

# Algoritmi e Strutture Dati

## Alberi

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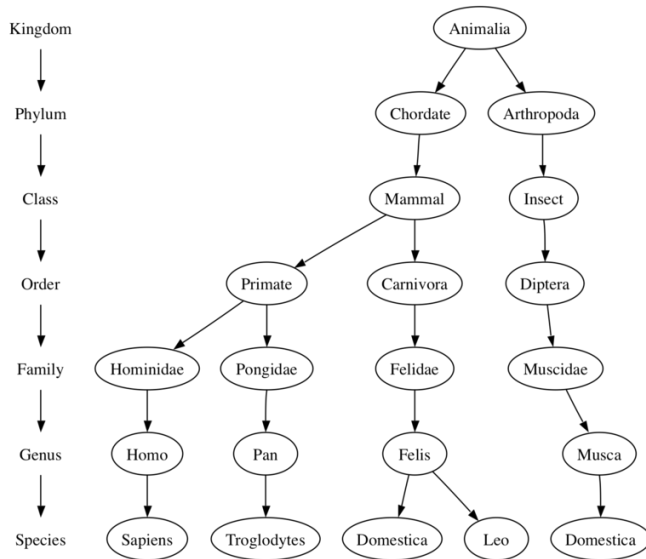
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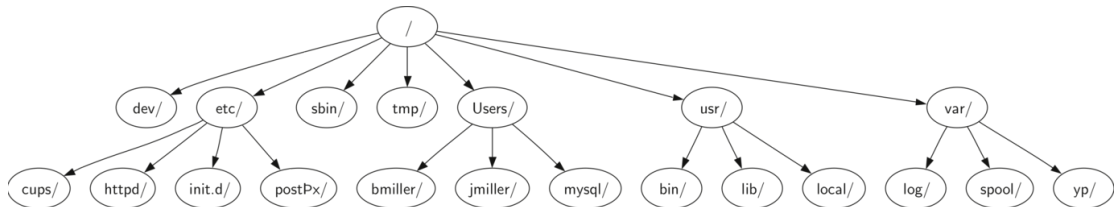
# Sommario

- 1 Introduzione
  - Esempi
  - Definizioni
- 2 Alberi binari
  - Introduzione
  - Implementazione
  - Visite
- 3 Alberi generici
  - Visite
  - Implementazione

# Esempio 1



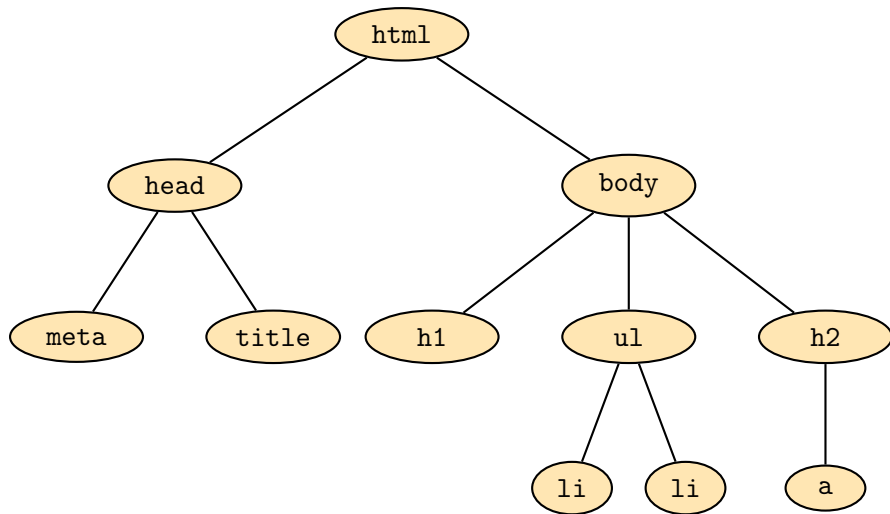
## Esempio 2



## Esempio 3

```
<html>
  <head>
    <meta http-equiv="Content-Type" content="text/html"/>
    <title>simple</title>
  </head>
  <body>
    <h1>A simple web page</h1>
    <ul>
      <li>List item one</li>
      <li>List item two</li>
    </ul>
    <h2>
      <a href="http://www.google.com">Google</a>
    </h2>
  </body>
</html>
```

## Esempio 3



# Albero radicato – Definizione 1

## Albero radicato (Rooted tree)

Un albero consiste di un insieme di nodi e un insieme di archi orientati che connettono coppie di nodi, con le seguenti proprietà:

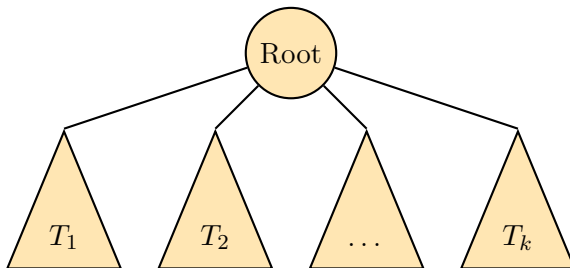
- Un nodo dell'albero è designato come nodo **radice**;
- Ogni nodo  $n$ , a parte la radice, ha esattamente un arco entrante;
- Esiste un cammino unico dalla radice ad ogni nodo;
- L'albero è connesso.

## Albero radicato – Definizione 2 (Ricorsiva)

### Albero radicato (Rooted tree)

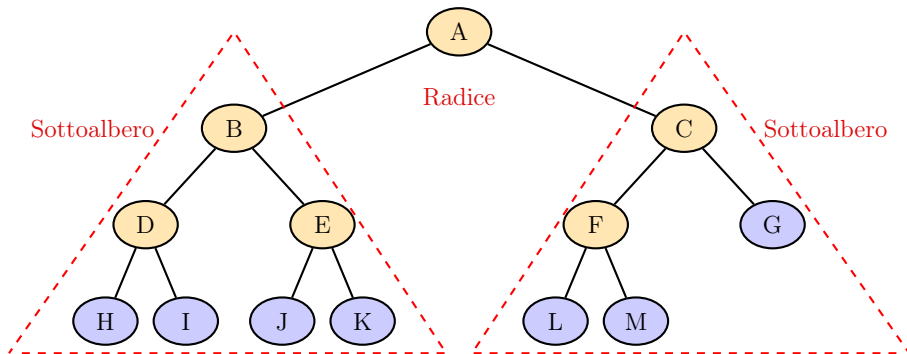
Un albero è dato da:

- un insieme vuoto, oppure
- un nodo **radice** e zero o più **sottoalberi**, ognuno dei quali è un albero; la radice è connessa alla radice di ogni sottoalbero con un arco orientato.



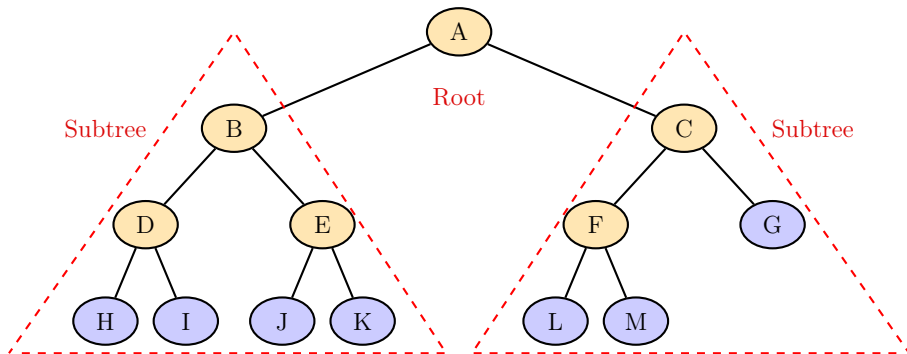


# Terminologia



- $A$  è la **radice**
- $B, C$  sono radici dei sottoalberi
- $D, E$  sono **fratelli**
- $D, E$  sono **figli** di  $B$
- $B$  è il **padre** di  $D, E$
- I nodi viola sono **foglie**
- Gli altri nodi sono **nodì interni**

# Terminology (English)



- A is the tree **root**
- B, C are roots of their subtrees
- D, E are **siblings**
- D, E are **children** of B
- B is the **parent** of D, E
- Purple nodes are **leaves**
- The other nodes are **internal nodes**

# Terminologia

## Profondità nodi (Depth)

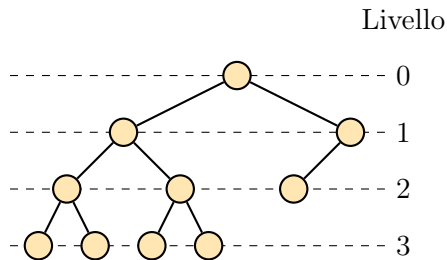
La lunghezza del cammino semplice dalla radice al nodo (misurato in numero di archi)

## Livello (Level)

L'insieme di nodi alla stessa profondità

## Altezza albero (Height)

La profondità massima della sue foglie



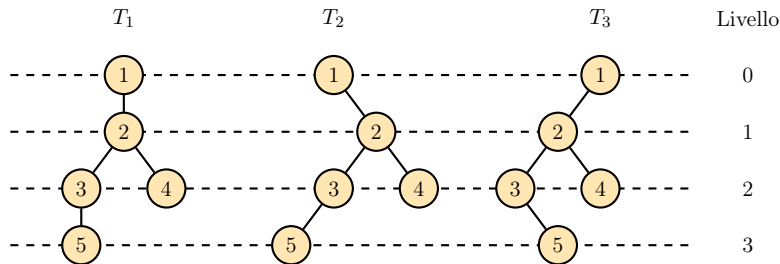
Altezza di questo albero = 3

# Albero binario

## Albero binario

Un **albero binario** è un albero radicato in cui ogni nodo ha al massimo due figli, identificati come figlio **sinistro** e figlio **destro**.

**Nota:** Due alberi  $T$  e  $U$  che hanno gli stessi nodi, gli stessi figli per ogni nodo e la stessa radice, sono distinti qualora un nodo  $u$  sia designato come figlio sinistro di  $v$  in  $T$  e come figlio destro di  $v$  in  $U$ .



## Specifica (Albero binario)

---

**TREE**

---

% Costruisce un nuovo nodo, contenente  $v$ , senza figli o genitori

**Tree**(ITEM  $v$ )

% Legge il valore memorizzato nel nodo

**ITEM** read()

% Modifica il valore memorizzato nel nodo

**write**(ITEM  $v$ )

% Restituisce il padre, oppure **nil** se questo nodo è radice

**TREE** parent()

---

## Specifica (Albero binario)

---

### TREE

---

% Restituisce il figlio sinistro (destro) di questo nodo; restituisce **nil** se assente

TREE left()

TREE right()

% Inserisce il sottoalbero radicato in  $t$  come figlio sinistro (destro) di questo nodo

insertLeft(TREE  $t$ )

insertRight(TREE  $t$ )

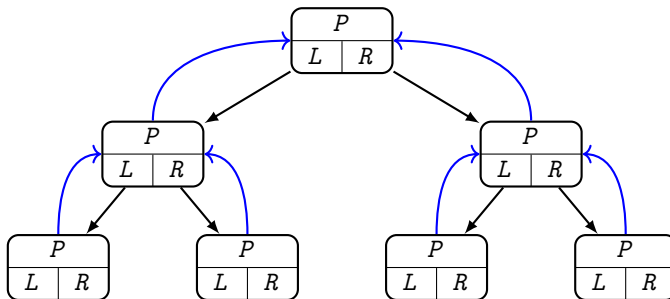
% Distrugge (ricorsivamente) il figlio sinistro (destro) di questo nodo

deleteLeft()

deleteRight()

---

# Memorizzare un albero binario



## Campi memorizzati nei nodi

- *parent*: reference al nodo padre
- *left*: reference al figlio sinistro
- *right*: reference al figlio destro

# Implementazione

## TREE

### Tree(ITEM *v*)

```

TREE t = new TREE
t.parent = nil
t.left = t.right = nil
t.value = v
return t

```

### insertLeft(TREE *T*)

```

if left == nil then
    T.parent = this
    left = T

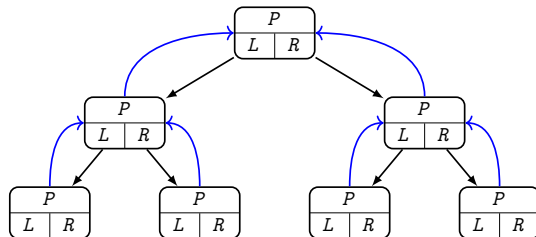
```

### insertRight(TREE *T*)

```

if right == nil then
    T.parent = this
    right = T

```





# Implementazione

---

## TREE

---

### deleteLeft()

```

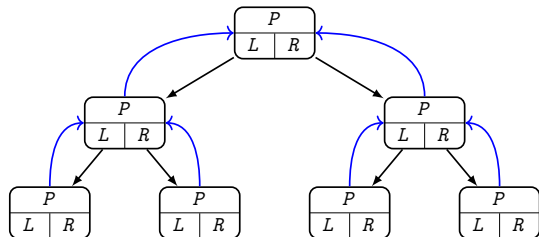
if left ≠ nil then
    left.deleteLeft()
    left.deleteRight()
    delete left
    left = nil
  
```

### deleteRight()

```

if right ≠ nil then
    right.deleteLeft()
    right.deleteRight()
    delete right
    right = nil
  
```

---



# Visite di alberi

## Visita di un albero / ricerca

Una strategia per analizzare (visitare) tutti i nodi di un albero.

### Visita in profondità Depth-First Search (DFS)

- Per visitare un albero, si visita ricorsivamente ognuno dei suoi **sottoalberi**
- Tre varianti: pre/in/post visita (**pre/in/post order**)
- Richiede uno **stack**

### Visita in ampiezza Breadth First Search (BFS)

- Ogni **livello** dell'albero viene visitato, uno dopo l'altro
- Si parte dalla radice
- Richiede una **queue**

# Depth-First Search

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t.\text{left}()$ )
```

```
    % in-order visit of  $t$ 
```

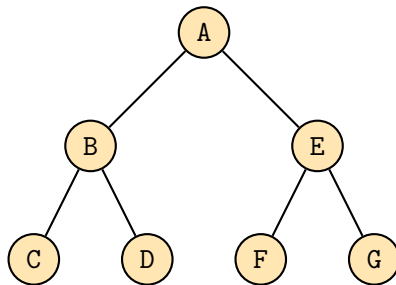
```
    print  $t$ 
```

```
    dfs( $t.\text{right}()$ )
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

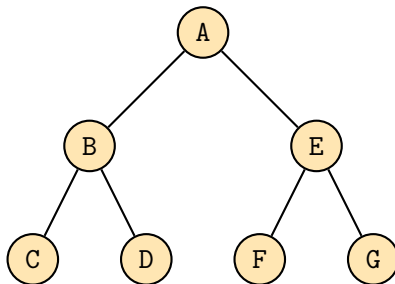
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A**

Stack: **A**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t.\text{left}()$ )
```

```
    % in-order visit of  $t$ 
```

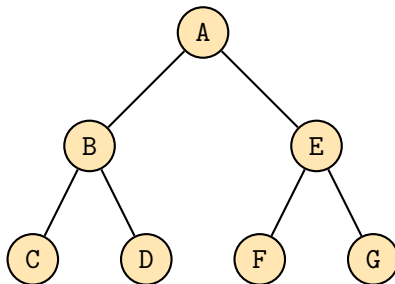
```
    print  $t$ 
```

```
    dfs( $t.\text{right}()$ )
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B**

Stack: **A B**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

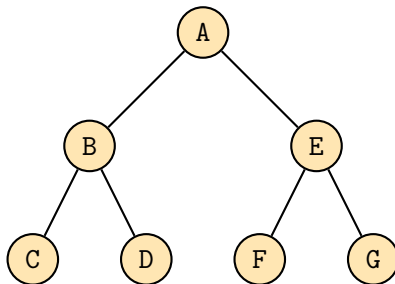
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C**

Stack: **A B C**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

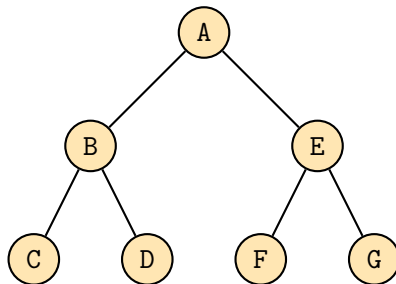
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C**

Stack: **A B**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t.\text{left}()$ )
```

```
    % in-order visit of  $t$ 
```

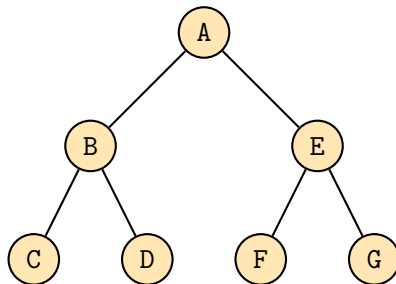
```
    print  $t$ 
```

```
    dfs( $t.\text{right}()$ )
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D**

Stack: **A B D**



# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t.\text{left}()$ )
```

```
    % in-order visit of  $t$ 
```

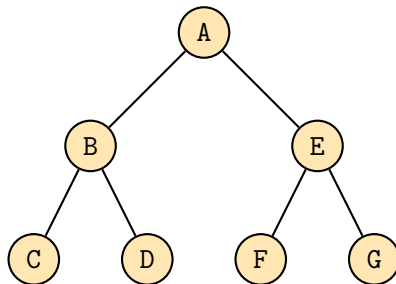
```
    print  $t$ 
```

```
    dfs( $t.\text{right}()$ )
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D**

Stack: **A B**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

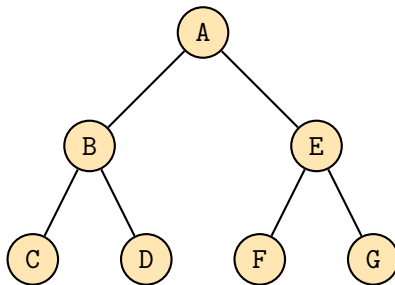
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D**

Stack: **A**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t.\text{left}()$ )
```

```
    % in-order visit of  $t$ 
```

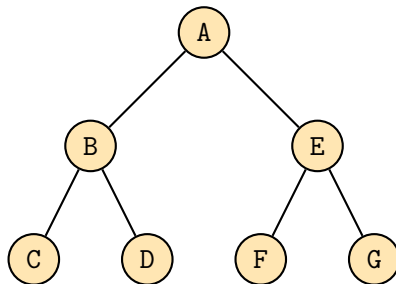
```
    print  $t$ 
```

```
    dfs( $t.\text{right}()$ )
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D E**

Stack: **A E**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

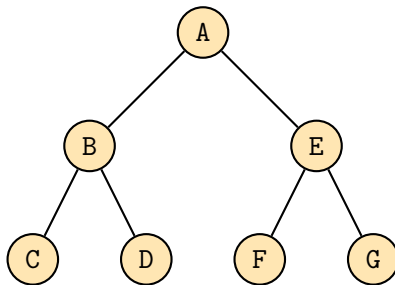
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D E F**

Stack: **A E F**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

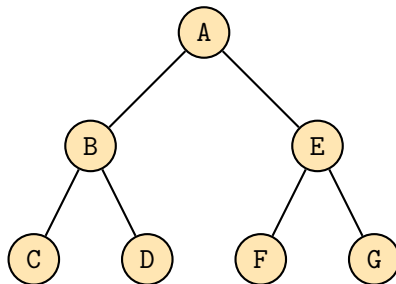
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D E F**

Stack: **A E**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

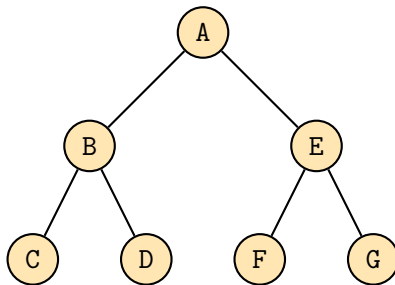
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D E F G**

Stack: **A E G**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

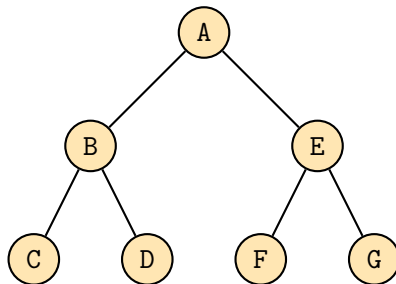
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D E F G**

Stack: **A E**

# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t.\text{left}()$ )
```

```
    % in-order visit of  $t$ 
```

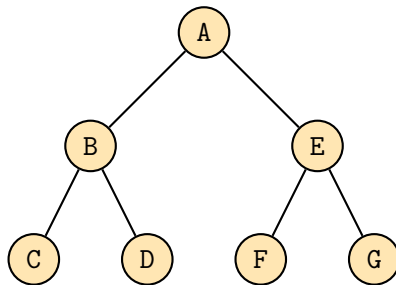
```
    print  $t$ 
```

```
    dfs( $t.\text{right}()$ )
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D E F G**

Stack: **A**



# Depth-First Search - Pre-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of  $t$ 
```

```
    print  $t$ 
```

```
    dfs( $t$ .left())
```

```
    % in-order visit of  $t$ 
```

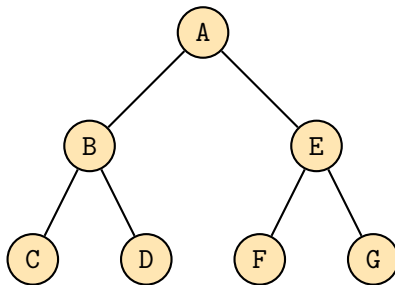
```
    print  $t$ 
```

```
    dfs( $t$ .right())
```

```
    % post-order visit of  $t$ 
```

```
    print  $t$ 
```

---



Sequence: **A B C D E F G**

Stack:

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

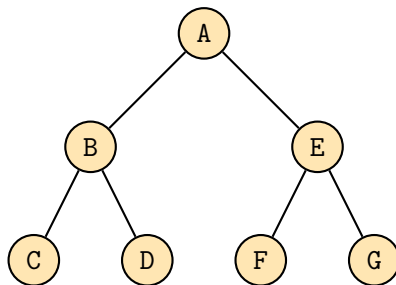
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence:

Stack: **A**

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

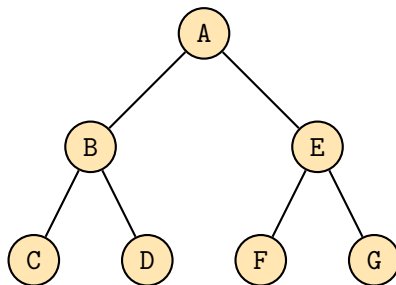
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence:

Stack: A B

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

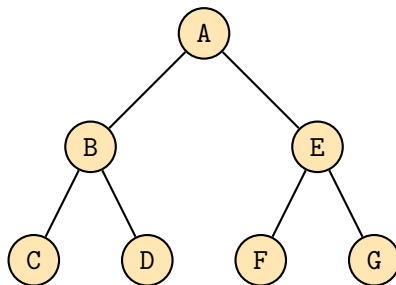
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: **C**

Stack: **A B C**

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

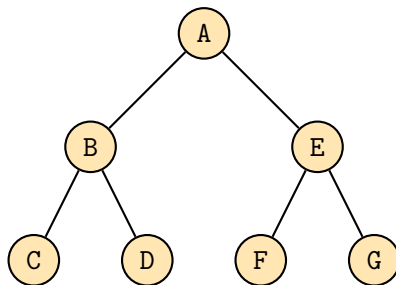
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B

Stack: A B

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

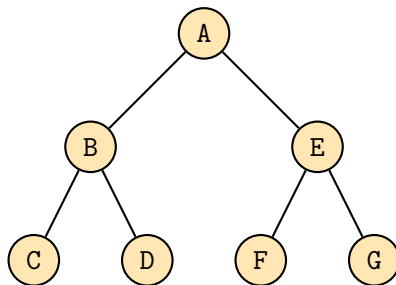
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D

Stack: A B D

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

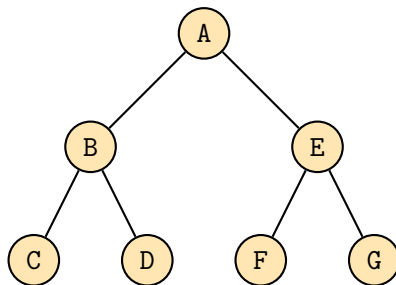
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D

Stack: A B

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

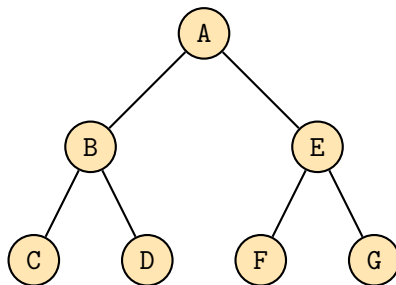
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A

Stack: A



# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

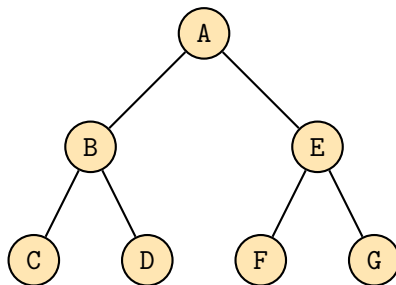
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A

Stack: A E

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

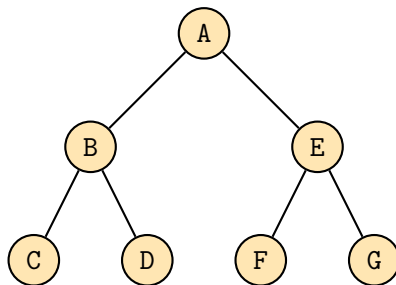
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A F

Stack: A E F

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

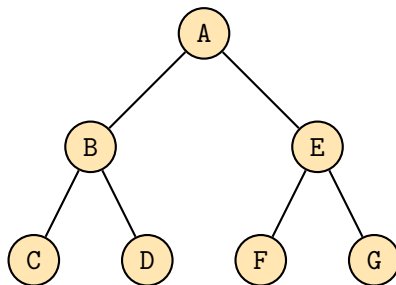
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A F E

Stack: A E

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

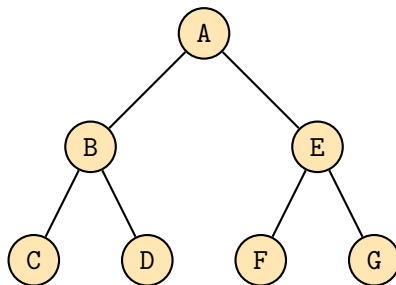
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A F E G

Stack: A E G

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

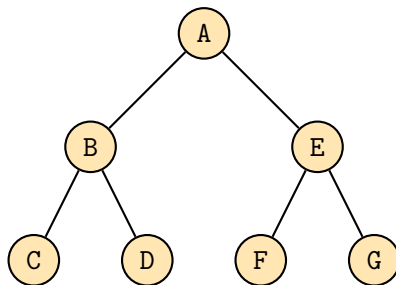
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A F E G

Stack: A E

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

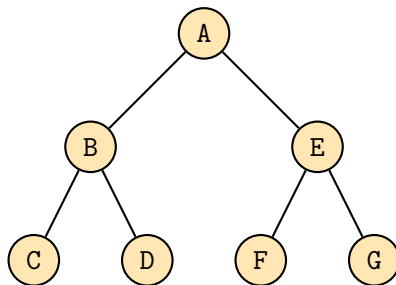
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A F E G

Stack: A

# Depth-First Search - In-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

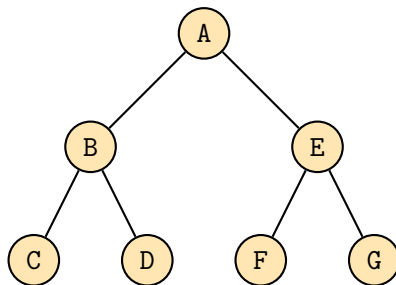
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C B D A F E G

Stack:

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

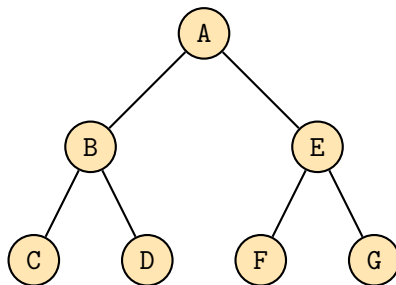
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence:

Stack: **A**



# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
  % pre-order visit of t
```

```
  print t
```

```
  dfs(t.left())
```

```
  % in-order visit of t
```

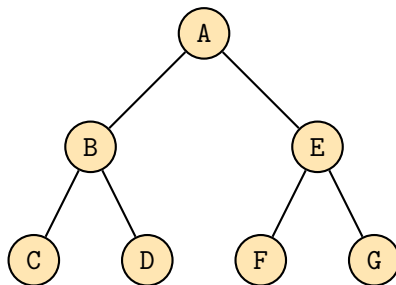
```
  print t
```

```
  dfs(t.right())
```

```
  % post-order visit of t
```

```
  print t
```

---



Sequence:

Stack: A B

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

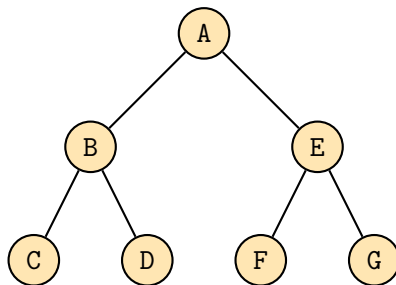
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: **C**

Stack: **A B C**

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
  % pre-order visit of t
```

```
  print t
```

```
  dfs(t.left())
```

```
  % in-order visit of t
```

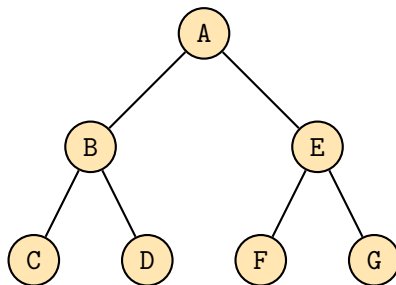
```
  print t
```

```
  dfs(t.right())
```

```
  % post-order visit of t
```

```
  print t
```

---



Sequence: **C**

Stack: **A B**

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

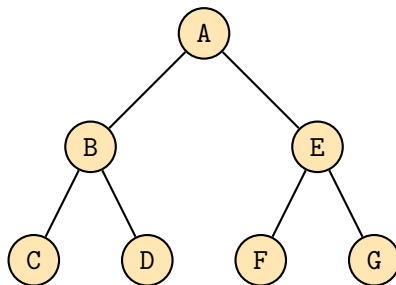
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D

Stack: A B D

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

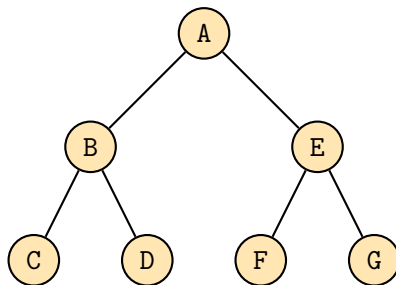
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D B

Stack: A B

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

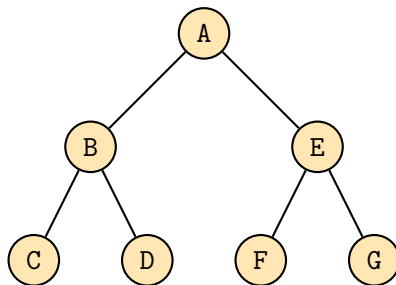
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D B

Stack: A

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
  % pre-order visit of t
```

```
  print t
```

```
  dfs(t.left())
```

```
  % in-order visit of t
```

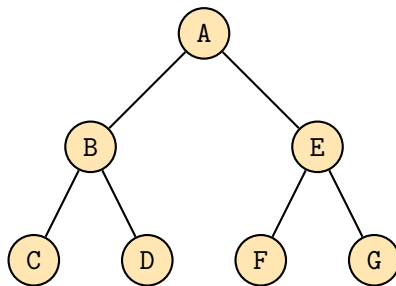
```
  print t
```

```
  dfs(t.right())
```

```
  % post-order visit of t
```

```
  print t
```

---



Sequence: C D B

Stack: A E

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

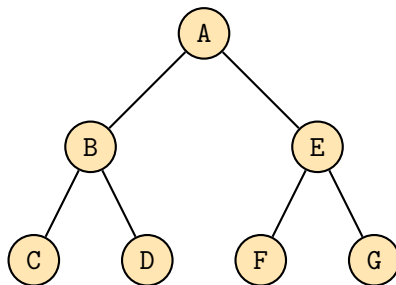
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D B F

Stack: A E F



# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

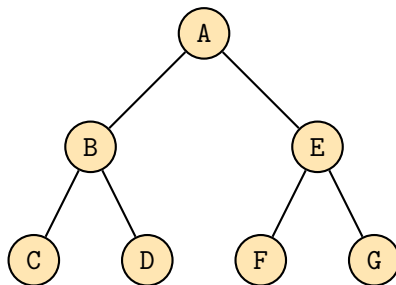
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D B F

Stack: A E

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

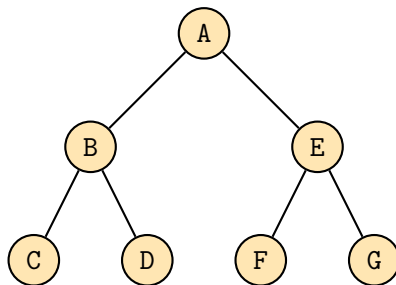
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D B F G

Stack: A E G

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

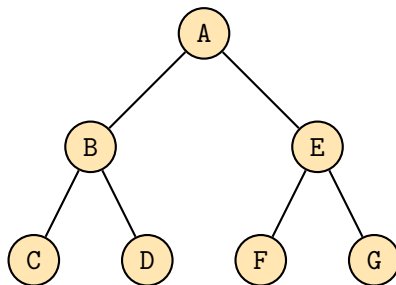
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D B F G E

Stack: A E

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of t
```

```
    print t
```

```
    dfs(t.left())
```

```
    % in-order visit of t
```

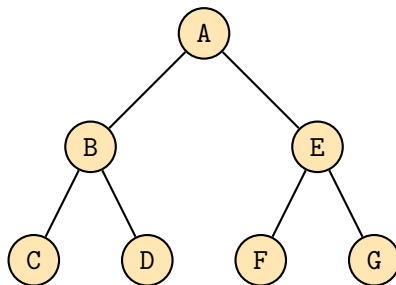
```
    print t
```

```
    dfs(t.right())
```

```
    % post-order visit of t
```

```
    print t
```

---



Sequence: C D B F G E A

Stack: A

# Depth-First Search - Post-Order

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
  % pre-order visit of t
```

```
  print t
```

```
  dfs(t.left())
```

```
  % in-order visit of t
```

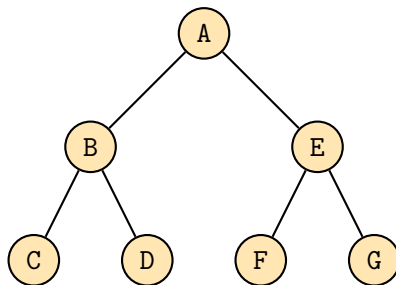
```
  print t
```

```
  dfs(t.right())
```

```
  % post-order visit of t
```

```
  print t
```

---



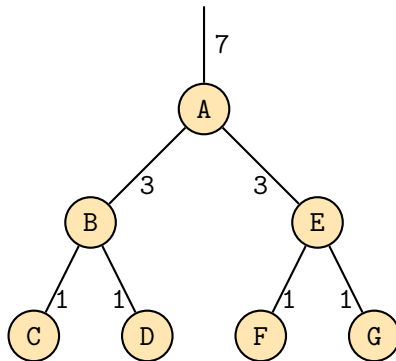
Sequence: C D B F G E A

Stack:

## Esempi di applicazione

### Contare nodi – Post-visita

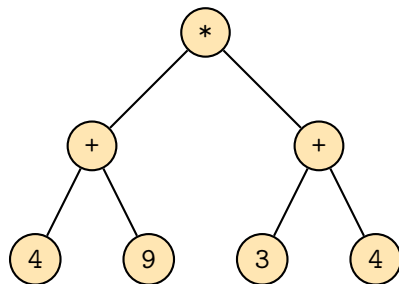
```
int count(TREE T)
if T == nil then
    return 0
else
     $C_\ell = \text{count}(T.\text{left}())$ 
     $C_r = \text{count}(T.\text{right}())$ 
    return  $C_\ell + C_r + 1$ 
```



## Esempi di applicazione

Stampare espressioni – In-visita

```
int printExp(TREE T)
if T.left() == nil and T.right() == nil
then
    print T.read()
else
    print "("
    printExp(T.left())
    print T.read()
    printExp(T.right())
    print ")"
```



$((4+9) * (3+4))$

## Costo computazionale

Il costo di una visita di un albero contenente  $n$  nodi è  $\Theta(n)$ , in quanto ogni nodo viene visitato al massimo una volta.



## Specifica (Albero generico)

---

### TREE

---

% Costruisce un nuovo nodo, contenente  $v$ , senza figli o genitori

**Tree**(ITEM  $v$ )

% Legge il valore memorizzato nel nodo

**ITEM** read()

% Modifica il valore memorizzato nel nodo

**write**(ITEM  $v$ )

% Restituisce il padre, oppure **nil** se questo nodo è radice

**TREE** parent()

---

## Specifica (Albero generico)

---

### TREE

---

% Restituisce il primo figlio, oppure **nil** se questo nodo è una foglia

TREE leftmostChild()

% Restituisce il prossimo fratello, oppure **nil** se assente

TREE rightSibling()

% Inserisce il sottoalbero  $t$  come primo nodo di questo nodo

insertChild(TREE  $t$ )

% Inserisce il sottoalbero  $t$  come prossimo fratello di questo nodo

insertSibling(TREE  $t$ )

% Distruggi l'albero radicato identificato dal primo figlio

deleteChild()

% Distruggi l'albero radicato identificato dal prossimo fratello

deleteSibling()

---

## Esempio: Class Node (Java 8)

```
package org.w3c.dom;

public interface Node {

    /** The parent of this node. */
    public Node    getParentNode();

    /** The first child of this node. */
    public Node    getFirstChild()

    /** The node immediately following this node. */
    public Node    getNextSibling()

    /** Inserts the node newChild before the existing child node refChild. */
    public Node    insertBefore(Node newChild, Node refChild)

    /** Adds the node newChild to the end of the list of children of this node. */
    public Node    appendChild(Node newChild)

    /** Removes the child node indicated by oldChild from the list of children. */
    public Node    removeChild(Node oldChild)

    [...]
}
```

# Depth-First Search

---

```
dfs(TREE t)
```

---

```
if  $t \neq \text{nil}$  then
```

```
    % pre-order visit of node  $t$ 
```

```
    print  $t$ 
```

```
    TREE  $u = t.\text{leftmostChild}()$ 
```

```
    while  $u \neq \text{nil}$  do
```

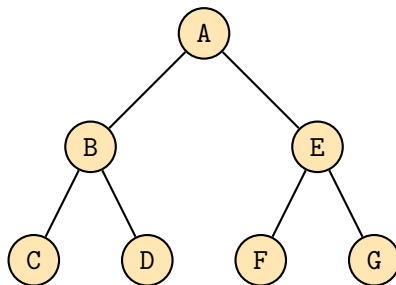
```
        | dfs( $u$ )
```

```
        |  $u = u.\text{rightSibling}()$ 
```

```
    % post-order visit of node  $t$ 
```

```
    print  $t$ 
```

---



# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
QUEUE Q = Queue()
```

```
Q.enqueue(t)
```

```
while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

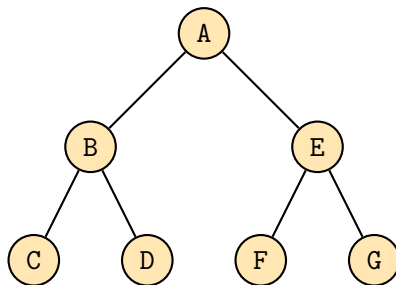
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
        Q.enqueue(u)
```

```
        u = u.rightSibling()
```

---



Sequence:

Queue: **A**

# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
  QUEUE Q = Queue()
```

```
  Q.enqueue(t)
```

```
  while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

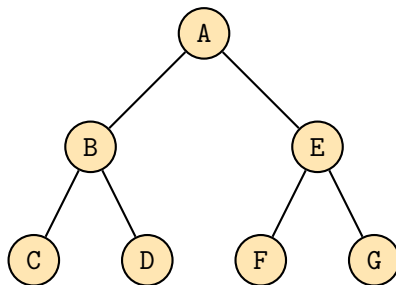
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
      Q.enqueue(u)
```

```
      u = u.rightSibling()
```

---



Sequence: **A**

Queue: **B E**

# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
QUEUE Q = Queue()
```

```
Q.enqueue(t)
```

```
while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

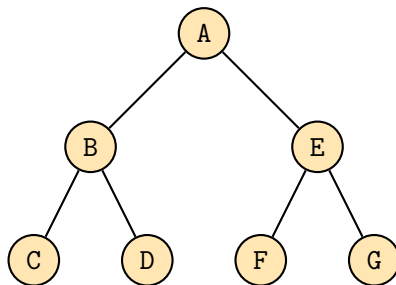
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
        Q.enqueue(u)
```

```
        u = u.rightSibling()
```

---



Sequence: A B

Queue: E C D

# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
QUEUE Q = Queue()
```

```
Q.enqueue(t)
```

```
while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

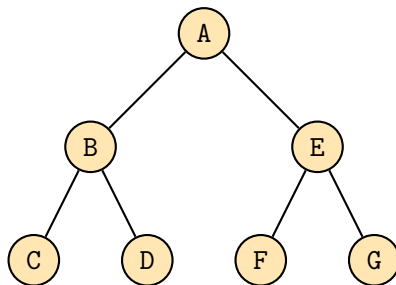
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
        Q.enqueue(u)
```

```
        u = u.rightSibling()
```

---



Sequence: A B E

Queue: C D F G



# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
QUEUE Q = Queue()
```

```
Q.enqueue(t)
```

```
while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

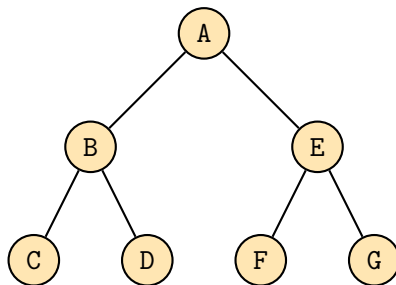
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
        Q.enqueue(u)
```

```
        u = u.rightSibling()
```

---



Sequence: A B E C

Queue: D F G

# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
QUEUE Q = Queue()
```

```
Q.enqueue(t)
```

```
while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

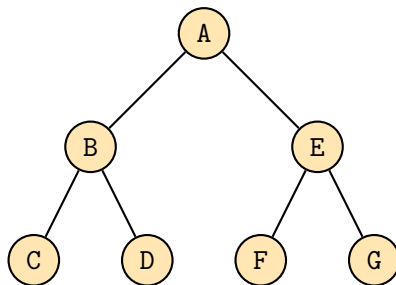
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
        Q.enqueue(u)
```

```
        u = u.rightSibling()
```

---



Sequence: A B E C D

Queue: F G

# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
QUEUE Q = Queue()
```

```
Q.enqueue(t)
```

```
while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

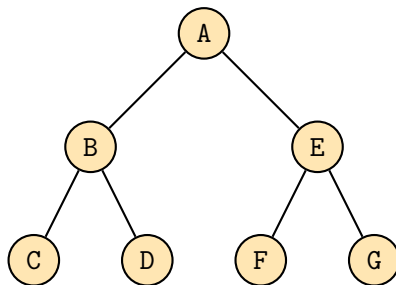
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
        Q.enqueue(u)
```

```
        u = u.rightSibling()
```

---



Sequence: A B E C D F

Queue: G

# Breadth-First Search

---

```
bfs(TREE t)
```

---

```
QUEUE Q = Queue()
```

```
Q.enqueue(t)
```

```
while not Q.isEmpty() do
```

```
    TREE u = Q.dequeue()
```

```
    % visita per livelli nodo u
```

```
    print u
```

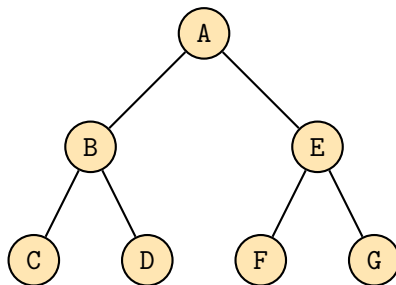
```
    u = u.leftmostChild()
```

```
    while u ≠ nil do
```

```
        Q.enqueue(u)
```

```
        u = u.rightSibling()
```

---



Sequence: A B E C D F G

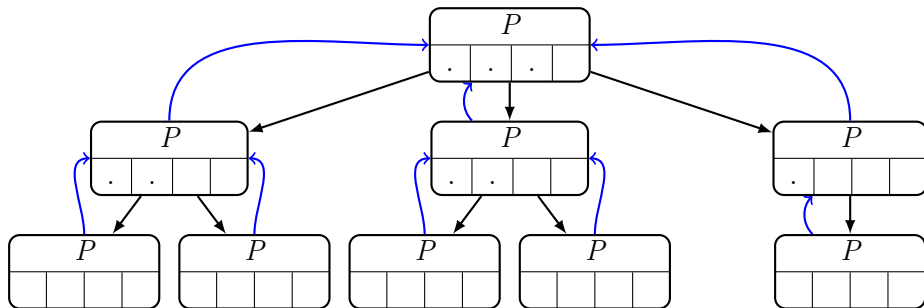
Queue:

# Memorizzazione

Esistono diversi modi per memorizzare un albero, più o meno indicati a seconda del numero massimo e medio di figli presenti.

- Realizzazione con vettore dei figli
- Realizzazione primo figlio, prossimo fratello
- Realizzazione con vettore dei padri

## Realizzazione con vettore dei figli

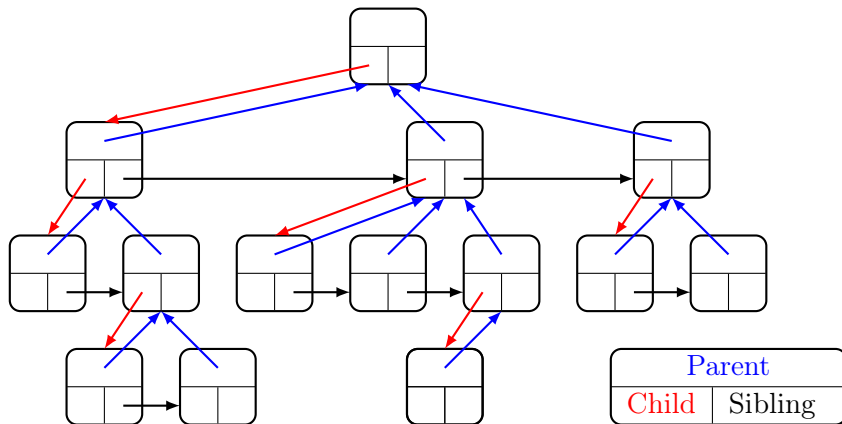


### Campi memorizzati nei nodi

- *parent*: reference al nodo padre
- **Vettore dei figli**: a seconda del numero di figli, può comportare una discreta quantità di spazio sprecato

# Realizzazione basata su Primo figlio, prossimo fratello

Implementato come una lista di fratelli



# Implementazione

---

## TREE

---

```

TREE parent                                % Reference al padre
TREE child                                % Reference al primo figlio
TREE sibling                              % Reference al prossimo fratello
ITEM value                                % Valore memorizzato nel nodo

Tree(ITEM v)                                % Crea un nuovo nodo
┌   TREE t = new TREE
  t.value = v
  t.parent = t.child = t.sibling = nil
└   return t

insertChild(TREE t)
┌   t.parent = self
  t.sibling = child
└   child = t                                % Inserisce t prima dell'attuale primo figlio

insertSibling(TREE t)
┌   t.parent = parent
  t.sibling = sibling
└   sibling = t                                % Inserisce t prima dell'attuale prossimo fratello

```



# Implementazione

---

## TREE

---

deleteChild()

```
    TREE newChild = child.rightSibling()
    delete(child)
    child = newChild
```

deleteSibling()

```
    TREE newBrother = sibling.rightSibling()
    delete(sibling)
    sibling = newBrother
```

delete(TREE t)

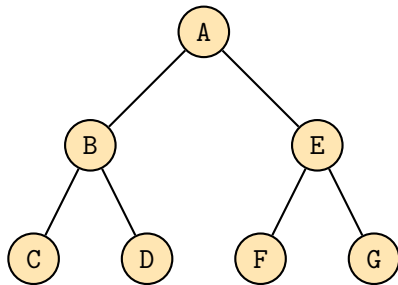
```
    TREE u = t.leftmostChild()
    while u ≠ nil do
        TREE next = u.rightSibling()
        delete(u)
        u = next
    delete t
```

---

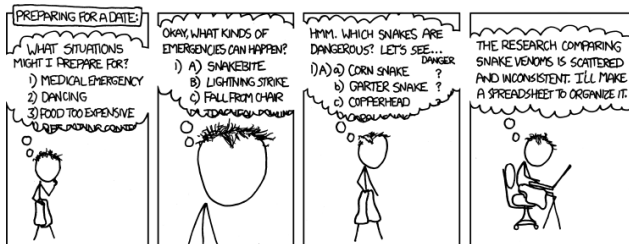
## Realizzazione con vettore dei padri

L'albero è rappresentato da un vettore i cui elementi contengono il valore associato al nodo e l'indice della posizione del padre nel vettore.

1	A	0
2	B	1
3	E	1
4	C	2
5	D	2
6	F	3
7	G	3



# DFS (<https://xkcd.com/>)



I REALLY NEED TO STOP USING DEPTH-FIRST SEARCHES.