CS2100 COMPUTER ORGANISATION

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Lecture #5

Arrays, Strings and Structures

Lecture #5: Arrays, Strings and Structures (1/2)

Lecture #5: Arrays, Strings and Structures (2/2)

4. Structures
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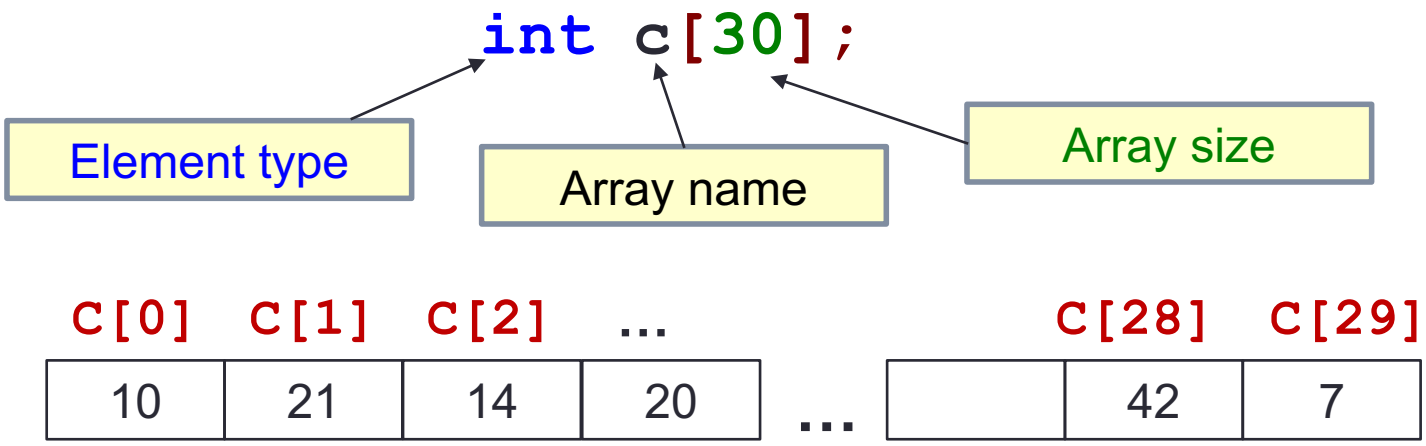
1. Collection of Data

- Besides the basic data types (int, float, double, char, etc.), C also provides means to organise data for the purpose of more logical representation and ease of manipulation.
- We will cover the following in this lecture:
  - Arrays
  - Strings
  - Structures

2. Arrays (1/2)

- An array is a homogeneous collection of data
- The declaration of an array includes the element type, array name and size (maximum number of elements)
- Array elements occupy contiguous memory locations and are accessed through indexing (from index 0 onwards)

Example: Declaring a 30-element integer array c.



2. Arrays (2/2)

ArraySumV1.c

```
#include <stdio.h>
#define MAX 5

int main(void) {
   int numbers[MAX];
   int i, sum = 0;

   printf("Enter %d integers: ", MAX);
   for (i=0; i<MAX; i++) {
      scanf("%d", &numbers[i]);
   }

   for (i=0; i<MAX; i++) {
      sum += numbers[i];
   }

   printf("Sum = %d\n", sum);
   return 0;
}
```

- Summing all elements in an integer array

ArraySumV2.c

```
#include <stdio.h>
#define MAX 5

int main(void) {
   int numbers[MAX] = {4,12,-3,7,6};
   int i, sum = 0;

   for (i=0; i<MAX; i++) {
      sum += numbers[i];
   }

   printf("Sum = %d\n", sum);
   return 0;
}
```

2.1 Array Declaration with Initializers

- As seen in ArraySumV2.c, an array can be initialized at the time of declaration.

```
// a[0]=54, a[1]=9, a[2]=10
int a[3] = {54, 9, 10};

// size of b is 3 with b[0]=1, b[1]=2, b[2]=3
int b[] = {1, 2, 3};

// c[0]=17, c[1]=3, c[2]=10, c[3]=0, c[4]=0
int c[5] = {17, 3, 10};
```

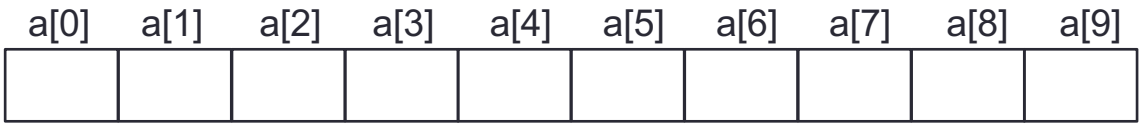
Note what happens when fewer initial values are provided.

- The following initializations are incorrect:

```
int e[2] = {1, 2, 3};  // warning issued: excess elements

int f[5];
f[5] = {8, 23, 12, -3, 6}; // too late to do this;
                           // compilation error
```

2.2 Arrays and Pointers

- Example: `int a[10]`



- When the array name `a` appears in an expression, it refers to the address of the first element (i.e. `&a[0]`) of that array.

```
int a[3];
printf("%p\n", a);
printf("%p\n", &a[0]);
printf("%p\n", &a[1]);
```

```
ffbff724
ffbff724
ffbff728
```

These 2 outputs will always be the same.

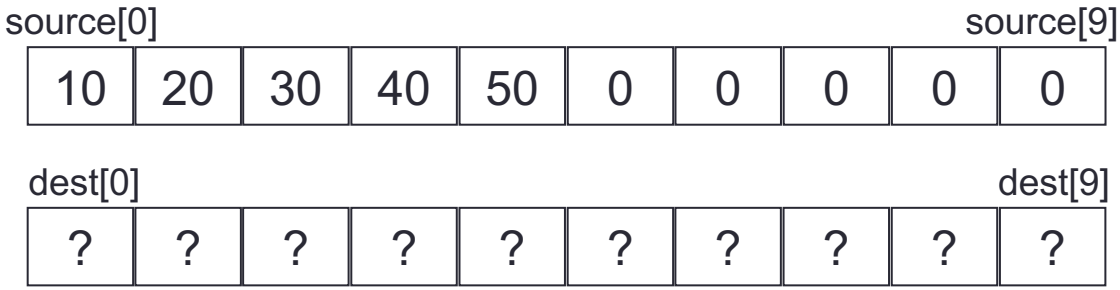
Output varies from one run to another. Each element is of int type, hence takes up 4 bytes (32 bits).

2.3 Array Assignment (1/2)

- The following is illegal in C:

ArrayAssignment.c

```
#define N 10
int source[N] = { 10, 20, 30, 40, 50 };
int dest[N];
dest = source;  // illegal!
```



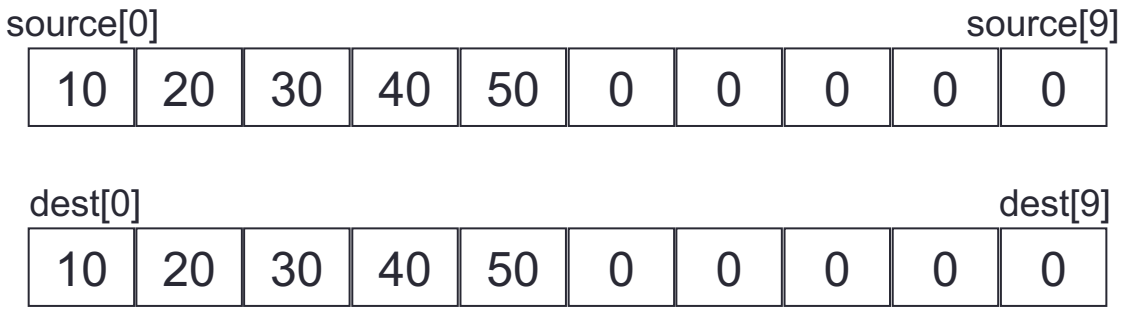
- Reason:
  - An array name is a fixed (constant) pointer; it points to the first element of the array, and this cannot be altered.
  - The code above attempts to alter **`dest`** to make it point elsewhere.

2.3 Array Assignment (2/2)

- How to do it properly? Write a loop:

ArrayCopy.c

```
#define N 10
int source[N] = { 10, 20, 30, 40, 50 };
int dest[N];
int i;
for (i = 0; i < N; i++) {
   dest[i] = source[i];
}
```

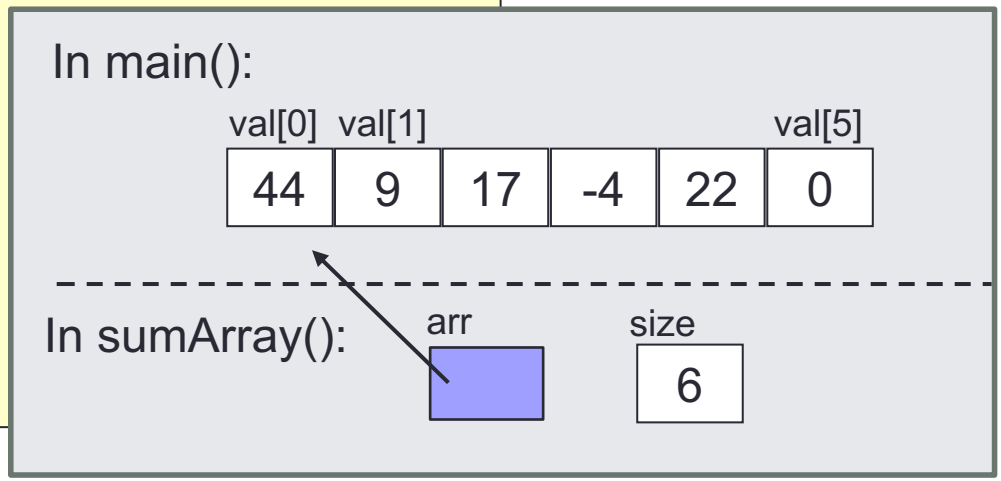


- (There is another method – use the <string.h> library function memcpy(), but this is outside the scope of this module.)

2.4 Array Parameters in Functions (1/3)

ArraySumFunction.c

```
#include <stdio.h>

int sumArray(int [], int);

int main(void) {
  int val[6] = {44, 9, 17, -4, 22};
  printf("Sum = %d\n", sumArray(val, 6));
  return 0;
}

int sumArray(int arr[], int size) {
  int i, sum=0;

  for (i=0; i<size; i++) {
    sum += arr[i];
  }
  return sum;
}
```



2.4 Array Parameters in Functions (2/3)

- Function prototype:
  - As mentioned before, name of parameters in a function prototype are optional and ignored by the compiler. Hence, both of the following are acceptable and equivalent:

```
int sumArray(int [], int);
```

```
int sumArray(int arr[], int size);
```

- Function header in function definition:
  - No need to put array size inside [ ]; even if array size is present, compiler just ignores it.
  - Instead, provide the array size through another parameter.

```
int sumArray(int arr[], int size) { ... }
```

```
int sumArray(int arr[8], int size) { ... }
```

Ignored by compiler

Actual number of elements you want to process

2.4 Array Parameters in Functions (3/3)

- Since an array name is a pointer, the following shows the alternative syntax for array parameter in function prototype and function header in the function definition

```
int sumArray(int *, int); // fn prototype
```

```
// function definition
int sumArray(int *arr, int size) {
    ...
}
```

- Compare this with the [ ] notation

```
int sumArray(int [], int); // fn prototype
```

```
// function definition
int sumArray(int arr[], int size) {
    ...
}
```

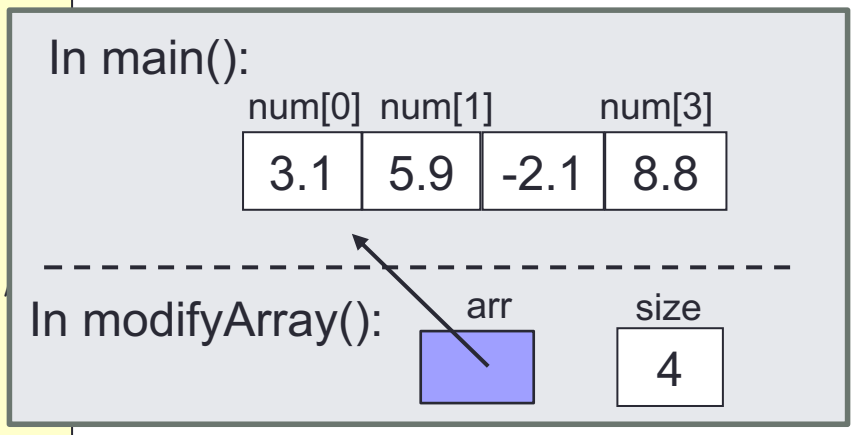
2.5 Modifying Array in a Function (1/2)

- We have learned that for a function to modify a variable (eg: v) outside it, the caller has to passed the address of the variable (eg: &v) into the function.
- What about an array? Since an array name is a pointer (address of its first element), there is no need to pass its address to the function.
- This also means that whether intended or not, a function can modify the content of the array it received.

2.5 Modifying Array in a Function (2/2)

ArrayModify.c

```
#include <stdio.h>

void modifyArray(float [], int);
void printArray(float [], int);

int main(void) {
   float num[4] = {3.1, 5.9, -2.1, 8.8};
   modifyArray(num, 4);
   printArray(num, 4);
   return 0;
}
```




```
6.20 11.80 -4.20 17.60
```

```
void modifyArray(float arr[], int size) {
   int i;

   for (i=0; i<size; i++) {
      arr[i] *= 2;
   }
}
```

```
void printArray(float arr[], int size) {
   int i;

   for (i=0; i<size; i++) {
      printf("%.2f", arr[i]);
   }
   printf("\n");
}
```

modifyArray() modifies the array; printArray() does not.

3. Strings (1/2)

ArrayOfChar.c

```
#include <stdio.h>

void modifyArray(char [], int);
void printArray(char [], int);

int main(void) {
  char chars[4] = {'C', 'h', 'a', 'r'};
  modifyArray(chars, 4);
  printArray(chars, 4);
  return 0;
}
```

- Array of characters

The following code is very similar to ArrayModify.c.
What does it do?
What is the output?

```
void modifyArray(char arr[], int size) {
   int i;

   for (i=0; i<size; i++) {
      arr[i]++;
   }
}
```

```
void printArray(char arr[], int size) {
   int i;

   for (i=0; i<size; i++) {
      printf("%c", arr[i]);
   }
   printf("\n");
}
```

❖

3. Strings (2/2)

- We can turn an array of characters into a string by adding a null character '\0' at the end of the array
- A string is an array of characters, terminated by a null character '\0' (which has an ASCII value of zero)
- We can use string functions (include <string.h>) to manipulate strings.

Example:

c	s	1	0	1	0	\0

3.1 Strings: Basic

- Declaration of an array of characters
  - `char str[6];`
- Assigning character to an element of an array of characters
  - `str[0] = 'e';`
  - `str[1] = 'g';`
  - `str[2] = 'g';`
  - `str[3] = '\0';`

Without '\0', it is just an array of character, not a string.

- Initializer for string
  - Two ways:
    - `char fruit_name[] = "apple";`
    - `char fruit_name[] = {'a','p','p','l','e','\0'};`

Do not need '\0' as it is automatically added.

3.2 Strings: I/O (1/3)

- Read string from stdin (keyboard)

```
fgets(str, size, stdin) // reads size - 1 char,
                        // or until newline
scanf("%s", str);  // reads until white space
```

- Print string to stdout (monitor)

```
puts(str);  // terminates with newline
printf("%s\n", str);
```

Note: There is another function gets(str) to read a string interactively. However, due to security reason, we avoid it and use fgets() function instead.

3.2 Strings: I/O (2/3)

- fgets()
  - On interactive input, fgets() also reads in the newline character

    User input: **eat**

e	a	t	\n	\0	?	?

  - Hence, we may need to replace it with '\0' if necessary

```
fgets(str, size, stdin);
len = strlen(str);
if (str[len - 1] == '\n')
    str[len - 1] = '\0';
```

3.2 Strings: I/O (3/3)

StringIO1.c

```
#include <stdio.h>
#define LENGTH 10

int main(void) {
   char str[LENGTH];

   printf("Enter string (at most %d characters): ", LENGTH-1);
   scanf("%s", str);
   printf("str = %s\n", str);
   return 0;
}
```

Test out the programs with this input:
My book

Output:
str = My

StringIO2.c

```
#include <stdio.h>
#define LENGTH 10

int main(void) {
   char str[LENGTH];

   printf("Enter string (at most %d characters): ", LENGTH-1);
   fgets(str, LENGTH, stdin);
   printf("str = ");
   puts(str);
   return 0;
}
```

Output:
str = My book

Note that puts(str) adds a newline automatically.

3.3 Example: Remove Vowels (1/2)

- Write a program RemoveVowels.c to remove all vowels in a given input string.
- Assume the input string has at most 100 characters.
- Sample run:

```
Enter a string: How HAVE you been, James?
Changed string: Hw HV y bn, Jms?
```

3.3 Example: Remove Vowels (2/2)

RemoveVowels.c

```
#include <stdio.h>
#include <string.h>
#include <ctype.h>
int main(void) {
   int i, len, count = 0;
   char str[101], newstr[101];

   printf("Enter a string (at most 100 characters): ");
   fgets(str, 101, stdin); //what happens if you use scanf() here?
   len = strlen(str); // strlen() returns number of char in string
   if (str[len - 1] == '\n')
      str[len - 1] = '\0';
   len = strlen(str); // check length again

   for (i=0; i<len; i++) {
      switch (toupper(str[i])) {
         case 'A': case 'E':
         case 'I': case 'O': case 'U': break;
         default: newstr[count++] = str[i];
      }
   }
   newstr[count] = '\0';
   printf("New string: %s\n", newstr);
   return 0;
}
```

Need to include <string.h> to use string functions such as strlen().

Need to include <ctype.h> to use character functions such as toupper().

3.4 String Functions (1/2)

- C provides a library of string functions
  - Must include <string.h>
  - Here are a few commonly used string functions
- strlen(s)
  - Return the number of characters in s
- strcmp(s1, s2)
  - Compare the ASCII values of the corresponding characters in strings s1 and s2.
  - Return
    - a negative integer if s1 is lexicographically less than s2, or
    - a positive integer if s1 is lexicographically greater than s2, or
    - 0 if s1 and s2 are equal.
- strncmp(s1, s2, n)
  - Compare first n characters of s1 and s2.

3.4 String Functions (2/2)

- strcpy(s1, s2)
  - Copy the string pointed to by s2 into array pointed to by s1.
  - Function returns s1.
  - Example:

```
char name[10];
strcpy(name, "Matthew");
```

M	a	t	t	h	e	w	\0	?	?

  - The following assignment statement does not work:

```
name = "Matthew";
```

  - What happens when string to be copied is too long?

```
strcpy(name, "A very long name");
```

A		v	e	r	y		l	o	n	g		n	a	m	e	\0

- strncpy(s1, s2, n)
  - Copy first n characters of string pointed to by s2 to s1.

3.5 Importance of '\0' in a String (1/2)

- To be treated as a string, the array of characters must be terminated with the null character '\0'.
- Otherwise, string functions will not work properly on it.
- For instance, the printf("%s", str) statement will print until it encounters a null character in str.
- Likewise, strlen(str) will count the number of characters up to (but not including) the null character.
- In many cases, a string that is not properly terminated with '\0' will result in illegal access of memory.

3.5 Importance of '\0' in a String (2/2)

- What is the output of this code?

WithoutNullChar.c

```
#include <stdio.h>
#include <string.h>

int main(void) {
  char str[10];

  str[0] = 'a';
  str[1] = 'p';
  str[2] = 'p';
  str[3] = 'l';
  str[4] = 'e';

  printf("Length = %d\n", strlen(str));
  printf("str = %s\n", str);

  return 0;
}
```

Compare the output if you add:

```
str[5] = '\0';
```

or, you have:

```
char str[10] = "apple";
```

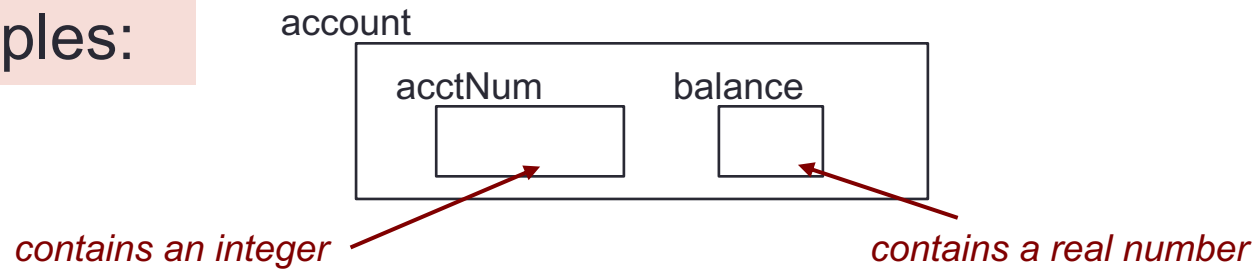
printf() will print %s from the starting address of str until it encounters the '\0' character.

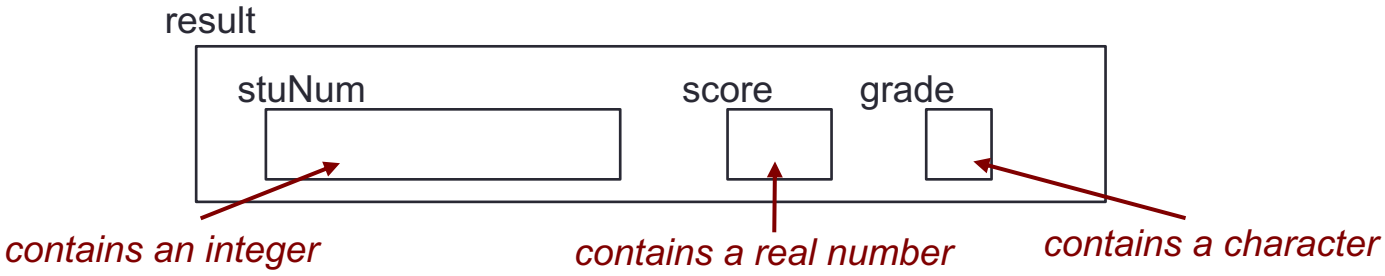
%s and string functions work only on "true" strings. Without the terminating null character '\0', string functions will not work properly.

4. Structures (1/2)

- Arrays contain homogeneous data (i.e. data of the same type)
- Structures allow grouping of heterogeneous members (of different types)

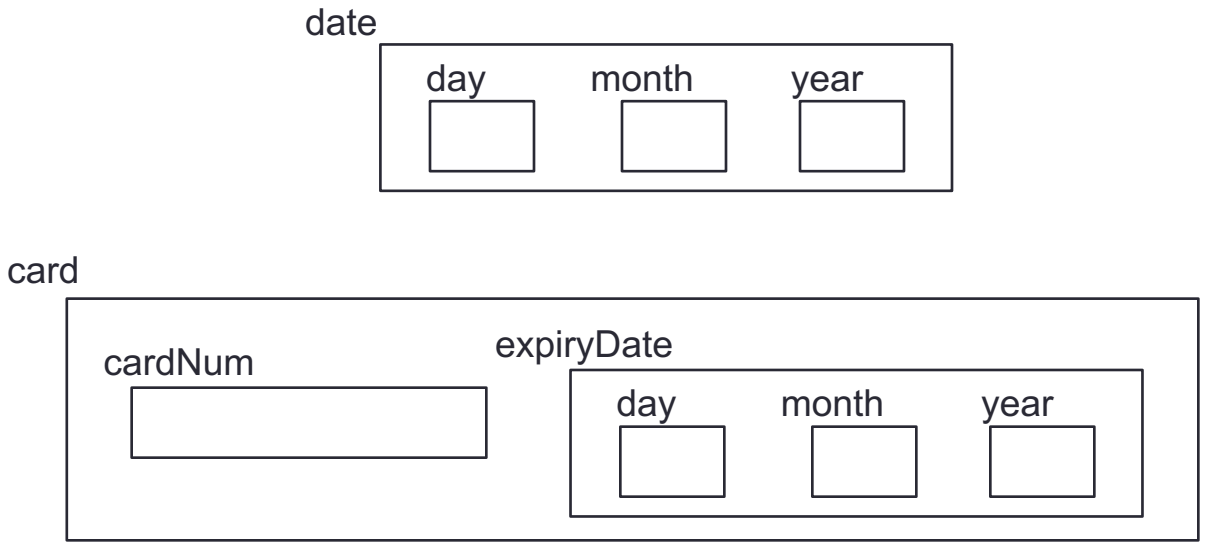
Examples:





4. Structures (2/2)

- A *group* can be a member of another *group*.
- Example: the expiry date of a membership card is of "date" group



4.1 Structure Types (1/2)

- Such a group is called structure type
- Examples of structure types:

```
typedef struct {
   int length, width, height;
} box_t;
```

This semi-colon ; is very important and is often forgotten!

Create a new type called box_t

```
typedef struct {
   int acctNum;
   float balance;
} account_t;
```

Create a new type called account_t

```
typedef struct {
   int stuNum;
   float score;
   char grade;
} result_t;
```

Create a new type called result_t

4.1 Structure Types (2/2)

- A type is NOT a variable!
  - what are the differences between a type and a variable?
- The following is a definition of a type, NOT a declaration of a variable
  - A type needs to be defined before we can declare variable of that type
  - No memory is allocated to a type

```
typedef struct {
   int acctNum;
   float balance;
} account_t;
```

4.2 Structure Variables

- Declaration
  - The syntax is similar to declaring ordinary variables.

```
typedef struct {
   int stuNum;
   float score;
   char grade;
} result_t;
```

Before function prototypes
(but after preprocessor directives)

```
result_t result1, result2;
```

Inside any function

4.3 Initializing Structure Variables

- The syntax is like array initialization
- Examples:

```
typedef struct {
   int day, month, year;
} date_t;

typedef struct {
   int cardNum;
   date_t expiryDate;
} card_t;

card_t card1 = {888888, {31, 12, 2020}};
```

```
typedef struct {
   int stuNum;
   float score;
   char grade;
} result_t;

result_t result1 = { 123321, 93.5, 'A' };
```

4.4 Accessing Members of a Structure Variable

- Use the dot (.) operator

```
result_t result2;

result2.stuNum = 456654;
result2.score = 62.0;
result2.grade = 'D';
```

```
card_t card2 = { 666666, {30, 6} };

card2.expiryDate.year = 2021;
```

4.5 Example: Initializing and Accessing

StructureEg1.c

```
result1: stuNum = 123321; score = 93.5; grade = A
result2: stuNum = 456654; score = 62.0; grade = D
```

```c
#include <stdio.h>

typedef struct  {
    int stuNum;
    float score;
    char grade;
} result_t;

int main(void) {
    result_t result1 = { 123321, 93.5, 'A' },
             result2;

    result2.stuNum = 456654;
    result2.score = 62.0;
    result2.grade = 'D';

    printf("result1: stuNum = %d; score = %.1f; grade = %c\n",
           result1.stuNum, result1.score, result1.grade);
    printf("result2: stuNum = %d; score = %.1f; grade = %c\n",
           result2.stuNum, result2.score, result2.grade);
    return 0;
}
```

Type definition

Initialization

Accessing members

4.6 Reading a Structure Member

- The structure members are read in individually the same way as we do for ordinary variables
- Example:

```
result_t result1;

printf("Enter student number, score and grade: ");

scanf("%d %f %c", &result1.stuNum, &result1.score,
                  &result1.grade);
```

4.7 Assigning Structures

- We use the dot operator (.) to access individual member of a structure variable.
- If we use the structure variable's name, we are referring to the entire structure.
- Unlike arrays, we may do assignments with structures

```
result2 = result1;
```

=

```
result2.stuNum = result1.stuNum;
result2.score = result1.score;
result2.grade = result1.grade;
```

Before:

result1

stuNum	score	grade
123321	93.5	'A'

result2

stuNum	score	grade
456654	62.0	'D'

After:

result1

stuNum	score	grade
123321	93.5	'A'

result2

stuNum	score	grade
123321	93.5	'A'

4.8 Returning Structure from Function (1/3)

- Example:
  - Given this structure type result_t,

```
typedef struct {
    int max;
    float ave;
} result_t;
```

  - Define a function func() that returns a structure of this type:

```
result_t func( ... ) {
   ...
}
```

  - To call this function:

```
result_t result;

result = func( ... );
```

4.8 Returning Structure from Function (2/3)

StructureEg2.c

```
#include <stdio.h>

typedef struct {
    int max;
    float ave;
} result_t;

result_t max_and_average(int, int, int);

int main(void) {
    int num1, num2, num3;
    result_t result;

    printf("Enter 3 integers: ");
    scanf("%d %d %d", &num1, &num2, &num3);
    result = max_and_average(num1, num2, num3);

    printf("Maximum = %d\n", result.max);
    printf("Average = %.2f\n", result.ave);
    return 0;
}
...
```

returned structure is **copied** to *result*

max and average are printed

4.8 Returning Structure from Function (3/3)

StructureEg2.c

```
// Computes the maximum and average of 3 integers
result_t max_and_average(int n1, int n2, int n3) {
    result_t result;

    result.max = n1;
    if (n2 > result.max)
      result.max = n2;
    if (n3 > result.max)
      result.max = n3;

    result.ave = (n1+n2+n3)/3.0;

    return result;
}
```

the answers are stored in the structure variable *result*.

result is returned here

4.9 Passing Structure to Function (1/2)

- Passing a structure to a parameter in a function is akin to assigning the structure to the parameter.
- The entire structure is **copied**, i.e., members of the actual parameter are copied into the corresponding members of the formal parameter.
  - *Pass-by-value*
- We use PassStructureToFn.c to illustrate this.

```
player1: name = Brusco; age = 23; gender = M
player2: name = July; age = 21; gender = F
```

4.9 Passing Structure to Function (2/2)

PassStructureToFn.c

```
// #include statements and definition
// of player_t are omitted here for brevity
void print_player(char [], player_t);

int main(void) {
    player_t player1 = { "Brusco", 23, 'M' }, player2;

    strcpy(player2.name, "July");
    player2.age = 21;
    player2.gender = 'F';

    print_player("player1", player1);
    print_player("player2", player2);

    return 0;
}

// Print player's information
void print_player(char header[], player_t player) {
    printf("%s: name = %s; age = %d; gender = %c\n", header,
           player.name, player.age, player.gender);
}
```

Passing a structure to a function

Receiving a structure from the caller

(For own reading)

4.10 Array of Structures

- Combining structures and arrays gives us a lot of flexibility in organizing data.
  - For example, we may have a structure comprising 2 members: student's name and an array of 5 test scores he obtained.
  - Or, we may have an array whose elements are structures.
  - Or, even more complex combinations such as an array whose elements are structures which comprises array as one of the members.
- Case study (Program: NearbyStores.c)
  - A startup company decides to provide location-based services. Its customers are a list of stores.
  - Each store has a name, a location given by (x, y) coordinates, a radius that defines a circle of influence.
  - We can define a structure type store_t for the stores, and have a store_t array store_t variables. We call this array storeList and it represents the list of stores.

4.11 Passing Address of Structure to Function (1/5)

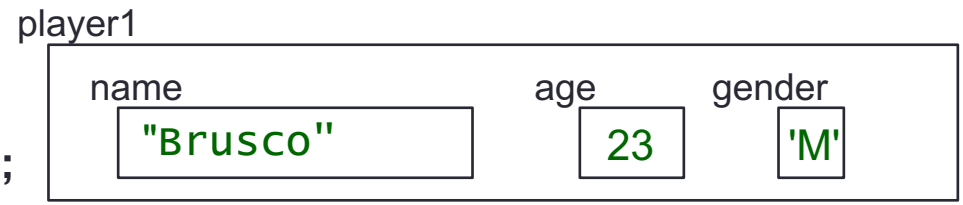
- Given this code, what is the output?

PassStructureToFn2.c

```
// #include statements, definition of player_t,
// and function prototypes are omitted here for brevity
int main(void) {
   player_t player1 = { "Brusco", 23, 'M' };

   change_name_and_age(player1);
   print_player("player1", player1);
   return 0;
}

// To change a player's name and age
void change_name_and_age(player_t player) {
   strcpy(player.name, "Alexandra");
   player.age = 25;
}

// Print player's information
void print_player(char header[], player_t player) {
   printf("%s: name = %s; age = %d; gender = %c\n", header,
          player.name, player.age, player.gender);
}
```

4.11 Passing Address of Structure to Function (2/5)

```
main()

change_name_and_age(player1);
```



```
change_name_and_age(player_t player)
```


```
strcpy(player.name, "Alexandra");
player.age = 25;
```

4.11 Passing Address of Structure to Function (3/5)

- Like an ordinary variable (eg: of type int, char), when a structure variable is passed to a function, a separate copy of it is made in the called function.
- Hence, the original structure variable will not be modified by the function.
- To allow the function to modify the content of the original structure variable, you need to pass in the address (pointer) of the structure variable to the function.
- (Note that passing an array of structures to a function is a different matter. As the array name is a pointer, the function is able to modify the array elements.)

4.11 Passing Address of Structure to Function (4/5)

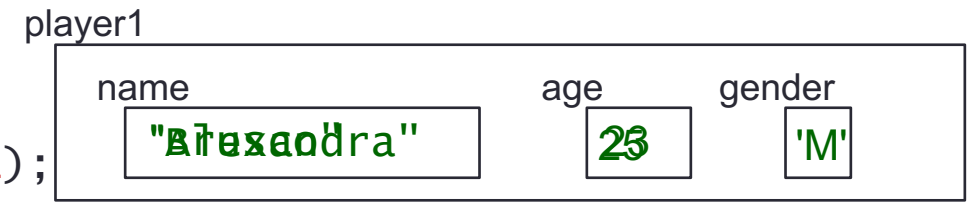
- Need to pass address of the structure variable

PassAddrStructToFn.c

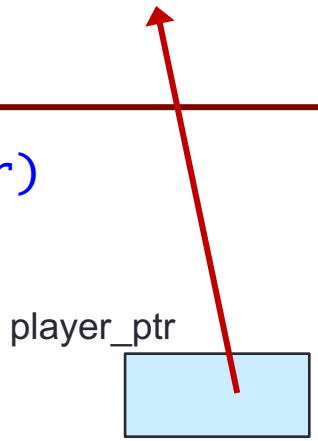
```
// #include statements, definition of player_t,
// and function prototypes are omitted here for brevity
int main(void) {
   player_t player1 = { "Brusco", 23, 'M' };

   change_name_and_age(&player1);
   print_player("player1", player1);
   return 0;
}

// To change a player's name and age
void change_name_and_age(player_t *player_ptr) {
   strcpy((*player_ptr).name, "Alexandra");
   (*player_ptr).age = 25;
}

// Print player's information
void print_player(char header[], player_t player) {
   printf("%s: name = %s; age = %d; gender = %c\n", header,
          player.name, player.age, player.gender);
}
```

4.11 Passing Address of Structure to Function (5/5)

```
main()

change_name_and_age(&player1);
```




```
change_name_and_age(player_t *player_ptr)
```




```
strcpy((*player_ptr).name, "Alexandra");
(*player_ptr).age = 25;
```

4.12 The Arrow Operator (->) (1/2)

- Expressions like `(*player_ptr).name` appear very often. Hence an alternative "shortcut" syntax is created for it.
- The arrow operator (->)

`(*player_ptr).name`	*is equivalent to*	`player_ptr->name`
`(*player_ptr).age`	*is equivalent to*	`player_ptr->age`

- Can we write *player_ptr.name instead of (*player_ptr).name?
- *No*, because . (dot) has higher precedence than *, so *player_ptr.name means *(player_ptr.name)!

4.12 The Arrow Operator (->) (2/2)

- Function change_name_and_age() in PassAddrStructToFn2.c modified to use the -> operator.

PassAddrStructToFn2.c

```
// To change a player's name and age
void change_name_and_age(player_t *player_ptr) {
   strcpy(player_ptr->name, "Alexandra");
   player_ptr->age = 25;
}
```

End of File