



PROGRAMMING METHODOLOGY (PHƯƠNG PHÁP LẬP TRÌNH)

UNIT 9: Arrays

Acknowledgement

- The contents of these slides have origin from School of Computing, National University of Singapore.
- We greatly appreciate support from Mr. Aaron Tan Tuck Choy for kindly sharing these materials.

Policies for students

- These contents are only used for students PERSONALLY.
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Recording of modifications

- Currently, there are no modification on these contents.

Unit 9: Arrays

Objectives:

- Understand the concept and application of arrays
- Understand the relationship between arrays and pointers

Reference:

- Chapter 6: Numeric Arrays

Unit 9: Arrays (1/2)

1. Motivation #1: Coin Change
2. Motivation #2: Vote Counting
3. Arrays
 - 3.1 Array Declaration: Syntax
 - 3.2 Array Variable
 - 3.3 Array Declarations with Initializers
 - 3.4 Demo #1: Using Array Initializer
 - 3.5 Demo #2: Coin Change Revisit
 - 3.6 Array Size

Unit 9: Arrays (2/2)

4. Arrays and Pointers
5. Array Assignment
6. Array Parameters in Functions
7. Passing Array Arguments
8. Standard I/O Functions for Arrays
9. Modifying Array Arguments

1. Motivation #1: Coin Change (1/2)

- Some of the programs we have written are “long-winded”, because we have not learned enough C constructs to do it simpler.
- Consider the **Coin Change** problem (Week 1 Task 2) with 6 denominations 1¢, 5¢, 10¢, 20¢, 50¢, and \$1:

Algorithm 1:

```
input: amt (in cents); output: coins  
coins  $\leftarrow$  0  
coins += amt/100; amt %=100;  
coins += amt/50; amt %= 50;  
coins += amt/20; amt %= 20;  
coins += amt/10; amt %= 10;  
coins += amt/5; amt %= 5;  
coins += amt/1; amt %= 1;  
print coins
```



1. Motivation #1: Coin Change (2/2)

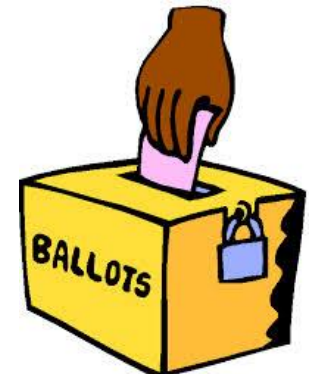
```
int minimumCoins(int amt) {  
    int coins = 0;  
  
    coins += amt/100;  
    amt %= 100;  
    coins += amt/50;  
    amt %= 50;  
    coins += amt/20;  
    amt %= 20;  
    coins += amt/10;  
    amt %= 10;  
    coins += amt/5;  
    amt %= 5;  
    coins += amt/1; // retained for regularity  
    amt %= 1;      // retained for regularity  
  
    return coins;  
}
```

Unit9_CoinChange.c

- Can we do better?

2. Motivation #2: Vote Counting

- A student election has just completed with 1000 votes cast for the three candidates: Tom, Dick and Harry.
- Write a program [Unit9_VoteCount.c](#) to read in all the votes and display the total number of votes received by each candidate. Each vote has one of three possible values:
 - 1: for candidate Tom
 - 2: for candidate Dick
 - 3: for candidate Harry



2. Motivation #2: Votes for 3 candidates

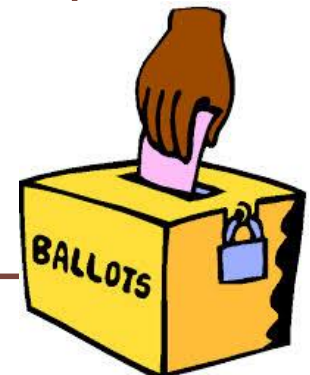
Unit9_VoteCount.c

```
#include <stdio.h>
#define NUM_VOTES 1000 // number of votes

int main(void) {
    int i, vote, tom = 0, dick = 0, harry = 0;

    printf("Enter votes:\n");
    for (i = 0; i < NUM_VOTES; i++) {
        scanf("%d", &vote);
        switch (vote) {
            case 1: tom++; break;
            case 2: dick++; break;
            case 3: harry++; break;
        }
    }
    printf("Tom: %d; Dick: %d; Harry: %d\n",
           tom, dick, harry);
    return 0;
}
```

What if there were **30**
instead of 3 candidates?

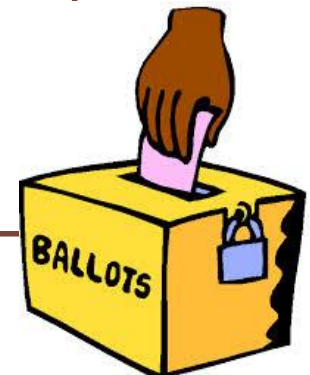


2. Motivation #2: Votes for 30 candidates

```
#include <stdio.h>
#define NUM_VOTES 1000    // number of votes

int main(void) {
    int i, vote, c1 = 0, c2 = 0, ..., c30 = 0;

    printf("Enter votes:\n");
    for (i = 0; i < NUM_VOTES; i++) {
        scanf("%d", &vote);
        switch (vote) {
            case 1: c1++; break;
            case 2: c2++; break;
            . . .
            case 30: c30++; break;
        }
    }
    . . .
}
```



3. Introducing Array (1/4)

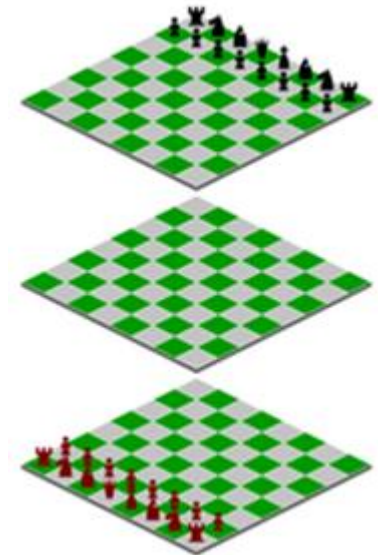
**“If a program manipulates a large amount of data,
it does so in a small number of ways.”**

Alan J. Perlis
Yale University

The first recipient of ACM Turing Award

$$\begin{bmatrix} 2 & 1 & 3 \\ -2 & 2 & 1 \end{bmatrix} * \begin{bmatrix} 2 & 1 \\ 3 & 2 \\ -2 & 2 \end{bmatrix} = \begin{bmatrix} 1 & 10 \\ 0 & 4 \end{bmatrix}$$

*	2	1			1	*	1
2	*	2	1	1	1	1	1
1	2	3	*	2	1	1	1
1	2	*	3	*	1	1	*
1	*	2	2	1	2	2	2
1	1	1			1	*	1
			1	1	2	1	1
			1	*	1		



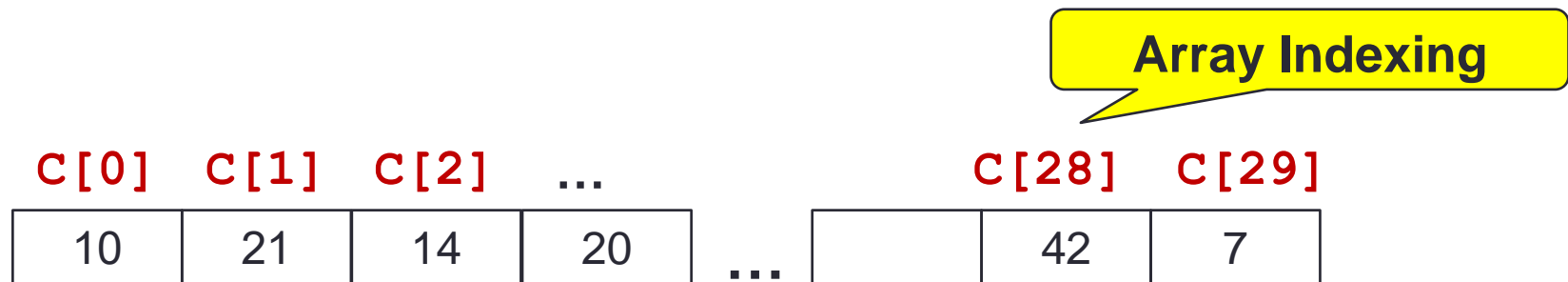
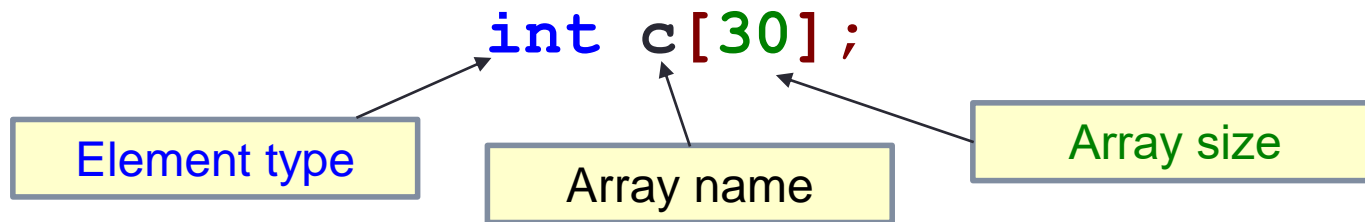
3. Introducing Array (2/4)

- In the vote counting problem, it's inconvenient to define and use a set of variables c_1, c_2, \dots, c_{30} , each for one candidate.
- We handle this problem by indexing the candidates:
 C_0, C_1, \dots, C_{29} (assuming that indexing begins at 0)

			C_0			C_1			C_2			...						C_{28}			C_{29}		
Votes for Candidates:			10	21	14	20						...							42	7			

3. Introducing Array (3/4)

- The indexing facility is implemented as a programming language feature called **ARRAY**.



3. Introducing Array (4/4)

Pseudo-code for Vote Counting:

Let C be an array such that C_i holds the vote count of Candidate i

for each i such that $0 \leq i < \text{Number_of_candidates}$
 $C_i \leftarrow 0$;

while there is a vote to be counted

$vote \leftarrow \text{read a vote}$

 if $1 \leq vote \leq \text{Number_of_candidate}$ then

$j \leftarrow vote - 1$

$C_j \leftarrow C_j + 1$

3.1 Array Declaration: Syntax

T arrname [**E**]

- **arrname** is name/identifier of array (same way you would name a variable)
- **T** is a data type (e.g., **int**, **double**, **char**, ...)
- **E** is an integer constant expression with a positive value
- Examples:

```
int arr[10]; // size of arr is 10
```

```
#define M 5  
#define N 10  
double foo[M*N+8]; // size of foo is 58
```

```
int i;  
float bar[i]; // variable-length array
```

Not encouraged to use variable-length arrays.
Not supported by ISO C90 standard.
gcc -pedantic will generate warning.

Note

For problem using arrays, we will state the maximum number of elements so there is no need for variable-length arrays.

3.2 Array Variable (1/4)

- In an array of type **T**, each element is a type **T** variable.

Unit9_VoteCountArray.c

```
#define NUM_VOTES 1000    // number of votes
#define NUM_CANDIDATES 30 // number of candidates
int main(void) {
    int i, vote, cand[NUM_CANDIDATES];
    for (i = 0; i < NUM_CANDIDATES; i++) { cand[i] = 0; }

    printf("Enter votes:\n");
    for (i = 0; i < NUM_VOTES; i++) {
        scanf("%d", &vote);
        cand[vote-1]++;
    }
    for (i = 0; i < NUM_CANDIDATES; i++) {
        printf("candidate %d: total %d, %.2f%%\n",
               i+1, cand[i], (cand[i] * 100.0)/NUM_VOTES);
    }
    return 0;
}
```

What is %%%?

3.2 Array Variable (2/4)

- In an array of type **T**, each element is a type **T** variable.

Unit9_VoteCountArray.c

```
#define NUM_VOTES 1000    // number of votes
#define NUM_CANDIDATES 30 // number of candidates
int main(void) {
    int i, vote, cand[NUM_CANDIDATES];
    for (i = 0; i < NUM_CANDIDATES; i++) { cand[i] = 0; }

    printf("Enter votes:\n");
    for (i = 0; i < NUM_VOTES; i++) {
        scanf("%d", &vote);
        cand[vote-1]++;
    }
    for (i = 0; i < NUM_CANDIDATES; i++) {
        printf("candidate %d: total %d, %.2f%%\n",
               i+1, cand[i], (cand[i] * 100.0)/NUM_VOTES);
    }
    return 0;
}
```

$0 \leq \text{index} < \text{array size}$

3.2 Array Variable (3/4)

- In an array of type **T**, each element is a type **T** variable.

Unit9_VoteCountArray.c

```
#define NUM_VOTES 1000    // number of votes
#define NUM_CANDIDATES 30 // number of candidates
int main(void) {
    int i, vote, cand[NUM_CANDIDATES];
    for (i = 0; i < NUM_CANDIDATES; i++) { cand[i] = 0; }

    printf("Enter votes:\n");
    for (i = 0; i < NUM_VOTES; i++) {
        scanf("%d", &vote);
        cand[vote-1]++;
    }
    for (i = 0; i < NUM_CANDIDATES; i++) {
        printf("candidate %d: total %d, %.2f%%\n",
               i+1, cand[i], (cand[i] * 100.0)/NUM_VOTES);
    }
    return 0;
}
```

Increment the value
of an array element

Assume no invalid vote

3.2 Array Variable (4/4)

- In an array of type **T**, each element is a type **T** variable.

Unit9_VoteCountArray.c

```
#define NUM_VOTES 1000    // number of votes
#define NUM_CANDIDATES 30 // number of candidates
int main(void) {
    int i, vote, cand[NUM_CANDIDATES];
    for (i = 0; i < NUM_CANDIDATES; i++) { cand[i] = 0; }

    printf("Enter votes:\n");
    for (i = 0; i < NUM_VOTES; i++) {
        scanf("%d", &vote);
        cand[vote-1]++;
    }
    for (i = 0; i < NUM_CANDIDATES; i++) {
        printf("candidate %d: total %d, %.2f%%\n",
               i+1, cand[i], (cand[i] * 100.0)/NUM_VOTES);
    }
    return 0;
}
```

Print out all vote counts

3.3 Array Declarations with Initializers

- Array variables 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};
```

- 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
```



3.4 Demo #1: Using Array_INITIALIZER

- Modify the program to use an **array initializer**.

Unit9_VoteCountArrayVer2.c

```
#define NUM_VOTES 1000    // number of votes
#define NUM_CANDIDATES 30 // number of candidates
int main(void) {
    int i, vote, cand[NUM_CANDIDATES];
    for (i = 0; i < NUM_CANDIDATES; i++) { cand[i] = 0; }
    int cand[NUM_CANDIDATES] = { 0 };

    printf("Enter votes:\n");
    for (i = 0; i < NUM_VOTES; i++) {
        scanf("%d", &vote);
        cand[vote-1]++;
    }
    for (i = 0; i < NUM_CANDIDATES; i++) {
        printf("candidate %d: total %d, %.2f%%\n",
               i+1, cand[i], (cand[i] * 100.0)/NUM_VOTES);
    }
    return 0;
}
```

3.5 Demo #2: Coin Change Revisit (1/2)

- Let's "roll" the common steps in Algorithm 1 into a loop:

Algorithm 1:

```
input: amt (in cents); output: coins
coins ← 0
coins += amt/100; amt %=100;
coins += amt/50; amt %= 50;
coins += amt/20; amt %= 20;
coins += amt/10; amt %= 10;
coins += amt/5; amt %= 5;
coins += amt/1; amt %= 1;
print coins
```

Algorithm 2:

```
input: amt (in cents); output: coins
coins ← 0
From the largest denomination to the smallest:
    coins += amt/denomination
    amt %= denomination
    go to next denomination
print coins
```

Now, we may use a list D to store the denominations – giving rise to an array!

Algorithm 3:

```
input: amt (in cents); output: coins
D is an array with 6 elements
coins ← 0
for i from 0 to 5 // there are 6 denominations
    coins += amt/Di
    amt %= Di
print coins
```

3.5 Demo #2: Coin Change Revisit (2/2)

- Compare:

```
int minimumCoins(int amt) {  
    int coins = 0;  
    coins += amt/100;  
    amt %= 100;  
    coins += amt/50;  
    amt %= 50;  
    coins += amt/20;  
    amt %= 20;  
    coins += amt/10;  
    amt %= 10;  
    coins += amt/5;  
    amt %= 5;  
    coins += amt/1;  
    amt %= 1;  
    return coins;  
}
```

Unit9_CoinChange.c

```
int minimumCoins(int amt) {  
    int denoms[] = {100,50,20,10,5,1};  
    int i, coins = 0;  
  
    for (i=0; i<6; i++) {  
        coins += amt/denoms[i];  
        amt %= denoms[i];  
    }  
  
    return coins;  
}
```

Unit9_CoinChangeArray.c

So much more elegant!

3.6 Array Size

- In **ANSI C** (which we are adopting), **the array is of fixed size**, and is **determined** at compile time
 - Hence, we need to specify the size of the array, eg:

```
int arr[8];
```

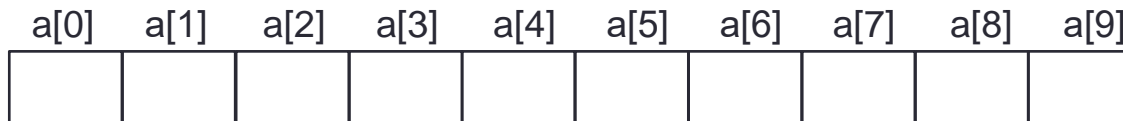
- The following is **not** allowed:

```
int size;  
  
printf("Enter array size: ");  
scanf("%d", &size);  
int arr[size]; // declare array arr with number of  
               // elements provided by user
```

- Hence, for problems on arrays, we will indicate the largest possible size of each array.

4. 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.

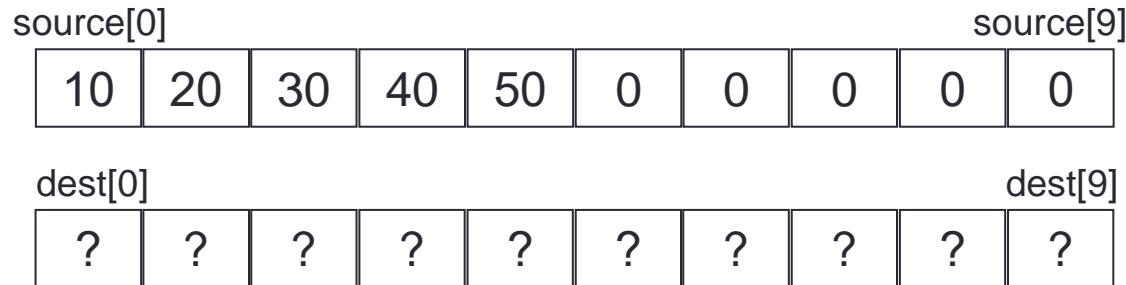
Output varies from one run to another. Each element is of `int` type, hence takes up 4 bytes (32 bits).

5. Array Assignment (1/2)

- The following is **illegal** in C:

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

Unit9_ArrayAssignment.c



- 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.

5. Array Assignment (2/2)

- How to do it properly? Write a loop:

```
#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];
}
```

Unit9_ArrayCopy.c

source[0]					source[9]				
10	20	30	40	50	0	0	0	0	0

dest[0]					dest[9]				
10	20	30	40	50	0	0	0	0	0

- (There is another method – use the <string.h> library function `memcpy()`, but this is outside the scope of CS1010.)

6. Array Parameters in Functions (1/3)

Unit9_SumArray.c

```
#include <stdio.h>

int sumArray(int [], int); // function prototype

int main(void) {
    int foo[8] = {44, 9, 17, 1, -4, 22};
    int bar[] = {2, 8, 6};
    printf("sum is %d\n", sumArray(foo, 8));
    printf("sum is %d\n", sumArray(foo, 3));
    printf("sum is %d\n", sumArray(bar, 3));
    return 0;
}

// size of array arr can be unspecified
// need an array size parameter
int sumArray(int arr[], int size) {
    int i, total=0;
    for (i=0; i<size; i++)
        total += arr[i];
    return total;
}
```

```
sum is 89
sum is 70
sum is 16
```

6. 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:

- 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*

6. Array Parameters in Functions (3/3)

■ Alternative syntax

- The following shows the alternative syntax for array parameter in function prototype and function header (more about it in discussion session)

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

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

- However, we **recommend** the `[]` notation


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

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

7. Passing Array Arguments (1/3)

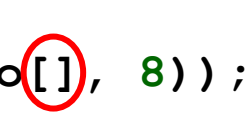
- Need to pass an array argument for **arr** as well as **size**, the number of elements to be processed.

```
int main(void) {  
    ...  
    printf("sum is %d\n", sumArray(foo, 8));  
    ...  
}  
int sumArray(int arr[], int size) {  
    ...  
}
```

A diagram with two red arrows. One arrow starts from the '8' in the printf statement and points to the 'size' parameter in the sumArray function definition. The other arrow starts from the 'foo' argument and points to the 'arr[]' parameter in the sumArray function definition.

- Note that array argument is specified by array name without []

```
int main(void) {  
    ...  
    printf("sum is %d\n", sumArray(foo[], 8));  
    ...  
}
```

A red 'X' mark is placed over the 'foo[]' argument in the printf statement. A red circle is drawn around the '[]' part of 'foo[]'.

Common mistake!



7. Passing Array Arguments (2/3)

■ Caution!

- When passing the value into the parameter representing the number of array elements to be processed, the value must **not** exceed the actual array size.

```
printf("sum is %d\n", sumArray(foo, 10));
```

Too big!

And compiler won't be able to detect such "error"!
May get "Segmentation Fault (core dumped)"
when you run the program!

7. Passing Array Arguments (3/3)

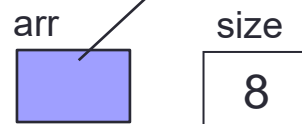
- Recall that the array name is the address of its first element. Hence `foo` means `&foo[0]`.

```
int main(void) {  
    ...  
    printf("sum is %d\n", sumArray(foo, 8));  
    ...  
}  
int sumArray(int arr[], int size) {  
    ...  
}
```

In main():



In sumArray():



8. Standard I/O Functions for Arrays (1/3)

- It might be advisable to write a function to read values into an array, and a function to print values in an array.
- Especially so for the latter, as you probably want to use it to check the values of your array elements at different stages of your program.
- The following illustrates an array **scores** of type **float**.

```
#define SIZE 6

int main(void) {
    float scores[SIZE];
    scanArray(scores, SIZE);
    printArray(scores, SIZE);
    return 0;
}
```

Unit9_ArrayInputOutput.c

8. Standard I/O Functions for Arrays (2/3)

■ Input function:

```
void scanArray(float arr[], int size) {  
    int i;  
    float value;  
    // You may add a prompt for user here  
    for (i=0; i<size; i++) {  
        scanf("%f", &value);  
        arr[i] = value;  
    }  
}
```

or

```
void scanArray(float arr[], int size) {  
    int i;  
    // You may add a prompt for user here  
    for (i=0; i<size; i++) {  
        scanf("%f", &arr[i]);  
    }  
}
```

8. Standard I/O Functions for Arrays (3/3)

■ Output function:

```
void printArray(float arr[], int size) {  
    int i;  
    // To print all values on one line  
    for (i=0; i<size; i++)  
        printf("%f ", arr[i]);  
  
    printf("\n");  
}
```

or

```
void printArray(float arr[], int size) {  
    int i;  
    // To print each value on one line  
    for (i=0; i<size; i++)  
        printf("%f\n", arr[i]);  
}
```

9. Modifying Array Arguments (1/2)

- Study this program:

Unit9_ModifyArrayArg.c

```
int main(void) {
    int foo[8] = {44, 9, 17, 1, -4, 22};
    doubleArray(foo, 4);
    printArray(foo, 8);
    return 0;
}

// To double the values of array elements
void doubleArray(int arr[], int size) {
    int i;
    for (i=0; i<size; i++)
        arr[i] *= 2;
}

// To print arr
void printArray(int arr[], int size) {
    int i;
    for (i=0; i<size; i++)
        printf("%d ", arr[i]);
    printf("\n");
}
```

9. Modifying Array Arguments (2/2)

```
int main(void) {  
    int foo[8] = {44, 9, 17, 1, -4, 22};  
    doubleArray(foo, 4);  
    . . .  
}  
// To double the values of array elements  
void doubleArray(int arr[], int size) {  
    int i;  
    for (i=0; i<size; i++)  
        arr[i] *= 2;  
}
```

In main():



In doubleArray():



Summary

- In this unit, you have learned about
 - Declaring array variables
 - Using array initializers
 - Relationship between array and pointer
 - How to pass an array into a function

End of File