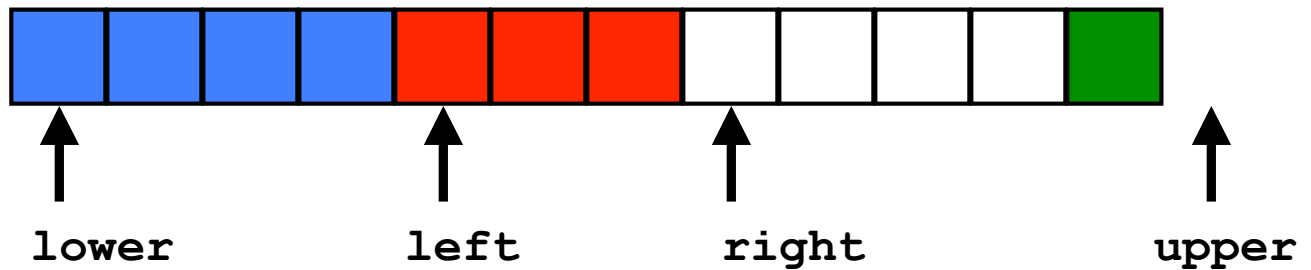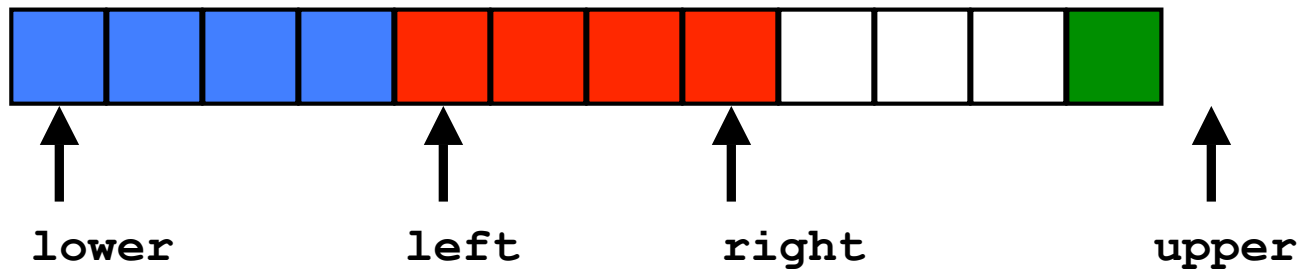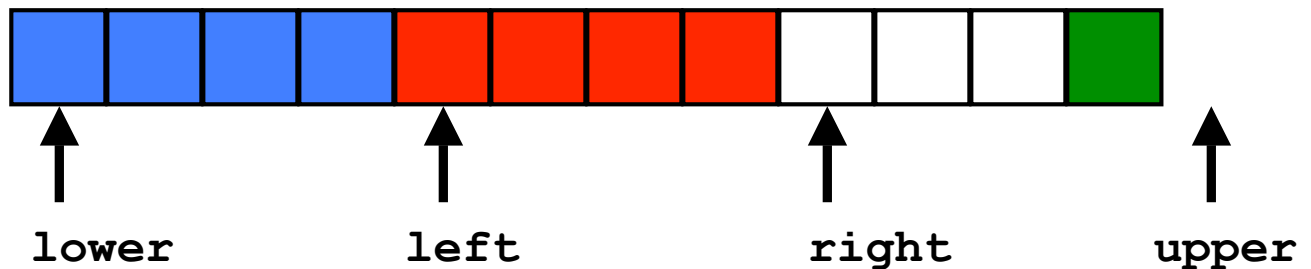Loop Invariants:

```
lower <= left && left <= right && right < upper
&& gt(pivot, A, lower, left)
&& leq(pivot, A, left, right)
&& pivot == A[upper-1]
```
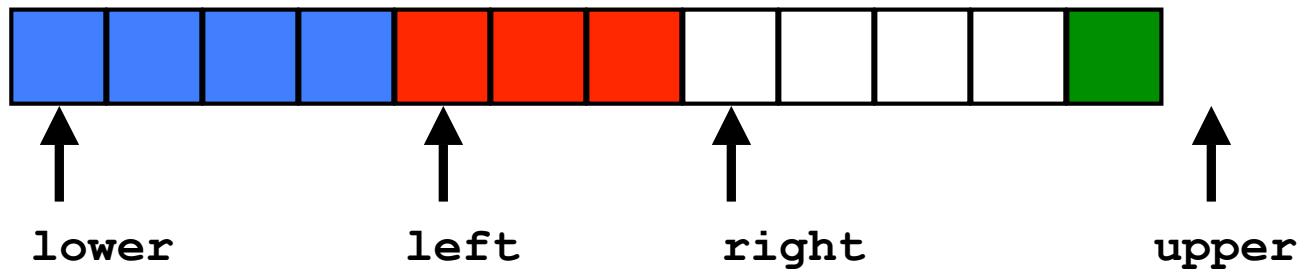


```
if (pivot <= A[right]):
```



```
then right = right + 1:
```
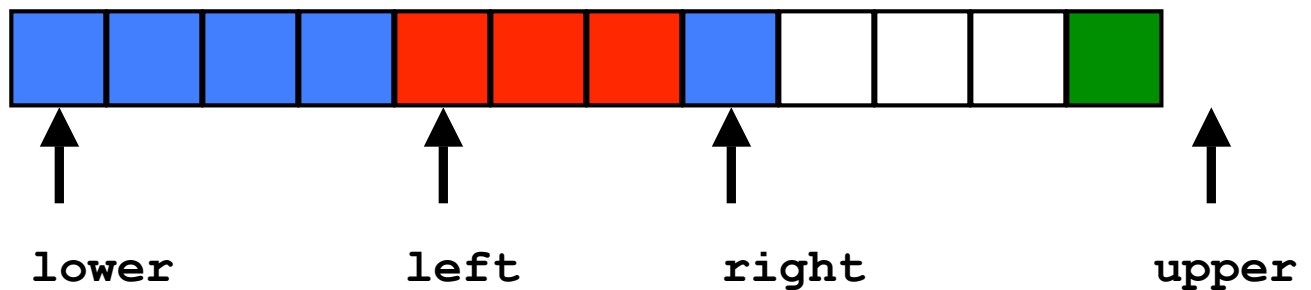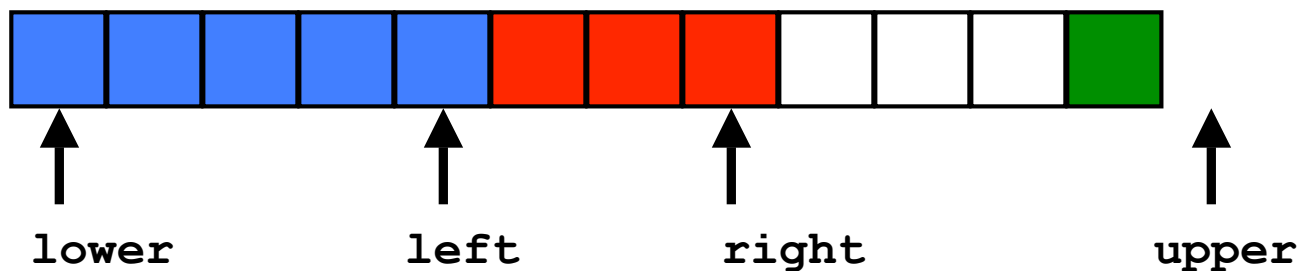
Loop Invariants:

```
lower <= left && left <= right && right < upper
&& gt(pivot, A, lower, left)
&& leq(pivot, A, left, right)
&& pivot == A[upper-1]
```

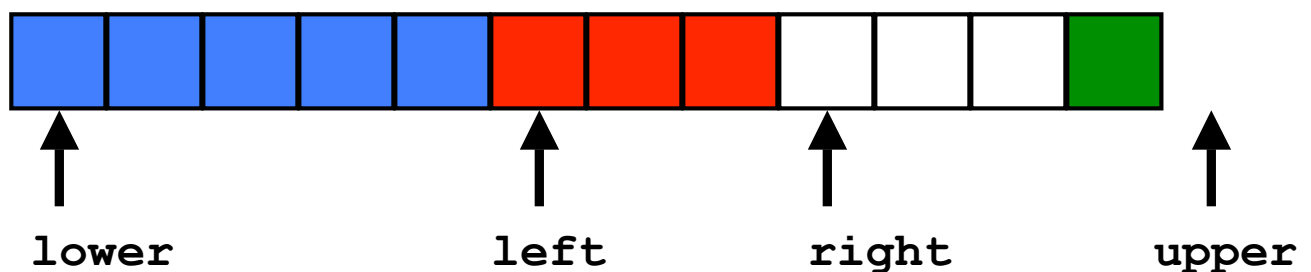lower   left   right   upper
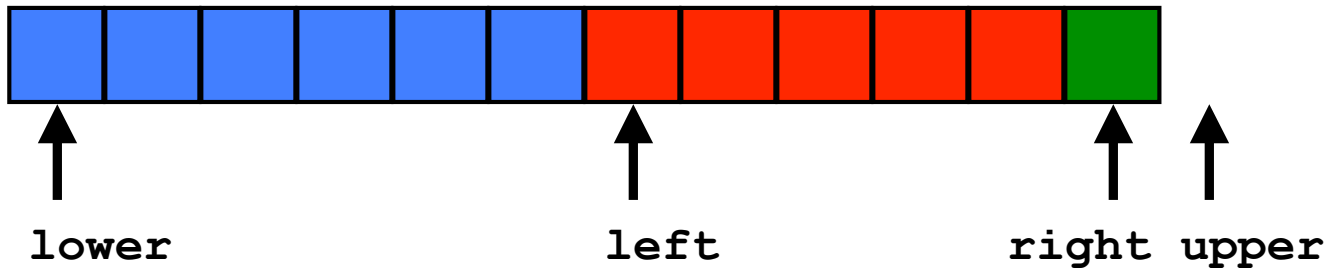
```
if (pivot > A[right]):
```

lower   left   right   upper

```
then swap(A, left, right):
```

lower   left   right   upper

```
and left++ and right++:
```

lower   left   right   upper

After the loop terminates:

```
lower                    left        right upper
```

swap(A, left, upper-1):

```
lower                    left        right upper
```

How do we start?

```
lower,left,right                          upper
```
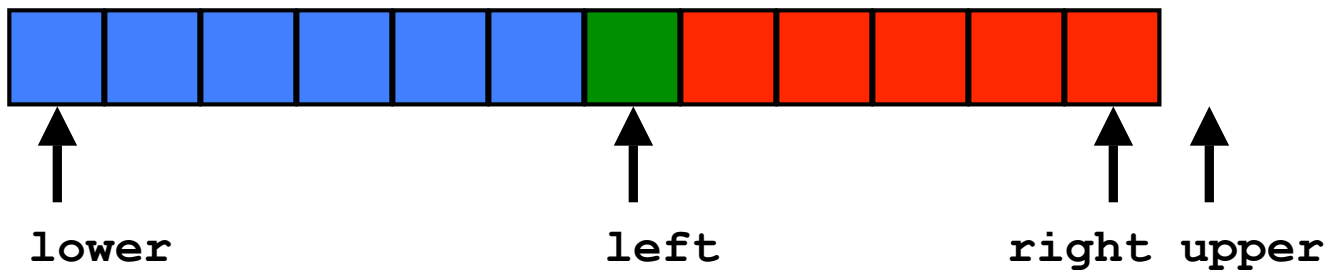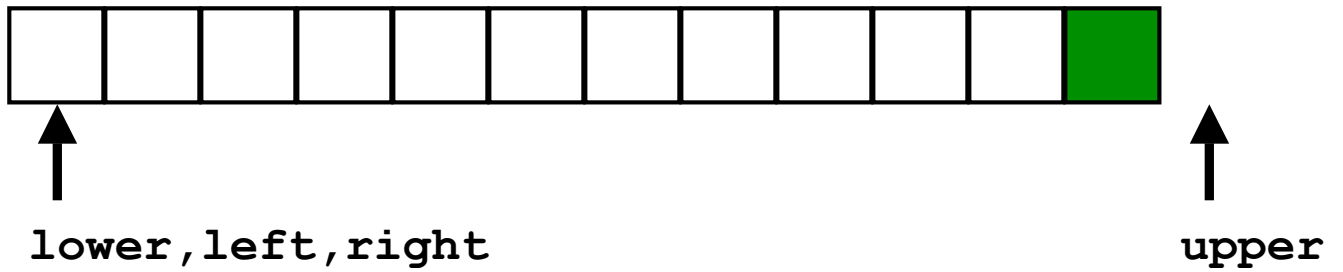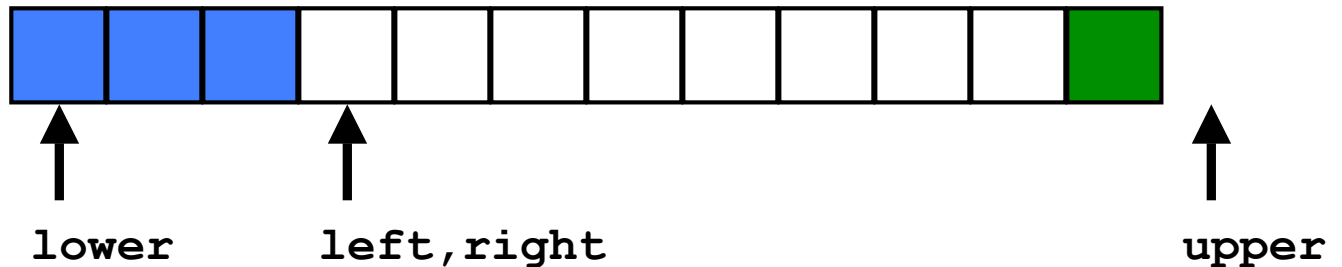
Consider the following additional assertions:

```
while (right < upper-1)
//@loop_invariant lower<=left && left<=right && right<upper;
//@loop_invariant gt(pivot, A, lower, left);
//@loop_invariant leq(pivot, A, left, right);
//@loop_invariant pivot == A[upper-1];
{
   if (pivot <= A[right]) {
      right++;
   } else {
      //@assert pivot > A[right];
      swap(A, left, right);
      //@assert pivot > A[left];
      //@assert pivot <= A[right];
      left++; right++;
   }
}
```

What's wrong?

HINT:

What if pivot > A[right]?