CHAPTER 4

LISTS

All the programs in this file are selected from

Ellis Horowitz, Sartaj Sahni, and Susan Anderson-Freed
"Fundamentals of Data Structures in C",
Computer Science Press, 1992.

Introduction

Array

successive items locate a fixed distance

disadvantage

- data movements during insertion and deletion
- waste space in storing n ordered lists of varying size

possible solution

- linked list

4.1.1 Pointer Can Be Dangerous

pointer

```
int i, *pi;
pi = &i;          i=10 or *pi=10
pi= malloc(size of(int));
/* assign to pi a pointer to int */
pf=(float *) pi;
/* casts an int pointer to a float pointer */
```

4.1.2 Using Dynamically Allocated Storage

```
int i, *pi;
float f, *pf;
pi = (int *) malloc(sizeof(int));
pf = (float *) malloc (sizeof(float));
*pi =1024;
*pf =3.14;
printf("an integer = %d, a float = %f\n", *pi, *pf);
free(pi);
free(pf);
```

request memory

return memory

***Program4.1:Allocation and deallocation of pointers (p.138)**

4.2 SINGLY LINKED LISTS

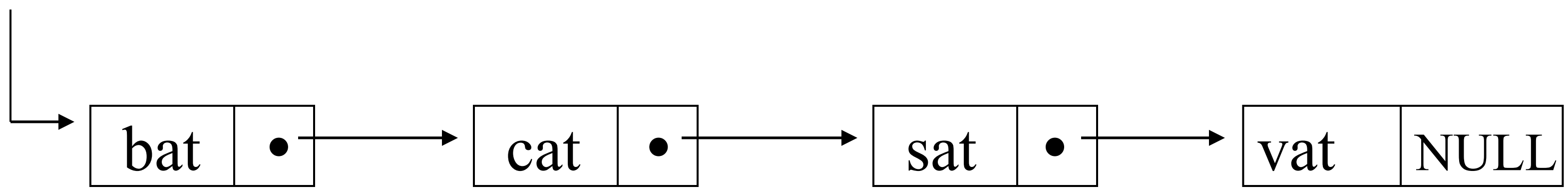


***Figure 4.1:** Usual way to draw a linked list (p.139)*

Insertion

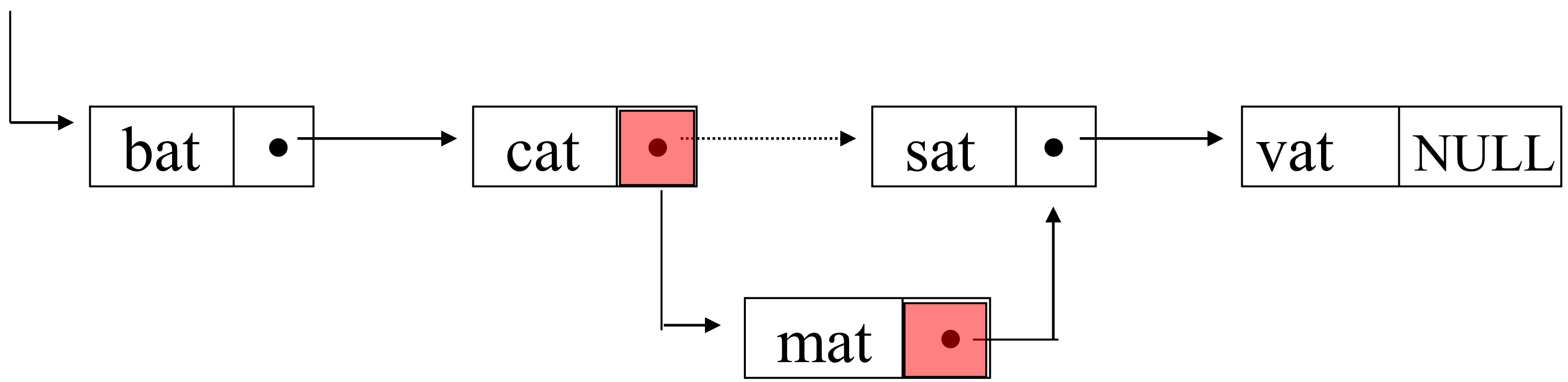


***Figure 4.2:** Insert mat after cat (p.140)*

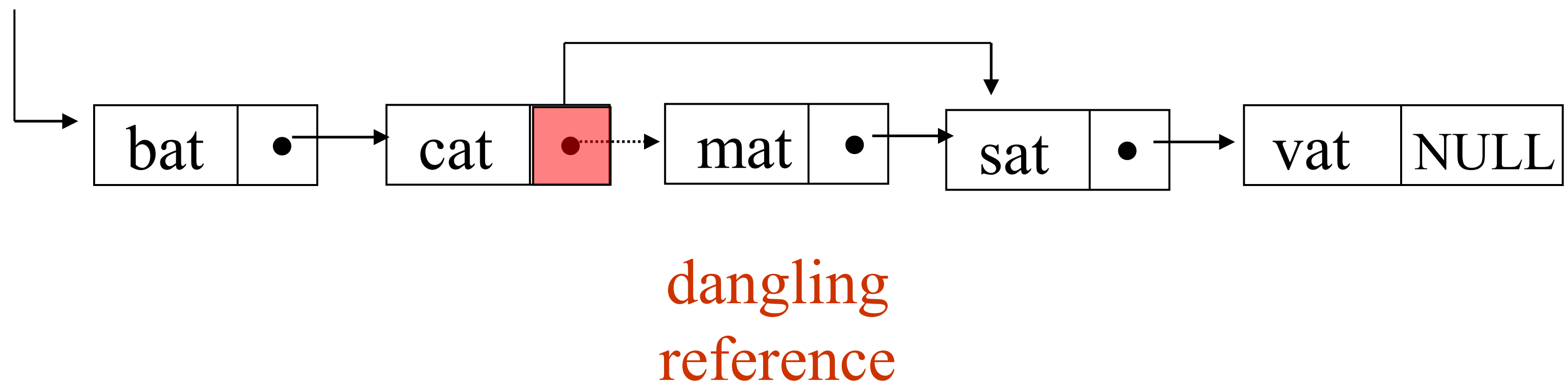


***Figure 4.3:** Delete *mat* from list (p.140)*

Example 4.1: create a linked list of words

Declaration

```
typedef struct list_node, *list_pointer;
typedef struct list_node {
        char data [4];
        list_pointer link;
        };
```

Creation

```
list_pointer ptr =NULL;
```

Testing

```
#define IS_EMPTY(ptr) (!(ptr))
```

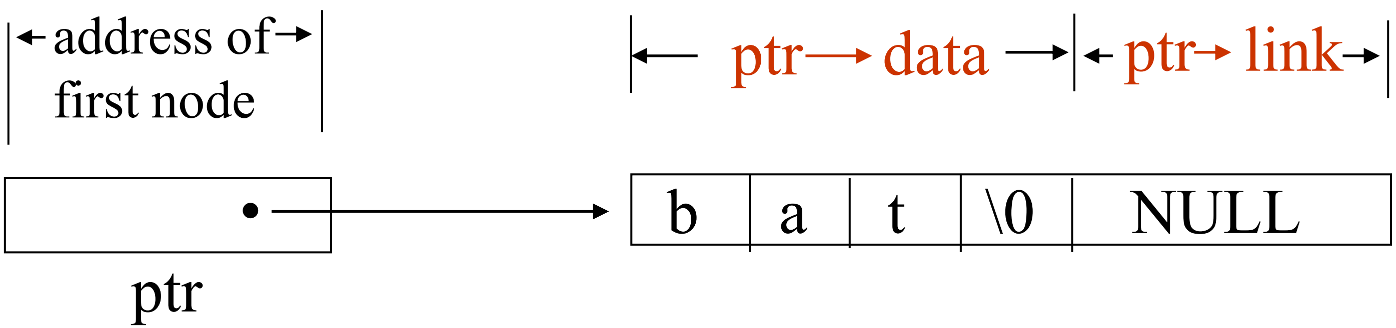
Allocation

```
ptr=(list_pointer) malloc (sizeof(list_node));
```

e -> name   (*e).name

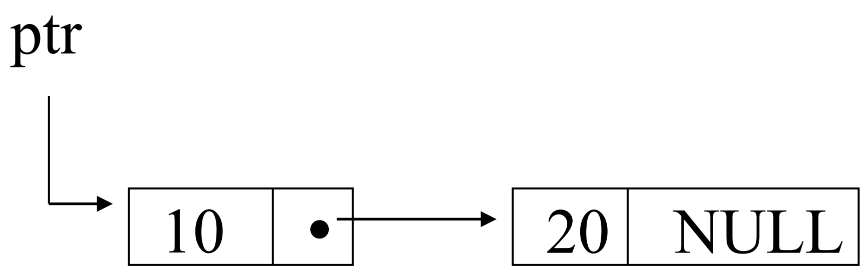
strcpy(ptr -> data, “bat”);

ptr -> link = NULL;



*<u>**Figure 4.4:**Referencing the fields of a node(p.142)</u>

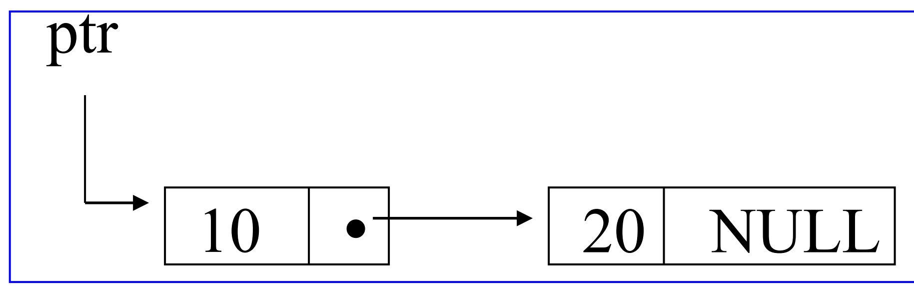
Example: create a two-node list




```
typedef struct list_node *list_pointer;
typedef struct list_node {
        int data;
        list_pointer link;
        };
list_pointer ptr =NULL
```

Example 4.2: (p.142)

```
list_pointer create2( )
{
/* create a linked list with two nodes */
    list_pointer first, second;
    first = (list_pointer) malloc(sizeof(list_node));
    second = ( list_pointer) malloc(sizeof(list_node));
    second -> link = NULL;
    second -> data = 20;
    first -> data = 10;
    first ->link = second;
    return first;
}
```



***Program 4.2:**Create a tow-node list (p.143)

Pointer Review (1)

int i, *pi;

i: 1000 — ?

pi: 2000 — ?

pi = &i;

i, *pi: 1000 — ?

pi: 2000 — 1000

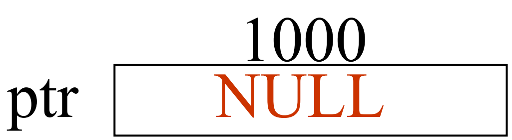
i = 10 or *pi = 10

i, *pi: 1000 — 10

pi: 2000 — 1000

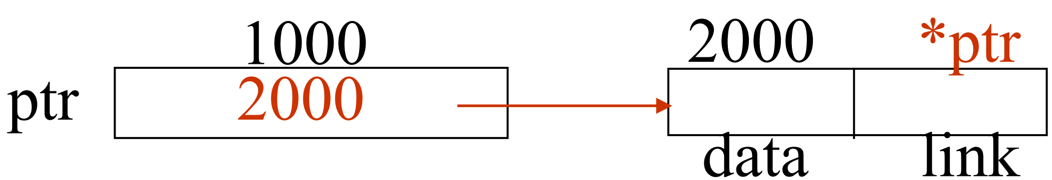
Pointer Review (2)

```
typedef struct list_node *list_pointer;
typedef struct list_node {
                    int data;
                    list_pointer link;
                  }
list_pointer ptr = NULL;
```



ptr->data   (*ptr).data

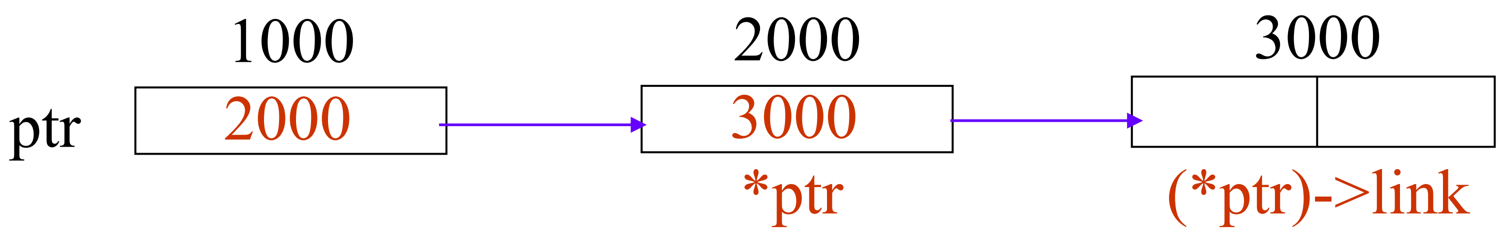
```
ptr = malloc(sizeof(list_node));
```



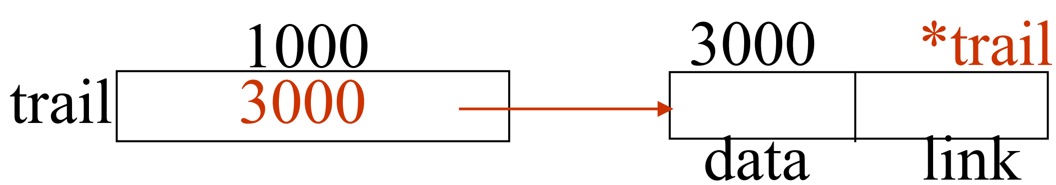
Pointer Review (3)

void delete(list_pointer *ptr, list_pointer trail, list_pinter node)

ptr: a pointer point to a pointer point to a list node



trail (node): a pointer point to a list node



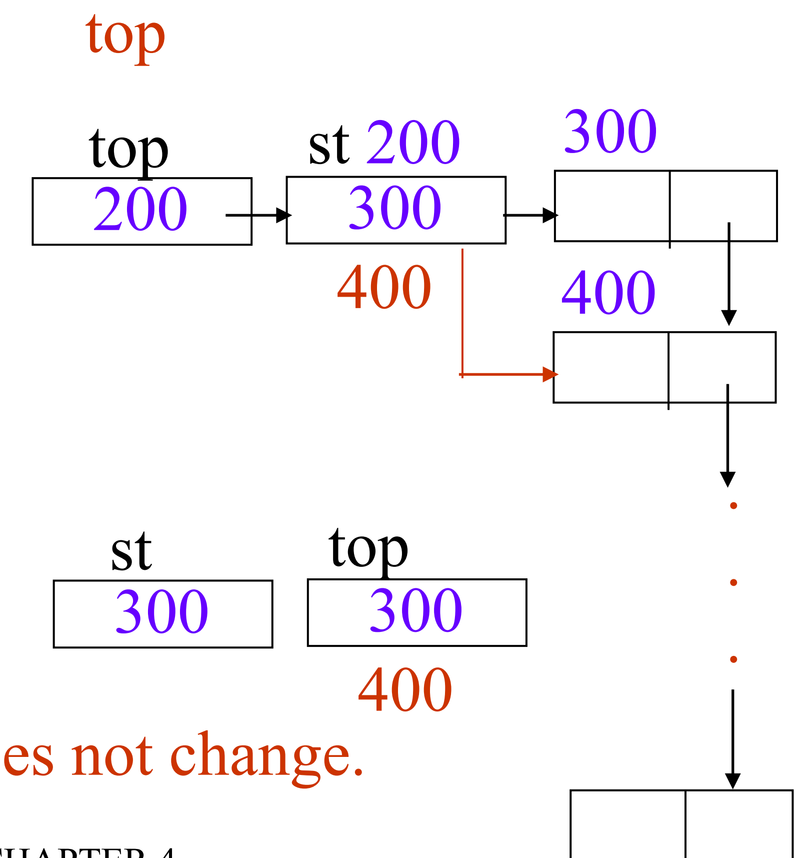
trail->link (*trail).link

Pointer Review (4)

element delete(stack_pointer *top)

delete(&st) vs. delete(st)

200 300



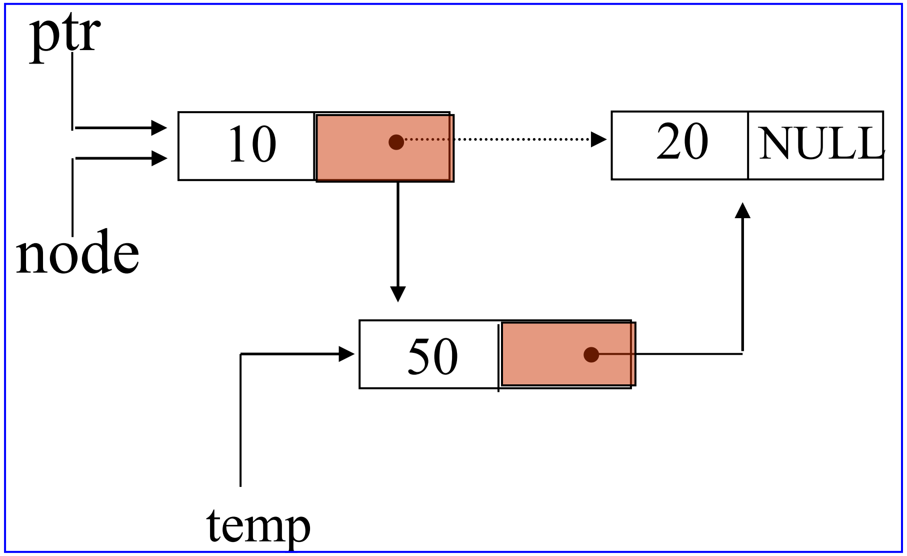
Does not change.

List Insertion:

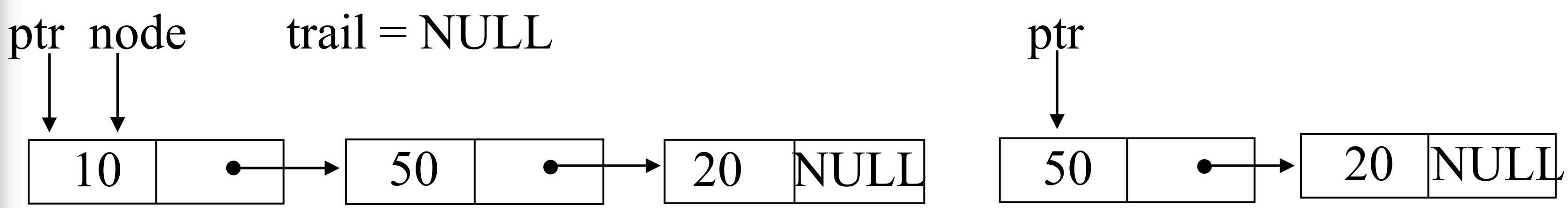
Insert a node after a specific node

```
void insert(list_pointer *ptr, list_pointer node)
{
/* insert a new node with data = 50 into the list ptr after node */
    list_pointer temp;
    temp = (list_pointer) malloc(sizeof(list_node));
    if (IS_FULL(temp)){
       fprintf(stderr, "The memory is full\n");
       exit (1);
    }
```

```
temp->data = 50;
if (*ptr) {  noempty list
    temp->link =node ->link;
    node->link = temp;
 }
 else {    empty list
    temp->link = NULL;
    *ptr =temp;
  }
}
```



***Program 4.3:**Simple insert into front of list (p.144)



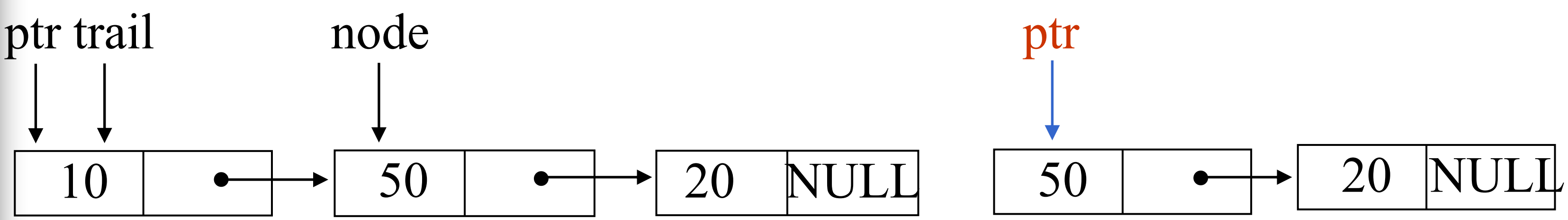
(a) before deletion

(b)after deletion

***Figure 4.7:** List after the function call *Delete*(&*ptr,NULL.ptr*);(p.145)

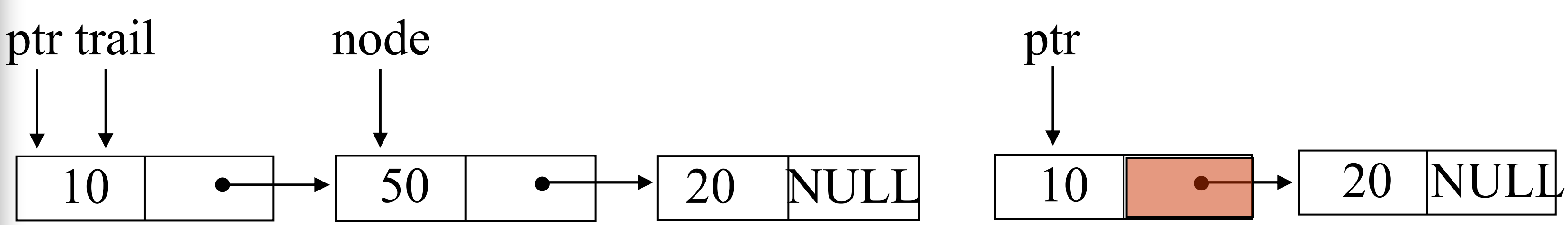
List Deletion

Delete the first node.

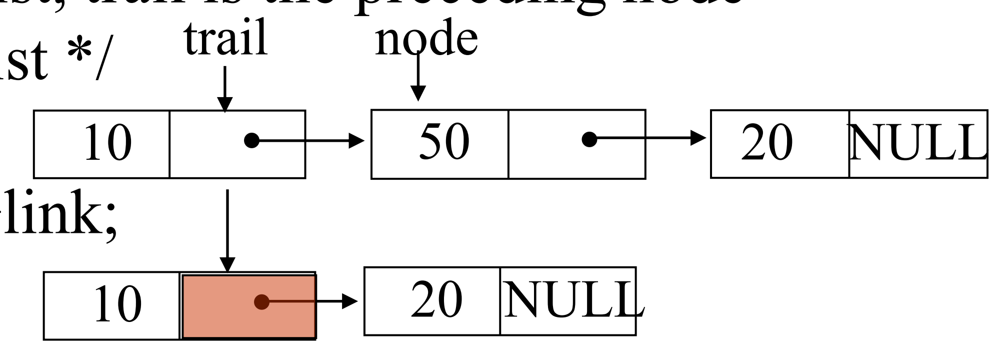


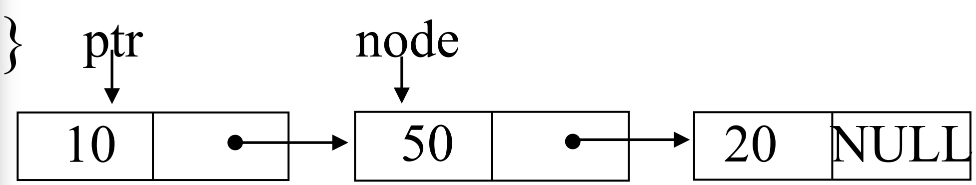
(a) before deletion (b)after deletion

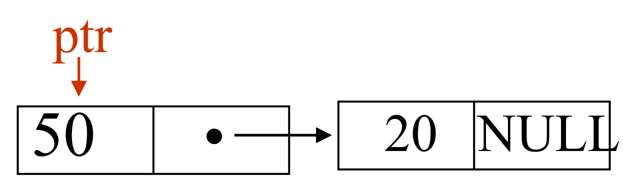
Delete node other than the first node.



```
void delete(list_pointer *ptr, list_pointer trail,
                                    list_pointer node)
{
/* delete node from the list, trail is the preceding node
   ptr is the head of the list */
   if (trail)
      trail->link = node->link;
   else
      *ptr = (*ptr) ->link;
   free(node);
}
```





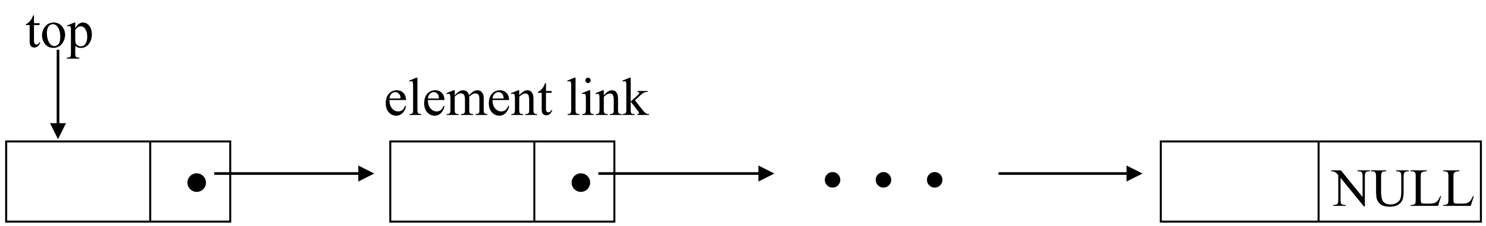


Print out a list (traverse a list)

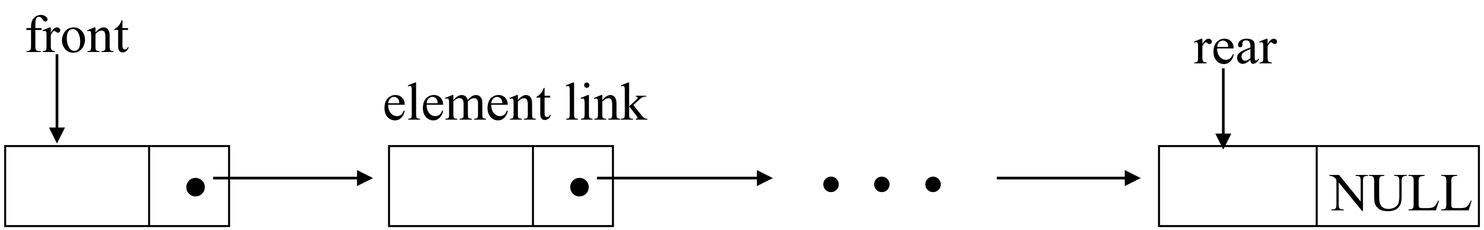
```
void print_list(list_pointer ptr)
{
   printf("The list ocntains: ");
   for ( ; ptr; ptr = ptr->link)
      printf("%4d", ptr->data);
   printf("\n");
}
```

***Program 4.5:** Printing a list (p.146)

4.3 DYNAMICALLY LINKED STACKS AND QUEUES



(a) Linked Stack



(b) Linked queue

*<u>**Figure 4.10:** Linked Stack and queue (p.147)</u>

Represent n stacks

```
#define MAX_STACKS 10 /* maximum number of stacks */
typedef struct {
        int key;
        /* other fields */
        } element;
typedef struct stack *stack_pointer;
typedef struct stack {
        element item;
        stack_pointer link;
        };
stack_pointer top[MAX_STACKS];
```

Represent n queues

```
#define MAX_QUEUES 10 /* maximum number of queues */
typedef struct queue *queue_pointer;
typedef struct queue {
            element item;
            queue_pointer link;
            };
queue_pointer front[MAX_QUEUE], rear[MAX_QUEUES];
```

Push in the linked stack

```
void add(stack_pointer *top, element item)
{
  /* add an element to the top of the stack */
  stack_pointer temp =
                   (stack_pointer) malloc (sizeof (stack));
  if (IS_FULL(temp)) {
     fprintf(stderr, " The memory is full\n");
     exit(1);
     }
     temp->item = item;
     temp->link = *top;
     *top= temp;
}
```

*__Program 4.6:__Add to a linked stack (p.149)

pop from the linked stack

```
element delete(stack_pointer *top) {
/* delete an element from the stack */
    stack_pointer temp = *top;
    element item;
    if (IS_EMPTY(temp))  {
       fprintf(stderr,  “The stack is empty\n”);
       exit(1);
    }
    item = temp->item;
    *top = temp->link;
     free(temp);
     return item;
}
```

***Program 4.7**: Delete from a linked stack (p.149)

enqueue in the linked queue

```
void addq(queue_pointer *front, queue_pointer *rear, element item)
{  /* add an element to the rear of the queue */
  queue_pointer temp =
                    (queue_pointer) malloc(sizeof (queue));
  if (IS_FULL(temp)) {
     fprintf(stderr, " The memory is full\n");
     exit(1);
     }
     temp->item = item;
     temp->link = NULL;
     if (*front) (*rear) -> link = temp;
     else *front = temp;
     *rear = temp;   }
```

dequeue from the linked queue (similar to push)

```
element deleteq(queue_pointer *front) {
/* delete an element from the queue */
    queue_pointer temp = *front;
    element item;
    if (IS_EMPTY(*front))  {
       fprintf(stderr, “The queue is empty\n”);
       exit(1);
    }
    item = temp->item;
    *front = temp->link;
     free(temp);
     return item;
}
```

Polynomials

$$A(x) = a_{m-1}x^{e_{m-1}} + a_{m-2}x^{e_{m-2}} + \ldots + a_0 x^{e_0}$$

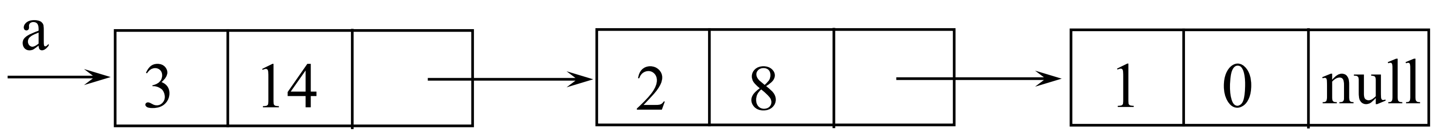
Representation

```
typedef struct poly_node *poly_pointer;
typedef struct poly_node {
    int coef;
    int expon;
    poly_pointer link;
};
poly_pointer a, b, c;
```

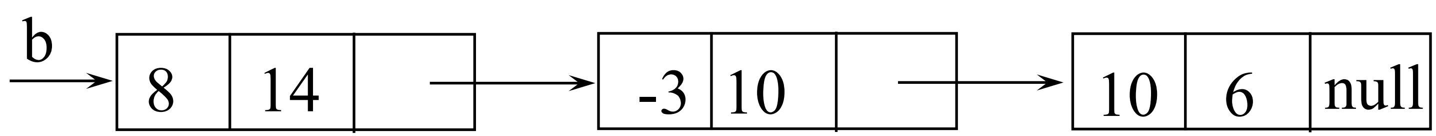
coef	expon	link

Examples

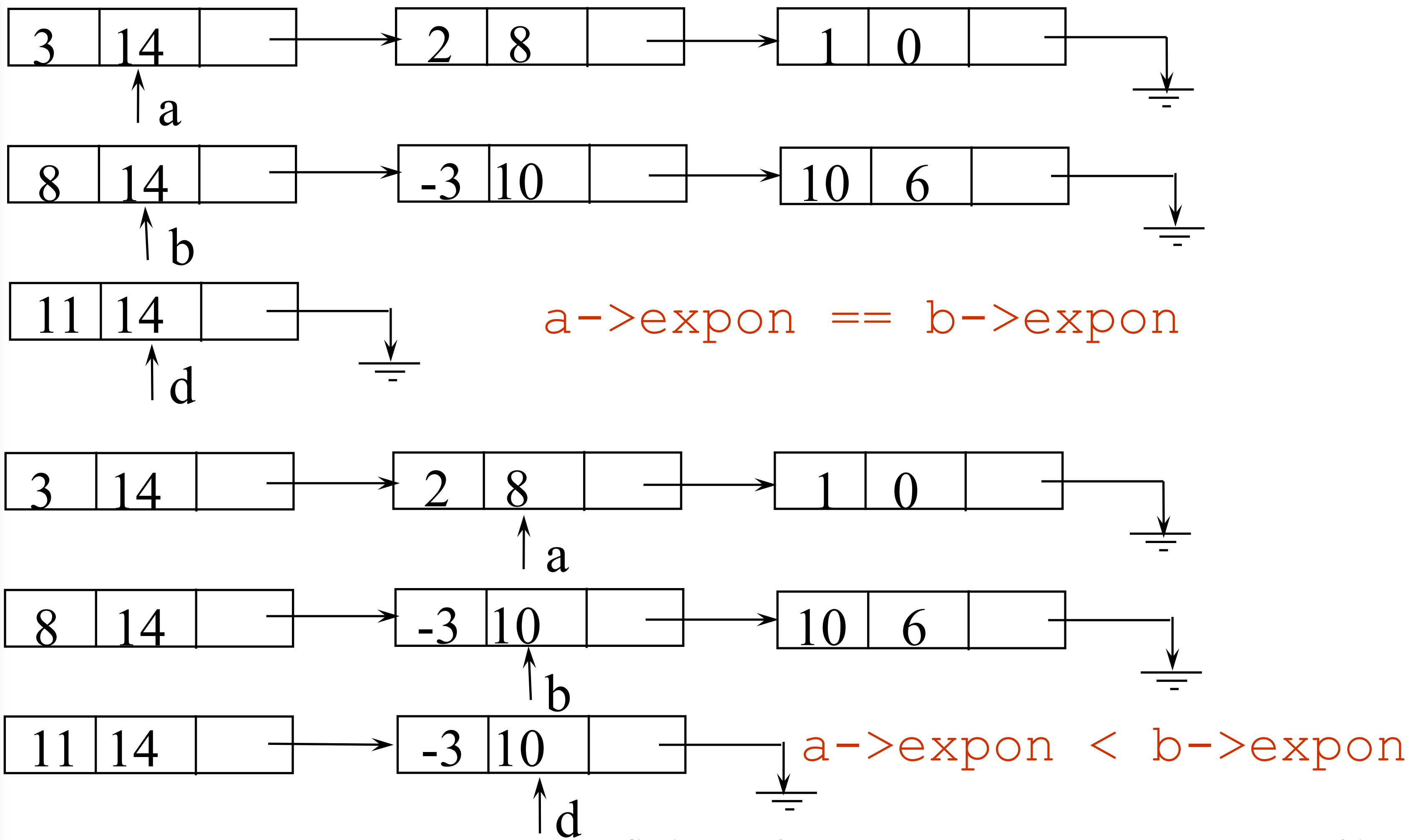
$$a = 3x^{14} + 2x^{8} + 1$$



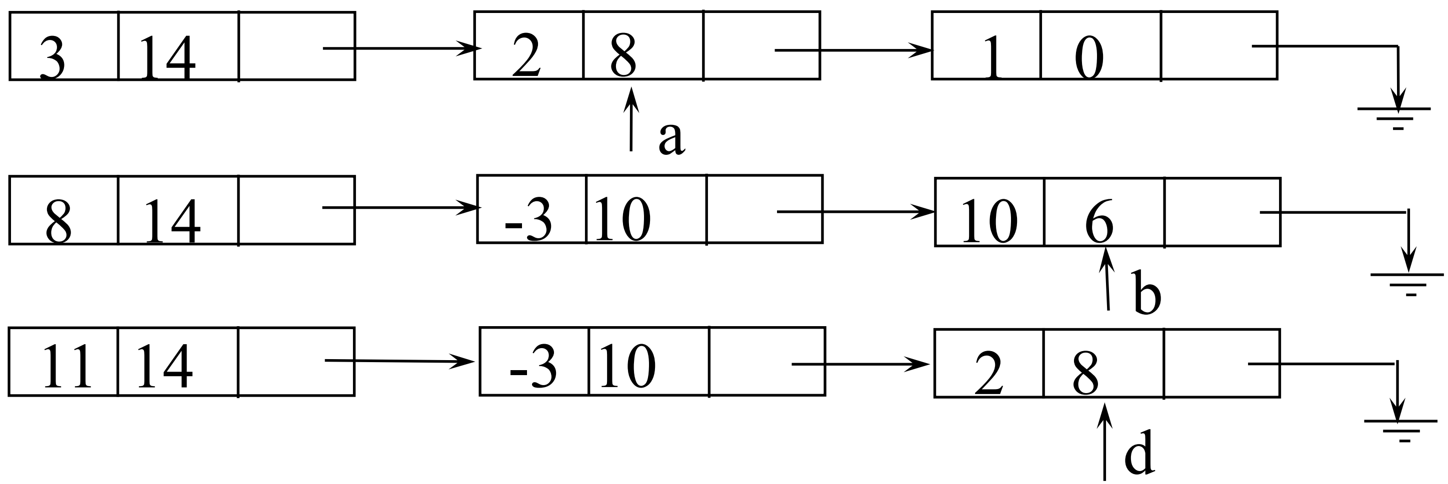
$$b = 8x^{14} - 3x^{10} + 10x^{6}$$



Adding Polynomials



Adding Polynomials (*Continued*)




```
a->expon > b->expon
```

Alogrithm for Adding Polynomials

```
poly_pointer padd(poly_pointer a, poly_pointer b)
{
    poly_pointer front, rear, temp;
    int sum;
    rear =(poly_pointer)malloc(sizeof(poly_node));
    if (IS_FULL(rear)) {
        fprintf(stderr, "The memory is full\n");
        exit(1);
    }
    front = rear;
    while (a && b) {
        switch (COMPARE(a->expon, b->expon)) {
```

```
        case -1: /* a->expon < b->expon */
            attach(b->coef, b->expon, &rear);
            b= b->link;
            break;
        case 0: /* a->expon == b->expon */
            sum = a->coef + b->coef;
            if (sum) attach(sum,a->expon,&rear);
            a = a->link;    b = b->link;
            break;
        case 1: /* a->expon > b->expon */
            attach(a->coef, a->expon, &rear);
            a = a->link;
    }
}
for (; a; a = a->link)
    attach(a->coef, a->expon, &rear);
for (; b; b=b->link)
    attach(b->coef, b->expon, &rear);
rear->link = NULL;
temp = front;  front = front->link;  free(temp);
return front;
}
```

Delete extra initial node.

Analysis

(1) coefficient additions

$0 \leq$ additions $\leq \min(m, n)$

where m (n) denotes the number of terms in A (B).

(2) exponent comparisons

extreme case

$e_{m-1} > f_{m-1} > e_{m-2} > f_{m-2} > \ldots > e_0 > f_0$

m+n-1 comparisons

(3) creation of new nodes

extreme case

m + n new nodes

summary $O(m+n)$

Attach a Term

```
void attach(float coefficient, int exponent,
            poly_pointer *ptr)
{
/* create a new node attaching to the node pointed to
   by ptr. ptr is updated to point to this new node. */
    poly_pointer temp;
    temp = (poly_pointer) malloc(sizeof(poly_node));
    if (IS_FULL(temp)) {
        fprintf(stderr, "The memory is full\n");
        exit(1);
    }
    temp->coef = coefficient;
    temp->expon = exponent;
    (*ptr)->link = temp;
    *ptr = temp;
}
```

A Suite for Polynomials

$e(x) = a(x) * b(x) + d(x)$

```
poly_pointer a, b, d, e;
...
a = read_poly();
b = read_poly();
d = read_poly();
temp = pmult(a, b);
e = padd(temp, d);
print_poly(e);
```

```
read_poly()
print_poly()
padd()
psub()
pmult()
```

temp is used to hold a partial result. By returning the nodes of temp, we may use it to hold other polynomials

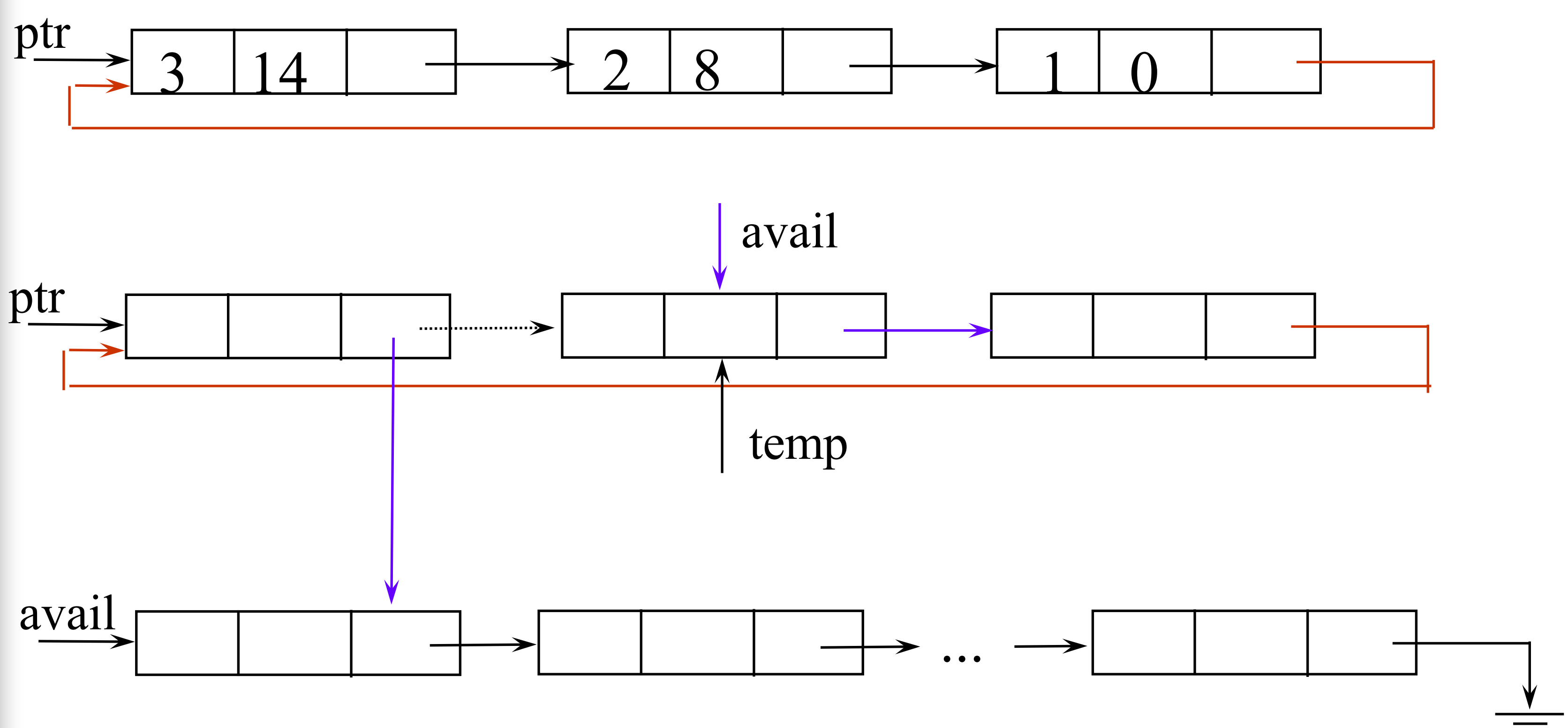
Erase Polynomials

```
void earse(poly_pointer *ptr)
{
/* erase the polynomial pointed to by ptr */

    poly_pointer temp;

    while (*ptr) {
        temp = *ptr;
        *ptr = (*ptr)->link;
        free(temp);
    }
}
```

O(n)

Circularly Linked Lists

circular list vs. chain



Maintain an Available List

```
poly_pointer get_node(void)
{
   poly_pointer node;
   if (avail) {
        node = avail;
        avail = avail->link:
   }
   else {
        node = (poly_pointer)malloc(sizeof(poly_node));
        if (IS_FULL(node)) {
            printf(stderr, "The memory is full\n");
            exit(1);
        }
   }
   return node;
}
```

Maintain an Available List *(Continued)*

Insert ptr to the front of this list

```
void ret_node(poly_pointer ptr)
{
  ptr->link = avail;
     avail = ptr;
}
```

Erase a circular list (see next page)

```
void cerase(poly_pointer *ptr)
{
     poly_pointer temp;
     if (*ptr) {
           temp = (*ptr)->link;
           (*ptr)->link = avail;      (1)
           avail = temp;      (2)
           *ptr = NULL;
     }
}
```

Independent of # of nodes in a list O(1) constant time

4.4.4 Representing Polynomials As Circularly Linked Lists

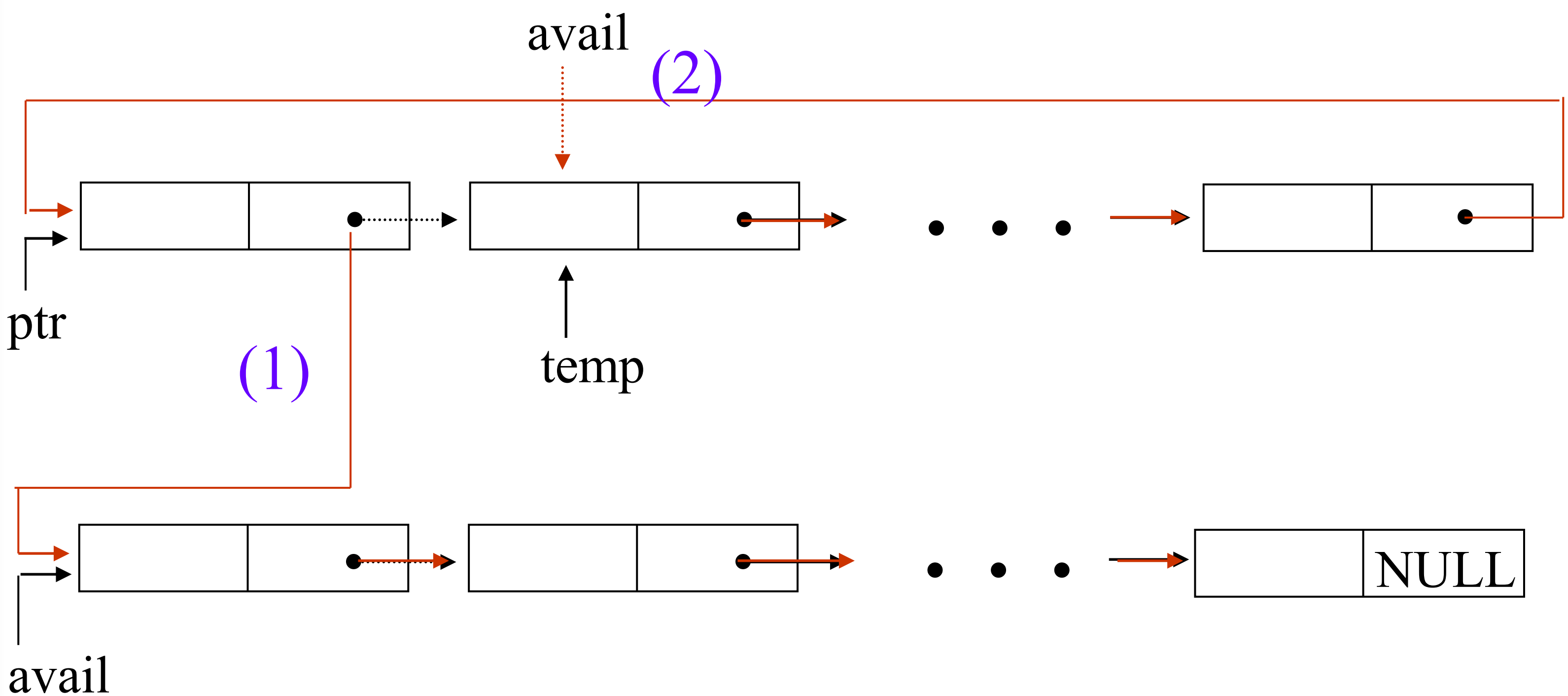
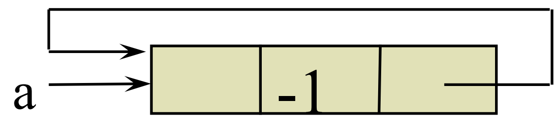


***Figure 4.14:** Returning a circular list to the avail list (p.159)

Head Node

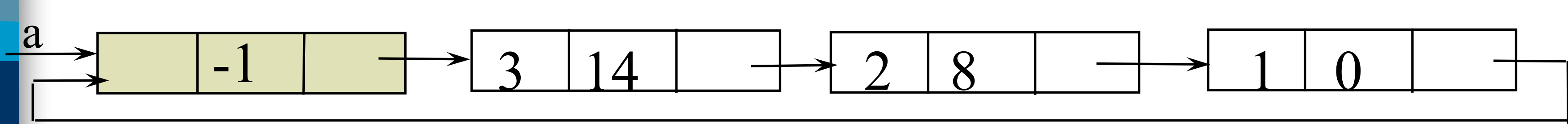
Represent polynomial as circular list.

(1) zero



Zero polynomial

(2) others



$$a = 3x^{14} + 2x^{8} + 1$$

Another Padd

```
poly_pointer cpadd(poly_pointer a, poly_pointer b)
{
  poly_pointer starta, d, lastd;
  int sum, done = FALSE;
  starta = a;
  a = a->link;
  b = b->link;
  d = get_node();
  d->expon = -1;     lastd = d;
  do {
    switch (COMPARE(a->expon, b->expon)) {
      case -1: attach(b->coef, b->expon, &lastd);
               b = b->link;
               break;
```

Set expon field of head node to -1.

Another Padd *(Continued)*

```
        case 0: if (starta == a) done = TRUE;
                else {
                  sum = a->coef + b->coef;
                  if (sum) attach(sum,a->expon,&lastd);
                  a = a->link;   b = b->link;
                }
                break;
        case 1: attach(a->coef,a->expon,&lastd);
                a = a->link;
    }
} while (!done);
lastd->link = d;
return d;
}
```

Link last node to first

Additional List Operations

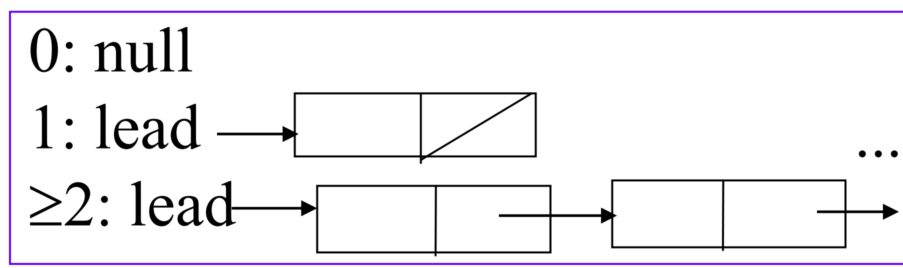
```
typedef struct list_node *list_pointer;
typedef struct list_node {
    char data;
    list_pointer link;
};
```

Invert single linked lists
Concatenate two linked lists

Invert Single Linked Lists

Use two extra pointers: middle and trail.

```
list_pointer invert(list_pointer lead)
{
    list_pointer middle, trail;
    middle = NULL;
    while (lead) {
        trail = middle;
        middle = lead;
        lead = lead->link;
        middle->link = trail;
    }
    return middle;
}
```



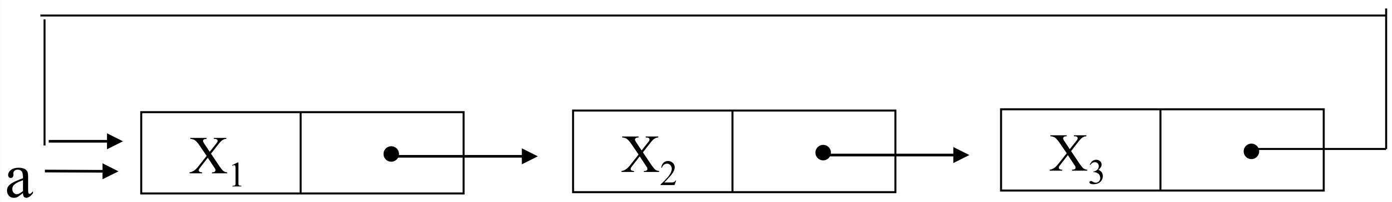
Concatenate Two Lists

```
list_pointer concatenate(list_pointer
                ptr1, list_pointer ptr2)
{
  list_pointer temp;
  if (IS_EMPTY(ptr1)) return ptr2;
  else {
    if (!IS_EMPTY(ptr2)) {
      for (temp=ptr1;temp->link;temp=temp->link);
      temp->link = ptr2;
    }
    return ptr1;
  }
}
```

O(m) where m is # of elements in the first list

4.5.2 Operations For Circularly Linked List

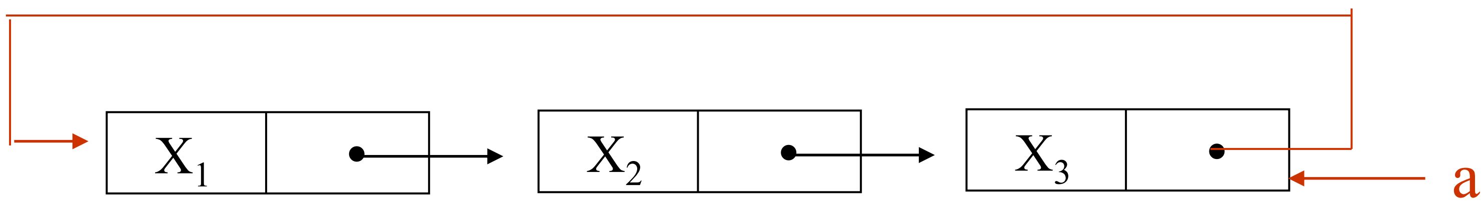
What happens when we insert a node to the front of a circular linked list?



Problem: move down the whole list.

***Figure 4.16:** Example circular list (p.165)

A possible solution:

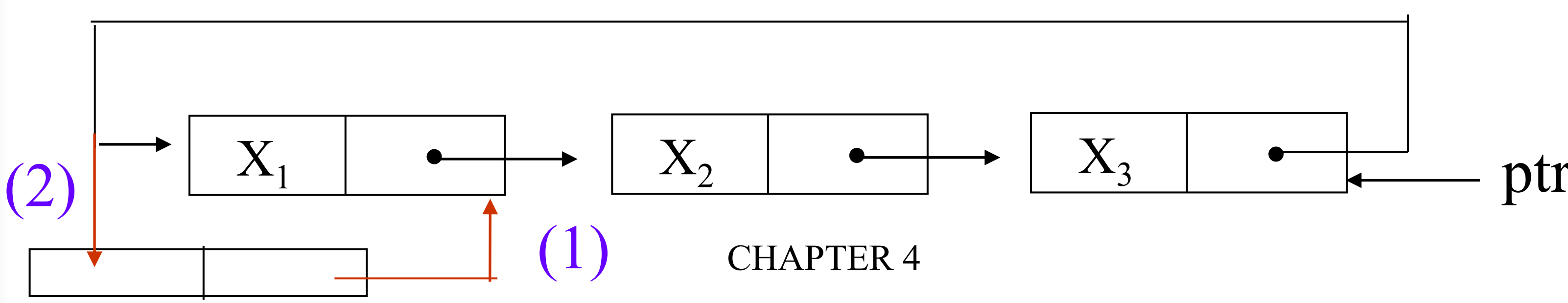


Note a pointer points to the last node.

***Figure 4.17:** Pointing to the last node of a circular list (p.165)

Operations for Circular Linked Lists

```
void insert_front (list_pointer *ptr, list_pointer
node)
{
    if (IS_EMPTY(*ptr)) {
        *ptr= node;
        node->link = node;
    }
    else {
        node->link = (*ptr)->link;   (1)
        (*ptr)->link = node;         (2)
    }
}
```



Length of Linked List

```
int length(list_pointer ptr)
{
    list_pointer temp;
    int count = 0;
    if (ptr) {
        temp = ptr;
        do {
            count++;
            temp = temp->link;
        } while (temp!=ptr);
    }
    return count;
}
```

Equivalence Relations

A relation over a set, S, is said to be an *equivalence relation* over S *iff* it is symmertric, reflexive, and transitive over S.

reflexive, x=x

symmetric, if x=y, then y=x

transitive, if x=y and y=z, then x=z

Examples

0=4, 3=1, 6=10, 8=9, 7=4,
6=8, 3=5, 2=11, 11=1

three equivalent classes
{0,2,4,7,11}; {1,3,5}; {6,8,9,10}

A Rough Algorithm to Find Equivalence Classes

Phase 1

Phase 2

```
void equivalenec()
{
    initialize;
    while (there are more pairs) {
        read the next pair <i,j>;
        process this pair;
    }
    initialize the output;
    do {
        output a new equivalence class;
    } while (not done);
}
```

What kinds of data structures are adopted?

First Refinement

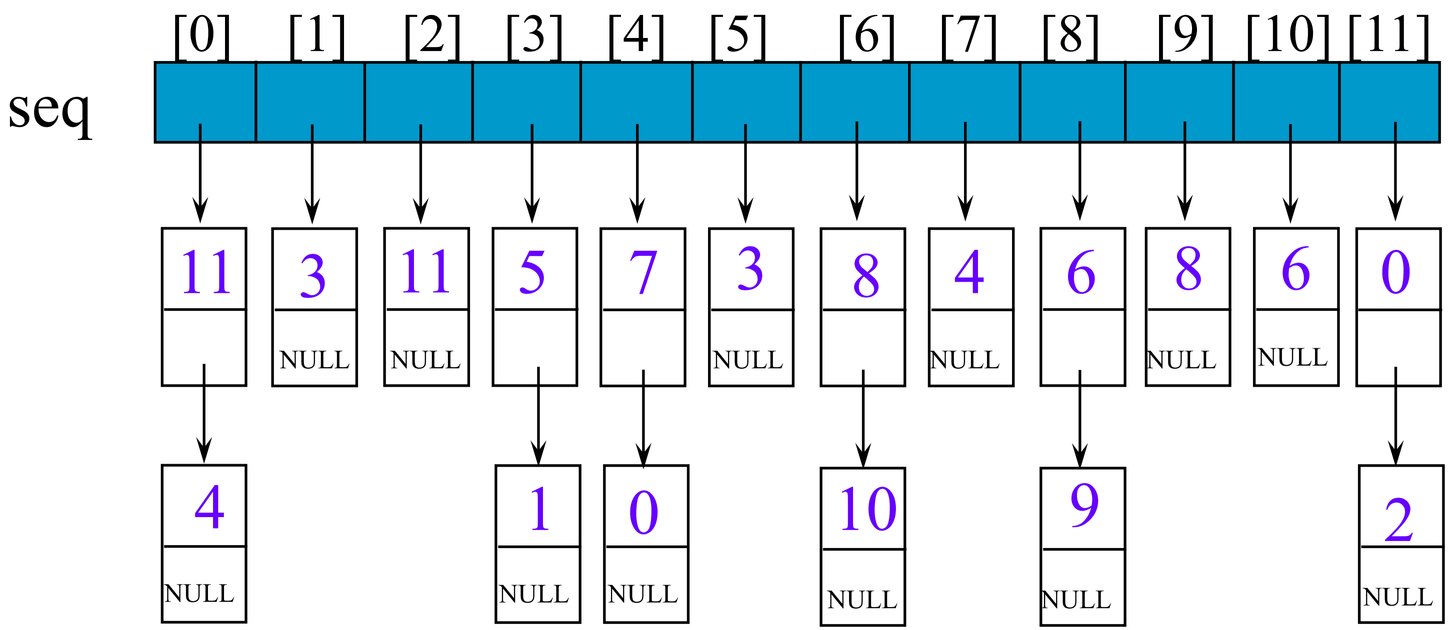
```
#include <stdio.h>
#include <alloc.h>
#define MAX_SIZE 24
#define IS_FULL(ptr)   (!(ptr))
#define FALSE  0
#define TRUE   1
void equivalence()
{
    initialize seq to NULL and out to TRUE
    while (there are more pairs) {
        read the next pair, <i,j>;
        put j on the seq[i] list;
        put i on the seq[j] list;
    }
    for (i=0; i<n; i++)
        if (out[i]) {
            out[i]= FALSE;
            output this equivalence class;
        }
}
```

direct equivalence

Compute indirect equivalence using transitivity

Lists After Pairs are input

$0 \equiv 4$
$3 \equiv 1$
$6 \equiv 10$
$8 \equiv 9$
$7 \equiv 4$
$6 \equiv 8$
$3 \equiv 5$
$2 \equiv 11$
$11 \equiv 0$




```
typedef struct node *node_pointer ;
typedef struct node {
     int data;
     node_pointer link;
};
```

Final Version for Finding Equivalence Classes

```
void main(void)
{
   short int out[MAX_SIZE];
   node_pointer seq[MAX_SIZE];
   node_pointer x, y, top;
   int i, j, n;
   printf("Enter the size (<= %d) ", MAX_SIZE);
   scanf("%d", &n);
   for (i=0; i<n; i++) {
       out[i]= TRUE;     seq[i]= NULL;
   }
   printf("Enter a pair of numbers (-1 -1 to quit): ");
   scanf("%d%d", &i, &j);
```

Phase 1: input the equivalence pairs:

```
while (i>=0) {
     x = (node_pointer) malloc(sizeof(node));
     if (IS_FULL(x))
       fprintf(stderr, "memory is full\n");
         exit(1);
     }     Insert x to the top of lists seq[i]
     x->data= j;  x->link= seq[i];  seq[i]= x;
     if (IS_FULL(x))
       fprintf(stderr, "memory is full\n");
         exit(1);
     }     Insert x to the top of lists seq[j]
     x->data= i;  x->link= seq[j];  seq[j]= x;
     printf("Enter a pair of numbers (-1 -1 to \
          quit): ");
     scanf("%d%d", &i, &j);
}
```

Phase 2: output the equivalence classes

```
for (i=0; i<n; i++) {
    if (out[i]) {
        printf("\nNew class: %5d", i);
        out[i]= FALSE;
        x = seq[i];    top = NULL;
        for (;;) {
            while (x) {
                j = x->data;
                if (out[j]) {
                    printf("%5d", j);
                    out[j] = FALSE;
                    y = x->link;  x->link = top;
                    top = x;  x = y;
                }
                else x = x->link;
            }
            if (!top) break;
            x = seq[top->data];  top = top->link;
        }
    }
}
```

push

pop

4.7 Sparse Matrices

$$\begin{bmatrix} 0 & 0 & 11 & 0 \\ 12 & 0 & 0 & 0 \\ 0 & -4 & 0 & 0 \\ 0 & 0 & 0 & -15 \end{bmatrix}$$

inadequates of sequential schemes

(1) # of nonzero terms will vary after some matrix computation

(2) matrix just represents intermediate results

new scheme

Each column (row): a circular linked list with a head node

Revisit Sparse Matrices

of head nodes = max{# of rows, # of columns}

head node

連同一行元素

down	head	right
next		

連同一列元素

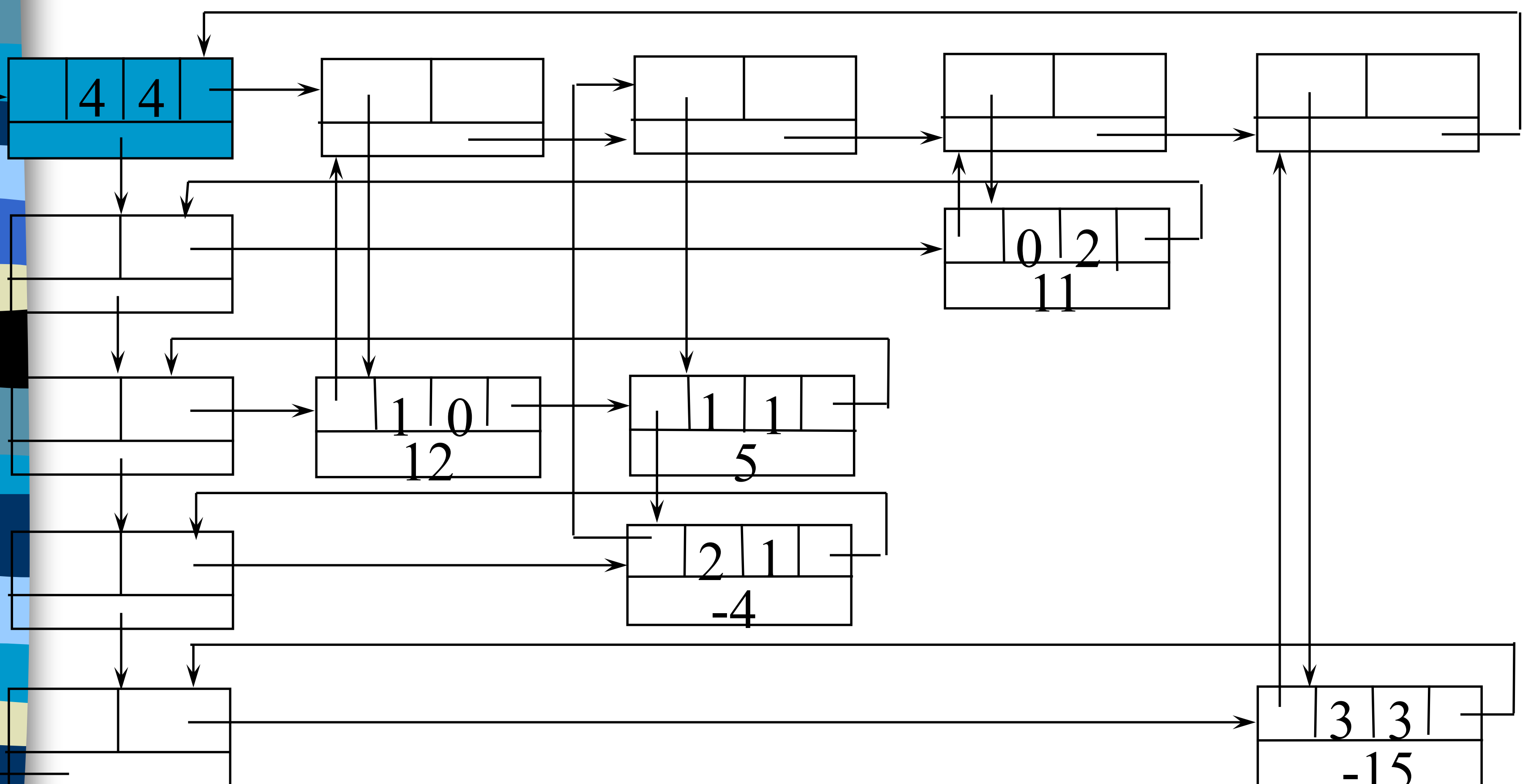
entry node

down	entry	row	col	right
value				

a_{ij}

	entry	i	j	
a_{ij}				

Linked Representation for Matrix



Circular linked list

```
#define MAX_SIZE 50 /* size of largest matrix */
typedef enum {head, entry} tagfield;
typedef struct matrix_node *matrix_pointer;
typedef struct entry_node {
        int row;
        int col;
        int value;
        };
typedef struct matrix_node {
        matrix_pointer down;
        matrix_pointer right;
        tagfield tag;
```

```
        union {
                matrix_pointer next;
                entry_node entry;
                } u;
         };
matrix_pointer hdnode[MAX_SIZE];
```

	[0]	[1]	[2]
[0]	4	4	4
[1]	0	2	11
[2]	1	0	12
[3]	2	1	-4
[4]	3	3	-15

***Figure 4.22: Sample input for sparse matrix (p.174)**

Read in a Matrix

```
matrix_pointer mread(void)
{
/* read in a matrix and set up its linked
 list. An global array hdnode is used */
  int num_rows, num_cols, num_terms;
  int num_heads, i;
  int row, col, value, current_row;
  matrix_pointer temp, last, node;

  printf("Enter the number of rows, columns
        and number of nonzero terms: ");
```

```
scanf("%d%d%d", &num_rows, &num_cols,
      &num_terms);
num_heads =
(num_cols>num_rows)? num_cols : num_rows;
/* set up head node for the list of head
   nodes */
node = new_node();     node->tag = entry;
node->u.entry.row = num_rows;
node->u.entry.col = num_cols;

if (!num_heads) node->right = node;
else { /* initialize the head nodes */
  for (i=0; i<num_heads; i++) {
    term= new_node();
    hdnode[i] = temp;
    hdnode[i]->tag = head;
    hdnode[i]->right = temp;
    hdnode[i]->u.next = temp;
  }
```

O(max(n,m))

```
current_row= 0;     last= hdnode[0];
for (i=0; i<num_terms; i++) {
  printf("Enter row, column and value:");
  scanf("%d%d%d", &row, &col, &value);
  if (row>current_row) {
    last->right= hdnode[current_row];
    current_row= row;  last=hdnode[row];
  }
```

```
  temp = new_node();
  temp->tag=entry; temp->u.entry.row=row;
  temp->u.entry.col = col;
  temp->u.entry.value = value;
  last->right = temp;/*link to row list */
  last= temp;
  /* link to column list */
  hdnode[col]->u.next->down = temp;
  hdnode[col]=>u.next = temp;
}
```

利用next field 存放column的last node

```
    /*close last row */
    last->right = hdnode[current_row];
    /* close all column lists */
    for (i=0; i<num_cols; i++)
      hdnode[i]->u.next->down = hdnode[i];
    /* link all head nodes together */
    for (i=0; i<num_heads-1; i++)
      hdnode[i]->u.next = hdnode[i+1];
    hdnode[num_heads-1]->u.next= node;
    node->right = hdnode[0];
  }
  return node;
}
```

O(max{#_rows, #_cols}+#_terms)

Write out a Matrix

```
void mwrite(matrix_pointer node)
{ /* print out the matrix in row major form */
  int i;
  matrix_pointer temp, head = node->right;
  printf("\n num_rows = %d, num_cols= %d\n",
         node->u.entry.row,node->u.entry.col);
  printf("The matrix by row, column, and
         value:\n\n");
  for (i=0; i<node->u.entry.row; i++) {
    for (temp=head->right;temp!=head;temp=temp->right)
      printf("%5d%5d%5d\n", temp->u.entry.row,
           temp->u.entry.col, temp->u.entry.value);
    head= head->u.next; /* next row */
  }
}
```

O(#_rows+#_terms)

Free the entry and head nodes by row.

Erase a Matrix

```
void merase(matrix_pointer *node)
{
  int i, num_heads;
  matrix_pointer x, y, head = (*node)->right;
  for (i=0; i<(*node)->u.entry.row; i++) {
    y=head->right;
    while (y!=head) {
      x = y;  y = y->right;  free(x);
    }
    x= head;  head= head->u.next; free(x);
  }
  y = head;
  while (y!=*node) {
    x = y;  y = y->u.next;  free(x);
  }
  free(*node);  *node = NULL;
}
```

O(#_rows+#_cols+#_terms)

Alternative: 利用Fig 4.14的技巧，把一列資料erase (constant time)

Doubly Linked List

Move in forward and backward direction.

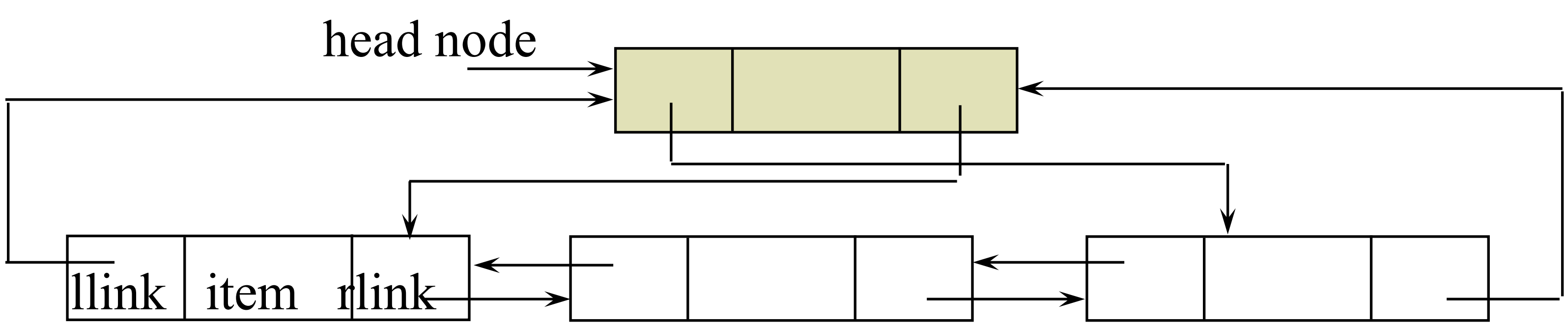
Singly linked list (in one direction only)
How to get the preceding node during deletion or insertion?
Using 2 pointers

Node in doubly linked list
left link field (llink)
data field (item)
right link field (rlink)

Doubly Linked Lists

```
typedef struct node *node_pointer;
typedef struct node {
    node_pointer llink;
    element item;
    node_pointer rlink;
}
```

ptr
= ptr->rlink->llink
= ptr->llink->rlink



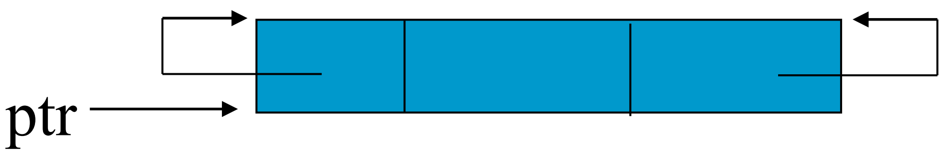


***Figure 4.24:**Empty doubly linked circular list with head node (p.180)

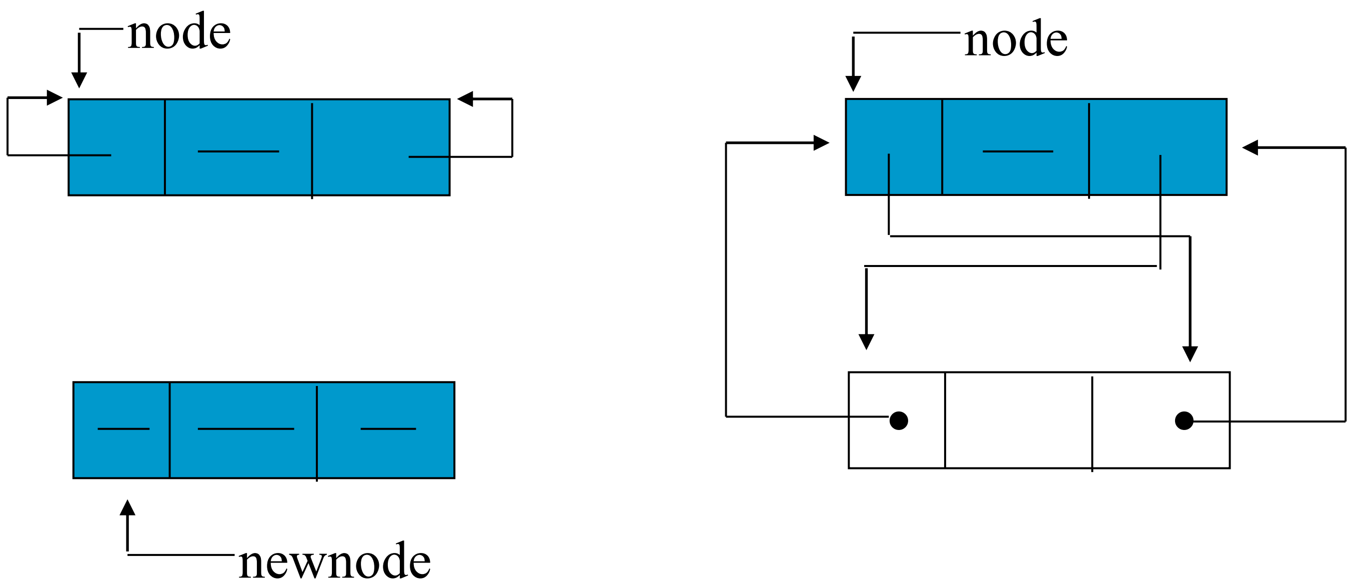
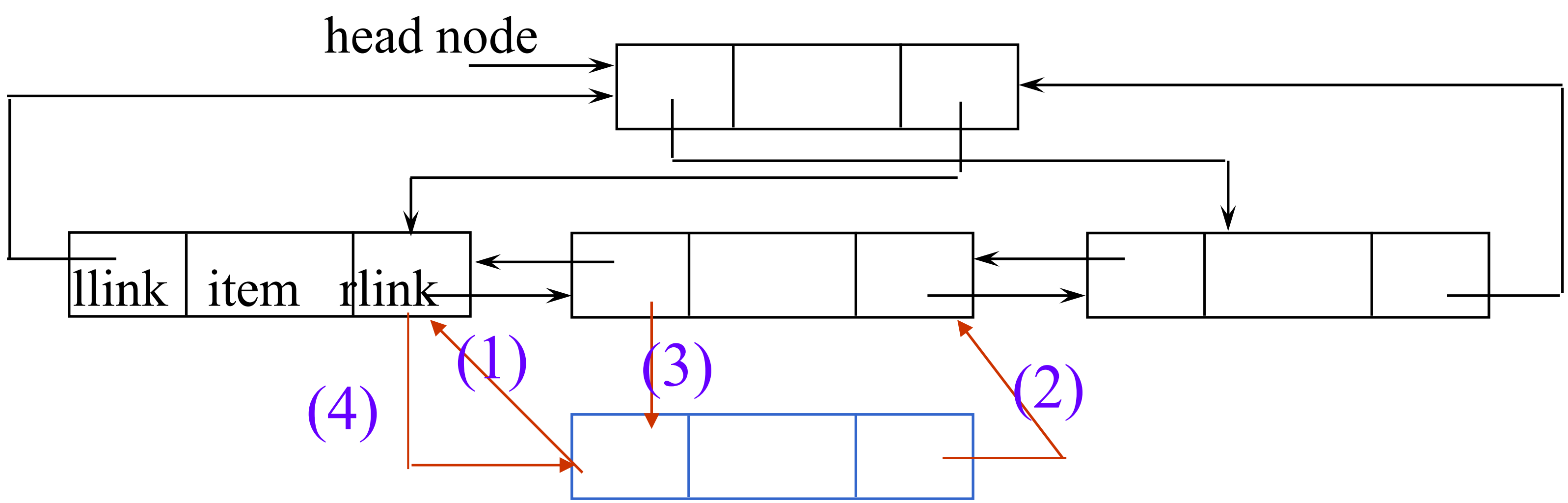


***Figure 4.25:** Insertion into an empty doubly linked circular list (p.181)

Insert

```
void dinsert(node_pointer node, node_pointer newnode)
{
     (1) newnode->llink = node;
     (2) newnode->rlink = node->rlink;
     (3) node->rlink->llink = newnode;
     (4) node->rlink = newnode;
}
```



Delete

```
void ddelete(node_pointer node, node_pointer deleted)
{
    if (node==deleted) printf("Deletion of head node
                                    not permitted.\n");
    else {
        (1) deleted->llink->rlink= deleted->rlink;
        (2) deleted->rlink->llink= deleted->llink;
            free(deleted);
    }
}
```