Visualizing heaps

Use the visualization at [http://www.cs.usfca.edu/~galles/visualization/Heap.html](http://www.cs.usfca.edu/~galles/visualization/Heap.html) to insert the following elements into a min-heap, in the given order.

5, 3, 6, 7, 2, 6

Priority queue client and library interface

We use heaps to efficiently implement the priority queue interface.

```c
/* Client interface */
typedef ______ elem;
typedef void* elem;

// f(x,y) returns true if e1 is STRICTLY higher priority than e2
typedef bool higher_priority_fn(elem e1, elem e2);

/* Library interface */
typedef ____* heap_t;

bool heap_empty(heap_t H);
bool heap_full(heap_t H);
heap_t heap_new(int capacity, higher_priority_fn* priority)
  /*@requires capacity > 0 && priority != NULL; @*/
  /*@ensures heap_empty(result); @*/;

void heap_add(heap_t H, elem x)
  /*@requires !heap_full(H); @*/;

elem heap_rem(heap_t H) // Removes highest priority element
  /*@requires !heap_empty(H); @*/
```

Checkpoint 0

If the client’s elem type is picked to be void*, will this client interface cause heap_new(20, &higher_priority) to return a min-heap, a max-heap, or something else?

```c
bool higher_priority(void* x, void* y)
  //@requires x != NULL && @hasag(int*, x);
  //@requires y != NULL && @hasag(int*, y);
{
  return *(int*)x > *(int*)y;
}
```

Checkpoint 1

Write a function (of type higher_priority_fn) that ensures that, in a priority queue of (pointers to) strings, the longest strings always gets returned first. The string_length function may be helpful.
Deletion of the highest-priority element from a heap

You may need the following functions: is_safe_heap, ok_above

```c
//elem heap_rem(heap* H)
//@requires is_heap(H) && !heap_empty(H);
//@ensures is_heap(H);
{
    int i = H->next;
    elem min = H->data[1];
    (H->next)--;
    if (H->next > 1) {
        H->data[1] = H->data[H->next];
        sift_down(H);
    }
    return min;
}

//void sift_down(heap* H)
//@requires ____________________________;
//@ensures is_heap(H);
{
    int i = 1;
    while (___________________________)
        //@loop_invariant 1 <= i && i < H->next;
        //@loop_invariant is_heap_except_down(H, i);
        //@loop_invariant grandparent_check(H, i);
        {
            int left = 2*i;
            int right = left+1;
            if (___________________________)
                return;
            if (___________________________) {
                swap_up(H, left);
                i = left;
            } else {
                //@assert ____________________________;
                swap_up(H, right);
                i = right;
            }
        }
```

**Checkpoint 2**

(a) Check that the preconditions imply the loop invariants hold initially, and that they are satisfied when sift_down is called from pq_rem.

(b) Show that the grandparent check is necessary as a loop invariant.

(c) Prove that the loop invariants imply the postcondition for the return on line 28 and on line 37.