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Contents

2.1 Arrays – three perspectives

- A consecutive set of memory locations
  - emphasis on implementation issues
  - not always true

- A set of pairs, <*index*, *value*>
  - set of *mappings* or *correspondence* between index and values
  - $array : i \rightarrow a_i$

- ADT
  - more concerned with the operations that can be performed on an array

2.1.1. The Abstract Data Type

ADT *Array* is

objects: A set of pairs <*index*, *value*> where for each value of *index* there is a value from the set *item*. *Index* is a finite ordered set of one or more dimensions, for example, {0, $\cdots$, $n-1$} for one dimension, {(0, 0), (0, 1), (0, 2), (1, 0), (1, 1), (1, 2), (2, 0), (2, 1), (2, 2)} for two dimensions, etc.

functions:

for all $A \in Array$, $i \in index$, $x \in item$, j, $size \in$ integer

Array Create(j, *list*)	::=	**return** an array of j dimensions where *list* is a j-tuple whose ith element is the the size of the ith dimension. *Items* are undefined.
※ Create (2, (3, 4)) 3행 4열의 2차원 배열 생성		
Item Retrieve(A, i)	::=	**if** ($i \in index$) **return** the item associated with index value i in array A **else return** error
Array Store(A,i,x)	::=	**if** (i in *index*) **return** an array that is identical to array A except the new pair <i, x> has been inserted **else return** error.

end *Array*

ADT 2.1: Abstract Data Type *Array*

2.1.2 Arrays in C

- one-dimensional array

int list[5];

list[0] [4]

i	i	i	i	i

int *plist[5];

plist[0] [4]

i*	i*	i*	i*	i*

※ i stands for int
i* stands for int pointer

cf) int (*ary)[5] ,배열포인터

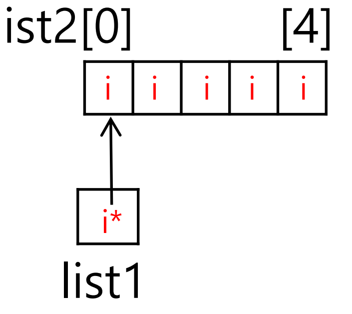
Variable	Memory address
list[0]	base address = α
list[1]	α + sizeof(int)
list[2]	α + 2·sizeof(int)
list[3]	α + 3·sizeof(int)
list[4]	α + 4·sizeof(int)

one-dimensional array & pointer

- interpretations of pointers: list1, list2

int *list1, list2[5];

list1 = list2;
variable constant




```
list2 == &list2[0]
list2 + i == &list2[i]
*(list2+i) == list2[i]


list1 == &list2[0]
list1 + i == &list2[i]
*(list1+i) == list2[i]
```

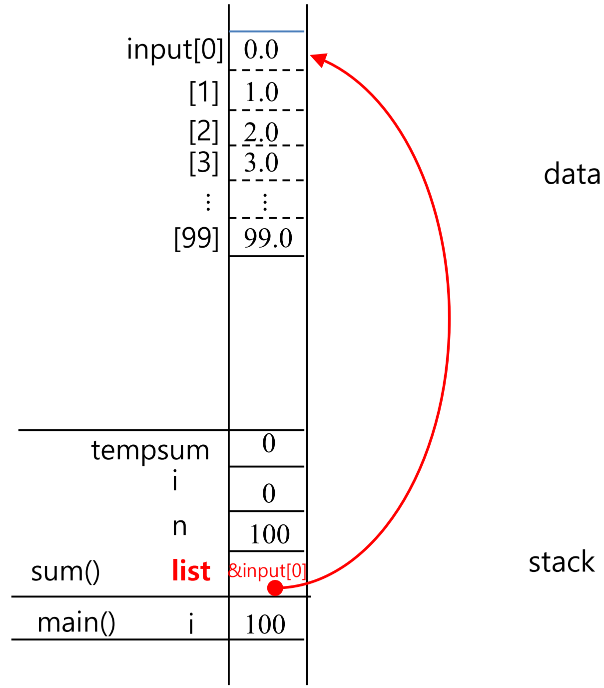
```
#include <stdio.h>
#define MAX_SIZE 100
float sum(float [], int);
float input[MAX_SIZE], answer;
void main(void)
{
   int i;
   for (i = 0; i < MAX_SIZE; i++)
      input[i] = i;
   answer = sum(          , MAX_SIZE);
   printf("The sum is: %f\n", answer);
}
float sum(                    , int n)
{
   int i;
   float tempsum = 0;
   for (i = 0; i < n; i++)
      tempsum +=            ;
   return tempsum;
}
```

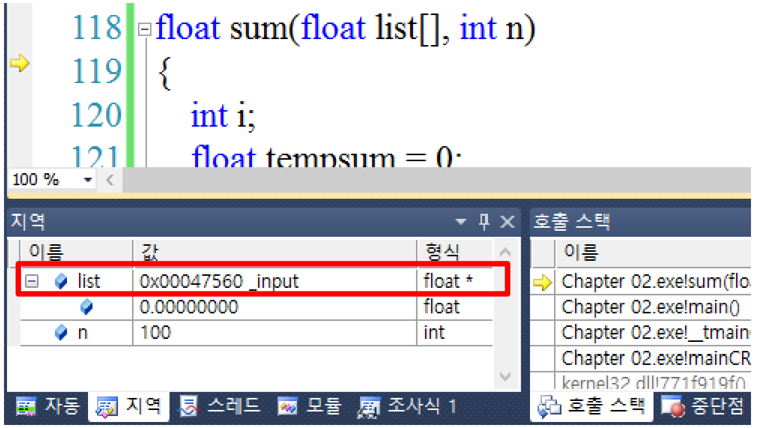
array parameter

float * list → pointer parameter

*(list+i)

Program 2.1: Example array program

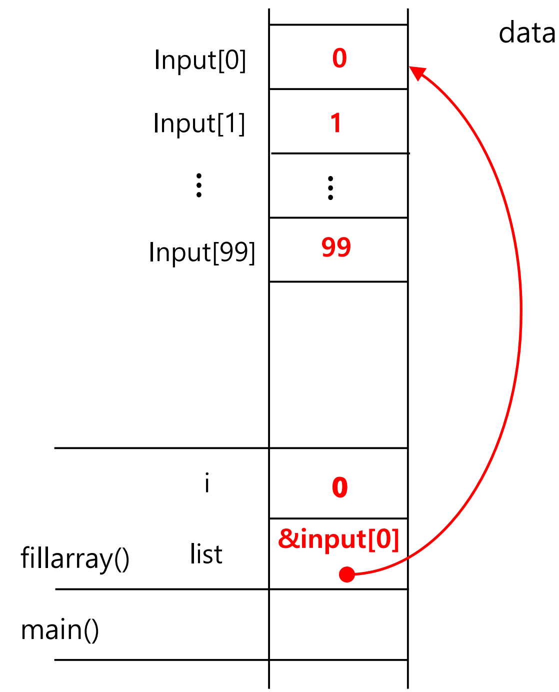




```c
#include <stdio.h>
#define MAX_SIZE 100
float sum(float[], int);
void fillarray(float[], int);
float input[MAX_SIZE], answer;
void main(void)
{
    fillarray(input, MAX_SIZE);
    answer = sum(input, MAX_SIZE);
    printf("The sum is: %f\n", answer);
}
void fillarray(float list[], int n)
{
    int i;
    for (i = 0; i < n; i++)
        list[i] = i;
}
float sum(float list[], int n)
{
    int i;
    float tempsum = 0;
    for (i = 0; i < n; i++)
        tempsum += list[i];
    return tempsum;
}
```

■ **left-side of equal sign**

- the value produced on the right-hand side is stored in the location (*list+i*)

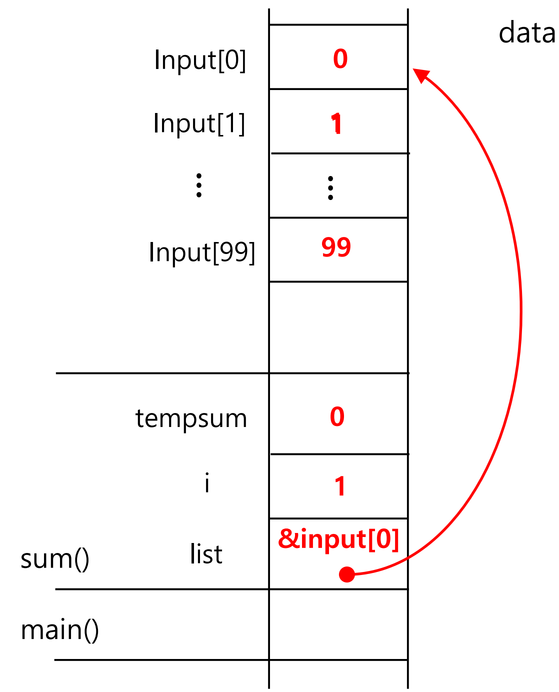


```c
#include <stdio.h>
#define MAX_SIZE 100
float sum(float[], int);
void fillarray(float[], int);
float input[MAX_SIZE], answer;
void main(void)
{
    fillarray(input, MAX_SIZE);
    answer = sum(input, MAX_SIZE);
    printf("The sum is: %f\n", answer);
}
void fillarray(float list[], int n)
{
    int i;
    for (i = 0; i < n; i++)
        list[i] = i;
}
float sum(float list[], int n)
{
    int i;
    float tempsum = 0;
    for (i = 0; i < n; i++)
        tempsum += list[i];
    return tempsum;
}
```

■ **right-side of equal sign**

- a dereference takes place

- the value pointed at by (*list+i*) is returned



```c
#include <stdio.h>
#define MAX_SIZE 100
float sum(float[], int);
void fillarray(float[], int);
float input[MAX_SIZE], answer;
void main(void)
{
	fillarray(input, MAX_SIZE);
	answer = sum(input, MAX_SIZE);
	printf("The sum is: %f\n", answer);
}
void fillarray(float list[], int n)
{
	int i;
	for (i = 0; i < n; i++)
		list[i] = i;
}
float sum(float list[], int n)
{
	int i;
	float tempsum = 0;
	for (i = 0; i < n; i++)
		tempsum += list[i];
	return tempsum;
}
```

- **left-side of equal sign**
  - **the value produced on the right-hand side is stored in the location (*list+i*)**
- **right-side of equal sign**
  - **a dereference takes place**
  - **the value pointed at by (*list+i*) is returned**

In C, array parameters have their values altered, despite the fact that the parameter passing is done using *call-by-value*.

int one[] = {0, 1, 2, 3, 4};

print1(&one[0], 5);

```
void print1(int *ptr, int rows)
{/* print out a one-dimensional array using a pointer */
   int i;
   printf("Address Contents\n");
   for (i = 0; i < rows; i++)
      printf("%8u%5d\n", ptr + i, *(ptr + i));
   printf("\n");
}
```

pointer

ptr[i]

Program 2.2: One-dimensional array accessed by address

Address	Contents
12244868	0
12344872	1
12344876	2
12344880	3
12344884	4

Assumption: sizeof(int) == 4

2.2 Dynamically Allocated Arrays

2.2.1 One-dimensional Arrays

```
pf = (float *) malloc(sizeof(float));
```

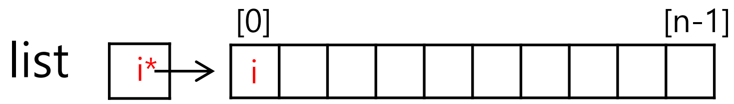
can be replaced by

```
#define MALLOC(p,s) \
   if (!((p) = malloc(s))) {\
      fprintf(stderr, "Insufficient memory"); \
      exit(EXIT_FAILURE);\
   }

MALLOC(pf, sizeof(float));
```

- Change the first few lines of *main* of Program 1.4 to:

```
int i,n,*list;
printf("Enter the number of numbers to generate: ");
scanf("%d",&n);
if( n < 1 ) {
  fprintf(stderr, "Improper value of n\n");
  exit(EXIT_FAILURE);
}
MALLOC(list, n * sizeof(int));
```



2.2.2 Two-Dimensional Arrays

- A multidimensional array in C
  - *Array-of-arrays* representation

int x[3][5];

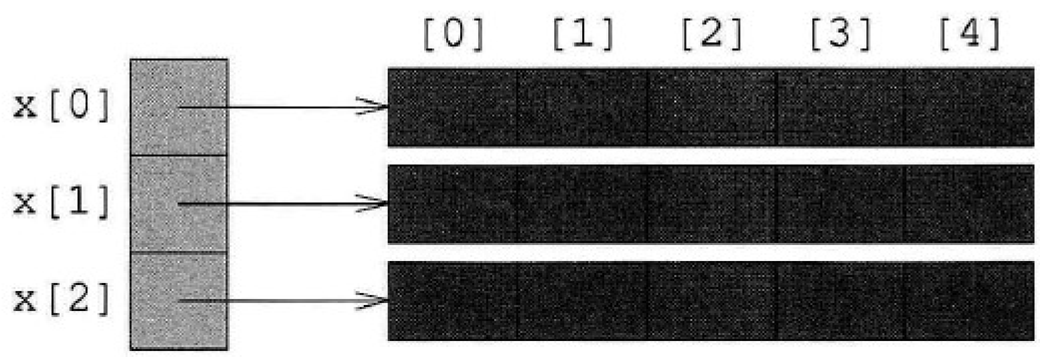


Figure 2.2: Array-of-arrays representation

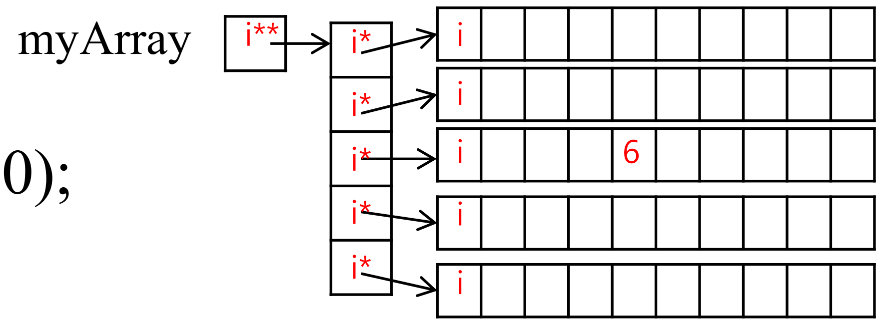
x[i] : a pointer to zeroth element of row i of the array

x[i][j] : an element accessed by the address, x[i]+j*sizeof(int)

int **myArray;

myArray = make2dArray(5,10);

myArray[2][4] = 6;




```
int** make2dArray(int rows, int cols)
{/* create a two dimensional rows × cols array */
   int **x, i;

   /* get memory for row pointers */
   MALLOC(x, rows * sizeof (*x));;

   /* get memory for each row */
   for (i = 0; i < rows; i++)
     MALLOC(x[i], cols * sizeof(**x));
   return x;
}
```

주소 포인터 배열

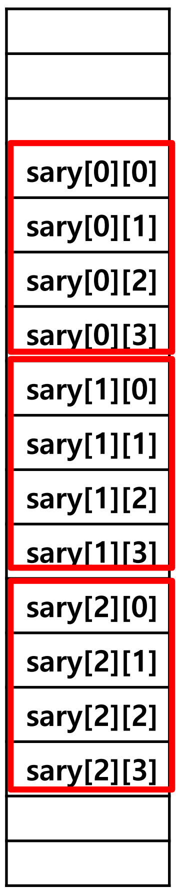
Program 2.3: Dynamically create a two-dimensional array

정적 arry 와 동적 array

정적 Array

int sary[3][4]

sary

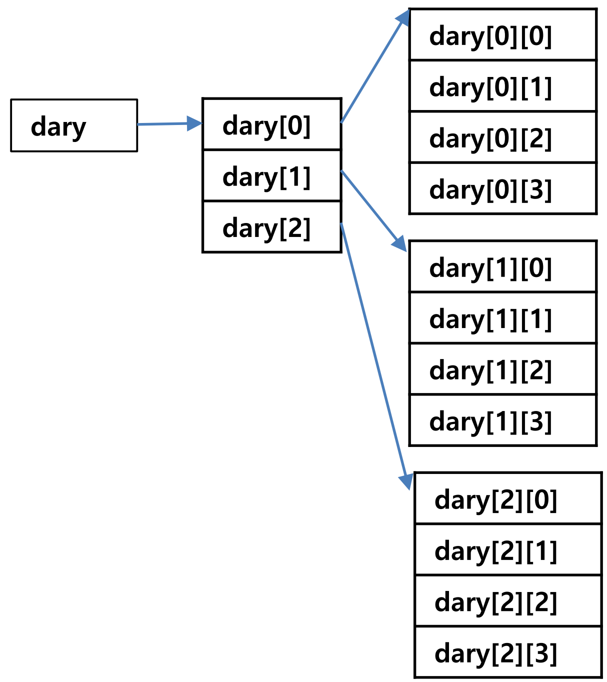


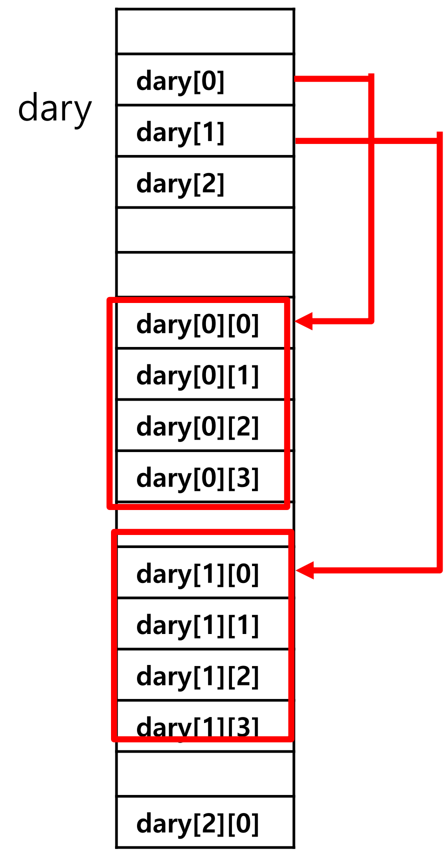
sary == &sary[0][0]
== sary[0]

동적 Array

int **dary

dary는 동적으로 할당 받은 2차원 배열[3][4]의 시작 주소를 가지고있는 포인터임





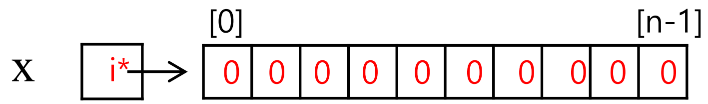
dary != &dary[0][0]
dary == &dary[0]
dary[0] == &dary[0][0]

- calloc

  int *x, n;

  x = (int *) calloc(n, sizeof(int));

  /* allocated bits are set to 0*/



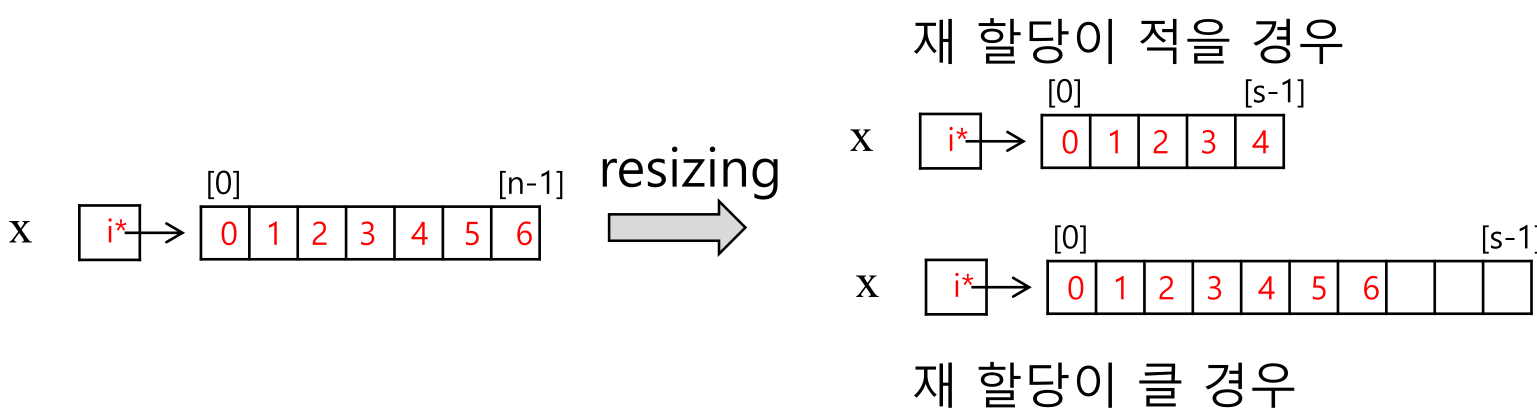

```
#define CALLOC(p,n,s)\
        if (!((p) = calloc(n,s))) {\
                fprintf(stderr, "Insufficient memory"); \
                exit(EXIT_FAILURE);\
        }
```

CALLOC(x, n, sizeof(int));

- realloc

```
int *old, *x, s;
...
old = x;
if ( (x = (int *)realloc(x, s*sizeof(int))) == NULL ){
        free(old);
        exit(EXIT_FAILURE);
}
…
free(x);
```

/* changes the size of memory block pointed by x to s*sizeof(int) */



- realloc(cont')

errata

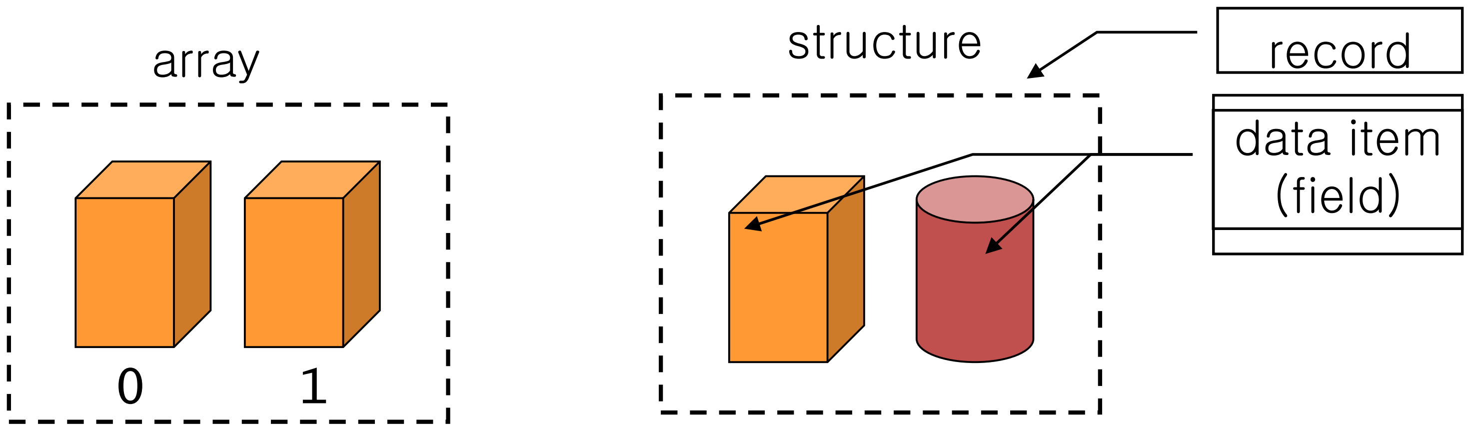
```
#define REALLOC(p,s)\
        if (!((p) = realloc(p,s))) {\
                fprintf(stderr, "Insufficient memory");\
                exit(EXIT_FAILURE);\
        }
 …
 REALLOC(x, s*sizeof(int));
```

```
#define REALLOC(o, p, s) \
        if (!((p) = realloc(o, s))) {\
                free(o);\
                fprintf(stderr, "Insufficient memory"); \
                exit(EXIT_FAILURE);\
        }
    ...
REALLOC(old, x, s*sizeof(int));//x = realloc(x, s*sizeof(int))
```

※ realloc() 실패 시 종료

2.3 Structures and Union

2.3.1 Structures




```
char carray[100];
```

```
struct example {
        char cfield;
        int ifield;
        float ffield;
        double dfield;
};
struct example s1;
```

2.3 Structures and Union

2.3.1 Structures

- Called a *record*
- Collection of data items
  - Each item is identified as to its type and name

```
struct {
        char name[10];
        int age;
        float salary;
        } person;
```

person is a variable.

  - Structure member operator : dot(.)

```
strcpy(person.name,"james");
person.age = 10;
person.salary = 35000;
```

- Using the **typedef** statement

```
typedef struct {
        char name[10];
        int age;
        float salary;
        } humanBeing;
```

humanBeing is a data type.

- Declaration of variables

```
humanBeing person1, person2;

if (strcmp(person1.name, person2.name))
   printf("The two people do not have the same name\n");
else
   printf("The two people have the same name\n");
```

- Structure assignment : person1=person2;
  - in ANSI C, OK!
    - However, don’t use the assignment operation when the structure has a pointer to a memory space. Why?
  - in older versions of C, NOT OK!

```
strcpy(person1.name, person2.name);
person1.age = person2.age;
person1.salary = person2.salary;
```

- Check of equality or inequality : if(person1==person2)
  - cannot be checked directly

- Check of equality or inequality(cont')

```
#define FALSE 0
#define TRUE 1

if (humansEqual(person1,person2))
  printf("The two human beings are the same\n");
else
  printf("The two human beings are not the same\n");
```

```
int humansEqual(humanBeing person1,
                humanBeing person2)
{/* return TRUE if person1 and person2 are the same human
    being otherwise return FALSE */
  if (strcmp(person1.name, person2.name))
    return FALSE;
  if (person1.age != person2.age)
    return FALSE;
  if (person1.salary != person2.salary)
    return FALSE;
  return TRUE;
}
```

Program 2.4: Function to check equality of structures

- A structure within a structure

```
typedef struct {
        int month;
        int day;
        int year;
        } date;

typedef struct {
        char name[10];
        int age;
        float salary;
        date dob;
        }humanBeing;
```

humanBeing person1;

```
person1.dob.month = 2;
person1.dob.day = 11;
person1.dob.year = 1944;
```

2.3.2 Unions

- The fields share their memory space
- Only one field is "active" at any given time.

```
typedef struct {
   enum tagField {female, male} sex;
   union {
      int children;
      int beard ;
      } u;
   } sexType;

typedef struct {
   char name[10];
   int age;
   float salary;
   date dob;
   sexType sexInfo;
   } humanBeing;

humanBeing person1, person2;

person1.sexInfo.sex = male;
person1.sexInfo.u.beard = FALSE;

person2.sexInfo.sex = female;
person2.sexInfo.u.children = 4;
```

2.3.4 Self-Referential Structures

- A structure in which one or more of its components is a pointer to itself.

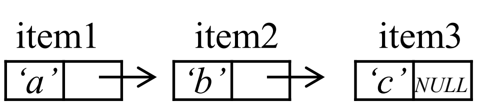
```
typedef struct list {
        char data;
        struct list *link ;
        } list ;
```

```
typedef struct list {
    int data;
    struct list* link;
} t_list;
```

```
list item1, item2, item3;
item1.data = 'a';
item2.data = 'b';
item3.data = 'c';
item1.link = item2.link = item3.link = NULL;
```

```
t_list item1, item2, item3;
```

```
item1.link = &item2;
item2.link = &item3;
```



2.4 Polynomials

2.4.1 The Abstract Data Type

- ***Ordered list*** **or** ***linear list***
  - an ordered set of data items

    ex) Days-of-week

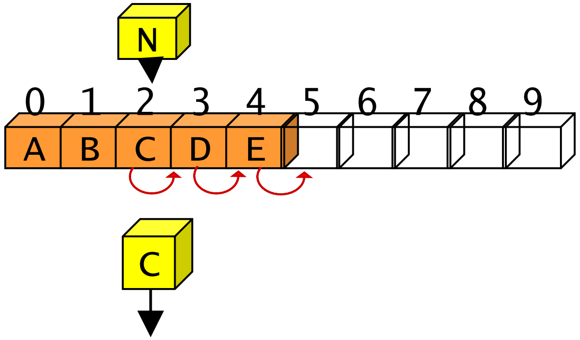
(Sun,	Mon,	Tue,	Wed,	Thu,	Fri,	Sat)	: *list*
1st	2nd	3rd	4th	5th	6th	7th	: *order*

    - denote as ($item_0$, $item_1$, …, $item_{n-1}$)
    - empty list : ( )
  - operations on ordered list

i. find the length n
ii. read the items in a list from right to left (or left to right)
iii. retrieve ith item, $0 \le i < n$
iv. replace ith item's value, $0 \le i < n$
v. insert ith position, $0 \le i < n$: i, i+1, ..., n-1 → i+1, i+2, ..., n
vi. delete ith item, $0 \le i < n$: i+1, ..., n-1 → i, i+1, ..., n-2

Implementation of Ordered List

- Array
  - associate the list element, *item*$_i$, with the array index i
  - *sequential mapping*
  - retrieve, replace an item, or find the length of a list, in constant time
  - problems in insertion and deletion
    - sequential mapping forces us to move items



- Linked List
  - *Non-sequential mapping*
  - Chapter 4

A Problem Requiring Ordered Lists

- Manipulation of symbolic polynomials

$$A(x) = 3x^{20} + 2x^5 + 4\,,\;\; B(x) = x^4 + 10x^3 + 3x^2 + 1$$

  - degree : the largest exponent of a polynomial

When $A(x) = \Sigma\, a_i x^i$ and $B(x) = \Sigma\, b_i x^i$,

$$A(x) + B(x) = \Sigma\,(a_i + b_i)x^i$$

$$A(x)\, B(x) = \Sigma\,(a_i x^i\, \Sigma\,(b_j x^j))$$

  - assumption: unique exponents arranged in decreasing order

ADT *Polynomial* is

objects: $p(x) = a_1 x^{e_1} + \cdots + a_n x^{e_n}$; a set of ordered pairs of $<e_i, a_i>$ where a_i in *Coefficients* and e_i in *Exponents*, e_i are integers >= 0

functions:

for all $poly, poly1, poly2 \in Polynomial$, $coef \in Coefficients$, $expon \in Exponents$

Polynomial Zero()	::=	**return** the polynomial, $p(x) = 0$
Boolean IsZero(*poly*)	::=	**if** (*poly*) **return** *FALSE* **else return** *TRUE*
Coefficient Coef(*poly*,*expon*)	::=	**if** ($expon \in poly$) **return** its coefficient **else return** zero
Exponent LeadExp(*poly*)	::=	**return** the largest exponent in *poly*
Polynomial Attach(*poly*, *coef*, *expon*)	::=	**if** ($expon \in poly$) **return** error **else return** the polynomial *poly* with the term <*coef*, *expon*> inserted
Polynomial Remove(*poly*, *expon*)	::=	**if** ($expon \in poly$) **return** the polynomial *poly* with the term whose exponent is *expon* deleted **else return** error
Polynomial SingleMult(*poly*, *coef*, *expon*)	::=	**return** the polynomial $poly \cdot coef \cdot x^{expon}$
Polynomial Add(*poly*1, *poly*2)	::=	**return** the polynomial $poly1 + poly2$
Polynomial Mult(*poly*1, *poly*2)	::=	**return** the polynomial $poly1 \cdot poly2$

end *Polynomial*

ADT 2.2: Abstract data type *Polynomial*

2.4.2 Polynomial Representation

```
#define COMPARE(x, y) ( ((x) < (y)) ? -1 : ((x) == (y)) ? 0: 1 )
```
※ p.12

```
/* d = a + b, where a, b, and d are polynomials */
d = Zero()
while (! IsZero(a) && ! IsZero(b)) do {
   switch COMPARE(LeadExp(a), LeadExp(b)) {
      case -1: d =
         Attach(d,Coef(b,LeadExp(b)),LeadExp(b));
         b = Remove(b,LeadExp(b));
         break;
      case 0: sum = Coef( a, LeadExp(a))
                    + Coef(b, LeadExp(b));
         if (sum) {
            Attach(d,sum,LeadExp(a));
            a = Remove(a,LeadExp(a));
            b = Remove(b,LeadExp(b));
            }
         break;
      case 1: d =
         Attach(d,Coef(a,LeadExp(a)),LeadExp(a));
         a = Remove(a,LeadExp(a));
   }
}
insert any remaining terms of a or b into d
```

Program 2.5: Initial version of *padd* function (representation-independent)

Initial version of *padd* function (cont')

$D(x) = 0$
$A(x) = 2x^{1000} + 2x^3$
$B(x) = x^4 + 10\,x^3 + 3\,x^2 + 1$

(step1)
$D(x) = 2x^{1000}$
$A(x) = 2x^3$
$B(x) = x^4 + 10\,x^3 + 3\,x^2 + 1$

(step2)
$D(x) = 2x^{1000} + x^4$
$A(x) = 2x^3$
$B(x) = 10\,x^3 + 3\,x^2 + 1$

(step3)
$D(x) = 2x^{1000} + x^4 + 12x^3$
$A(x) = 0$
$B(x) = 3\,x^2 + 1$

(step4)
$D(x) = 2x^{1000} + x^4 + 12x^3 + 3\,x^2 + 1$
$A(x) = 0$
$B(x) = 0$

Representation of polynomials in C

(1)
```
#define MAX_DEGREE 101 /*Max degree of polynomial+1*/
typedef struct {
        int degree;
        float coef[MAX_DEGREE];
        } polynomial;
```

```
polynomial a;
```

$A(x) = \Sigma_{i=0}^{n} a_i x^i$ would be represented as :

a.degree $= n$
a.coef[i] $= a_{n-i},\ 0 \le i \le n$, $n <$ MAX_DEGREE

※ *a.coef[i] is the coefficient of* x^{n-i}

$A(x) = 2x^{1000} + 1$ and $B(x) = x^4 + 10\, x^3 + 3\, x^2 + 1$

1000

2	0	0	0	0	0	....	0	0	0	0	0	0	0	1

4

1	10	3	0	1

Representation of polynomials in C(cont')

(2)
```
#define MAX_TERMS 100 /*size of terms array*/
typedef struct {
          float coef;
          int expon;
          }term;
term terms[MAX_TERMS];
int avail = 0;
```

$A(x) = 2x^{1000} + 1$ and $B(x) = x^4 + 10\, x^3 + 3\, x^2 + 1$

coef	2	1
exp	1000	0
	0	1

Using one array to represent two polynominals

$A(x) = 2x^{1000} + 1$ and $B(x) = x^4 + 10\,x^3 + 3\,x^2 + 1$

	startA	*finishA*	*startB*			*finishB*	*avail*
	↓	↓	↓			↓	↓
coef	2	1	1	10	3	1	
exp	1000	0	4	3	2	0	
	0	1	2	3	4	5	6

```
void padd(int startA,int finishA,int startB, int finishB,
                                  int *startD,int *finishD)
{/* add A(x) and B(x) to obtain D(x) */
  float coefficient;
  *startD = avail;
  while (startA <= finishA && startB <= finishB)
    switch(COMPARE(terms[startA].expon,
                   terms[startB].expon)) {
      case -1: /* a expon < b expon */
            attach(terms[startB].coef,terms[startB].expon);
            startB++;
            break;
      case 0: /* equal exponents */
            coefficient = terms[startA].coef +
                          terms[startB].coef;
            if (coefficient)
              attach(coefficient,terms[startA].expon);
            startA++;
            startB++;
            break;
      case 1: /* a expon > b expon */
            attach(terms[startA].coef,terms[startA].expon);
            startA++;
  }
  /* add in remaining terms of A(x) */
  for(; startA <= finishA; startA++)
    attach(terms[startA].coef,terms[startA].expon);
  /* add in remaining terms of B(x) */
  for( ; startB <= finishB; startB++)
    attach(terms[startB].coef, terms[startB].expon);
  *finishD = avail-1;
}
```

iterations $\leq m+n-1$

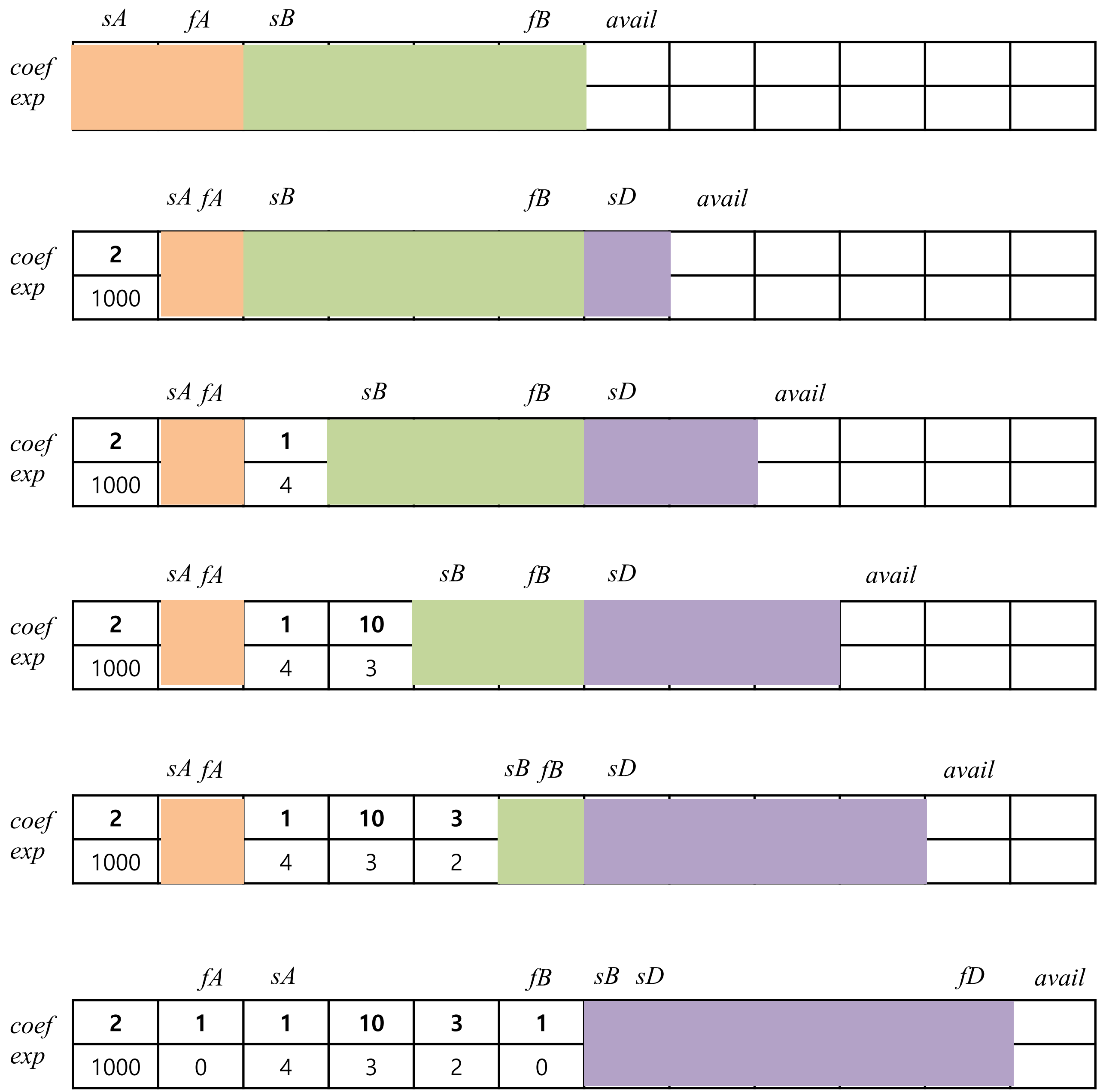
$\leq m$

$\leq n$

Program 2.6: Function to add two polynomials ※ using (2)

```
void attach(float coefficient, int exponent)
{/* add a new term to the polynomial */
   if (avail >= MAX_TERMS) {
      fprintf(stderr,"Too many terms in the polynomial\n");
      exit(EXIT_FAILURE);
   }
   terms[avail].coef = coefficient;
   terms[avail++].expon = exponent;
}
```

Program 2.7: Function to add a new term


sA fA sB fB avail
coef
exp
sA fA sB fB sD avail
coef
exp
2
1000
sA fA sB fB sD avail
coef
exp
2
1000
1
4
sA fA sB fB sD avail
coef
exp
2
1000
1
4
10
3
sA fA sB fB sD avail
coef
exp
2
1000
1
4
10
3
3
2
fA sA fB sB sD fD avail
coef
exp
2
1000
1
0
1
4
10
3
3
2
1
0

- **Analysis of *padd***
  - Let m and n be the number of nonzero terms in A and B, respectively.
  - ① If $m>0$ and $n>0$, **while loop**
    - each iteration : O(1)
    - The iteration terminates when either *startA* or *startB* exceeds *finishA* or *finishB*, respectively
    - The number of iterations is bounded by $m+n-1$
      - the worst case : ex) $a(x) = x^6+x^4+x^2+x^0$, $b(x) = x^7+x^5+x^3+x^1$
  - ② The remaining **two for loops** → $O(m+n)$
  - ①&② → $\mathbf{O(m+n)}$