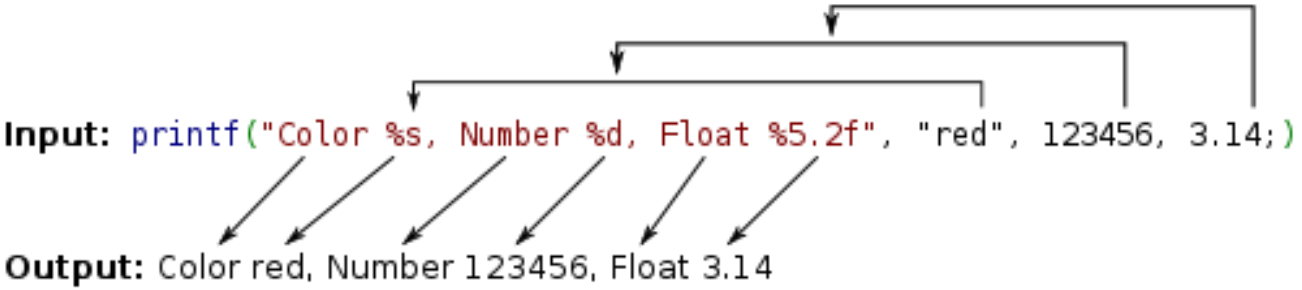
Libraries, clients, printf



A foundation for programming

any program you might want to write

http://www.flickr.com/photos/vermegrigio/5923415248/

objects

functions and modules

build bigger programs and reuse code

graphics, sound, and image I/O

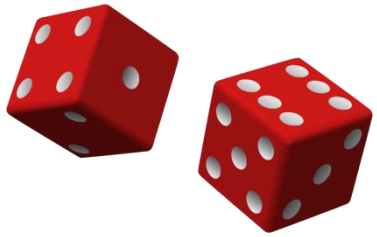
arrays

conditionals and loops

Math | text I/O

primitive data types | assignment statements

Programs thus far



- Problems with one big `main()`:
  - Doesn't scale to complex programs
  - Often find ourselves repeating similar code

```
public class DiceRolling
{
   public static void main(String [] args)
   {
      int rolls  = 0;
      int sum    = 0;
      int target = (int) (Math.random() * 12) + 2;

      System.out.println("Rolling dice until I get " + target);

      do
      {
         int dice1 = (int) (Math.random() * 6) + 1;
         int dice2 = (int) (Math.random() * 6) + 1;
         sum = dice1 + dice2;
         ...
```

Calling our new method

- Use handy new method in `DiceRolling`
  - Add somewhere inside `public class {}'s`

```
public class DiceRolling
{
   public static int getRandomNum(int start, int end)
   {
      return (int) (Math.random() *
                    (end - start + 1)) + start;
   }

   public static void main(String [] args)
   {
      int rolls  = 0;
      int sum    = 0;
      int target = getRandomNum(1, 12);

      System.out.println("Rolling dice until I get " + target + ".");
      do
      {
         int dice1 = getRandomNum(1, 6);
         int dice2 = getRandomNum(1, 6);
         sum = dice1 + dice2;
         ...
```

Calling our new method

- Alternative: put method in new class
  - Allows us to create a class with a bunch of helper methods (just like `StdIn.java, StdDraw.java`)

```
public class RandomUtil
{
   // Return random integer in [start, end] inclusive
   public static int getRandomNum(int start, int end)
   {
      return (int) (Math.random() *
                    (end - start + 1)) + start;
   }

   // Return random integer in [0, end] inclusive
   public static int getRandomNum(int end)
   {
      return (int) (Math.random() * (end + 1));
   }
}
```

`getRandomInt()` is ***overloaded:*** Two methods with same name, but different signatures (e.g. different number of parameters)

Using our new class

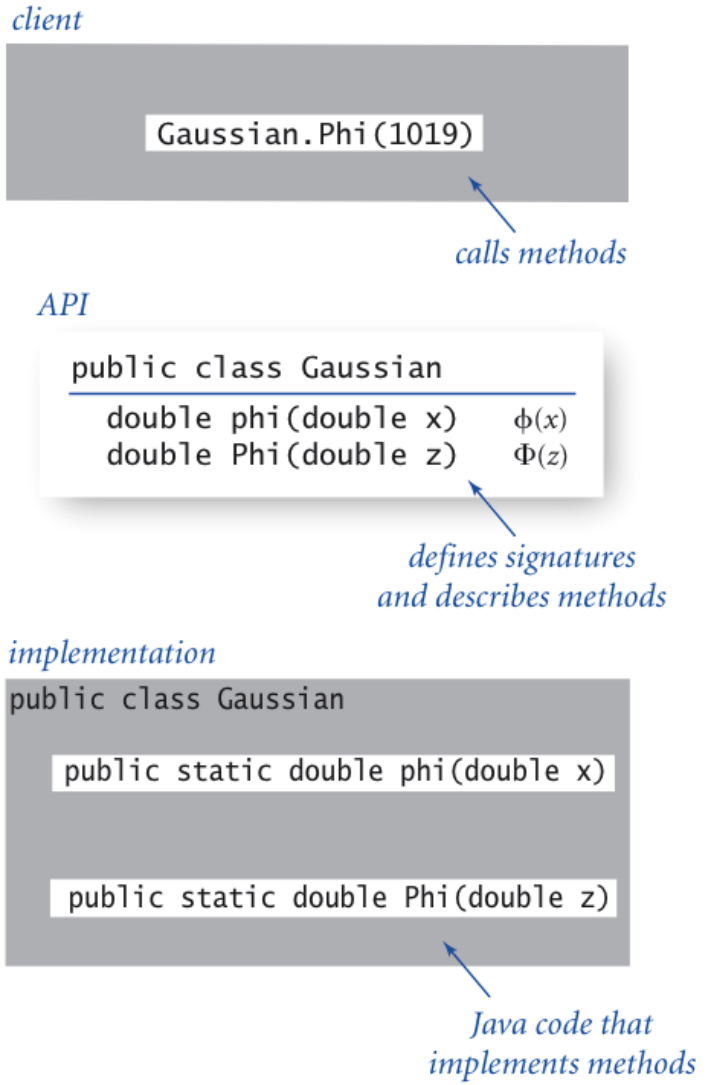
- Put `RandomUtil.java` in same directory
  - Methods qualified with `RandomUtil.` in front

```
public class DiceRolling
{
   public static void main(String [] args)
   {
      int rolls  = 0;
      int sum    = 0;
      int target = RandomUtil.getRandomNum(2, 12);

      System.out.println("Rolling dice until I get " + target + ".");
      do
      {
         int dice1 = RandomUtil.getRandomNum(1, 6);
         int dice2 = RandomUtil.getRandomNum(1, 6);
         sum = dice1 + dice2;
         System.out.println(dice1 + " + " + dice2 + " = " + sum);
         rolls++;
      }
      while (sum != target);
      System.out.println("It took " + rolls + " rolls.");
   }
}
```

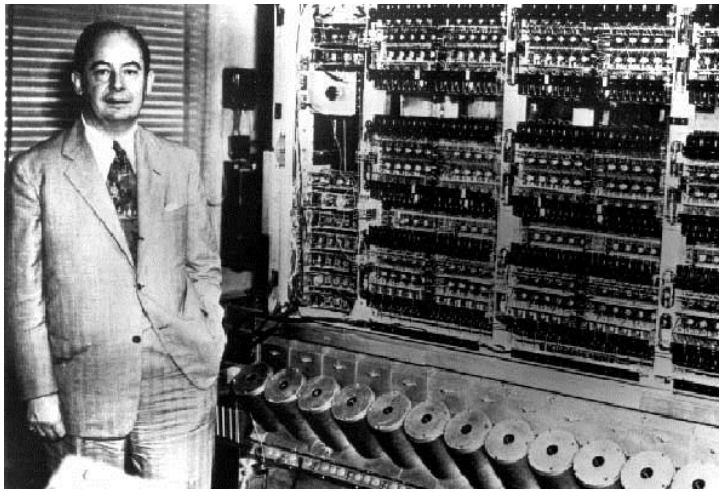
Libraries

- Library
  - A module whose methods are primarily intended for use by many other programs
- Client
  - Program that calls a library
- API
  - Application Programming Interface
  - Contract between client and implementation
- Implementation
  - Program that implements the methods in an API



Random numbers

> *“The generation of random numbers is far too important to leave to chance. Anyone who considers arithmetical methods of producing random digits is, of course, in a state of sin.”*



Jon von Neumann (left), ENIAC (right)

RANDOM.ORG

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Google™ Custom Search Search

True Random Number Service

What's this fuss about *true* randomness?

Perhaps you have wondered how predictable machines like computers can generate randomness. In reality, most random numbers used in computer programs are *pseudo-random*, which means they are generated in a predictable fashion using a mathematical formula. This is fine for many purposes, but it may not be random in the way you expect if you're used to dice rolls and lottery drawings.

RANDOM.ORG offers *true* random numbers to anyone on the Internet. The randomness comes from atmospheric noise, which for many purposes is better than the pseudo-random number algorithms typically used in computer programs. People use RANDOM.ORG for holding drawings, lotteries and sweepstakes, to drive games and gambling sites, for scientific applications and for art and music. The service has existed since 1998 and was built and is being operated by Mads Haahr of the School of Computer Science and Statistics at Trinity College, Dublin in Ireland.

As of today, RANDOM.ORG has generated 1.18 trillion random bits for the Internet community.

True Random Number Generator

Min: 1

Max: 100

Generate

Result:

50

Powered by RANDOM.ORG

Coin Flipper

You flipped 3 coins of type American Voting Coin 2004:

Timestamp: 2012-10-06 16:50:22 UTC

Flip Again Go Back

Standard Random

- Standard random
  - Library to generate pseudo-random numbers
  - Application Programming Interface (API):

public class StdRandom	
int uniform(int N)	*integer between* 0 *and* N-1
double uniform(double lo, double hi)	*real between* lo *and* hi
boolean bernoulli(double p)	true *with probability* p
double gaussian()	*normal, mean* 0, *standard deviation* 1
double gaussian(double m, double s)	*normal, mean* m, *standard deviation* s
int discrete(double[] a)	i *with probability* a[i]
void shuffle(double[] a)	*randomly shuffle the array* a[]

Standard random, implementation

```
public class StdRandom
{
   // between a and b
   public static double uniform(double a, double b)
   {
      return a + Math.random() * (b-a);
   }

   // between 0 and N-1
   public static int uniform(int N)
   {
      return (int) (Math.random() * N);
   }

   // true with probability p
   public static boolean bernoulli(double p)
   {
      return Math.random() < p;
   }

   // gaussian with mean = 0, stddev = 1
   public static double gaussian()
      /* see Exercise 1.2.27 */

   // gaussian with given mean and stddev
   public static double gaussian(double mean, double stddev)
   {
      return mean + (stddev * gaussian());
   }
   …
}
```

Unit testing

- Include `main()` to test each library

```
public static void main(String[] args)
{
   int N = Integer.parseInt(args[0]);
   if (args.length == 2) StdRandom.setSeed(Long.parseLong(args[1]));
      double[] t = { .5, .3, .1, .1 };

   StdOut.println("seed = " + StdRandom.getSeed());
   for (int i = 0; i < N; i++)
   {
      StdOut.printf("%2d "   , uniform(100));
      StdOut.printf("%8.5f ", uniform(10.0, 99.0));
      StdOut.printf("%5b "   , bernoulli(.5));
      StdOut.printf("%7.5f ", gaussian(9.0, .2));
      StdOut.println();
   }
```

These "random" numbers are the same as the first run!

```
% java StdRandom 5
seed = 1349544048443
72 34.23045 false 8.86067
10 47.24745  true 8.83698
65 35.25313  true 9.28941
17 34.37725 false 9.56543
52 90.80849 false 8.84883
```

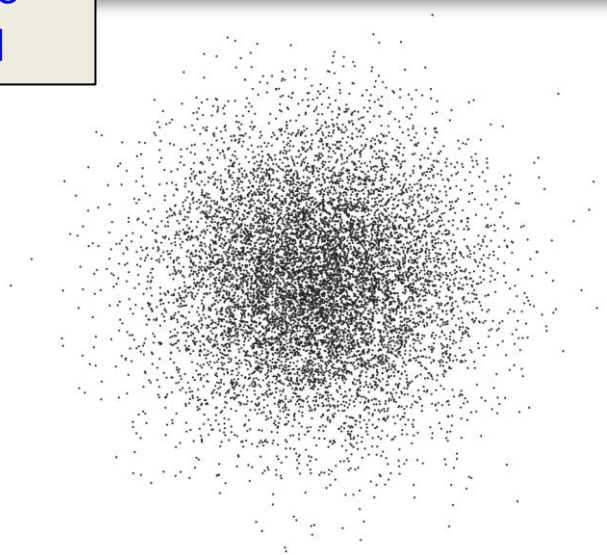
```
% java StdRandom 5
seed = 1349544178256
18 23.68569 false 8.85914
71 70.97195 false 8.71287
17 93.72297 false 9.14421
24 93.54278 false 9.48963
41 52.23556 false 9.10782
```

```
% java StdRandom 5 1349544048443
seed = 1349544048443
72 34.23045 false 8.86067
10 47.24745  true 8.83698
65 35.25313  true 9.28941
17 34.37725 false 9.56543
52 90.80849 false 8.84883
```

Using a library

```
public class RandomPoints
{
   public static void main(String args[])
   {
      int N = Integer.parseInt(args[0]);
      for (int i = 0; i < N; i++)
      {
         double x = StdRandom.gaussian(0.5, 0.2);
         double y = StdRandom.gaussian(0.5, 0.2);
         StdDraw.point(x, y);
      }
   }
}
```

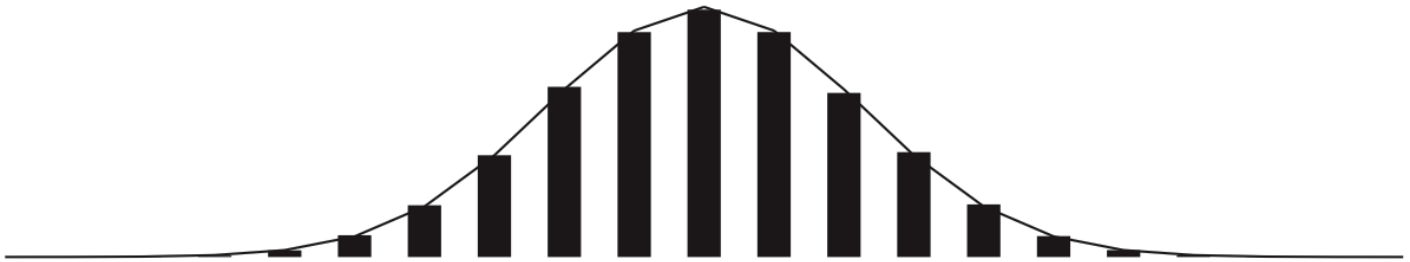
Use library name to invoke the method



Modular Programming

- Modular programming
  - Divide program into self-contained pieces.
  - Test each piece individually.
  - Combine pieces to make program.
- Example: Flip N coins. How many heads?
  - Read arguments from user.
  - Flip one fair coin.
  - Flip N fair coins and count number of heads.
  - Repeat simulation, counting number of times each outcome occurs.
  - Plot histogram of empirical results.
  - Compare with theoretical predictions.

```
% java Bernoulli 20 100000
```



Bernoulli Trials

```
public class Bernoulli {
   public static int binomial(int N) {
      int heads = 0;
      for (int j = 0; j < N; j++)
         if (StdRandom.bernoulli(0.5)) heads++;
      return heads;
   }

   public static void main(String[] args) {
      int N = Integer.parseInt(args[0]);
      int T = Integer.parseInt(args[1]);

      int[] freq = new int[N+1];
      for (int i = 0; i < T; i++)
         freq[binomial(N)]++;

      double[] normalized = new double[N+1];
      for (int i = 0; i <= N; i++)
         normalized[i] = (double) freq[i] / T;
      StdStats.plotBars(normalized);

      double mean = N / 2.0, stddev = Math.sqrt(N) / 2.0;
      double[] phi  = new double[N+1];
      for (int i = 0; i <= N; i++)
         phi[i] = Gaussian.phi(i, mean, stddev);
      StdStats.plotLines(phi);
   }
}
```

flip **N** fair coins; return # heads

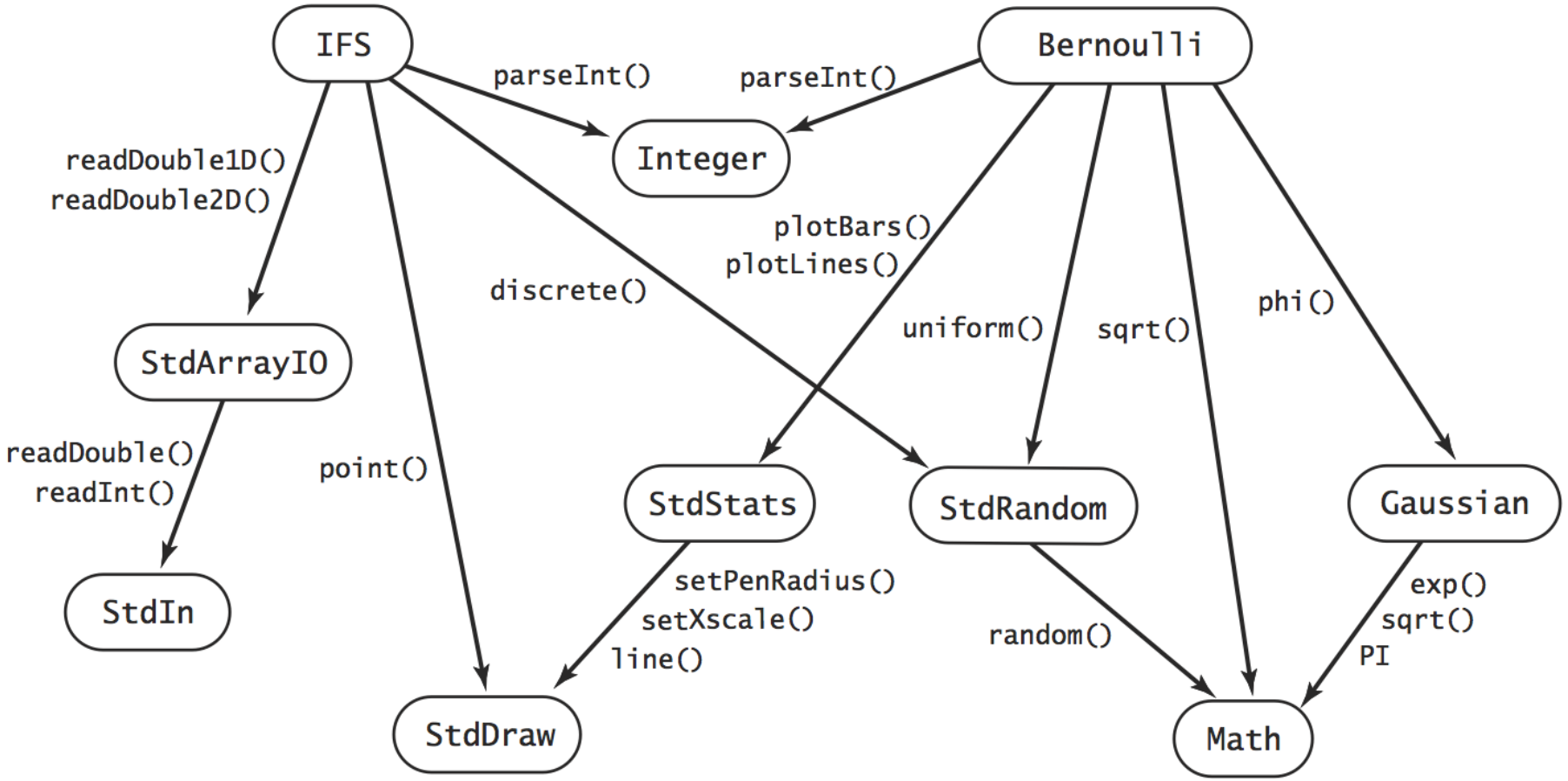
perform **T** trials of **N** coin flips each

plot histogram of number of heads

theoretical prediction

Dependency Graph

- Modular programming
  - Build relatively complicated program by combining several small, independent, modules.



Pretty text formatting

- printf-style formatting
  - Common way to nicely format output
  - Present in many programming languages
    - Java, C++, Perl, PHP, ...
  - Use a special format language:
    - Format string with special codes
    - One or more variables get filled in
- In Java, used via:
  - `System.out.printf()` – output to standard out
  - `String.format()` – returns a formatted String

Floating-point formatting

```
double d = 0.123456789;
float  f = 0.123456789f;

// %f code is used with double or float variables
// %f defaults to rounding to 6 decimal places
System.out.printf("d is about %f\n", d);
System.out.printf("f is about %f\n", f);

// Number of decimal places specified by .X
// Output is rounded to that number of places
System.out.printf("PI is about %.1f\n", Math.PI);
System.out.printf("PI is about %.2f\n", Math.PI);
System.out.printf("PI is about %.3f\n", Math.PI);
System.out.printf("PI is about %.4f\n", Math.PI);


// %e code outputs in scientific notation
// .X specifies number of significant figures
final double C = 299792458.0;
System.out.printf("speed of light = %e\n", C);
System.out.printf("speed of light = %.3e\n", C);
```

\n means line feed

```
d is about 0.123457
f is about 0.123457
```

```
PI is about 3.1
PI is about 3.14
PI is about 3.142
PI is about 3.1416
```

```
C = 2.99792e+08
C = 2.998e+08
```

Integer formatting

```
// %d code is for integer values, int or long
// Multiple % codes can be used in a single printf()
long power = 1;
for (int i = 0; i < 8; i++)
{
   System.out.printf("%d = 2^%d\n", power, i);
   power = power * 2;
}
```

You can have multiple % codes that are filled in by a list of parameters to printf()

```
1 = 2^0
2 = 2^1
4 = 2^2
8 = 2^3
16 = 2^4
32 = 2^5
64 = 2^6
128 = 2^7
```

```
// A number after the % indicates the minimum width
// Good for making a nice looking tables of values
power = 1;
for (int i = 0; i < 8; i++)
{
   System.out.printf("%5d = 2^%d\n", power, i);
   power = power * 2;
}
```

Minimum width of this field in the output. Java will pad with whitespace to reach this width (but can exceed this width if necessary).

```
    1 = 2^0
    2 = 2^1
    4 = 2^2
    8 = 2^3
   16 = 2^4
   32 = 2^5
   64 = 2^6
  128 = 2^7
```

Flags

```
// Same table, but left justify the first field
power = 1;
for (int i = 0; i < 8; i++)
{
   System.out.printf("%-5d = 2^%d\n", power, i);
   power = power * 2;
}
```

- flag causes this field to be left justified

```
1     = 2^0
2     = 2^1
4     = 2^2
8     = 2^3
16    = 2^4
32    = 2^5
64    = 2^6
128   = 2^7
```

```
// Use commas when displaying numbers
power = 1;
for (int i = 0; i < 17; i++)
{
   System.out.printf("%,5d = 2^%d\n", power, i);
   power = power * 2;
}
```

, flag causes commas between groups of 3 digits

```
    1 = 2^0
    2 = 2^1
    4 = 2^2
    8 = 2^3
   16 = 2^4
   32 = 2^5
   64 = 2^6
  128 = 2^7
  256 = 2^8
  512 = 2^9
1,024 = 2^10
2,048 = 2^11
4,096 = 2^12
8,192 = 2^13
16,384 = 2^14
32,768 = 2^15
65,536 = 2^16
```

Text formatting

```
// Characters can be output with %c, strings using %s
String name = "Bill";
char grade = 'B';
System.out.printf("%s got a %c in the class.\n", name, grade);
```

```
Bill got a B in the class.
```

```
// This prints the same thing without using printf
System.out.println(name + " got a " + grade + " in the class.");
```

An equivalent way to print the same thing out using good old println().

Creating formatted strings

- Formatted `String` creation
  - You don't always want to immediately print formatted text to standard output
  - Save in a String variable for later use

```
// Formatted Strings can be created using format()
String lines = "";
for (int i = 0; i < 4; i++)
   lines += String.format("Random number %d = %.2f\n", i, Math.random());
System.out.print(lines);
```

```
Random number 0 = 0.54
Random number 1 = 0.50
Random number 2 = 0.39
Random number 3 = 0.64
```

The format specifier

Which argument to use in this slow (not as commonly used).

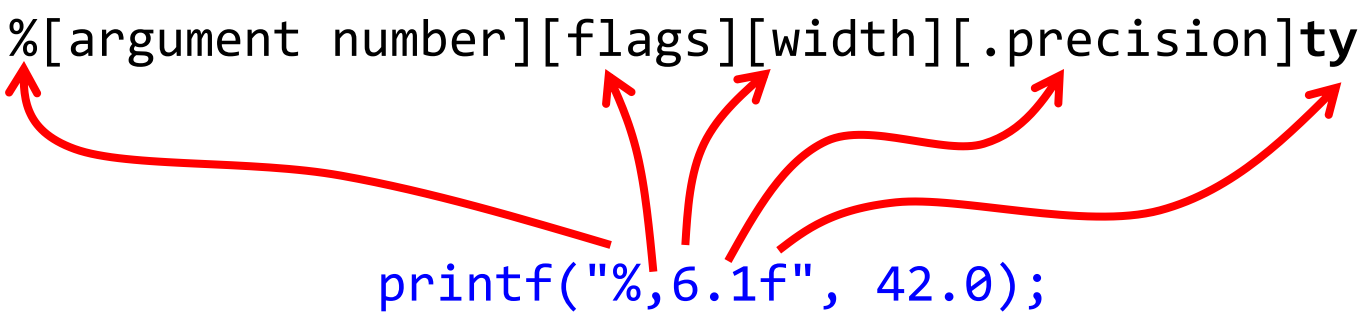
Minimum number of character used, but if number is longer it won't get cut off

```
%[argument number][flags][width][.precision]type
```

Special formatting options like inserting commas, making left justified, etc.

Sets the number of decimal places, don't forget the .

Type is only required part of specifier. "d" for an integer, "f" for a floating-point number.



printf gone wild

- Format string specifies:
  - Number of variables to fill in
  - Type of those variables
- Make sure format string agrees with arguments afterwards
  - Runtime error otherwise
  - Compiler / Eclipse won't protect you

```
// Runtime error %f expects a floating-point argument
System.out.printf("crash %f\n", 1);

// Runtime error, %d expects an integer argument
System.out.printf("crash %d\n", 1.23);

// Runtime error, not enough arguments
System.out.printf("crash %d %d\n", 2);
```

printf puzzler

Code	Letter
`System.out.printf("%f", 4242.00);`	E
`System.out.printf("%d", 4242);`	A
`System.out.printf("%.2f", 4242.0);`	B
`System.out.printf("%.3e", (double) 4242);`	C
`System.out.printf("%,d", 4242);`	D

Letter	Output
A	4242
B	4242.00
C	4.242e+03
D	4,242
E	4242.000000

Code	#
`System.out.printf("%d%d", 42, 42);`	2
`System.out.printf("%d+%d", 42, 42);`	1
`System.out.printf("%d %d", 42);`	5
`System.out.printf("%8d", 42);`	3
`System.out.printf("%-8d", 42);`	4
`System.out.printf("%d", 42.0);`	5

#	Output
1	42+42
2	4242
3	42
4	42
5	runtime error

Summary

- Libraries
  - Collection of useful methods for use by clients
  - Implements a specific API
  - Why?
    - Makes code easier to understand
    - Makes code easier to debug
    - Makes code easier to maintain and improve
    - Makes code easier to reuse
- Formatting output
  - `printf()` method
  - First parameter: specifies output format using % codes
  - Variable number of other parameters
    - Must match number and types of "slots" in the format specifier