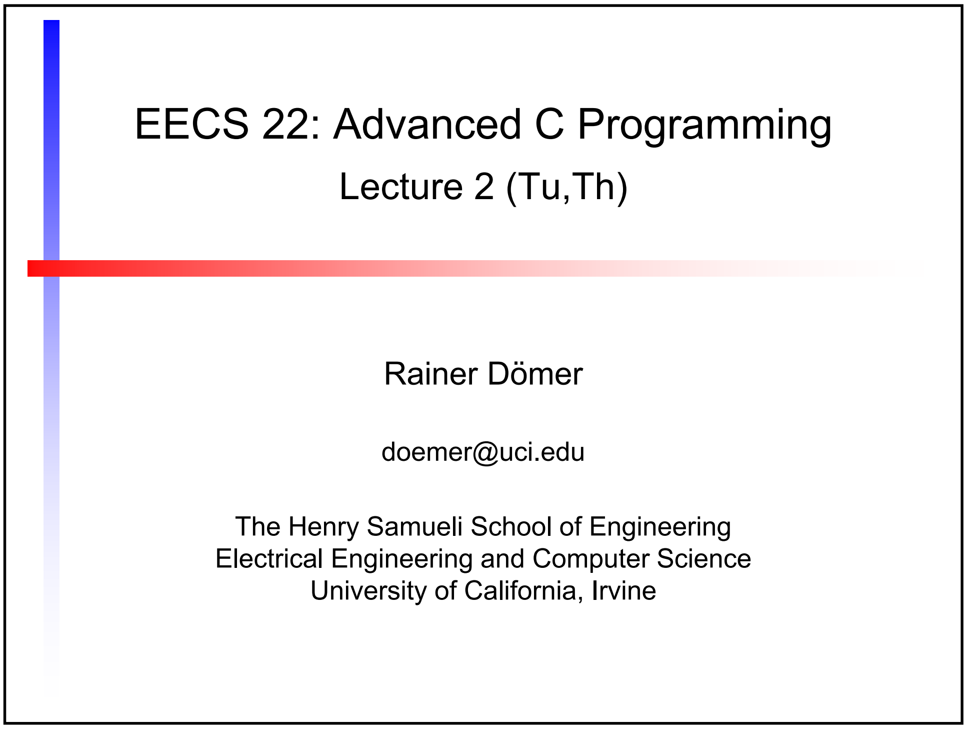

EECS 22: Advanced C Programming

Lecture 2 (Tu,Th)

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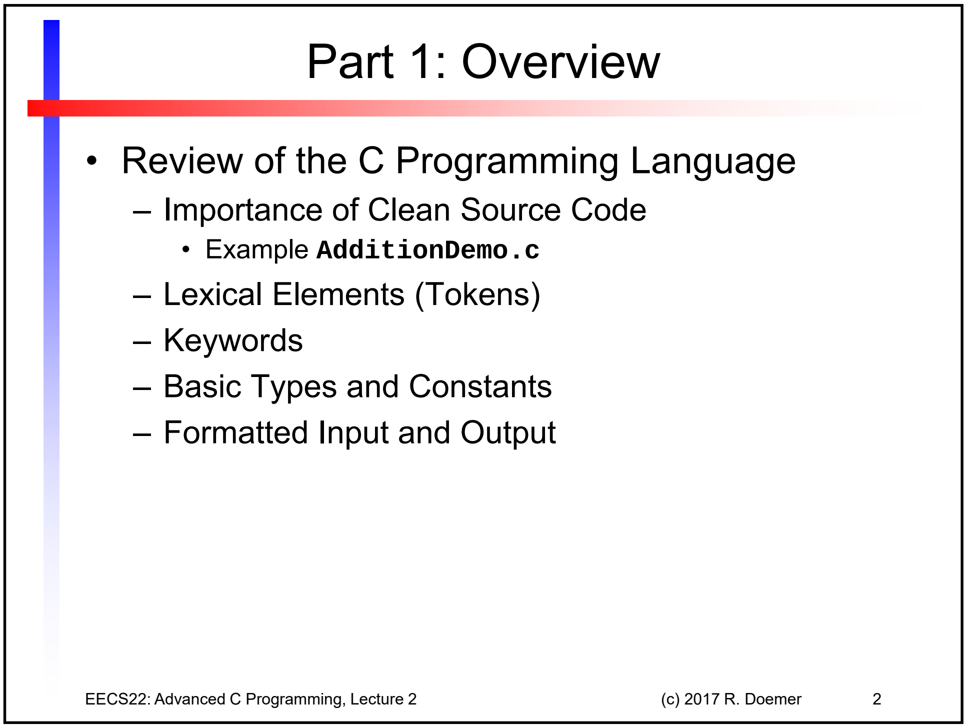
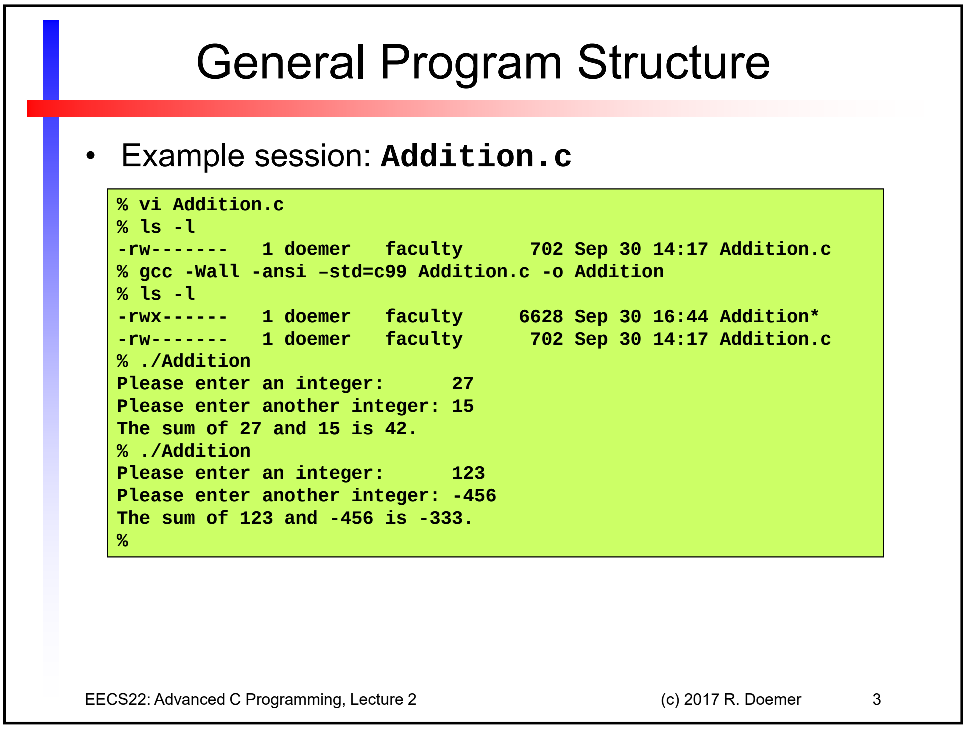


Part 1: Overview

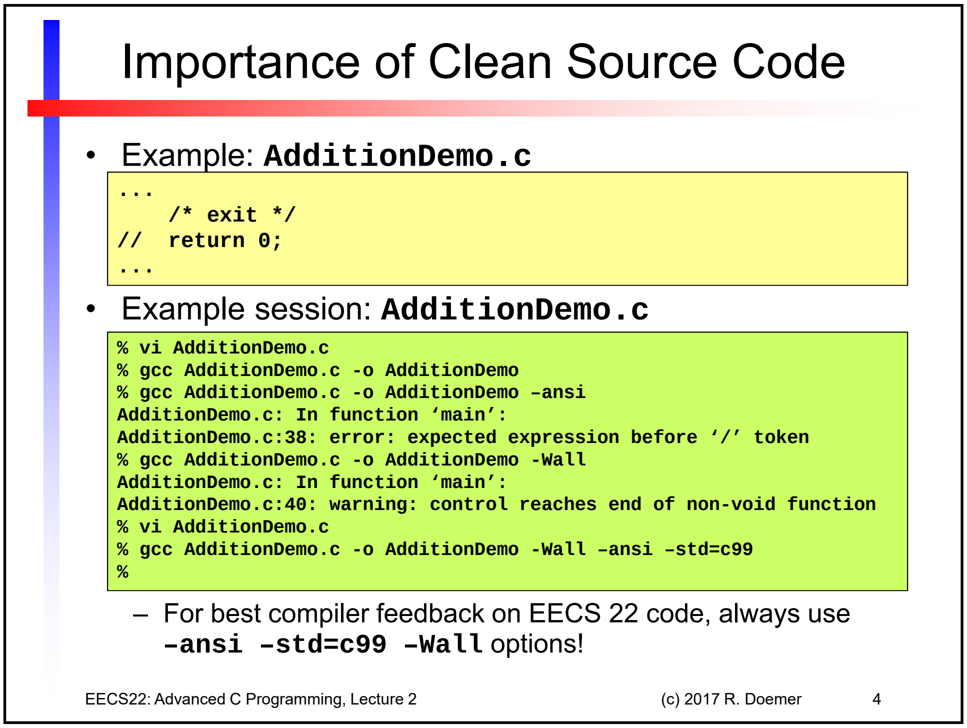
- Review of the C Programming Language
  - Importance of Clean Source Code
    - Example **`AdditionDemo.c`**
  - Lexical Elements (Tokens)
  - Keywords
  - Basic Types and Constants
  - Formatted Input and Output



General Program Structure

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

```
% vi Addition.c
% ls -l
-rw-------   1 doemer   faculty      702 Sep 30 14:17 Addition.c
% gcc -Wall -ansi –std=c99 Addition.c -o Addition
% ls -l
-rwx------   1 doemer   faculty     6628 Sep 30 16:44 Addition*
-rw-------   1 doemer   faculty      702 Sep 30 14:17 Addition.c
% ./Addition
Please enter an integer:      27
Please enter another integer: 15
The sum of 27 and 15 is 42.
% ./Addition
Please enter an integer:      123
Please enter another integer: -456
The sum of 123 and -456 is -333.
%
```



Importance of Clean Source Code

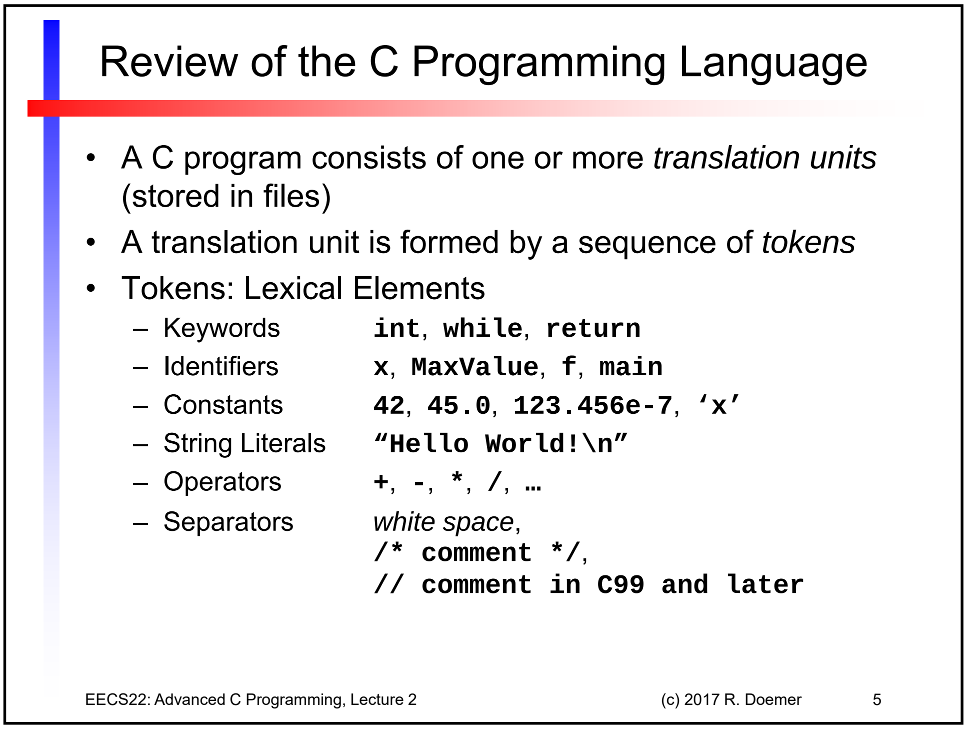
- Example: **`AdditionDemo.c`**

```
...
    /* exit */
//  return 0;
...
```

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

```
% vi AdditionDemo.c
% gcc AdditionDemo.c -o AdditionDemo
% gcc AdditionDemo.c -o AdditionDemo –ansi
AdditionDemo.c: In function ‘main’:
AdditionDemo.c:38: error: expected expression before ‘/’ token
% gcc AdditionDemo.c -o AdditionDemo -Wall
AdditionDemo.c: In function ‘main’:
AdditionDemo.c:40: warning: control reaches end of non-void function
% vi AdditionDemo.c
% gcc AdditionDemo.c -o AdditionDemo -Wall –ansi –std=c99
%
```

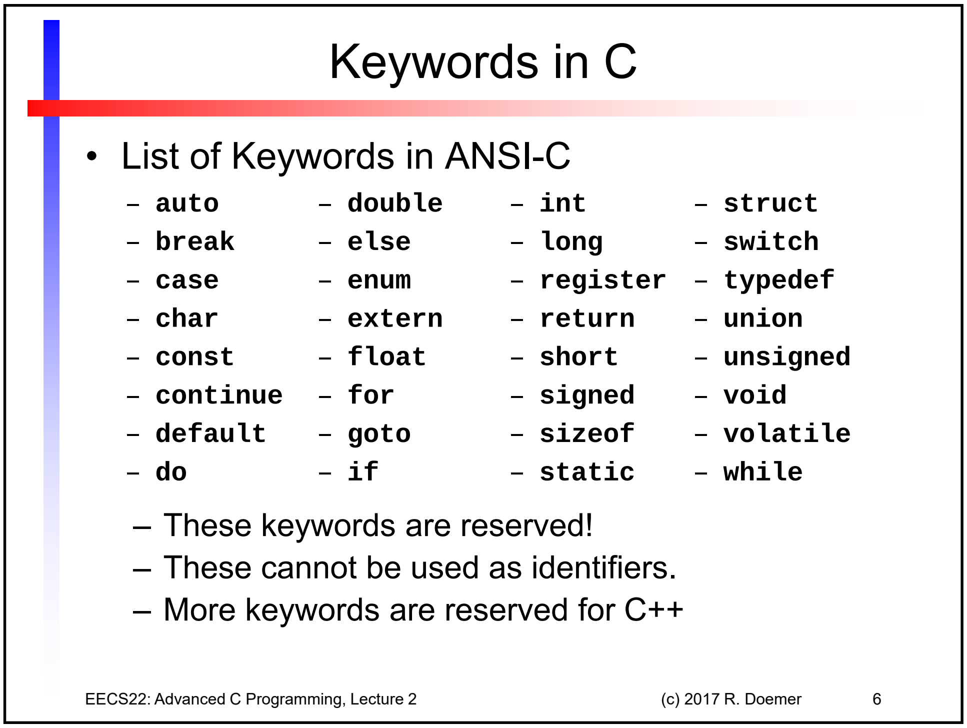
  - For best compiler feedback on EECS 22 code, always use **`–ansi –std=c99 –Wall`** options!



Review of the C Programming Language

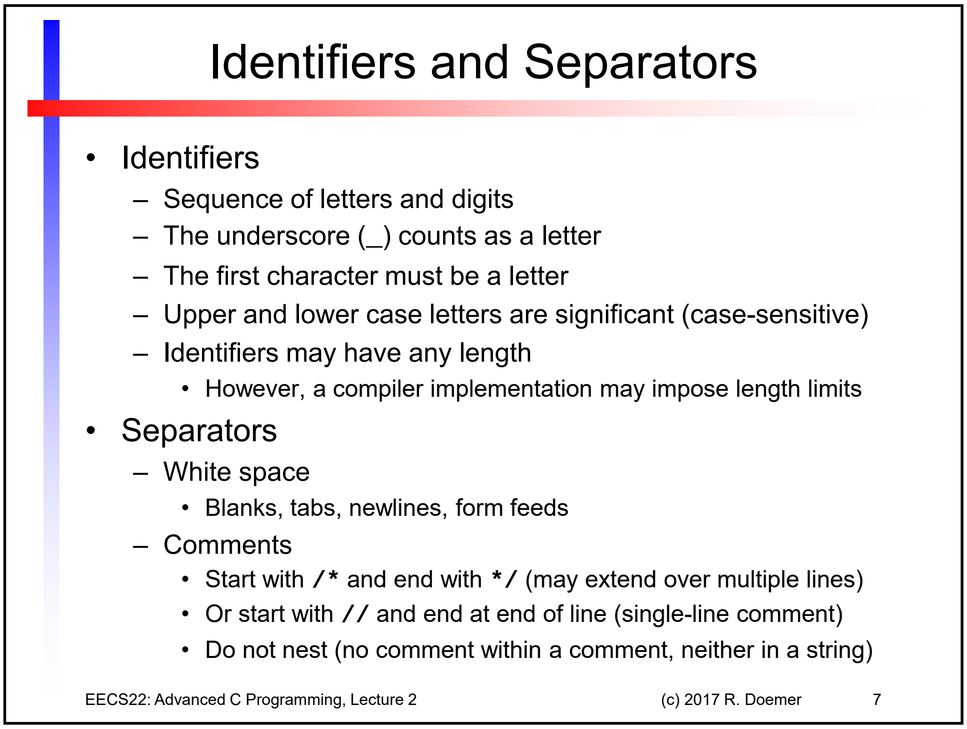
- A C program consists of one or more *translation units* (stored in files)
- A translation unit is formed by a sequence of *tokens*
- Tokens: Lexical Elements

– Keywords	**`int`**, **`while`**, **`return`**
– Identifiers	**`x`**, **`MaxValue`**, **`f`**, **`main`**
– Constants	**`42`**, **`45.0`**, **`123.456e-7`**, **`‘x’`**
– String Literals	**`“Hello World!\n”`**
– Operators	**`+`**, **`-`**, **`*`**, **`/`**, **…**
– Separators	*white space*, **`/* comment */`**, **`// comment in C99 and later`**



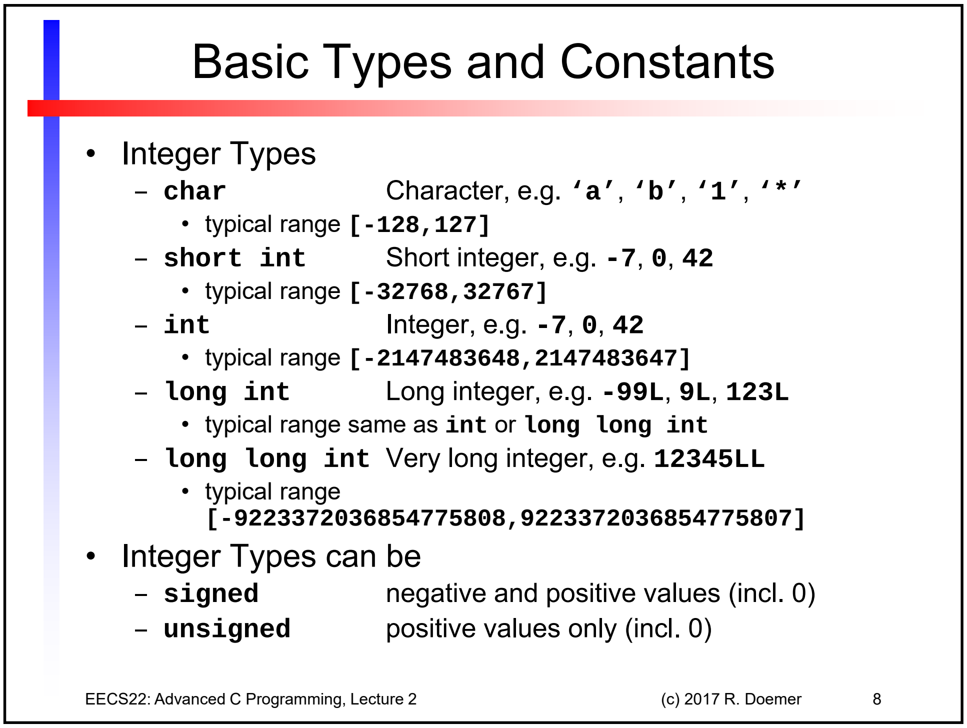
Keywords in C

- List of Keywords in ANSI-C
  - **`auto`**
  - **`break`**
  - **`case`**
  - **`char`**
  - **`const`**
  - **`continue`**
  - **`default`**
  - **`do`**
  - **`double`**
  - **`else`**
  - **`enum`**
  - **`extern`**
  - **`float`**
  - **`for`**
  - **`goto`**
  - **`if`**
  - **`int`**
  - **`long`**
  - **`register`**
  - **`return`**
  - **`short`**
  - **`signed`**
  - **`sizeof`**
  - **`static`**
  - **`struct`**
  - **`switch`**
  - **`typedef`**
  - **`union`**
  - **`unsigned`**
  - **`void`**
  - **`volatile`**
  - **`while`**
  - These keywords are reserved!
  - These cannot be used as identifiers.
  - More keywords are reserved for C++



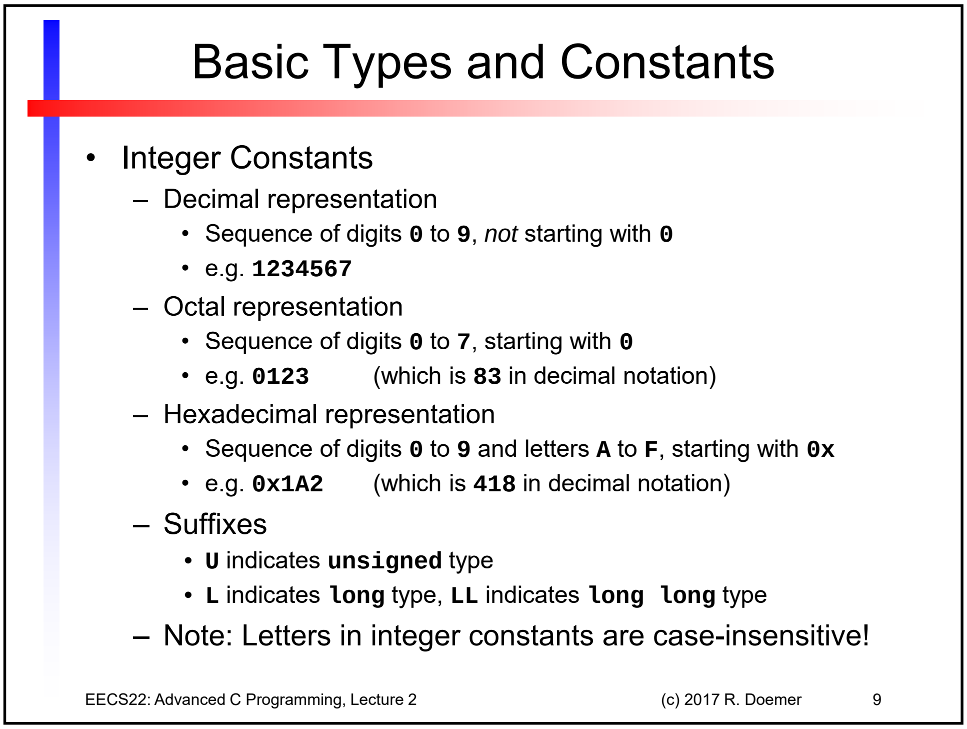
Identifiers and Separators

- Identifiers
  - Sequence of letters and digits
  - The underscore (_) counts as a letter
  - The first character must be a letter
  - Upper and lower case letters are significant (case-sensitive)
  - Identifiers may have any length
    - However, a compiler implementation may impose length limits
- Separators
  - White space
    - Blanks, tabs, newlines, form feeds
  - Comments
    - Start with `/*` and end with `*/` (may extend over multiple lines)
    - Or start with `//` and end at end of line (single-line comment)
    - Do not nest (no comment within a comment, neither in a string)



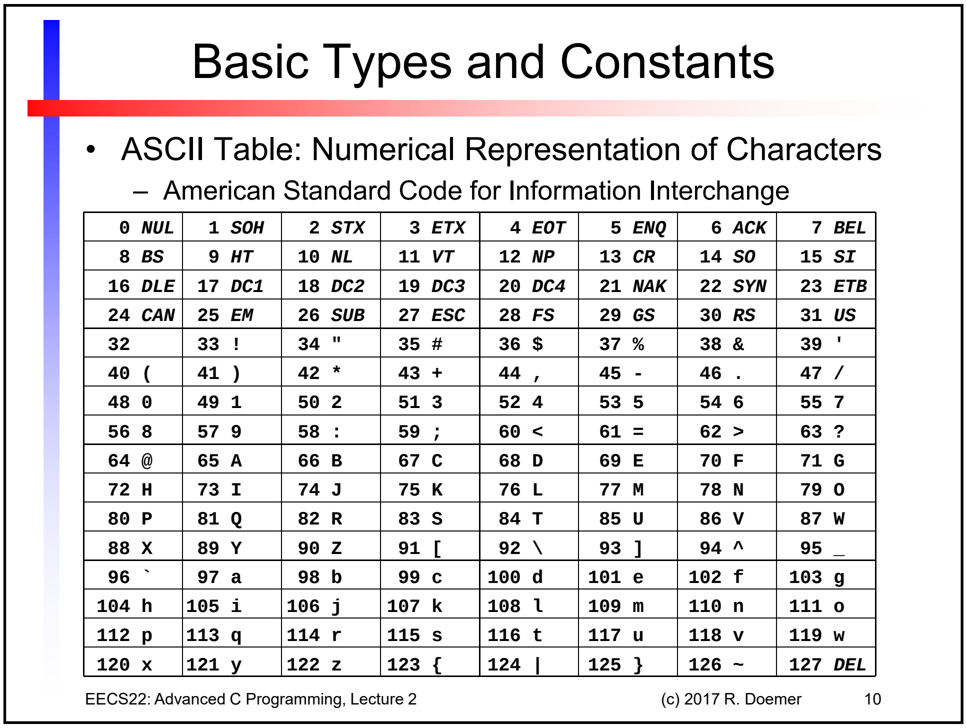
Basic Types and Constants

- Integer Types
  - **`char`** Character, e.g. **`‘a’`**, **`‘b’`**, **`‘1’`**, **`‘*’`**
    - typical range **`[-128,127]`**
  - **`short int`** Short integer, e.g. **`-7`**, **`0`**, **`42`**
    - typical range **`[-32768,32767]`**
  - **`int`** Integer, e.g. **`-7`**, **`0`**, **`42`**
    - typical range **`[-2147483648,2147483647]`**
  - **`long int`** Long integer, e.g. **`-99L`**, **`9L`**, **`123L`**
    - typical range same as **`int`** or **`long long int`**
  - **`long long int`** Very long integer, e.g. **`12345LL`**
    - typical range **`[-9223372036854775808,9223372036854775807]`**
- Integer Types can be
  - **`signed`** negative and positive values (incl. 0)
  - **`unsigned`** positive values only (incl. 0)



Basic Types and Constants

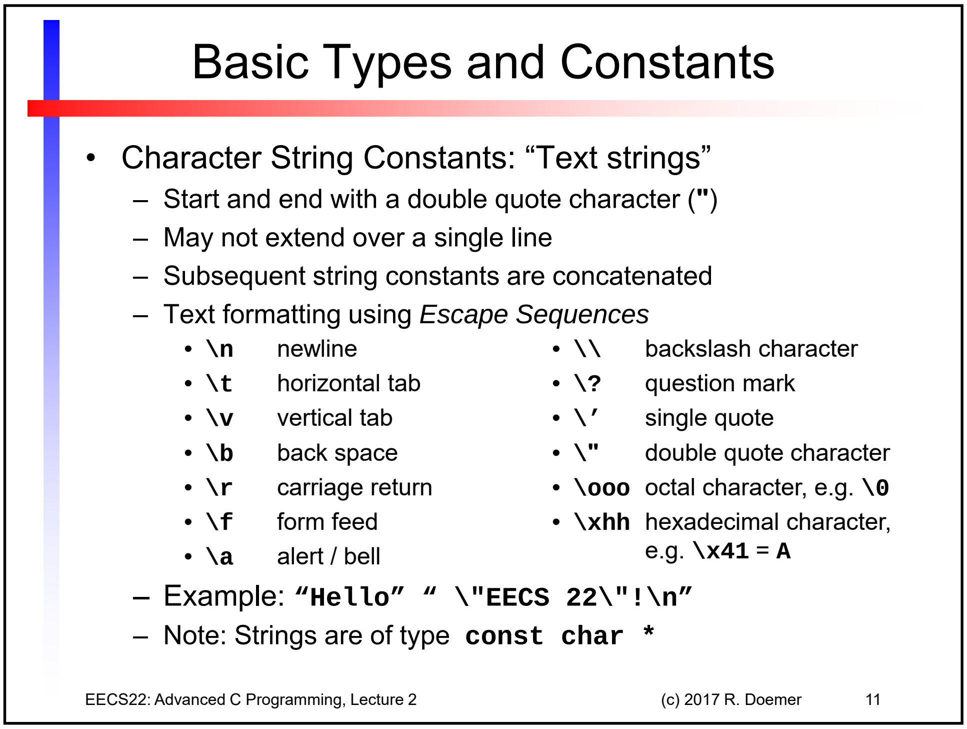
- Integer Constants
  - Decimal representation
    - Sequence of digits **`0`** to **`9`**, *not* starting with **`0`**
    - e.g. **`1234567`**
  - Octal representation
    - Sequence of digits **`0`** to **`7`**, starting with **`0`**
    - e.g. **`0123`** (which is **`83`** in decimal notation)
  - Hexadecimal representation
    - Sequence of digits **`0`** to **`9`** and letters **`A`** to **`F`**, starting with **`0x`**
    - e.g. **`0x1A2`** (which is **`418`** in decimal notation)
  - Suffixes
    - **`U`** indicates **`unsigned`** type
    - **`L`** indicates **`long`** type, **`LL`** indicates **`long long`** type
  - Note: Letters in integer constants are case-insensitive!



Basic Types and Constants

- ASCII Table: Numerical Representation of Characters
  - American Standard Code for Information Interchange

0 *NUL*	1 *SOH*	2 *STX*	3 *ETX*	4 *EOT*	5 *ENQ*	6 *ACK*	7 *BEL*
8 *BS*	9 *HT*	10 *NL*	11 *VT*	12 *NP*	13 *CR*	14 *SO*	15 *SI*
16 *DLE*	17 *DC1*	18 *DC2*	19 *DC3*	20 *DC4*	21 *NAK*	22 *SYN*	23 *ETB*
24 *CAN*	25 *EM*	26 *SUB*	27 *ESC*	28 *FS*	29 *GS*	30 *RS*	31 *US*
32	33 !	34 "	35 #	36 $	37 %	38 &	39 '
40 (	41)	42 *	43 +	44 ,	45 -	46 .	47 /
48 0	49 1	50 2	51 3	52 4	53 5	54 6	55 7
56 8	57 9	58 :	59 ;	60 <	61 =	62 >	63 ?
64 @	65 A	66 B	67 C	68 D	69 E	70 F	71 G
72 H	73 I	74 J	75 K	76 L	77 M	78 N	79 O
80 P	81 Q	82 R	83 S	84 T	85 U	86 V	87 W
88 X	89 Y	90 Z	91 [	92 \	93]	94 ^	95 _
96 `	97 a	98 b	99 c	100 d	101 e	102 f	103 g
104 h	105 i	106 j	107 k	108 l	109 m	110 n	111 o
112 p	113 q	114 r	115 s	116 t	117 u	118 v	119 w
120 x	121 y	122 z	123 {	124 |	125 }	126 ~	127 *DEL*

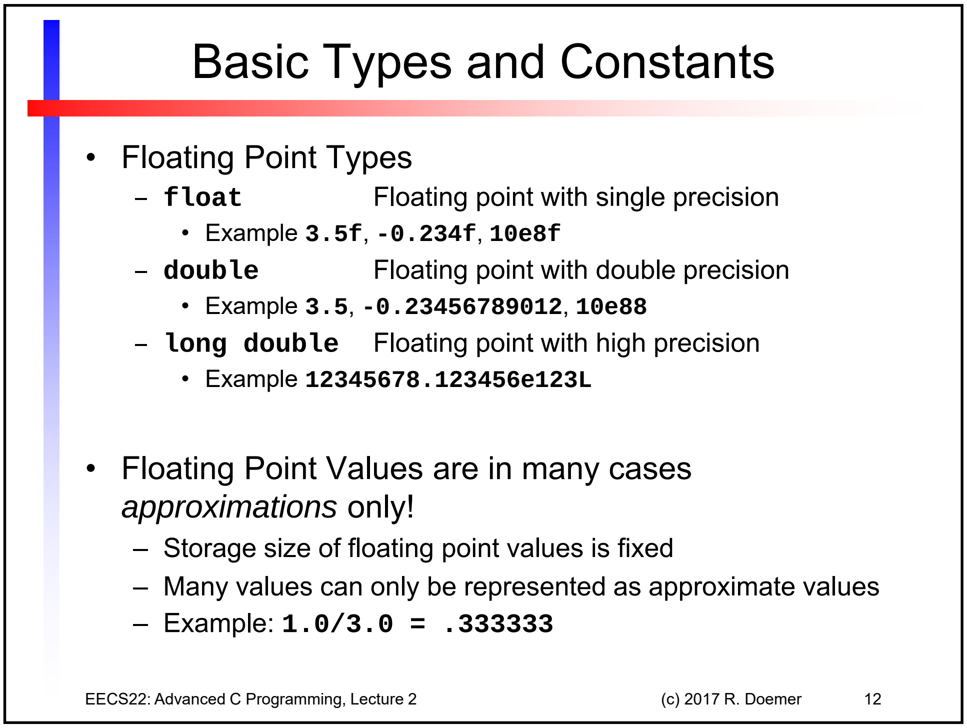


Basic Types and Constants

- Character String Constants: “Text strings”
  - Start and end with a double quote character (**"**)
  - May not extend over a single line
  - Subsequent string constants are concatenated
  - Text formatting using *Escape Sequences*

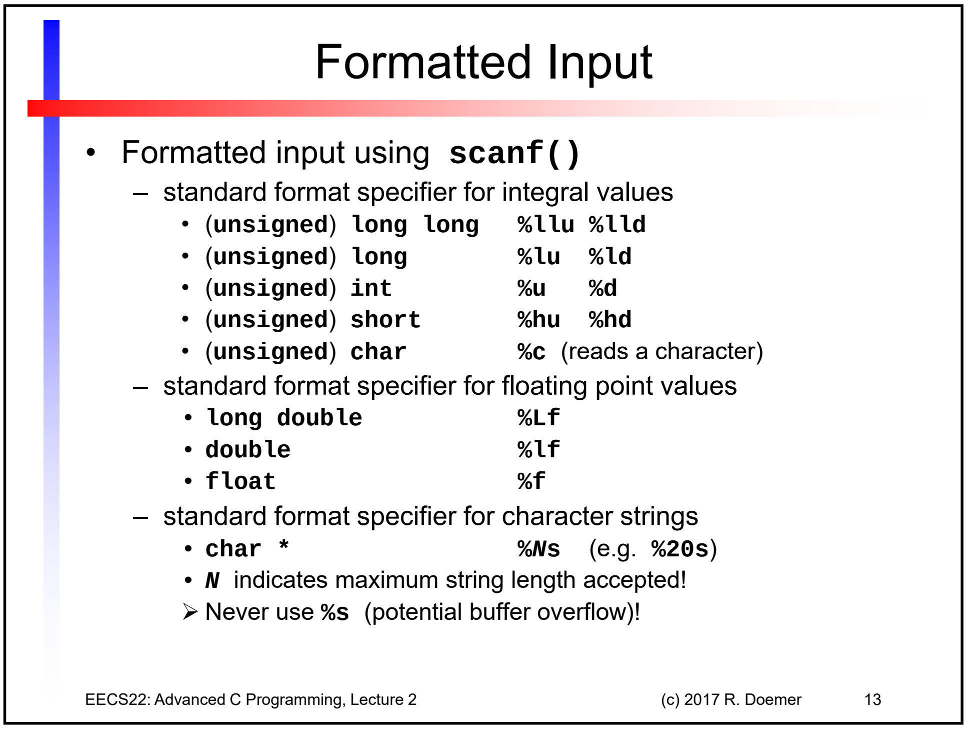
\n	newline	\\	backslash character
\t	horizontal tab	**\?**	question mark
\v	vertical tab	**\’**	single quote
\b	back space	**\"**	double quote character
\r	carriage return	**\ooo**	octal character, e.g. **\0**
\f	form feed	**\xhh**	hexadecimal character, e.g. **\x41** = **A**
\a	alert / bell		

  - Example: **“Hello” “ \"EECS 22\"!\n”**
  - Note: Strings are of type **const char ***



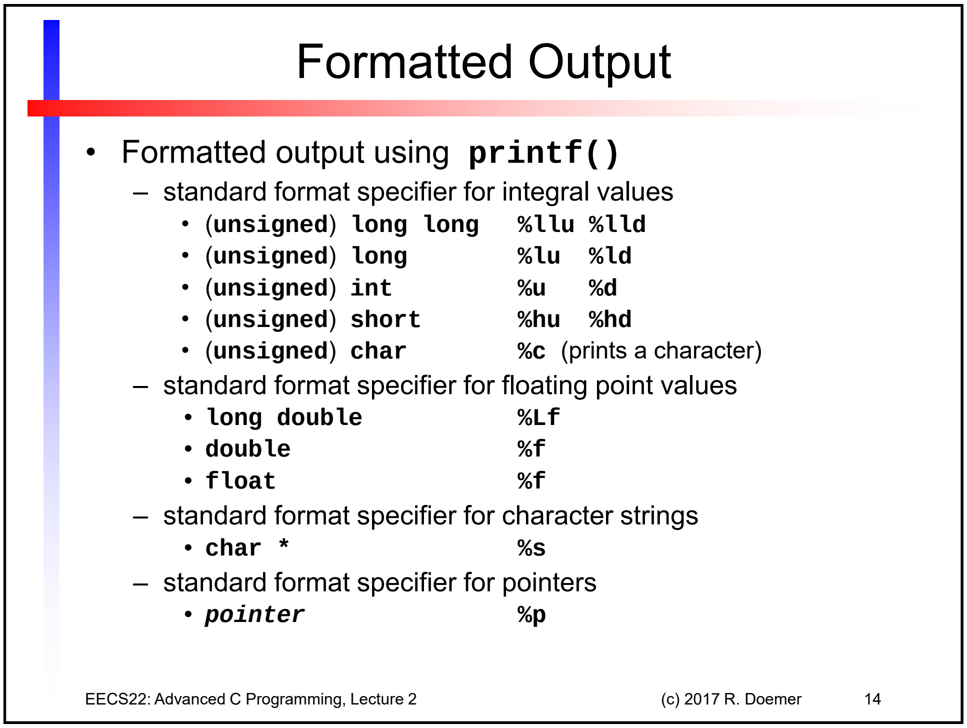
Basic Types and Constants

- Floating Point Types
  - **float** Floating point with single precision
    - Example **3.5f**, **-0.234f**, **10e8f**
  - **double** Floating point with double precision
    - Example **3.5**, **-0.23456789012**, **10e88**
  - **long double** Floating point with high precision
    - Example **12345678.123456e123L**
- Floating Point Values are in many cases *approximations* only!
  - Storage size of floating point values is fixed
  - Many values can only be represented as approximate values
  - Example: **1.0/3.0 = .333333**



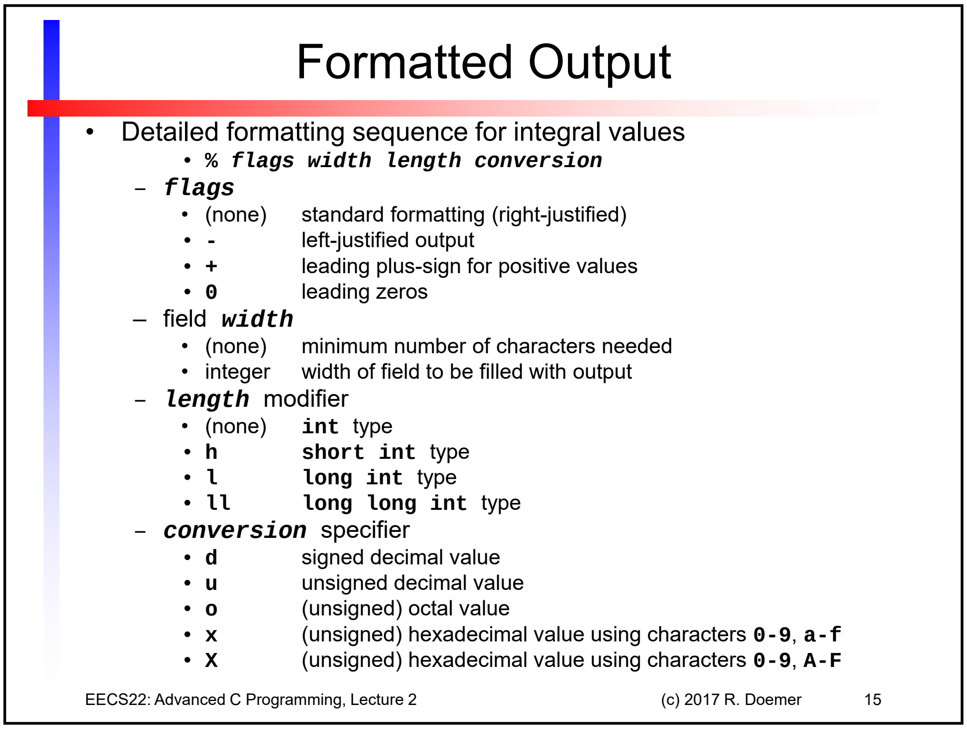
Formatted Input

- Formatted input using **`scanf()`**
  - standard format specifier for integral values
    - (**`unsigned`**) **`long long`** **`%llu %lld`**
    - (**`unsigned`**) **`long`** **`%lu %ld`**
    - (**`unsigned`**) **`int`** **`%u %d`**
    - (**`unsigned`**) **`short`** **`%hu %hd`**
    - (**`unsigned`**) **`char`** **`%c`** (reads a character)
  - standard format specifier for floating point values
    - **`long double`** **`%Lf`**
    - **`double`** **`%lf`**
    - **`float`** **`%f`**
  - standard format specifier for character strings
    - **`char *`** **`%`*`N`*`s`** (e.g. **`%20s`**)
    - ***`N`*** indicates maximum string length accepted!
    - ➢ Never use **`%s`** (potential buffer overflow)!



Formatted Output

- Formatted output using **`printf()`**
  - standard format specifier for integral values
    - (**`unsigned`**) **`long long`** **`%llu %lld`**
    - (**`unsigned`**) **`long`** **`%lu %ld`**
    - (**`unsigned`**) **`int`** **`%u %d`**
    - (**`unsigned`**) **`short`** **`%hu %hd`**
    - (**`unsigned`**) **`char`** **`%c`** (prints a character)
  - standard format specifier for floating point values
    - **`long double`** **`%Lf`**
    - **`double`** **`%f`**
    - **`float`** **`%f`**
  - standard format specifier for character strings
    - **`char *`** **`%s`**
  - standard format specifier for pointers
    - ***`pointer`*** **`%p`**



Formatted Output

- Detailed formatting sequence for integral values
  - `% flags width length conversion`
  - ***flags***
    - (none) standard formatting (right-justified)
    - **`-`** left-justified output
    - **`+`** leading plus-sign for positive values
    - **`0`** leading zeros
  - field ***width***
    - (none) minimum number of characters needed
    - integer width of field to be filled with output
  - ***length*** modifier
    - (none) **`int`** type
    - **`h`** **`short int`** type
    - **`l`** **`long int`** type
    - **`ll`** **`long long int`** type
  - ***conversion*** specifier
    - **`d`** signed decimal value
    - **`u`** unsigned decimal value
    - **`o`** (unsigned) octal value
    - **`x`** (unsigned) hexadecimal value using characters **`0-9`**, **`a-f`**
    - **`X`** (unsigned) hexadecimal value using characters **`0-9`**, **`A-F`**

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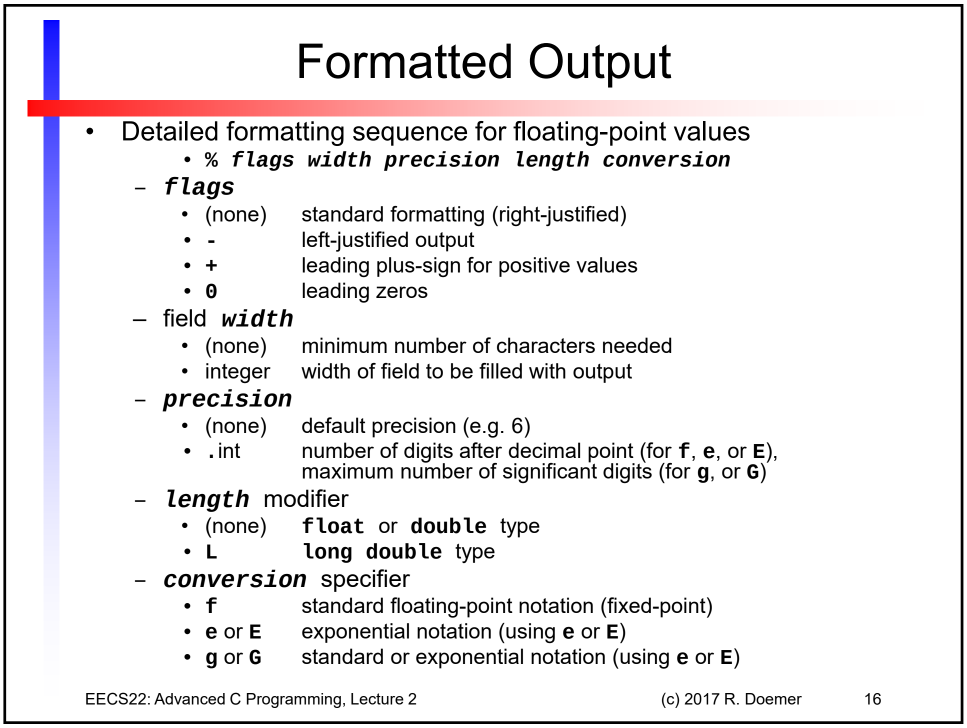

Formatted Output

- Detailed formatting sequence for floating-point values
  - `% flags width precision length conversion`
  - ***flags***
    - (none) standard formatting (right-justified)
    - **`-`** left-justified output
    - **`+`** leading plus-sign for positive values
    - **`0`** leading zeros
  - field ***width***
    - (none) minimum number of characters needed
    - integer width of field to be filled with output
  - ***precision***
    - (none) default precision (e.g. 6)
    - `.`int number of digits after decimal point (for **`f`**, **`e`**, or **`E`**), maximum number of significant digits (for **`g`**, or **`G`**)
  - ***length*** modifier
    - (none) **`float`** or **`double`** type
    - **`L`** **`long double`** type
  - ***conversion*** specifier
    - **`f`** standard floating-point notation (fixed-point)
    - **`e`** or **`E`** exponential notation (using **`e`** or **`E`**)
    - **`g`** or **`G`** standard or exponential notation (using **`e`** or **`E`**)

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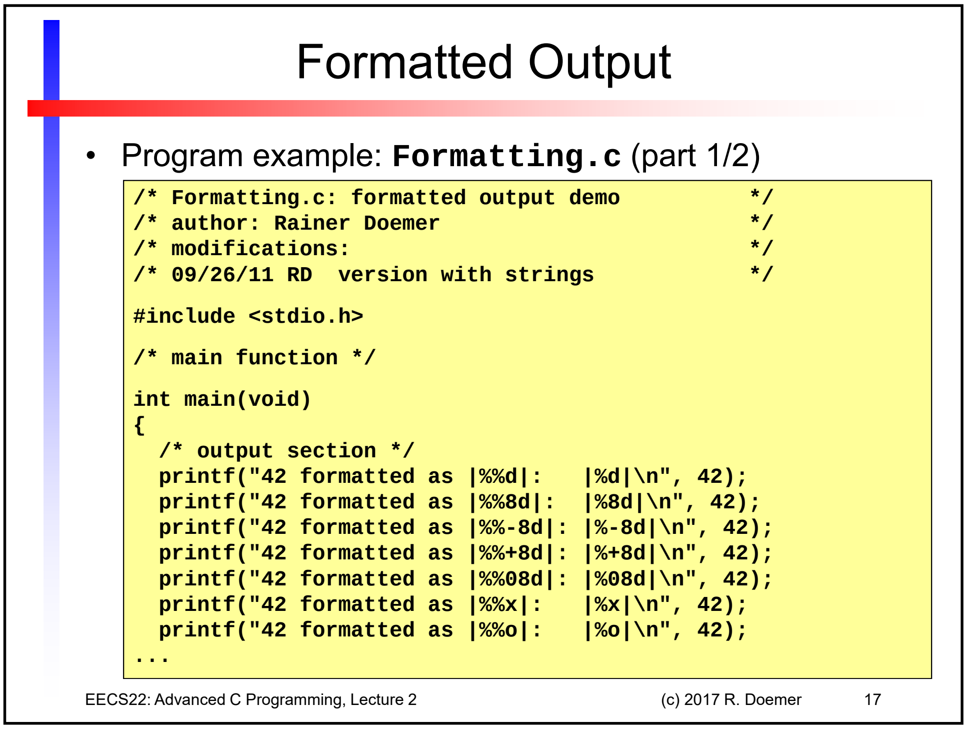

Formatted Output

- Program example: **`Formatting.c`** (part 1/2)

```
/* Formatting.c: formatted output demo          */
/* author: Rainer Doemer                        */
/* modifications:                               */
/* 09/26/11 RD  version with strings            */

#include <stdio.h>

/* main function */

int main(void)
{
  /* output section */
  printf("42 formatted as |%%d|:   |%d|\n", 42);
  printf("42 formatted as |%%8d|:  |%8d|\n", 42);
  printf("42 formatted as |%%-8d|: |%-8d|\n", 42);
  printf("42 formatted as |%%+8d|: |%+8d|\n", 42);
  printf("42 formatted as |%%08d|: |%08d|\n", 42);
  printf("42 formatted as |%%x|:   |%x|\n", 42);
  printf("42 formatted as |%%o|:   |%o|\n", 42);
...
```

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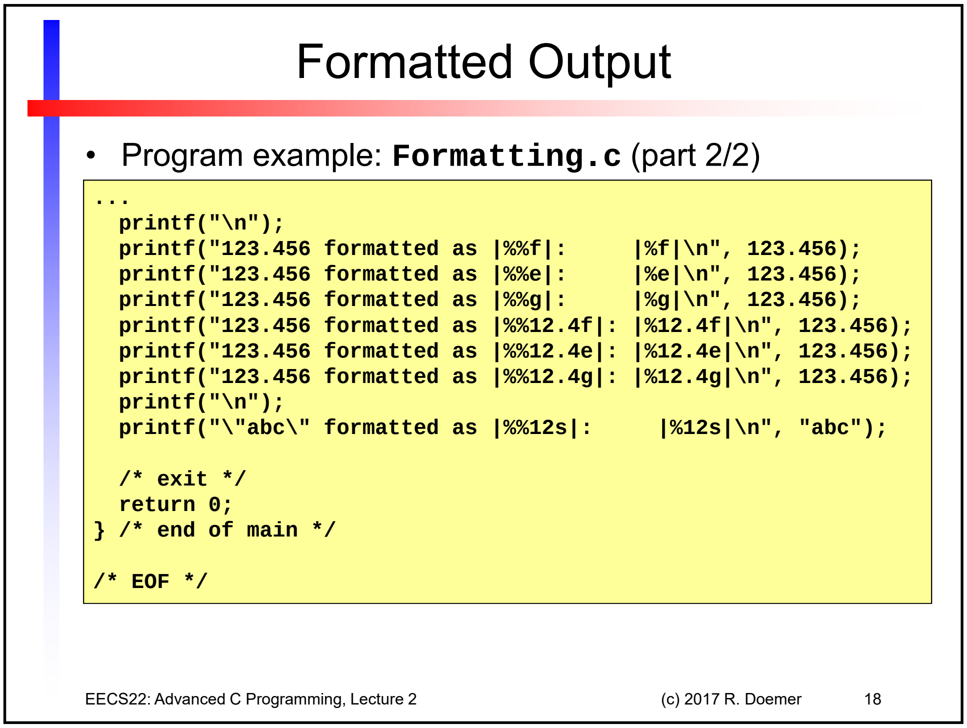

Formatted Output

- Program example: **`Formatting.c`** (part 2/2)

```
...
  printf("\n");
  printf("123.456 formatted as |%%f|:     |%f|\n", 123.456);
  printf("123.456 formatted as |%%e|:     |%e|\n", 123.456);
  printf("123.456 formatted as |%%g|:     |%g|\n", 123.456);
  printf("123.456 formatted as |%%12.4f|: |%12.4f|\n", 123.456);
  printf("123.456 formatted as |%%12.4e|: |%12.4e|\n", 123.456);
  printf("123.456 formatted as |%%12.4g|: |%12.4g|\n", 123.456);
  printf("\n");
  printf("\"abc\" formatted as |%%12s|:     |%12s|\n", "abc");

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

/* EOF */
```

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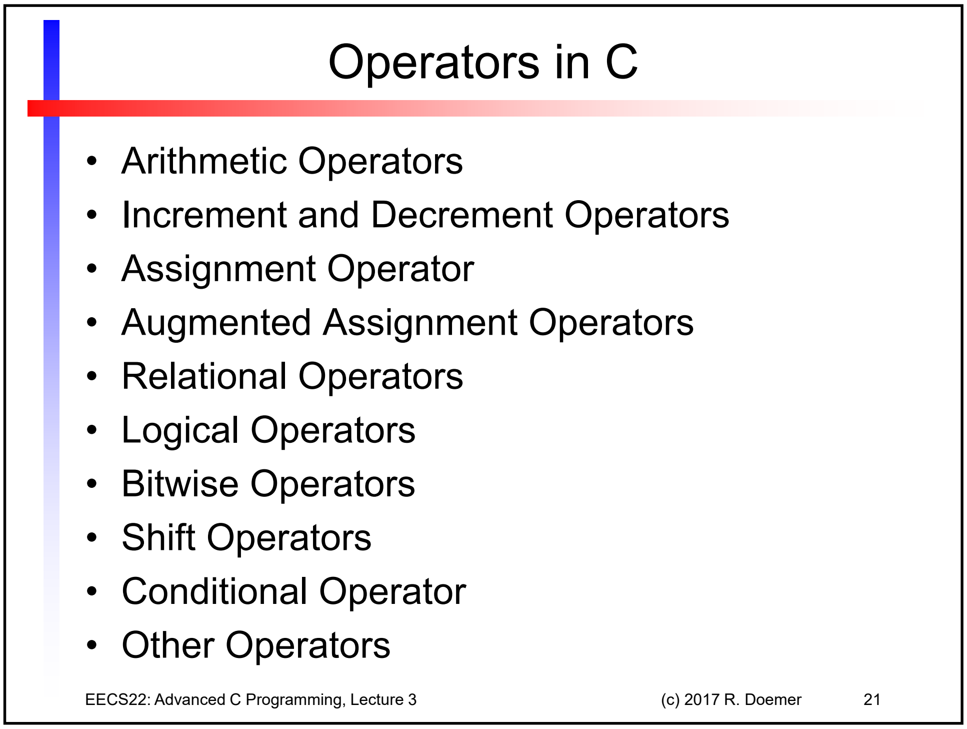
Formatted Output

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

```
% vi Formatting.c
% gcc Formatting.c -o Formatting -Wall –ansi –std=c99
% ./Formatting
42 formatted as |%d|:   |42|
42 formatted as |%8d|:  |      42|
42 formatted as |%-8d|: |42      |
42 formatted as |%+8d|: |     +42|
42 formatted as |%08d|: |00000042|
42 formatted as |%x|:   |2a|
42 formatted as |%o|:   |52|

123.456 formatted as |%f|:     |123.456000|
123.456 formatted as |%e|:     |1.234560e+02|
123.456 formatted as |%g|:     |123.456|
123.456 formatted as |%12.4f|: |    123.4560|
123.456 formatted as |%12.4e|: |  1.2346e+02|
123.456 formatted as |%12.4g|: |       123.5|

"abc" formatted as |%12s|:     |         abc|
%
```

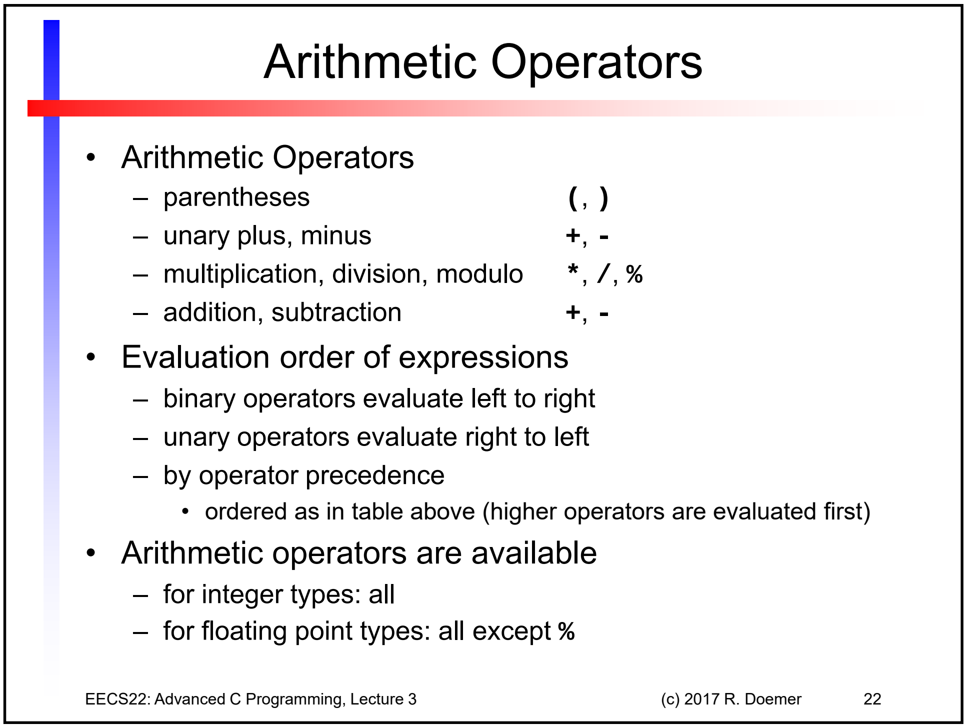
Part 2: Overview

- Review of the C Programming Language
  - Operators and Expressions
    - Arithmetic, Increment, Decrement, Assignment
    - Relational, Logical, Bitwise, Shift, Conditional
    - Others
  - Operator Precedence and Associativity



Operators in C

- Arithmetic Operators
- Increment and Decrement Operators
- Assignment Operator
- Augmented Assignment Operators
- Relational Operators
- Logical Operators
- Bitwise Operators
- Shift Operators
- Conditional Operator
- Other Operators

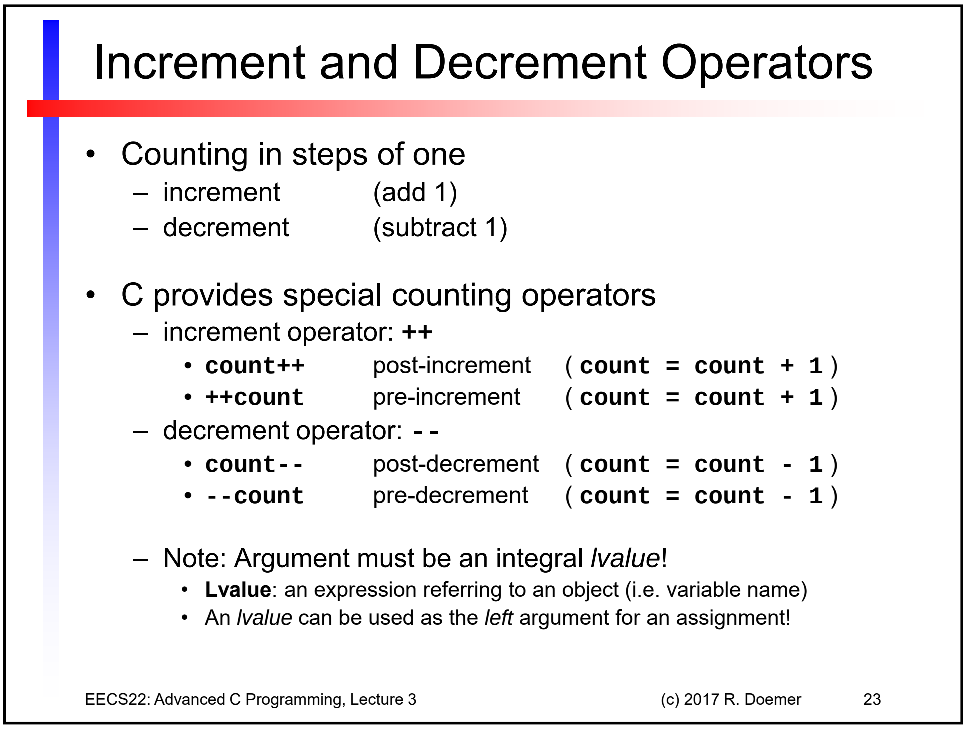


Arithmetic Operators

- Arithmetic Operators

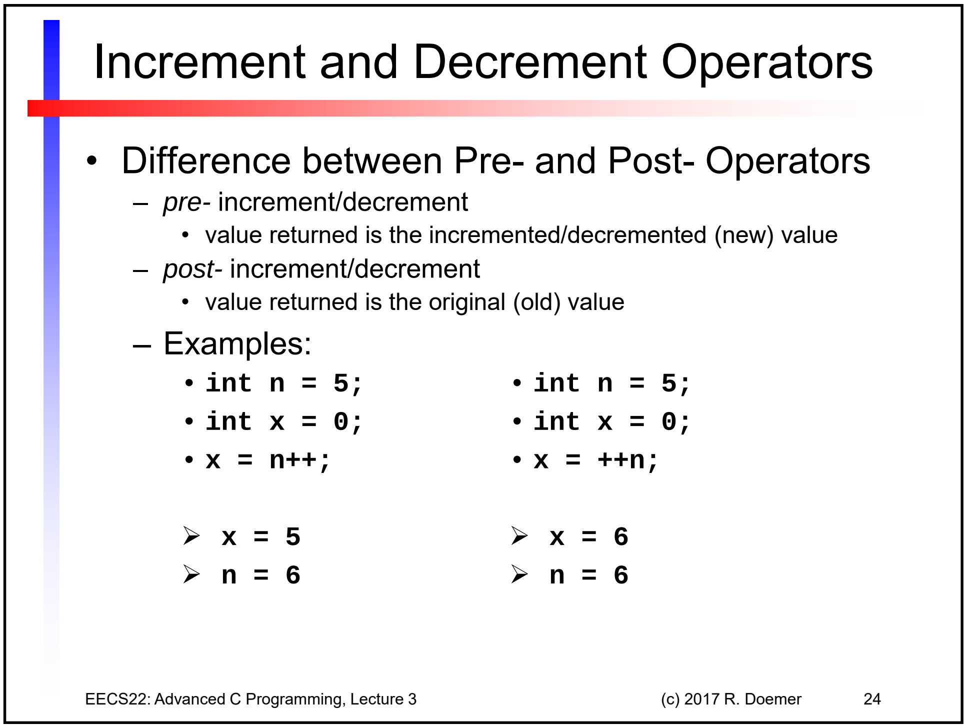
– parentheses	**(**, **)**
– unary plus, minus	**+**, **-**
– multiplication, division, modulo	*****, **/**, **%**
– addition, subtraction	**+**, **-**

- Evaluation order of expressions
  - binary operators evaluate left to right
  - unary operators evaluate right to left
  - by operator precedence
    - ordered as in table above (higher operators are evaluated first)
- Arithmetic operators are available
  - for integer types: all
  - for floating point types: all except **%**



Increment and Decrement Operators

- Counting in steps of one
  - increment (add 1)
  - decrement (subtract 1)
- C provides special counting operators
  - increment operator: **++**
    - **count++** post-increment (**count = count + 1**)
    - **++count** pre-increment (**count = count + 1**)
  - decrement operator: **--**
    - **count--** post-decrement (**count = count - 1**)
    - **--count** pre-decrement (**count = count - 1**)
  - Note: Argument must be an integral *lvalue*!
    - **Lvalue**: an expression referring to an object (i.e. variable name)
    - An *lvalue* can be used as the *left* argument for an assignment!

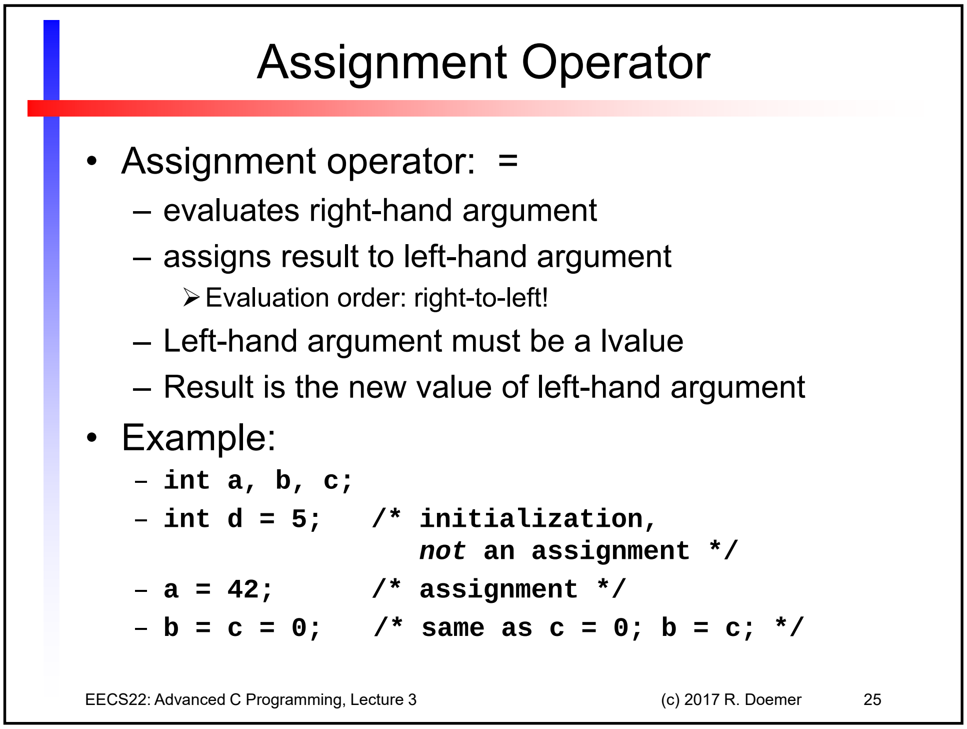


Increment and Decrement Operators

- Difference between Pre- and Post- Operators
  - *pre*- increment/decrement
    - value returned is the incremented/decremented (new) value
  - *post*- increment/decrement
    - value returned is the original (old) value
  - Examples:

```
• int n = 5;
• int x = 0;
• x = n++;

➢ x = 5
➢ n = 6
```

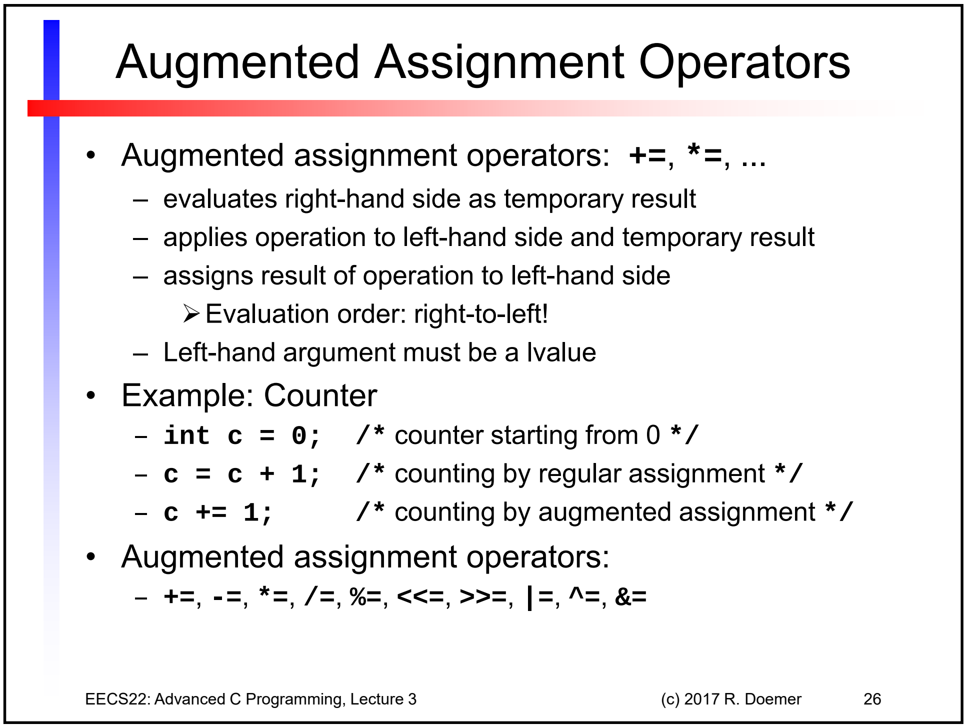
```
• int n = 5;
• int x = 0;
• x = ++n;

➢ x = 6
➢ n = 6
```



Assignment Operator

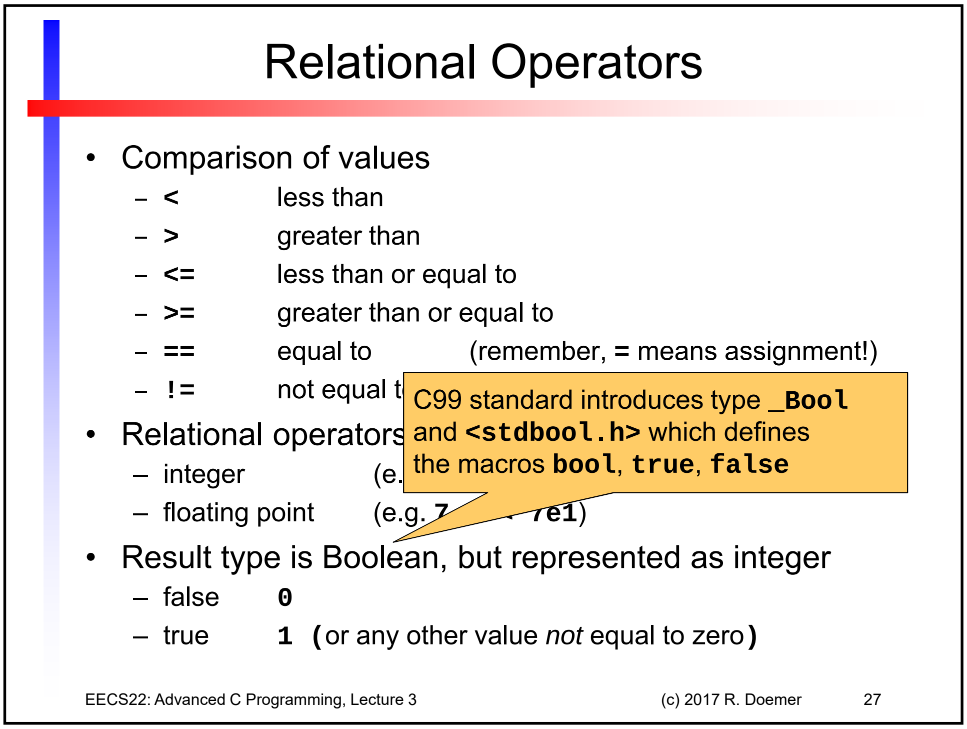
- Assignment operator: =
  - evaluates right-hand argument
  - assigns result to left-hand argument
    - ➢ Evaluation order: right-to-left!
  - Left-hand argument must be a lvalue
  - Result is the new value of left-hand argument
- Example:

```
– int a, b, c;
– int d = 5;   /* initialization,
                  not an assignment */
– a = 42;      /* assignment */
– b = c = 0;   /* same as c = 0; b = c; */
```



Augmented Assignment Operators

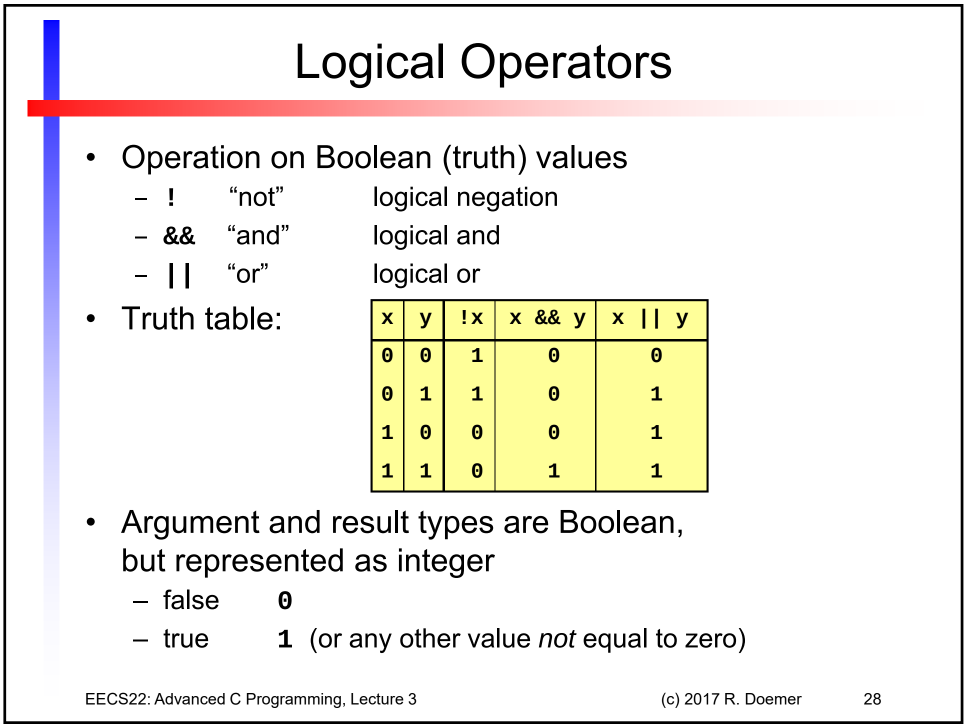
- Augmented assignment operators: **+=**, ***=**, ...
  - evaluates right-hand side as temporary result
  - applies operation to left-hand side and temporary result
  - assigns result of operation to left-hand side
    - ➢ Evaluation order: right-to-left!
  - Left-hand argument must be a lvalue
- Example: Counter
  - `int c = 0;` `/*` counter starting from 0 `*/`
  - `c = c + 1;` `/*` counting by regular assignment `*/`
  - `c += 1;` `/*` counting by augmented assignment `*/`
- Augmented assignment operators:
  - `+=`, `-=`, `*=`, `/=`, `%=`, `<<=`, `>>=`, `|=`, `^=`, `&=`



Relational Operators

- Comparison of values
  - **<** less than
  - **>** greater than
  - **<=** less than or equal to
  - **>=** greater than or equal to
  - **==** equal to (remember, **=** means assignment!)
  - **!=** not equal t
- Relational operators
  - integer (e.
  - floating point (e.g. **7** < **7e1**)
- Result type is Boolean, but represented as integer
  - false **0**
  - true **1 (**or any other value *not* equal to zero**)**

C99 standard introduces type **_Bool** and **<stdbool.h>** which defines the macros **bool**, **true**, **false**

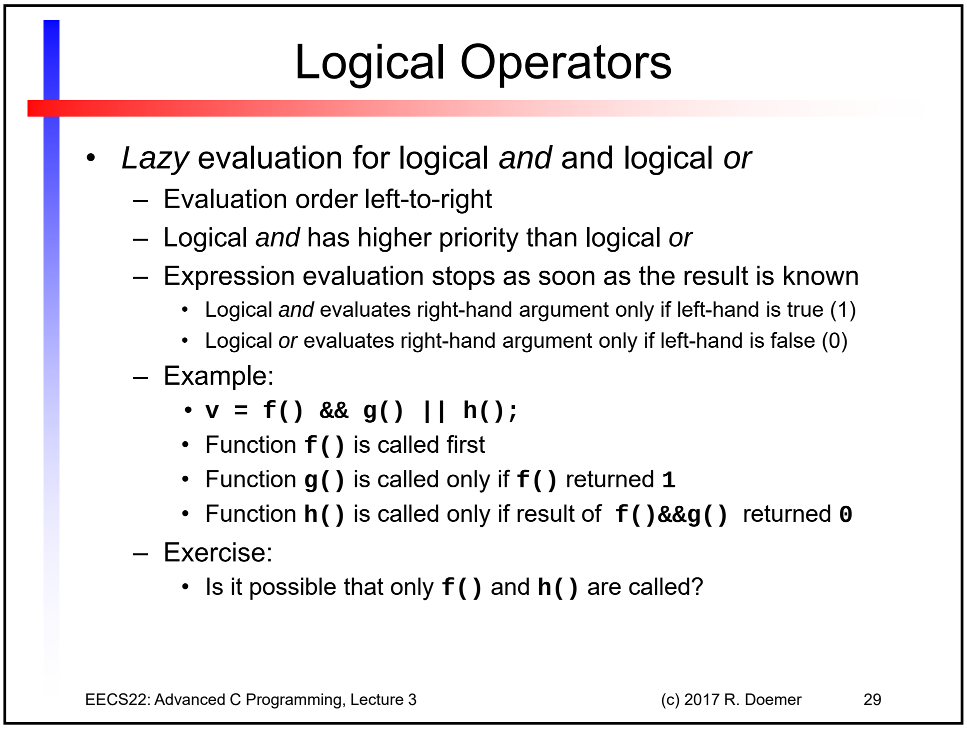


Logical Operators

- Operation on Boolean (truth) values
  - **!** "not" logical negation
  - **&&** "and" logical and
  - **||** "or" logical or
- Truth table:

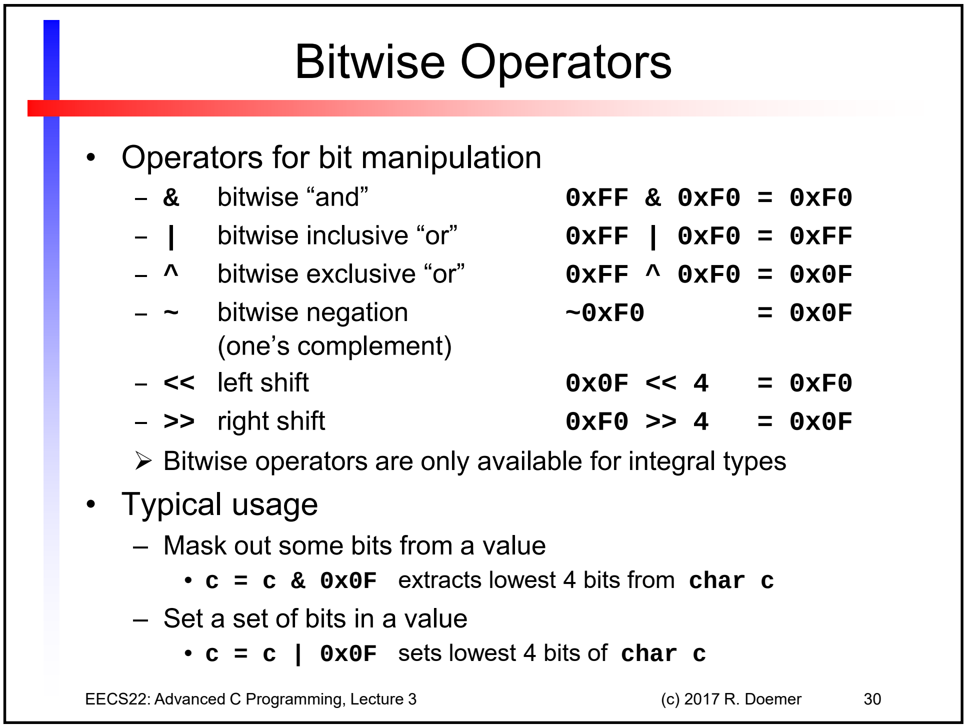
x	y	!x	x && y	x || y
0	0	1	0	0
0	1	1	0	1
1	0	0	0	1
1	1	0	1	1

- Argument and result types are Boolean, but represented as integer
  - false **0**
  - true **1** (or any other value *not* equal to zero)



Logical Operators

- *Lazy* evaluation for logical *and* and logical *or*
  – Evaluation order left-to-right
  – Logical *and* has higher priority than logical *or*
  – Expression evaluation stops as soon as the result is known
    - Logical *and* evaluates right-hand argument only if left-hand is true (1)
    - Logical *or* evaluates right-hand argument only if left-hand is false (0)
  – Example:
    - **`v = f() && g() || h();`**
    - Function **`f()`** is called first
    - Function **`g()`** is called only if **`f()`** returned **`1`**
    - Function **`h()`** is called only if result of **`f()&&g()`** returned **`0`**
  – Exercise:
    - Is it possible that only **`f()`** and **`h()`** are called?

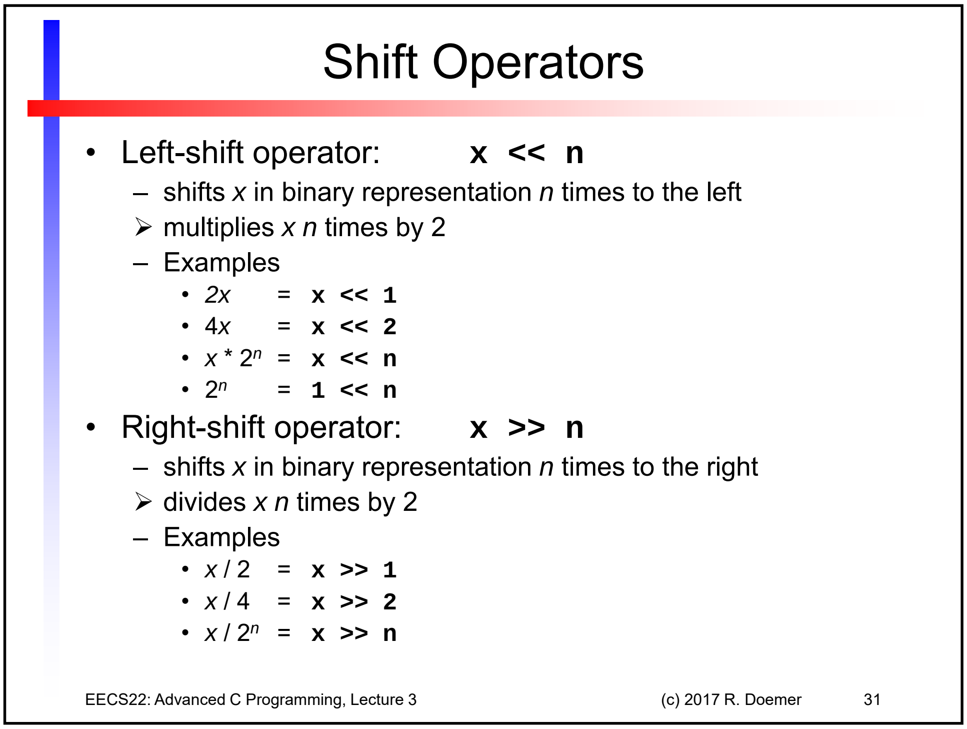


Bitwise Operators

- Operators for bit manipulation

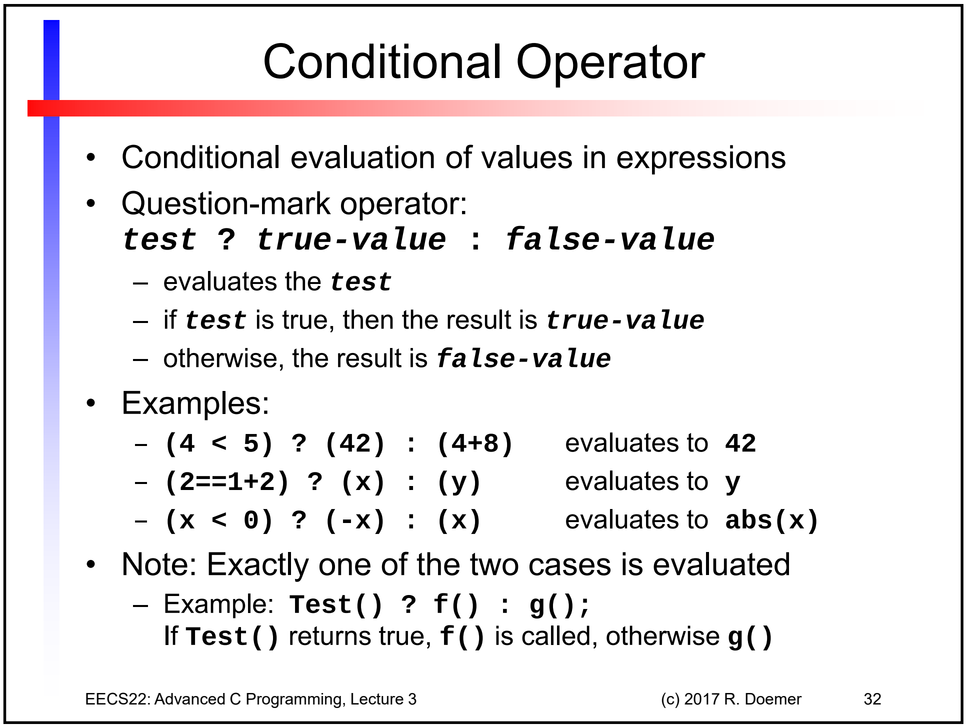
– **&**	bitwise "and"	**`0xFF & 0xF0 = 0xF0`**
– **|**	bitwise inclusive "or"	**`0xFF | 0xF0 = 0xFF`**
– **^**	bitwise exclusive "or"	**`0xFF ^ 0xF0 = 0x0F`**
– **~**	bitwise negation (one's complement)	**`~0xF0 = 0x0F`**
– **<<**	left shift	**`0x0F << 4 = 0xF0`**
– **>>**	right shift	**`0xF0 >> 4 = 0x0F`**

  ➢ Bitwise operators are only available for integral types
- Typical usage
  – Mask out some bits from a value
    - **`c = c & 0x0F`** extracts lowest 4 bits from **`char c`**
  – Set a set of bits in a value
    - **`c = c | 0x0F`** sets lowest 4 bits of **`char c`**



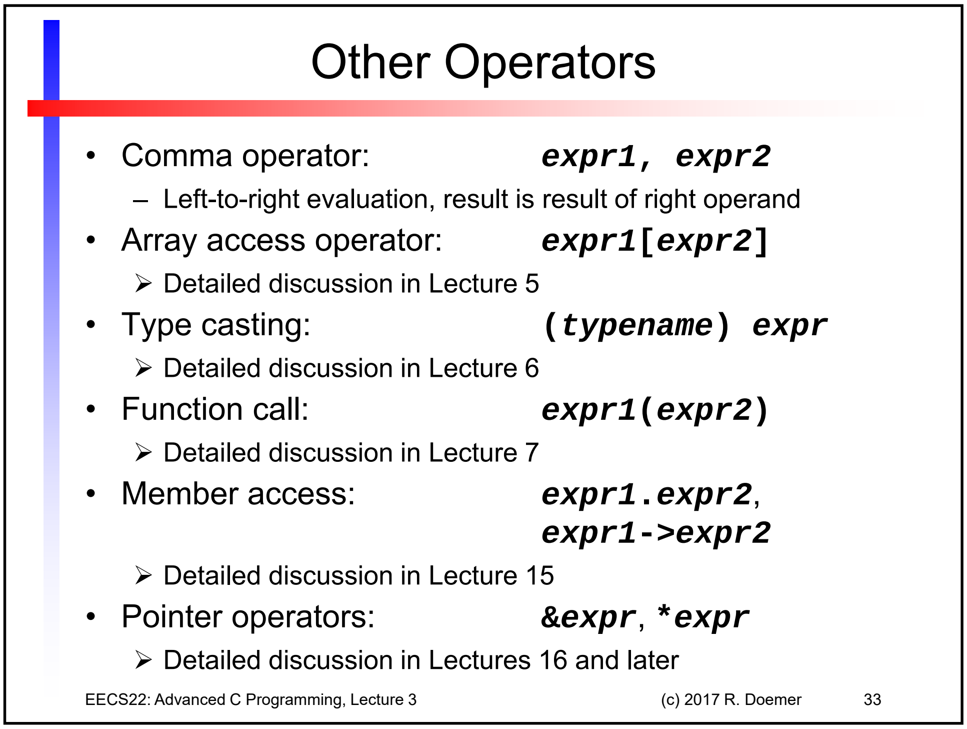
Shift Operators

- Left-shift operator: **`x << n`**
  - shifts *x* in binary representation *n* times to the left
  - ➢ multiplies *x* *n* times by 2
  - Examples
    - $2x$ = **`x << 1`**
    - $4x$ = **`x << 2`**
    - $x * 2^n$ = **`x << n`**
    - 2^n = **`1 << n`**
- Right-shift operator: **`x >> n`**
  - shifts *x* in binary representation *n* times to the right
  - ➢ divides *x* *n* times by 2
  - Examples
    - $x / 2$ = **`x >> 1`**
    - $x / 4$ = **`x >> 2`**
    - $x / 2^n$ = **`x >> n`**



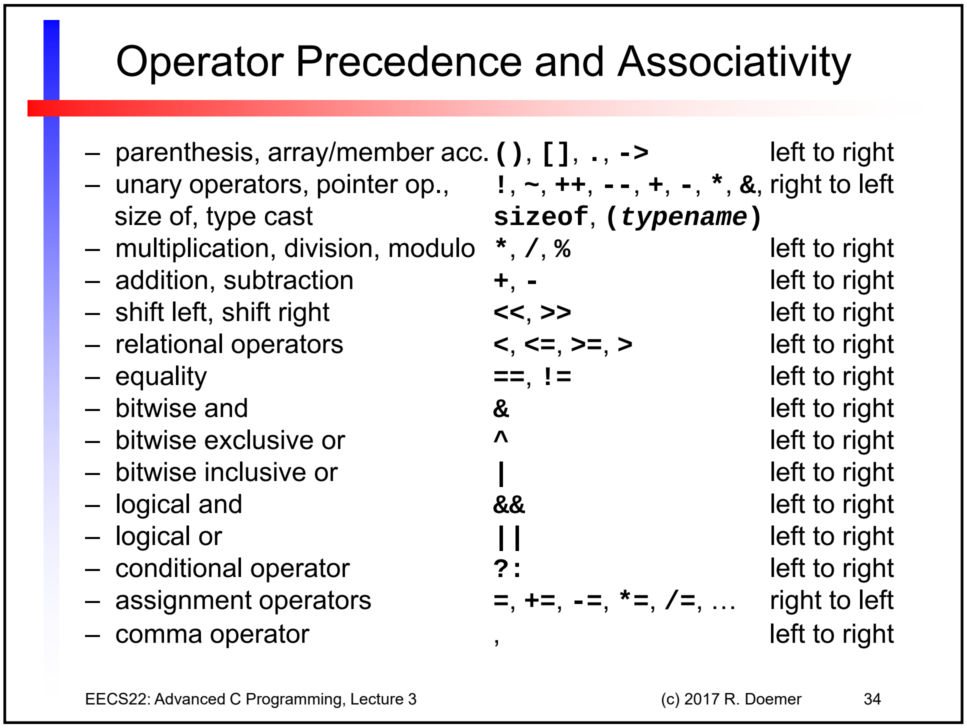
Conditional Operator

- Conditional evaluation of values in expressions
- Question-mark operator:
  `test ? true-value : false-value`
  - evaluates the ***`test`***
  - if ***`test`*** is true, then the result is ***`true-value`***
  - otherwise, the result is ***`false-value`***
- Examples:
  - **`(4 < 5) ? (42) : (4+8)`** evaluates to **`42`**
  - **`(2==1+2) ? (x) : (y)`** evaluates to **`y`**
  - **`(x < 0) ? (-x) : (x)`** evaluates to **`abs(x)`**
- Note: Exactly one of the two cases is evaluated
  - Example: **`Test() ? f() : g();`**
    If **`Test()`** returns true, **`f()`** is called, otherwise **`g()`**



Other Operators

- Comma operator: `expr1, expr2`
  - – Left-to-right evaluation, result is result of right operand
- Array access operator: `expr1[expr2]`
  - ➢ Detailed discussion in Lecture 5
- Type casting: `(typename) expr`
  - ➢ Detailed discussion in Lecture 6
- Function call: `expr1(expr2)`
  - ➢ Detailed discussion in Lecture 7
- Member access: `expr1.expr2`, `expr1->expr2`
  - ➢ Detailed discussion in Lecture 15
- Pointer operators: `&expr`, `*expr`
  - ➢ Detailed discussion in Lectures 16 and later



Operator Precedence and Associativity

<table>
<tr><td>– parenthesis, array/member acc.</td><td><code>()</code>, <code>[]</code>, <code>.</code>, <code>-></code></td><td>left to right</td></tr>
<tr><td>– unary operators, pointer op.,
size of, type cast</td><td><code>!</code>, <code>~</code>, <code>++</code>, <code>--</code>, <code>+</code>, <code>-</code>, <code>*</code>, <code>&</code>,
<code>sizeof</code>, <code>(typename)</code></td><td>right to left</td></tr>
<tr><td>– multiplication, division, modulo</td><td><code>*</code>, <code>/</code>, <code>%</code></td><td>left to right</td></tr>
<tr><td>– addition, subtraction</td><td><code>+</code>, <code>-</code></td><td>left to right</td></tr>
<tr><td>– shift left, shift right</td><td><code><<</code>, <code>>></code></td><td>left to right</td></tr>
<tr><td>– relational operators</td><td><code><</code>, <code><=</code>, <code>>=</code>, <code>></code></td><td>left to right</td></tr>
<tr><td>– equality</td><td><code>==</code>, <code>!=</code></td><td>left to right</td></tr>
<tr><td>– bitwise and</td><td><code>&</code></td><td>left to right</td></tr>
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<tr><td>– logical and</td><td><code>&&</code></td><td>left to right</td></tr>
<tr><td>– logical or</td><td><code>||</code></td><td>left to right</td></tr>
<tr><td>– conditional operator</td><td><code>?:</code></td><td>left to right</td></tr>
<tr><td>– assignment operators</td><td><code>=</code>, <code>+=</code>, <code>-=</code>, <code>*=</code>, <code>/=</code>, …</td><td>right to left</td></tr>
<tr><td>– comma operator</td><td><code>,</code></td><td>left to right</td></tr>
</table>