Discovery

September 3, 2024

1 Read and Discover Causal Graphs

1.1 Import all the necessary libraries

[ ]:

```
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import os
import math
import networkx as nx

from causallearn.search.ConstraintBased.PC import pc
from causallearn.search.ScoreBased.GES import ges
from causallearn.search.ConstraintBased.FCI import fci
```

```
c:\Users\Francisco\anaconda3\envs\thesis\lib\site-packages\tqdm\auto.py:21:
TqdmWarning: IProgress not found. Please update jupyter and ipywidgets. See
https://ipywidgets.readthedocs.io/en/stable/user_install.html
  from .autonotebook import tqdm as notebook_tqdm
```

1.2 Custom functions

[ ]:

```
# Retrieves name for filename
def get_file_name(var:str):
    return var[7:-4]
```

1.3 Show datasets in folders

[ ]:

```
# Specify the directory path
directory_path = 'G:\\My Drive\\Master Thesis\\Simulation\\Dataset'

# 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):
        if item[:7] != 'Results':
            print(f"\nFolder: {item}")
            folder_contents = os.listdir(folder_path)
            for file in folder_contents:
                file_path = os.path.join(folder_path, file)
                print(f"    -> {file}")
```

```
Folder: Dataset_2024-08-01_14-21-20
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv

Folder: Dataset_2024-08-01_20-12-23
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv
```

```
Folder: Dataset_2024-08-01_21-53-40
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv

Folder: Dataset_2024-08-06_00-47-34
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv

Folder: Dataset_2024-08-06_01-23-37
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv

Folder: Dataset_2024-08-06_14-32-37
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv

Folder: Dataset_2024-08-06_15-17-43
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv

Folder: Dataset_2024-08-06_16-12-33
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_size_1.csv
    -> data_2_event.csv
    -> data_3_feeder_3.csv
    -> data_3_event.csv
    -> data_4_gripper_1.csv
    -> data_4_event.csv
    -> data_5_max_Vel_2.csv
    -> data_5_event.csv
    -> data_6_size_1.csv
    -> data_6_event.csv
    -> data_7_feeder_3.csv
    -> data_7_event.csv
    -> data_8_gripper_1.csv
    -> data_8_event.csv
    -> data_9_max_Vel_2.csv
    -> data_9_event.csv

Folder: Dataset_2024-08-28_16-22-43
    -> data_1_normal.csv
    -> data_1_event.csv
    -> data_2_gripper_1.csv
    -> data_2_event.csv
    -> data_3_normal.csv
    -> data_3_event.csv
    -> data_4_size_1.csv
    -> data_4_event.csv
```

1.4 Select folder to read

The specific folder will be asked. The files from the folder will be used to plot the various graphs.

[ ]:

```
folder_input = input("Please select folder.")
```

[ ]:

```
# Specify the directory path
directory_path = 'G:\\My Drive\\Master Thesis\\Simulation\\Dataset'
files = {}
folder = folder_input

folder_path = os.path.join(directory_path, folder)
if os.path.isdir(folder_path):
    print(f"Chosen folder: {folder}")
    folder_contents = os.listdir(folder_path)
    for file in folder_contents:
        file_path = os.path.join(folder_path, file)
        if file[0:4] == 'data' and file[7:12] != 'event':
            files[f"{file[5:6]}_{get_file_name(file)}"] = file_path
            print(f"-> {file[5:6]}_{get_file_name(file)}")
        if file[7:12] == 'event':
            files[f"{file[5:6]}_{get_file_name(file)}"] = file_path

file_input = '1_normal'
file_selected = files[file_input]
file_selected
```

```
Chosen folder: Dataset_2024-08-06_16-12-33
-> 1_normal
-> 2_size_1
-> 3_feeder_3
-> 4_gripper_1
-> 5_max_Vel_2
-> 6_size_1
-> 7_feeder_3
-> 8_gripper_1
-> 9_max_Vel_2
```

```
[ ]: 'G:\\My Drive\\Master
     Thesis\\Simulation\\Dataset\\Dataset_2024-08-06_16-12-33\\data_1_normal.csv'
```

1.4.1 Nodes

```
[ ]: EoL_nodes = ['EoL_1_X', 'EoL_1_Y',
                  'EoL_2_X', 'EoL_2_Y',
                  'EoL_3_X', 'EoL_3_Y',
                  'EoL_4_X', 'EoL_4_Y',
                  'EoL_5_X','EoL_5_Y',
                  'EoL_6_X', 'EoL_6_Y']

     con_nodes = ['con_1','con_2','con_3']

     rob_mv_nodes = ['rob_1_1', 'rob_1_2','rob_1_3', 'rob_1_4',
                  'rob_2_1', 'rob_2_2','rob_2_3', 'rob_2_4']

     rob_ctrl_nodes =['rob_1_maxVel', 'rob_1_supply','rob_1_vacuum',
                  'rob_2_maxVel', 'rob_2_supply','rob_2_vacuum']

     cam_nodes = ['cam_1_X', 'cam_2_X', 'cam_3_X',
                  'cam_1_Y', 'cam_2_Y', 'cam_3_Y']

     nodes = EoL_nodes+con_nodes+rob_mv_nodes+rob_ctrl_nodes+cam_nodes+ ['score']
```

[ ]:

```python
nodes_dict = {index: node for index, node in enumerate(nodes)}
normal_data_df = pd.read_csv(file_selected)
normal_data_df = normal_data_df[nodes]
```

1.4.2 PC Algorithm

[ ]:

```python
graph_discovered_pc = pc(normal_data_df.to_numpy(), node_names=nodes)
graph_discovered_pc.to_nx_graph()
graph_pc = graph_discovered_pc.G
```

```
Depth=5, working on node 35: 100%|      | 36/36 [00:00<00:00, 119.69it/s]
```

1.4.3 FCI Algorithm

[ ]:

```python
graph_discovered_fci,_ = fci(normal_data_df.to_numpy(), node_names=nodes)
graph_fci = graph_discovered_fci
```

```
Depth=0, working on node 0:   0%|          | 0/36 [00:00<?, ?it/s]

Depth=0, working on node 35: 100%|      | 36/36 [00:01<00:00, 19.51it/s]

X1 --> X3
X1 --> X7
X36 --> X1
X2 --> X12
X10 --> X4
X8 --> X7
X36 --> X8
X9 --> X36
X36 --> X10
X19 --> X18
```

[ ]:

```python
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':(8,6),'con_3':(3,6)
}
```

```python
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'
}

G = nx.from_numpy_array(graph_pc.graph)

G_new = nx.relabel_nodes(G,nodes_dict)

print('Number of edges: '+str(len(G_new.edges)))
print('Number of nodes: '+str(len(G_new.nodes)))

plt.figure(figsize=(12, 10))
plt.xlim((-12,14))
plt.ylim((-12,8))
plt.title(f'Discovered Causal Graph', fontsize=12)
nx.draw(G_new, pos,with_labels=True,node_size=2000, node_color=[colors[node]␣
  ↪for node in G_new.nodes()], font_size=6, arrowsize=8,width=0.5)
```

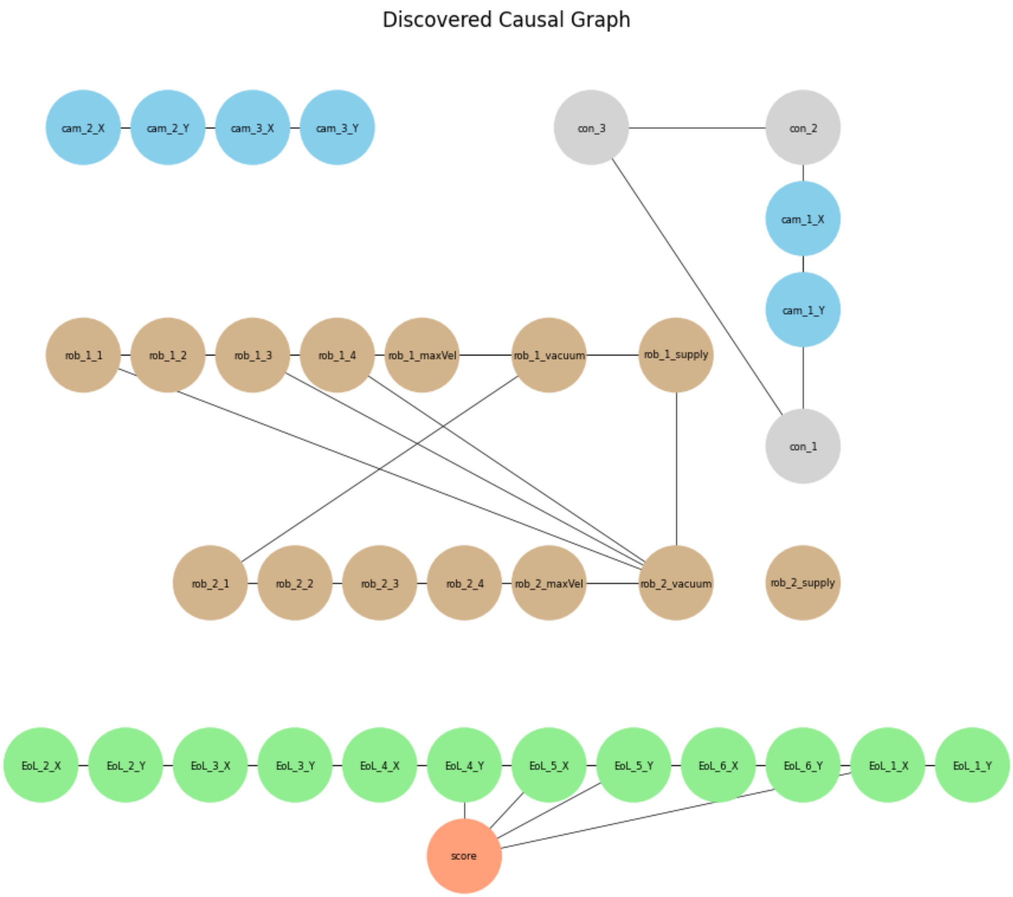
```
Number of edges: 49
Number of nodes: 36
```

```
c:\Users\Francisco\anaconda3\envs\thesis\lib\site-
packages\networkx\drawing\nx_pylab.py:305: UserWarning:

The arrowsize keyword argument is not applicable when drawing edges
with LineCollection.

To make this warning go away, either specify `arrows=True` to
force FancyArrowPatches or use the default value for arrowsize.
Note that using FancyArrowPatches may be slow for large graphs.

  draw_networkx_edges(G, pos, arrows=arrows, **edge_kwds)
```

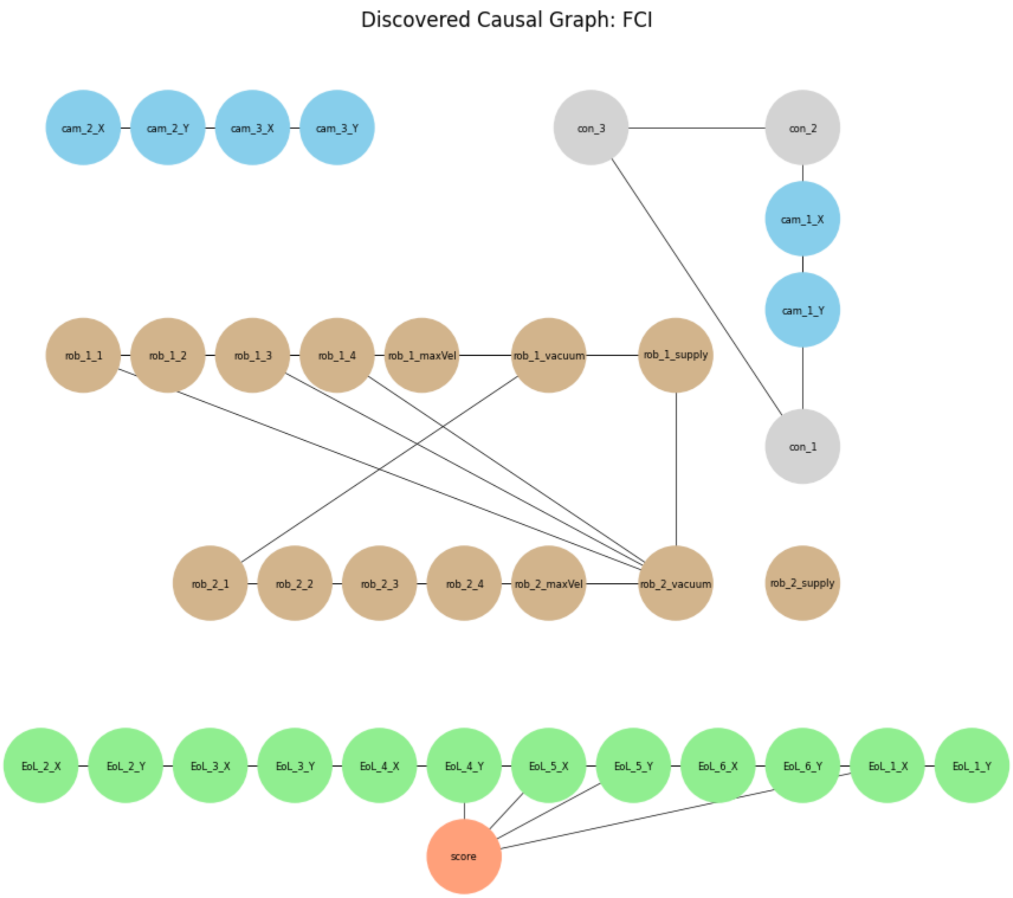


```
[ ]: G = nx.from_numpy_array(graph_fci.graph)
     G_new = nx.relabel_nodes(G,nodes_dict)

     print('Number of edges: '+str(len(G_new.edges)))
     print('Number of nodes: '+str(len(G_new.nodes)))

     plt.figure(figsize=(12, 10))
     plt.xlim((-12,14))
     plt.ylim((-12,8))
     plt.title(f'Discovered Causal Graph: FCI', fontsize=12)
     nx.draw(G_new, pos,with_labels=True,node_size=2000, node_color=[colors[node]␣
       ↪for node in G_new.nodes()], font_size=6, arrowsize=8,width=0.5)
```

```
Number of edges: 49
Number of nodes: 36
```


Discovered Causal Graph: FCI
cam_2_X
cam_2_Y
cam_3_X
cam_3_Y
con_3
con_2
cam_1_X
cam_1_Y
con_1
rob_1_1
rob_1_2
rob_1_3
rob_1_4
rob_1_maxVel
rob_1_vacuum
rob_1_supply
rob_2_1
rob_2_2
rob_2_3
rob_2_4
rob_2_maxVel
rob_2_vacuum
rob_2_supply
EoL_2_X
EoL_2_Y
EoL_3_X
EoL_3_Y
EoL_4_X
EoL_4_Y
EoL_5_X
EoL_5_Y
EoL_6_X
EoL_6_Y
EoL_1_X
EoL_1_Y
score