Mark-sweep GC

How do we mark reachable objects?

Disadvantages of mark-sweep GC

- Stop-the-world algorithm
  - Computation suspended while GC runs
  - Pause time may be high
    - Not practical for real-time, interactive applications, video games
- High cost:
  - proportional to size of heap (not just live objects)
  - Why?
    - Active objects visited by mark phase
    - All of memory visited by sweep phase

Mark-sweep algorithm

```
// The mark-sweep collector
mark_sweep() {
    for R in Roots
        mark(*R)
    sweep()
    if free_pool is empty
        abort "Memory exhausted"
}
// Simple recursive marking
mark(N) {
    if mark_bit(N) == unmarked
        mark_bit(N) = marked
        for M in Children(N)
            mark(*M)
}
```

```
// The eager sweep of the heap
sweep() {
    N = Heap_bottom
    while N < Heap_top
        if mark_bit(N) == unmarked
            free(N)
        else mark_bit(N) = unmarked
        N = N + size(N)
}
```

How can we improve marking?

- Using a marking stack
  - Problem:
    - Recursion may cause system stack to overflow
    - Procedure overhead: both time and space
  - Solutions:
    - Replace recursive calls with iterative loops
    - Use auxiliary data structures (*e.g.*, a stack data structure)
      - Stack holds pointers to objects known to be live
      - Unmarked children marked, pushed on stack if have pointers
      - Objects without pointers only marked
      - Marking phase terminates when stack is empty

Marking stack

- Maximum depth of stack
  - Depends on longest path through graph that has to be marked
  - In most systems stacks are generally shallow
- Safe GC must be able to handle exceptional cases
  - May need to minimize stack depth

Iterative Marking

```
mark_heap() {
    mark_stack = empty
    for R in Roots
        mark_bit(*R) = marked
        push(*R, mark_stack)
        mark()
}
```

```
mark() {
    while mark_stack != empty
        N = pop(mark_stack)
        for M in Children(N)
            if mark_bit(*M) == unmarked
                mark_bit(*M) = marked
                if not atom(*M)
                    push(*M, mark_stack)
}
```

Marking with resumption stack

Minimizing stack depth

- Why is this important?
  - Stack can overflow
  - Whys is GC needed?
    - What if the GC runs out of storage?
- How can it be done?
  - push constituent pointers of large objects in small groups onto the stack (Boehm-Demers-Weiser)
  - Using pointer reversal

Addressing stack overflow

- Marking stack can make detection easier and recovery action taken
  - Check in each push operation ($$$$$$)
  - Single check by counting # of pointers in each popped node
  - Use guard page (if OS support)
    - Read-only page. Cannot push unto guard page
- How to handle stack overflow?
  - Knuth's approach
  - Kurokawa's approach

Knuth proposed in 1973

- Treat marking stack circularly

```
for R in Roots
    push(*R, new_roots);
overflow = false;

while true
    overflow = cyclic_stack_mark(new_roots);
    if overflow == true
        new_roots = scan_heap();
    else break;
```

- scan_heap returns marked nodes pointing to unmarked nodes

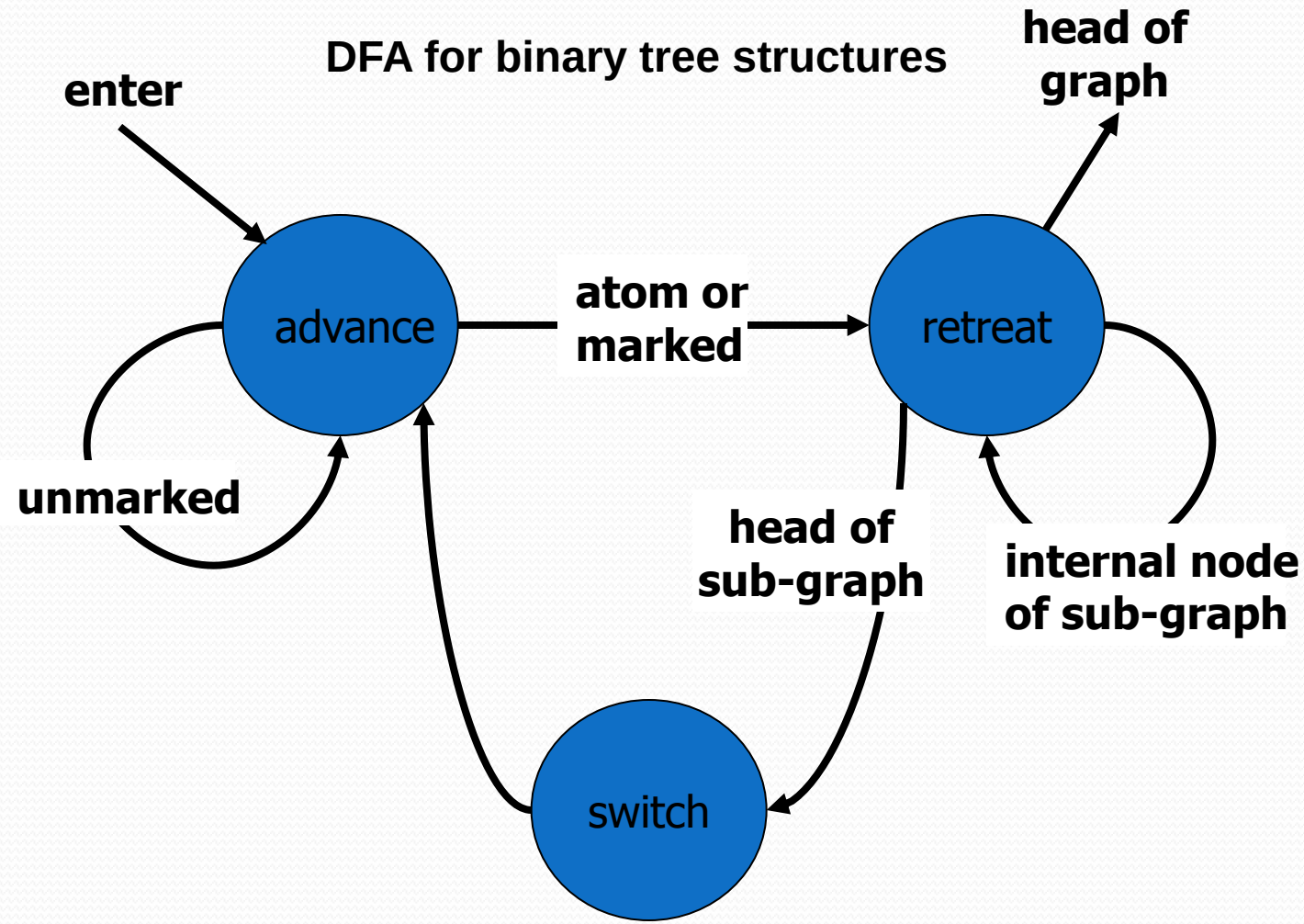
Kurokawa proposal in 1981

- On overflow run ***Stacked Node Checking*** algorithm
- remove items from stack that have fewer than 2 unmarked children
  - no child is unmarked: clear slot
  - one child is unmarked: replace slot entry by a descendent with ***2 or more unmarked*** children marking the passed ones
- Not robust
  - Possible that no additional space will be found on the stack

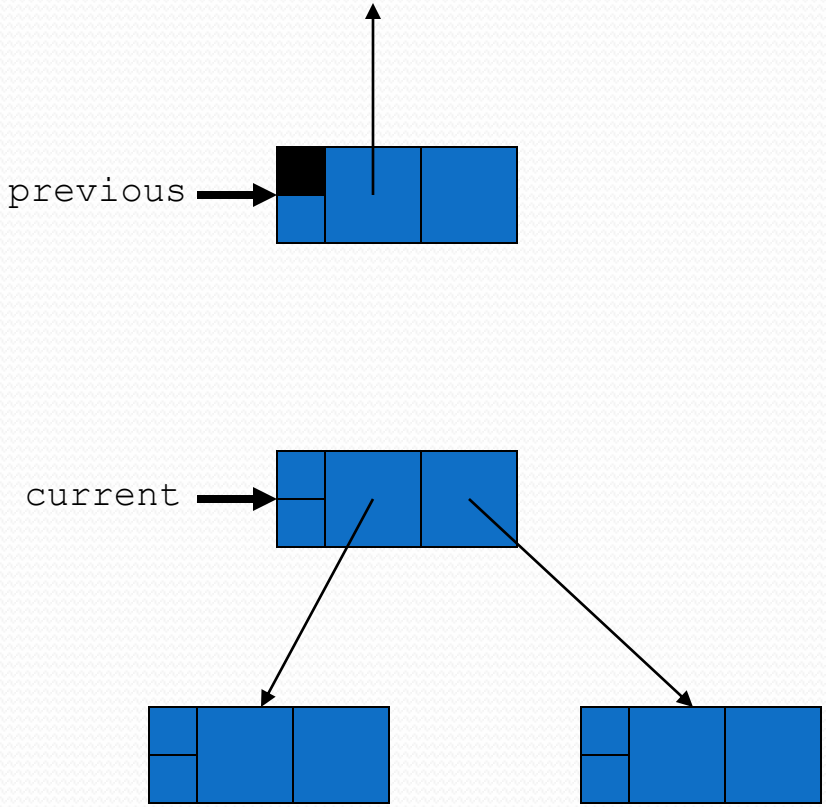
Pointer reversal

- Eliminate need for marking stack
  - Push stack in heap nodes
  - Maintains 3 variables: previous, current, and next
- Any efficient marking process must record the branch-points it passed
- Temporarily reversing of pointers traversed by mark
  - child-pointers become ancestor-pointers
- restore pointer fields when tracing back
- developed independently by Schorr and Waite (1967) and by Deutsch (1973)

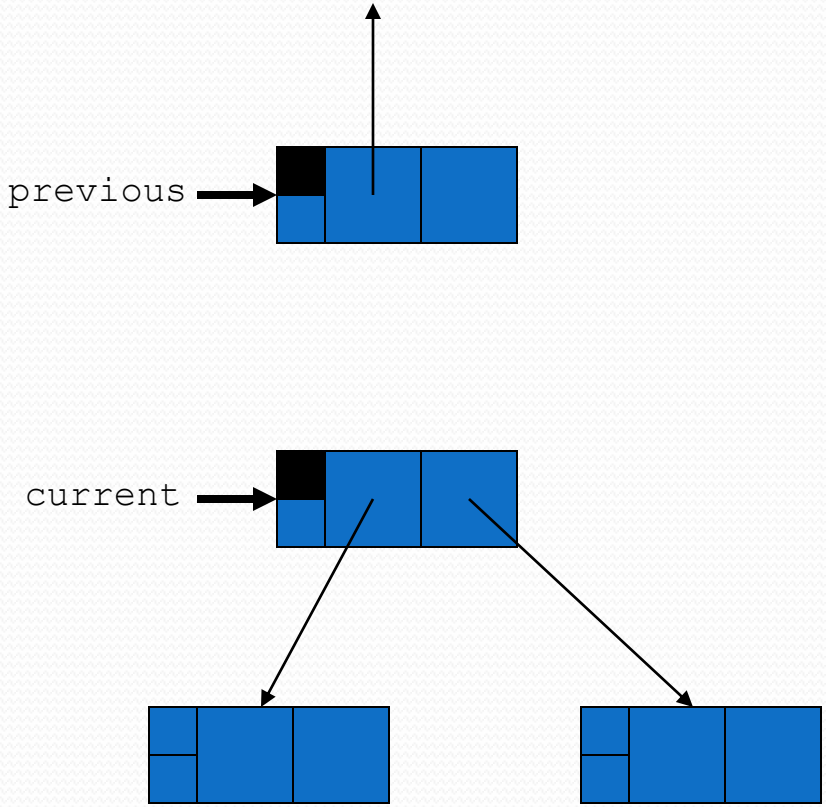
Pointer reversal



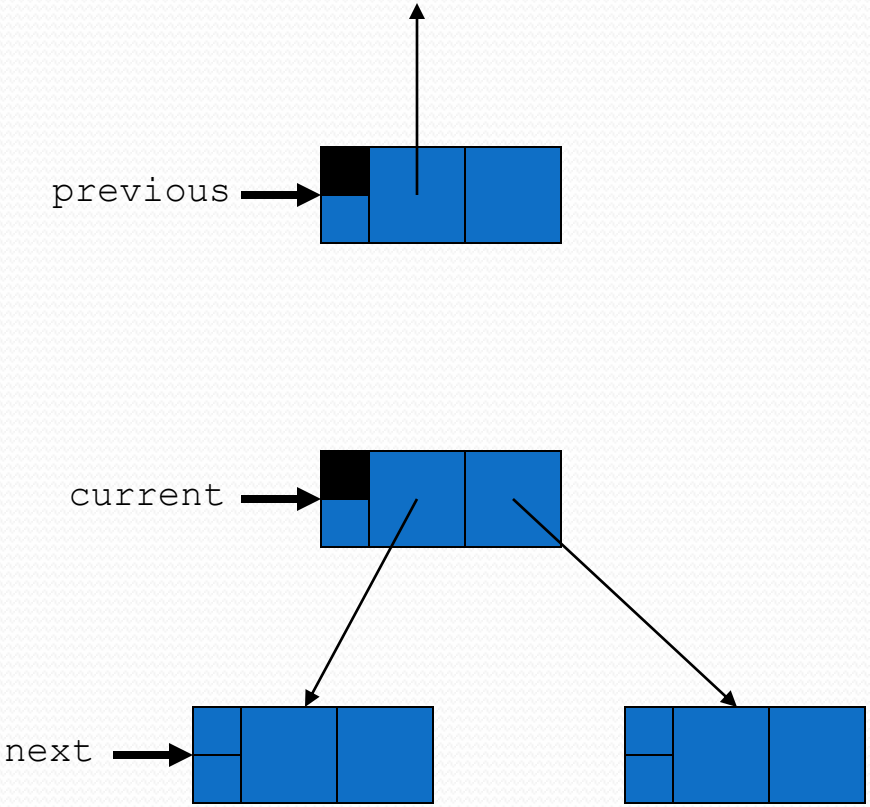
Pointer reversal (advance phase)



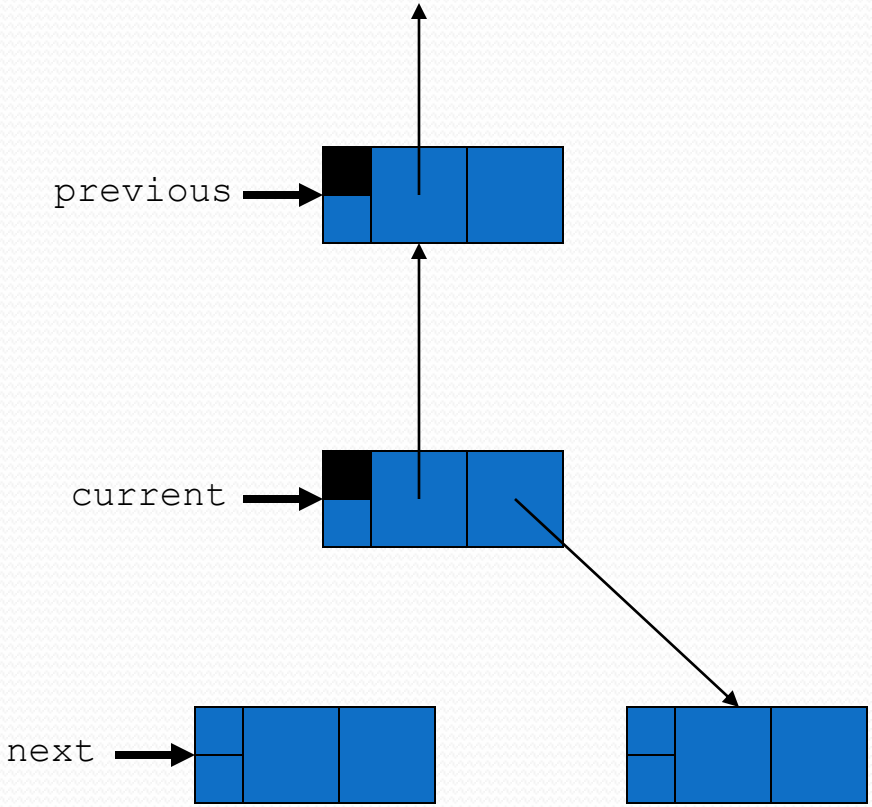
Pointer reversal (advance phase)



Pointer reversal (advance phase)



Pointer reversal (advance phase)



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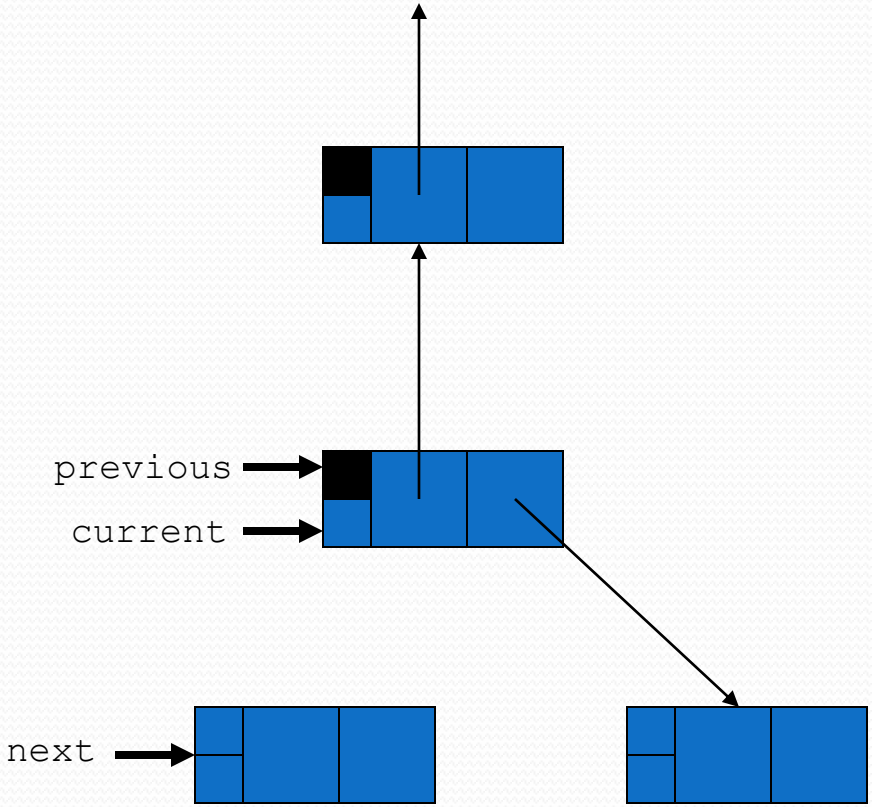
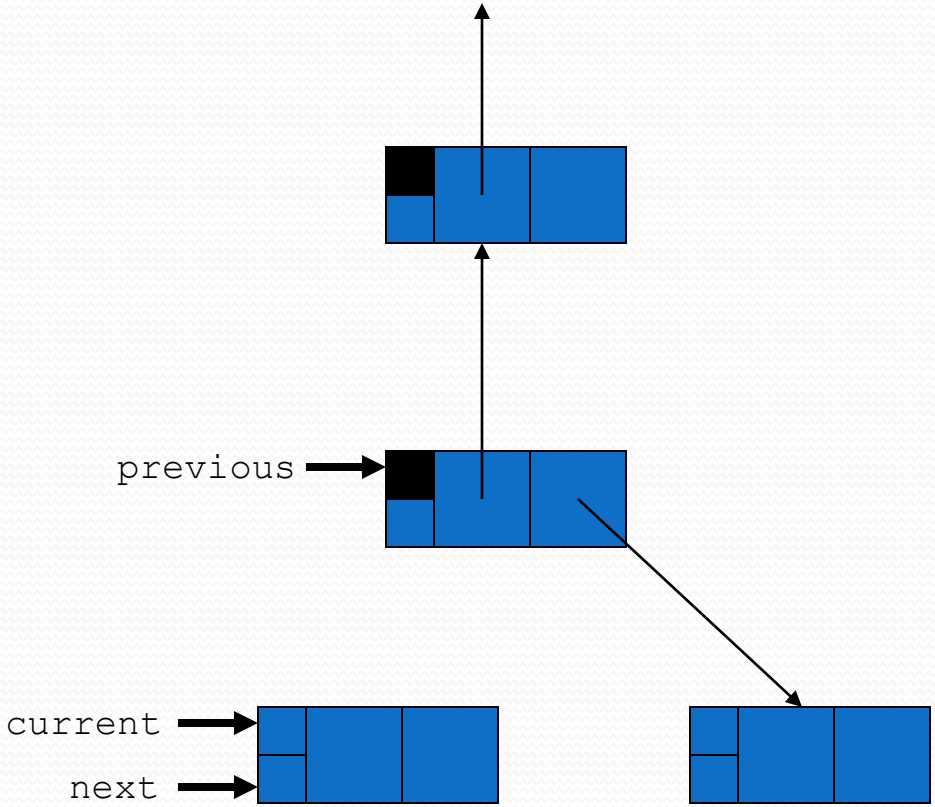
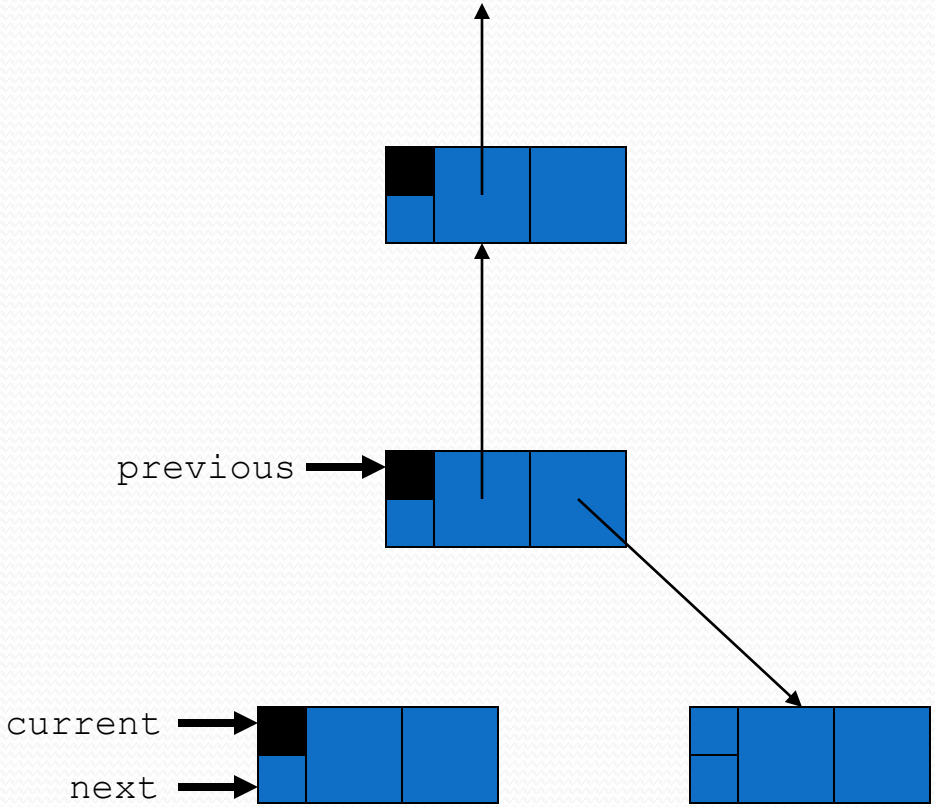


Pointer reversal (advance phase)



Pointer reversal (switch phase)



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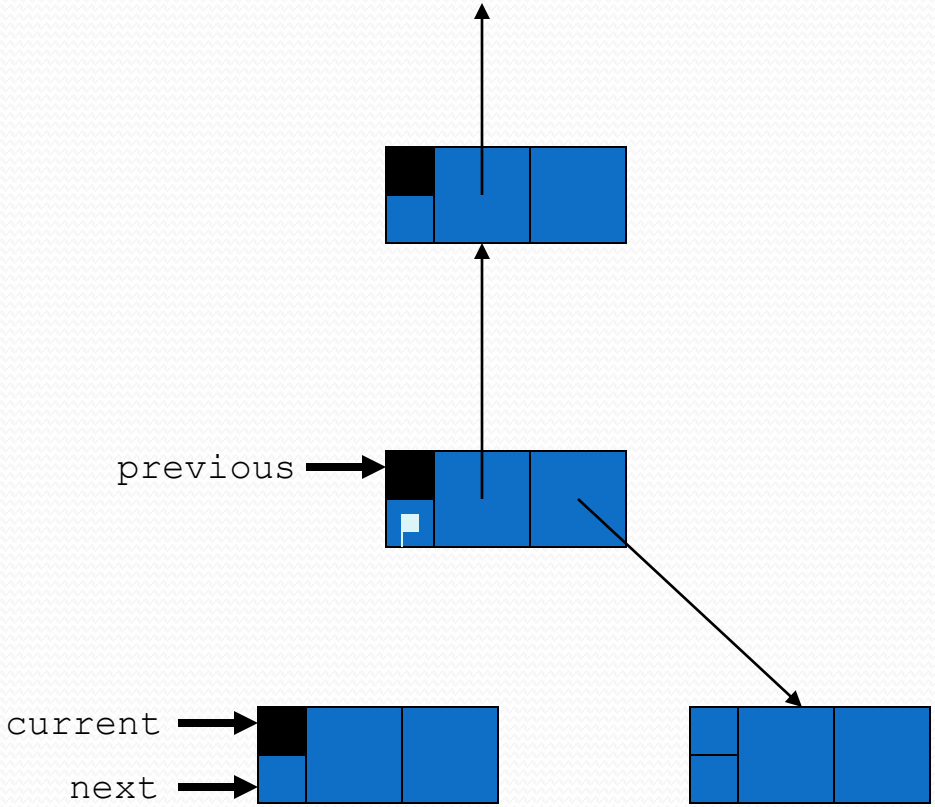

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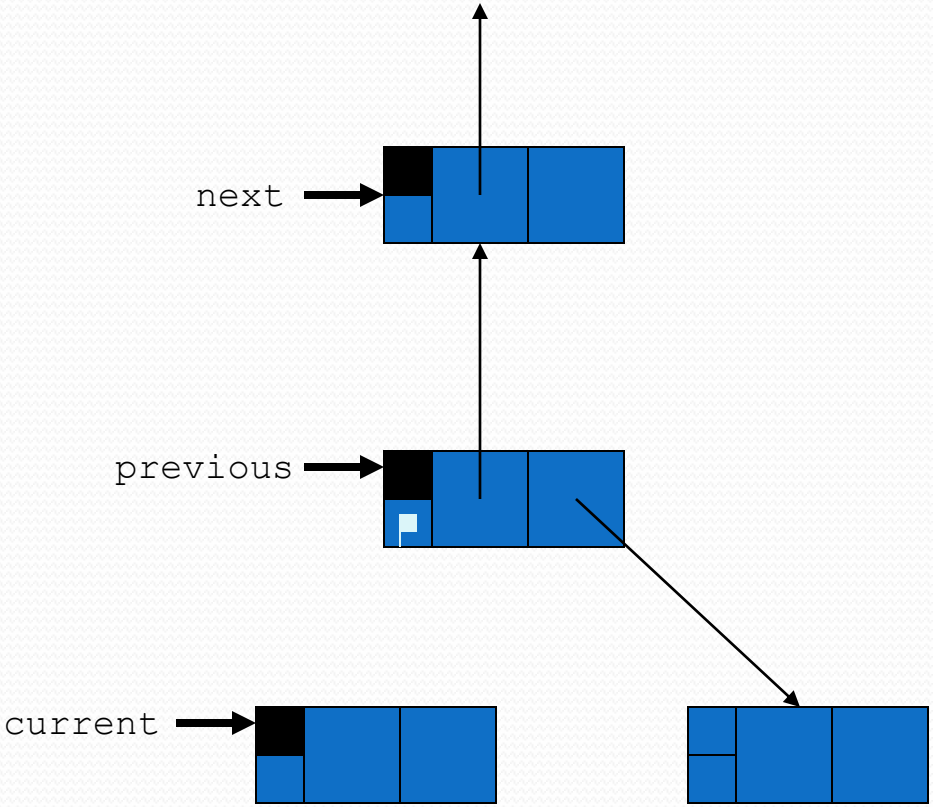
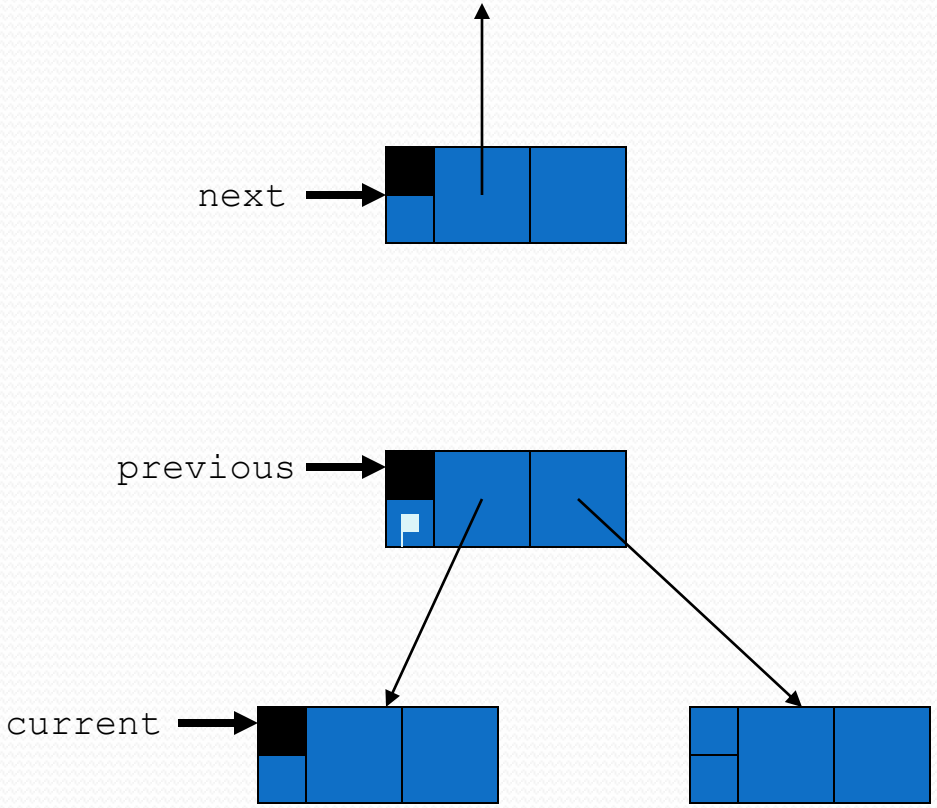
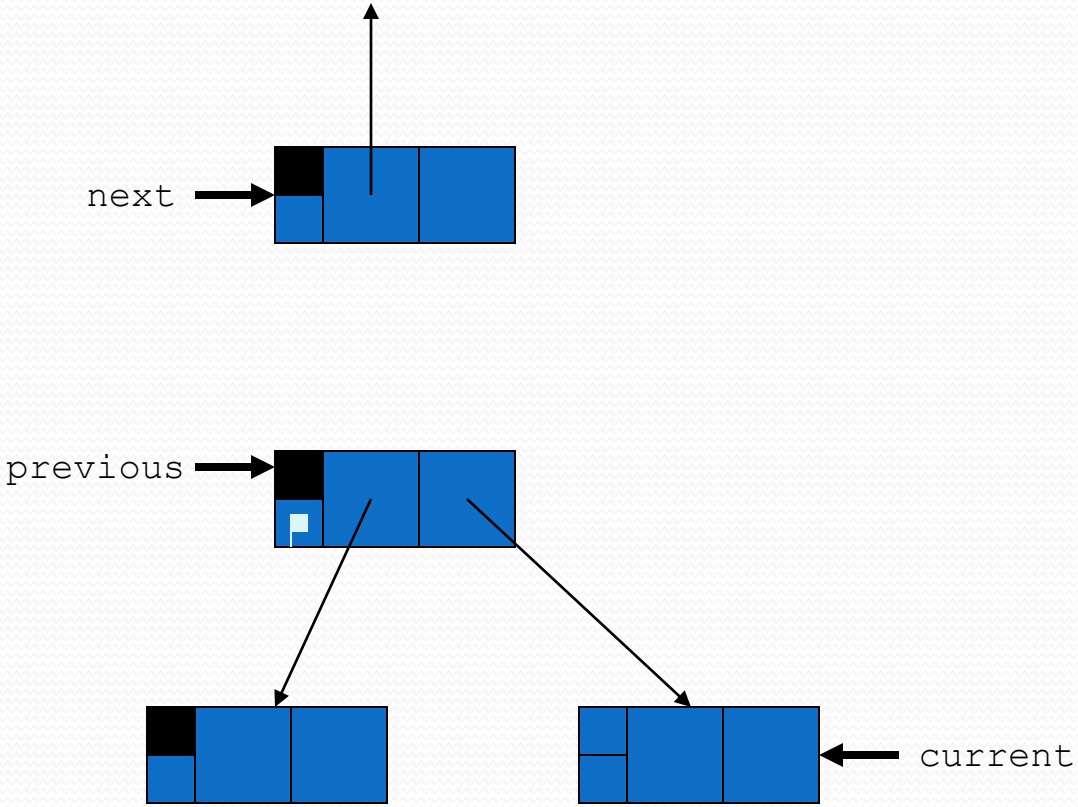


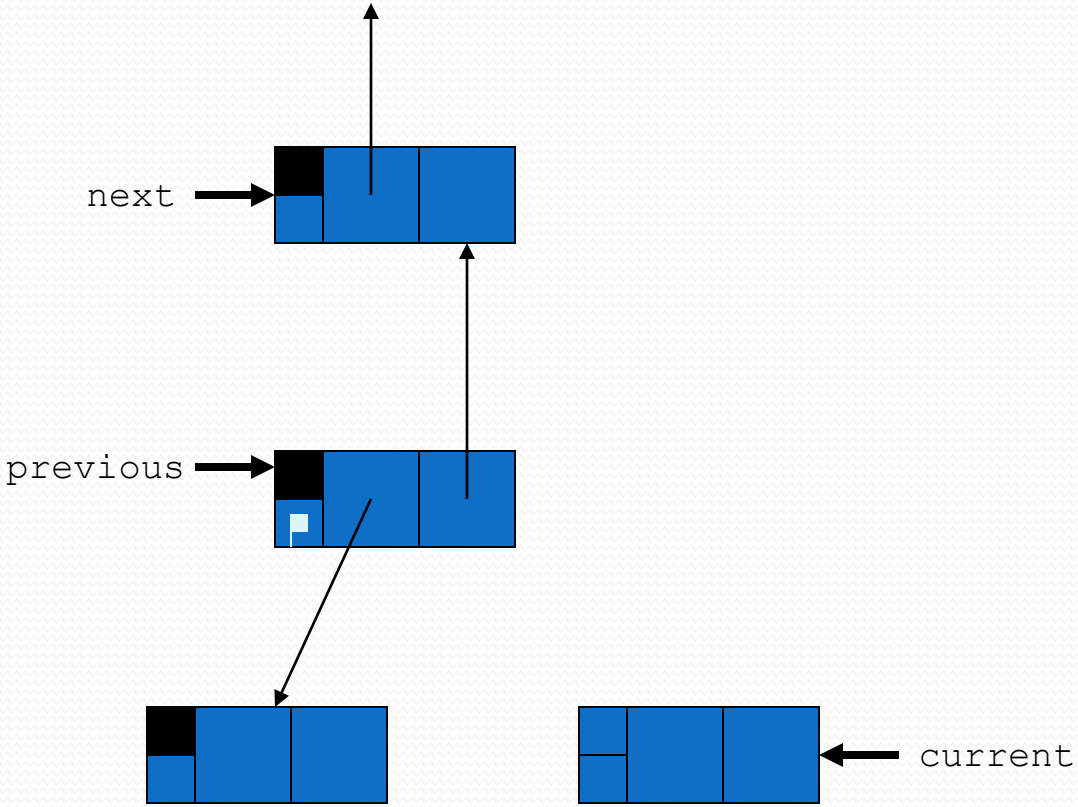
Pointer reversal (switch phase)



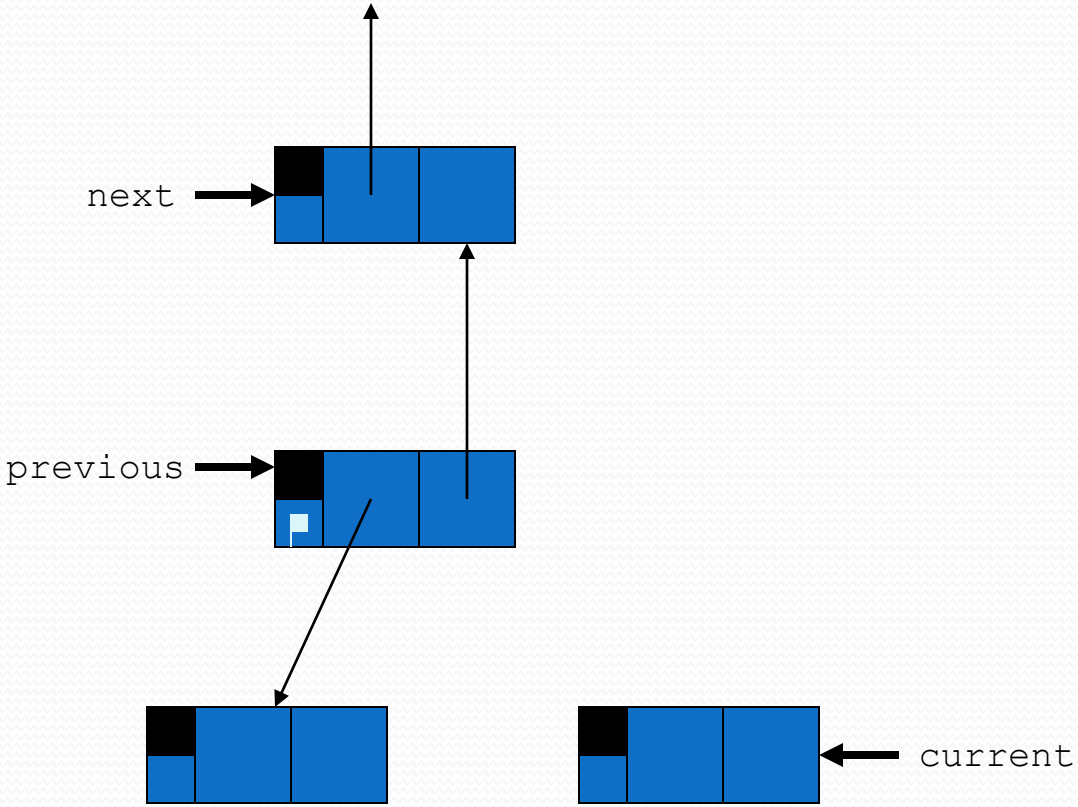
Pointer reversal (switch phase)



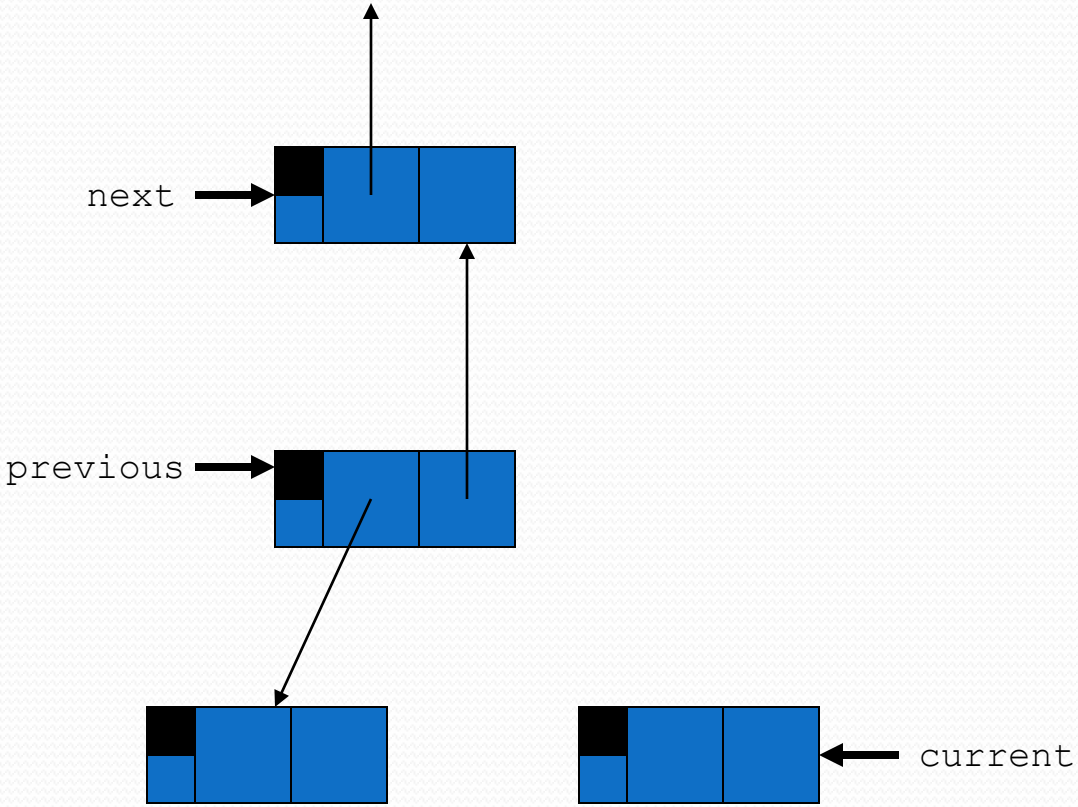
Pointer reversal (switch phase)



Pointer reversal (retreat phase)



Pointer reversal (retreat phase)



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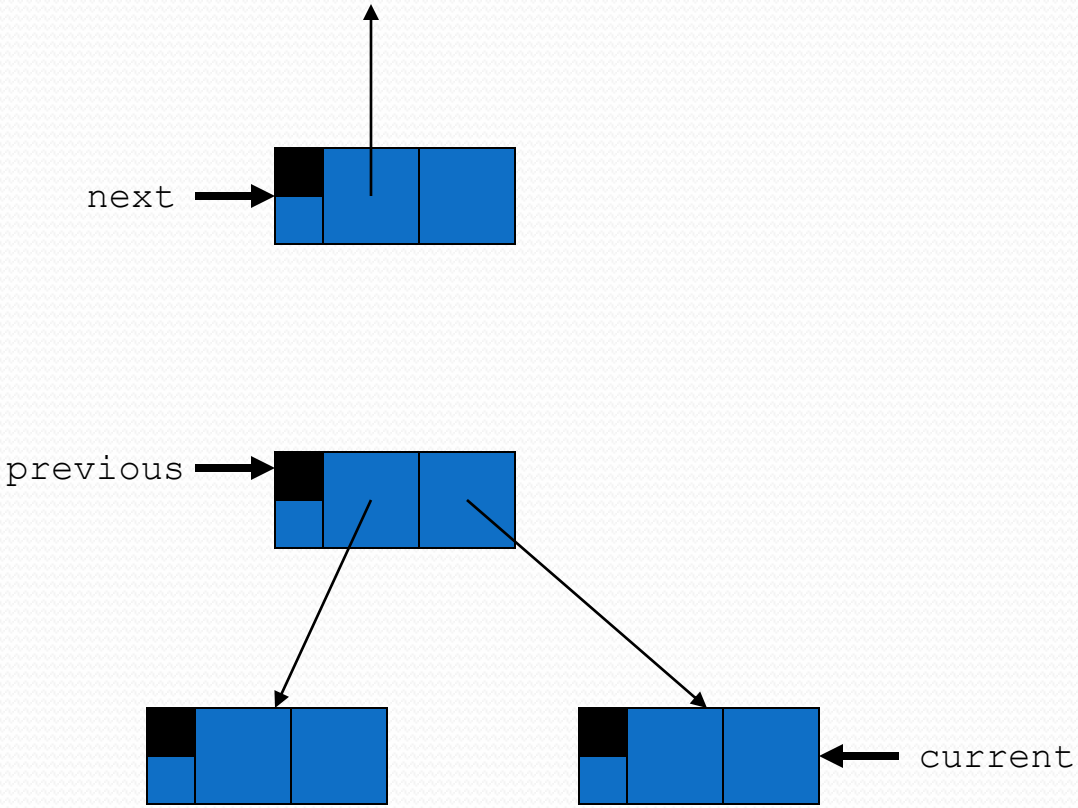

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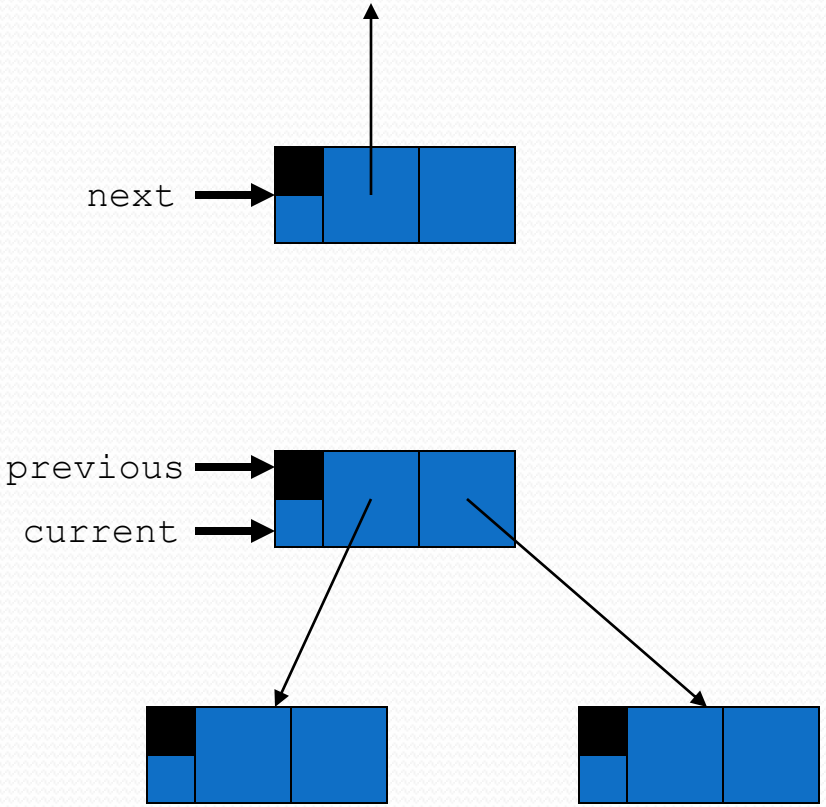

Pointer reversal (retreat phase)