

# Estrutura de Dados II

## Busca em Grafos

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Material compilado de: Cormen e material de Cid et al.  
IC-UNICAMP.

# Sumário

- 1 Busca em Grafos
- 2 Busca em profundidade
- 3 Complexidade
- 4 Classificação de arestas

## Busca em grafos

Grafos são estruturas mais complicadas do que listas, vetores e árvores (binárias). Precisamos de métodos para **explorar/percorrer** um grafo (orientado ou não-orientado). Buscas são utilizadas para extração de várias **informações** sobre a estrutura do grafo (úteis para projetar algoritmos eficientes para determinados problemas). Tipos de busca:

- **Busca em profundidade** (Depth-First-Search)
- **Busca em largura** (Breadth-First-Search)

## Notação

Para um grafo  $G$  (orientado ou não) podemos denotar por  $V[G]$  seu conjunto de vértices e por  $E[G]$  seu conjunto de arestas. Para denotar complexidades nas expressões com  $\mathcal{O}$  ou  $\Theta$  usaremos  $V$  e  $E$  em vez de  $|V[G]|$  ou  $|E[G]|$ . Por exemplo,  $\Theta(V + E)$  ou  $\mathcal{O}(V^2)$ .

# Sumário

- 1 Busca em Grafos
- 2 Busca em profundidade
- 3 Complexidade
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**Busca em profundidade (depth first search)**: a estratégia consiste em pesquisar o grafo o mais “profundamente” sempre que possível. Aplicável tanto a grafos orientados quanto não-orientados. Possui um número enorme de aplicações:

- determinar os componentes de um grafo;
- ordenação topológica, ...

## Busca em profundidade

Recebe um grafo  $G = (V, E)$  (representado por listas de adjacências). A busca inicia-se em um vértice qualquer. Busca em profundidade é um **método recursivo**. A idéia básica consiste no seguinte:

## Busca em profundidade

- Suponha que a busca atingiu um vértice  $u$ .
- Escolhe-se um vizinho não visitado  $v$  de  $u$  para prosseguir a busca.
- “Rekursivamente” a busca em profundidade prossegue a partir de  $v$ .
- Terminada a busca, tenta-se prosseguir a busca a partir de outro vizinho de  $u$ . Se não for possível, ela retorna (backtracking) ao nível anterior da recursão.



## Busca em profundidade

É possível imaginar uma busca em profundidade através do uso de uma **pilha**:

- Suponha que a busca atingiu um vértice  $u$ .
- Escolhe-se um vizinho não visitado  $v$  de  $u$  para prosseguir a busca.
- Empilhe  $v$  e repita o passo anterior com  $v$ .
- Se todos os vizinhos foram visitados, então desempilhe um vértice, digamos  $u$ , e volte ao primeiro passo.

## Busca em profundidade

A medida que o grafo é percorrido, os vértices visitados vão sendo coloridos. Cada vértice tem uma das seguintes cores:

- Cor branca = não visitado
- Cor **cinza** = visitado mas não finalizado
- Cor **preta** = visitado e finalizado

## Busca em profundidade

A busca em profundidade associa a cada vértice  $x$  dois rótulos:

- $d[x]$ : instante de descoberta de  $x$ . Neste instante  $x$  torna-se cinza.
- $f[x]$ : instante de finalização de  $x$ . Neste instante  $x$  torna-se preto.

Os rótulos são inteiros entre 1 e  $2|V|$ .

## Busca em profundidade

- Cada vértice  $v$  (diferente de  $s$ ) possui um pai  $\pi[v]$ .
- O caminho de  $v$  a  $s$  é dado por:  
 $v, \pi[v], \pi[\pi[v]], \pi[\pi[\pi[v]]], \dots, s$ .

### BUSCA-EM-PROFUNDIDADE ( $G$ )

Recebe um grafo  $G$  (na forma de listas de adjacências) e devolve: (i) os instantes  $d[v]$ ,  $f[v]$  para cada  $v \in V$  e (ii) uma floresta de busca em profundidade.

# BUSCA-EM-PROFUNDIDADE (G)

▷ Para cada  $u \in V[G]$  faça

$\text{cor}[u] \leftarrow \text{branco};$

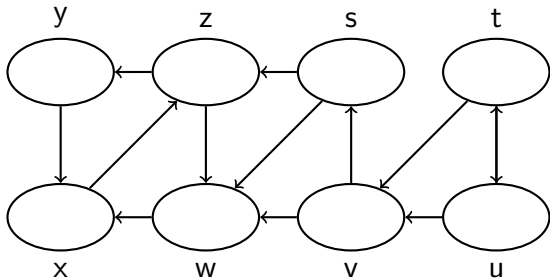
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

Para cada  $u \in V[G]$  faça

    Se  $\text{cor}[u] = \text{branco}$  então

        DFS-VISIT( $G, V, u, \text{tempo}$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

▷  $\text{cor}[u] \leftarrow \text{branco};$

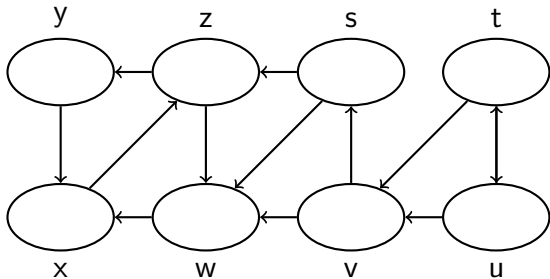
$\pi[u] \leftarrow \text{NIL};$

$\text{tempo} \leftarrow 0;$

**Para cada  $u \in V[G]$  faça**

**Se  $\text{cor}[u] = \text{branco}$  então**

$\text{DFS-VISIT}(G, V, u, \text{tempo});$



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

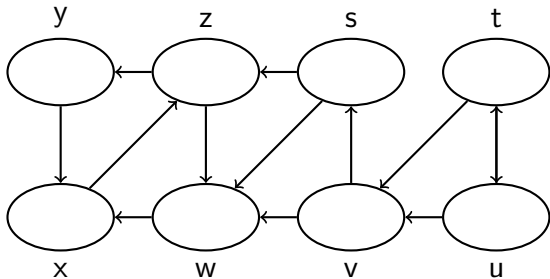
▷  $\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada  $u \in V[G]$  faça**

**Se**  $\text{cor}[u] = \text{branco}$  **então**

        DFS-VISIT( $G, V, u, \text{tempo}$ );





# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

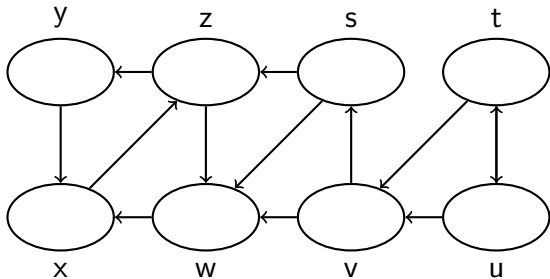
$\pi[u] \leftarrow \text{NIL};$

▷  $\text{tempo} \leftarrow 0;$

**Para cada  $u \in V[G]$  faça**

**Se  $\text{cor}[u] = \text{branco}$  então**

        DFS-VISIT( $G, V, u, \text{tempo}$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

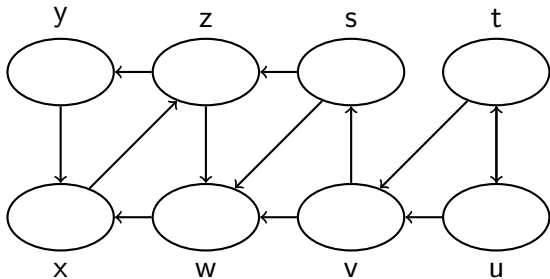
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ **Para cada  $u \in V[G]$  faça**

**Se  $\text{cor}[u] = \text{branco}$  então**

        DFS-VISIT( $G, V, u, \text{tempo}$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

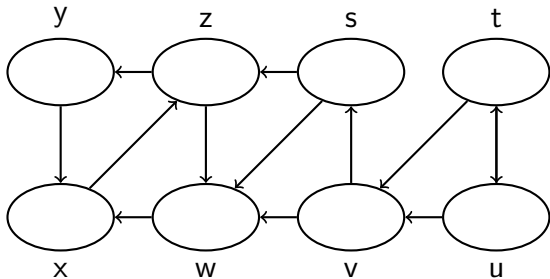
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0$ ;

**Para cada  $u \in V[G]$  faça**

$\triangleright$  **Se  $\text{cor}[s] = \text{branco}$  então**

        DFS-VISIT( $G, V, s, \text{tempo}$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

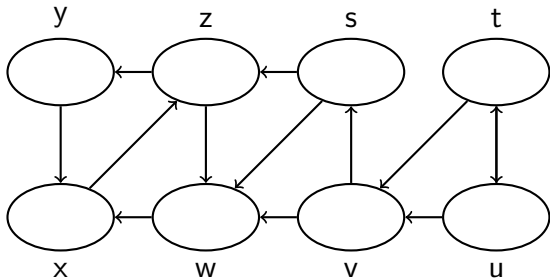
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $u \in V[G]$  **faça**

**Se**  $\text{cor}[s] = \text{branco}$  **então**

$\triangleright \quad \text{DFS-VISIT}(G, V, s, \text{tempo});$



# DFS-VISIT (G, V, **s**, 0)

▷  $\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

tempo  $\leftarrow ++\text{tempo};$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{z} \in \text{Adj}[\mathbf{s}]$  **faça**

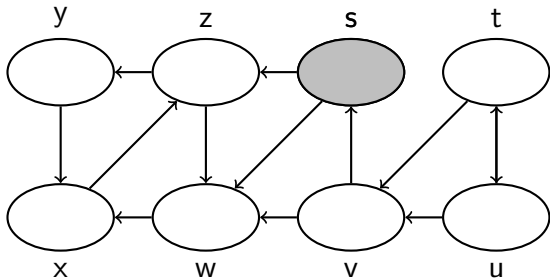
**Se**  $\text{cor}[\mathbf{z}] = \text{branco}$  **então**

$\pi[\mathbf{z}] \leftarrow \mathbf{s};$

DFS-VISIT (G, V,  $\mathbf{z}$ , 1);

$\text{cor}[\mathbf{s}] \leftarrow \text{preto};$

$f[\mathbf{s}] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, s, 0$ )

$\text{cor}[s] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[s] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[s]$  **faça**

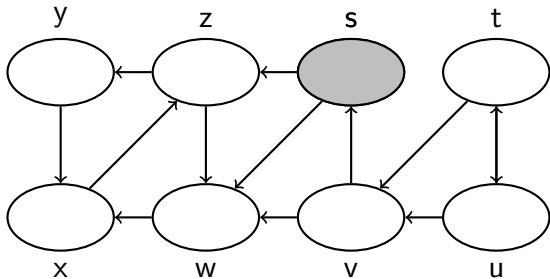
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[z] \leftarrow s;$

DFS-VISIT ( $G, V, z, 1$ );

$\text{cor}[s] \leftarrow \text{preto};$

$f[s] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **s**, 0)

$\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 1;$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{z} \in \text{Adj}[\mathbf{s}]$  **faça**

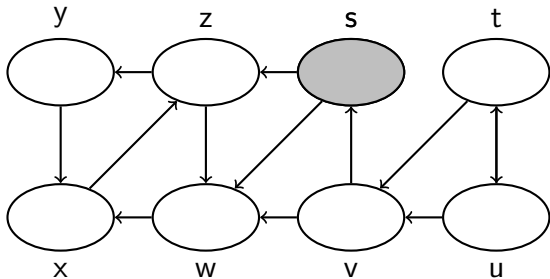
**Se**  $\text{cor}[\mathbf{z}] = \text{branco}$  **então**

$\pi[\mathbf{z}] \leftarrow \mathbf{s};$

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$\text{cor}[\mathbf{s}] \leftarrow \text{preto};$

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# DFS-VISIT ( $G, V, s, 0$ )

$\text{cor}[s] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 1;$

$\triangleright \text{d}[s] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[s]$  **faça**

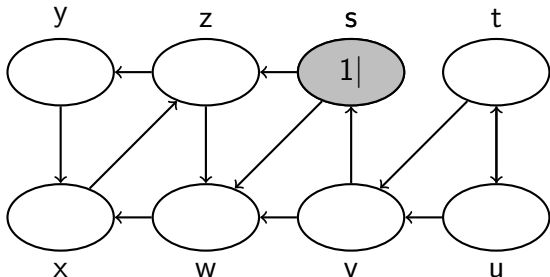
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[z] \leftarrow s;$

DFS-VISIT ( $G, V, z, 1$ );

$\text{cor}[s] \leftarrow \text{preto};$

$f[s] \leftarrow ++\text{tempo};$





# DFS-VISIT ( $G, V, s, 0$ )

$cor[s] \leftarrow \text{cinza};$

$tempo \leftarrow 1;$

$d[s] \leftarrow tempo;$

▷ **Para cada**  $z \in Adj[s]$  **faça**

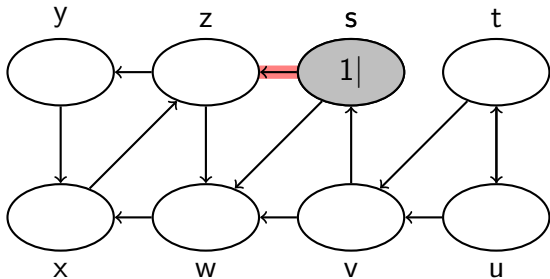
**Se**  $cor[z] = \text{branco}$  **então**

$\pi[z] \leftarrow s;$

        DFS-VISIT ( $G, V, z, 1$ );

$cor[s] \leftarrow \text{preto};$

$f[s] \leftarrow ++tempo;$



# DFS-VISIT ( $G, V, s, 0$ )

$cor[s] \leftarrow \text{cinza};$

$tempo \leftarrow 1;$

$d[s] \leftarrow tempo;$

**Para cada**  $z \in Adj[s]$  **faça**

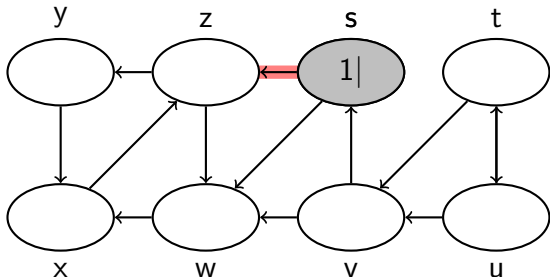
▷ **Se**  $cor[z] = \text{branco}$  **então**

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# DFS-VISIT ( $G, V, s, 0$ )

$cor[s] \leftarrow \text{cinza};$

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$d[s] \leftarrow tempo;$

**Para cada**  $z \in Adj[s]$  **faça**

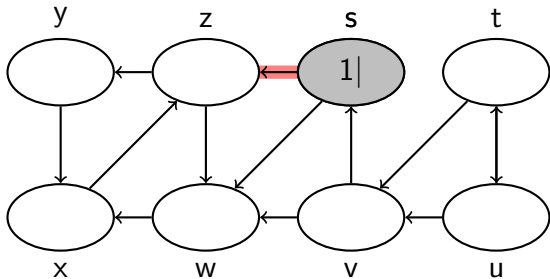
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$f[s] \leftarrow ++tempo;$



# DFS-VISIT (G, V, **s**, 0)

$\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 1;$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{z} \in \text{Adj}[\mathbf{s}]$  **faça**

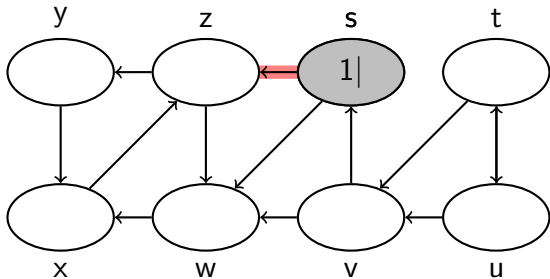
**Se**  $\text{cor}[\mathbf{z}] = \text{branco}$  **então**

$\pi[\mathbf{z}] \leftarrow \mathbf{s};$

▷ DFS-VISIT (G, V,  $\mathbf{z}$ , 1);

$\text{cor}[\mathbf{s}] \leftarrow \text{preto};$

$f[\mathbf{s}] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, z, 1$ )

$\triangleright \text{cor}[z] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[z] \leftarrow \text{tempo};$

**Para cada**  $y \in \text{Adj}[z]$  **faça**

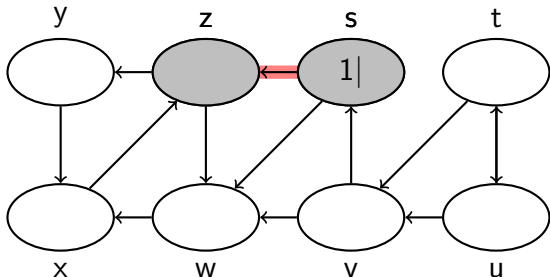
**Se**  $\text{cor}[y] = \text{branco}$  **então**

$\pi[y] \leftarrow z;$

DFS-VISIT ( $G, V, y, \text{tempo}$ );

$\text{cor}[z] \leftarrow \text{preto};$

$f[z] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, z, 1$ )

$\text{cor}[z] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[z] \leftarrow \text{tempo};$

**Para cada**  $y \in \text{Adj}[z]$  **faça**

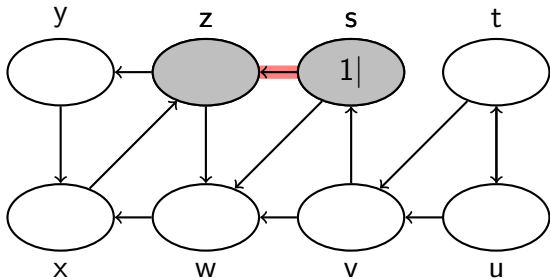
**Se**  $\text{cor}[y] = \text{branco}$  **então**

$\pi[y] \leftarrow z;$

DFS-VISIT ( $G, V, y, \text{tempo}$ );

$\text{cor}[z] \leftarrow \text{preto};$

$f[z] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, z, 1$ )

$\text{cor}[z] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 2;$

$d[z] \leftarrow \text{tempo};$

**Para cada**  $y \in \text{Adj}[z]$  **faça**

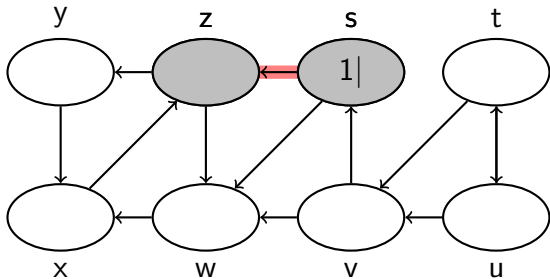
**Se**  $\text{cor}[y] = \text{branco}$  **então**

$\pi[y] \leftarrow z;$

DFS-VISIT ( $G, V, y, \text{tempo}$ );

$\text{cor}[z] \leftarrow \text{preto};$

$f[z] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, z, 1$ )

$\text{cor}[z] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 2;$

$\triangleright \text{d}[z] \leftarrow \text{tempo};$

**Para cada**  $y \in \text{Adj}[z]$  **faça**

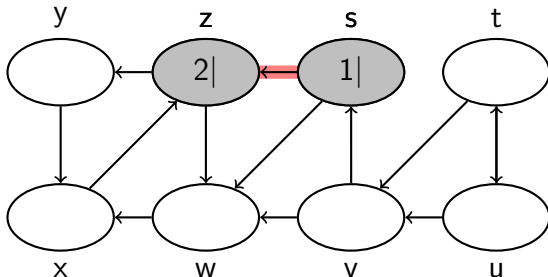
**Se**  $\text{cor}[y] = \text{branco}$  **então**

$\pi[y] \leftarrow z;$

DFS-VISIT ( $G, V, y, \text{tempo}$ );

$\text{cor}[z] \leftarrow \text{preto};$

$f[z] \leftarrow ++\text{tempo};$





# DFS-VISIT ( $G, V, z, 1$ )

$\text{cor}[z] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 2;$

$d[z] \leftarrow \text{tempo};$

▷ **Para cada**  $y \in \text{Adj}[z]$  **faça**

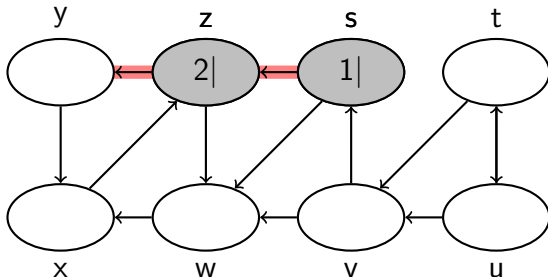
**Se**  $\text{cor}[y] = \text{branco}$  **então**

$\pi[y] \leftarrow z;$

        DFS-VISIT ( $G, V, y, \text{tempo}$ );

$\text{cor}[z] \leftarrow \text{preto};$

$f[z] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, z, 1$ )

$\text{cor}[z] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 2;$

$d[z] \leftarrow \text{tempo};$

**Para cada**  $y \in \text{Adj}[z]$  **faça**

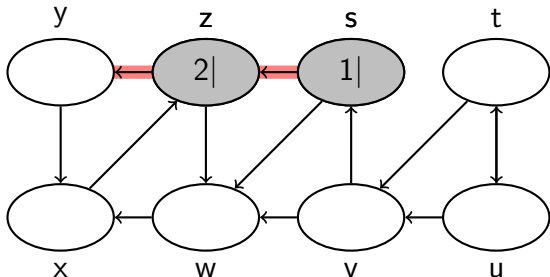
▷ **Se**  $\text{cor}[y] = \text{branco}$  **então**

$\pi[y] \leftarrow z;$

DFS-VISIT ( $G, V, y, \text{tempo}$ );

$\text{cor}[z] \leftarrow \text{preto};$

$f[z] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, z, 1$ )

$\text{cor}[z] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 2;$

$d[z] \leftarrow \text{tempo};$

**Para cada**  $y \in \text{Adj}[z]$  **faça**

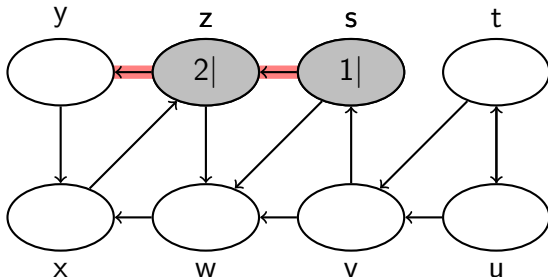
**Se**  $\text{cor}[y] = \text{branco}$  **então**

▷  $\pi[y] \leftarrow z;$

DFS-VISIT ( $G, V, y, \text{tempo}$ );

$\text{cor}[z] \leftarrow \text{preto};$

$f[z] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 1)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 2;$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{y} \in \text{Adj}[\mathbf{z}]$  **faça**

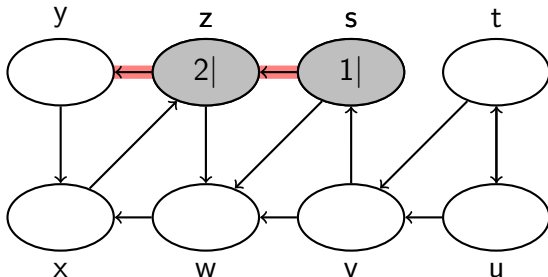
**Se**  $\text{cor}[\mathbf{y}] = \text{branco}$  **então**

$\pi[\mathbf{y}] \leftarrow \mathbf{z};$

▷ DFS-VISIT (G, V,  $\mathbf{y}$ , *tempo*);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 1)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 2;$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada** **y**  $\in \text{Adj}[\mathbf{z}]$  **faça**

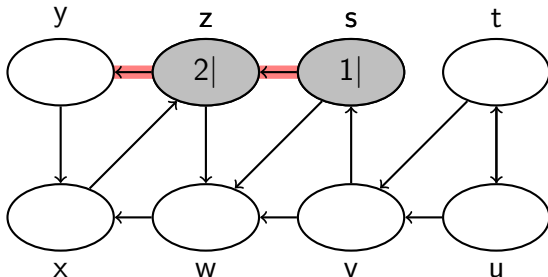
**Se**  $\text{cor}[\mathbf{y}] = \text{branco}$  **então**

$\pi[\mathbf{y}] \leftarrow \mathbf{z};$

▷ DFS-VISIT (G, V, **y**, 2);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **y**, 2)

$\triangleright \text{cor}[\mathbf{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{y}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{x} \in \text{Adj}[\mathbf{y}]$  **faça**

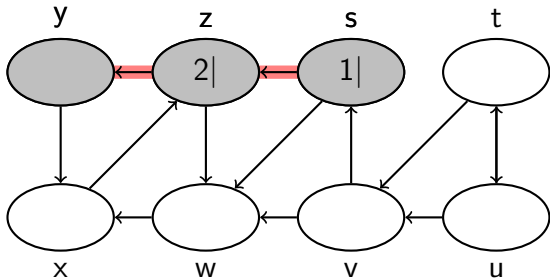
**Se**  $\text{cor}[\mathbf{x}] = \text{branco}$  **então**

$\pi[\mathbf{x}] \leftarrow \mathbf{y};$

DFS-VISIT (G, V,  $\mathbf{x}$ , *tempo*);

$\text{cor}[\mathbf{y}] \leftarrow \text{preto};$

$f[\mathbf{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **y**, 2)

$\text{cor}[\mathbf{y}] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{y}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{x} \in \text{Adj}[\mathbf{y}]$  **faça**

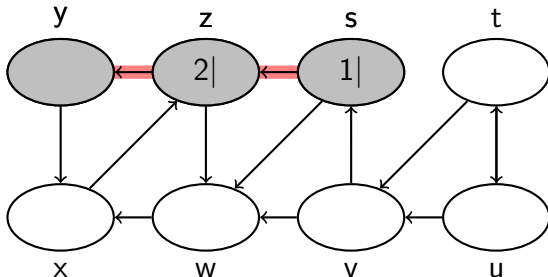
**Se**  $\text{cor}[\mathbf{x}] = \text{branco}$  **então**

$\pi[\mathbf{x}] \leftarrow \mathbf{y};$

DFS-VISIT (G, V,  $\mathbf{x}$ , *tempo*);

$\text{cor}[\mathbf{y}] \leftarrow \text{preto};$

$f[\mathbf{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, y, 2$ )

$\text{cor}[y] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 3;$

$d[y] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[y]$  **faça**

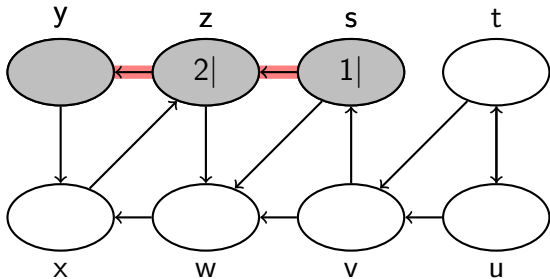
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow y;$

DFS-VISIT ( $G, V, x, \text{tempo}$ );

$\text{cor}[y] \leftarrow \text{preto};$

$f[y] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, *y*, 2)

$\text{cor}[\textcolor{blue}{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 3;$

$\triangleright \text{d}[\textcolor{blue}{y}] \leftarrow \text{tempo};$

**Para cada**  $\textcolor{red}{x} \in \text{Adj}[\textcolor{blue}{y}]$  **faça**

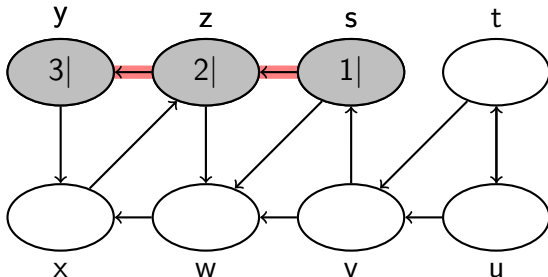
**Se**  $\text{cor}[\textcolor{red}{x}] = \text{branco}$  **então**

$\pi[\textcolor{red}{x}] \leftarrow \textcolor{blue}{y};$

DFS-VISIT (G, V,  $\textcolor{red}{x}$ , *tempo*);

$\text{cor}[\textcolor{blue}{y}] \leftarrow \text{preto};$

$\text{f}[\textcolor{blue}{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **y**, 2)

$\text{cor}[\mathbf{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 3;$

$d[\mathbf{y}] \leftarrow \text{tempo};$

▷ **Para cada**  $\mathbf{x} \in \text{Adj}[\mathbf{y}]$  **faça**

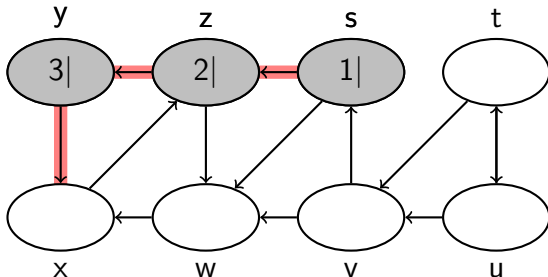
**Se**  $\text{cor}[\mathbf{x}] = \text{branco}$  **então**

$\pi[\mathbf{x}] \leftarrow \mathbf{y};$

        DFS-VISIT (G, V,  $\mathbf{x}$ , *tempo*);

$\text{cor}[\mathbf{y}] \leftarrow \text{preto};$

$f[\mathbf{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **y**, 2)

$\text{cor}[\mathbf{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 3;$

$d[\mathbf{y}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{x} \in \text{Adj}[\mathbf{y}]$  **faça**

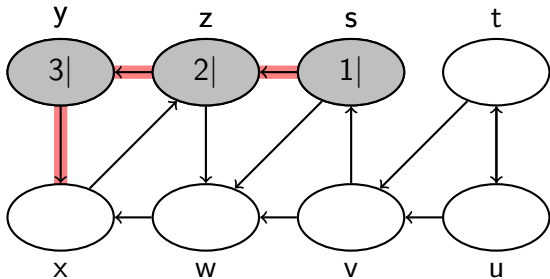
▷ **Se**  $\text{cor}[\mathbf{x}] = \text{branco}$  **então**

$\pi[\mathbf{x}] \leftarrow \mathbf{y};$

DFS-VISIT (G, V,  $\mathbf{x}$ , *tempo*);

$\text{cor}[\mathbf{y}] \leftarrow \text{preto};$

$f[\mathbf{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **y**, 2)

$\text{cor}[\mathbf{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 3;$

$d[\mathbf{y}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{x} \in \text{Adj}[\mathbf{y}]$  **faça**

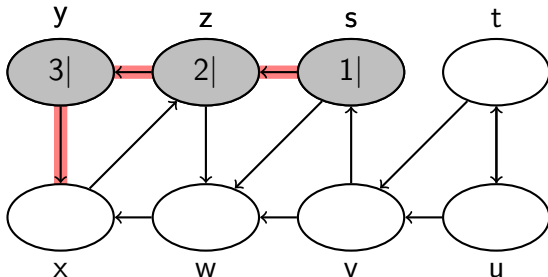
**Se**  $\text{cor}[\mathbf{x}] = \text{branco}$  **então**

▷  $\pi[\mathbf{x}] \leftarrow \mathbf{y};$

DFS-VISIT (G, V,  $\mathbf{x}$ , *tempo*);

$\text{cor}[\mathbf{y}] \leftarrow \text{preto};$

$f[\mathbf{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, *y*, 2)

$\text{cor}[\textcolor{blue}{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 3;$

$d[\textcolor{blue}{y}] \leftarrow \text{tempo};$

**Para cada**  $\textcolor{red}{x} \in \text{Adj}[\textcolor{blue}{y}]$  **faça**

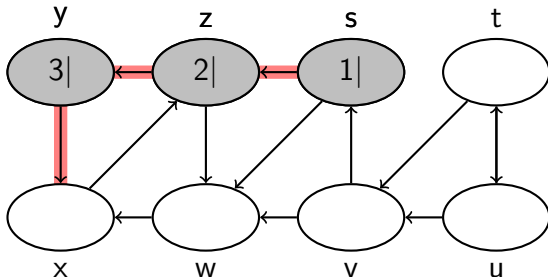
**Se**  $\text{cor}[\textcolor{red}{x}] = \text{branco}$  **então**

$\pi[\textcolor{red}{x}] \leftarrow \textcolor{blue}{y};$

▷ DFS-VISIT (G, V,  $\textcolor{red}{x}$ , *tempo*);

$\text{cor}[\textcolor{blue}{y}] \leftarrow \text{preto};$

$f[\textcolor{blue}{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **y**, 2)

$\text{cor}[\mathbf{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 3;$

$d[\mathbf{y}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{x} \in \text{Adj}[\mathbf{y}]$  **faça**

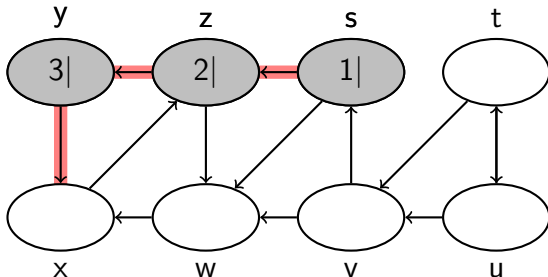
**Se**  $\text{cor}[\mathbf{x}] = \text{branco}$  **então**

$\pi[\mathbf{x}] \leftarrow \mathbf{y};$

▷ DFS-VISIT (G, V,  $\mathbf{x}$ , 3);

$\text{cor}[\mathbf{y}] \leftarrow \text{preto};$

$f[\mathbf{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $x$ , 3)

$\triangleright \text{cor}[x] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

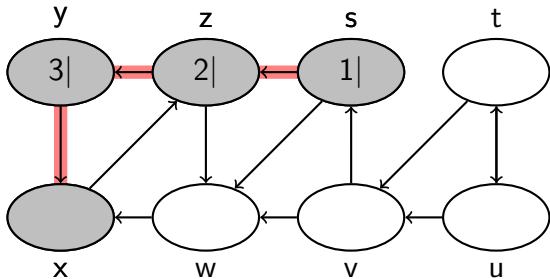
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[x] \leftarrow y;$

DFS-VISIT (G, V,  $x$ ,  $\text{tempo}$ );

$\text{cor}[x] \leftarrow \text{preto};$

$f[x] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, x, 3$ )

$\text{cor}[x] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

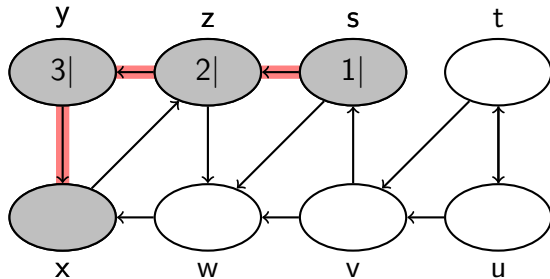
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[z] \leftarrow x;$

DFS-VISIT ( $G, V, z, \text{tempo}$ );

$\text{cor}[x] \leftarrow \text{preto};$

$f[x] \leftarrow ++\text{tempo};$





# DFS-VISIT ( $G, V, x, 3$ )

$\text{cor}[x] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 4;$

$d[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

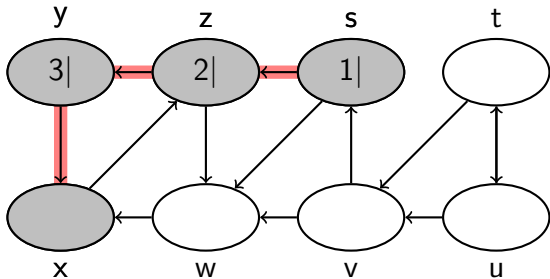
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[x] \leftarrow y;$

DFS-VISIT ( $G, V, x, \text{tempo}$ );

$\text{cor}[x] \leftarrow \text{preto};$

$f[x] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $x$ , 3)

$\text{cor}[x] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 4;$

$\triangleright \text{d}[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

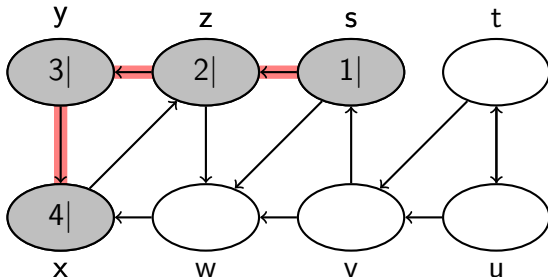
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[x] \leftarrow y;$

DFS-VISIT (G, V,  $x$ ,  $\text{tempo}$ );

$\text{cor}[x] \leftarrow \text{preto};$

$f[x] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, x, 3$ )

$\text{cor}[x] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 4;$

$d[x] \leftarrow \text{tempo};$

▷ **Para cada**  $z \in \text{Adj}[x]$  **faça**

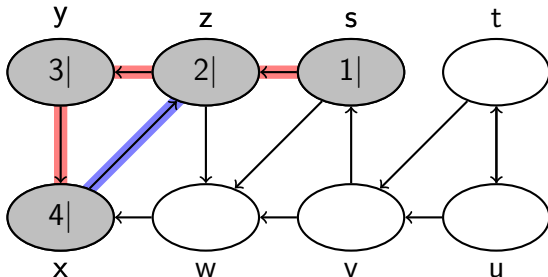
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[z] \leftarrow x;$

        DFS-VISIT ( $G, V, z, \text{tempo} + 1$ );

$\text{cor}[x] \leftarrow \text{preto};$

$f[x] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, x, 3$ )

$\text{cor}[x] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 4;$

$d[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

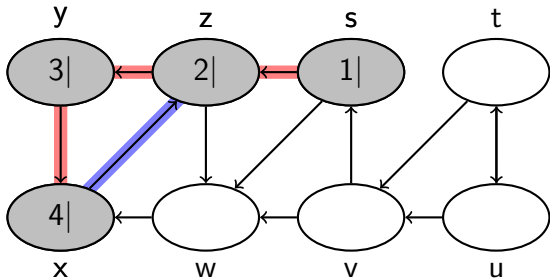
▷ **Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[x] \leftarrow y;$

DFS-VISIT ( $G, V, x, \text{tempo}$ );

$\text{cor}[x] \leftarrow \text{preto};$

$f[x] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $x$ , 3)

$\text{cor}[x] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 4;$

$d[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

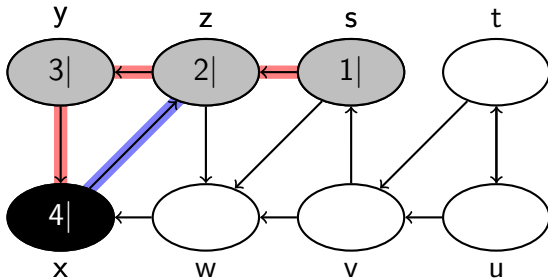
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[x] \leftarrow y;$

DFS-VISIT (G, V,  $x$ ,  $\text{tempo}$ );

$\triangleright \text{cor}[x] \leftarrow \text{preto};$

$f[x] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $x$ , 3)

$\text{cor}[x] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 4;$

$d[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

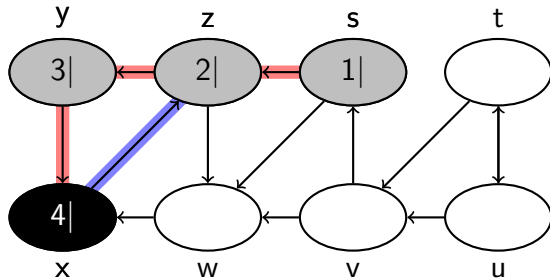
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[z] \leftarrow x;$

DFS-VISIT (G, V,  $z$ ,  $\text{tempo} + 1$ );

$\text{cor}[x] \leftarrow \text{preto};$

$\triangleright f[x] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $x$ , 3)

$\text{cor}[x] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 4;$

$d[x] \leftarrow \text{tempo};$

**Para cada**  $z \in \text{Adj}[x]$  **faça**

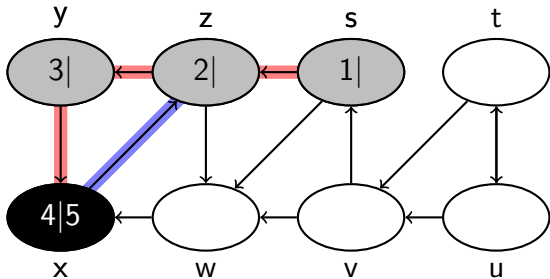
**Se**  $\text{cor}[z] = \text{branco}$  **então**

$\pi[z] \leftarrow x;$

DFS-VISIT (G, V,  $z$ ,  $\text{tempo} + 1$ );

$\text{cor}[x] \leftarrow \text{preto};$

$\triangleright f[x] \leftarrow 5;$



# DFS-VISIT (G, V, *y*, 2)

$\text{cor}[\textcolor{blue}{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\textcolor{blue}{y}] \leftarrow \text{tempo};$

**Para cada**  $\textcolor{red}{x} \in \text{Adj}[\textcolor{blue}{y}]$  **faça**

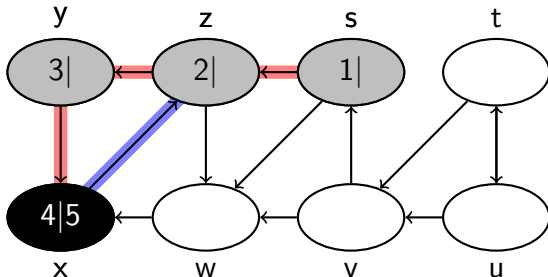
**Se**  $\text{cor}[\textcolor{red}{x}] = \text{branco}$  **então**

$\pi[\textcolor{red}{x}] \leftarrow \textcolor{blue}{y};$

$\triangleleft \text{DFS-VISIT (G, V, } \textcolor{red}{x}, 5); //$ **retorna da recursão**

$\text{cor}[\textcolor{blue}{y}] \leftarrow \text{preto};$

$f[\textcolor{blue}{y}] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, **y**, 2)

$\text{cor}[\mathbf{y}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{y}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{x} \in \text{Adj}[\mathbf{y}]$  **faça**

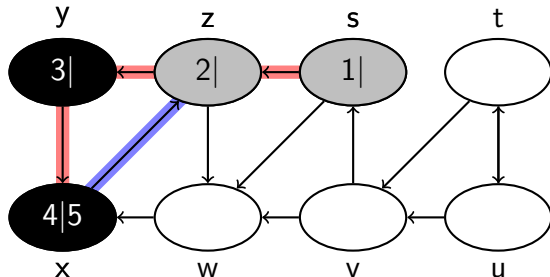
**Se**  $\text{cor}[\mathbf{x}] = \text{branco}$  **então**

$\pi[\mathbf{x}] \leftarrow \mathbf{y};$

DFS-VISIT (G, V,  $\mathbf{x}$ , 5);

$\triangleright \text{cor}[\mathbf{y}] \leftarrow \text{preto};$

$f[\mathbf{y}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $y$ , 2)

$\text{cor}[y] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[y] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[y]$  **faça**

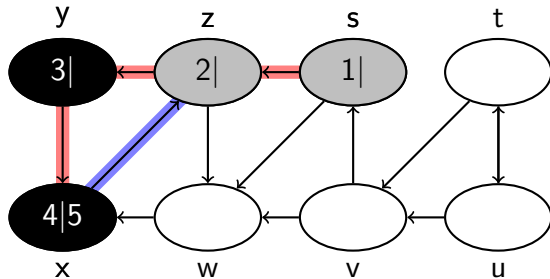
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow y;$

DFS-VISIT (G, V,  $x$ , 5);

$\text{cor}[y] \leftarrow \text{preto};$

$\triangleright f[y] \leftarrow ++\text{tempo};$



DFS-VISIT (G, V, *y*, 2)

```
cor[y] ← cinza;
```

```
tempo ← ++tempo;
```

$$d[y] \leftarrow \text{tempo};$$

Para cada  $x \in Adj[y]$  faça

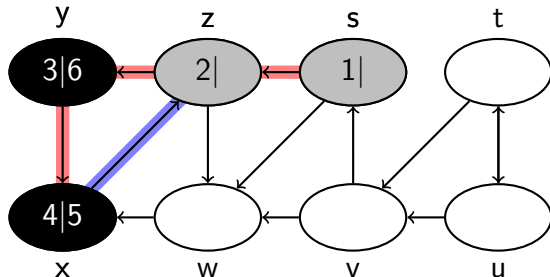
**Se cor[x] = branco então**

$$\pi[\mathbf{x}] \leftarrow \mathbf{y};$$

```
DFS-VISIT (G, V, x, 5);
```

```
cor[y] ← preto;
```

▷  $f[\mathbf{y}] \leftarrow 6;$



# DFS-VISIT (G, V, **z**, 1)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{y} \in \text{Adj}[\mathbf{z}]$  **faça**

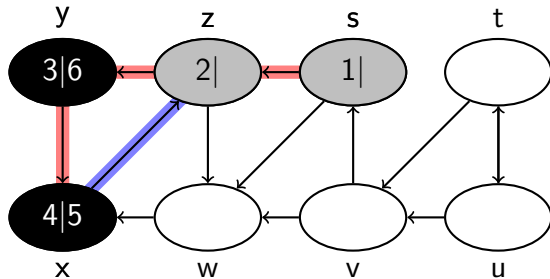
**Se**  $\text{cor}[\mathbf{y}] = \text{branco}$  **então**

$\pi[\mathbf{y}] \leftarrow \mathbf{z};$

◁ DFS-VISIT (G, V,  $\mathbf{y}$ , 6); **//retorna da recursão**

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 1)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

▷ **Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

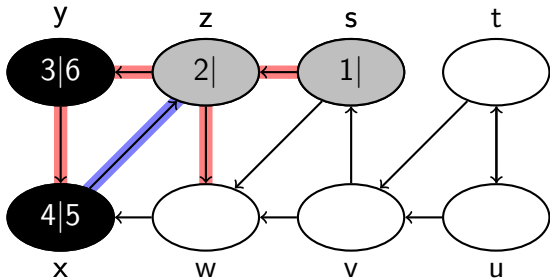
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{z};$

        DFS-VISIT (G, V,  $\mathbf{w}$ , 6);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 1)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

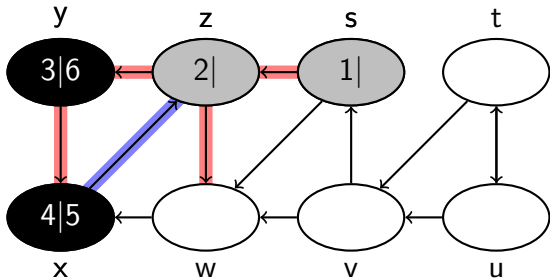
▷ **Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{z};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 6);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 1)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

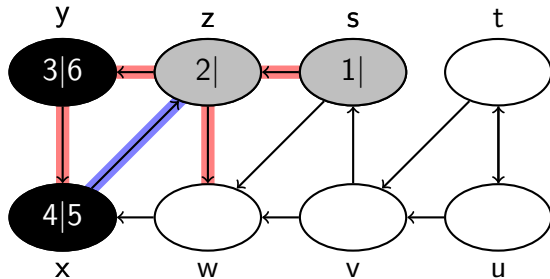
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

▷  $\pi[\mathbf{w}] \leftarrow \mathbf{z};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 6);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 1)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

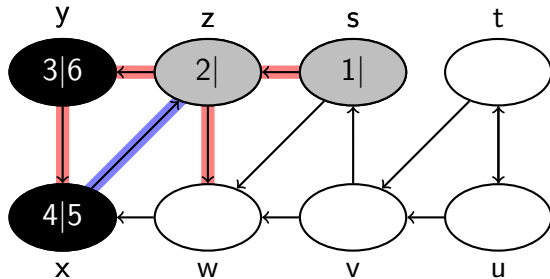
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{z};$

▷ DFS-VISIT (G, V,  $\mathbf{w}$ , 6);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, $w$ , 6)

$\triangleright \text{cor}[w] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

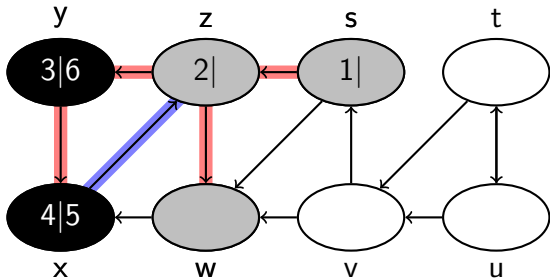
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

DFS-VISIT (G, V,  $x$ ,  $\text{tempo}$ );

$\text{cor}[w] \leftarrow \text{preto};$

$f[w] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $w$ , 6)

$\text{cor}[w] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

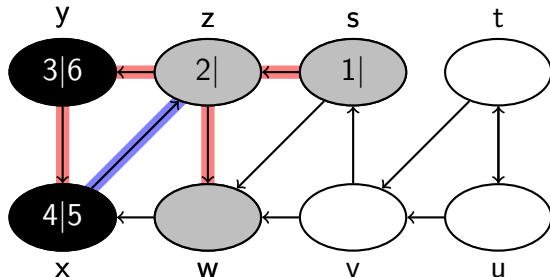
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

DFS-VISIT (G, V,  $x$ ,  $\text{tempo}$ );

$\text{cor}[w] \leftarrow \text{preto};$

$f[w] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $w$ , 6)

$\text{cor}[w] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 7;$

$d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

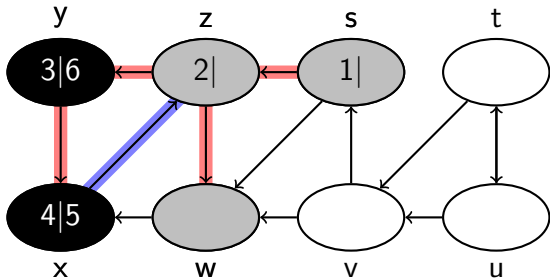
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

DFS-VISIT (G, V,  $x$ ,  $\text{tempo}$ );

$\text{cor}[w] \leftarrow \text{preto};$

$f[w] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $w$ , 6)

$\text{cor}[w] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 7;$

$\triangleright d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

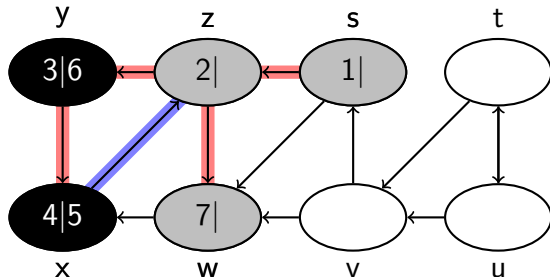
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

$\triangleright \text{DFS-VISIT (G, V, } x, \text{tempo)};$

$\text{cor}[w] \leftarrow \text{preto};$

$f[w] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, w, 6$ )

$\text{cor}[w] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 7;$

$d[w] \leftarrow \text{tempo};$

▷ Para cada  $x \in \text{Adj}[w]$  faça

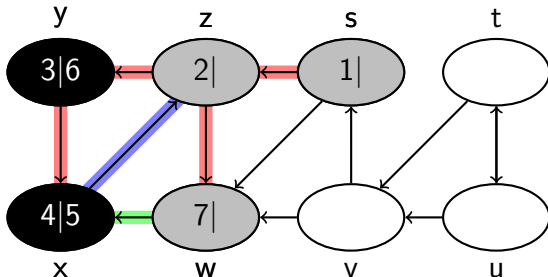
Se  $\text{cor}[x] = \text{branco}$  então

$\pi[x] \leftarrow w;$

DFS-VISIT ( $G, V, x, \text{tempo}$ );

$\text{cor}[w] \leftarrow \text{preto};$

$f[w] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, w, 6$ )

$\text{cor}[w] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 7;$

$d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

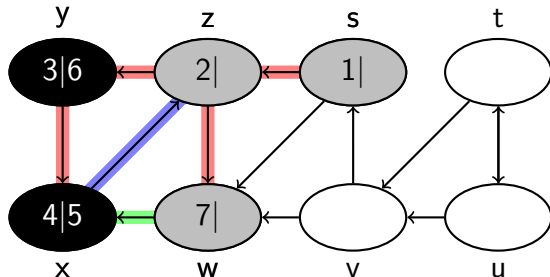
▷ **Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

DFS-VISIT ( $G, V, x, \text{tempo}$ );

$\text{cor}[w] \leftarrow \text{preto};$

$f[w] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $w$ , 6)

$\text{cor}[w] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 7;$

$d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

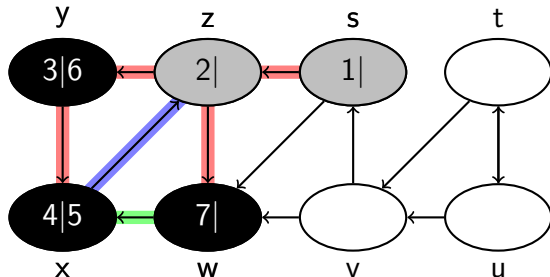
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

DFS-VISIT (G, V,  $x$ ,  $\text{tempo}$ );

$\triangleright \text{cor}[w] \leftarrow \text{preto};$

$f[w] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, w, 6$ )

$\text{cor}[w] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 7;$

$d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

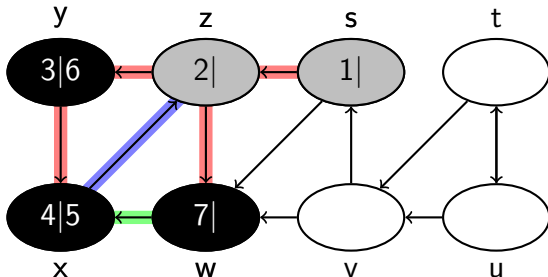
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

DFS-VISIT ( $G, V, x, \text{tempo}$ );

$\text{cor}[w] \leftarrow \text{preto};$

$\triangleright f[w] \leftarrow ++\text{tempo};$





# DFS-VISIT ( $G, V, w, 6$ )

$\text{cor}[w] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 7;$

$d[w] \leftarrow \text{tempo};$

**Para cada**  $x \in \text{Adj}[w]$  **faça**

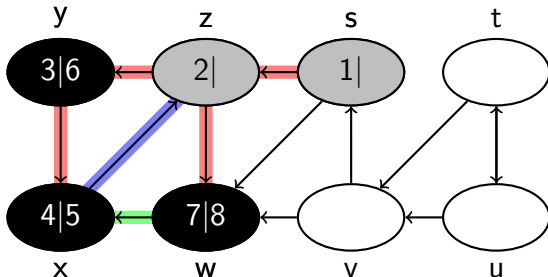
**Se**  $\text{cor}[x] = \text{branco}$  **então**

$\pi[x] \leftarrow w;$

DFS-VISIT ( $G, V, x, \text{tempo}$ );

$\text{cor}[w] \leftarrow \text{preto};$

$\triangleright f[w] \leftarrow 8;$



# DFS-VISIT (G, V, **z**, 2)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

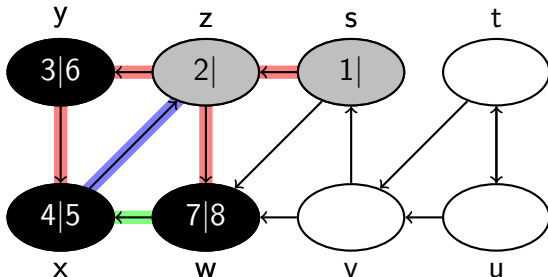
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{z};$

◁ DFS-VISIT (G, V,  $\mathbf{w}$ , 8); **//retorna da recursão**

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 2)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

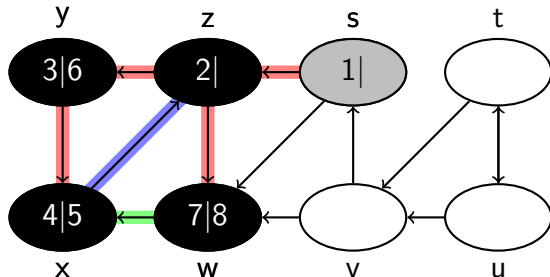
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{z};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 8);

$\triangleright \text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 2)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

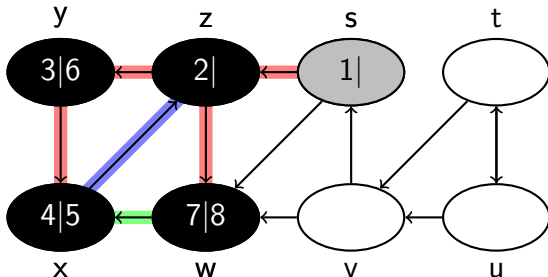
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{z};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 8);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$\triangleright f[\mathbf{z}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **z**, 2)

$\text{cor}[\mathbf{z}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{z}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{z}]$  **faça**

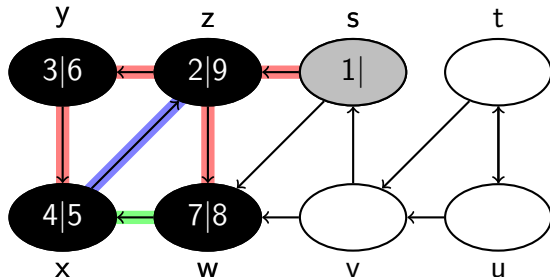
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{z};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 8);

$\text{cor}[\mathbf{z}] \leftarrow \text{preto};$

$\triangleright f[\mathbf{z}] \leftarrow 9;$



# DFS-VISIT (G, V, **s**, 1)

$\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{z} \in \text{Adj}[\mathbf{s}]$  **faça**

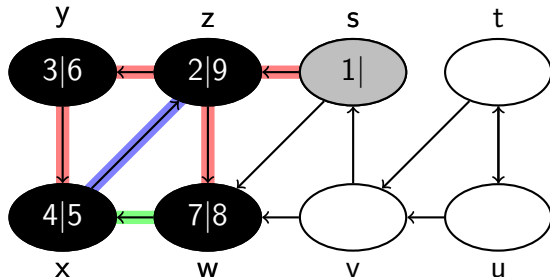
**Se**  $\text{cor}[\mathbf{z}] = \text{branco}$  **então**

$\pi[\mathbf{z}] \leftarrow \mathbf{s};$

◁ DFS-VISIT (G, V,  $\mathbf{z}$ , 9); **//retorna da recursão**

$\text{cor}[\mathbf{s}] \leftarrow \text{preto};$

$f[\mathbf{s}] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, s, 1$ )

$\text{cor}[s] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[s] \leftarrow \text{tempo};$

▷ Para cada  $w \in \text{Adj}[s]$  faça

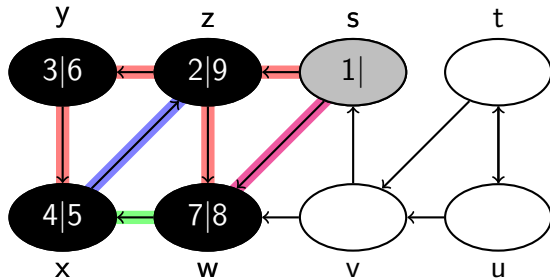
Se  $\text{cor}[w] = \text{branco}$  então

$\pi[w] \leftarrow s;$

DFS-VISIT ( $G, V, w, 9$ );

$\text{cor}[s] \leftarrow \text{preto};$

$f[s] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **s**, 1)

$\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{s}]$  **faça**

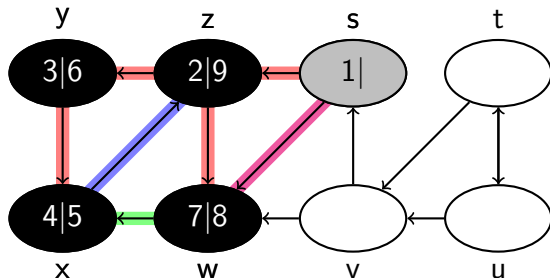
▷ **Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{s};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 9);

$\text{cor}[\mathbf{s}] \leftarrow \text{preto};$

$f[\mathbf{s}] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, **s**, 1)

$\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{s}]$  **faça**

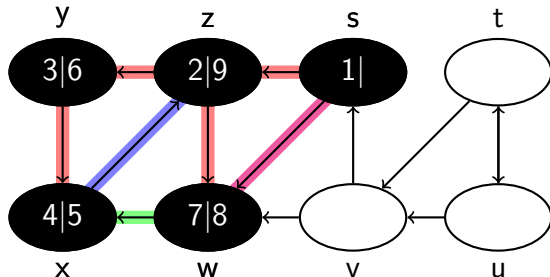
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{s};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 9);

$\triangleright \text{cor}[\mathbf{s}] \leftarrow \text{preto};$

$f[\mathbf{s}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **s**, 1)

$\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{s}]$  **faça**

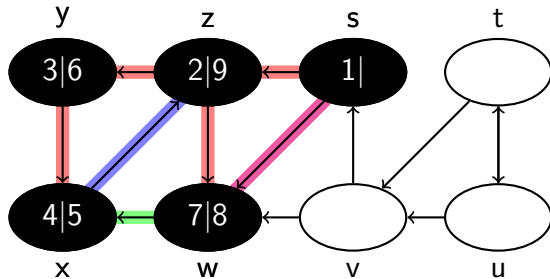
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{s};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 9);

$\text{cor}[\mathbf{s}] \leftarrow \text{preto};$

$\triangleright f[\mathbf{s}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **s**, 1)

$\text{cor}[\mathbf{s}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{s}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{s}]$  **faça**

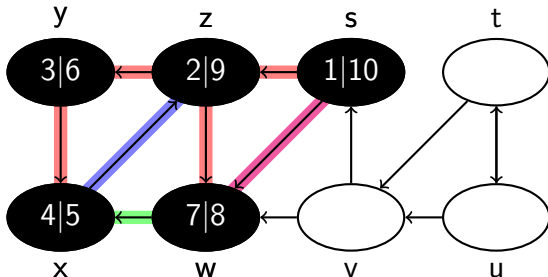
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{s};$

DFS-VISIT (G, V,  $\mathbf{w}$ , 9);

$\text{cor}[\mathbf{s}] \leftarrow \text{preto};$

$\triangleright f[\mathbf{s}] \leftarrow 10;$



# BUSCA-EM-PROFUNDIDADE (G)

Para cada  $u \in V[G]$  faça

$\text{cor}[u] \leftarrow \text{branco};$

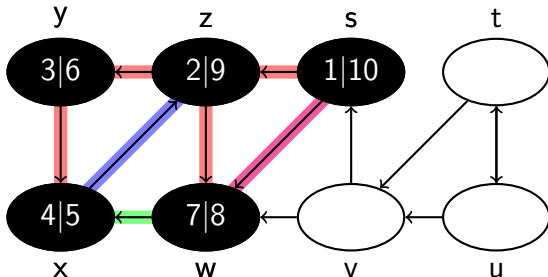
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

Para cada  $s \in V[G]$  faça

    Se  $\text{cor}[s] = \text{branco}$  então

        ◁      DFS-VISIT( $G, V, s, 10$ ); //retorna da recursão



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

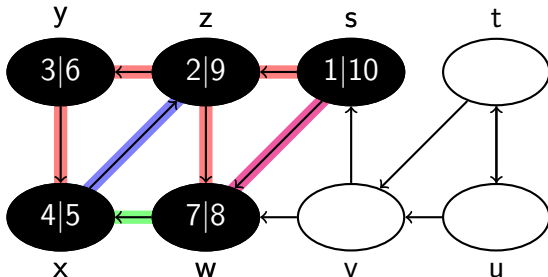
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ **Para cada**  $t \in V[G]$  **faça**

**Se**  $\text{cor}[t] = \text{branco}$  **então**

        DFS-VISIT( $G, V, t, 10$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

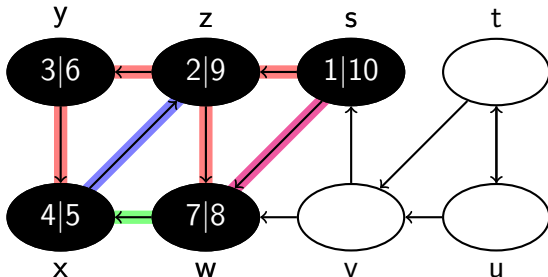
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $t \in V[G]$  **faça**

$\triangleright$  **Se**  $\text{cor}[t] = \text{branco}$  **então**

        DFS-VISIT( $G, V, t, 10$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

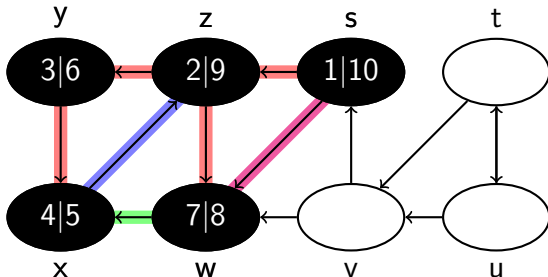
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $t \in V[G]$  **faça**

**Se**  $\text{cor}[t] = \text{branco}$  **então**

$\triangleright \text{DFS-VISIT}(G, V, t, 10);$



# DFS-VISIT (G, V, *t*, 10)

▷ cor[*t*] ← cinza;

tempo ← ++tempo;

d[*t*] ← tempo;

**Para cada** *v* ∈ Adj[*t*] **faça**

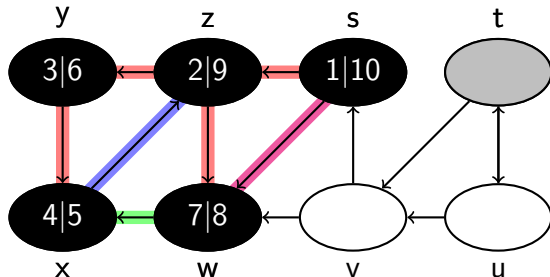
**Se** cor[*v*] = branco **então**

        π[*v*] ← *t*;

        DFS-VISIT (G, V, *v*, tempo);

cor[*t*] ← preto;

f[*t*] ← ++tempo;





# DFS-VISIT ( $G, V, t, 10$ )

$\text{cor}[t] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[t]$  **faça**

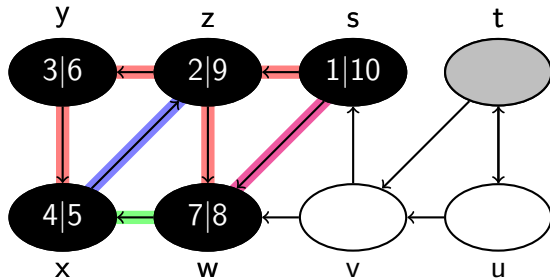
**Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

DFS-VISIT ( $G, V, v, \text{tempo}$ );

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, *t*, 10)

$\text{cor}[\mathbf{t}] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 11;$

$d[\mathbf{t}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{v} \in \text{Adj}[\mathbf{t}]$  **faça**

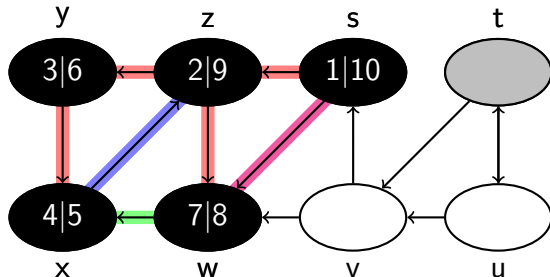
**Se**  $\text{cor}[\mathbf{v}] = \text{branco}$  **então**

$\pi[\mathbf{v}] \leftarrow \mathbf{t};$

DFS-VISIT (G, V,  $\mathbf{v}$ , *tempo*);

$\text{cor}[\mathbf{t}] \leftarrow \text{preto};$

$f[\mathbf{t}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, *t*, 10)

$\text{cor}[\mathbf{t}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 11;$

$\triangleright \text{d}[\mathbf{t}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{v} \in \text{Adj}[\mathbf{t}]$  **faça**

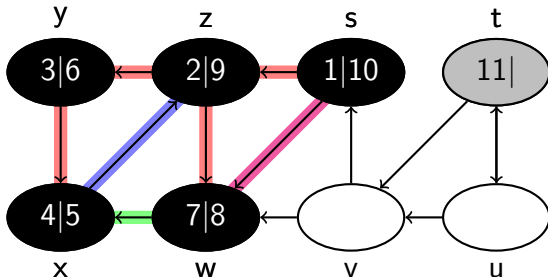
**Se**  $\text{cor}[\mathbf{v}] = \text{branco}$  **então**

$\pi[\mathbf{v}] \leftarrow \mathbf{t};$

DFS-VISIT (G, V,  $\mathbf{v}$ , *tempo*);

$\text{cor}[\mathbf{t}] \leftarrow \text{preto};$

$\text{f}[\mathbf{t}] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, t, 10$ )

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 11;$

$d[t] \leftarrow \text{tempo};$

▷ Para cada  $v \in \text{Adj}[t]$  faça

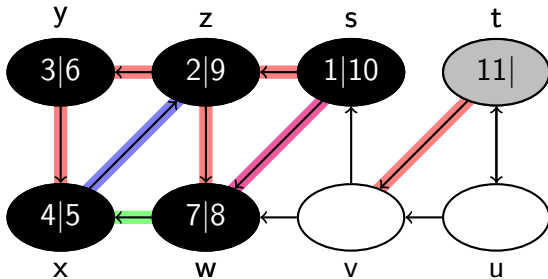
Se  $\text{cor}[v] = \text{branco}$  então

$\pi[v] \leftarrow t;$

DFS-VISIT ( $G, V, v, \text{tempo}$ );

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT ( $G, V, t, 10$ )

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 11;$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[t]$  **faça**

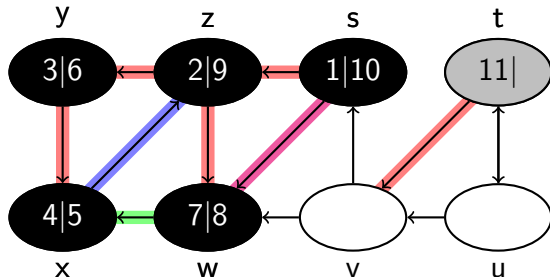
▷ **Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

DFS-VISIT ( $G, V, v, \text{tempo}$ );

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 11;$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[t]$  **faça**

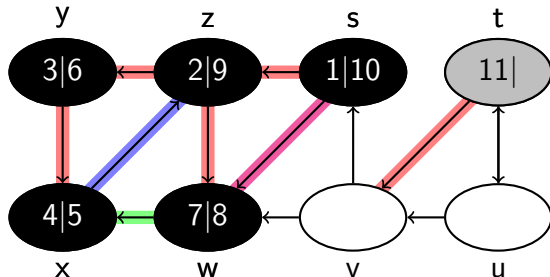
**Se**  $\text{cor}[v] = \text{branco}$  **então**

▷  $\pi[v] \leftarrow t;$

DFS-VISIT (G, V,  $v$ ,  $\text{tempo}$ );

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, *t*, 10)

$\text{cor}[\mathbf{t}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 11;$

$d[\mathbf{t}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{v} \in \text{Adj}[\mathbf{t}]$  **faça**

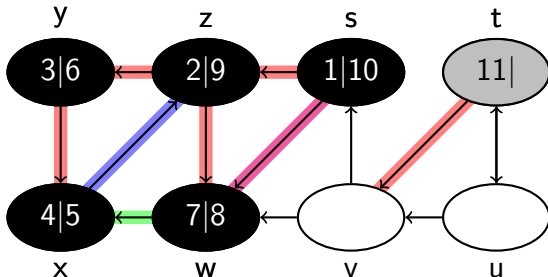
**Se**  $\text{cor}[\mathbf{v}] = \text{branco}$  **então**

$\pi[\mathbf{v}] \leftarrow \mathbf{t};$

▷ DFS-VISIT (G, V,  $\mathbf{v}$ , *tempo*);

$\text{cor}[\mathbf{t}] \leftarrow \text{preto};$

$f[\mathbf{t}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 11;$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[t]$  **faça**

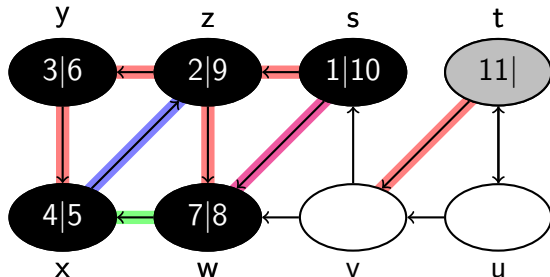
**Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

▷ DFS-VISIT (G, V,  $v$ , 11);

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, **v**, 11)

$\triangleright \text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **w**  $\in \text{Adj}[\mathbf{v}]$  **faça**

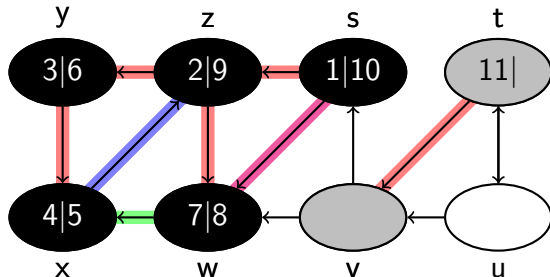
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **w**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **w**  $\in \text{Adj}[\mathbf{v}]$  **faça**

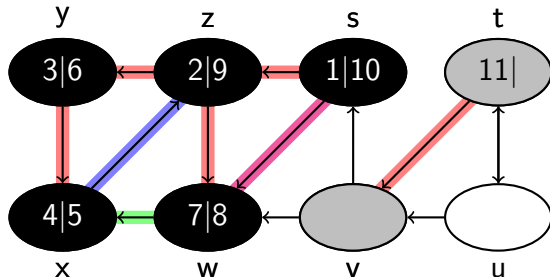
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **w**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada**  $\mathbf{w} \in \text{Adj}[\mathbf{v}]$  **faça**

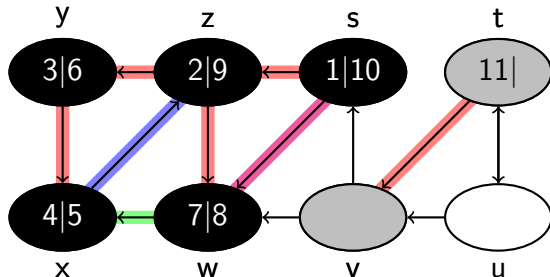
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V,  $\mathbf{w}$ , *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$\triangleright \text{d}[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **w**  $\in \text{Adj}[\mathbf{v}]$  **faça**

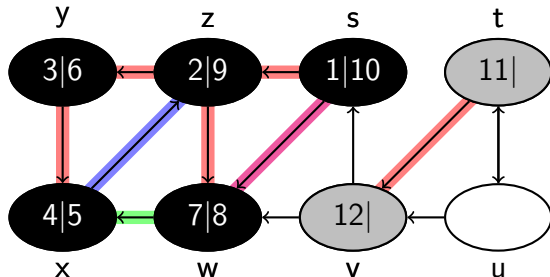
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **w**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$\text{f}[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

▷ **Para cada** **w**  $\in \text{Adj}[\mathbf{v}]$  **faça**

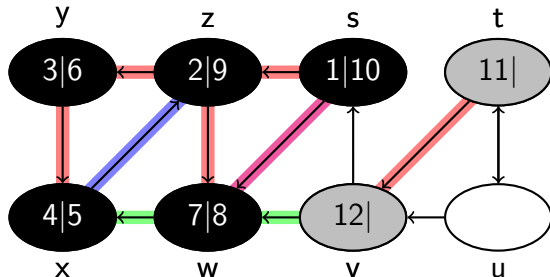
**Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{v};$

        DFS-VISIT (G, V, **w**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **w**  $\in \text{Adj}[\mathbf{v}]$  **faça**

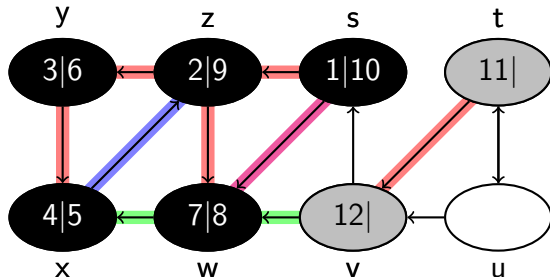
▷ **Se**  $\text{cor}[\mathbf{w}] = \text{branco}$  **então**

$\pi[\mathbf{w}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **w**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

▷ **Para cada** **s**  $\in \text{Adj}[\mathbf{v}]$  **faça**

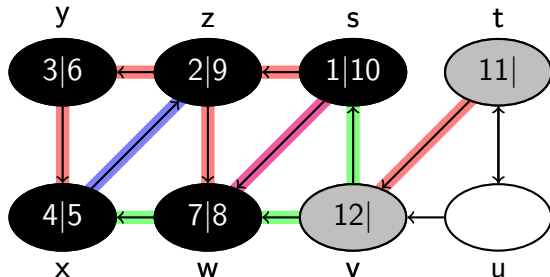
**Se**  $\text{cor}[\mathbf{s}] = \text{branco}$  **então**

$\pi[\mathbf{s}] \leftarrow \mathbf{v};$

        DFS-VISIT (G, V, **s**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **s**  $\in \text{Adj}[\mathbf{v}]$  **faça**

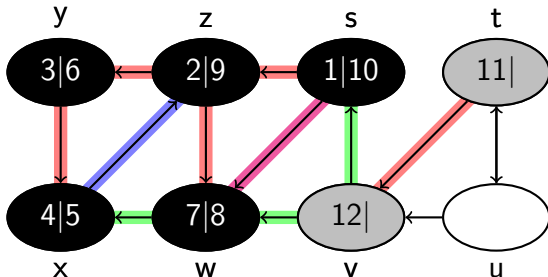
▷ **Se**  $\text{cor}[\mathbf{s}] = \text{branco}$  **então**

$\pi[\mathbf{s}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **s**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **s**  $\in \text{Adj}[\mathbf{v}]$  **faça**

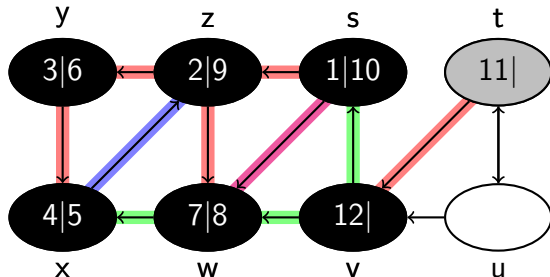
**Se**  $\text{cor}[\mathbf{s}] = \text{branco}$  **então**

$\pi[\mathbf{s}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **s**, *tempo*);

$\triangleright \text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **s**  $\in \text{Adj}[\mathbf{v}]$  **faça**

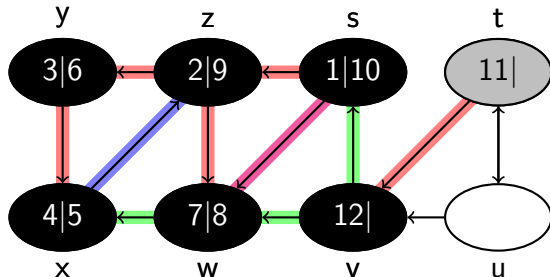
**Se**  $\text{cor}[\mathbf{s}] = \text{branco}$  **então**

$\pi[\mathbf{s}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **s**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$\triangleright f[\mathbf{v}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, **v**, 11)

$\text{cor}[\mathbf{v}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 12;$

$d[\mathbf{v}] \leftarrow \text{tempo};$

**Para cada** **s**  $\in \text{Adj}[\mathbf{v}]$  **faça**

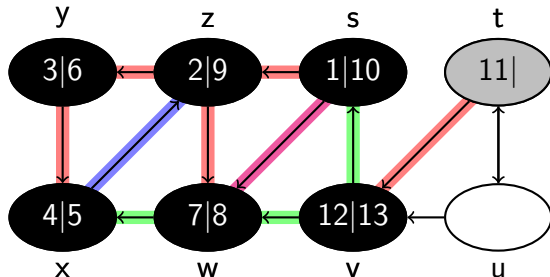
**Se**  $\text{cor}[\mathbf{s}] = \text{branco}$  **então**

$\pi[\mathbf{s}] \leftarrow \mathbf{v};$

DFS-VISIT (G, V, **s**, *tempo*);

$\text{cor}[\mathbf{v}] \leftarrow \text{preto};$

$\triangleright f[\mathbf{v}] \leftarrow 13;$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[t]$  **faça**

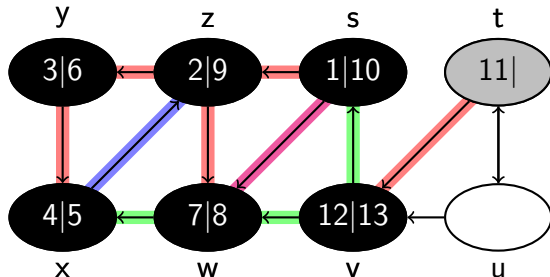
**Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

$\triangleleft$  DFS-VISIT (G, V,  $v$ , 13); **//retorna da recursão**

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, *t*, 10)

$\text{cor}[\mathbf{t}] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[\mathbf{t}] \leftarrow \text{tempo};$

▷ Para cada  $\mathbf{u} \in \text{Adj}[\mathbf{t}]$  faça

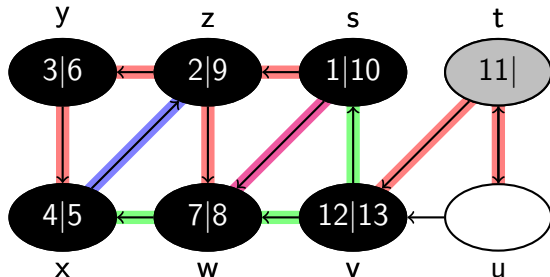
Se  $\text{cor}[\mathbf{u}] = \text{branco}$  então

$\pi[\mathbf{u}] \leftarrow \mathbf{t};$

DFS-VISIT (G, V,  $\mathbf{u}$ , 13);

$\text{cor}[\mathbf{t}] \leftarrow \text{preto};$

$f[\mathbf{t}] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $u \in \text{Adj}[t]$  **faça**

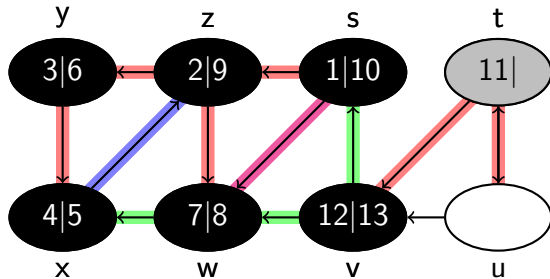
▷ **Se**  $\text{cor}[u] = \text{branco}$  **então**

$\pi[u] \leftarrow t;$

DFS-VISIT (G, V,  $u$ , 13);

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $u \in \text{Adj}[t]$  **faça**

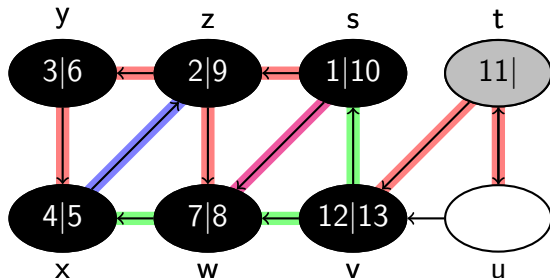
**Se**  $\text{cor}[u] = \text{branco}$  **então**

▷  $\pi[u] \leftarrow t;$

DFS-VISIT (G, V,  $u$ , 13);

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $u \in \text{Adj}[t]$  **faça**

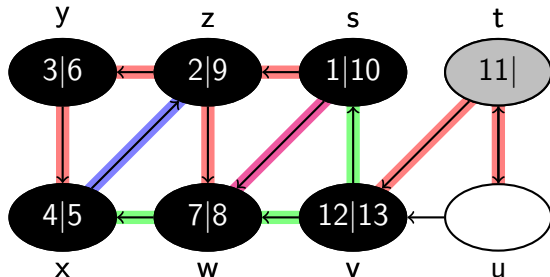
**Se**  $\text{cor}[u] = \text{branco}$  **então**

$\pi[u] \leftarrow t;$

▷ DFS-VISIT (G, V,  $u$ , 13);

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, $u$ , 13)

$\triangleright \text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[u]$  **faça**

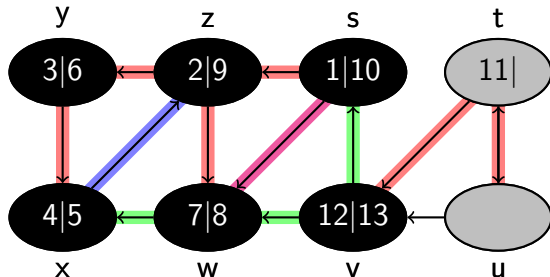
**Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow v;$

DFS-VISIT (G, V,  $v$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow ++\text{tempo};$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[u]$  **faça**

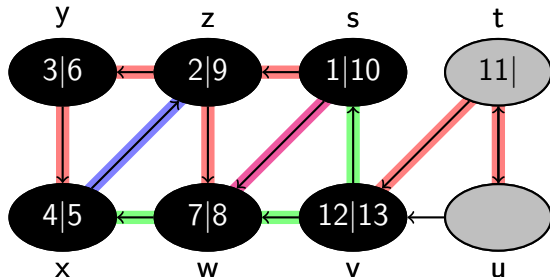
**Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow v;$

DFS-VISIT (G, V,  $v$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\triangleright \text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[u]$  **faça**

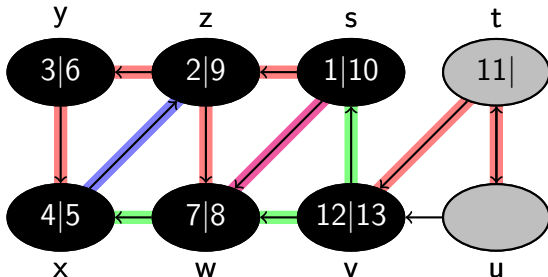
**Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow v;$

DFS-VISIT (G, V,  $v$ , *tempo*);

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$\triangleright \text{d}[u] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[u]$  **faça**

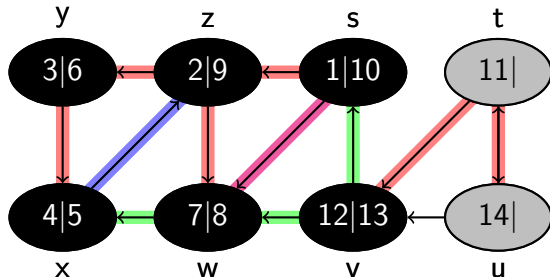
**Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow v;$

DFS-VISIT (G, V,  $v$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

▷ Para cada  $v \in \text{Adj}[u]$  faça

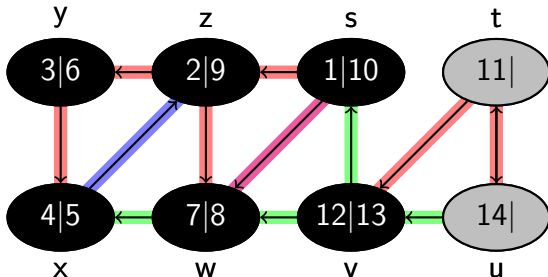
Se  $\text{cor}[v] = \text{branco}$  então

$\pi[v] \leftarrow v;$

DFS-VISIT (G, V,  $v$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $v \in \text{Adj}[u]$  **faça**

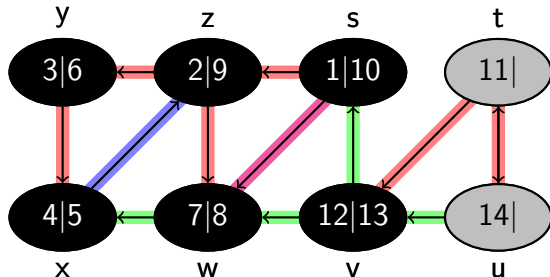
▷ **Se**  $\text{cor}[v] = \text{branco}$  **então**

$\pi[v] \leftarrow v;$

DFS-VISIT (G, V,  $v$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

▷ Para cada  $t \in \text{Adj}[u]$  faça

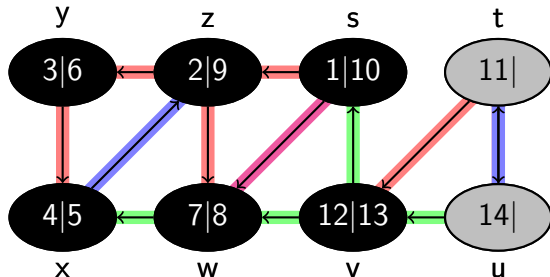
Se  $\text{cor}[t] = \text{branco}$  então

$\pi[v] \leftarrow t;$

DFS-VISIT (G, V,  $t$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $t \in \text{Adj}[u]$  **faça**

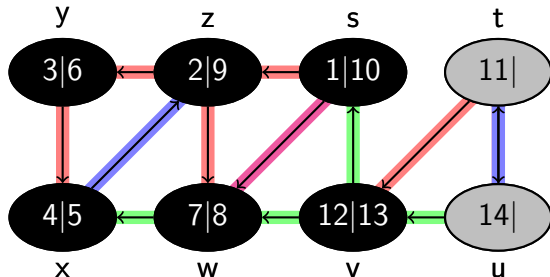
▷ **Se**  $\text{cor}[t] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

DFS-VISIT (G, V,  $t$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$





# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $t \in \text{Adj}[u]$  **faça**

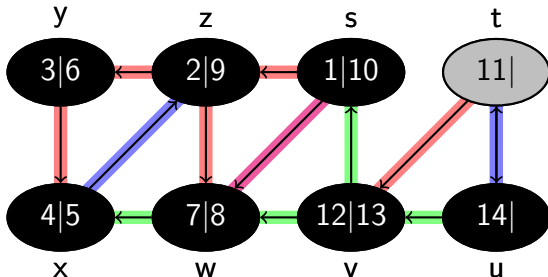
**Se**  $\text{cor}[t] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

DFS-VISIT (G, V,  $t$ ,  $\text{tempo}$ );

$\triangleright \text{cor}[u] \leftarrow \text{preto};$

$f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $t \in \text{Adj}[u]$  **faça**

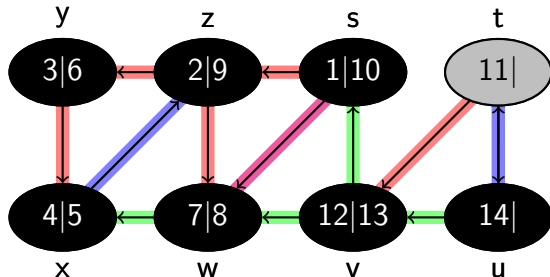
**Se**  $\text{cor}[t] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

DFS-VISIT (G, V,  $t$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$\triangleright f[u] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $u$ , 13)

$\text{cor}[u] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow 14;$

$d[u] \leftarrow \text{tempo};$

**Para cada**  $t \in \text{Adj}[u]$  **faça**

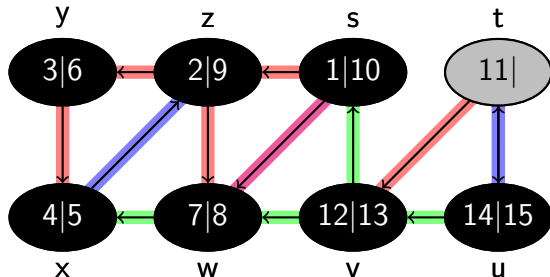
**Se**  $\text{cor}[t] = \text{branco}$  **então**

$\pi[v] \leftarrow t;$

DFS-VISIT (G, V,  $t$ ,  $\text{tempo}$ );

$\text{cor}[u] \leftarrow \text{preto};$

$\triangleright f[u] \leftarrow 15;$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $u \in \text{Adj}[t]$  **faça**

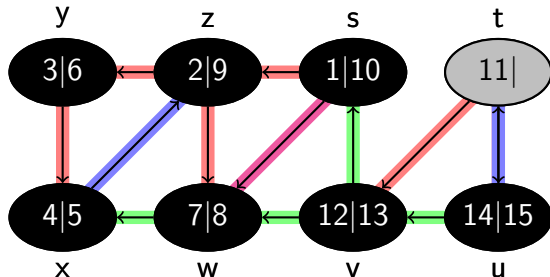
**Se**  $\text{cor}[u] = \text{branco}$  **então**

$\pi[u] \leftarrow t;$

$\triangleleft$  DFS-VISIT (G, V,  $u$ , 15); **//retorna da recursão**

$\text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $u \in \text{Adj}[t]$  **faça**

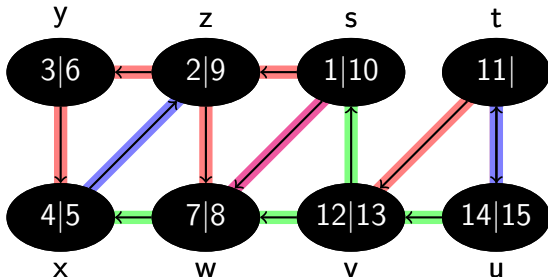
**Se**  $\text{cor}[u] = \text{branco}$  **então**

$\pi[u] \leftarrow t;$

DFS-VISIT (G, V,  $u$ , 15);

$\triangleright \text{cor}[t] \leftarrow \text{preto};$

$f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $u \in \text{Adj}[t]$  **faça**

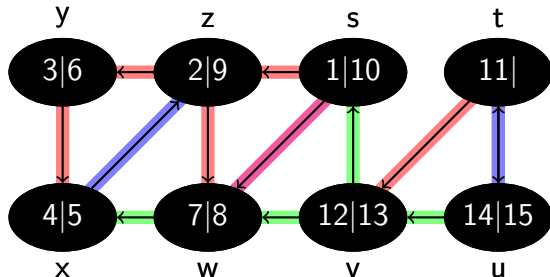
**Se**  $\text{cor}[u] = \text{branco}$  **então**

$\pi[u] \leftarrow t;$

DFS-VISIT (G, V,  $u$ , 15);

$\text{cor}[t] \leftarrow \text{preto};$

$\triangleright f[t] \leftarrow ++\text{tempo};$



# DFS-VISIT (G, V, $t$ , 10)

$\text{cor}[t] \leftarrow \text{cinza};$

$\text{tempo} \leftarrow ++\text{tempo};$

$d[t] \leftarrow \text{tempo};$

**Para cada**  $u \in \text{Adj}[t]$  **faça**

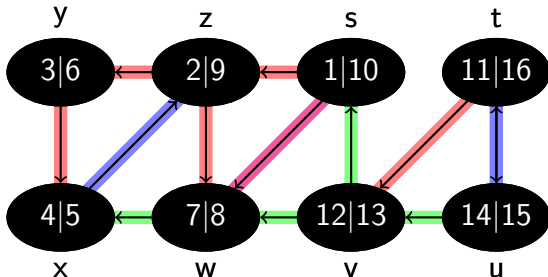
**Se**  $\text{cor}[u] = \text{branco}$  **então**

$\pi[u] \leftarrow t;$

DFS-VISIT (G, V,  $u$ , 15);

$\text{cor}[t] \leftarrow \text{preto};$

$\triangleright f[t] \leftarrow 16;$



# BUSCA-EM-PROFUNDIDADE (G)

Para cada  $u \in V[G]$  faça

$\text{cor}[u] \leftarrow \text{branco};$

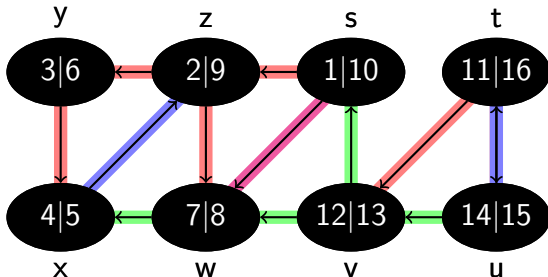
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

Para cada  $t \in V[G]$  faça

    Se  $\text{cor}[t] = \text{branco}$  então

        ◁      DFS-VISIT( $G, V, t, 16$ ); //retorna da recursão





# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

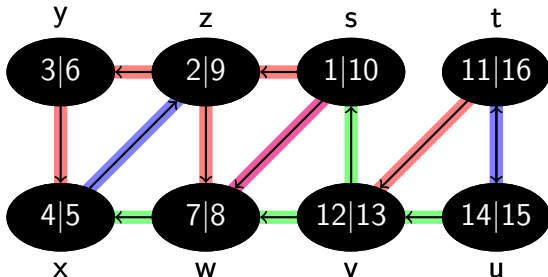
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ **Para cada  $u \in V[G]$  faça**

**Se  $\text{cor}[u] = \text{branco}$  então**

        DFS-VISIT( $G, V, u, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

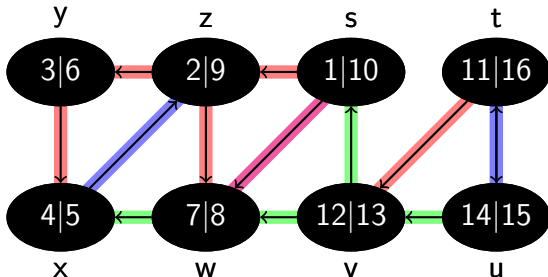
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $u \in V[G]$  **faça**

$\triangleright$  **Se**  $\text{cor}[u] = \text{branco}$  **então**

        DFS-VISIT( $G, V, u, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

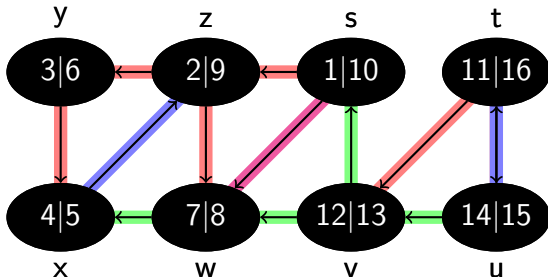
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ **Para cada  $v \in V[G]$  faça**

**Se  $\text{cor}[v] = \text{branco}$  então**

        DFS-VISIT( $G, V, v, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

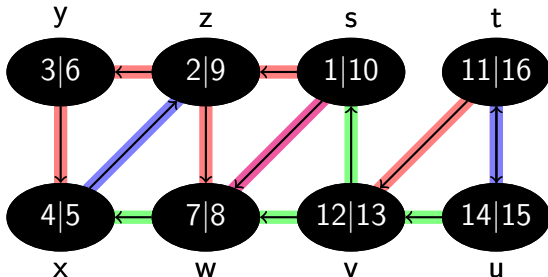
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $v \in V[G]$  **faça**

$\triangleright$  **Se**  $\text{cor}[v] = \text{branco}$  **então**

        DFS-VISIT( $G, V, v, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

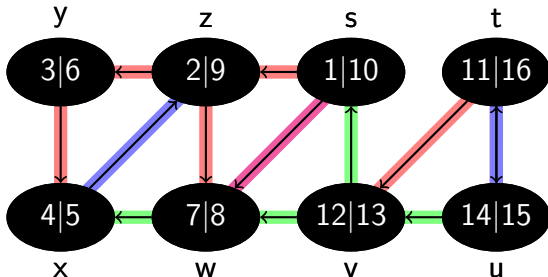
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ **Para cada  $w \in V[G]$  faça**

**Se**  $\text{cor}[w] = \text{branco}$  **então**

        DFS-VISIT( $G, V, w, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

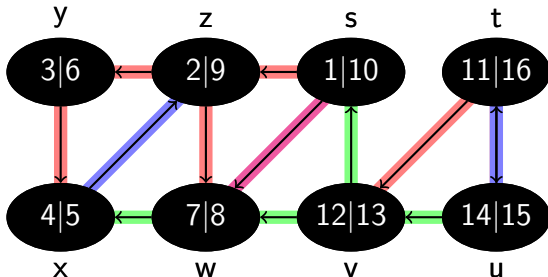
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada  $w \in V[G]$  faça**

$\triangleright$  **Se  $\text{cor}[w] = \text{branco}$  então**

        DFS-VISIT( $G, V, w, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

Para cada  $u \in V[G]$  faça

$\text{cor}[u] \leftarrow \text{branco};$

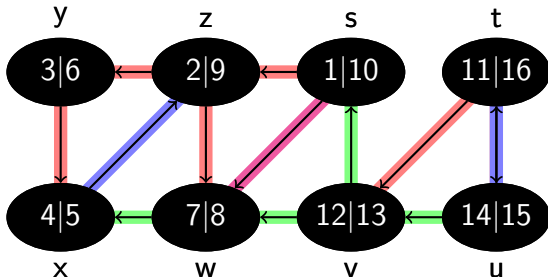
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ Para cada  $x \in V[G]$  faça

    Se  $\text{cor}[x] = \text{branco}$  então

        DFS-VISIT( $G, V, x, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

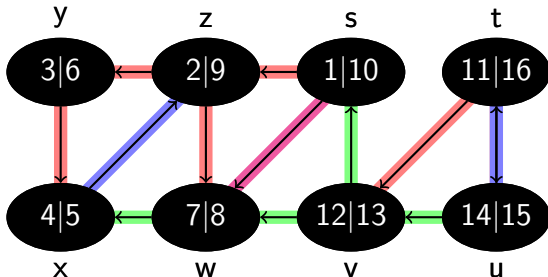
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $x \in V[G]$  **faça**

$\triangleright$  **Se**  $\text{cor}[x] = \text{branco}$  **então**

        DFS-VISIT( $G, V, x, 16$ );





# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

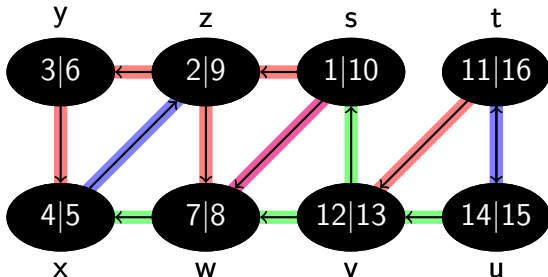
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ **Para cada  $y \in V[G]$  faça**

**Se  $\text{cor}[y] = \text{branco}$  então**

        DFS-VISIT( $G, V, y, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

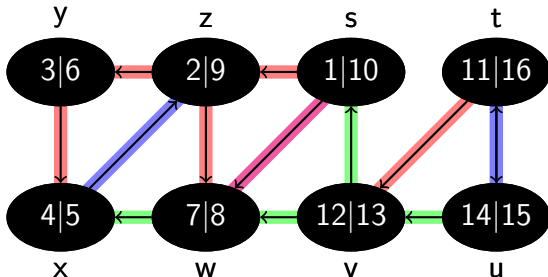
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $y \in V[G]$  **faça**

$\triangleright$  **Se**  $\text{cor}[y] = \text{branco}$  **então**

        DFS-VISIT( $G, V, y, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada  $u \in V[G]$  faça**

$\text{cor}[u] \leftarrow \text{branco};$

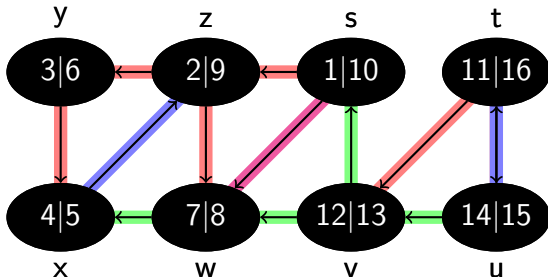
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

▷ **Para cada  $z \in V[G]$  faça**

**Se  $\text{cor}[z] = \text{branco}$  então**

        DFS-VISIT( $G, V, z, 16$ );



# BUSCA-EM-PROFUNDIDADE (G)

**Para cada**  $u \in V[G]$  **faça**

$\text{cor}[u] \leftarrow \text{branco};$

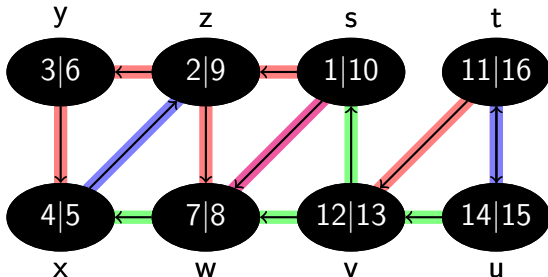
$\pi[u] \leftarrow \text{NIL};$

tempo  $\leftarrow 0;$

**Para cada**  $z \in V[G]$  **faça**

$\triangleright$  **Se**  $\text{cor}[z] = \text{branco}$  **então**

        DFS-VISIT( $G, V, z, 16$ );



# Sumário

- 1 Busca em Grafos
- 2 Busca em profundidade
- 3 Complexidade**
- 4 Classificação de arestas

# Complexidade

## BUSCA-EM-PROFUNDIDADE (G)

---

1. **Para cada**  $u \in V[G]$  **faça**
2.      $\text{cor}[u] \leftarrow \text{branco};$
3.      $\pi[u] \leftarrow \text{NIL};$
4.      $\text{tempo} \leftarrow 0;$
5. **Para cada**  $u \in V[G]$  **faça**
6.     **Se**  $\text{cor}[u] = \text{branco}$  **então**
7.         DFS-VISIT ( $G, V, u, \text{tempo}$ );

**Linhas 1–3:**  $\mathcal{O}(V)$

**Linhas 5–7:**  $V$  chamadas a DFS-visit.

# Complexidade

DFS-VISIT ( $G, V, u, tempo$ )

---

1.  $cor[u] \leftarrow \text{cinza};$
2.  $tempo \leftarrow ++tempo;$
3.  $d[u] \leftarrow tempo;$
4. **Para cada**  $v \in Adj[u]$  **faça**
5.     **Se**  $cor[v] = \text{branco}$  **então**
6.          $\pi[v] \leftarrow u;$
7.         DFS-VISIT ( $G, V, v, tempo$ );
8.  $cor[u] \leftarrow \text{preto};$
9.  $f[u] \leftarrow tempo \leftarrow ++tempo;$

DFS-visit( $v$ ) é executado exatamente uma vez para cada  $v \in V$ .

# Complexidade

DFS-VISIT ( $G, V, u, tempo$ )

---

1.  $cor[u] \leftarrow \text{cinza};$
2.  $tempo \leftarrow ++tempo;$
3.  $d[u] \leftarrow tempo;$
4. **Para cada**  $v \in Adj[u]$  **faça**
5.     **Se**  $cor[v] = \text{branco}$  **então**
6.          $\pi[v] \leftarrow u;$
7.         DFS-VISIT ( $G, V, v, tempo$ );
8.  $cor[u] \leftarrow \text{preto};$
9.  $f[u] \leftarrow tempo \leftarrow ++tempo;$

Em uma execução de DFS-visit( $v$ ), o laço das linhas 4-7 é executado  $|Adj[u]|$  vezes.



# Complexidade

DFS-VISIT ( $G, V, u, tempo$ )

---

1.  $cor[u] \leftarrow \text{cinza};$
2.  $tempo \leftarrow ++tempo;$
3.  $d[u] \leftarrow tempo;$
4. **Para cada**  $v \in Adj[u]$  **faça**
5.     **Se**  $cor[v] = \text{branco}$  **então**
6.          $\pi[v] \leftarrow u;$
7.         DFS-VISIT ( $G, V, v, tempo$ );
8.  $cor[u] \leftarrow \text{preto};$
9.  $f[u] \leftarrow tempo \leftarrow ++tempo;$

Assim, o custo total de todas as chamadas é  $\sum_{v \in V} |Adj(v)| = \Theta(E)$ .

# Complexidade

DFS-VISIT ( $G, V, \mathbf{u}, tempo$ )

---

1.  $cor[\mathbf{u}] \leftarrow \text{cinza};$
2.  $tempo \leftarrow ++tempo;$
3.  $d[\mathbf{u}] \leftarrow tempo;$
4. **Para cada**  $\mathbf{v} \in Adj[\mathbf{u}]$  **faça**
5.     **Se**  $cor[\mathbf{v}] = \text{branco}$  **então**
6.          $\pi[\mathbf{v}] \leftarrow \mathbf{u};$
7.         DFS-VISIT ( $G, V, \mathbf{v}, tempo$ );
8.  $cor[\mathbf{u}] \leftarrow \text{preto};$
9.  $f[\mathbf{u}] \leftarrow tempo \leftarrow ++tempo;$

**Conclusão:** a complexidade de tempo de Busca-em-profundidade é  $\mathcal{O}(V + E)$ .

# Sumário

- 1 Busca em Grafos
- 2 Busca em profundidade
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- 4 Classificação de arestas

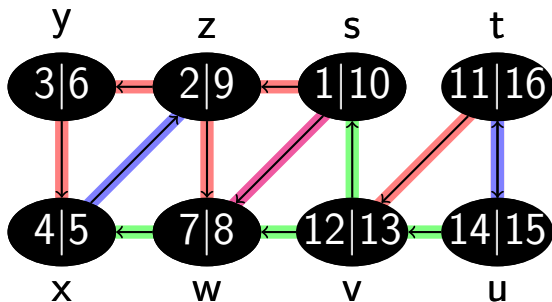
## Busca em profundidade

A busca em profundidade pode ser usada para **classificar as arestas** de um grafo  $G = (V, E)$ . Ela classifica as arestas em quatro tipos:

- arestas da árvore
- arestas de retorno
- arestas de avanço
- arestas de cruzamento

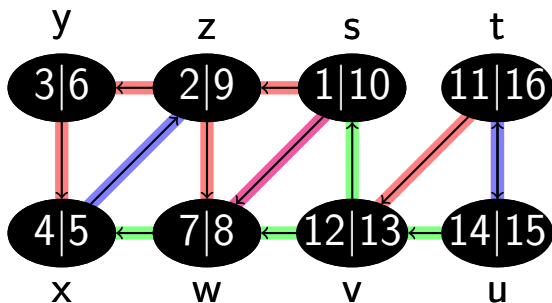
## Busca em profundidade

**Arestas da árvore** (**vermelhas**): arestas que pertencem à floresta da busca em profundidade.



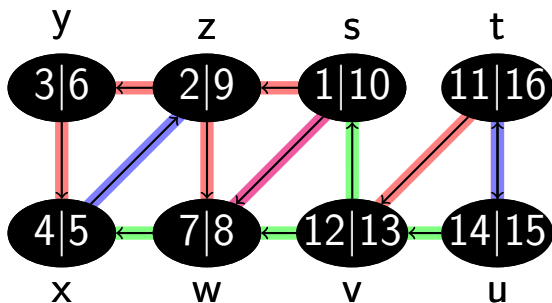
## Busca em profundidade

**Arestas de retorno** (azuis): arestas  $(u, v)$  ligando um vértice  $u$  a um ancestral  $v$  na árvore de busca em profundidade.



## Busca em profundidade

**Arestas de avanço** (roxas): arestas  $(u, v)$  ligando um vértice  $u$  a um descendente próprio  $v$  na árvore de busca em profundidade.



## Busca em profundidade

**Arestas de cruzamento** (**verdes**): todas as outras arestas.

