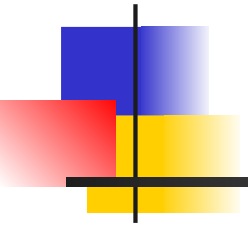

Primitive Data Types

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Primitive Data Types

- A primitive data type has only a value, such as a number.
- Primitive types are things the CPU can directly manipulate. Example: 2 + 3 (cpu can add int)
- Java has 8 primitive types, such as:

```
boolean
char
int
long
double
```

Data Type: Values and Operations

- A data type has a set of ***operations*** that it supports
- The operations are what make data useful!

Essential Information About a Data Type

1. what *values* can a data type store?
2. what *operations* can we perform on a data type?

Operations for int, long, float, and double are:

arithmetic: a + b, a - b, a * b, a / b, a % b (modulo)

comparison: a < b, a > b, a >= b, a == b (equality test)

negate: -a

`int` Data Type

1. what *values* can the **`int`** type store?

"int" can store integer values in the range

−2,147,483,648 to +2,147,483,647

`int` Operations

Arithmetic (result is int)

a + b

a - b

a * b

a / b

a % b a modulo b

Comparison (result boolean)

a < b

a > b

a <= b

a >= b

a == b

a != b

Operations that shift bits

a <<n shift bits left n times

a >>n shift right with sign

a >>>n shift right w/o sign

Bit mask operations

a | b bitwise "or" of a, b

a & b bitwise "and" of a, b

a ^ b bitwise exclusive or

Example using "int" type

Add the numbers 1 to 100.

```
int max = 100;

int sum = 0;

for( int k=1; k <= max; k++ )

  sum = sum + k;

System.out.println( "sum  is " + sum );
```

`int` Special Values

The Integer *class* has 2 special "int" values:

`Integer.MIN_VALUE` is the minimum value of "int" type.

`Integer.MAX_VALUE` is the maximum value of "int" type.

Rules for int operations

1. If the result is TOO BIG for "int" type, the higher order bits are lost. The result will be incorrect:

   1,000,000,000 + 1,000,000,000 is 2,000,000,000

   2,000,000,000 + 1,000,000,000 is -1,294,967,296

2. On division of int/int the remainder is discarded.

   28 / 10 is 2

   -28 / 10 is -2

   1 / 2 is 0 even 999999 / 1000000 is 0

   1 / 0 is error. Throws DivisionByZero exception.

3. Modulo (%): m = a % b is such that b*(a/b) + m == a

   7 % 3 is 1, -7 % 3 is -1 but 7 % -3 is 1

Java Primitive Data Types

Name	Values	Examples
boolean	**true false**	true, false
char	**character**	'a', 'A', '1', 'ก', 'ค', 'โ', '\t'
byte	8-bit integer	-127, ..., -1, 0, 1, ..., 127
short	16-bit integer	-32768 ... 0 ... 32767
int	**32-bit integer**	-400 47 20000000
long	64-bit integer	-1234567890L 0L 888L
float	decimal	3.14159F 0.0F -2.5E-8F
double	**64-bit decimal**	3.14159265358979E234

Primitive Data Types: values

Data Type	Size in Memory	Range of Values
boolean	1 byte	true false
char	2 bytes	0 (null) - \uFFFF (Unicode)
byte	1 byte	-128 to 127
short	2 bytes	-32,768 to 32,767
int	4 bytes	-2,147,483,648 to 2,147,483,647
long	8 bytes	-9,223,372,036,854,775,808L 9,223,372,036,854,775,807L
float	4 bytes	±3.402823E+38
double	8 bytes	±1.7976931346231 57E+308

double

1. Any number written with "." or exponential is automatically of type `double` (not float).

double: **`1.0  3.14159  2.99E+8  3e-12`**

2. If you do +, -, *, / with int and double, the result is a double. The "int" value is promoted to double first.

   2 * 7.0 --> 14.0 (double)

   10.0 * 2 / 5 --> 4.0 (double)

   but: 2 / 5 * 10.0 -- > 0 ("2/5" is done first as int/int)

3. * , / , and % are always done before + and -

   1.5 + 10 * 7.0 --> 71.5

Special values: Infinity and NaN

Java uses the IEEE floating point standard.
There are 3 special values: **`+Infinity`**, **`-Infinity`**, and **`NaN`** (not a number).

`2.5 / 0.0` is `+Infinity`

`-2.5 / 0.0` is `-Infinity`

`0.0 / 0.0` is `NaN` (not a number)

`Infinity * 0.0` is `NaN`

For int and long, n / 0 is error (DivisionByZeroException) but for float and double, x / 0 is +/-Infinity.

Double class has special values

Java has a class named `Double` -- not same as primitive type double. Double (class) has some special values:

```
Double.POSITIVE_INFINITY
Double.NEGATIVE_INFINITY
Double.NaN
Double.MAX_VALUE = 1.7976931348523E+308
Double.MIN_VALUE = 4.9E-324
```

and some useful static methods:

```
Double.parseDouble("2.14") // returns primitive 2.14
Double.toString(2.14)          // returns String "2.14"
```

What Data Type?

_____	1234, -9999
_____	6010541234 (in Java: 6010541234L)
_____	3.14159 (*what is this?*)
_____	3E+08
_____	3000.0F
_____	true
_____	'2'
_____	"2"
_____	'ด'
_____	3 == 4

Rules for numeric values

- Java has rules for how it interprets numerical values.

Value	Meaning
4	an "int" value 4
4L	a "long" with value 4 (8 bytes) - must write L or l
4.	a "double" with value 4.0
3e4, 3.0E4, 3e+4	a "double" with value 3000.0 (3 x 10^4)
0.1	a "double" value 0.1 *approximately*
4.0F	a "float" value 4.0 (4 bytes) - must write F or f
'4'	a "char" with (int) value 52

Type Conversion

If your code contains: `2+3`

then Java sees that you are adding int + int and produces an **`int`** result (`5`).

But, if your code contains: `2+3.0`

it means to add "int" + "double" values.

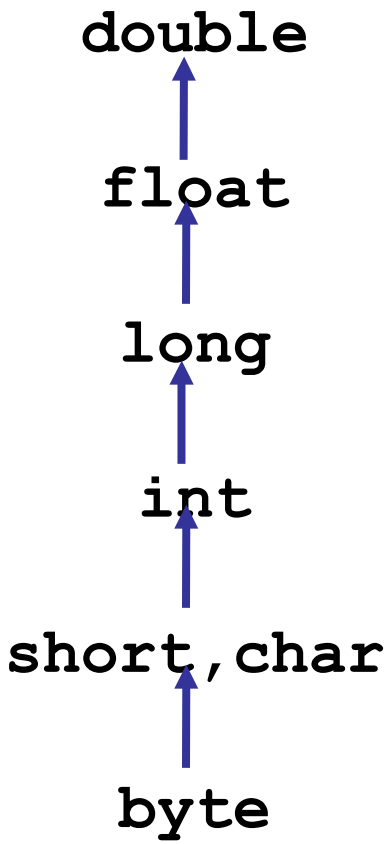
In this case, Java will convert 2 to a double (2.0) and add 2.0+3.0. The result is a **`double`**.

Type conversion may also occur when you call a method. For example: `Math.sqrt(2)`

The `sqrt` method requires a double parameter, so Java "promotes" `2` (int) to `2.0` (double).

Automatic Type Promotion

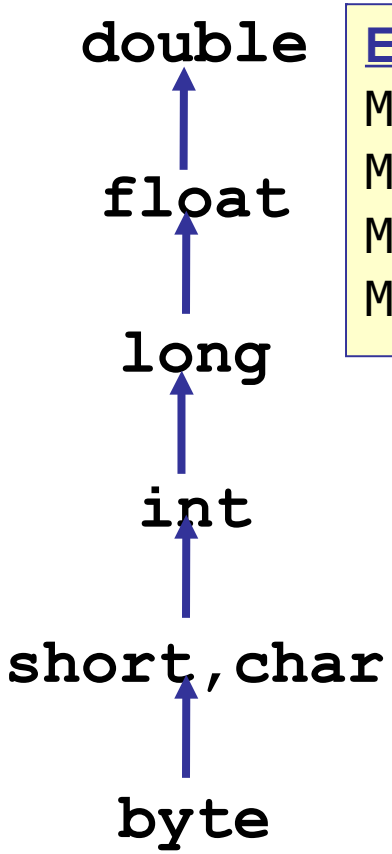
If you do arithmetic on different data types, Java "promotes" one argument to the type with *widest* range.



Example	Promotion	Result
2 + 4L	2 -> (long)2L	6L (long)
2 * 4.0	2 -> (double)2.0	6.0 (double)
2F + 3	3 -> (float)3F	5.0F (float)
2.0 * 3	3 -> (double)3.0	5.0 (double)
Weird:		
'a'+1	'a' -> int (97)	98

Type Promotion & Functions

If you invoke a function (method) using a numeric value, Java may "promote" the values of arguments.



Example	Promotion	Then Call
`Math.sqrt( 2 )`	`2 to 2.0`	`sqrt(2.0)`
`Math.max( 2, 10.0F )`	`2 to 2.0F`	`max(2F,10F)`
`Math.max(-1, -4L )`	`-1 to -1L`	`max(-1L,-4L)`
`Math.max( 3, 2.236 )`	`3 to 3.0`	`max(3.0,2.236)`

Type Conversion May Lose Precision

Java "type promotion" always perform a widening conversions that will never "overflow" the result data type.

But it may lose precision (accuracy).

Example: (float)123456789 -> 1.2345679E+8

What about boolean?

boolean type (true, false) cannot be converted to any other type!

This is done to prevent accidental errors.

A classic error in C programming is:

```
int n = 1;
if (n = 2) printf("its true!");   // set n=2, result is true!
should be:
if (n == 2) . . . ;
```

Common Type Errors

Here are some common errors.

What is the mistake? How to correct it?

```
// Compute typing speed in words/minute
int wordsTyped = 38; // number of words typed
int time = 45;   // time in seconds
double speed = wordsTyped/time * 60.0;   // speed = 0

// The midterm exam has a maximum of 90 points.
// "Normalize" the score to be 0-100 (e.g. 90 -> 100%).
int midtermScore = 85;
double score = 100.0 * (midtermScore / 90);
```

boolean values

- Boolean has 2 values: true or false
- Used for *conditional execution* of statements.
- Boolean is used in "if", "while", and "for" statements.

```
/** Compute the sales tax on a purchase */

public void getTax( int amount ) {
  boolean PAY_TAX = true;
  double tax;  // amount of tax owed
  if ( PAY_TAX ) tax = 0.07 * amount;
  else  tax = 0.0;
  System.out.println("The tax is: "+tax);
}
```

A javadoc comment for this method.

if (*condition*)
  statement1 ;
else
  statement2 ;

boolean operations

! b	NOT b (`!true -> false, !false -> true`)
b1 && b2	b1 AND b2
b1 || b2	b1 OR b2
b1 ^ b2	b1 XOR b2 true if *exactly one* of b1, b2 is true

```
boolean hasDog = true;
boolean hasCat = false;

// test: does he have a dog or a cat?
if ( hasDog || hasCat ) petOwner( );
// test: does he have dog or cat, not both?
if ( hasDog ^ hasCat ) happyPetOwner( );
// does he have both dog and cat?
if ( hasDog && hasCat ) unhappyPetOwner( );
```

boolean operations

It is *always* possible to rewrite ^ (exclusive or) using AND, OR, and NOT (&&, ||, !)

Exercise: rewrite expression without using ^

```
boolean hasDog = true;
boolean hasCat = false;
happyPetOwner = ( hasDog ^ hasCat );

// write happyPetOwner
// using only &&, ||, and !
happyPetOwner =
```

char for character data

- The char data type is for character data.
- Java uses 2-byte Unicode for character data, in order to hold the world's alphabets. Including Thai.
- Unicode: `http://www.unicode.org`

```
// Get the first character from a String.
String word = "George Bush";
char first;
first = word.charAt(0);
System.out.println("The string "+ word
    + " begins with " + first);
// Get the last character from a String!
int last = word.length() - 1; // why -1 ??
first = word.charAt( last );
```

`charAt( )` is a method of the String class.

`length( )` returns number of chars in a string.

char values

- You can also use char to hold special values:
  - `'\t'` tab character
  - `'\n'` new-line character
  - `'\u03C0'` Unicode sequence number for π (pi)

```
char TAB = '\t';
char NEWLINE  = '\n';
char PI  = '\u03C0';
// Print greek pi symbol
System.out.println("I love cake and "+PI);
// Use tab to align output
System.out.print("Hello" + NEWLINE
           + TAB + "world"+NEWLINE);
```

Must enclose character values in ***single quotes***

NOT *double quotes*

Escape Sequences for special chars

These ‘\x’ values represent special characters:

Code	Name	meaning
\t	Horizontal Tab	advance to next tab stop
\n	New line	start a new line
\v	Vertical Tab	performs a vertical tab (maybe)
\f	Form feed	start a new page on printed media
\r	Carriage return	move to beginning of line
\0	Null	null character, has value 0
\"	Double Quote	use for " inside of String
\'	Single Quote	use for ' inside of char
\\	Backslash	display a \

byte, short for "raw" data

- byte and short are for integer data and input/output
- byte is used for low-level input, holding character codes (as 1 byte), and groups of "flag" bits
- byte and short are not used for arithmetic.
  Java *promotes* all arithmetic to "int" data type.

```
/* read bytes of data into byte array.
 * This is soooo boring.
 */
byte[] b = new byte[80];
System.in.read( b );
```

`read( )` gets input data as bytes.

Detailed Look at Float & Double

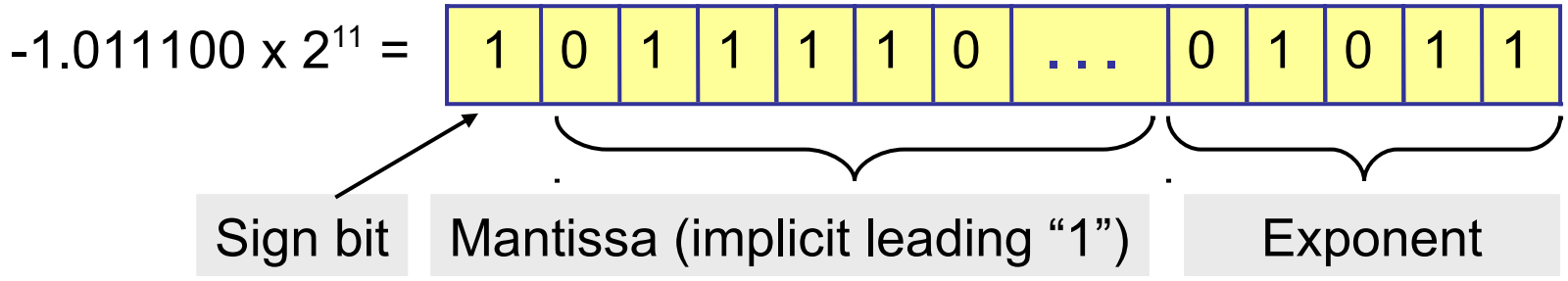
The next few slides explain how float and double values are stored.

You can skip them if you want.

But, to understand the *behavior* of arithmetic operations it helps to know how values are stored.

float, double: Floating Point Data

Java has 2 data types for storing non-integer values, called *floating point* because they store numeric data as a *mantissa* and *exponent*.



Float:	1 bit	23 bits	8 bits
Double:	1 bit	52 bits	11 bits
		Precision	Range
Float:		24 bits =~ 7 dec. digits	10^{-38} - 10^{+38}
Double:		53 bits =~ 15 dec. digits	10^{-308} - 10^{+308}

float, double: Floating Point Data

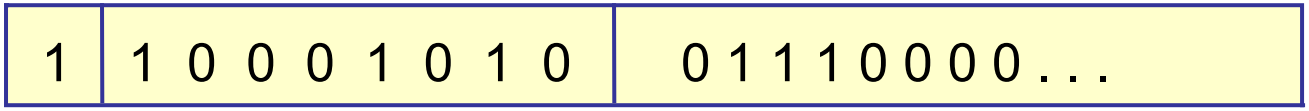
Data Type	Size of mantissa	Accuracy (precision)
`float`	23 bits	6-7 decimal digits
`double`	52 bits	15 decimal digits

- Use **`double`** for most applications (more accurate).
- Use **`float`** where 6-decimal digits is enough, *or* you need to optimize space/performance.

```
// Be careful when using floating point!
float x = 0.2F;
float y;
y = 1.0F - x - x - x - x - x; // should be zero!
System.out.println("y = "+y); // y = 2.9802322E-8
```

IEEE Floating Point Data Format

$-1.011100 \times 2^{11} =$



	Sign bit	Biased Exponent	Mantissa
Float:	1	8 bits bias= 127	23 bits
Double:	1	11 bits bias=1023	52 bits

	Range	Precision
Float:	10^{-38} - 10^{+38}	24 bits =~ 7 dec. digits
Double:	10^{-308} - 10^{+308}	53 bits =~ 15 dec. digits

Stored exponent = actual exponent + **bias**

Wrapper Classes

Primitive	Wrapper
boolean	Boolean
char	Character
byte	Byte
short	Short
int	Integer
long	Long
float	Float
double	Double

```
double root = Math.sqrt( 2.0 );
Double d1 = new Double( root );
// same thing: automatic boxing
Double d2 = root;


// print as a string
out.println(  d2.toString( ) );
// static method to make a string
out.println( Integer.toString( 2 ) );
```

Why Wrapper Classes?

1. Some methods and data structures only work with *references (e.g. objects)*.

   Example: a List can only contain *references*.

   If we want a List of double, we need to "wrap" each double in an object.

```
// ERROR: can't create a list of primitives
ArrayList<double> list = new ArrayList<double>( );
// CORRECT: use wrapper for double
ArrayList<Double> list = new ArrayList<Double>( );
// Java automatically "wraps" 2.0 in a Double
list.add( 2.0 );
```

Why Wrapper Classes?

2. Primitives don't have methods. The wrappers provide useful methods and static constants.

Example: get the double value of a String.

```
// convert a String to a double
double x = Double.parseDouble( "2.98E_08" );
// convert double to a String
x = Math.sqrt( x );
String value = Double.toString( x );
```

Example: what is the largest value an "int" can store?

```
int max = Integer.MAX_VALUE;
```

Wrapper to convert to/from String

```
int n = 1234;
// convert n to a String
String id = Integer.toString(n);

String s = "2.5";
// convert s to a double?
```

Range limits of numeric types

- What is the largest "int" value?
- What is the smallest "long" value?
- What is the range (smallest, biggest) of double?

```
int biggest =

long smallest =

double minimum =

double maximum =
```

What happens if you go beyond?

```
int n = Integer.MAX_VALUE;
n = n + 1;
System.out.println( n );
double d = Double.MAX_VALUE;
d = d + 1;
System.out.println( d );
d = d * 1.000001;
System.out.println( d );
```

What happens if you go beyond?

```
int n = Integer.MAX_VALUE;
n = n + 1;
n is -2147483648
double d = Double.MAX_VALUE;
d = d + 1;
no change. +1 insignificant (too small)
d = d * 1.000001;
d is Infinity
```

C# numerics are different

- "int", "float", "double" are struct types.

```
// This is C#
int n = int.MaxValue;
String s = "Biggest int is "
                + n.ToString( ) ;
// range checking is enforced
n = n + 1;
```

System.OverflowException: Arithmetic operation resulted in an overflow.

Review

1) Is this correct? Give a reason why or why not.

```
int n = 1234;

System.out.println( n.toString() );
```

2) How can you convert a String value to a double?

```
String s = "9.8E+6";

double value = ?
```

Review

Taksin deposited 1,000,000,000 Baht at the bank on 3 occasions. The first 2 times the balance was correct. But the third time the balance was negative. Why?

Here is the code (you can run this in BlueJ codepad):

```
int balance = 0; // initial balance
int deposit = 1000000000; // a small deposit
for(int count=0; count < 3; count++)  {
  balance = balance + amount;
  System.out.println("Balance is "+balance);
}
```