Lists

CSE 373 - Data Structures

April 5, 2002

Readings and References

- Reading
  - › Sections 3.1 - 3.2.8, *Data Structures and Algorithm Analysis in C*, Weiss
- Other References

Review: Pointers and Memory

- Recall that memory is a one-dimensional array of bytes, each with an address
- Pointer variables contain an address

```
int y, *aP, *bP;      // pointer vars use * in declaration

y = 3;
aP = &y;
*aP = 17;

printf("aP: %p\n",aP);
printf("*aP = %d\n",y);        // prints out what?
printf("bP: %p\n",bP);
*bP = 1;                       // what happens? (hint: DOOM)
```

Example result

```
#include <stdio.h>
int main(int argc, char *argv[]) {
  int y, *aP, *bP;     // pointer vars use * in declaration
  y = 3;
  aP = &y;
  *aP = 17;
  printf("aP: %p\n",aP);
  printf("*aP = %d\n",y);      // prints out what?
  printf("bP: %p\n",bP);
  *bP = 1;             // what happens? (hint: DOOM)
  return 0;
}
```

```
aP: 0xbffffa54
*aP = 17
bP: 0x8048441
Segmentation fault (core dumped)
```

Review: Memory Management

- Use “malloc” to allocate a specified number of bytes for new variables

```
aP = (int *) malloc(sizeof(int));
```

  - Use the sizeof operator to compute the number of bytes needed for the data type
  - malloc does not initialize the memory
- To deallocate memory, use “free” and pass a pointer to an object allocated with malloc

```
free(aP);
```

List ADT

- What is a List?
  - Ordered sequence of elements $A_1, A_2, \ldots, A_N$
- Elements may be of arbitrary type, but all are the same type
- Common List operations are
  - Insert, Find, Delete, IsEmpty, IsLast, FindPrevious, First, Kth, Last

List Implementations

- Two types of implementation:
  - › Array-Based
  - › Pointer-Based

List: Array Implementation

- Basic Idea:
  - › Pre-allocate a big array of size MAX_SIZE
  - › Keep track of current size using a variable **`count`**
  - › Shift elements when you have to insert or delete

0	1	2	3	…	count-1		MAX_SIZE-1
A_1	A_2	A_3	A_4	…	A_N		

List: Array Implementation

```
typedef struct _ListInfo (
   ElementType *theArray; //= malloc(MAX_SIZE*sizeof(ElementType))
   int count; // = 0
   int maxsize;  //=MAX_SIZE
}
typedef ListInfo *List;
typedef int Position;

//Empty list has allocated array and count = 0

Need to define: void Insert(List L, ElementType E, Position P)
// Example: Insert E at position P = 2
```

0	1	2	3	…	count-1		MAX_SIZE-1
A_1	A_2	A_3	A_4	…	A_N		

Array List Insert Operation

- Basic Idea: Insert new item and shift old items to the right.

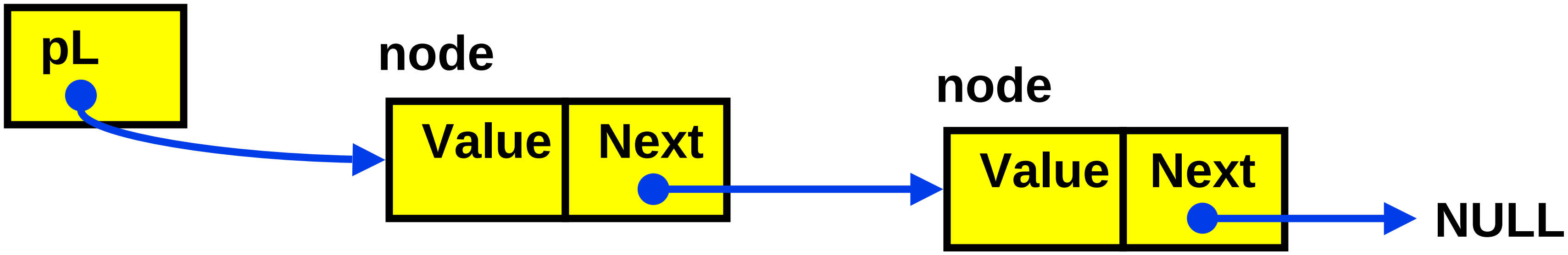
```
void Insert(List L, ElementType e, Position p) {
  Position current;
  if (p > L->count || L->count == MAX_SIZE) exit(1);
  current = L->count;
  while (current != p) {
    L->a[current] = L->a[current-1];
    current--;
  }
  L->a[current] = e;
  L->count++;
}
```

Array List Insert Running Time

- Running time for N elements?
- On average, must move half the elements to make room
- Worst case is insert at position 0. Must move all N items down one position before the insert
- This is O(N) running time.

List: Pointer Implementation

- Basic Idea:
  - › Allocate little blocks of memory (nodes) as elements are added to the list
  - › Keep track of list by linking the nodes together
  - › Change links when you want to insert or delete



List: A Pointer Implementation

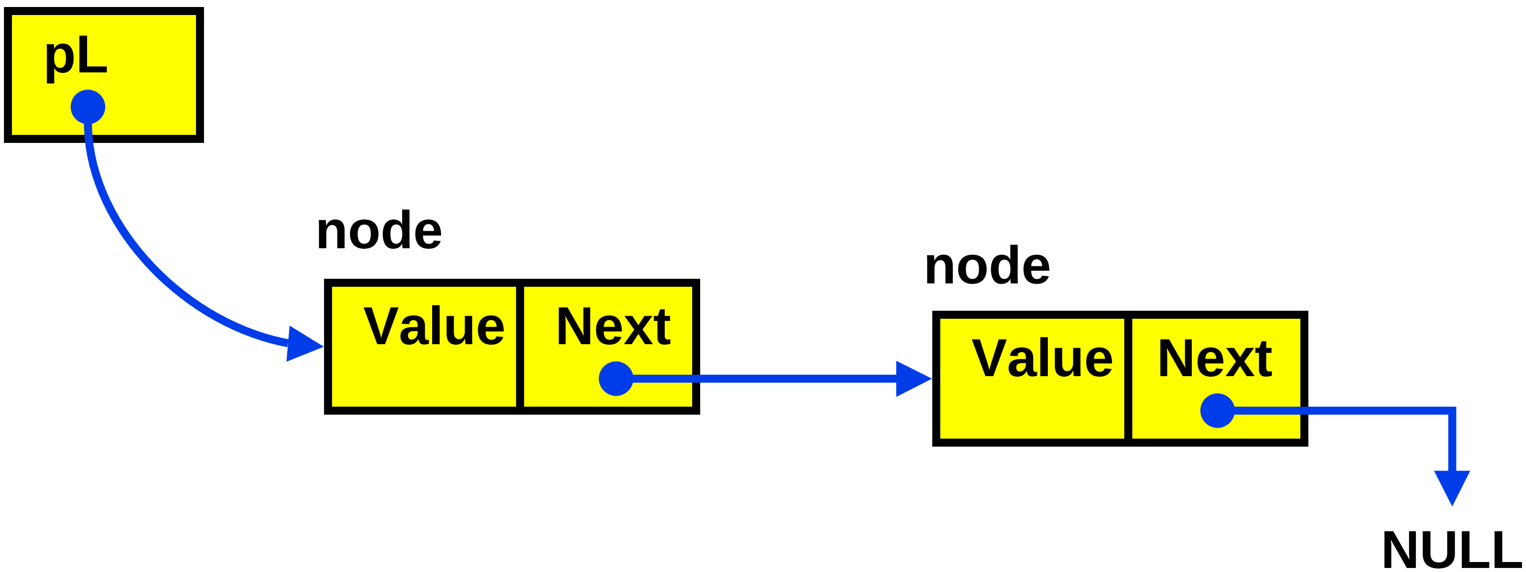
```
typedef struct Node {
   ElementType Value;
   struct Node *next;
};
typedef struct Node *List;
typedef struct Node *Position;

// Pointer to an empty list = NULL

void Insert(List *pL, ElementType E, Position P)

// Insert adds new node after the one pointed to by P
// if P is NULL or list is empty (pL=NULL), insert at
   beginning of list
```

Pointer-Based Linked List

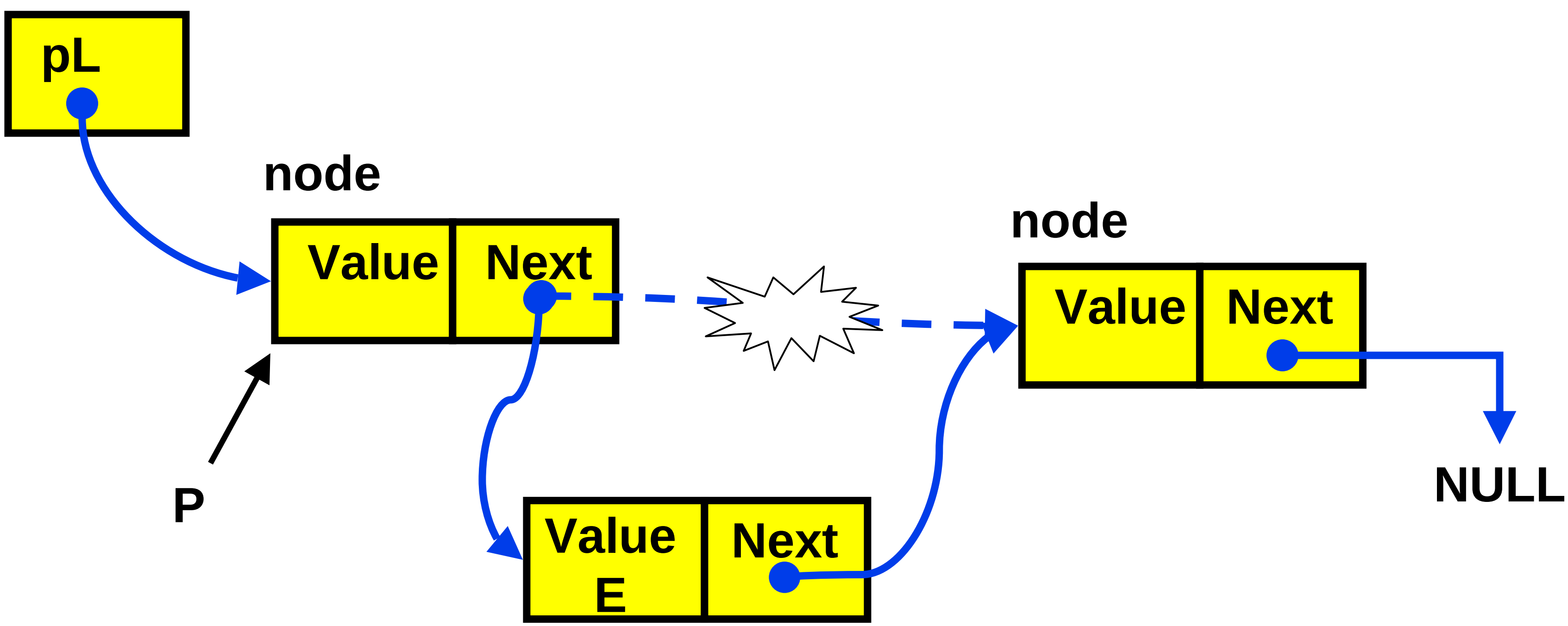


List: A Pointer Implementation

```
// Insert adds new node after the one pointed to by P
// if P is NULL or list is empty, insert at beginning of list

void Insert(List *pL, ElementType E, Position P)
   Position newItem;
   newItem = (struct Node *)malloc(sizeof(struct Node));
   FatalErrorMemory(newItem);
   newItem->Value = E;
   if (pL == NULL || P == NULL) { //insert at head of list
        newItem->next = pL;
        pL = newItem;
   }
   else { // insert newItem after the node pointed to by P
        newItem->next = P->next;
        P->next = newItem;
   }
```

Pointer-based Insert Operation

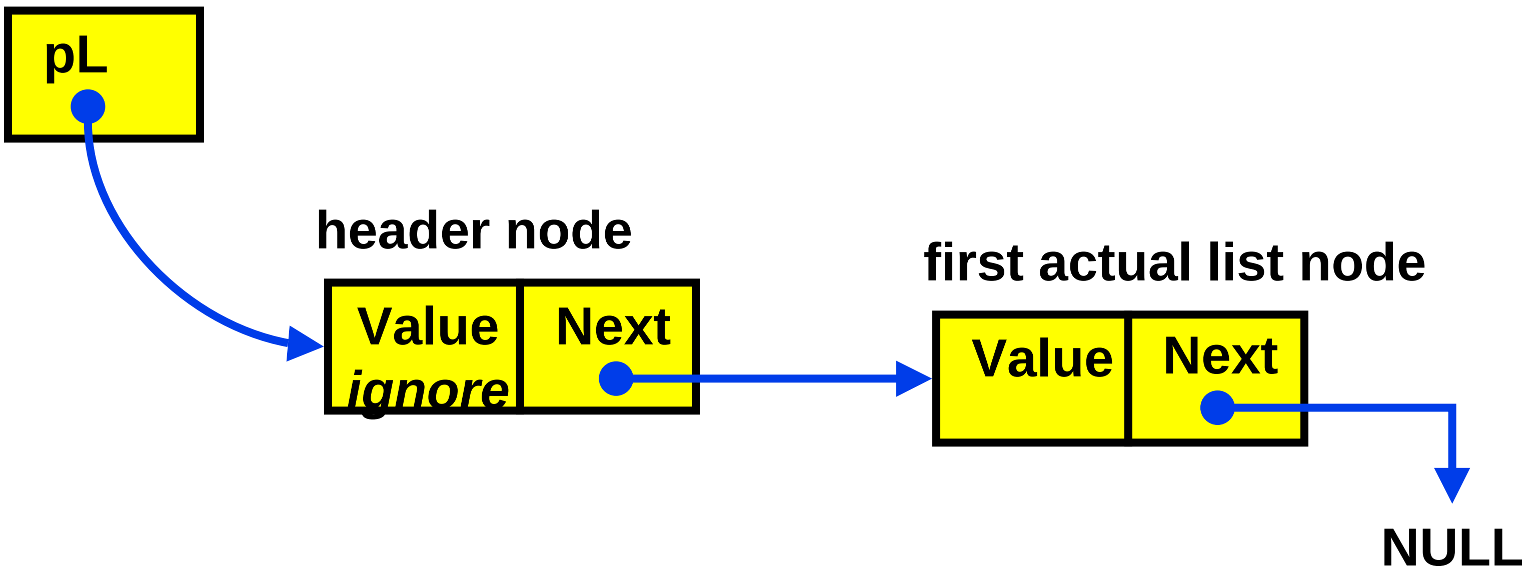


Insert the value E after P

Using a Header Node

- If the List pointer points to first item, then
  - › any change in first item changes List itself
  - › need special checks if List pointer is NULL
  - › **`L->next`** is invalid (L is not a Node struct)
- Solution: Use “header node” at beginning of all lists (see text)
  - › List pointer always points to header node, which points to first actual list item
  - › Simplifies the code, but you need to remember that there is an "empty" node at the start of the list

Linked List with Header Node



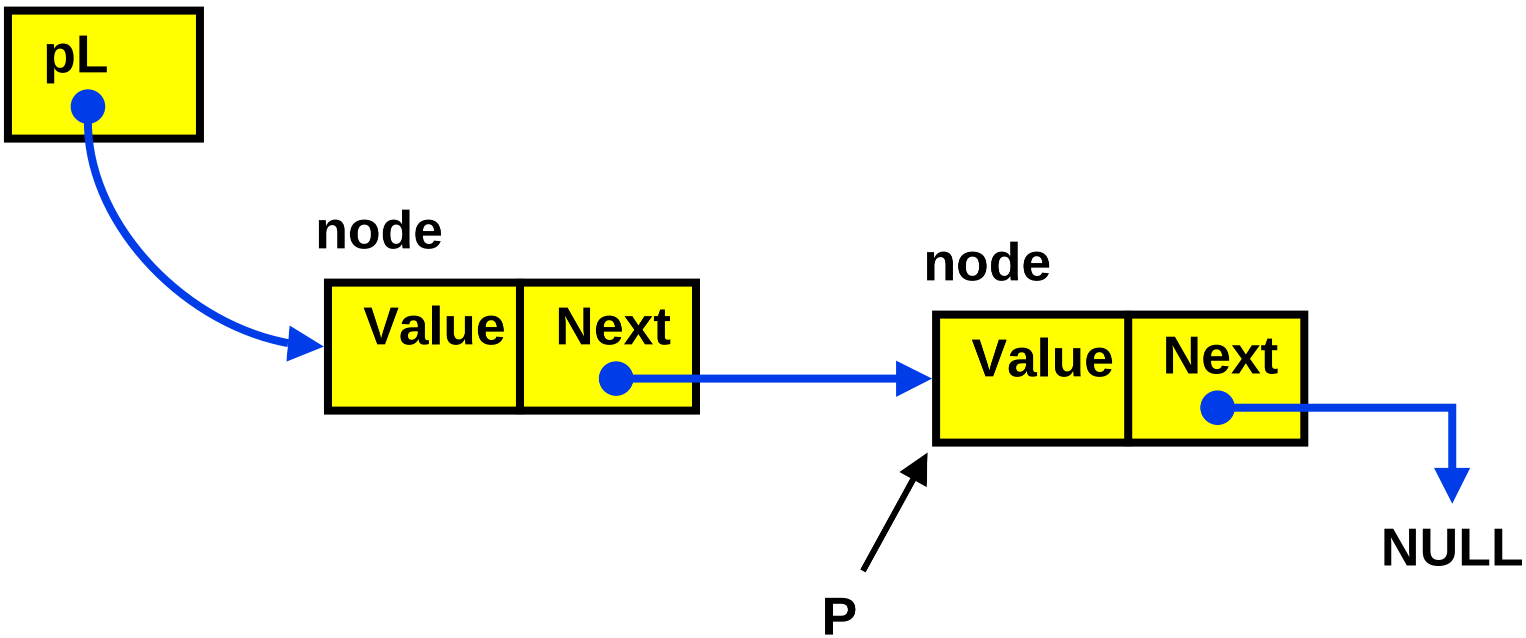
Pointer Implementation Issues

- Whenever you break a list, your code should fix the list up as soon as possible
  - › Draw pictures of the list to visualize what needs to be done
- Pay special attention to boundary conditions:
  - › Empty list
  - › Single item – same item is both first and last
  - › Two items – first, last, but no middle items
  - › Three or more items – first, last, and middle items

Pointer List Insert Running Time

- Running time for N elements?
- Insert takes constant time (O(1))
- Does not depend on input size
- Compare to array bases list which is O(N)

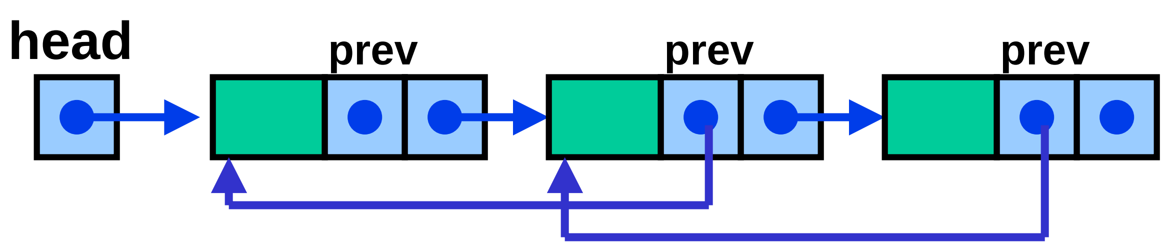
Pointer-Based Linked List Delete



To delete the node pointed to by P, need a pointer to the previous node

Doubly Linked Lists

- FindPrev (and hence Delete) is slow because we cannot go directly to previous node
- Solution: Keep a "previous" pointer at each node



Double Link Pros and Cons

- Advantage
  - › Delete and FindPrev are fast like Insert is
- Disadvantages:
  - › More space used up (double the number of pointers at each node)
  - › More book-keeping for updating the two pointers at each node

Circularly Linked Lists

- Set the pointer of the last node to first node instead of NULL
- Useful when you want to iterate through whole list starting from any node
  - › No need to write special code to wrap around at the end
- Circular doubly linked lists speed up both the Delete and Last operations

Polynomial ADT

- Store and manipulate single variable polynomials with non-negative exponents
  - › $10x^3 + 4x^2 + 7$ (= $10x^3 + 4\ x^2 + 0\ x^1 + 7\ x^0$)
  - › Store coefficients C_i and exponents i
- ADT operations
  - › Addition: `C[i] = A[i] + B[i];`
  - › Multiplication: `C[i+j] = C[i+j] + A[i]*B[j];`

Polynomial Implementation

- Array Implementation: $C[i] = C_i$
  - › E.g. C[3] = 10, C[2] = 4, C[1] = 0, C[0] = 7
- Problem with Array implementation
  - › High-order sparse polynomials require large sparse arrays
  - › E.g. $10X^{3000} + 4 X^2 + 7$ → Waste of space and time (C_i are mostly 0s)
- Instead, use singly linked lists, sorted in decreasing order of exponents

Bucket Sort: Sorting integers

- Bucket sort: N integers in the range 0 to B-1
  - › Array Count has B elements (“buckets”), initialized to 0
  - › Given input integer i, Count[i]++
  - › After reading all N numbers go through the B buckets and read out the resulting sorted list
  - › N operations to read and record the numbers plus B operations to recover the sorted numbers

Radix Sort: Sorting integers

- Radix sort = multi-pass bucket sort of integers in the range 0 to B^P-1
  - › Bucket-sort from least significant to most significant "digit" (base B)
  - › Use linked list to store numbers that are in same bucket
  - › Requires P*(B+N) operations where P is the number of passes (the number of base B digits in the largest possible input number)