CMPSC 465: LECTURE XIII

Strongly Connected Components

Ke Chen

September 29, 2025

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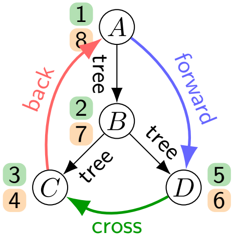

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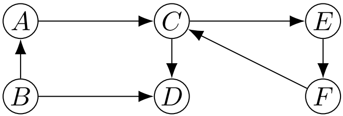

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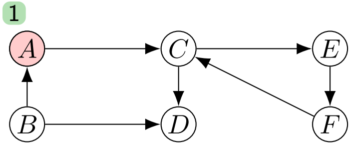

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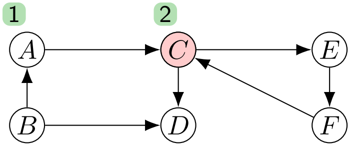

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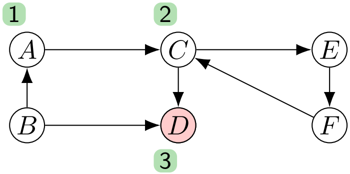

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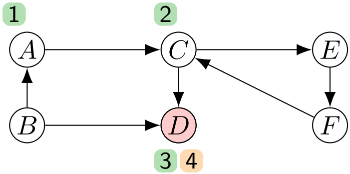

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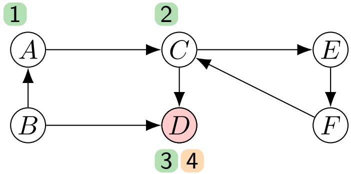

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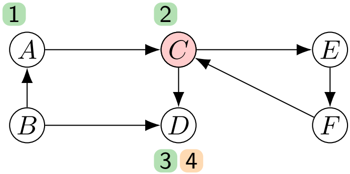

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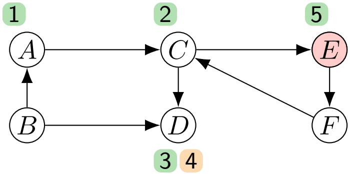

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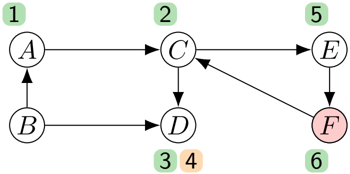

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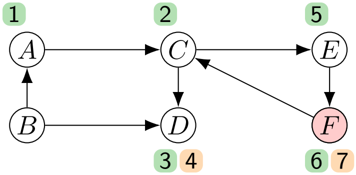

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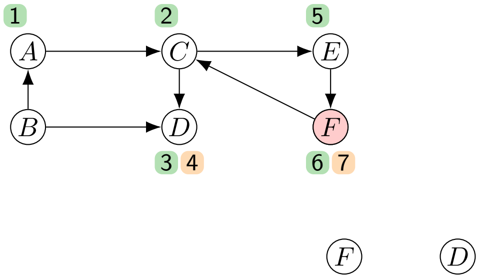

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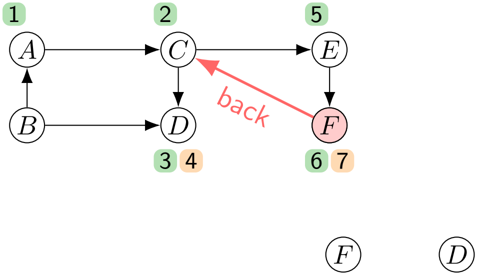

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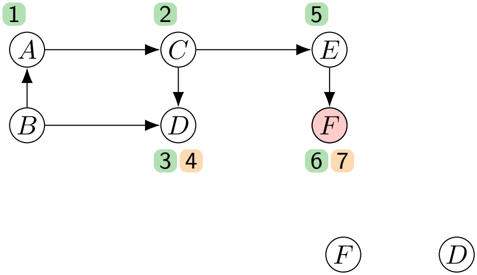

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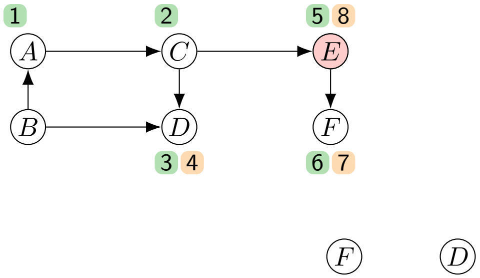

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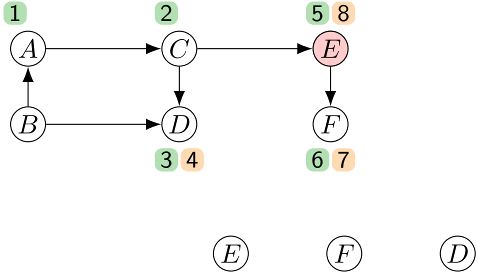

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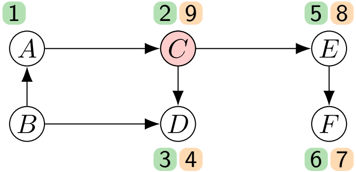

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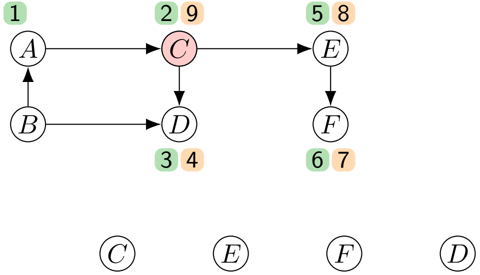

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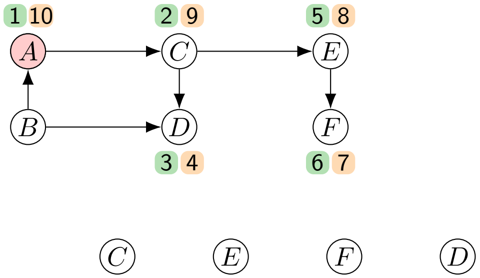

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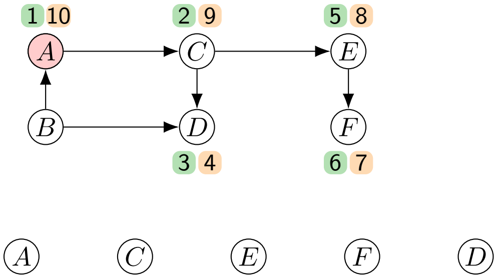

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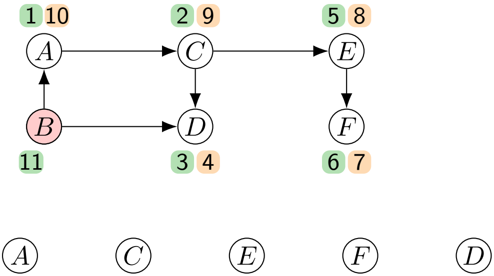

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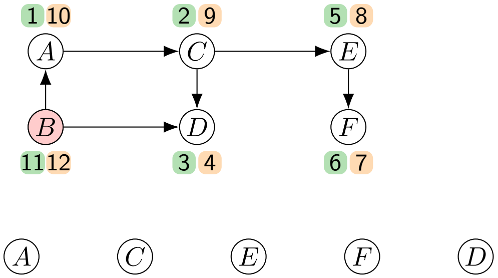

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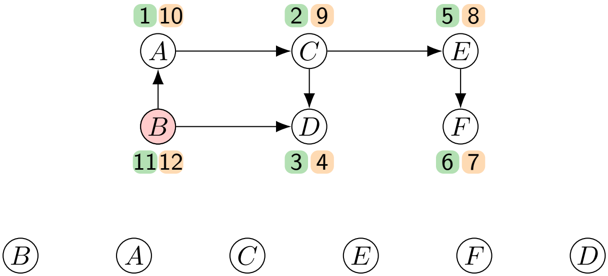

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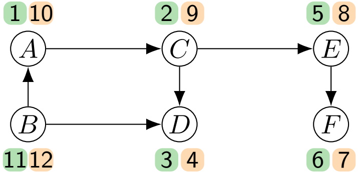

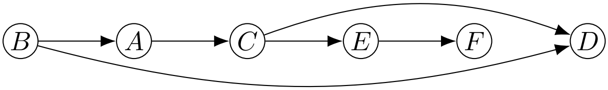

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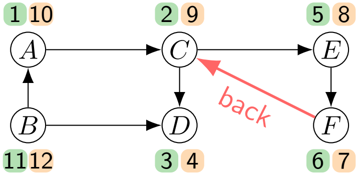

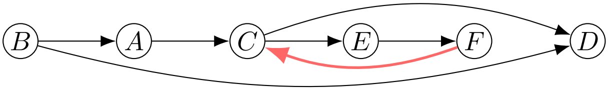

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- Each subset is called a strongly connected component (SCC).

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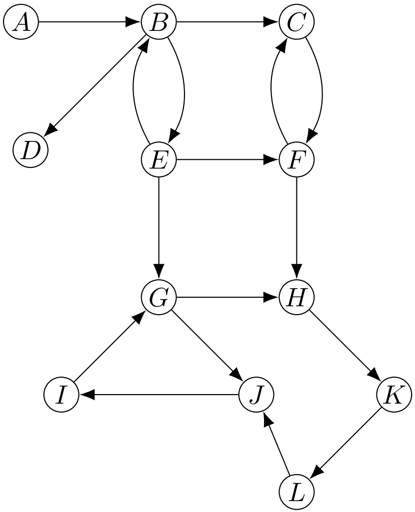

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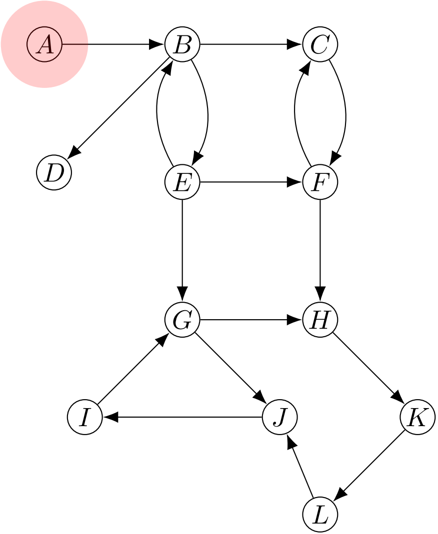

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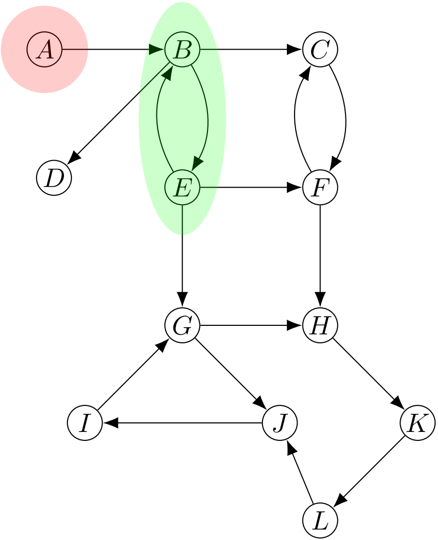

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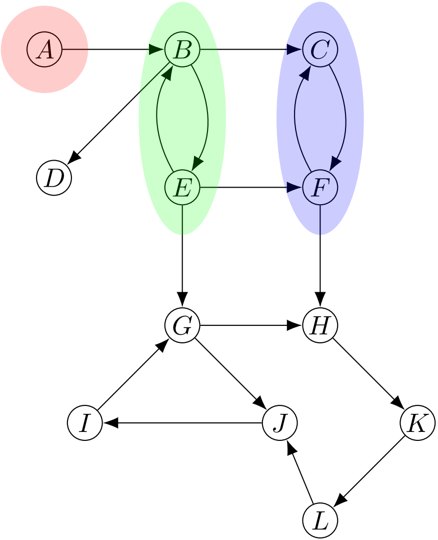

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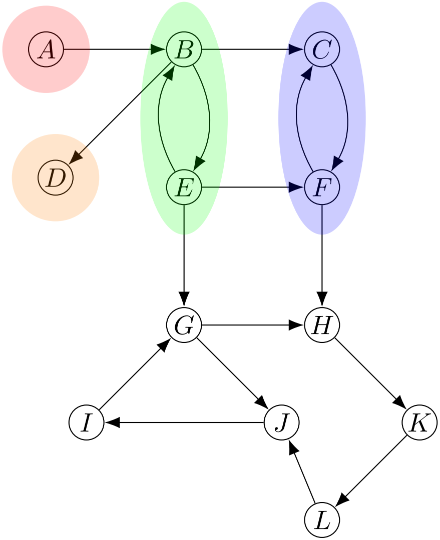

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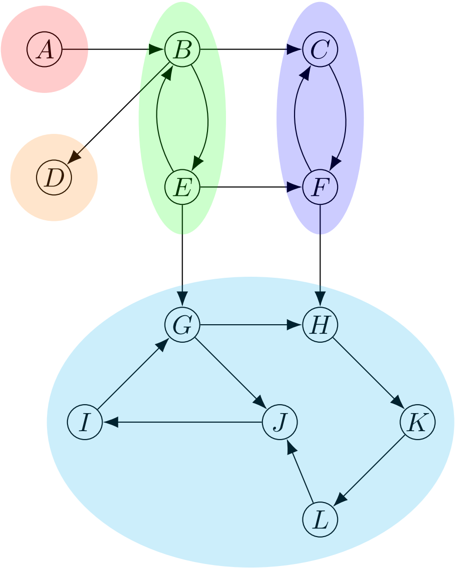

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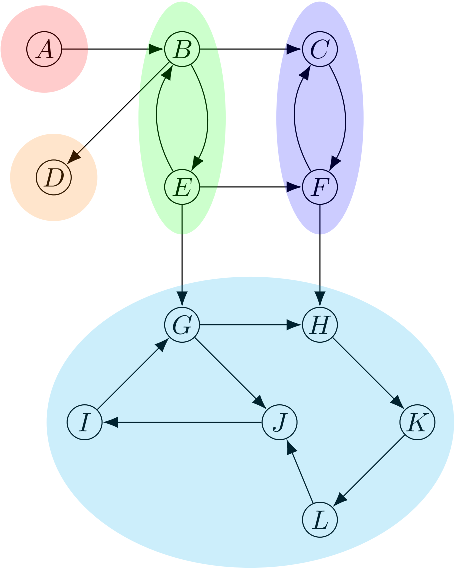

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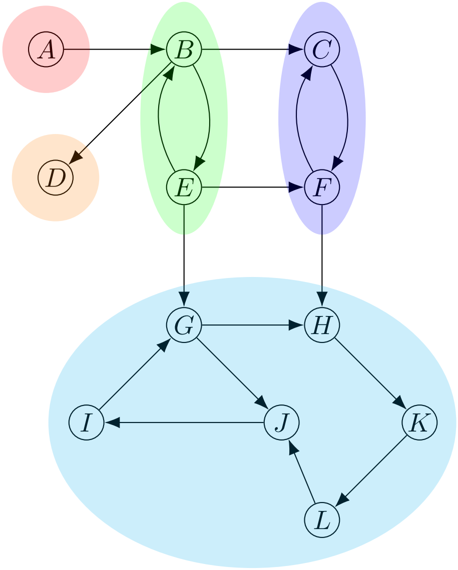

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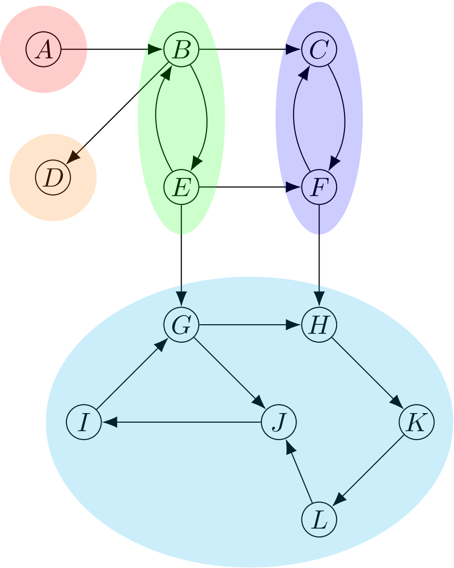
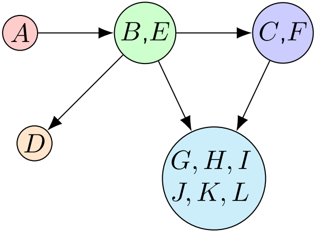
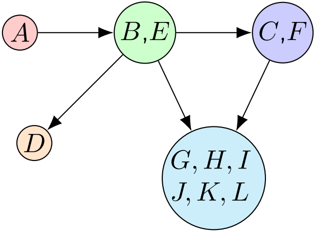




Meta graph



Each directed graph has a corresponding meta graph

- Vertices correspond to SCC's.
- Edges correspond to paths between SCC's.

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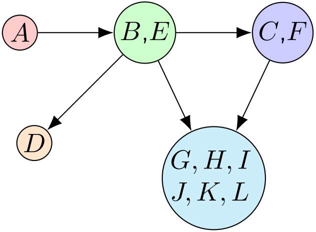

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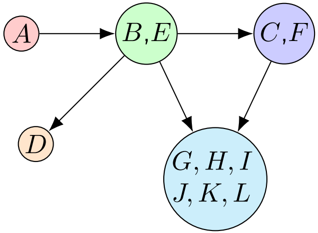

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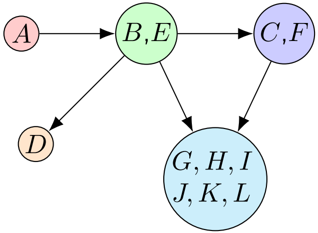
Fact The meta graph is a DAG.

Proof. If there was a cycle in the meta graph, then the SCC's in the cycle would be merged together.

Meta graph



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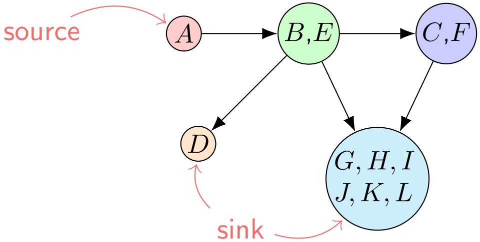

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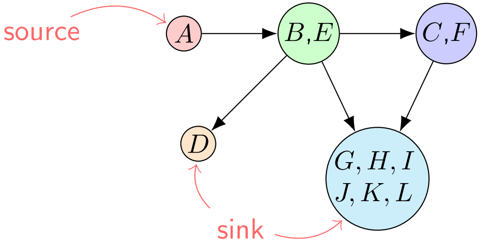

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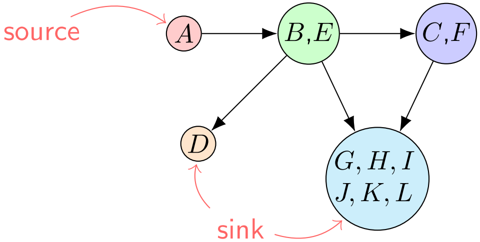

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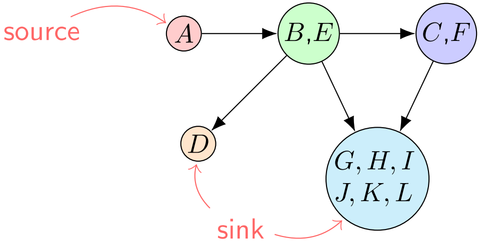

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2. Call Explore on it.
3. Remove the found SCC and repeat.

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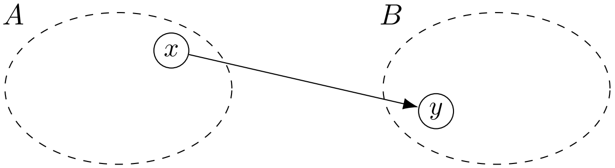

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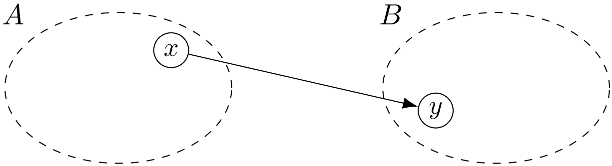

Proof. Among all vertices in $A \cup B$, if DFS first visits

- a node v in A,
- a node v in B.

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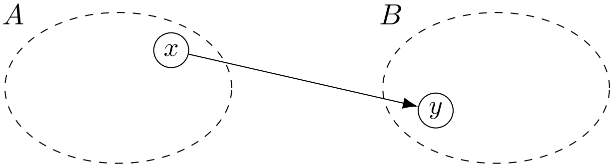

Proof. Among all vertices in $A \cup B$, if DFS first visits

- a node v in A, will finish all B before going back to v.
- a node v in B.

Find a vertex in a sink SCC

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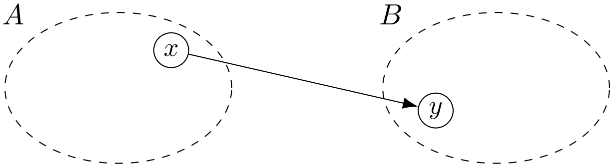

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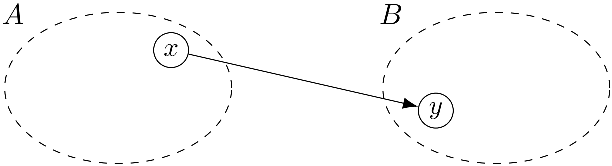

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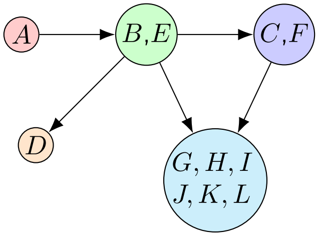
A key consequence of this fact is that the vertex with the largest post number must be in a source SCC.



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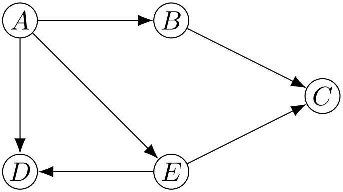

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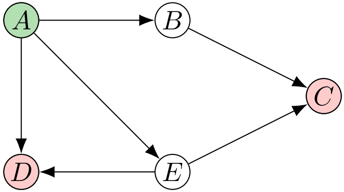

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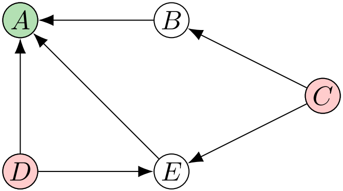

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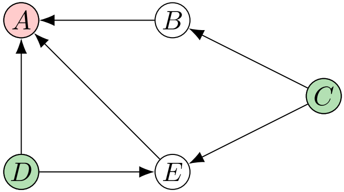

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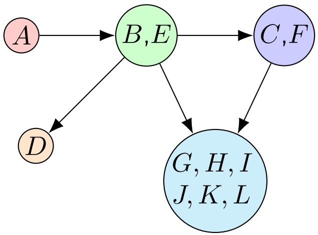
- G and G^R have the same SCC's.
- In the meta graph of G^R, every source SCC corresponds to a sink SCC in G.



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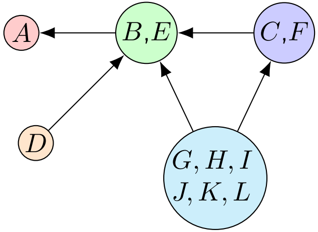

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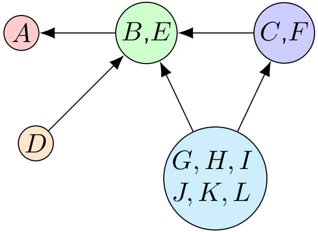
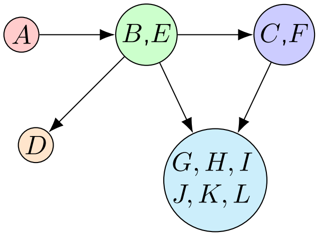


Therefore, if we run DFS on G^R and choose the node with the highest post number, it must be in a sink SCC of G!

Find SCC's

Recall our plan:

1. Find a vertex in a sink SCC.
2. Call Explore on it.
3. Remove the found SCC and repeat.



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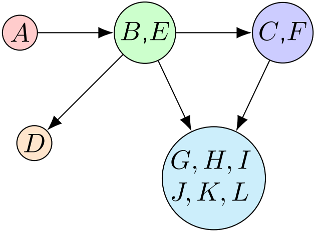

Find SCC's

Input: Graph $G = (V, E)$ in adjacency list.

1. Build adjacency list for G^R.

2. Run DFS on G^R, assign pre/post numbers and output nodes sorted in descending order of post number. Let $v_1, v_2, \ldots, v_n$ be the ordering of the vertices.

3. Run DFS on G using the this ordering:

   // $visited$ is an array of size n filled with 0's
   $color = 1$
   for $i = 1$ **to** n **do**
       if $visited[i] == 0$ **then**
           Explore(G, v_i, $color$)
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Time complexity?

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```

Time complexity? Steps 1, 2, and 3 each takes $O(|V|+|E|)$, so overall $O(|V| + |E|)$.

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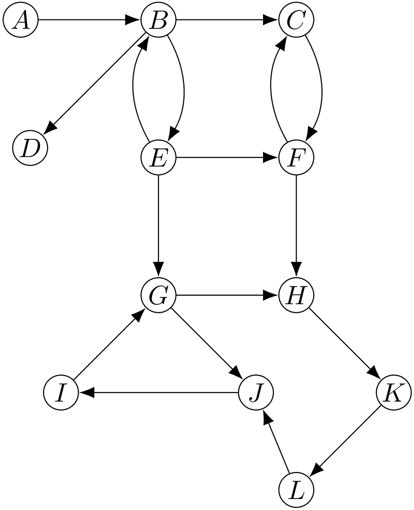
Final remark Note that we don't need to actually "remove" any SCC. Any node with a nonzero entry in $visited$ is no longer part of the graph for DFS.

Find SCC's



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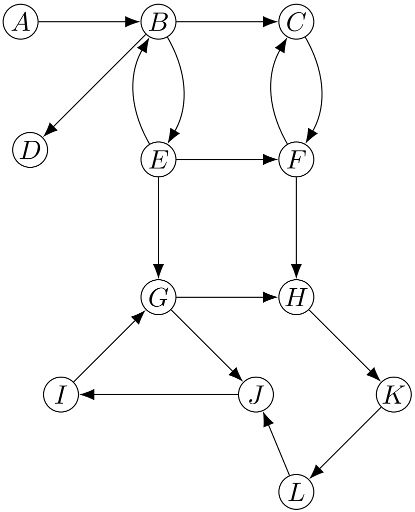

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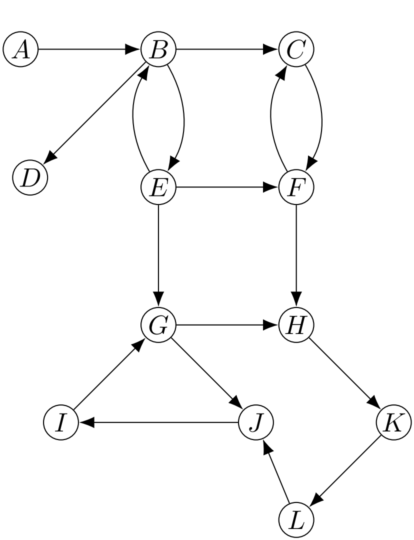

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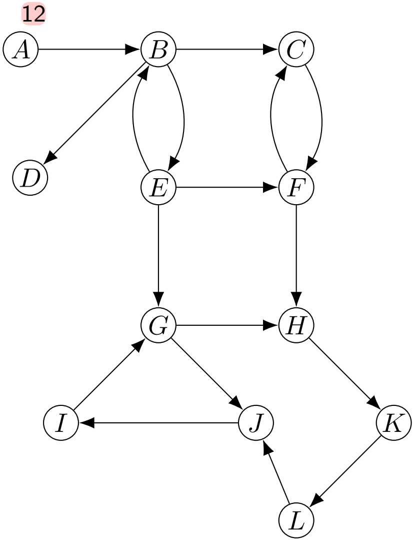

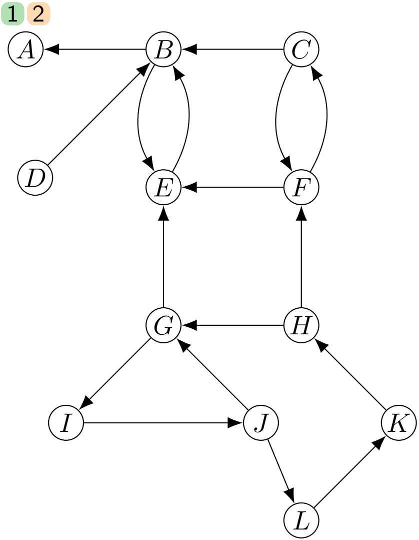

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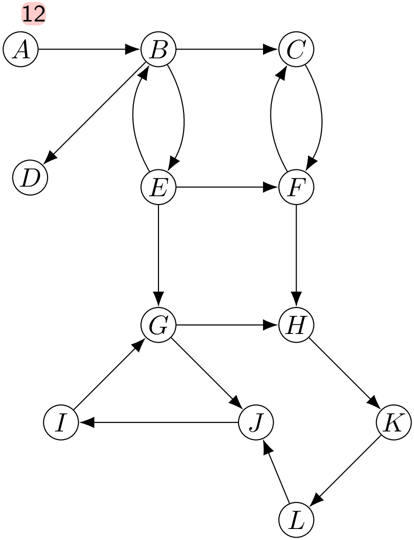

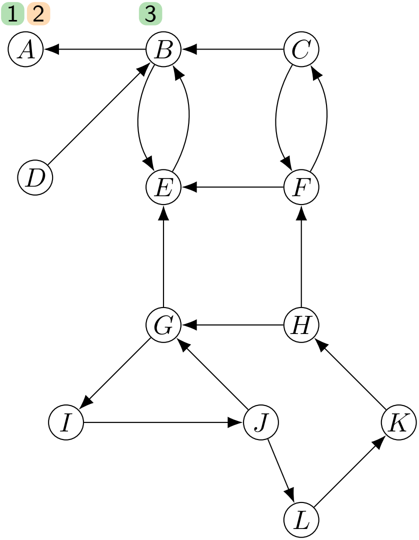

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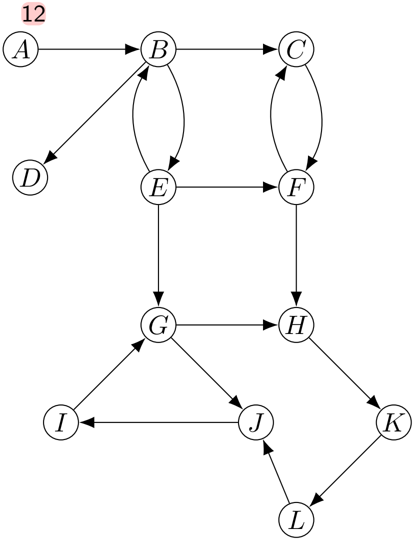

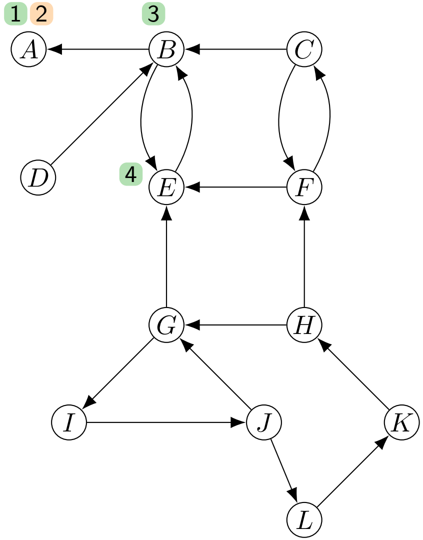

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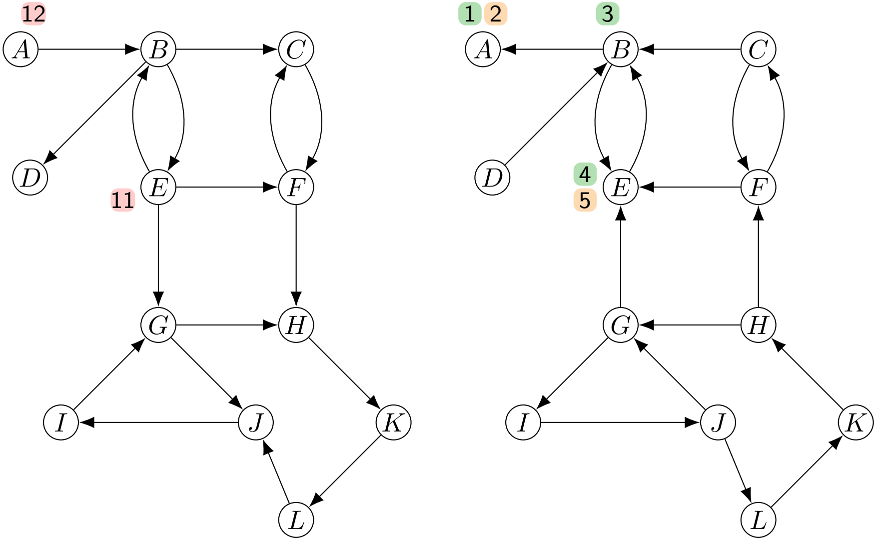

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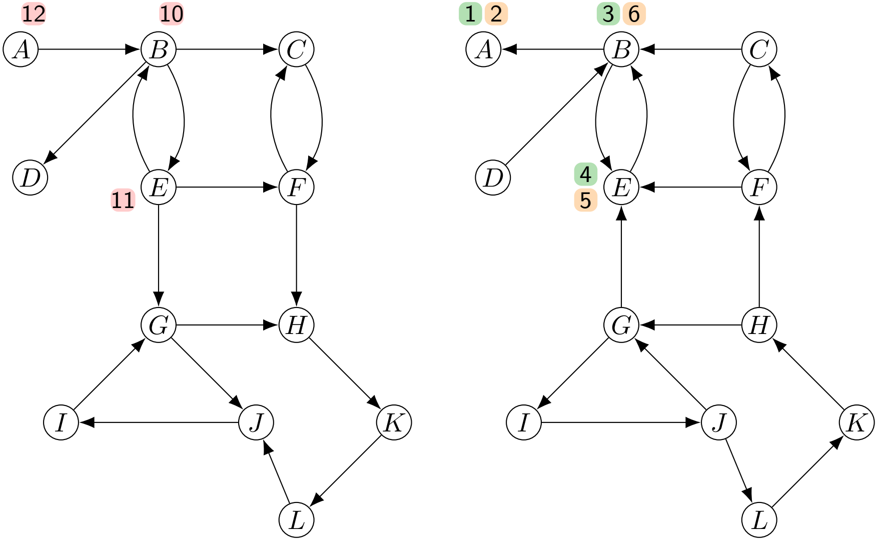

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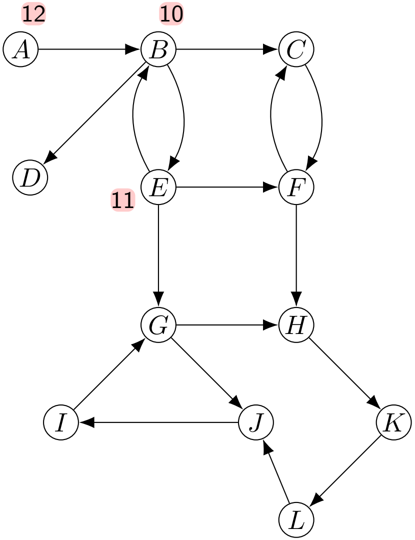

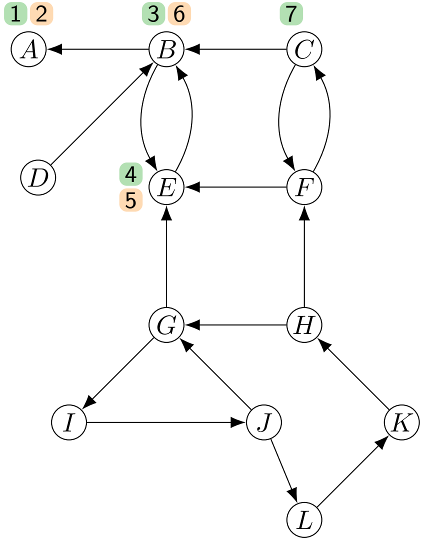

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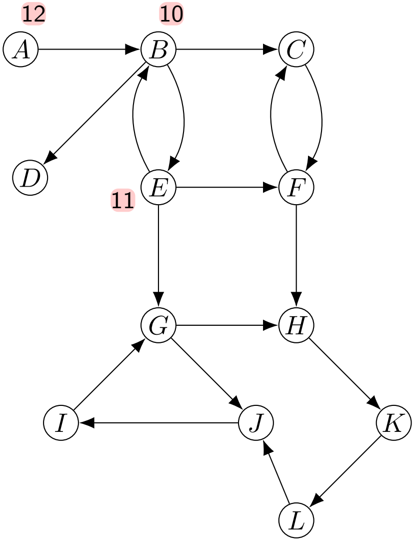

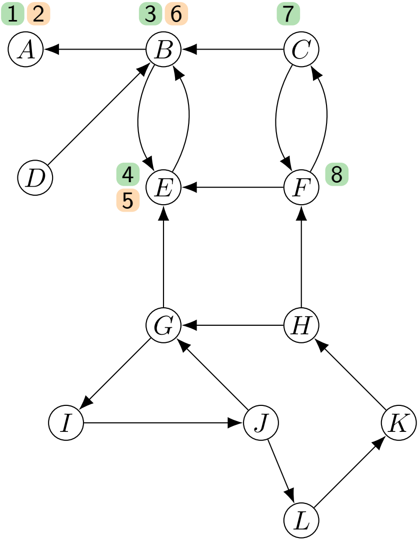

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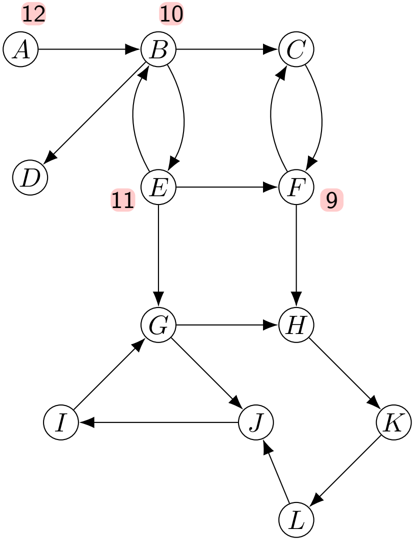

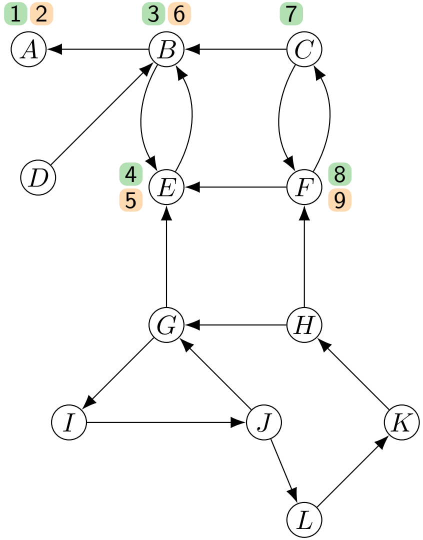

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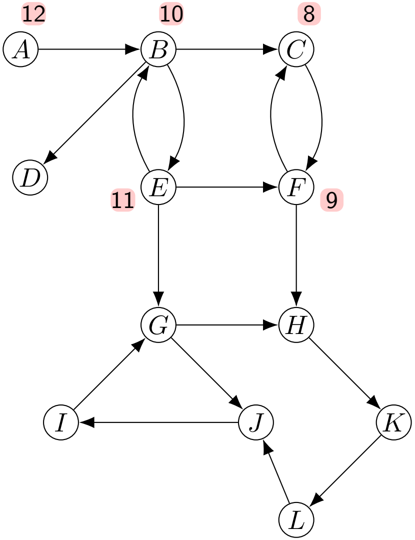

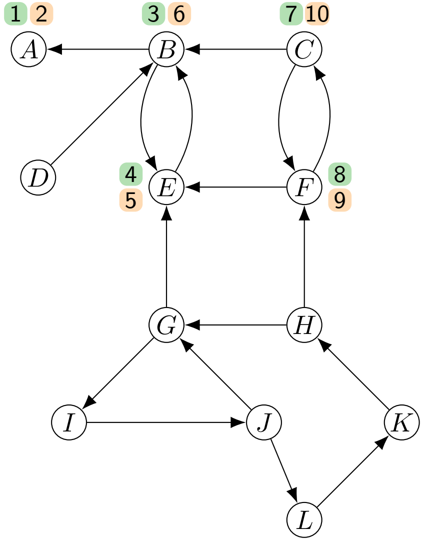

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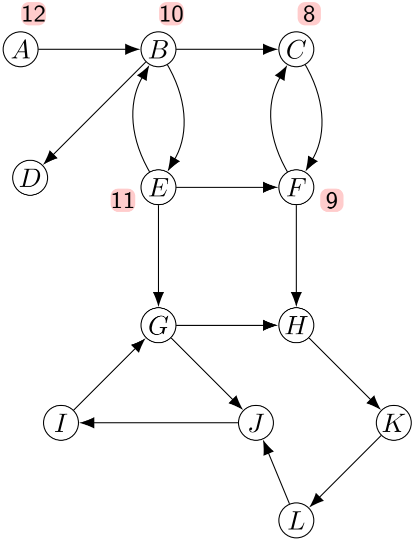

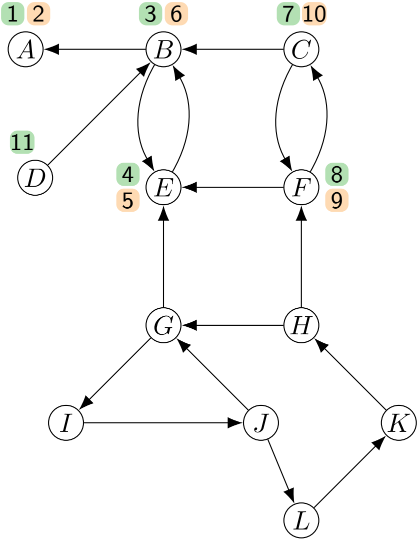

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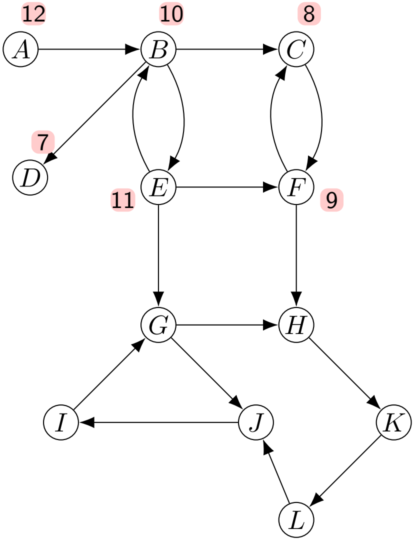

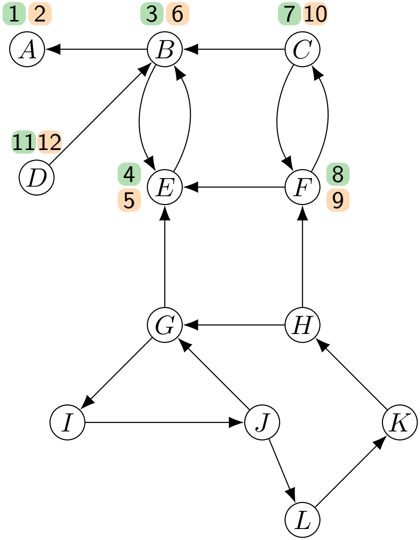

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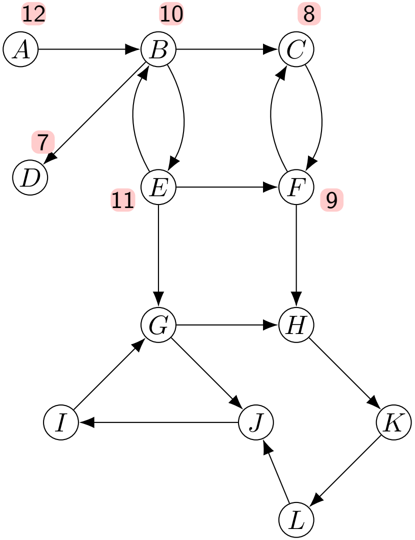

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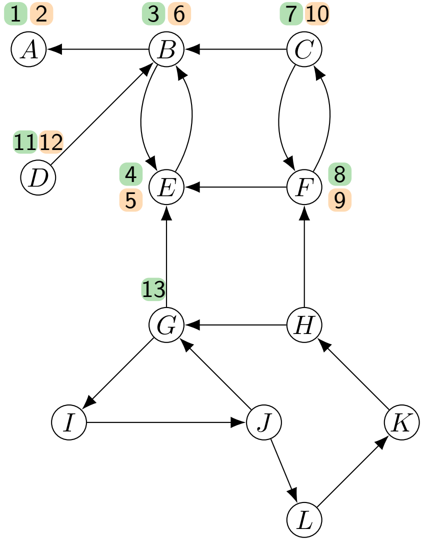

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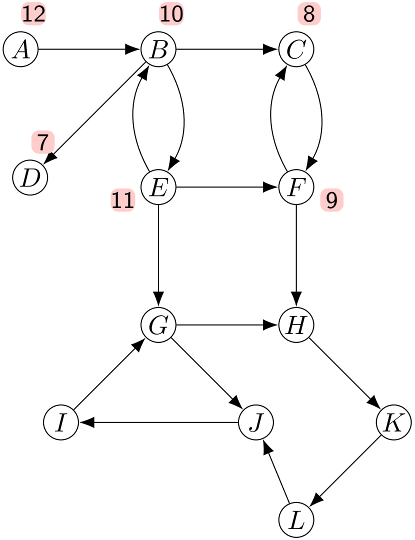

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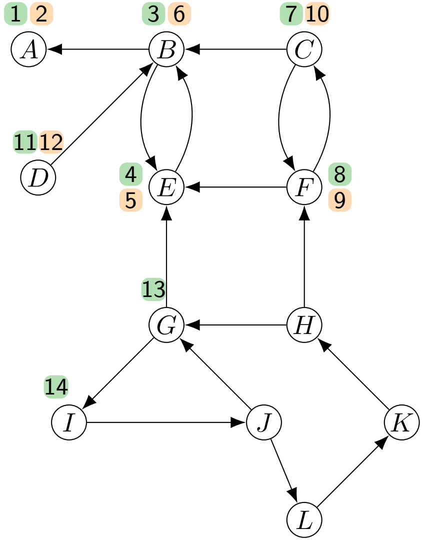

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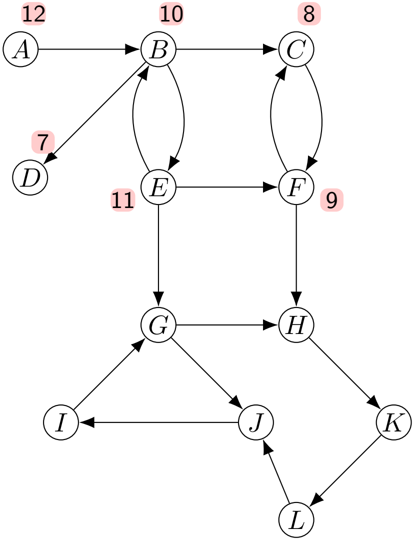
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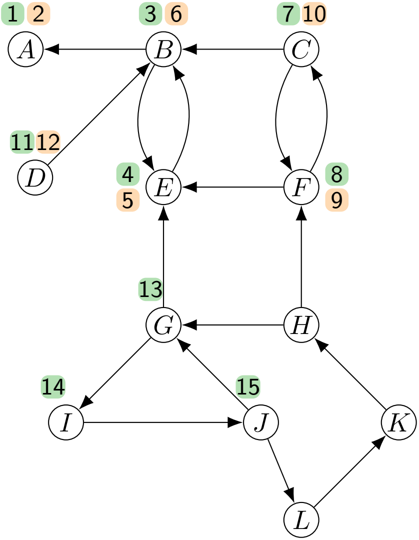
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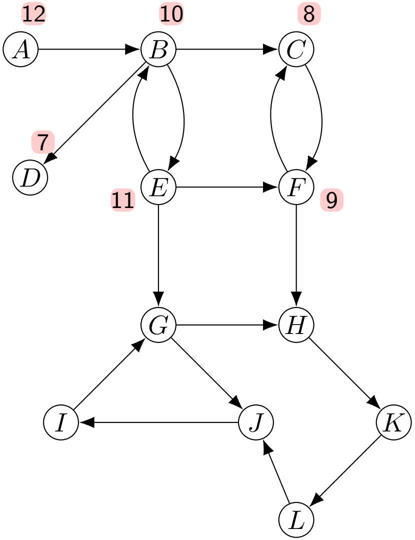
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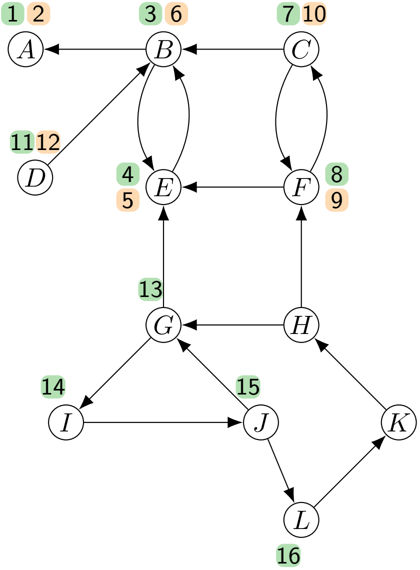
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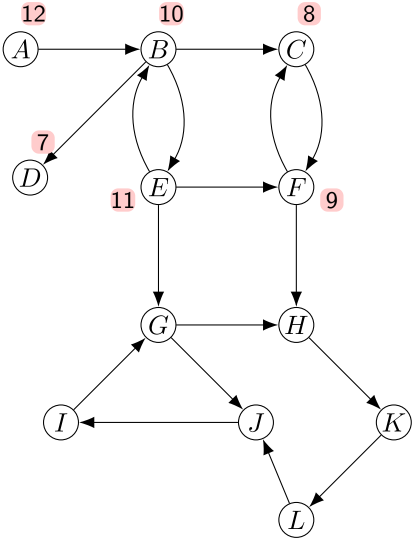

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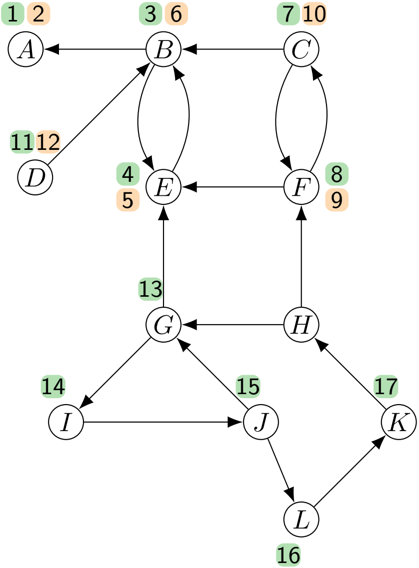

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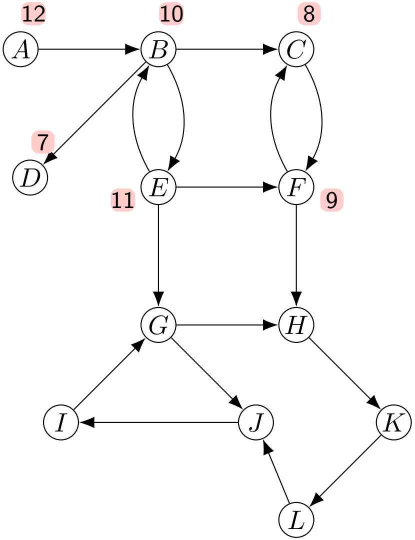
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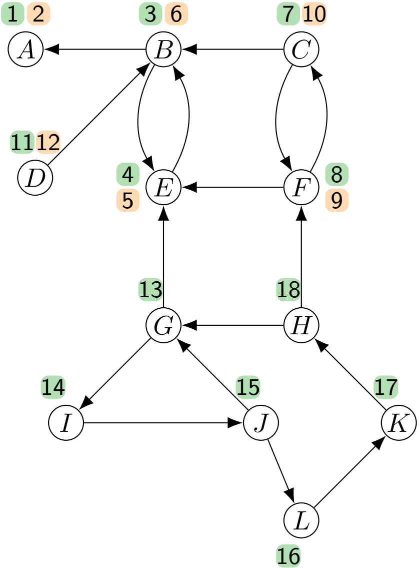
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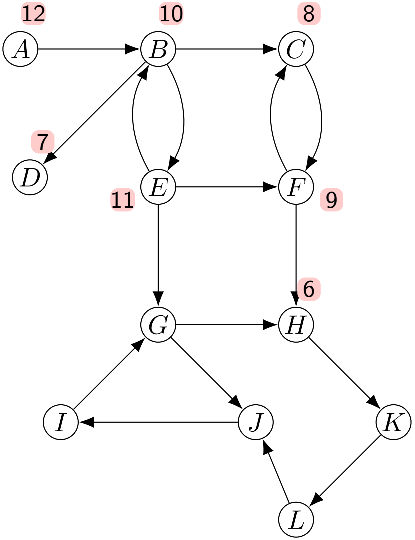
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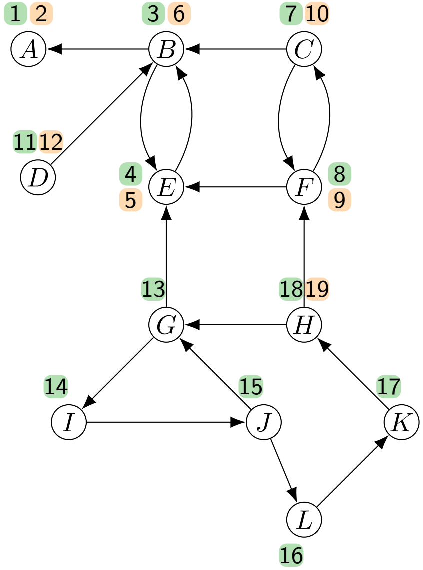
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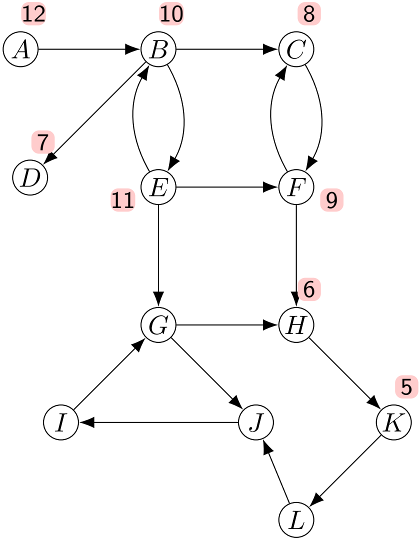
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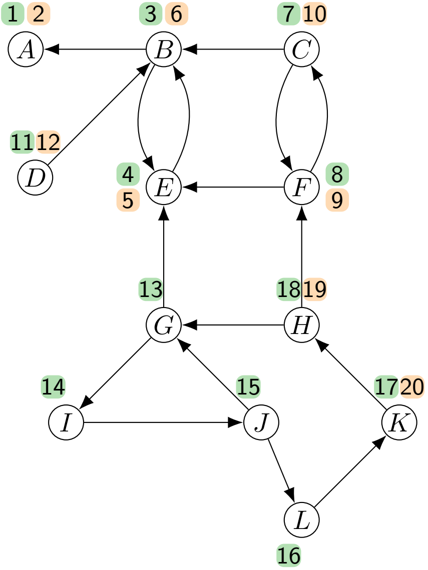
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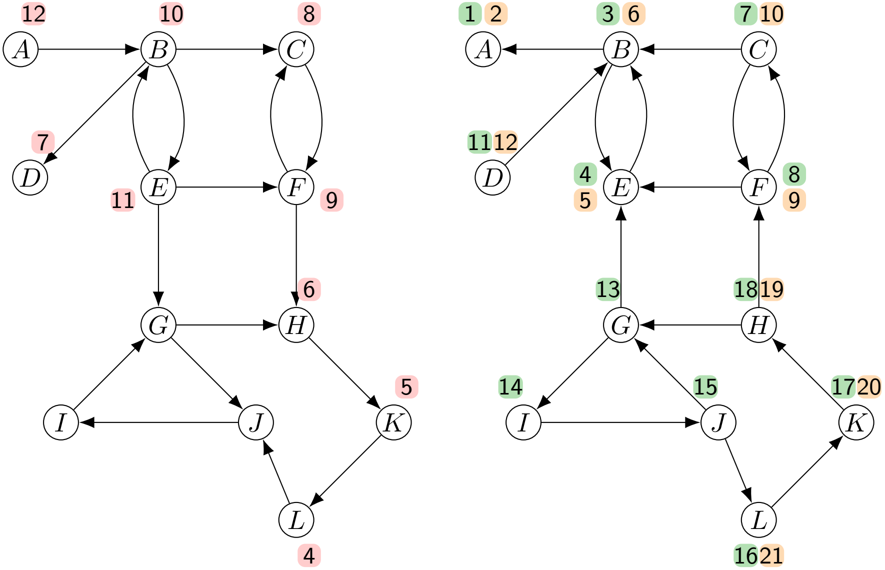

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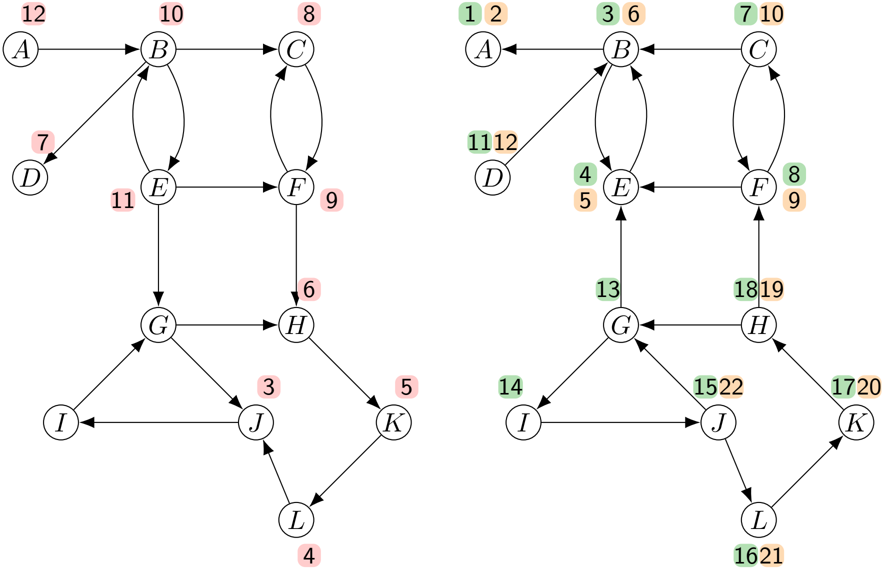
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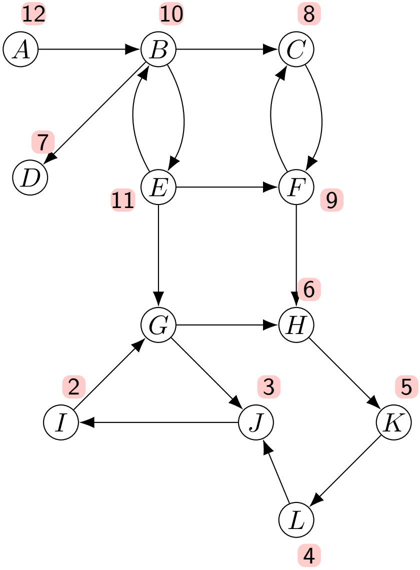

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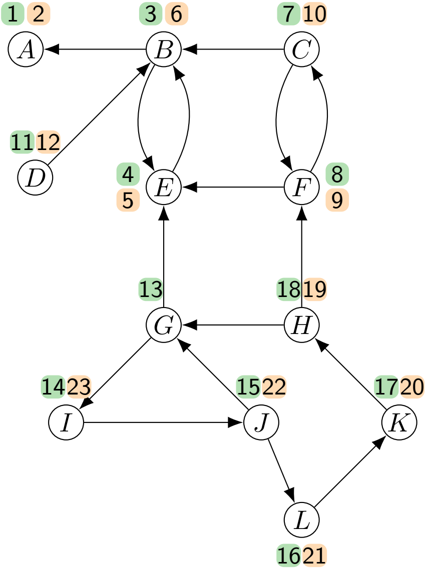

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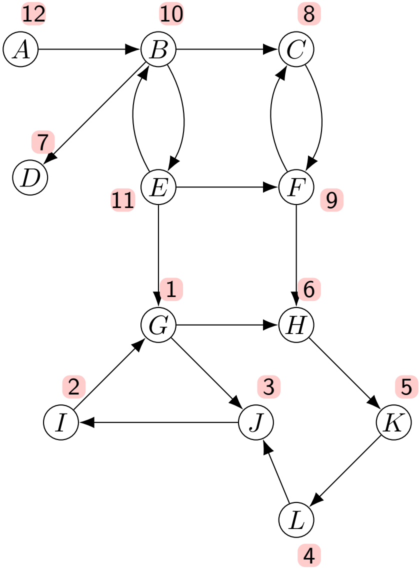
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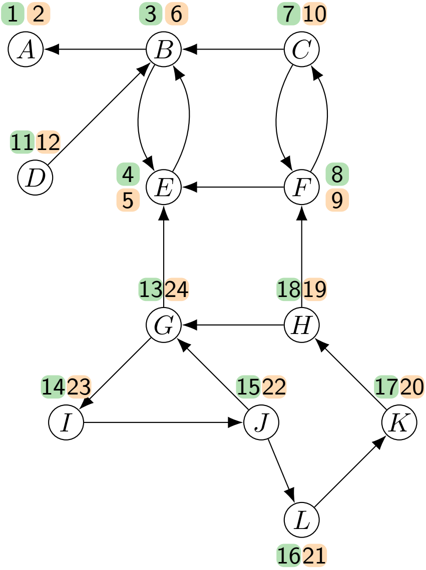
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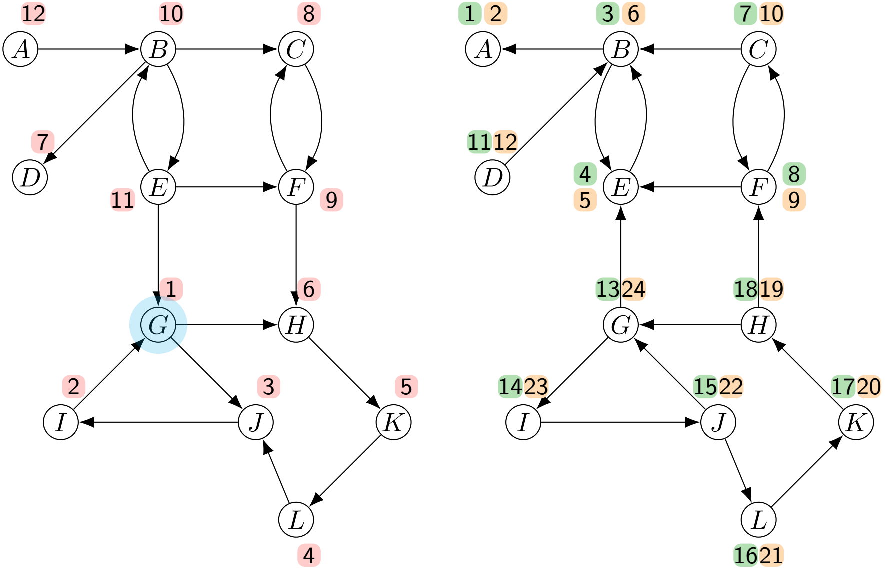

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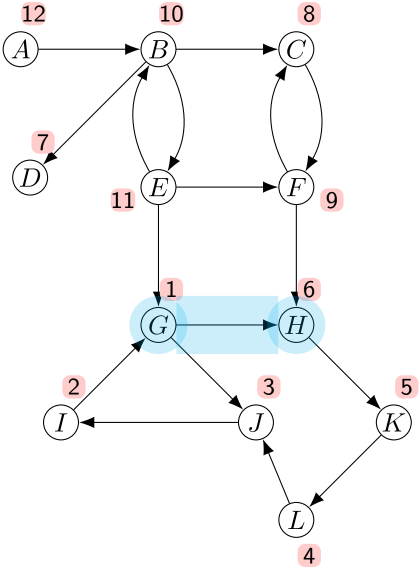

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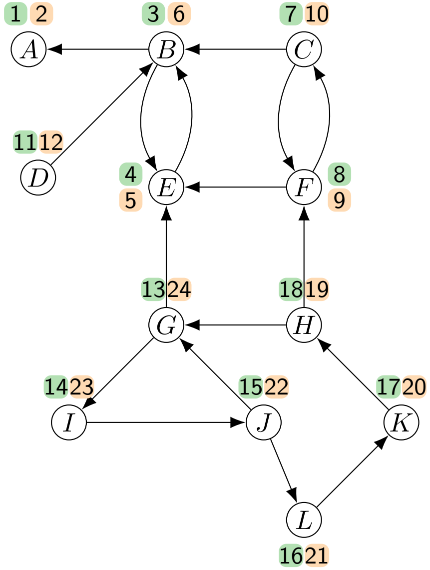

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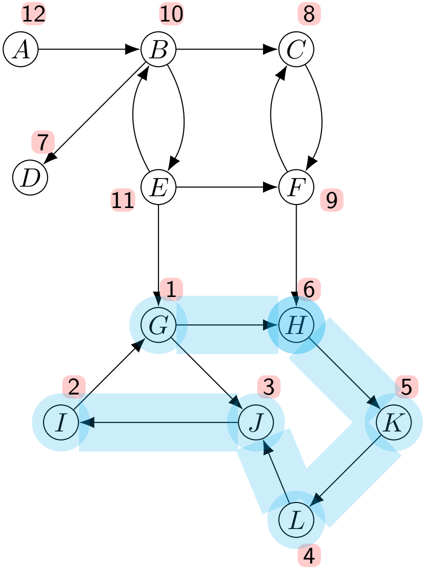

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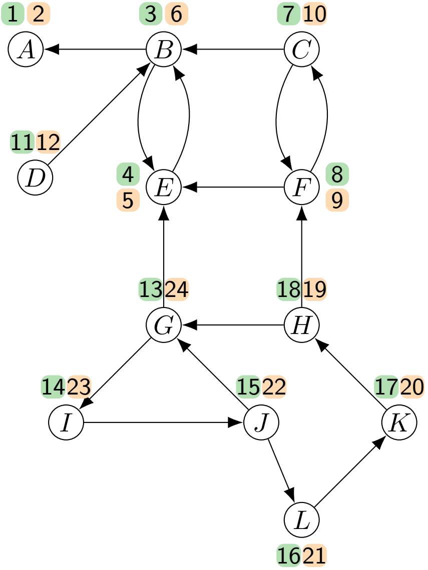

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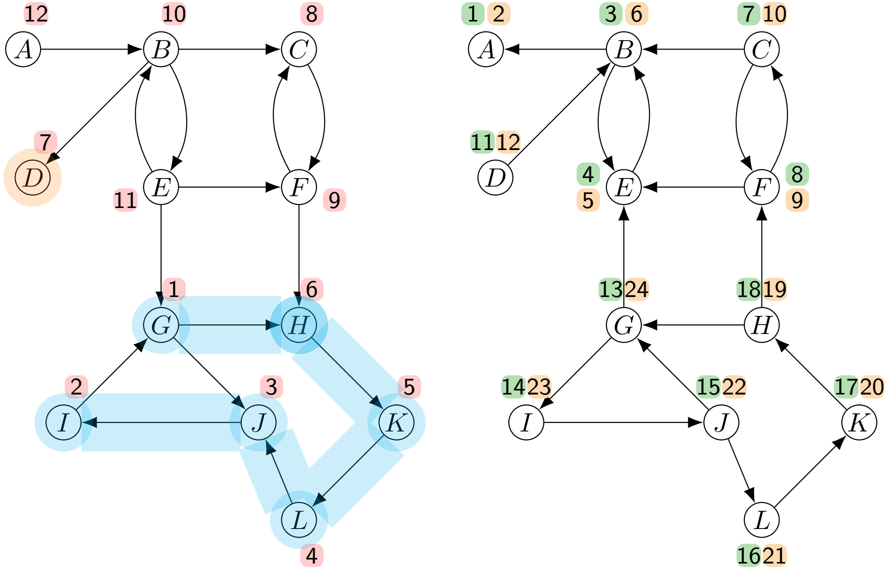

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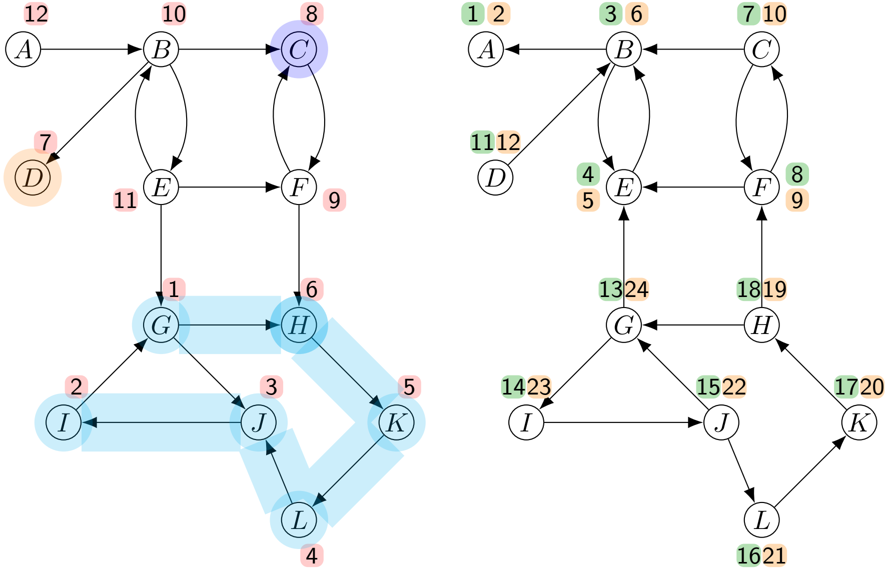
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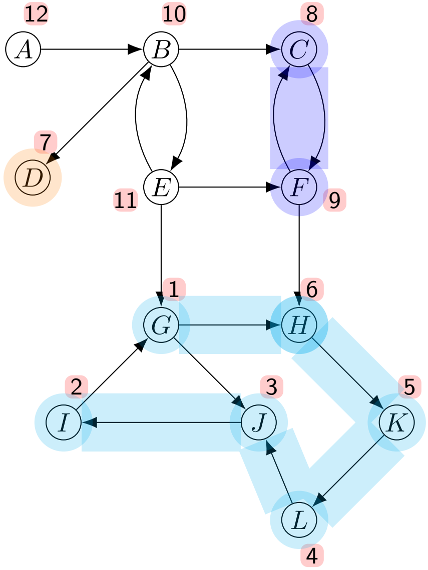

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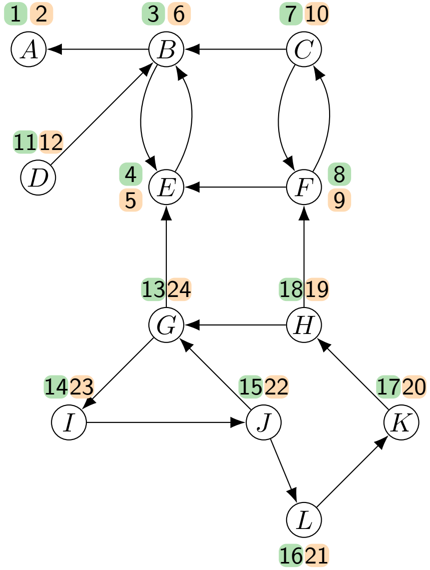

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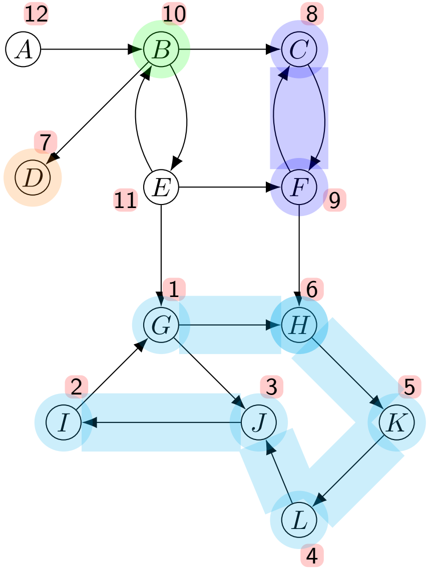

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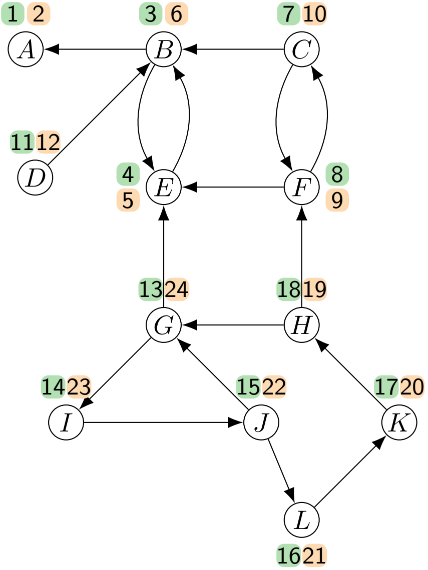

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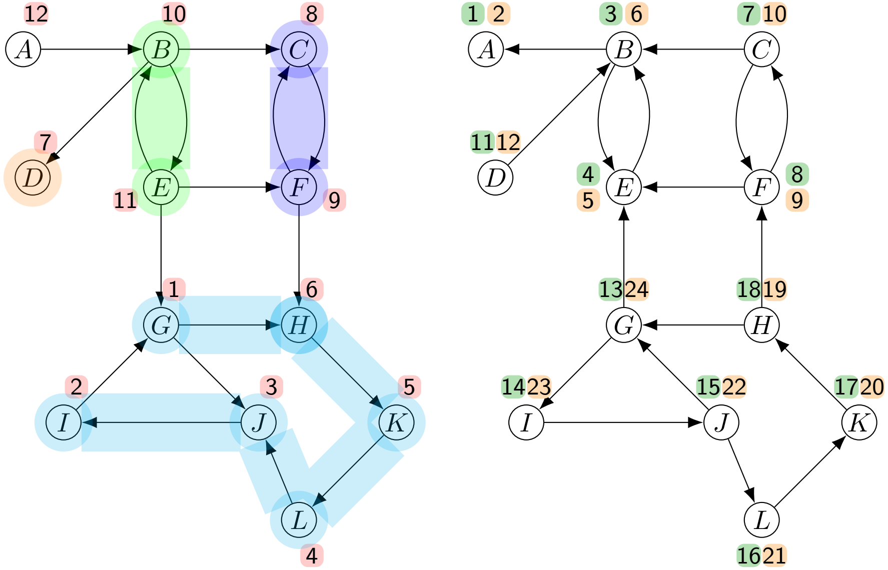

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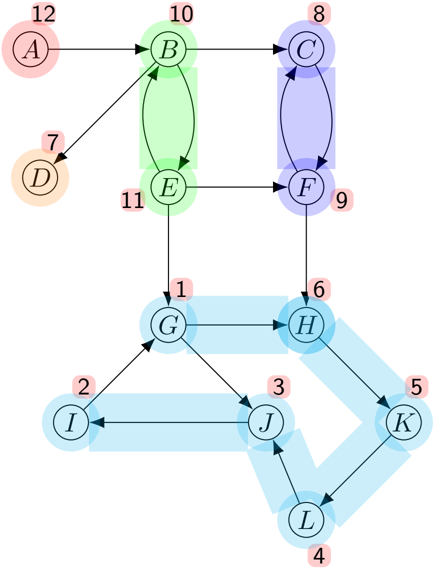

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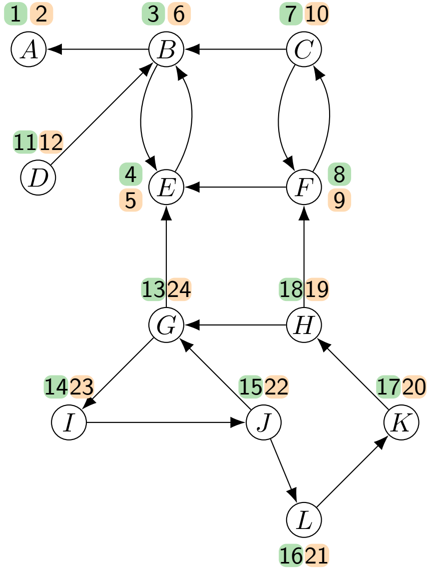

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