Programming Assignment Report:

Signal Flow Graphs & Routh Stability Criterion

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1.Problem Statement:

- **Part 1**: Analyze a signal flow graph (SFG) to compute:
  - Forward paths, loops, and non-touching loops.
  - Determinants and the overall transfer function using Mason's Gain Formula.
- **Part 2**: Determine system stability using the Routh-Hurwitz criterion for a given characteristic equation.

2.Main Features:

- **Signal Flow Graph Solver:**
  - Parses SFG input (nodes, edges, gains) using **SignalFlowGraphSolverSchema.**
  - Computes paths/loops using graph traversal (implied by **networkx**).
  - Calculates determinants and transfer function symbolically (**sympy**).
- **Routh Stability Analyzer:**
  - Parses polynomial input (s^5 + s^4 + 10s^3).
  - Constructs Routh array and checks for sign changes.
  - Handles edge cases.
- **Additional Features:**
  - Input validation by **marshmallow**.
  - Symbolic math for precise calculations (**sympy**).

3.Data Structures:

- **Signal Flow Graph:**
  - Represented as a directed multigraph (**networkx.MultiDiGraph**).
  - Nodes: Strings ("A", "B").
  - Edges: Tuples (source, target, gain) with **sympy**-parsed gains.
- **Paths/Loops:**
  - **Path** class stores nodes/edges and computes gains.
  - **ForwardPath** extends **Path** with determinant tracking.
- **Routh Table:**
  - 2D NumPy array for coefficients.
  - Auxiliary polynomial handling for zero rows.

4.Main Modules:

1. Signal Flow Graph (SFG) Solver Module

- **Files**: sfg.py, marshaller.py, path.py, classes.py (implied).
- **Responsibilities:**
  - **Input Validation**: Uses **marshmallow** (**SignalFlowGraphSolverSchema**) to validate JSON input for nodes, edges, and gains.
  - **Graph Representation**: Constructs a directed multigraph (**networkx.MultiDiGraph**) from validated input.
  - **Path/Loop Analysis**:
    - **Path** and **ForwardPath** classes store nodes/edges and compute gains.
    - Algorithms (DFS/BFS) traverse the graph to find forward paths and loops.
  - **Mason's Gain Formula**: Computes determinants (Δ, Δ*k*) and transfer function symbolically (**sympy**).

2. Routh Stability Analyzer Module

- **Files**: solver.py.
- **Responsibilities**:
  - **Polynomial Parsing**: Converts input strings to sympy expressions.
  - **Routh Table Construction**:
    - Builds the Routh array from polynomial coefficients.
    - Handles edge cases.
  - **Stability Check**: Counts sign changes in the first column of the Routh table to determine stability.

3. Data Marshalling Module

- **Files**: marshaller.py.
- **Responsibilities**:

- **Input/Output Standardization**:
  - **marshall_input:** Validates and converts raw input (JSON) into a graph object.
  - **marshall_output:** Formats results (paths, determinants, etc.) for display/storage.

4. Core Utilities

- **Dependencies**:
  - **sympy**: Symbolic math for determinants and transfer functions.(v1.13.1)
  - **networkx**: Graph traversal and cycle detection.
  - **numpy**: Numerical operations for Routh array.

5.Algorithms:

Part 1: Signal Flow Graph

1. **Graph Traversal**:
   - **Forward Paths**: DFS/BFS from input to output node.
   - **Loops**: Cycle detection in **networkx**.
2. **Mason's Gain Formula**:
   - $\Delta = 1 - \sum L_i + \sum L_i L_j - \sum L_i L_j L_k + \ldots$
   - Δk: Determinant for the k-th forward path.
3. **Non-Touching Loops:**
   - Combinations of loops with no common nodes (combinatorial search).

Part 2: Routh-Hurwitz Criterion

1. **Polynomial Parsing:**
   - Convert input string to **sympy** expression.
2. **Routh Array Construction:**

- Fill rows recursively:

$$r_{i,j} = (r_{i-1,0} * r_{i-2,j+1} - r_{i-2,0} * r_{i-1,j+1}) / (r_{i-1,0})$$

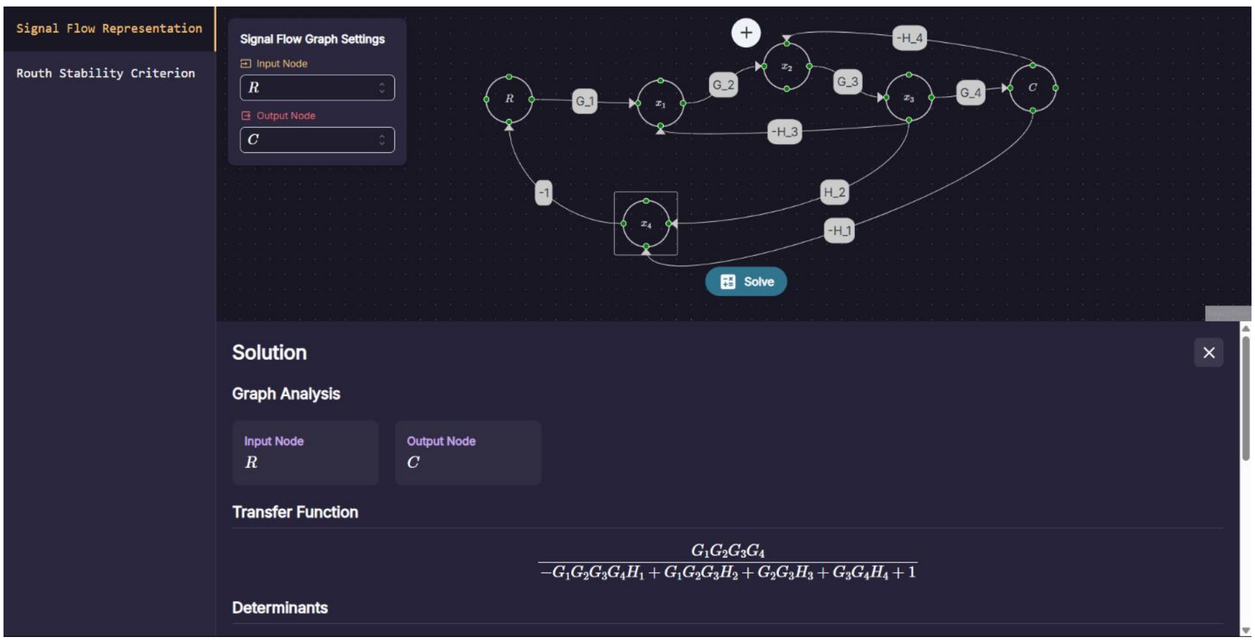
- Handle zero rows with auxiliary polynomials.

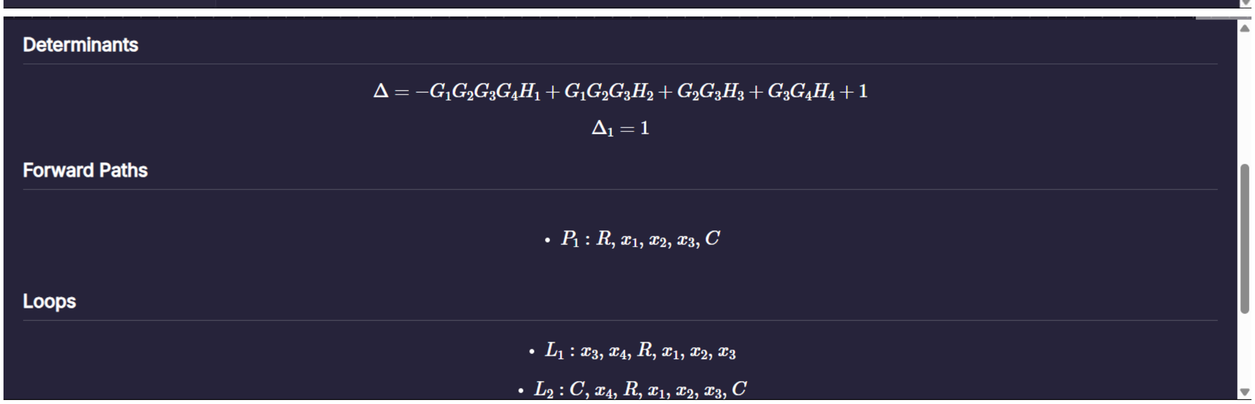
3. **Stability Check:**

   - Count sign changes in the first column (unstable if > 0).

6.Sample Runs:

Signal Flow Representation:





Loops

- $L_1 : x_3, x_4, R, x_1, x_2, x_3$
- $L_2 : C, x_4, R, x_1, x_2, x_3, C$
- $L_3 : C, x_2, x_3, C$
- $L_4 : x_3, x_1, x_2, x_3$

Non Touching Loops

Signal Flow Representation

Routh Stability Criterion

Signal Flow Graph Settings

Input Node

R

Output Node

C

Solve

Solution

Graph Analysis

Input Node
R

Output Node
C

Transfer Function

$$\frac{G_1G_2G_3G_4}{G_1G_2G_3G_4H_6 + G_1G_2G_3H_1H_5 + G_1G_3H_1H_3 + G_1G_4H_1H_4 + G_1H_1 + G_2G_3H_5 + G_2G_4H_2H_4 + G_2H_2 + G_3H_3 + G_4H_4 + 1}$$

Determinants

Determinants

$$\Delta = G_1G_2G_3G_4H_6 + G_1G_2G_3H_1H_5 + G_1G_3H_1H_3 + G_1G_4H_1H_4 + G_1H_1 + G_2G_3H_5 + G_2G_4H_2H_4 + G_2H_2 + G_3H_3 + G_4H_4 + 1$$

$$\Delta_1 = 1$$

Forward Paths

- $P_1 : R, x_1, x_2, x_3, x_4, x_5, C$

Loops

- $L_1 : C, x_5, C$
- $L_2 : x_3, x_4, x_2, x_3$

Loops

- $L_1 : C, x_5, C$
- $L_2 : x_3, x_4, x_2, x_3$
- $L_3 : x_2, x_1, x_2$
- $L_4 : C, R, x_1, x_2, x_3, x_4, x_5, C$
- $L_5 : x_3, x_4, x_5, x_3$
- $L_6 : x_4, x_5, x_4$

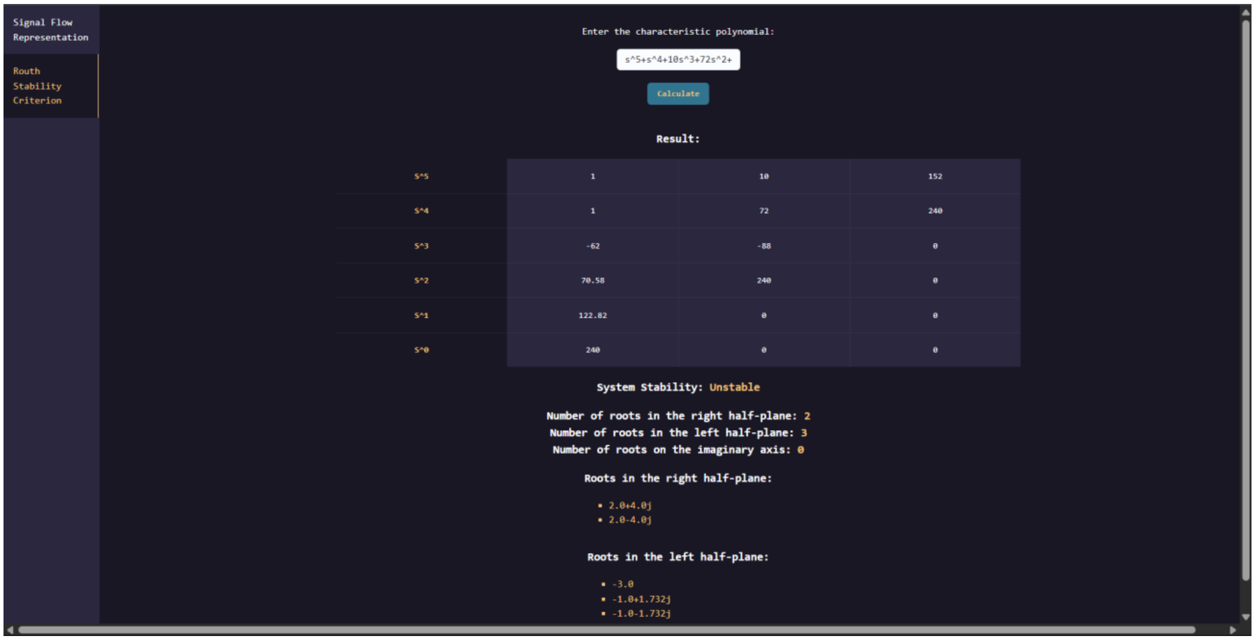
Non Touching Loops

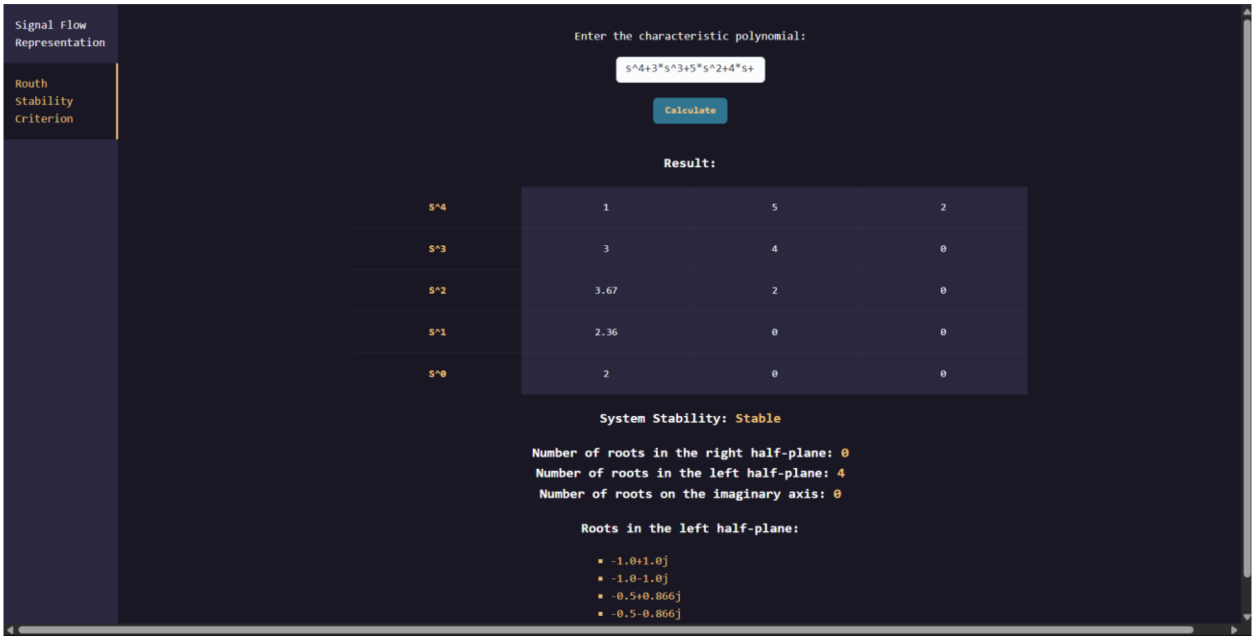
- Combinations of 2 non-touching loops:

Non Touching Loops

- Combinations of 2 non-touching loops:
  - $(C, x_5, C), (x_3, x_4, x_2, x_3)$
  - $(C, x_5, C), (x_2, x_1, x_2)$
  - $(x_2, x_1, x_2), (x_3, x_4, x_5, x_3)$
  - $(x_2, x_1, x_2), (x_4, x_5, x_4)$

Routh Stability Criterion:





7.User Guide:

1. **Installation**:
   - Run “pip install flask flask_cors networkx sympy numpy marshmallow”.
   - Note: make sure the version of **sympy** is **1.13.1**.

2. **Running the Program:**
   - **Run frontend:**

     While in the “react-frontend” folder:

     1. Run “npm install” in the terminal.
     2. Run “npm run dev” to run the front end.

   - **Run backend:**

     While in the “flask-backend” folder:

     1. Run “python app.py” in the terminal to run the back end.

        Note: make sure port 5000 is free on the machine.

3. **Input Format:**
   - **SFG:** the input is in the form of graph, so the user draws the signal flow graph using the (+) sign on top and connects using the small colored dots.
   - **Polynomial:** String with **^** or ****** for exponential relations (example: s^5 + 10s^3).

Repo: GitHub - Abdelrahman-Nasr6161/SignalFlowChartSolver