Principles of Software Construction

What you see is what you get?

Josh Bloch **Charlie Garrod**

School of Computer Science
institute for SOFTWARE RESEARCH

Administrivia

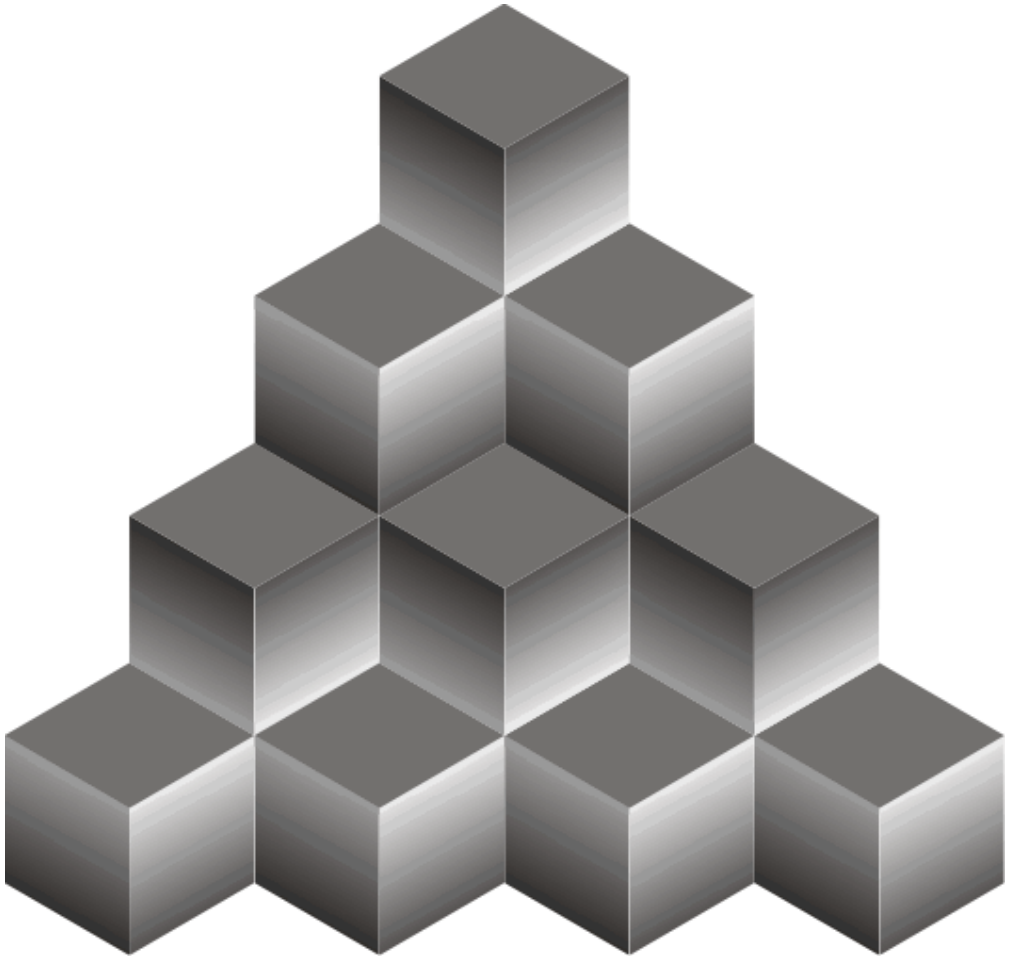
- Homework 6 due tonight, 11:59 p.m.
- Final exam Friday, Dec 16th 5:30–8:30 pm, GHC 4401
- Review session Wednesday, Dec 14th 7–9:30 pm, DH 1112

Key topics from Tuesday

Today: A finale of puzzlers

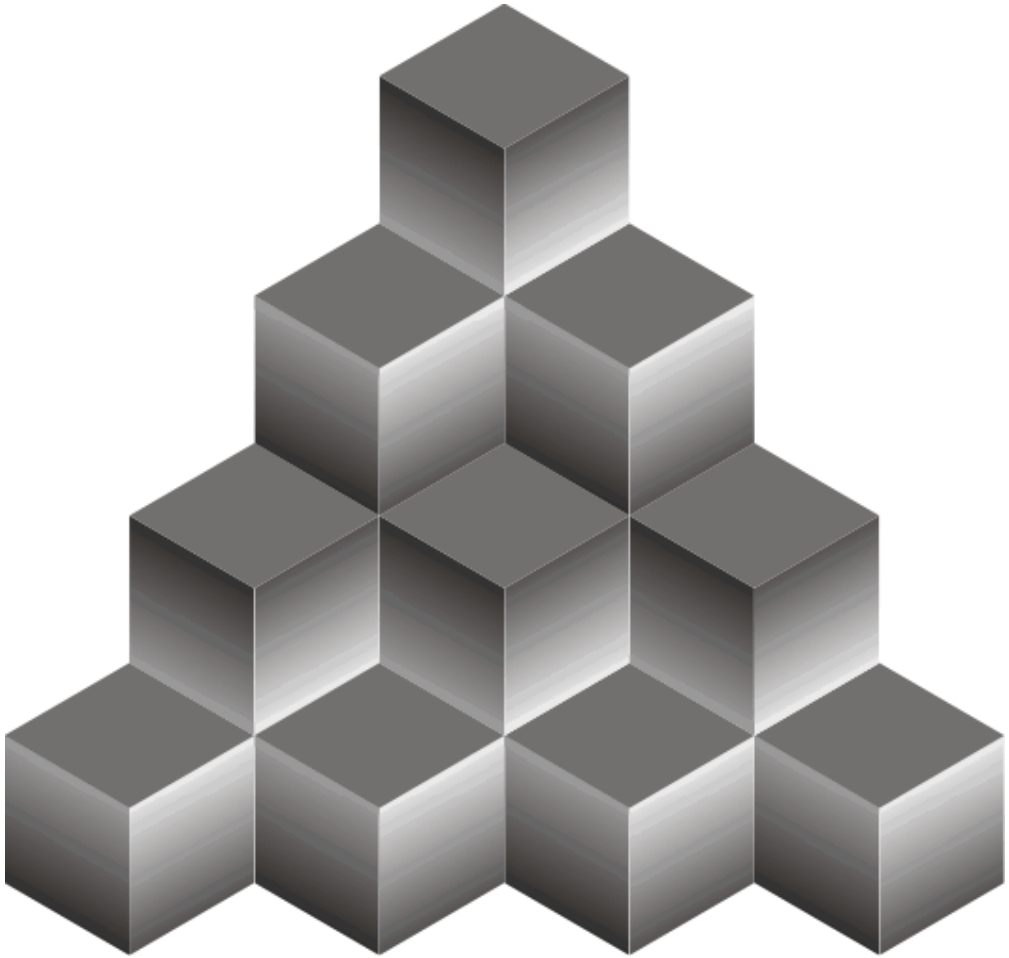
A quick challenge: Implement binary search

```
/**
 * Searches the specified array of ints for the specified value
 * using the binary search algorithm. If the array is not sorted,
 * the results are undefined. If the array contains multiple
 * elements with the specified value, there is no guarantee which
 * one will be found.
 *
 * @returns  the index of the search key if it is in the array;
 *   otherwise ~(insertion point).  (Or for you, -1 is fine.)
 */
 public static int binarySearch(int[] a, int key);
```

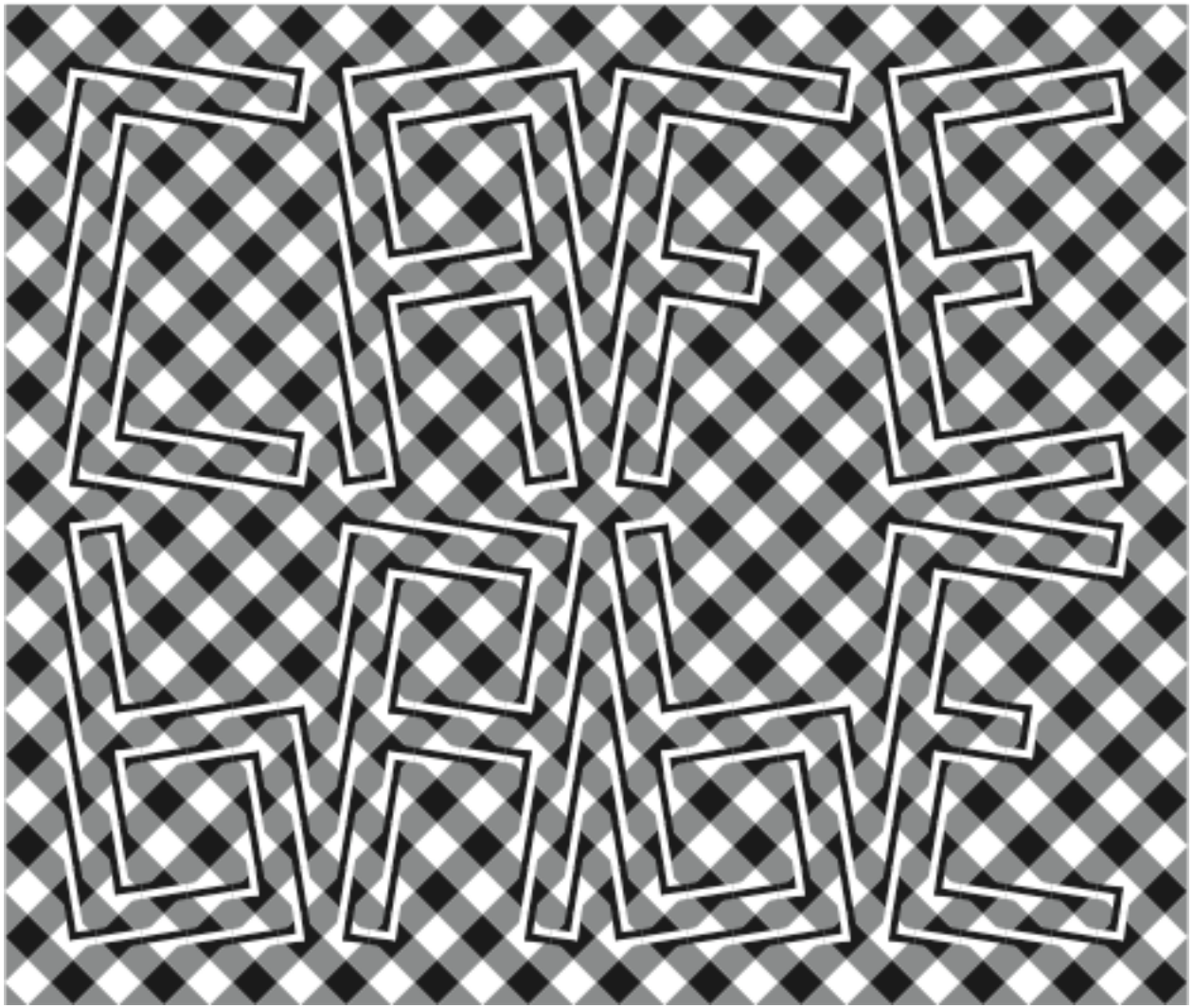


Logvinenko 1999

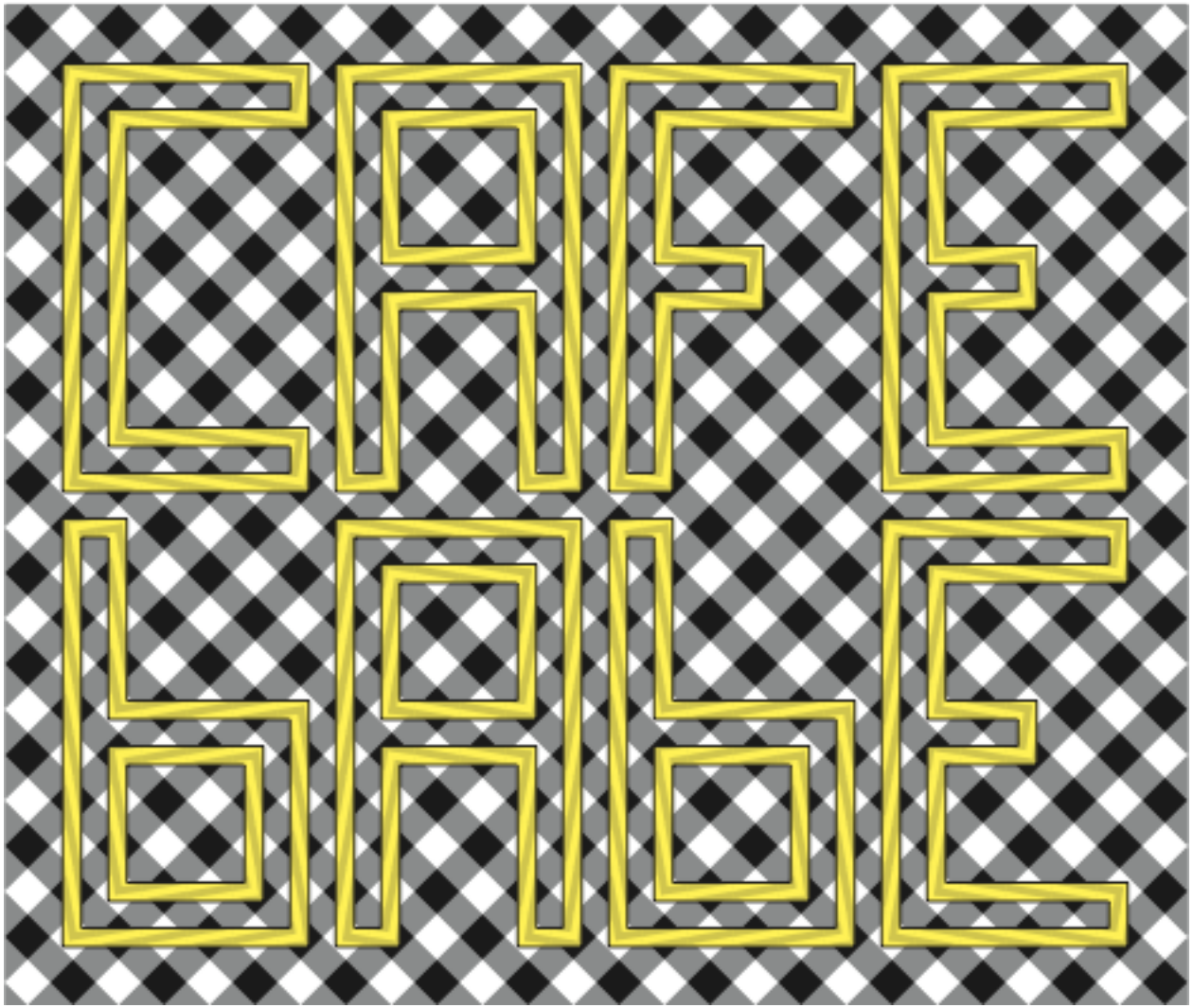
Logvinenko 1999



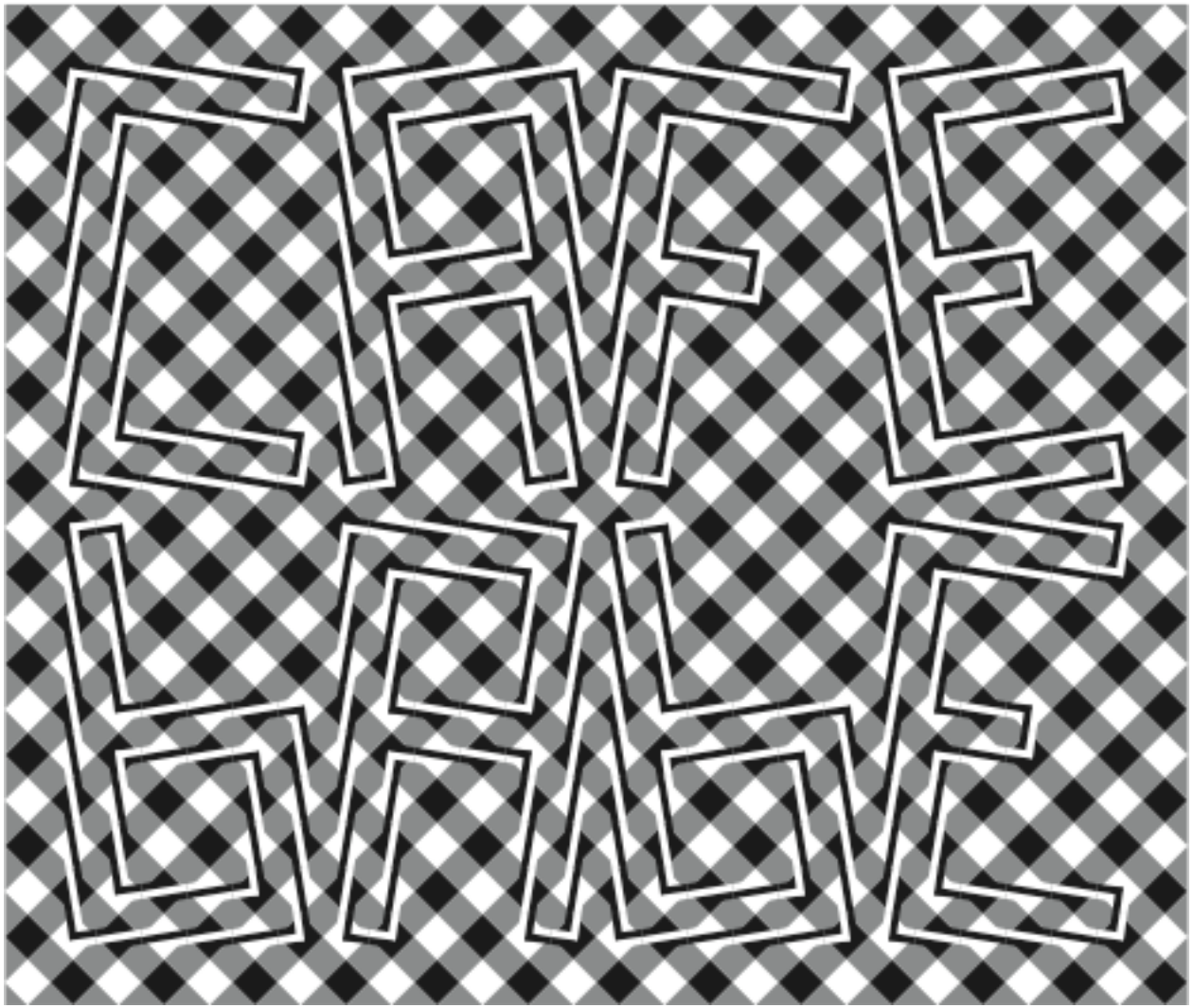
Logvinenko 1999



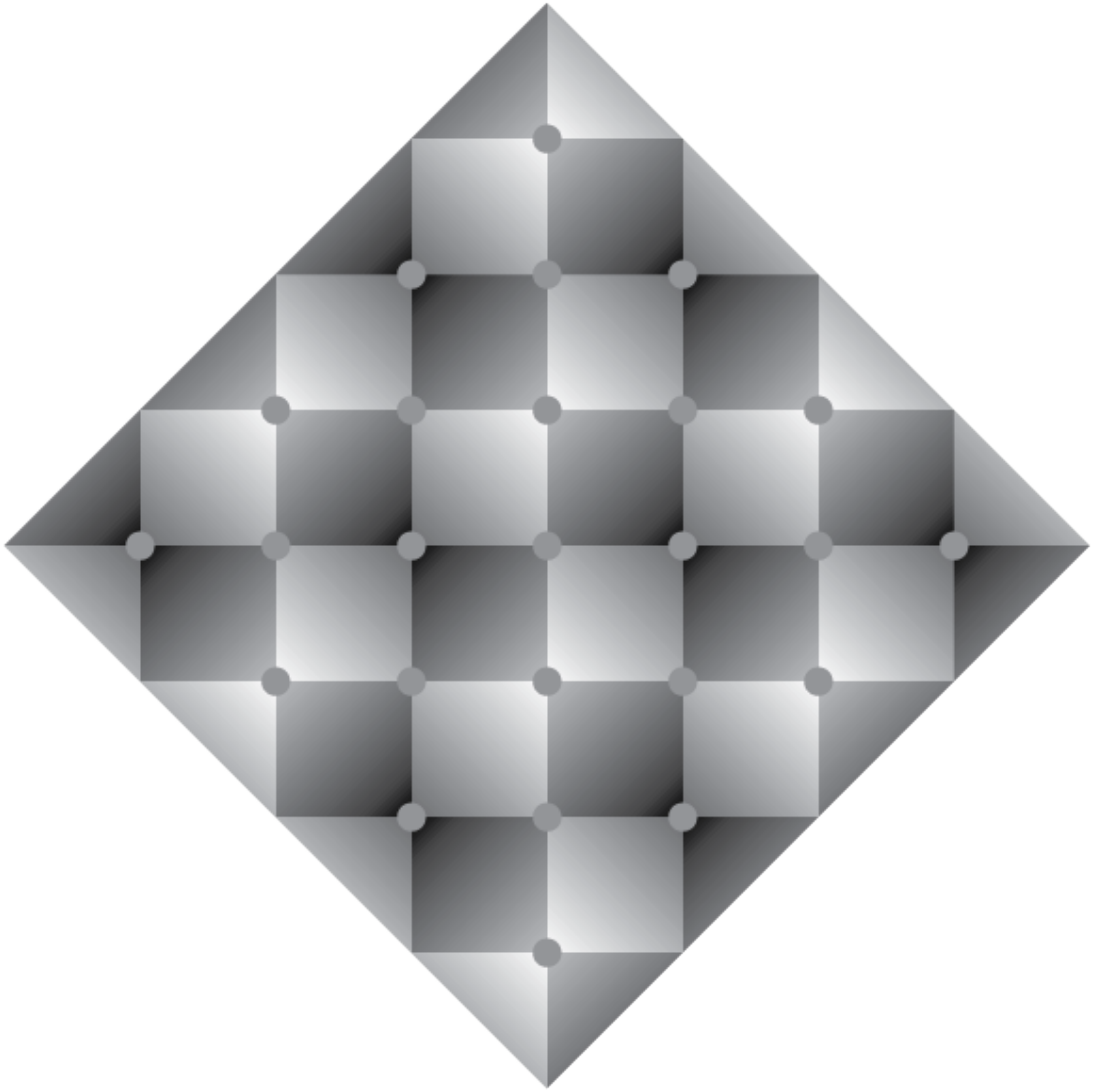
Fraser 1908



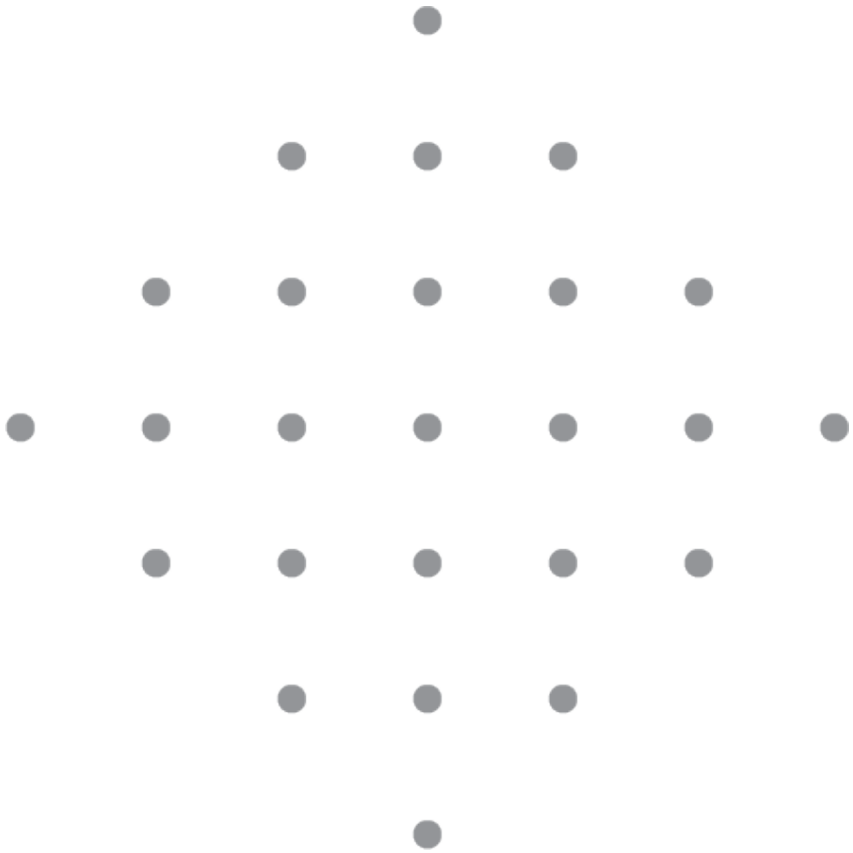
Fraser 1908



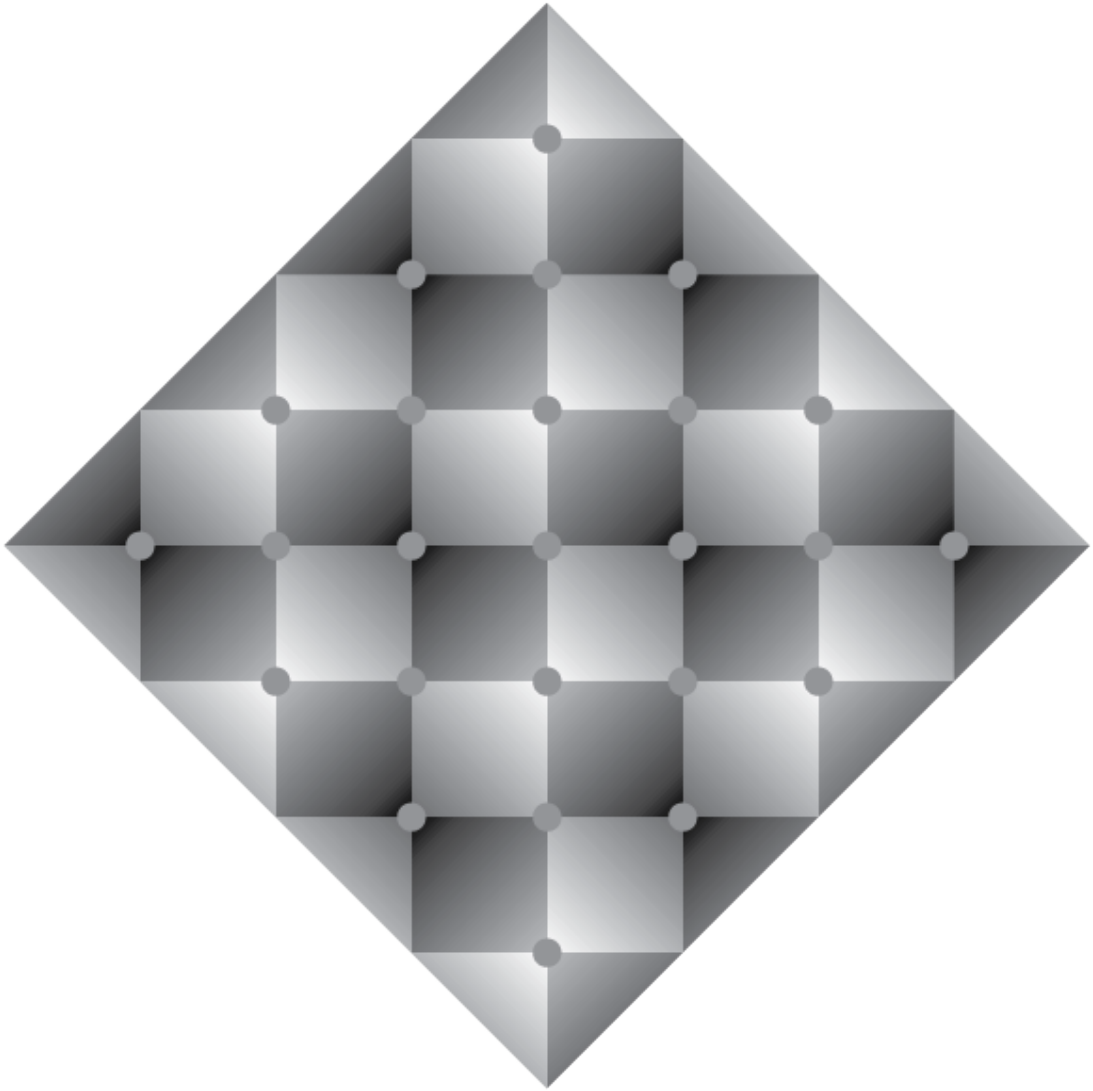
Fraser 1908



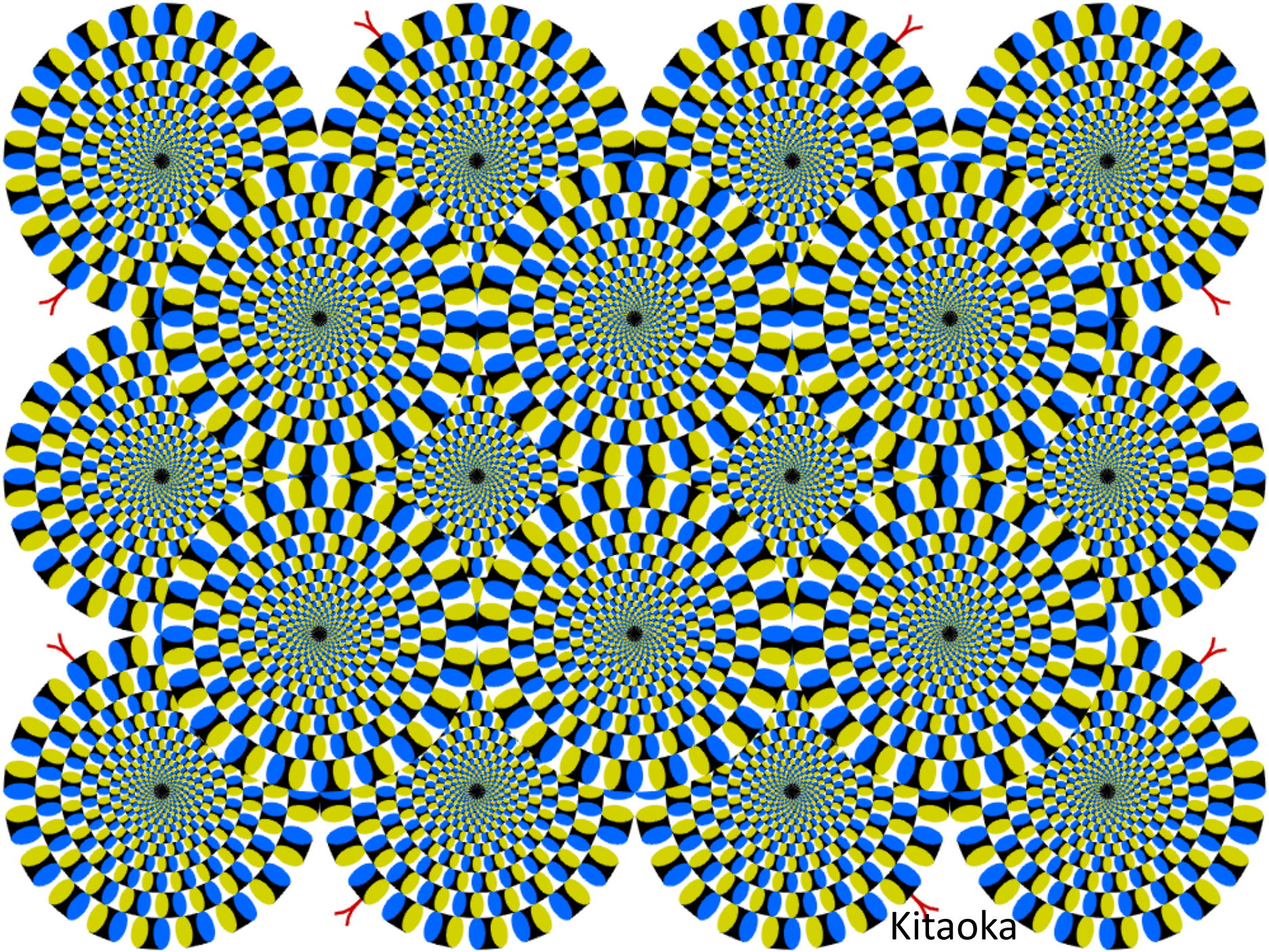
Todorovic 1997



Todorovic 1997



Todorovic 1997


Kitaoka

A correct binary search solution?

A correct binary search solution?

```
public static int binarySearch(int[] a, int key) {
    int low = 0;
    int high = a.length – 1;

    while (low <= high) {
        int mid = (low + high) / 2;
        int midVal = a[mid];

        if (midVal < key)
            low = mid + 1;
        else if (midVal > key)
            high = mid - 1;
        else
            return mid; // key found
    }
    return -(low + 1);  // key not found.
}
```

Integer overflows for large values of `low` and `high`:

```
public static int binarySearch(int[] a, int key) {
    int low = 0;
    int high = a.length – 1;

    while (low <= high) {
        int mid = (low + high) / 2;
        int midVal = a[mid];

        if (midVal < key)
            low = mid + 1;
        else if (midVal > key)
            high = mid - 1;
        else
            return mid; // key found
    }
    return -(low + 1);  // key not found.
}
```

One possible fix

- Avoid overflow, using signed ints:

```
int mid = (low + high) / 2;
int mid = low + ((high - low) / 2);
```

Lessons

- Keep it simple
- Use all the tools you know:
  - A good IDE
  - Static analysis tools like FindBugs
  - Verification tools for critical code
  - Unit tests and regression testing
  - Assert statements for known invariants
  - Code review for all code intended for other developers or users
  - Continuous integration testing for any project with multiple developers

“Strange Saga of a Sordid Sort”

```
public class SordidSort {
    static final Integer BIG   = 2_000_000_000;
    static final Integer SMALL = -2_000_000_000);
    static final Integer ZERO  = 0;

    public static void main(String args[]) {
        Integer[] arr = new Integer[] {BIG, SMALL, ZERO};
        Arrays.sort(arr, (i1, i2) -> i1 - i2);
        System.out.println(Arrays.toString(arr));
    }
}
```

What does it print?

```
public class SordidSort {
    static final Integer BIG   = 2_000_000_000;
    static final Integer SMALL = -2_000_000_000;
    static final Integer ZERO  = 0;

    public static void main(String args[]) {
        Integer[] arr = new Integer[] {BIG, SMALL, ZERO};
        Arrays.sort(arr, (i1, i2) -> i1 - i2);
        System.out.println(Arrays.toString(arr));
    }
}
```

(a) [-2000000000, 0, 2000000000]
(b) [2000000000, 0, -2000000000]
(c) [-2000000000, 2000000000, 0]
(d) None of the above

What does it print?

(a) `[-2000000000, 0, 2000000000]`

(b) `[2000000000, 0, -2000000000]`

(c) `[-2000000000, 2000000000, 0]`

(d) None of the above: Unspecified;
In practice, `[2000000000, -2000000000, 0]`

Comparator is broken!

- It relies on **`int`** subtraction
- **`int`** too small to hold difference of 2 arbitrary **`int`**s

Another Look

```
public class SordidSort {
    static final Integer BIG   = 2_000_000_000;
    static final Integer SMALL = -2_000_000_000;
    static final Integer ZERO  = 0;

    public static void main(String args[]) {
        Integer[] arr = new Integer[] {BIG, SMALL, ZERO};
        Arrays.sort(arr, (i1, i2) -> i1 - i2);
        System.out.println(Arrays.toString(arr));
    }
}
```

Subtraction overflows.

A possible fix?

```
public class SordidSort {
    static final Integer BIG   = 2_000_000_000;
    static final Integer SMALL = -2_000_000_000;
    static final Integer ZERO  = 0;

    public static void main(String args[]) {
        Integer[] arr = new Integer[] {BIG, SMALL, ZERO};
        Arrays.sort(arr, (i1, i2) ->
                                i1 < i2 ? -1 : (i1 == i2 ? 0 : 1));
        System.out.println(Arrays.toString(arr));
    }
}
```

…Another bug!

```
public class SordidSort {
    static final Integer BIG   = 2_000_000_000;
    static final Integer SMALL = -2_000_000_000;
    static final Integer ZERO  = 0;

    public static void main(String args[]) {
        Integer[] arr = new Integer[] {BIG, SMALL, ZERO};
        Arrays.sort(arr, (i1, i2) ->
                                i1 < i2 ? -1 : (i1 == i2 ? 0 : 1));
        System.out.println(Arrays.toString(arr));
    }
}
```

Unspecified behavior

== checks for identity, not equality, of object refrerences!

You could fix it like this…

```
public class SordidSort {
    static final Integer BIG   = 2_000_000_000;
    static final Integer SMALL = -2_000_000_000;
    static final Integer ZERO  = 0;

    public static void main(String args[]) {
        Integer[] arr = new Integer[] {BIG, SMALL, ZERO};
        Arrays.sort(arr, (i1, i2) ->
                                i1 < i2 ? -1 : (i1 > i2 ? 1 : 0));
        System.out.println(Arrays.toString(arr));
    }
}
```

Prints `[-2000000000, 0, 2000000000]`

Works, but fragile!

…But this is better

```
public class SordidSort {
    static final Integer BIG   = 2_000_000_000;
    static final Integer SMALL = -2_000_000_000;
    static final Integer ZERO  = 0;

    public static void main(String args[]) {
        Integer[] arr = new Integer[] {BIG, SMALL, ZERO};
        Arrays.sort(arr, Integer::compareTo);
        System.out.println(Arrays.toString(arr));
    }
}
```

Prints `[-2000000000, 0, 2000000000]`

Moral (1 of 2)

- `ints` aren't integers
  - Think about overflow
- The comparison technique `(i1, i2) -> i1 - i2` requires |i1 - i2| <= `Integer.MAX_VALUE`
  - For example: all values non-negative
- Don't write overly clever code
- Use standard idioms
  - But beware; some idioms are broken

Moral (2 of 2)

- `ints` aren't `Integers`
  - Think about identity vs. equality
  - Think about null
- For language designers
  - Don't violate the principle of least astonishment
  - Don't insist on backward compatibility

“Indecision”

```
class Indecisive {
    public static void main(String[] args) {
        System.out.println(decision());
    }

    static boolean decision() {
        try {
            return true;
        } finally {
            return false;
        }
    }
}
```

What does it print?

(a) `true`

(b) `false`

(c) None of the above

What does it print?

(a) `true`

(b) `false`

(c) None of the above

(d) Who cares?!?

What does it print?

(a) `true`

(b) `false`

(c) None of the above

The `finally` is processed after the `try`.

Another look

```
class Indecisive {
    public static void main(String[] args) {
        System.out.println(decision());
    }

    static boolean decision() {
        try {
            return true;
        } finally {
            return false;
        }
    }
}
```

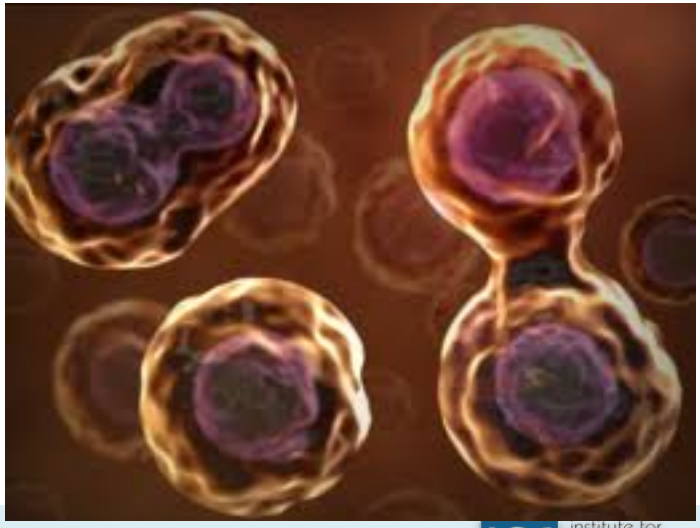
The moral

- Don't rely on obscure language or library details
- Here: Avoid abrupt completion of `finally` blocks
  - Don't return or throw exception from `try`
  - Wrap unpredictable actions with nested `try`

“Long Division” (2004)

```
public class LongDivision {
    private static final long MILLIS_PER_DAY
        = 24 * 60 * 60 * 1000;
    private static final long MICROS_PER_DAY
        = 24 * 60 * 60 * 1000 * 1000;

    public static void main(String[] args) {
        System.out.println(MICROS_PER_DAY / MILLIS_PER_DAY);
    }
}
```



What does it print?

```
public class LongDivision {
    private static final long MILLIS_PER_DAY
        = 24 * 60 * 60 * 1000;
    private static final long MICROS_PER_DAY
        = 24 * 60 * 60 * 1000 * 1000;

    public static void main(String[] args) {
        System.out.println(MICROS_PER_DAY / MILLIS_PER_DAY);
    }
}
```

(a) 5
(b) 1000
(c) 5000
(d) Throws an exception

What does it print?

(a) 5

(b) `1000`

(c) `5000`

(d) Throws an exception

Computation overflows

Another look

```
public class LongDivision {
    private static final long MILLIS_PER_DAY
        = 24 * 60 * 60 * 1000;
    private static final long MICROS_PER_DAY
        = 24 * 60 * 60 * 1000 * 1000; // >> Integer.MAX_VALUE

    public static void main(String[] args) {
        System.out.println(MICROS_PER_DAY / MILLIS_PER_DAY);
    }
}
```

How do you fix it?

```
public class LongDivision {
    private static final long MILLIS_PER_DAY
        = 24L * 60 * 60 * 1000;
    private static final long MICROS_PER_DAY
        = 24L * 60 * 60 * 1000 * 1000;

    public static void main(String[] args) {
        System.out.println(MICROS_PER_DAY / MILLIS_PER_DAY);
    }
}
```

Prints 1000

The moral

- When working with large numbers, watch out for overflow—it's a silent killer
- Just because variable can hold result doesn't mean computation won't overflow
- When in doubt, use larger type

“It’s Elementary” (2004; 2010 remix)

```
public class Elementary {
    public static void main(String[] args) {
        System.out.println(12345 + 5432l);
        System.out.println(01234 + 43210);
    }
}
```

The Periodic Table of the Elements

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

What does it print?

```
public class Elementary {
    public static void main(String[] args) {
        System.out.println(12345 + 5432l);
        System.out.println(01234 + 43210);
    }
}
```

(a) 17777 44444

(b) 17777 43878

(c) 66666 44444

(d) 66666 43878

What does it print?

(a) 17777 44444

(b) 17777 43878

(c) 66666 44444

(d) 66666 43878

Program doesn't say what you think it does!

Also, leading zeros can cause trouble.

Another look

```
public class Elementary {
    public static void main(String[] args) {
        System.out.println(12345 + 5432l);
        System.out.println(01234 + 43210);
    }
}
```

1 - the numeral one
l - the lowercase letter el

Another look, continued

```
public class Elementary {
    public static void main(String[] args) {
        System.out.println(12345 + 54321);
        System.out.println(01234 + 43210);
    }
}
```

01234 is an octal literal equal to $1{,}234_8$, which is 668

How do you fix it?

```
public class Elementary {
    public static void main(String[] args) {
        System.out.println(12345 + 54321);
        System.out.println(1234 + 43210); // No leading 0
    }
}
```

Prints `66666 44444`

The moral

- Always use uppercase el (L) for long literals
  - Lowercase el makes the code unreadable
  - `5432L` is clearly a long, `5432l` is misleading
- Never use lowercase el (l) as a variable name
  - Not this: `List<String> l = ... ;`
  - But this: `List<String> list = ...;`
- Never precede an int literal with 0 unless you actually want to express it in octal (base 8)
  - And add a comment if this is your intent

Lessons (reprise)

- Keep it simple
- Use all the tools you know:
  - A good IDE
  - Static analysis tools like FindBugs
  - Verification tools for critical code
  - Unit tests
  - Assert statements for known invariants
  - Code review for all code intended for other developers or users
  - Continuous integration testing for any project with multiple developers