# CS 225

**Data Structures**

*October 28 – Hashing Analysis*

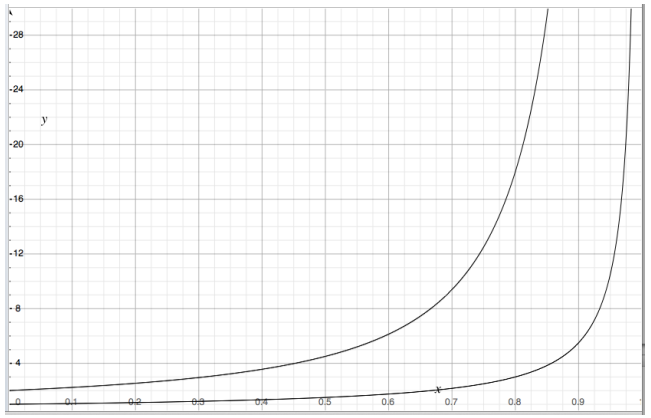
*G Carl Evans*

# Running Times

*The expected number of probes for find(key) under SUHA*

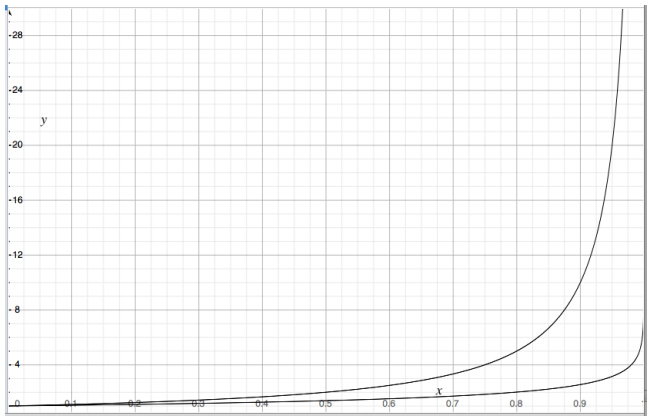
**Linear Probing:**

- Successful: **½(1 + 1/(1-α))**
- Unsuccessful: **½(1 + 1/(1-α))²**



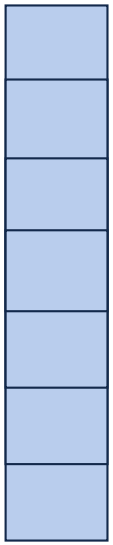

**Double Hashing:**

- Successful: **1/α * ln(1/(1-α))**
- Unsuccessful: **1/(1-α)**



# ReHashing

What if the array fills?



**Which collision resolution strategy is better?**

- Big Records:

- Structure Speed:

**What structure do hash tables replace?**

**What constraint exists on hashing that doesn't exist with BSTs?**

**Why talk about BSTs at all?**

# Running Times

| | Hash Table | AVL | Linked List |
|---|---|---|---|
| **Find** | SUHA:<br><br>Worst Case: | | |
| **Insert** | SUHA:<br><br>Worst Case: | | |
| **Storage Space** | | | |

# std data structures

**std::map**

# std data structures

**std::map**

::operator[]

::insert

::erase

::lower_bound(key) ➔ Iterator to first element ≤ key

::upper_bound(key) ➔ Iterator to first element > key

# std data structures

**std::unordered_map**

::operator[]

::insert

::erase

~~::lower_bound(key) → Iterator to first element ≤ key~~

~~::upper_bound(key) → Iterator to first element > key~~

# std data structures

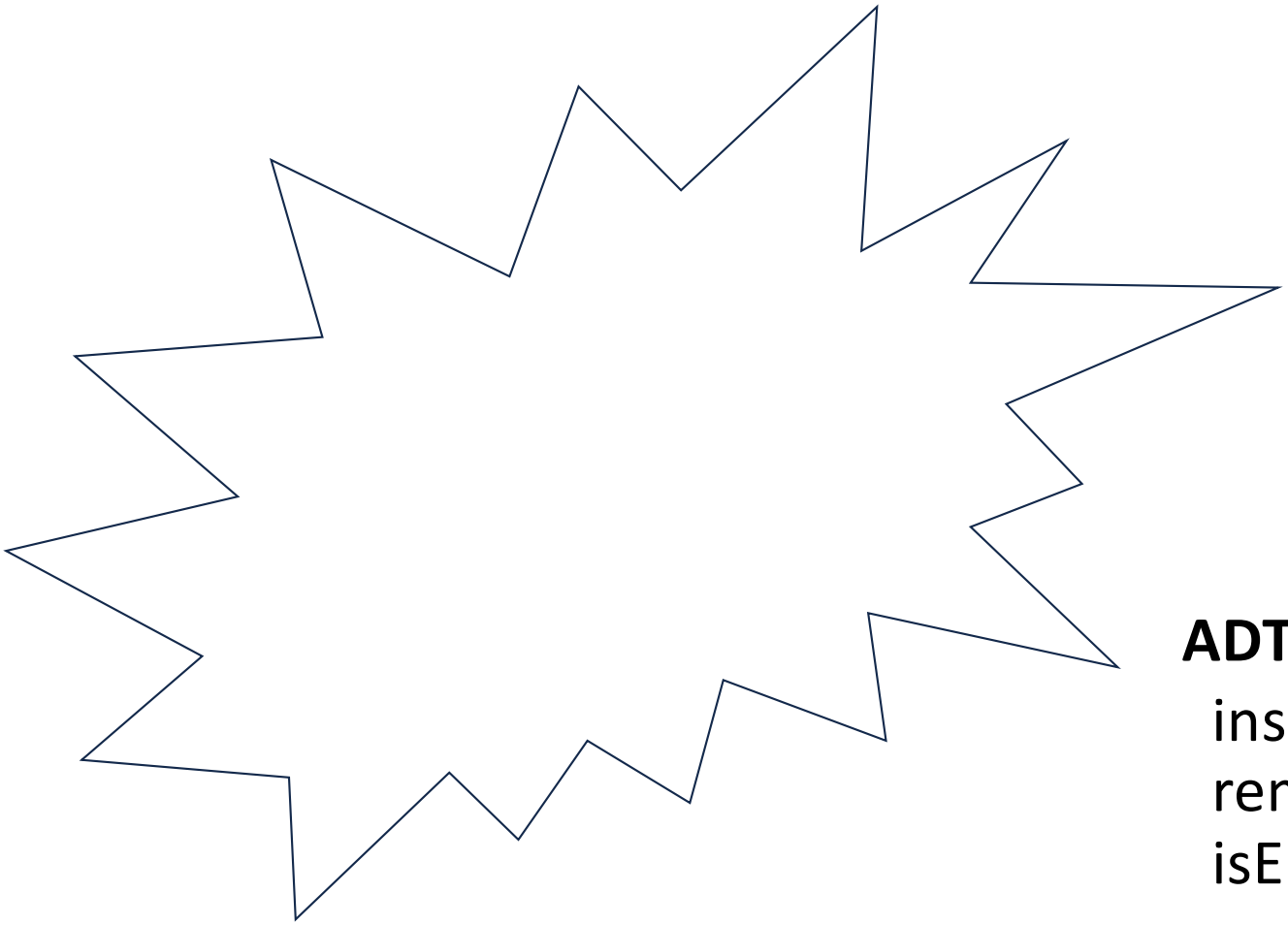
**std::unordered_map**

::operator[]
::insert
::erase

~~::lower_bound(key) → Iterator to first element ≤ key~~
~~::upper_bound(key) → Iterator to first element > key~~

::load_factor()
::max_load_factor(ml) → Sets the max load factor

# Secret, Mystery Data Structure

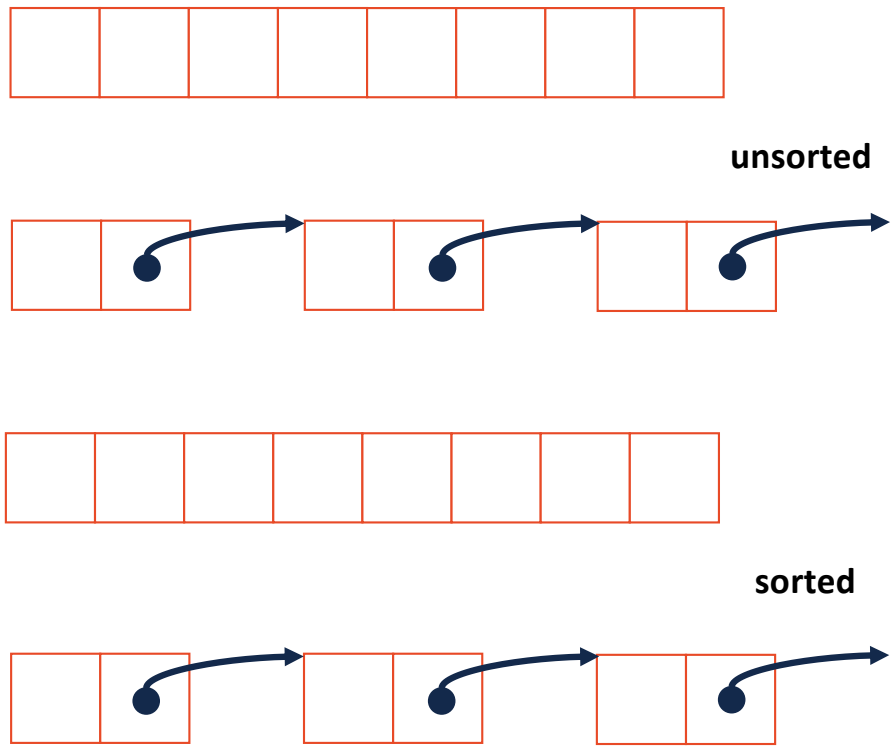


**ADT:**

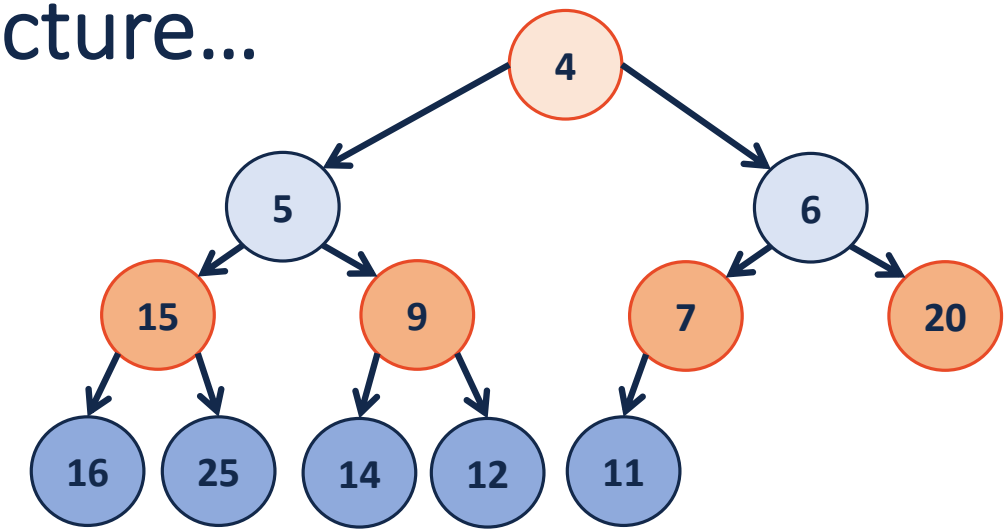
insert
remove
isEmpty

# Priority Queue Implementation

| insert | removeMin |
|---|---|
| O(n) | O(n) |
| O(1) | O(n) |
| O( lg(n) ) | O(1) |
| O( lg(n) ) | O(1) |



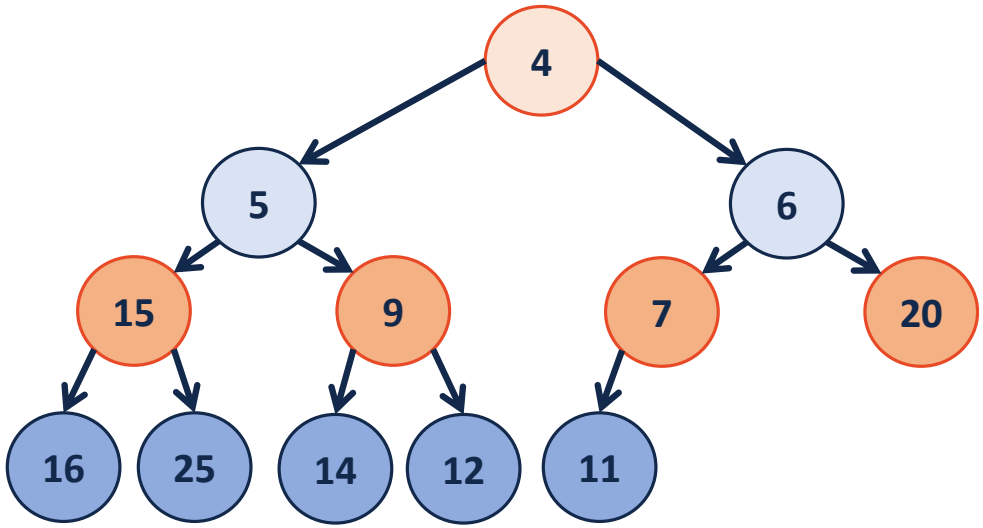
# Another possibly structure…



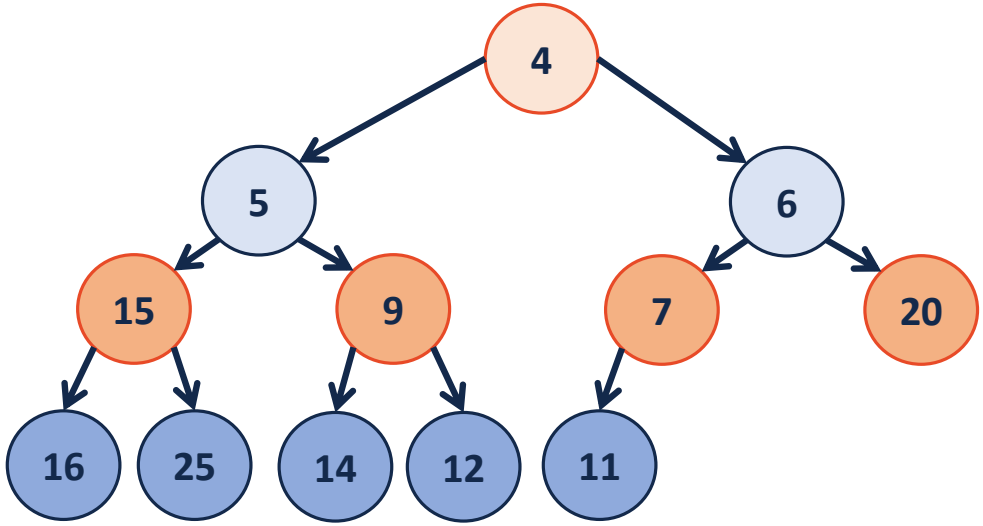
# (min)Heap

A complete binary tree T is a min-heap if:

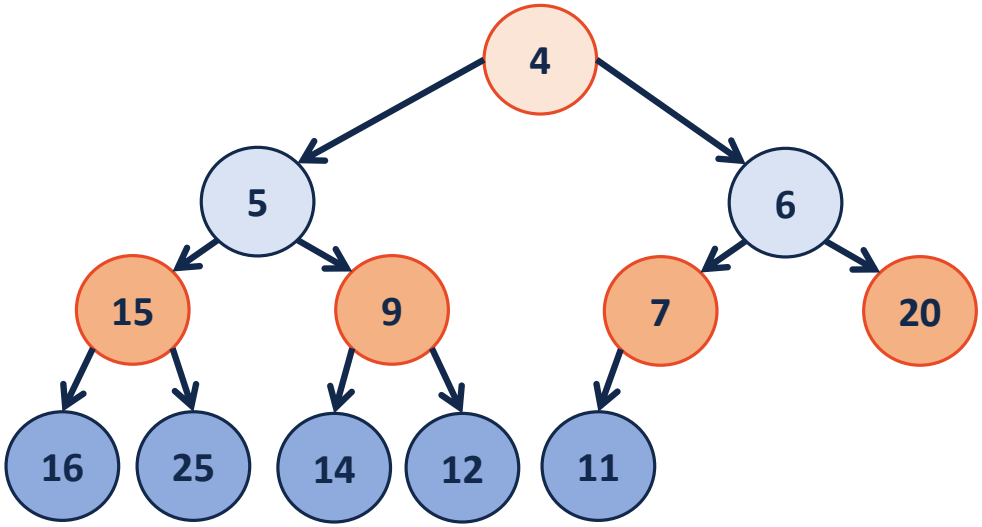
- **T = {}** or
- **T = {r, $T_L$, $T_R$}**, where **r** is less than the roots of {$T_L$, $T_R$} and {$T_L$, $T_R$} are min-heaps.



# (min)Heap

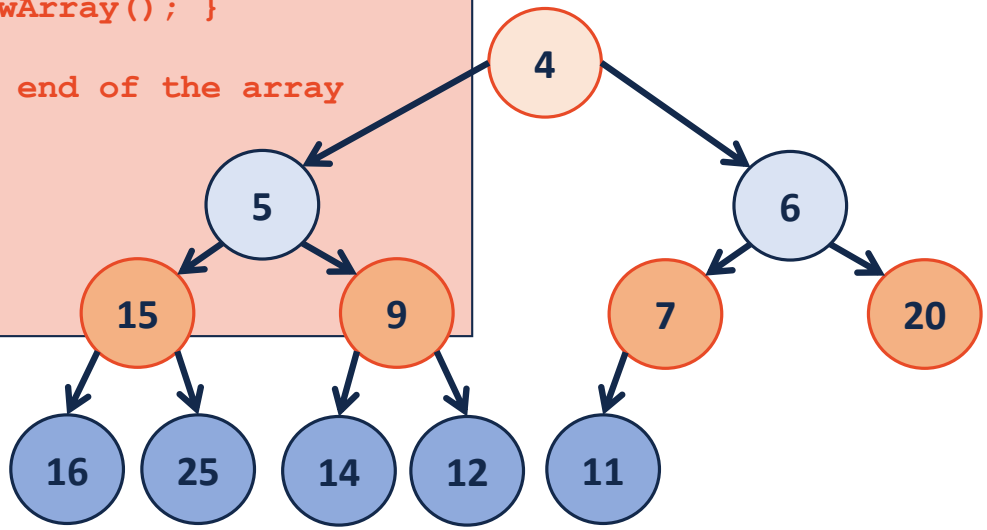



# insert

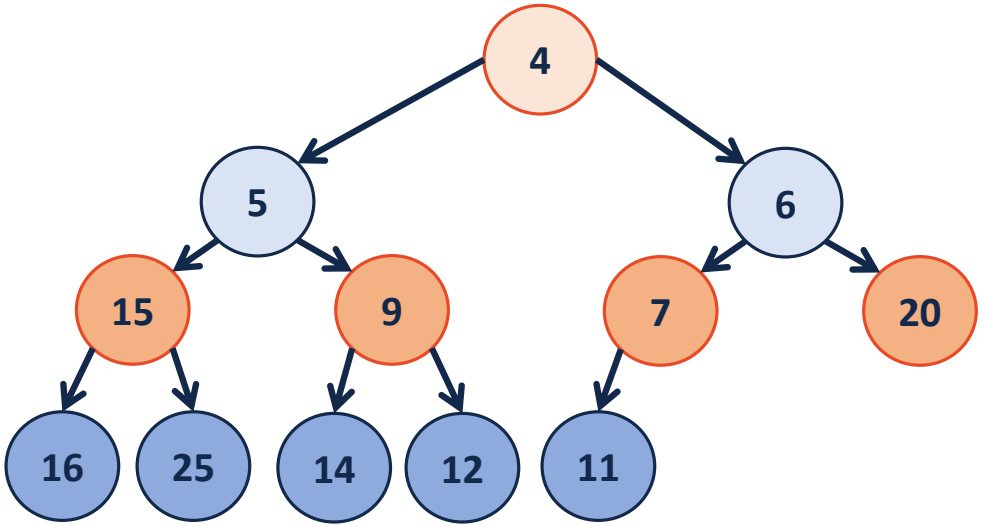



# insert

```
1  template <class T>
2  void Heap<T>::_insert(const T & key) {
3    // Check to ensure there's space to insert an element
4    // ...if not, grow the array
5    if ( size_ == capacity_ ) { _growArray(); }
6
7    // Insert the new element at the end of the array
8    item_[++size] = key;
9
10   // Restore the heap property
11   _heapifyUp(size);
12 }
```




# growArray

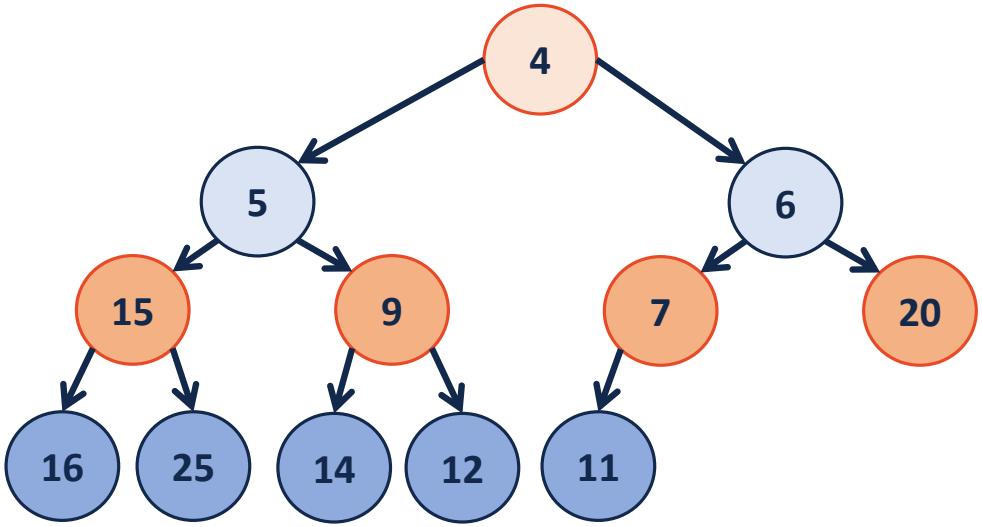



# insert - heapifyUp

```
1  template <class T>
2  void Heap<T>::_insert(const T & key) {
3    // Check to ensure there's space to insert an element
4    // ...if not, grow the array
5    if ( size_ == capacity_ ) { _growArray(); }
6
7    // Insert the new element at the end of the array
8    item_[++size] = key;
9
10   // Restore the heap property
11   _heapifyUp(size);
12 }
```

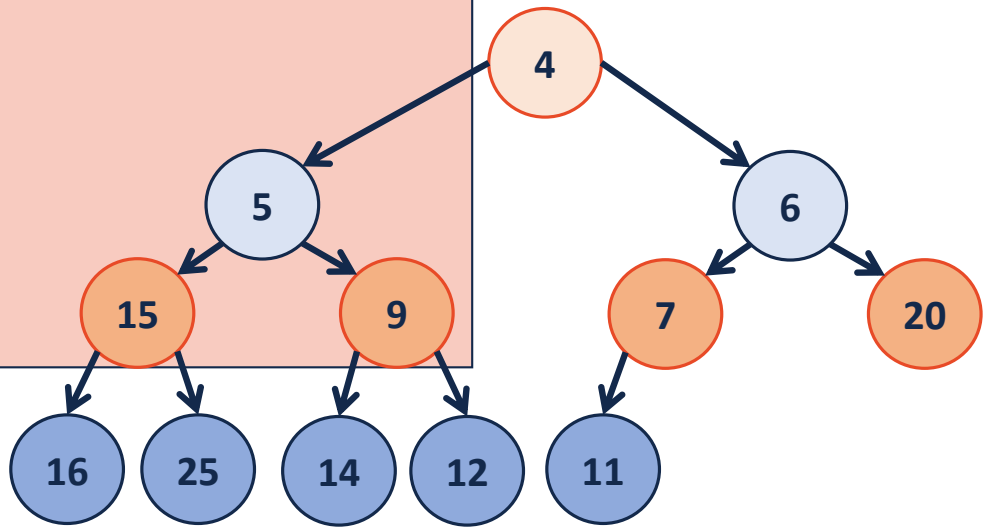
```
1  template <class T>
2  void Heap<T>::_heapifyUp( ____________________ ) {
3    if ( index > __________ ) {
4      if ( item_[index] < item_[ parent(index) ] ) {
5         std::swap( item_[index], item_[ parent(index) ] );
6         _heapifyUp( ____________________ );
7      }
8    }
9  }
```

# removeMin




# removeMin

```
 1  template <class T>
 2  void Heap<T>::_removeMin() {
 3    // Swap with the last value
 4    T minValue = item_[1];
 5    item_[1] = item_[size_];
 6    size--;
 7
 8    // Restore the heap property
 9    heapifyDown();
10
11    // Return the minimum value
12    return minValue;
13  }
```




# removeMin - heapifyDown

```
 1  template <class T>
 2  void Heap<T>::_removeMin() {
 3    // Swap with the last value
 4    T minValue = item_[1];
 5    item_[1] = item_[size_];
 6    size--;
 7
 8    // Restore the heap property
 9    _heapifyDown();
10
11    // Return the minimum value
12    return minValue;
13  }
```

```
 1  template <class T>
 2  void Heap<T>::_heapifyDown(int index) {
 3    if ( !_isLeaf(index) ) {
 4      T minChildIndex = _minChild(index);
 5      if ( item_[index] ___ item_[minChildIndex] ) {
 6         std::swap( item_[index], item_[minChildIndex] );
 7         _heapifyDown( ________________ );
 8      }
 9    }
10  }
```

# Array Abstractions