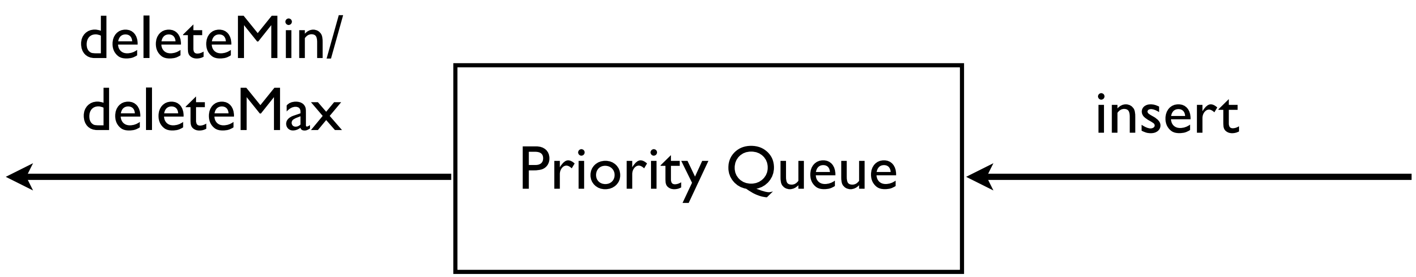
Data Structure:
Heap

priority queue (heap)

- the element to be deleted is the one with the highest (or lowest) priority
- priority queue Q supports
  - insert (x, Q)
  - y = pop(Q) (=deleteMin(Q) or deleteMax(Q))

- priority queue is used for scheduling



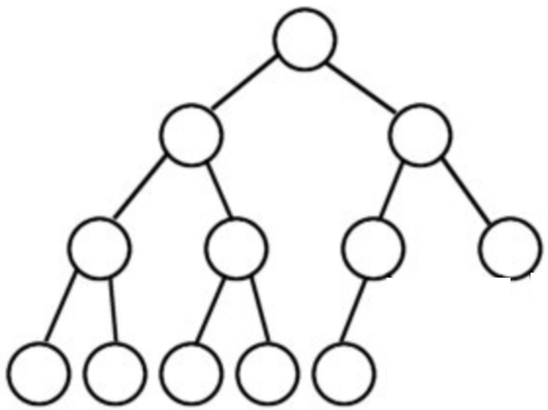
unordered linear list

heap

binary (min) heap

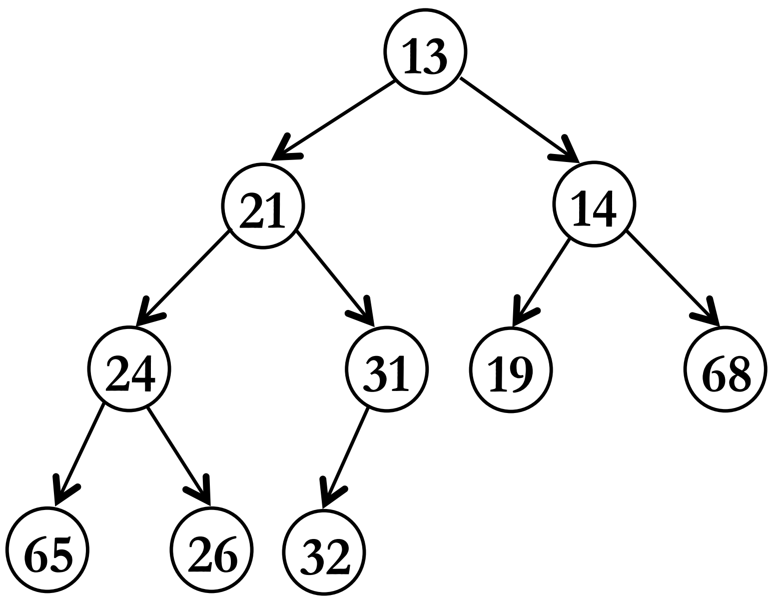
- a min heap is a complete binary tree and partially ordered tree in which the key value in each node is no larger than the key values in its children

- complete tree
  - every level of tree is completely filled, with the exception of the bottom level, which is filled from left to right

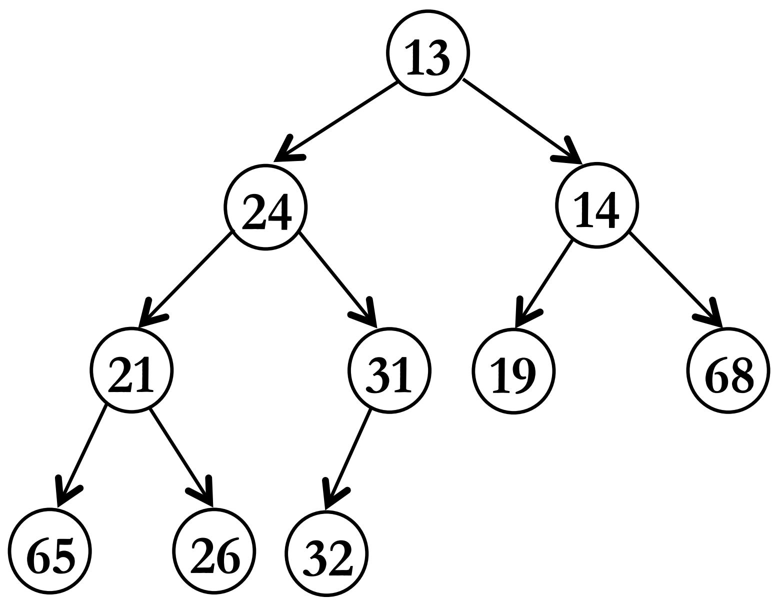


binary (min) heap

- partially ordered tree
  - the key of each internal node is less than or equal to the keys of its children
  - the smallest element should be at the root



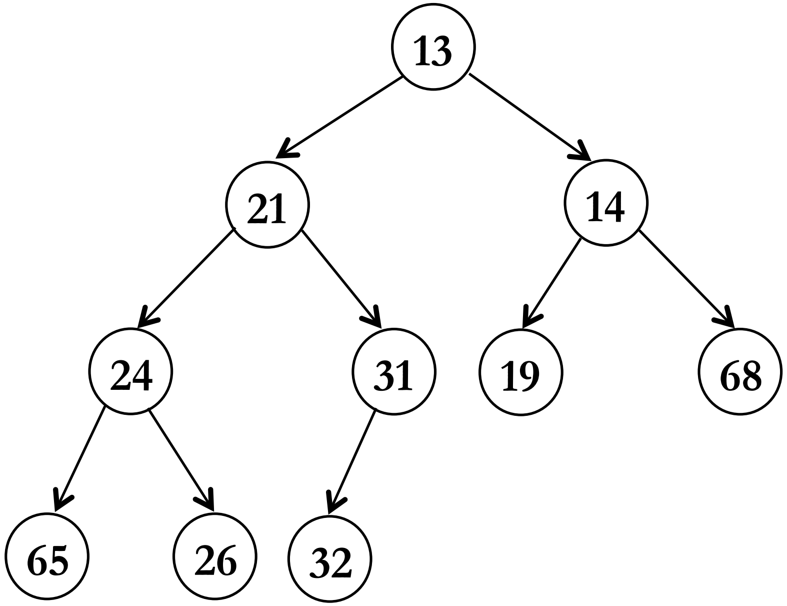
?



?

binary heap

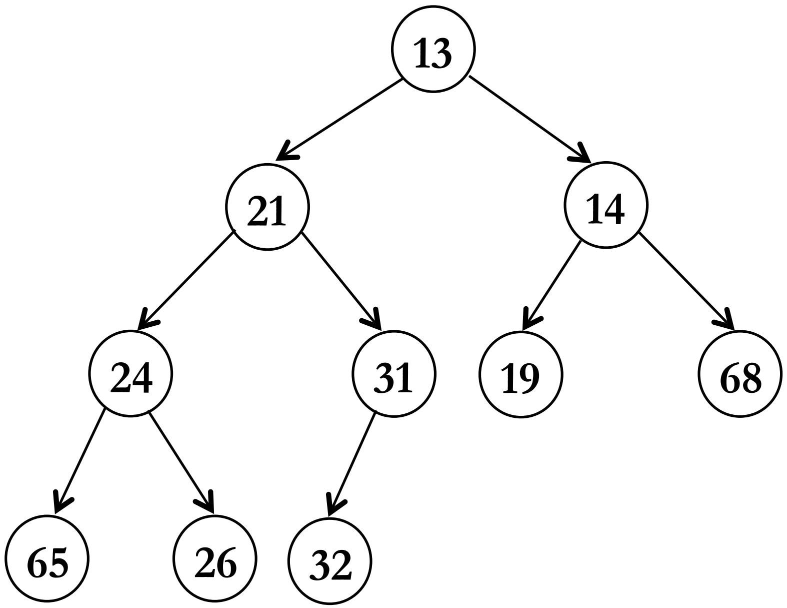
- binary heap can be stored in array since it is a complete tree



- left_child(i) = 2i (when 2i <= n)
- right_child(i) = 2i + 1 (when 2i+1 <=n)
- parent(i) = floor(i/2)   (when i>=2)

array		13	21	14	24	31	19	68	65	26	32	
index	0	1	2	3	4	5	6	7	8	9	10	11

binary heap

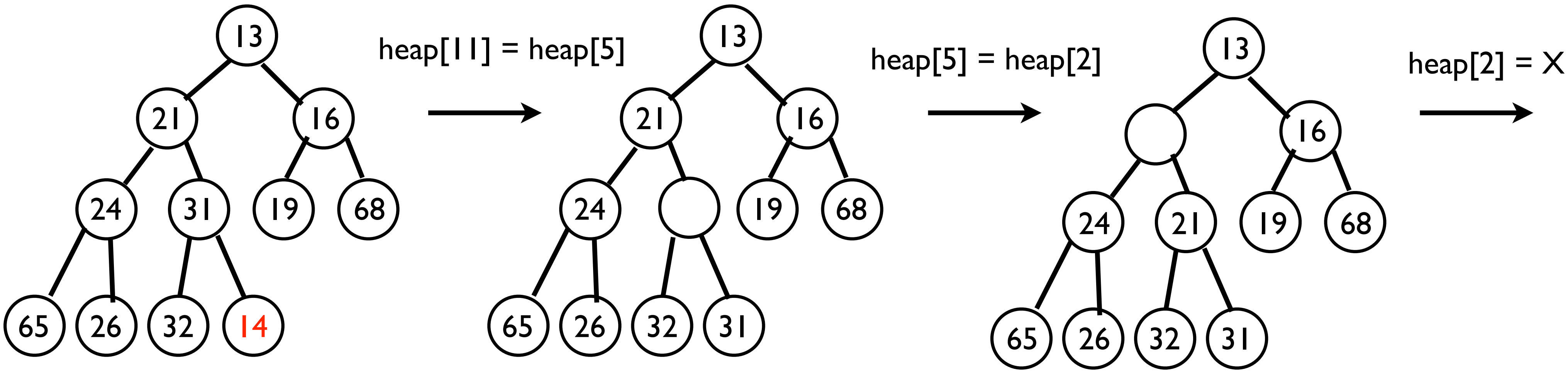



```
struct HeapStruct
{
   int Capacity;   // max heap capacity
   int Size;       // current heap size
   ElementType *Elements;
};
```

insertion

insertion of 14

x=14



i=11
heap[floor(i/2)] $\leq$ X ?

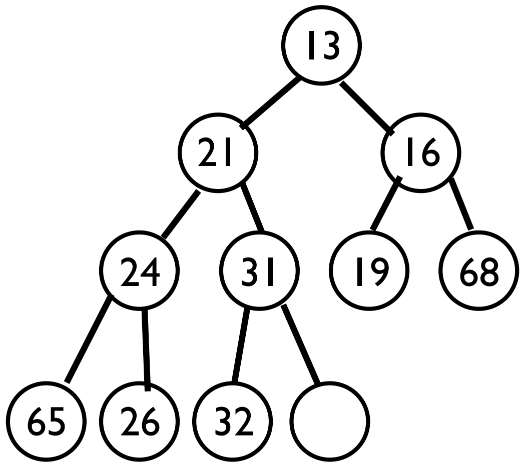
i=5
heap[floor(i/2)] $\leq$ X ?

i=2
heap[floor(i/2)] $\leq$ X ?

		13	21	16	24	31	19	68	65	26	32	14
i	0	1	2	3	4	5	6	7	8	9	10	11

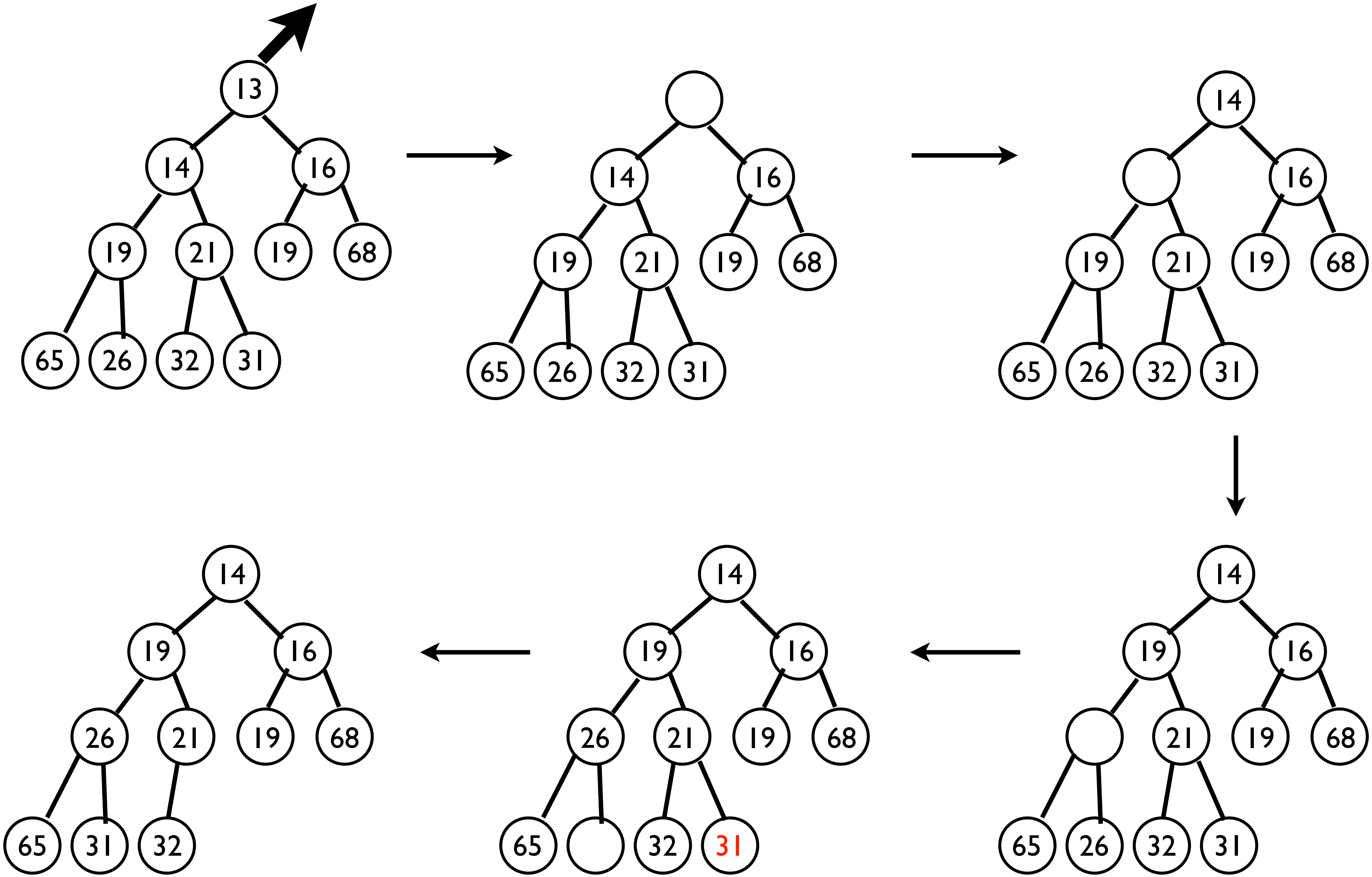
insertion

```
void Insert( ElementType X, PriorityQueue H )
{

   int i;
   if (IsFull( H ) )
   {
         Error( "Priority queue is full" );
         return;
   }

   /*percolating up*/
   for( i = ++H->size;    H->Elements[ i/2 ] > X;    i /= 2 )
            H->Elements[ i ] = H->Elements[ i/2 ];

   H->Elements[ i ] = X;
}
```

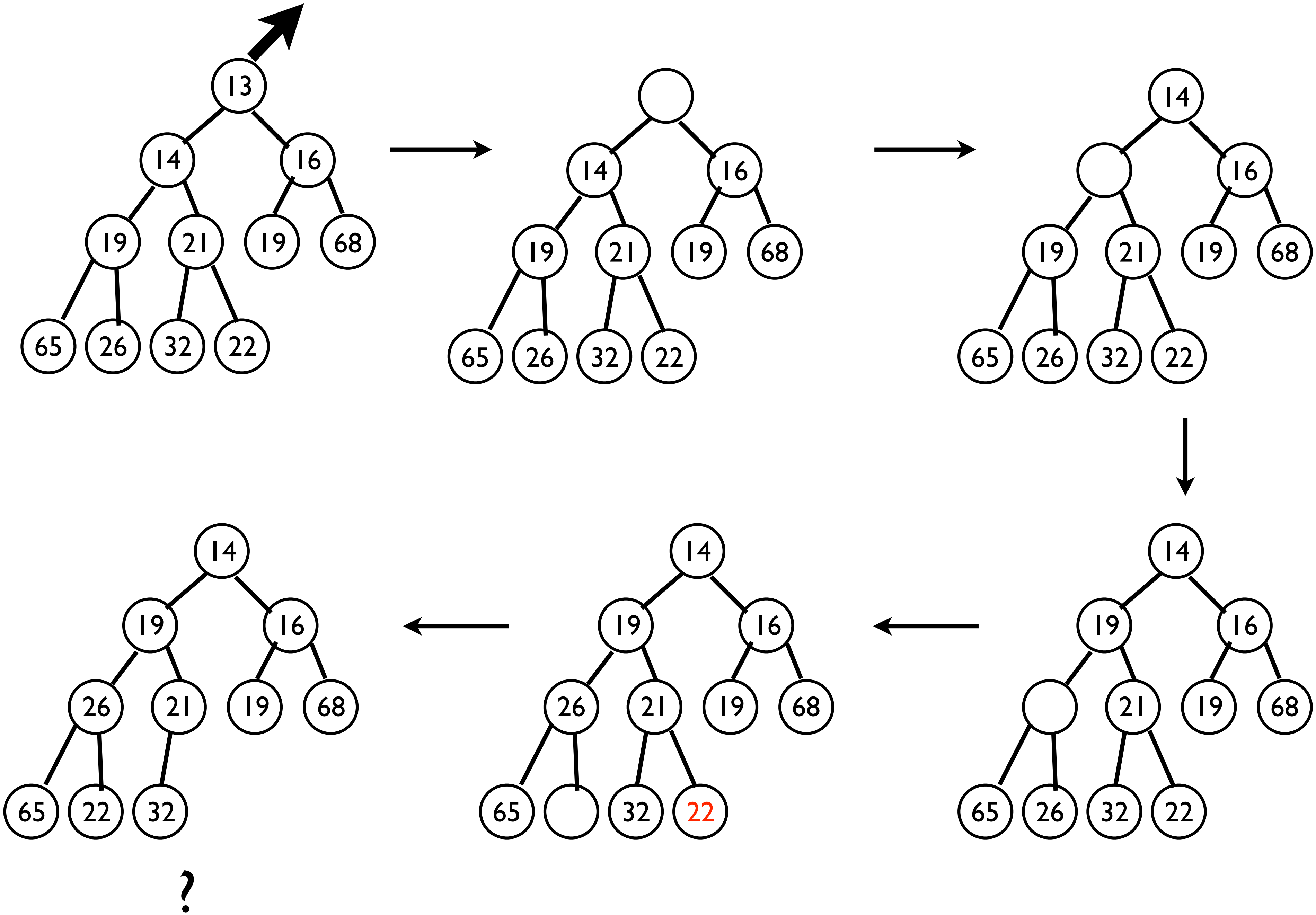


the complexity of the insertion function is $O(\log_2 n)$

DeleteMin: a possible way?

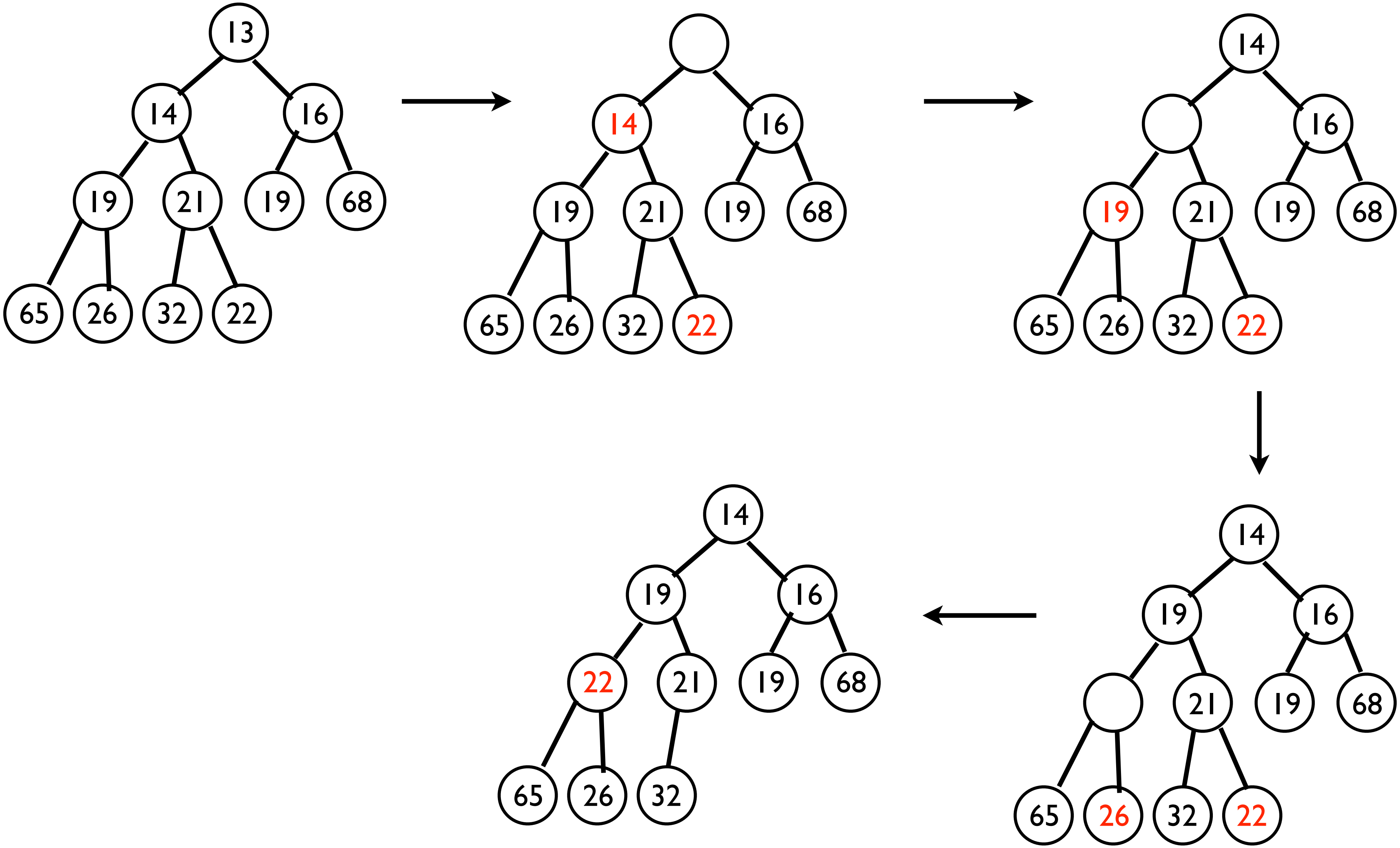


DeleteMin: what if?



DeleteMin

- choose the smaller one between H->Elements[LChild] and H->Elements[RChild]
- choose the smaller one between LastElement and H->Elements[Child]



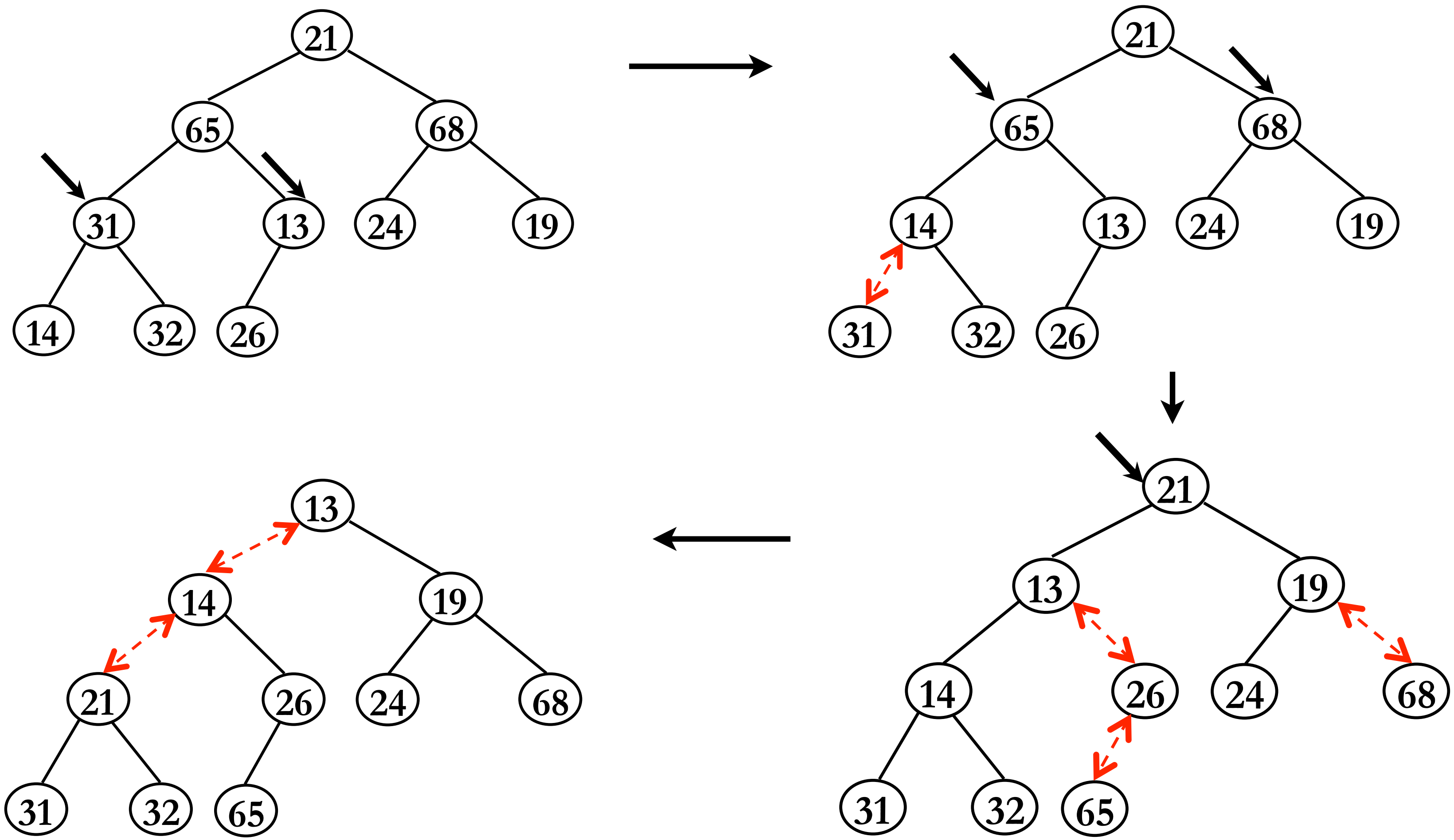
DeleteMin

```
ElementType DeleteMin( PriorityQueue H )
{
        int i, Child;
        ElementType MinElement, LastElement;

        MinElement = H->Elements[ 1 ];
        LastElement = H->Elements[ H->Size-- ];

       /*percolating down*/
       for( i = 1; i*2 <= H->Size; i = Child )
       {
            Child = i * 2;
            if( Child != H->Size && H->Elements[ Child + 1 ] < H->Elements[ Child ] )
                    Child++;

            if( LastElement > H->Elements[ Child ] )
                    H->Elements[ i ] = H->Elements[ Child ];
           else
                    break;
       }

       H->Elements[ i ] = LastElement;
       return MinElement;
}
```

the complexity of the deletion function is $O(\log_2 n)$

BuildHeap

- Build a Heap containing n keys takes $O(n \log n)$ with consecutive insertions
- But it can take $O(n)$ if they are already in array.
- Starting with the lowest non-leaf node, working back towards root, perform percolating-down on each node of the tree.



BuildHeap

Let's assume that the tree is complete:

There is one key at level 0, which might sift down h levels.

There are two keys at level 1, which might sift down h – 1 levels

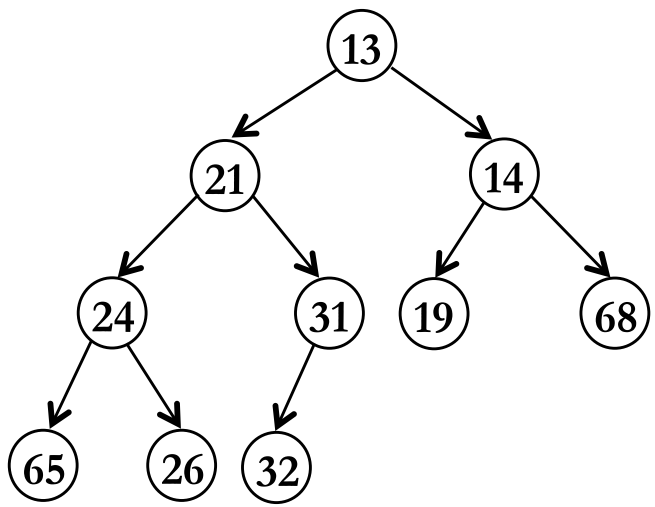
There are four keys at level 2, which might sift down h – 2 levels

...

$$S = h + 2(h-1) + 4(h-2) + \ldots + 2^{h-1}(1)$$

$$2S = 2h + 4(h-1) + 8(h-2) + \ldots + 2^{h-1}(2) + 2^{h}(1)$$

$$\begin{aligned} 2S - S &= -h + (2 + 4 + \ldots + 2^{h-1}) + 2^{h} \\ &= -h - 1 + (1 + 2 + 4 + \ldots + 2^{h-1}) + 2^{h} \\ &= 2^{h} + 2^{h} - (h+2) = 2 \cdot 2^{h} - h - 2 \\ &= 2 \cdot 2^{\log n} - \log n - 2 \le 2n \end{aligned}$$



heap sort

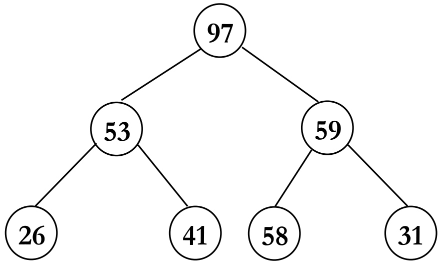
- building a binary heap of n elements: O(n)
- DeleteMin operation n times: O(n log n)
- need extra space to save the sorted list: use the last cell in the previous heap

```
void HeapSort (ElementType A[], int N)
{
      int   i;
      for (i = N/2;   i >0;   i --)       /* Build Heap */
             PercDown (A,  i,  N);

      for (i = N;  i > 0;   i --)
      {
              Swap(&A[1],  &A[i] );     /*DeleteMax */
              PercDown(A, 1, i-1);
      }
}
```

heap sort (by increasing order with max heap)

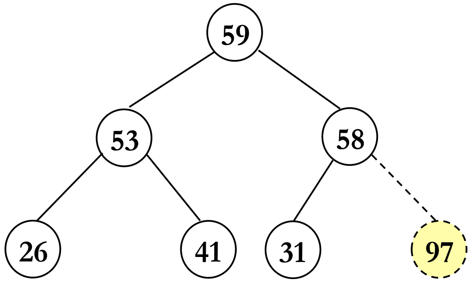
	31	41	59	26	53	58	97		
0	1	2	3	4	5	6	7	8	9

BuildHeap

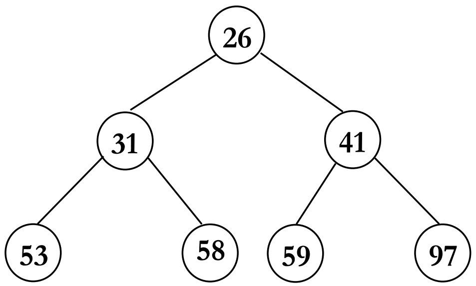


	97	53	59	26	41	58	31		
0	1	2	3	4	5	6	7	8	9

DeleteMax



	59	53	58	26	41	31	97		
0	1	2	3	4	5	6	7	8	9



	26	31	41	53	58	59	97		
0	1	2	3	4	5	6	7	8	9