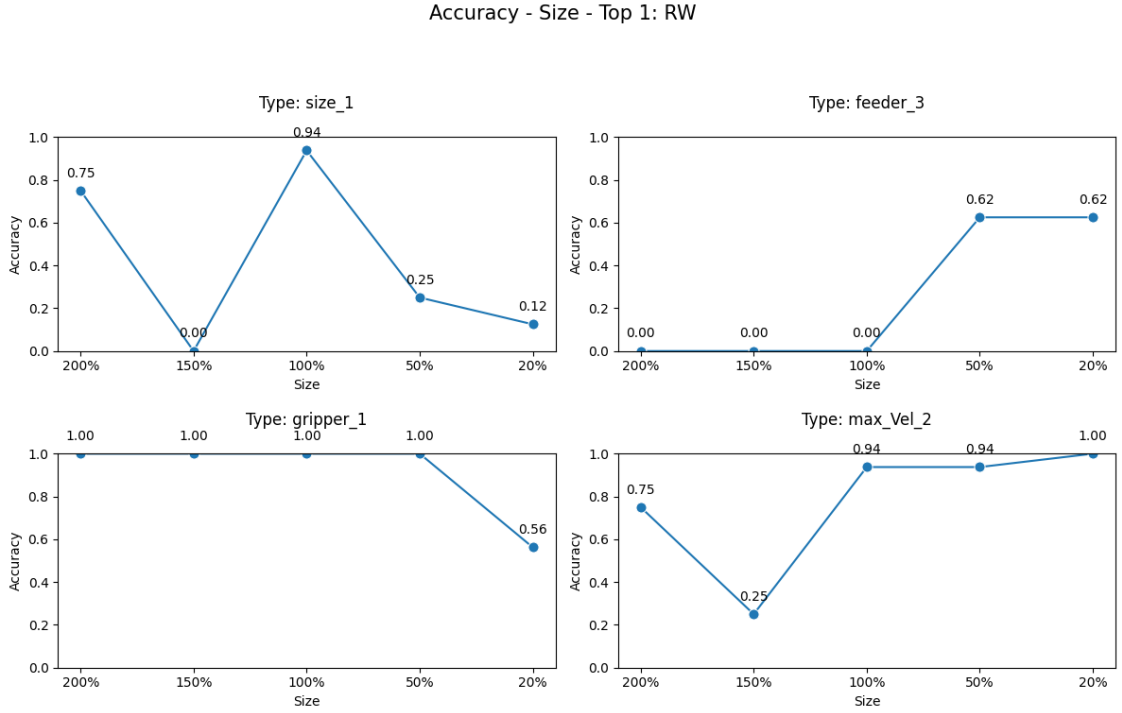
[ ]:
```
result_data_3top = results_top_3(result_size_RW,abnormal_sets)
result_data_1top = results_top_1(result_size_RW,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_RW.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_RW.csv'))
```

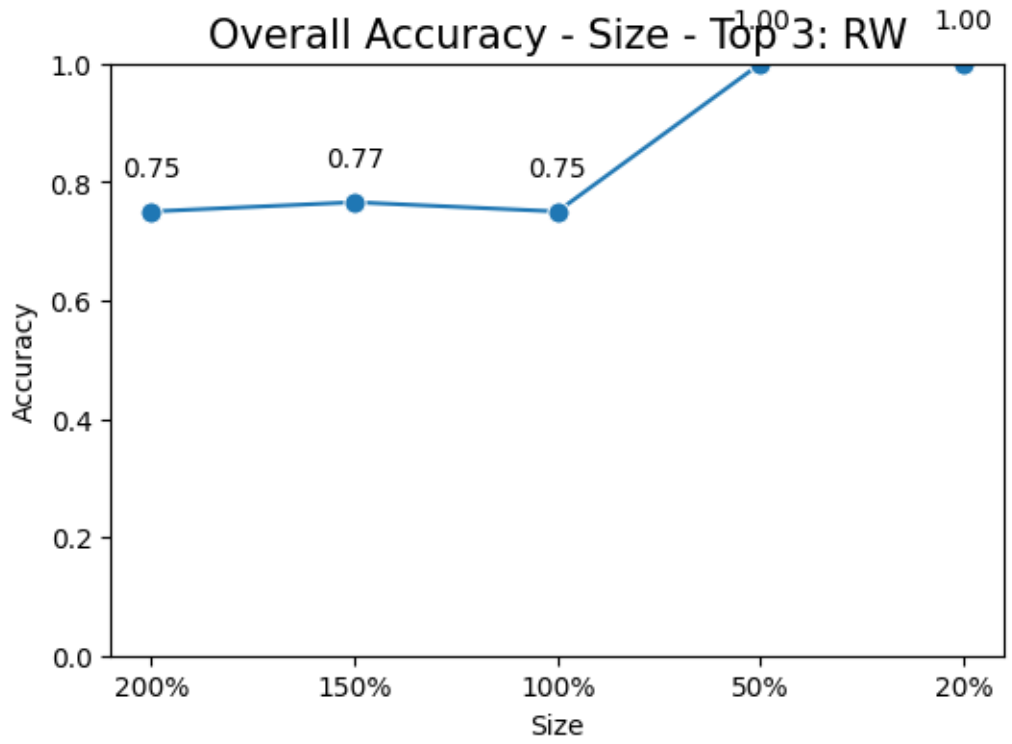
[ ]:
```
algo='RW'
var='Size'
var_save='size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
```

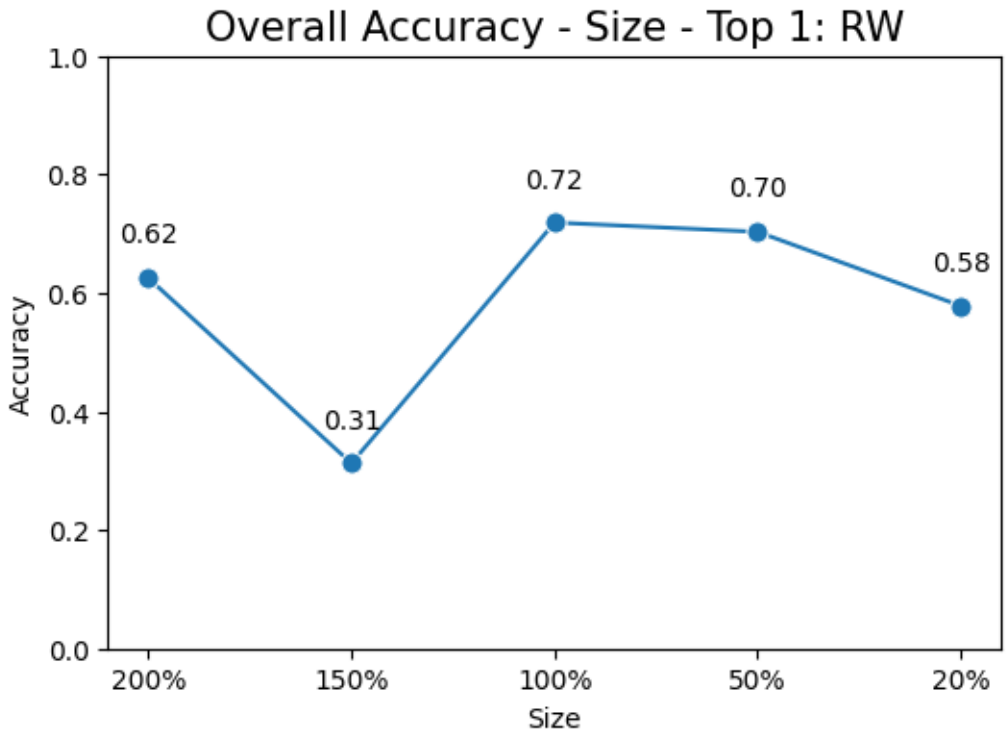
```
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

Accuracy - Size - Top 3: RW




Accuracy - Size - Top 1: RW
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Size
200%
150%
100%
50%
20%


Overall Accuracy - Size - Top 3: RW
Accuracy
Size
0.75
0.77
0.75
1.00
1.00
200%
150%
100%
50%
20%



1.11.4 RCD - Algorithm

[ ]:
```
result_RCD_size_1, runtime_RCD_size_1 =␣
 ↪run_RCD_size(folder_path,files,startrow=950,size_p=2,nodes=nodes,edges_list=edges,key_nodes
result_RCD_size_2, runtime_RCD_size_2 =␣
 ↪run_RCD_size(folder_path,files,startrow=950,size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_size_3, runtime_RCD_size_3 =␣
 ↪run_RCD_size(folder_path,files,startrow=950,size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_size_4, runtime_RCD_size_4 =␣
 ↪run_RCD_size(folder_path,files,startrow=950,size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
result_RCD_size_5, runtime_RCD_size_5 =␣
 ↪run_RCD_size(folder_path,files,startrow=950,size_p=0.
 ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes)
```

[ ]:
```
result_size_RCD = pd.DataFrame()
result_size_RCD = pd.
 ↪concat([result_RCD_size_1,result_RCD_size_2,result_RCD_size_3,result_RCD_size_4,result_RCD_
 ↪ignore_index=True)
```

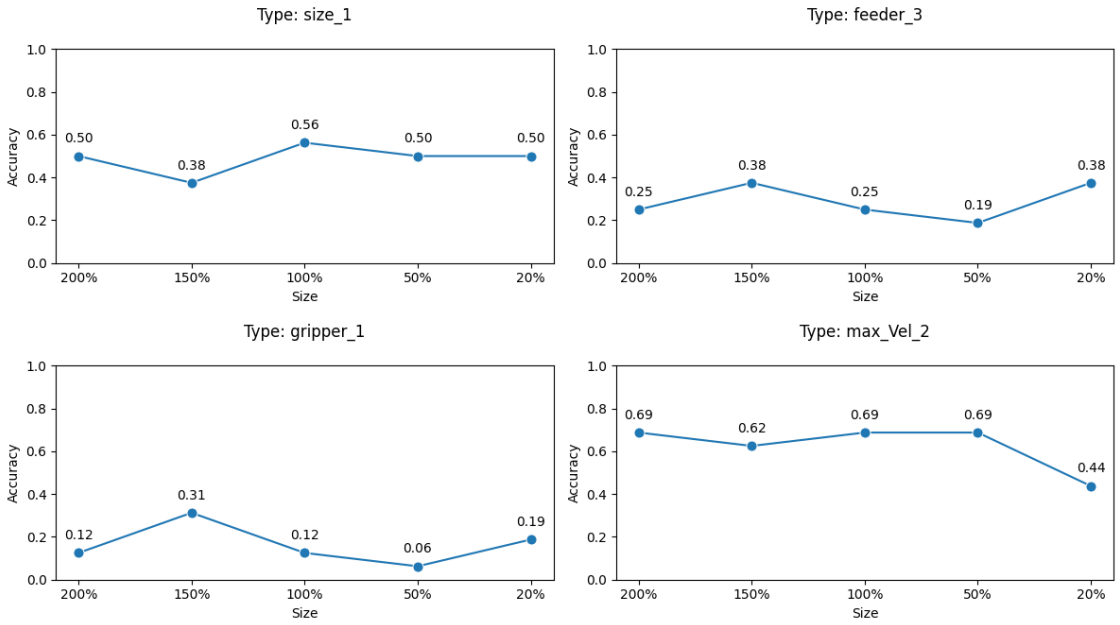
```
result_size_RCD['Data Size'] = pd.DataFrame({'RCD':
 ↪['200%','150%','100%','50%','20%']})
result_size_RCD.set_index('Data Size', inplace=True)
```

[ ]:
```
runtime_size_RCD = pd.DataFrame()
runtime_size_RCD = pd.concat([runtime_RCD_size_1.T,runtime_RCD_size_2.
 ↪T,runtime_RCD_size_3.T,runtime_RCD_size_4.T,runtime_RCD_size_5.T],␣
 ↪ignore_index=True)
runtime_size_RCD['Data Size'] = pd.DataFrame({'RCD':
 ↪['200%','150%','100%','50%','20%']})
runtime_size_RCD.set_index('Data Size', inplace=True)
```

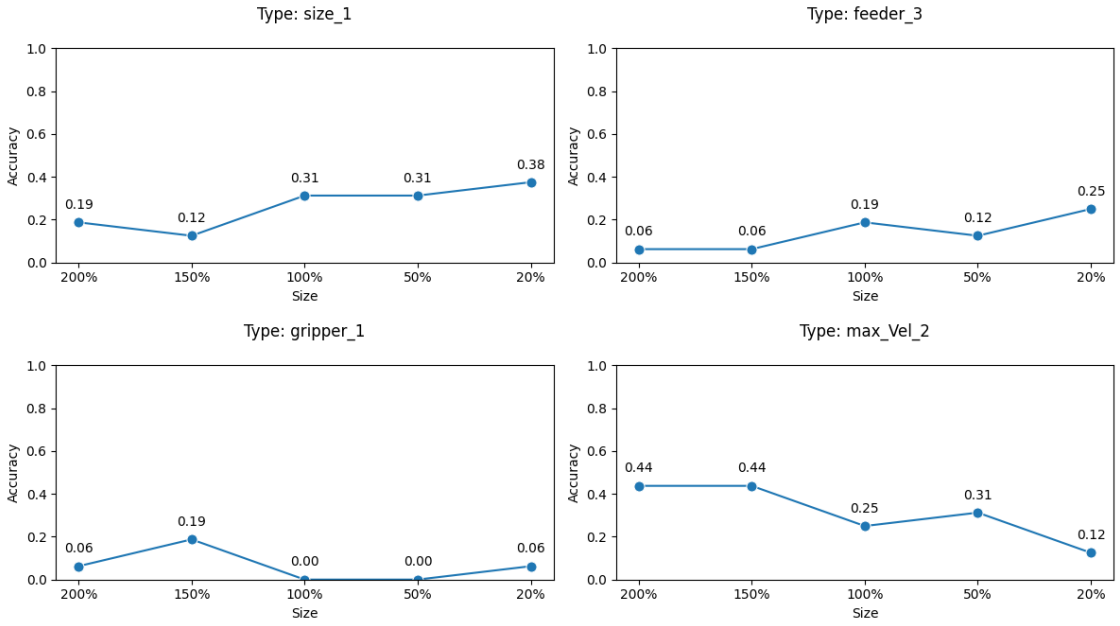
[ ]:
```
result_data_3top = results_top_3(result_size_RCD,abnormal_sets)
result_data_1top = results_top_1(result_size_RCD,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_RCD.csv'))
```

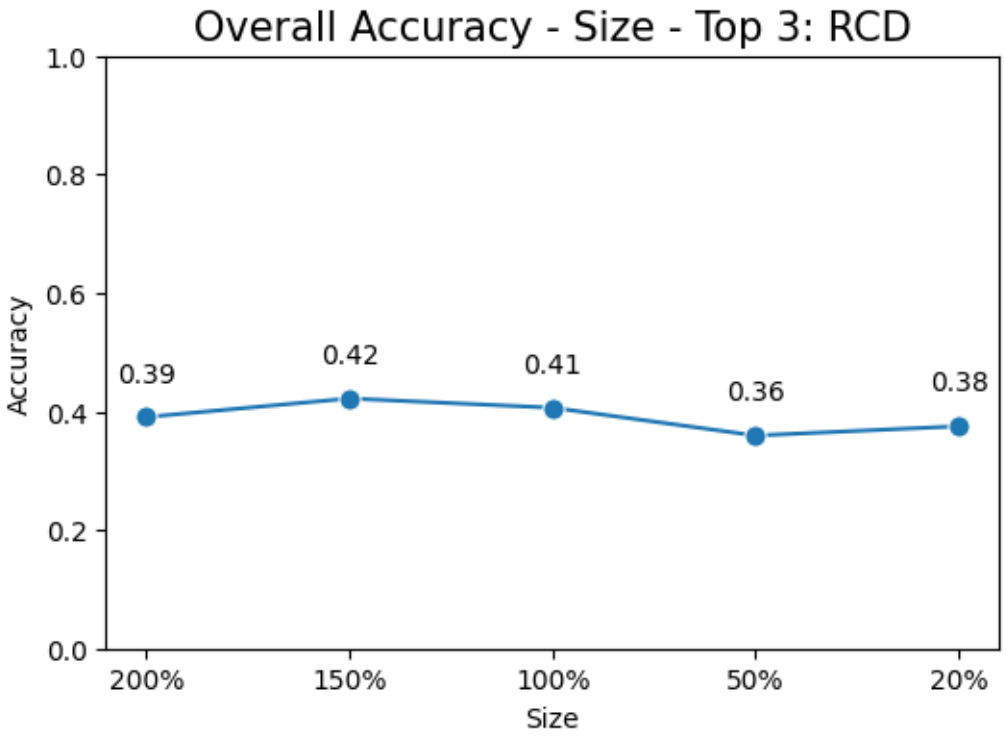
[ ]:
```
algo='RCD'
var='Size'
var_save='size'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

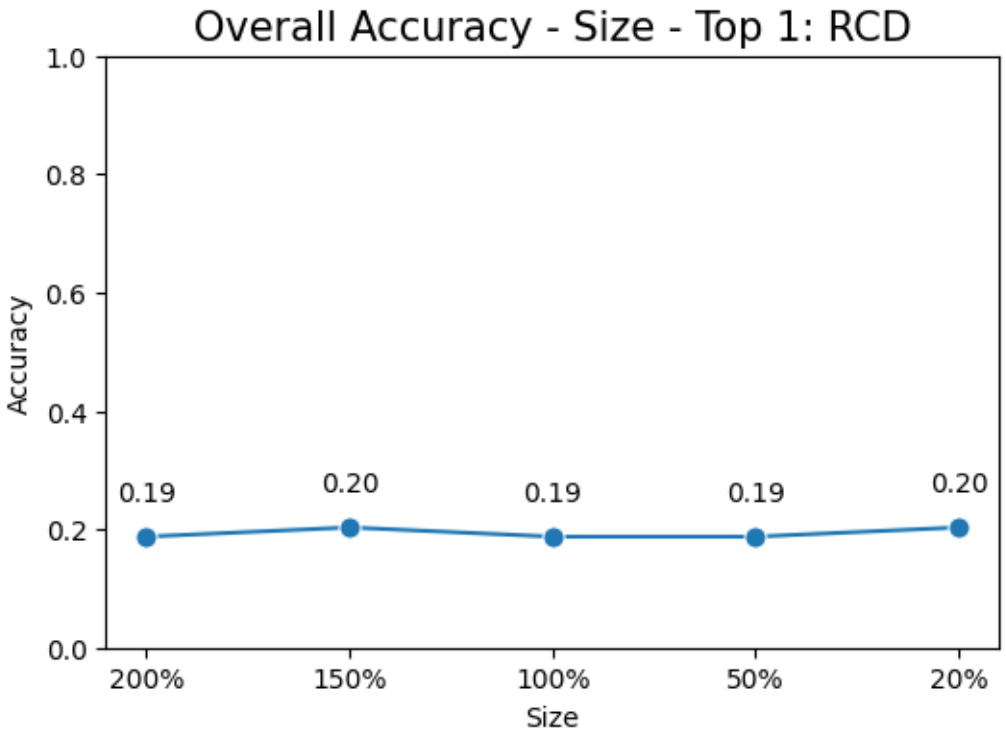
Accuracy - Size - Top 3: RCD



Accuracy - Size - Top 1: RCD

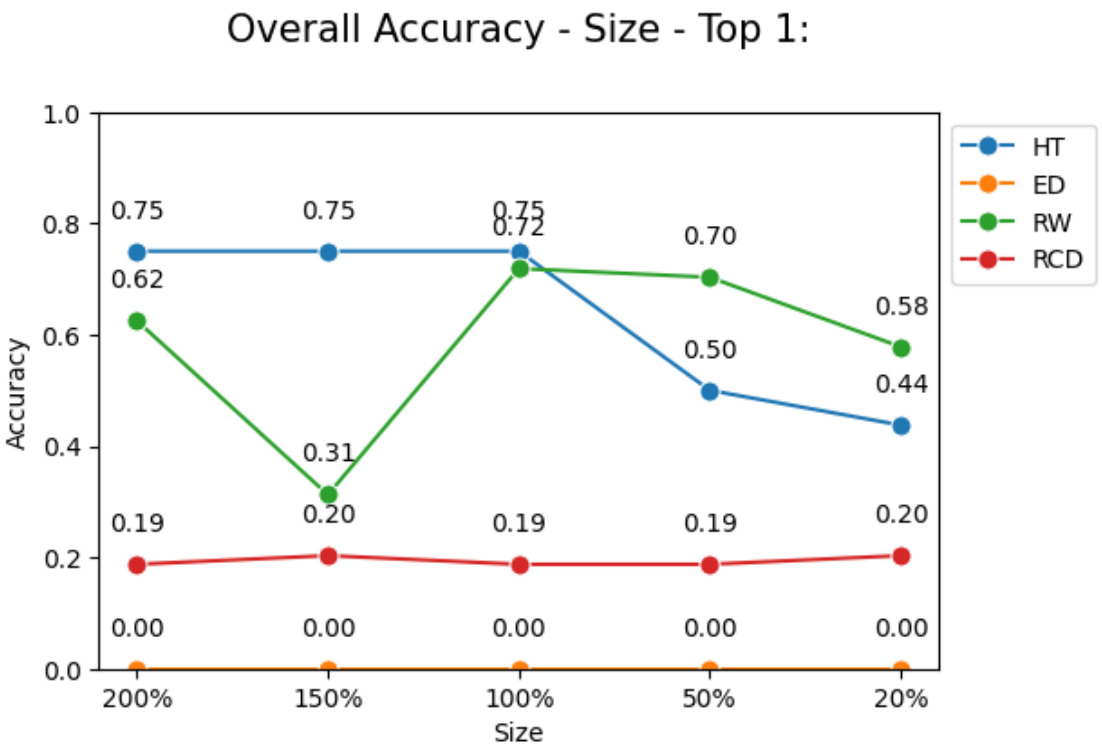



Overall Accuracy - Size - Top 3: RCD
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.39
0.42
0.41
0.36
0.38
200%
150%
100%
50%
20%
Size

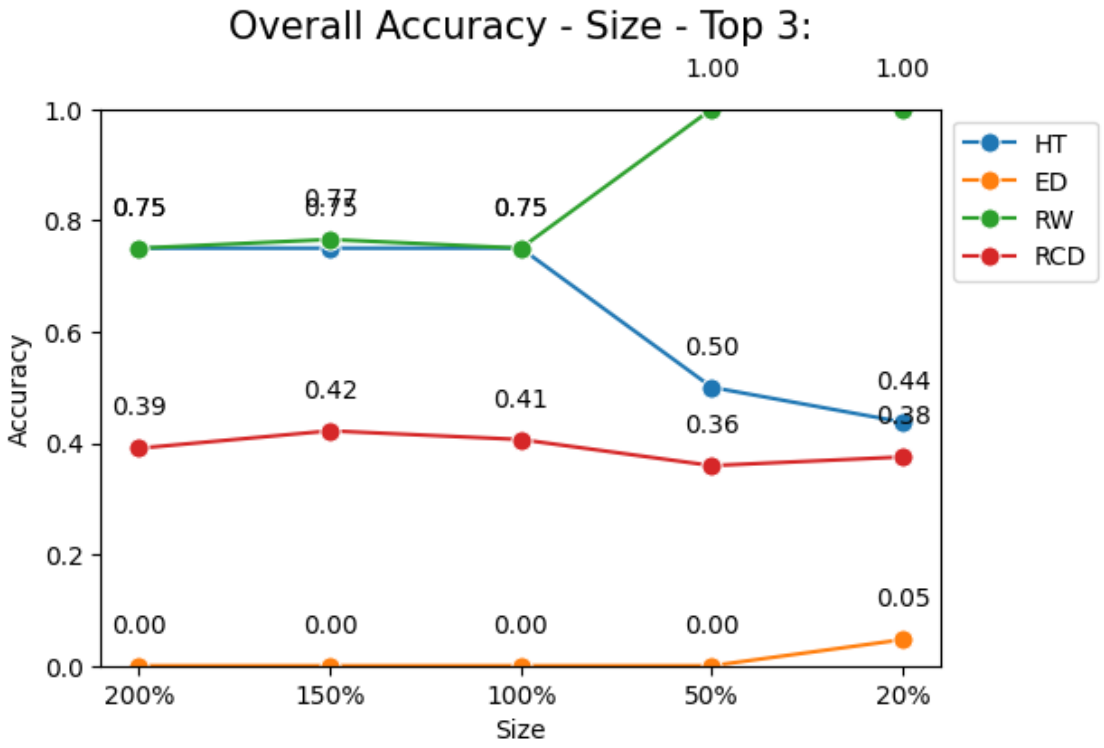

Overall Accuracy - Size - Top 1: RCD
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.19
0.20
0.19
0.19
0.20
200%
150%
100%
50%
20%
Size

1.11.5 All together

[ ]:
```
result1 = results_top_1(result_size_HT,abnormal_sets)
result2 = results_top_1(result_size_ED,abnormal_sets)
result3 = results_top_1(result_size_RW,abnormal_sets)
result4 = results_top_1(result_size_RCD,abnormal_sets)

results_dfs = [result1,result2,result3,result4]
plot_avg_var_total_combined(results_dfs,['HT','ED','RW','RCD']␣
 ↪,directory_figures_path,'1top_size_total','Size','Overall Accuracy - Size -␣
 ↪Top 1:')
```



[ ]:
```
result1 = results_top_3(result_size_HT,abnormal_sets)
result2 = results_top_3(result_size_ED,abnormal_sets)
result3 = results_top_3(result_size_RW,abnormal_sets)
result4 = results_top_3(result_size_RCD,abnormal_sets)

results_dfs = [result1,result2,result3,result4]
plot_avg_var_total_combined(results_dfs,['HT','ED','RW','RCD']␣
 ↪,directory_figures_path,'3top_size_total','Size','Overall Accuracy - Size -␣
 ↪Top 3:')
```



1.12 Variation 6 - Training Data

1.12.1 HT - Algorithm

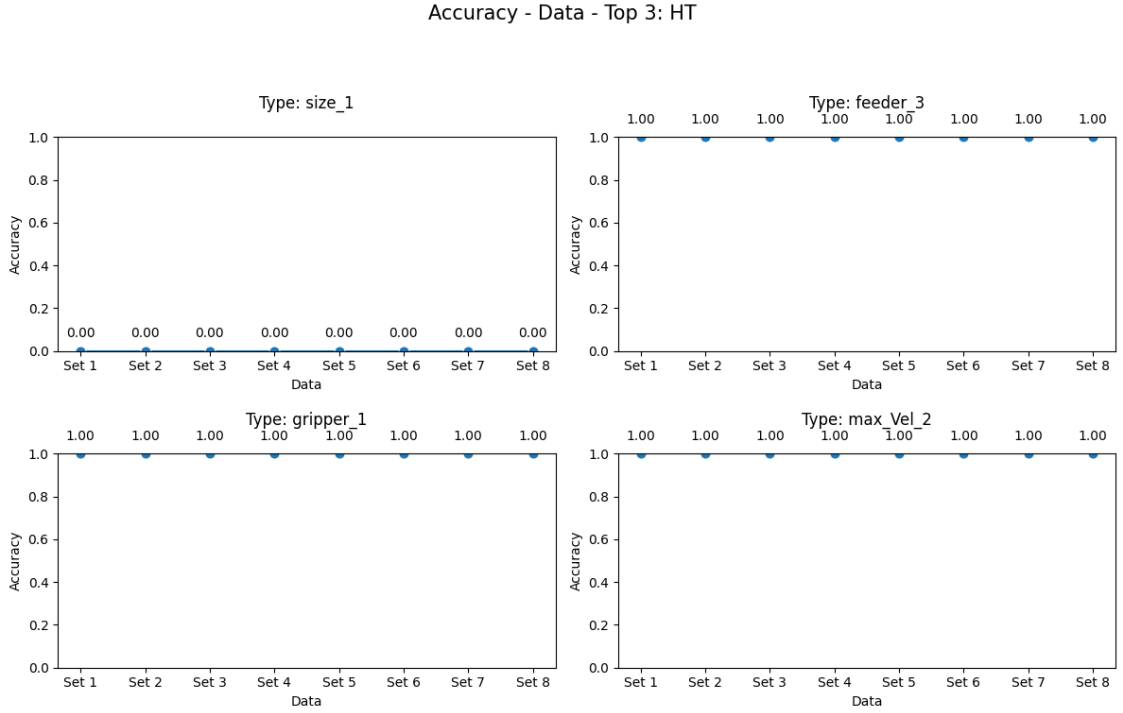
[ ]:
```
result_HT_data_1, runtime_HT_data_1 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-1',nodes=nodes,edges_
result_HT_data_2, runtime_HT_data_2 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-2',nodes=nodes,edges_
result_HT_data_3, runtime_HT_data_3 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-3',nodes=nodes,edges_
result_HT_data_4, runtime_HT_data_4 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-4',nodes=nodes,edges_
result_HT_data_5, runtime_HT_data_5 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-5',nodes=nodes,edges_
result_HT_data_6, runtime_HT_data_6 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-6',nodes=nodes,edges_
result_HT_data_7, runtime_HT_data_7 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-7',nodes=nodes,edges_
result_HT_data_8, runtime_HT_data_8 =␣
 ↪run_HT_normal_data(folder_path,files,startrow=950,normal_data='normal-8',nodes=nodes,edges_
```

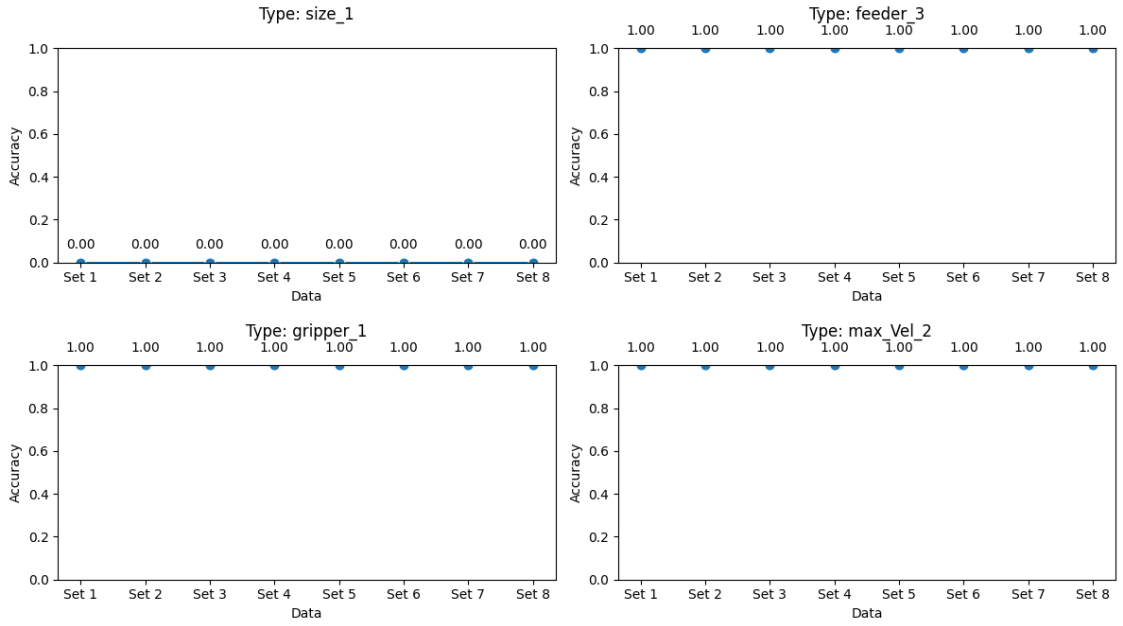
```
[ ]: result_data_HT = pd.DataFrame()
result_data_HT = pd.
 ↪concat([result_HT_data_1,result_HT_data_2,result_HT_data_3,result_HT_data_4,result_HT_data_
 ↪ignore_index=True)
result_data_HT['Normal Data'] = pd.DataFrame({'HT':['Set 1','Set 2','Set␣
 ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
result_data_HT.set_index('Normal Data', inplace=True)
```

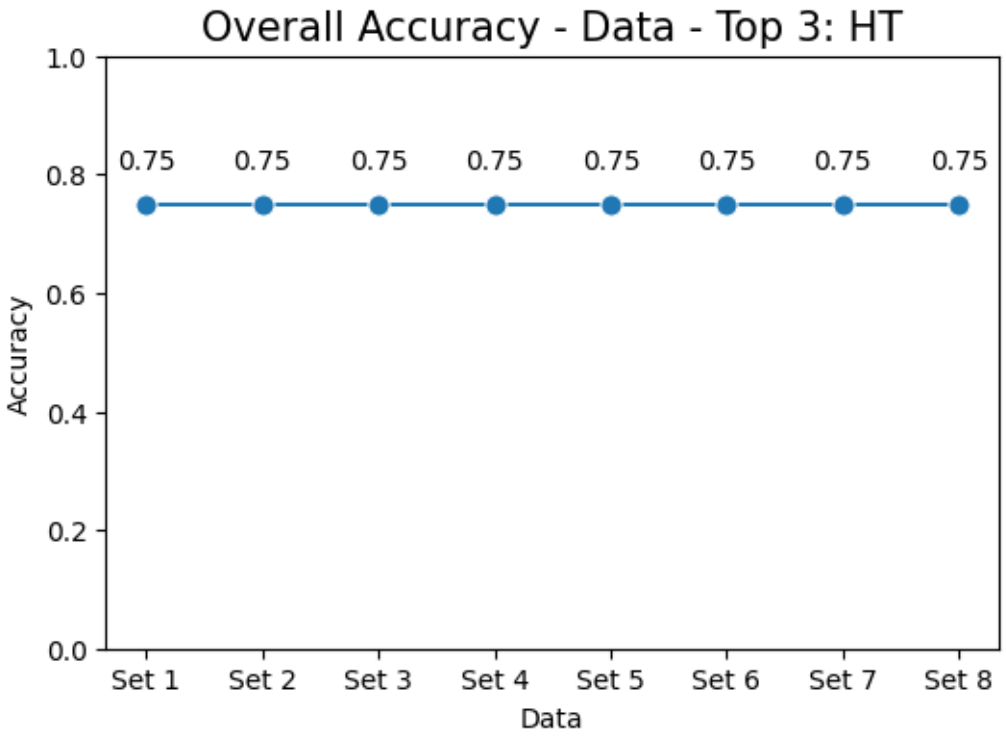
```
[ ]: runtime_data_HT = pd.DataFrame()
runtime_data_HT = pd.concat([runtime_HT_data_1.T,runtime_HT_data_2.
 ↪T,runtime_HT_data_3.T,runtime_HT_data_4.T,runtime_HT_data_5.
 ↪T,runtime_HT_data_6.T,runtime_HT_data_7.T,runtime_HT_data_8.T],␣
 ↪ignore_index=True)
runtime_data_HT['Normal Data'] = pd.DataFrame({'HT':['Set 1','Set 2','Set␣
 ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
runtime_data_HT.set_index('Normal Data', inplace=True)
```

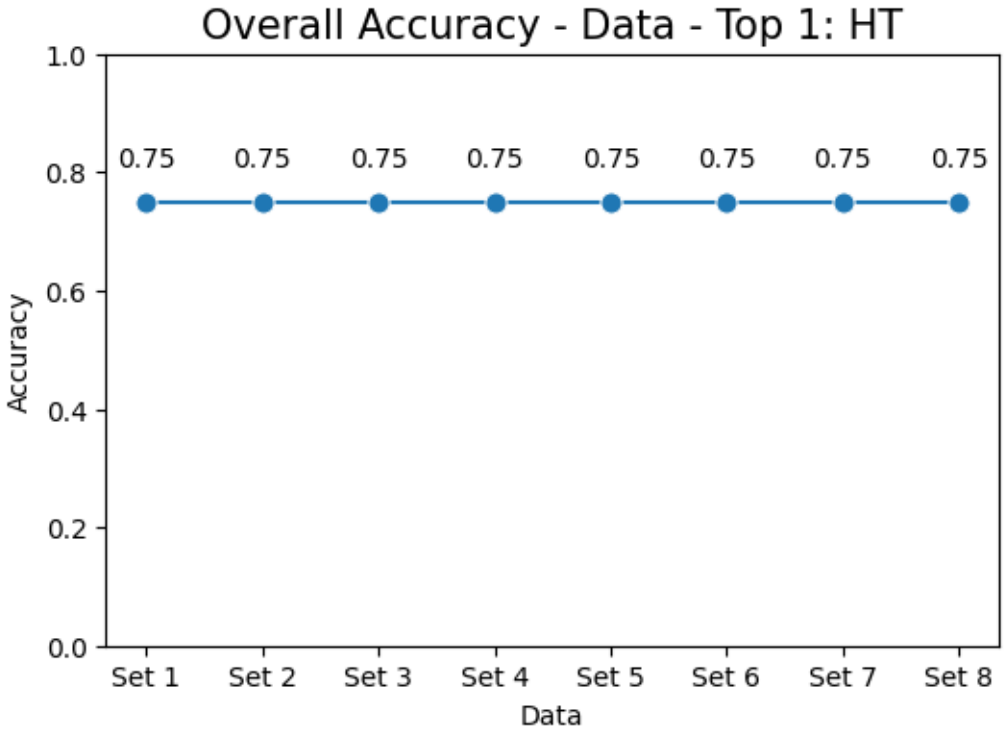
```
[ ]: result_data_3top = results_top_3(result_data_HT,abnormal_sets)
result_data_1top = results_top_1(result_data_HT,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_6_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_6_HT.csv'))
```

```
[ ]: algo='HT'
var='Data'
var_save='data'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

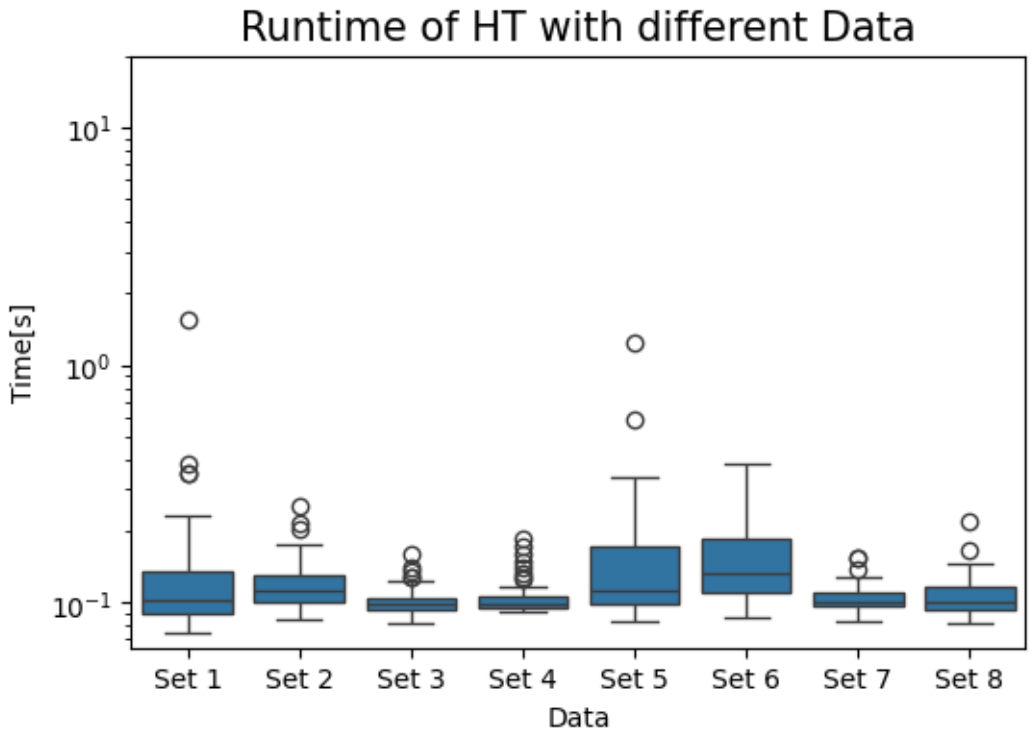

Accuracy - Data - Top 3: HT
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Data
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
0.00
1.00


Accuracy - Data - Top 1: HT
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Data
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
0.00
1.00


Overall Accuracy - Data - Top 3: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.75
0.75
0.75
0.75
0.75
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Data


Overall Accuracy - Data - Top 1: HT
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.75
0.75
0.75
0.75
0.75
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Data

```
[ ]: plot_data_runtime(runtime_data_HT.T,directory_figures_path,'runtime_data_6_HT.
     ↪csv','Data',' HT ')
```



1.12.2 ED - Algorithm

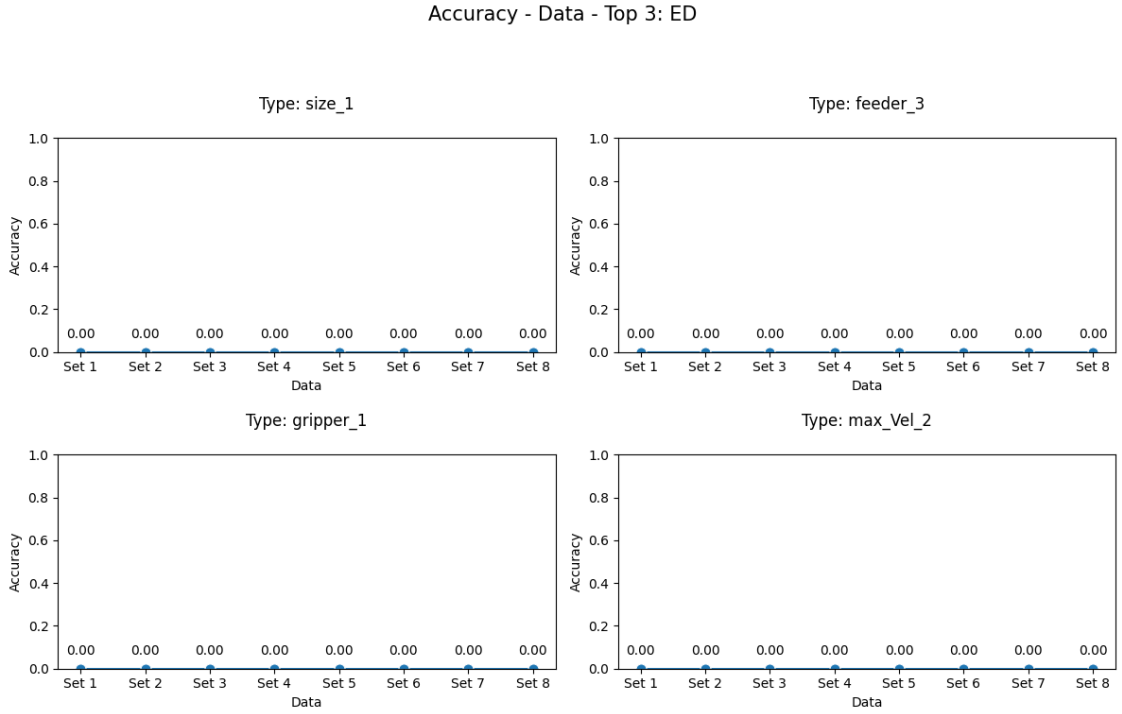
```
[ ]: result_ED_data_1, runtime_ED_data_1 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-1',nodes=nodes,edges_
     result_ED_data_2, runtime_ED_data_2 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-2',nodes=nodes,edges_
     result_ED_data_3, runtime_ED_data_3 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-3',nodes=nodes,edges_
     result_ED_data_4, runtime_ED_data_4 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-4',nodes=nodes,edges_
     result_ED_data_5, runtime_ED_data_5 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-5',nodes=nodes,edges_
     result_ED_data_6, runtime_ED_data_6 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-6',nodes=nodes,edges_
     result_ED_data_7, runtime_ED_data_7 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-7',nodes=nodes,edges_
     result_ED_data_8, runtime_ED_data_8 =␣
     ↪run_ED_normal_data(folder_path,files,startrow=950,normal_data='normal-8',nodes=nodes,edges_
```

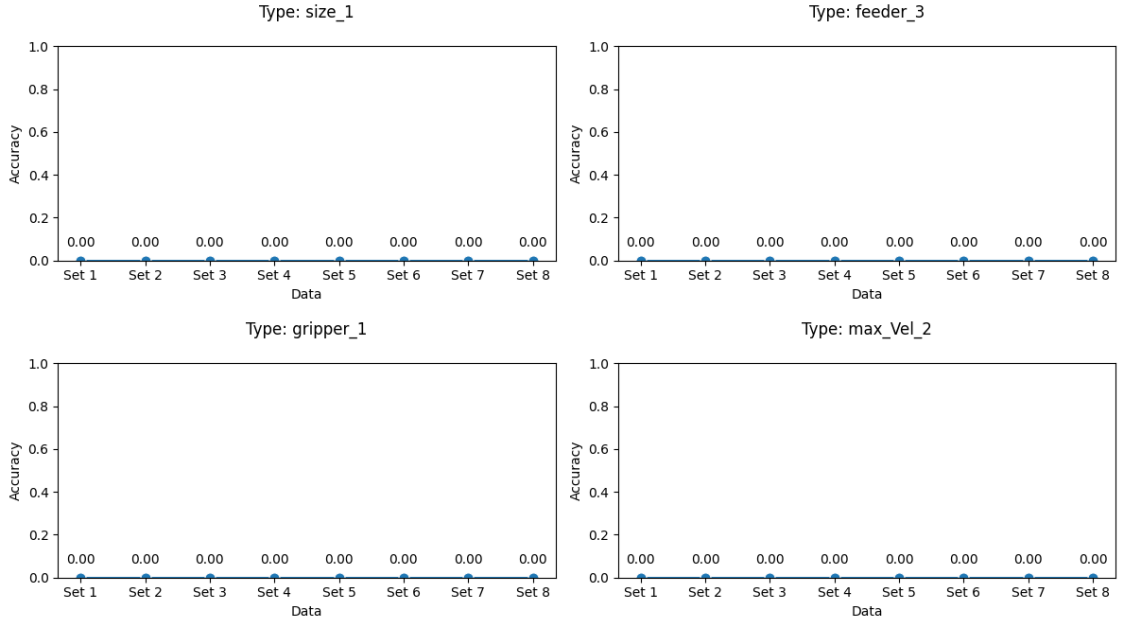
[ ]:
```
result_data_ED = pd.DataFrame()
result_data_ED = pd.
 ↪concat([result_ED_data_1,result_ED_data_2,result_ED_data_3,result_ED_data_4,result_ED_data_
 ↪ignore_index=True)
result_data_ED['Normal Data'] = pd.DataFrame({'ED':['Set 1','Set 2','Set␣
 ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
result_data_ED.set_index('Normal Data', inplace=True)
```

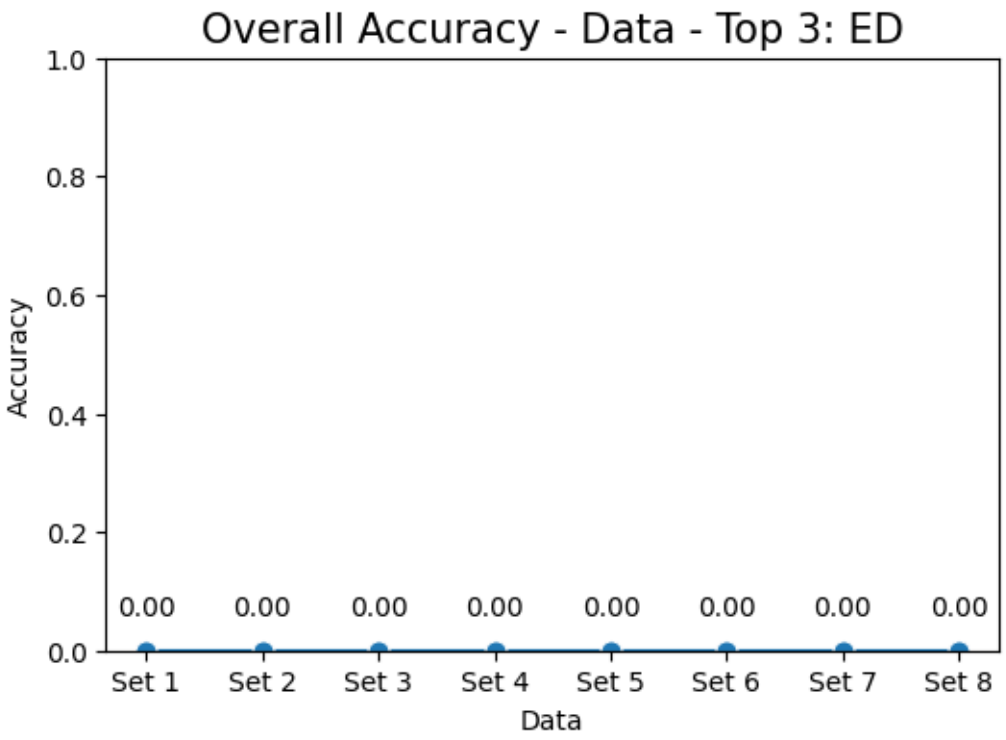
[ ]:
```
runtime_data_ED = pd.DataFrame()
runtime_data_ED = pd.concat([runtime_ED_data_1.T,runtime_ED_data_2.
 ↪T,runtime_ED_data_3.T,runtime_ED_data_4.T,runtime_ED_data_5.
 ↪T,runtime_ED_data_6.T,runtime_ED_data_7.T,runtime_ED_data_8.T],␣
 ↪ignore_index=True)
runtime_data_ED['Normal Data'] = pd.DataFrame({'ED':['Set 1','Set 2','Set␣
 ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
runtime_data_ED.set_index('Normal Data', inplace=True)
```

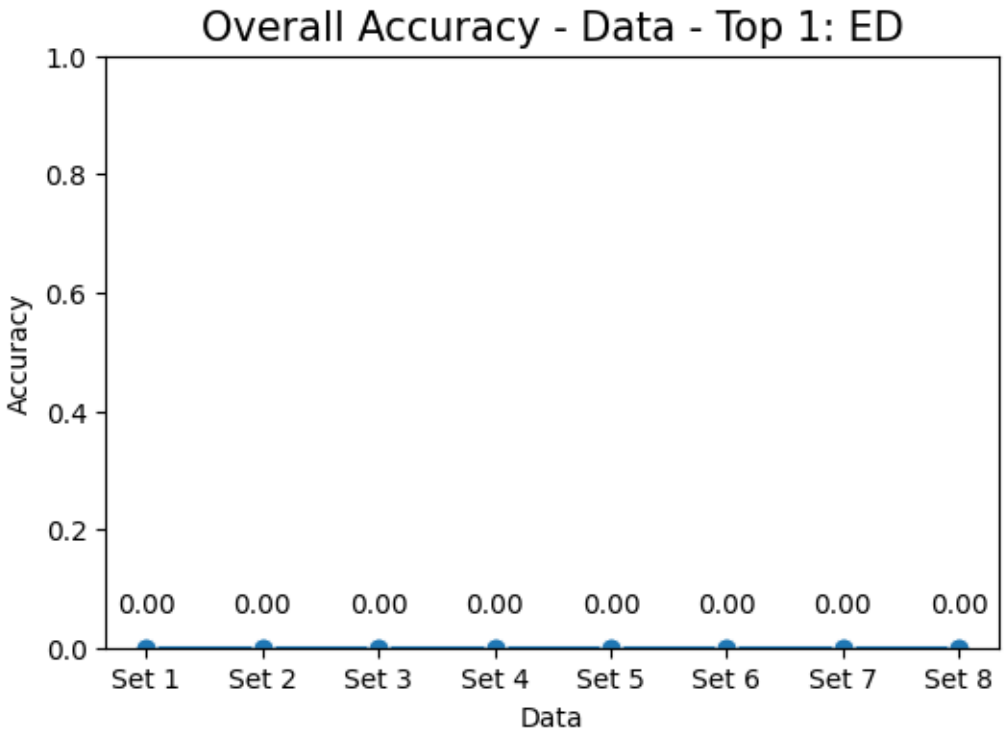
[ ]:
```
result_data_3top = results_top_3(result_data_ED,abnormal_sets)
result_data_1top = results_top_1(result_data_ED,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_6_ED.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_6_ED.csv'))
```

[ ]:
```
algo='ED'
var='Data'
var_save='data'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

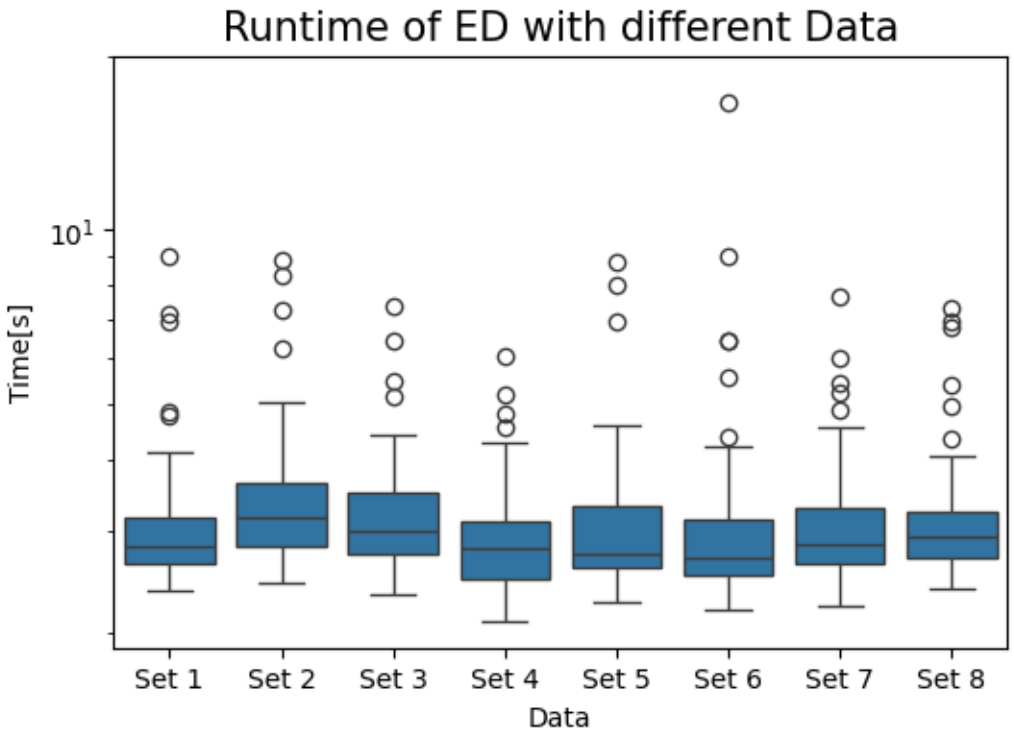

Accuracy - Data - Top 3: ED
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Data
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
0.00


Accuracy - Data - Top 1: ED
Type: size_1
Type: feeder_3
Type: gripper_1
Type: max_Vel_2
Accuracy
Data
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
0.00


Overall Accuracy - Data - Top 3: ED
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Data


Overall Accuracy - Data - Top 1: ED
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Data

[ ]:
```
plot_data_runtime(runtime_data_ED.T,directory_figures_path,'runtime_data_6_ED.
↪csv','Data',' ED ')
```



1.12.3 RW - Algorithm

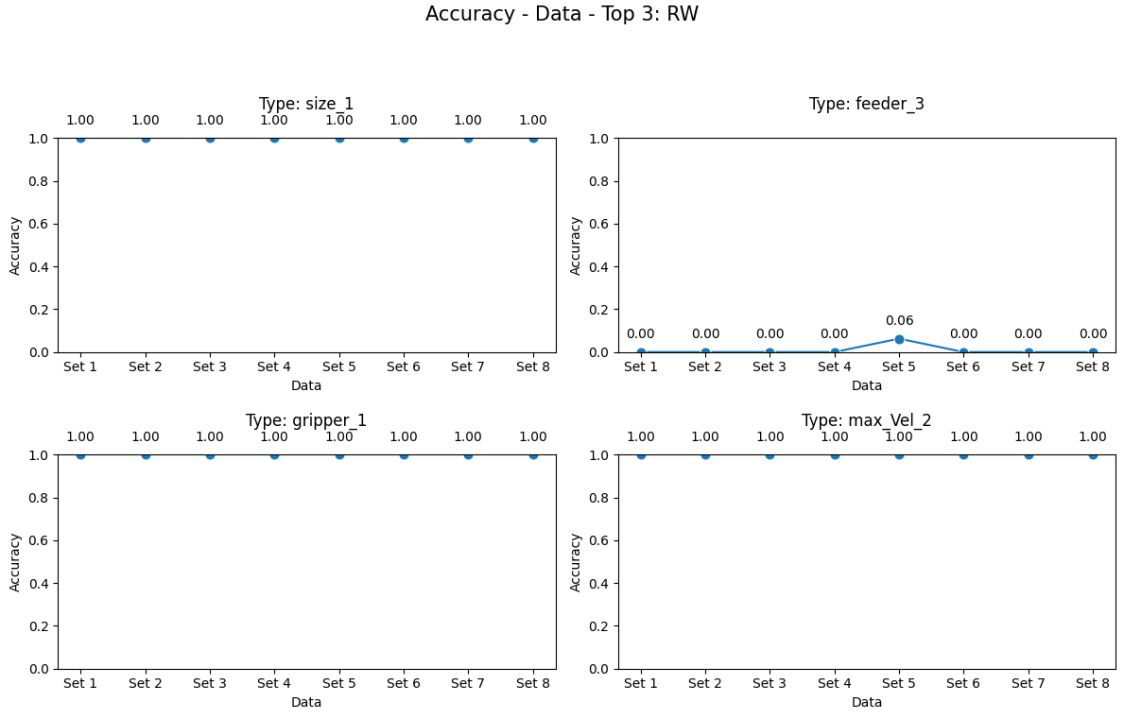
[ ]:
```
result_RW_data_1, runtime_RW_data_1 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-1',nodes=nodes,edges_
result_RW_data_2, runtime_RW_data_2 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-2',nodes=nodes,edges_
result_RW_data_3, runtime_RW_data_3 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-3',nodes=nodes,edges_
result_RW_data_4, runtime_RW_data_4 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-4',nodes=nodes,edges_
result_RW_data_5, runtime_RW_data_5 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-5',nodes=nodes,edges_
result_RW_data_6, runtime_RW_data_6 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-6',nodes=nodes,edges_
result_RW_data_7, runtime_RW_data_7 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-7',nodes=nodes,edges_
result_RW_data_8, runtime_RW_data_8 =␣
↪run_RW_normal_data(folder_path,files,startrow=950,normal_data='normal-8',nodes=nodes,edges_
```

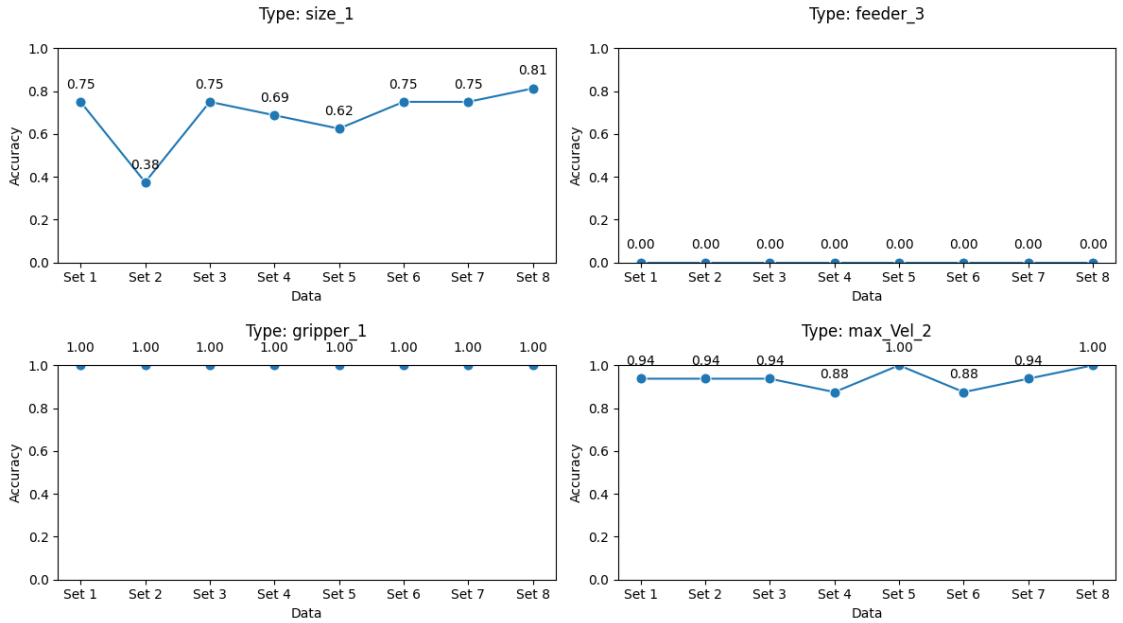
```
[ ]: result_data_RW = pd.DataFrame()
     result_data_RW = pd.
      ↪concat([result_RW_data_1,result_RW_data_2,result_RW_data_3,result_RW_data_4,result_RW_data_
      ↪ignore_index=True)
     result_data_RW['Normal Data'] = pd.DataFrame({'RW':['Set 1','Set 2','Set␣
      ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
     result_data_RW.set_index('Normal Data', inplace=True)
```

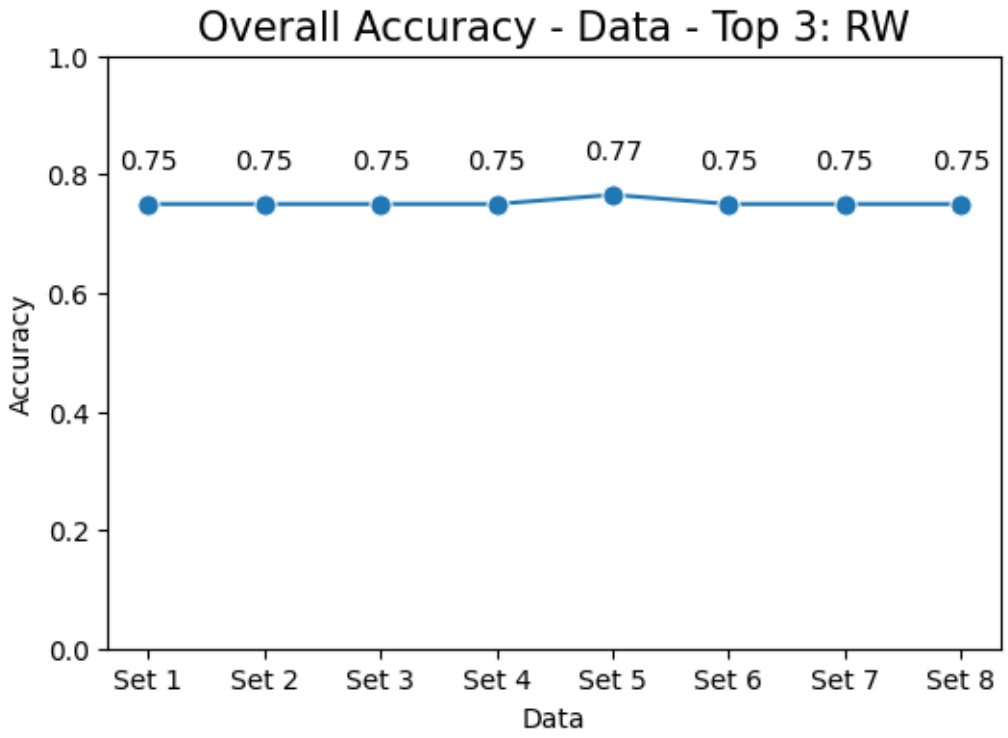
```
[ ]: runtime_data_RW = pd.DataFrame()
     runtime_data_RW = pd.concat([runtime_RW_data_1.T,runtime_RW_data_2.
      ↪T,runtime_RW_data_3.T,runtime_RW_data_4.T,runtime_RW_data_5.
      ↪T,runtime_RW_data_6.T,runtime_RW_data_7.T,runtime_RW_data_8.T],␣
      ↪ignore_index=True)
     runtime_data_RW['Normal Data'] = pd.DataFrame({'RW':['Set 1','Set 2','Set␣
      ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
     runtime_data_RW.set_index('Normal Data', inplace=True)
```

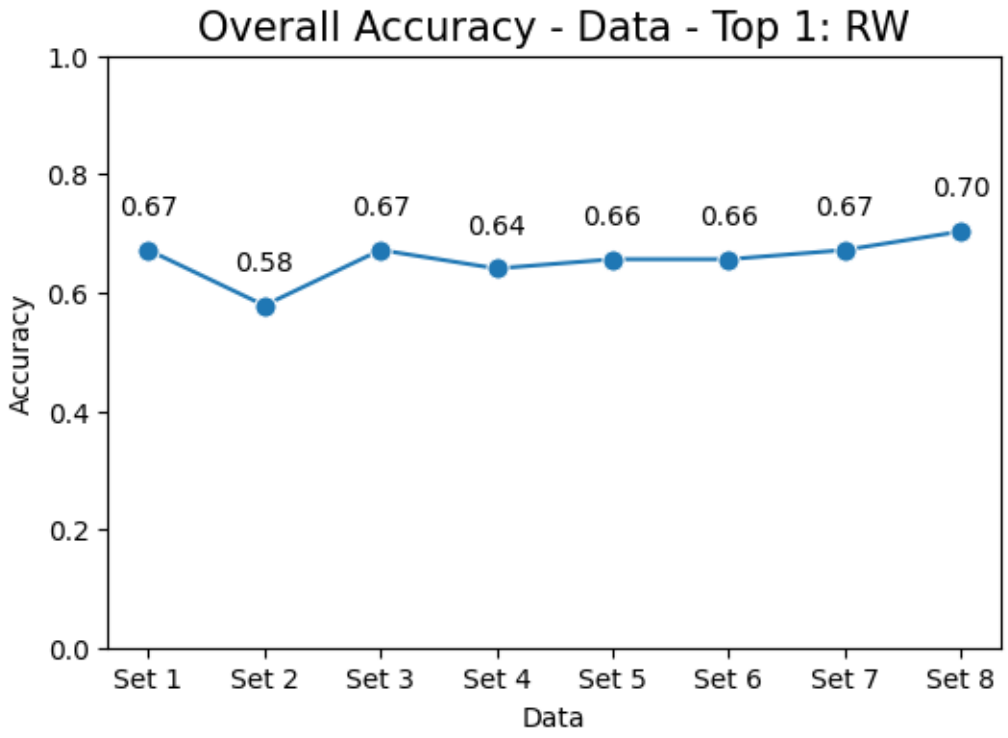
```
[ ]: result_data_3top = results_top_3(result_data_RW,abnormal_sets)
     result_data_1top = results_top_1(result_data_RW,abnormal_sets)
     result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_6_RW.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_6_RW.csv'))
```

```
[ ]: algo='RW'
     var='Data'
     var_save='data'
     plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
      ↪- '+var+' - Top 3:')
     plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
      ↪- '+var+' - Top 1:')
     plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
      ↪Accuracy - '+var+' - Top 3:')
     plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
      ↪Accuracy - '+var+' - Top 1:')
```

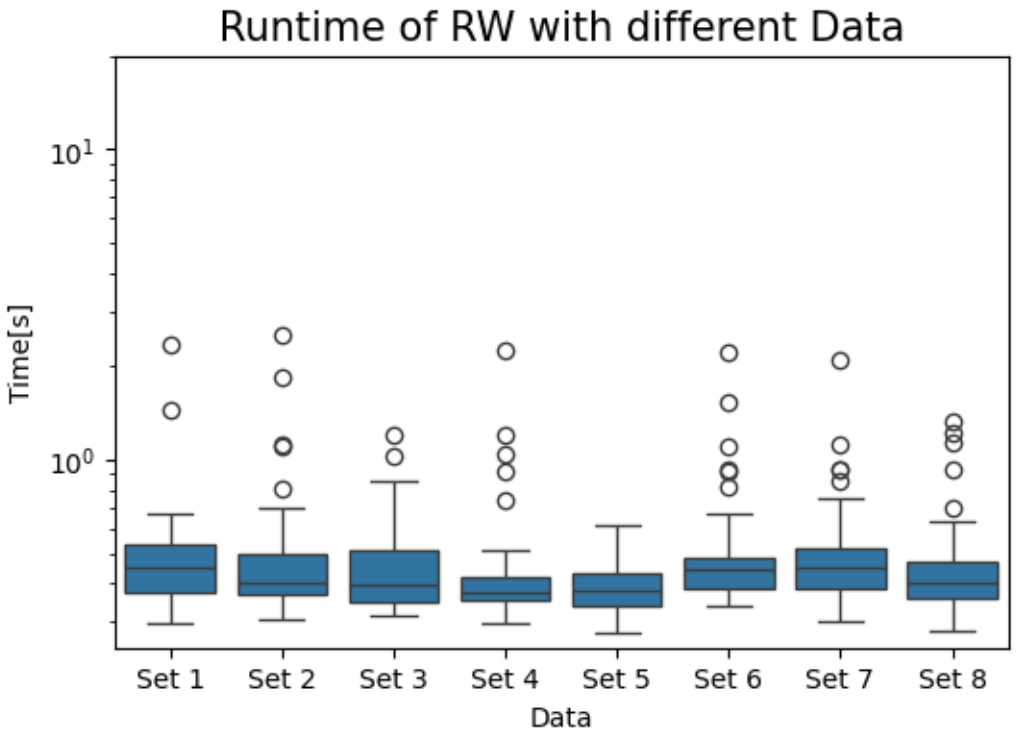

Accuracy - Data - Top 3: RW
Type: size_1
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
Type: feeder_3
0.00 0.00 0.00 0.00 0.06 0.00 0.00 0.00
Type: gripper_1
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
Type: max_Vel_2
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
Accuracy
Data
Set 1 Set 2 Set 3 Set 4 Set 5 Set 6 Set 7 Set 8


Accuracy - Data - Top 1: RW
Type: size_1
0.75 0.38 0.75 0.69 0.62 0.75 0.75 0.81
Type: feeder_3
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
Type: gripper_1
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
Type: max_Vel_2
0.94 0.94 0.94 0.88 1.00 0.88 0.94 1.00
Accuracy
Data
Set 1 Set 2 Set 3 Set 4 Set 5 Set 6 Set 7 Set 8


Overall Accuracy - Data - Top 3: RW
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.75
0.75
0.75
0.75
0.77
0.75
0.75
0.75
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Data


Overall Accuracy - Data - Top 1: RW
1.0
0.8
0.6
0.4
0.2
0.0
Accuracy
0.67
0.58
0.67
0.64
0.66
0.66
0.67
0.70
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
Data

[ ]:
```
plot_data_runtime(runtime_data_RW.T,directory_figures_path,'runtime_data_6_RW.
↪csv','Data',' RW ')
```



1.12.4 RCD - Algorithm

[ ]:
```
result_RCD_data_1, runtime_RCD_data_1 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-1',nodes=nodes,edges
result_RCD_data_2, runtime_RCD_data_2 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-2',nodes=nodes,edges
result_RCD_data_3, runtime_RCD_data_3 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-3',nodes=nodes,edges
result_RCD_data_4, runtime_RCD_data_4 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-4',nodes=nodes,edges
result_RCD_data_5, runtime_RCD_data_5 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-5',nodes=nodes,edges
result_RCD_data_6, runtime_RCD_data_6 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-6',nodes=nodes,edges
result_RCD_data_7, runtime_RCD_data_7 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-7',nodes=nodes,edges
result_RCD_data_8, runtime_RCD_data_8 =␣
↪run_RCD_normal_data(folder_path,files,startrow=950,normal_data='normal-8',nodes=nodes,edges
```

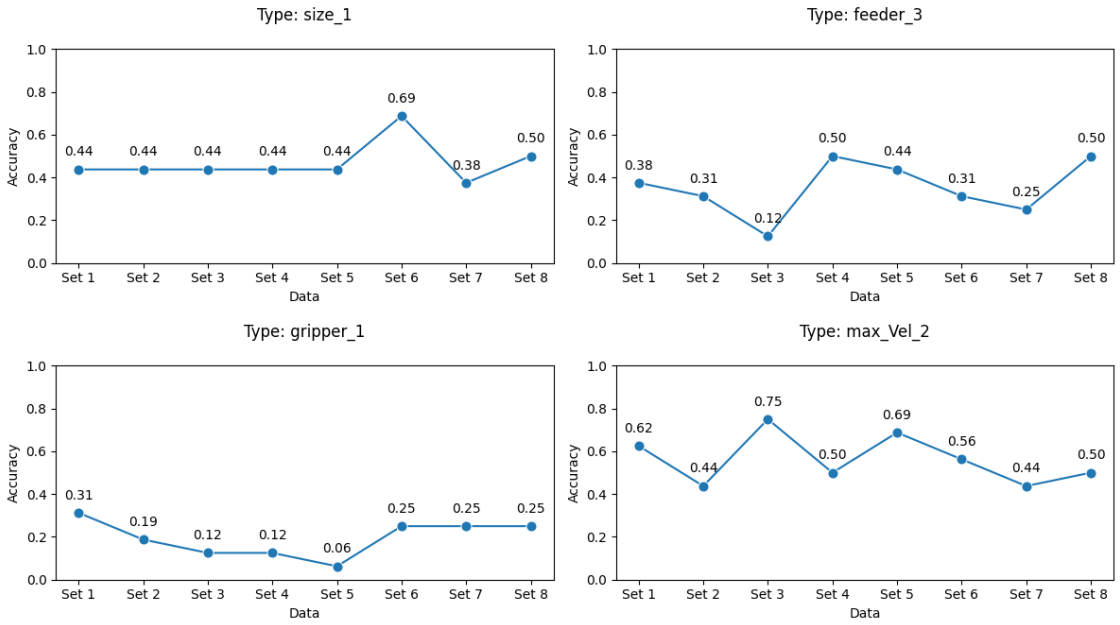
[ ]:
```
result_data_RCD = pd.DataFrame()
result_data_RCD = pd.
 ↪concat([result_RCD_data_1,result_RCD_data_2,result_RCD_data_3,result_RCD_data_4,result_RCD_
 ↪ignore_index=True)
result_data_RCD['Normal Data'] = pd.DataFrame({'RCD':['Set 1','Set 2','Set␣
 ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
result_data_RCD.set_index('Normal Data', inplace=True)
```

[ ]:
```
runtime_data_RCD = pd.DataFrame()
runtime_data_RCD = pd.concat([runtime_RCD_data_1.T,runtime_RCD_data_2.
 ↪T,runtime_RCD_data_3.T,runtime_RCD_data_4.T,runtime_RCD_data_5.
 ↪T,runtime_RCD_data_6.T,runtime_RCD_data_7.T,runtime_RCD_data_8.T],␣
 ↪ignore_index=True)
runtime_data_RCD['Normal Data'] = pd.DataFrame({'RW':['Set 1','Set 2','Set␣
 ↪3','Set 4','Set 5','Set 6','Set 7','Set 8']})
runtime_data_RCD.set_index('Normal Data', inplace=True)
```

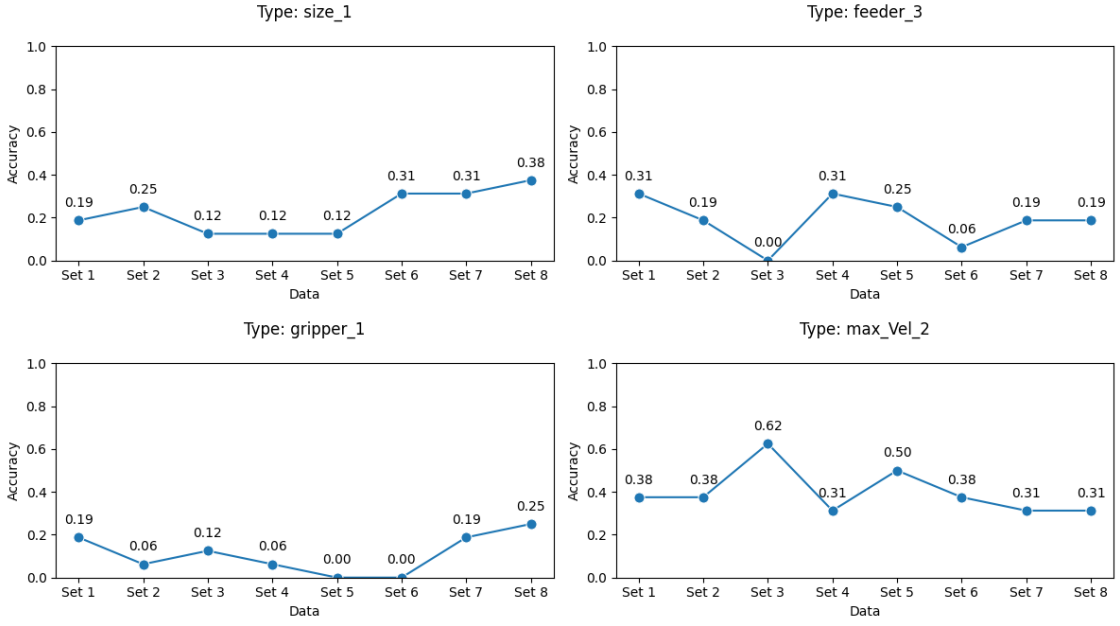
[ ]:
```
result_data_3top = results_top_3(result_data_RCD,abnormal_sets)
result_data_1top = results_top_1(result_data_RCD,abnormal_sets)
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_6_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_6_RCD.csv'))
```

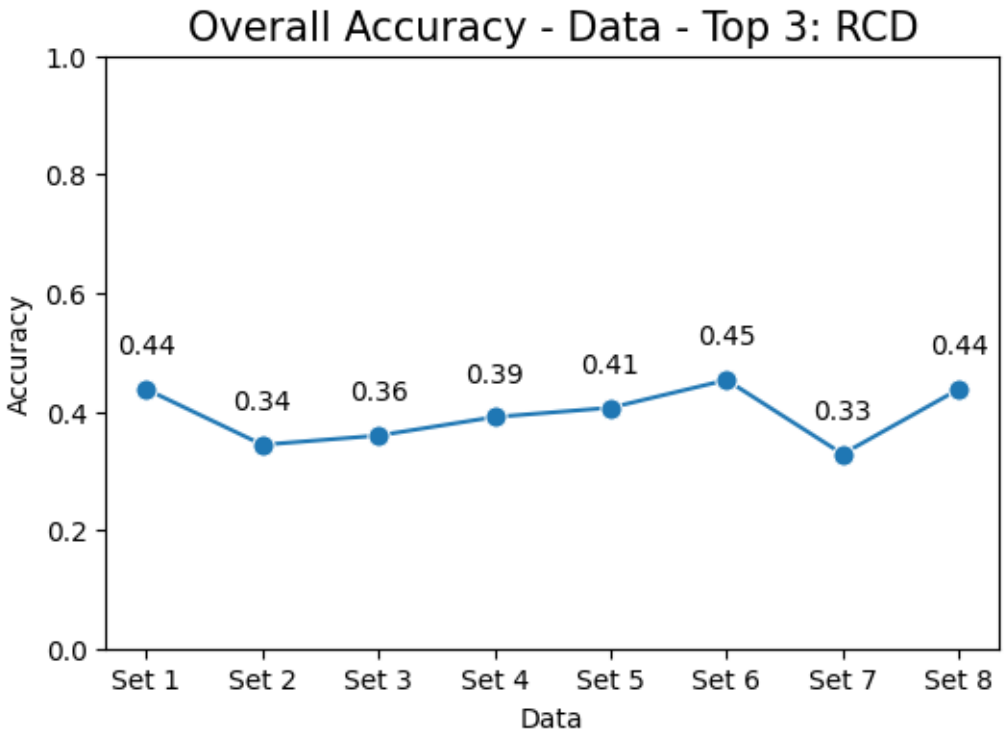
[ ]:
```
algo='RCD'
var='Data'
var_save='data'
plot_avg_var_inter(result_data_3top,directory_figures_path,'3top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 3:')
plot_avg_var_inter(result_data_1top,directory_figures_path,'1top_'+var_save+'_'+algo,var,algo,
 ↪- '+var+' - Top 1:')
plot_avg_var_total(result_data_3top,directory_figures_path,'3top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 3:')
plot_avg_var_total(result_data_1top,directory_figures_path,'1top_'+var_save+'_total_'+algo,var
 ↪Accuracy - '+var+' - Top 1:')
```

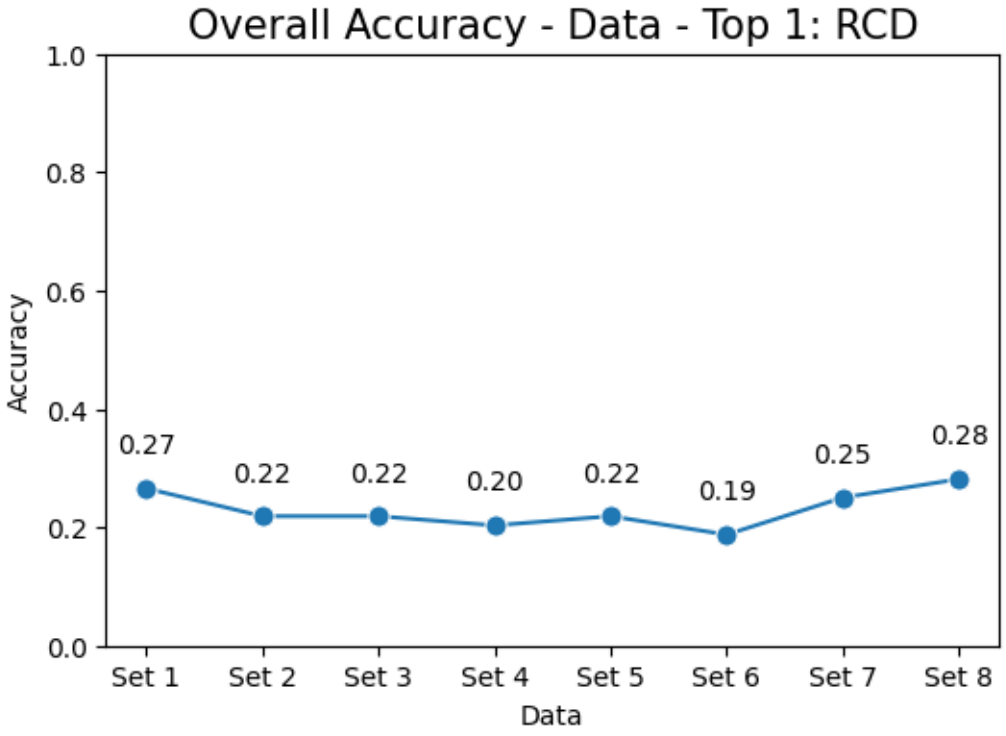
Accuracy - Data - Top 3: RCD



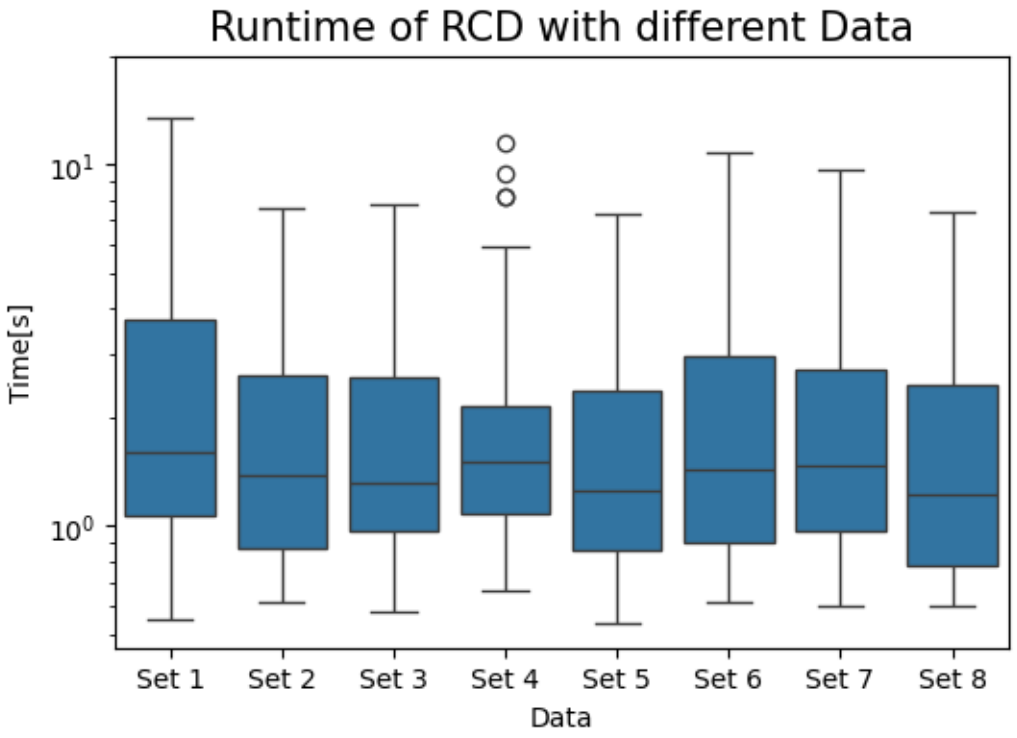
Accuracy - Data - Top 1: RCD




Overall Accuracy - Data - Top 3: RCD
Accuracy
Data
1.0
0.8
0.6
0.4
0.2
0.0
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
0.44
0.34
0.36
0.39
0.41
0.45
0.33
0.44

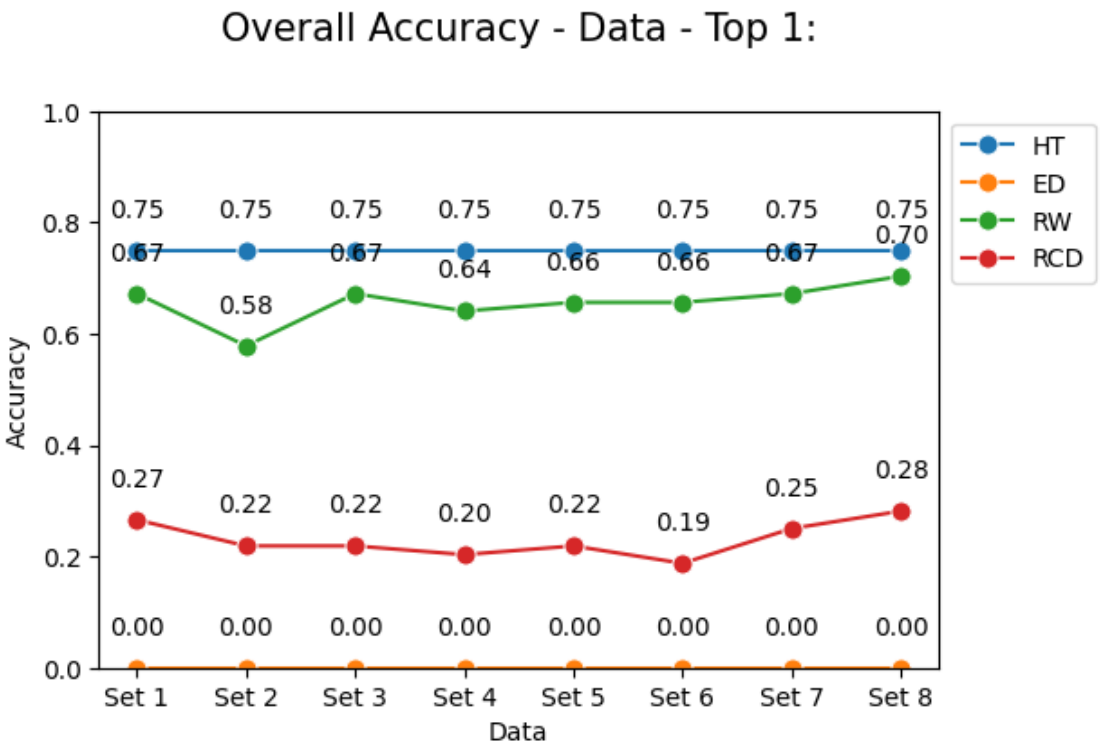

Overall Accuracy - Data - Top 1: RCD
Accuracy
Data
1.0
0.8
0.6
0.4
0.2
0.0
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
0.27
0.22
0.22
0.20
0.22
0.19
0.25
0.28

[ ]:
```
plot_data_runtime(runtime_data_RCD.T,directory_figures_path,'runtime_data_6_RCD.
↪csv','Data',' RCD ')
```

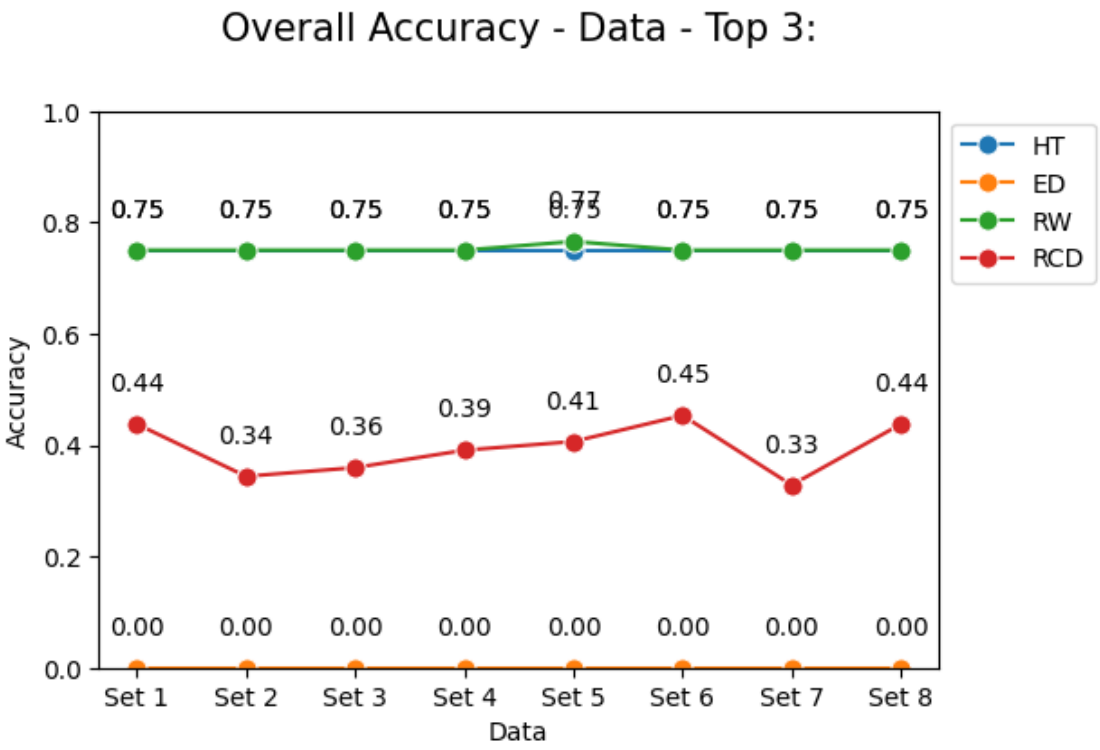


1.12.5 All together

[ ]:
```
result1 = results_top_1(result_data_HT,abnormal_sets)
result2 = results_top_1(result_data_ED,abnormal_sets)
result3 = results_top_1(result_data_RW,abnormal_sets)
result4 = results_top_1(result_data_RCD,abnormal_sets)

results_dfs = [result1,result2,result3,result4]
plot_avg_var_total_combined(results_dfs,['HT','ED','RW','RCD']␣
↪,directory_figures_path,'1top_data_total','Data','Overall Accuracy - Data -␣
↪Top 1:')
```




```
[ ]: result1 = results_top_3(result_data_HT,abnormal_sets)
     result2 = results_top_3(result_data_ED,abnormal_sets)
     result3 = results_top_3(result_data_RW,abnormal_sets)
     result4 = results_top_3(result_data_RCD,abnormal_sets)

     results_dfs = [result1,result2,result3,result4]
     plot_avg_var_total_combined(results_dfs,['HT','ED','RW','RCD']␣
      ↪,directory_figures_path,'3top_data_total','Data','Overall Accuracy - Data -␣
      ↪Top 3:')
```


Overall Accuracy - Data - Top 3:
Accuracy
Data
HT
ED
RW
RCD
1.0
0.8
0.6
0.4
0.2
0.0
Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8
0.75
0.75
0.75
0.75
0.77
0.75
0.75
0.75
0.44
0.34
0.36
0.39
0.41
0.45
0.33
0.44
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00