Midterm Review -1

Yan Yan

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1. C review -- pointers
2. Complexity
   1. Calculations of Big-O, Big Omega, & Theta
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Pointers: what for?

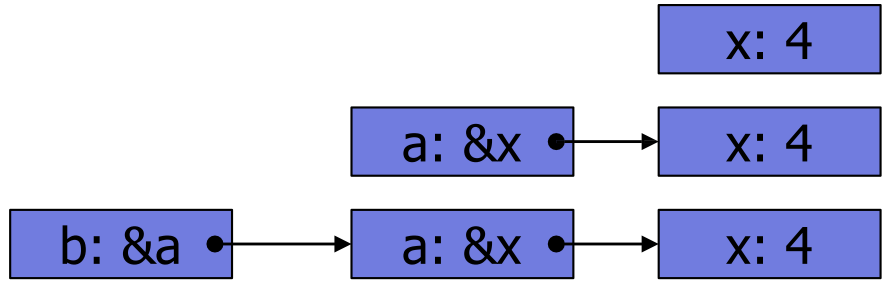
- A pointer is defined by its type and holds a value
- value: indicates where in memory the pointer refers to
  - always a memory address
- type: indicates what in memory the pointer refers to
  - almost always indicates the object's size – there are two exceptions:
    - Pointer to void
    - Pointer to function

Pointers Examples

int x = 4;

int *a = &x;

int **b = &a;



x	4	a	addr(x)	b	addr(a)
&x	addr(x)	&a	addr(a)	&b	addr(b)
*x	illegal	*a	4	*b	addr(x)
*(&x)	4	**a	illegal	**b	4
				***b	illegal

*b == a == &x
**b == *a == x

Pointers and Arrays

- Array name is a pointer as well.
- In an array X, element index i
  - Address: &X[i] or (X+i)
  - Value: X[i] or *(X+i)
- First element address is the base address of the array
  - E.g. X or &X[0]
- Increment of Array name is illegal
  - E.g. X++ // illegal

```
int *pX = X;
pX++; // legal
```

Analyzing Algorithm -- Operations

- Best Case $B(n)$:
  - constraints on the input, other than size, resulting in the fastest possible running time.
- Worst Case $W(n)$:
  - constraints on the input, other than size, resulting in the slowest possible running time.
- Average Case $A(n)$:
  - average running time over every possible type of input (usually involves the probabilities of different types of input).

Analyzing Algorithm -- Operations

Some examples – what's the total operations?

- $x = x + 1;$ *Constant*

- for $(i = 1; i <= n; i++)$
  $x = x + 1;$ *Linear Loop*

- for $(i = 1; i <= n; i++)$
  for $(j = 1; j <= n; j++)$
  $x = x + 1;$ *Nested Loop (Quadratic)*

Order of Growth

- Sub-linear, Linear, Polynomial and Exponential

$$1 < \log n < n < n \log n < n^2 < n^3 < 2^n < n!$$

Big-O

- **Definition**

Let f and g be two functions $f, g : N \rightarrow R^{+}$.

We say that $f(n) \in O(g(n))$

if $\exists c \in R^{+}$ and $n_0 \in N$ such that for every integer $n \geq n_0$, $f(n) \leq cg(n)$.

Omega Notation (Ω)

- **Definition**

Let f and g be two functions $f, g : N \rightarrow R^{+}$.

We say that $f(n) \in \Omega(g(n))$

if $\exists c \in R^{+}$ and $n_0 \in N$ such that for every integer $n \geq n_0$, $f(n) \geq cg(n)$.

Theta Notation (Θ)

- **Definition**

Let f and g be two functions $f, g : N \rightarrow R^+$.

We say that $f(n) \in \Theta(g(n))$

if $f \in \Omega(g)$ and $f \in O(g)$

(or $\exists c_1, c_2 \in R^+$ *and* $n_0 \in N$, $c_1 g(n) \leq f(n) \leq$ $c_2 g(n)$, $\forall n \geq n_0$ *)*

Little-o

- **Definition**

Let f and g be two functions $f,\ g : N \rightarrow\ R^{+}$.

We say that $f(n) \in o(g(n))$

if $\exists c \in\ R^{+}$ and $n_0 \in\ N$ such that for any $c > 0$, $n_0 > 0$,

$f(n) \leq cg(n)$, for every integer $n \geq\ n_0$

Little Omega Notation (ϖ)

- **Definition**

Let f and g be two functions $f, g : N \rightarrow R^+$.

We say that $f(n) \in \boldsymbol{\varpi}(g(n))$

if $\exists c \in R^+$ and $n_0 \in N$ such that for any $c > 0$, $n_0 > 0$,

$f(n) \geq cg(n)$, for every integer $n \geq n_0$

Sample Long Answer Questions

- Show that $2n^2 + n = \Theta(n^2)$
- Show that $2n = \Omega(n)$

- Questions and examples in the course slides and A1

Sample Long Answer Questions

- Describe the difference between big-O and little-o

Sorting

- **Sorting**: Rearranging the values in an array or collection into a specific order (usually into their "natural ordering").
  - one of the fundamental problems in computer science
- Input: A sequence of n objects
  - $s = \langle a_1, a_2, \ldots, a_n \rangle$
- Output: A permutation (reordering) $\langle a'_1, a'_2, \ldots, a'_n \rangle$ such that $a'_1 \leq a'_2 \leq \ldots \leq a'_n$.

Sorting Algorithms

- Bubble sort
- Insertion sort
- Selection sort

Implement and write the pseudocode/steps

- Merger sort
- Quick sort

Describe the process

Sorting Algorithms

- **bubble sort**: swap adjacent pairs that are out of order
- **selection sort**: look for the smallest element, move to front
- **insertion sort**: build an increasingly large sorted front portion
- **merge sort**: recursively divide the array in half and sort it
- **quick sort**: recursively partition array based on a middle value

Insertion Sort Algorithm

- Uses only a fixed amount of storage that needed for the data:
- Pseudocode:

```
Algorithm: Insertion-Sort(A)
for j = 2 to A.length
    key = A[j]
    i = j - 1
    while i > 0 and A[i] > key
        A[i + 1] = A[i]
        i = i -1
    A[i + 1] = key
```

Bubble Sort Algorithm

- Uses only a fixed amount of storage that needed for the data:
- Pseudocode:

```
Algorithm: Sequential-Bubble-Sort (A)
fori ← 1 to length [A] do
for j ← length [A] down-to i +1 do
   if A[A] < A[j-1] then
      Exchange A[j] ⟷ A[j-1]
```

Selection Sort Algorithm

- Uses only a fixed amount of storage that needed for the data:
- Pseudocode:

```
Algorithm: Selection-Sort (A)
fori← 1 to n-1 do
   min j ←i;
   min x ← A[i]
   for j ←i + 1 to n do
      if A[j] < min x then
         min j ← j
         min x ← A[j]
   A[min j] ← A [i]
   A[i] ← min x
```

Sorting Algorithms Complexity Summary

Algorithm	Time Complexity		Space Complexity
	Best	Worst	Worst
Bubble Sort	$\Omega(n)$	$O(n^2)$	$O(1)$
Selection Sort	$\Omega(n^2)$	$O(n^2)$	$O(1)$
Insertion Sort	$\Omega(n)$	$O(n^2)$	$O(1)$
Merge Sort	$\Omega(n \log(n))$	$O(n \log(n))$	$O(n)$
Quick Sort	$\Omega(n \log(n))$	$O(n^2)$	$O(n)$

Sample Short Answer Questions

- Some sorting algorithms are applied to the following data [25, 23, 17, 5, 13]. After 2 passes, the rearrangement of the data are shown below. Match the data with the sorting algorithms used.

[17, 5, 13, 23, 25]

[17, 23, 25, 5, 13]

[5, 13, 17, 25, 23]

Insertion Sort

Selection Sort

Bubble Sort

Sample Short Answer Questions

- Some sorting algorithms are applied to the following data [25, 23, 17, 5, 13]. After 2 passes, the rearrangement of the data are shown below. Match the data with the sorting algorithms used.

[17, 5, 13, 23, 25]

Bubble Sort

[17, 23, 25, 5, 13]

Insertion Sort

[5, 13, 17, 25, 23]

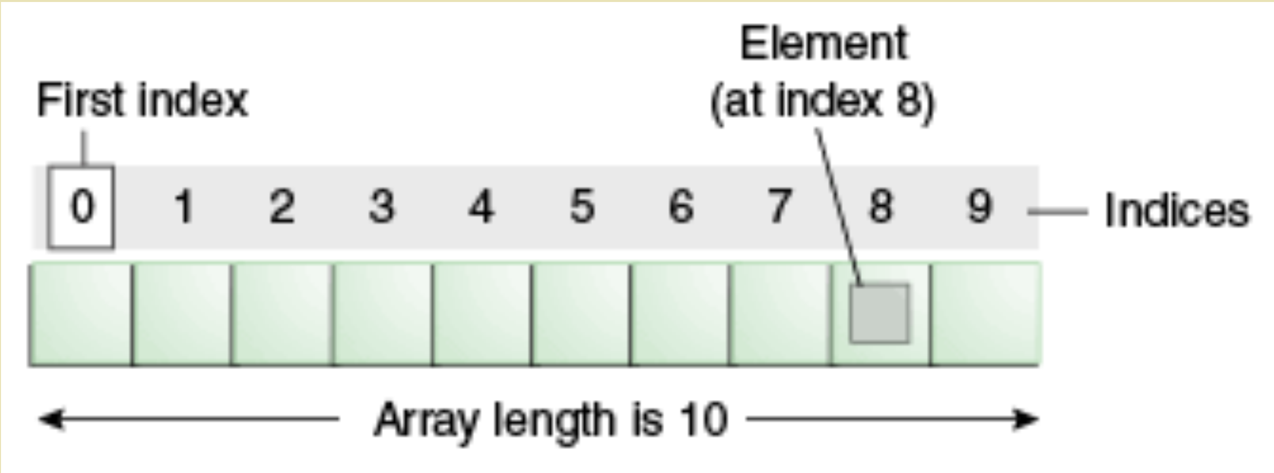
Selection Sort

Sample Short Answer Questions

- In the **worst** case, **selection** sort has a time complexity of _____.
- In the **worst** case, **insertion** sort has a time complexity of _____.
- In the **worst** case, **merge** sort has a time complexity of _____.
- In the **best** case, **insertion** sort has a time complexity of _____.

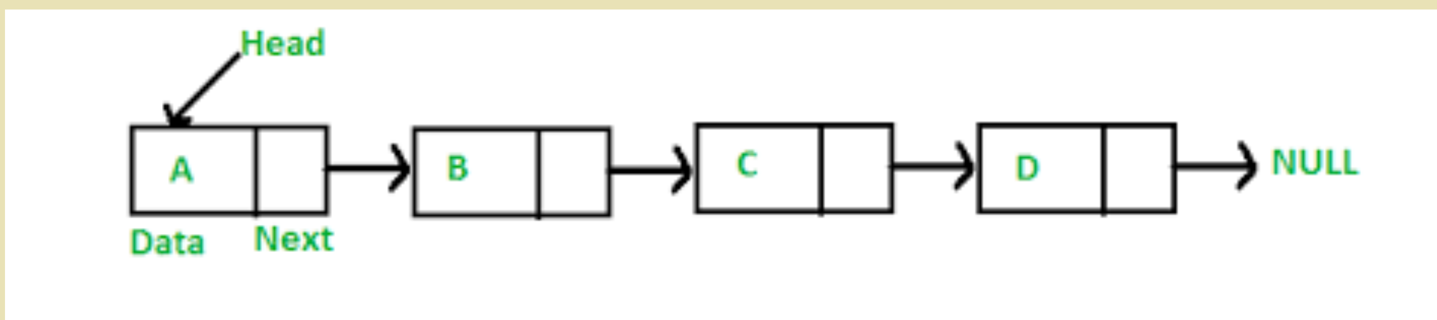
List Implementations

- **Array**:
  – a container object that holds a fixed number of values of a single type. The length of an array is established when the array is created.



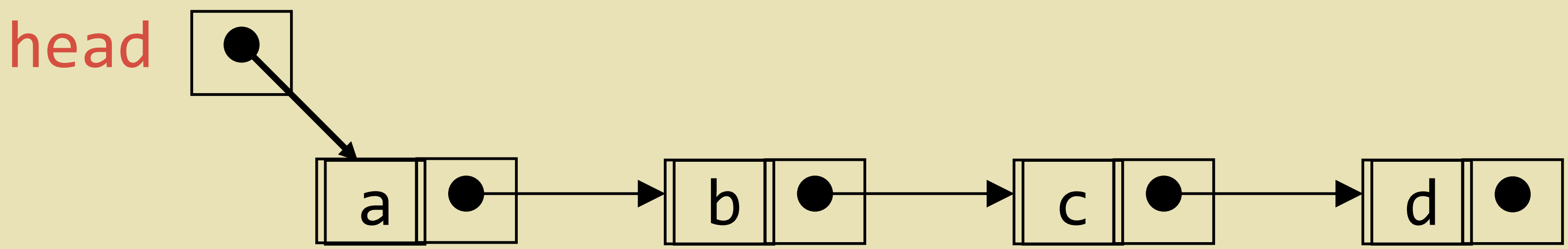
List Implementations

- **Linked Lists**
  - data structure which can change during execution. Successive elements are connected by pointers. Last element points to NULL.



Anatomy of a linked list

- A linked list consists of:
  - A sequence of nodes



Each node contains a value
and a link (pointer or reference) to some other node

The last node contains a null link

More terminology

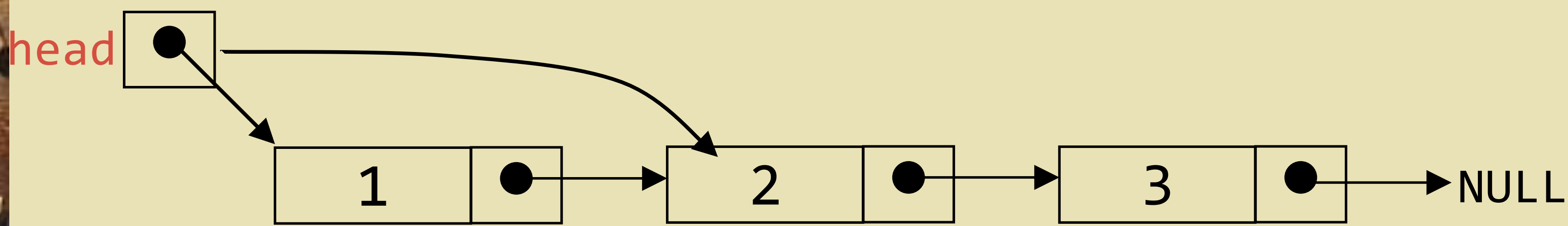
- A node's successor is the next node in the sequence
  - The last node has no successor
- A node's predecessor is the previous node in the sequence
  - The first node has no predecessor
- A list's length is the number of elements in it
  - A list may be empty (contain no elements)

Inserting a node into a SLL

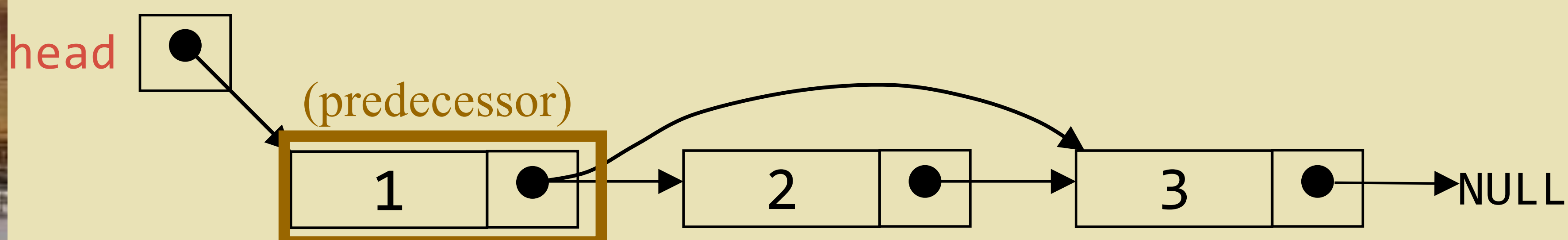
- Insert a new node into a list:
  - As the new first element
  - As the new last element
  - After a given node
  - After a given value
- Review the course slides to understand the implementation.

Deleting an element from a SLL

- To delete the first element, change the head

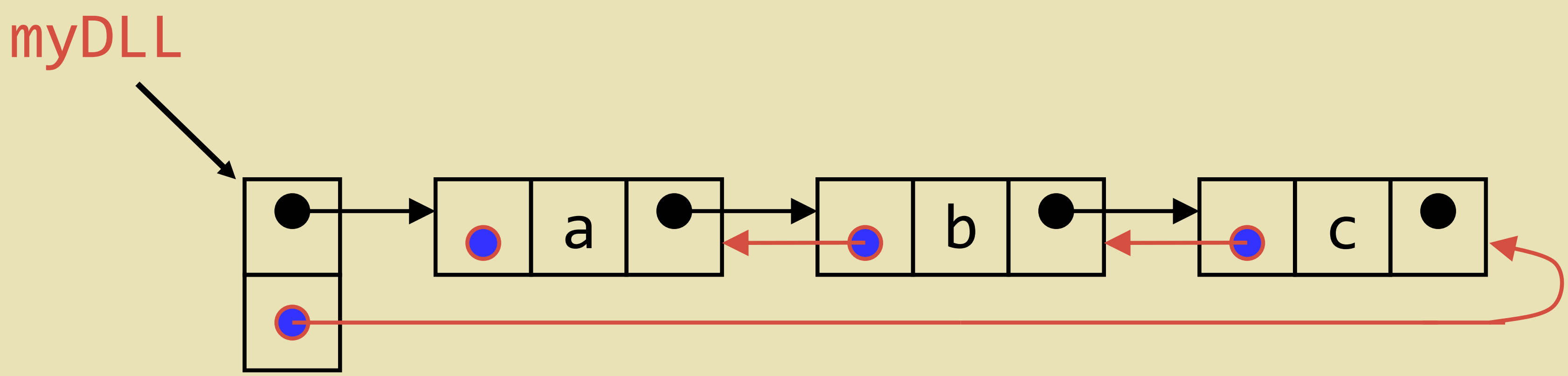


- To delete some other element, change the link in its predecessor



Doubly-linked lists

- Here is a doubly-linked list (DLL):



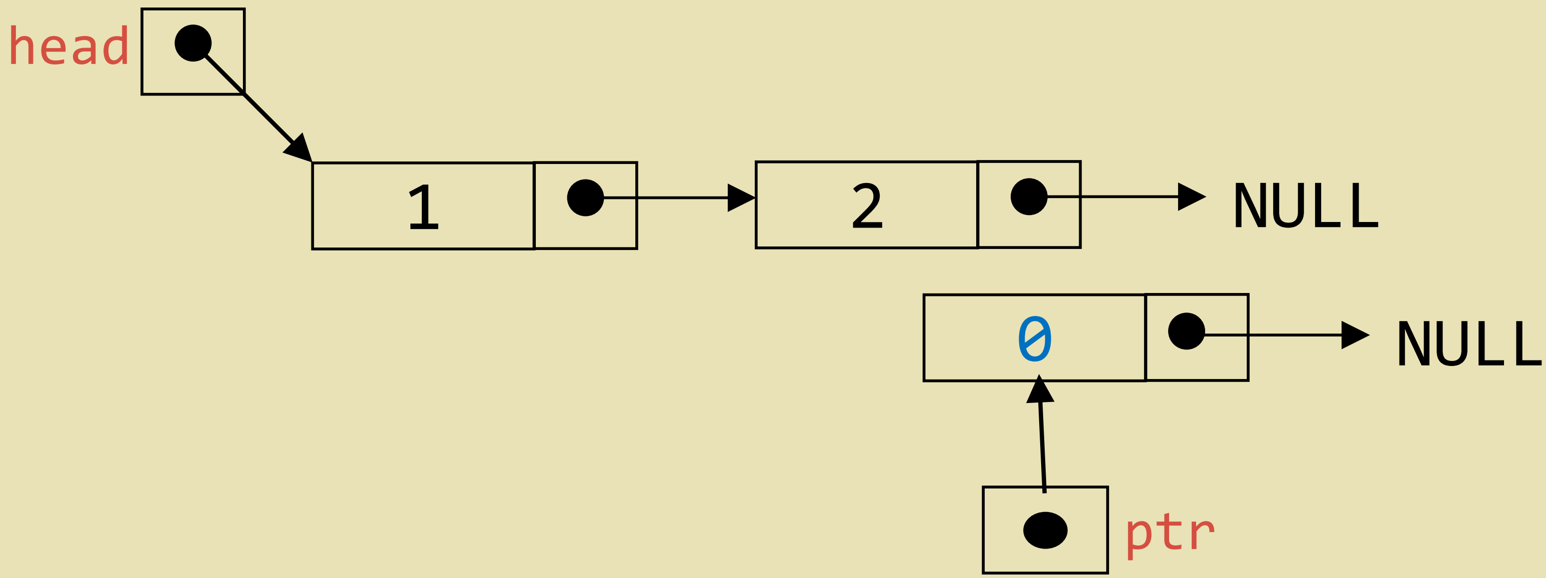
- Each node contains a value, a link to its successor (if any), *and* a link to its predecessor (if any)
- The head points to the first node in the list *and* to the last node in the list (or contains null links if the list is empty)。 The two pointers are also called head and tail.
- DLL structure -- *two* pointers for each node

Doubly-linked lists

- Operations
  - Append
  - Prepend
  - Traversal and Reverse Traversal
- Review course slides for examples

Sample Long Answer Questions

- Assume we have the following linked list created and a new node 0 created



- If you need to insert 0 before 1, how are the pointers will be updated?
- If you need to insert 0 after 2, how are the pointers will be updated?

Sample Long Answer Questions

- Write down one advantage and one disadvantage of doubly-linked list compared with singly-linked list.

More on Midterm Questions

- Please review ALL questions/examples/exercise in the lecture slides, labs, and A1.