CS1010 http://www.comp.nus.edu.sg/~cs1010/

Programming Methodology

UNIT 8

Arrays

UNIT 8: Arrays

Objectives:

- Understand the concept and application of arrays
- Problem solving using arrays

Reference:

- Chapter 7: Array Pointers
  - Sections 7.1 – 7.5

UNIT 8: Arrays (1/2)

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2. Motivation #2: Vote Counting
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   - 3.1 Array Declaration: Syntax
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UNIT 8: Arrays (2/2)

4. Arrays and Pointers
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7. Passing Array Arguments
8. Standard I/O Functions for Arrays
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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 ← 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)

Unit8_CoinChange.c

```
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;
}
```

- 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 Unit8_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

Unit8_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

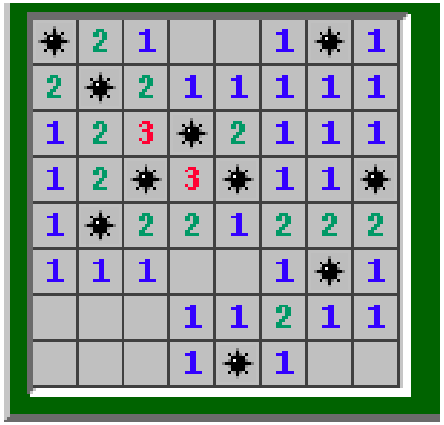
```
#include <stdio.h>
#define NUM_VOTES 1000    // number of votes

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;
      }
   }
   . . .
}
```

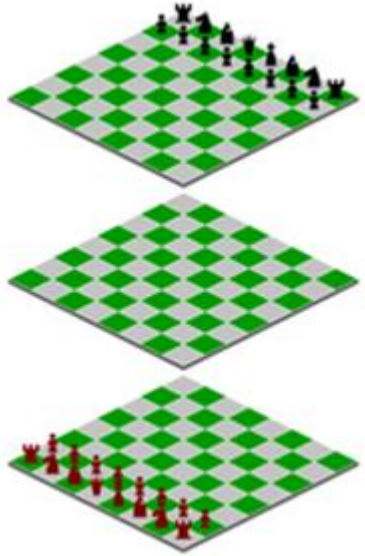
3. Introducing Array (1/4)

"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

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

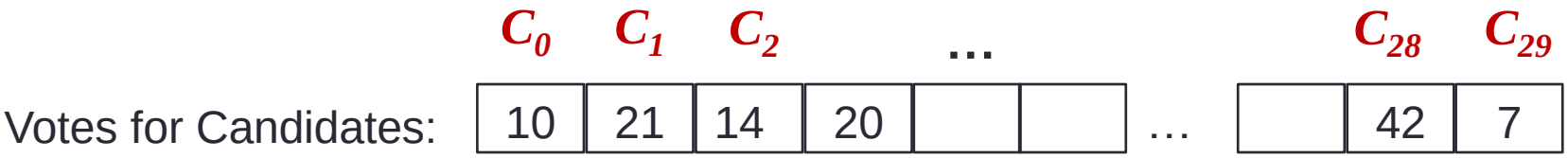




3. Introducing Array (2/4)

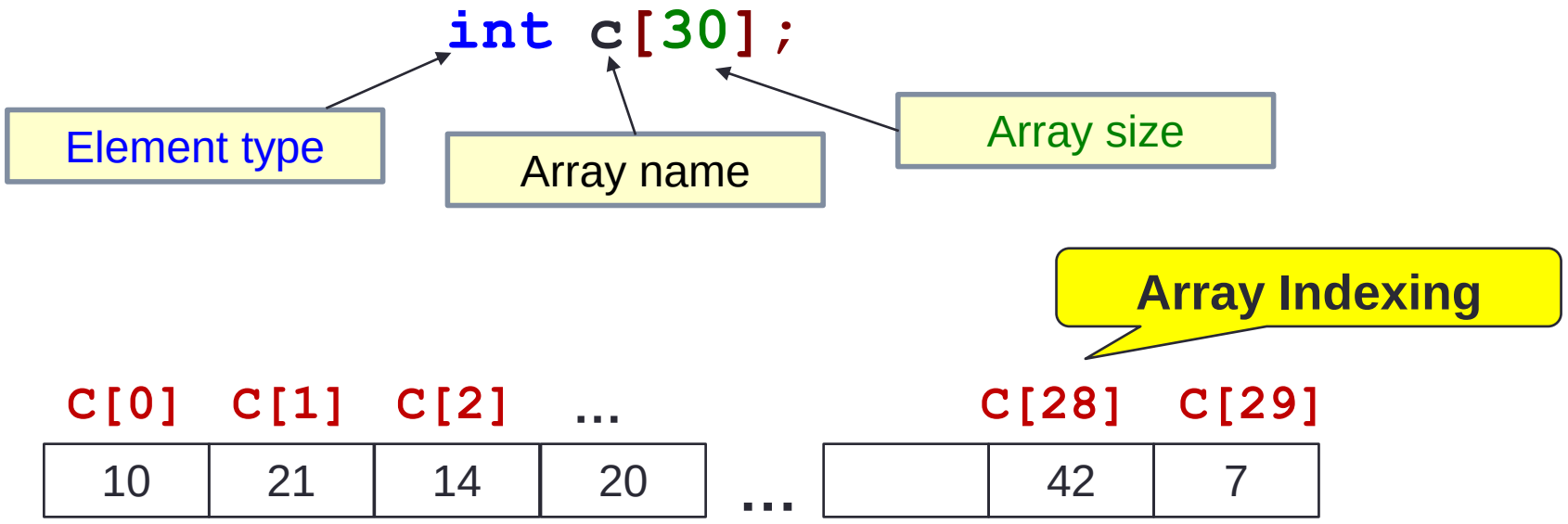
- In the vote counting problem, it's inconvenient to define and use a set of variables c1, c2, ..., c30, each for one candidate.
- We handle this problem by indexing the candidates:

  $C_0, C_1, \ldots, C_{29}$ (assuming that indexing begins at 0)



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 $0 \le i <$ Number_of_candidates
    $C_i \leftarrow 0$;

while there is a vote to be counted
    vote ← read a vote
    if $1 \le vote \le$ 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.

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.

Unit8_VoteCountArray.c

```
#define NUM_VOTES 1000
#define NUM_CANDIDATES 30
int main(void) {
   int i, vote, cand[NUM_CANDIDATES];
   for (i = 0; i < NUM_CANDIDATES; i++) // initialize array
      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)/
   }
   return 0;
}
```

What is %%?

Why 100.0 and not 100?

3.2 Array Variable (2/4)

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

Unit8_VoteCountArray.c

```
#define NUM_VOTES 1000
#define NUM_CANDIDATES 30
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 ≤ index < array size

3.2 Array Variable (3/4)

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

Unit8_VoteCountArray.c

```
#define NUM_VOTES 1000
#define NUM_CANDIDATES 30
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.

Unit8_VoteCountArray.c

```
#define NUM_VOTES 1000
#define NUM_CANDIDATES 30
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.

Unit8_VoteCountArrayVer2.c

```
#define NUM_VOTES 1000
#define NUM_CANDIDATES 30
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/D_i
    amt %= D_i
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;
}
```

Unit8_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;
}
```

Unit8_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];
```

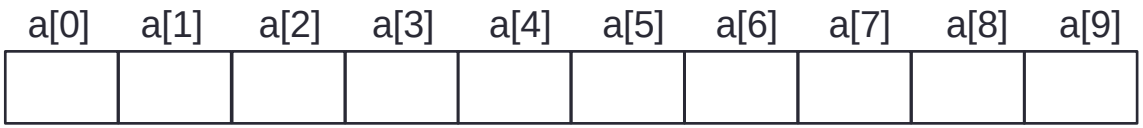
- The following is not allowed:

```
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.

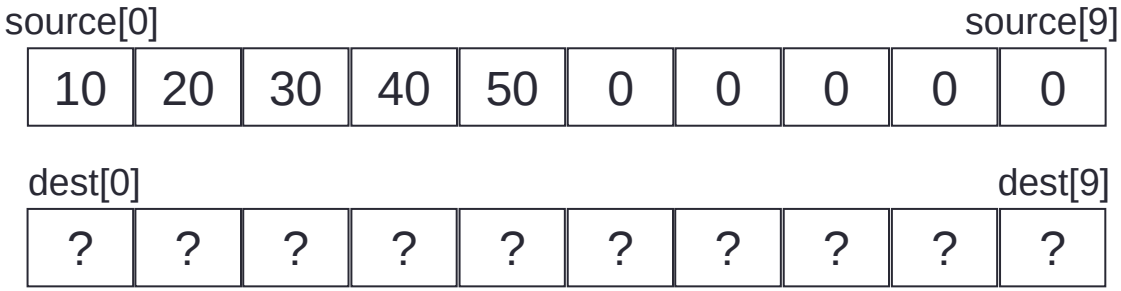
Output varies from one run to another. Each element is of int type, hence takes up 4 bytes (32 bits).

5. Array Assignment (1/2)

- The following is illegal in C:

Unit8_ArrayAssignment.c

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



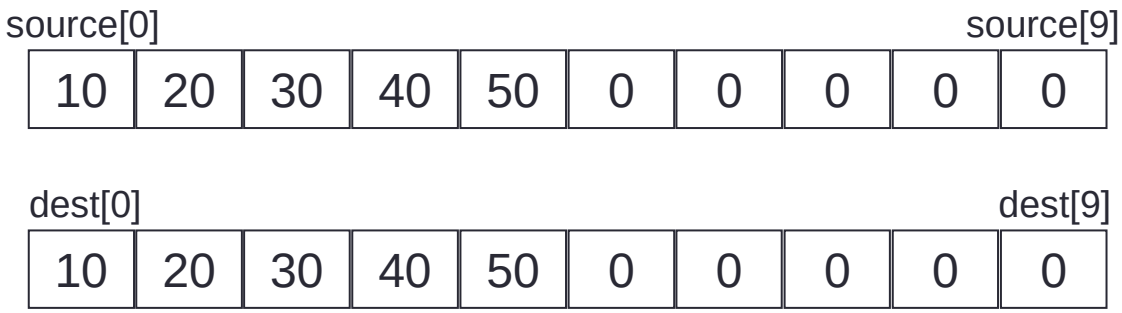
- Reason:
  - An array name is a fixed (constant) pointer; it points to the first element of the array, and this cannot be altered.
  - The code above attempts to alter **`dest`** to make it point elsewhere.

5. Array Assignment (2/2)

- How to do it properly? Write a loop:

Unit8_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 CS1010.)

6. Array Parameters in Functions (1/3)

Unit8_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 (This will be clearer after we cover Pointers later.)

```
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) {
   ...
}
```

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

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

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!

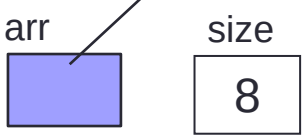
7. Passing Array Arguments (3/3)

- 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.

Unit8_ArrayInputOutput.c

```
#define SIZE 6

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

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:

Unit8_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;
}
```

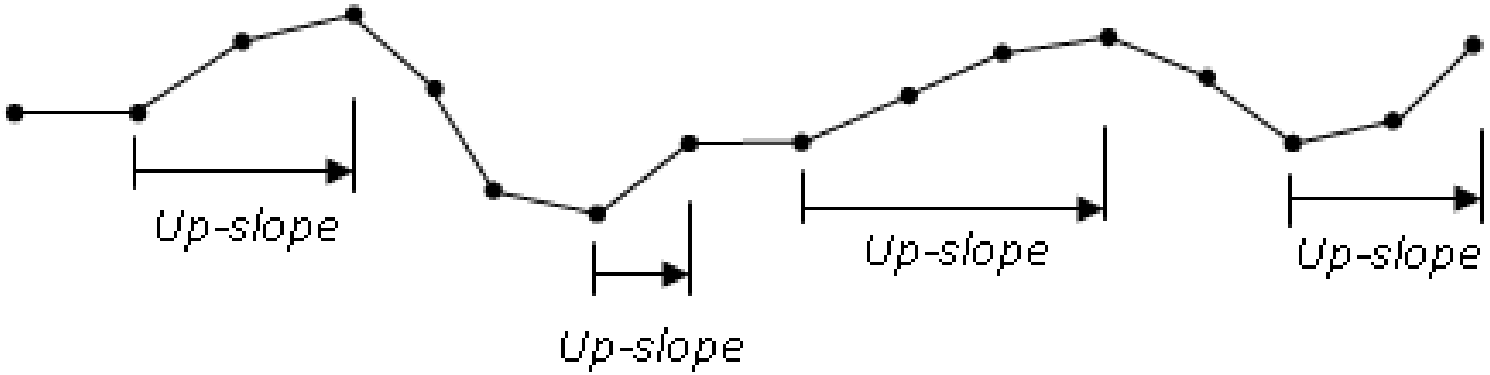
In main():

In doubleArray():

10. Exercise: Up-slopes (1/3)

You are an avid runner. Given a running route consisting of heights of points at regular interval on the route, you want to find the number of up-slopes in the route. An up-slope is a contiguous group of heights of increasing values.

```
Enter data:
3
3
4
:
2.9
3.65
-1
Number of up-slopes = 4
```



10. Exercise: Up-slopes (2/3)

Unit8_UpSlopes.c

```c
#include <stdio.h>
#define MAX 100 // maximum length of a route
// function prototypes omitted
int main(void) {
    float route[MAX];
    int route_length;

    route_length = read_route(route);
    printf("Number of up-slopes = %d\n", compute_upslopes(route, route_length));
    return 0;
}
// This function reads a list of ...
int read_route(float route[]) {
    float height;
    int length = 0; // length of route; number of values read

    printf("Enter data: ");
    scanf("%f", &height);
    while (height >= 0) {
        route[length++] = height;
        scanf("%f", &height);
    }
    return length;
}
```

10. Exercise: Up-slopes (3/3)

Unit8_UpSlopes.c

```
// This function takes a route and computes the number of upslopes.
int compute_upslopes(float route[], int size) {
    int upslopes = 0; // number of upslopes









    return upslopes;
}
```

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

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