EECS 22: Advanced C Programming

Lecture 5

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Lecture 5: Overview

- Review of the C Programming Language
  - Introduction to Data Structures
  - Arrays
    - Introduction
    - Indexing
    - Initialization
  - Multi-Dimensional Arrays
  - Program Example **`Histogram.c`**

Review of the C Programming Language

- Introduction to Data Structures
  - Until now, we have used only single data elements of basic (non-composite) type
    - integral types
    - floating point types
  - Most programs, however, require complex *data structures* using composite types
    - arrays, lists, queues, stacks
    - trees, graphs
    - dictionaries
  - ANSI C provides built-in support for
    - arrays
    - structures, unions, enumerators
    - pointers

Arrays

- Array data type in C
  - Composite data type
    - Type is an array of a sub-type (e.g. array of **`int`**)
  - Fixed number of elements
    - Array size is fixed at time of definition (e.g. 100 elements)
  - Element access by index (aka. subscript)
    - Element-access operator: ***`array[index]`*** (e.g. **`A[42]`**)
- Example:

```
int A[10];   /* array of ten integers */

A[0] = 42;   /* access to elements */
A[1] = 100;
A[2] = A[0] + 5 * A[1];
```

Arrays

- Array Indexing
  - Start counting from 0
    - First element has index 0
    - Last element has index *Size*-1
- Example:

```
int A[10];

A[0] = 42;
A[1] = 100;
A[2] = A[0] + 5 * A[1];
A[3] = -1;
A[4] = 44;
A[5] = 55;
/* ... */
A[9] = 99;
```

	A
0	42
1	100
2	542
3	-1
4	44
5	55
6	0
7	0
8	0
9	99

Arrays

- Array Indexing
  - `for` loops are often very helpful
    - `for(i=0; i<N; i++) {...A[i]...}`
- Example:

```
int A[10];
int i;

for(i=0; i<10; i++)
   { A[i] = i*10 + i;
    }
for(i=0; i<10; i++)
   { printf("%d, ", A[i]);
    }
```

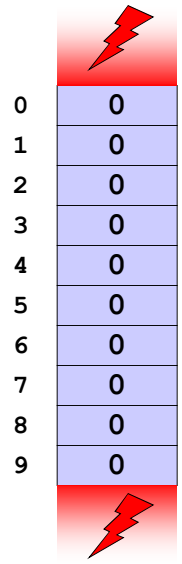
```
0, 11, 22, 33, 44, 55, 66, 77, 88, 99,
```

	A
0	0
1	11
2	22
3	33
4	44
5	55
6	66
7	77
8	88
9	99

Arrays

- Array Indexing
  - Array indices are *not* checked by the compiler, nor at runtime!
  - Accessing an array with an *index out of range* results in undefined behavior!
- Example:

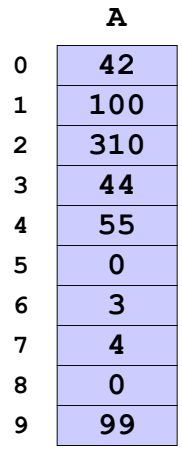
```
int A[10];
int i;

A[-1] = 42; /* INVALID ACCESS! */

for(i=0; i<=10; i++)
   /* INVALID LOOP RANGE! */
   { printf("%d, ", A[i]);
    }
```



Arrays

- Array Initialization
  - Static initialization at time of array definition
  - Initial elements listed in { }
- Example:

```
int A[10] = { 42, 100,
              310,  44,
               55,   0,
                3,   4,
                0,  99};
```



Arrays

- Array Initialization
  - Static initialization at time of array definition
  - Initial elements listed in { }
- Example:

```
int A[  ] = { 42, 100,
              310,  44,
               55,   0,
                3,   4,
                0,  99};
```

- With given initializer list, array size may be omitted
  - automatically determined

	A
0	42
1	100
2	310
3	44
4	55
5	0
6	3
7	4
8	0
9	99

Arrays

- Array Initialization
  - Static initialization at time of array definition
  - Initial elements listed in { }
- Example:

```
int A[10] = { 1, 2, 3};
```

- With given initializer list *and* array size, unlisted elements are zero-initialized
  - array is filled up with zeros

	A
0	1
1	2
2	3
3	0
4	0
5	0
6	0
7	0
8	0
9	0

Arrays

- Array Initialization
  - C99 standard introduces *Designated Initializers*
  - Designated elements listed in { }
- Example:

```
int A[10] = { A[2]=2,
              A[4]=4,
              A[8]=8 };
```

  - Designated elements are initialized as specified
  - Unspecified elements are zero-initialized

	A
0	0
1	0
2	2
3	0
4	4
5	0
6	0
7	0
8	8
9	0

Multi-Dimensional Arrays

- Multi-dimensional arrays are modeled as *Arrays of arrays (of arrays...)*
- Example:

```
int M[3][2] = {{1, 2},
               {3, 4},
               {5, 6}};
int i, j;

for(i=0; i<3; i++)
   { for(j=0; j<2; j++)
        { printf("%d ",
                 M[i][j]);
        }
     printf("\n");
   }
```

M	0	1
0	1	2
1	3	4
2	5	6

```
1 2
3 4
5 6
```

Multi-Dimensional Arrays

- Storage Allocation for Multi-Dimensional Arrays
  - Example: **`Array[Dim1][Dim2]…[DimN]`**
  - ➢ Need space for *Dim1*Dim2*…*DimN* elements
  - ▪ **`sizeof(int[5][100]) = sizeof(int)*5*100`**
- Storage in Linear Address Space in Memory
  - ➢ In storage order, right-most index varies the fastest
  - ➢ To obtain the linear offset of a given array element, left indices need to be multiplied by the sizes on the right
  - ▪ **`int A[10];`** **`A[5]`** is the 5th element (starting with 0th element)
  - ▪ **`int M[6][7];`** **`M[3][2]`** is the 3*7+2 = 23rd element
  - ▪ **`int T[2][8][5];`** **`T[1][2][3]`** is the 1*8*5+2*5+3 = 53rd element
  - ➢ When declaring arrays as parameters for functions, the left-most size is irrelevant and can be omitted
    - ▪ **`int f(int M[][7]);`**

Multi-Dimensional Arrays

- Example: Allocation of 2-dimensional Arrays: Tables
  - Rows (major)
  - Columns (minor)

```
#define ROWS 3
#define COLS 2
int M[ROWS][COLS]
 = {{1, 2},
    {3, 4},
    {5, 6}};
```

M	0	1
0	1	2
1	3	4
2	5	6

  - Linear memory layout:

```
int M[ROWS][COLS] = {{1, 2}, {3, 4}, {5, 6}};
```

M[0][0]	M[0][1]	M[1][0]	M[1][1]	M[2][0]	M[2][1]
1	2	3	4	5	6

Program Example

- **`Histogram.c`**
  - Display a simple bar chart for 10 integer values
- Desired output:

```
% ./Histogram
Please enter data value  1: 111
Please enter data value  2: 222
Please enter data value  3: 33
Please enter data value  4: 333
[...]
Please enter data value 10: 111
 1:  111 **************
 2:  222 ***************************
 3:   33 ****
 4:  333 ****************************************
[...]
10:  111 **************
%
```


Program Example

- **`Histogram.c`** (part 1/3)

```
/* Histogram.c: print a histogram of data values        */
/* author: Rainer Doemer                                */
/* modifications:                                       */
/* 11/02/04 RD  initial version                         */

#include <stdio.h>

/* constants */

#define NUM_ROWS 10

/* main function */

int main(void)
{
   /* variable definitions */
   int Data[NUM_ROWS];
   int i, j, max;
   double scale;

...
```

Program Example

- **`Histogram.c`** (part 2/3)

```
...
   /* input section */
   for(i = 0; i < NUM_ROWS; i++)
      { printf("Please enter data value %2d: ", i+1);
        scanf("%d", &Data[i]);
       } /* rof */

   /* computation section */
   max = 0;
   for(i = 0; i < NUM_ROWS; i++)
      { if (Data[i] > max)
           { max = Data[i];
            } /* fi */
       } /* rof */
   scale = 70.0 / max;

...
```


Program Example

- **`Histogram.c`** (part 3/3)

```
...
/* output section */
   for(i = 0; i < NUM_ROWS; i++)
      { printf("%2d: %5d ", i+1, Data[i]);
        for(j = 0; j < Data[i]*scale; j++)
           { printf("*");
            } /* rof */
        printf("\n");
       } /* rof */

   /* exit */
   return 0;
} /* end of main */

/* EOF */
```

Program Example

- Example session: **`Histogram.c`**

```
% vi Histogram.c
% gcc Histogram.c -o Histogram -Wall -ansi -std=c99
% ./Histogram
Please enter data value  1: 11
Please enter data value  2: 22
Please enter data value  3: 3
Please enter data value  4: 33
Please enter data value  5: 44
Please enter data value  6: 55
Please enter data value  7: 66
Please enter data value  8: 33
Please enter data value  9: 22
Please enter data value 10: 22
 1:    11 ***********
 2:    22 **********************
 3:     3 ****
 4:    33 *********************************
 5:    44 ********************************************
 6:    55 *******************************************************
 7:    66 ************************************************************
 8:    33 *********************************
 9:    22 **********************
10:    22 **********************
%
```

Variable-Length Arrays (C99)

- Arrays have a fixed number of elements
  - Size is allocated at time of variable definition
  - Size cannot change after allocation
- C/C++ standard has evolved over time
  - Traditional C: array size is a compile-time constant
  - C99: *variable-length array* size is determined at run-time
  - C11: variable-length array support is optional (*not* guaranteed)
  - C++: variable-length arrays are *not* supported
- ➢ Example revised for C99 standard:
  - Allow the user to input the number of data values desired
  - Allocate the Data array with size defined by variable value

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Program Example (C99)

- **`Histogram2.c`** (part 1/3)

```
/* Histogram2.c: print a histogram of data values       */
/* author: Rainer Doemer                                */
/* modifications:                                       */
/* 09/18/17 RD  version with variable-length array      */
/* 11/02/04 RD  initial version                         */

#include <stdio.h>

/* main function */

int main(void)
{  /* input section */
   int NumRows;
   printf("Number of data values: ");
   scanf("%d", &NumRows);

   /* variable definitions */
   int Data[NumRows]; // variable-length array (C99)
   int i, j, max;
   double scale;
...
```


Program Example (C99)

- **`Histogram2.c`** (part 2/3)

```
...
   /* input section */
   for(i = 0; i < NumRows; i++)
      { printf("Please enter data value %2d: ", i+1);
        scanf("%d", &Data[i]);
       } /* rof */

   /* computation section */
   max = 0;
   for(i = 0; i < NumRows; i++)
      { if (Data[i] > max)
           { max = Data[i];
            } /* fi */
       } /* rof */
   scale = 70.0 / max;

...
```

Program Example (C99)

- **`Histogram2.c`** (part 3/3)

```
...
/* output section */
   for(i = 0; i < NumRows; i++)
      { printf("%2d: %5d ", i+1, Data[i]);
        for(j = 0; j < Data[i]*scale; j++)
           { printf("*");
            } /* rof */
        printf("\n");
       } /* rof */

   /* exit */
   return 0;
} /* end of main */

/* EOF */
```


Program Example (C99)

- Example session: **`Histogram2.c`**

```
% vi Histogram2.c
% gcc Histogram2.c -o Histogram2 -Wall -ansi -std=c99
% ./Histogram2
Number of data values: 8
Please enter data value  1: 11
Please enter data value  2: 22
Please enter data value  3: 3
Please enter data value  4: 33
Please enter data value  5: 44
Please enter data value  6: 55
Please enter data value  7: 66
Please enter data value  8: 33
 1:    11 ***********
 2:    22 **********************
 3:     3 ****
 4:    33 *********************************
 5:    44 ********************************************
 6:    55 ***********************************************************
 7:    66 ****************************************************************
 8:    33 *********************************
%
```