Estruturas de Dados II

Grafos: Busca em Largura

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

Sumário

Busca em largura

Dizemos que um vértice v é **alcançável** a partir de um vértice s em um grafo G se existe um caminho de s a v em G.

Definição: a distância de s a v é o comprimento de um caminho mais curto de s a v. Se v não é alcançável a partir de s, então dizemos que a distância de s a v é ∞ (infinita).

Busca em largura

Busca em largura recebe um grafo $G = (V, E)$ e um vértice especificado s chamado **fonte (source)**. Percorre todos os vértices alcançáveis a partir de s em ordem de distância deste. Vértices a mesma distância podem ser percorridos em qualquer ordem.

Busca em largura

Constrói uma árvore de busca em largura com raiz s. Cada caminho de s a um vértice v nesta árvore corresponde a um caminho mais curto de s a v.

Busca em largura

Inicialmente a árvore de busca em largura contém apenas o vértice fonte s. Para cada vizinho v de s, o vértice v e a aresta (s, v) são acrescentadas à árvore.

Busca em largura

O processo é repetido para os vizinhos dos vizinhos de s e assim por diante, até que todos os vértices atingíveis por s sejam inseridos na árvore. Este processo é implementado através de uma **fila Q**.

Busca em largura

Para facilitar o entendimento do algoritmo, vamos atribuir cores durante a busca em largura. Ou seja, para cada vértice **v** guarda-se sua cor atual **cor[v]** que pode ser branco, cinza ou preto.

- Cor branca = "não visitado".
- Cor **cinza** = "visitado pela primeira vez".
- Cor **preta** = "teve seus vizinhos visitados".

Para efeito de implementação, isto não é realmente necessário.

Busca em largura

- A raiz da árvore de busca em largura é s.
- Cada vértice v (diferente de s) possui um pai $\pi[v]$.
- O caminho de v a s na árvore é dado por: $v, \pi[v], \pi[\pi[v]], \pi[\pi[\pi[v]]], \ldots, s$.
- Uma variável $d[v]$ é usada para armazenar a distância de s a v (que será determinada durante a busca).

Busca em largura

Recebe um grafo G (na forma de listas de adjacências) e um vértice $s \in V[G]$ e devolve: (i) para cada vértice v, a distância de s a v em G; e (ii) uma árvore de busca em largura.

Busca-em-largura (G, s)

▷ **Para cada u** $\in V[G] - \{s\}$
    cor[**u**] $\leftarrow$ branco;
    d[**u**] $\leftarrow \infty$;
    π[**u**] $\leftarrow$ NIL;
cor[**s**] $\leftarrow$ cinza;
d[**s**] $\leftarrow$ 0;
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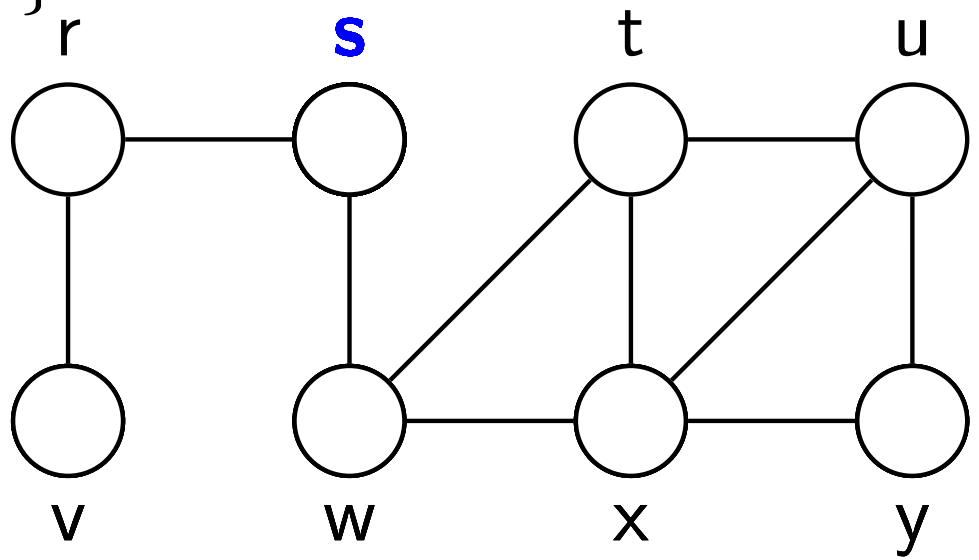
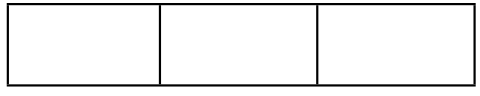


Q = 

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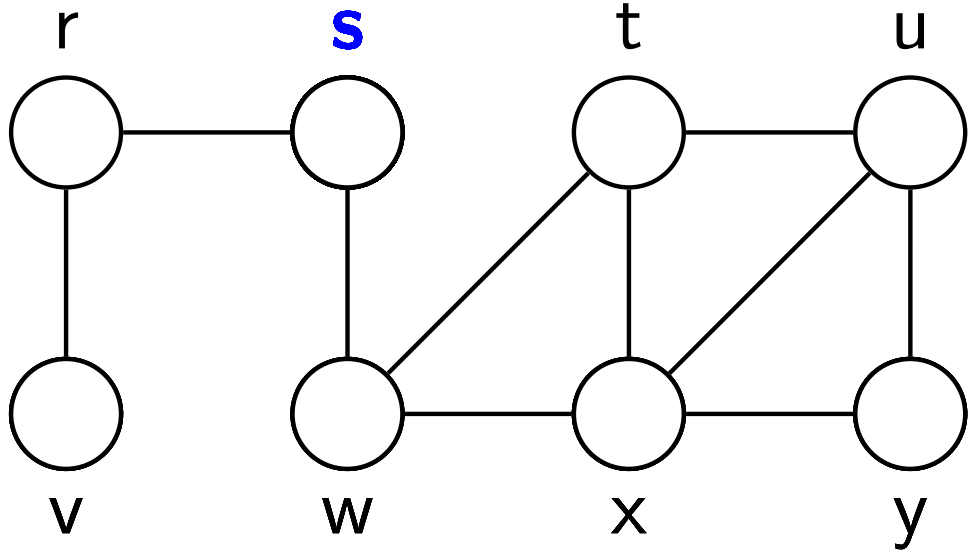
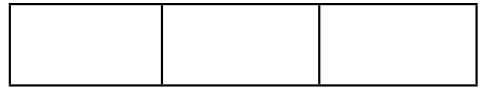


Q = 

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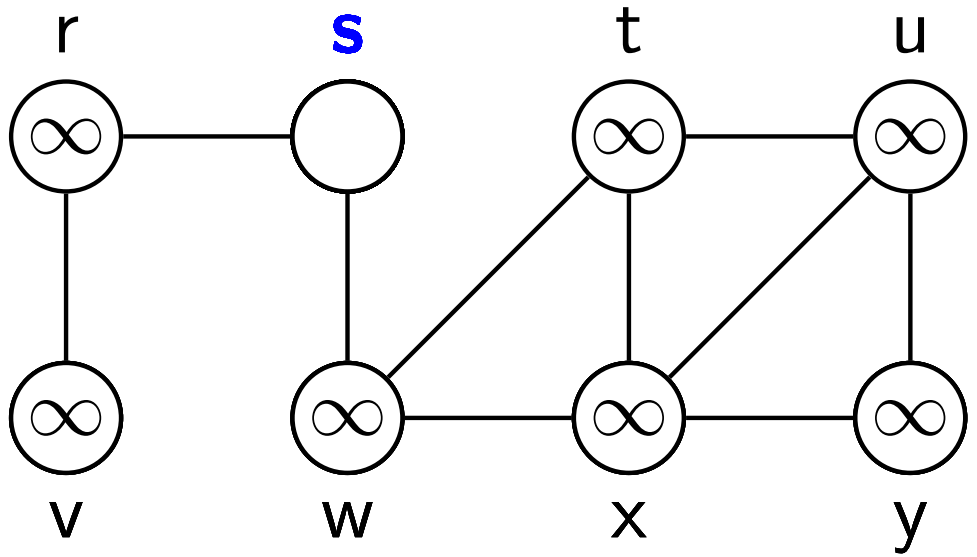

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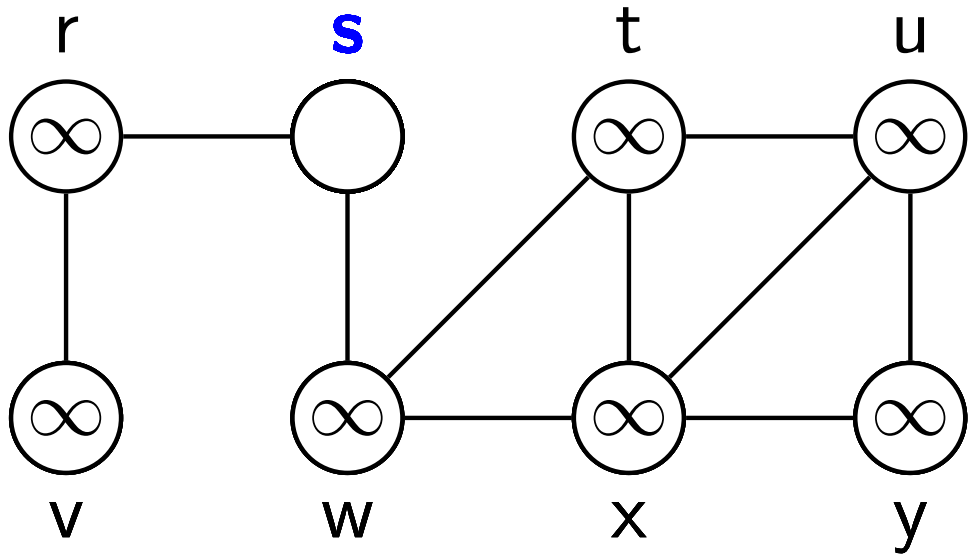
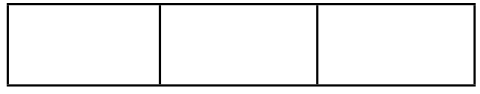


Q = 

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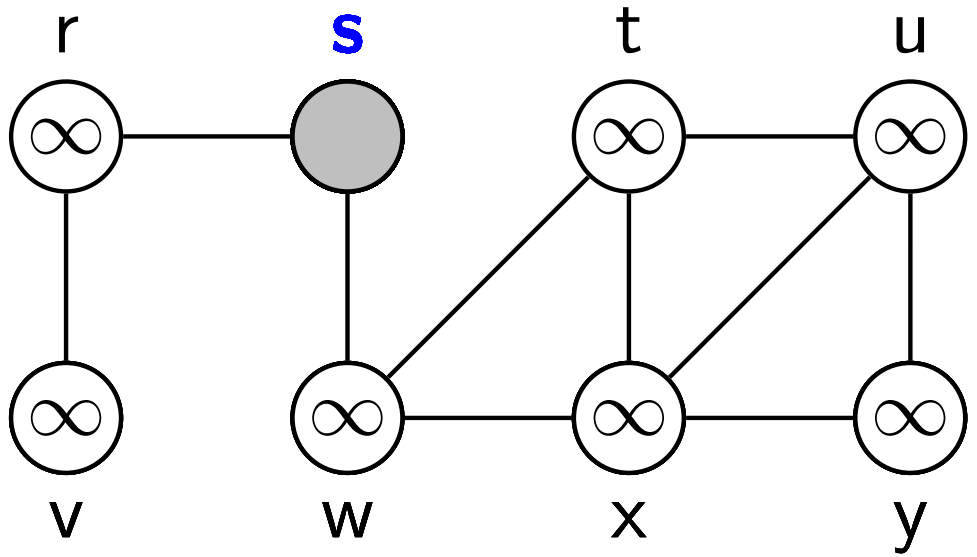

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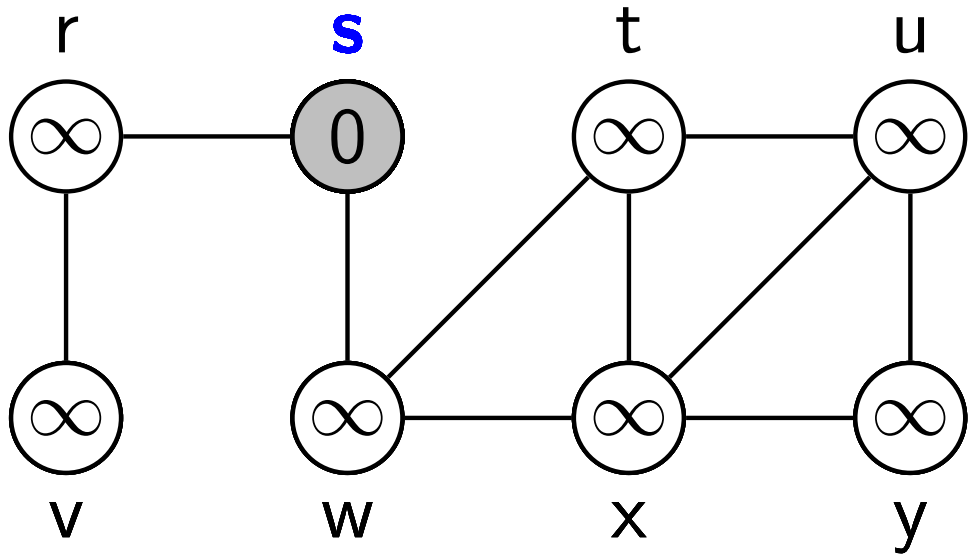
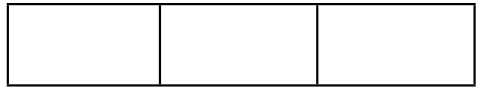


Q = 

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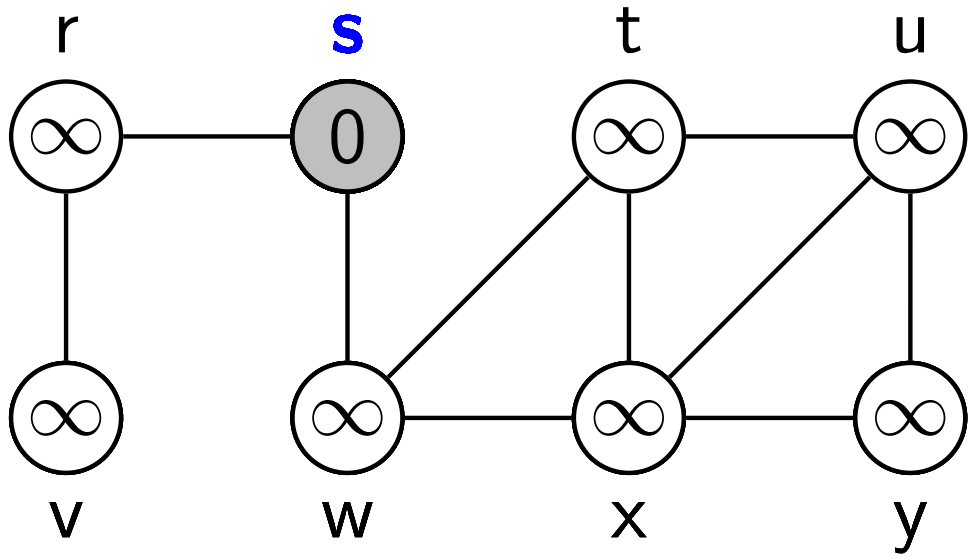
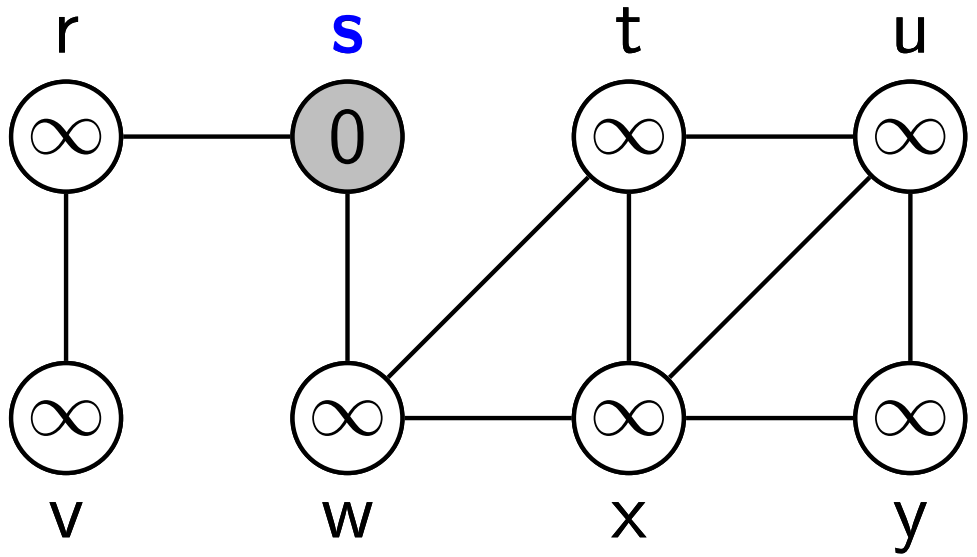
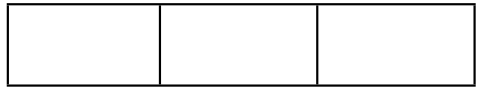


Q =

Busca-em-largura (G, s)

$\triangleright$Q $\leftarrow \emptyset$;
ENQUEUE (Q,*s*);
Enquanto $Q \neq \emptyset$
    u $\leftarrow$ DEQUEUE (Q);
    Para cada **v** $\in Adj$[**u**]
        Se cor[**v**] $=$ branco;
            cor[**v**] $\leftarrow$ cinza;
            d[**v**] $\leftarrow$ d[**u**] $+ 1$;
            π[**v**] $\leftarrow$ **u**;
            ENQUEUE (Q,**v**);
    cor[**u**] $\leftarrow$ preto;
Retorne d, π;



Q $=$ 

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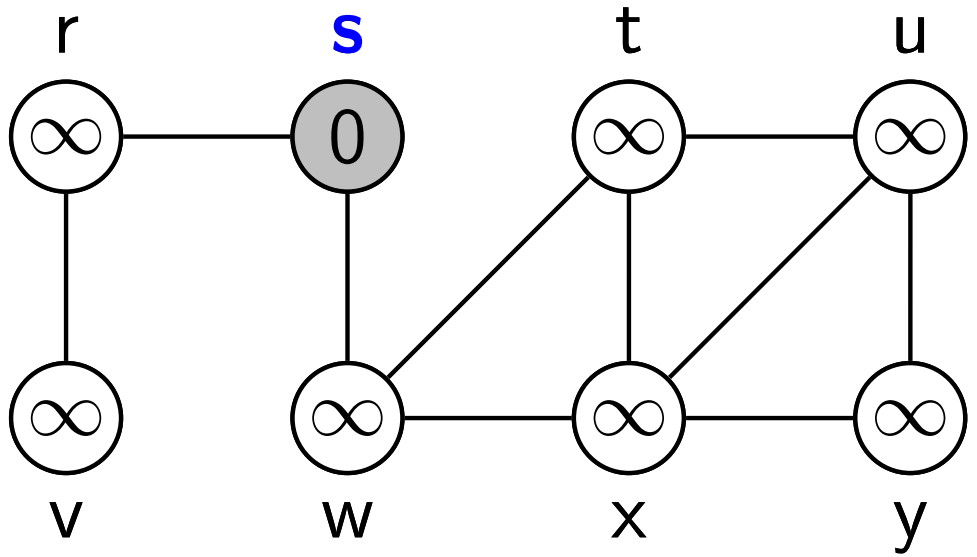

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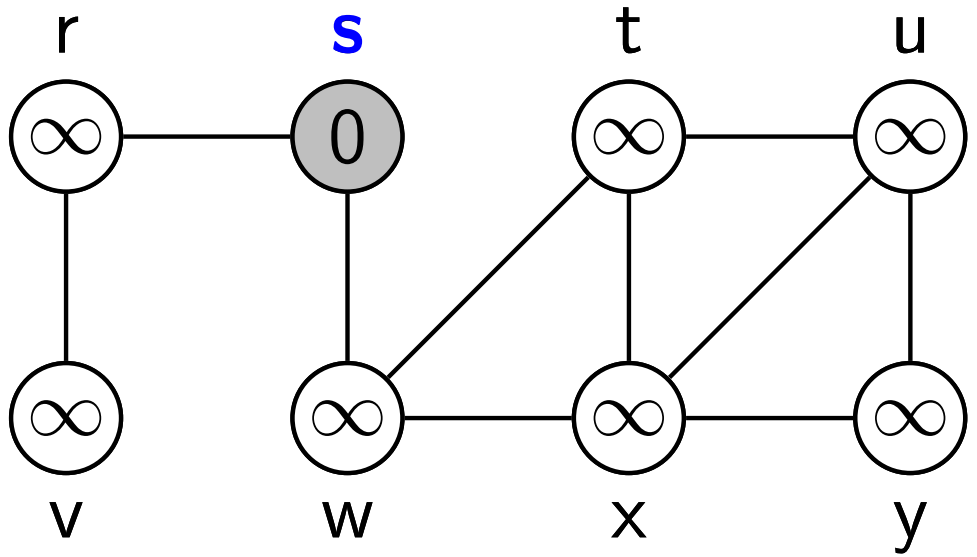

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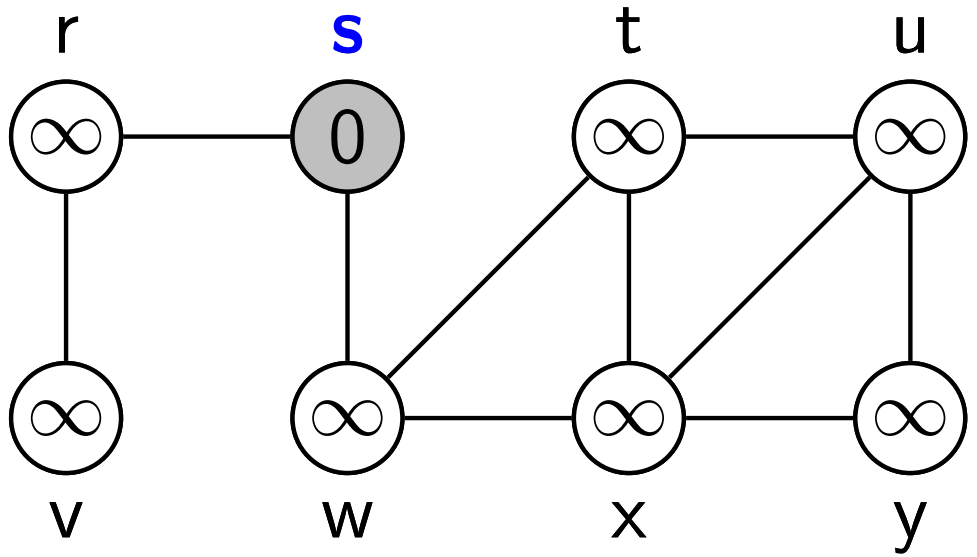

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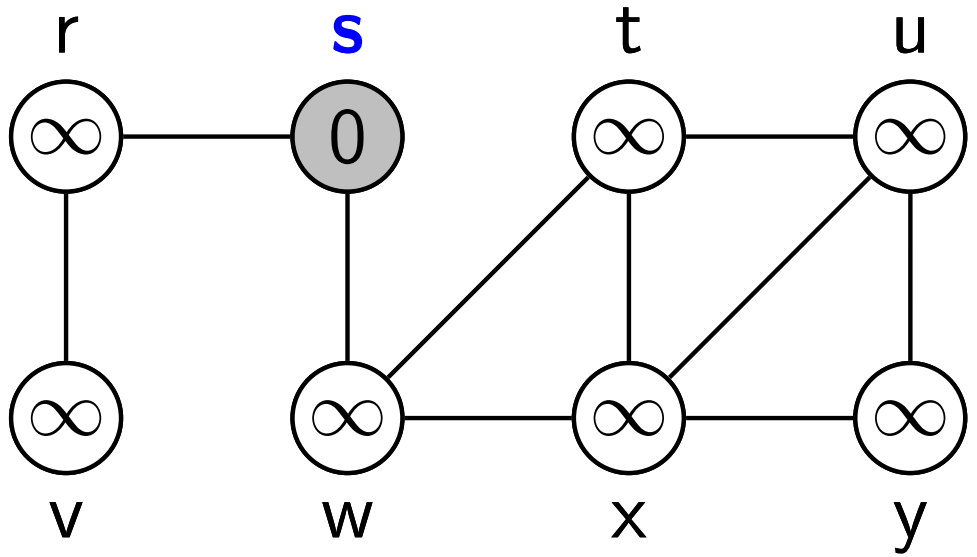
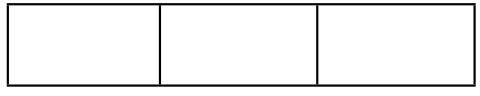


Q = 

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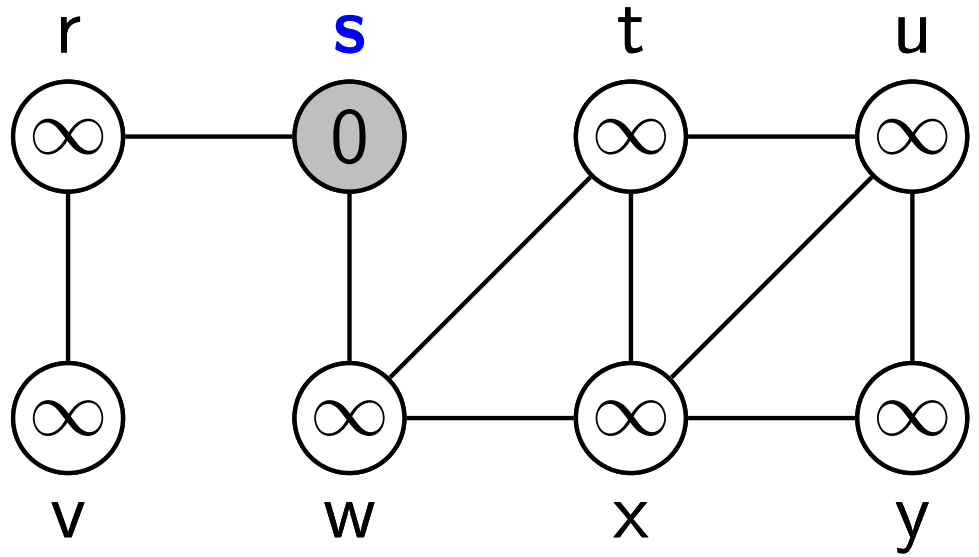
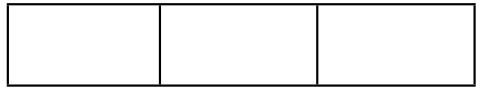


Q = 

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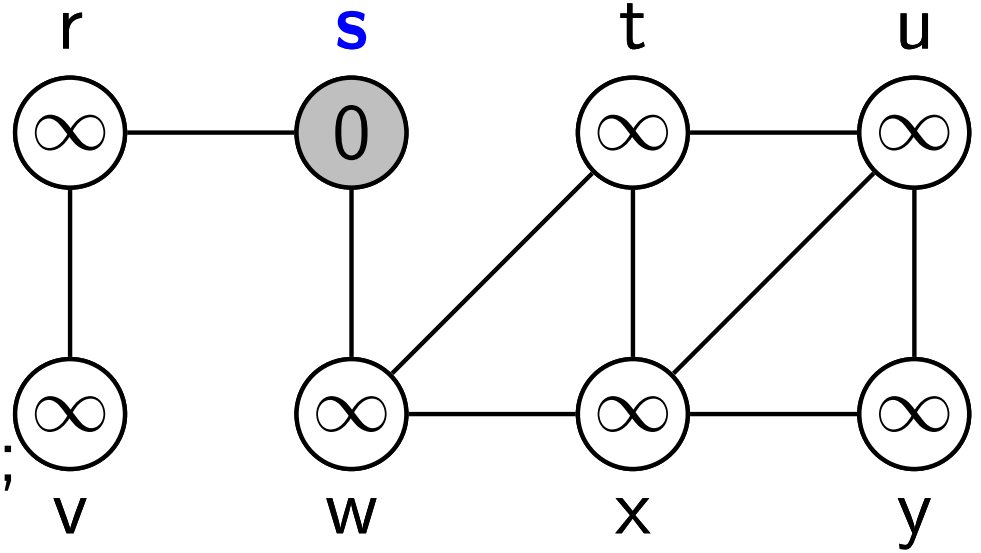
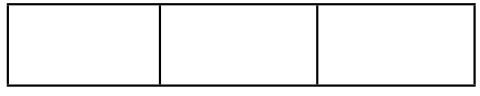


Q = 

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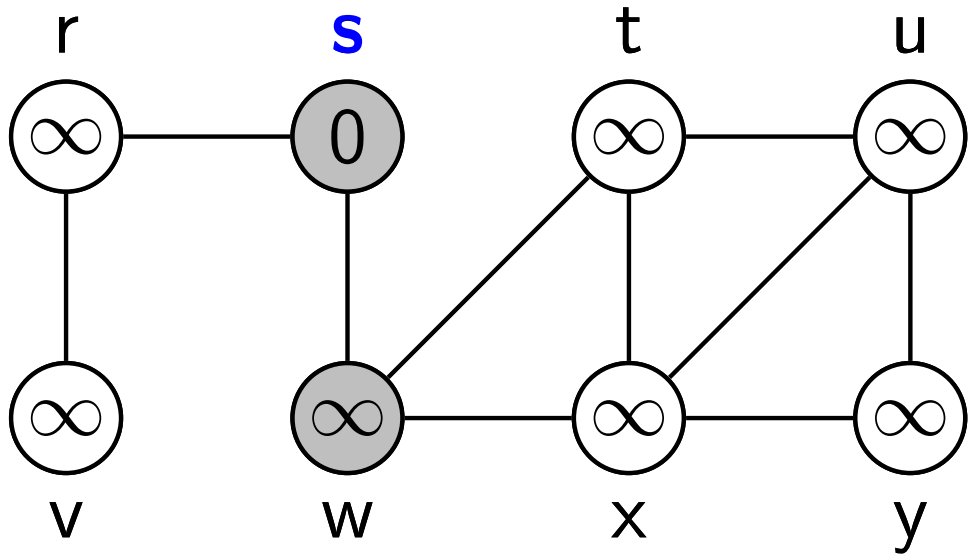
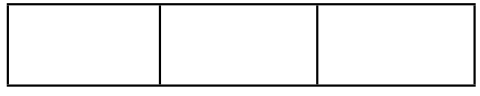


Q = 

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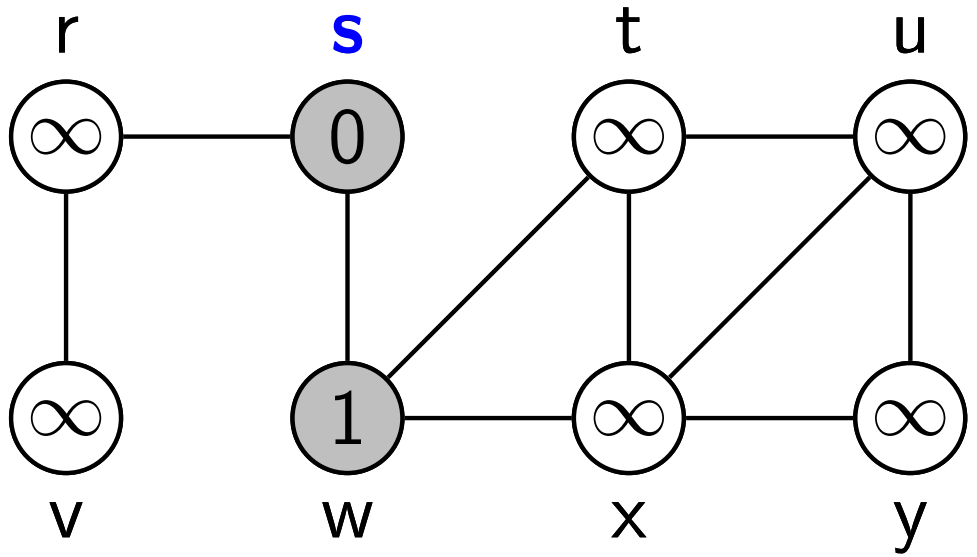

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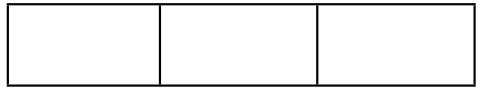

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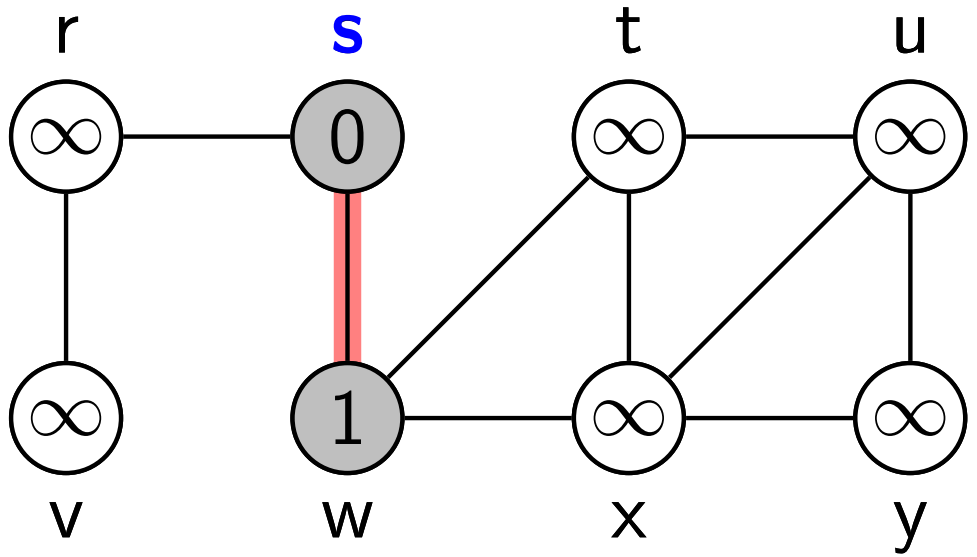
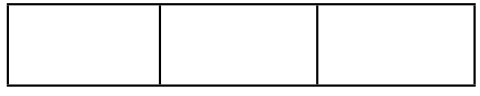


Q = 

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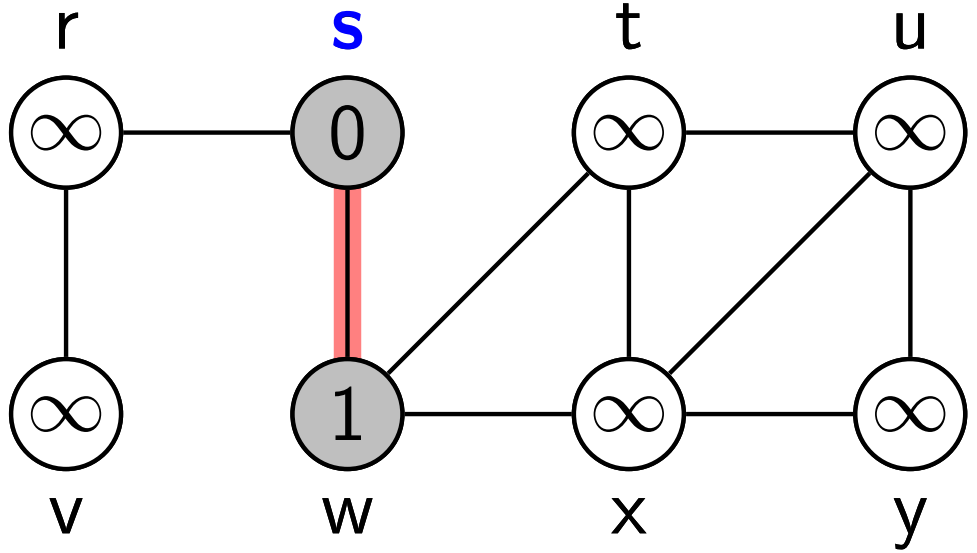

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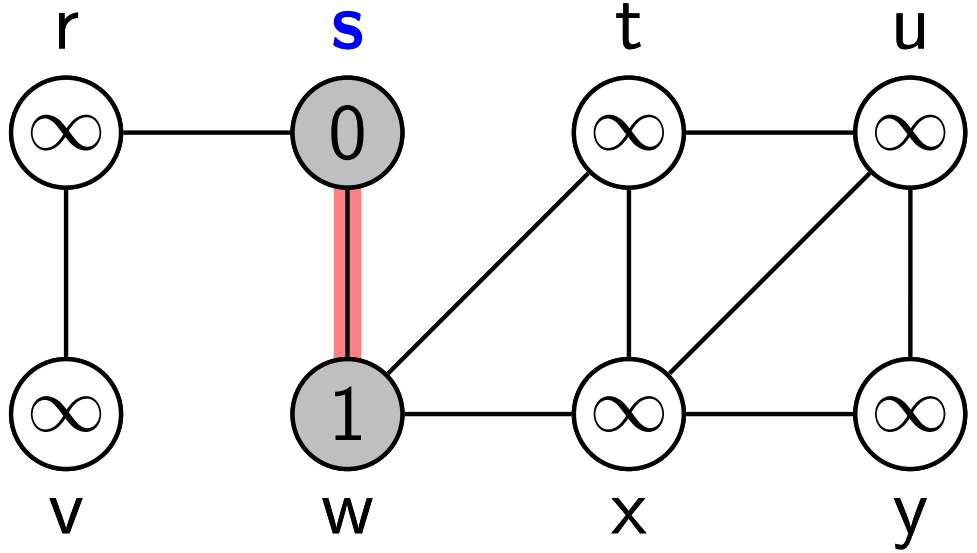
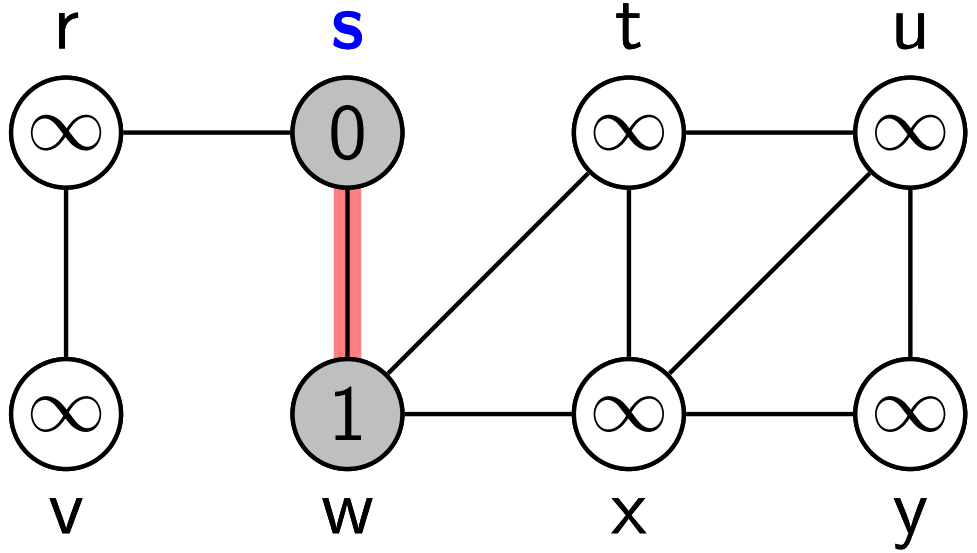
            π[r] ← s;
            ENQUEUE (Q,r);
    cor[s] ← preto;
Retorne d, π;
```



Q = | **w** | | |

Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← s;
    Para cada r ∈ Adj[s]
▷       Se cor[r] = branco;
          cor[r] ← cinza;
          d[r] ← d[s] + 1;
          π[r] ← s;
          ENQUEUE (Q,r);
    cor[s] ← preto;
Retorne d, π;
```



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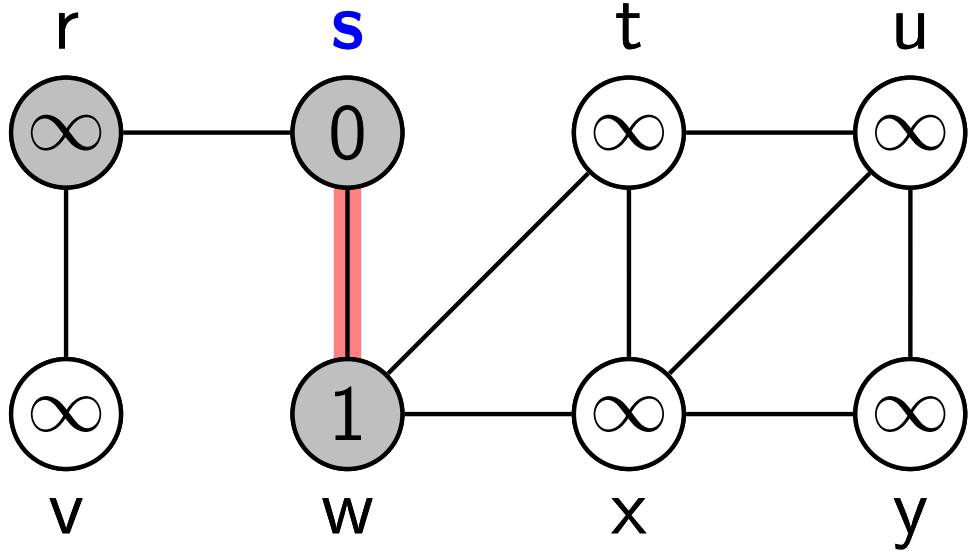

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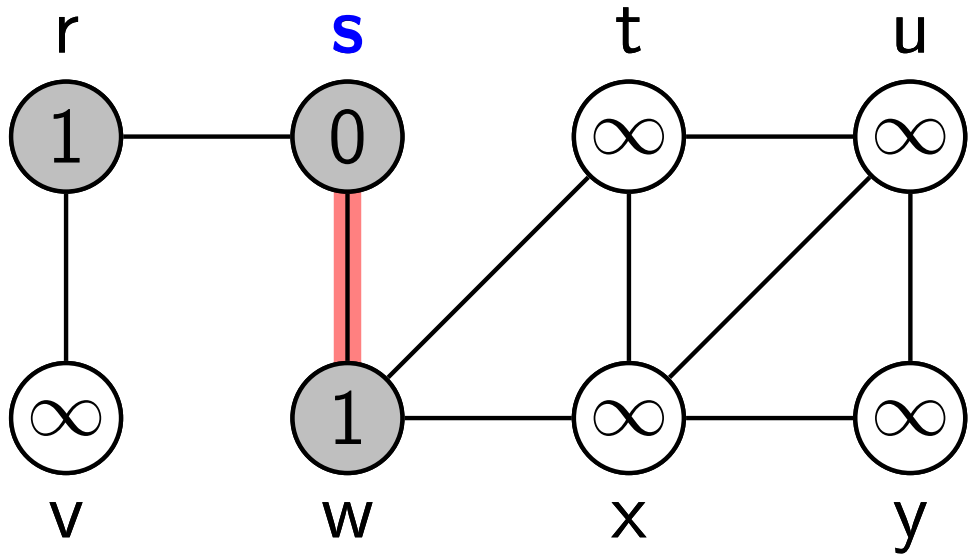

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Busca-em-largura (G, s)

Q $\leftarrow \emptyset$;
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Enquanto $Q \neq \emptyset$
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            ENQUEUE (Q,**r**);
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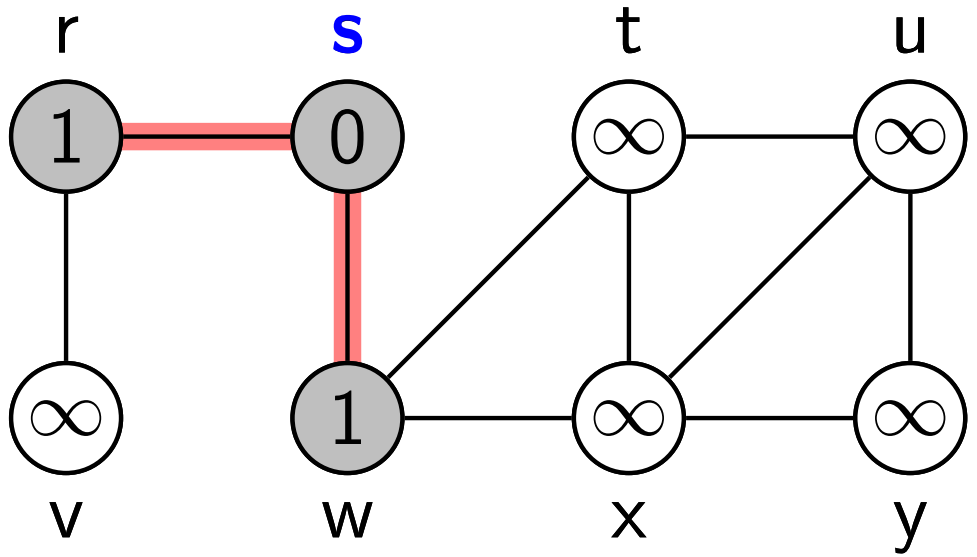

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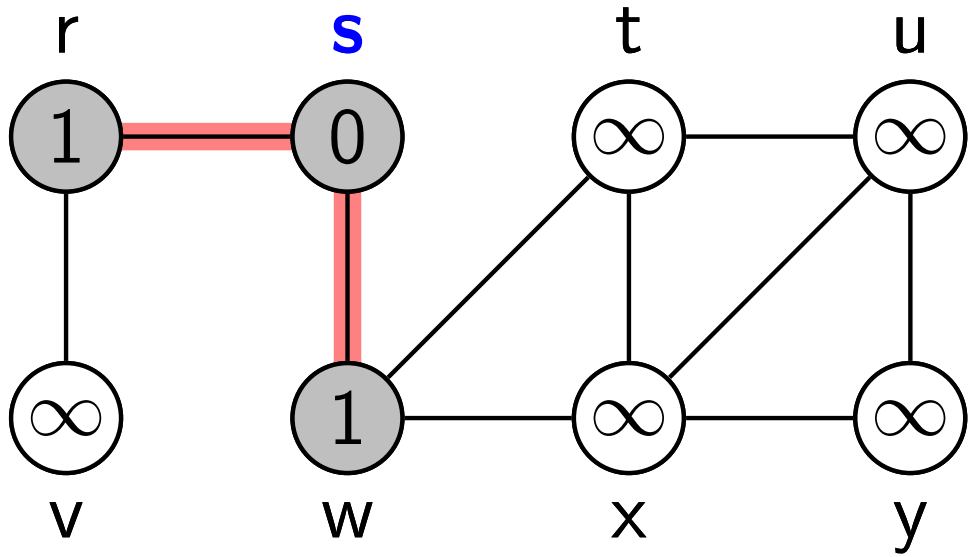

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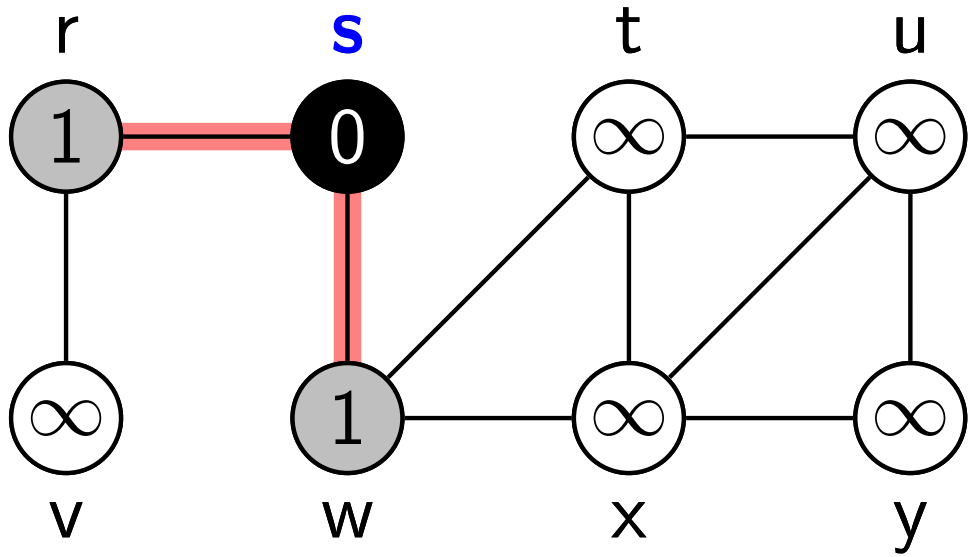

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Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
▷     u ← DEQUEUE (Q);
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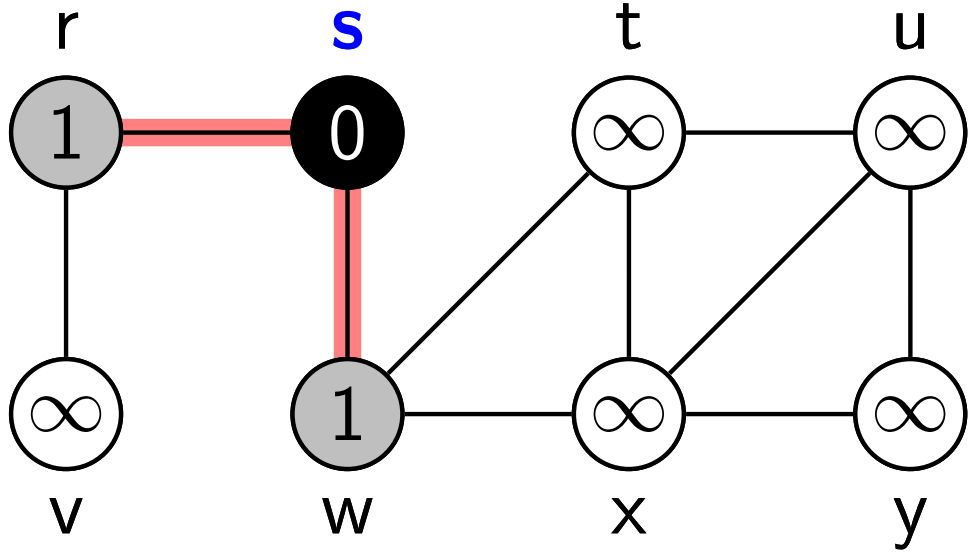
            Se cor[t] = branco;
                  cor[t] ← cinza;
                  d[t] ← d[w] + 1;
                  π[t] ← w;
                  ENQUEUE (Q,t);
      cor[w] ← preto;
Retorne d, π;
```



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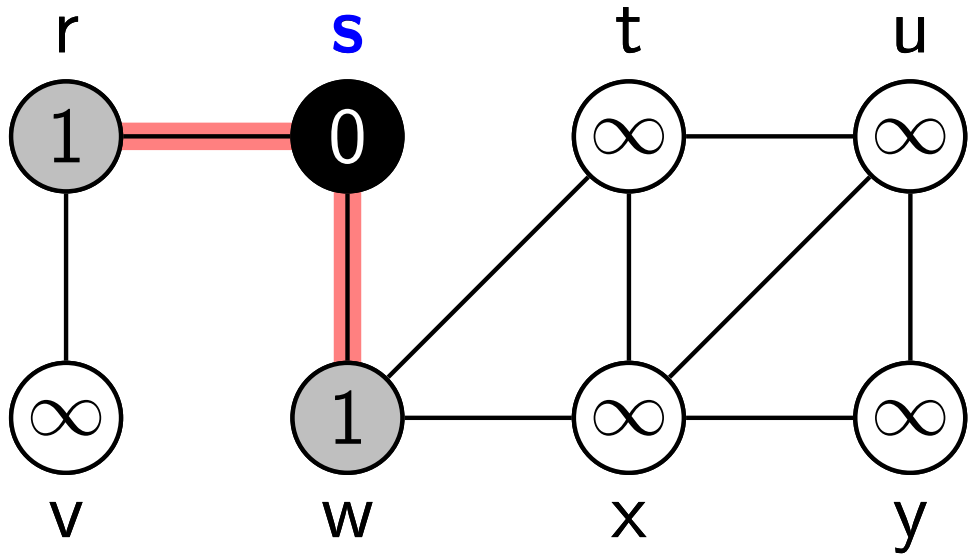

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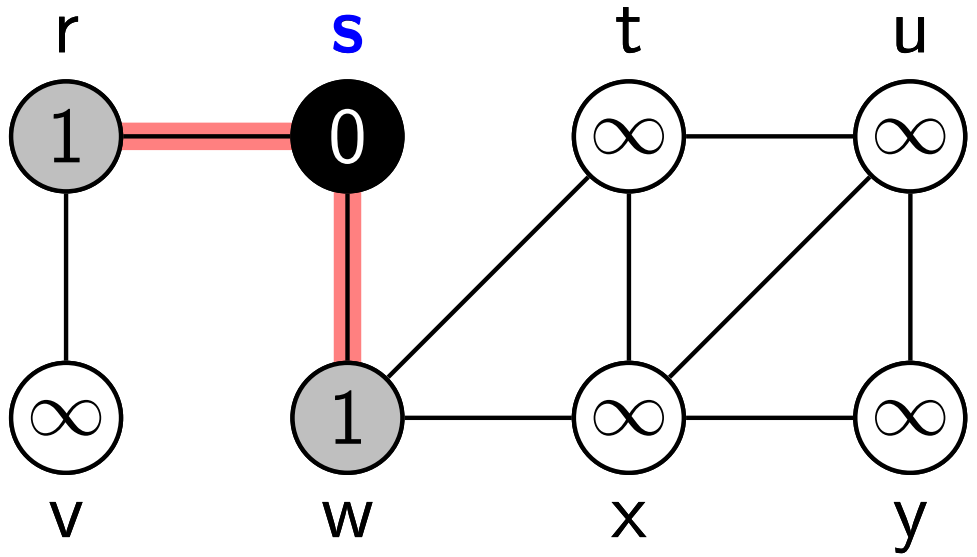

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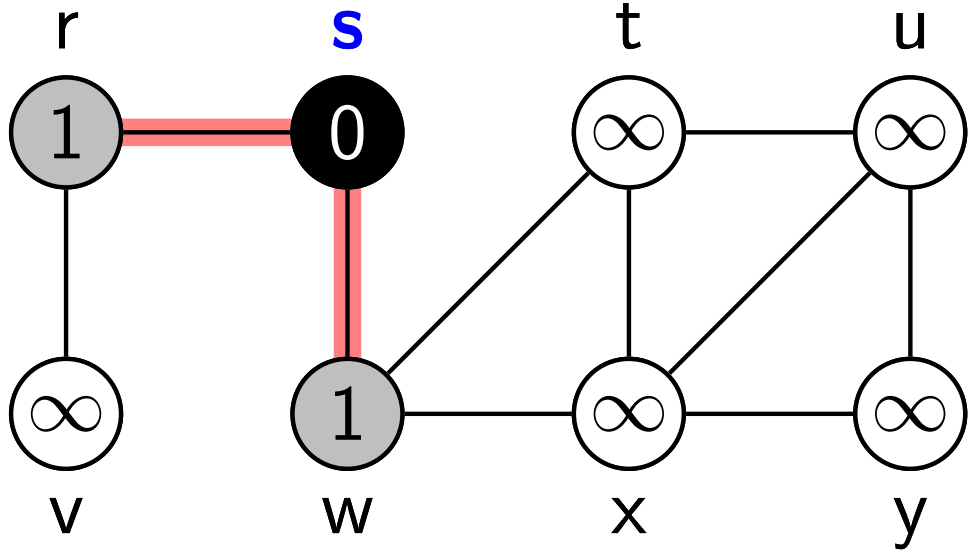

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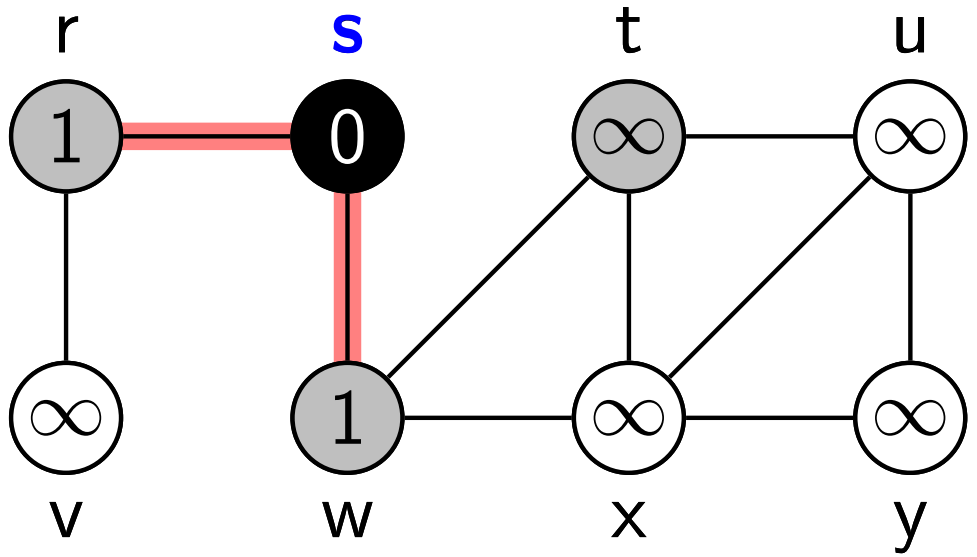

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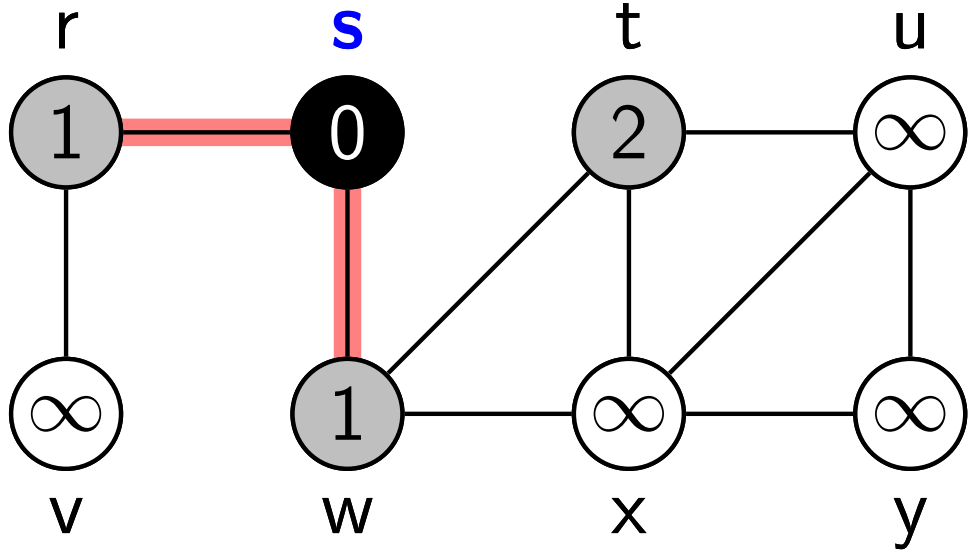

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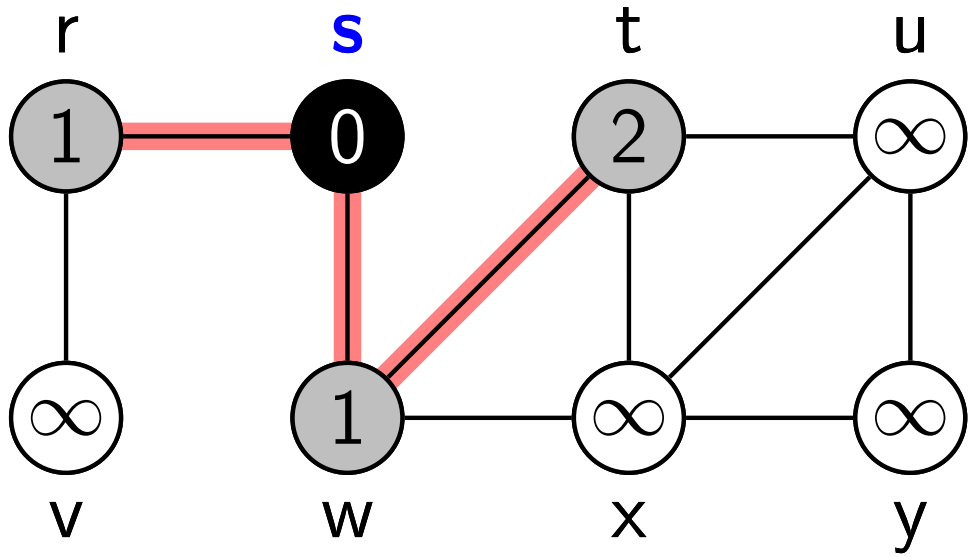

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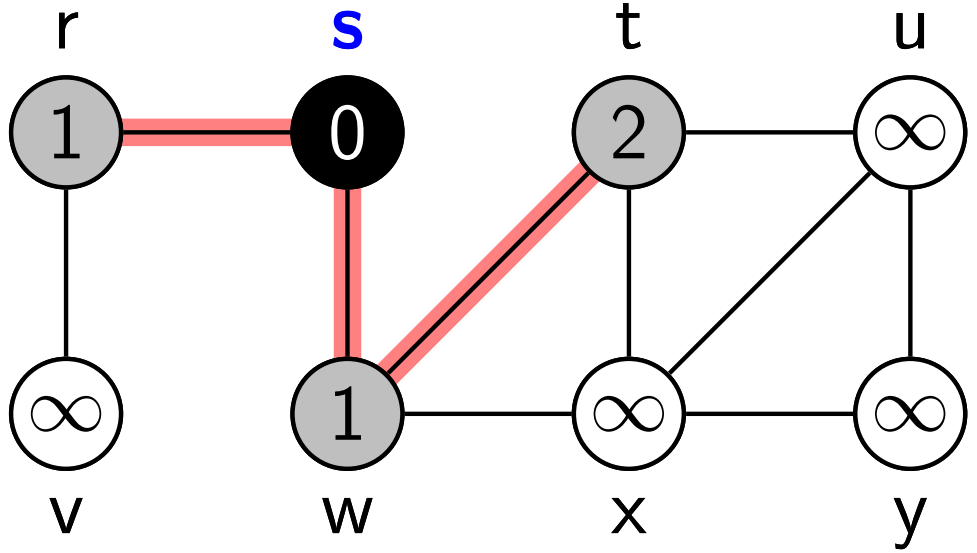

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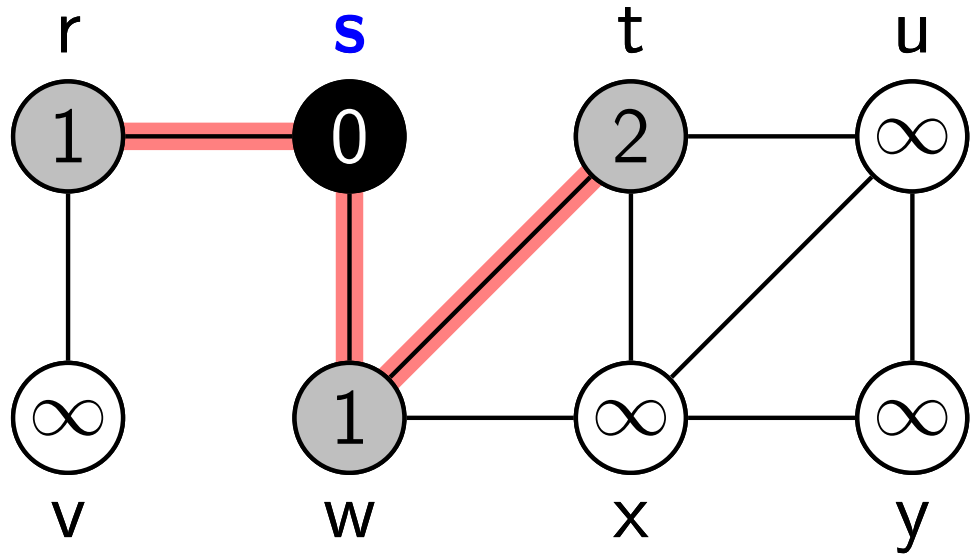

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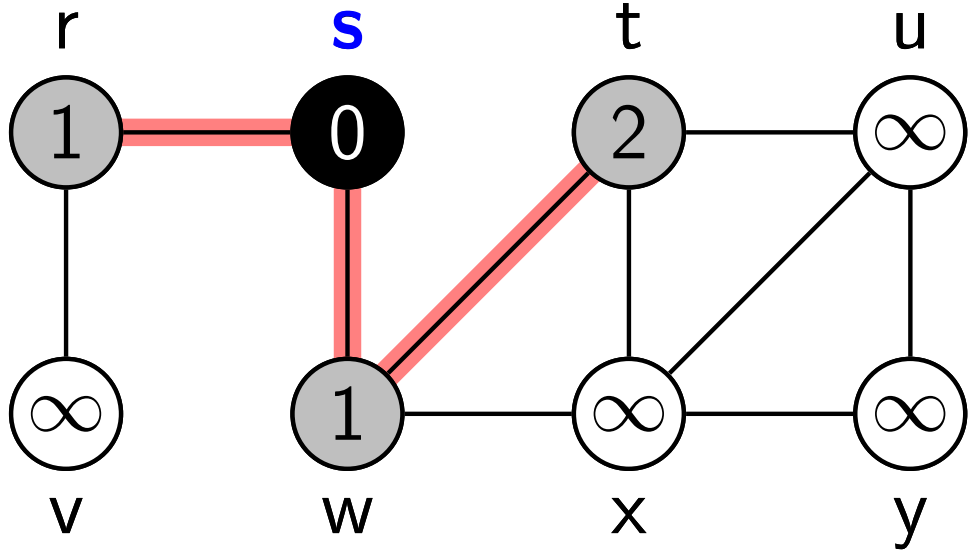

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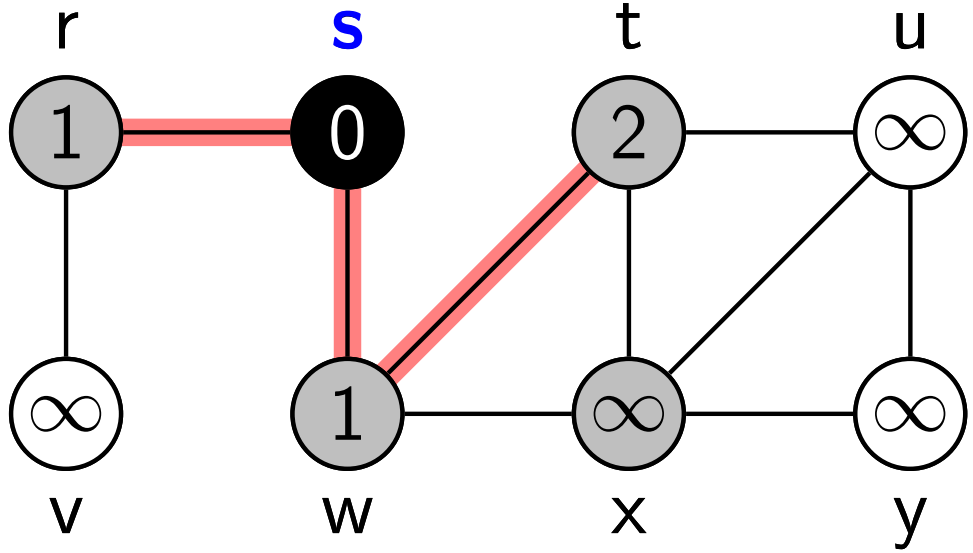

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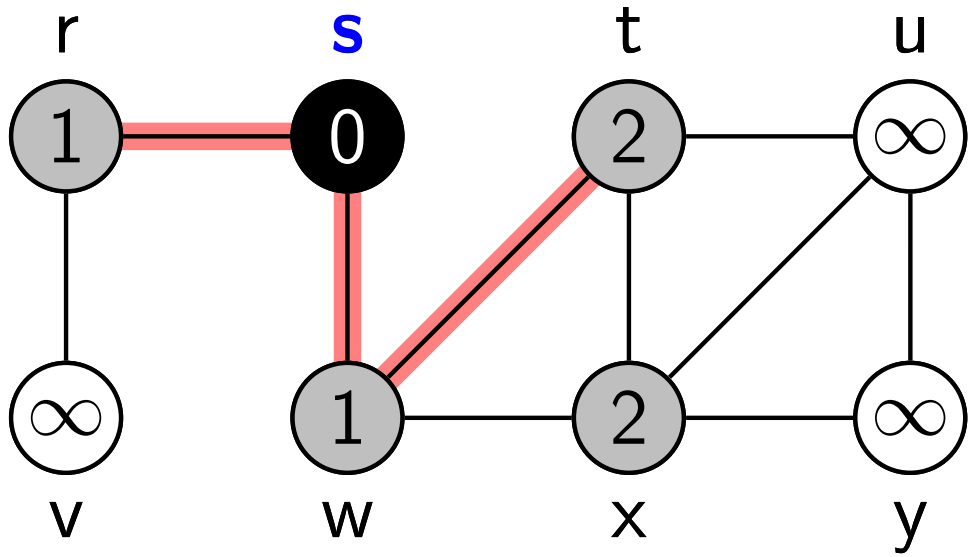

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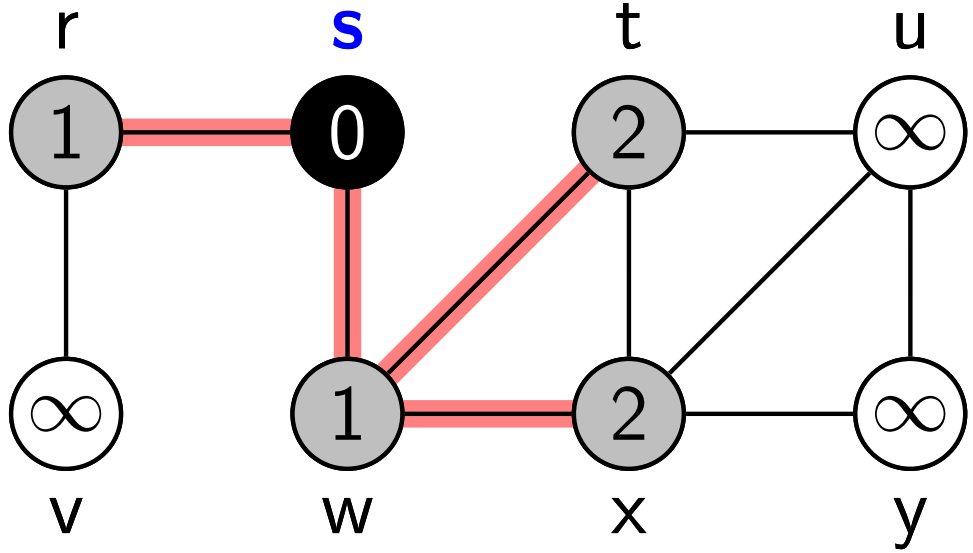

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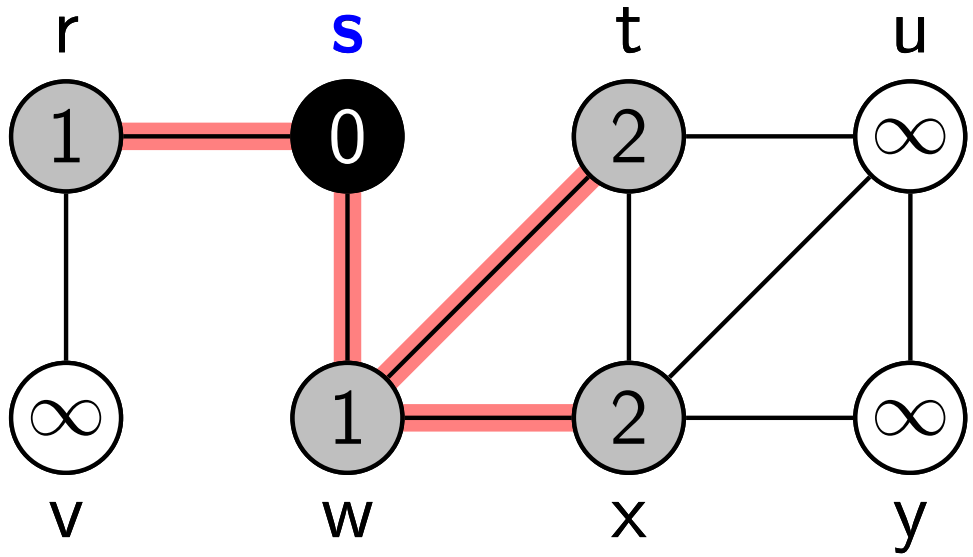

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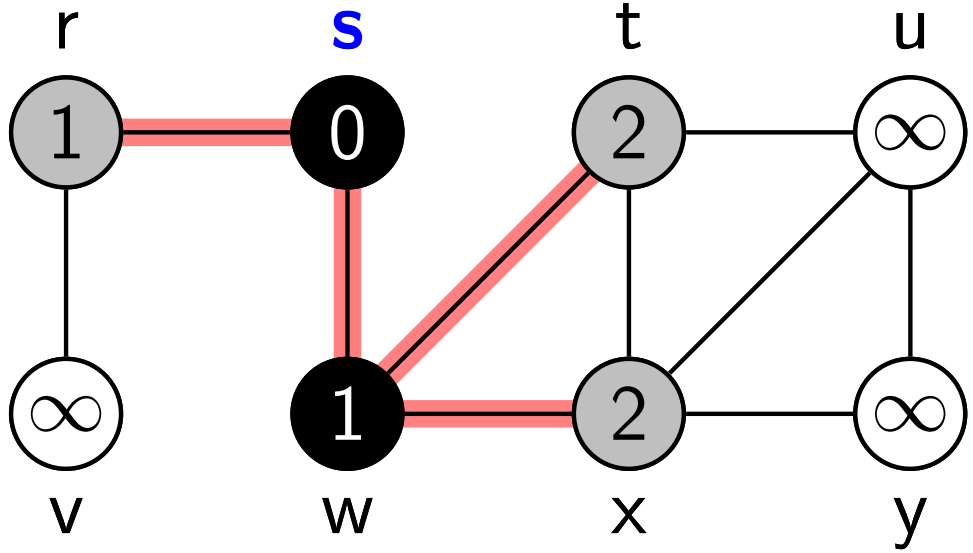

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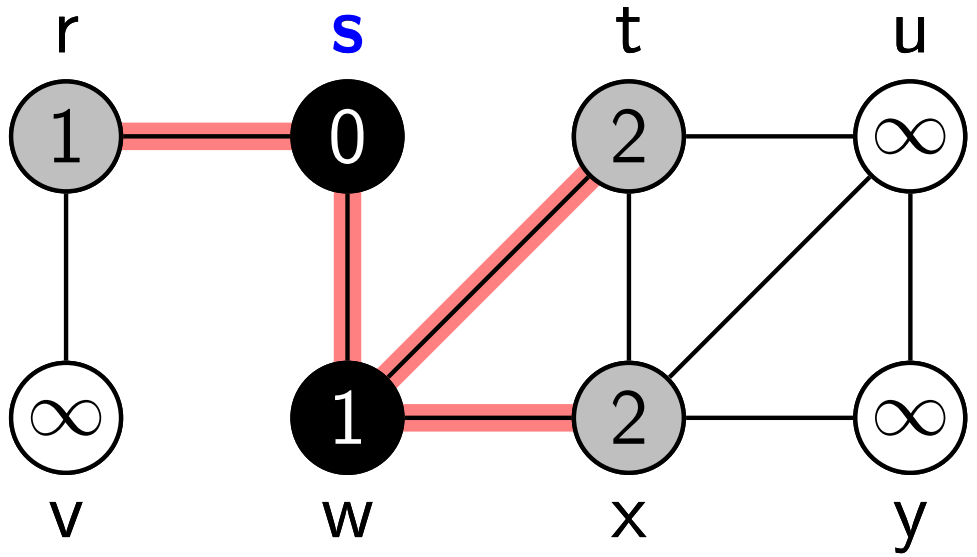

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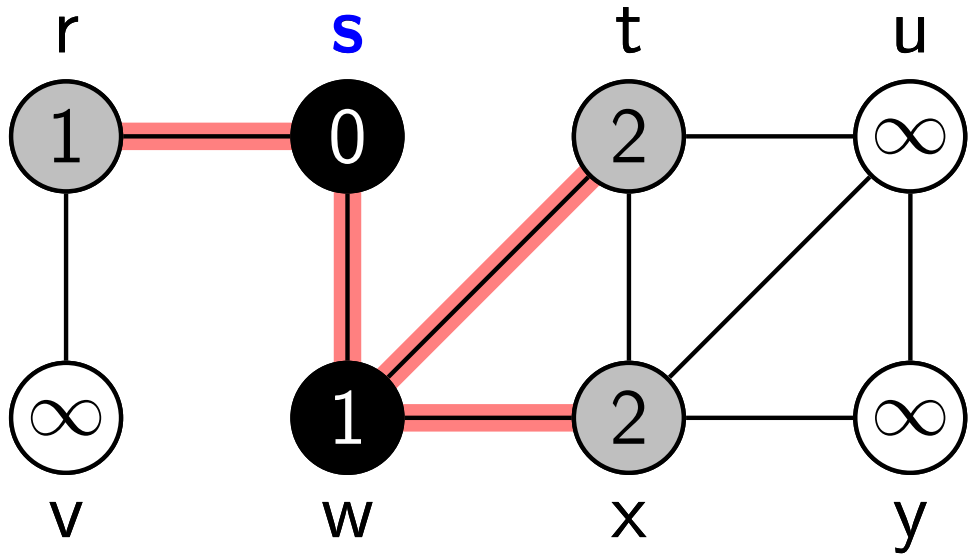

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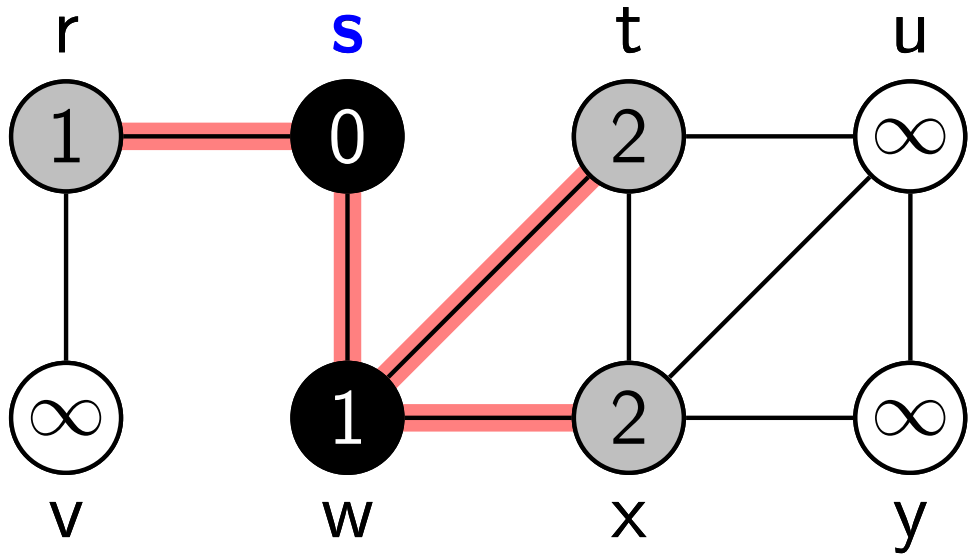

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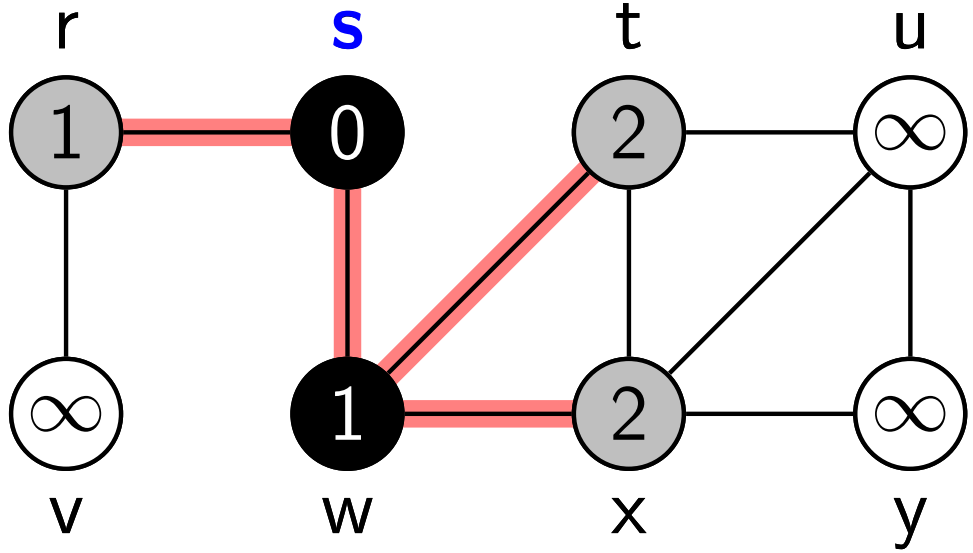
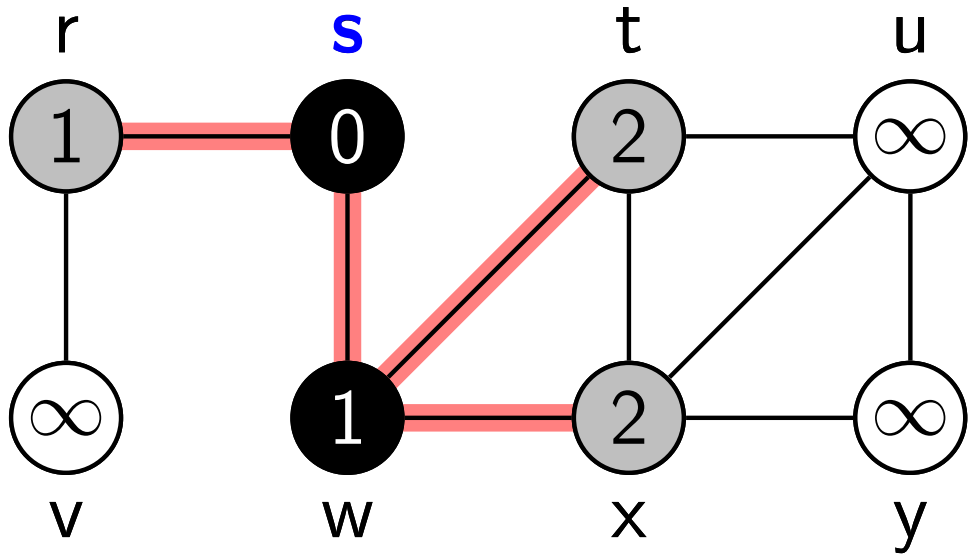
Retorne d, π;
```



Q = | **t** | **x** | |

Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← r;
▷   Para cada v ∈ Adj[r]
      Se cor[v] = branco;
          cor[v] ← cinza;
          d[v] ← d[r] + 1;
          π[v] ← r;
          ENQUEUE (Q,v);
    cor[r] ← preto;
Retorne d, π;
```



Q = | **t** | **x** | |

Busca-em-largura (G, s)

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Q ← ∅;
ENQUEUE (Q,s);
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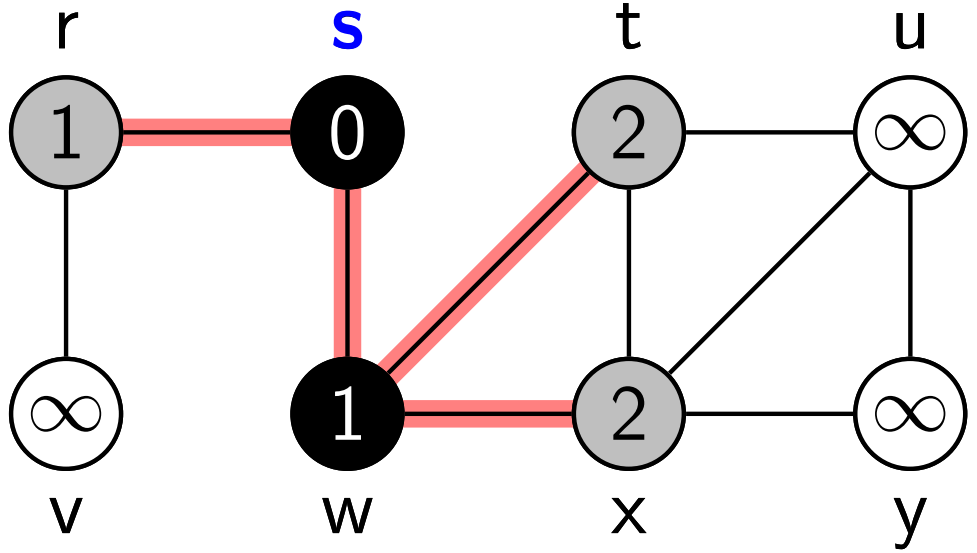
          π[v] ← r;
          ENQUEUE (Q,v);
    cor[r] ← preto;
Retorne d, π;
```



Q = | **t** | **x** | |

Busca-em-largura (G, s)

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Enquanto Q ≠ ∅
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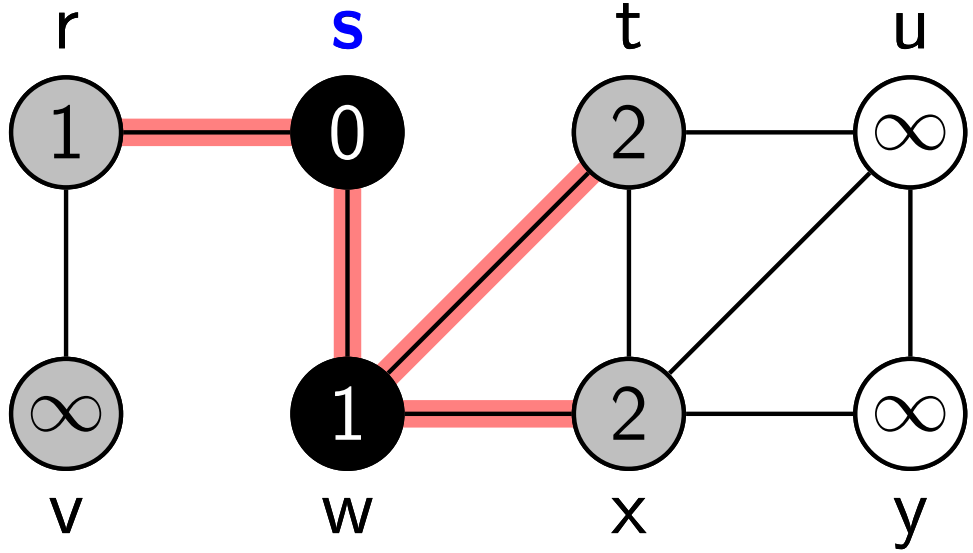
                  π[v] ← r;
                  ENQUEUE (Q,v);
    cor[r] ← preto;
Retorne d, π;
```



Q = | **t** | **x** | |

Busca-em-largura (G, s)

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    u ← r;
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            π[v] ← r;
            ENQUEUE (Q,v);
    cor[r] ← preto;
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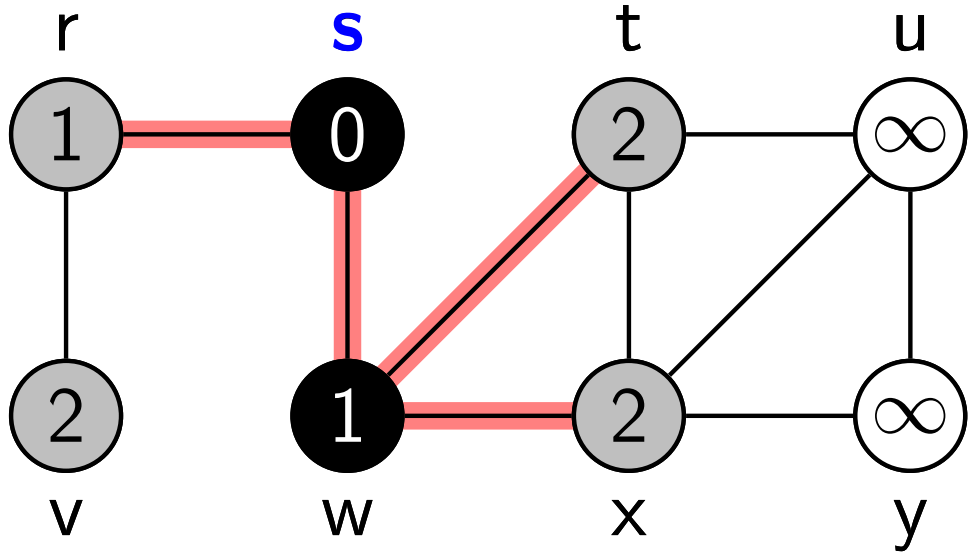
```



Q = | **t** | **x** | |

Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← r;
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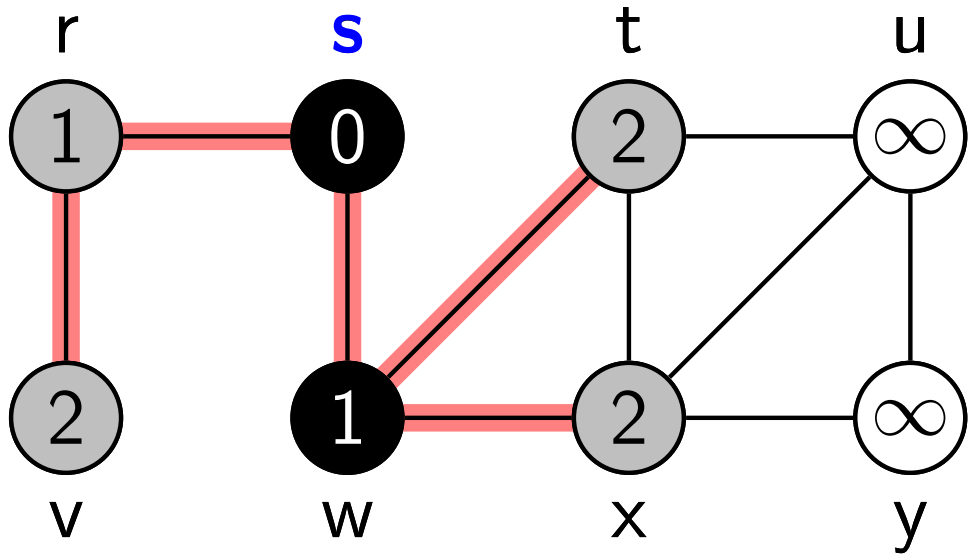
▷               π[v] ← r;
            ENQUEUE (Q,v);
    cor[r] ← preto;
Retorne d, π;
```



Q = | **t** | **x** | |

Busca-em-largura (G, s)

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Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
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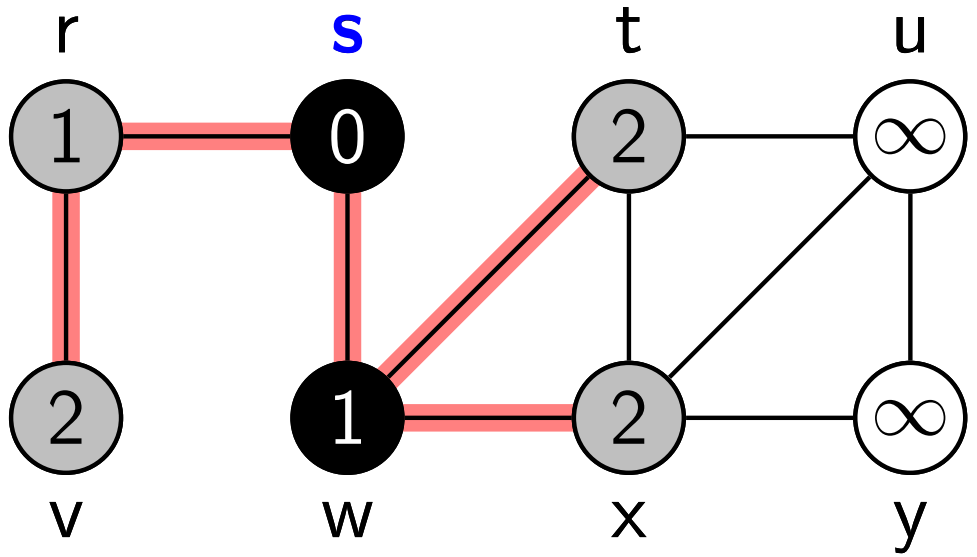
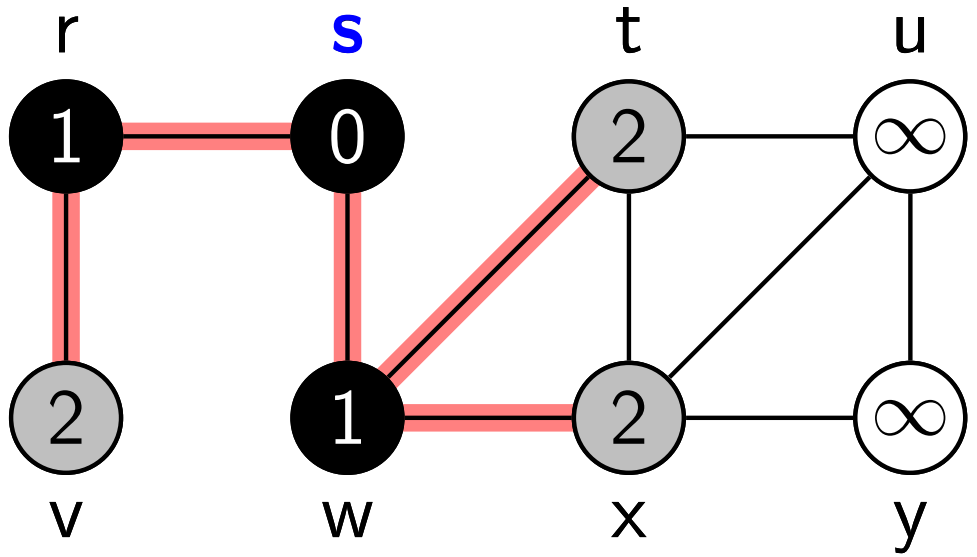
▷               ENQUEUE (Q,v);
    cor[r] ← preto;
Retorne d, π;
```



Q = | **t** | **x** | **v** |

Busca-em-largura (G, s)

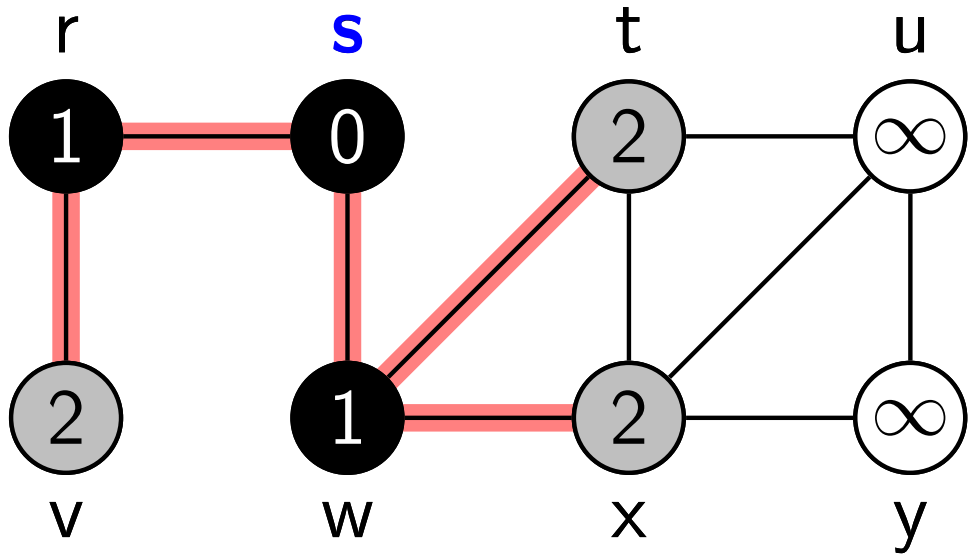
```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← r;
    Para cada v ∈ Adj[r]
        Se cor[v] = branco;
            cor[v] ← cinza;
            d[v] ← d[r] + 1;
            π[v] ← r;
            ENQUEUE (Q,v);
▷   cor[r] ← preto;
Retorne d, π;
```



Q = | **t** | **x** | **v** |

Busca-em-largura (G, s)

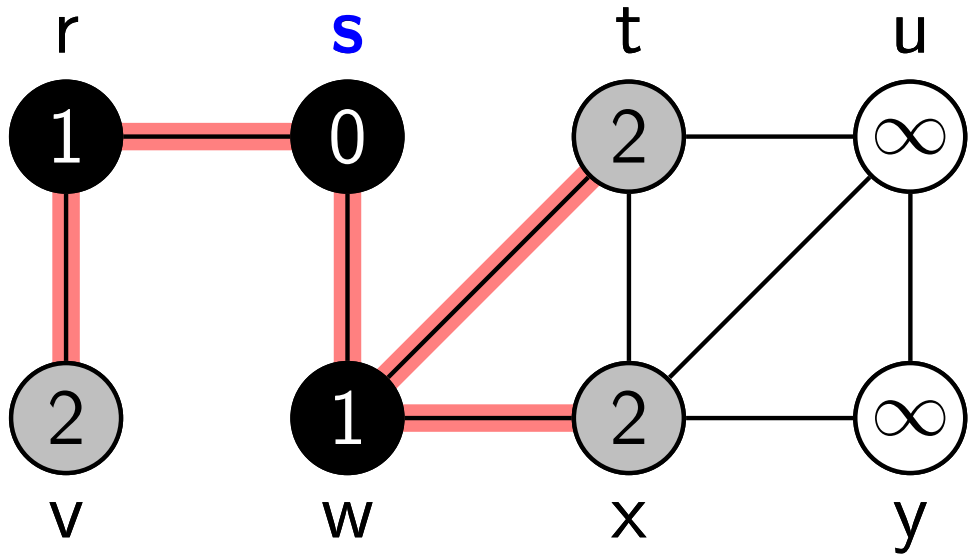
```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
▷     u ← DEQUEUE (Q);
      Para cada u ∈ Adj[t]
            Se cor[u] = branco;
                  cor[u] ← cinza;
                  d[u] ← d[t] + 1;
                  π[u] ← t;
                  ENQUEUE (Q,u);
      cor[t] ← preto;
Retorne d, π;
```



Q = | **t** | **x** | **v** |

Busca-em-largura (G, s)

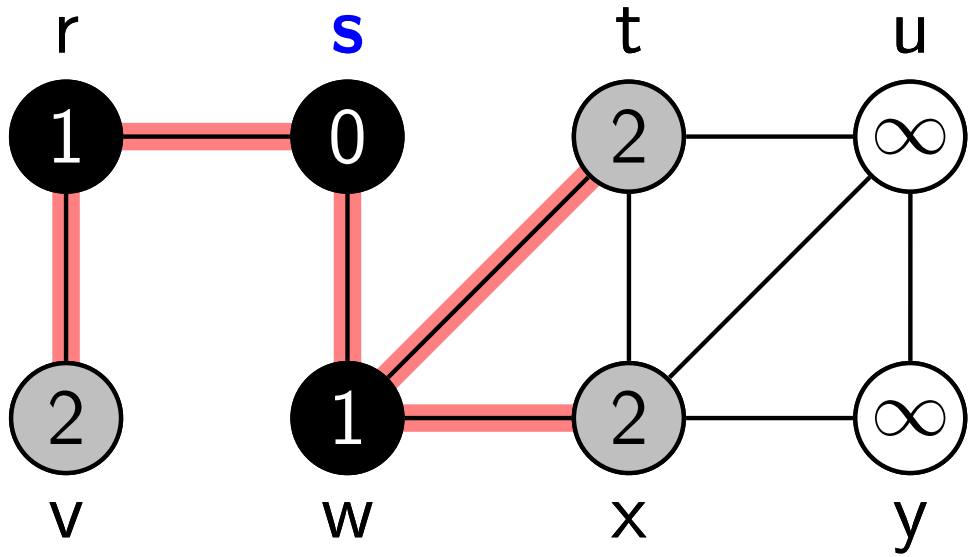
```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
▷     u ← t;
    Para cada u ∈ Adj[t]
        Se cor[u] = branco;
            cor[u] ← cinza;
            d[u] ← d[t] + 1;
            π[u] ← t;
            ENQUEUE (Q,u);
    cor[t] ← preto;
Retorne d, π;
```



Q = | **x** | **v** | |

Busca-em-largura (G, s)

Q $\leftarrow \emptyset$;
ENQUEUE (Q,*s*);
Enquanto $Q \neq \emptyset$
    u $\leftarrow$ **t**;
▷   **Para cada u** $\in Adj$[**t**]
        Se cor[**u**] = branco;
            cor[**u**] $\leftarrow$ cinza;
            d[**u**] $\leftarrow$ d[**t**] + 1;
            π[**u**] $\leftarrow$ **t**;
            ENQUEUE (Q,**u**);
    cor[**t**] $\leftarrow$ preto;
Retorne d, π;



Q = | **x** | **v** | |

Busca-em-largura (G, s)

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ENQUEUE (Q,s);
Enquanto Q ≠ ∅
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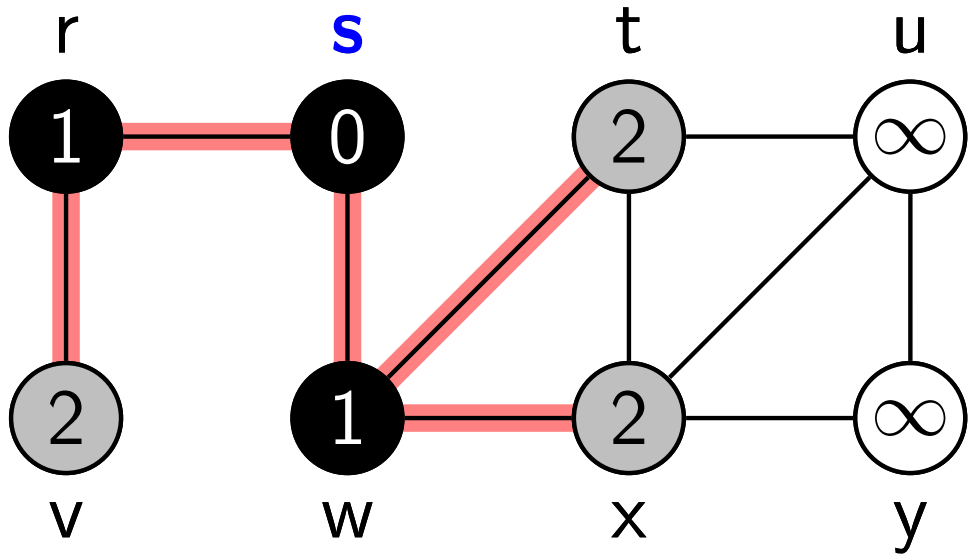
          d[u] ← d[t] + 1;
          π[u] ← t;
          ENQUEUE (Q,u);
    cor[t] ← preto;
Retorne d, π;
```



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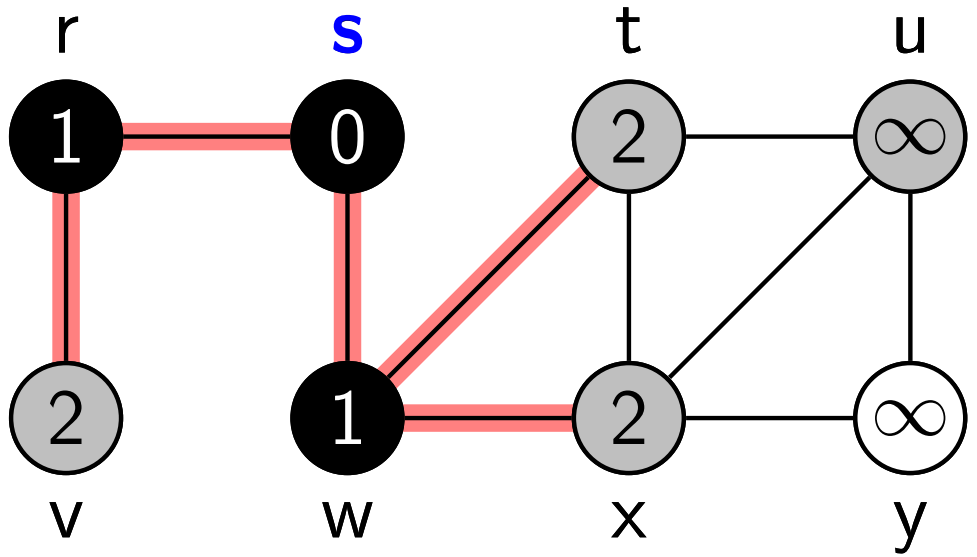
                  ENQUEUE (Q,u);
    cor[t] ← preto;
Retorne d, π;
```



Q = | **x** | **v** | |

Busca-em-largura (G, s)

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            ENQUEUE (Q,u);
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Retorne d, π;
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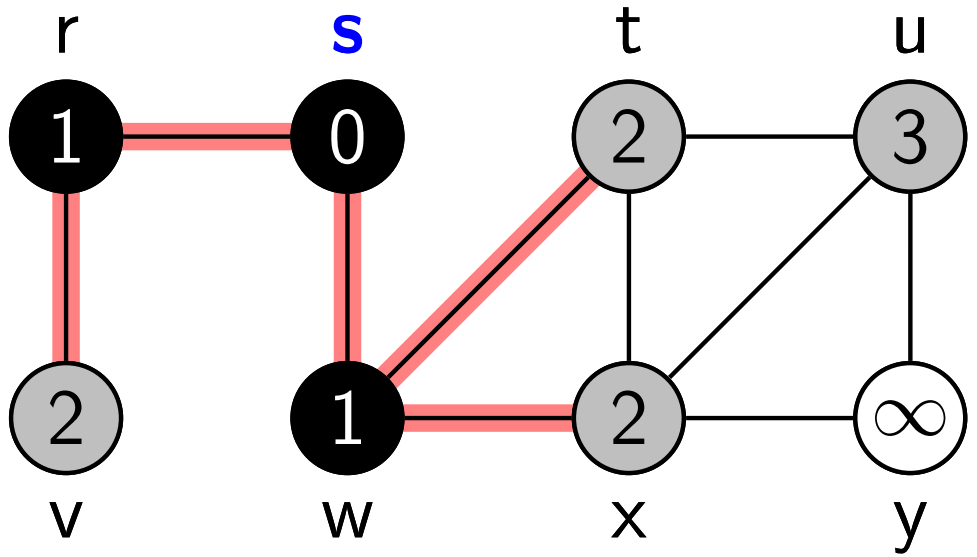

Q = | x | v | |

Busca-em-largura (G, s)

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ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← t;
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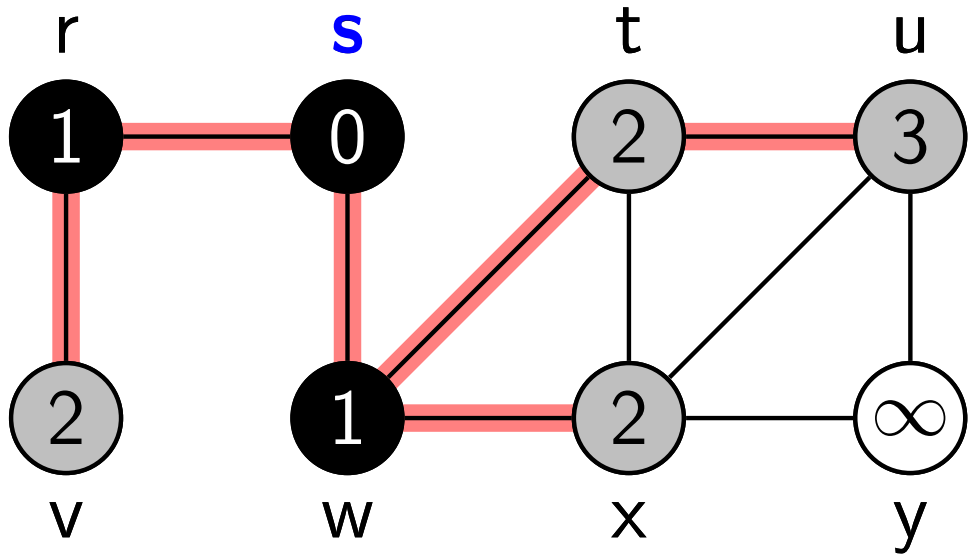
▷           π[u] ← t;
            ENQUEUE (Q,u);
    cor[t] ← preto;
Retorne d, π;
```



Q = | x | v | |

Busca-em-largura (G, s)

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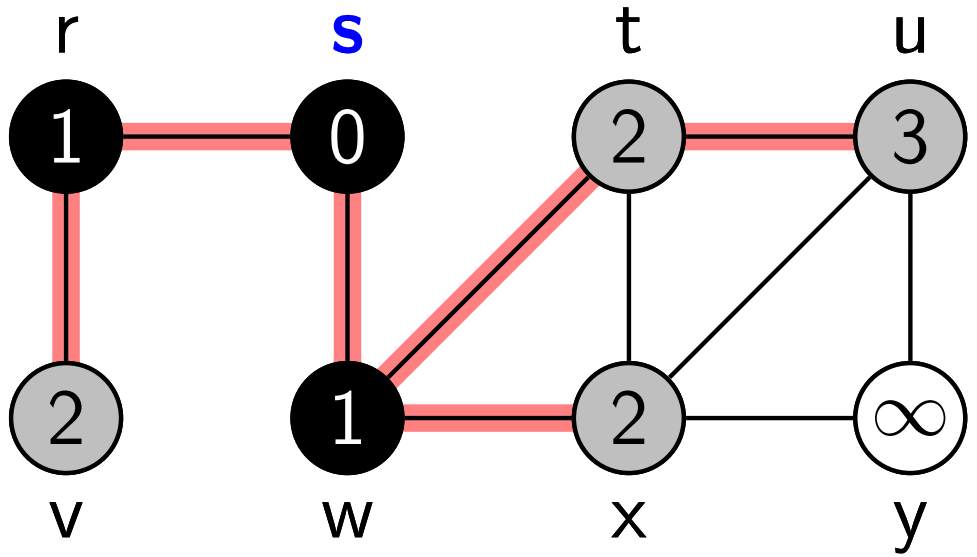

Q = | x | v | u |

Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← t;
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        Se cor[x] = branco;
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            d[x] ← d[t] + 1;
            π[x] ← t;
            ENQUEUE (Q,x);
    cor[t] ← preto;
Retorne d, π;
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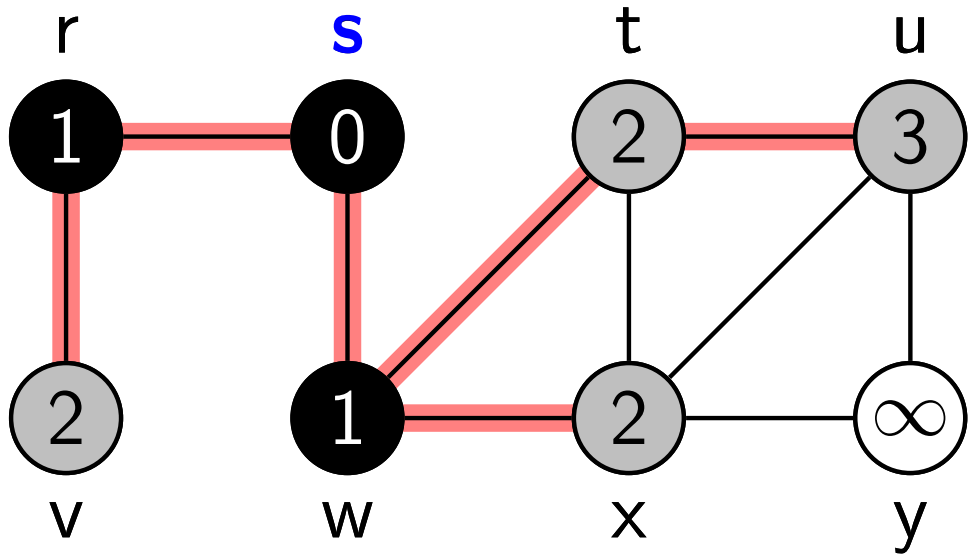

Q = | **x** | **v** | **u** |

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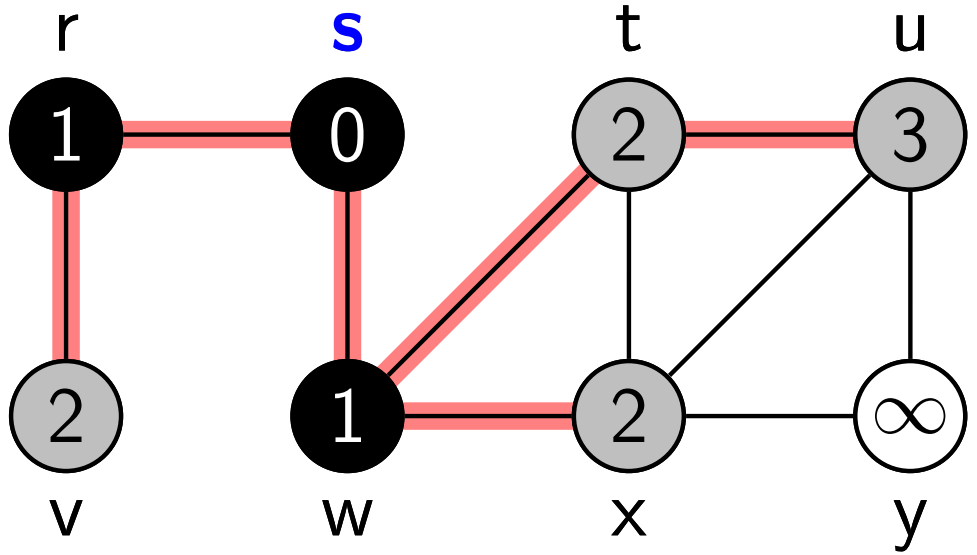

Q = | x | v | u |

Busca-em-largura (G, s)

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            ENQUEUE (Q,x);
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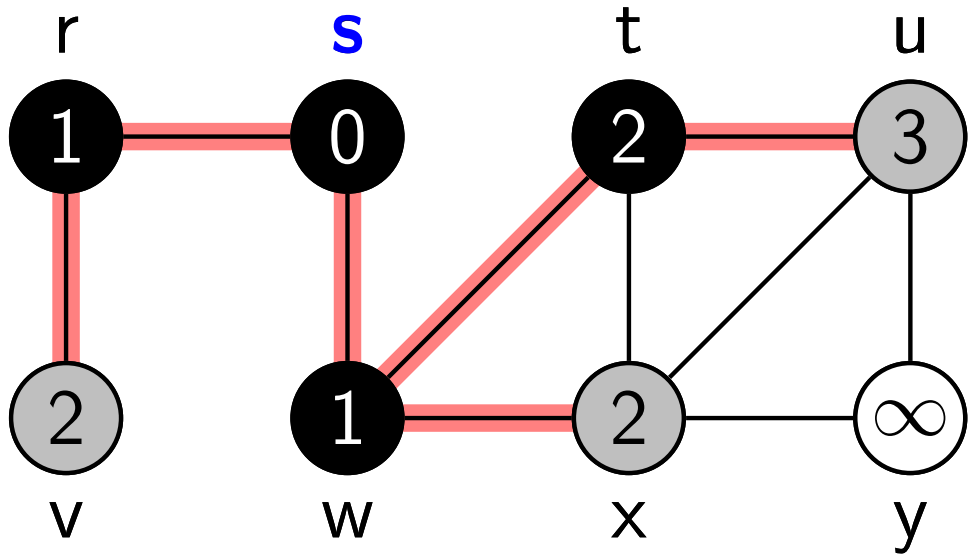

Q = | **x** | **v** | **u** |

Busca-em-largura (G, s)

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ENQUEUE (Q,s);
Enquanto Q ≠ ∅
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                  d[t] ← d[x] + 1;
                  π[t] ← x;
                  ENQUEUE (Q,t);
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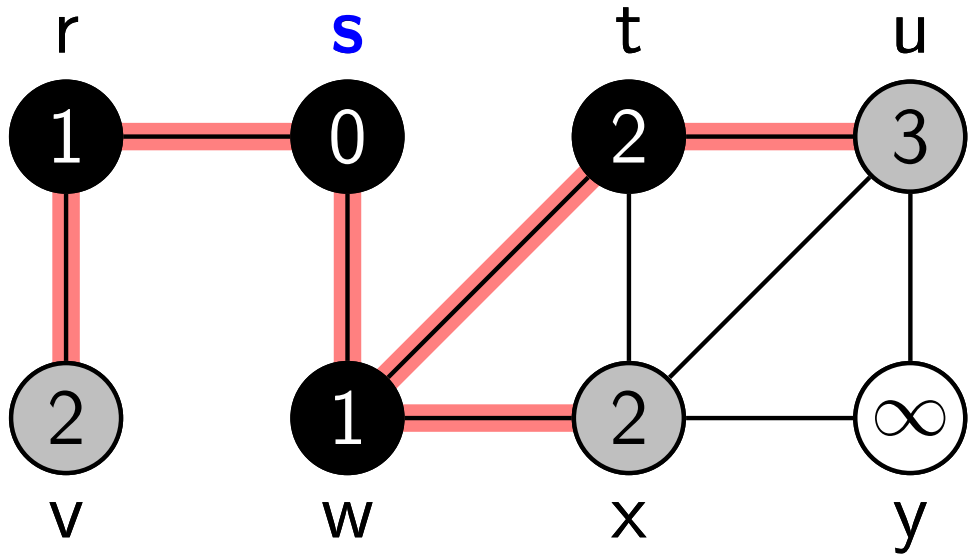

Q = | x | v | u |

Busca-em-largura (G, s)

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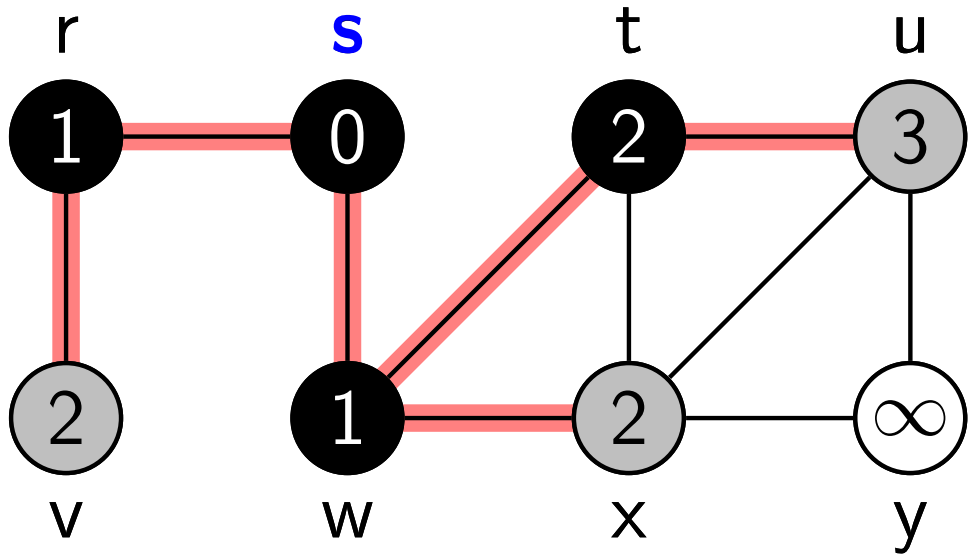

Q = | **v** | **u** | |

Busca-em-largura (G, s)

```
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ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← x;
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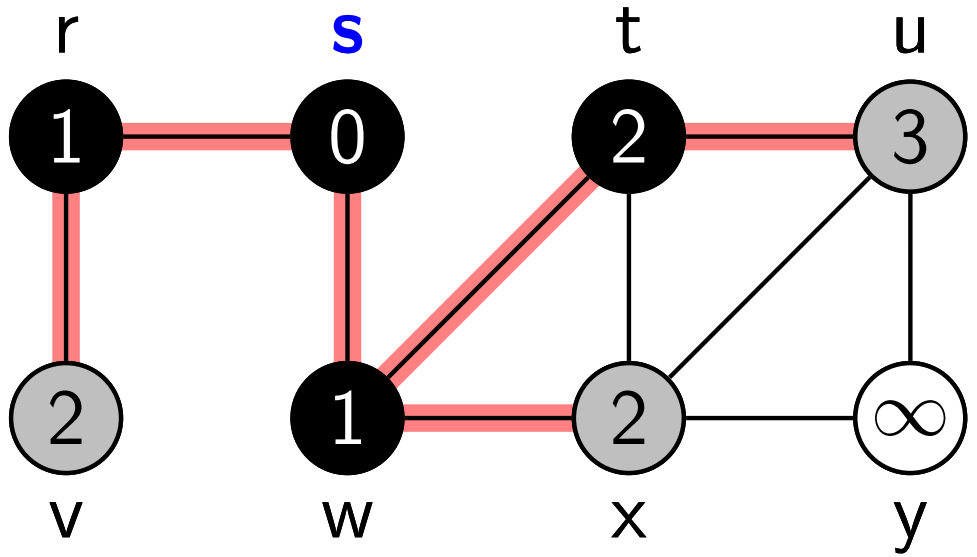
          cor[t] ← cinza;
          d[t] ← d[x] + 1;
          π[t] ← x;
          ENQUEUE (Q,t);
    cor[x] ← preto;
Retorne d, π;
```



Q = | **v** | **u** | |

Busca-em-largura (G, s)

```
Q ← ∅;
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    u ← x;
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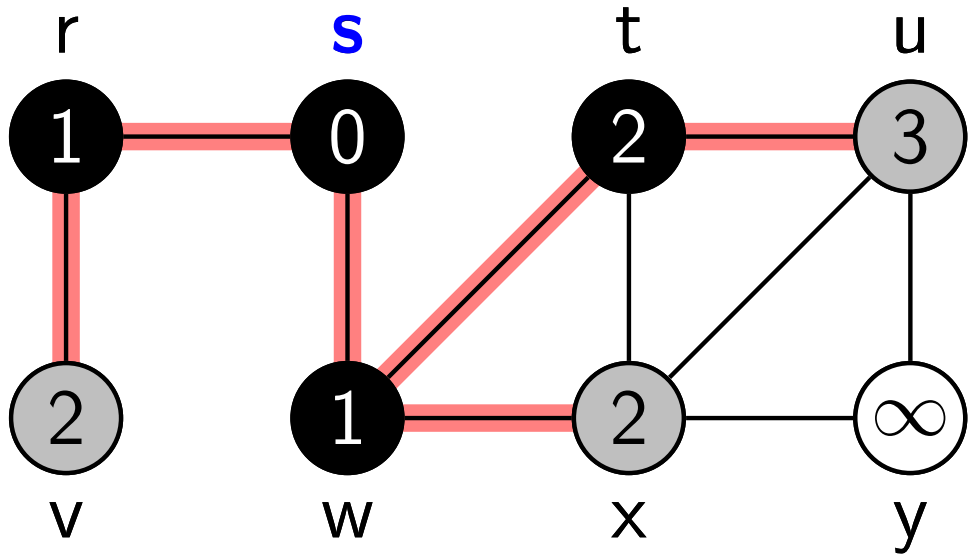
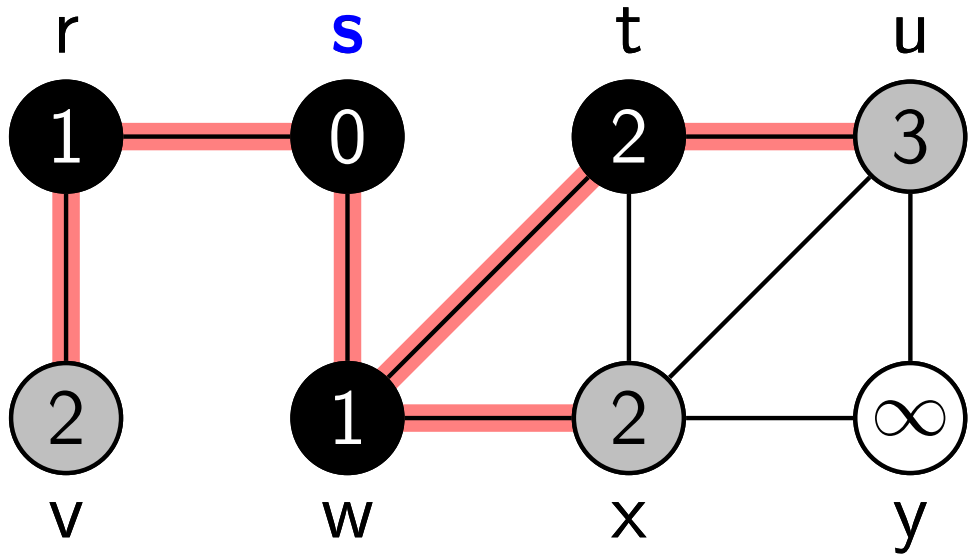
          π[t] ← x;
          ENQUEUE (Q,t);
    cor[x] ← preto;
Retorne d, π;
```



Q = | **v** | **u** | |

Busca-em-largura (G, s)

Q $\leftarrow \emptyset$;
ENQUEUE (Q,*s*);
Enquanto $Q \neq \emptyset$
    u $\leftarrow$ **x**;
▷ **Para cada u** $\in Adj$[**x**]
        Se cor[**u**] $=$ branco;
            cor[**u**] $\leftarrow$ cinza;
            d[**u**] $\leftarrow$ d[**x**] $+ 1$;
            π[**u**] $\leftarrow$ **x**;
            ENQUEUE (Q,**u**);
    cor[**x**] $\leftarrow$ preto;
Retorne d, π;

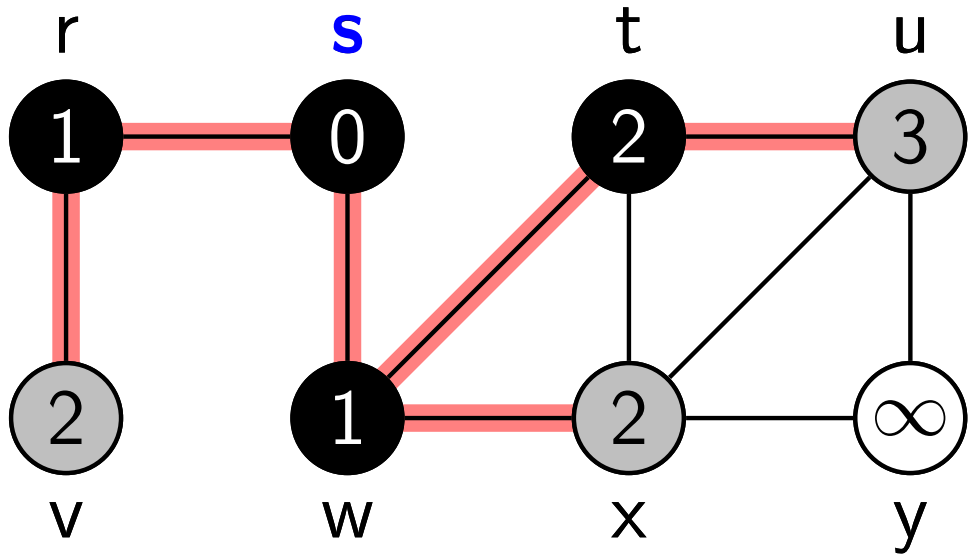


Q $=$

v	**u**	

Busca-em-largura (G, s)

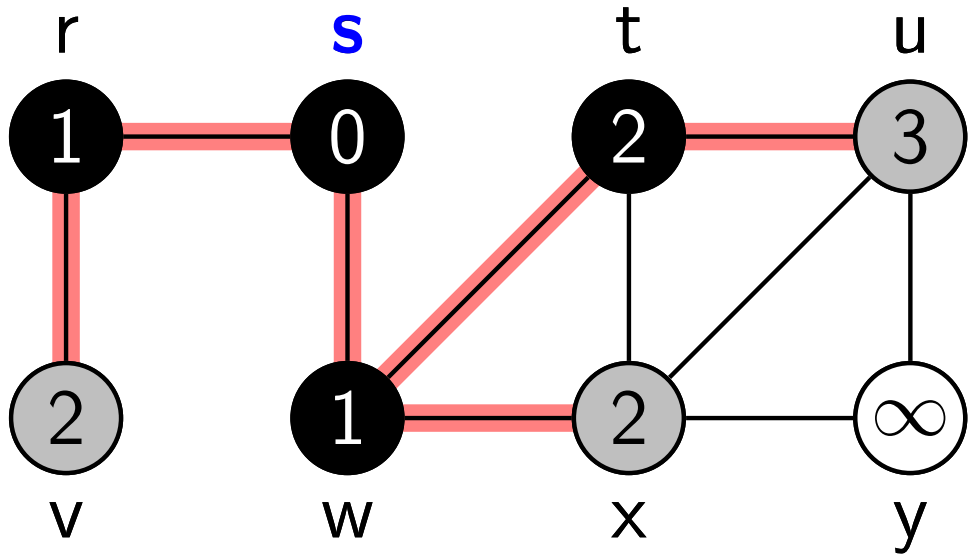
```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← x;
    Para cada u ∈ Adj[x]
▷       Se cor[u] = branco;
          cor[u] ← cinza;
          d[u] ← d[x] + 1;
          π[u] ← x;
          ENQUEUE (Q,u);
    cor[x] ← preto;
Retorne d, π;
```



Q = | **v** | **u** | |

Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← x;
▷     Para cada y ∈ Adj[x]
        Se cor[y] = branco;
            cor[y] ← cinza;
            d[y] ← d[x] + 1;
            π[y] ← x;
            ENQUEUE (Q,y);
    cor[x] ← preto;
Retorne d, π;
```



Q = | **v** | **u** | |

Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← x;
    Para cada y ∈ Adj[x]
▷       Se cor[y] = branco;
          cor[y] ← cinza;
          d[y] ← d[x] + 1;
          π[y] ← x;
          ENQUEUE (Q,y);
    cor[x] ← preto;
Retorne d, π;
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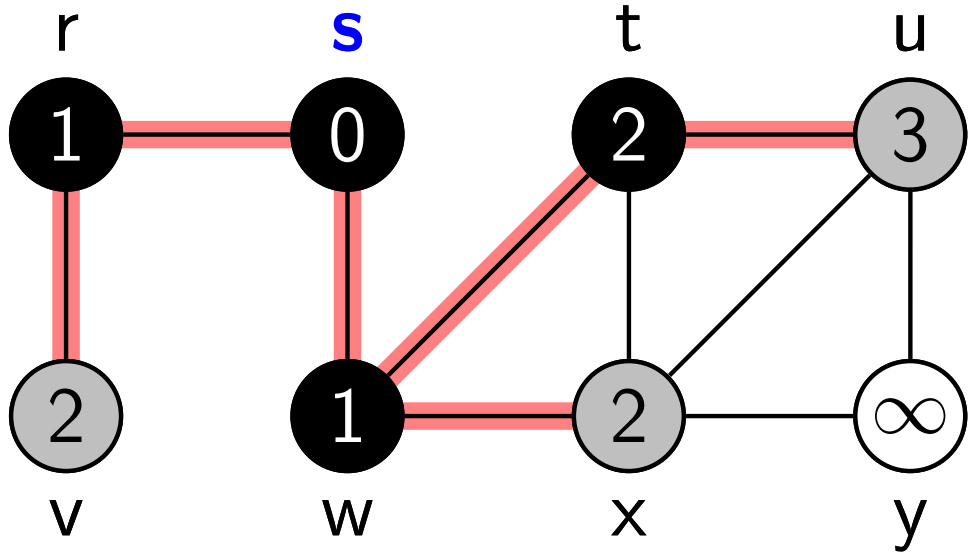

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Busca-em-largura (G, s)

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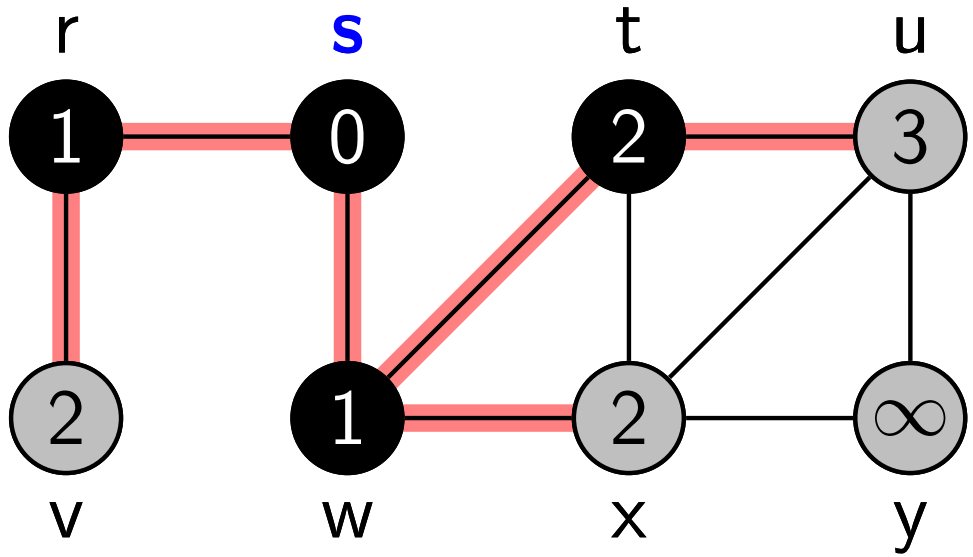

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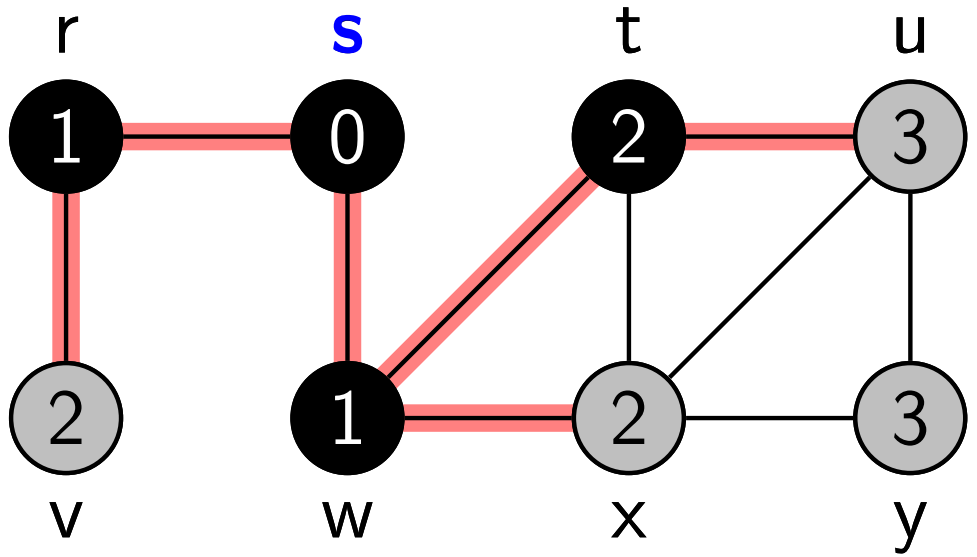

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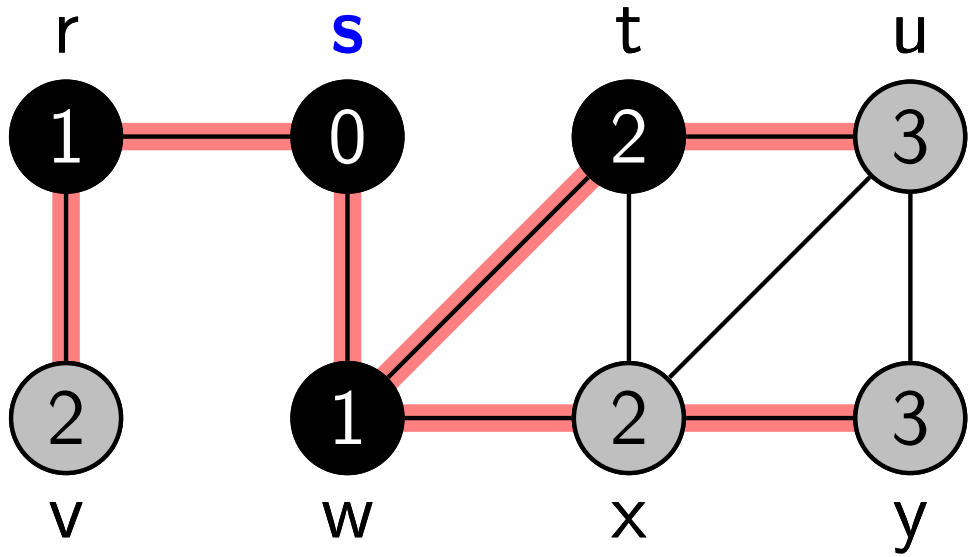

Q $=$

v	**u**	

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Enquanto Q ≠ ∅
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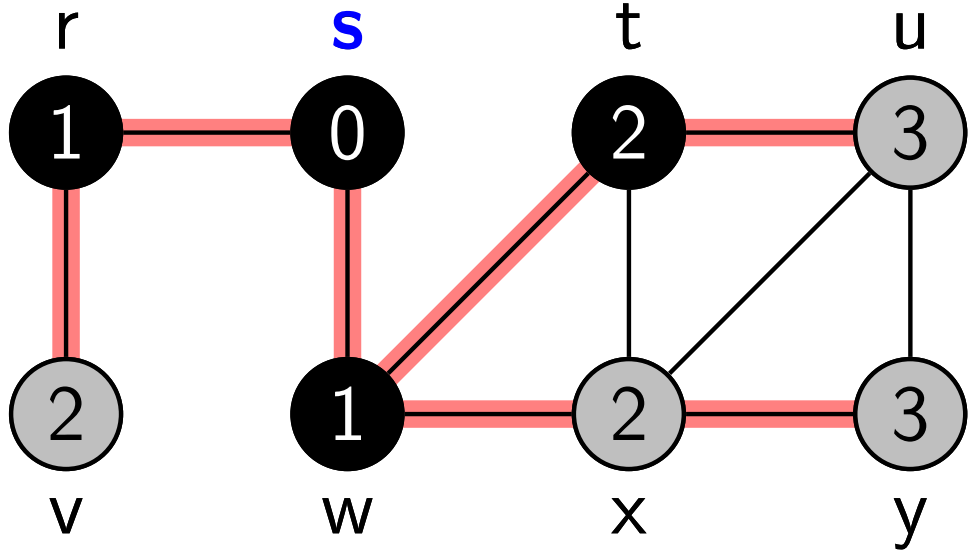

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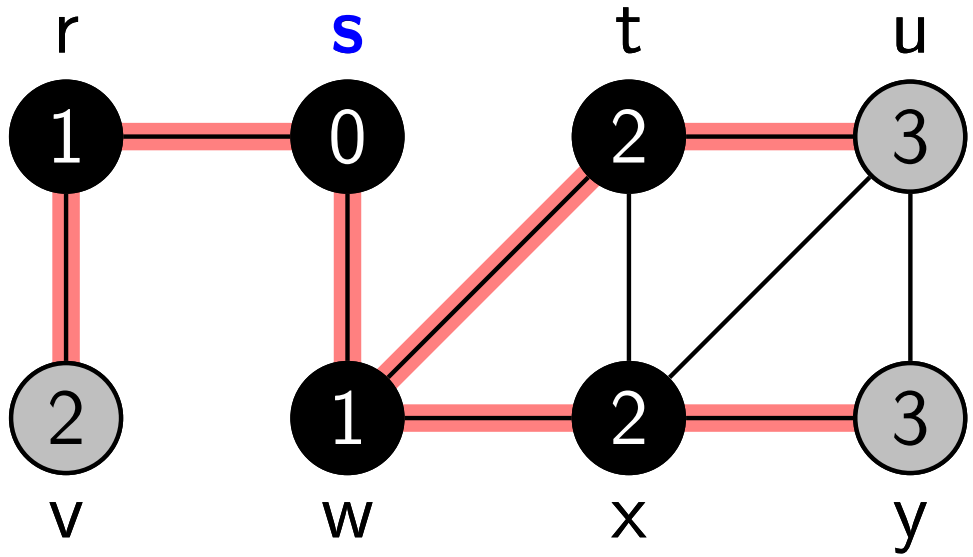

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```
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Enquanto Q ≠ ∅
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      Para cada r ∈ Adj[v]
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                  d[r] ← d[v] + 1;
                  π[r] ← v;
                  ENQUEUE (Q,r);
      cor[v] ← preto;
Retorne d, π;
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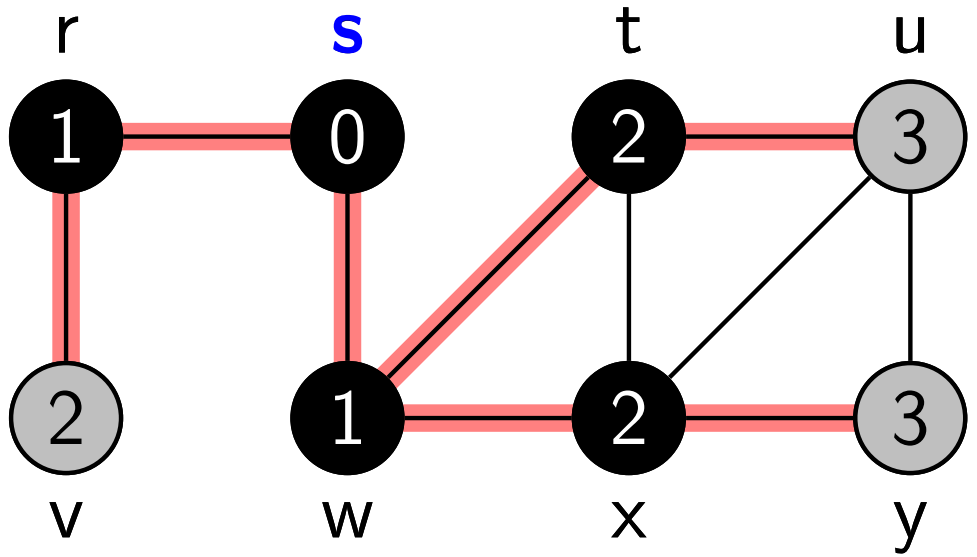

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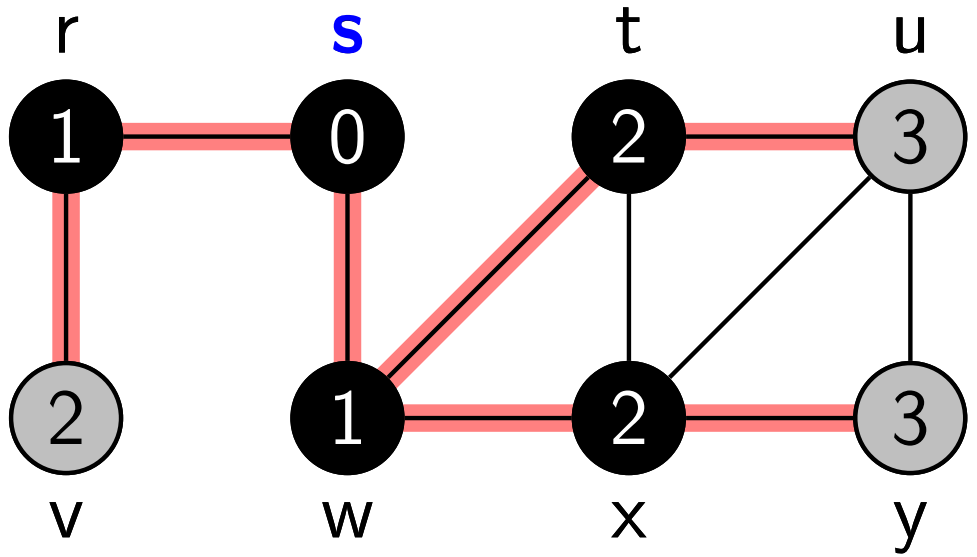

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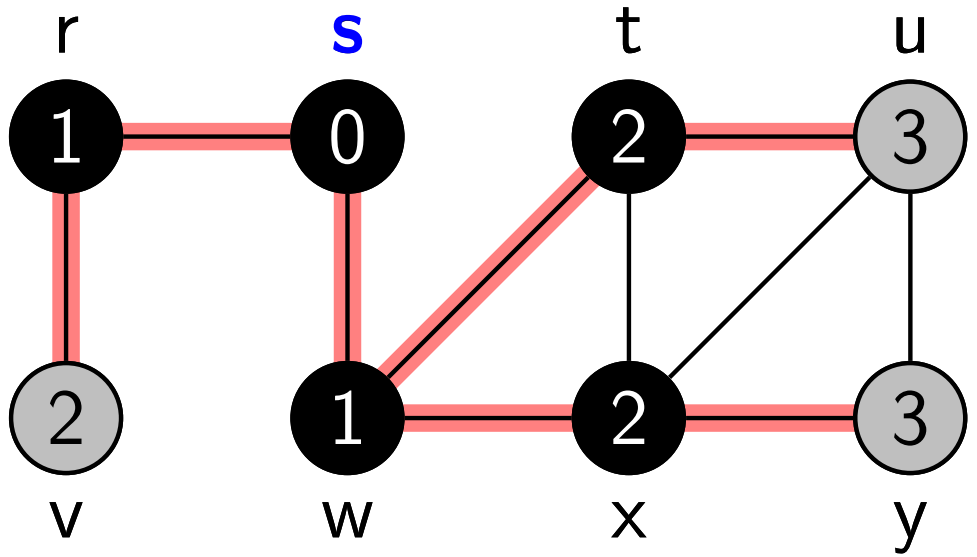

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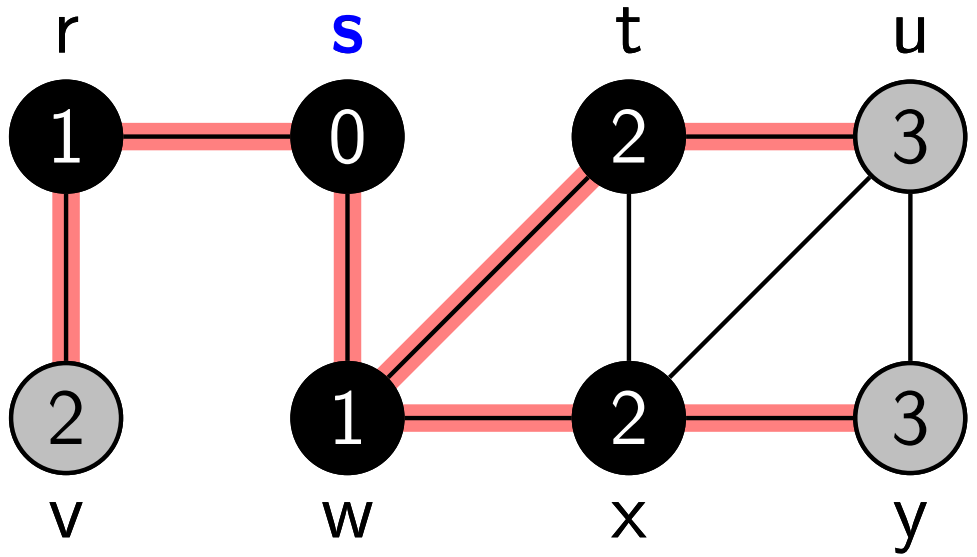

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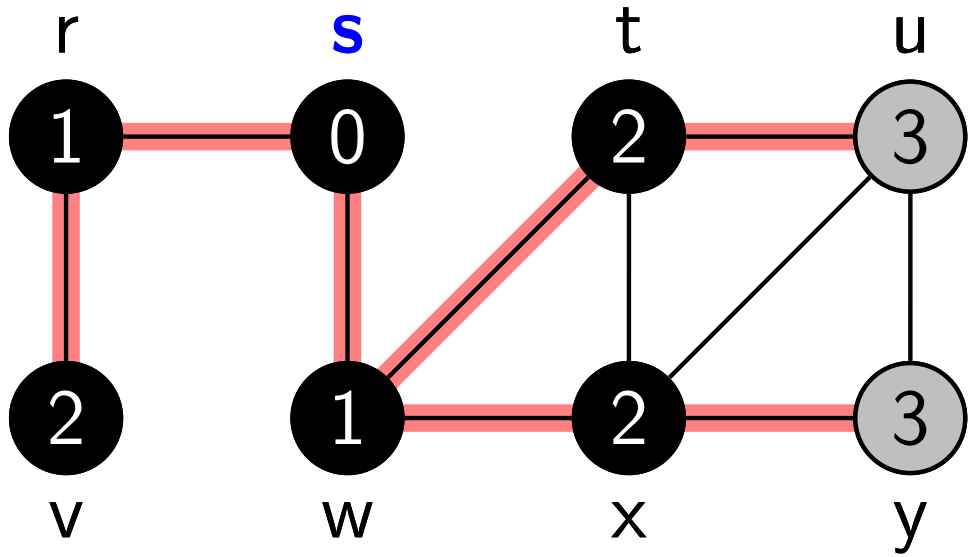

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            π[t] ← u;
            ENQUEUE (Q,t);
    cor[u] ← preto;
Retorne d, π;
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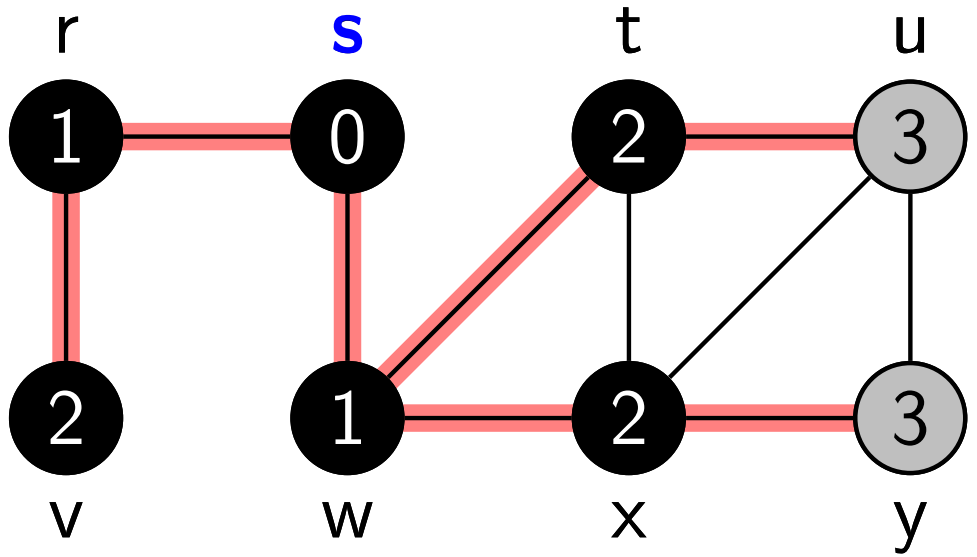

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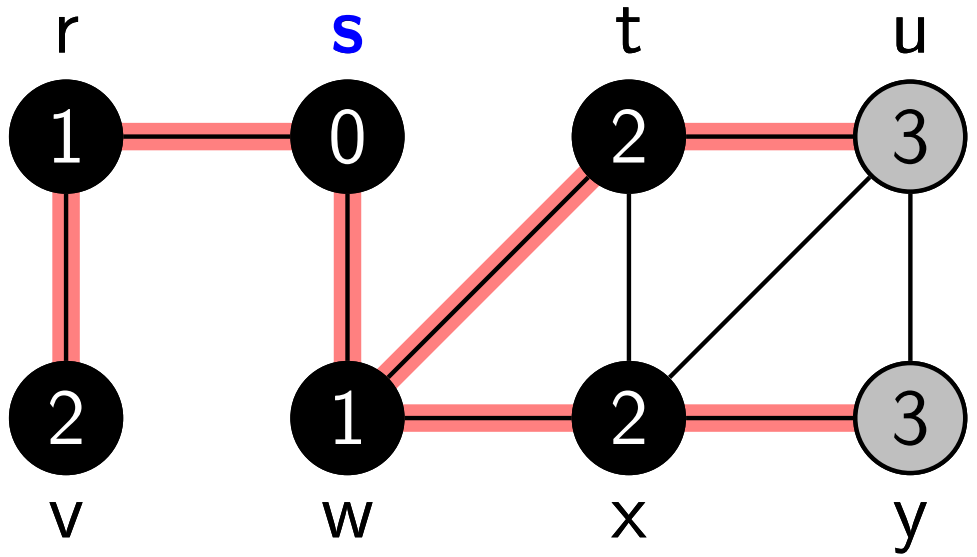

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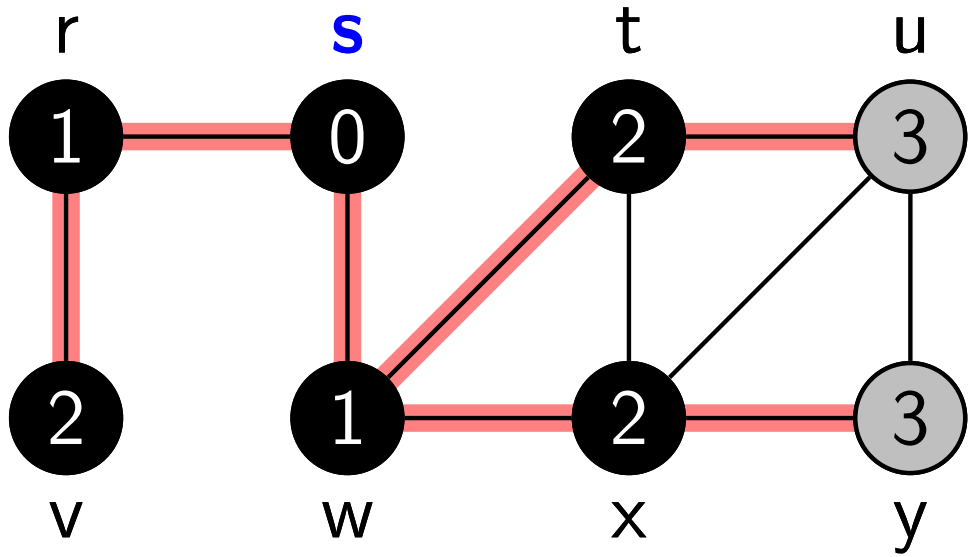

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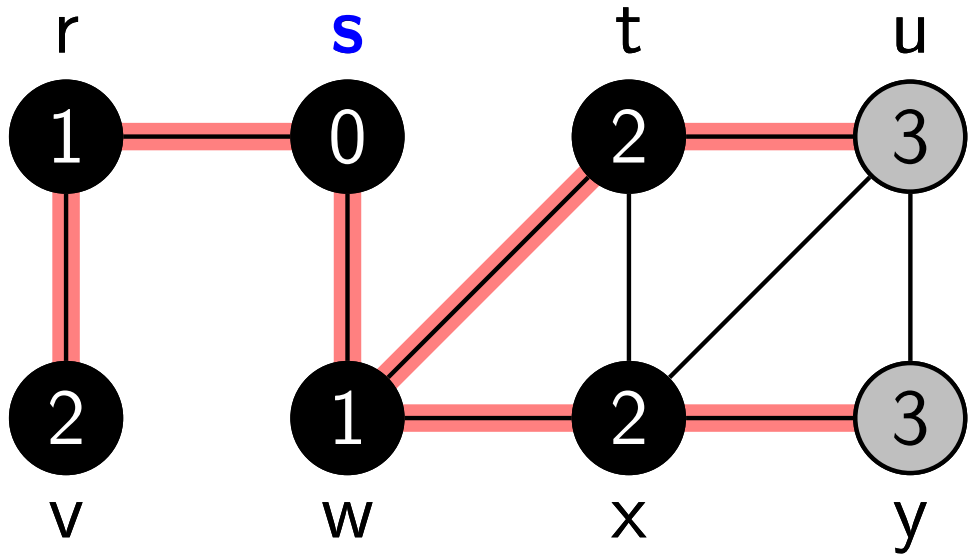

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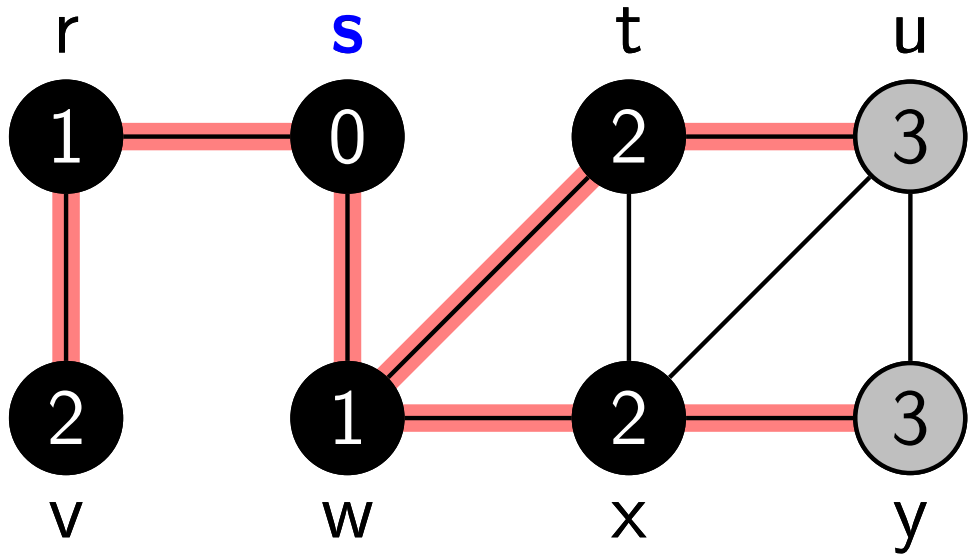

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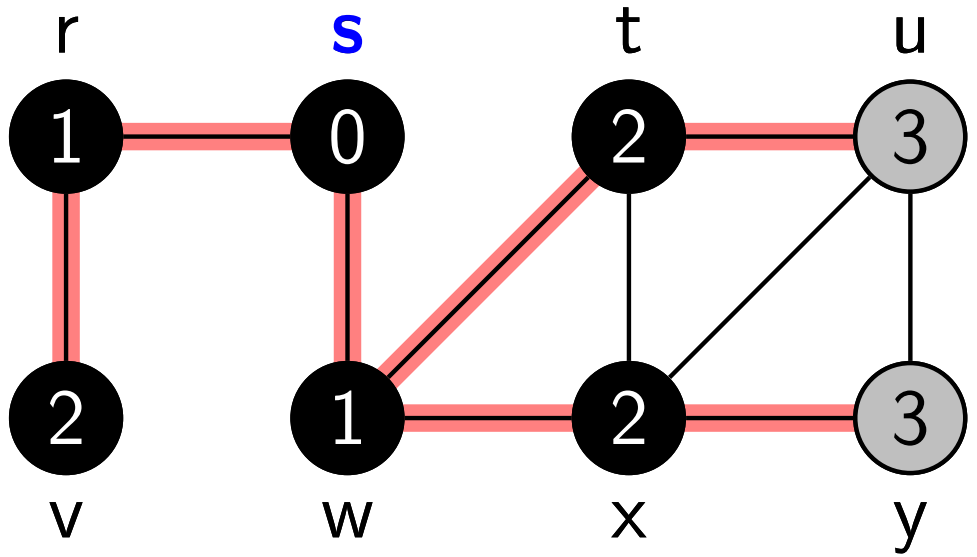

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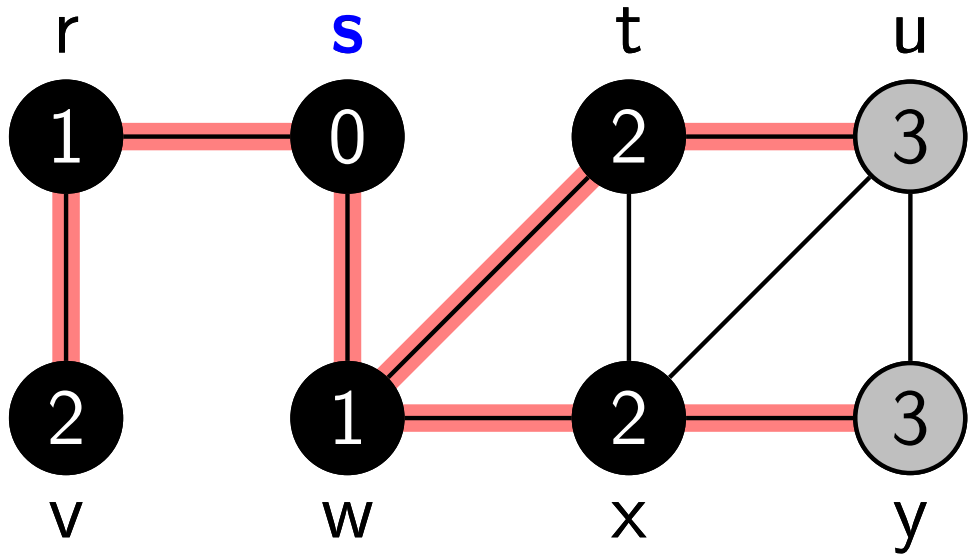

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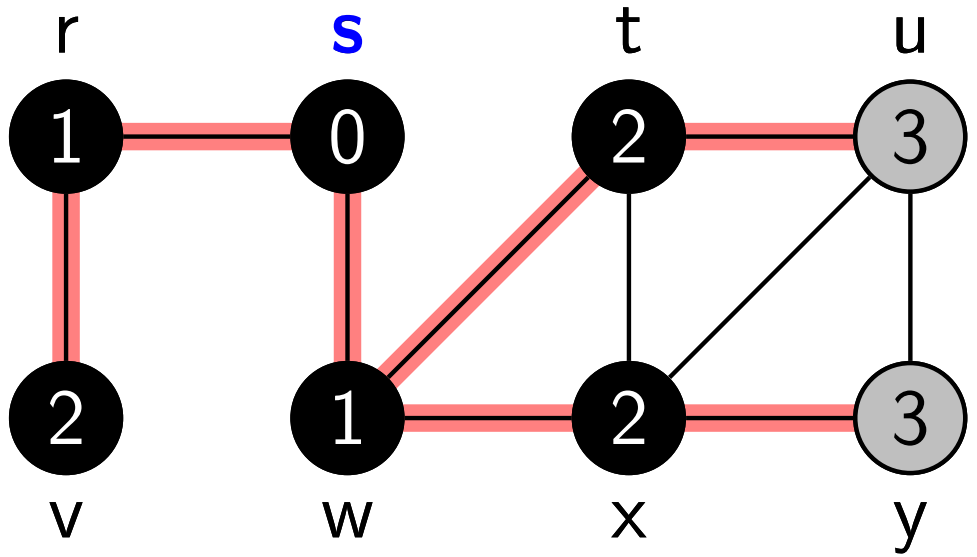

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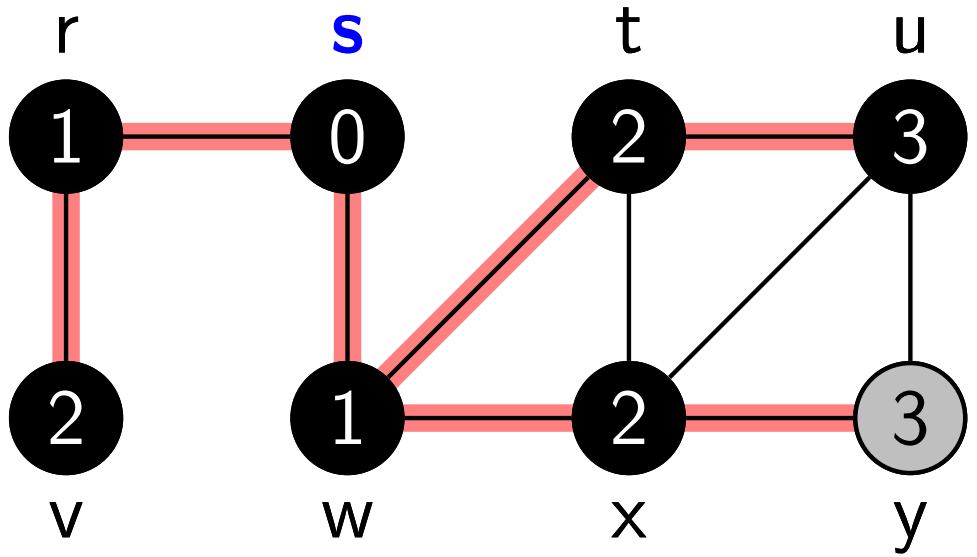

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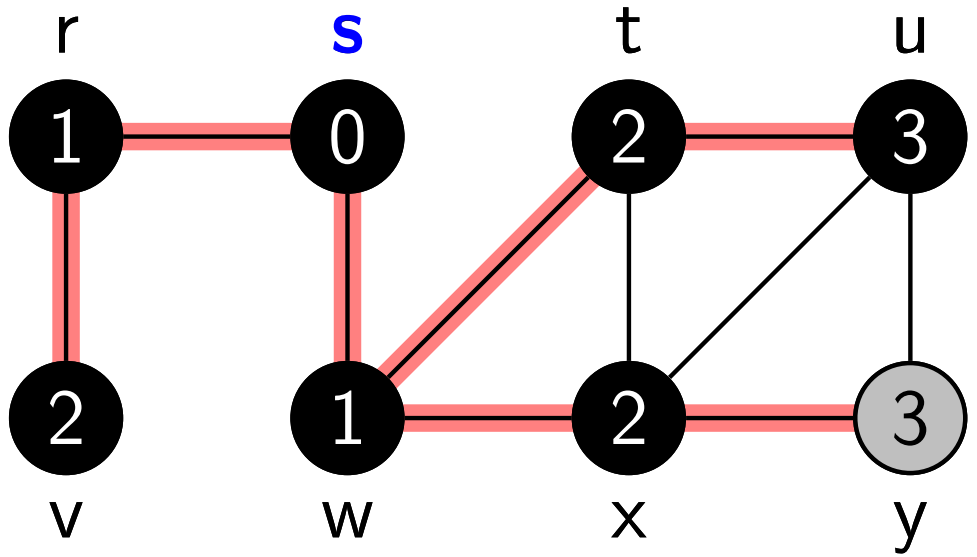

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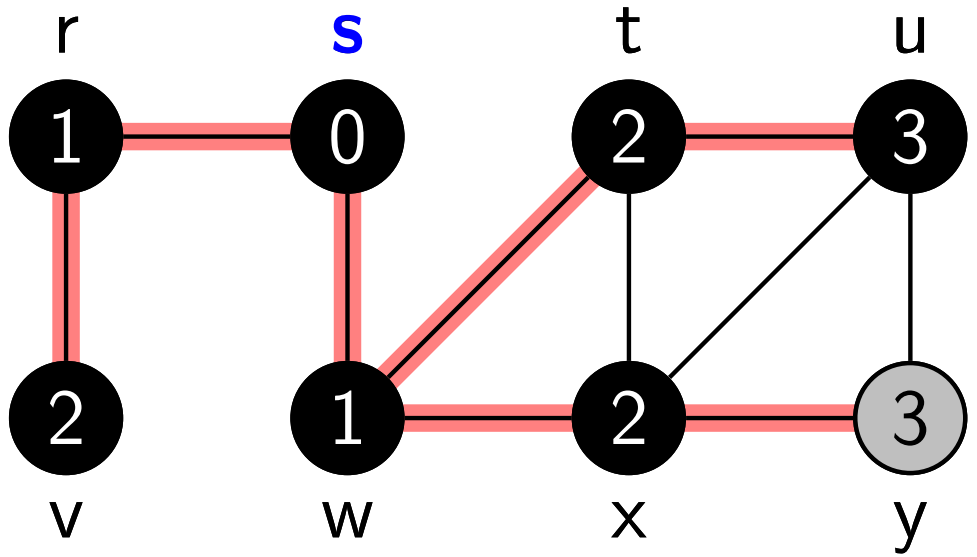
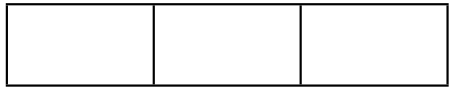


Q = 

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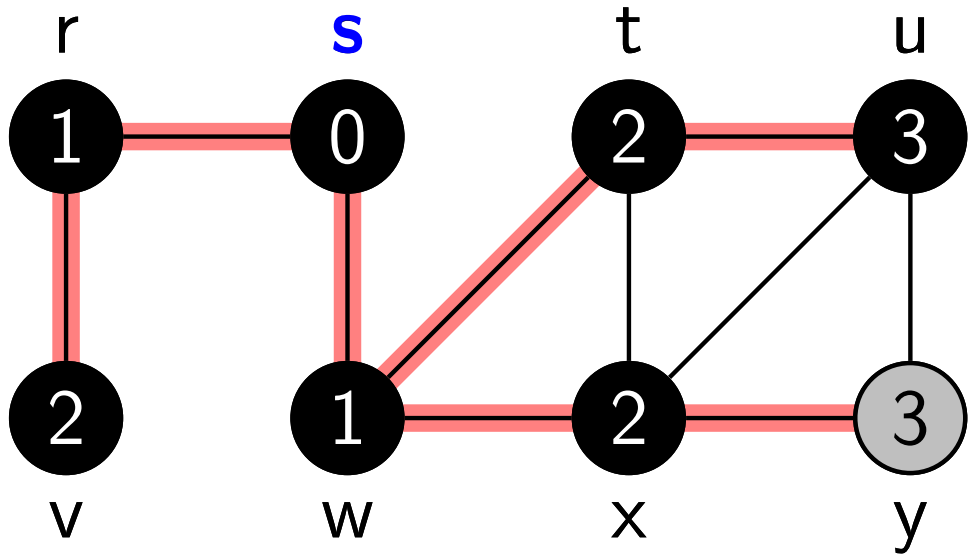
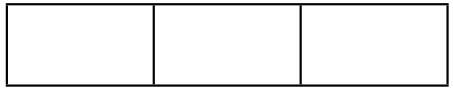


Q = 

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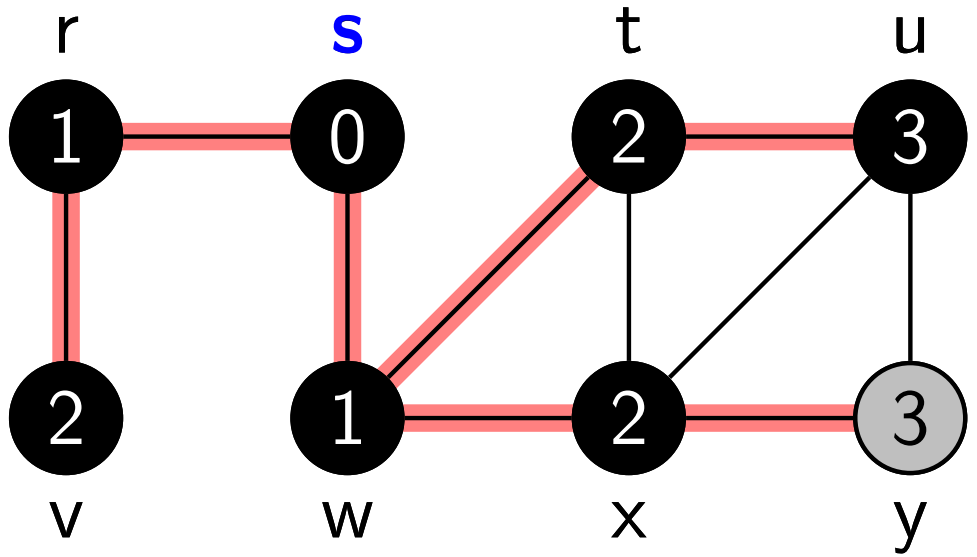
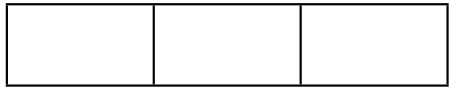
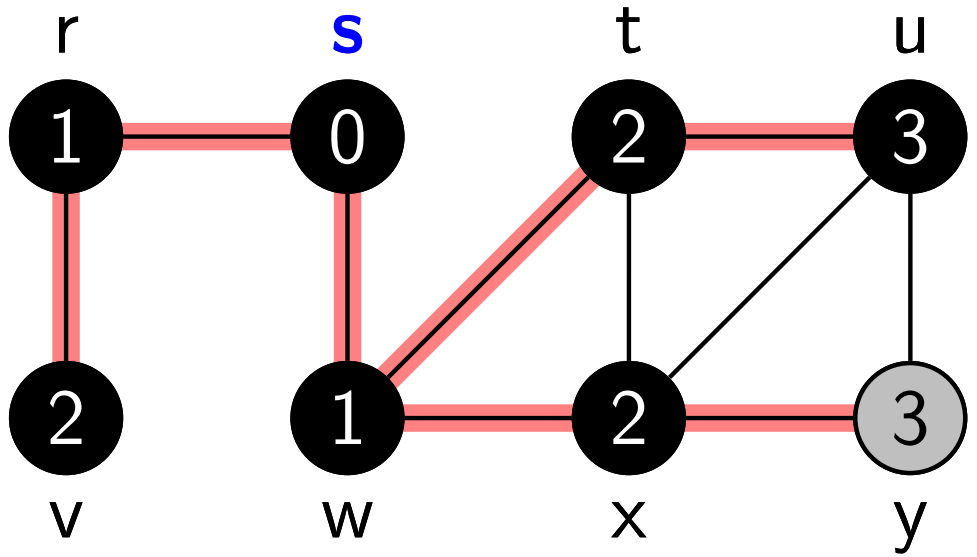
Retorne d, π;
```

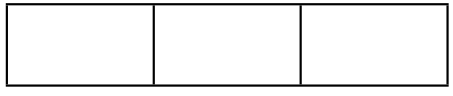


Q = 

Busca-em-largura (G, s)

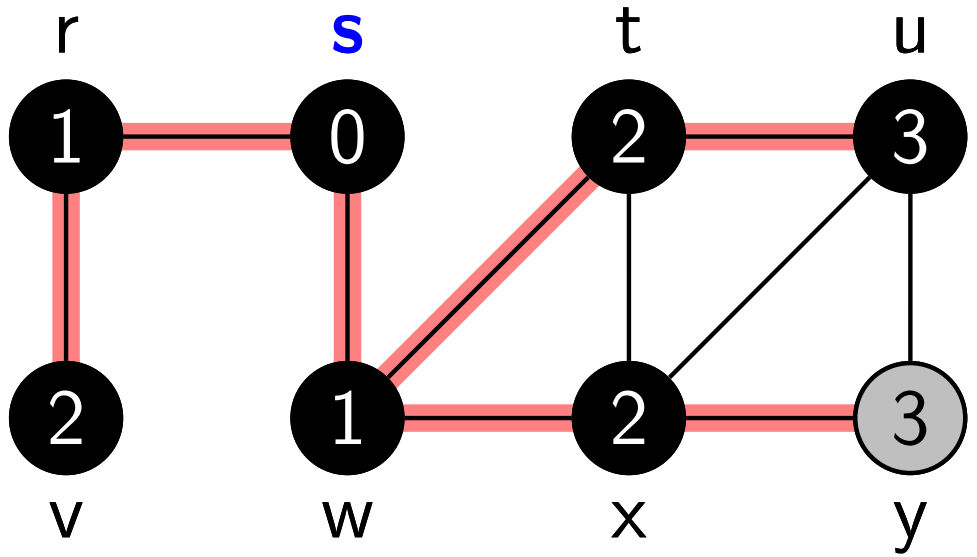
Q $\leftarrow \emptyset$;
ENQUEUE (Q,s);
Enquanto $Q \neq \emptyset$
    u $\leftarrow$ **y**;
▷   **Para cada u** $\in Adj$[**y**]
        Se cor[**u**] $=$ branco;
            cor[**u**] $\leftarrow$ cinza;
            d[**u**] $\leftarrow$ d[**y**] $+ 1$;
            π[**u**] $\leftarrow$ **y**;
            ENQUEUE (Q,**u**);
    cor[**y**] $\leftarrow$ preto;
Retorne d, π;

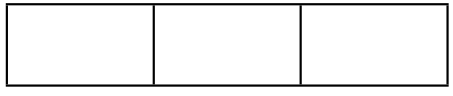


Q $=$ 

Busca-em-largura (G, s)

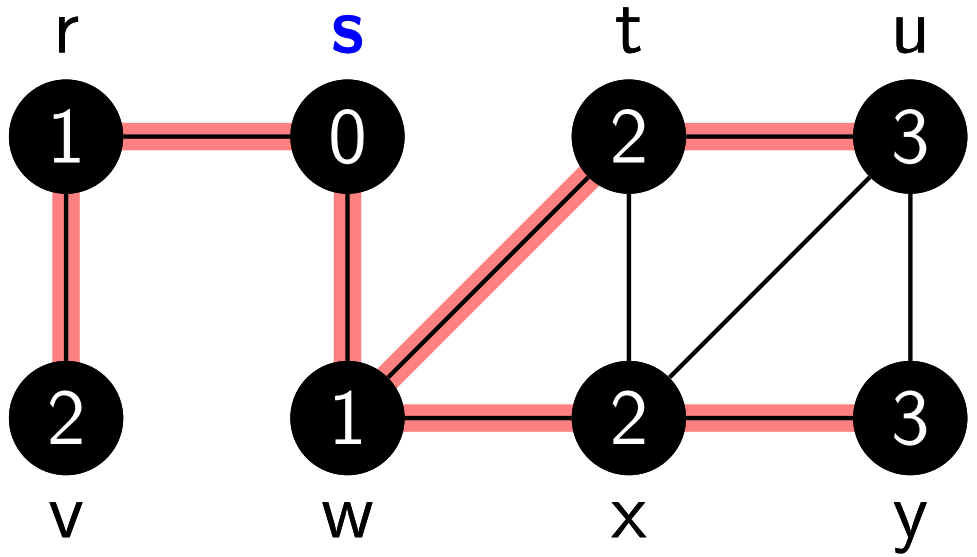
```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← y;
    Para cada u ∈ Adj[y]
▷       Se cor[u] = branco;
          cor[u] ← cinza;
          d[u] ← d[y] + 1;
          π[u] ← y;
          ENQUEUE (Q,u);
    cor[y] ← preto;
Retorne d, π;
```

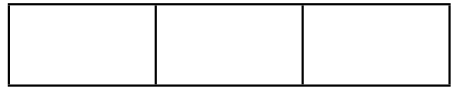


Q = 

Busca-em-largura (G, s)

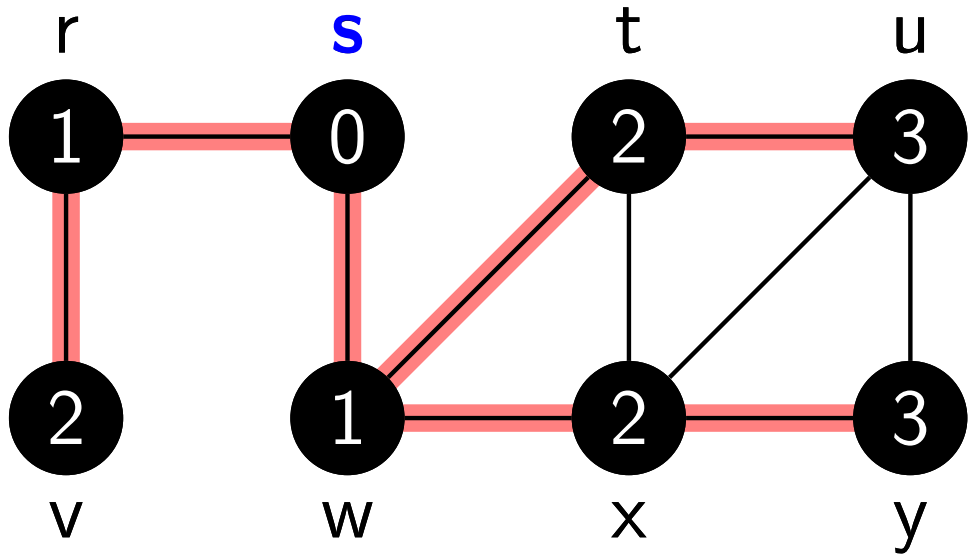
```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← y;
    Para cada u ∈ Adj[y]
        Se cor[u] = branco;
            cor[u] ← cinza;
            d[u] ← d[y] + 1;
            π[u] ← y;
            ENQUEUE (Q,u);
▷   cor[y] ← preto;
Retorne d, π;
```

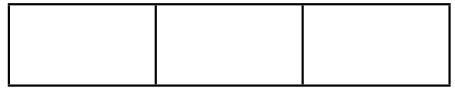


Q = 

Busca-em-largura (G, s)

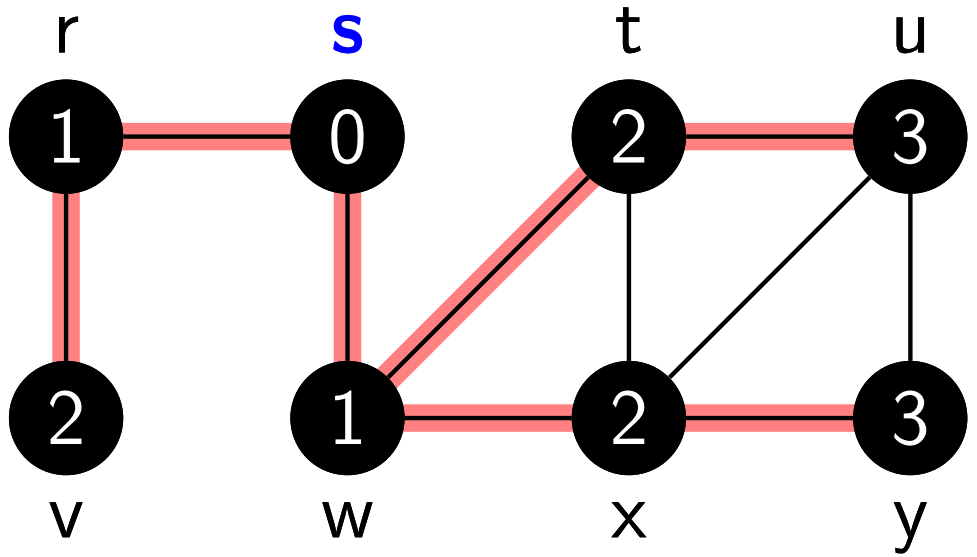
```
Q ← ∅;
ENQUEUE (Q,s);
▷Enquanto Q ≠ ∅
    u ← y;
    Para cada u ∈ Adj[y]
        Se cor[u] = branco;
            cor[u] ← cinza;
            d[u] ← d[y] + 1;
            π[u] ← y;
            ENQUEUE (Q,u);
    cor[y] ← preto;
Retorne d, π;
```

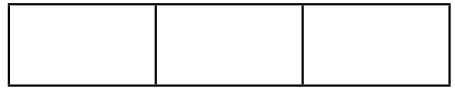


Q = 

Busca-em-largura (G, s)

```
Q ← ∅;
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← y;
    Para cada u ∈ Adj[y]
        Se cor[u] = branco;
            cor[u] ← cinza;
            d[u] ← d[y] + 1;
            π[u] ← y;
            ENQUEUE (Q,u);
    cor[y] ← preto;
▷Retorne d, π;
```



Q = 

Busca em largura - Complexidade

A inicialização consome tempo $\Theta(V)$.

Para cada **u** $\in V[G] - \{s\}$
    cor[**u**] $\leftarrow$ branco;
    d[**u**] $\leftarrow \infty$;
    π[**u**] $\leftarrow$ NIL;
cor[**s**] $\leftarrow$ cinza;
d[**s**] $\leftarrow 0$;
π[**s**] $\leftarrow$ NIL;

Busca em largura - Complexidade

Depois que um vértice deixa de ser branco, ele não volta a ser branco novamente. Assim, cada vértice é inserido na fila Q no máximo uma vez. Cada operação sobre a fila consome tempo $\Theta(1)$ resultando em um total de $\mathcal{O}(V)$.

```
ENQUEUE (Q,s);
Enquanto Q ≠ ∅
    u ← y;
    Para cada u ∈ Adj[y]
        Se cor[u] = branco;
            cor[u] ← cinza;
            d[u] ← d[y] + 1;
            π[u] ← y;
            ENQUEUE (Q,u);
    cor[y] ← preto;
Retorne d, π;
```

Busca em largura - Consumo de tempo

- Em uma lista de adjacência, cada vértice é percorrido apenas uma vez. A soma dos comprimentos das listas é $\Theta(E)$. Assim, o tempo gasto para percorrer as listas é $\mathcal{O}(E)$.
- **Conclusão**: A complexidade de tempo de BUSCA-EM-LARGURA é $\mathcal{O}(V + E)$.