Data Structures at the Low Level

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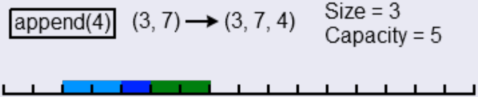
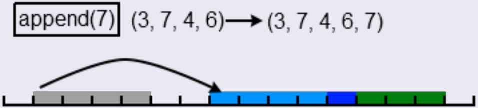
Vectors

- Vectors are basically resizeable arrays
- Vectors have a capacity. They reserve some extra memory where new elements are added



- Once capacity is exceeded the following is done:
  1. A new memory block with (2x) larger capacity is allocated
  2. The old data is copied over into the new block
  3. The old block is deallocated



Exercises

- Suppose we create pointers that point to elements of a vector. What are the risks of doing that?
- Suppose we fill a vector by appending m times. How many operations do we have to do asymptotically (in Big O)?
- Suppose we create a vector of vectors of integers (vector<vector<int> >). Suppose that:
  1. We add m integers in total to subvectors
  2. All subvectors will end up non-empty
  3. The subvectors can be added at any time

  What is the worst case complexity (Big O of the number of operations) if in the top-level vector reallocation we:
  1. Move only the metadata of the lower-level vectors
  2. Move the whole contents of the lower-level vectors

- Deques are resizeable sequences like vectors, but internally they behave differently
- Deques store elements in (reasonably large) equal-size chunks and when capacity is exceeded they simply add a new chunk

- The data is more consecutive than in a list, but less than in a vector
- As a result in practice it's much faster than a list, but somewhat slower than a vector
- The main benefit over a vector is that no reallocation is performed, so pointers to its data don't get invalidated

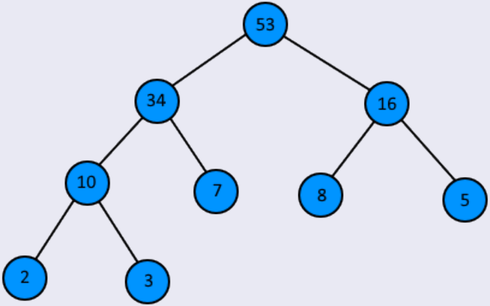
Deques

Exercises

- How would you keep track of where chunks are situated?
- How does the memory overhead of a deque compare to that of a vector?

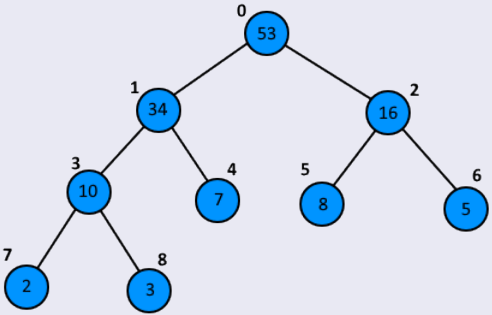
Heap

- A heap is simply a balanced binary tree where the value of a node is always greater or equal to the values of its children
- Example:



- The root always contains the maximum element

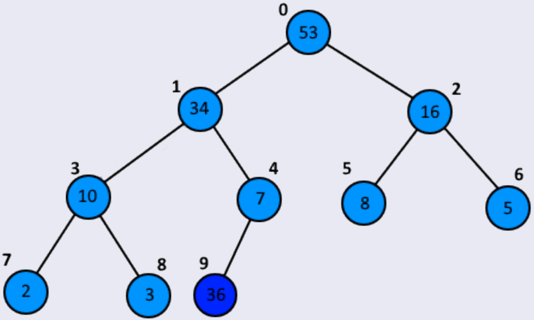
- Let's number the nodes from top to bottom and left to right:



- Do you notice a pattern? Given node index i, what are the indices of its children?
- How many levels (up to down) does a heap with n nodes have?

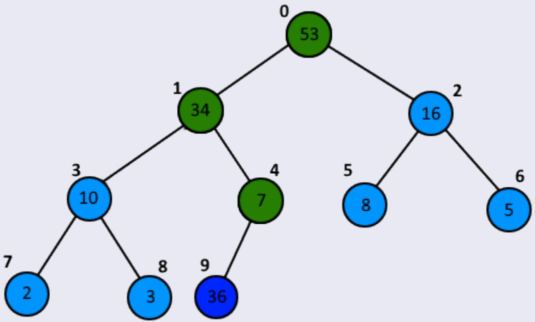
Heap Insertion

- To insert an element, we first create a new node according to the aforementioned numbering:



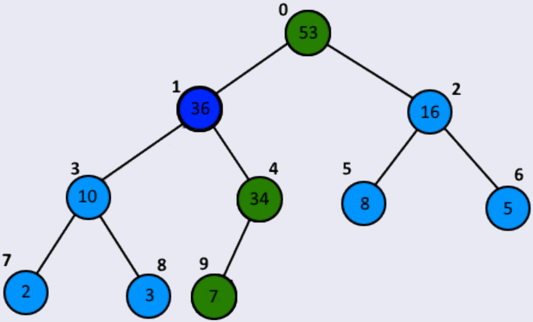
Heap Insertion

- Next look at a path from that node to root:



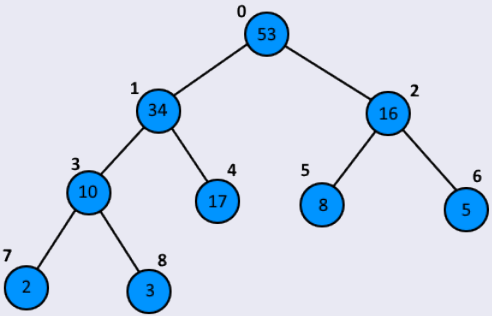
Heap Insertion

- Finally move the node up along this path, so the path would be decreasing:



- Why is the result of those operations still a heap?
- What is the worst-case time complexity of insertion?

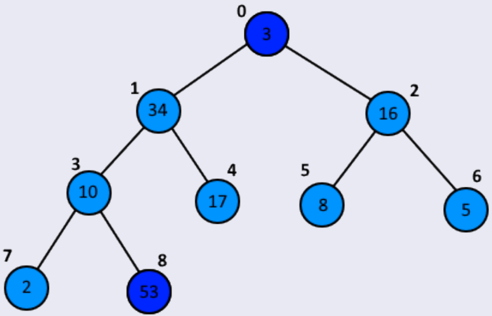
- Let's look at some heap:



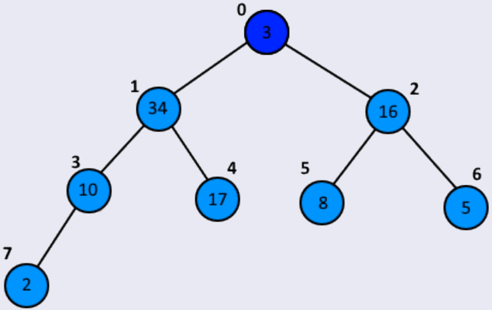
- How would we delete the root from it?

Heap Deletion

- First swap the root node with the last one:

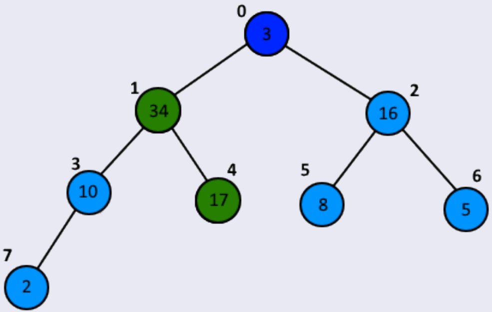


- Next we delete the last node:



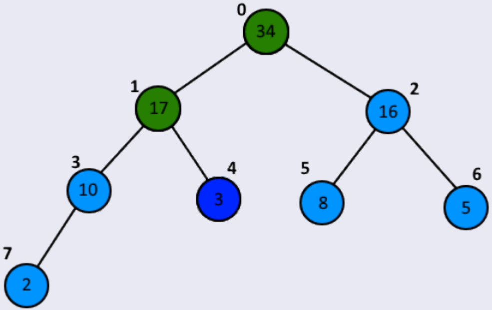
Heap Deletion

- Next we look at the "max-path" (path that always picks the highest value child):



Heap Deletion

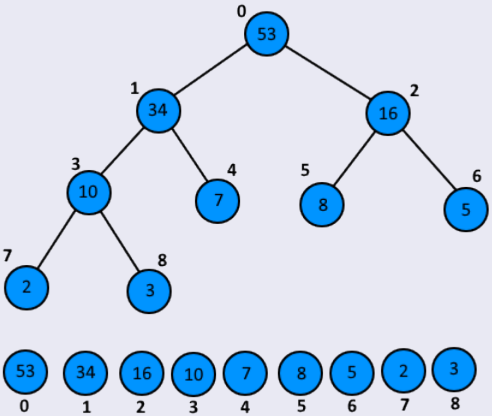
- Finally move the root down along the path until it has no children with greater value:



- Why is the result still a heap?
- What is the time complexity of deletion?

Heap in Practice

- You can place a heap in an array, all structural information can be derived from indices:



Heap Code

Example

```
int heap[MAX_HEAP_SIZE];
int heap_size;
void insert(int value) {
    int i = heap_size;
    heap_size++;
    heap[i] = value;
    while(i > 0) {
        int pi = (i-1)/2; // This is division rounded down
        if(heap[pi] < heap[i]) {
            swap(heap[pi], heap[i]);
        } else {
            break;
        }
        i = pi;
    }
}
```

Heap Exercises

Exercises

- How would you perform deletion in a location other than root?
- What about changing the value of a random node?
- How would you sort an array using a heap? What would be the time complexity?