CSE221

Linked Lists

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Acknowledgment: The content of this file is based on the slides of the textbook as well as the slides provided in former lectures at UNIST.

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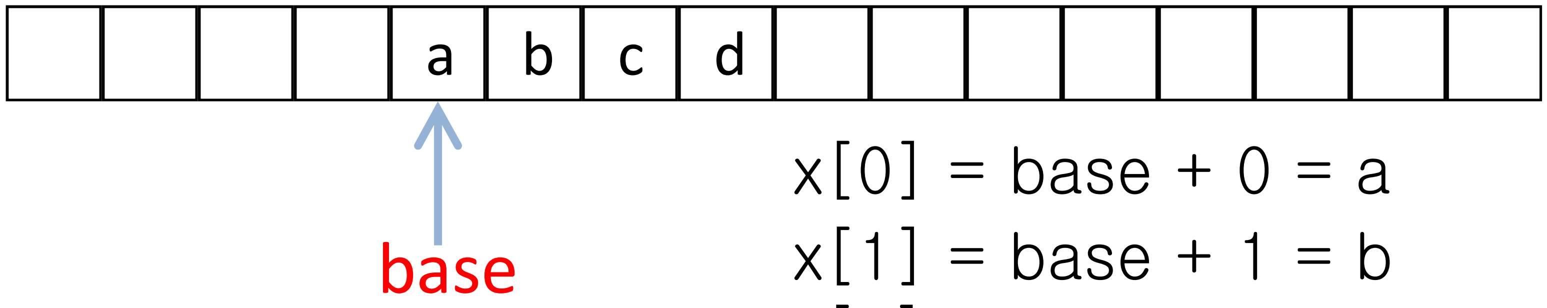
Recap: Arrays

1-dimensional array



x[0] = base + 0 = a

x[1] = base + 1 = b

x[2] = base + 2 = c

x[3] = base + 3 = d

- Map into contiguous memory space
- Use index to locate a particular element
  - Location of ist element = base + i

Recap: Two Ways to Store a 2D-Matrix

1 integer

$$
\begin{array}{c|cccccc|}
 & 0 & 1 & 2 & 3 & 4 & 5 \\
\hline
0 & 15 & 0 & 0 & 22 & 0 & -15 \\
1 & 0 & 11 & 3 & 0 & 0 & 0 \\
2 & 0 & 0 & 0 & -6 & 0 & 0 \\
3 & 0 & 0 & 0 & 0 & 0 & 0 \\
4 & 91 & 0 & 0 & 0 & 0 & 0 \\
5 & 0 & 0 & 28 & 0 & 0 & 0
\end{array}
\longrightarrow
$$

3 integers
(3x more space)

	row	col	val
[0]	0	0	15
[1]	0	3	22
[2]	0	5	-15
[3]	1	1	11
[4]	1	2	3
[5]	2	3	-6
[6]	4	0	91
[7]	5	2	28

space saving = 12
(36/24 integers in dense/sparse matrix)

- Sparse representation is more effective when there are many empty elements

Recap: Sparse Matrix

- Array of triples <row, col, value> for nonzeros
  - Effective when there are many empty elements

$$\begin{array}{c|cccccc|} & 0 & 1 & 2 & 3 & 4 & 5 \\ \hline 0 & 15 & 0 & 0 & 22 & 0 & -15 \\ 1 & 0 & 11 & 3 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & -6 & 0 & 0 \\ 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 91 & 0 & 0 & 0 & 0 & 0 \\ 5 & 0 & 0 & 28 & 0 & 0 & 0 \end{array} \longrightarrow$$

	row	col	val
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[7]	5	2	28

In fact not a good use case: space saving = 1

Question: Use Arrays for Sparse Matrix?

- It depends
  - Sparse matrix is mainly for optimizing space
  - Recall Array Abstract Data Type (ADT)
    - Mapping between index and value
    - Operators like retrieve value or store value
    - Using array is just an implementation issue
  - Array vs Linked List can be decided by some factors
    - Does the program perform insert() and delete() heavily?
    - Does the program frequently scan the data?

Outline

- Singly linked list
- Doubly linked list
- Circular lists

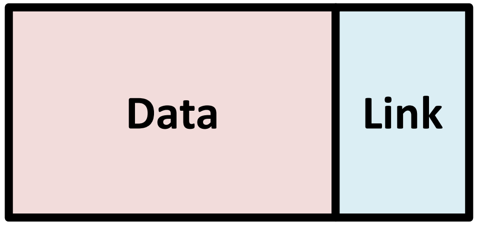
List

- Collection of elements (nodes)
  - that forms a linear ordering
- Examples
  - Shopping list, Laundry list, Black/white list
- Implement with an array
  - static, fixed

Linked List

- Elements are stored in an arbitrary order in memory
  - Each element can be put any physical location
  - Order is maintained by using link

- Node of linked list
  - Data field
  - Link (pointer) fields



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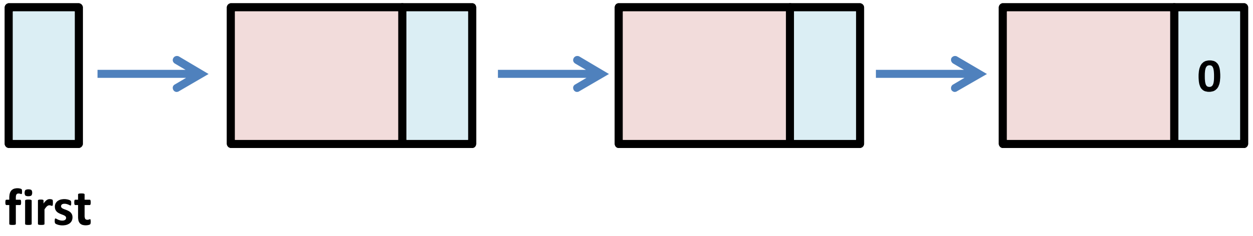
Singly Linked List Representation

- First (or head) pointer points to first node
- A sequential list of nodes through links
- Null terminated at the end

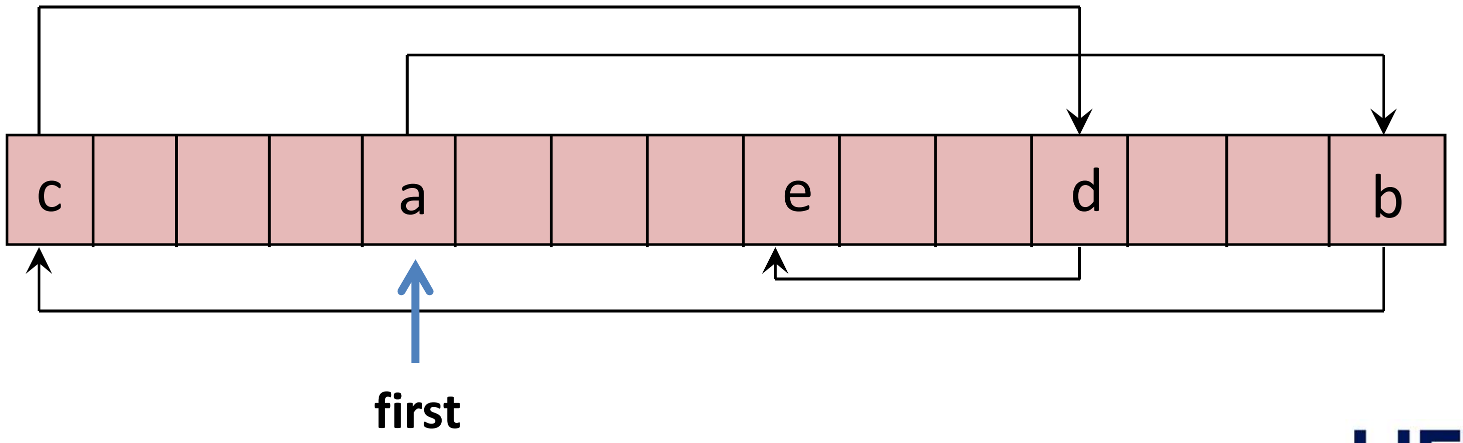


Memory Layout

- L=(a,b,c,d,e)
- Array representation

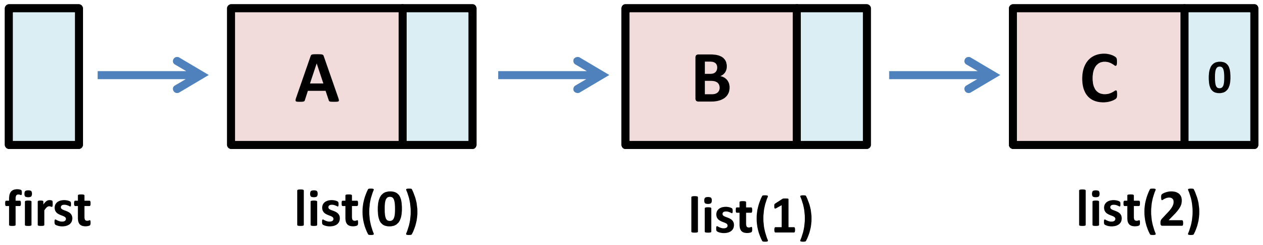
a	b	c	d	e										

- Linked list representation



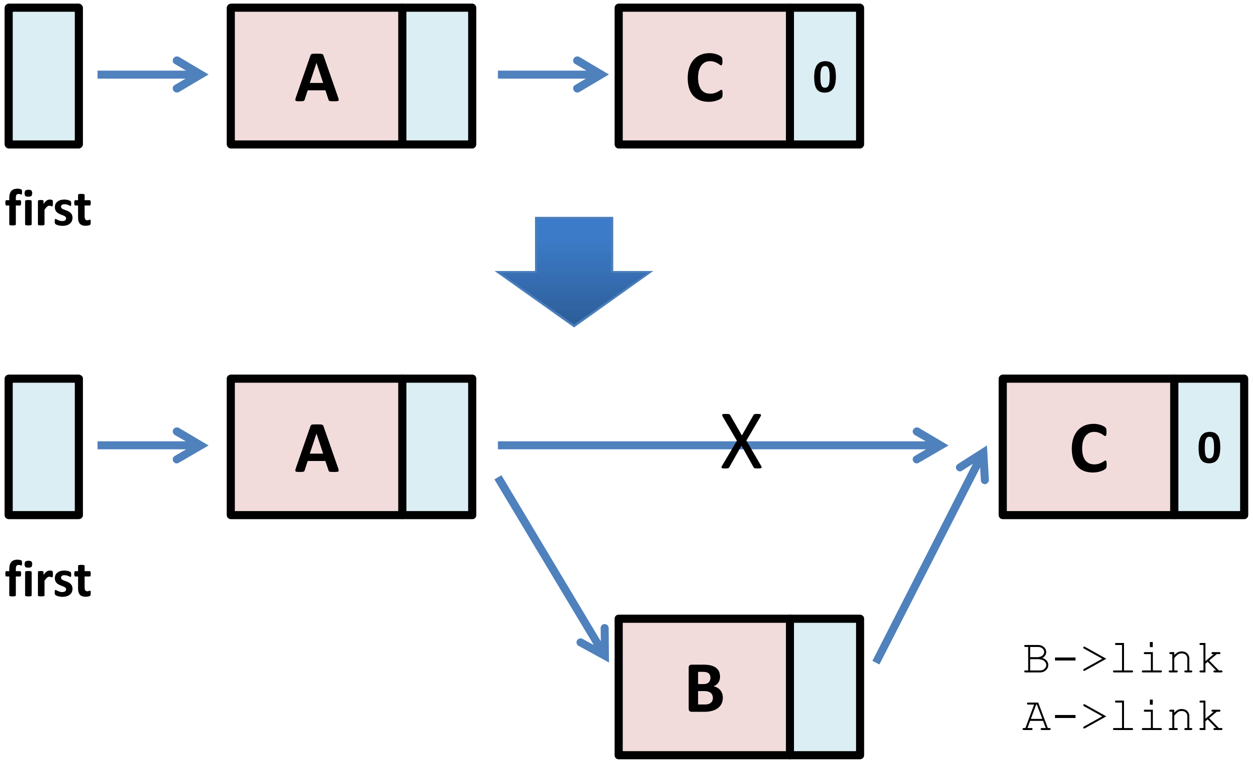
Basic Operations

- Access element
  - list(0) = first->data = A
  - list(1) = first->link->data = B
  - list(2) = first->link->link->data = C



Basic Operations

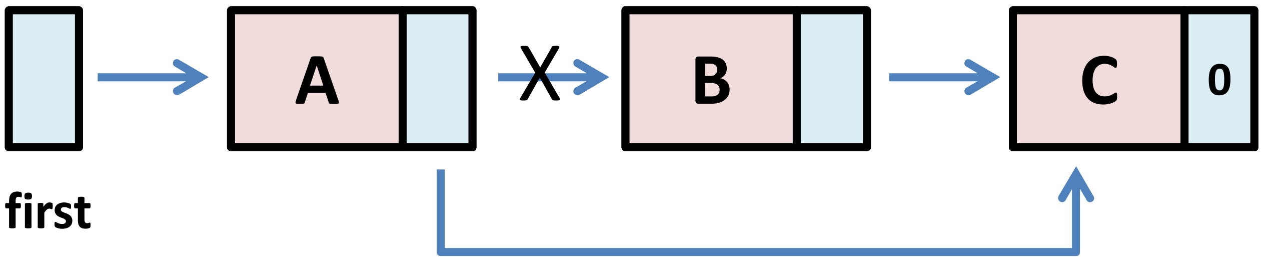
- Insert B after A



```
B->link = A->link
A->link = B
```

Basic Operations

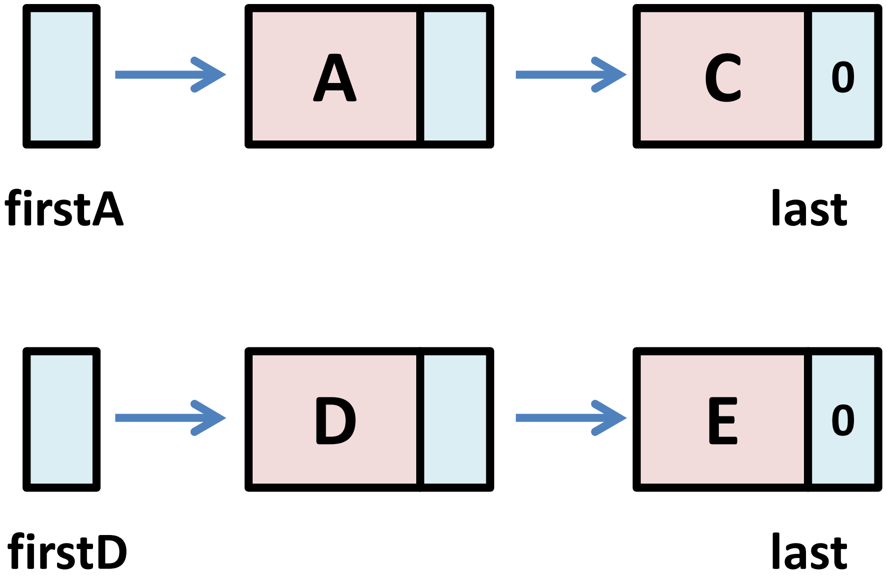
- Delete B
  - –Need A preceding B
    - A has to be either given or searched



```
A->link = B->link
delete B
```

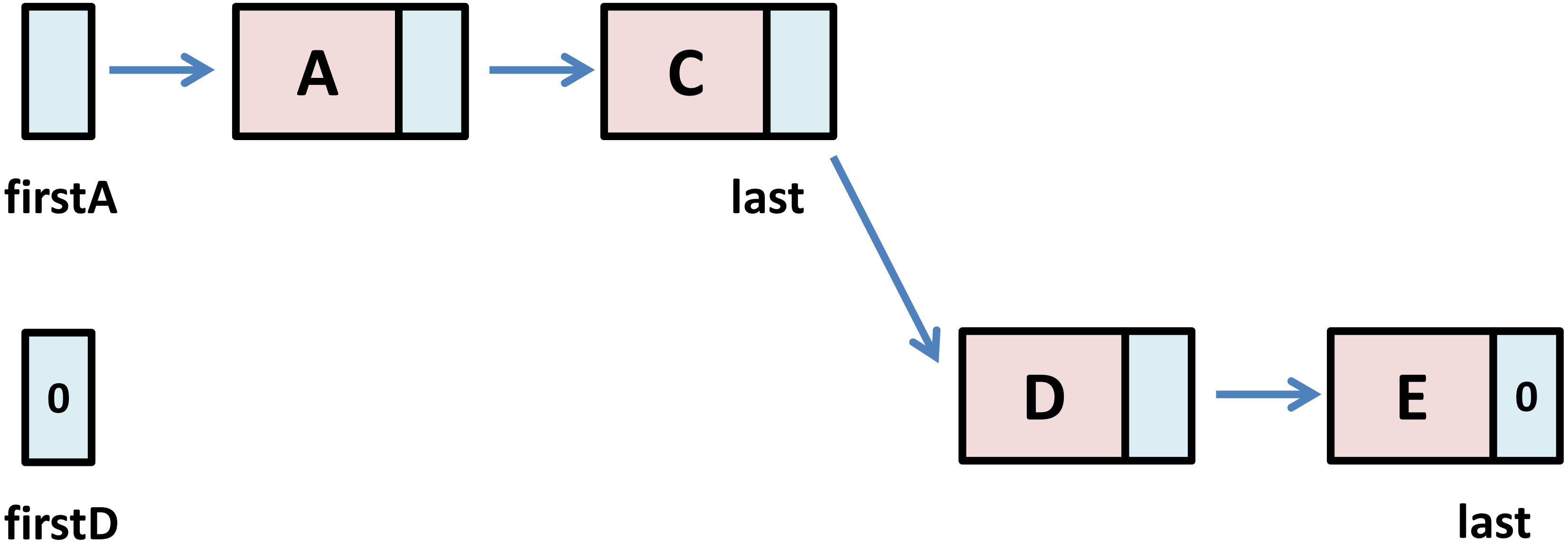
Basic Operations

- Concatenation



Basic Operations

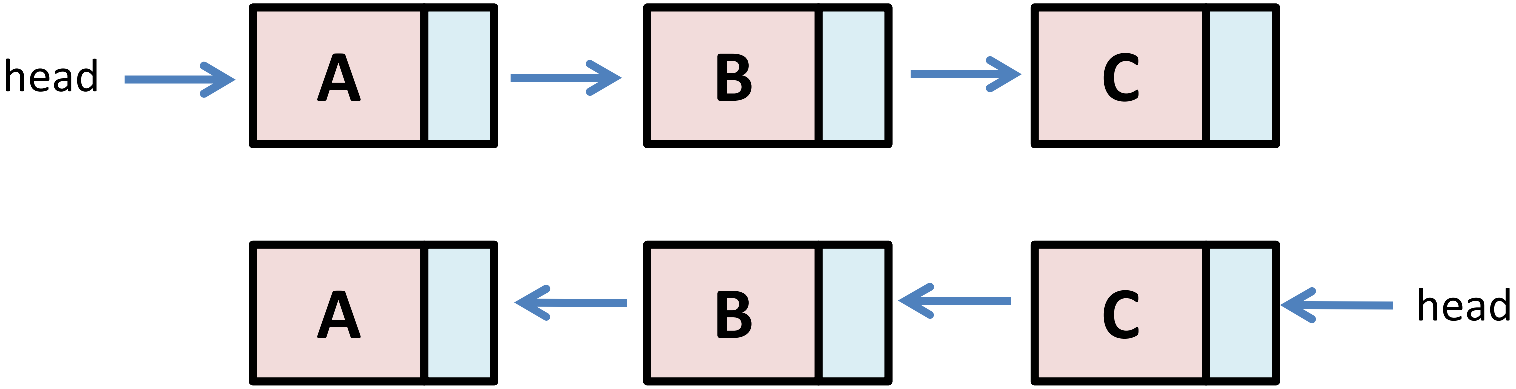
- Concatenation



```
C->link = firstD
firstD = NULL
```

Basic Operations

- Reverse



```
Initially, prev=NULL, current=head, next=NULL

while(current != NULL){
    next= current->next;
    current->next = prev;
    prev=current;
    current=next;
}
head=prev;
```

Recap: Array v.s. Linked List

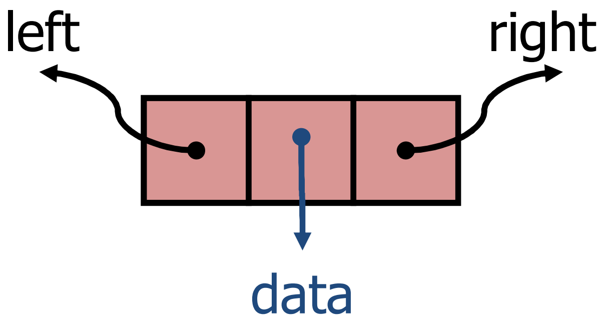
- Arrays
  - –Good for random access and sequential access
    - Indexing
    - Modern architecture reads data at a chunk
- Linked list
  - –Good for frequent inserting and deleting
    - Array must shift data for each inserting and deleting
  - –Resizing is easier
    - Array typically given with non-growable fixed space

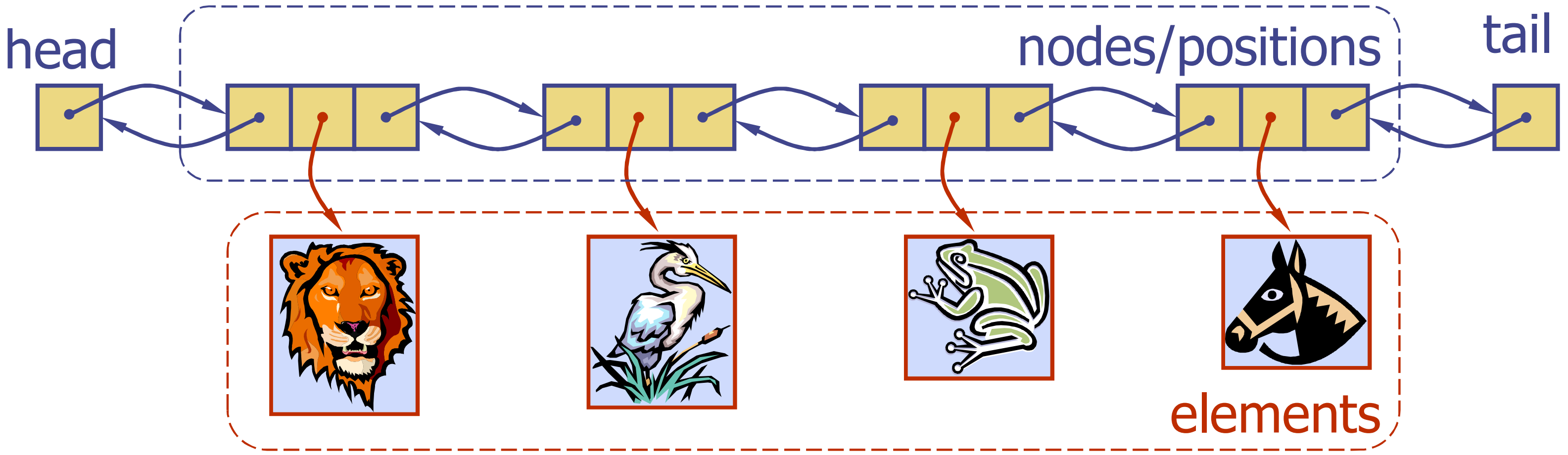
Outline

- Singly linked list
- Doubly linked list
- Circular lists

Doubly Linked List

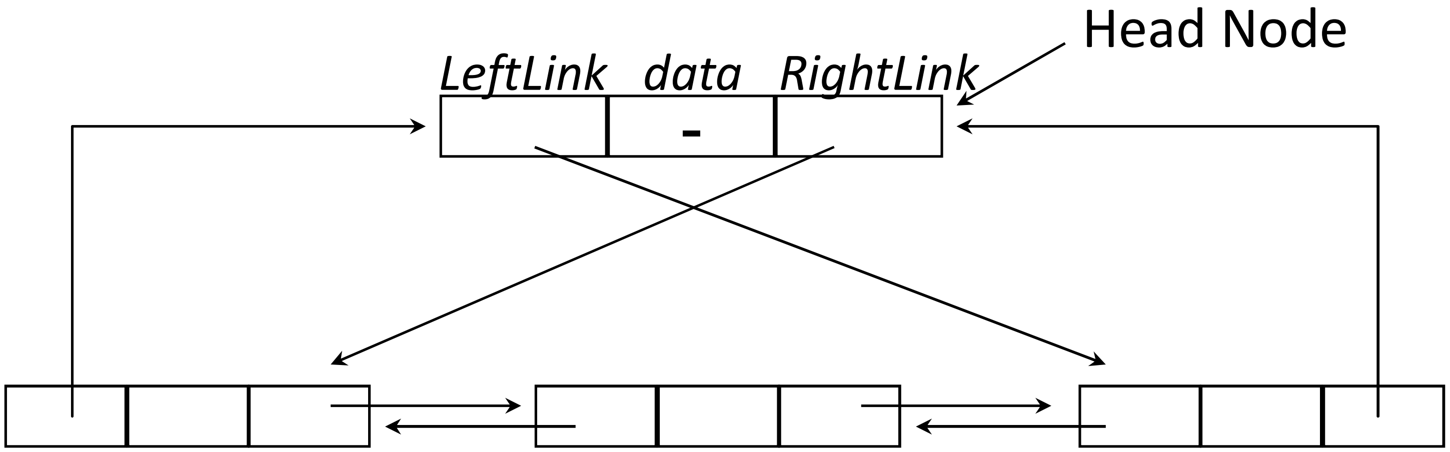
- Two link pointers
  - –Left, right
- Can traverse both directions





Doubly Linked List

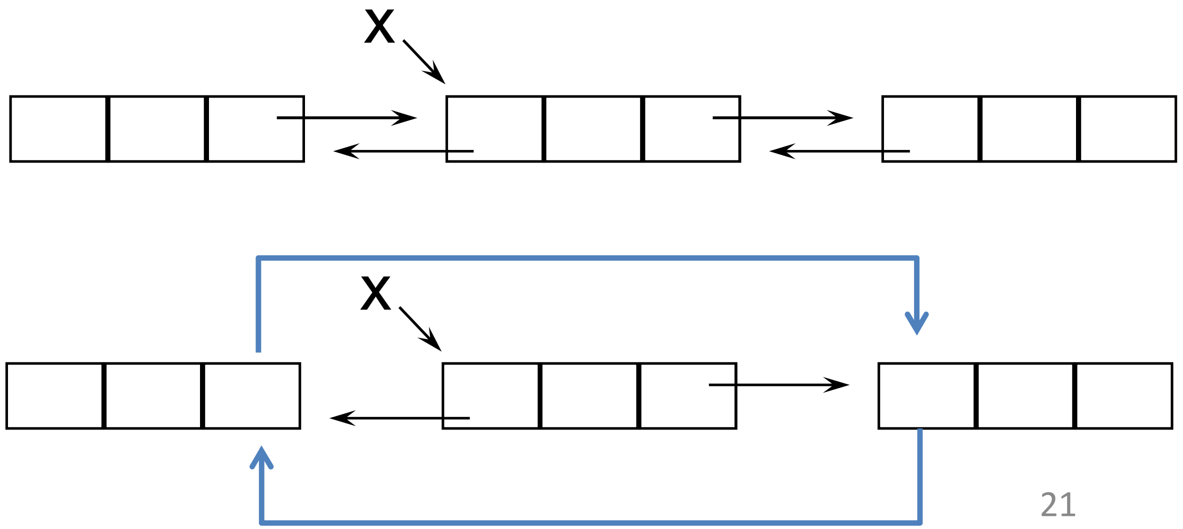
- Using a head node (version 2)
  - Can point to head and tail using a single node



Doubly Linked List

- Delete: no preceding node needed

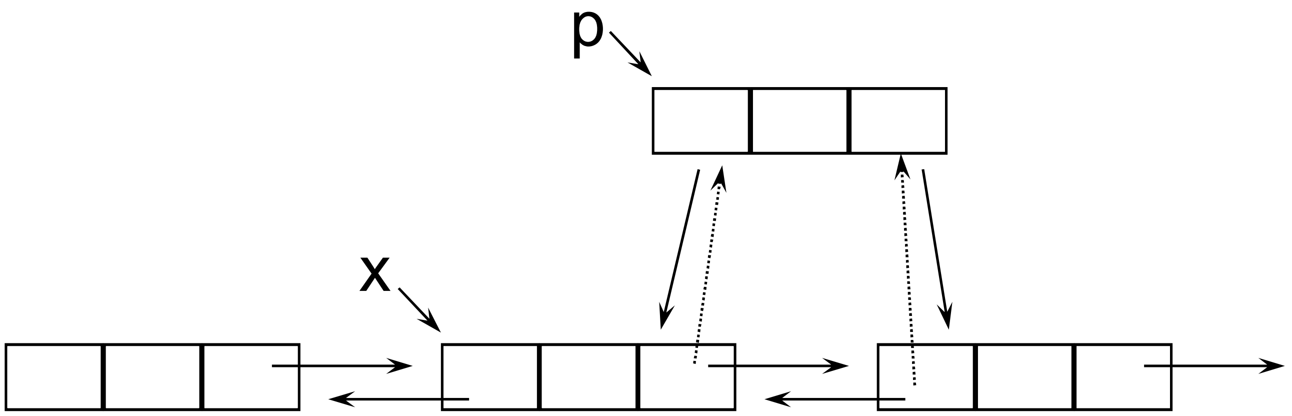
```
void DblList::Delete(DblListNode *x)
{
   x->left->right = x->right;
   x->right->left = x->left;
   delete x;
}
```



Doubly Linked List

- Insert

```
void DblList::Insert(DblListNode *p, DblListNode *x)
{
    p->llink = x;
    p->rlink = x->rlink;
    x->rlink->llink = p;
    x->rlink = p;
}
```

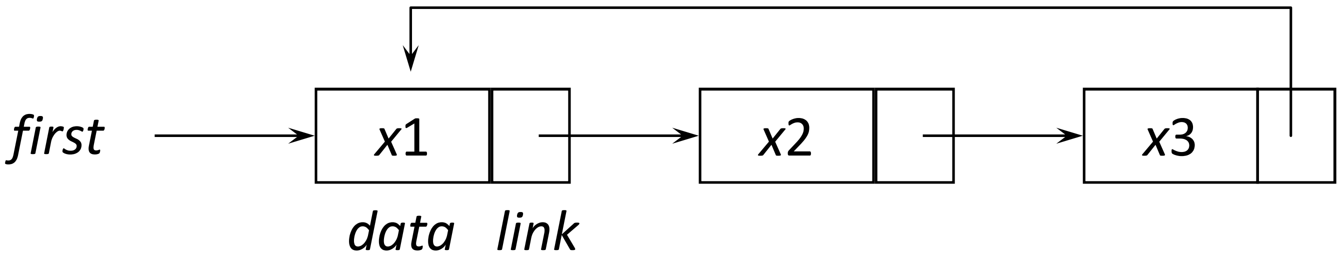


Outline

- Singly linked list
- Doubly linked list
- Circular lists

Circular Linked List

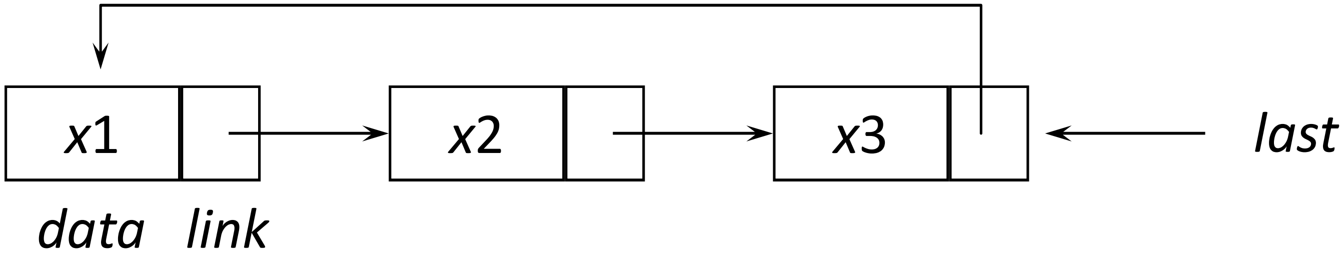
- Link of the last node points to the first node
  - last->link = first
  - No null pointer
- Efficient for circular accessing problems
  - Round-robin scheduling



Circular Linked List

- Insert at the end is inefficient
  - Need to search *last* from *first*

- Keep *last* instead of *first*
  - Insert at the end and front can be O(1)
  - first = last-> link



Tradeoff among Linked Lists

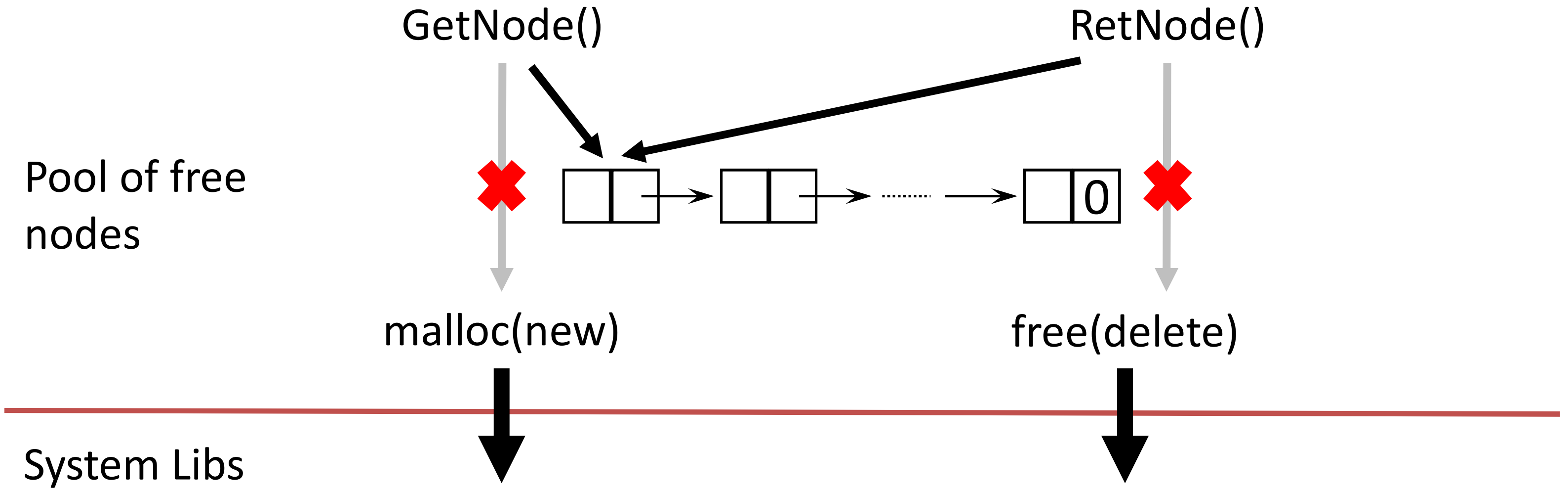
- Singly Linked List ↔ Circular Linked List
  - No difference in space consumption
  - When heavily accessing the first and last element
    - Circular can keep only one pointer (last)
    - Singly needs to keep two pointers (first and last)
- Circular Linked List ↔ Doubly Linked List
  - Doubly consumes roughly 50% more space for pointers
  - More efficient in several use cases, though
    - E.g., 1: accessing the second last elem
    - E.g., 2: delete(index) incurs half memory accesses (no prev pt)

Available Space Lists

- New (malloc) and delete (free) are expensive
  - Need O(n) time to delete all nodes in list of size n
- We can manage a pool (list) of free nodes
  - When allocating a new node, we instead get a free node from the pool
  - When a node is deleted, we return it to the pool
  - Can delete all nodes at O(1)

Available Space Lists

- Deferring and reducing memory function calls
  - –Call malloc() when the list is empty
  - –Call free() when the list is too full



Expensive!

Available Space Lists

- *avail*: first pointer of available space list
- GetNode()

```
template <class Type>
ListNode<Type>* CircList::GetNode()
// Getting a node from the pool
{
    ListNode<Type>* x;
    if(!avail) x = new ListNode<Type>;
    else { x = avail; avail = avail->link; }
    return x;
}
```

System lib call:
expensive

Available Space Lists

- RetNode()

```
template <class Type>
void CircList<Type>::RetNode(ListNode<Type>* x)
// Return x to the free node pool
{
   x->link = avail;
   avail = x;
   x = 0;
}
```

Zeroing. Why?

Available Space Lists

- Delete entire circular list in O(1)

```
template <class KeyType>
void CircList<Type>::~CircList()
// Delete the circular linked list
{
   if (last) {
      ListNode<Type>* first = last->link; // assume we store last
      last->link = avail; // last node linked to avail
      avail = first;  // first node of list becomes front of avail
                         list
      last = 0;
   }
}
```

Questions?