CMPSC 465: LECTURE XI

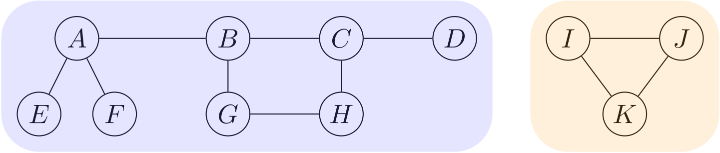
DFS on Undirected Graphs

Ke Chen

September 24, 2025

Connected component

Recall that the connected component of an undirected graph is defined as a maximal set of connected vertices.



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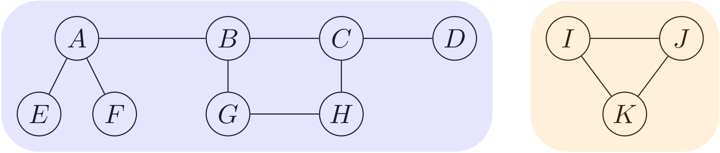

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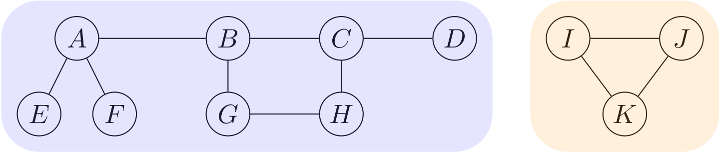

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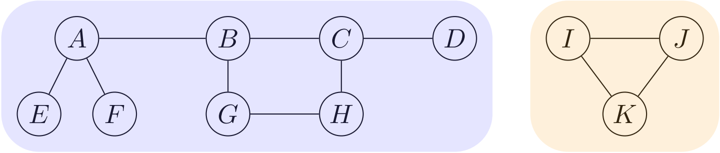

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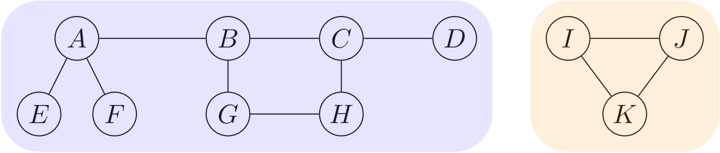
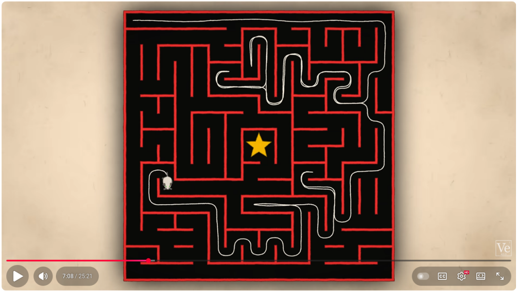


- Finding the connected components helps answer queries like "is node v connected to node w?".
- How? Just explore!

Explore by Depth First Search (DFS)

Intuition Explore a maze with a chalk and a string.



The Fastest Maze-Solving Competition On Earth by Veritasium

Explore by Depth First Search (DFS)

DFS on a graph follows the same idea:

- The graph is the maze, with vertices corresponding to intersections.
- Integer array (one int per vertex) as the colored cyber-chalk.
- String can be modeled by a stack, to backtrack we pop from the stack.

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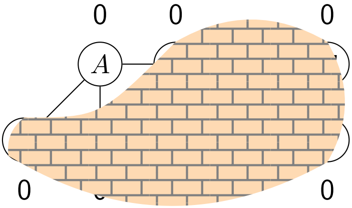

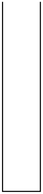

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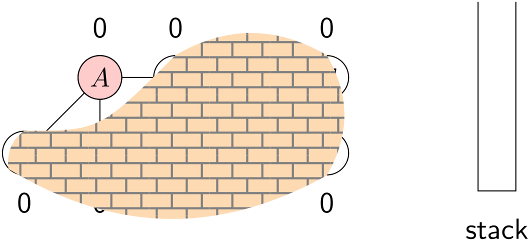

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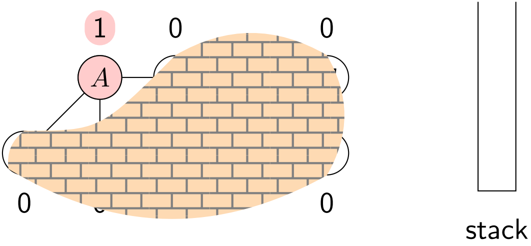

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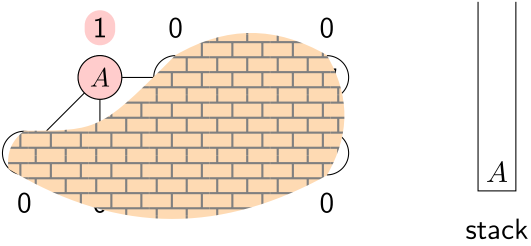

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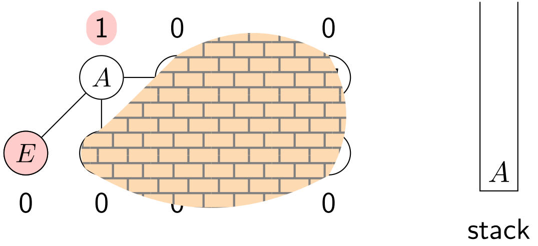

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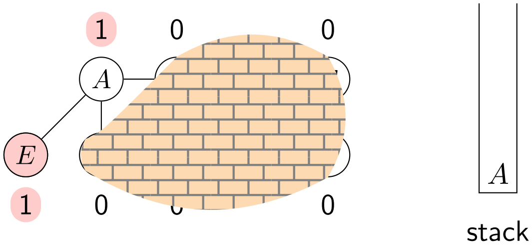

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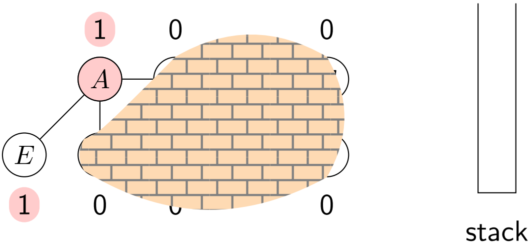

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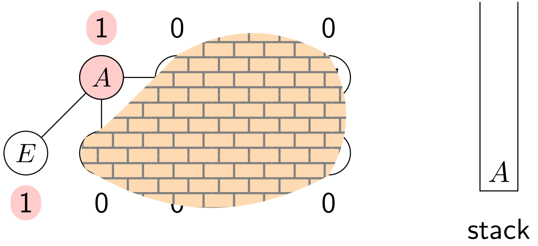

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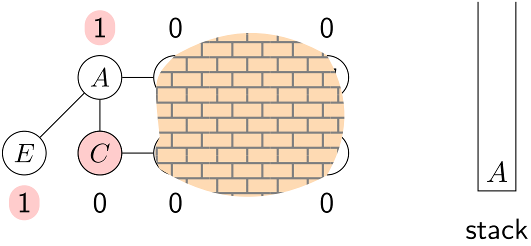

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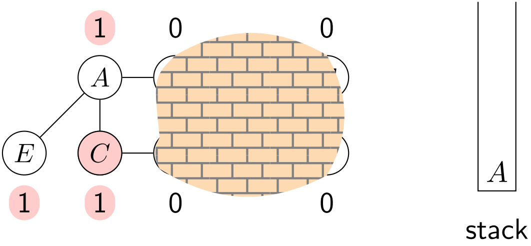

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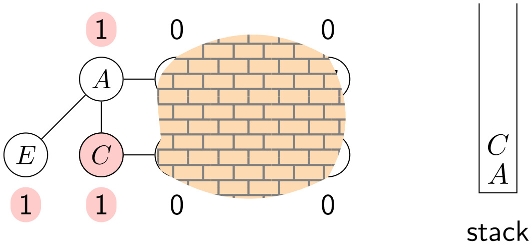

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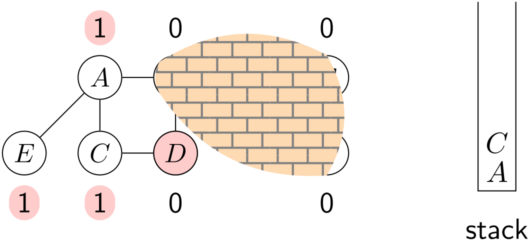

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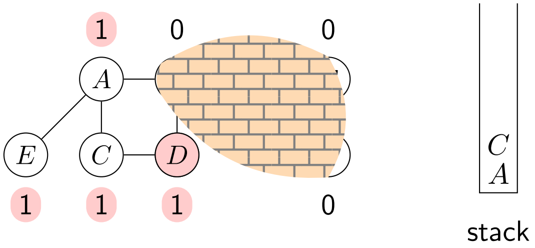

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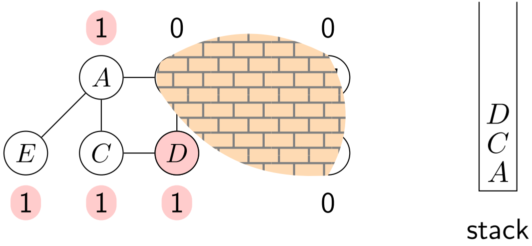

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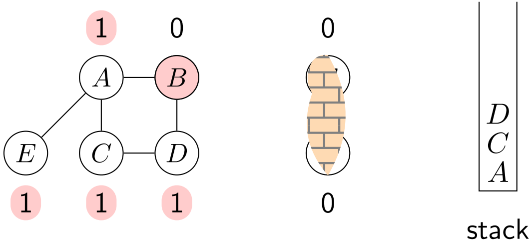

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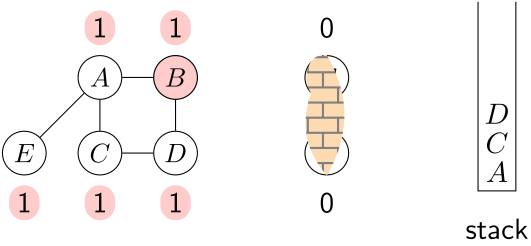

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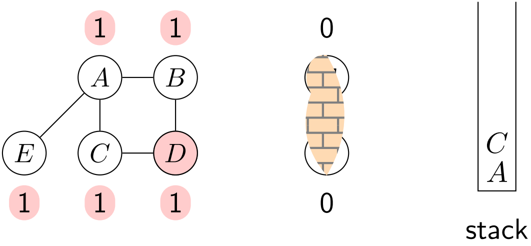

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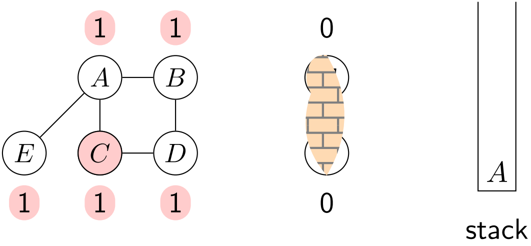

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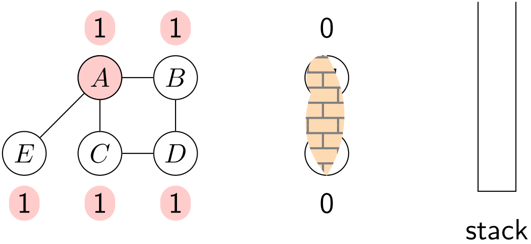

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Input: Graph $G = (V, E)$, starting vertex s, chalk $color$
Output: Mark all nodes reachable from s with $color$

Explore(G, s, $color$)

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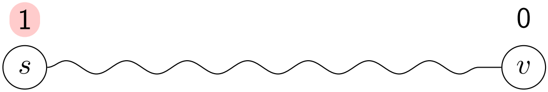

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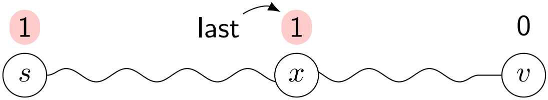

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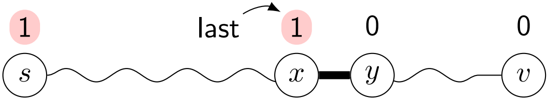

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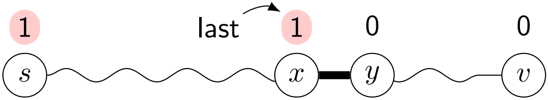

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DFS($G = (V, E)$)

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visited is an array of length |V|, filled with 0's
color = 1
foreach s ∈ V do
    if visited[s] == 0 then
        Explore(G, s, color)
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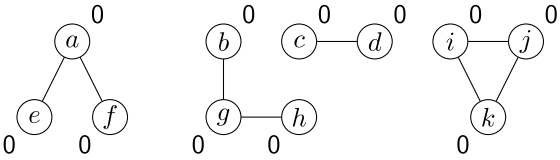

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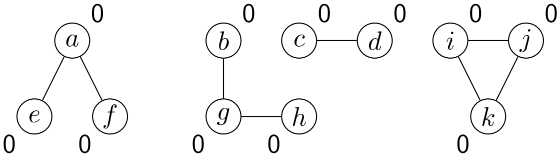

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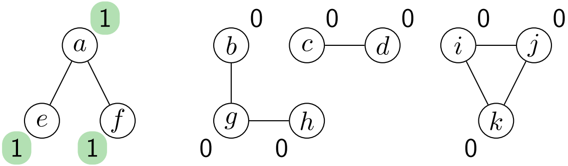

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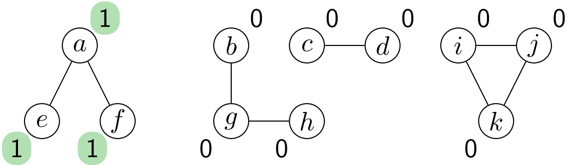
Example Explore(G, b, 2)



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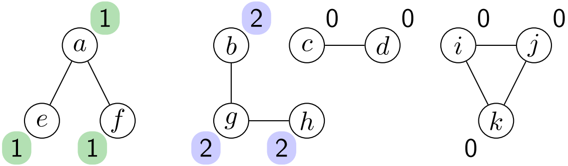

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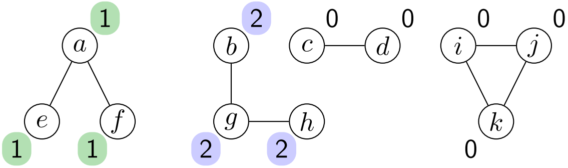

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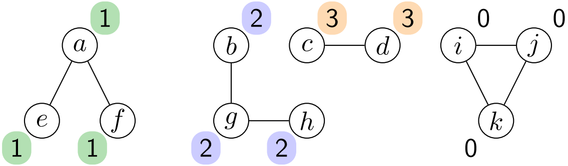
Example Explore(G, c, 3)



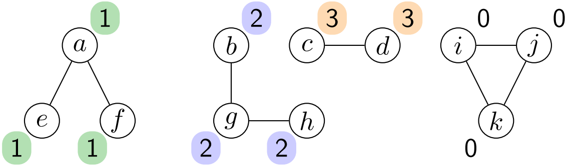
The Depth First Search (DFS) algorithm

- The Explore procedure reveals one connected component.
- DFS works by repeatedly calling Explore.

DFS($G = (V, E)$)

$visited$ is an array of length $|V|$, filled with 0's
$color = 1$
foreach $s \in V$ **do**
  if $visited[s] == 0$ **then**
    Explore(G, s, $color$)
    $color = color + 1$

Example   Explore(G, i, 4)



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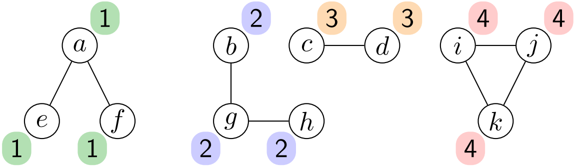

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Time complexity?

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Explore is called on each vertex in V.

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G in adjacency matrix representation:

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$O\left(|V|^2\right)$

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G in adjacency list representation:

- Explore checks each edge twice.

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Can we do better?

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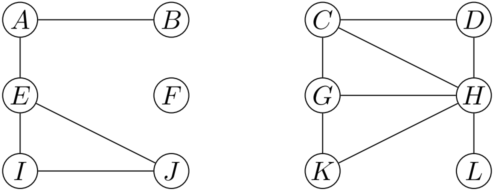
Can we do better?

$O(|V| + |E|)$ is the best possible, since we need to read the graph.

Edge types in DFS forest (undirected)

Example Suppose nodes are visited in lexicographical



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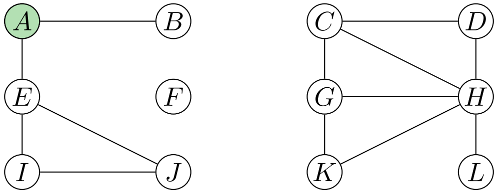

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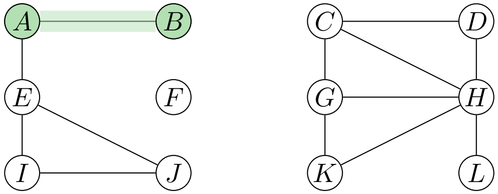

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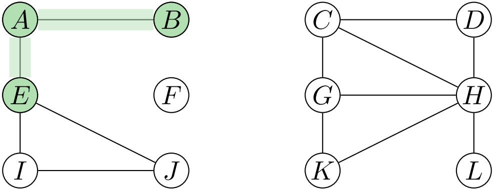

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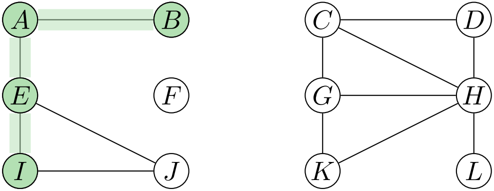

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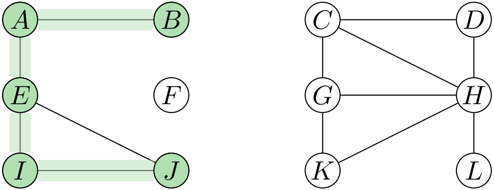

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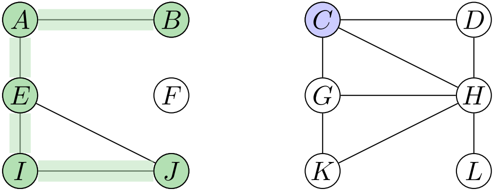

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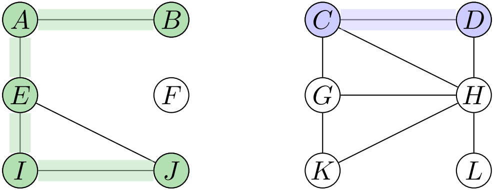

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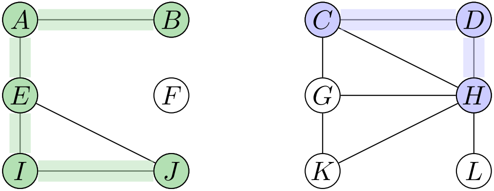

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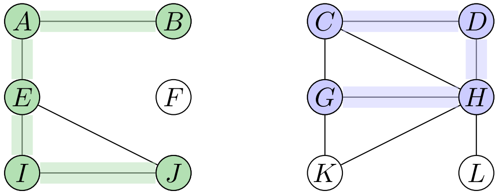

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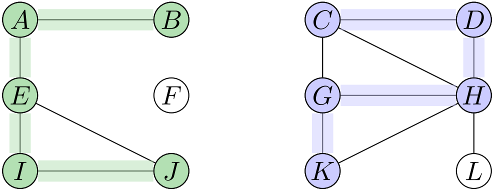

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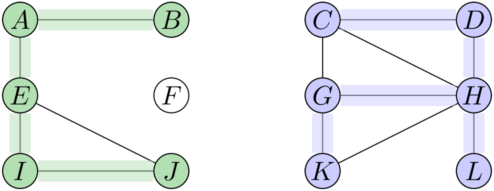

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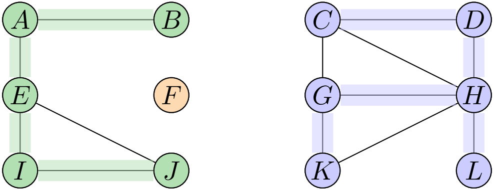

- This is a DFS forest.

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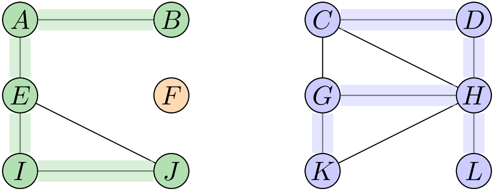

- This is a DFS forest.
- Colored edges are called tree edges.

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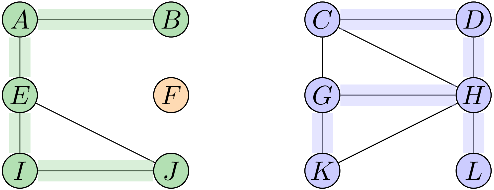

- This is a DFS forest.
- Colored edges are called tree edges.
- Unused edges are called back edges.

Edge types in DFS forest (undirected)

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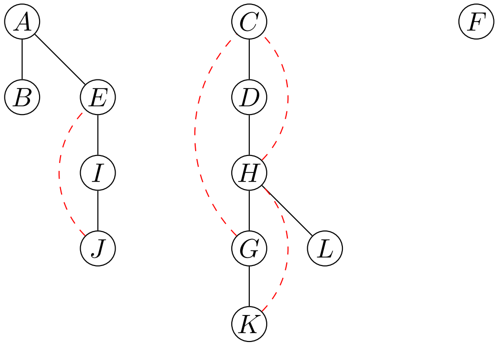

- This is a DFS forest.
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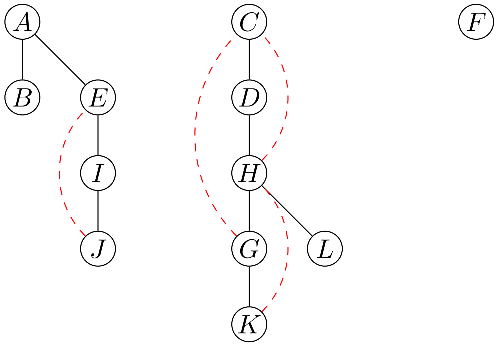

- This is a DFS forest.
- Solid edges are called tree edges.
- Dashed edges are called back edges.
- Back edges correspond to cycles.

Cycle detection (undirected)

To find cycles, it is sufficient to find back edges, which can be done with a simple modification to the Explore procedure.

Explore(G, s, $color$, $previous$)

```
visited[s] = color
foreach edge {s, v} ∈ E do
    if visited[v] == 0 then
        Explore(G, v, color, s)
    if visited[v] ≠ 0  and  v ≠ previous then
        Output {v, s} is a back edge or "found cycle"
```

Pre- and post-visit timestamps (undirected)

We can collect more information during Explore by keeping a global clock that ticks every time we:

- visit a node for the first time, and
- leave a node for good.

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```
// pre and post are integer arrays of size |V|
// clock is an integer counter starting at 1
Explore(G, s, color)
    visited[s] = color
    pre[s] = clock
    clock = clock + 1
    foreach edge {s, v} ∈ E do
        if visited[v] == 0 then
            Explore(G, v, color)
    post[s] = clock
    clock = clock + 1
```

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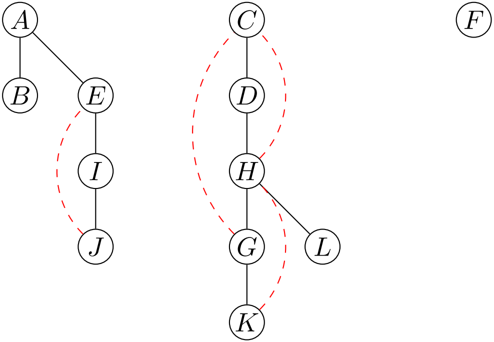

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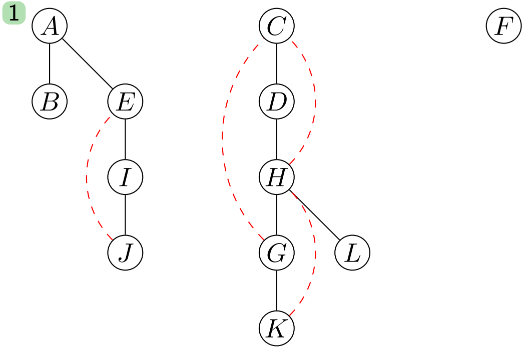

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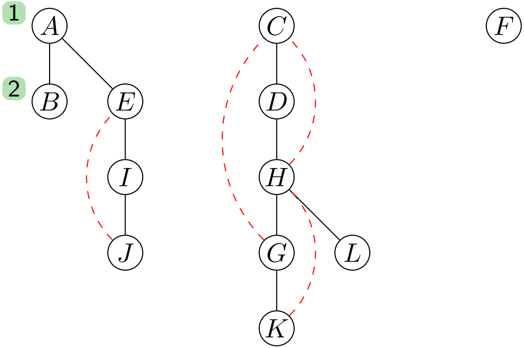

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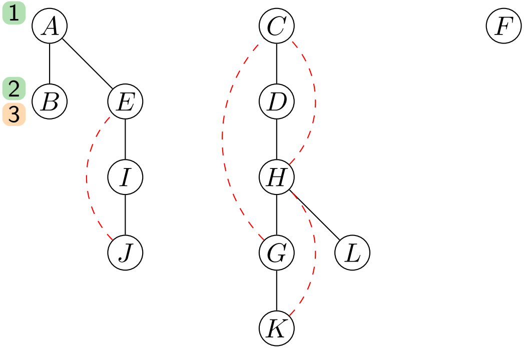

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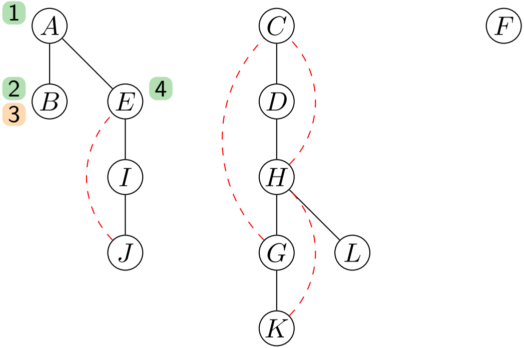

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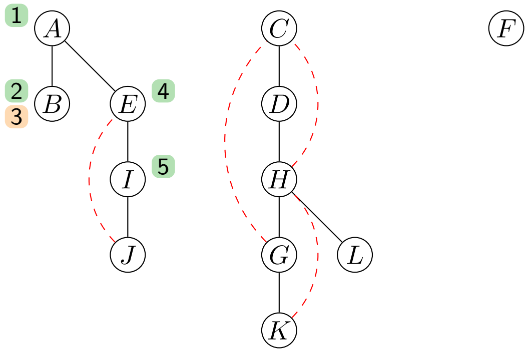

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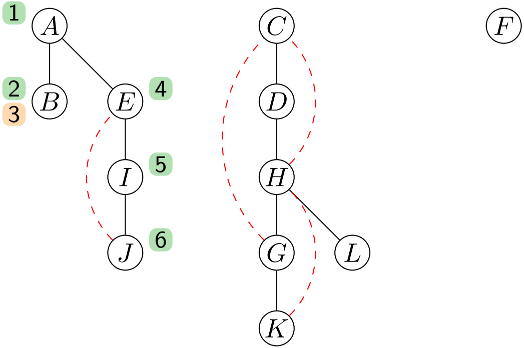

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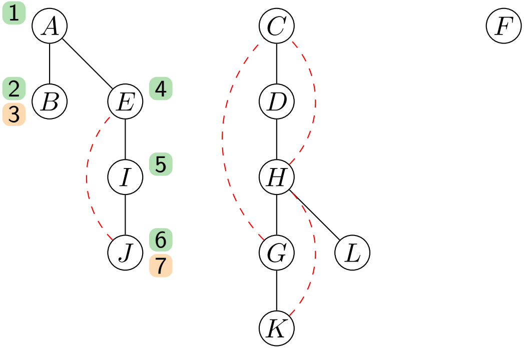

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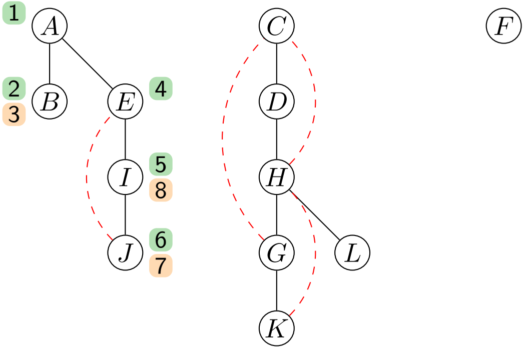

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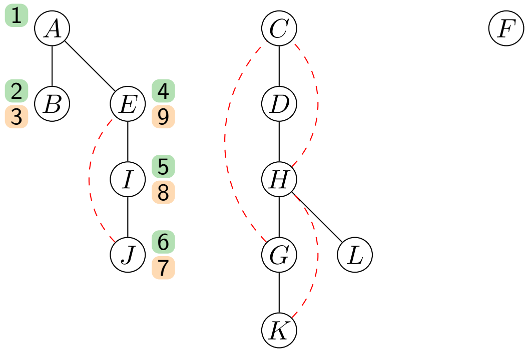

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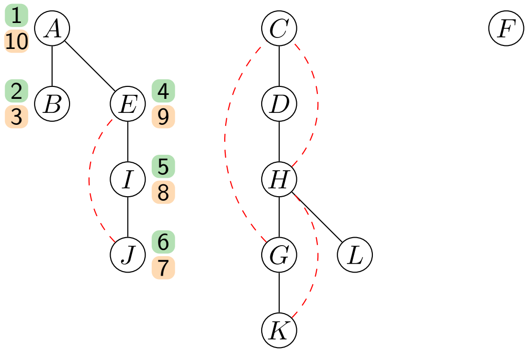

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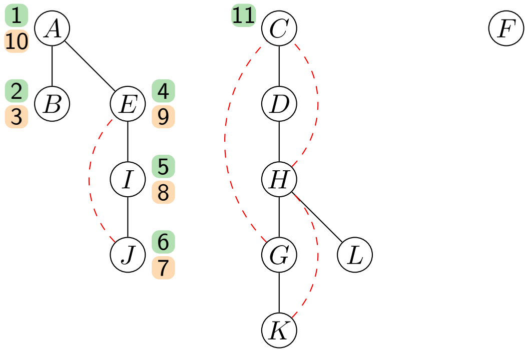

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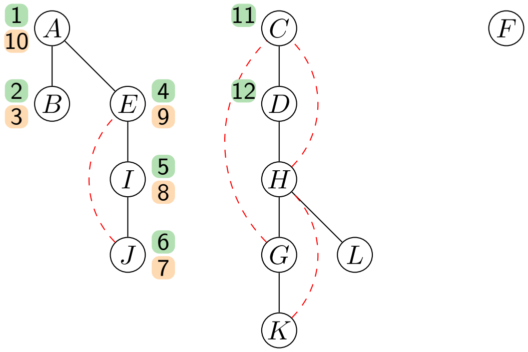

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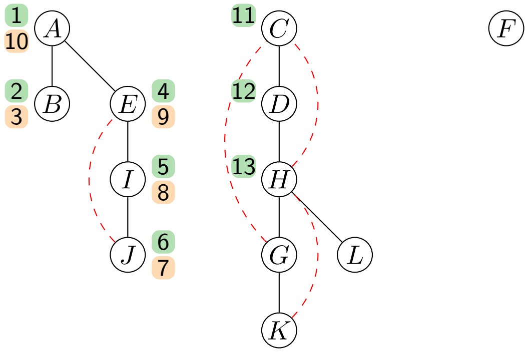

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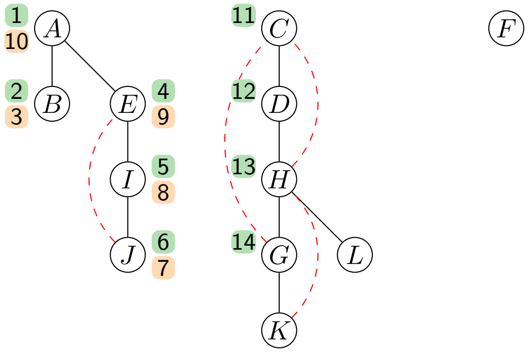

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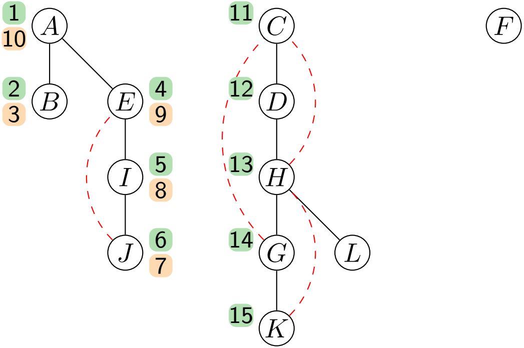

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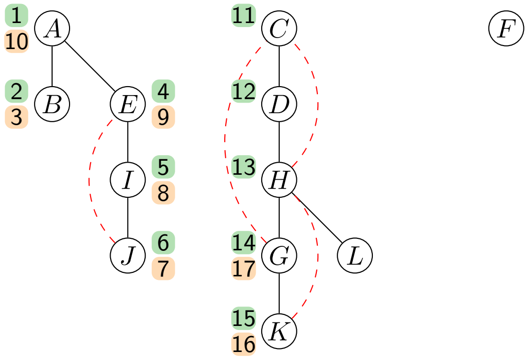

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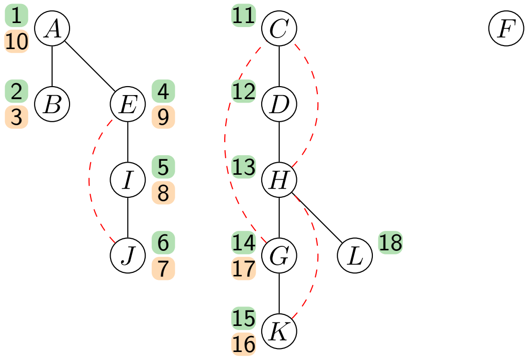

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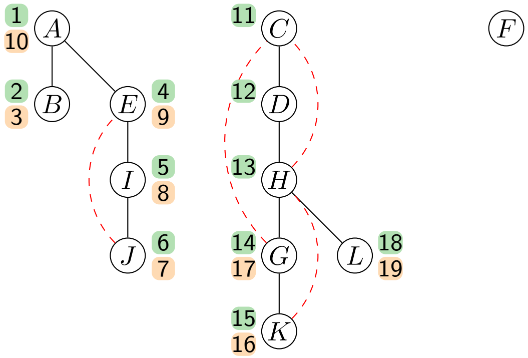

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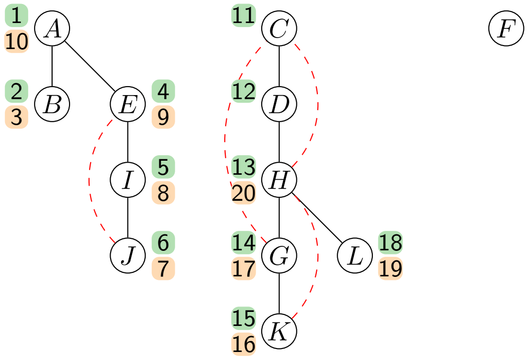

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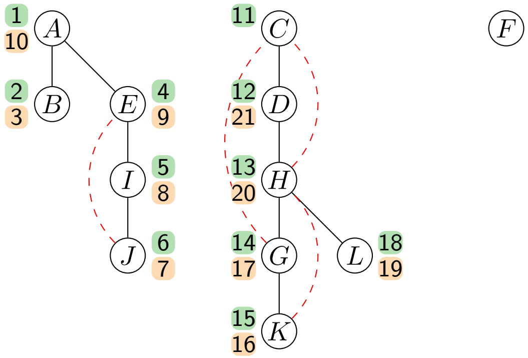
Example

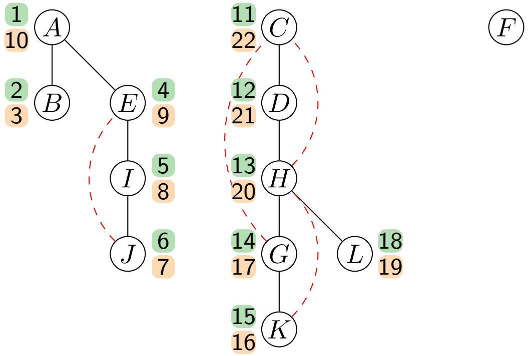


Pre- and post-visit timestamps (undirected)

We can collect more information during Explore by keeping a global clock that ticks every time we:

- visit a node for the first time, and
- leave a node for good.

Example



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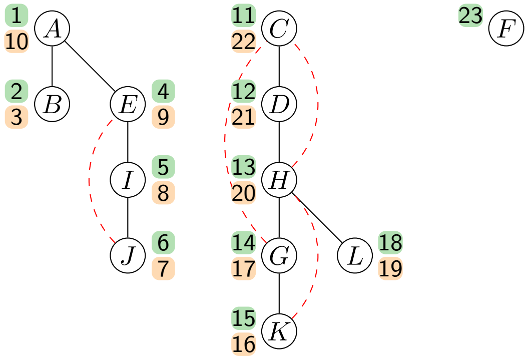

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