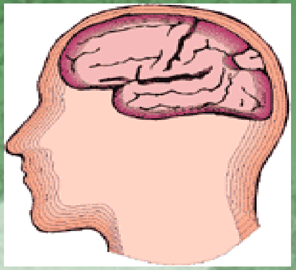
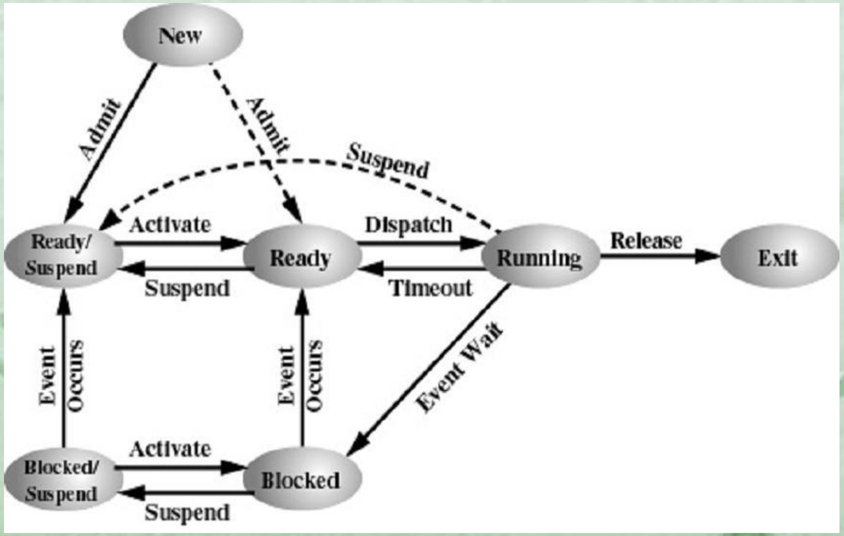


Assignment 2 and Discrete Event Simulation



Problem Specification

- For this assignment, you are to write a Discrete Event Simulation to analyze different CPU scheduling algorithms.
- A number of simultaneous processes (threads) will be simulated, each alternating between bursts of CPU usage and I/O waiting. The process data will be read in from a data file.

Discrete Event Simulation

- Set up a loop, jump forward in time with each iteration to whenever the next meaningful event occurs. Some time steps may be small (even 0 if two or more things happen at the same time) and some may be large.
- Some events may trigger other events, which are then put on the schedule to be processed when their time comes.
- This approach is called Discrete Event Simulation (DES).
- An important data structure in DES is Priority Queue which holds events to be scheduled.

Priority Queue ADT

- A priority queue stores a collection of items
- An item is a pair (key, element)
- Main methods of the Priority Queue ADT
  - insertItem(k, e)
    inserts an item with key k and element e
  - e = removeMin()
    removes the item with smallest key and returns its element e
- Additional methods
  - minKey()
    returns, but does not remove, the smallest key of an item
  - minElement()
    returns, but does not remove, the element of an item with smallest key
  - size(), isEmpty()
- Applications:
  - Standby flyers
  - Auctions
  - Discrete Event Simulation

Example: Priority Queue

Operator	Output	Priority Queue
insertItem(5, A)	_	(5,A)
insertItem(9, C)	_	(5,A),(9,C)
insertItem(3, B)	_	(3,B),(5,A),(9,C)
insertItem(7, D)	_	(3,B),(5,A),(7,D),(9,C)
minElement()	B	(3,B),(5,A),(7,D),(9,C)
minKey()	3	(3,B),(5,A),(7,D),(9,C)
removeMin()	B	(5,A),(7,D),(9,C)
size()	3	(5,A),(7,D),(9,C)
removeMin()	A	(7,D),(9,C)
removeMin()	D	(9,C)
removeMin()	C	
removeMin()	error	
isEmpty()	true	

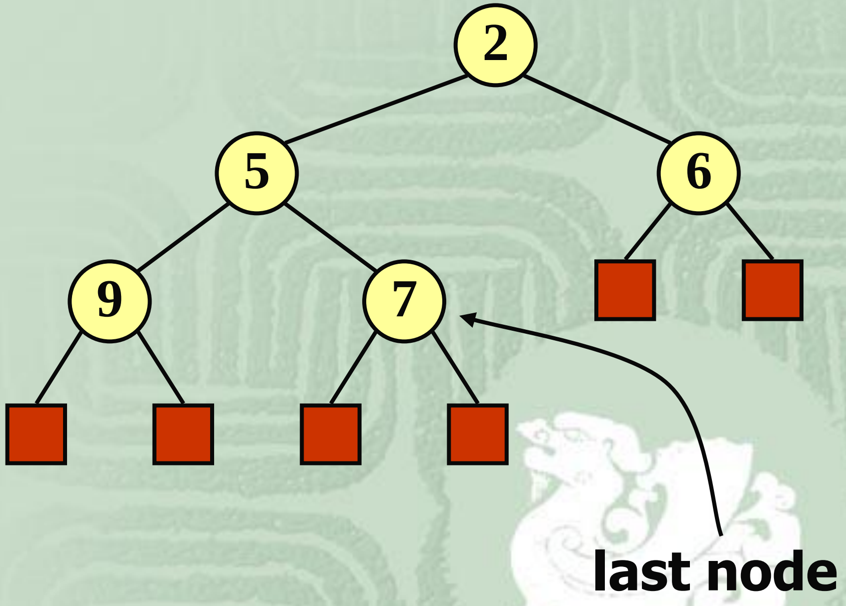
Total Order Relation

- Keys in a Priority Queue can be arbitrary objects on which an order is defined. For example, simulation time.
- Two distinct items in a priority queue can have the same key. For example, two processes arrive at the same time.
- For a pair events: (t1, p1) and (t2, p2), we define a “happen before” relation $\Rightarrow$ such that:
  - (t1, p1) $\Rightarrow$ (t2, p2) if t1 < t2
  - Or (t1, p1) $\Rightarrow$ (t2, p2) if t1== t2 and p1 < p2 (where pids are unique)

Using heap to implement PQ

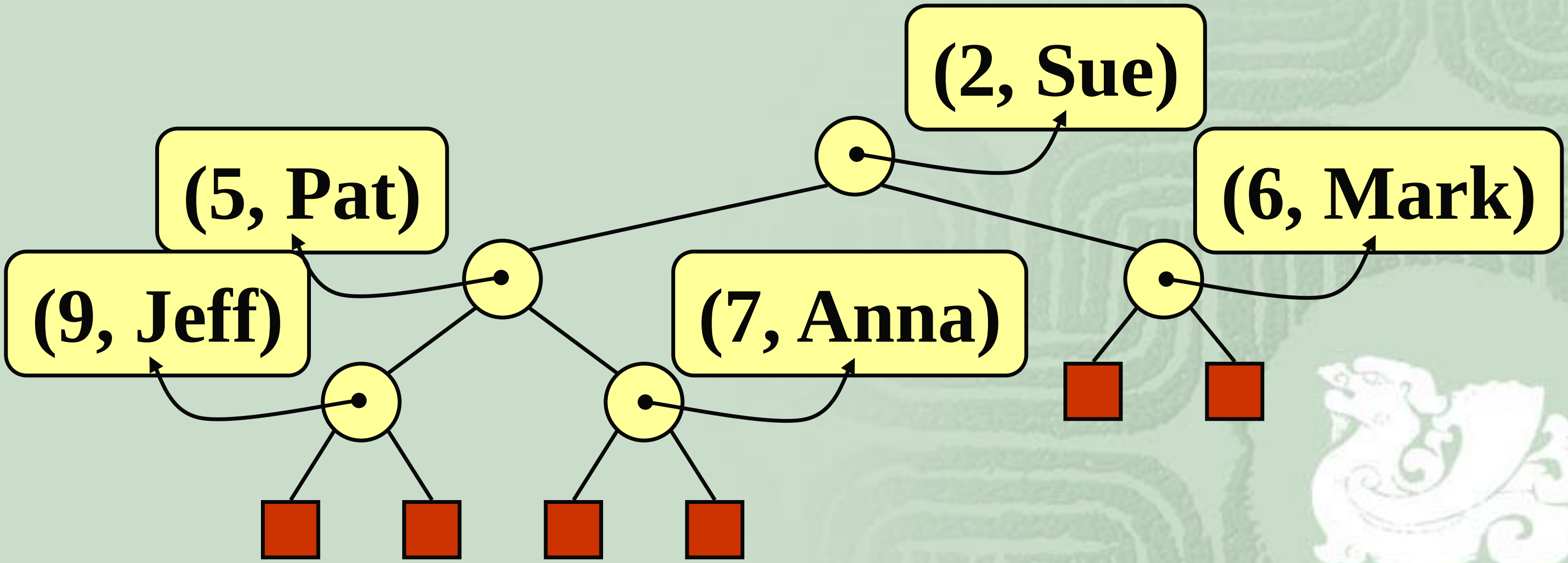
- A heap is a binary tree storing keys at its internal nodes and satisfying the following properties:
  - Heap-Order: for every internal node v other than the root,
    $key(v) \geq key(parent(v))$
  - Complete Binary Tree: let h be the height of the heap
    - for $i = 0, \ldots, h - 1$, there are 2^i nodes of depth i
    - at depth $h - 1$, the internal nodes are to the left of the external nodes

- The last node of a heap is the rightmost internal node of depth $h - 1$



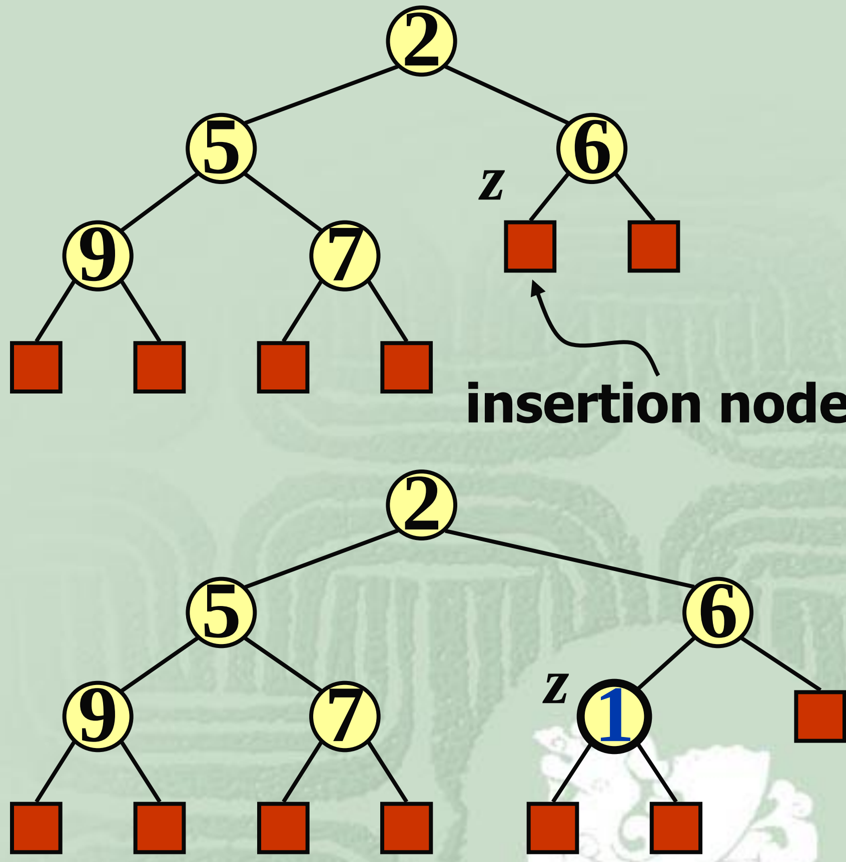
Heaps and Priority Queues

- We can use a heap to implement a priority queue
- We store a (key, element) item at each internal node
- We keep track of the position of the last node
- For simplicity, we show only the keys in the pictures



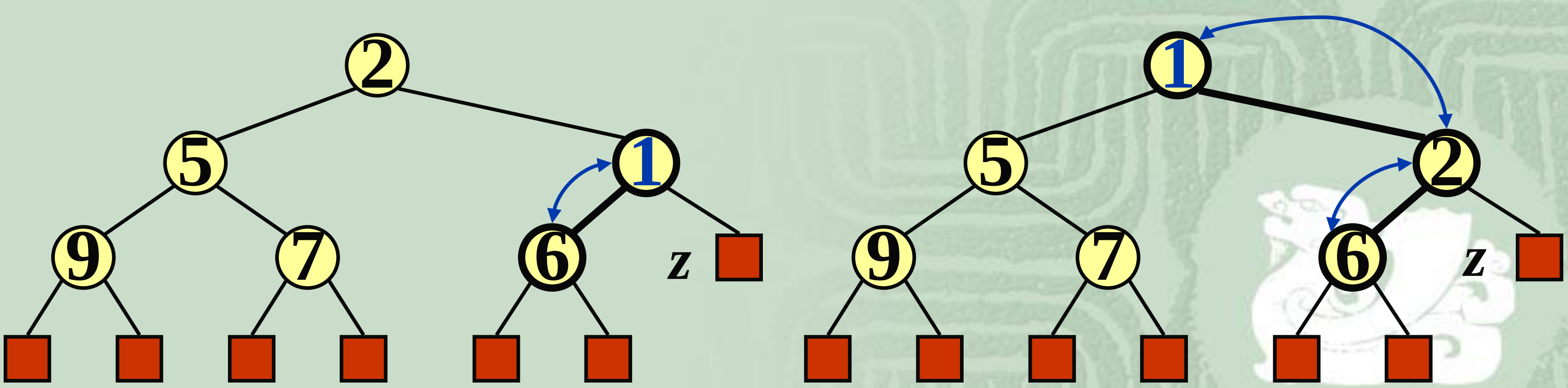
Insertion into a Heap

- The insertion algorithm consists of three steps
  - Find the insertion position z (the new last node)
  - Store k at z and expand z into an internal node
  - Restore the heap-order property (discussed next)



Upheap

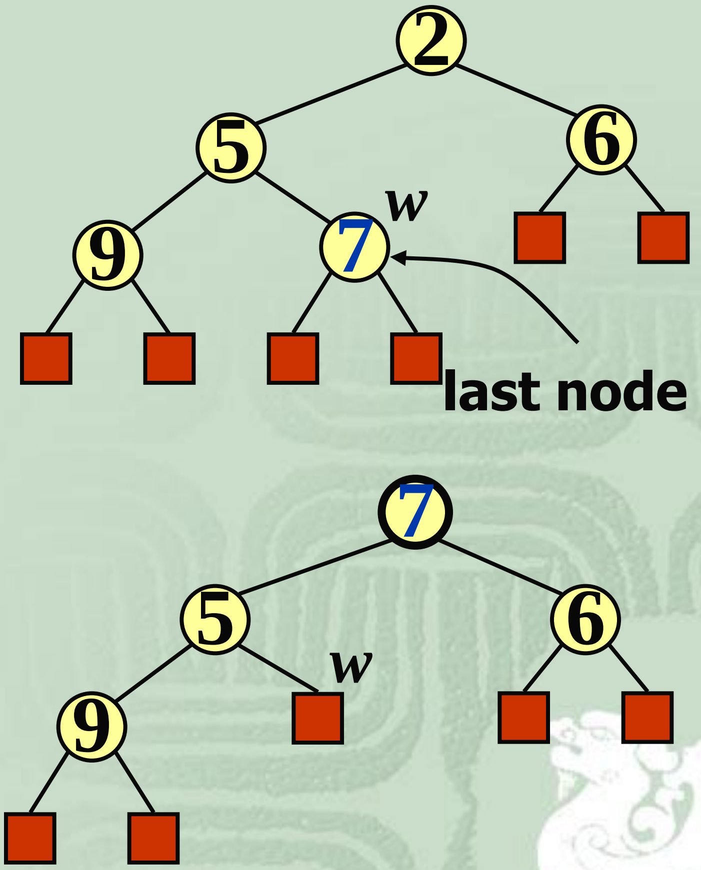
- After the insertion of a new key k, the heap-order property may be violated
- Algorithm upheap restores the heap-order property by swapping k along an upward path from the insertion node
- Upheap terminates when the key k reaches the root or a node whose parent has a key smaller than or equal to k
- Since a heap has height $O(\log n)$, upheap runs in $O(\log n)$ time



Removal from a Heap

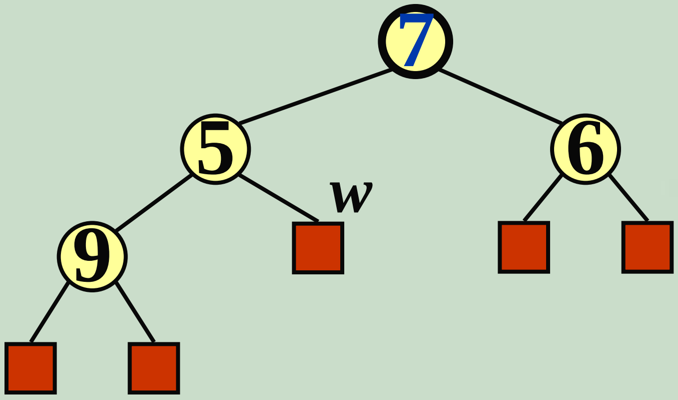
The removal algorithm consists of three steps

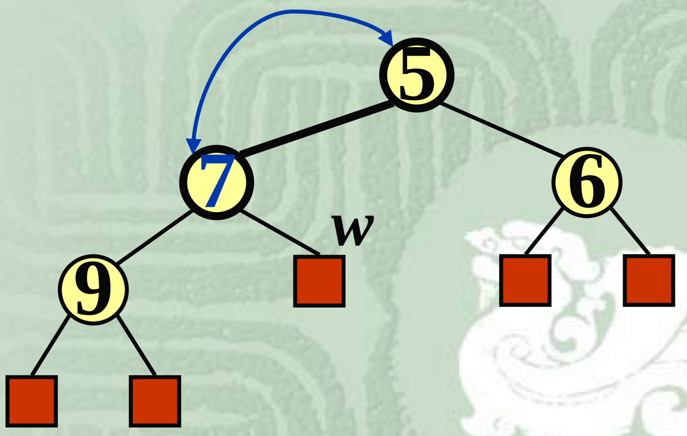
- Replace the root key with the key of the last node ***w***
- Delete ***w***
- Restore the heap-order property (discussed next)



Downheap

- After replacing the root key with the key k of the last node, the heap-order property may be violated
- Algorithm downheap restores the heap-order property by swapping key k along a downward path from the root
- Downheap terminates when key k reaches a leaf or a node whose children have keys greater than or equal to k
- Since a heap has height $O(\log n)$, downheap runs in $O(\log n)$ time





The general pseudo code for a DES is as follows:

```
Initialize PQ.
while( PQ not empty ) {
        extract an Event from the PQ.
        update time to match the Event.
        switch( type of Event ) {
                Process this event, possibly adding
                new Events to the PQ.
        } // switch
} // while
Process statistics collected during Event processing & report.
```

Input file format

number_of_processes thread_switch process_switch

process_number(1)   number_of_threads(1)

thread_number(1) arrival_time(1) number_of_CPU(1)
1   cpu_time io_time
2   cpu_time io_time
.
.
number_of_CPU(1)   cpu_time

…

Example

```
2 3 7        // number_of_processes  thread_switch  process_switch

1 4          // process_number(1)   number_of_threads(1)
1 0 6        // thread_number(1) arrival_time(1)  number_of_CPU(1)
1 15 400     // 1   cpu_time  io_time
2 18 200     // 2   cpu_time  io_time
3 15 100     // 3   cpu_time  io_time
4 15 400     // 4   cpu_time  io_time
5 25 100     // 5   cpu_time  io_time
6 240        // 6   cpu_time

2 12 4       // thread_number(2) arrival_time(2)  number_of_CPU(2)

…
```