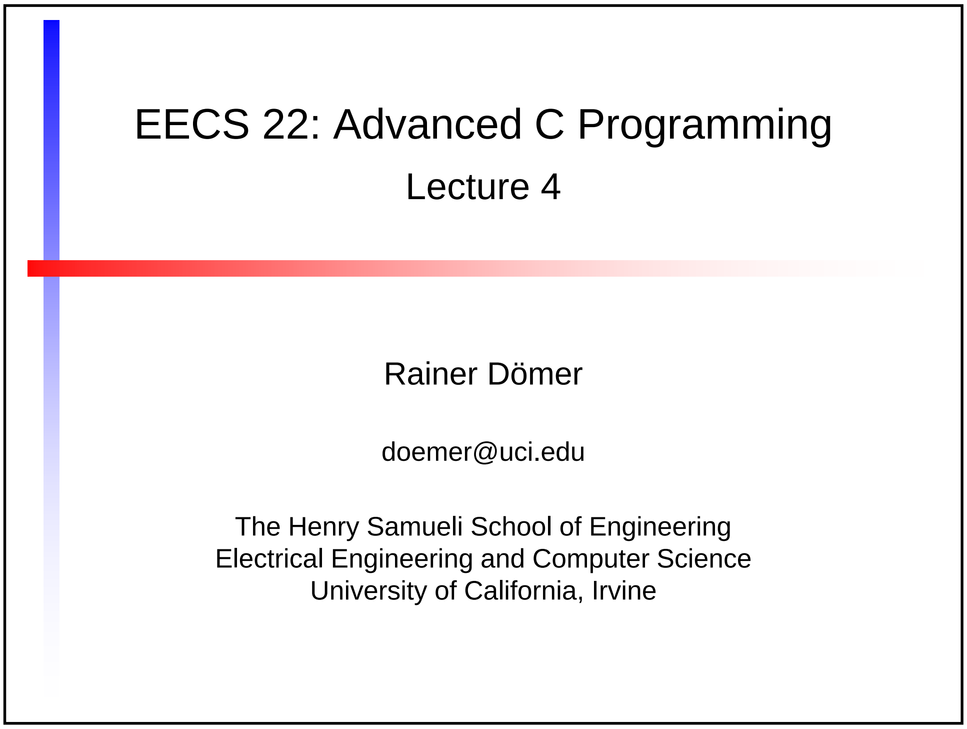

EECS 22: Advanced C Programming

Lecture 4

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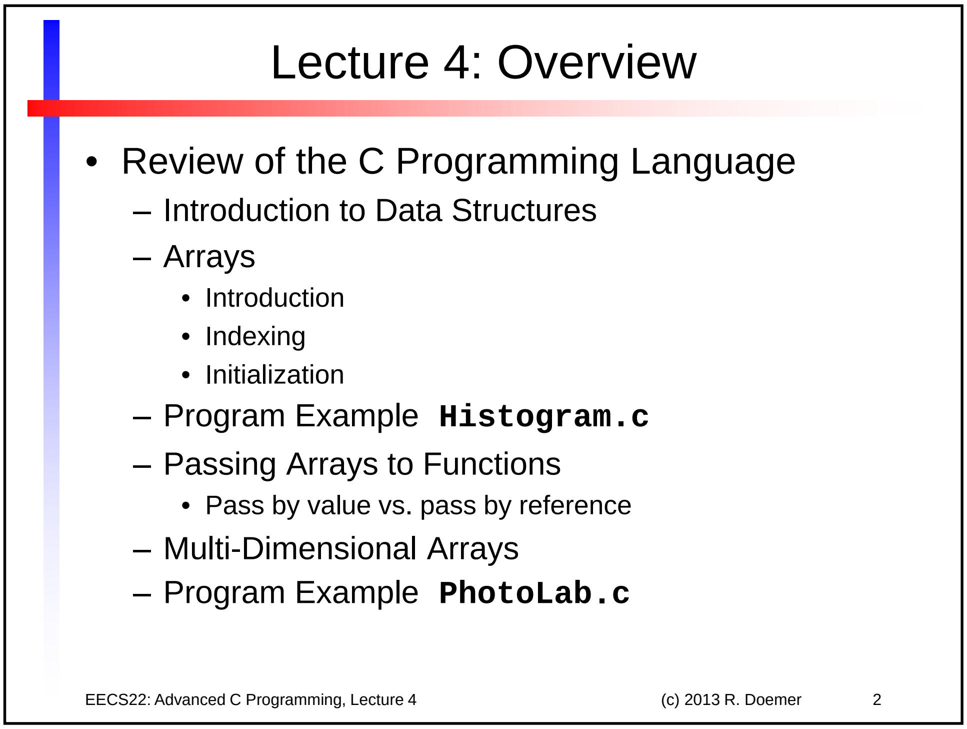
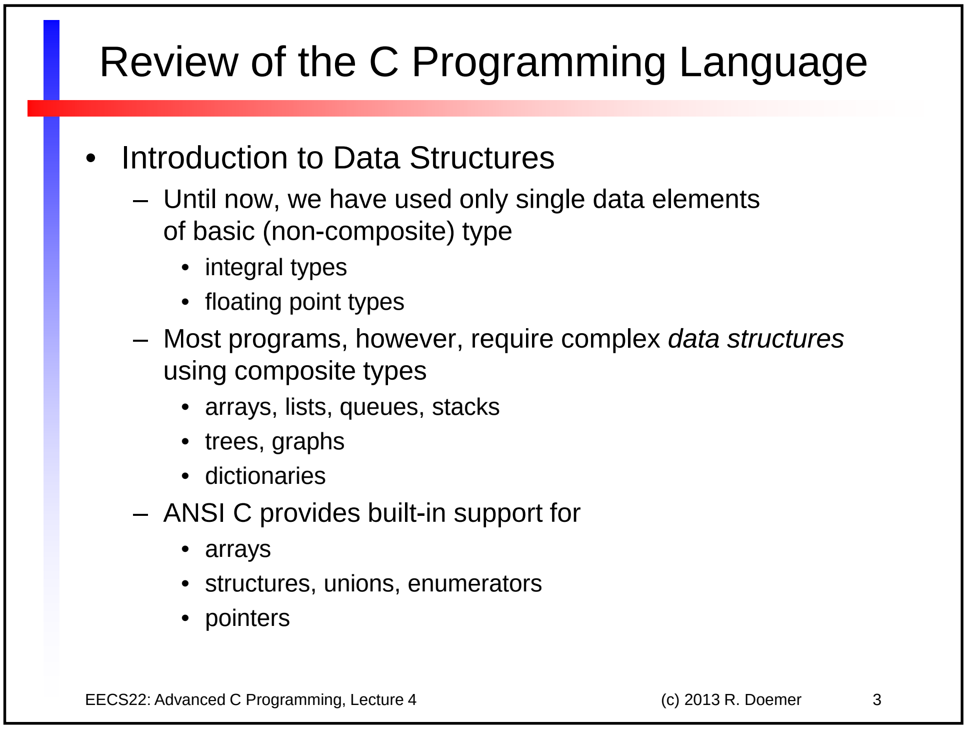


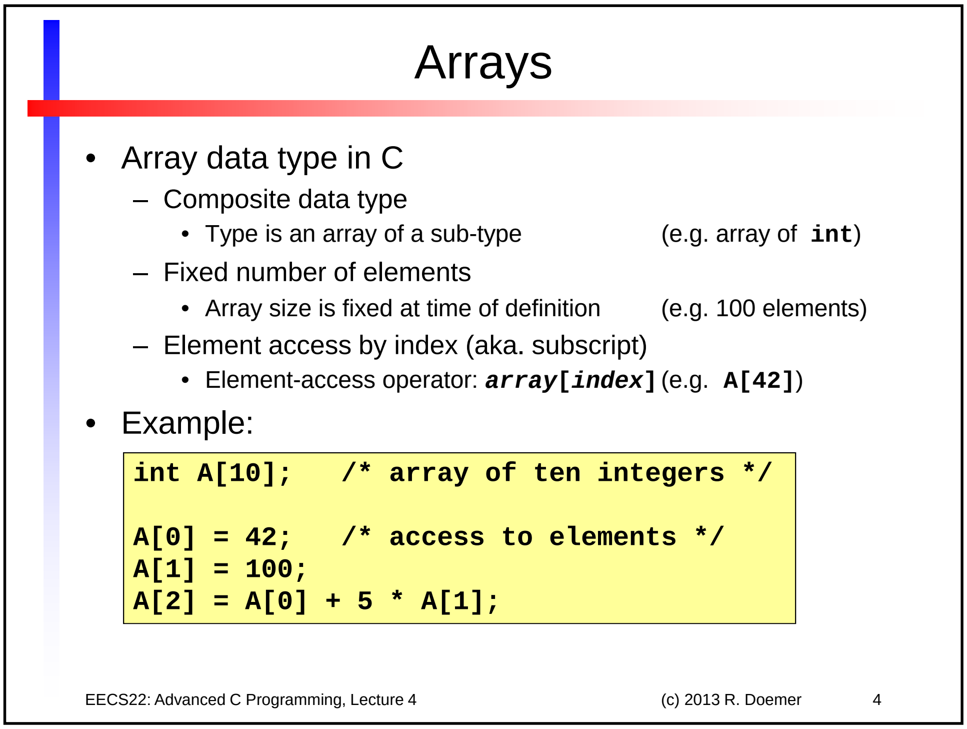
Lecture 4: Overview

- Review of the C Programming Language
  - Introduction to Data Structures
  - Arrays
    - Introduction
    - Indexing
    - Initialization
  - Program Example **`Histogram.c`**
  - Passing Arrays to Functions
    - Pass by value vs. pass by reference
  - Multi-Dimensional Arrays
  - Program Example **`PhotoLab.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

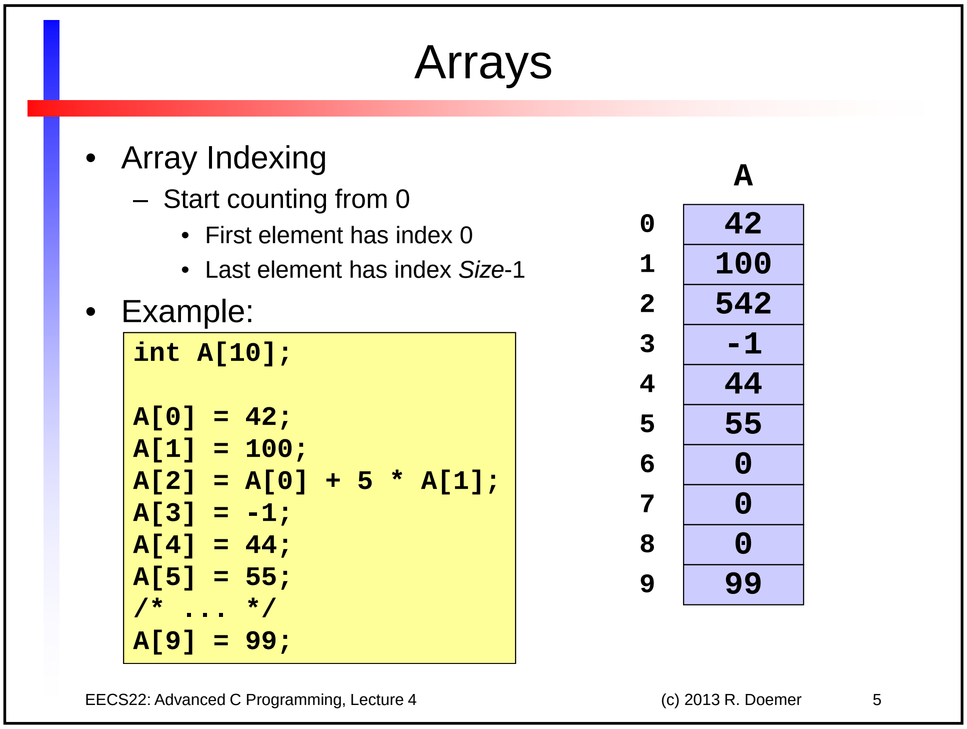


Arrays

- 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

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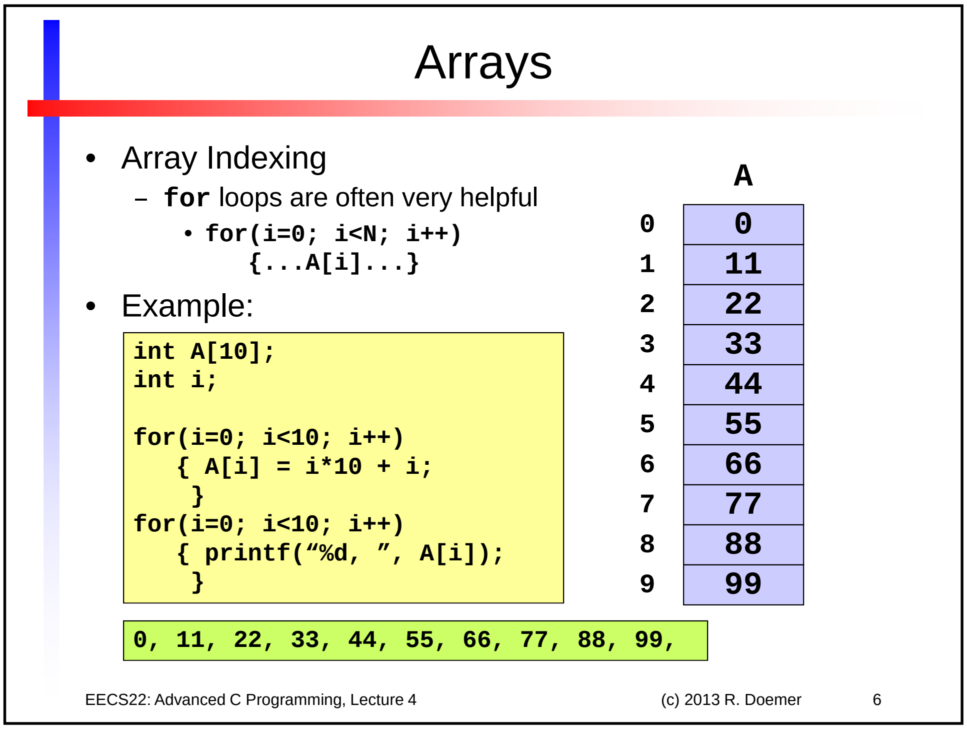

Arrays

- 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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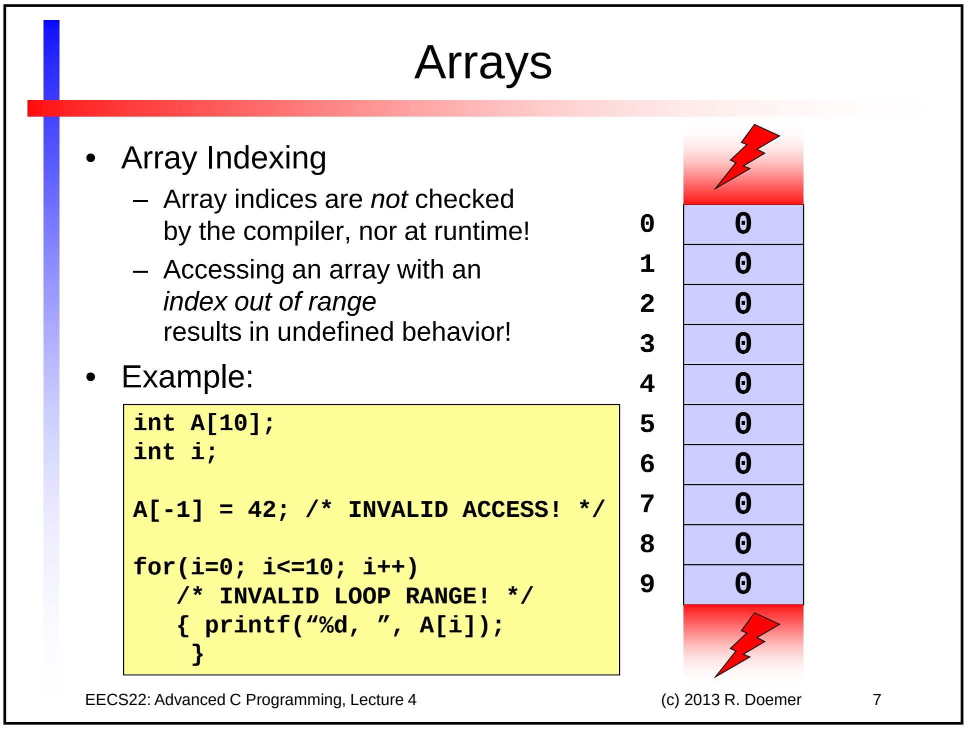


Arrays

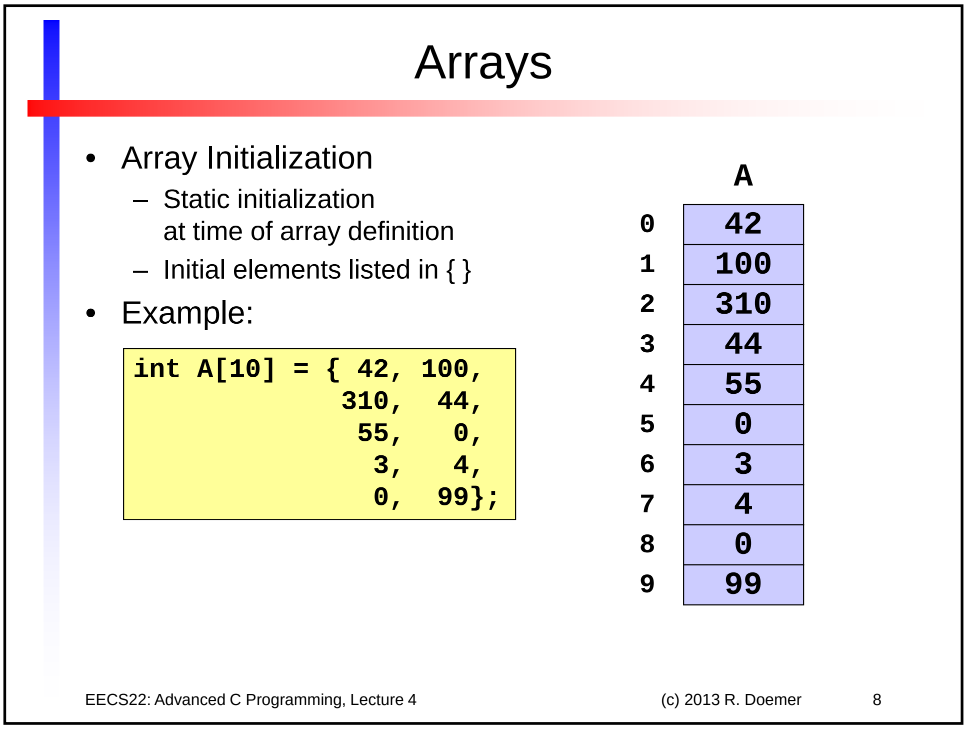
- Array Indexing
  - Array indices are *not* checked by the compiler, nor at runtime!
  - Accessing an array with an *index out of range* results in undefined behavior!
- Example:

```
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

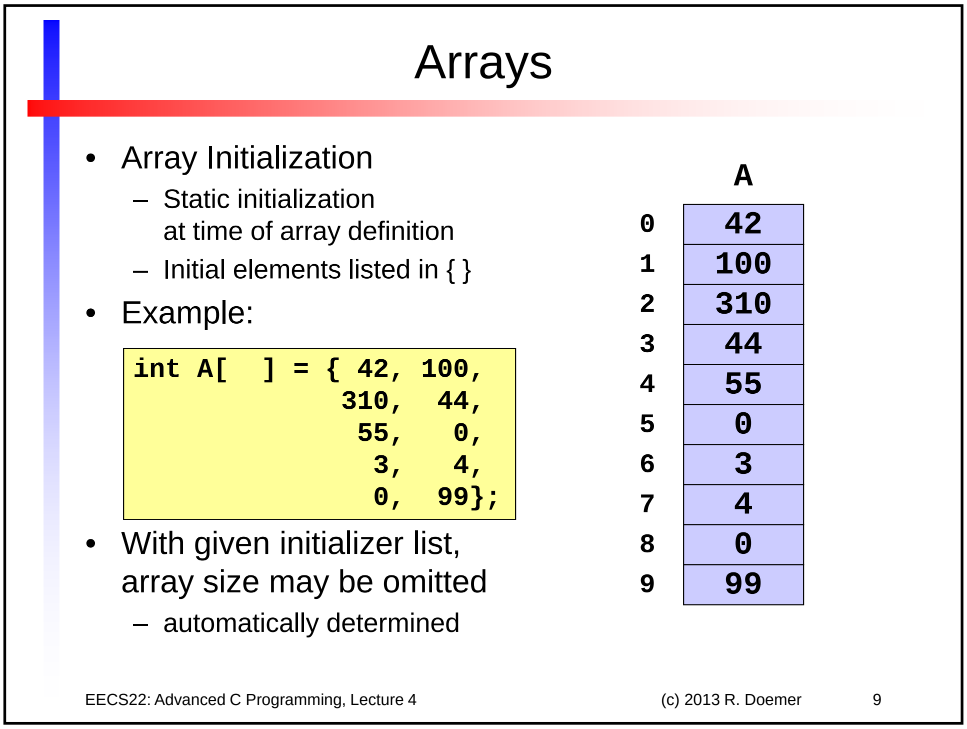


Arrays

- 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



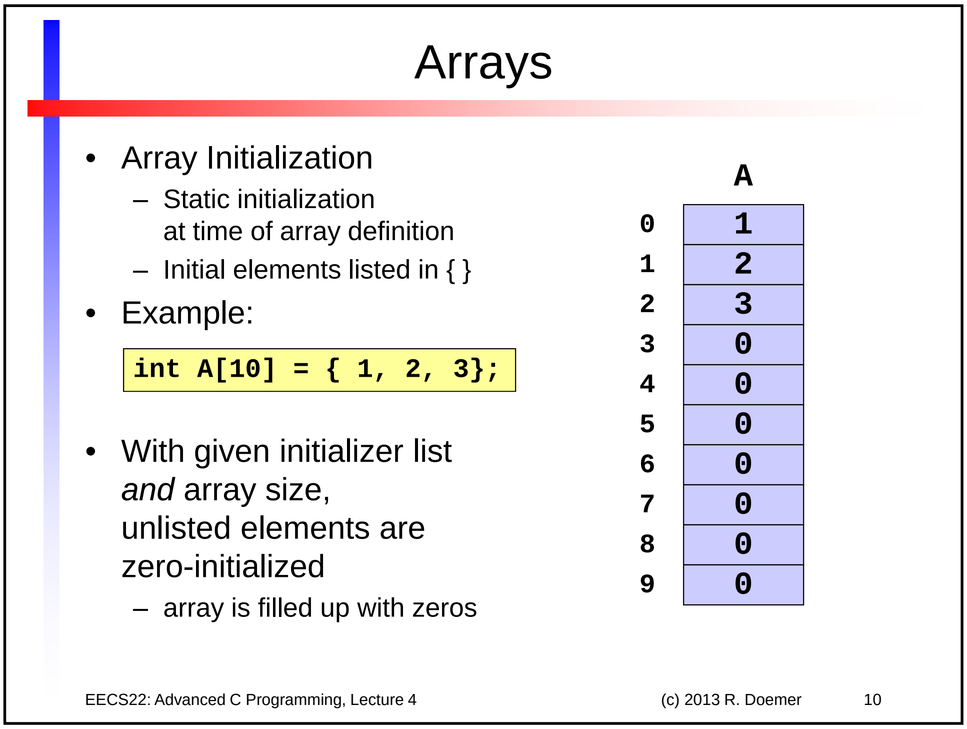
Arrays

- 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



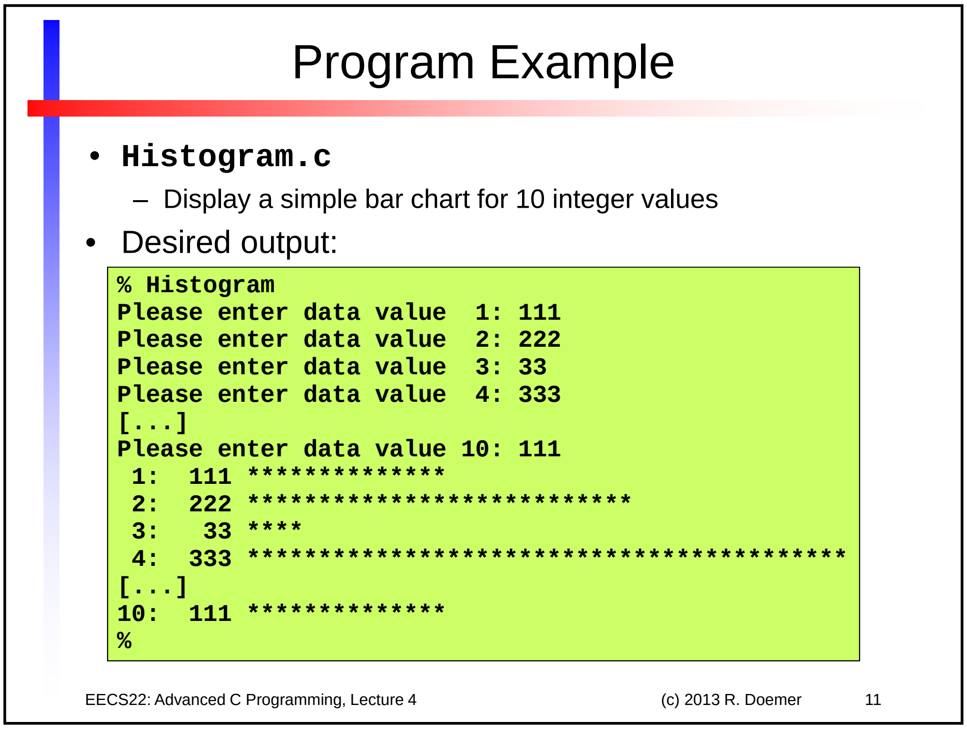
Arrays

- 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



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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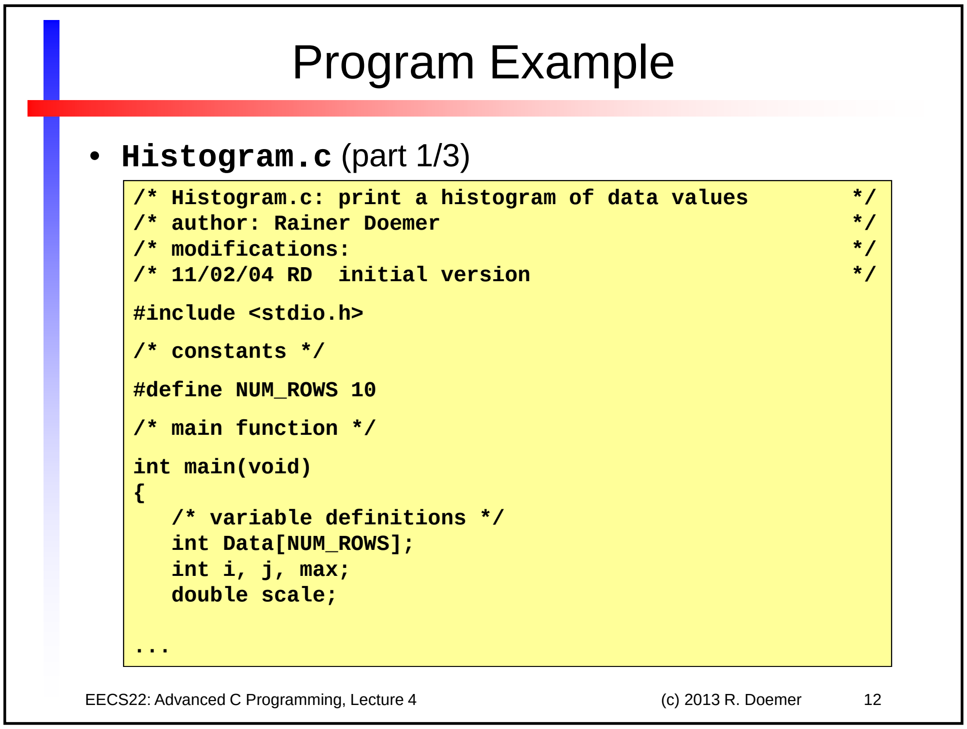

Program Example

- **`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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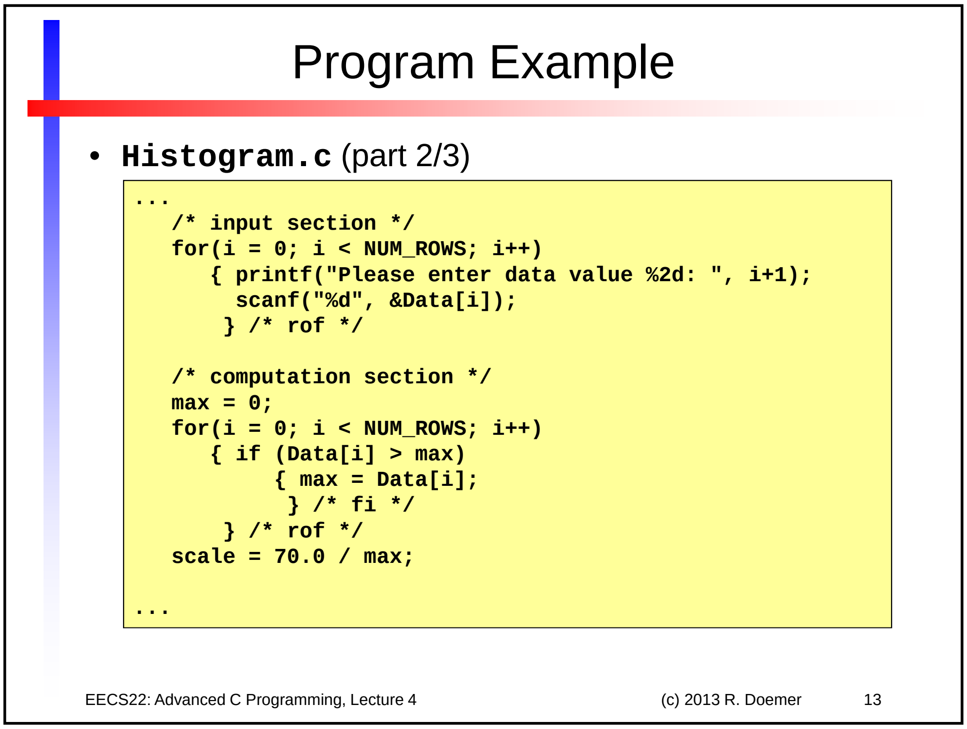

Program Example

- **`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;

...
```

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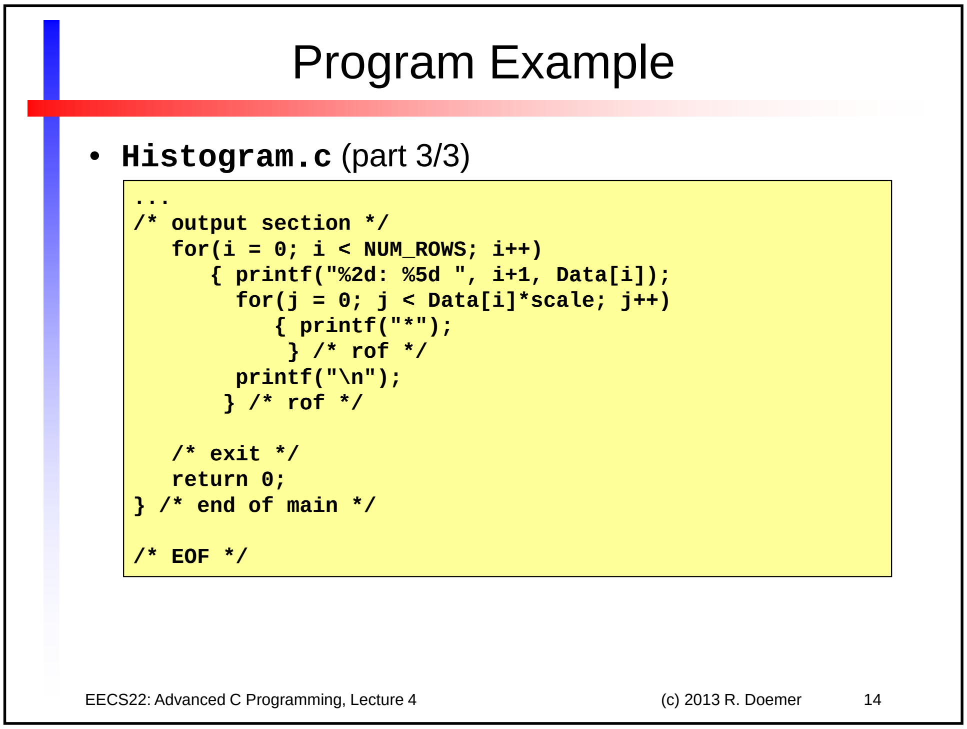

Program Example

- **`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 */
```

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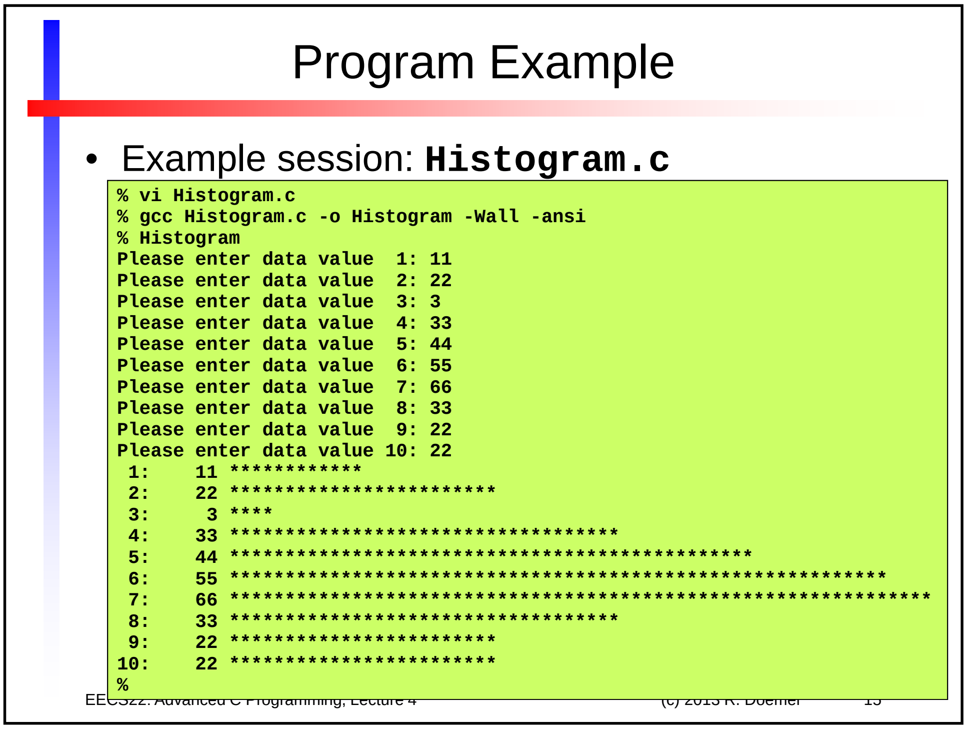

Program Example

- 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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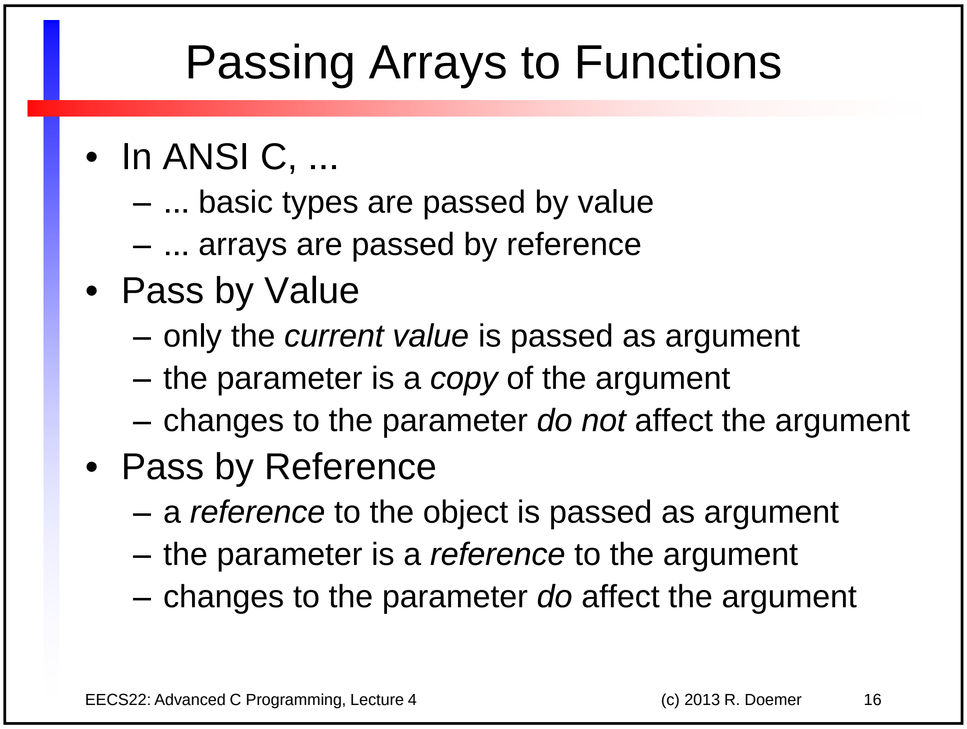

Passing Arrays to Functions

- In ANSI C, ...
  - ... basic types are passed by value
  - ... arrays are passed by reference
- Pass by Value
  - only the *current value* is passed as argument
  - the parameter is a *copy* of the argument
  - changes to the parameter *do not* affect the argument
- Pass by Reference
  - a *reference* to the object is passed as argument
  - the parameter is a *reference* to the argument
  - changes to the parameter *do* affect the argument

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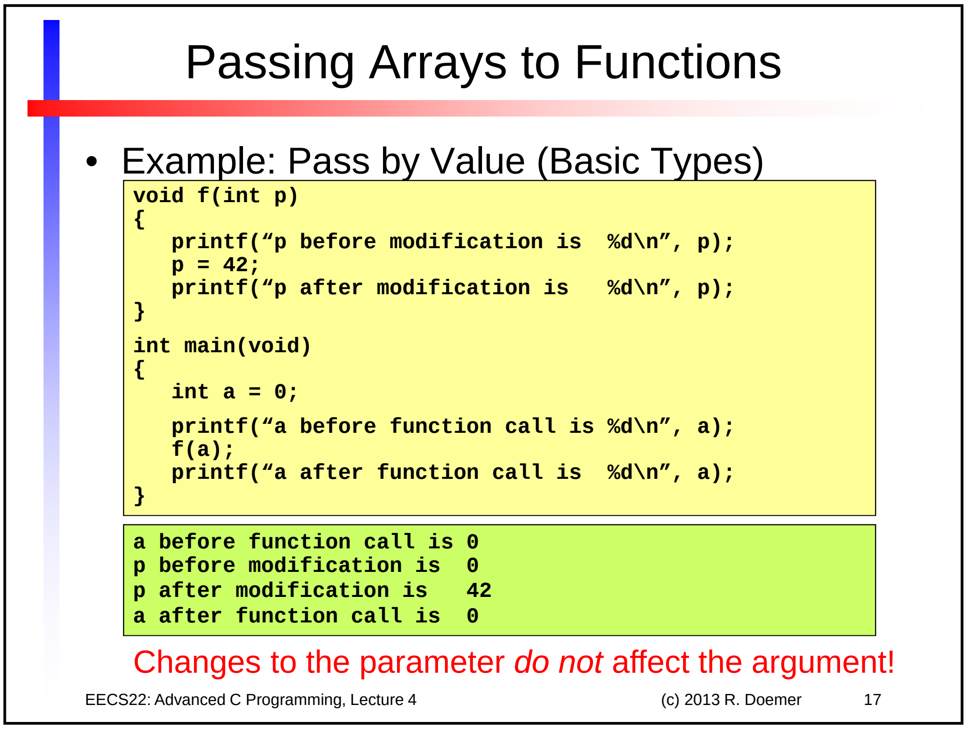

Passing Arrays to Functions

- Example: Pass by Value (Basic Types)

```
void f(int p)
{
   printf(“p before modification is  %d\n”, p);
   p = 42;
   printf(“p after modification is   %d\n”, p);
}
int main(void)
{
   int a = 0;
   printf(“a before function call is %d\n”, a);
   f(a);
   printf(“a after function call is  %d\n”, a);
}
```

```
a before function call is 0
p before modification is  0
p after modification is   42
a after function call is  0
```

Changes to the parameter *do not* affect the argument!

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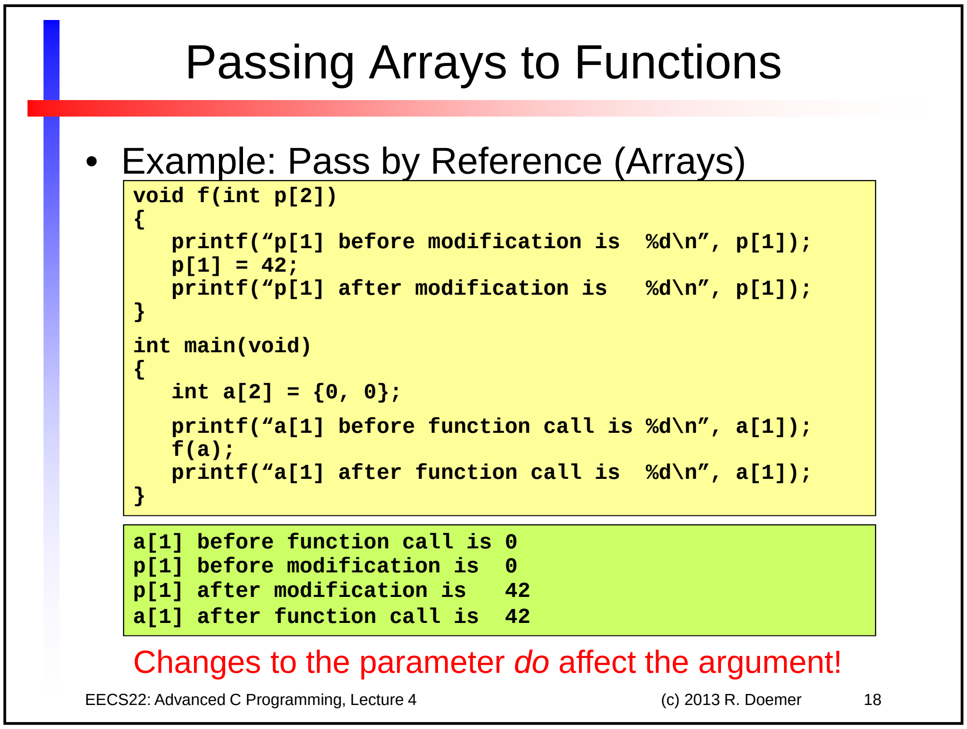

Passing Arrays to Functions

- Example: Pass by Reference (Arrays)

```
void f(int p[2])
{
   printf(“p[1] before modification is  %d\n”, p[1]);
   p[1] = 42;
   printf(“p[1] after modification is   %d\n”, p[1]);
}
int main(void)
{
   int a[2] = {0, 0};
   printf(“a[1] before function call is %d\n”, a[1]);
   f(a);
   printf(“a[1] after function call is  %d\n”, a[1]);
}
```

```
a[1] before function call is 0
p[1] before modification is  0
p[1] after modification is   42
a[1] after function call is  42
```

Changes to the parameter *do* affect the argument!

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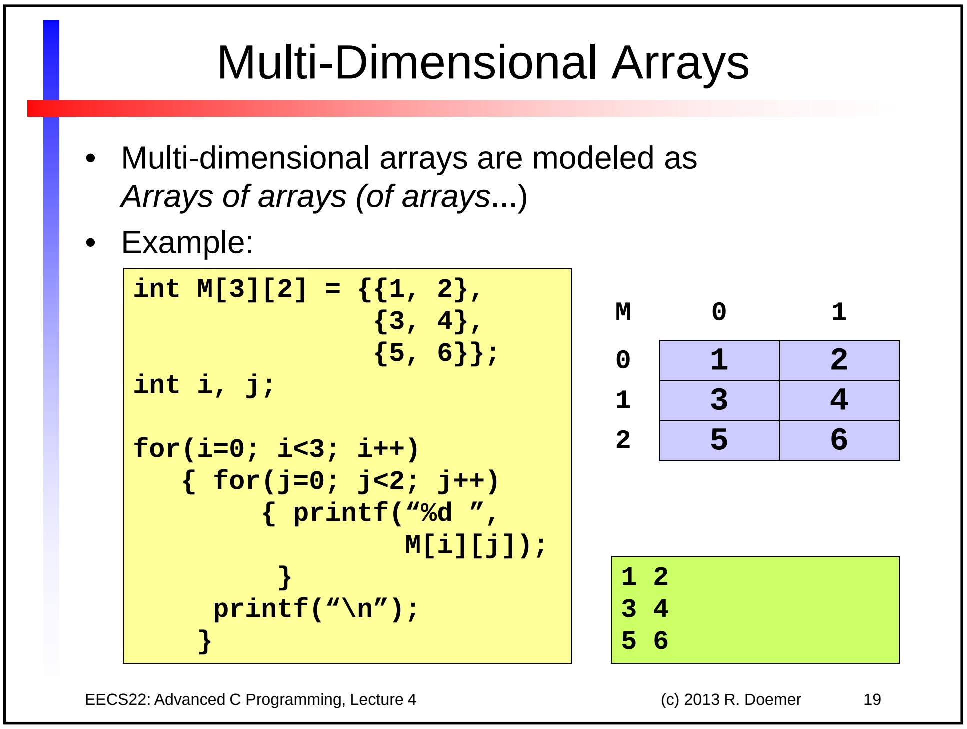


Multi-Dimensional Arrays

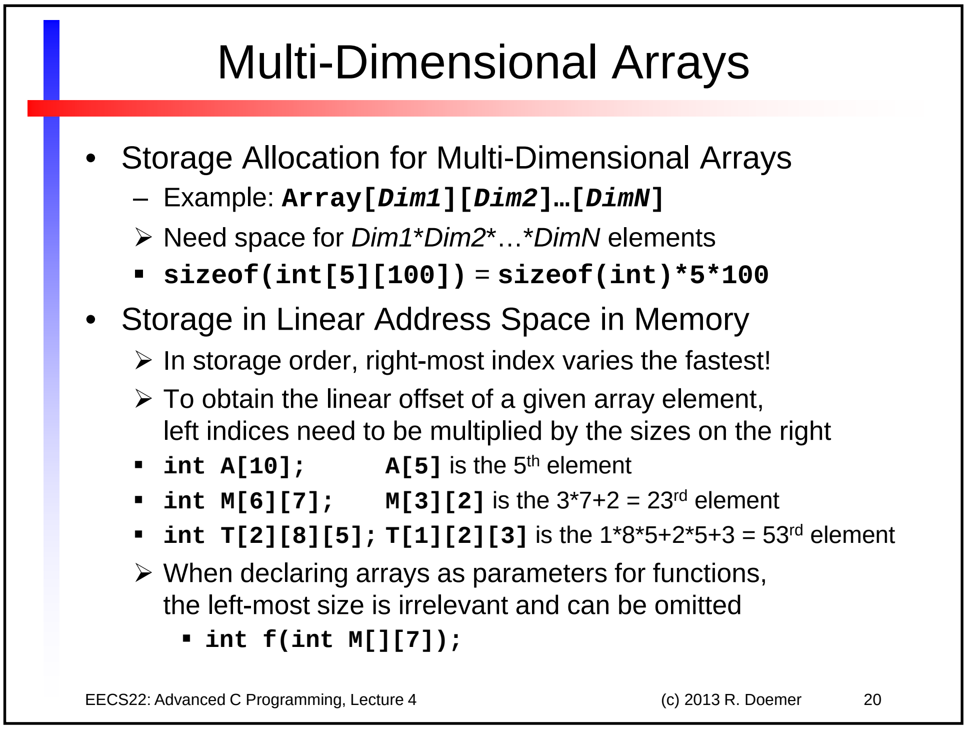
- Multi-dimensional arrays are modeled as *Arrays of arrays (of arrays*...)
- Example:

```
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”);
    }
```

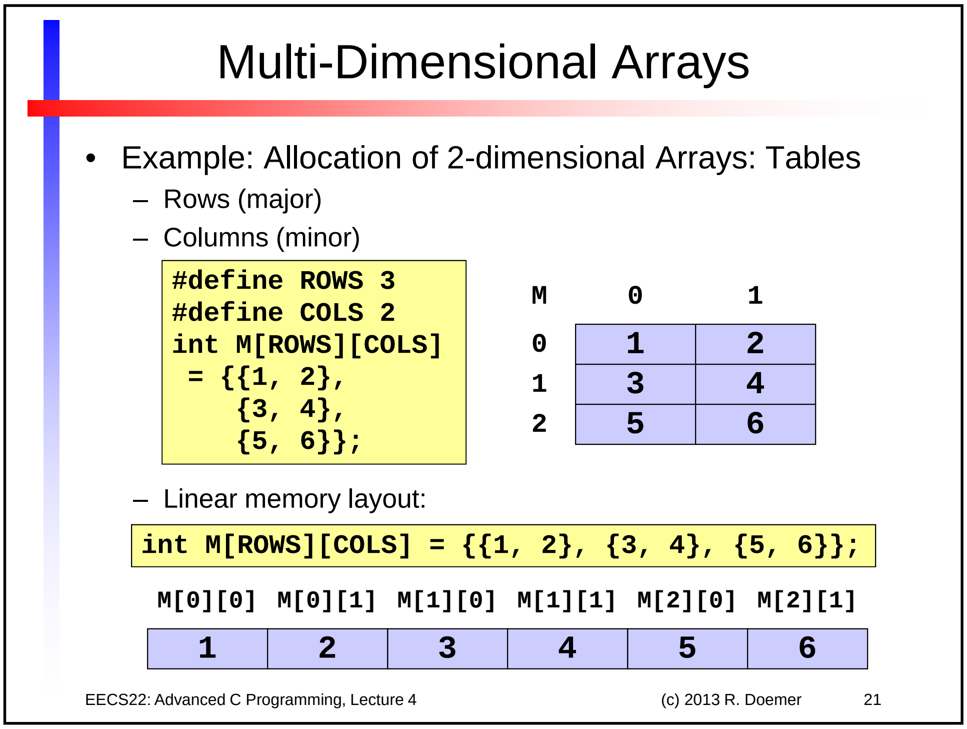
M	0	1
0	1	2
1	3	4
2	5	6

```
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
  - ▪ **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)

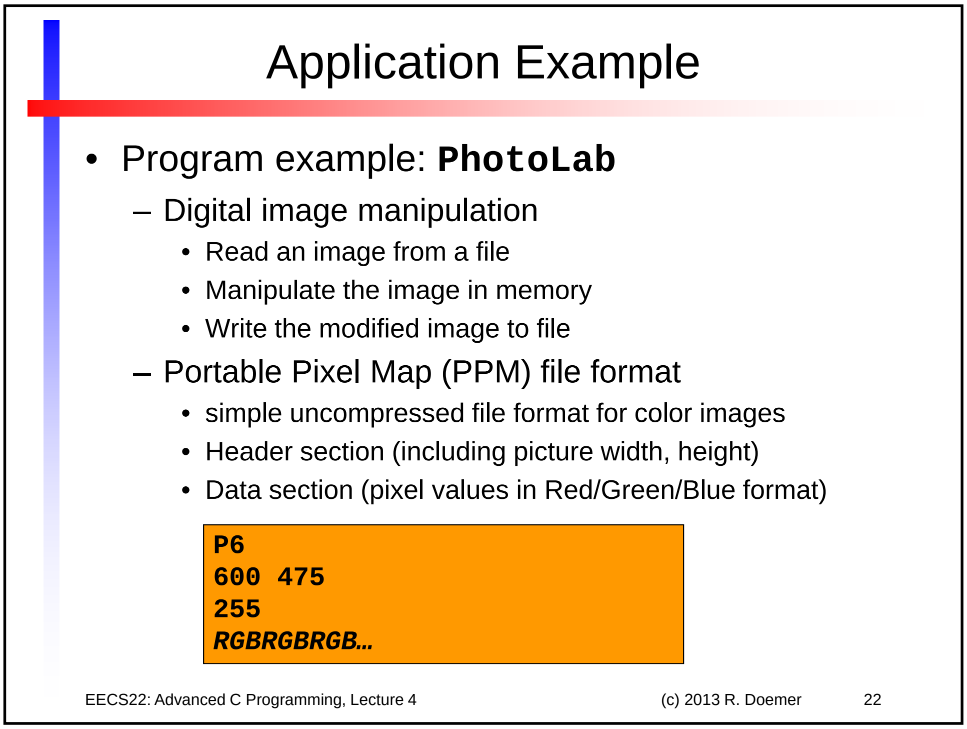
```
#define ROWS 3
#define COLS 2
int M[ROWS][COLS]
 = {{1, 2},
    {3, 4},
    {5, 6}};
```

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}};
```

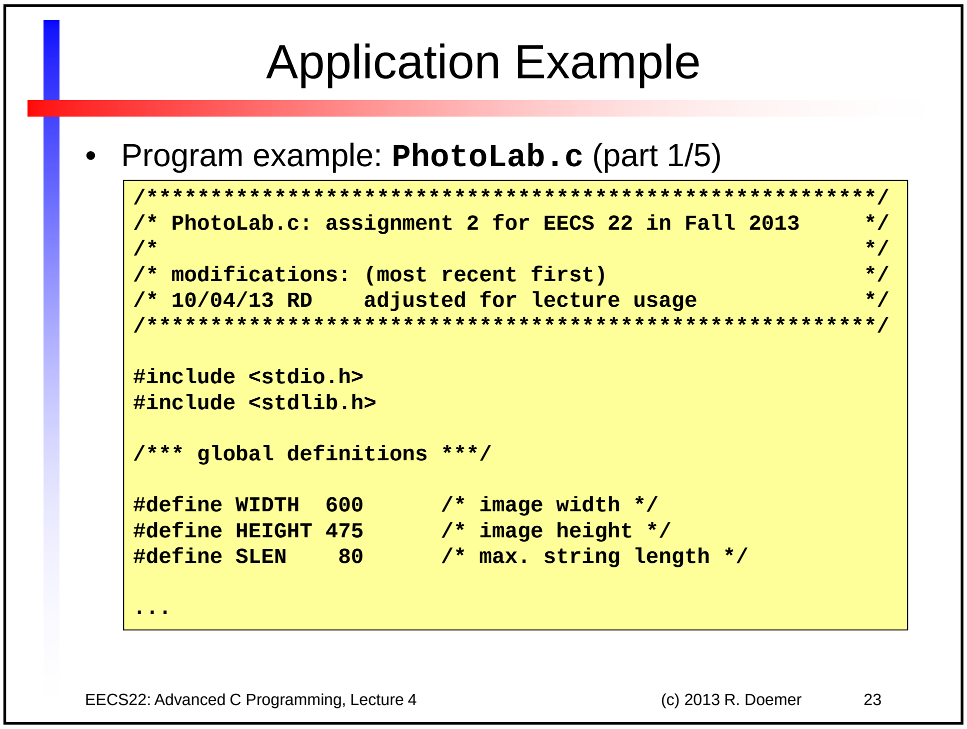
M[0][0]	M[0][1]	M[1][0]	M[1][1]	M[2][0]	M[2][1]
1	2	3	4	5	6



Application Example

- Program example: **PhotoLab**
  - Digital image manipulation
    - Read an image from a file
    - Manipulate the image in memory
    - Write the modified image to file
  - Portable Pixel Map (PPM) file format
    - simple uncompressed file format for color images
    - Header section (including picture width, height)
    - Data section (pixel values in Red/Green/Blue format)

```
P6
600 475
255
RGBRGBRGB…
```



Application Example

- Program example: **PhotoLab.c** (part 1/5)

```
/*********************************************************/
/* PhotoLab.c: assignment 2 for EECS 22 in Fall 2013     */
/*                                                       */
/* modifications: (most recent first)                    */
/* 10/04/13 RD    adjusted for lecture usage             */
/*********************************************************/

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

/*** global definitions ***/

#define WIDTH  600      /* image width */
#define HEIGHT 475      /* image height */
#define SLEN    80      /* max. string length */

...
```

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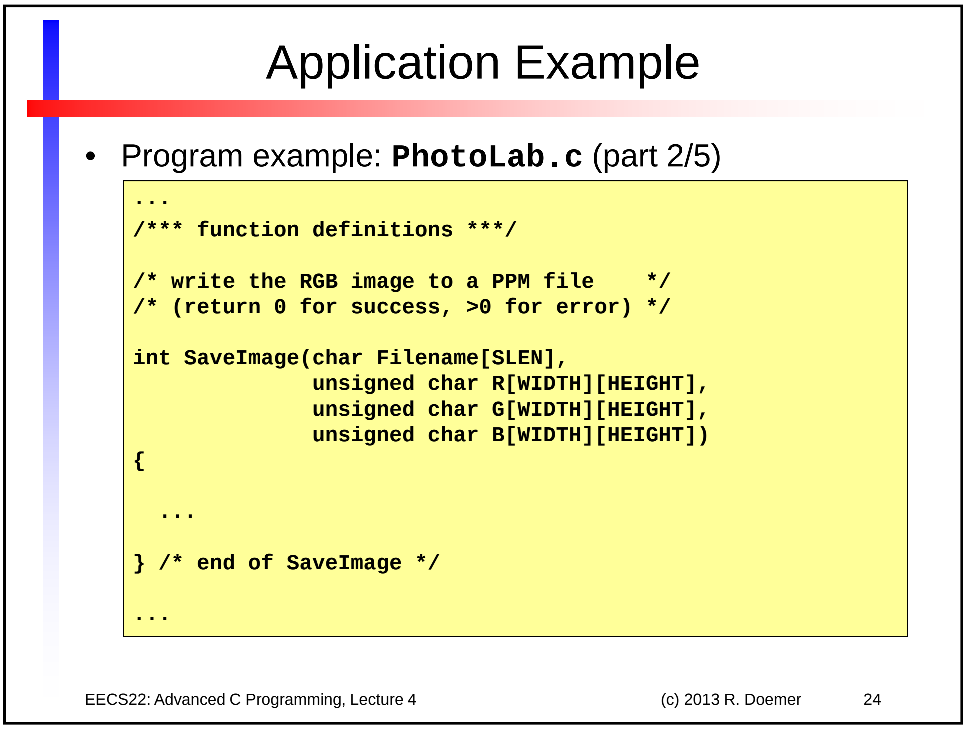

Application Example

- Program example: **PhotoLab.c** (part 2/5)

```
...
/*** function definitions ***/

/* write the RGB image to a PPM file    */
/* (return 0 for success, >0 for error) */

int SaveImage(char Filename[SLEN],
              unsigned char R[WIDTH][HEIGHT],
              unsigned char G[WIDTH][HEIGHT],
              unsigned char B[WIDTH][HEIGHT])
{

  ...

} /* end of SaveImage */

...
```

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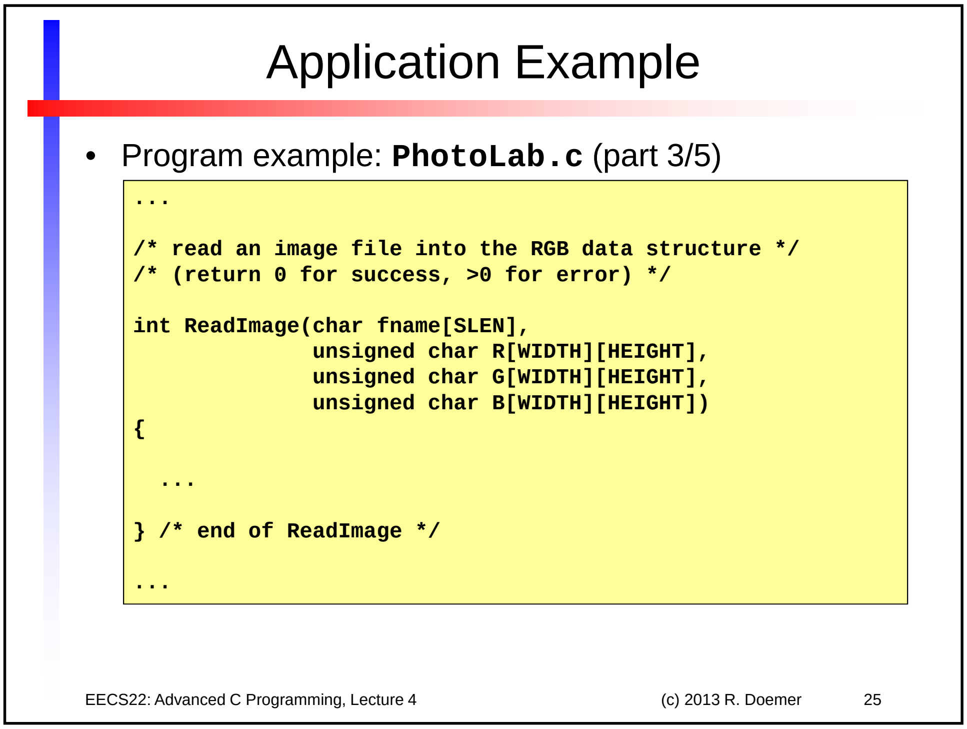
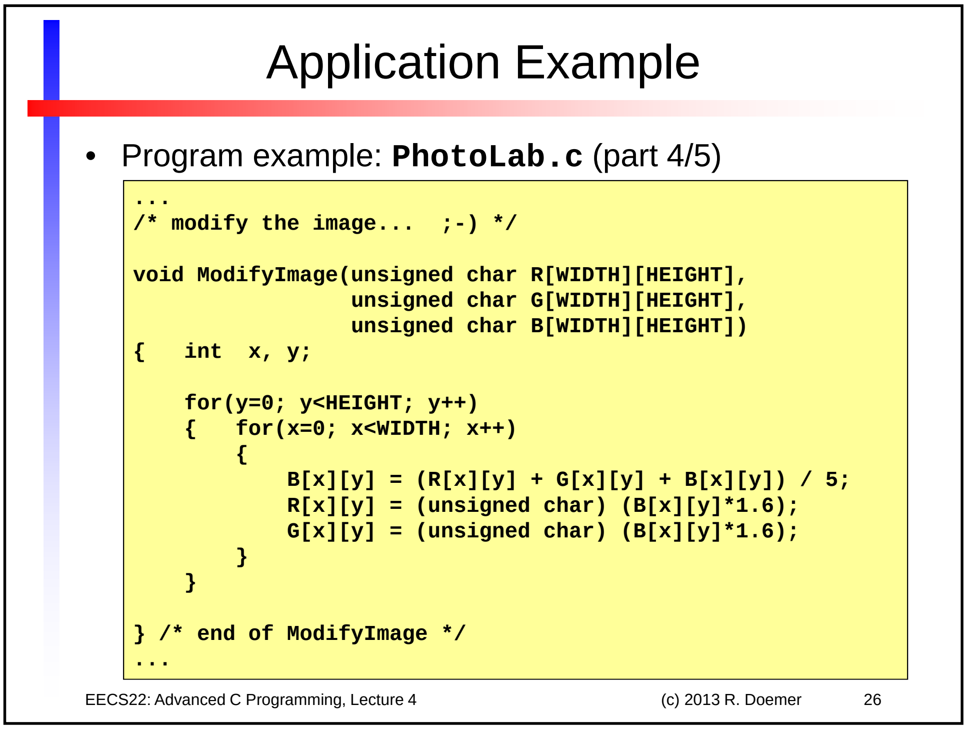


Application Example

- Program example: **`PhotoLab.c`** (part 3/5)

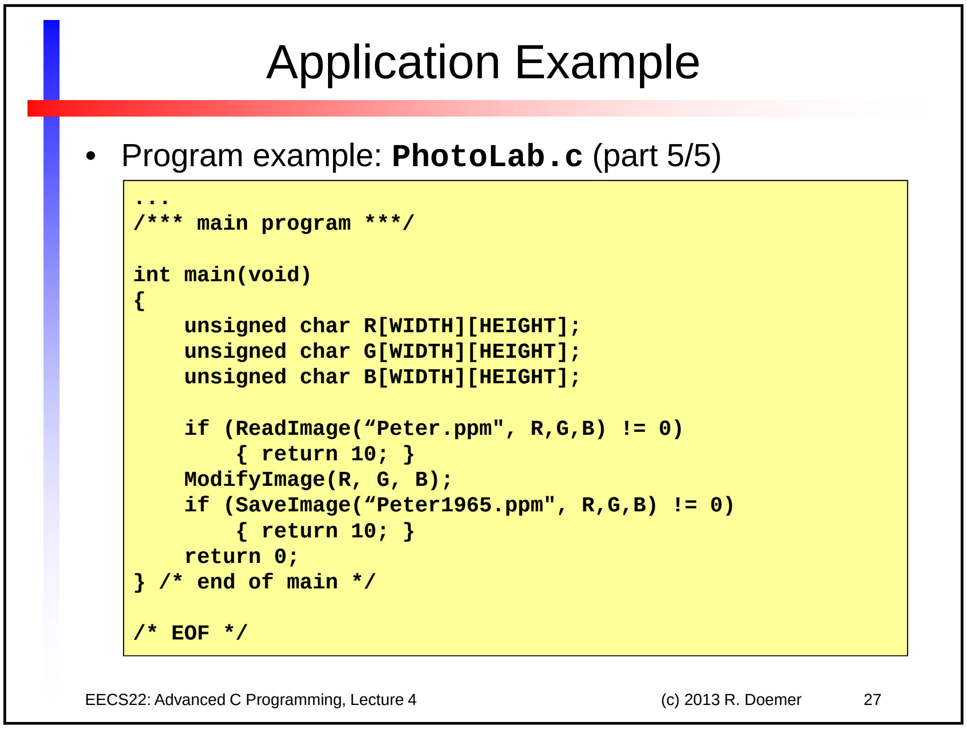
```
...

/* read an image file into the RGB data structure */
/* (return 0 for success, >0 for error) */

int ReadImage(char fname[SLEN],
              unsigned char R[WIDTH][HEIGHT],
              unsigned char G[WIDTH][HEIGHT],
              unsigned char B[WIDTH][HEIGHT])
{

  ...

} /* end of ReadImage */

...
```



Application Example

- Program example: **`PhotoLab.c`** (part 4/5)

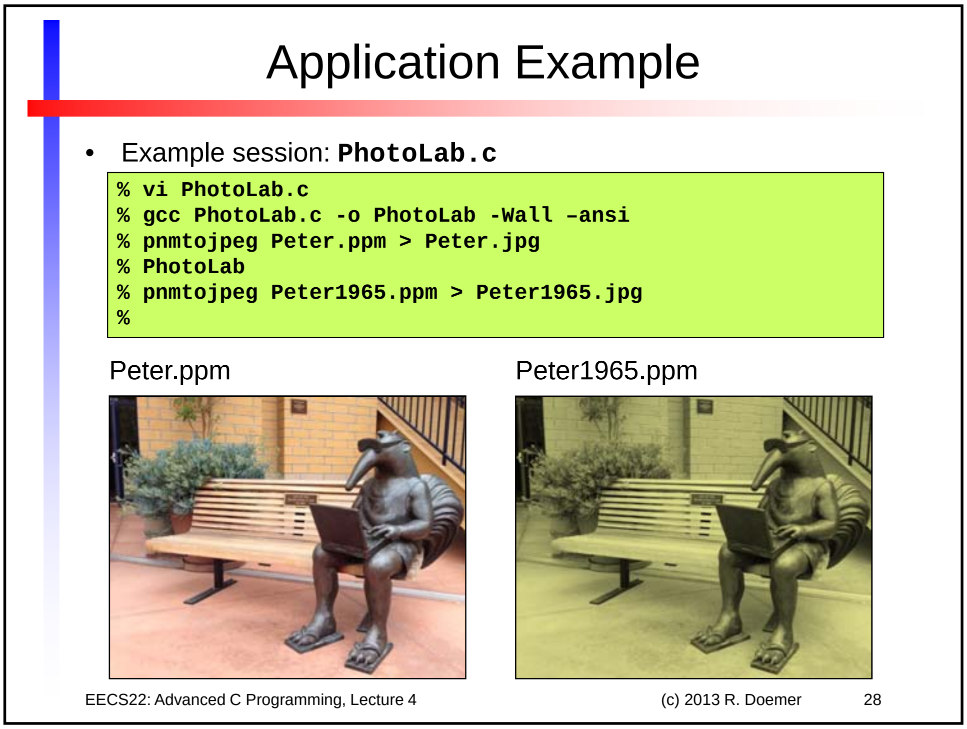
```
...
/* modify the image...  ;-) */

void ModifyImage(unsigned char R[WIDTH][HEIGHT],
                 unsigned char G[WIDTH][HEIGHT],
                 unsigned char B[WIDTH][HEIGHT])
{   int  x, y;

    for(y=0; y<HEIGHT; y++)
    {   for(x=0; x<WIDTH; x++)
        {
            B[x][y] = (R[x][y] + G[x][y] + B[x][y]) / 5;
            R[x][y] = (unsigned char) (B[x][y]*1.6);
            G[x][y] = (unsigned char) (B[x][y]*1.6);
        }
    }

} /* end of ModifyImage */
...
```



Application Example

- Program example: **PhotoLab.c** (part 5/5)

```
...
/*** main program ***/

int main(void)
{
    unsigned char R[WIDTH][HEIGHT];
    unsigned char G[WIDTH][HEIGHT];
    unsigned char B[WIDTH][HEIGHT];

    if (ReadImage(“Peter.ppm", R,G,B) != 0)
        { return 10; }
    ModifyImage(R, G, B);
    if (SaveImage(“Peter1965.ppm", R,G,B) != 0)
        { return 10; }
    return 0;
} /* end of main */

/* EOF */
```



Application Example

- Example session: **PhotoLab.c**

```
% vi PhotoLab.c
% gcc PhotoLab.c -o PhotoLab -Wall –ansi
% pnmtojpeg Peter.ppm > Peter.jpg
% PhotoLab
% pnmtojpeg Peter1965.ppm > Peter1965.jpg
%
```

Peter.ppm

Peter1965.ppm