

# EECS 10: Computational Methods in Electrical and Computer Engineering

## Lecture 11

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## Lecture 11: Overview

- Data Structures
  - Introduction
  - Arrays
    - Introduction
    - Indexing
    - Initialization
    - Multi-dimensional arrays
    - Operator associativity and precedence
  - Example 1
    - `Dice2.c`
  - Example 2
    - `Histogram.c`

## Data Structures

- Introduction
  - Until now, we have used (mostly) 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

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3

## 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];
```

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4

## 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

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5

## 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]);
  }
```

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

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

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6

## 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]);
  }
```

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

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## 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};
```

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

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## 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

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9

## 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

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10

## Arrays

- Multi-dimensional Arrays

- Array of an array...

- 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
```

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11

## Arrays

- Operator associativity and precedence

– parentheses, <b>array access</b>	( ), [ ]	left to right
– unary operators	+, -, !, ++, --	right to left
– type casting	( <i>typename</i> )	right to left
– multiplication, division, modulo	*, /, %	left to right
– addition, subtraction	+, -	left to right
– shift left, shift right	<<, >>	left to right
– relational operators	<, <=, >=, >	left to right
– equality	==, !=	left to right
– logical and	&&	left to right
– logical or		left to right
– conditional operator	?:	left to right
– assignment operators	=, +=, *=, etc.	right to left
– comma operator	,	left to right

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12

## Arrays

- Review program example: `Dice.c` (part 1/4)

```

/* Dice.c: roll the dice                                     */
/* author: Rainer Doemer                                    */
/* modifications:                                          */
/* 10/28/04 RD  initial version                            */

#include <stdio.h>
#include <stdlib.h>
#include <time.h>

/* function definition */

int roll(void)
{
    int r;

    r = rand() % 6 + 1;
    /* printf("Rolled a %d.\n", r); */
    return r;
} /* end of roll */
...

```

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13

## Arrays

- Review program example: `Dice.c` (part 2/4)

```

...
/* main function */

int main(void)
{
    /* variable definitions */
    int i, n;
    int count1 = 0, count2 = 0, count3 = 0,
        count4 = 0, count5 = 0, count6 = 0;

    /* random number generator initialization */
    srand(time(0));

    /* input section */
    printf("Roll the dice: How many times? ");
    scanf("%d", &n);

    ...

```

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14

## Arrays

- Review program example: `Dice.c` (part 3/4)

```
... /* computation section */
for(i = 0; i < n; i++)
{ switch(roll())
  { case 1:
    { count1++; break; }
    case 2:
    { count2++; break; }
    case 3:
    { count3++; break; }
    case 4:
    { count4++; break; }
    case 5:
    { count5++; break; }
    case 6:
    { count6++; break; }
    default:
    { printf("INVALID ROLL!");
      exit(10); }
  } /* hctiws */
} /* rof */
...
```

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15

## Arrays

- Review program example: `Dice.c` (part 4/4)

```
...

/* output section */
printf("Rolled a 1 %5d times.\n", count1);
printf("Rolled a 2 %5d times.\n", count2);
printf("Rolled a 3 %5d times.\n", count3);
printf("Rolled a 4 %5d times.\n", count4);
printf("Rolled a 5 %5d times.\n", count5);
printf("Rolled a 6 %5d times.\n", count6);

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

/* EOF */
```

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16



## Arrays

- Improved program example: `Dice2.c` (part 1/3)

```

/* Dice2.c: roll the dice */
/* author: Rainer Doemer */
/* modifications: */
/* 11/04/04 RD version using arrays */
/* 10/28/04 RD initial version */

#include <stdio.h>
#include <stdlib.h>
#include <time.h>

/* function definition */
int roll(void)
{
    int r;

    r = rand() % 6 + 1;
    /* printf("Rolled a %d.\n", r); */
    return r;
} /* end of roll */

...

```

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17

## Arrays

- Improved program example: `Dice2.c` (part 2/3)

```

...
/* main function */

int main(void)
{
    /* variable definitions */
    int i, n;
    int count[6] = { 0, 0, 0, 0, 0, 0 };

    /* random number generator initialization */
    srand(time(0));

    /* input section */
    printf("Roll the dice: How many times? ");
    scanf("%d", &n);

    ...

```

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18

## Arrays

- Improved program example: `Dice2.c` (part 3/3)

```

...
/* computation section */
for(i = 0; i < n; i++)
{ count[roll()-1]++;
} /* rof */

/* output section */
for(i = 0; i < 6; i++)
{ printf("Rolled a %d %5d times.\n",
        i+1, count[i]);
} /* rof */

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

/* EOF */

```

## Arrays

- Example session: `Dice2.c`

```

% vi Dice2.c
% gcc Dice2.c -o Dice2 -Wall -ansi
% Dice2
Roll the dice: How many times? 6000
Rolled a 1 1009 times.
Rolled a 2 1005 times.
Rolled a 3 962 times.
Rolled a 4 998 times.
Rolled a 5 996 times.
Rolled a 6 1030 times.
% Dice2
Roll the dice: How many times? 6000
Rolled a 1 1042 times.
Rolled a 2 983 times.
Rolled a 3 972 times.
Rolled a 4 979 times.
Rolled a 5 1022 times.
Rolled a 6 1002 times.
%

```

## Arrays

- 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 *****
%
```

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21

## Arrays

- 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;

    ...
}
```

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22

## Arrays

- 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;
...

```

## Arrays

- 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 */

```

## Arrays

- Example session: `Histogram.c`

```
% vi Histogram.c
% gcc Histogram.c -o Histogram -Wall -ansi
% 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 *****
%
```

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