

Algorithms 2016: Data Structures

A Supplement (Based on [Manber 1989])

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1 Heaps

Heaps

- A (max) heap is a **binary tree** whose keys satisfy the heap property:
the key of every node is greater than or equal to the key of any of its children.
- It supports the two basic operations of a **priority queue**:
 - *Insert(x)*: insert the key x into the heap.
 - *Remove()*: remove and return the largest key from the heap.

Heaps (cont.)

- A binary tree can be represented implicitly by an array A as follows:
 1. The root is stored in $A[1]$.
 2. The **left child** of $A[i]$ is stored in $A[2i]$ and the **right child** is stored in $A[2i + 1]$.

Heaps (cont.)

Algorithm Remove_Max_from_Heap (A, n);

begin

if $n = 0$ **then** print “the heap is empty”

else $Top_of_the_Heap := A[1]$;

$A[1] := A[n]$; $n := n - 1$;

$parent := 1$; $child := 2$;

while $child \leq n - 1$ **do**

if $A[child] < A[child + 1]$ **then**

$child := child + 1$;

if $A[child] > A[parent]$ **then**

$swap(A[parent], A[child])$;

$parent := child$;

$child := 2 * child$

else $child := n$

end

Heaps (cont.)

```
Algorithm Insert_to_Heap (A, n, x);
begin
  n := n + 1;
  A[n] := x;
  child := n;
  parent := n div 2;
  while parent ≥ 1 do
    if A[parent] < A[child] then
      swap(A[parent], A[child]);
      child := parent;
      parent := parent div 2;
    else parent := 0;
  end
end
```

2 AVL Trees

AVL Trees

Definition 1. An AVL tree is a binary search tree such that, for every node, the difference between the heights of its left and right subtrees is at most 1 (the height of an empty tree is defined as 0).

This definition guarantees a maximal height of $O(\log n)$ for any AVL tree of n nodes.

AVL Trees (cont.)

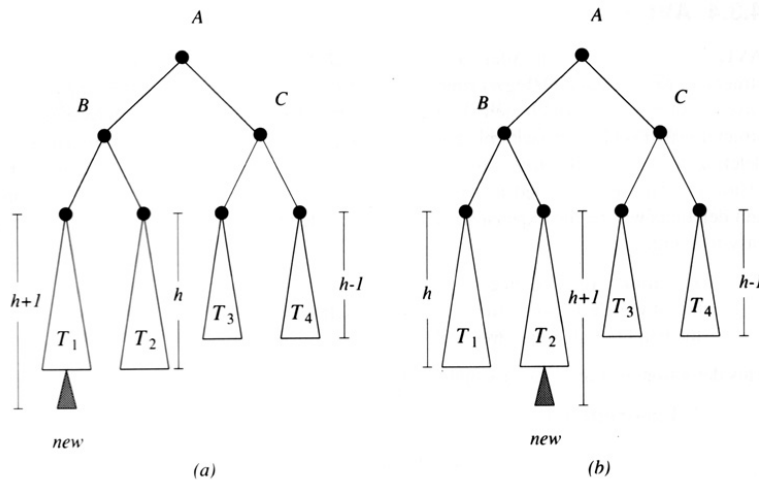


Figure 4.13 Insertions that invalidate the AVL property.

Source: [Manber 1989].

AVL Trees (cont.)

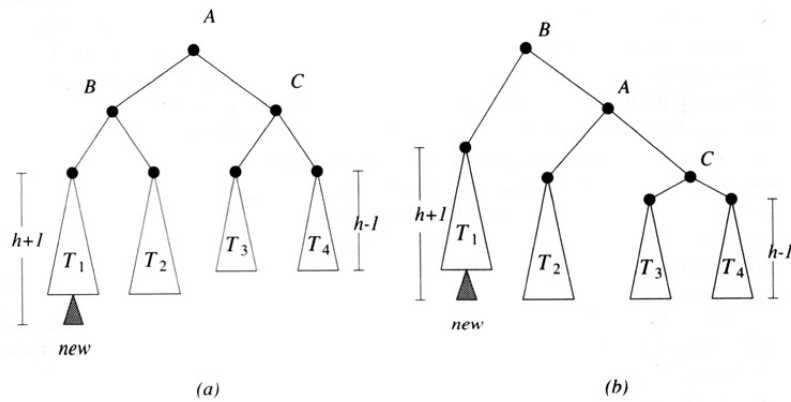


Figure 4.14 A single rotation: (a) Before. (b) After.

Source: [Manber 1989].

AVL Trees (cont.)

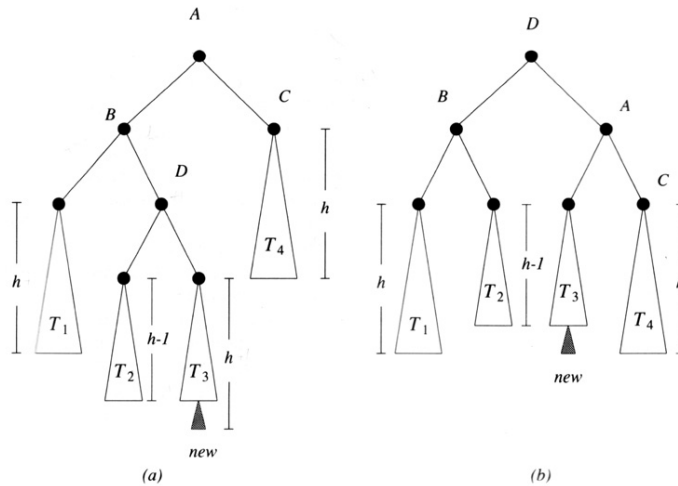


Figure 4.15 A double rotation: (a) Before. (b) After.

Source: [Manber 1989].

3 Union-Find

Union-Find

- There are n elements x_1, x_2, \dots, x_n divided into groups. Initially, each element is in a group by itself.
- Two operations on the elements and groups:
 - $find(A)$: returns the name of A 's group.

- $union(A, B)$: combines A 's and B 's groups to form a new group with a unique name.
- To tell if two elements are in the same group, one may issue a find operation for each element and see if the returned names are the same.

Union-Find (cont.)

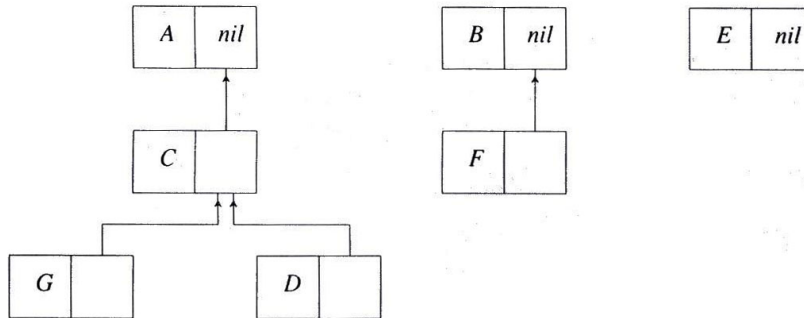


Figure 4.16 The representation for the union-find problem.

Source: [Manber 1989].

Balancing

- The root also stores the number of elements in (i.e., the size of) its group.
- To *balance* the tree resulted from a union operation, *let the smaller group join the larger group* and update the size of the larger group accordingly.

Theorem 2 (Theorem 4.2). *If balancing is used, then any tree of height h must contain at least 2^h elements.*

- Any sequence of m find or union operations (where $m \geq n$) takes $O(m \log n)$ steps.

Union-Find (cont.)

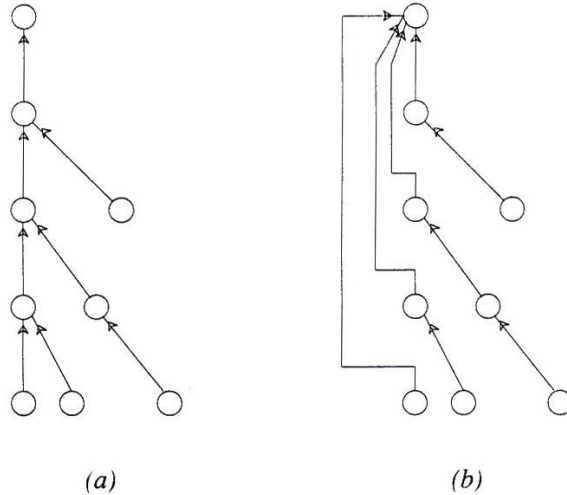


Figure 4.17 Path compression: (a) Before. (b) After.

Source: [Manber 1989].

Effect of Path Compression

Theorem 3 (Theorem 4.3). *If both balancing and path compression are used, any sequence of m find or union operations (where $m \geq n$) takes $O(m \log^* n)$ steps.*

The value of $\log^* n$ intuitively equals the number of times that one has to apply \log to n to bring its value down to 1.

Code for Union-Find

```

Algorithm Union_Find_Init(A,n);
begin
  for i := 1 to n do
    A[i].parent := nil;
    A[i].size := 1
  end
end

Algorithm Find(a);
begin
  if A[a].parent <> nil then
    A[a].parent := Find(A[a].parent);
    Find := A[a].parent;
  else
    Find := a
  end
end

```

Code for Union-Find (cont.)

```

Algorithm Union(a,b);
begin
  x := Find(a);

```

```
y := Find(b);  
if x <> y then  
  if A[x].size > A[y].size then  
    A[y].parent := x;  
    A[x].size := A[x].size + A[y].size;  
  else  
    A[x].parent := y;  
    A[y].size := A[y].size + A[x].size  
end
```