# Data Structure and Algorithm

## Class 3

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# Table of contents

# Array

# Array

an **array** is a set of pairs, **<index, value>**, such that each index that is defined has a value associated with it

- "a consecutive set of memory locations" in C
- logical order is the same as physical order

operations

- creating a new array
- retrieves a value
- stores a value
- insert a value into array - delete a value at the array

# Array

A one-dimensional array in C is declared implicitly by appending brackets to the name of a variable

```
int list[5], int *plist[5];
```

arrays start at index 0 in C

# Array

consider the implementation of one-dimensional arrays

```
int list[5];
```

- allocates five consecutive memory locations
- each memory location is large enough to hold a single integer
- base address is address of the first element

```
list = &list[0]
```

| list[0] | list[1] | list[2] | list[3] | list[4] |
|---|---|---|---|---|
| trash value | trash value | trash value | trash value | trash value |

# Array

| Variable | Memory Address |
|---|---|
| `&list[0]` | base address = $\alpha$ |
| `&list[1]` | $\alpha$ + `sizeof(int)` |
| `&list[2]` | $\alpha + 2 \cdot$ `sizeof(int)` |
| `&list[3]` | $\alpha + 3 \cdot$ `sizeof(int)` |
| `&list[4]` | $\alpha + 4 \cdot$ `sizeof(int)` |

- Because different architectures have different int sizes, we have to use "sizeof"

`&list[i]` in a C programs

- C interprets it as a pointer to an integer or its value

# Array

```
int *list1; // pointer variable to an int
```

```
int *list2[5]; // list2 : pointer constant to an int,
                  // and five memory locations for holding
                  // integers are reserved
```

```
int list[] = { 0,1,2,3,4,5 };

printf("%d\n", list[3]); // 3
printf("%d\n", *(&list[0]+3)); // 3
printf("%d\n", *(list+3)); // 3 ...All is the same expression
```

`(list2+i)` equals `&list2[i]`, and `*(list2+i)` equals `list2[i]`

- regardless of the type of the array list2

# Array

How about this ?

```
printf("%d\n", ++list[0]);
```

- `++list[0]` -> `list[0]+1`
- the result is same as `list[1]`

# Array

consider the way C treats an array when it is a parameter to a function

- the parameter passing is done using call-by-value in C
- but array parameters have their values altered

# Array: Example 2.1

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

float sum(float list[], int n) {
    int i;
    float tempsum = 0;
    for(i = 0; i < n; i++)
        tempsum += list[i];
    return tempsum;
}
```

# Recap: On Pointer

Pointer Variable stores address

- & : Starting address of allocated variable
- * : Value stored on the address of the pointer variable

```
1  // pointer_variable.c
2  #include <stdio.h>
3
4  int main(){
5      int nNum, *pNum;
6
7      nNum = 10;
8      pNum = &nNum;
9
10     printf("nNum = %d, &nNum = %d \n", nNum, (int)&nNum);
11     printf("pNum = %d, pNum = %d, &pNum = %d \n",
12                           *pNum, (int)pNum, (int)&pNum);
13 }
```

# Recap: On Pointer

Do Not!

- pointer variable is not referencing an address, so cannot store a value

```
int *ptr;
*ptr = 100;
```

It is better to handle NULL for the pointer that do not refer to address right away

# Recap: On Pointer

Do Not!

- the data type must equal

```
double Pi = 3.14;
int *pPi = &Pi;
```

- cannot dereference a non-pointer variable

```
int num;
*num = 100;
```

# Recap: On Pointer

Do!

- it is recommended to initialize a pointer value with NULL ('\0')
  See the example

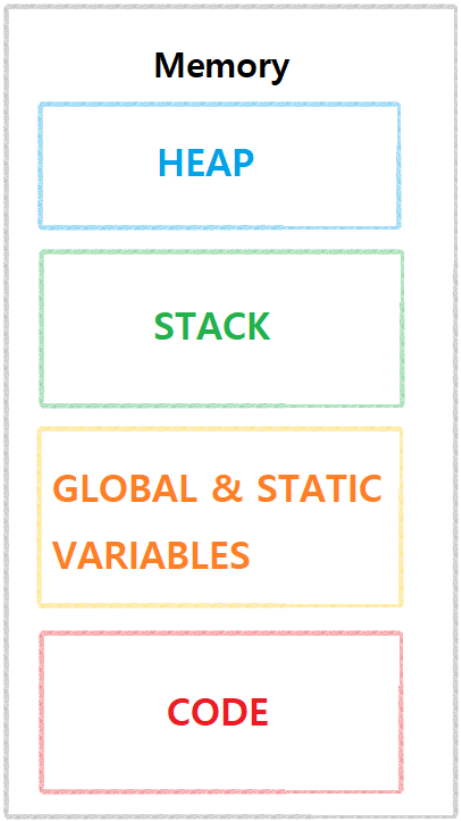
```
1  // null_pointer.c
2  #include <stdio.h>
3
4  int main(){
5      int *pNum = NULL, Num=103;
6      if (pNum == '\0')
7          pNum = &Num;
8      else
9          *pNum = 100;
10     printf("pNum %d", (int)*pNum);
11     return 0;
12 }
```

# Recap: On Pointer

```
#include <stdlib.h>

void *malloc(size_t size); // allocates size bytes of memory and returns
     a pointer to the allocated memory

void *free(void *ptr); // frees allocation that were created via the
    preceding allocation function

void *calloc(size_t count, size_t size); // contiguously allocates
    enough space for count objects that are size bytes of memory each
    and returns a pointer to the allocated memory. The allocated memory
     is filled with bytes of value zero.

void *realloc(void *ptr, size_t size); // change the size of the
    allocation pointed to by ptr to size, and returns ptr
```

# Recap: On Pointer

if the memory is not freed after being allocated, a memory leak will occur



# Array: Ex 2.2, 1-dimensional array addressing

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

write a function that prints out both the address of the $i^{th}$ element of the array and the value found at this address

# Array: Ex 2.2 One dimensional array accessed by address

```c
// codes/array_address.c
#include <stdio.h>

void print1(int *ptr,int rows) {
    int i;
    printf("Address\t\tContents\n");
    for(i=0;i<rows;i++)
        printf("%8u\t%5d\n", (unsigned int)ptr+i, *(ptr+i));
    printf("\n");
}

int main() {
  int one[] = {0, 1, 2, 3, 4};
  print1(one, 5);
  return 0;
}
```

## One-dimensional array accessed by address

- address of `i` th element `ptr + i`
- obtain the value of the `i` th value `*(ptr + i)`

# Array

```
Address  Contents
1518325632 0
1518325633 1
1518325634 2
1518325635 3
1518325636 4
```

One-dimensional array addressing

- the addresses increase by two on an Intel 386 machine
- Example shown is the result of Mac OS X on Intel Core i5 Machine

# Structures and Unions

# Structures and Unions: struct

**struct**

- structure or record
- the mechanism of grouping data
- permits the data to vary in type

collection of data items where

- each item is identified as to its type and name

# Structures and Unions: struct

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

creating a variable

- whose name is person and
- has three fields
  1. a name that is a character array
  2. an integer value representing the age of the person
  3. a float value representing the salary of the individual

# Structures and Unions: struct

use of the .(period) as the structure member operator

```
strcpy(person.name, "james");
person.age = 30;
person.salaray = 35000;
```

- select a particular member of the structure

# Structures and Unions: struct

`typedef statement`

- create our own structure data type

type 1

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

type 2

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

# Structures and Unions: struct

`human_being`

- the name of the type defined by the structure definition

```
human_being 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");
```

# Structures and Unions: Assignment

**assignment**

- permits structure assignment in ANSI C

```
person1 = person2;
```

- but, in most earlier versions of C assignment of structures is not permitted

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

# Structures and Unions: Equality or Inequality

**equality or inequality**

- cannot be directly checked
- Example function to check equality of struct

```
int humans_equal(human_being person1, human_being person2) {
    if(strcmp(person1.name,person2.name))
        return FALSE;
    if(person1.age!=person2.age)
        return FALSE;
    if(person1.salary!=person2.salary)
        return FALSE;
    return TRUE;
}
```

# Structures and Unions: Embedding Structure

Embedding of a structure within a structure

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

typedef struct human_being {
    char name[10];
    int age;
    float salary;
    date dob; // embedded structure
};
```

# Structures and Unions: Embedding Structure

Ex. A person boar on Feb 14 1992

```
human_begin person1;
person1.dob.month = 2;
person1.dob.day = 14;
person1.dob.year = 1992;
```

# Structures and Unions: Unions

## Unions

- similar to a structure, but
- the fields of a union must share their memory space
- only one field of the union is “active” at any given time

# Structures and Unions: Unions

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

typedef struct human_being {
    char name[10];
    int age;
    float salary;
    date dob;
    sex_type sex_info;
};

human_being person1,person2;
```

# Structures and Unions: Unions

Assign values to person1 and person2

```
persone1.sex_info.sex = male;
person1.sex_info.u.beard = FALSE; /* FALSE: 0 */
```

and

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

# Structures and Unions: Differences between structure and union

What are differences between structure and union ?

- Structure

```
typedef struct example{
   int x, y;
   double d;
}struct_example;

struct_example se;

printf("%d\n", sizeof(se));
printf("%p %p %p\n", &se.x, &se.y, &se.d);
```

» 16

» 0x7ff0 0x7ff4 0x7ff8

- 16byte size, different address

# Structures and Unions: Differences between structure and union

- Union

```
typedef union example{
   int x, y;
   double d;
}union_example;

union_example ue;

printf("%d\n", sizeof(ue));
printf("%p %p %p\n", &ue.x, &ue.y, &ue.d);
```

» 8

» 0x7ff0 0x7ff0 0x7ff0

- 8byte size, same address

# Structures and Unions: Internal Implementation of Structure

```
struct {
    int i, j; float a, b;
}
```

or

```
struct {
    int i; int j; float a; float b;
};
```

stored in the same way

- increasing address locations in the order specified in the structure definition

size of an object of a struct or union type

- the amount of storage necessary to represent the largest component

# Structures and Unions: Self-referential structures

- one or more of its components is a pointer to itself
- usually require dynamic storage management routines to explicitly obtain and release memory

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

the value of `link`

- address in memory of an instance of `list` or `null` pointer

# Structures and Unions: Self-referential structures

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

# Structures and Unions: Self-referential structures

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

attach these structures together

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

# Sparse Matrices

# The Sparse Matrix: representing matrix by using array

- $m$ by $n$ ($m$ rows, $n$ columns)
- use two-dimensional array
- space complexity
  $S(m,n) = m * n$

$$
\begin{array}{c} \\ row0 \\ row1 \\ row2 \\ row3 \\ row4 \end{array}
\begin{array}{c}
\begin{array}{ccc} col0 & col1 & col2 \end{array} \\
\begin{bmatrix} -27 & 3 & 4 \\ 6 & 82 & -2 \\ 109 & -64 & 11 \\ 12 & 8 & 9 \\ 48 & 27 & 47 \end{bmatrix}
\end{array}
$$

# The Sparse Matrix

`A[6,6]`

$$
\begin{array}{c}
 & col0 & col1 & col2 & col3 & col4 & col5 \\
row0 & \left[\begin{array}{cccccc} 15 & 0 & 0 & 22 & 0 & 15 \end{array}\right. \\
row1 & \begin{array}{cccccc} 0 & 11 & 3 & 0 & 0 & 0 \end{array} \\
row2 & \begin{array}{cccccc} 0 & 0 & 0 & -6 & 0 & 0 \end{array} \\
row3 & \begin{array}{cccccc} 0 & 0 & 0 & 0 & 0 & 0 \end{array} \\
row4 & \begin{array}{cccccc} 91 & 0 & 0 & 0 & 0 & 0 \end{array} \\
row5 & \left[\begin{array}{cccccc} 0 & 0 & 28 & 0 & 0 & 0 \end{array}\right.
\end{array}
$$

# The Sparse Matrix

common characteristics

- most elements are zero's
- inefficient memory utilization

solutions

- store only nonzero elements
- using the triple `<row,col,value>`
- must know
  - the number of rows
  - the number of columns
  - the number of non-zero elements

# The Sparse Matrix

```
#define MAX_TERMS 101

typedef struct {
    int col;
    int row;
    int value;
} term;

term a[MAX_TERMS];
```

- a[0].row: the number of rows
- a[0].col: the number of columns
- a[0].value: the total number of non-zoros
- choose row-major order

# The Sparse Matrix: As Triples

| | row | col | value |
|---|---|---|---|
| a[0] | 6 | 6 | 8 |
| a[1] | 0 | 0 | 15 |
| a[2] | 0 | 3 | 22 |
| a[3] | 0 | 5 | -15 |
| a[4] | 1 | 1 | 11 |
| a[5] | 1 | 2 | 3 |
| a[6] | 2 | 3 | -6 |
| a[7] | 4 | 0 | 91 |
| a[8] | 5 | 2 | 28 |

- space complexity (*variable space requirement)
  `S(m,n) = 3 * t` where
  `t` : the number of non-zero's
- independent of the size of rows and columns

# The Sparse Matrix: Transpose

Transpose a matrix

- interchange rows and columns
- move `a[i][j]` to `a[j][i]`

| | row | col | value |
|---|---|---|---|
| b[0] | 6 | 6 | 8 |
| b[1] | 0 | 0 | 15 |
| b[2] | 0 | 4 | 91 |
| b[3] | 1 | 1 | 11 |
| b[4] | 2 | 1 | 3 |
| b[5] | 2 | 5 | 28 |
| b[6] | 3 | 0 | 22 |
| b[7] | 3 | 2 | -6 |
| b[8] | 5 | 0 | -15 |

# The Sparse Matrix

```
algorithm BAD_TRANS
for each row i
    take element <i,j,value>;
    store it as element <j,i,value> of the transpose;
end;
```

The problem

# The Sparse Matrix

```
algorithm BAD_TRANS
for each row i
    take element <i,j,value>;
    store it as element <j,i,value> of the transpose;
end;
```

The problem

- data movement

# The Sparse Matrix

```
algorithm BAD_TRANS
for each row i
    take element <i,j,value>;
    store it as element <j,i,value> of the transpose;
end;
```

The problem

- data movement

```
algorithm TRANS
for all elements in column j
    place element <i,j,value> in element <j,i,value> end;
```

The problem

# The Sparse Matrix

```
algorithm BAD_TRANS
for each row i
    take element <i,j,value>;
    store it as element <j,i,value> of the transpose;
end;
```

The problem

- data movement

```
algorithm TRANS
for all elements in column j
    place element <i,j,value> in element <j,i,value> end;
```

The problem

- unnecessary loop for each column

# The Sparse Matrix: Transpose

```
void transpose(term a[], term b[]) {
    int n, i, j, currentb;
    n = a[0].value;
    b[0].row = a[0].col;
    b[0].col = a[0].row;
    b[0].value = n;
    if(n > 0){
        currentb = 1;
        for (i = 0; i < a[0].col; i++)
            for(j = 1; j <= n; j++)
                if(a[j].col == i) {
                  b[currentb].row = a[j].col;
                  b[currentb].col = a[j].row;
                  b[currentb].value = a[j].value;
                  cuurentb++;
            }
    }
}
```

Space and Time complexity?

# The Sparse Matrix: Transpose

**Complexity**

- space: 3× t
- time: O(cols× t)

create better algorithm by using a little more storage

- row_terms the number of element in each row
- starting_pos the starting point of each row

# The Sparse Matrix: Better Transpose I

```
void fast_transpose(term a[], term b[]){
    int row_terms[MAX_COL];
    int starting_pos[MAX_COL];

    int i, j;

    int num_cols = b[0].row = a[0].col;
    int num_terms = b[0].value = a[0].value;

    b[0].col = a[0].row;

    if(num_terms > 0) {
        for(i = 0; i < num_cols; i++)
            row_terms[i] = 0;

        for(i = 1; i <= num_terms; i++)
            row_terms[a[i].col]++;

        starting_pos[0] = 1;
```

# The Sparse Matrix: Better Transpose II

```
        for(i = 1; i < num_cols; i++)
            starting_pos[i] = starting_pos[i-1] + row_terms[i-1];

        for(i = 1; i <= num_terms; i++){
            j = starting_pos[a[i].col]++;
            b[j].row = a[i].col;
            b[j].col = a[i].row;
            b[j].value = a[i].value;
        }
    }
}
```

# The Sparse Matrix: Better Transpose

| | [0] | [1] | [2] | [3] | [4] | [5] |
|---|---|---|---|---|---|---|
| row_terms= | 2 | 1 | 2 | 2 | 0 | 1 |
| starting_pos= | 1 | 3 | 4 | 6 | 8 | 8 |

**complexity**

- space: 3× t + extra
- time: O(cols + t)