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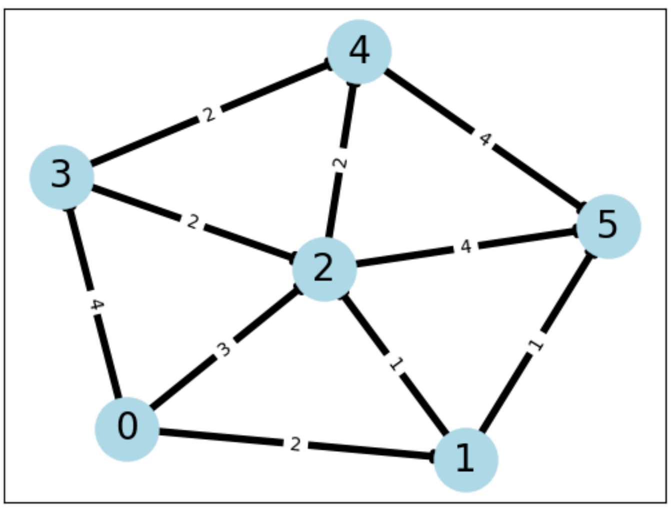
All pictures are taken from my collab code. These are the best case output that the program gives. Reproducing such outcome may or may not be possible as the graph and the graph flow is generated at random each time.

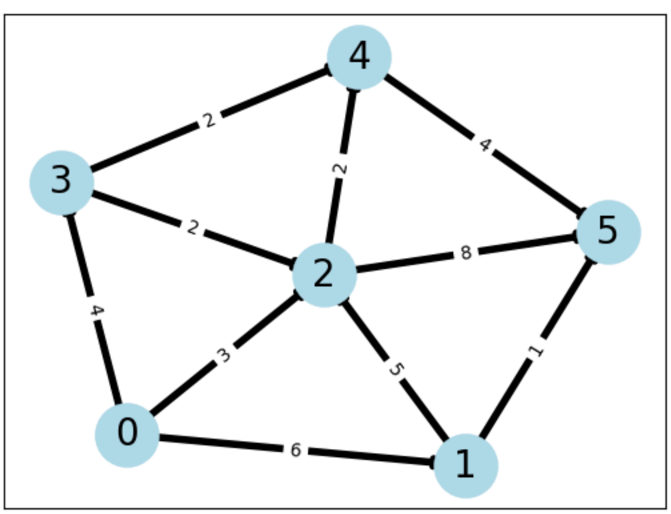
Requirement 1

This part of the program will optimize the static graph that was provide to us in the assignment. As from the result in the collab file. The algorithm performs as expected and does exactly as illustrated in the trace.

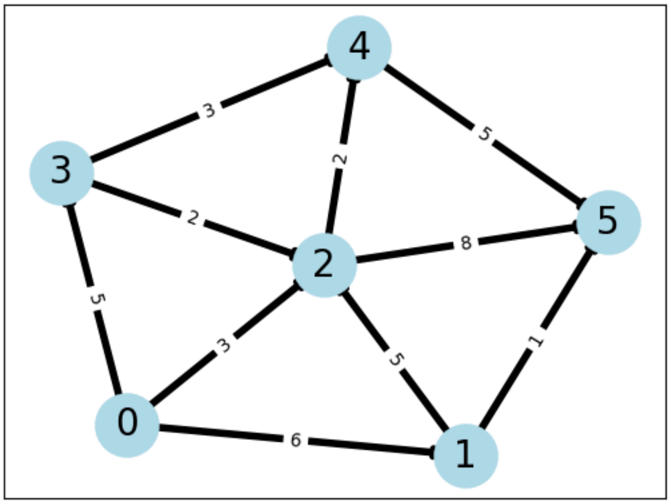
This is the initial graph



This is the graph after the first optimization.



This is the graph after the second and the final optimization.



Requirement 2

The values of Hill climbing flow (tf) and Edmond Karp flow (tf_net) are as:

Tf_net(OPTIMAL FLOW) : 19
Tf(optimized flow) : 18

```
OPTIMAL FLOW 19
Done optimizing
optimised flow 18
```

This is the most realist and expected outcome I could find after running the code a multiple time. Where EK flow is greater than our HC flow. My code normally overfits and the HC flow is much greater than the EK flow.

Requirement 3a

The values of Hill climbing flow (tf) and Edmond Karp flow (tf_net) are as:

Tf_net(OPTIMAL FLOW) : 15.2
Tf(optimized flow) : 23.86

```
Average EK flow = 15.2
Average HC flow = 23.866666666666667
```

Requirement 3b

The values of Hill climbing flow (tf) and Edmond Karp flow (tf_net) are as:

Tf_net(OPTIMAL FLOW) : 9.16
Tf(optimized flow) : 13.6

```
Average EK flow = 9.166666666666666
Average HC flow = 13.6
```

Requirement 3c

Yes, there is a significant difference between these flows. This is mainly because as the connectivity decreases the number of edges between any two nodes decreases from 3 to 2. Our code also removes all back flows so if node 3 had a flow to node 2 then such flow gets removed. I used the back flow code provided to us my Professor Pears and this is how it behaves.
As a result the edges between nodes decreases which reduces the overall flow in the system and the sink node has a lower flow as compared the flow when connectivity was 3.

Assignment2

October 24, 2023

[ ]:
```
import matplotlib.pyplot as plt
import networkx as nx
from networkx.algorithms.flow import edmonds_karp
import random
import sys
import numpy as np
import graphviz
```

[ ]:
```
!apt install libgraphviz-dev
!pip install pygraphviz
```

[ ]:
```
class Graph:
    def __init__(self, no_of_nodes, connectivity, increase, seed):
        while 1:
            self.graph=nx.gnp_random_graph(no_of_nodes, connectivity, seed,␣
↪True)
            if nx.is_weakly_connected(self.graph):
                break
            else:
                seed += increase

        #remove backflow
        for u in self.graph.nodes():
            adj_list = self.graph.adj[u]
            for nbr,datdict in adj_list.copy().items():
                # print (u,nbr)
                if (u>nbr) and self.graph.has_edge(u,nbr):
                    self.graph.remove_edge(u,nbr) # prune reverse edges from␣
↪graph

        #add flow and capacity at random
        for u, v in self.graph.edges():
            capacity=random.randint(1,10)
            flow=random.randint(1,capacity)
            self.graph.add_edges_from([(u, v, {'flow':flow }), (u,␣
↪v,{'capacity': capacity})])
```

```
        self.graph_flow_edges = nx.get_edge_attributes(self.graph, 'flow')
        self.graph_capacity_edges = nx.get_edge_attributes(self.graph,␣
↪'capacity')

        #insure the conservation is maintained
        inflow = [0 for i in range(no_of_nodes)] #an array of zeros
        for u in self.graph.nodes():
            e_in = self.graph.in_edges(u)
            e_out = self.graph.out_edges(u)
            if len(e_in) != 0 and len(e_out) != 0:
                #check and conserve flow
                for x,y in e_in:
                    search_tuple = (x,y)
                    result_tuple = self.getEdgeFlowAndCapacity(search_tuple)
                    inflow[y] += result_tuple[0]
                sum = inflow[u]
                edge_num = 0
                for u,w in e_out:
                    search_tuple = (u,w)
                    result_tuple = self.getEdgeFlowAndCapacity(search_tuple)
                    capacity = result_tuple[1]
                    if (edge_num < len(e_out) - 1):
                        while 1:
                            val = int(random.uniform(0,1) * sum)
                            if val <= capacity  and val <= sum:
                                break
                        sum = sum - val
                        self.updateFlow(u,w, val, capacity)
                        edge_num = edge_num + 1
                    else:
                        if sum > capacity:
                            #change the capacity
                            difference = sum - capacity
                            factor = random.randint(difference, difference + 9)
                            self.updateFlow(u,w, sum, capacity + factor)
                        else:
                            self.updateFlow(u,w, sum, capacity)

        self.graph_flow_edges = nx.get_edge_attributes(self.graph, 'flow')
        self.graph_capacity_edges = nx.get_edge_attributes(self.graph,␣
↪'capacity')
        # for u, v in self.graph.edges():
        #     search_tuple = (u,v)
        #     result_flow = self.getEdgeFlowAndCapacity(search_tuple)
        #     print("u,v,flow, capacity", u,v,result_flow[0], result_flow[1])
        self.no_of_nodes = self.graph.number_of_nodes()
```

```python
        path_iterator = nx.all_simple_edge_paths(self.graph, source=0, target=no_of_nodes - 1, cutoff=9)
        self.path = []
        for p in path_iterator:
            self.path.append(p)

    def getEdges(self, node):
        result = []
        for u,v in self.graph.edges():
            if u == node or v == node:
                result.append((u,v))
        return result

    def getFlows(self, node_pairs, node):
        in_flow = 0
        out_flow = 0
        for u,v in node_pairs:
            search_tuple = (u,v)
            flow = self.getEdgeFlowAndCapacity(search_tuple)
            if v == node:
                in_flow += flow[0]
            else:
                out_flow += flow[0]
        return [in_flow, out_flow]

    def checkConservation(self):
        a = len(self.graph.nodes())
        #only need to loop a - 2 times as we will not check the flow conservation for the sink and source node
        for i in range(1,a-1):
            # go over the edges and find all (u,v) combination that has i either in u or v
            node_pair = self.getEdges(i)
            # for (u,v) that has i in 1st index add the flow to inflow
            # for (u,v) that has i in the 2nd index add the flow to outflow
            flows = self.getFlows(node_pair, i)
            out_flow = flows[1]
            in_flow = flows[0]
            if in_flow != out_flow and in_flow != 0 and out_flow != 0:
                print('the flow for the node is not conserverd')
                print('node in out', i, flows[0], flows[1])
            # else:
            #     print("conserved")

    # search_tuple is made of nodes.
    # (1, 2) represents the tuple of node 1 and node 2
    def getEdgeFlowAndCapacity(self, search_tuple):
```

```python
        flow = -1
        capacity = -1
        for key in self.graph_flow_edges:
            if key == search_tuple:
                flow = self.graph_flow_edges[key]
                capacity = self.graph_capacity_edges[key]
        return (flow, capacity)

    # where u and v are nodes
    def updateFlow(self, u, v, new_flow, capacity):
        self.graph.add_edges_from([(u, v, {'flow': new_flow}), (u, v,{'capacity': capacity})])
        self.graph_flow_edges = nx.get_edge_attributes(self.graph, 'flow')

    def plotGraph(self):
        links = [(u, v) for (u, v, d) in self.graph.edges(data=True)]
        pos = nx.nx_agraph.graphviz_layout(self.graph)
        nx.draw_networkx_nodes(self.graph, pos, node_size=1200, node_color='lightblue', linewidths=0.25) # draw nodes
        nx.draw_networkx_edges(self.graph, pos, edgelist=links, width=4)                     # draw edges
        nx.draw_networkx_labels(self.graph, pos, font_size=20, font_family="sans-serif")                 # node labels
        edge_labels = nx.get_edge_attributes(self.graph, 'flow')                     # edge weight labels
        # print('edge labels', edge_labels)
        nx.draw_networkx_edge_labels(self.graph, pos, edge_labels)
        plt.show()

    def simulateGraph(self):
        self.graph = nx.DiGraph()
        self.graph.add_edges_from([
            (0, 1, {'flow': 2}), (0, 1,{'capacity': 6}),
            (0, 2,{'flow': 3}), (0, 2,{'capacity': 3}),
            (0,3,{'flow': 4}), (0,3,{'capacity': 5}),
            (1,2, {'flow': 1}), (1,2,{'capacity': 5}),
            (1,5, {'flow': 1}), (1,5,{'capacity': 3}),
            (2,4, {'flow': 2}), (2,4,{'capacity': 9}),
            (2,5, {'flow': 4}), (2,5,{'capacity': 8}),
            (3,2, {'flow': 2}), (3,2,{'capacity': 2}),
            (3,4,{'flow': 2}), (3,4,{'capacity': 3}),
            (4,5, {'flow': 4}), (4,5,{'capacity': 5})])

        self.graph_flow_edges = nx.get_edge_attributes(self.graph, 'flow')
        self.graph_capacity_edges = nx.get_edge_attributes(self.graph, 'capacity')
```

```
        self.no_of_nodes = self.graph.number_of_nodes()
        path_iterator = nx.all_simple_edge_paths(self.graph, source=0,␣
 ↪target=5, cutoff=9)
        self.path = []
        for p in path_iterator:
            self.path.append(p)

    def makeFlowConsistent(self):
        pass
```

[ ]:
```
class Agent:
    def __init__(self, no_of_nodes, connectivity, simulate = 0):
      seed = 1000
      self.graph = Graph( no_of_nodes, connectivity, 0.01, seed)
      if simulate == 1:
        self.graph.simulateGraph()
        print("INITIAL GRAPH")
        self.graph.plotGraph()

    def getMaxIndex(self, heuristic_value_list):
        maxx = -1
        maxIndex = -1
        index = 0
        for v in heuristic_value_list:
          if v > maxx:
            maxIndex = index
            maxx = v
          index += 1
        return (maxIndex, maxx)


    def heuristicFunction(self):
        # 1. calculate the heuristic value for each path and store in␣
 ↪heuristic_value_list
        # Nodes make up edges and collection of nodes make up path so,
        # iterate over each path
        heuristic_value_list = []
        for p in self.graph.path:
            minn = sys.maxsize
            # print('path ', p)
            # once inside the path iterate over each edges i.e the connectors␣
 ↪between nodes
            for u,v in p:
                search_tuple = (u,v)
                result_tuple = self.graph.getEdgeFlowAndCapacity(search_tuple)
                remaining_flow = result_tuple[1] - result_tuple[0]
                # print(u,v , remaining_flow)
```

```
                if remaining_flow == 0:
                    minn = 0
                    break
                else:
                    minn = min(minn, remaining_flow)
            # print('heuristic value is', minn)
            heuristic_value_list.append(minn)
        # 2. find the max heuristic in the heuristic_value_list and return the␣
↪path
        if np.any(heuristic_value_list):
            result = self.getMaxIndex(heuristic_value_list)
            max_heuristic_index = result[0]
            max_heuristic_value = result[1]
            return (self.graph.path[max_heuristic_index], max_heuristic_value)
        else:
            print("all zeross")
            return ()

    def stocasticHeuristicFunction(self):
        # 1. calculate the heuristic value for each path and store in␣
↪heuristic_value_list
        # Nodes make up edges and collection of nodes make up path so,
        # iterate over each path
        heuristic_value_list = []
        for p in self.graph.path:
            minn = sys.maxsize
            # once inside the path iterate over each edges i.e the connectors␣
↪between nodes
            for u,v in p:
                search_tuple = (u,v)
                result_tuple = self.graph.getEdgeFlowAndCapacity(search_tuple)
                remaining_flow = result_tuple[1] - result_tuple[0]
                if remaining_flow == 0:
                    minn = 0
                    break
                else:
                    minn = min(minn, remaining_flow)
            heuristic_value_list.append(minn)
        # 2. find the max heuristic in the heuristic_value_list and return the␣
↪path stocastically
        # calculate the probability of each heuristic value
        sum_array = sum(heuristic_value_list)
        probability_weight = []

        if sum_array != 0:
            for h in heuristic_value_list:
                probability_weight.append(int((h/sum_array) * 100 ))
```

```
            result = random.choices(heuristic_value_list, weights=␣
↪probability_weight, k=1)
            heuristic_index = heuristic_value_list.index(result[0])
            return (self.graph.path[heuristic_index], result[0])
        else:
            # print("all zeross")
            return ()


    def optimizeHeuristic(self, max_heuristic_child_list, increase_factor):
        for u, v in max_heuristic_child_list:
            search_tuple = (u, v)
            result_tuple = self.graph.getEdgeFlowAndCapacity(search_tuple)
            new_flow = result_tuple[0] + increase_factor
            self.graph.updateFlow(u,v, new_flow, result_tuple[1])

    def getOptimizedFlow(self):
        # do not consider the nodes that cant be reached to as edmonds karp␣
↪does the same
        ignore_node = []
        for n in range(self.graph.no_of_nodes):
            e_in = self.graph.graph.in_edges(n)
            e_out = self.graph.graph.out_edges(n)
            source_node = 0
            sink_node = self.graph.no_of_nodes - 1
            if len(e_in) == 0 and n != source_node:
                ignore_node.append(n)
            else:
                #check if the only in node is from the ignored node
                if len(e_in) == 1:
                    for u,v in e_in:
                        for i in ignore_node:
                            if u == i:
                                ignore_node.append(n)
                                break

        sink_node = self.graph.no_of_nodes - 1
        flow = 0
        for u,v in self.graph.graph_flow_edges:
            if v == sink_node:
                if u in ignore_node:
                    continue
                search_tuple = (u, v)
                result_tuple = self.graph.getEdgeFlowAndCapacity(search_tuple)
                flow = flow + result_tuple[0]
        return flow
```

```
    def optimize(self):
        # 1. compute the optimized flow using edmonds karp algorithm
        R = edmonds_karp(self.graph.graph, 0, self.graph.no_of_nodes - 1,␣
↪'capacity')
        flow_value = nx.maximum_flow_value(self.graph.graph, 0, self.graph.
↪no_of_nodes - 1)

        print('OPTIMAL FLOW', flow_value)

        while(1):
            # 2. compute heuristic function on each path
            res = self.heuristicFunction()

            # 3. optimize the flow for the chosen path
            if res == ():
                print("Done optimizing")
                break
            else:
                max_heuristic_child_list = res[0]
                heuristic = res[1]
                self.optimizeHeuristic(max_heuristic_child_list, heuristic)

            print("After applying heuristic function")
            self.graph.plotGraph()

        print("The optimised flow and capacity are")
         # 4. print the edges flow and capacity
        for u, v in self.graph.graph.edges():
            search_tuple = (u,v)
            result_flow = self.graph.getEdgeFlowAndCapacity(search_tuple)
            print("u -> v, flow , capacity", u,v,result_flow[0], result_flow[1])

        # 5. once optimized print the optimized flow
        optimised_flow = self.getOptimizedFlow()
        print('optimised flow', optimised_flow)

    def optimizeStostacilly(self):
        # 1. compute the optimized flow using edmonds karp algorithm
        R = edmonds_karp(self.graph.graph, 0, self.graph.no_of_nodes - 1,␣
↪'capacity')
        flow_value = nx.maximum_flow_value(self.graph.graph, 0, self.graph.
↪no_of_nodes - 1)

        print('OPTIMAL FLOW', flow_value)

        while(1):
            # 2. compute heuristic function on each path
```

```python
            res = self.stocasticHeuristicFunction()

            # 3. optimize the flow for the chosen path
            if res == ():
                print("Done optimizing")
                break
            else:
                max_heuristic_child_list = res[0]
                heuristic = res[1]
                self.optimizeHeuristic(max_heuristic_child_list, heuristic)

        # 4. once optimized print the optimized flow
        optimised_flow = self.getOptimizedFlow()
        print('optimised flow', optimised_flow)

        return (flow_value, optimised_flow)
```

[ ]:
```python
# Requirement 1
if __name__ == "__main__":
    agent = Agent(30,0.1,1)
    agent.graph.checkConservation()
    agent.optimize()
```

[ ]:
```python
# Requirement 2
# Mostly overfits (performs better than the edmonds karp algorithm), sometimes
 ↪underperforms or has equal flow
# The output in 3a will give you an idea of what I mean
# The hill climbing algorithm works perfectly though
if __name__ == "__main__":
    agent = Agent(30,0.1,0)
    agent.graph.checkConservation()
    flows = agent.optimizeStostacilly()
```

[ ]:
```python
# Requirement 3a
if __name__ == "__main__":

    max = 0
    hill = 0
    for i in range(30):
        agent = Agent(30,0.1,0)
        agent.graph.checkConservation()
        flows = agent.optimizeStostacilly()
        max += flows[0]
        hill += flows[1]
        print()

    print("Average EK flow =", max/30)
```

```
    print("Average HC flow =", hill/30)
```

[ ]:
```
# Requirement 3b
if __name__ == "__main__":

    max = 0
    hill = 0
    for i in range(30):
        agent = Agent(30,0.07)
        agent.graph.checkConservation()
        flows = agent.optimizeStostacilly()
        max += flows[0]
        hill += flows[1]
        print()

    print("Average EK flow =", max/30)
    print("Average HC flow =", hill/30)
```

[ ]:
```
# !sudo apt-get install texlive-xetex texlive-fonts-recommended␣
 ↪texlive-plain-generic

!jupyter nbconvert --to pdf /content/drive/MyDrive/Colab\ Notebooks/Assignment2.
 ↪ipynb
```