University of Washington Slides adapted for CPE 101

Lecture 17:
Multidimensional Arrays

Overview

Review
- 1-D arrays

Concepts this lecture:
- 2-D arrays
- 2-D arrays as parameters
- Layout of 2-D arrays in memory

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Arrays as Data Structures

Review: *An array is an ordered collection of values of identical type*
- Name the collection; number the elements

Arrays are the natural choice for organizing a large number of values, all of identical type

Beyond Simple Arrays

Sometimes the collection of values has some additional regular pattern or structure

One common such structure is the matrix or table

In C, we can express this as a two-dimensional array

Higher-dimensional arrays (3-D, 4-D, …) are possible.

2-Dimensional Arrays

An ordered collection of values of identical type
Name the collection; number the elements
Like 1-D arrays, but a different numbering scheme
Example: scores for 7 students on 4 homeworks

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Example: scores for 7 students on 4 homeworks

score hw	0	1	2	3
student 0	22	15	25	25
student 1	12	12	25	20
student 2	5	17	25	24
student 3	15	19	25	13
student 4	2	0	25	25
student 5	25	22	24	21
student 6	8	4	25	12

2-Dimensional Arrays

An ordered collection of values of identical type
Name the collection; number the elements
Like 1-D arrays, but a different numbering scheme
Example: scores for 7 students on 4 homeworks

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student 3	15	19	25	13
student 4	2	0	25	25
student 5	25	22	24	21
student 6	8	4	25	12

C expressions:
- score[0][0]   is 22
- score[6][3]   is 12
- 2*score[3][0] is 30

Declaring a 2-D Array

Declaring a 2-D Array

int score [MAX_STUDENTS] [MAX_HWS] ;

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Declaring a 2-D Array

```
#define MAX_STUDENTS    80
#define MAX_HWS     6
...
int score [MAX_STUDENTS] [MAX_HWS] ;
```

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2-D Arrays: Terminology

type name[#rows][#columns]

int score[80][6];

score is a *two-dimensional array of int* of size 80 by 6

score[0][0], score[0][1], ... , score[79][5] are the elements of the array

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An Alternate View

int score[80][6];

We could also view each row as an element:

"score is an array of size 80"

With this view, each element (row) is a 1-D array,of type "array of size 6 of int"

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Bookkeeping

As with 1-D arrays, often we only use part of the space available in a 2-D array

Declared size of the array specifies its *maximum capacity.*

The *current size* (# of rows and columns currently in use) needs to be noted somewhere (keep in special vars)

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Reading in Data

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Reading in Data

Problem: Read in data for student assignments

Input data format: The number of students, then the number of assignments, followed by the data per student

A *nested loop* is the right program structure for reading in the data details (finally, a real use for a nested loop :-)

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Reading in Data

Problem: Read in data for student assignments

Input data format: The number of students, then the number of assignments, followed by the data per student

A nested loop is the right program structure for reading in the data details

```
int score [MAX_STUDENTS] [MAX_HWS] ;
int nstudents, nhws, i, j ;
```

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Reading a 2-D Array: Code

```
/* Read the number of students and assignments,
   then loop to read detailed data */

scanf ("%d %d", &nstudents, &nhws) ;
```

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Reading a 2-D Array: Code

```
/* Read the number of students and assignments,
   then loop to read detailed data */

scanf ("%d %d", &nstudents, &nhws) ;
if (nstudents <= MAX_STUDENTS &&
        nhws <= MAX_HWS) {
    for ( i = 0 ;  i < nstudents ;  i = i + 1 )
        for ( j = 0 ;  j < nhws ;  j = j + 1 )
            scanf("%d", &score [i] [j]) ;
}
```

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Reading a 2-D Array: Code

```
/* Read the number of students and assignments,
   then loop to read detailed data */

scanf ("%d %d", &nstudents, &nhws) ;
if (nstudents <= MAX_STUDENTS &&
        nhws <= MAX_HWS) {
    for ( i = 0 ;  i < nstudents ;  i = i + 1 )
        for ( j = 0 ;  j < nhws ;  j = j + 1 )
            scanf("%d", &score [i] [j]) ;
}
```

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Part of the array is unused; which part?

Array Input Trace

Input: 7 4 0 1 2 3 4 5 6 7 8 9 ...

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Array Input Trace

Input: 7 4 0 1 2 3 4 5 6 7 8 9 ...

```
score     j= 0  1  2  3  4  5 ...
      i=0
      i=1
      i=2
      ...
      i=6
      i=7
```

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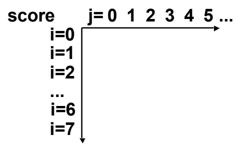
Array Input Trace

Input: 7 4 0 1 2 3 4 5 6 7 8 9 ...



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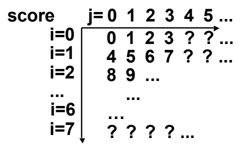
Array Input Trace

Input: 7 4 0 1 2 3 4 5 6 7 8 9 ...



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Printing a 2-D Array

```
if (nstudents <= MAX_STUDENTS &&
        nhws <= MAX_HWS) {
    for ( i = 0 ;  i < nstudents ;  i = i + 1 ) {
        for ( j = 0 ;  j < nhws ;  j = j + 1 )
            printf("%d", score [i] [j]) ;
        printf("\n") ;
    }
}
```

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2-D Arrays as Parameters

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2-D Arrays as Parameters

Same as 1-D arrays (almost):

- Individual array elements can be either value or pointer parameters
- Entire arrays are always passed as pointer parameters (value of an address) - values of elements never copied en masse…
- <u>Don't use & and * with entire array parameters</u>

Difference:

- *No empty brackets [ ] in formal parameters, must have the sizes explicit for 2-D arrays. (experiment with this!!!)*
- Actually, [ ] allowed sometimes, but don't worry about that during this course.

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2-D Array As Parameter

A function to read into array *a* the grade information for the given number of students and assignments

```
void read_2D ( int a [MAX_STUDENTS] [MAX_HWS],
                              int nstudents, int nhws)
{...
```

2-D Array As Parameter

```
/* Read into array a the grade information for */
/* the given number of students and assignments */
void read_2D ( int a [MAX_STUDENTS] [MAX_HWS] ,
                    int nstudents, int nhws)
{
    int i, j ;
    for ( i = 0 ;  i < nstudents ;  i = i + 1 )
        for ( j = 0 ;  j < nhws ;  j = j + 1 )
            scanf("%d", &a[i][j]) ;
 }
```

Array Function Arguments

```
int main(void)
{
   int score [MAX_STUDENTS] [MAX_HWS] ;
   int nstudents, nhws ;

   scanf ("%d %d", &nstudents, &nhws) ;
   if (  nstudents <= MAX_STUDENTS &&
         nhws <= MAX_HWS)
              read_2D (score, nstudents, nhws) ;
     ...
}
```

$\xleftarrow{\qquad}$ no &

/* Notice you can't use "score[x][y]" in the call because that is a variable! */

Example - Digital Image

Example - Digital Image

A *digital image* is a rectangular grid of *pixels*

Pixel representation: integer value giving brightness from 0 (off) to 255 (full on)
- Black & White: one int per pixel
- Color: 3 ints per pixel - one each for red, green, and blue

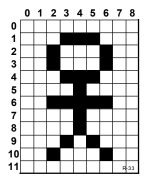
An image is normally stored as a 2D array

Problem - Shift Image

Write a function that shifts a B&W image right one pixel

Strategy: shift columns one at a time

To shift a column, shift the pixels 1 row at a time



A couple of definitions

```
/* Number of rows and columns in image */
#define NROWS 768
#define NCOLS 1024

/* Representation of a white pixel */
#define WHITE 255
```

Code

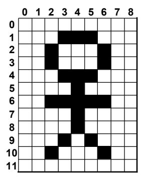
Code

```
/* Shift image right one column */
void shift_right(int image[NROWS][NCOLS]) {
   int row, col;

   /* shift all columns */
   for (col = … ) {
      /* shift column col one space to the right */
      for (row = 0; row < NROWS; row++)
          image[row][col+1] = image[row][col];
   }

   /* set leftmost column to white */
   for (row = 0; row < NROWS; row++)
       image[row][0] = WHITE;
}
```

Column Sequence

Question: Does it matter if we shift from left to right vs right to left?
Question: What are the correct loop bounds for col?
0 to NCOLS-1? 0 to NCOLS-2? 1 to NCOLS-1? Something else?

```
/* shift all columns */
for (col = … ) {
    /* shift column col one space to the right */
    for (row = 0; row < NROWS; row++)
        image[row][col+1] = image[row][col];
}
```



Order

Answer: Yes it does. If we shift from left to right, we wind up making copies of column 0 in every column of the image. Correct code looks like this.

```
/* shift all columns */
for (col = NCOLS - 2; col >= 0; col-- ) {
    /* shift column col one space to the right */
    for (row = 0; row < NROWS; row++)
        image[row][col+1] = image[row][col];
}
```

Column Sequence

Question: Does it matter if we shift from left to right vs right to left?
Question: What are the correct loop bounds for col?
0 to NCOLS-1? 0 to NCOLS-2? 1 to NCOLS-1? Something else?

```
/* shift all columns */
for (col = … ) {
    /* shift column col one space to the right */
    for (row = 0; row < NROWS; row++)
        image[row][col+1] = image[row][col];
}
```

Image Scrolling

Finally, we can use our function to scroll an image completely off the screen

```
int main(void) {
    int image[NROWS][NCOLS];  /* the image */
    int k;

    /* assume image is initialized elsewhere */
    …
    /* scroll image completely off the screen */
    for (k = 0; k < NCOLS; k++)
        shift_right(image);

    return 0;
}
```

Note: no & (it's an array)

Representation of Arrays

A computer's memory is a one dimensional array of cells

How is a 2-D array stored?

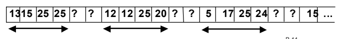
Answer: In C, the array rows are stored sequentially: row 0, 1, 2, …

Representation of Arrays

score	hw 0	1	2	3	4	5
student 0	13	15	25	25	?	?
student 1	12	12	25	20	?	?
student 2	5	17	25	24	?	?
student 3	15	19	25	13	?	?
student 4	2	0	25	25	?	?
student 5	25	22	24	21	?	?
student 6	8	4	25	12	?	?
student 7	?	?	?	?	?	?

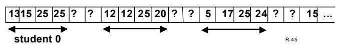
Representation of Arrays

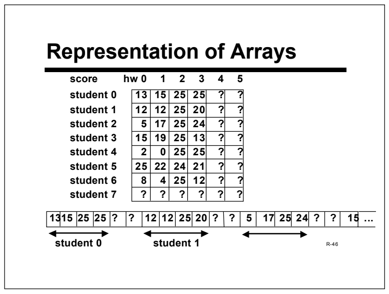
score	hw 0	1	2	3	4	5
student 0	13	15	25	25	?	?
student 1	12	12	25	20	?	?
student 2	5	17	25	24	?	?
student 3	15	19	25	13	?	?
student 4	2	0	25	25	?	?
student 5	25	22	24	21	?	?
student 6	8	4	25	12	?	?
student 7	?	?	?	?	?	?



Representation of Arrays

score	hw 0	1	2	3	4	5
student 0	13	15	25	25	?	?
student 1	12	12	25	20	?	?
student 2	5	17	25	24	?	?
student 3	15	19	25	13	?	?
student 4	2	0	25	25	?	?
student 5	25	22	24	21	?	?
student 6	8	4	25	12	?	?
student 7	?	?	?	?	?	?





Representation of Arrays

score	hw 0	1	2	3	4	5
student 0	13	15	25	25	?	?
student 1	12	12	25	20	?	?
student 2	5	17	25	24	?	?
student 3	15	19	25	13	?	?
student 4	2	0	25	25	?	?
student 5	25	22	24	21	?	?
student 6	8	4	25	12	?	?
student 7	?	?	?	?	?	?

13	15	25	25	?	?	12	12	25	20	?	?	5	17	25	24	?	?	15	...

$\longleftrightarrow$ student 0 $\longleftrightarrow$ student 1 $\longleftrightarrow$

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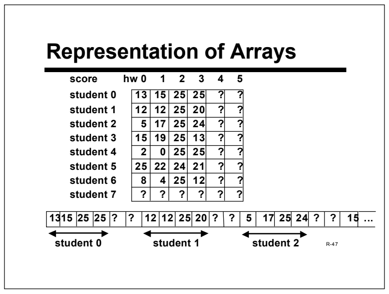

Representation of Arrays

score	hw 0	1	2	3	4	5
student 0	13	15	25	25	?	?
student 1	12	12	25	20	?	?
student 2	5	17	25	24	?	?
student 3	15	19	25	13	?	?
student 4	2	0	25	25	?	?
student 5	25	22	24	21	?	?
student 6	8	4	25	12	?	?
student 7	?	?	?	?	?	?

13	15	25	25	?	?	12	12	25	20	?	?	5	17	25	24	?	?	15	...

$\longleftrightarrow$ student 0 $\longleftrightarrow$ student 1 $\longleftrightarrow$ student 2

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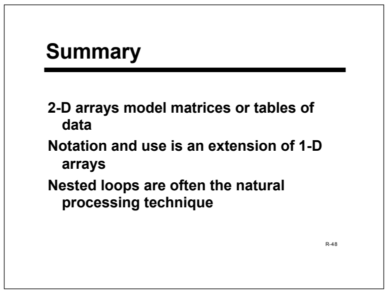

Summary

- 2-D arrays model matrices or tables of data
- Notation and use is an extension of 1-D arrays
- Nested loops are often the natural processing technique

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